NTIA TM-13-489

Antenna Models For Electromagnetic Compatibility Analyses

technical memorandum

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration

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EXECUTIVE SUMMARY

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency principally responsible for advising the President on telecommunications and information policy issues. NTIA's responsibilities include developing and articulating domestic and international telecommunications and information policies concerning spectrum allocation and utilization, presenting executive branch views on telecommunications and information matters to Congress, the Federal Communications Commission (FCC), and the public, and providing guidance to federal agencies to ensure their telecommunication activities are consistent with these policies.

To fulfill these responsibilities, NTIA has undertaken numerous spectrum-related studies to assess spectrum utilization and recommend changes to promote efficient and effective spectrum utilization, examine the feasibility of reallocating spectrum used by the federal government to the private sector, recommend changes to improve federal spectrum management procedures, and identify existing or potential electromagnetic compatibility (EMC) problems between radio systems and provide recommendations to resolve EMC conflicts.

NTIA and the federal agencies have long relied on engineering analyses and technical studies to assess compatibility between federal and non-federal radio systems and to evaluate emerging radio technologies. Unfortunately, regulators and the spectrum management community have yet to recognize a common set of approaches for conducting these analyses and studies. Moreover, in light of the increasing spectrum demands, federal regulators and spectrum managers must use analysis methods that accurately represent interference between radio systems to ensure efficient and effective spectrum utilization.

To make the analyses and studies more effective and accurate, NTIA, in coordination with the federal agencies and the FCC, is developing a Best Practices Handbook of engineering analytical tools and procedures with the aim of optimizing spectrum utilization. The handbook will include appropriate transmitter and receiver technical standards, radio service-specific interference protection criteria, limits of unwanted emission, frequency dependent environmental characteristics, engineering models of antennas and radiowave propagation, and a description of radio service-specific analysis models that address single and aggregate interference.

To support the development of the handbook, NTIA's Office of Spectrum Management, Spectrum Engineering and Analysis Division developed this technical memorandum to address the antenna characteristics for EMC analyses. The memorandum covers the antenna gain requirements, radiation patterns, sidelobe requirements, and other technical data. The results of this memorandum will be incorporated into the Best Practices Handbook.

This memorandum contains two compilations of antenna parameters. The first one is the collection of rules, regulations, and recommendations regarding antennas that are published by authoritative institutions and are relevant to EMC analyses. Various authoritative institutions have published rules, regulations, and recommendations regarding antennas for regulating, as well as improving, EMC, with the aim of optimizing spectrum efficiency. NTIA technical staff conducted an extensive search for the rules, regulations, and recommendations published by itself, the FCC, International Telecommunication Union, RTCA, Inc. (formerly Radio Technical Commission for Aeronautics), etc., and compiled the findings in this memorandum. The information includes the antenna gain values, reference radiation patterns, sidelobe requirements, and other technical data. Thus, this memorandum is a library of the rules, regulations, and recommendations regarding antennas that are relevant to EMC analyses. This will enable regulators and spectrum managers to easily identify the appropriate antenna parameters for their EMC analyses.

The second compilation is the recommendations of antenna parameters for NTIA and the federal agencies to conduct their EMC analysis tasks. NTIA conducts the following EMC analysis tasks for the federal agencies: system review for equipment approval, frequency assignment, and spectrum sharing studies. The official source of antenna parameters for these tasks is the NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management*. However, the Manual only provides antenna parameters for some radio services. NTIA technical staff evaluated the characteristics of the radio services, the federal usage of the radio spectrum, and the technical merit and practicality of the antenna parameters in the rules, regulations, and recommendations, and then developed recommendations of antenna parameters for all of the radio services. These recommendations are compiled in this memorandum. Thus, this memorandum is also a library of the antenna parameters for NTIA and the federal agencies to conduct their EMC analysis tasks.

This technical memorandum is a living document. The content will be periodically reviewed for new and revised technical parameters from the authoritative institutions, and the memorandum will be revised accordingly.

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ACRONYMS ABBREVIATIONS AND SYMBOLS

List of Acronyms and Abbreviations

14 CFR	Code Of Federal Regulations, Title 14, Aeronautics and Space
47 CFR	Code Of Federal Regulations, Title 47, Telecommunication
AM	Amplitude Modulation
AMS	Aeronautical Mobile Service
AMSS	Aeronautical Mobile-Satellite Service
ARNS	Aeronautical Radionavigation Service
ARNSS	Aeronautical Radionavigation-Satellite Service
Az	Azimuth
BS	Broadcasting Service
BSS	Broadcasting-Satellite Service
C/I	Carrier Power-to-Interference Power Ratio
C/N	Carrier Power-to-Noise Power Ratio
dB	Decibel
dBd	Signal Strength or Power Level with Respect to a Reference Dipole Antenna, in dB
dBi	Signal Strength or Power Level with Respect to an Isotropic Radiator, in dB
dBic	dBi, Circular Polarization
deg	Degree(s)
DEMS	Digital Electronic Messaging Service
DoD	Department of Defense
DRS	Data Relay Satellite
ECAC	Electromagnetic Compatibility Analysis Center, Department of Defense
EESS	Earth Exploration Satellite Service
EIRP	Equivalent Isotropic Radiated Power
El	Elevation
ELT	Emergency Locator Transmitters
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EPIRB	Emergency Position Indicating Radio Beacon
ERP	Equivalent Radiated Power
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FM	Frequency Modulation
FS	Fixed Service
FSS	Fixed-Satellite Service
G/T	Gain-over-Noise Temperature
GHz	Gigahertz
GLONASS	Global Navigation Satellite System of Russian Federation
GMF	Government Master File
GNSS	Global Navigation Satellite System

GPS	Global Positioning System
GSO	Geostationary Orbit
HAPS	High Altitude Platform Stations
HF	High Frequency (3–30 MHz Band)
HPBW	Half Power Beamwidth
Hz	Hertz
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMO	International Maritime Organization
IMT-2000	International Mobile Telecommunications-2000
ISS	Inter-Satellite Service
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
JSC	Joint Spectrum Center
kHz	Kilohertz
LEO	Low Earth Orbit
LF	Low Frequency (30–300 kHz Band)
LHCP	Left-Hand Circular Polarization
LMS	Land Mobile Service
LMSS	Land Mobile-Satellite Service
MEO	Medium Earth Orbit
MetAids	Meteorological Aids Service
MetSat	Meteorological Satellite Service
MF	Medium Frequency (300 kHz–3 MHz Band)
MHz	Megahertz
MMS	Maritime Mobile Service
MMSS	Maritime Mobile-Satellite Service
MRNS	Maritime Radionavigation Service
MRNSS	Maritime Radionavigation-Satellite Service
MS	Mobile Service
MSS	Mobile-Satellite Service
N/A	Not Available
n/a	Not Applicable
n/s	Not Specified
NEC	Numerical Electromagnetic Code
NEC-BSC	Numerical Electromagnetic Code-Basic Scattering Code
NGSO	Non- Geostationary Orbit
NTIA	National Telecommunications And Information Administration
PAR	Photosynthetically Active Radiation
pfd	Power Flux Density
PLB	Personal Locator Beacon
P-MP	Point-to-Multipoint Connection
P-P	Point-to-Point Connection
rad	Radian
RAS	Radio Astronomy Service

RDS	Radiodetermination Service
RDSS	Radiodetermination-Satellite Service
Rec.	Recommendation
RHCP	Right-Hand Circular Polarization
RLS	Radiolocation Service
RLSS	Radiolocation-Satellite Service
RNS	Radionavigation Service
RNSS	Radionavigation-Satellite Service
RR	Radio Regulations
RSS	Remote Sensing Service
RTCA	Formerly Radio Technical Commission For Aeronautics, now RTCA, Inc.
RTCM	Radio Technical Commission For Maritime Services
Rx	Receive or Receiving
SA	Space Applications Service
SAR	Search and Rescue
SARP	SAR Processor
SARR	SAR Repeater
S/N	Signal Power-to-Noise Power Ratio
SOS	Space Operation Service
SRS	Radio Research Service
THz	Terahertz
TSO	Technical Standard Order (published by FAA)
Tx	Transmit or Transmitting
UHF	Ultra High Frequency (300–3000 MHz Band)
UTD	Uniform Theory of Diffraction
VHF	Very High Frequency (30–300 MHz Band)
VSAT	Very Small Aperture Terminals
WPR	Wind Profiler Radars

List of Symbols

(Bold italic characters are vector variables)

$\hat{\boldsymbol{r}}$	Unit Vector of $\boldsymbol{r}$
σ	Ground Soil Conductivity
ε_r	Ground Soil Reflection Coefficient
(r, θ, φ)	Spherical Coordination System
B	Bandwidth
c	Velocity of Light in Vacuum
$\mathcal{D}$	Directivity
D	Diameter of Aperture of Circular Reflector Antenna
e	Antenna Efficiency
f	Frequency
g	Peak Gain, Gain, numerical value

G, G_{max}	Peak Gain, On-Axis Gain, Gain, in dB
$g_d(\theta, \varphi)$	Directive Gain in the (θ, φ) Direction, numerical value
$G_d(\theta, \varphi)$	Directive Gain in the (θ, φ) Direction, in dB
$g_p(\theta, \varphi)$	Power Gain in the (θ, φ) Direction, numerical value
$G_p(\theta, \varphi)$	Power Gain in the (θ, φ) Direction, in dB
K	Degree Kelvin
k	Boltzmann's Constant
L_{pol}	Polarization Loss
N or N_{sys}	Antenna System Noise Power
N_{ant}	Antenna Noise Power
N_r	Receiver Noise Power
P_{ant}	Antenna Power
P_{rad}	Far-Field Radiated Power, Or Radiated Power
r	Distance From Origin
t	Time Variable
$U(\theta, \varphi)$	Radiation Intensity
U_{ave}	Average Radiation Intensity
λ	Wavelength
ϕ_{bw}	Half Power Beamwidth
φ	Azimuth Angle
θ	Elevation Angle
ϕ	For Circular Beam, Angle Off Mainbeam Axis; For Elliptical Beam, Angle Off Mainbeam Axis in Direction of Interest

SECTION 1. INTRODUCTION

1.1 Background

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency principally responsible for advising the President on telecommunications and information policy issues. NTIA's responsibilities include developing and articulating domestic and international telecommunications and information policies concerning spectrum allocation and utilization, presenting executive branch views on telecommunications and information matters to Congress, the Federal Communications Commission (FCC), and the public, and providing guidance to federal agencies to ensure their telecommunication activities are consistent with these policies.

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To make the analyses and studies more effective and accurate, NTIA, in coordination with the federal agencies and the FCC, is developing a Best Practices Handbook of engineering analytical tools and procedures with the aim of optimizing spectrum utilization. The handbook will include appropriate transmitter and receiver technical standards, radio service-specific interference protection criteria, limits of unwanted emission, frequency dependent environmental characteristics, engineering models of antennas and radiowave propagation, and a description of radio service-specific analysis models that address single and aggregate interference.

To support the development of the handbook, NTIA's Office of Spectrum Management, Spectrum Engineering and Analysis Division developed this technical memorandum to address the antenna characteristics for EMC analyses. The memorandum covers the antenna gain requirements, radiation patterns, sidelobe requirements, and other technical data. The results of this technical memorandum will be incorporated into the Best Practices Handbook.

1.2 Objective

This technical memorandum serves two purposes. The first one is to serve as a library of rules, regulations, and recommendations regarding antennas that are published by authoritative institutions and are relevant to EMC analyses. Federal agencies and international institutions have published many rules, regulations, and recommendations regarding antennas for regulating, as well as improving, EMC, with the aim of optimizing spectrum utilization. However, the diverse sources of these rules, regulations, and recommendations make it difficult for regulators and spectrum managers to find the correct information for their EMC analyses. NTIA technical staff collected these rules, regulations, and recommendations, and compiled them in this technical memorandum. This will make the necessary information regarding antennas more easily accessible to regulators and spectrum managers.

The second purpose is to serve as a library of the antenna parameters for NTIA and the federal agencies to conduct their EMC analysis tasks. NTIA conducts the following EMC analysis tasks for the federal agencies: system review for equipment approval, frequency assignment, and spectrum sharing studies. The official source of antenna parameters for these tasks is the NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management*.[1] However, the Manual only provides antenna parameters for some radio services. In order to provide the complete information, NTIA technical staff developed recommendations of antenna parameters for all of the radio services, and compiled them in this memorandum. This will provide regulators and spectrum managers with all of the necessary antenna parameters for their EMC analysis tasks.

1.3 Approach

To develop the library of rules, regulations, and recommendations regarding antennas that are relevant to EMC analyses, NTIA technical staff searched for documentations from the authoritative institutions whose information has regulatory status for the spectrum management tasks. These institutions include NTIA, FCC, International Telecommunication Union (ITU), RTCA, Inc. (formerly Radio Technical Commission for Aeronautics), etc. Technical journals with the most up-to-date information on antenna technologies, e.g., publications from the Institute of Electrical and Electronics Engineers (IEEE), were not searched. Almost all of the information is publically available either from the Internet or published documents.

To develop the library of antenna parameters for NTIA and the federal agencies to conduct their EMC analysis tasks, NTIA evaluated the characteristics of the radio services, the federal usage of the radio spectrum, and the technical merit and practicality of the antenna parameters from the authoritative institutions, and then developed the recommendations. The recommendations only cover the radio services for which NTIA conducts the EMC analysis tasks; therefore, recommendations for the Broadcasting Service and Broadcasting-Satellite Service were not developed. A summary of these recommendations will be included in the Best Practices Handbook.

This technical memorandum is a living document. The content will be periodically reviewed for new or revised technical parameters from authoritative institutions, and the memorandum will be revised accordingly.

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1 National Telecommunications and Information Administration, U.S. Department of Commerce, *Manual of Regulations and Procedures for Federal Radio Frequency Management* (2008).

1.4 Scope

This technical memorandum contains three parts. The first part, in Sections 2 to 4, provides a brief introduction of the antenna fundamentals, antenna types, and common techniques associated with antenna modeling.

Section 2 presents the basics of antenna characteristics most often encountered by the spectrum managers, e.g., gain, radiated power, reference radiation pattern, efficiency, beamwidth, polarization, noise, bandwidth, and near-field and far-field regions.

Section 3 presents the fundamental types of antennas applicable to all the radio services, e.g., linear antennas, aperture antennas, fractal antennas, microstrip antennas, and array antennas. It also presents photographs, diagrams, and radiation patterns of antennas. Since many spectrum managers work with only one or a few radio services that employ only a few types of antennas, the information in Section 3 may broaden a spectrum manager's knowledge of antenna types beyond her/his regular work requirement.

Section 4 provides the following information for modeling antenna performance: equations to calculate gain and beamwidth, reference radiation patterns currently used by the federal government for system planning purposes, and algorithms commonly used to develop antenna models.

The second part, in Section 5, is the compilation of rules, regulations, and recommendations published by authoritative institutions such as NTIA, FCC, ITU, and RTCA. The content is organized by the categories of radio services classified in the ITU Radiocommunication Sector (ITU-R). Typical technical parameters are provided when the rules, regulations, and recommendations are not available. A summary list of these rules, regulations, recommendations, data, and specifications are provided in Table 5-83 at the end of Section 5 for easy reference.

The third part, in Sections 6 and 7, provides the antenna parameters for NTIA and the federal agencies to conduct their EMC analysis tasks. The recommendations cover the antenna radiation performance standards for system review, the antenna radiation patterns for frequency assignment, and the representative antenna radiation patterns for spectrum sharing analyses. Section 6 provides the complete processes for developing the recommendations, and Section 7 is the summary of recommendations in Section 6. The content is also organized by the categories of radio services classified in ITU-R.

SECTION 2. ANTENNA FUNDAMENTALS

2.1 Introduction

An antenna is the component of a radio system that transmits and/or receives radio signals via electromagnetic (EM) wave. This section presents a discussion of some of the antenna technical parameters relevant to EMC analyses that are regularly encountered by the spectrum managers. These include the near-field and far-field regions, radiated power, directivity, gain, radiation pattern, efficiency, beamwidth, polarization, noise, and bandwidth.

The presentation is intended to be conceptual rather than theoretical; hence, equations are used only when necessary. It is hoped that the presentation allows the spectrum managers to gain an understanding of the physical concepts of these antenna characteristics. Also, since the spectrum managers should already have working knowledge of antennas, the presentation is not meant to simulate a textbook; thus, it is not as organized or rigid as one.

In this section, all the parameters are expressed in the spherical coordinate system. The graphic presentation of the spherical coordinate system is shown in Figure 2-1. The origin of the coordinate system is ***o***. The coordinates of point ***p*** is (r, θ, φ), where r is the radius distance, θ is the elevation angle, and φ is the azimuth angle. The unit vectors at ***p*** are $(\hat{\mathbf{r}}, \hat{\theta}, \hat{\varphi})$.[2]

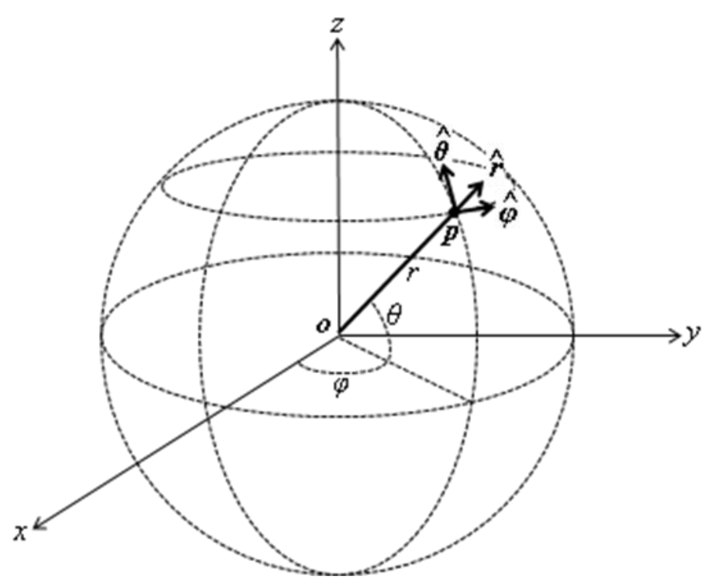

Figure 2-1. Spherical Coordinate System

The basic equation in EMC analyses to calculate the signal power received by a radio system is

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2 This is not the conventional spherical configuration system where the angle θ is measured from the z-axis downward and is called the inclination angle. The configuration in Figure 2-1 is suitable for describing the antenna operation using azimuth and elevation angles to specify its pointing direction.

$$P_r = P_t + G_t(\phi_t) + G_r(\phi_r) - F(f_t, B_t, M_t, f_r, B_r, M_r) - L_p \qquad (2\text{-}1)$$

where

P_r: received power, dBW;
P_t: transmitter power, dBW;
G_t: transmitting antenna power gain, dBi;
ϕ_t: angle off transmitting antenna mainbeam axis;
G_r: receiving antenna power gain, dBi;
ϕ_r: angle off receiving antenna mainbeam axis;
$F(f_t, B_t, M_t, f_r, B_r, M_r)$: frequency dependent rejection factor, dB;
f_t: transmitting signal carrier frequency;
B_t: transmitting signal bandwidth;
M_t: transmitting signal modulation;
f_r: receiver filter center frequency;
B_r: receiver filter bandwidth;
M_r: receiver filter modulation; and
L_p: propagation loss, dB.

This equation is used for both the intended signals and the unintended interfering signals. The transmitting and receiving antenna gain characteristics, $G_t(\phi_t)$ and $G_r(\phi_r)$, play an important role in interference management. These two parameters, or specifically ϕ_t and ϕ_r, are controlled in the system planning process to manage the interfering signals. Better spectrum management and frequency utilization may be achieved by effectively controlling these parameters to minimize the impact of interference.

2.2 Near-Field and Far-Field Regions

The EM field generated by an antenna has three components that differ in their distance-dependencies. The first one is the inductive near-field, the second one is the radiated near-field, and the third one is the radiated far-field. The inductive field stores energy near the antenna, and the radiated fields dissipate energy into space. The near-fields are large compared with the far-field in the vicinity of the antenna, but their strengths decrease more rapidly than the far-field as the distance of propagation increases. Beyond a certain distance, the far-field becomes the dominant component. The area where the far-field dominates is called the far-field region, where the far-field can be approximated as a plane wave. The area between the far-field region and the antenna is called the near-field region.

It has been generally accepted that the plane-wave approximation is valid when at least one of the following conditions is met:

$$r > 2L^2/\lambda \qquad (2\text{-}2a)$$

$$r >> L \qquad (2\text{-}2b)$$

$$r >> \lambda \qquad (2\text{-}2c)$$

where

r: distance from the antenna,
L: maximum linear dimension of the antenna radiation portion or surface,
λ: wavelength, and
>>: much larger.

Eq. (2-2a) alone is sufficient for antennas operating in the Very High Frequency (VHF, 30–300 MHz range) and higher frequency bands, and Eqs. (2-2a–c) should all be satisfied for antennas operating below the VHF band.

EMC analyses almost always consider only the far-field radiation characteristics. However, in some special cases, the dominant interfering signals are the near-field. For instance, broadband power-line communications utilize the electric power lines as the telecommunication media to transmit the signals, and other radio systems near the power lines may be interfered with by the near-field. This case is documented in two NTIA reports.[3] [4] Another example is the co-site issue when two antennas with overlapping frequency bands are installed nearby, e.g., in the same hosting tower. This is a system design issue, not a spectrum management issue. Co-site analysis tools are available commercially.

2.3 Power and Gain

2.3.1 Radiated Power

The *antenna power*, P_{ant}, is the total power input to the antenna system. It generates the radiating EM wave that dissipates power into the far field, the non-radiating EM field that stores energy in the near field, and joule heat.

The far-field radiated power, commonly referred to as the *radiated power*, P_{rad}, is the total radiated power carried by the far-field EM wave. P_{rad} is independent of the propagation distance r and is a constant.

The *power flux density* (*pfd*) is a measure of the radiated power density at a particular location in space. In designing a radio system, one of the specifications is the lower limit *pfd* at the front end of a receiving antenna to guarantee required signal qualities. When regulating radio interference between radio systems, one of the specifications could be the maximum allowable *pfd*, either for a single-entry interfering signal or aggregated interfering signals, at the front end of a receiving antenna to limit radio interference from other radio systems.

The *radiation intensity*, $U(\theta, \varphi)$, from an antenna in a given direction (θ, φ) is the far-field radiated power per unit solid angle in the direction (θ, φ).[5] $U(\theta, \varphi)$ is independent of the propagation distance r.

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3 NTIA, U.S. Department of Commerce, NTIA 04-413, *Broadband-Over-Powerline Report* (2004).

4 NTIA, U.S. Department of Commerce, NTIA 08-450, *Potential Interference From Broadband Over Power Line (BPL] Systems To Federal Government Radiocommunication Systems at 1.7 - 80 MHz Phase 2 Study* (2007).

5 Solid angle is the angle of an object seen from the center of a sphere. The unit of solid angle is the steradian (or square radian). The total solid angle is the solid angle over a sphere and is equal to 4π steradian.

2.3.2 Directive Gain and Power Gain

The *directive gain*, $g_d(\theta, \varphi)$, of an antenna in a given direction (θ, φ) is the ratio of the *radiation intensity* $U(\theta, \varphi)$ in a given direction (θ, φ) to the average radiation intensity, i.e.,

$$g_d(\theta, \varphi) = \frac{4\pi U(\theta, \varphi)}{P_{rad}} \qquad (2\text{-}3)$$

where ($P_{rad}/4\pi$) is the average radiation intensity over the complete spherical steradian angle of 4π. The $g_d(\theta, \varphi)$ value of Eq. (2-3) is numerical. Usually, it is more practical for antenna engineers and spectrum managers to express the gain value in decibels. Denoting the *directive gain* in decibel as $G_d(\theta, \varphi)$, then

$$G_d(\theta, \varphi) = 10 \times \log[g_d(\theta, \varphi)] \qquad \text{(dB)} \qquad (2\text{-}4)$$

The *directivity*, $\mathcal{D}$, of an antenna is the peak *directive gain* at the mainbeam axis.

The *power gain*, $g_p(\theta, \varphi)$, of an antenna in a given direction (θ, φ) is the ratio of the *radiation intensity* $U(\theta, \varphi)$ to the average radiation intensity if the antenna power were completely radiated, i.e.,

$$g_p(\theta, \varphi) = \frac{4\pi U(\theta, \varphi)}{P_{ant}} \qquad (2\text{-}5)$$

The $g_p(\theta,\varphi)$ value of Eq. (2-5) is numerical. Often, its value is expressed in decibel; denoting the *power gain* in decibel as $G_p(\theta, \varphi)$, then

$$G_p(\theta, \varphi) = 10 \times \log[g_p(\theta, \varphi)] \qquad \text{(dB)} \qquad (2\text{-}6)$$

The *peak gain*, g, or *on-axis gain*, or simply *Gain*, is the peak *power gain* at the mainbeam axis. The *peak gain* in decibels is usually denoted G.

2.4 Radiation Pattern

2.4.1 Characteristics

The antenna radiation pattern is a graphical representation of the geometrical distribution of the radiated power over all space. It is typically expressed in the spherical coordinates as a function of space coordinates and is independent of distance.

A radiation pattern usually consists of a mainbeam, one or a few near sidelobes adjacent to the mainbeam and many far sidelobes further away from the mainbeam. The mainbeam can be of various shapes, e.g., toroidal beam, pencil beam, or elliptical beam. The near sidelobes usually have predictable power levels and directions. The far sidelobes are very random in their power levels and directions, but generally the power levels decrease rapidly and level off at a threshold value. The randomness of the far sidelobes depends on the detailed structure of the antenna, e.g., the accuracy of the surface, the shape of the edge, and the antenna supporting elements.

Radiation patterns can be seriously affected by the environment. For instance, the radiation pattern of an antenna operating in the Low Frequency (LF, 30–300 kHz range) or Medium Frequency (MF, 300–3000 kHz range) band and installed above the ground is profoundly influenced by the lossy earth. Or, the radiation pattern of an antenna installed onboard a ship or an airplane is distorted by the metallic structure in its surrounding.

2.4.2 Types of Patterns

Antennas generate three types of radiation patterns: isotropic, omnidirectional, and directional. These types of radiation patterns are discussed here.

(a) Isotropic Radiation Pattern

An isotropic radiator is a theoretical antenna that radiates power uniformly in all directions. Therefore, it is sometimes called a non-directional radiator. Such three-dimensionally uniform radiation capability is possible only with a point radiator.

Although purely theoretical, it is best known for its usage as a reference. An isotropic radiator is used as a reference antenna to specify the directional gain of an antenna. As a common practice, an antenna gain value is expressed as "x dB above an isotropic radiator" and labeled as “x dBi”.

(b) Omnidirectional Radiation Pattern

An omnidirectional antenna is an antenna that can provide uniform radiation in a reference plane; this reference plane is referred to as the peak gain plane where $G = G_{max}$ in all radiant directions. The radiation pattern of an omnidirectional antenna is shown in Figure 2-2.[6] The pattern is a toroid (i.e., doughnut) or a figure-eight, with the axis of the toroid aligned with the axis of the antenna. In most of the radio systems using omnidirectional antennas, the peak gain plane is the horizontal plane parallel to the local Earth surface; this is the case shown in Figure 2-2.

6 http://www.tpub.com/content/neets/14182/css/14182_186.htm, accessed Nov. 9, 2011.

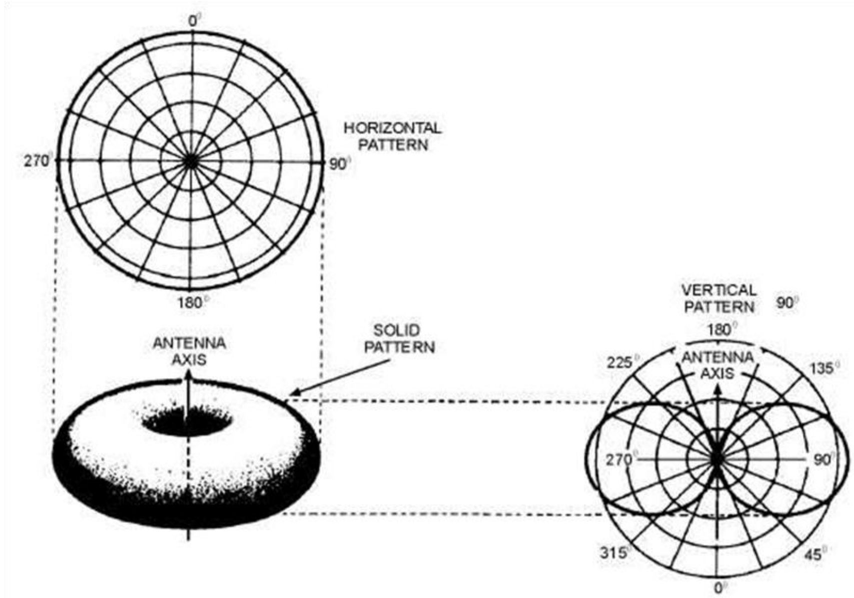


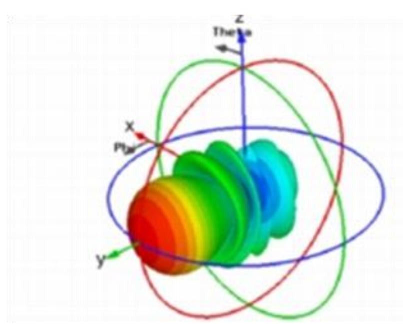
Figure 2-2. Radiation Pattern of an Omnidirectional Antenna

The *effective (or equivalent) radiated power* (ERP) of an omnidirectional antenna refers to the radiated power strength in any direction in the reference plane. ERP can be obtained by multiplying the total radiated power, P_{rad}, with the peak gain reference to a dipole antenna (discussed in Section 3.2.2(b)), g_{dipole}, i.e.,

$$ERP = P_{rad} \times g_{dipole} \tag{2-7}$$

(c) Directional Radiation Pattern

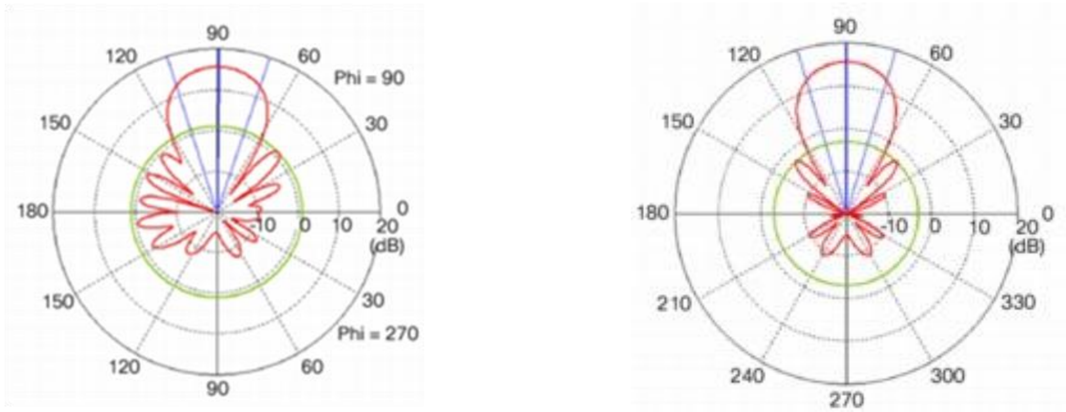
A directional antenna can generate a cone-shaped mainbeam within which most of the radiated power is contained. An example of the radiation pattern of a directional antenna is shown in Figure 2-3; here the antenna mainbeam axis is in the horizontal plane.[7]



(a) 3-Dimentional Radiation Pattern

(Figure 2-3)

7 http://www.cisco.com/en/US/prod/collateral/wireless/ps7183/ps469/prod_white_paper0900aecd806a1a3e.html, accessed July 14, 2011.



(b) Elevation Plane Radiation Pattern **(c) Azimuth Plane Radiation Pattern**

Figure 2-3. Directional Antenna Radiation Pattern

The *effective (or equivalent) isotropic radiated power* (EIRP) of a directional antenna refers to the radiated power strength in the direction of the mainbeam axis. EIRP can be obtained by multiplying the total radiated power, P_{rad}, with the peak power gain, g_p, i.e.,

$$\text{EIRP} = P_{rad} \times g_p \tag{2-8}$$

2.4.3 Reference Radiation Pattern

Because of the randomness of the far sidelobes, a reference or envelope radiation pattern is usually used for EMC analyses. A reference radiation pattern is the envelope of the actual radiation pattern, and is usually artificially shaped to be symmetric to the mainbeam axis. A measured radiation pattern and its reference radiation pattern are shown in Figure 2-4.[8] A reference radiation pattern should be applicable to almost all antennas of similar design. Recommendation (Rec.) ITU-R F.732 provides a methodology to develop the antenna sidelobe reference radiation pattern from the measurement data.[9]

8 Rec. ITU-R F.699-7, *Reference Radiation Patterns for Fixed Wireless System Antennas for Use in Coordination Studies and Interference Assessment in the Frequency Range from 100 MHz to about 70 GHz* (2006).

9 Rec. ITU-R S.732, *Method for Statistical Processing of Earth-station Antenna Side-Lobe Peaks* (1992).

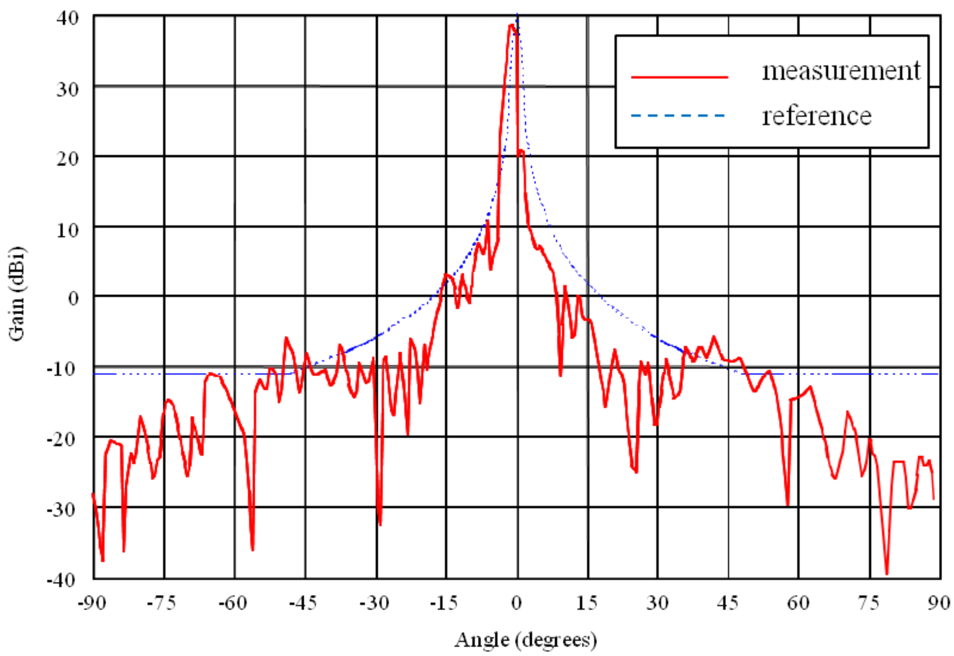


Figure 2-4. Comparison of Measured and Reference Radiation Patterns

Reference radiation patterns have been developed for many radio services for coordination studies, interference assessments, and as antenna design objectives. For coordination studies and interference assessments, however, the actual radiation pattern should always be used if it is available. As design objectives, the reference radiation pattern regulates the sidelobe levels with the provision of certain pre-determined error margin, e.g., no more than 5% of the real sidelobes should exceed the envelope by no more than 3 dB.

2.4.4 Reciprocity

The principle of reciprocity is a physics theorem. It is the extension of Newton's third law of motion that action and reaction are equivalent. Its application to the EM theory is that the same physics and mathematical formulas for describing the electric current in a radiator and the EM wave it generates can be used to describe the EM wave radiating upon the radiating device and the electric current induced in the device.

The application of this EM theory to the antenna theory is that an antenna's transmitting and receiving radiation patterns are the same.

2.5 Efficiency

The antenna *efficiency*, *e*, is the measure of an antenna's capability to convert the input power to the radiated power. It is the ratio of the radiated power P_{rad} to the antenna power P_{ant}, which is the same as the ratio of the power gain g_p to the directive gain g_d, i.e.,

$$e = \frac{P_{rad}}{P_{ant}} = \frac{g_p}{g_d} \qquad (2\text{-}9)$$

The antenna efficiency is the result of many effects: reflection mismatch, conduction or joule heating, dielectric, etc.

Depending on the requirements of a radio service or radio system, its antennas will have different practical *e* values. For instance, a space system should maximize the power utilization while minimizing interference from the sidelobe, and the resulting practical *e* value for an earth station dish antenna is between 0.6 and 0.65. Mobile cellular systems require small handheld phone sets with limited power supply, and the resulting practical *e* value for a monopole antenna is 0.7 or larger. Terrestrial systems have less concern about power conservation than the space systems, and the practical *e* value for the terrestrial antennas is approximately 0.55.

2.6 Beamwidth

The *half power beamwidth* (HPBW), ϕ_{bw}, or beamwidth, is the angle between the two directions of a two-dimensional radiation pattern at which the power gains are one-half of the peak gain. A toroidal beam or a circular torch beam has a single ϕ_{bw} parameter, and an elliptically shaped torch beam has two ϕ_{bw} parameters. Its value depends on the shape of the reflector, the method of illumination, and other factors.

A sketch of an antenna radiation pattern, its mainbeam, and ϕ_{bw} is shown in Figure 2-5.

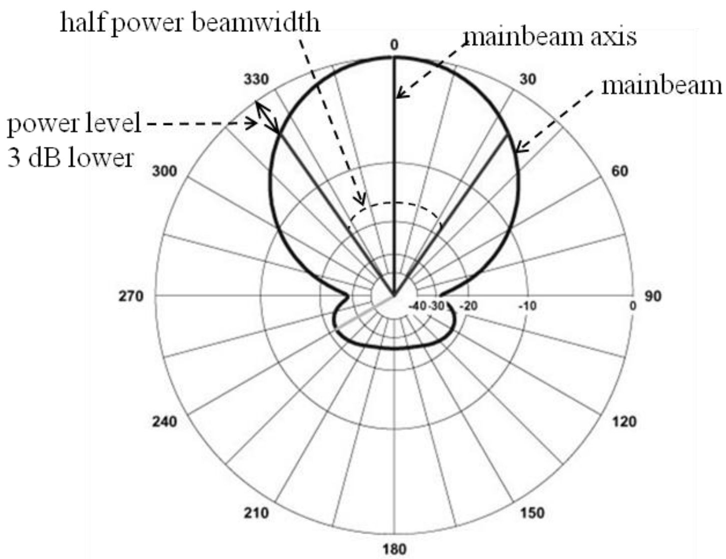


Figure 2-5. Antenna Beam and HPBW

2.7 Polarization

2.7.1 Characteristics

The *antenna polarization* refers to the polarization of the far-field EM wave generated by the antenna, while the polarization of the EM wave refers to the polarization of the electric-field of the EM wave. The EM wave can be linearly, circularly, or elliptically polarized. For a linearly polarized EM wave, the direction of its electric field is constant with respect to the direction of the wave propagation. For an elliptically polarized EM wave, the direction of its electric field rotates with respect to the direction of the wave propagation, and it can be either right-hand circular polarization (RHCP) or left-hand circular polarization (LHCP). Circular polarization is a special case of elliptical polarization where the major and minor axes of the rotation are the same.

In radio communications, linear polarization is designated according to the relationship of the polarization to the Earth, and is usually horizontal or vertical. For the terrestrial radio services, a radio signal is horizontally polarized when its electric-field is parallel to the horizontal plane (or ground), and it is vertically polarized when its electric-field is perpendicular to the horizontal plane. For the space radio services, a radio signal is horizontally polarized when its electric-field is parallel to the equatorial plane (or the east-west direction), and it is vertically polarized when its electric-field is perpendicular to the equatorial plane (or the north-south direction).

Characteristics of a radio system's propagation environment and operation may dictate the selection of polarization. For instance, in the case of propagation environment, vertical polarization is the preferred choice for a terrestrial radio relay system or broadcasting system due to the lossy characteristics of the ground. Or, circular polarization is the preferred choice for a space system operating in frequency bands subject to Faraday rotation in the ionosphere.[10] In the case of operation, circular polarization is the preferred choice for the mobile satellite systems because it is difficult to align the linear polarization of the mobile earth station terminals.

2.7.2 Co-Polarization and Cross-Polarization

When a radio signal has the same polarization as the antenna's designated polarization, the signal and the antenna are mutually "co-polarized." When the radio signal has orthogonal polarization to the antenna's designated polarization, i.e., horizontal vs. vertical or RHCP vs. LHCP, the signal and the antenna are mutually "cross-polarized."

While an antenna is designed with a specific polarization, the unavoidable imperfection of the antenna geometry and its mounting structures can cause the antenna to have cross-polarization characteristics in its operations. Therefore, an antenna is always associated with a co-polarization radiation pattern and a cross-polarization radiation pattern, and it always transmits and receives cross-polarized radio signals. A graph of an antenna co- and cross-polarization radiation patterns are shown in Figure 2-6.[11]

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10 The Faraday effect describes the reaction of an EM wave when it passes through a magnetic field. When an EM wave passes through a medium possessing magnetic field, e.g., ionosphere, the Faraday effect causes the polarization of the wave to rotate gradually. Therefore, this effect is also called Faraday rotation. The magnitude of the rotation is proportional to the square of the wavelength and the strength of the magnetic field in the direction of propagation. It causes polarization tiltation of a linearly polarized EM wave and phase shift of a circularly polarized EM wave.

11 http://www.nearfield.com/amta/Images/AMTA00_TS_Thm_05.jpg, accessed Nov. 9, 2011.

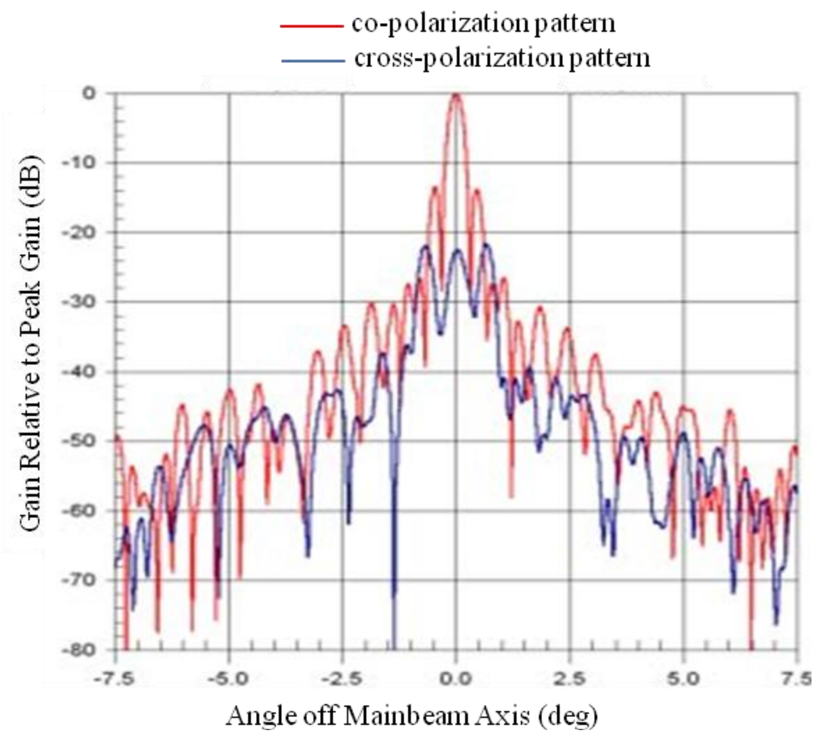


Figure 2-6. Comparison of Co- and Cross-Polarization Radiation Patterns

Most of the antennas operate with one polarization. An antenna can be dual-polarized if it can support both polarizations. A dual-polarization antenna is generally two antennas of orthogonal polarizations merged into one physical structure. If it is a wire antenna, the two wire antennas are in two layers. For a reflector antenna, it usually has two exciting sources of orthogonal polarizations and the microwave component capable of supporting both polarizations.

2.7.3 System Degradation due to Cross-Polarization

Reception of cross-polarized radio signals is undesirable, and the received signal power is considered part of the total noise power in EMC analyses. When a radio system interferes with another radio system of opposite polarization, EMC analyses should account for two cross-polarization interference components. The first one is the signal generated from the interfering antenna co-polarization radiation pattern and received by the victim antenna cross-polarization radiation pattern, and the second one is the signal generated from the interfering antenna cross-polarization radiation pattern and received by the victim antenna co-polarization radiation pattern.

A radio system is designed with the receiving antenna co-polarized with the intended incoming EM wave. However, when the polarization of the receiving antenna is misaligned with the polarization of the intended incident EM wave, part of the intended radio signal is not received by the receiver. This is called polarization mismatch, and the loss is called the polarization loss. This may occur when the atmosphere re-aligns the polarization of the EM wave during propagation, e.g., in satellite communications, a linearly polarized EM wave may experience Faraday rotation while passing through the ionosphere.

2.7.4 Orthogonal Polarization Frequency Reuse

Utilizing mutual discrimination between orthogonal polarizations, two radio systems may co-exist in the same environment while using the same frequency band with orthogonal polarizations. This is referred to as orthogonal polarization frequency reuse. With this practice, while both systems have to accept more noises from the cross-polarization signals, thus reducing each system's spectrum efficiency, the overall spectrum reuse more than makes up the loss.

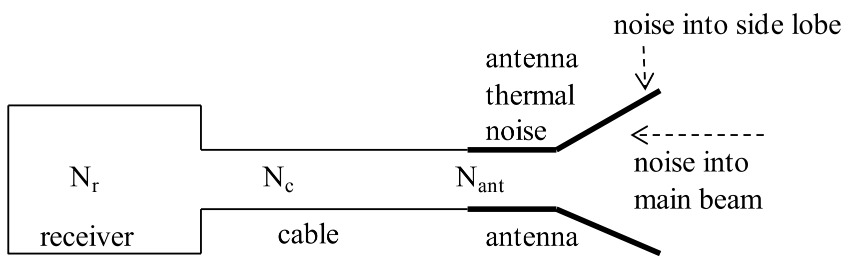
Space systems have benefit most from this practice. Due to the limited amount of spectrum allocated to space telecommunications, virtually all of the space telecommunication systems are designed with orthogonal polarization frequency reuse. Also, terrestrial radio systems have used orthogonal polarization frequency reuse to ease the congestion in frequency assignment.

2.8 Antenna Noise and System Noise

Antenna noise, N_{ant}, is the noise characteristics of a receiving antenna. It is the noise signals received by an antenna from the environment plus the noise generated by the antenna itself. It is measured at the antenna flange or output.

Environmental noise includes noise from the ground, the atmosphere, man-made noise, and noise from extraterrestrial objects. Ground noise is affected by the sizes and elevation angles of the lobes in the antenna radiation pattern. Atmospheric noise comes from rain, cloud, and snow, and the level of contribution is frequency dependent.

System noise, N_{sys} or simply N*,* is different from the antenna noise. N_{sys} is used to characterize a received signal's carrier power-to-noise power ratio (C/N) or signal power-to-noise power ratio (S/N). It is measured at the output of the receiver low noise amplifier; therefore it is confined within the receiver bandwidth *B*. It includes the antenna noise, noise from the transmission line between the antenna output and the receiver input, and noise from the receiver low noise amplifier. A block diagram of the receiving chain and accumulation of system noise is shown in Figure 2-7.



N_{ant} = antenna noise

N_c = cable noise

N_r = receiver noise

N_{sys} = system noise, $N_{sys} = N_{ant} + N_c + N_r$

Figure 2-7. Antenna Noise and System Noise

2.9 Bandwidth

Antennas are usually designed with a specific frequency, and their performance characteristics, e.g., gain and radiation pattern, are generally specified with that specific frequency. These characteristics change, generally deteriorate, as the operating frequency deviates from the specified frequency. The frequency range within which the performance characteristics maintain certain level with respect to the specified performance characteristics, e.g., 90%, is referred to as the antenna bandwidth.

Different types of antennas, e.g., wire or aperture antenna to be discussed in Section 3, have different bandwidth characteristics. In general, wire antennas have narrower bandwidths than aperture antennas. For instance, the bandwidth of a simple linear wire antenna is about 8–16% of its designed frequency. Therefore, much effort had been spent to develop broadband wire antennas by changing the physical shapes of the antennas.

SECTION 3. COMMON ANTENNA TYPES

3.1 Introduction

Antennas come in many structures, shapes, and sizes. The most common types of antennas are the wire antennas, aperture antennas, fractal antenna, and microstrip antennas. Another common type is the array antenna that consists of multiple radiating elements arranged and operated in specific correlation. Some of the common types of antennas are presented here.

3.2 Wire Antenna

Wire antennas are antennas that are constructed with wires. The shapes of the wires can be straight, circular, helix, and other variations. Sometimes the wires can be flattened to become long plates. Some of the common wire antennas, i.e., dipole antenna and its variations, loop antenna, helical antenna, Yagi-Uda antenna, and rhombic antenna, are presented here.

3.2.1 Dipole Antenna

A dipole antenna consists of two straight electric lines separated by a small gap at the center, and the power is fed at the center gap. A dipole antenna is shown in Figure 3-1.[12] The electric lines should be very thin, i.e., the linear dimension of its cross section is much smaller than the length of the line. It is an omnidirectional antenna, and its polarization is determined by the orientation of the electric line which can be horizontal, vertical, or at a slant.

Figure 3-1. Dipole Antenna

3.2.2 Variations of Dipole Antenna

Variations of a dipole antenna include short dipole antenna, half-wavelength dipole antenna, monopole antenna, V-shaped antenna, folded dipole antenna, Yagi-Uda antenna, whip antenna, etc.

12 http://www.fmdxantenna.com/proddetail.php?prod=FMDipUS, accessed Jan. 28, 2011.

(a) A short dipole antenna is a dipole antenna whose linear dimension is small compared with λ, i.e., < λ/10. Its gain is 1.5, or 1.8 dBi, and its HPBW is 90°. Short dipole antennas and its variations are commonly used in mobile communication devices.

(b) A half-wavelength dipole antenna is a dipole antenna whose linear dimension from tip to tip is λ/2. Its *directivity* $\mathcal{D}$ is 1.64, or 2.1 dBi, and its HPBW is 78°.

A half-wavelength dipole antenna provides a good match between the radiation resistance and the impedance of the transmission line. Therefore, it is used as the reference dipole antenna to specify the directive gain of an omnidirectional antenna. As a common practice, an omnidirectional antenna gain value is expressed as "x dB above a reference dipole antenna" and labeled as "x dBd".

(c) A monopole antenna is an antenna formed by replacing half of a dipole antenna with a perpendicular ground plane. When the ground plane is large enough, the reflection of the EM wave makes it behave exactly the same as the missing half of the dipole, and the monopole becomes a dipole. Therefore, it is also called a half-dipole antenna. It has a half-toroidal radiation pattern. Its radiation pattern in the vertical plane is shown in Figure 3-2.[13] The null at θ = 0° is the result of the lossy ground affecting the radiation pattern; this was discussed in Section 2.4.

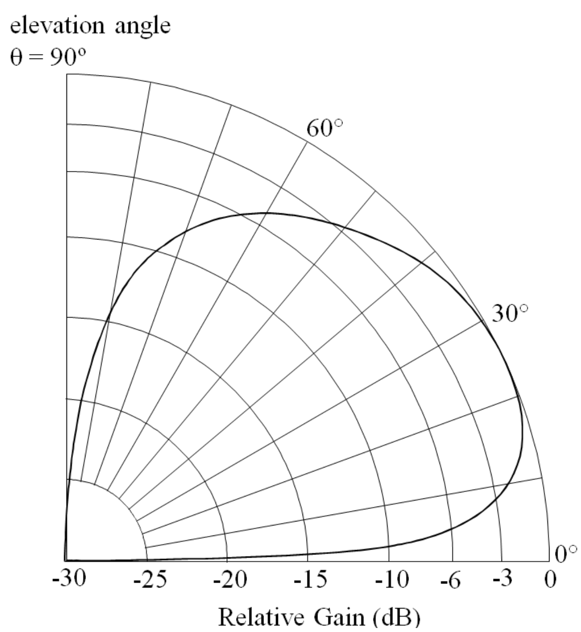


Figure 3-2. Monopole Antenna Radiation Pattern

(d) A folded dipole antenna is a dipole antenna with an additional electric line linking the two ends of the dipole. A folded dipole antenna is shown in Figure 3-3.[14] A folded half-wavelength dipole antenna works the same as a regular half-wavelength dipole, but is more efficient because its radiation resistance is 300 ohms instead of 75 ohms of a regular dipole.

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13 Rec. ITU-R BS.705-1, *HF transmitting and receiving antennas characteristics and diagrams* (1995).

14 http://www.starantenna.com/product-detail.asp?id=25, accessed Jan. 11, 2010.

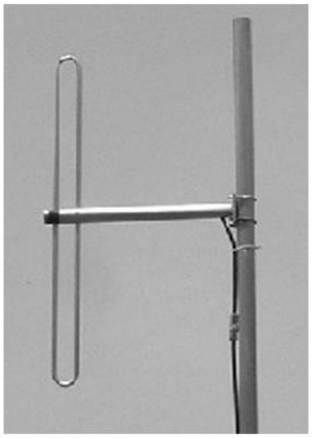

Figure 3-3. Folded Dipole Antenna

(e) A whip antenna is a monopole antenna whose electric line is stiff yet flexible. Whip antennas are widely used for mobile applications and hand-held radios. A vehicle-mounted whip antenna is shown in Figure 3-4.[15]

Figure 3-4. Vehicle-Mounted Whip Antenna

(f) A T-antenna is a monopole antenna whose end point is connected to the center of an orthogonal wire. The orthogonal wire provides capacitance load to the monopole antenna; it increases the radiation resistance but does not contribute to the radiation. A T-antenna and its radiation pattern are shown in Figure 3-5.[16] [17]

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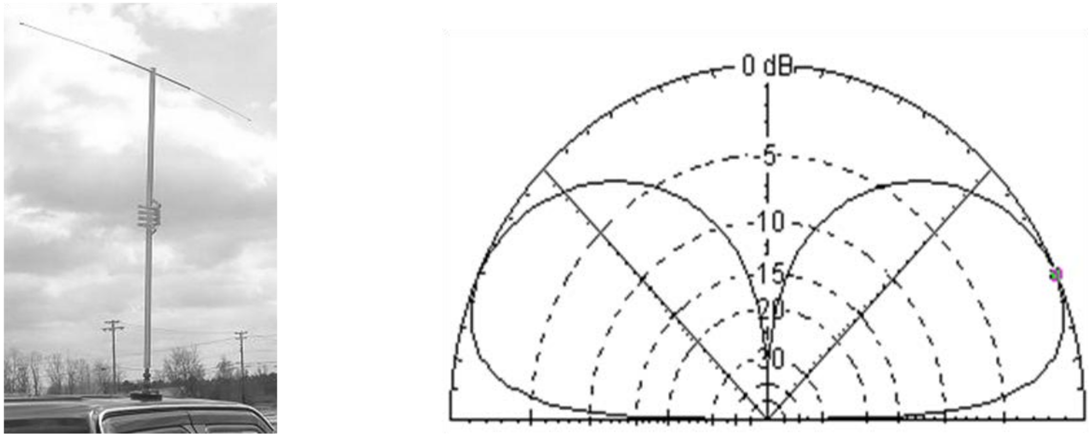
15 http://www.arraysolutions.com/Products/mobilewhip.htm, accessed Jan. 11, 2010.

16 http://www.chargercharger.com/Antennas.html, accessed Jan. 12, 2010.

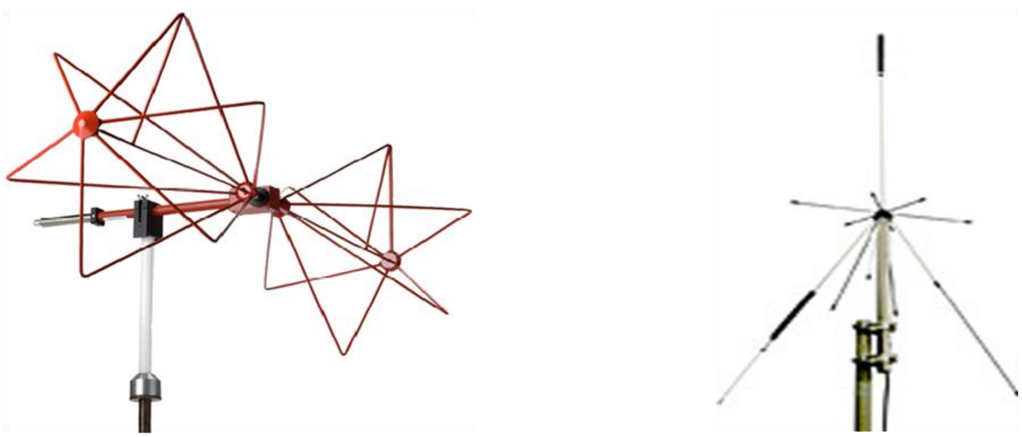
17 http://www.beru.org.uk/Antennas/ant160tee.htm, accessed Jan. 12, 2010.



(a) Vehicle-Top T-Antenna **(b) Vertical Radiation Pattern**

Figure 3-5. T-antenna

(g) A biconical antenna is a dipole antenna whose electric lines are replaced by cones of electric lines, with the cones having common axis and vertex, and facing opposite directions. In one variation, the conical electric lines may be replaced by mesh electric lines. In another variation, one of the cones has a vertex angle of 180º or becomes a ground plane; this is a discone antenna. A biconical antenna and a discone antenna are shown in Figure 3-6.[18] [19]



(a) Biconical Antenna **(b) Discone Antenna**

Figure 3-6. Biconical and Discone Antennas

(h) A V antenna is a dipole antenna whose electric lines are tilted to form a V shape. Large V antennas are usually hung vertically; it is a regular V antenna if the two end points are suspended and the corner is closer to the ground, or it can be an inverted-V antenna if the corner is suspended and the two end points are closer to the ground. Small V antennas, such as the TV set-top antennas, are commonly referred to as the "rabbit ears." The diagram of an inverted V antenna and the picture of a rabbit antenna are shown in Figure 3-7.

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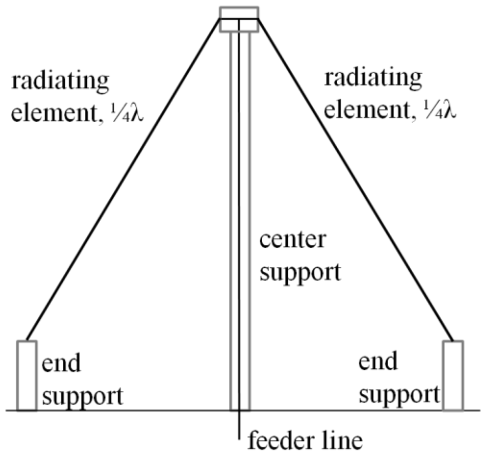
18 https://www.ets-lindgren.com/manuals/3110C.pdf, accessed Jan. 12, 2010.

19 http://www.diamond-ant.jp/ama2/eng_ama_2_5_1.asp, accessed Jan. 12, 2010.



(a) Diagram of Inverted V Antenna

(b) TV Set-Top Antenna

Figure 3-7. V Antenna

3.2.3 Loop Antenna

A loop antenna is a loop of electric line with two ends connecting to the two conductors of a transmission line. The loop may be of arbitrary shape, e.g., circular, square, triangular, or rhombic, and the antenna gain is proportional to the area enclosed by the loop. A circular loop requires rigid wire. Square and triangular loops are more practical because they can be installed with flexible electric lines. A loop antenna is more immune to the environmental noise because it does not need a ground plane. It is commonly used under the following conditions:

- when there is no available space for a long-wire antenna,
- to eliminate unwanted signals and noise,
- for radio direction finding, and
- to improve the performance of a simple receiving system by providing pre-selection that improves image rejection and adjacent channel selectivity.

A circular loop antenna has a similar radiation pattern to that of a dipole antenna; its radiation pattern is shown in Figure 3-8, where the axis of the toroidal radiation pattern coincides with the axis of the loop. The typical circumference of a circular loop is a multiple of $\lambda/2$. The *directivity* $\mathcal{D}$ can be approximated by

$$\mathcal{D} \approx 60\pi^2(C/\lambda) \qquad (3\text{-}3)$$

where C is the circumference of the loop.

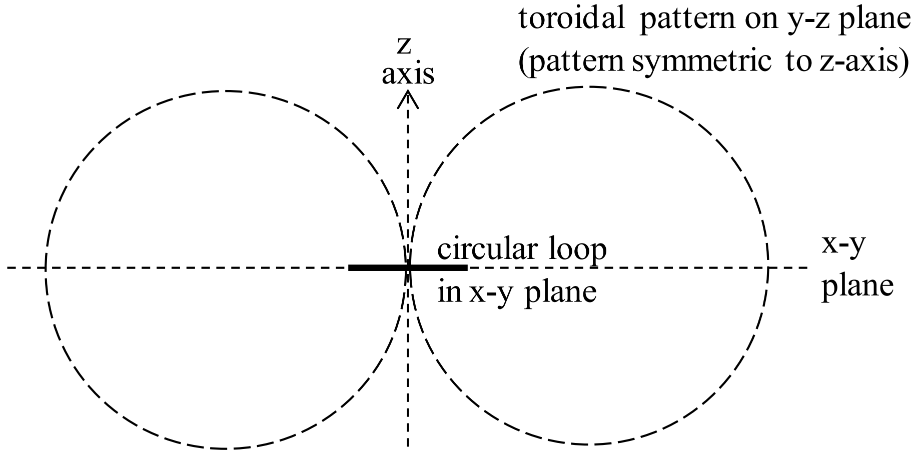


Figure 3-8. Circular Loop Antenna Radiation Pattern

When the circumference of a loop antenna is much less than λ, and typically less than λ/10, it is called a small loop antenna. Samples of small loop antennas are shown in Figure 3-9.[20] [21] It is also called a magnetic loop antenna because it reacts to the magnetic field of the EM wave. It is commonly used as the radio broadcasting receiving antenna.

(a) Loop Antenna

(b) Ferrite Rod Antenna

Figure 3-9. Small Loop Antenna

3.2.4 Helical Antenna

A helical antenna is a helically coiled electric line mounted on a ground plane. The diagram of a helical antenna is shown in Figure 3-10.[22] It is characterized by:

- L: length of the antenna,
- N: the number of turns of the coil,
- d: diameter of the coil,
- S: distance between the coils, and

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20 http://www.radioshack.com/product/index.jsp?productId=2405978, accessed Jan. 12, 2010.

21 http://www.galsys.co.uk/modules/ferrite-antenna.html.

22 http://www.w1ghz.org/antbook/conf/Helical_feed_antennas.pdf, accessed Jan. 12, 2010.

- a: diameter of the wire.

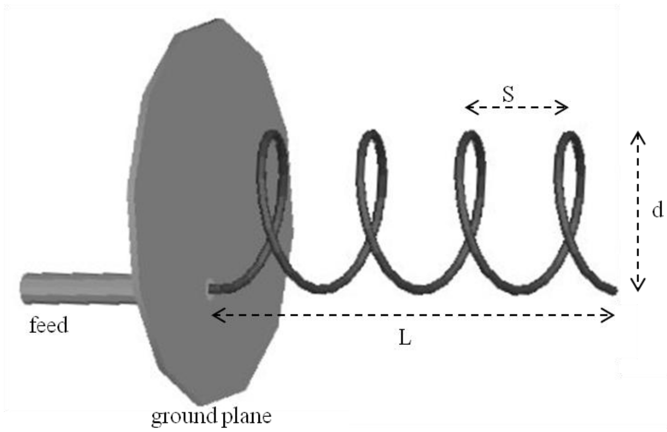


Figure 3-10. Helical Antenna

A helical antenna can operate in the axial or normal mode. The general polarization is elliptical, but linear and circular polarizations can be achieved under special conditions. The orientation of the polarization, RHCP or LHCP, is determined by the orientation of the coil.

Helical antennas operate in the axial, or end-fire, mode when L is comparable to λ. Its radiation pattern has a single mainbeam in the direction of the axis of the helix. It generates circular polarized EM wave when $\pi d/\lambda$ is in the range of 3/4–4/3, and optimum circular polarization occurs when $\pi d/\lambda = 1$ and $S = \lambda/4$. The orientation of the polarization is determined by the orientation of the coil. The image of an axial mode helical antenna installed on a satellite is shown in Figure 3-11(a).[23]

Helical antennas operate in the normal, or broadside, mode when L is much smaller than λ. It behaves like a monopole antenna with similar half-toroidal radiation pattern. One application of this antenna is the rubber ducky antenna widely used in portable radio devices, e.g., walkie-talkies, cell phones. The picture of a rubber ducky antenna installed on a hand-held device is shown in Figure 3-11(b).[24]

23 http://www.boeing.com/defense-space/space/bss/factsheets/376/gms/gms.html

24 http://www.californiasailplanes.com/RubberDuck.html

(a) Japan's Geostationary Meteorological Satellite

(b) Rubber Ducky Antenna on a Mobile Device

Figure 3-11. Applications of Helical Antennas

3.2.5 Yagi-Uda Antenna

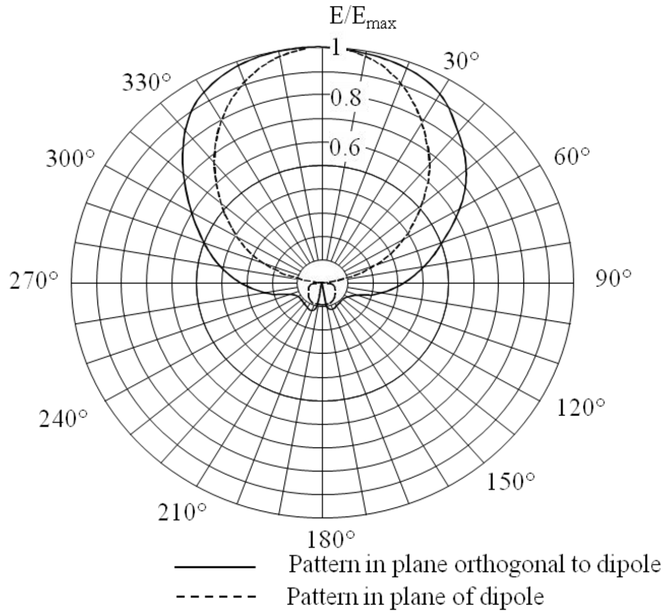
A Yagi-Uda antenna, sometimes called a Yagi antenna, consists of a dipole antenna and additional passive elements. A Yagi-Uda antenna and its radiation patterns are shown in Figure 3-12.[25] [26] The dipole antenna is the center element and the radiator. The longer pole at the right of the dipole antenna is a passive element and the reflector; it can be a single pole or a panel of poles. The shorter pole on the left is the second passive element and the director; the director may consist of more than one pole. This arrangement gives the antenna a directional beam from the reflector toward the director, and the antenna gain is proportional to its length.

(a) Antenna

(Figure 3-12)

25 http://www.starantenna.com/product-detail.asp?id=6, accessed Jan. 11, 2010.

26 Rec. ITU-R BS.1195, *Transmitting Antenna Characteristics at VHF and UHF* (1995).

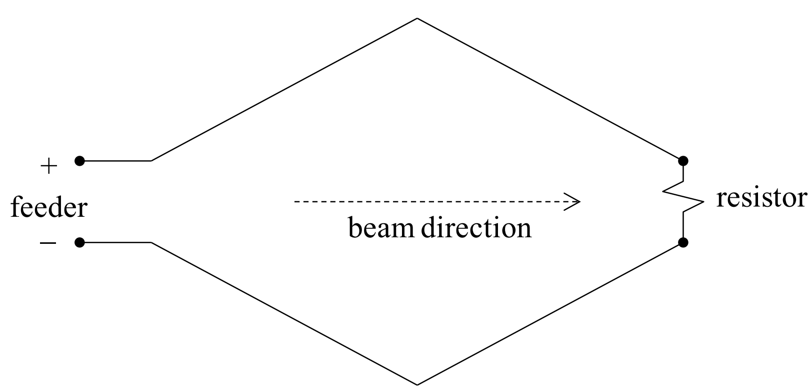


(b) Radiation Pattern

Figure 3-12. Yagi-Uda Antenna

3.2.6 Rhombic Antenna

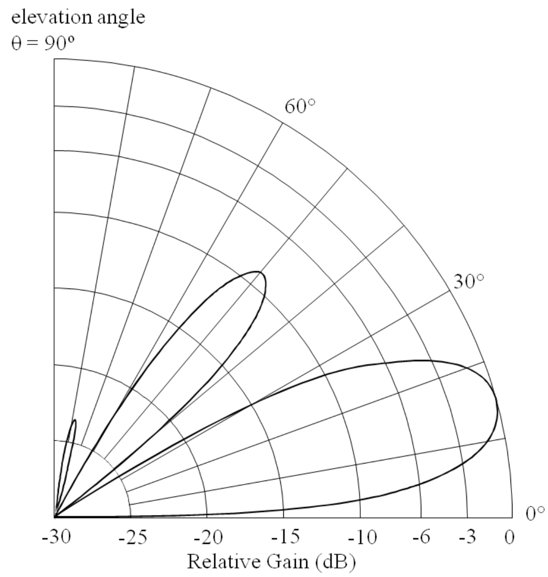
A rhombic antenna has four electric lines connected in a "rhombic" diamond shape, with each line typically one λ long. The diagram of a rhombic antenna and its vertical and horizontal radiation patterns are shown in Figure 3-13.[27] In the vertical pattern, the null in the horizontal plane is the result of the lossy ground affecting the radiation pattern; this was discussed in Section 2.4. It is fed at one of corners with an acute angle (i.e., less than 90°), and is terminated with a resistor at the opposite corner with an acute angle. The beam direction is toward the resistor end, and the gain depends on the rhombic geometry.



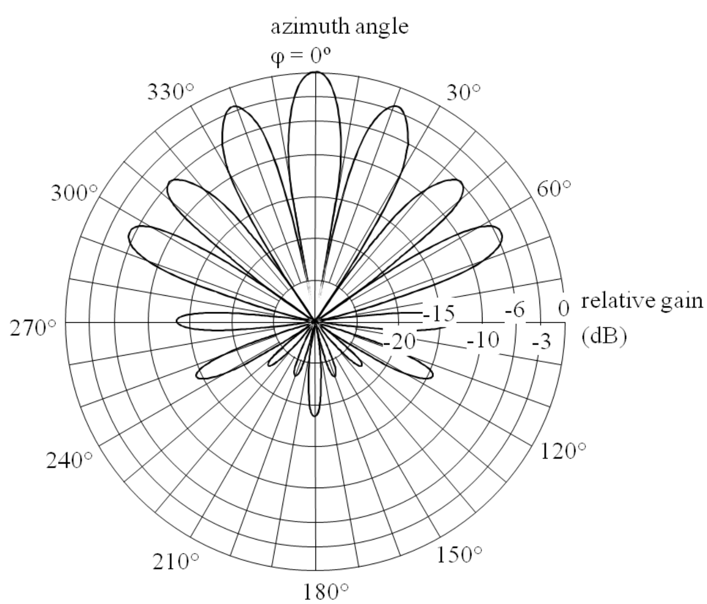
(a) Diagram

(Figure 3-13)

27 Rec. ITU-R BS.705-1, *HF transmitting and receiving antennas characteristics and diagrams*, Figures 88a, 88b (1995).



(b) Vertical Radiation Pattern



(c) Horizontal Radiation Pattern

Figure 3-13. Rhombic Antenna

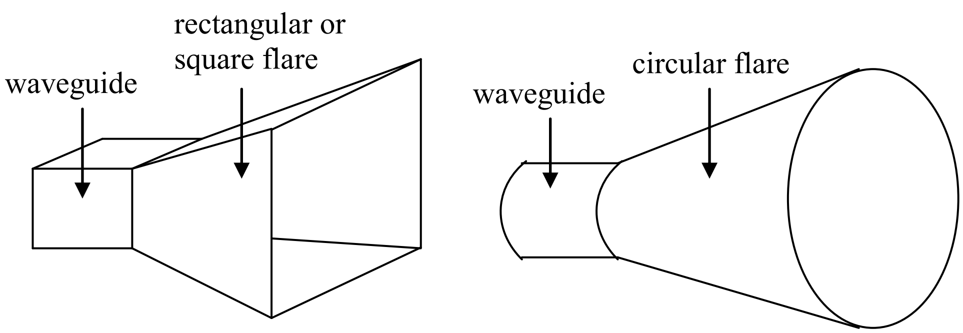
3.3 Aperture Antenna

Aperture antennas include waveguide antennas, slot antennas, horn antennas, and others.

(a) A waveguide antenna is a waveguide with an open end either in free space or mounted to a ground plane.

(b) A slot antenna is a metallic plate with a hole or slot cut out. The slot can radiate EM waves when the plate carries an electric current. The shape and size of the slot determine the radiation pattern and the gain.

(c) A horn antenna is a waveguide with an open end flared out like a horn. The flare can be square, rectangular, or circular. A rectangular or square flare forms a pyramidal horn, and a circular flare forms a conical horn. The diagrams of a pyramidal horn and a conical horn are shown in Figure 3-14. The gain of a horn antenna is proportional to the size of the aperture. A horn antenna offers moderate gain in a small and rugged package with no need for adjustment.



(a) Pyramidal Horn **(b) Conical Horn**

Figure 3-14. Horn Antenna

Variations of flare design create variations of horn antennas. For instance, the flare may be curved instead of straight, and the inner wall of the flare may be corrugated instead of smooth. Since the flare serves as a transducer of the EM wave from the waveguide to the open space, variation of the flare design modifies the field distribution at the aperture, which modifies the beam size and efficiency.

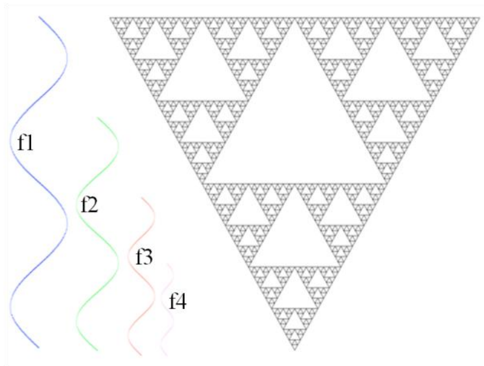
3.4 Fractal Antenna

A fractal is a geometric shape that can be divided into parts whose shapes are the reduced-size copy of the whole. Fractals are generally self-similar and independent of scale.

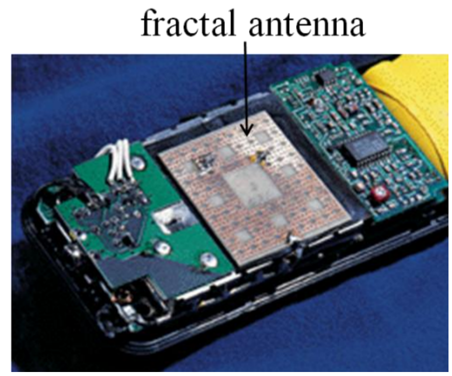
A fractal antenna uses a fractal to design its radiating part. Combining the property of a fractal and the scaling property in the antenna theory, a fractal antenna may operate in multiple frequency bands or wide frequency band. The diagram of a fractal antenna with four operating frequencies is shown in Figure 3-15(a).[28] Fractal antennas are compact, and are widely used in mobile devices, e.g., cell phones; the picture of a fractal antenna imbedded in a cell phone is shown in Figure 3-15(b).[29]

28 http://large.stanford.edu/courses/2012/ph250/ferguson1/images/f3big.png, accessed Oct. 15, 2012.

29 http://www.scienceprog.com/wp-content/uploads/2007i/fractal/cell_antenna.gif, accessed Oct. 15, 2012.



(a) Fractal Antenna and its Operating Frequencies

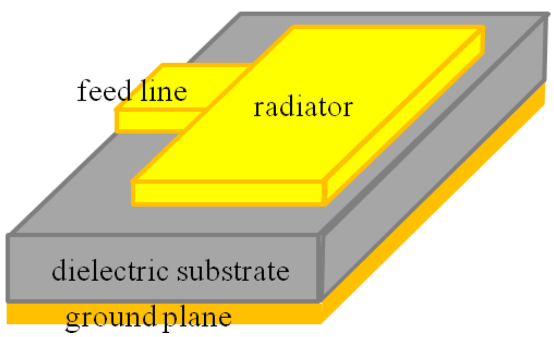


(b) Cell Phone with Fractal Antenna

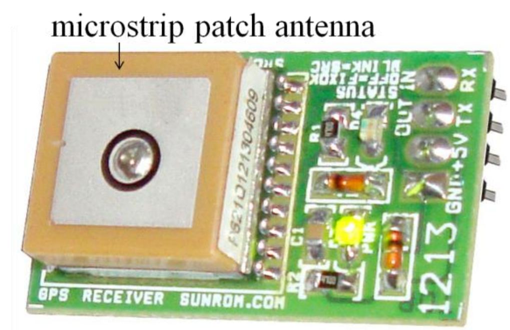
Figure 3-15. Fractal Antenna

3.5 Microstrip Antenna

A microstrip antenna, also known as patch antenna or printed antenna, consists of three layers: a metallic ground plane at the bottom, a dielectric substrate, and the metallic radiator. The radiator is fed with either a microstrip in the top layer or a coaxial line under the radiator through the ground plane and the substrate. The diagram of a microstrip antenna with the feed line in the top layer is shown in Figure 3-16(a).



(a) Sketch of Microstrip Antenna



(b) Microstrip Patch Antenna in GPS Receiver Circuit Board

Figure 3-16. Microstrip Antenna

A microstrip antenna is a narrowband, wide-beam antenna. It has low profile, it is lightweight, inexpensive to manufacture, and easy to integrate with accompanying electronics. Because of these features, it has become popular for cell phones or the global positioning system (GPS) receivers; the picture of a microstrip patch antenna mounted on a GPS receiver circuit board is shown in Figure 3-16(b).[30]

3.6 Lens Antenna

A lens antenna is a dielectric or glass device with the shape of convex paraboloid that causes light to either converge or diverge. A lens antenna and its mount are shown in Figure

30 http://www.sunrom.com/files/1213-datasheet.pdf, accessed Oct. 15, 2012.

3-17.[31] It is an optical device; therefore, it is suitable for transmitting and receiving EM wave in the optical frequency range. Lens antennas are used as meteorological aids optical sensors, radio telescopes, and in radio astronomy.

(a) Fresnel Lens (Showing Four Superimposed Lenses)

(b) Fresnel Lens Mounted in Conical Housing

Figure 3-17. Lens Antenna

3.7 Reflector Antenna

A reflector antenna has a radiator and at least one reflecting surface. The radiator, also called a feeder, can be a linear antenna or a horn antenna. The most common reflector antennas are the corner reflector antenna, parabolic antenna, paraboloidal antenna, and Cassegrain antenna. The paraboloidal and Cassegrain antennas are also called dish antennas.

Dish antenna sidelobe radiation level can be reduced with feeders of better radiation patterns and/or with the reflector edge modified from sharp corner to curvature in order to reduce edge diffraction, thus lowering the sidelobe and backlobe radiation levels. This has been a common practice to improve dish antenna sidelobe performance.

(a) A corner reflector antenna has two flat panels of either grid or solid plate and a radiator, usually a dipole, inside the corner. A corner reflector antenna is shown in Figure 3-18.[32]

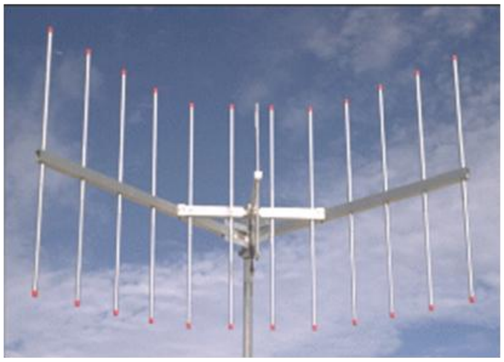


Figure 3-18. Corner Reflector Antenna

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31 http://www.quinstar.com/qla_lens_antennas.html, accessed Jan. 12, 2010.

32 http://www.ncjrs.gov/pdffiles1/nij/185030b.pdf, accessed Jan. 12, 2010.

(b) A parabolic antenna has one reflector that is a linear or curved continuation of a parabolic curve, and the radiator is typically a dipole antenna. The diagram of a parabolic antenna is shown in Figure 3-19. The radiator is located in the center of the linear structure at the focal point of the parabolic curve. It has an elliptical beam.

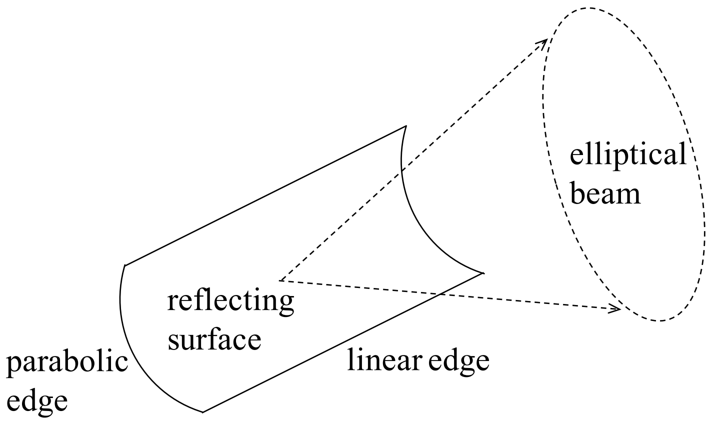
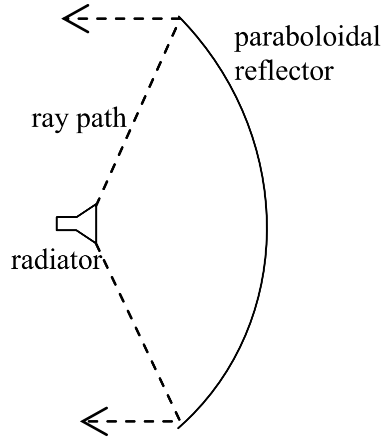


Figure 3-19. Diagram of Parabolic Antenna

(c) A paraboloidal antenna has a single reflector in the shape of a paraboloid, and the radiator is a horn antenna. A paraboloidal antenna and its diagram are shown in Figure 3-20.[33] The radiator is located at the focal point of the paraboloid. It has a circular mainbeam. To reduce weight as well as lessen the affect of the wind loading, the reflector may be made with grid or mesh instead of a solid surface; such an antenna is also called a grid antenna. The antenna in Figure 3-20(a) is a grid antenna.

(a) Paraboloidal Antenna

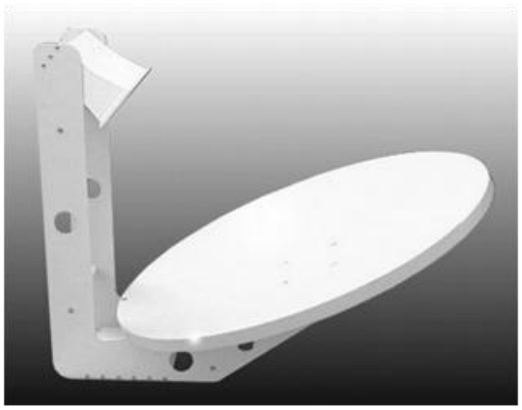


(b) Diagram

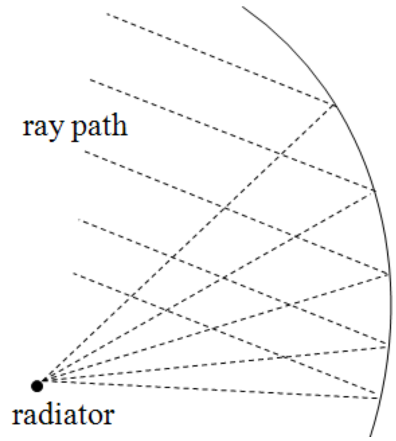
Figure 3-20. Paraboloidal Antenna

33 http://www.starantenna.com/product-detail.asp?id=10, accessed Jan. 13, 2010.

(d) An offset-fed reflector antenna is a variation of the reflector antenna. The reflector, either parabolic or paraboloidal, is only a portion of the conventional reflector. The radiator, still located at the focal point, is kept away from the EM wave propagation path. An offset-fed reflector antenna and the diagram of the radiator position relative to the EM wave propagation path are shown in Figure 3-21.[34] The main purpose of this design is to lower the sidelobe levels.



(a) Offset-Fed Antenna

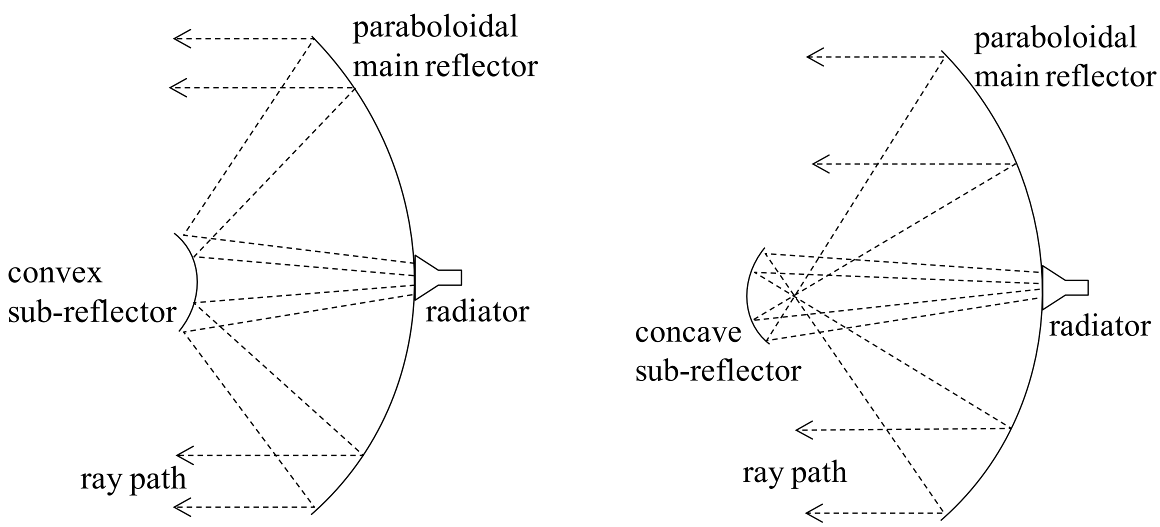


(b) Diagram

Figure 3-21. Offset-Fed Antenna

(e) A Cassegrain antenna or the Gregory antenna is another variation of the reflector antenna. Diagrams of the Cassegrain and Gregory antennas are shown in Figure 3-22. The radiator is a horn antenna, and the main reflector has a hole at the center of the paraboloidal surface to accommodate the opening of the horn antenna. A sub-reflector is positioned in front of the radiator to reflect the EM wave back to the main reflector. The sub-reflector of the Cassegrain antenna is convex relative to the main reflector, and the sub-reflector of the Gregory antenna is concave relative to the main reflector.

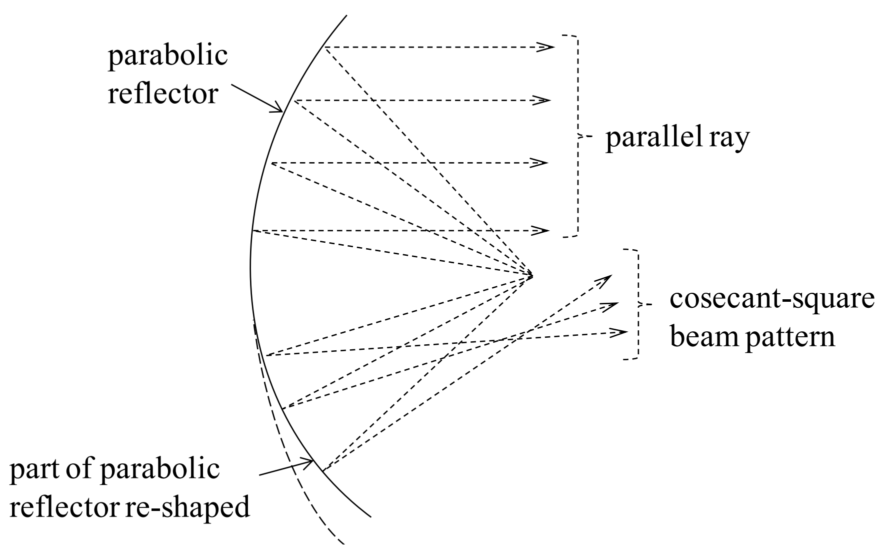
34 http://www.q-par.com/products/reflector-antennas/1-2-m-reflector-antennas, accessed Jan. 12, 2010.



(a) Cassegrain Antenna **(b) Gregory Antenna**

Figure 3-22. Diagrams of Cassegrain and Gregory Antennas

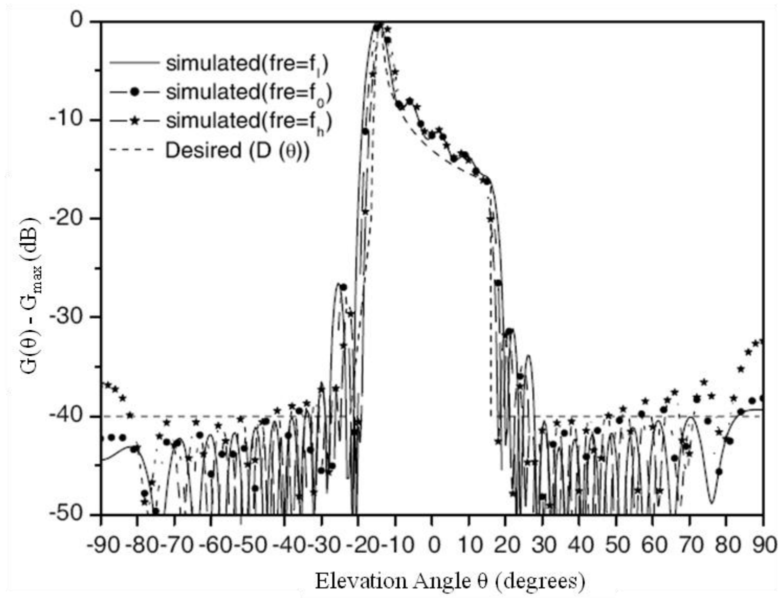
(f) A cosecant-square antenna is a modified parabolic antenna with part of the reflector surface re-shaped to form an asymmetric radiation pattern. The diagram of the reflector surface re-shaping and the resulting radiation pattern are shown in Figure 3-23.[35] This antenna is suitable for surveillance operation, with the cosecant-square part of the mainbeam covering the intended space of surveillance.



(a) Beam Shaping by Re-Shaping the Reflector

(Figure 3-23)

35 http://www.jpier.org/PIERC/pierc15/20.10072506.pdf, accessed Nov. 1, 2010.



(b) Radiation Pattern

Figure 3-23. Cosecant-Square Antenna

3.8 Array Antenna

An array antenna consists of a group of radiators arranged in a special geometrical configuration and operated coherently as a single unit. The individual radiator can be any antenna, e.g., wire, aperture, fractal, or microstrip antenna. The array format is usually linear or planar. By correlating the excitation amplitudes and phases of the radiators, an array antenna may perform beam scanning and other functions electronically rather than mechanically. Some of the typical array antennas, i.e., log-periodic antenna, phased array, collinear array, and slotted array, are discussed here.

(a) A log-periodic antenna is a dipole array where the length and spacing of the diploes increase logarithmically from one end to the other. It is a broadband, unidirectional, narrow-beam antenna. The picture of a log-periodic dipole array, its diagram, and radiation patterns are shown in Figure 3-24.[36] [37]

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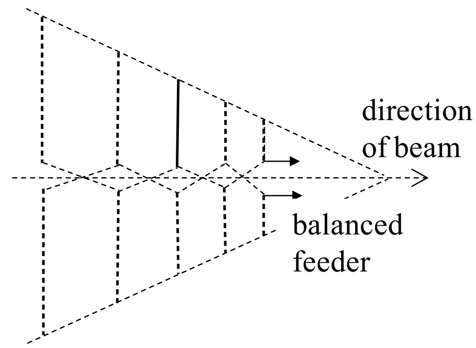
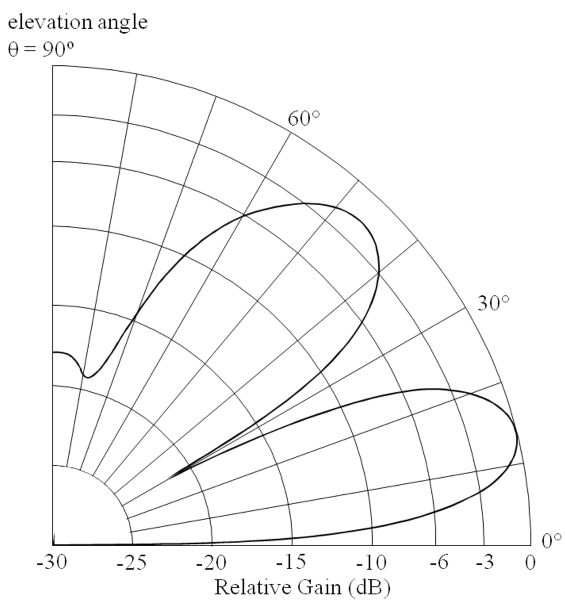
36 http://www.ncjrs.gov/pdffiles1/nij/185030b.pdf, accessed Jan. 12, 2010.

37 Rec. ITU-R BS.705-1, *HF transmitting and receiving antennas characteristics and diagrams*, Figures 84a, 84b (1995).

(a) **Horizontal Log-Periodic Antenna**

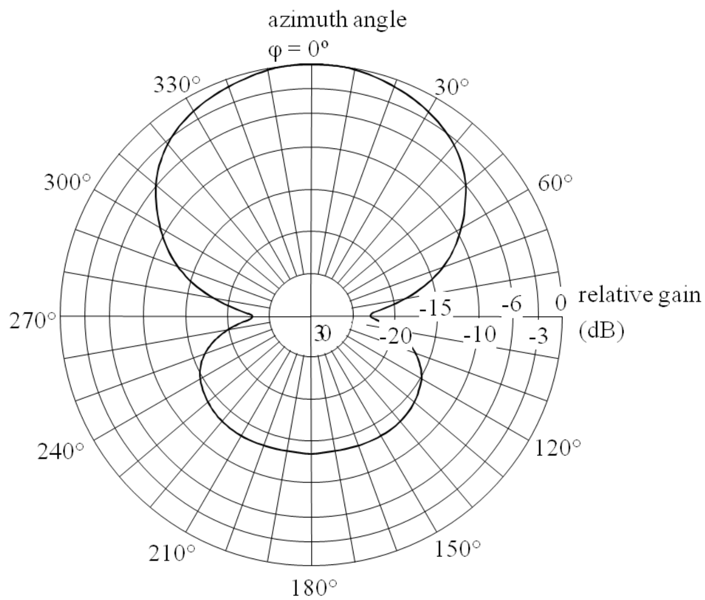


(b) **Diagram**



(c) Vertical Radiation Pattern of Horizontal Log-Periodic Antenna

(Figure 3-24)



(d) Horizontal Radiation Pattern of Horizontal Log-Periodic Antenna

Figure 3-24. Log-Periodic Antenna

(b) A phased array is an array antenna in which the relative phases of the antenna elements are varied coherently in a controlled format such that the radiation pattern, e.g., the beamwidth and direction of the mainbeam, can change as desired. Therefore, the complete system includes the array elements, the electronic circuit behind the array elements, and the computer system controlling the electronic circuit. Pictures of land-based phased array radar and shipborne phased array radar are shown in Figure 3-25; the arrays are the flat panels mounted on the walls.[38] [39]

(a) Land-Based Radar

(b) Shipborne Radar

Figure 3-25. Phased Arrays

38 http://en.wikipedia.org/wiki/File:SSPARS_radar,_Clear_AFB.JPG, accessed Jan. 13, 2010.

39 http://www.nssl.noaa.gov/research/radar/par.php, accessed Jan. 13, 2010.

When the spacing between array elements is larger than half a wavelength, the levels of some sidelobes can approach the level of the main lobe; these are called the grating lobes. Interference caused by the grading lobes can seriously affect the antenna performance. Grading lobes do not appear when the spacing between array elements is less than half a wavelength.

(c) A collinear array is a dipole array; the dipoles are either parallel or orthogonal to the axis of the array, and the centers of the dipoles may be offset from the axis of the array. Two types of collinear arrays are shown in Figure 3-26.[40 41] The array can flatten the toroidal radiation pattern of a standard dipole antenna to provide higher gain.

(a) Vertically Aligned Array

(b) Horizontally Aligned Array

Figure 3-26. Collinear Array Antenna

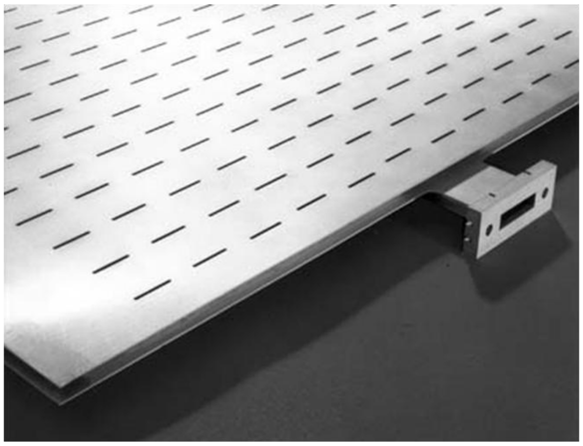
(d) A slotted array is an array of radiating slots. The array may be slots cut into a waveguide plane, with each slot interrupting the current flow and coupling power from the waveguide modal field into free space. It also may be constructed with waveguides whose radiating ends are placed side-by-side to form the slotted plane; this makes it a phased array. These two types of slotted arrays are shown in Figure 3-27.[42 43] Slotted arrays can be used in terrestrial telecommunication systems and airborne radars.

40 http://home.comcast.net/~ross_anderson/sc.htm, accessed Jan. 13, 2010 .

41 http://www.electronics-tutorials.com/antennas/antenna-basics.htm, accessed Jan. 13, 2010.

42 http://www.l-3com.com/randtron/slotarry.htm, accessed Jan. 13, 2010.

43 http://www.es.northropgrumman.com/solutions/aesaradar/assets/review_aesa.pdf, accessed Jan. 13, 2010.



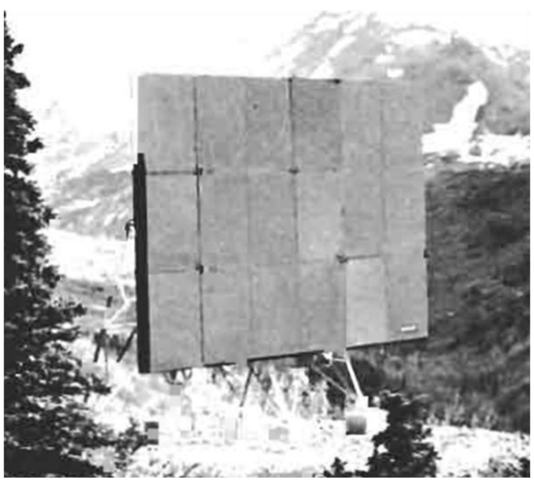
(a) Array on a Single Waveguide

(b) Array with Independent Feeds

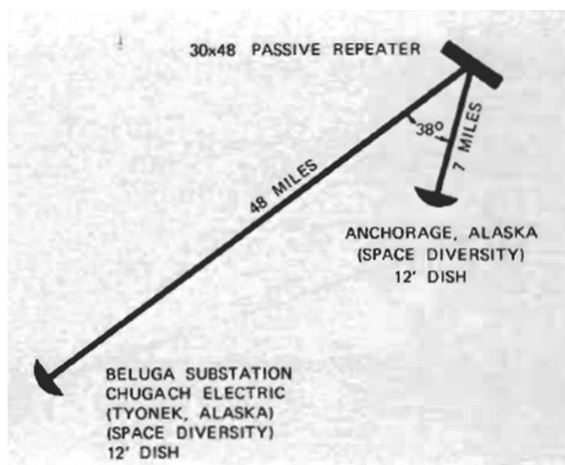
Figure 3-27. Slotted Array

3.7 Billboard Reflector

A billboard reflector is a passive repeater that redirects the EM wave to a new direction. It is usually a flat panel of rectangular or square shape. The picture of a billboard reflector is shown in Figure 3-28(a).[44] Technically, it is not an antenna because it is not attached to an active device, i.e., a transmitter or a receiver. Nevertheless, it has been used in terrestrial radio systems to overcome obstructions or reduce the number of active repeaters. The sketch of its role in a terrestrial radio link is shown in Figure 3-28(b). More information, including the radiation patterns, can be found in a handbook widely referred to in the industry. [Ref. 44]



(a) Billboard Reflector



(b) Billboard Reflector in Terrestrial Radio Link

Figure 3-28. Billboard Reflector

44 Microflect, Manual No. 161A, *Passive Repeater Engineering*, http://www.valmont.com/userfiles/file/specialty_structures/Catalog161A.pdf, accessed Sep. 12, 2012.

3.8 Gains of Typical HF-Band Linear Antennas and Arrays

For easy reference for the spectrum managers, the typical gain data of some common linear antennas and arrays operating in the High Frequency (HF, 3–30 MHz range) band are presented in Table 3-1. These data are from the *Antenna Engineering Handbook* published by the former DoD Electromagnetic Compatibility Analysis Center (ECAC).[45]

Table 3-1. Typical Gain Values of Selected Linear Antennas and Arrays Operating in the HF Band

Antenna Type	Gain Range (dBi)
Horizontal Rhombic (Approximately 6λ Leg Length)	18 – 20
Sloping Rhombic (Termination Height < Feed Height)	15 – 17
Sloping Double Rhombic	22 – 25
Vertical Half-Rhombic (6λ to 8λ Leg Length)	8 – 10
Curtain Array (4-Stack, 2-Bay)	18 – 22
Yagi-Uda (5-Element)	10 – 12
Horizontal Log-Periodic (12-Element)	8 – 10
Vertical Log-Periodic (12-Element)	7 – 8
Terminated Sloping V	7 – 8
Sloping Long Wire	7 – 10
Half-Wavelength Horizontal Dipole	5 – 6
Half-Wavelength Vertical Dipole	0 – 2
Arbitrarily-Tilted Half-Wavelength Dipole	3 – 4
Inverted-L	3 – 5
Quarter-Wavelength Vertical Monopole with Large Ground Screen	4 – 5
Quarter-Wavelength Vertical Monopole Without Ground Screen	-1 – 1
Monopoles Wit Lengths Varying between 0.0155λ and 0.35λ	-20 – 5

45 *ECAC Antenna Engineering Handbook*, Department of Defense Joint Spectrum Center, Annapolis, MD 1985, Section 2.3.4.

SECTION 4. ANTENNA ESTIMATION AND MODELING TECHNIQUES

4.1 Introduction

Several commonly used tools for modeling antenna performance are presented in this section. These include equations, algorithms, etc.

4.2 Directional Antenna Directivity Calculation

For directional antennas, the directivity $\mathcal{D}$ is related to the size of the mainbeam by

$$\mathcal{D} = \frac{4\pi}{\Omega(\text{steradian})} \tag{4-1}$$

where Ω is the mainbeam solid angle.

For an elliptical-beam antenna, $\mathcal{D}$ can be estimated with

$$\mathcal{D} \approx \frac{41253}{\phi_{bw1}(\deg)\times\phi_{bw2}(\deg)} \tag{4-2}$$

where ϕ_{bw1}, ϕ_{bw2} are the maximum and minimum ϕ_{bw} of the elliptical beam. An antenna of circular beam has $\phi_{bw1} = \phi_{bw2} = \phi_{bw}$.

4.3 Circular Reflector Antenna Gain and Beamwidth Calculation

The gain, g, of an aperture antenna is

$$g = e\frac{4\pi}{\lambda^2}A \tag{4-3}$$

where

e: efficiency,
λ: wavelength, and
A: the area size of the aperture cross section.

Therefore, the gain of a circular reflector antenna is

$$g = \frac{e\pi^2 D^2}{\lambda^2} = \frac{e\pi^2 D^2 f^2}{c^2} \tag{4-4}$$

where

D: diameter of the aperture of the circular reflector,
f: frequency, and
c: speed of light.

Assuming $e = 0.55$, the following equations can be used to estimate the gain value g of a circular reflector antenna:

$$g \approx 60.314 \times D(\text{meter})^2 \times f(\text{GHz})^2 \quad \text{(number)} \quad \text{(4-5a)}$$

$$G \approx 20 \times \log\left[D(\text{meter}) \times f(\text{GHz})\right] + 17.8 \quad \text{(dBi)} \quad \text{(4-5b)}$$

$$G \approx 20 \times \log\left[D(\text{feet}) \times f(\text{GHz})\right] + 7.5 \quad \text{(dBi)} \quad \text{(4-5c)}$$

The HPBW, ϕ_{bw}, can be estimated with

$$\phi_{bw} \approx \frac{70 \times \lambda}{D} \quad \text{(4-6a)}$$

$$\phi_{bw} \approx \frac{21}{f(\text{GHz}) \times D(\text{meter})} \quad \text{(deg.)} \quad \text{(4-6b)}$$

$$\phi_{bw} \approx \frac{69}{f(\text{GHz}) \times D(\text{feet})} \quad \text{(deg.)} \quad \text{(4-6c)}$$

4.4 Formulas for Modeling

Federal agencies use various formulas to model the antenna radiation pattern. For instance, the Wolfgain and Statgain models, developed by the Department of Defense (DoD) Joint Spectrum Center (JSC), are the current default radiation patterns for the low-gain and high-gain antennas in the spectrum management software programs *Spectrum XXI* and *iQ•link*. NTIA uses both software programs to conduct the frequency assignment task for the federal radio systems. Also, the *Antenna Engineering Handbook* from ECAC provided three masks for developing the antenna reference radiation patterns. These formulas and masks are presented here. In general, an antenna of $G < 10$ dBi is classified as low-gain, and an antenna of $G \geq 10$ dBi is classified as high-gain.[46]

4.4.1 Wolfgain Formula for Low-Gain Antenna

The Wolfgain formula provides a simple and conservative method to calculate the Fixed Service and Land Mobile Service antenna reference radiation patterns when $G_{max} < 10$ dBi.[47]

The reference radiation pattern, $G(\phi)$, as a function of the angle off mainbeam axis, ϕ, is

$$G(\phi) = G_{max}\left\{1 + \frac{2 \cdot G_{max}}{Q}\left[1 - \cos(\phi)\right]\right\}^{-1.25} \quad \text{(dBi)} \quad \text{(4-7a)}$$

where

46 Another convention of classifying antenna gain is as follows. Antennas of $G_{max} < 10$ dBi, $10 < G_{max}(\text{dBi}) < 25$, and $G_{max} > 25$ dBi are classified as low-gain, medium-gain, and high-gain, respectively.

47 H. Maddoxs, *Antenna Gain Estimation*, Joint Spectrum Center, Annapolis, MD (1974).

$$Q = 3.0 \times \left(1 + 3400 \times e^{-0.77G_{max}}\right) \qquad (4\text{-}7b)$$

e: Euler's number, base of the natural logarithm.

Figure 4-1 shows the Wolfgain patterns for G_{max} = 3, 6, and 9 dBi.

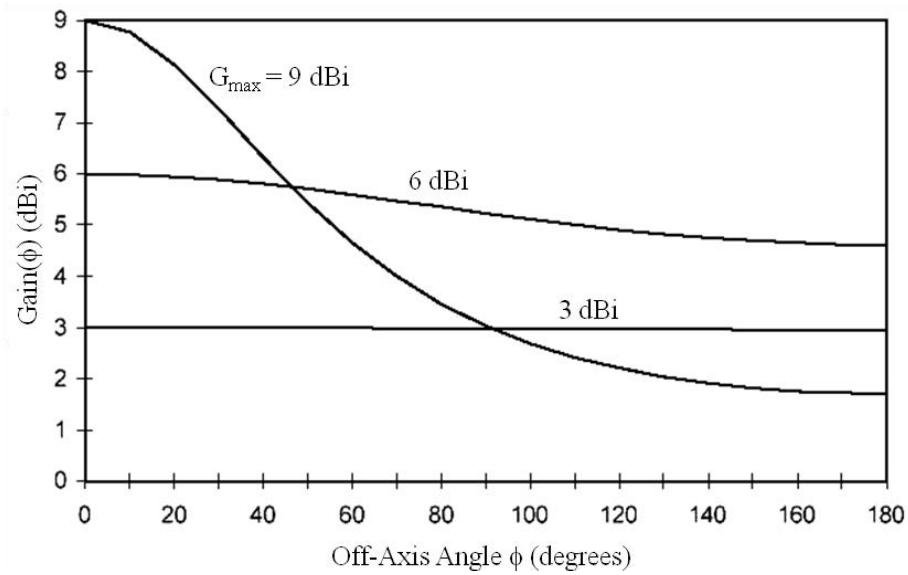


Figure 4-1. Wolfgain Pattern

4.4.2 Statgain Formula for High-Gain Antenna

The Statgain formulas are used to calculate the Fixed Service antenna reference radiation pattern when $G_{max} \geq 10$ dBi.[48]

The reference radiation patterns, G(ϕ), as a function of the angle off mainbeam axis, ϕ, are shown in Table 4-1, and the Statgain pattern is presented in Figure 4-2.

Table 4-1. Statgain Formulas

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 4 \times 10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(dBi) < 48$	$G_{max} - 4 \times 10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$

48 *EASY Statistical Antenna Gain Model for Fixed-Azimuth Antennas*, ECAC-TN-85-023, Joint Spectrum Center, Annapolis, MD (1985).

$10 \le G_{max}(dBi) < 22$	$G_{max} - 4 \times 10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \le \phi_{b3}$
	0	$\phi_{b3} < \phi \le 180°$

All angles are in deg.

$$\phi_m = 50(0.25G_{max} + 7)^{0.5} / \left(10^{G_{max}/20}\right)$$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250 / \left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

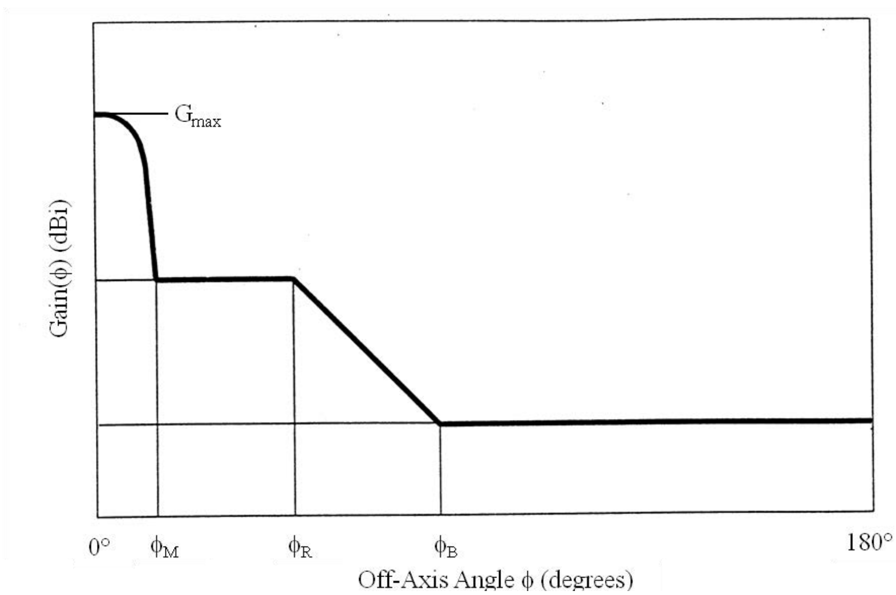


Figure 4-2. Statgain Pattern

4.4.3 ECAC Masks for Developing Reference Radiation Pattern

To develop an antenna reference radiation pattern, ECAC provides three groups of masks applicable to antennas of G_{max} < 10 dBi, 10 dBi ≤ G_{max} ≤ 25 dBi, and G_{max} > 25 dBi.[49] The masks are for antennas with elliptical beams. Each group has masks for co-polarization and cross-polarization radiation patterns. Also, each group covers the following three types of operating environments:

- open: environment with few surrounding buildings, towers, antennas, or other man-made or natural objects within sight of the antenna to reflect, refract, or scatter the EM wave,
- crowded: environment with great number of such objects, and
- average: environment within the above two extremes.

49 *ECAC Antenna Engineering Handbook*, Department of Defense Joint Spectrum Center, Annapolis, MD 1985, Sections 3.2.6.3 and 3.2.6.4.

The mask for antennas of G_{max} < 10 dBi has two regions: the mainbeam and sidelobe regions. This mask is presented in Table 4-2. The formulas in Table 4-2 are re-formatted from the original ECAC specification. ECAC specifies masks for the elevation and azimuth planes separately, and ϕ_{bw} for the two masks have different values. However, technically the characteristics of an elliptical beam should be specified in terms of the maximum and minimum ϕ_{bw} in the major and minor axes of the ellipse, and the orientation of the beam is a matter of antenna operation. By specifying ϕ_{bw} in the elevation and azimuth planes, it implies that the antenna mainbeam axis is in the horizontal plane, which then implies that the antenna is for terrestrial radio services.

Table 4-2. ECAC Antenna Radiation Mask for G_{max} < 10 dBi

Polarization	Max. Gain Value (dBi)	Angular Range
Co-polarization	G_{max}	$0 \le \phi \le \phi_{bw}$
	x	$\phi_{bw} < \phi$
Cross-polarization	G_{max} - 3	$0 \le \phi \le 1.5\phi_{bw}$
	x	$1.5\phi_{bw} < \phi$
ϕ: angle off mainbeam axis in the direction of interest ϕ_{bw}: HPBW in the direction of interest x = -7, -5, -3 for open, average, and crowded environment, respectively.		

The mask for antennas of $G_{max} \ge 10$ dBi has the following patterns. The co-polarization pattern has three regions: the mainbeam, near sidelobe, and far sidelobe regions. The cross-polarization pattern has two regions: the mainbeam and sidelobe regions. This mask is presented in Table 4-3.

Table 4-3. ECAC Antenna Radiation Mask for $G_{max} \ge 10$ dBi

(a) Mask

Polarization	Max. Gain Value (dBi)	Angular Range
Co-polarization	G_{max}	$0 \le \phi \le \phi_{bw}$
	G_{max} - a	$\phi_{bw} < \phi \le c\phi_{bw}$
	b	$c\phi_{bw} < \phi$
Cross-polarization	G_{max} - x	$0 \le \phi \le z\phi_{bw}$
	y	$z\phi_{bw} < \phi$
ϕ: angle off mainbeam axis in the direction of interest ϕ_{bw}: HPBW in the direction of interest		

(b) Parametric Value

G_{max} Range	Environment	Parametric Value					
		Co-polarization			Cross-polarization		
		a	b	c	x	y	z
G_{max} > 25 dBi	Open	35	-15	8	15	-15	7
	Average	31	-10	8	15	-10	7
	Crowded	27	-5	8	15	-5	7
$G_{max} \leq$ 25 dBi	Open	20	-10	2	10	-10	3
	Average	18	-8	2	10	-8	3
	Crowded	15	-5	2	10	-5	3

4.5 Numerical Methods for Computational Modeling

Antenna modeling by numerical methods implemented with computer software can estimate antenna radiation patterns. Two widely used methods for developing modeling software, the *Method of Moments* and *Uniform Theory of Diffraction* (UTD), are introduced here. Detailed explanations of these methods are available in many *Antenna Theory* textbooks.[50] [51]

4.5.1 Method of Moments

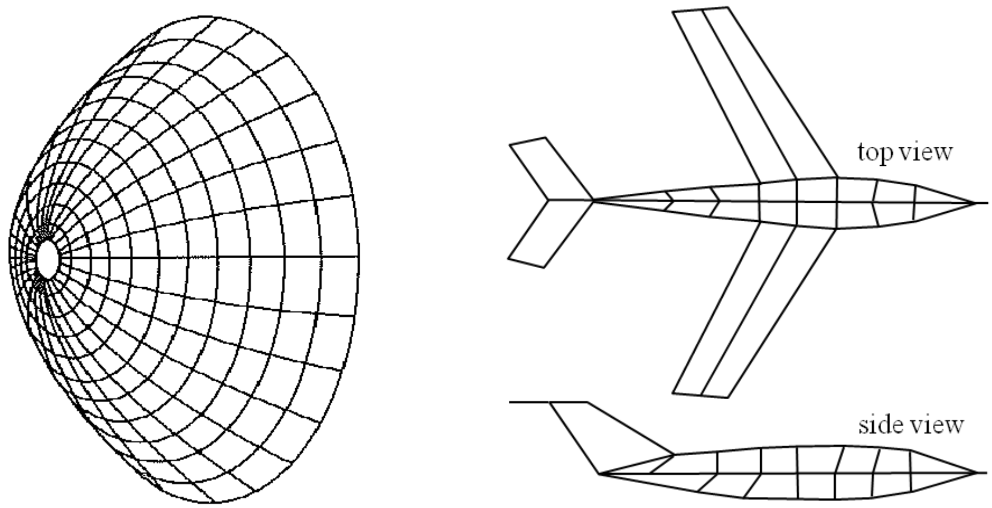
An antenna radiation pattern can be developed when the electric current over its metallic surface is known.

For wire antennas, the *Method of Moments* derives the current from a set of base functions and the boundary condition of zero electric field at the surface of the metallic object.

When the antenna has a solid planar surface, e.g., a reflector antenna, the *Method of Moments* can be implemented by modeling the planar antenna as a structure of meshed wire. Physically, this is similar to the same functionalities of a solid reflector antenna and a mesh reflector antenna as described in Section 3.7. The schematic diagram of modeling a paraboloidal antenna with meshed wire is shown in Figure 4-3(a). When an antenna is embedded in a metallic structure, e.g., airborne antenna on an aircraft, the *Method of Moments* can be implemented by modeling the whole airplane platform as a structure of wire grid. The schematic diagram of modeling an airplane with wire grid is shown in Figure 4-3(b); in this figure, the antenna is the stick in front of the nosecone.

50 Stutzman, W.L., and Theile, G.A., *Antenna Theory and Design*, John Wiley & Sons, Inc., New York (1981).

51 Balanis, C.A., *Antenna Theory Analysis and Design*, Harper & Row, Inc., New York, NY (1982).



(a) Paraboloidal Antenna as Meshed Wire **(b) Airplane as Wire Grid**

Figure 4-3. Modeling Antenna with Wires

There are many commercially available software packages that implement the *Method of Moments* for modeling antenna performance. One example is the Numerical Electromagnetic Code (NEC) developed by the Lawrence Livermore National Laboratory; this software is suitable for antennas operating in the HF and VHF bands.[52]

4.5.2 Uniform Theory of Diffraction

Diffraction is the physical phenomenon of electric current on the surface of a conductive object radiating an EM wave when the surface is not a flat plane. When the EM wave is obstructed by a conductive object, the wave cannot penetrate the object, and there should not be EM field in the shadow region. However, in reality, the EM field still exists in the shadow region, and it is generated by diffraction from surface current at the wedge. The EM field in the shadow region can be derived with UTD.

When the antenna has a solid planar surface, e.g., reflector antenna, UTD can be implemented by modeling the planar antenna as a structure of connecting flat plates and curved plates. When an antenna is embedded in a metallic structure, e.g., airborne antenna on an airplane, UTD can be implemented by modeling the whole airplane platform as a structure of connecting flat plates, curved plates, and cylinders. The diagrams in Figure 4-3 are still applicable here, except that the graphs should be viewed as structures of connecting flat plates, curved plates, and cylinders.

There are many commercially available software packages that use UTD. For instance, the NEC-Basic Scattering Code (NEC-BSC), developed by the Lawrence Livermore National Laboratory, is suitable for antennas operating in the Ultra High Frequency (UHF, 300–3000 MHz range) band and above.

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52 http://ipo.llnl.gov/?q=technologies-software-browse_software-app&s=NEC, accessed Aug. 4, 2010.

SECTION 5. ANTENNA REFERENCE RADIATION PATTERNS AND CHARACTERISTICS

5.1 Introduction

This section contains the rules, regulations, and recommendations about antennas that are relevant to EMC analyses. Most of the information here is the antenna radiation performance standards, antenna reference radiation patterns, and antenna operational requirements. The sources of these rules, regulations, and recommendations are the NTIA Manual, Title 47 of the Code of Federal Regulations (47 CFR) for FCC, the ITU-R Radio Regulations (RR), the ITU-R Recommendations, and publications from RTCA and other institutions.[53] [54] [55] [56]

Antenna radiation performance standards and reference radiation patterns are developed from measured radiation patterns, and then established as reference with consensus from radio spectrum regulators and antenna engineers. Regulators use them as reference in EMC analyses, and engineers use them as compliance guidelines in antenna design and production. While measured radiation patterns should always be used in interference analyses, the reference radiation patterns are the best alternatives when the measured radiation patterns are not available.

The information in this section is organized by the class of radio services categorized by ITU-R. Antenna data for the Fixed Service (FS), Fixed-Satellite Service (FSS), Broadcasting Service (BS), Broadcasting-Satellite Service (BSS), Mobile Service (MS), Mobile-Satellite Service (MSS), Radiodetermination Service (RDS), Radiodetermination-Satellite Service (RDSS), Radio Astronomy Service (RAS), Remote Sensing Service (RSS), and Space Application Service (SA) are presented in Sections 5.2 through 5.12. Some radio services are partitioned into subsets of services, and these subsets are discussed separately. A summary list is provided in Section 5.13 for easy reference.

Within a radio service or subset service, the antenna data are presented in the order of authority, i.e., NTIA, FCC, ITU-R RR, authoritative institutions, and the ITU-R Recommendations. A note is given if NTIA does not provide the specifications. The antenna data are presented in the order of frequency bands when there are numerous entries from one source.

Unless specifically stated, the reference radiation patterns are the co-polarization patterns, the gain and directivity values are in dB or dBi, and the angles are in degrees. For easy reference, some of the symbols and acronyms that are extensively used in this section are listed here:

- D: diameter of a circular object or circular aperture;
- dBic: dBi and circular polarization;

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53 Code of Federal Regulations, Title 47, *Telecommunication*, ("47 CFR"), U.S., FCC, http://www.access.gpo.gov/cgi-bin/cfrassemble.cgi?title=201147, accessed Feb. 9, 2012.

54 *Manual of Regulations and Procedures for Federal Radio Frequency Management*, U.S. Department of Commerce, NTIA, ("NTIA Manual").

55 *Radio Regulations*, ITU-R ("RR") (2008).

56 RTCA, http://www.rtca.org/doclist.asp (2011).

- *f*: frequency;
- G_{max}: peak power gain;
- G_1: level of the first sidelobe of an actual radiation pattern, or the first plateau of a reference radiation pattern representing the first sidelobe of the actual radiation pattern;
- G(Ω): power gain in the Ω direction, where Ω is the solid angle in the spherical coordinate;
- N/A: not available;
- n/a: not applicable;
- n/s: not specified;
- λ: wavelength;
- φ: azimuth angle;
- θ: elevation angle; and
- ϕ: angle off mainbeam axis for a circular beam, or angle off mainbeam axis in the direction of interest for an elliptical beam.

5.2 Fixed Service

The FS line-of-sight radio relay operation may be either a land-based system of point-to-point (P-P) or point-to-multipoint (P-MP) connections, or a system using high altitude platform station (HAPS). The P-P systems use mostly paraboloidal antennas. The P-MP systems use mostly omnidirectional or sectoral antennas at the central stations and paraboloidal antennas at the outer stations. Antenna data of these systems are presented here. When not specified, the antenna radiation patterns apply to both the vertical and horizontal polarizations.

5.2.1 Point-to-Point System

This sub-section contains the following FS P-P system antenna radiation performance standards:

- from NTIA Manual Chapter 5, for federal systems with fixed stations;[57]
- from 47 CFR Part 101, for non-federal systems operating at or above 932.5 MHz;[58] [59]
- from 47 CFR Part 78, for non-federal systems of cable TV relay service;[60]
- from RR Appendix 5, for EMC analyses between FS systems and MSS system space-to-Earth links operating in 1–3 GHz;[61] and
- from RR Appendix 7, for deriving the coordination area around a space system earth station operating in 100 MHz–105 GHz.[62]

It also contains the following recommended reference radiation patterns from ITU-R:

57 NTIA Manual, Chapter 5, *Spectrum Standards*, §5.3.

58 47 CFR, Part 101, *Fixed Microwave Services*, §101.115.

59 47 CFR, Part 101, *Fixed Microwave Services*, §101.117.

60 47 CFR, Part 78, *Cable Television Relay Service*, §78.105.

61 RR, Appendix 5, *Identification of Administrations with Which Coordination is to Be Effected or Agreement Sought Under the Provisions of Article 9*, Annex 1.

62 RR, Appendix 7, *Methods for the Determination of the Coordination Area Around an Earth Station in Frequency Bands between 100 MHz and 105 GHz*, Annex 6.

- from Rec. ITU-R F.699-7, for single-entry EMC analyses between FS systems and between FS systems and space radiocommunication systems sharing frequency in 100 MHz–70 GHz;[63]
- from Rec. ITU-R F.1245, for aggregate EMC analyses between FS systems and between FS systems and space radiocommunication systems sharing frequency in 100 MHz–70 GHz;[64] and
- from Rec. ITU-R F.1245, for statistical EMC analyses between FS systems and between FS systems and space radiocommunication systems sharing frequency in 100 MHz–70 GHz.

(a) NTIA Manual Chapter 5

For the federal P-P systems, the FS antenna radiation performance standard in NTIA Manual §5.3 is shown in Table 5-1.

Table 5-1. FS P-P System Antenna Radiation Performance Standard from NTIA for Federal Systems

(a) For Systems Operating HF Single Sideband and Independent Sideband Equipment in 2–29.7 MHz

Frequency Range	G_{max}	Sidelobe
< 4 MHz	Directive antenna not required	
$4 \le f \le 10$ MHz	$G_{max} \ge 10$ dBi	Any sidelobe must be 6 dB less than G_{max}
$10 < f \le 30$ MHz	$G_{max} \ge 15$ dBi	
The manual does not distinguish the G_{max} value at the 10 MHz break point. The lower value, i.e., G_{max} = 10 dBi at f = 10 MHz, is used here because it is a minimum value.		

(b) For Systems Operating in 406–15350 MHz

Frequency Band (MHz)	Max. ϕ_{bw} (°)	Minimum Radiation Suppression to G_{max} (dB)						
		Angle Off Mainbeam Axis (°)						
		5−10	10−15	15−20	20−30	30−100	100−140	140−180
406.1−420 [1]	80	n/a	n/a	n/a	n/a	10	10	10
(a) 932.5−935, 941.5−944 [2]	14	n/a	6	11	14	17	20	24
(b) 932.5−935, 941.5−944 [2]	20	n/a	n/a	6	10	13	15	20
(c) 1710−1850 [3]	10	n/a	14	16	18	23	24	30
(d) 1710−1850 [4]	8	5	18	20	20	25	28	36
2200−2400	8.5	4	12	16	16	24	25	30

63 Rec. ITU-R F.699-7, *Reference Radiation Patterns for Fixed Wireless System Antennas for Use in Coordination Studies and Interference Assessment in the Frequency Range from 100 MHz to About 70 GHz* (2006).

64 Rec. ITU-R F.1245-1, *Mathematical Model of Average and Related Radiation Patterns for Line of Sight Point-To-Point Radio-Relay System Antennas for Use in Certain Coordination Studies and Interference Assessment in the Frequency Range from 1 GHz to About 70 GHz* (2000).

4400−4990	4	13	20	23	24	29	31	31
7125−8500	2.5	19	23	28	30	34	35	43
14400−15350	1.5	21	26	31	35	37	41	48
21800–22075, 23000–23275	3.3	18	26	26	33	33	55	55

- These standards are not applicable to transportable antennas in tactical and training operations.
- n/a: not applicable.

1 Any secondary lobe.
2 Stations in this service must employ an antenna that meets the performance standard (a). Standard (b) may be employed in areas not subject to frequency congestion or subject to frequency coordination along the borders of the U.S. Note, however, the use of a high performance antenna may be required where interference problems can be resolved by the use of such antennas.
3 Standard (c) could be met, e.g., by a 1.2-meter (4-foot) diameter parabolic antenna.
4 Standard (d) is applicable to new stations in 1710–1850 MHz placed in service after January 1, 1985, except for those located on the military test ranges. These suppression levels could be met, e.g., by a 1.83-meter (6-foot) diameter parabolic antenna.

(b) 47 CFR Part 101, Antenna Radiation Performance Standard

For the non-federal P-P systems operating at or above 932.5 MHz, the FS antenna (other than antennas of temporary fixed stations and Digital Electronic Message Service nodal stations) radiation performance standard in 47 CFR Part 101 is shown in Table 5-2. Standard A is for general applications. Standard B is for antennas in areas not subject to frequency congestion, with the condition that the transmitting and receiving antenna mainbeam axes must be directed toward each other. These standards apply to both the transmitting and receiving antennas except for the second receiving antennas for operations such as space diversity.

Table 5-2. FS P-P System Antenna Radiation Performance Standard from FCC for Non-Federal Systems

(a) Standard A

Frequency Band (MHz)	Max. ϕ_{bw} (°)[1]	Min. G_{max} (dBi)	Minimum Radiation Suppression to G_{max} (dB) Angle Off Mainbeam Axis (°)						
			5–10	10–15	15–20	20–30	30–100	100–140	140–180
932.5−935	14	n/a	n/a	6	11	14	17	20	24
941.5−944	14	n/a	n/a	6	11	14	17	20	24
952−960[2, 3]	14	n/a	n/a	6	11	14	17	20	24
1850−2500[4]	5	n/a	12	18	22	25	29	33	39
3700−4200	2.7	36	23	29	33	36	42	55	55
5925−6425[5]	2.2	38	25	29	33	36	42	55	55
5925−6425[6]	2.2	38	25	29	33	36	42	55	55
6525−6875[5]	2.2	38	25	29	33	36	42	55	55
6525−6875[6]	1.5	n/a	26	29	32	34	38	41	49

10550−10680[7]	3.5	33.5	18	24	28	32	35	55	55
10700-11700[5]	2.2	38	25	29	33	36	42	55	55
12200−13250[9]	1	n/a	23	28	35	39	41	42	50
17700−18820	2.2	38	25	29	33	36	42	55	55
18920−19700[10]	2.2	38	25	29	33	36	42	55	55
21200−23600[7, 11]	3.3	33.5	18	26	26	33	33	55	55
24250−25250[10]	2.8	38	25	29	33	36	42	55	60
38600−40000[14]	n/a	38	25	29	33	36	42	55	55

(b) Standard B

Frequency Band (MHz)	Max. ϕ_{bw} (°)[1]	Min. G_{max} (dBi)	Minimum Radiation Suppression to G_{max} (dB)						
			Angle Off Mainbeam Axis (°)						
			5−10	10−15	15−20	20−30	30−100	100−140	140−180
932.5−935	20	n/a	n/a	n/a	6	10	13	15	20
941.5−944	20	n/a	n/a	n/a	6	10	13	15	20
952−960[2, 3]	20	n/a	n/a	n/a	6	10	13	15	20
1850−2500[4]	8	n/a	5	18	20	20	25	28	36
3700−4200	2.7	36	20	24	28	32	32	32	32
5925−6425[5]	2.2	38	21	25	29	32	35	39	45
5925−6425[6]	2.2	38	20	24	28	32	35	36	36
6525−6875[5]	2.2	38	21	25	29	32	35	39	45
6525−6875[6]	2.0	n/a	21	25	29	32	35	39	45
10550−10680[7]	3.5	33.5	17	24	28	32	35	40	45
10700-11700[5]	3.5	33.5	17	24	28	32	35	40	45
12200−13250[9]	2.0	n/a	20	25	28	30	32	37	47
17700−18820	2.2	38	20	24	28	32	35	36	36
18920−19700[10]	2.2	38	20	24	28	32	35	36	36
21200−23600[7, 11]	3.3	33.5	17	24	24	29	29	40	50
24250−25250[10]	2.8	38	20	24	28	32	35	36	45
38600−40000[14]	n/a	38	20	24	28	32	35	36	36

(c) Non-Specific Standard

Frequency Band (MHz)	Max. ϕ_{bw} (°)[1]	Min. G_{max} (dBi)	Minimum Radiation Suppression to G_{max} (dB)						
			Angle Off Mainbeam Axis (°)						
			5−10	10−15	15−20	20−30	30−100	100−140	140−180
10565−10615	360	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
10630−10680[8]	3.5	34	20	24	28	32	35	36	36
31000−31300[12, 13]	4	38	n/a	n/a	n/a	n/a	n/a	n/a	n/a
71000−76000 (co-pol.)[15]	1.2	43	35	40	45	50	50	55	55
71000−76000 (cross-pol.)[15]	1.2	43	45	50	50	55	55	55	55
81000−86000 (co-pol.)[15]	1.2	43	35	40	45	50	50	55	55

81000−86000 (cross-pol.)[15]	1.2	43	45	50	50	55	55	55	55
92000−95000	0.6	50	36	40	45	50	55	55	55

(d) Footnotes for the Table

n/a: not available.

(1) If a licensee chooses to show compliance using maximum beamwidth to 3 dB points, the beamwidth limit shall apply in both the azimuth and the elevation planes.

(2) Except for Multiple Address System frequencies listed in Sec. 101.147(b)(1) through (b)(4), where omnidirectional antennas may be used.

(3) Antennas used at outlying stations as part of a central protection alarm system need conform to only the following 2 standards:
(i) The minimum on-beam forward gain must be at least 10 dBi, and
(ii) The minimum front-to-back ratio must be at least 20 dB.

(4) Omnidirectional antennas may be authorized in 2150−2160 MHz.

(5) These antenna standards apply to all point-to-point stations authorized after June 1, 1997. Existing licensees and pending applicants on that date are grandfathered and need not comply with these standards.

(6) These antenna standards apply to all point-to-point stations authorized on or before June 1, 1997.

(7) Except for antennas between 140° and 180° authorized or pending on January 1, 1989, in 10550−10565 MHz for which minimum radiation suppression to angle (in degrees) from centerline of main beam is 36 dB.

(8) These antenna standards apply only to DEMS (Digital Electronic Messaging Service) User Stations licensed, in operation, or applied for prior to July 15, 1993.

(9) Except for Temporary-fixed operations in 13200−13250 MHz with output powers less than 250 mW and as provided in Sec. 101.147(q), and except for antennas in the MVDDS (Multichannel Video and Data Distribution Service) service in 12.2−12.7 GHz.

(10) DEMS User Station antennas in this band must meet performance Standard B and have a minimum antenna gain of 34 dBi. The maximum beamwidth requirement does not apply to DEMS User Stations. DEMS Nodal Stations need not comply with these standards. Stations authorized to operate in 24250−25250 MHz do not have to meet these standards, however, the Commission may require the use of higher performance antennas where interference problems can be resolved by the use of such antennas.

(11) Except as provided in Sec. 101.147(s).

(12) The minimum front-to-back ratio shall be 38 dBi.

(13) Mobile, except aeronautical mobile, stations need not comply with these standards.

(14) Stations authorized to operate in 38600−40000 MHz may use antennas other than those meeting the Category A standard. However, the Commission may require the use of higher performance antennas where interference problems can be resolved by the use of such antennas.

(15) Antenna gain less than 50 dBi (but greater than or equal to 43 dBi) is permitted only with a proportional reduction in maximum authorized EIRP in a ratio of 2 dB of power per 1 dB of gain, so that the maximum allowable EIRP (in dBW) for antennas of less than 50 dBi gain becomes +55 - 2×(50 - G_{max}), where G_{max} is the antenna gain in dBi. In addition, antennas in these bands must meet two additional standards for minimum radiation suppression: At angles between 1.2° and 5° from the centerline of the main beam, co-polar discrimination must be G_{max} - 28, where G_{max} is the antenna gain in dBi; and at angles of less than 5° from the centerline of main beam, cross-polar discrimination must be at least 25 dB.

(c) 47 CFR Part 101, Antenna Polarization

47 CFR does not limit the polarization of the FS P-P system antenna, but FCC can regulate the polarization when concerns about excessive interference arise.

For Local Multipoint Distribution Service systems, antennas may use any polarization within its service area, but only vertical and/or horizontal polarization for antennas located within 20 kilometers of the outermost edge of their service area.

(d) 47 CFR Part 78

For the fixed stations of the FS cable TV relay service operating in 12.7–13.2 and 17.7–19.7 GHz, the antenna radiation performance standard in 47 CFR Part 78 is shown in Table 5-3. FCC may require higher performance antennas under stringent interference environment.

Table 5-3. Television Broadcast Auxiliary Station Antenna Radiation Performance Standard from FCC for Non-Federal Systems

Standard	Frequency (GHz)	Max. ϕ_{bw} (º)	Min. G_{max} (dBi)	Minimum Radiation Suppression to G_{max} (dB)						
				Angle Off Mainbeam Axis (º)						
				5–10	10–15	15–20	20–30	30–100	100–140	140–180
A	12.7–13.25	1.0	n/a	23	28	35	39	41	42	50
	17.7–19.7	2.2	38	25	29	33	36	42	55	55
B	12.7–13.25	2.0	n/a	20	25	28	30	32	37	47
	17.7–19.7	2.2	38	20	24	28	32	35	36	36

- n/a: not available.
- Standard A must be used in areas subject to frequency congestion.
- Standard B is the minimum requirement.

(e) RR Appendix 5

For coordination studies and interference assessment between FS P-P systems and GSO or non-GSO (NGSO) MSS system space-to-Earth links sharing frequency in 1–3 GHz, the FS antenna reference radiation pattern in RR Appendix 5 is shown in Table 5-4.

Table 5-4. FS P-P System Antenna Reference Radiation Pattern in RR Appendix 5 for EMC Analyses between FS Systems and MSS System Space-to-Earth Links in 1–3 GHz

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
$39 - 5 \times \log(D/\lambda) - 2.5 \times \log(\phi)$	$\phi_m \le \phi < 48°$
$-3 - 5 \times \log(D/\lambda)$	$48° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$G_1 = 2 + 15\times\log(D/\lambda)$, dBi

The sidelobe radiation pattern is the average radiation pattern. Individual sidelobe of an actual radiation pattern may exceed the average radiation pattern by up to 3 dB.

(f) RR Appendix 7

For deriving coordination areas around space system earth stations operating in 100 MHz–105 GHz, the FS antenna reference radiation pattern in RR Appendix 7 is shown in Table 5-5.

Table 5-5. FS Antenna Reference Radiation Pattern in RR Appendix 7 for Deriving Coordination Area around Earth Station Operating in 100 MHz–105 GHz

Category	Gain Function (dBi)	Angular Range
$D/\lambda > 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < \phi_r$
	$32 - 25 \times \log(\phi)$	$\phi_r \le \phi < 48°$
	-10	$48° \le \phi \le 180°$
$D/\lambda \le 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	for $0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < (100\lambda/D)°$
	$52 - 10\times\log(D/\lambda) - 25 \log(\phi)$	$(100\lambda/D)° \le \phi < 48°$
	$10 - 10\times\log(D/\lambda)$	$48° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = 2 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg., $\phi_r = 1°$ for $D/\lambda = 100$ If D/λ is not given, it can be estimated by $20\times\log(D/\lambda) \approx G_{max}(\text{dBi}) - 7.7$.		

(g) Rec. ITU-R F.699-7

For coordination studies and single-entry interference assessments between FS P-P systems and between FS P-P systems and space radiocommunication systems sharing frequency in 100 MHz–70 GHz, the recommended FS antenna reference radiation pattern in Rec. ITU-R F.699-7 is shown in Table 5-6. This radiation pattern covers low-gain antennas of $G_{max} < 10$ dBi. However, when it is necessary to use a low-gain antenna that has a large HPBW, it may be more practical to use an elliptical-beam antenna with the major axis aligned horizontally and the minor axis aligned vertically such that the radiated energy is not wasted into the sky. In such a case, the radiation pattern of a dish antenna in the category "100 MHz $\le f <$ 1 GHz, $D/\lambda > 0.63$" is not applicable anymore.

Table 5-6. Recommended FS P-P System Antenna Reference Radiation Pattern for Single-Entry EMC Analyses between FS Systems and between FS Systems and Space Systems in 100 MHz–70 GHz

Category	Gain Function (dBi)	Angular Range
100 MHz $\leq f <$ 1 GHz, $D/\lambda > 0.63$, $G_{max} > 3.7$ dBi	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < (100\lambda/D)°$
	$52 - 10\times\log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < \phi_s$
	$-2 - 5 \times \log(D/\lambda)$	$\phi_s \leq \phi \leq 180°$
$1 \leq f < 70$ GHz, $D/\lambda > 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_r$
	$32 - 25 \times \log(\phi)$	$\phi_r \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$1 \leq f < 70$ GHz, $D/\lambda \leq 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < (100\lambda/D)°$
	$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < 48°$
	$10 - 10 \times \log(D/\lambda)$	$48° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = 2 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_s = 144.5(D/\lambda)^{-0.2}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.		
For horn reflector antennas or offset feed antennas with very low illumination on the edge of the reflector, $G(\phi) = 88 - 30\times\log(D/\lambda) - 40\times\log(\phi)$, dBi, for $\phi_m \leq \phi < 90°$ may be used in the horizontal plane.		

(h) Rec. ITU-R F.1245

For coordination studies and the aggregate interference assessments between FS P-P systems and between FS P-P systems and space radiocommunication systems sharing frequency in 1−70 GHz, the recommended FS antenna average reference radiation pattern in Rec. ITU-R F.1245 is shown in Table 5-7.

Table 5-7. Recommended FS P-P System Antenna Average Reference Radiation Pattern for Aggregate EMC Analyses between FS Systems and between FS Systems and Space Systems in 1−70 GHz

Category	Gain Function (dBi)	Angular Range
$D/\lambda > 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \max(\phi_m, \phi_r)$
	$29 - 25 \times \log(\phi)$	$\max(\phi_m, \phi_r) \leq \phi < 48°$
	-13	$48° \leq \phi \leq 180°$
$D/\lambda \leq 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$

	39 - 5 × log(D/λ) - 25 × log(ϕ)	$\phi_m \le \phi < 48°$
	-3 - 5 × log(D/λ)	48° ≤ ϕ ≤ 180°

ϕ: angle off mainbeam axis, deg.

$G_1 = 2 + 15\times\log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_r = 12.02(D/\lambda)^{-0.6}$, deg.

When the interference signals are circularly polarized, e.g., from space systems employing circular polarization, the effective gain, $G_{eff}(\phi)$, for the pattern of D/λ ≤ 100 in the mainbeam region may become:

$$G_{eff}(\phi) = 10\log\left(10^{0.1G(\phi)} + 0.02\times 10^{0.1G_{max}}\right) - 3 \quad \text{dBi} \quad \text{for } 0° < \phi < \phi_m$$

where G(ϕ) is the mainbeam gain formula in that pattern. This formula assumes that the antenna cross-polarized gain in the mainbeam region is 17 dB below G_{max}. The cross-polarization advantage should not be expected for $\phi > \phi_m$. A similar formula for the pattern of D/λ > 100 is not available.

For statistical interference assessments between FS P-P systems and between FS P-P systems and space radiocommunication systems sharing frequency in 1−70 GHz, the recommended mathematical model of the generalized FS antenna reference radiation pattern in Rec. ITU-R F.1245-1 is shown in Table 5-8. This pattern is used only for spatial statistical analysis, e.g., deriving the probability distribution function of interference from a few GSO satellite systems into a large number of victim FS systems.

Table 5-8. Recommended FS P-P System Antenna Reference Radiation Pattern for Statistical EMC Analyses between FS Systems and between FS Systems and Space Systems in 1−70 GHz

Category	Gain Function (dBi)	Angular Range
D/λ > 100	$\max(G_a(\phi), G_b(\phi))$	$0° \le \phi < \phi_b$
	$32 - 25\times\log(\phi) + F_b(\phi)$	$\phi_b \le \phi < 48°$
	$-10 + F_b(\phi)$	48° ≤ ϕ ≤ 180°
D/λ ≤ 100	$\max(G_a(\phi), G_c(\phi))$	$0° \le \phi < \phi_c$
	$42 - 5\times\log(D/\lambda) - 25\times\log(\phi) + F_c(\phi)$	$\phi_c \le \phi < 48°$
	$-5\times\log(D/\lambda) + F_c(\phi)$	48° ≤ ϕ ≤ 180°

ϕ: angle off mainbeam axis, deg.

$G_a(\phi) = G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2$, dBi

$G_b(\phi) = G_1 + F_b(\phi)$, dBi

$G_c(\phi) = G_1 + F_c(\phi)$, dBi

$G_1 = 2 + 15\times\log(D/\lambda)$, dBi

$F_b(\phi) = 10\times\log[0.9\sin^2(1.5\pi\phi/\phi_b) + 0.1]$, dB

$F_c(\phi) = 10\times\log[0.9\sin^2(1.5\pi\phi/\phi_c) + 0.1]$, dB

$\phi_b = 15.85(D/\lambda)^{-0.6}$, deg.
$\phi_c = 39.8(D/\lambda)^{-0.8}$, deg.

5.2.2 Point-to-Multipoint System

NTIA does not provide the FS P-MP system antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains the following FS P-MP system antenna characteristics:

- from RR Appendix 5 [Ref. 61], radiation performance standard for EMC analyses between FS systems and MSS system space-to-Earth links sharing frequency in 1–3 GHz; and
- from Rec. ITU-R F.1336-3, recommended reference radiation pattern for EMC analyses between FS systems and between FS systems and space radiocommunication systems.[65]

(a) RR Appendix 5

For coordination studies and interference assessments between the FS P-MP systems and the GSO or NGSO MSS system space-to-Earth links sharing frequency in 1–3 GHz, the FS antenna reference radiation pattern in RR Appendix 5 is shown in Table 5-9.

Table 5-9. FS P-MP System Antenna Reference Radiation Pattern in RR Appendix 5 for EMC Analyses between FS Systems and MSS System Space-to-Earth Links in 1–3 GHz

Gain Function (dBi)	Angular Range
$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \le \theta \le \theta_{bw}$
$G_{max} - 12 - 10 \times \log(\theta/\theta_{bw})$	$\theta_{bw} < \theta \le 90°$
θ: angle above the horizontal plane. G_{max}: maximum gain in the horizontal plane. θ_{bw}: HPBW in the vertical plane, $\theta_{bw} = 1/(\alpha^2 - 0.818)$, deg. $\alpha = \left(10^{0.1G_{max}} + 172.4)/191\right)$	

(b) Rec. ITU-R F.1336-3

For coordination studies and interference assessments between P-MP FS systems and between P-MP FS systems and space radiocommunication systems, the recommended FS antenna reference radiation patterns in Rec. ITU-R F.1336-3 are shown in Table 5-10. Table 5-10(a) is for omnidirectional antennas operating in 1–70 GHz, Table 5-10(b) is for sectoral antennas operating in 1–70 GHz, and Table 5-10(c) is for low-cost antennas with G_{max} < 20 dBi, pencil-shaped beams, and operating in 1–3 GHz.

65 Rec. ITU-R F.1336-3, *Reference Radiation Patterns of Omnidirectional, Sectoral and Other Antennas in Point-To-Multipoint Systems for Use in Sharing Studies in The Frequency Range From 1 to About 70 GHz* (2012)

Table 5-10. Recommended FS P-MP System Antenna Reference Radiation Pattern for EMC Analyses between FS Systems and between FS Systems and Space Systems in 1–70 GHz

(a) Omnidirectional Antenna

Envelope Type	Gain Function (dBi)	Angular Range
Peak Sidelobe	$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \le \|\theta\| < \theta_p$
	$G_{max} - 12 + 10 \times \log(k + 1)$	$\theta_p \le \|\theta\| < \theta_{bw}$
	$G_{max} - 12 + 10 \times \log\{(\|\theta\|/\theta_{bw})^{-1.5} + k\}$	$\theta_{bw} \le \|\theta\| \le 90°$
Average Sidelobe	$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \le \|\theta\| < \theta_{bw}$
	$G_{max} - 15 + 10 \times \log(k + 1)$	$\theta_{bw} \le \|\theta\| < \theta_a$
	$G_{max} - 15 + 10 \times \log\{(\|\theta\|/\theta_{bw})^{-1.5} + k\}$	$\theta_a \le \|\theta\| \le 90°$

G_{max}: the maximum gain in the azimuth plane, dBi

θ: elevation angle relative to the angle of maximum gain, deg., $-90° \le \theta \le 90°$,

θ_{bw}: HPBW in the elevation plane, deg.

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

$$\theta_p = \theta_{bw}\sqrt{1 - \frac{\log(k+1)}{1.2}}$$

$$\theta_a = \theta_{bw}\sqrt{1.25 - \frac{\log(k+1)}{1.2}}$$

k: parameter that accounts for increased sidelobe levels above what would be expected for an antenna with improved sidelobe performance,

- k = 0.7 for typical antennas operating in $1 \le f < 3$ GHz, and
- k = 0 for antennas with improved sidelobe performance operating in $1 \le f < 3$ GHz or all antennas operating in $3 \le f \le 70$ GHz.*

If the antenna mainbeam is downward tilted, i.e., cone-shape instead flat, by electrical means, the radiation patterns above and below the horizontal plane are stretched and compressed, respectively. The formulas are still applicable with the following modifications.

Define

β: downward tilt angle, the positive angle that the main beam axis is below the horizontal plane at the site of the antenna, deg., and

θ_h: elevation angle measured from the horizontal plane at the site of the antenna, deg., $-90° \le \theta_h \le 90°$,

the formulas are applicable with θ replaced with θ_e of

$$\theta_e = \frac{90(\theta_h + \beta)}{90 + \beta} \quad \text{for } \theta_h + \beta \ge 0$$

$$\theta_e = \frac{90(\theta_h + \beta)}{90 - \beta} \quad \text{for } \theta_h + \beta < 0$$

*: Rec. ITU-R F.1336-3 does not distinguish the value of k for typical antennas at 3 GHz breaking point.

(b) Sectoral Antenna

Frequency Range	Envelope Type	Gain Function (dBi)	Angular Range
$1 \le f < 6$ GHz	Peak Sidelobe	$G_{max} - 12x^2$	$0 \le x < x_p$
		$G_{max} - 12 + 10 \times \log(x^{-1.5} + k_p)$	$x_p \le x < 4$
		$G_{max} - s_p - 15 \times \log(x)$	$4 \le x$
	Average Sidelobe	$G_{max} - 12x^2$	$0 \le x < x_a$
		$G_{max} - 15 + 10 \times \log(x^{-1.5} + k_a)$	$x_a \le x < 4$
		$G_{max} - s_a - 3 - 15 \times \log(x)$	$4 \le x$
$6 \le f < 70$ GHz	Peak Sidelobe	$G_{max} - 12x^2$	$0 \le x < 1$
		$G_{max} - 12 - 15 \times \log(x)$	$1 \le x$
	Average Sidelobe	$G_{max} - 12x^2$	$0 \le x < 1.152$
		$G_{max} - 15 - 15 \times \log(x)$	$1.152 \le x$

G_{max}: the maximum gain in or near the horizontal plane, dBi

θ: elevation angle relative to the local horizontal plane when the maximum gain is in that plane, deg., $-90° \le \theta \le 90°$,

θ_{bw}: HPBW in the elevation plane, deg.

φ: azimuth angle relative to the angle of maximum gain in the horizontal plane, deg.

φ_{bw}: HPBW in the azimuth plane (generally equal to the sectoral beamwidth,) deg.

$$\alpha = \tan^{-1}\left(\frac{\tan(\theta)}{\sin(\varphi)}\right)$$

$\psi = \cos^{-1}[\cos(\varphi)\cos(\theta)]$, deg., $0° \le \psi \le 180°$,

$$\psi_0 = \left\{\left(\frac{\cos(\alpha)}{\varphi_{bw}}\right)^2 + \left(\frac{\sin(\alpha)}{\theta_{bw}}\right)^2\right\}^{-0.5}, \text{ deg.}$$

$x = \psi/\psi_0$

This pattern is valid for $\varphi_{bw} < 120°$.

If only G_{max} and φ_{bw} are given but not θ_{bw}, then θ_{bw} can be calculated provisionally with

$$\theta_{bw} = \frac{31000 \times 10^{-0.1 G_{max}}}{\varphi_{bw}}$$

For the peak sidelobe case in $1 \le f < 6$ GHz:

$x_p = (1 - 0.36k_p)^{0.5}$

$s_p = 12 - 10 \times \log(1+8k_p)$

k_p: parameter that accounts for increased sidelobe levels above what would be expected for an antenna with improved sidelobe performance:

- $k_p = 0.7$ for typical antennas, yielding $x_p = 0.86$ and $s_p = 3.8$; and
- $k_p = 0$ for antennas with improved sidelobe performance, yielding $x_p = 1$ and $s_p = 12$.

For the average sidelobe case in $1 \leq f < 6$ GHz:

$x_a = (1.25 - 0.36k_a)^{0.5}$

$s_a = 12 - 10 \times \log(1+8k_a)$

k_a: parameter that accounts for increased sidelobe levels above what would be expected for an antenna with improved sidelobe performance:

- $k_a = 0.2$ for typical antennas, yielding $x_a = 1.08$ and $s_a = 7.85$; and
- $k_a = 0$ for antennas with improved sidelobe performance, yielding $x_a = 1.118$ and $s_a = 12$.

If the antenna mainbeam is downward tilted by electrical means, the radiation patterns above and below the horizontal plane are stretched and compressed, respectively. The formulas are still applicable with the following modifications.

Define

β: downward tilt angle, the positive angle that the main beam axis is below the horizontal plane at the site of the antenna, deg., and

θ_h: elevation angle measured from the horizontal plane at the site of the antenna, deg., $-90° \leq \theta_h \leq 90°$,

the formulas are applicable with θ replaced with θ_e of

$$\theta_e = \frac{90(\theta_h + \beta)}{90 + \beta} \qquad \text{for } \theta_h + \beta \geq 0$$

$$\theta_e = \frac{90(\theta_h + \beta)}{90 - \beta} \qquad \text{for } \theta_h + \beta < 0$$

If the antenna mainbeam is downward tilted by mechanical means, the formulas are still applicable with the following modifications.

Define

β: downward tilt angle, the positive angle that the main beam axis is below the horizontal plane at the site of the antenna, deg.,

θ_h: elevation angle measured from the horizontal plane at the site of the antenna, deg., $-90° \leq \theta_h \leq 90°$, and

φ_h: azimuth angle in the horizontal plane at the site of the antenna measured from the azimuth of maximum gain, deg., $-180° < \varphi_h \leq 180°$,

the formulas are applicable with θ and φ replaced with θ_m and φ_m of

θ_m: elevation angle measured from the plane defined by the axis of maximum gain and the axis about which the pattern is tilted, (θ_{bw} is also measured from this plane,) deg.

φ_m: azimuth angle measured from the azimuth of maximum gain in the plane defined by the axis of maximum gain and the axis about which the pattern is tilted, deg.

derived with:

$$\theta_m = \sin^{-1}\left[\sin(\theta_h)\cos(\beta) + \cos(\theta_h)\cos(\varphi_h)\sin(\beta)\right], \qquad -90° \le \theta_m \le 90°$$

$$\varphi_m = \cos^{-1}\left(\frac{\left[-\sin(\theta_h)\sin(\beta) + \cos(\theta_h)\cos(\varphi_h)\cos(\beta)\right]}{\cos(\theta_m)}\right), \qquad 0° \le \varphi_m \le 180°$$

Within 90° < ψ ≤ 180°, the sidelobe patterns may result in conservative gains in particular in the azimuth angles. For cases involving significant interferences from such angles, the formulas are still applicable with the following modifications.

Define

φ_{th}: the boundary azimuth angle, deg., derived with

$\varphi_{th} = x_p \times \varphi_{bw}$ for peak sidelobe pattern in $1 \le f < 6$ GHz

$\varphi_{th} = x_a \times \varphi_{bw}$ for average sidelobe pattern in $1 \le f < 6$ GHz

$\varphi_{th} = \varphi_{bw}$ for $6 \le f < 70$ GHz

φ_{bwm}: the equivalent HPBW in the azimuth plane for an adjustment of horizontal gains, deg., derived with

$$\varphi_{bwm} = \varphi_{bw} \qquad \text{for } 0° \le |\varphi| \le \varphi_{th}$$

$$\varphi_{bwm} = \left\{\left(\frac{\cos\left(90\,\frac{|\varphi| - \varphi_{th}}{180 - \varphi_{th}}\right)}{\varphi_{bw}}\right)^2 + \left(\frac{\sin\left(90\,\frac{|\varphi| - \varphi_{th}}{180 - \varphi_{th}}\right)}{\theta_{bw}}\right)^2\right\}^{-0.5} \qquad \text{for } \varphi_{th} \le |\varphi| \le 180°$$

the formulas are applicable with ψ_0 replaced with ψ_α of

$$\psi_\alpha = \left\{\left(\frac{\cos(\alpha)}{\varphi_{bwm}}\right)^2 + \left(\frac{\sin(\alpha)}{\theta_{bw}}\right)^2\right\}^{-0.5} \qquad \text{for } 0° \le \psi \le 90°$$

$$\psi_\alpha = \left\{\left(\frac{\cos(\theta)}{\varphi_{bwm}}\right)^2 + \left(\frac{\sin(\theta)}{\theta_{bw}}\right)^2\right\}^{-0.5} \qquad \text{for } 90° < \psi \le 180°$$

(c) Low-Cost Antenna of G_{max} < 20 dBi Operating in $1 \le f < 3$ GHz

Envelope Type	Gain Function (dBi)	Angular Range
Peak Sidelobe	$G_{max} - 12(\phi/\phi_{bw})^2$	$0° \le \phi < 1.08\phi_{bw}$
	$G_{max} - 14$	$1.08\phi_{bw} \le \phi < \phi_1$
	$G_{max} - 14 - 32 \times \log(\phi/\phi_1)$	$\phi_1 \le \phi < \phi_2$
	-8	$\phi_2 \le \phi \le 180°$
Average	Table 5-7 from Rec. ITU-R F.1245 [Ref. 64]	

Sidelobe	
$\phi_{bw} = \left(27000 \times 10^{-0.1 G_{max}}\right)^{0.5}$, deg. $\phi_1 = 1.9\ \phi_{bw}$ $\phi_2 = \phi_1 \times 10^{(G_{max} - 6)/32}$	
This reference radiation pattern applies when $G_{max} \leq 20$ dBi and Rec. ITU-R F.699 produces inadequate results.	

5.2.3 System with High Altitude Platform Station

NTIA does not provide the HAPS FS antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains one recommended reference radiation pattern from ITU-R.

Rec. ITU-R F.1500

The recommended FS HAPS system antenna reference radiation pattern in Rec. ITU-R F.1500 is shown in Table 5-11.[66]

Table 5-11. Recommended FS Antenna Reference Radiation Pattern for Systems Using High Altitude Platform Stations

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^{\alpha}$	$0.5 < \phi/\phi_{bw} < a$
$G_{max} + L_n + 20 \times \log(z)$	$a \leq \phi/\phi_{bw} < 1.58$
$G_{max} + L_n$	$1.58 \leq \phi/\phi_{bw} < 3.16$
$x - 25 \times \log(\phi)$	$3.16 \leq \phi/\phi_{bw} < y$
L_f	$y \leq \phi/\phi_{bw} < 90/\phi_{bw}$
L_b	$90° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW in the direction of interest, deg. L_n: near sidelobe level relative to G_{max} required by the system design, dB α = 2 for L_n = -20, -25 = N/A for L_n = -30 a = $1.29[1 - \log(z)]^{0.5}$ for L_n = -20 = $1.29[1 - 0.8\times\log(z)]^{0.5}$ for L_n = -25 = N/A for L_n = -30 z = (major axis)/(minor axis).	

66 Rec. ITU-R F.1500, *Preferred Characteristics of Systems in the Fixed Service Using High Altitude Platforms Operating in the Bands 47.2-47.5 GHz and 47.9-48.2 GHz* (2000). This pattern conforms to the satellite antenna reference radiation pattern in Rec. ITU-R S.672-4.

$x = G_{max} + L_n + 25\times\log(3.16\phi_{bw})$, dBi

$y = 3.16\times10^{0.04(G_{max}+L_n-L_f)}$

L_f: far sidelobe level, $L_f = 0$ dBi

L_b: back lobe level, $L_b = \max[0, 15 + L_n + 0.25G_{max} + 5\times\log(z)]$, dBi

5.3 Fixed-Satellite Service

Antenna data for the earth station and satellite are presented here.

Earth station antennas are mostly land-based antennas, although they can also be shipborne antennas. Earth station antennas are mostly single-feed paraboloidal antennas that generate pencil shaped beams.

Satellite antennas are mostly multiple-feed paraboloidal antennas or multiple-horn antennas to generate shaped beams. Satellite antennas also use single-feed parabolic or paraboloidal antennas to generate elliptical or circular beams.

5.3.1 Earth Station Antenna

NTIA does not provide FSS earth station antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains the following earth station antenna radiation performance standards:

- from 47 CFR Part 25, co- and cross-polarization standards for non-federal GSO and NGSO systems;[67]
- from RR Article 22, co-polarization reference radiation pattern for establishing the downlink *pfd* limit of the NGSO systems operating in 3.7–4.2 GHz;[68]
- from RR Appendix 8, co-polarization reference radiation pattern for coordination studies involving GSO systems;[69] and
- from RR Appendix 30B, co-polarization reference radiation pattern for the GSO FSS Allotment Plan.[70]

It also contains the following recommended earth station antenna reference radiation patterns from ITU-R:

- from Rec. ITU-R S.465-6, co-polarization pattern for EMC analyses between FSS systems and between FSS systems and systems of other radio services sharing frequency in 2−30 GHz;[71]

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67 47 CFR, Part 25, *Satellite Communications*, §25.209.

68 RR, Article 22, *Space Services*, §22.5C.12.

69 RR, Appendix 8, *Method of calculation for determining if coordination is required between geostationary-satellite networks sharing the same frequency bands*, Annex 3.

70 RR, Appendix 30B, *Provisions and Associated Plan for the Fixed-Satellite Service in the Frequency Bands 4500-4800 MHz, 6725-7025 MHz, 10.70-10.95 GHz, 11.20-11.45 GHz and 12.75-13.25 GHz*, Annex 1.

71 Rec. ITU-R S.465-6, *Reference Earth-Station Radiation Pattern for Use in Coordination and Interference Assessment in the Frequency Range from 2 to About 30 GHz* (2010).

- from Rec. ITU-R S.580-6, co-polarization pattern as the design objective for new GSO systems;[72]
- from Rec. ITU-R S.1428-1, co-polarization pattern for EMC analyses involving NGSO FSS systems sharing frequency in 10.7−30 GHz;[73]
- from Rec. ITU-R S.731-1, cross-polarization pattern for EMC analyses in 2−30 GHz;[74] and
- from Rec. ITU-R S.728-1, co- and cross-polarization patterns for VSAT antennas.[75]

Some of the reference radiation patterns contain only the region off the mainbeam because it is perceived that EMC analyses require only this part of the specifications.

(a) 47 CFR Part 25

For the non-federal FSS systems, the earth station antenna radiation performance standards in 47 CFR Part 25 are shown in Table 5-12.

Table 5-12. FSS Earth Station Antenna Radiation Performance Standards from FCC for Non-Federal Systems

(a) GSO Space System Co-Polarization Standards in the GSO Plane

Category	Gain Function (dBi)	Angular Range
Not in K_a or conventional K_u band	29 - 25 × log(ϕ)	1.5° ≤ ϕ ≤ 7°
	8	7° < ϕ ≤ 9.2°
	32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
	-10	48° < ϕ ≤ 180°
In K_a and conventional K_u bands	29 - 25 × log(ϕ)	1.5° ≤ ϕ ≤ 7°
	8	7° < ϕ ≤ 9.2°
	32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
	-10	48° < ϕ ≤ 85°
	0	85° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. The actual radiation pattern shall meet the following conditions: • in 1.5° ≤ ϕ ≤ 7°, it may not exceed the specification; and • for ϕ > 7°, it may exceed the specification by no more than 10% with individual sidelobe not exceeding the specification by more than 3 dB.		

72 Rec. ITU-R S.580-6, *Radiation Diagrams for Use As Design Objectives for Antennas of Earth Stations Operating with Geostationary Satellites* (2004).

73 Rec. ITU-R S.1428-1, *Reference FSS Earth-Station Radiation Patterns for Use in Interference Assessment Involving Non-GSO Satellites in Frequency Bands between 10.7 GHz and 30 GHz* (2001).

74 Rec. ITU-R S.731-1, *Reference Earth-Station Cross-Polarized Radiation Pattern for Use in Frequency Coordination and Interference Assessment in the Frequency Range from 2 to about 30 GHz* (2005).

75 Rec. ITU-R S.728-1, *Maximum Permissible Level of Off-Axis E.I.R.P. Density from Very Small Aperture Terminals (VSATs)* (1995).

(b) GSO Space System Co-Polarization Standards not in the GSO Plane

Category	Gain Function (dBi)	Angular Range
Not in K_a or conventional K_u band	$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
	-10	$48° < \phi \le 180°$
In K_a and conventional K_u bands	$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
	-10	$48° < \phi \le 85°$
	0	$85° < \phi \le 180°$

- ϕ: angle off mainbeam axis, deg.
- This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.
- The envelope may be exceeded by no more than 10% of the sidelobes, and individual sidelobe may not exceed the envelope by more than 6 dB.

(c) GSO Space System Cross-Polarization Standard

Gain Function (dBi)	Angular Range
$19 - 25 \times \log(\phi)$	$x° < \phi \le 7°$
-2	$7° < \phi \le 9.2°$

- ϕ: angle off mainbeam axis, deg.
- x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.

(d) NGSO Space System Co-Polarization Standard

Gain Function (dBi)	Angular Range
$29 - 25 \times \log(\phi)$	$1° \le \phi \le 36°$
-10	$36° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

- This is for gateway antenna operating in 10.7–11.7, 12.75–13.15, 13.2125–13.25, 13.8–14.0, and 14.4–14.5 GHz.
- The actual radiation pattern may not exceed the specification.

(b) RR Article 22

For establishing the downlink *pfd* limit of the NGSO FSS systems operating in 3.7–4.2 GHz, the earth station antenna reference radiation pattern in RR Article 22 is shown in Table 5-13.

Table 5-13. FSS Earth Station Antenna Reference Radiation Pattern in RR Article 22 for Establishing Downlink *pfd* Limit of NGSO System in 3.7–4.2 GHz

Category	Gain Function (dBi)	Angular Range
$100 \le D/\lambda$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_{m1}$
	G_1	$\phi_{m1} \le \phi < \phi_r$
	$29 - 25 \times \log(\phi)$	$\phi_r \le \phi < 20°$

	-3.5	$20° \le \phi < 26.3°$
	$32 - 25 \times \log(\phi)$	$26.3° \le \phi < 48°$
	-10	$48° \le \phi \le 180°$
$42 \le D/\lambda < 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_{m1}$
	G_1	$\phi_{m1} \le \phi < (100\lambda/D)°$
	$29 - 25 \times \log(\phi)$	$(100\lambda/D)° \le \phi < 20°$
	-3.5	$20° \le \phi < 26.3°$
	$32 - 25 \times \log(\phi)$	$26.3° \le \phi < 48°$
	-10	$48° \le \phi \le 180°$
$D/\lambda < 42$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_{m2}$
	G_2	$\phi_{m2} \le \phi < (100\lambda/D)°$
	$32 - 25 \times \log(\phi)$	$(100\lambda/D)° \le \phi < 48°$
	-10	$48° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $G_{max} = 7.7 + 20\times\log(D/\lambda)$, dBi (derived from $e = 0.6$) $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $G_2 = 2 + 15\times\log(D/\lambda)$, dBi $\phi_{m1} = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{m2} = 20(\lambda/D)(G_{max} - G_2)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg., $\phi_r = 1°$ for $D/\lambda = 100$		
• Parameter G_1 in Article 22 is inaccurate, and has been corrected here. • Parameters ϕ_m, ϕ_r, $(100\lambda/D)°$, etc. do not produce smooth curves. Hence, it is recommended that the patterns in Rec. ITU-R S.1428-1, to be presented later, should be used as the NGSO FSS earth station antenna reference radiation patterns.		

(c) RR Appendix 8

For coordination studies involving GSO FSS satellite networks, the earth station antenna reference radiation pattern in RR Appendix 8 is shown in Table 5-14. This pattern applies to earth stations of all the GSO satellite networks, including FSS and other space services, and the pattern applies to both the transmitting and receiving antennas. This pattern, however, should be used only if a relevant ITU-R recommendation of a particular space service is not available.

Table 5-14. FSS Earth Station Antenna Reference Radiation Pattern in RR Appendix 8 for Coordination Studies Involving GSO Networks

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < \phi_r$
	$32 - 25 \times \log(\phi)$	$\phi_r \le \phi < 48°$
	-10	$48° \le \phi \le 180°$
$D/\lambda < 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$

	G_1	$\phi_m \le \phi < (100\lambda/D)°$
	$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \le \phi < 48°$
	$10 - 10 \times \log(D/\lambda)$	$48° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = 2 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.		

(d) RR Appendix 30B

For the GSO FSS Allotment Plan with downlink bands in the 4 and 10–11 GHz regions and uplink bands in the 6 and 13 GHz regions, the earth station antenna reference radiation pattern in RR Appendix 30B is shown in Table 5-15. The Plan allots a nominal GSO location to every nation for its FSS system to operate in the expanded FSS frequency bands. The patterns are used as a design objective and for coordination studies and interference assessments when the allotments are implemented.

Table 5-15. FSS Earth Station Antenna Reference Radiation Pattern in RR Appendix 30B for the GSO Allotment Plan

Category	Gain Function (dBi)	Angular Range
For achieving aggregate carrier power-to-interference power ratio (C/I) ≥ 26 dB	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	$\min[G_1, 29 - 25\times\log(\phi)]$	$\phi_m \le \phi < 19.95°$
	$\max\{\min[(-3.5, 32-25\times\log(\phi)], -10\}$	$19.95° \le \phi \le 180°$
For achieving aggregate carrier power-to-interference power ratio (C/I) ≥ 23 dB if C/I > 26 dB cannot be obtained	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < \phi_r$
	$29 - 25 \times \log(\phi)$	$\phi_r \le \phi < 36.3°$
	-10	$36.3° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $G_{max} = 10\times\log[e(\pi D/\lambda)^2]$, dBi $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $e \ge 0.7$* $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.		
* RR Appendix 30B stipulates that $e = 0.7$.		
RR Appendix 30B stipulates that D = 5.5 and 2.7 meters in the 6/4 and 13/10–11 GHz bands, respectively. This, with $e = 0.7$, gives G_{max} = 50.4, 47.0, 49.8, and 48.4 dBi at 6.875, 4.65, 13.0, and 11.075 GHz.		

(e) Rec. ITU-R S.465-6

For coordination studies and interference assessments between the FSS systems and between the FSS systems and systems of other radio services sharing frequency in 2−30 GHz, the recommended FSS earth station antenna reference radiation pattern in Rec. ITU-R S.465-6 is shown in Table 5-16.

Table 5-16. Recommended FSS Earth Station Antenna Reference Radiation Pattern for EMC Analyses between FSS Systems and between FSS Systems and Other Radio Systems in 2−30 GHz

Category	Gain Function (dBi)	Angular Range
General	$32 - 25 \times \log(\phi)$	$\phi_m \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda \leq 100$ and networks coordinated prior to 1993	$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < 48°$
	$10 - 10 \times \log(D/\lambda)$	$48° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg.		
$\phi_m = \max[1, 100(\lambda/D)]$, deg.	for $D/\lambda \geq 50$	
$= \max[2, 114(D/\lambda)^{-1.09}]$, deg.	for $33.3 \leq D/\lambda < 50$	
$= 2.5°$	for $D/\lambda < 33.3$	

(f) Rec. ITU-R S.580-6

As the design objective for new GSO FSS systems, the recommended earth station antenna reference radiation pattern in Rec. ITU-R S.580-6 is shown in Table 5-17.

Table 5-17. Recommended FSS Earth Station Antenna Reference Radiation Pattern as Design Objective for New GSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 50$, co-polarization	$29 - 25 \times \log(\phi)$	$\phi_{min} \leq \phi < 20°$
	-3.5	$20° \leq \phi < 26.3°$
	$32 - 25 \times \log(\phi)$	$26.3° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $\phi_{min} = \max(1, 100\lambda/D)$, deg.		
Within $\phi_{min} \leq \phi < 20°$, an actual antenna radiation pattern should have at least 90% of the sidelobe peaks below the '29 - 25× log(ϕ), dBi' envelope in any off mainbeam axis direction within 3° of the GSO plane.		

(g) Rec. ITU-R S.1428-1

For coordination studies and interference assessments involving the NGSO FSS systems operating in 10.7−30 GHz, the recommended earth station antenna reference radiation pattern in Rec. ITU-R S.1428-1 is shown in Table 5-18. In the interference scenario involving the NGSO FSS systems, a moving object is a moving interfering source or a moving victim receiver. A moving earth station is a tracking earth station and not a mobile earth station.

Table 5-18. Recommended FSS Earth Station Antenna Reference Radiation Pattern for EMC Analyses Involving NGSO Systems Operating in 10.7−30 GHz

Category	Gain Function (dBi)	Angular Range
$100 < D/\lambda$	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \le \phi < \phi_r$
	$29 - 25 \times \log(\phi)$	$\phi_r \le \phi < 10°$
	$34 - 30 \times \log(\phi)$	$10° \le \phi < 34.1°$
	-12	$34.1° \le \phi < 80°$
	-7	$80° \le \phi < 120°$
	-12	$120° \le \phi \le 180°$
$25 < D/\lambda \le 100$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \le \phi < (95\lambda/D)°$
	$29 - 25 \times \log(\phi)$	$(95\lambda/D)° \le \phi < 33.1°$
	-9	$33.1° \le \phi < 80°$
	-4	$80° \le \phi < 120°$
	-9	$120° \le \phi \le 180°$
$20 \le D/\lambda \le 25$	$G_{mc} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{mc}$
	G_{1c}	$\phi_{mc} \le \phi < (95\lambda/D)°$
	$29 - 25 \times \log(\phi)$	$(95\lambda/D)° \le \phi < 33.1°$
	-9	$33.1° \le \phi < 80°$
	-5	$80° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{mb} = G_{mc} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$G_{1b} = G_{1c} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.

$\phi_{mb} = \phi_{mc} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

(h) Rec. ITU-R S.731-1

For coordination studies and interference assessment involving GSO FSS systems operating in 2−30 GHz, the recommended earth station antenna cross-polarization reference radiation pattern in Rec. ITU-R S.731-1 is shown in Table 5-19. Rec. ITU-R S.731-1 stipulates that this pattern should be used with caution when $D/\lambda < 50$ or when the feed system may cause high levels of spill over.

Table 5-19. Recommended FSS Earth Station Antenna Cross-Polarization Reference Radiation Pattern for EMC Analyses in 2−30 GHz

Gain Function (dBi)	Angular Range
$23 - 20 \times \log(\phi)$	$\phi_{min} \leq \phi \leq 7°$
$20.2 - 16.7 \times \log(\phi)$	$7° < \phi \leq 26.3°$
$32 - 25 \times \log(\phi)$	$26.3° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $\phi_{min} = \max(1, 100\lambda/D)$, deg.	

(i) Rec. ITU-R S.728-1

For the FSS earth stations with very small aperture terminal (VSAT) antennas and operating in the 14 GHz band, the recommended antenna maximum permissible off-axis EIRP density level in any direction within 3° of the GSO is provided in Rec. ITU-R S.728-1; this is shown in Table 5-20(a). VSAT refers to parabolic antennas of size D < 2.4 meters, which corresponds to $D/\lambda < 50$ at 6 GHz.[76] With the EIRP density level, a profile of the VSAT reference radiation pattern can be developed as shown in Table 5-20(b).

Table 5-20. Recommended FSS VSAT Earth Station Antenna Co- and Cross-Polarization Reference Radiation Patterns

(a) Maximum Permissible E.I.R.P. Profile

Maximum EIRP in Any 40 kHz Band (dBW)		Angular Range
Co-Polarization	Cross-Polarization	
$33 - 25 \times \log(\phi)$	$23 - 25 \times \log(\phi)$	$2° \leq \phi \leq 7°$
12	2	$7° < \phi \leq 9.2°$
$36 - 25 \times \log(\phi)$	n/s	$9.2° < \phi \leq 48°$
-6	n/s	$48° < \phi$
n/s: not specified.		

76 Rec. ITU-R S.725, *Technical Characteristics for Very Small Aperture Terminals (VSATs)* (1992).

(b) Profile of Reference Radiation Pattern

Reference Radiation Pattern (dBi)		Angular Range
Co-Polarization	**Cross-Polarization**	
$x + 29 - 25 \times \log(\phi)$	$x + 19 - 25 \times \log(\phi)$	$2° \leq \phi \leq 7°$
$x + 8$	$x - 2$	$7° < \phi \leq 9.2°$
$x + 32 - 25 \times \log(\phi)$	n/a	$9.2° < \phi \leq 48°$
$x - 10$	n/a	$48° < \phi$
x: parameter to be determined. x = 0 is achievable with the current antenna manufacturing technologies. n/a: not available.		

5.3.2 Satellite Antenna

This sub-section contains one satellite antenna radiation performance standard from RR Appendix 30B [Ref. 70] for the FSS Allotment Plan and the following recommended satellite antenna reference radiation patterns from ITU-R:

- from Rec. ITU-R S.672-4, GSO system single-feed circular or elliptical beam antenna;[77]
- from Rec. ITU-R S.672-4, GSO system multiple-feed shaped beam antenna; and
- from Rec. ITU-R S.1528, NGSO system antenna operating below 30 GHz.[78]

(a) RR Appendix 30B

For the FSS Allotment Plan, the satellite antenna circular or elliptical beam reference radiation pattern in RR Appendix 30B is shown in Table 5-21. The satellite antenna efficiency should be 0.55 or better. The patterns are used as design objectives and for interference analysis when the allotments are implemented.

Table 5-21. FSS Satellite Antenna Circular or Elliptical Beam Reference Radiation Patterns in RR Appendix 30B for the Allotment Plan

Category	Gain Function (dBi)	Angular Range
Antenna mainbeam does not have fast roll-off	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} < 1.45$
	$\max[0, G_{max} - 22 - 20\times\log(\phi/\phi_{bw})]$	$1.45 \leq \phi/\phi_{bw}$
Antenna mainbeam has fast roll-off	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} \leq 0.5$
	$G_{max} - 12[(\phi - a\phi_{bw})/\phi_{min}]^2$	$0.5 < \phi/\phi_{bw} \leq x$
	$G_{max} - 25.23$	$x < \phi/\phi_{bw} \leq 1.45$
	$\max[0, G_{max} - 22 - 20\times\log(\phi/\phi_{bw})]$	$1.45 < \phi/\phi_{bw}$
ϕ: angle off mainbeam axis in the direction of interest, deg. $G_{max} = 44.45 - 10\times\log(\phi_{bw1} \times \phi_{bw2})$, dBi		

77 Rec. ITU-R S.672-4, *Satellite Antenna Radiation Pattern for Use as a Design Objective in the Fixed-Satellite Service Employing Geostationary Satellites* (1997).

78 Rec. ITU-R S.1528, *Satellite Antenna Radiation Patterns for Non-Geostationary Orbit Satellite Antennas Operating in the Fixed-Satellite Service below 30 GHz* (2001).

ϕ_{bw1}, ϕ_{bw2}: HPBW in major and minor axes, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
ϕ_{min}: required minimum HPBW, deg.
$\phi_{min} = 1.6°$ in 6/4 GHz band
$\phi_{min} = 0.8°$ in 13/10−11 GHz band
$x = 1.45\phi_{min}/\phi_{bw} + a$
$a = 0.5(1 - \phi_{min}/\phi_{bw})$
Antenna efficiency $e \geq 0.55$ (RR Appendix 30B stipulates that $e = 0.55$.)

(b) Contour Map

For EMC analyses, the most useful tool about the satellite antenna radiation pattern is the coverage contour map. Contour maps are available from satellite operators. A contour map from the HughesNet is shown in Figure 5-1.[79] The numbers along the contour lines are the EIRP values in dBW.

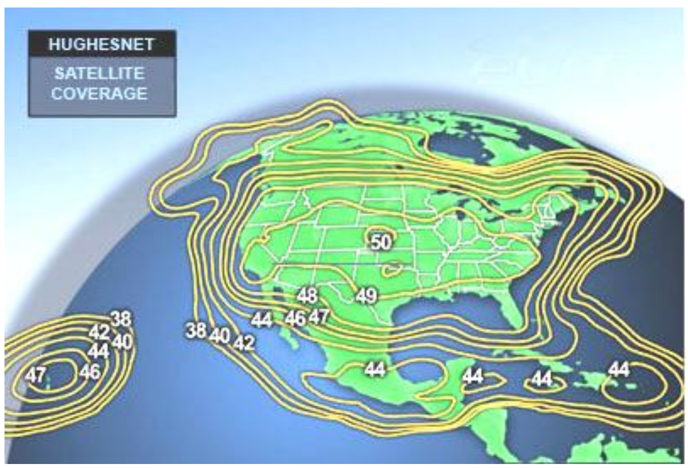

Figure 5-1. Satellite Coverage Contour Map

(c) Rec. ITU-R S.672-4

As a design objective for the GSO FSS systems, the recommended FSS satellite single-feed circular or elliptical beam antenna reference radiation pattern in Rec. ITU-R S.672-4 is shown in Table 5-22.

Table 5-22. Recommended GSO FSS Satellite Single-Feed Circular or Elliptical Beam Antenna Reference Radiation Pattern as Design Objective

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^{\alpha}$	$0.5 < \phi/\phi_{bw} < a$
$G_{max} + L_n + 20 \times \log(z)$	$a \leq \phi/\phi_{bw} < 1.58$
$G_{max} + L_n$	$1.58 \leq \phi/\phi_{bw} < 3.16$

79 http://www.elitesat.com/hn_coverage.asp, accessed at Jan. 13, 2010.

$x - 25 \times \log(\phi)$	$3.16 \le \phi/\phi_{bw} < y$
L_f	$y \le \phi/\phi_{bw} < 90/\phi_{bw}$
L_b	$90° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
L_n = near sidelobe level relative to G_{max} required by the system design, dB

α	$= 2$	for $L_n = -20, -25$
	= N/A	for $L_n = -30$
a	$= 1.29[1 - \log(z)]^{0.5}$	for $L_n = -20$
	$= 1.29[1 - 0.8 \times \log(z)]^{0.5}$	for $L_n = -25$
	= N/A	for $L_n = -30$

z = (major axis)/(minor axis)
$x = G_{max} + L_n + 25 \times \log(3.16\phi_{bw})$, dBi
$y = 3.16 \times 10^{0.04(G_{max}+L_n-L_f)}$
L_f: far sidelobe level; L_f = 0 dBi
L_b: back lobe level; $L_b = \max[0, 15 + L_n + 0.25G_{max} + 5 \times \log(z)]$, dBi

(d) Rec. ITU-R S.672-4

The recommended classification methodology for the GSO FSS satellite multiple-feed shaped beam antennas in Rec. ITU-R S.672-4 are defined by the scan ratio as follows:

- S_1: the angular distance between the center of coverage (defined as the center of the minimum area ellipse) and a point on the edge of the coverage, divided by the beamwidth of the component beam; and
- S_2: angular distance between the antenna boresight and a point on the edge of the coverage, divided by the beamwidth of the component beam.

The recommended reference radiation pattern as a design objective is shown in Table 5-23.

Table 5-23. Recommended GSO FSS Satellite Multiple-Feed Shaped Beam Antenna Reference Radiation Pattern as Design Objective

(a) Class A Antenna with Scan Ratio $S_1 \le 3.5$

Gain Function (dBi)	Angular Range
$G_{ep} + 0.256 - 13.065 \times [\psi/(q\psi_{bw}) + 0.5]^2$	$0 \le \psi/\psi_{bw} \le 0.8904q$
$G_{ep} - 25$	$0.8904q < \psi/\psi_{bw} \le 1.9244q$
$G_{ep} - 25 + 20 \times \log(1.9244q\psi_{bw}/\psi)$	$1.9244q < \psi/\psi_{bw} \le 18/\psi_{bw}$

ψ: angle from the convex coverage contour to a point outside the coverage region in a direction normal to the sides of the contour, deg.
ψ_{bw}: HPBW of component beams; $\psi_{bw} = 72\lambda/D$, deg.
G_{ep}: equivalent peak gain; $G_{ep} = G_e - 3.0$, dBi

G_e: gain at edge of coverage, dBi

$$q = 10^{\left\{\frac{0.000075(S_1 - 0.5)^2}{\left[(F/p)^2 + 0.02\right]^2}\right\}}$$

D: physical diameter of the reflector
F: reflector focal length
p: diameter of parent parabola; $p = 2(a + h)$
a: projected aperture diameter of the offset paraboloid
h: offset height to the edge of the reflector

(b) Class A Antenna with Scan Ratio $S_2 \geq 5$

Gain Function (dBi)	Angular Range
$G_e - b[(1 + \psi/\psi_b)^2 - 1]$	$0 \leq \psi/\psi_b \leq r$
$G_e - 22$	$r < \psi/\psi_b \leq r + 4.5$
$G_e - 22 + 20 \times \log[(r + 4.5)\psi_b/\psi]$	$r + 4.5 < \psi/\psi_b \leq 18/\psi_b$

ψ: angle from the convex coverage contour in a direction normal to the sides of the contour, deg.
ψ_b: beamlet radius; $\psi_b = 36\lambda/D$, deg.
G_e: gain at edge of coverage, dBi
$b = 2.05 + 0.5(f/D - 1) + 0.0025D/\lambda - (S_2 - 1.25)\ [1.65 \times (D/\lambda)^{-0.55}]$
f: focal length
D: physical diameter of the reflector
$r = (1 + 22/b)^{0.5} - 1$

(c) Class B Antenna with Scan Ratio $S_2 \geq 0$

Gain Function (dBi)	Angular Range
$G_e - b[(1 + \psi/\psi_b)^2 - 1]$	$0 \leq \psi/\psi_b \leq s$
$G_e - 17 + 18.7012 \times \log[\cos(\psi/\psi_b - s)]$	$s < \psi/\psi_b \leq s + 1$
$G_e - 22$	$s + 1 < \psi/\psi_b \leq s + 4.5$
$G_e - 22 + 20 \times \log[(s + 4.5)\psi_b/\psi]$	$s + 4.5 < \psi/\psi_b \leq 18/\psi_b$

ψ: angle from the convex coverage contour in a direction normal to the sides of the contour
ψ_b: beamlet radius; $\psi_b = 36\lambda/D$, deg.
G_e: gain at edge of coverage, dBi
$b = 2.05 + 0.5(f/D - 1) + 0.0025D/\lambda - (S_2 - 1.25)\ [1.65 \times (D/\lambda)^{-0.55}]$
f: focal length
D: physical diameter of the reflector
$s = (1 + 17/b)^{0.5} - 1$

(e) Rec. ITU-R S.1528

For coordination studies, interference assessments, and as design objective for NGSO FSS systems operating below 30 GHz, the recommended FSS satellite antenna reference radiation pattern in Rec. ITU-R S.1528 is shown in Table 5-24. Some of the parameters in the $D/\lambda < 35$ pattern are provisional.

Table 5-24. Recommended FSS Satellite Antenna Reference Radiation Pattern for EMC Analyses and as Design Objective for NGSO Systems below 30 GHz

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 35$	$G_{max} - 12(\phi/\phi_{bw})^{1.5}$	$0 \leq \phi/\phi_{bw} \leq a$
	$G_{max} + L_n + 20 \times \log(z)$	$a < \phi/\phi_{bw} \leq 1.58$
	$G_{max} + L_n$	$1.58 < \phi/\phi_{bw} \leq 3.16$
	$x - 25 \times \log(\phi)$	$3.16 < \phi/\phi_{bw} \leq y/\phi_{bw}$
	L_f	$y < \phi \leq 90°$
	L_b	$90° < \phi \leq 180°$
$D/\lambda < 35$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0.5\ \phi_{bw} < \phi \leq r$
	$G_{max} + L_s - 25 \times \log(\phi/r)$	$r < \phi \leq s$
	L_f	$s < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.
ϕ_{bw}: HPBW in the plane of interest. Use actual value if known, or
$\phi_{bw} = 2\ (1200)^{0.5}/(D/\lambda)$, deg., for minor axis,
$\phi_{bw} = 2\ z\ (1200)^{0.5}/(D/\lambda)$, deg., for major axis,
z = (major axis)/(minor axis).
L_n: near sidelobe level relative to G_{max} required by the system design, dB
L_f: far sidelobe level; $L_f = 0$ dBi
L_b: back lobe level; $L_b = \max[0, 15 + L_n + 0.25G_{max} + 5\times\log(z)]$, dBi

$a = 1.29\ [1 - 1.4 \times \log(z)]^{0.5}$ for $L_n = -15$
$= 1.29\ [1 - \log(z)]^{0.5}$ for $L_n = -20$
$= 1.29\ [1 - 0.6 \times \log(z)]^{0.5}$ for $L_n = -25$
$= 1.29\ [1 - 0.4 \times \log(z)]^{0.5}$ for $L_n = -30$

$x = G_{max} + L_n + 25 \times \log(3.16\phi_{bw})$, dBi

$y = 3.16\phi_{bw} \times 10^{\left[0.04\left(G_{max} + L_n - L_f\right)\right]}$

$L_s = -12$ dB for medium Earth orbit (MEO)
$= -6.75$ dB for low-Earth orbit (LEO)

$r = \phi_{bw}$ for MEO
$= 0.75\phi_{bw}$ for LEO

$s = r \times 10^{\left[0.04\left(G_{max} + L_n - L_f\right)\right]}$

(f) Rec. ITU-R S.1553

Rec. ITU-R S.1553 provides information for evaluating and determining the variances of FSS satellite antenna radiation patterns due to environmental, operational, ageing and other factors.[80]

5.4 Broadcasting Service

BS provides amplitude modulation (AM) audio, frequency modulation (FM) audio, and TV services. The BS stations can be broadcasting stations with transmitting antennas and receiving stations with receiving antennas.

NTIA does not provide the BS antenna radiation performance standards for the federal systems because federal agencies do not operate domestic BS system.[81]

5.4.1 AM Audio

AM audio programming operates mostly in the LF and MF bands. It also operates in the HF bands, where it is referred to as the short-wave radio. The transmitting and receiving antennas for the AM audio system are discussed here.

5.4.1.1 Transmitting Antenna

The AM audio transmitting antenna in the LF and MF bands can be either an omnidirectional or directional antenna. The omnidirectional antennas can be short vertical monopoles whose electric length is much shorter than λ/4. The directional antennas are mostly arrays of either vertical radiators or combination of vertical radiators and passive elements. The radiation pattern of an array antenna is designed for the service area of interest, and is usually obtained from numerical analyses and then verified by measurements. Various radiating structures, such as self-supporting towers, guyed masts and wire elements, are commonly used. The picture of an AM audio transmitting antenna is shown in Figure 5-2.[82]

80 Rec. ITU-R S.1553, *A Possible Method to Account for Environmental and Other Effects on Satellite Antenna Patterns* (2002).

81 The Federal Government operates Voice of America whose service areas are not domestic.

82 http://www.flickr.com/photos/theslowlane/6111796632/in/set-72157627464774731/, accessed Jan. 14, 2010.

Figure 5-2. AM Audio Broadcasting Antenna

This sub-section contains one LF/MF transmitting antenna radiation performance standard from 47 CFR Part 73 and the following recommendations from ITU-R:[83] [84]

- from Rec. ITU-R BS.1386-1, methodology to calculate the LF/MF transmitting antenna radiation pattern for EMC analyses;[85]
- from Rec. ITU-R BS.80-3, guideline to select the HF transmitting antenna;[86]
- from Rec. ITU-R BS.705-1, formulas and computer programs for EMC analyses of the HF transmitting antenna;[87] and
- from Rec. ITU-R BS.139, transmitting antenna characteristics for operating in the tropical zone.[88]

(a) 47 CFR Part 73, Subpart A, Domestic Services

The methodology to calculate the AM audio transmitting array antenna radiation pattern in 47 CFR Part 73, Subpart A is as follows. The radiation pattern, $f_{std}(\theta, \varphi)$, in the direction (θ, φ) is the inverse distance fields at one kilometer that are produced by the directional antenna in the horizontal and vertical planes. It is derived from

$$f_{std}(\theta, \varphi) = 1.05 \left[f_{th}(\theta, \varphi)^2 + Q^2 \right]^{0.5} \qquad (5\text{-}1)$$

The function $f_{th}(\theta, \varphi)$ in Eq. (5-1) is the theoretical inverse distance fields at one kilometer in the direction (θ, φ),

83 47 CFR, Part 73, *Radio Broadcast Services*, Subpart A, *AM Broadcast Stations*, §73.150, §73.160.

84 47 CFR, Part 73, *Radio Broadcast Services*, Subpart F, *International Broadcast Stations.*

85 Rec. ITU-R BS.1386-1, *LF and MF Transmitting Antennas Characteristics and Diagrams* (2001).

86 Rec. ITU-R BS.80-3, *Transmitting Antennas in HF Broadcasting* (1990).

87 Rec. ITU-R BS.705-1, *HF Transmitting and Receiving Antennas Characteristics and Diagrams* (1995).

88 Rec. ITU-R BS.139-3, *Transmitting Antennas for Sound Broadcasting in the Tropical Zone* (1990).

$$f_{th}(\theta,\varphi) = \left| k \left\{ \sum_{i=1}^{n} \frac{F_i f_i(\theta)}{S_i \cos(\theta)\cos(\varphi_i - \varphi) + \psi_i} \right\} \right| \qquad (5\text{-}2)$$

where

k: the multiplying constant that determines the basic pattern size,
i: i^{th} array element or i^{th} tower,
n: the total number of elements in the array,
F_i: the field ratio of the i^{th} array element,
$f_i(\theta)$: the vertical plane radiation characteristic of the i^{th} array element,
S_i: electrical spacing of the i^{th} array element from the reference point,
φ_i: azimuth (with respect to true north) of the i^{th} array element, and
Ψ_i: electrical phase angle of the current in the i^{th} array element.

The value of k in Eq. (5-2) is chosen so that the root-mean-square value of the theoretical field in the horizontal plane is no greater than the value computed on the assumption that nominal station power is delivered to the directional array, and that a lumped loss resistance of one ohm exists at the current loop of each element of the array, or at the base of each element of electrical height lower than 0.25 wavelength, and no less than the value required in §73.189(b)(2) for a station of the class and nominal power for which the pattern is designed.

The value of $f_i(\theta)$ in Eq. (5-2) depends on the tower height as well as whether the tower is top-loaded or sectionalized:

(1) For a typical tower that is not top-loaded nor sectionalized,

$$f(\theta) = \frac{\cos[G\sin(\theta)] - \cos(G)}{[1-\cos(G)]\cos(\theta)} \qquad (5\text{-}3)$$

where *G* is the electrical height of the tower, not including the base insulator and pier, in electrical degrees. In the case of a folded monopole tower, the entire radiating structure's electrical height is used.

(2) For a top-loaded tower,

$$f(\theta) = \frac{\cos(B)\cos[A\sin(\theta)] - \sin(\theta)\sin(B)\sin[A\sin(\theta)] - \cos(A+B)}{\cos(\theta)[\cos(B) - \cos(A+B)]} \qquad (5\text{-}4)$$

where

A: the physical height of the tower, in electrical degrees,
G: the apparent electrical height of the tower, based on current distribution, in electrical degrees,
B = *G* – A.

(3) For a sectionalized tower,

$$f(\theta) = \frac{\sin(\Delta)f_1 + \sin(B)f_2}{\cos(\theta)\{\sin(\Delta)[\cos(B) - \cos(G)] + \sin(B)[\cos(D) - \cos(\Delta)]\}} \quad (5\text{-}5)$$

where

$f_1 = \cos(B)\cos[A\times\sin(\theta)] - \cos(G)$,

$f_2 = \cos(D)\cos[C\times\sin(\theta)] - \sin(\theta)\sin(D)\sin[C \sin(\theta)] - \cos(\Delta)\cos[A\times\sin(\theta)]$,

A: the physical height of the lower section of the tower, in electrical degrees,

G: the apparent electrical height of the lower section of the tower, based on current distribution, in electrical degrees,

B = *G* - A,

C: the physical height of the entire tower, in electrical degrees,

H: the apparent electrical height of the tower, based on current distribution, in electrical degrees,

D = *H* - C, D = 0 if the sectionalized tower is not top-loaded, and

Δ = *H* - A.

Here "height in electrical degrees" means height divided by λ then multiplied by 360°.

The value of Q in Eq. (5-1) is calculated with

$$Q = \max\,[0.025\times g(\theta)\, E_{rss}\, ,\ 10\times g(\theta)(P_{kW})^{0.5}] \quad (5\text{-}6)$$

where

$g(\theta)$: the shortest element of the $f_i(\theta)$ array. If the shortest element has an electrical height in excess of 0.5λ, then

$$g(\theta) = [f(\theta)^2 + 0.0625]^{0.5}/1.030776 \quad (5\text{-}7)$$

E_{rss}: the root sum square of the amplitudes of the inverse fields of the elements in the horizontal plane, i.e.,

$$E_{rss} = k\left(\sum_{i=1}^{n} F_i^2\right)^{0.5} \quad (5\text{-}8)$$

P_{kW}: the nominal station power expressed in kilowatts. $P_{kW} = 1$ if the nominal power is less than one kilowatt.

(b) 47 CFR Part 73, Subpart F, International Services

The standard for the international HF AM audio broadcasting transmitting antenna is not specified in 47 CFR Part 73, Subpart F.

(c) Rec. ITU-R BS.1386-1

For system planning, coordination studies, and antenna performance evaluation of the LF/MF AM audio systems, the recommended methodology to calculate the transmitting antenna radiation pattern in Rec. ITU-R BS.1386-1 is provided here. The electric field E(θ, φ) is related to the radiation pattern f(θ, φ) by

$$|E(\theta, \varphi)| = k\,|f(\theta, \varphi)| \qquad (5\text{-}9)$$

where

$|E(\theta, \varphi)|$ is the magnitude of the electrical field,
$|f(\theta, \varphi)|$ is the radiation pattern function, and
k is the normalizing factor to set $|E(\theta, \varphi)|_{max} = 1$ (or 0 dB).

(d) Rec. ITU-R BS.80-3

The recommended guideline to select the HF AM audio transmitting antenna in Rec. ITU-R BS.80-3 is shown in Table 5-25.

Table 5-25. Recommended Guideline for Selecting HF AM Audio Transmitting Antennas

Distance	Radiation Pattern	ϕ_{bw}	Antenna Type	Characteristics
Short (≤ 2000 km)	Omni-directional	n/a	Tropical antenna, horizontal antenna, vertical antenna	N/A
	Directional	Narrow	Curtain array (HR 4/1/h, HR 4/2/h)	$0.25 \le h \le 0.6$, $15° \le \theta \le 50°$, $\phi_{bw} \le 35°$, $13 \le G_{max}(dBi) \le 19$
		Wide	Curtain array (HR m/n/h, m & n = 1 or 2)	$0.25 \le h \le 0.6$, $15° \le \theta \le 50°$, $70° \le \phi_{bw} \le 180°$, $9 \le G_{max}(dBi) \le 16$
			Log-periodic antenna of single plane	$0.65 \le \tau \le 0.8$, $17° \le \theta \le 50°$, $80° \le \phi_{bw} \le 130°$, $8 \le G_{max}(dBi) \le 14$
Medium, long	Directional	Narrow	Curtain array (HR 4/3/h, HR 4/4/h)	$0.4 \le h \le 1.5$, $6° \le \theta \le 13°$, $\phi_{bw} \approx 35°$, $19 \le G_{max}(dBi) \le 22$

		Wide	Curtain array (HR 2/3/h, HR 2/4/h)	$0.4 \leq h \leq 1.2$, $6° \leq \theta \leq 13°$, $\phi_{bw} \approx 70°$, $16 \leq G_{max}(dBi) \leq 19$
θ: elevation angle HR: horizontal dipole curtain antenna with reflector curtain m of HR m/n/h: number of λ/2 elements in each row n of HR m/n/h: number of λ/2 elements in each vertical or slanted column h of HR m/n/h: height of bottom row above ground, in λ τ: taper ratio of log periodic antenna				

(e) Rec. ITU-R BS.705-1

For system planning and antenna performance evaluation of the HF AM audio systems, the recommended formulas and computer programs for the transmitting antenna are provided in Rec. ITU-R BS.705-1. They cover the following antennas:

- omnidirectional antenna: horizontal or slanted dipole and its variations;
- omnidirectional array:
  - quadrant antenna, and
  - crossed dipole antenna;
- directional array:
  - curtain antenna: array of horizontal dipoles arranged vertically, and
  - tropical antenna: array of horizontal dipoles arranged horizontally;
- log-periodic antenna:
  - horizontal log-periodic antenna, and
  - vertical log-periodic antenna;
- vertical monopole; and
- Rhombic antenna.

The radiation pattern, $F(\theta, \varphi)$, of an array is calculated by

$$F(\theta, \varphi) = k\,|E(\theta, \varphi)| = k\,|f(\theta, \varphi)| \times |S| \qquad (5\text{-}10)$$

where

$E(\theta, \varphi)$: total field contributed by the array,
$f(\theta, \varphi)$: radiation pattern of one element,
k: normalizing factor to set $|F(\theta, \varphi)|_{max} = 1$ (or 0 dB), and
S: array factor, function of the spatial distribution of the elements.

Radiation patterns are affected by permittivity and conductivity of the ground, which can be obtained from numerical analyses and then verified by measurements. Numerous radiation patterns are shown graphically in Rec. ITU-R BS.705-1.

(f) Rec. ITU-R BS.139

For the AM audio system operating in the tropical zone, the recommended transmitting antenna characteristics in Rec. ITU-R BS.139 are as follows:

- the radiated power at high elevation angles required to meet the needs of the service area should be as large as possible,
- the radiated power at elevation angles necessary to serve the fringe of the service area should be maintained at a sufficient level, and
- the radiated power at elevation angles lower than those used to serve the fringe of the service area should be as low as possible.

It is preferable to locate the antenna at the center of the service area, requiring the antenna radiation pattern to be omnidirectional. When this is not practical, ionospheric reflection becomes the choice of propagation mechanism, and the antenna should be a dipole array antenna slewed such that the radiation pattern generates vertical incidence. Types of array antennas commonly used for vertical incidence are as follows:[89]

- Trinidad antenna;
- Jamaica antenna, which is an array antenna of four half-wavelength end-fed dipoles in the same horizontal plane with the elements approximately 0.2 λ above ground, its elements fed with currents of the same magnitude and phase;
- 16-element array; and
- high incidence array, an array consisting of four full-wavelength dipoles arranged in the form of a square with the elements approximately 0.15λ above ground, its elements fed with currents of the same magnitude and phase in any two adjoining elements.

5.4.1.2 Receiving Antenna

LF/MF AM audio receiving antennas are usually dipole antennas or loop antennas, e.g., short dipole antenna in Section 3.2.2(a) or small loop antenna in Section 3.2.3. This sub-section contains one recommended reference radiation pattern from ITU-R.

Rec. ITU-R BS.705-1

For system planning and antenna performance evaluation of the HF AM audio systems, the recommended receiving antenna reference radiation pattern in Rec. ITU-R BS.705-1 [Ref. 87] is shown in Figure 5-3. The patterns are the vertical radiation patterns of an omnidirectional short whip antenna.

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89 CCIR publication, *Broadcasting in Band 7 (HF) in the Tropical Zone,* ITU (1969).

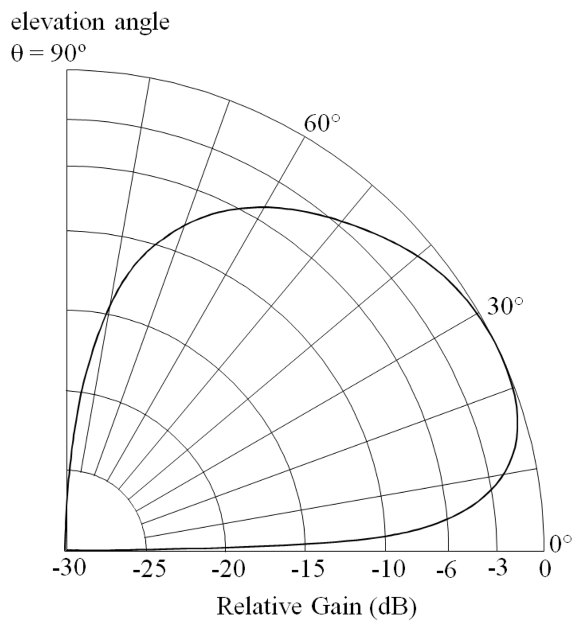

Figure 5-3. Recommended Reference Receiving Radiation Pattern for AM HF Broadcasting for Performance Evaluation and System Planning

5.4.2 FM Audio

FM audio operates in the VHF, UHF and higher frequency bands. This sub-section contains the following antenna characteristics:

- from 47 CFR Part 73, transmitting antenna radiation performance standard for the aural broadcast auxiliary station;[90]
- from 47 CFR Part 74, transmitting antenna radiation performance standard for the aural broadcast auxiliary station; [91]
- from Rec. ITU-R BS.1195, recommended VHF receiving antenna directivity for system planning Recommendation;[92] and
- from Rec. ITU-R BS.599, recommended receiving antenna directivities.[93]

(a) 47 CFR Part 73, Subpart B

The application for the FM audio directional transmitting antennas in 47 CFR Part 73, Subpart B, requires that:

- the ratio of the maximum to minimum radiation in the horizontal plane be no more than 15 dB, and
- for antennas used to protect short-spaced stations, pursuant to 47 CFR §73.213 or §73.215, the radiation pattern must not vary more than 2 dB per 10° in azimuth.

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90 47 CFR, Part 73, *Radio Broadcast Services*, Subpart B, *FM Broadcast Stations*, §73.316.

91 47 CFR, Part 74, E*xperimental Radio, Auxiliary, Special Broadcast and Other Program Distributional Service,* Subpart E, *Aural Broadcast Auxiliary Stations*, §74.536.

92 Rec. ITU-R BS.1195, *Transmitting Antenna Characteristics at VHF and UHF* (1995).

93 Rec. ITU-R BS.599, *Directivity of Antennas for the Reception of Sound Broadcasting in Band 8 (VHF)* (1982).

(b) 47 CFR Part 73, Subpart G, Low Power Stations

The antenna radiation performance standard for the low power FM audio transmitting antenna is not specified in 47 CFR Part 73, Subpart G.[94]

(c) 47 CFR Part 74, Subpart E, Auxiliary Services

For the FM audio systems operating in 17.7–19.7 GHz serving aural broadcast studio-to-transmitter-links or intercity-relay stations, the transmitting antenna radiation performance standard in 47 CFR Part 74, Subpart E is shown in Table 5-26.

Table 5-26. FCC Antenna Radiation Performance Standard for Aural Broadcast Stations for Non-Federal Systems

Standard	Max. ϕ_{bw} (°)	Min. G_{max} (dBi)	Min. Radiation Suppression to G_{max} (dB) Angle Off Mainbeam Axis (°) 5–10	10–15	15–20	20–30	30–100	100–140	140–180
A	2.2	38	25	29	33	36	42	55	55
B	2.2	38	20	24	28	32	35	36	36
Standard A is the general requirement. Standard B may be applied in areas not subject to frequency congestion.									

(d) Rec. ITU-R BS.1195

For system planning and antenna performance evaluation of the VHF/UHF FM audio systems, the recommended formulas and computer programs to calculate the transmitting antenna radiation patterns are provided in Rec. ITU-R BS.1195. Because of the peculiarity of the each service area, FM audio broadcasting generally uses Yagi antennas or array antennas to generate the desired radiation patterns. The array element can be a dipole, a loop, a slot or a helix, with the dipole being the most common element. The linear array can be a broadside array of either a vertical array of horizontal dipoles or an omnidirectional collinear array of vertical dipoles. Horizontal polarization has traditionally been used for FM audio broadcasting, but other polarizations, e.g., circular and slant, suitable for car radios or receivers with built-in antennas, have also been used.

(e) Rec. ITU-R BS.599

For system planning of the VHF FM audio systems, the recommended receiving antenna directivities in Rec. ITU-R BS.599 are shown in Figure 5-4. They are applicable to both the vertical or horizontal polarizations.

94 47 CFR, Part 73, *Radio Broadcast Services*, Subpart G, *Low Power FM Broadcast Stations.*

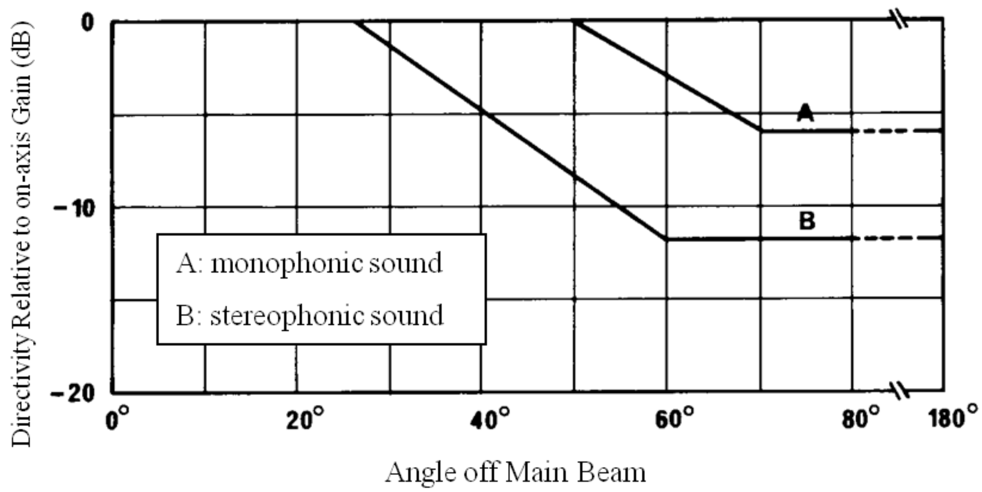

Figure 5-4. Recommended Directivity of VHF Audio Broadcasting Receiving Antenna for System Planning

For portable or mobile reception of sound broadcasts, no directivity of the reception antenna should be applied in planning.

5.4.3 TV

This sub-section contains the following antenna characteristics:

- from 47 CFR Part 74, transmitting antenna radiation performance standard for the broadcast auxiliary service;[95] and
- from Rec. ITU-R BT.419-3, recommended receiving antenna co-polarization reference directivity for system planning purposes.[96]

(a) 47 CFR Part 73

The antenna radiation performance standard for the TV transmitting antenna is not specified in 47 CFR Part 73.[97]

(b) 47 CFR Part 74, Auxiliary Services

For the TV broadcast auxiliary service, the transmitting antenna radiation performance standards in 47 CFR Part 74 are shown in Table 5-27.

95 47 CFR, Part 74, E*xperimental Radio, Auxiliary, Special Broadcast and Other Program Distributional Service*, §74.641.

96 Rec. ITU-R BT.419-3, *Directivity and Polarization Discrimination of Antennas in the Reception of Television Broadcasting* (1990).

97 47 CFR, Part 73, *Radio Broadcast Services*, Subpart E, *Television Broadcast Stations.*

Table 5-27. FCC Antenna Radiation Performance Standard for TV Broadcast Auxiliary Station for Non-Federal Systems

Standard	Frequency (GHz)	Max. ϕ_{bw} (°)	Min. G_{max} (dBi)	Min. Radiation Suppression to G_{max} (dB) Angle Off Mainbeam Axis (°)						
				5–10	10–15	15–20	20–30	30–100	100–140	140–180
A	1.99–2.11	5	n/a	12	18	22	25	29	33	39
	6.875–7.125	1.5	n/a	26	29	32	34	38	41	49
	12.7–13.25	1	n/a	23	28	35	39	41	42	50
	17.7–19.7	2.2	38	25	29	33	36	42	55	55
B	1.99–2.11	8	n/a	5	18	20	20	25	28	36
	6.875–7.125	2	n/a	21	25	29	32	35	39	45
	12.7–13.25	2	n/a	20	25	28	30	32	37	47
	17.7–19.7	2.2	38	20	24	28	32	35	36	36

n/a: not available.
Standard B is the minimum requirement. Standard A antennas must be employed in areas subject to frequency congestion and the proposed services cannot be supported by the Standard B antennas.

(c) Rec. ITU-R BT.419-3

For system planning of the TV systems, the recommended receiving antenna co-polarization reference directivities in Rec. ITU-R BT.419-3 are shown in Figure 5-5. The band designation data in Figure 5-5 can be found in Rec. ITU-R BT.417-5;[98] they are

band I: 41-68 MHz,
band III: 162-230 MHz,
band IV: 470-582 MHz, and
band V: 582-960 MHz.

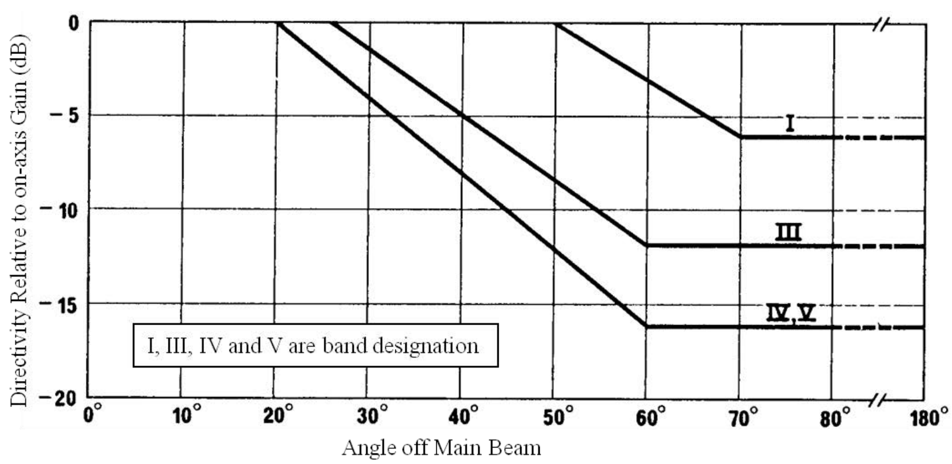

Figure 5-5. Recommended Directivity for TV Receiving Antenna for System Planning

98 Rec. ITU-R BT.417-5, *Minimum Field Strengths for Which Protection May Be Sought in Planning an Analogue Terrestrial Television Service* (2002).

These directivity discriminations should be available at the majority of antenna locations in the built-up areas, and slightly higher values could be obtained at clear sites in open country. There is no recommended cross-polarization directivity, but it has been found in practice that a combined cross-polarization discrimination value of 16 dB may be applied to all azimuthal angles. Also, the recommended antenna directivities of the cable distribution systems for planning purposes will be at least equal to the directivities depicted in Figure 5-5.

5.5 Broadcasting-Satellite Service

A BSS system consists of an uplink that feeds the program to the satellite for downlink broadcasting, and many receive-only earth stations to receive the program. The uplink is also called the feeder link. Antenna data for the earth stations and satellite are presented here.

NTIA does not provide the BSS antenna radiation performance standards for the federal systems because federal agencies do not provide BSS.

5.5.1 Earth Station Antenna

There are two types of BSS earth stations, i.e., the feeder link transmitting earth station and the downlink receive-only earth station. This sub-section contains the following earth station antenna radiation performance standards:

- from RR Appendix 30A, for the transmitting antennas of the BSS Allotment Plan in Region 2;[99]
- from RR Appendix 8 [Ref. 69], for the transmitting antenna, for determining if coordination is required between GSO satellite networks; and
- from RR Appendix 30, for the receive-only antennas of the BSS Allotment Plan in Region 2.[100]

It also contains the following recommended reference radiation patterns from ITU-R:

- from Rec. ITU-R BO.652-1, for the transmitting antenna, for system planning in Region 2 in the 14 and 17 GHz bands;[101]
- from Rec. ITU-R BO.1213-1, for the receiving antenna operating in 11.7–12.75 GHz;[102]
- from Rec. ITU-R BO.652-1, for the receiving antenna, for system planning in Region 2 in the 12 GHz band; and

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99 RR, Appendices 30A, *Provisions and Associated Plans and List1 for Feeder Links for the Broadcasting-Satellite Service (11.7-12.5 GHz in Region 1, 12.2-12.7 GHz in Region 2 and 11.7-12.2 GHz in Region 3) in the Frequency Bands 14.5-14.8 GHz and 17.3-18.1 GHz in Regions 1 and 3, and 17.3-17.8 GHz in Region 2*, Annex 3.

100 RR, Appendices 30, *Provisions for All Services and Associated Plans and List1 for the Broadcasting-Satellite Service in the Frequency Bands 11.7-12.2 GHz (in Region 3), 11.7-12.5 GHz (in Region 1) and 12.2-12.7 GHz (in Region 2)*, Annex 5.

101 Rec. ITU-R BO.652-1, *Reference Patterns for Earth-station and Satellite Antennas for the Broadcasting-satellite Service in the 12 GHz Band and for the Associated Feeder Links in the 14 GHz and 17 GHz Bands* (1992).

102 Rec. ITU-R BO.1213-1, *Reference Receiving Earth Station Antenna Pattern for the Broadcasting-Satellite Service in the 11.7-12.75 GHz Band* (2005).

- from Rec. ITU-R BO.1443-2, for the receiving antenna, for EMC analyses between systems of the Region 2 Allotment Plan and NGSO FSS satellites.[103]

5.5.1.1 Feeder Link Transmitting Antenna

(a) RR Appendix 30A

For the feeder links of the BSS Allotment Plan in Region 2 in 17.3–17.8 GHz, the earth station antenna reference radiation pattern in RR Appendix 30A is shown in Table 5-28.

Table 5-28. BSS Feeder Links Earth Station Transmitting Antenna Reference Radiation Pattern in RR Appendix 30A for Region 2 Allotment Plan

Category	Gain Function (dBi)	Angular Range
Co-Polarization	G_{max}	$0° \leq \phi < 0.1°$
	$36 - 20 \times \log(\phi)$	$0.1° \leq \phi < 0.32°$
	$51.3 - 53.2 \times \phi^2$	$0.32° \leq \phi < 0.54°$
	$\max[29 - 25 \times \log(\phi), -10]$	$0.54° \leq \phi \leq 180°$
Cross-Polarization	$G_{max} - 30$	$0° \leq \phi < (0.6/D)°$
	$\max[9 - 20 \times \log(\phi), -10]$	$(0.6/D)° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.
D: antenna diameter, meters, $D \geq 2.5$

- The actual co-polarization gain must not exceed the reference pattern in the angular range between 0.1° and 0.54°.
- The actual cross-polarization gain must not exceed the reference pattern in the angular range between 0° and (0.6/D)°.
- The actual gain must not exceed the reference pattern for 90% of all sidelobe peaks for $\phi > 0.54°$.

(b) RR Appendix 8

For determining if coordination is required between the GSO satellite networks, the earth station antenna reference radiation pattern in RR Appendix 8 is shown in Table 5-29. Appendix 8 applies to earth stations of all GSO satellite networks, including FSS, BSS and others. The pattern applies to both the transmitting and receiving antennas; however, it should be used only if a relevant ITU-R recommendation is unavailable.

Table 5-29. GSO Space System Earth Station Antenna Reference Radiation Pattern in RR Appendix 8 for Determining If Coordination Is Required between GSO Space Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_r$
	$32 - 25 \times \log(\phi)$	$\phi_r \leq \phi < 48°$

103 Rec. ITU-R BO.1443-2, *Reference BSS Earth Station Antenna Patterns for Use in Interference Assessment Involving Non-GSO Satellites in Frequency Bands Covered by RR Appendix 30* (2006).

	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < (100\lambda/D)°$
	$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < 48°$
	$10 - 10 \times \log(D/\lambda)$	$48° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = 2 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.		

(c) Rec. ITU-R BO.652-1

For system planning of the BSS systems in Region 2 in the 14 and 17 GHz bands, the recommended feeder link earth station transmitting antenna reference radiation pattern in Rec. ITU-R BO.652-1 is the same as the RR Appendix 30A pattern of Table 5-28. The requirement for the actual antenna radiation patterns in RR Appendix 30A is also recommended in Rec. ITU-R BO.652-1.

5.5.1.2 Downlink Receive-Only Antenna

(a) RR Appendix 30

For developing the BSS Allotment Plan in Region 2 in 12.2–12.7 GHz, the earth station receive-only antenna reference radiation pattern in RR Appendix 30 is shown in Table 5-30. It is valid for $D/\lambda \geq 11$. It requires

- the actual co-polarization and cross-polarization gain must not exceed the reference patterns within $0.1 \leq \phi/\phi_{bw} \leq 1.13$, and
- the actual gain must not exceed the reference pattern for 90% of all sidelobe peaks for $\phi > 1.13\phi_{bw}$.

Table 5-30. BSS Earth Station Receive-Only Antenna Reference Radiation Pattern in RR Appendix 30 for Region 2 Allotment Plan

Category	Gain Function Relative to G_{max} (dB)	Angular Range
Co-polarization, no sidelobe suppression	0	$0 \leq \phi/\phi_{bw} < 0.25$
	$-12(\phi/\phi_{bw})^2$	$0.25 \leq \phi/\phi_{bw} < 1.13$
	$-14 - 25 \times \log(\phi/\phi_{bw})$	$1.13 \leq \phi/\phi_{bw} < 14.7$
	-43.2	$14.7 \leq \phi/\phi_{bw} < 35$
	$-85.2 + 27.2 \times \log(\phi/\phi_{bw})$	$35 \leq \phi/\phi_{bw} < 45.1$
	-40.2	$45.1 \leq \phi/\phi_{bw} < 70$
	$55.2 - 51.7 \times \log(\phi/\phi_{bw})$	$70 \leq \phi/\phi_{bw} < 80$
	-43.2	$80 \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$
Cross-polarization	-25	$0 \leq \phi/\phi_{bw} < 0.25$

	$-30 - 40 \times \log(1 - \phi/\phi_{bw})$	$0.25 \le \phi/\phi_{bw} < 0.44$
	-20	$0.44 \le \phi/\phi_{bw} < 1.28$
	$-17.3 - 25 \times \log(\phi/\phi_{bw})$	$1.28 \le \phi/\phi_{bw} < 3.22$
	-30	$3.22 \le \phi/\phi_{bw}$
	as co-polarization pattern	after intersection with co-polarization pattern
ϕ: angle off mainbeam axis, deg.		

(b) Rec. ITU-R BO.1213-1

For the BSS systems operating in 11.7–12.75 GHz, the recommended earth station receiving antenna reference radiation pattern in Rec. ITU-R BO.1213-1 is shown in Table 5-31. They are valid for $D/\lambda \ge 11$.

Table 5-31. Recommended BSS Earth Station Receiving Antenna Reference Radiation Pattern in 11.7–12.75 GHz

Category	Gain Function (dBi)	Angular Range
Co-polarization	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < \phi_r$
	$29 - 25 \times \log(\phi)$	$\phi_r \le \phi < \phi_b$
	-5	$\phi_b \le \phi < 70°$
	0	$70° \le \phi \le 180°$
Cross-polarization	$G_{max} - 25$	$0° \le \phi < 0.25\ \phi_{bw}$
	$G_{max} - 25 + 8[(\phi - 0.25\phi_{bw})/(0.19\phi_{bw})]$	$0.25\ \phi_{bw} \le \phi < 0.44\ \phi_{bw}$
	$G_{max} - 17$	$0.44\ \phi_{bw} \le \phi < \phi_{bw}$
	$G_{max} - 17 + c\lvert(\phi - \phi_{bw})/(\phi_1 - \phi_{bw})\rvert$	$\phi_{bw} \le \phi < \phi_1$
	$21 - 25 \times \log(\phi)$	$\phi_1 \le \phi < \phi_2$
	-5	$\phi_2 \le \phi < 70°$
	0	$70° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $G_{max} = 10\times\log[e(\pi D/\lambda)^2]$, dBi $G_1 = 29 - 25\times\log(\phi_r)$, dBi $\phi_{bw} = 2(\lambda/D)[3/0.0025]^{0.5}$, deg. $\phi_m = (\lambda/D)[(G_{max} - G_1)/0.0025]^{0.5}$, deg. $\phi_r = 95(\lambda/D)$, deg. $\phi_b = 10^{(34/25)}$, deg. $\phi_1 = (10.1875)^{0.5}\phi_{bw}/2$, deg. $\phi_2 = 10^{(26/25)}$, deg. $c = 21 - 25\times\log(\phi_1) - (G_{max} - 17)$; $c < 0$ for any combination of e and D/λ		

(c) Rec. ITU-R BO.652-1

For system planning of the BSS systems in Region 2 in the 12 GHz band, the recommended earth station receiving antenna reference radiation pattern in Rec. ITU-R BO.652-1 is identical to the pattern of RR Appendix 30 in Table 5-30. The requirement for actual antenna radiation pattern in RR Appendix 30 is also recommended in Rec. ITU-R BO.652-1.

The recommendations in Recs. ITU-R BO.652-1 and BO.1213-1 are different. Rec. ITU-R BO.652-1 provides different reference radiation patterns for Region 2 and Regions 1 and 3, while Rec. ITU-R BO.1213-1 provides a single general-purpose reference radiation pattern; the last version of Rec. ITU-R BO.652-1 was issued in 1992, and the last version of Rec. ITU-R BO.1213-1 was issued in 2005.

(d) Rec. ITU-R BO.1443-2

For interference assessment involving the NGSO FSS satellites in the BSS Allotment Plan in Region 2 in 12.2–12.7 and 17.3–17.8 GHz, the recommended BSS earth station receiving antenna reference radiation pattern in Rec. ITU-R BO.1443-2 is shown in Table 5-32.

Table 5-32. Recommended BSS Earth Station Receiving Antenna Reference Radiation Pattern for Interference Assessment Involving NGSO FSS Satellites in Region 2 BSS Allotment Plan Bands

Category	Gain Function (dBi)		Angular Range
$D/\lambda > 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$		$0° \leq \phi < \phi_m$
	G_1		$\phi_m \leq \phi < \phi_r$
	$29 - 25 \times \log(\phi)$		$\phi_r \leq \phi < 10°$
	$34 - 30 \times \log(\phi)$		$10° \leq \phi < 34.1°$
	-12		$34.1° \leq \phi < 80°$
	-7		$80° \leq \phi < 120°$
	-12		$120° \leq \phi \leq 180°$
$25.5 < D/\lambda \leq 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$		$0° \leq \phi < \phi_n$
	G_2		$\phi_n \leq \phi < (95\lambda/D)°$
	$29 - 25 \times \log(\phi)$		$(95\lambda/D)° \leq \phi < 33.1°$
	-9		$33.1° \leq \phi < 80°$
	-4		$80° \leq \phi < 120°$
	-9		$120° \leq \phi \leq 180°$
$11 \leq D/\lambda \leq 25.5$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$		$0° \leq \phi < \phi_n$
	G_2		$\phi_n \leq \phi < (95\lambda/D)°$
	$29 - 25 \times \log(\phi)$		$(95\lambda/D)° \leq \phi < 36.3°$
	-10		$36.3° \leq \phi < 50°$
	for $0° \leq \theta < 56.25°$	$M_1 \times \log(\phi) - b_1$	$50° \leq \phi < 120°$
		$M_2 \times \log(\phi) - b_2$	$120° \leq \phi \leq 180°$
	for $56.25° \leq \theta < 123.75°$	$M_3 \times \log(\phi) - b_3$	$50° \leq \phi < 90°$
		$M_4 \times \log(\phi) - b_4$	$90° \leq \phi \leq 180°$

	for 123.75° ≤ θ < 180°	$M_1 \times \log(\phi) - b_1$	50° ≤ φ < 120°
		$M_2 \times \log(\phi) - b_2$	120° ≤ φ ≤ 180°
	for 180° ≤ θ < 360°	$M_5 \times \log(\phi) - b_5$	50° ≤ φ < 120°
		$M_6 \times \log(\phi) - b_6$	120° ≤ φ ≤ 180°

φ: angle off mainbeam axis, deg.
θ: planar angle of the satellite relative to the 0° plane of the antenna model.

$G_{max} = 20\times\log(D/\lambda) + 8.1$, dBi

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$G_2 = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_m = (\lambda/D)[(G_{max} - G_1)/0.0025]^{0.5}$, deg.

$\phi_n = (\lambda/D)[(G_{max} - G_2)/0.0025]^{0.5}$, deg.

$\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.

$M_1= [2 + 8 \sin(\theta)]/\log(2.4)$

$b_1= M_1\times\log(50) + 10$

$M_2= [-9 - 8 \sin(\theta)]/\log(1.5)$

$b_2= M_2\times\log(180) + 17$

$M_3= [2 + 8 \sin(\theta)]/\log(1.8)$

$b_3 = M_3\times\log(50) + 10$

$M_4= [-9 - 8 \sin(\theta)]/\log(2)$

$b_4= M_4\times\log(180) + 17$

$M_5= 2/\log(2.4)$

$b_5= M_5\times\log(50) + 10$

$M_6= -9/\log(1.5)$

$b_6= M_6\times\log(180) + 17$

5.5.2 Satellite Antenna

This sub-section contains the following satellite antenna characteristics:

- from RR Appendix 30 [Ref. 100], the transmitting antenna radiation performance standard for the Allotment Plan;
- from RR Appendix 30A [Ref. 99], the receiving antenna radiation performance standard for the Allotment Plan; and
- from Rec. ITU-R BO.652-1 [Ref. 101], the recommended transmitting and receiving antenna reference radiation patterns.

5.5.2.1 Downlink Transmitting Antenna

(a) RR Appendix 30

For developing the BSS Allotment Plan in Region 2 in 12.2–12.7 GHz, the satellite transmitting antenna reference radiation pattern of circular or elliptical beams in RR Appendix 30 is shown in Table 5-33.

Table 5-33. BSS Satellite Transmitting Antenna Reference Radiation Pattern in RR Appendix 30 for Region 2 Allotment Plan

Polarization	Gain Function Relative to G_{max} (dB)	Angular Range
Co-polarization, mainbeam without fast roll-off (A)	$-12\ (\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} < 1.45$
	$\max[-22 - 20 \times \log(\phi/\phi_{bw}), -G_{max}]$	$1.45 \leq \phi/\phi_{bw}$
Co-polarization, mainbeam with fast roll-off	$-12\ (\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} \leq 0.5$
	$-18.75 \times \phi_{bw}^2 \times (\phi/\phi_{bw} - x)^2$	$0.5 < \phi/\phi_{bw} \leq 1.16/\phi_{bw} + x$
	-25.23	$1.16/\phi_{bw} + x < \phi/\phi_{bw} \leq 1.45$
	$\max[-22 - 20 \times \log(\phi/\phi_{bw}), -G_{max}]$	$1.45 < \phi/\phi_{bw}$
Cross-polarization, mainbeam with or without fast roll-off	-30	$0 \leq \phi/\phi_{bw} \leq 2.51$
	as (A)	after intersection with (A)
ϕ: off mainbeam axis angle in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest of the minimum elliptical beam fitted to the service area, deg. $x = 0.5\ (1 - 0.8/\phi_{bw})$		

(b) Rec. ITU-R BO.652-1

For the BSS systems in Region 2 in the 12 GHz band, the recommended satellite transmitting antenna reference radiation pattern in Rec. ITU-R BO.652-1 is the same as that of RR Appendix 30 in Table 5-33. In addition, it is recommended that the actual antenna radiation pattern not exceed the reference radiation pattern.

5.5.2.2 Feeder Link Receiving Antenna

(a) RR Appendix 30A

For developing the BSS Allotment Plan in Region 2 in 17.3–17.8 GHz, the feeder link satellite receiving antenna reference radiation pattern in RR Appendix 30A is shown in Table 5-34.

Table 5-34. BSS Feeder Link Satellite Receiving Antenna Reference Radiation Pattern in RR Appendix 30A for Region 2 Allotment Plan

<table>
<tr><th>Polarization</th><th>Gain Function Relative to G_{max} (dB)</th><th>Angular Range</th></tr>
<tr><td rowspan="2">Co-polarization, mainbeam without fast roll-off (A)</td><td>$-12\ (\phi/\phi_{bw})^2$</td><td>$0 \le \phi/\phi_{bw} \le 1.45$</td></tr>
<tr><td>$\max[-22 - 20\times\log(\phi/\phi_{bw}), -G_{max}]$</td><td>$1.45 < \phi/\phi_{bw}$</td></tr>
<tr><td rowspan="4">Co-polarization, mainbeam with fast roll-off</td><td>$-12\ (\phi/\phi_{bw})^2$</td><td>$0 \le \phi/\phi_{bw} \le 0.5$</td></tr>
<tr><td>$-33.33\ \phi_{bw}^2\ (\phi/\phi_{bw} - y)^2$</td><td>$0.5 < \phi/\phi_{bw} \le 0.87/\phi_{bw} + y$</td></tr>
<tr><td>-25.23</td><td>$0.87/\phi_{bw} + y < \phi/\phi_{bw} \le 1.45$</td></tr>
<tr><td>$\max[-22 - 20\times\log(\phi/\phi_{bw}), -G_{max}]$</td><td>$1.45 < \phi/\phi_{bw}$</td></tr>
<tr><td rowspan="2">Cross-polarization, mainbeam with or without fast roll-off</td><td>-30</td><td>$0 \le \phi/\phi_{bw} \le 2.51$</td></tr>
<tr><td>as (A)</td><td>after intersection with (A)</td></tr>
<tr><td colspan="3">ϕ: off mainbeam axis angle in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest of the minimum elliptical beam fitted to the service area, deg.
$y = 0.5\ (1 - 0.6/\phi_{bw})$</td></tr>
</table>

(b) Rec. ITU-R BO.652-1

For the BSS systems in Region 2 in the 14/17 GHz bands, the recommended feeder link satellite receiving antenna reference radiation pattern in Rec. ITU-R BO.652-1 is the same as that of RR Appendix 30 in Table 5-33. In addition, it is recommended that the actual antenna radiation pattern does not exceed the reference radiation pattern.

5.6 Mobile Service

MS includes the land MS (LMS), maritime MS (MMS) and aeronautical MS (AMS). These services are discussed here.

MS systems consist of base stations and mobile stations. The base station creates a radio coverage area to provide radio services to mobile stations within its coverage area.

5.6.1 Land Mobile Service

The LMS systems can be simplex systems with singular coverage area or cellular systems with contiguous coverage areas. The base stations usually use dipole antennas, sectoral antennas, or array antennas, and the mobile stations usually use monopole antennas mounted on mobile vehicles or small antennas embedded in mobile phones.

This sub-section contains the following antenna radiation performance standards:

- From NTIA Manual Chapter 5, for federal systems with mobile stations [Ref. 57];
- from 47 CFR Part 90, for private radio services;[104]

104 47 CFR, Part 90, *Private Land Mobile Radio Services.*

- from 47 CFR Part 95, for personal radio services;[105] and
- from RR Resolution 221, for HAPS antennas.[106]

It also contains one recommended reference radiation pattern from Rec. ITU-R M.1652-1.[107]

(a) NTIA Manual Chapter 5

NTIA does not provide the LMS antenna radiation performance standards for the federal systems. However, NTIA Manual §5.3 states that, to the extent practicable, land stations operating HF single sideband and independent sideband transmission in 2–29.7 MHz must use antennas designed so as to reduce their radiation and/or their susceptibility to interference in those directions where service is not required.

(b) 47 CFR Part 90

For the LMS private radio services, the antenna radiation performance standards in 47 CFR Part 90 are as follows:

- §90.35: For industrial/business pool,
  - operational fixed stations must use directional antennas having a front-to-back ratio ≥ 20 dB, and
  - omnidirectional antennas may be employed for stations communicating with at least three receiving locations within a 160º arc in azimuth.
- §90.241: For radio call box operations,
  - the antenna gain shall not exceed 0 dBd in any horizontal direction, and
  - the transmission must be vertically polarized.
- §90.242: For travelers' information stations,
  - conventional radiating antenna (e.g., vertical monopole, directional array) must use vertical polarization, and
  - length of the leaky cable antenna must be less than 3.0 km (1.9 miles).
- §90.261: For fixed operations in 450–470 MHz,
  - all fixed systems must employ directional antennas with a front-to-back ratio of 15 dB, and
  - omnidirectional antennas may be employed by stations communicating with at least three receiving locations within a 160º arc in azimuth.

(c) 47 CFR Part 95

In the LMS personal radio service, for the Family Radio Service, and the Radio Control Radio Service transmitting in 72–76 MHz, the antenna radiation performance standard in 47 CFR Part 95 is 0 dBd gain and vertical polarization.

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105 47 CFR, Part 95, P*ersonal Radio Services,* §95.647.

106 RR, Resolution 221, *Use of high altitude platform stations providing IMT-2000 in the bands 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz in Regions 1 and 3 and 1885-1980 MHz and 2110-2160 MHz in Region 2*.

107 Rec. ITU-R M.1652-1, *Dynamic frequency selection (DFS) in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band* (2011).

(d) RR Resolution 221

HAPS can be used as base stations in the terrestrial component of the International Mobile Telecommunications-2000 (IMT-2000). For interference protection of the IMT-2000 stations operating in neighboring countries, the HAPS antenna reference radiation pattern in RR Resolution 221 is shown in Table 5-35.

Table 5-35. HAPS Antenna Reference Radiation Pattern in RR Resolution 221 for Interference Protection of IMT-2000 Stations Operating in Neighboring Countries

Gain Function (dBi)	Angular Range
$G_{max} - 12\,(\phi/\phi_{bw})^2$	$0° \le \phi \le \phi_1$
$G_{max} + L_n$	$\phi_1 < \phi \le \phi_2$
$x - 60 \times \log(\phi)$	$\phi_2 < \phi \le \phi_3$
L_f	$\phi_3 < \phi \le 90°$

ϕ: angle off mainbeam axis, deg.

$\phi_1 = 0.5\,\phi_{bw}\,(-L_n/3)^{0.5}$, deg.

$\phi_2 = 1.8725\,\phi_{bw}$, deg.

$\phi_3 = 10^{(x-L_f)/60}$, deg.

$\phi_{bw} \approx 2 \times \left[7442/\left(10^{0.1\,G_{max}}\right)\right]^{0.5}$, deg.

L_n: near sidelobe level relative to G_{max} required by the system design ; $L_n \le -25$ dB
L_f: far sidelobe level; $L_f = G_{max} - 73$, dBi

$x = G_{max} + L_n + 60 \times \log(\phi_2)$, dBi

(e) Rec. ITU-R M.1652-1

For assessing interference from the LMS systems to the RDS systems in the 5 GHz band, the recommended LMS antenna reference radiation pattern in Rec. ITU-R M.1652-1 is shown in Table 5-36. The LMS systems are wireless access systems that include radio local area networks. The antenna is omnidirectional and the gain is a function of the elevation angle.

Table 5-36. Recommended LMS Antenna Reference Radiation Pattern for Assessing Interference from LMS System to RDS System in the 5 GHz Band

Elevation Angle θ (º)	Gain (dBi)	Elevation Angle θ (º)	Gain (dBi)
$-90 < \theta \le -60$	-5	$0 < \theta \le 35$	0
$-60 < \theta \le -30$	-6	$35 < \theta \le 45$	-3
$-30 < \theta \le -15$	-4	$45 < \theta \le 90$	-4
$-15 < \theta \le 0$	-1		

If the system requires 1-Watt EIRP, an antenna of 6 dBi gain with the following reference vertical radiation pattern should be used:

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (5\text{-}11)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi;

$G_b(\theta) = G_{max} - 12 + 10\times\log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + 0.5 \}$, dBi;

$G_{max} = 6$ dBi;

θ: elevation angle off the peak gain plane, deg;

θ_{bw}: HPBW in the vertical plane; and

$\theta_{bw} = 107.6 \times 10^{-0.1 G_{max}}$, deg.

This pattern is adopted from Rec. ITU-R F.1336-3 of the FS P-MP system omnidirectional antenna reference radiation pattern, but modifies the sidelobe-performance parameter in $G_b(\theta)$ to 0.5 [Ref. 65 and Table 5-10].

(f) Rec. ITU-R M.478-5

The recommended FM LMS antenna operational characteristic in Rec. ITU-R M.478-5 is vertical polarization.[108]

5.6.2 Maritime Mobile Service

In MMS, the base stations are the coast stations that use directional antennas or array antennas with directional beams to cover marine surfaces. The mobile stations are the ship or aircraft stations at sea that use omnidirectional antennas.

NTIA does not provide the MMS antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains an antenna radiation performance standard from 47 CFR Part 80 and recommended antenna technical characteristics from Rec. ITU-R M.489-2.[109] [110]

(a) 47 CFR Part 80

The MMS antenna radiation performance standards in 47 CFR Part 80 are as follows:

- §80.72: for coast stations, antennas operating in 30–200 MHz must be vertically polarized;
- §80.81: for ship stations, antennas operating in 30–200 MHz must be vertically polarized;
- §80.268: for compulsory ships, antennas must be as omnidirectional and efficient as practicable;
- §80.863: for cargo vessels not required to comply with the Global Maritime Distress and Safety System, antennas must be as omnidirectional and efficient as practicable;

108 Rec. ITU-R M.478-5, *Technical Characteristics of Equipment and Principles Governing the Allocation of Frequency Channels between 25 and 3000 MHz for the FM Land Mobile Service* (1995).

109 47 CFR, Part 80, *Stations in the Maritime Services.*

110 Rec. ITU-R M.489-2, *Technical Characteristics of VHF Radiotelephone Equipment Operating in the Maritime Mobile Service in Channels Spaced by 25 kHz* (1995).

- §80.876: for cargo vessels not required to comply with the Global Maritime Distress and Safety System, antennas for the VHF telephones must be omnidirectional and vertically polarized;
- §80.923: for small passenger boats, antennas for the compulsory radiotelephones must be vertically polarized and as efficient as practicable;
- §80.967: for vessels on the Great Lakes, antennas for the compulsory radiotelephones must be omnidirectional and vertically polarized; and
- §80.1017: for radiotelephones required for the Bridge-to-Bridge Act, antennas must be omnidirectional and vertically polarized.

(b) Rec. ITU-R M.489-2

For MMS communications operating on the frequencies specified in RR Appendix 18, the recommended antenna technical characteristic in Rec. ITU-R M.489-2 is vertical polarization.[111] The channel spacing of frequency assignments is 25 kHz.

(c) Radio Technical Commission for Maritime Services (RTCM)

RTCM is in the process of developing antenna standards for MMS.

5.6.3 Aeronautical Mobile Service

In AMS, the base stations are the land stations, and the mobile stations are the aircraft stations. The land-based antennas are usually parabola or paraboloidal antennas, and the airborne antennas are ideally isotropic radiators whose radiation patterns are significantly varied by the structures of the aircrafts. Pictures of airborne antennas are shown in Figure 5-6.[112]

(a). VHF antenna

(b). UHF antenna

Figure 5-6. AMS Airborne Antennas

NTIA does not provide the AMS antenna radiation performance standards for the federal systems. The Federal Aviation Administration (FAA) is the federal agency in charge of aeronautical and space aviation regulations; however, it does not provide the AMS antenna

111 RR, Appendix 18, *Table of Transmitting Frequencies in the VHF Maritime Mobile Band.*

112 http://www.cobham.com/about-cobham/aerospace-and-security/about-us/antenna-systems/fullerton/products/datalink--satcom.aspx/, accessed Jan. 14, 2010.

performance standards in Title 14 of the Code of Federal Regulations (14 CFR).[113] Otherwise, this sub-section contains one antenna radiation performance standard from RTCA DO-186A and recommended antenna technical characteristics for telemetry and telecommand operations from Rec. ITU-R M.1459.[114] [115]

(a) RTCA DO-186A

For the AMS radio communications in 117.975–137 MHz, the airborne transmitting and receiving antenna radiation performance standards in RTCA DO-186A are as follows:

- The average field strength in the horizontal plane shall not be down more than 6 dB.
- The difference between the maximum and minimum field strengths in the horizontal plane shall not exceed 6 dB, when compared to a standard vertically polarized monopole antenna.

(b) Rec. ITU-R M.1459

For the AMS telemetry and telecommand operations in 1.452−1.525 and 2.31−2.36 GHz, the recommended antenna technical characteristics in Rec. ITU-R M.1459 are as follows:

- For airborne transmitting antennas that are isotropic radiators, the probability, P_1, that a given gain, G_1, is not exceeded can be expressed as

$$P_1(G \leq G_1) = [1 - \exp(-3.46\ G_1)]^{1.25} \qquad (5\text{-}12)$$

  This probability is obtained from the measurement data and taking into account the propagation effects.
- For the land-based paraboloidal receiving antennas, a composite reference radiation pattern is developed from the radiation patterns of a 2.4-meter and a 10-meter antenna of G_{max} = 29 and 41.2 dBi, respectively, such that their sidelobes exceed or do not exceed each other for 50% of the time. This composite reference radiation pattern, applicable for any G_{max} value between 29 and 41.2 dBi, is shown in Table 5-37.

Table 5-37. Recommended AMS Land-Based Receiving Antenna Reference Radiation Pattern for Telemetry and Telecommand Operations in 1.452−1.525 and 2.31−2.36 GHz

Gain Function (dBi)	Angular Range
$41.2 + 20 \times \log[\sin(1.952\phi)/(1.952\phi)]$	$0° \leq \phi \leq 0.94°$
$35.1 - 20\times\log(\phi)$	$0.94° < \phi \leq 3.82°$
$29 + 20 \times \log[\sin(0.479\phi)/(0.479\phi)]$	$3.82° < \phi \leq 5.61°$
$27.27 - 18.75 \times \log(\phi)$	$5.61° < \phi \leq 12.16°$

113 Code of Federal Regulations, Title 14, *Aeronautics and Space*, ("14 CFR"), U.S., FAA, http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title14/14tab_02.tpl, accessed Feb. 9, 2012.

114 RTCA DO-186A, *Minimum Operational Performance Standards for Airborne Radio Communications Equipment operating within the Radio Frequency Range117.975–137.000 MHz* (1995).

115 Rec. ITU-R M.1459, *Protection Criteria for Telemetry Systems in the Aeronautical Mobile Service and Mitigation Techniques to Facilitate Sharing with Geostationary Broadcasting-Satellite and Mobile-Satellite Services in the Frequency Bands 1452-1525 MHz and 2310-2360 MHz* (2000).

$34.05 - 25 \times \log(\phi)$	$12.16° < \phi \leq 48°$
-8	$48° < \phi \leq 180°$
• ϕ: off mainbeam axis angle, deg. • "Sin(x)/x" is one of the formulas to model the antenna mainbeam radiation pattern. Since there are two sin(x)/x formulas here, it is apparent that this reference radiation pattern is the combination of two reference radiation patterns of different antenna sizes.	

5.7 Mobile Satellite Service

MSS includes the land MSS (LMSS), maritime MSS (MMSS) and aeronautical MSS (AMSS). These services are discussed here.

5.7.1 Land Mobile Satellite Service

This section covers the earth station antennas and satellite antennas.

5.7.1.1 Earth Station Antenna

NTIA does not provide the LMSS earth station antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains one recommended earth station antenna reference radiation pattern from Rec. ITU-R M.1091.[116]

Rec. ITU-R M.1091

For the LMSS systems operating in 1−3 GHz, the recommended earth station antenna reference radiation pattern in Rec. ITU-R M.1091 is provided in Table 5-38.

Table 5-38. Recommended LMSS Earth Station Antenna Reference Radiation Patterns in 1−3 GHz

(a) Transportable or Vehicle-Mounted Antenna with Axis-Symmetric or Near-Symmetric Beam and $12 \leq G_{max}(dBi) \leq 18$

Gain Function (dBi)	Angular Range
$\leq 44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
≤ -5	$90° \leq \phi$
ϕ: angle off mainbeam axis, deg.	

(b) Vehicle-Mounted Vertical Array Antenna with Toroidal Beam and $7 \leq G_{max}(dBi) \leq 13$

Gain Function (dBi)	Angular Range
$G_{max} - 10$	$45° < (\theta - \theta_o)$
$G_{max} - 0.3 \times [(\theta - \theta_o)/10]^{2.3}$	$20° \leq (\theta - \theta_o) \leq 45°$
$G_{max} - 0.3 \times [(\theta_o - \theta)/10]^{2.3}$	$20° \leq (\theta_o - \theta) \leq 50°$
$G_{max} - 13$	$50° < (\theta_o - \theta)$

116 Rec. ITU-R M.1091, *Reference Off-mainbeam axis Radiation Patterns for Mobile Earth Station Antennas Operating in the Land Mobile-Satellite Service in the Frequency Range 1 to 3 GHz* (1994).

θ: elevation angle, deg. θ_o: mainbeam elevation angle, deg. This is an omnidirectional beam with narrow beamwidth in elevation direction.

(c) Vehicle-Mounted Tracking Antenna with Fan-Beam and Operating in Low Elevation Angle

Gain Function (dBi)	Angular Range
≤ 4	0° ≤ θ ≤ 60°, [30°+k(θ)] ≤ |φ−φ₀| ≤ 180°
(θ, φ): elevation and azimuth angles, deg. (θ_o, φ_o): mainbeam elevation and azimuth angles, deg. k(θ) = 0.33° for G_{max} = 11−15, dBi. k(θ) is TBD for G_{max} = 9−11, dBi.	

(d) Vehicle-Mounted Near-Omnidirectional Antenna

Gain Function (dBi)	Angular Range
≤ 5	-20° ≤ θ ≤ 20°
≤ 0	θ < -20° & θ > 20°
θ: elevation angle, deg.	
The expression in Rec. ITU-R M.1091 is G ≤ 5 dBi for θ ≥ -20° G ≤ 0 dBi for θ < -20° this is not an accurate formula for the omnidirectional pattern.	

5.7.1.2 Satellite Antenna

The LMSS satellite antennas are usually array antennas generating shaped beams to cover the intended coverage area.

5.7.2 Maritime Mobile Satellite Service

This section covers the earth station antennas and satellite antennas.

5.7.2.1 Earth Station Antenna

The MMSS earth station antennas are either ship earth station antennas or coastal earth station antennas. NTIA does not provide the MMSS earth station antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains one recommended shipborne antenna reference radiation pattern from Rec. ITU-R M.694-1.[117] The RTCM is in the process of developing antenna standards for the MMSS.

117 Rec. ITU-R M.694-1, *Reference Radiation Pattern for Ship Earth Station Antennas* (2005).

(a) Rec. ITU-R M.694-1

For coordination studies and interference assessment between the MSS and terrestrial or space radio services sharing frequency in 1.518−1.6605 GHz, the recommended MMSS shipborne antenna reference radiation pattern in Rec. ITU-R M.694-1 is shown in Table 5-39.

Table 5-39. Recommended MMSS Shipborne Antenna Reference Radiation Pattern for EMC Analyses between MSS and Terrestrial or Space Radio Services in 1.518−1.6605 GHz

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
$2 + 15 \times \log(D/\lambda)$	$\phi_m \le \phi < (100\lambda/D)°$
$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \le \phi < \phi_1$
0	$\phi_1 \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $\phi_m = 20(\lambda/D)[G_{max} - 2 - 15 \times \log(D/\lambda)]^{0.5}$, deg. $\phi_1 = 120\ (\lambda/D)^{0.4}$, deg.	
This pattern should be used for paraboloidal antennas with diameters of 0.8−1.3 meters.	

(b) International Mobile Satellite Organization (INMARSAT)

The INMARSAT standard-A ship earth station antenna reference radiation pattern, available in Rec. ITU-R M.694-1, is shown in Table 5-40.[118]

Table 5-40. INMARSAT Standard-A Shipborne Antenna Reference Radiation Pattern

Gain Function (dBi)	Angular Range
8	$16° < \phi < 21°$
$41 - 25 \times \log(\phi)$	$21° \le \phi < 57°$
-3	$57° \le \phi$
ϕ: angle off mainbeam axis, deg.	

INMARSAT is virtually the only commercial MMSS service provider. Other maritime antenna specifications from INMARSAT can be found in its System Definition Manuals.

5.7.2.2 Satellite Antenna

The MMSS satellites are generally GSO satellites with paraboloidal antennas of one global beam plus numerous spot beams that cover areas of heavy maritime traffic.

5.7.3 Aeronautical Mobile Satellite Service

This section covers the earth station antennas and satellite antennas.

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118 The company's original name was International Maritime Satellite Organization. It was changed to International Mobile Satellite Organization, while keeping the acronym INMARSAT, when it started providing LMSS and AMSS.

5.7.3.1 Earth Station Antenna

The AMSS earth station antennas are either airborne earth station antennas or land-based aeronautical earth station antennas. NTIA does not provide the AMSS earth station antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains the airborne antenna radiation performance standard from RTCA DO-210D.[119]

RTCA DO-210D

As design objectives and installation guidelines for the AMSS systems operating in the 1.6 GHz uplink band and the 1.5 GHz downlink band, the recommended airborne antenna radiation performance standards in RTCA DO-210D are as follows:

- Polarization: RHCP.
- For "high-gain" antenna:
  - the coverage volume comprises no less than 75% of the solid angle of the upper hemisphere above 5º elevation;
  - the coverage volume covers the effect of the aircraft body, the antenna pointing error, and the radome;
  - $12 \le G(dBic) \le 17$ within the coverage volume; and
  - $G \ge 0$ dBic outside the coverage volume.
- For "intermediate-gain" antenna:
  - the coverage volume comprises no less than 85% of the solid angle of the upper hemisphere above 5º elevation;
  - the coverage volume covers the effect of the aircraft body, the antenna pointing error, and the radome;
  - $6 \le G(dBic) \le 12$ within the coverage volume;
  - the coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith in straight and level flight, and $G \ge 4$ dBic within this cone;
  - $G \ge 0$ dBic for 99% of the solid angle above 5º elevation; and
  - to the maximum extent possible, $G \ge 6$ dBic for 100% of the solid angle above 5º elevation.
- For "low-gain" antenna:
  - the coverage volume comprises no less than 85% of the solid angle of the upper hemisphere above 5º elevation;
  - the coverage volume covers the effect of the aircraft body and the radome;
  - $0 \le G(dBic) \le 5$ within the coverage volume;
  - the coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith (in normal cruise attitude) in straight and level flight, and $G \ge -2$ dBic within this cone; and
  - $G \ge -5$ dBic outside the coverage volume.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

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119 RTCA DO-210D, *Minimum Operational Performance Standards for Geosynchronous Orbit Aeronautical Mobile Satellite Services (AMSS) Avionics,* §2.2.3 with Change No. 2 (Nov. 28, 2001).

The RTCA DO-210D specifications have two ambiguities. It uses "not less than", i.e., "≥", and "not exceed", i.e., "≤", in specifying the gain ranges of both the high- and intermediate-gain antennas, and this creates conflict when G = 12 dBic. Also, there is a gap in the gain ranges between the intermediate- and low-gain antennas, and this leaves antennas of 5 < G(dBic) < 6 un-classified.

5.7.3.2 Satellite Antenna

The AMSS satellites are generally GSO satellites with paraboloidal antennas of global beams.

5.8 Radiodetermination Service

RDS includes the radiolocation service (RLS) and radionavigation service (RNS). The antenna characteristics for RDS in general, and RLS and RNS in specific, are presented here. The following nomenclatures are used in this sub-section:

- Az: azimuth,
- Csc^2: Cosecant square radiation pattern,
- El: elevation,
- Rx: receive or receiving, and
- Tx: transmit or transmitting.

5.8.1 General Radiodetermination Service

NTIA Manual Chapter 5 provides four criteria for the RDS radar antenna radiation patterns for the federal systems.[120] Otherwise, this sub-section contains the following RDS radar antenna characteristics from ITU-R:

- from Rec. ITU-R M.1851, recommended antenna reference radiation patterns for interference analysis;[121]
- from Rec. ITU-R M.1652-1, recommended antenna reference radiation pattern for interference assessment from the LMS systems to the RDS systems sharing frequency in the 5 GHz band; and
- from Rec. ITU-R M.1463-1, representative antenna characteristics of land-based RDS radars operating in 1.215−1.4 GHz for search, tracking and surveillance.[122]

(a) NTIA Manual Chapter 5

NTIA classifies five groups of RDS radars for performance specification in NTIA Manual §5.5, and each group is associated with a criterion of antenna radiation pattern. The criteria are shown in Table 5-41.

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120 NTIA Manual, Chapter 5, *Spectrum Standards*, §5.5.

121 Rec. ITU-R M.1851, *Mathematical Models for Radiodetermination Radar Systems Antenna Patterns for Use in Interference Analyses* (2009).

122 Rec. ITU-R M.1463-1, *Characteristics of and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 1215-1400 MHz* (2007).

Table 5-41. Criteria of RDS Radar Antenna Radiation Patterns in NTIA Manual

(a) Classes of Radars

Group	Types of Radar	Applicable Criterion
A	Non-pulsed radar of 40 watts or less rated average power, Pulsed radar of 1 kW or less rated peak power, Radar with operating frequency above 40 GHz, Portable (by man power) radar, Transportable (by vehicle) radar, RNS radar in 9.3–9.5 GHz, and Expendable, non-recoverable radar on missiles.	A
B	Radar having a rated peak power of more than 1 kW but not more than 100 kW and operating between 2.9 GHz and 40 GHz	B
C	All radars not included in Group A, B, D, or E.	C
D	All fixed radars in 2.7–2.9 GHz.	D
E	Wind Profiler Radar operating on 449 MHz	E

(b) Criteria of Radar Antenna Radiation Patterns

<table>
<tr><th>Criterion</th><th colspan="2">Description</th></tr>
<tr><td>A</td><td colspan="2">Presently exempt.</td></tr>
<tr><td>B</td><td colspan="2">Currently no requirement is specified.</td></tr>
<tr><td>C, D</td><td colspan="2">Antennas operated in 360°-rotation over the horizontal plane shall have a “median gain” of -10 dBi or less in the principal horizontal plane.[123] For other antennas, sidelobe suppression below the mainbeam shall be
• first three sidelobes: 17 dB, and
• all other lobes: 26 dB.</td></tr>
<tr><td rowspan="7">E</td><td>Antenna Radiation Profile (dB)</td><td>Elevation Angle θ</td></tr>
<tr><td>x</td><td>70° ≤ θ</td></tr>
<tr><td>x - 15</td><td>60° ≤ θ < 70°</td></tr>
<tr><td>x - 20</td><td>45° ≤ θ < 60°</td></tr>
<tr><td>x - 25</td><td>5° ≤ θ < 45°</td></tr>
<tr><td>x - 40</td><td>θ < 5°</td></tr>
<tr><td colspan="2">• Radiation profile derived from EIRP profile requirement.
• Symbol “<” is used instead of “≤” for the angular range in the NTIA Manual.</td></tr>
<tr><td colspan="3">For antennas operated in 360°-rotation over the horizontal plane, the EMC analysis must cover all directions. Thus, the allowable radar antenna radiation pattern may be usefully specified by its “median gain” relative to an isotropic radiator.</td></tr>
</table>

123 NTIA Manual uses “-10 dB” instead of “-10 dBi”. This should be a mistake because antenna gain should be expressed in dBi.

(b) Rec. ITU-R M.1851

For interference analysis, the recommended RDS radar antenna reference radiation patterns in Rec. ITU-R M.1851 are shown in Table 5-42. The first four patterns, shown in Table 5-42(a), are derived from the aperture current distribution function of

$$\cos^{n}(\pi x/2) \qquad (5\text{-}13)$$

where

n = 0, 1, 2, and 3,

x: normalized distance along aperture $-1 \leq x \leq 1$.

The fifth pattern, shown in Table 5-42(b) and referred to as the cosecant-square, or $\csc^2$, pattern, is the cosecant-square antenna reference radiation pattern in the vertical mainbeam plane.

Table 5-42. Recommended RDS Radar Antenna Reference Radiation Pattern for Interference Analysis

(a) Radiation Pattern of Cos^n() Aperture Current Distribution

Aperture Current	Section of Pattern		$G_r(\phi)$, Gain Relative to G_{max} (dB)	Applicable Range (dB)
constant	Mainbeam		$20 \times \log\left\{\left\lvert\frac{\sin(\mu)}{\mu}\right\rvert\right\}$, $\mu = \frac{50.8\pi \times \sin(\phi)}{\phi_{bw}}$, $\phi_{bw} = 50.8\left(\frac{\lambda}{l}\right)$	
	Near Side-lobe	SE	$-8.584 \times \ln\left(2.876\frac{\lvert\phi\rvert}{\phi_{bw}}\right)$	$-5.75 < G_r < -30$
		Agg	$-8.584 \times \ln\left(2.876\frac{\lvert\phi\rvert}{\phi_{bw}}\right) - 3.72$	$-12.16 < G_r < -30$
	Far Sidelobe		-30	
Cos()	Mainbeam		$20 \times \log\left\{\frac{\pi}{2}\left\lvert\frac{\cos(\mu)}{(\pi/2)^2 - \mu^2}\right\rvert\right\} + 3.92$, $\mu = \frac{68.8\pi \times \sin(\phi)}{\phi_{bw}}$, $\phi_{bw} = 68.8\left(\frac{\lambda}{l}\right)$	
	Near Side-	SE	$-17.51 \times \ln\left(2.33\frac{\lvert\phi\rvert}{\phi_{bw}}\right)$	$-14.4 < G_r < -50$

	lobe	Agg	$-17.51\times\ln\left(2.33\frac{\lvert\phi\rvert}{\phi_{bw}}\right)-4.32$	$-20.6 < G_r < -50$
	Far Sidelobe		-50	
Cos²()	Mainbeam		$20\times\log\left\{\frac{\pi^2}{2\mu}\left\lvert\frac{\sin(\mu)}{(\pi^2-\mu^2)}\right\rvert\right\}+6.02$, $\mu=\frac{83.2\pi\times\sin(\phi)}{\phi_{bw}}$, $\phi_{bw}=83.2\left(\frac{\lambda}{l}\right)$	
	Near Side-lobe	SE	$-26.882\times\ln\left(1.962\frac{\lvert\phi\rvert}{\phi_{bw}}\right)$	$-22.3 < G_r < -60$
		Agg	$-26.882\times\ln\left(1.962\frac{\lvert\phi\rvert}{\phi_{bw}}\right)-4.6$	$-29 < G_r < -60$
	Far Sidelobe		-60	
Cos³()	Mainbeam		$20\times\log\left\{\left\lvert\frac{3\pi\times\cos(\mu)}{8}\left[\frac{1}{(\pi/2)^2-\mu^2}-\frac{1}{(3\pi/2)^2-\mu^2}\right]\right\rvert\right\}+7.44$, $\mu=\frac{95\pi\times\sin(\phi)}{\phi_{bw}}$, $\phi_{bw}=95\left(\frac{\lambda}{l}\right)$	
	Near Side-lobe	SE	$-35.84\times\ln\left(1.756\frac{\lvert\phi\rvert}{\phi_{bw}}\right)$	$-31.5 < G_r < -70$
		Agg	$-35.84\times\ln\left(1.756\frac{\lvert\phi\rvert}{\phi_{bw}}\right)-4.2$	$-37.6 < G_r < -70$
	Far Sidelobe		-70	

G_{max}: on-axis gain, dBi
ϕ: angle off mainbeam axis
$\mu=\pi(l/\lambda)\sin(\phi)$
l: overall length of aperture
λ: wavelength
SE: for single-entry interference analysis
Agg: for aggregate interference analysis or statistical interference analysis
ln: natural log
All far sidelobe levels are proposed values in Rec. ITU-R M.1851.

The application of these patterns requires further examination. Rec. ITU-R M.1851 states that these are the "proposed theoretical antenna patterns", and does not distinguish the conditions for selecting one of the patterns. Moreover, this current distribution function has been widely used in antenna textbooks to examine the effect of electric current tapering on the antenna radiation pattern; therefore, the current distribution functions are hypothetical current distribution functions, and the radiation patterns are hypothetical radiation patterns.[124]

(b) Cosecant-Square Pattern

Section of Pattern		G(θ) (dBi)	Angular Range
Mainbeam	Circular	$G_{max} + 20 \times \log\left\{\left\lvert \frac{\sin(\mu)}{\mu} \right\rvert\right\}$, $\mu = \frac{50.8\pi \times \sin(\theta)}{\theta_{bw}}$, $\theta_{bw} = 50.8\left(\frac{\lambda}{l}\right)$	$\frac{-\theta_{bw}}{0.88} \le \theta \le \frac{\theta_{bw}}{2}$
	Cosecant-Square	$(G_{max} - 3) + 20 \times \log\left(\frac{\csc(\theta)}{\csc\left(\frac{\theta_{bw}}{2}\right)}\right)$	$\frac{\theta_{bw}}{2} \le \theta \le \theta_m$
Sidelobe		-55	$\theta_m \le \theta \le 180°$

G_{max}: on-axis gain, dBi
The mainbeam axis is in the horizontal plane, i.e., no elevation angle.
θ: elevation angle off the mainbeam axis
$\mu = \pi(l/\lambda)\sin(\theta)$
  l: overall length of aperture
  λ: wavelength
θ_m: angle where cosecant-square pattern reaches sidelobe level
Sidelobe level is tentative.

- The circular beam pattern is from Table 5-42(a) with n = 0.
- The break point from the circular pattern to the cosecant-square pattern is the half power point, which should be $0.5\theta_{bw}$. However, θ_{bw} is used in the formula, which is incorrect.
- Numerous errors in Rec. ITU-R M.1851 are corrected.

(c) Rec. ITU-R M.1652-1

For interference assessment from the LMS systems to the RDS systems sharing frequency in the 5 GHz band, Rec. ITU-R M.1652-1 [Ref. 107] also provides a RDS antenna reference radiation pattern. This is shown in Table 5-43, this pattern is identical to the Statgain formula in Table 4-1.

124 For instance: Ref. 50, Section 4.2; Ref. 51, Section 11.5.4.

Table 5-43. Recommended Baseline RDS Antenna Reference Radiation Pattern for Interference Assessment from LMS Systems to RDS Systems in the 5 GHz Band

Category	Gain Function (dBi)	Angular Range
$G_{max} \geq 48$ dBi	$G_{max} - 4\times10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0° \leq \phi \leq \phi_m$
	$0.75\ G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq 48°$
	-13	$48° < \phi \leq 180°$
$22 \leq G_{max}(dBi) < 48$	$G_{max} - 4\times10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0° \leq \phi \leq \phi_m$
	$0.75\ G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - G_{max}/2 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq 48°$
	$11 - G_{max}/2$	$48° < \phi \leq 180°$
$10 \leq G_{max}(dBi) < 22$	$G_{max} - 4\times10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0° \leq \phi \leq \phi_m$
	$0.75\ G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - G_{max}/2 - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_b$
	0	$\phi_b < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$\phi_m = 50\left(0.25G_{max} + 7\right)^{0.5} / \left(10^{G_{max}/20}\right)$, deg.

$\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$, deg.

$\phi_{r2} = \phi_{r3} = 250 / (10^{G_{max}/20})$, deg.

$\phi_b = 131.8257\,(10^{-G_{max}/50})$, deg.

The functions in Rec. ITU-R M.1652-1 do not specify the gain values at the break points in the angular range. However, there should not be confusion because the function should be continuous at the break points.

(d) Rec. ITU-R M.1463-1

The antenna characteristics of the typical land-based RDS radar systems operating in 1.215−1.4 GHz for search, tracking and surveillance are provided in Rec. ITU-R M.1463-1; they are shown in Table 5-44.

Table 5-44. Antenna Characteristics of Typical RDS Radar in 1.215−1.4 GHz

Charac-teristics	Parametric Value						
System*	1	2	3	4	5	6	7
Platform	Fixed	Fixed	Transpor-table	Transpor-table	Fixed	Fixed	Fixed
Type	Horn-fed reflector	Stack beam reflector	Rotating phased array	Parabolic cylinder	Planar array	Cosecant squared	Cosecant squared
G_{max} (dBi)	Tx: 34.5, Rx: 33.5	Tx: 32.4−34.2, Rx: 1.7−38.9	Tx: 38.9, Rx: 38.2	32.5	38.5	34	35
Elevation ϕ_{bw} (°)	3.6 shaped to 44	Tx 3.63−5.61, Rx 2.02−8.79	1.3	4.5 shaped to 40	2	3.75	3.75

Azimuthal ϕ_{bw} (°)	1.2	1.4	3.2	3.0	2.2	1.2	1.3
Polariza-tion	Linear, circular	Linear, circular	Linear	Linear	Linear	Linear, circular	Linear, circular
*: Refer to Rec. ITU-R M.1463-1 for more information on these systems.							

5.8.2 Radiolocation Service

NTIA does not provide the RLS radar antenna radiation performance standards for the federal systems, nor does ITU-R have recommendations for the radar antenna reference radiation patterns. Otherwise, this sub-section contains antenna characteristics of the representative RLS radar systems in the frequency bands shown in Table 5-45; the information is from ITU-R.

Table 5-45. Summary of Representative RLS Radar Systems

Frequency Band (GHz)	Platform	Antenna Characteristics		Source (Rec. ITU-R)
		Type	G_{max} (dBi)	
0.03−0.3	Land station	Phased array	Tx: 24−25 Rx: 30	M.1802-1[125]
0.42−0.45	Land station	Paraboloid reflector, planar array	38.5	M.1462[126]
	Ship	Parabolic reflector	30	
	Aircraft	Planar array, Yagi	22	
2.7−2.9	Land station	Shaped reflector, planar array	33.5−43	M.1464-1[127]
	Ship	Shaped reflector, planar array	< 43	
2.9−3.1	Land station	N/A	31.9−41	M.1460-1[128]
	Ship	N/A	33.5−38.5	
3.1−3.7	Land station	Parabolic reflector	39−40	M.1465-1[129]
	Ship	Parabolic reflector, phased array	32−42	
	Aircraft	Slotted array	40	
5.25−5.85	Land station	Parabolic reflector,	38.3−54	M.1638[130]

125 Rec. ITU-R M.1802-1, *Characteristics and protection criteria for radars operating in the radiolocation service in the frequency band 30-300 MHz* (2010).

126 Rec. ITU-R M.1462, *Characteristics of and Protection Criteria for Radars Operating in the Radiolocation Service in the Frequency Range 420-450 MHz* (2000).

127 Rec. ITU-R M.1464-1, *Characteristics of Radiolocation Radars, and Characteristics and Protection Criteria for Sharing Studies for Aeronautical Radionavigation and Meteorological Radars in the Radiodetermination Service Operating in the Frequency Band 2700-2900 MHz* (2003).

128 Rec. ITU-R M.1460-1, *Technical and Operational Characteristics and Protection Criteria of Radiodetermination Radars in the 2900-3100 MHz Band* (2006).

129 Rec. ITU-R M.1465-1, *Characteristics of and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 3100-3700 MHz* (2007).

		phased array		
	Ship	Parabolic reflector, horn array	28−30	
	Aircraft	Horn, slotted array	26−40	
9.2−9.5	Ship	N/A	Min. 30	M.628-4[131]
13.75−14	Land station	Slotted array	36	M.1644[132]
	Ship	Parabolic reflector, slotted array	37.5−38.5	
	Aircraft	N/A	> 20	
15.4−17.3	Land station	Parabolic reflector, curved reflector	37−43	M.1730-1[133]
	Ship	Phased array	43	
	Aircraft	Waveguide, phased array	25.6−38	
33.4−36	Land station	N/A	28.7−52	M.1640[134]

(a) Rec. ITU-R M.1802-1

The antenna characteristics of the representative RLS radar systems operating in 30−300 MHz are provided in Rec. ITU-R M.1802-1; they are shown in Table 5-46. The land-based radars are for space object recognition and tracking.

Table 5-46. Antenna Characteristics of Representative RLS Radars in 30−300 MHz

Characteristics	Parametric Value	
System*	1	2
Platform	Land station	Land station
Type	Phased array	Phased array
G_{max} (dBi)	Tx: 25, Rx: 30	Tx: 24, Rx: N/A
Horizontal ϕ_{bw} (°)	Tx: 5.2, Rx: 2.6	±8
Azimuthal ϕ_{bw} (°)	Tx: 2.6, Rx: 2.6	±20
Polarization	Linear	Linear

130 Rec. ITU-R M.1638, *Characteristics of and Protection Criteria for Sharing Studies for Radiolocation, Aeronautical Radionavigation and Meteorological Radars Operating in the Frequency Bands between 5250 and 5850 MHz* (2003).

131 Rec. ITU-R M.628-4, *Technical Characteristics for Search and Rescue Radar Transponders* (2006).

132 Rec. ITU-R M.1644, *Technical and Operational Characteristics, and Criteria for Protecting the Mission of Radars in the Radiolocation and Radionavigation Service Operating in the Frequency Band 13.75-14 GHz* (2003).

133 Rec. ITU-R M.1730-1, *Characteristics of and Protection Criteria for the Radiolocation Service in the Frequency Band 15.4-17.3 GHz* (2009).

134 Rec. ITU-R M.1640, *Characteristics of, and Protection Criteria for Sharing Studies for Radars Operating in the Radiodetermination Service in the Frequency Band 33.4-36 GHz* (2003).

*: Refer to Rec. ITU-R M.1802-1 for more information on these systems.

(b) Rec. ITU-R M.1462

The antenna characteristics of the representative RLS radar systems operating in 420−450 MHz are provided in Rec. ITU-R M.1462; they are shown in Table 5-47. The land-based radars are for detection, identification and tracking of space objects, the shipborne radars are for surveillance, and the airborne radars are for air traffic control.

Table 5-47. Antenna Characteristics of Representative RLS Radars in 420−450 MHz

Characteristics	Parametric Value		
System*	1	2	3
Platform	Land station	Ship	Aircraft
Type	Paraboloid reflector, planar array	Parabolic reflector	Planar array, Yagi antenna
G_{max} (dBi)	38.5	30	22
ϕ_{bw} (°)	2.2	N/A	El: 6−20, Az: 6
Sidelobe (dBi)	N/A	Median value: 0	N/A
Polarization	Circular	N/A	Linear
*: Refer to Rec. ITU-R M.1462 for more information on these systems.			

(c) Rec. ITU-R M.1464-1

The antenna characteristics of the representative military RLS radar systems operating in 2.7−2.9 GHz for air traffic control, naval surveillance, and land-based air defense systems are provided in Rec. ITU-R M.1464-1; they are shown in Table 5-48.

Table 5-48. Antenna Characteristics of Representative RLS Radars in 2.7−2.9 GHz

Characteristics	Parametric Value			
System*	1	2	3	4
Platform	Land station fixed and transportable	Land station fixed and transportable	Land station fixed, ship	Land station fixed, ship
Type	Shaped reflector	Planar array, reflector	Planar array, shaped reflector	Array
Radiation Pattern	Csc^2	Pencil beam	Csc^2, pencil beam	Pencil beam
G_{max} (dBi)	33.5	> 40	< 40	< 43
ϕ_{bw} (°)	El: 4.8, Az: 1.5	El: 1, Az: 1.2	El: 1.5−30, Az: 1.1−2	N/A
First Sidelobe Suppression (dB)	26	> 26	> 32	N/A
Far Sidelobe Suppression (dB)	35	N/A	N/A	N/A

Far Sidelobe Level (dBi)	N/A	< 0	< -10	N/A
Polarization	Linear, circular	Linear, circular	Linear, circular	Linear
*: Refer to Rec. ITU-R M.1464-1 for more information on these systems.				

(d) Rec. ITU-R M.1460

The antenna characteristics of the representative RLS radar systems operating in 2.9−3.1 GHz for detecting airborne objects are provided in Rec. ITU-R M.1460; they are shown in Table 5-49.

Table 5-49. Antenna Characteristics of Representative RLS Radars in 2.9−3.1 GHz

Characteristics	Parametric Value				
System*	1	2	3	4	5
Platform	Land station	Land station	Land station	Ship	Ship
G_{max} (dBi)	41	Tx: 34.5, Rx: 38	Tx: 35, Rx: 31.9−36.7	37	38.5
ϕ_{bw} (°)	El: 0.84, Az: 2.15	El: 20Csc^2, Az: 1.1	El: Tx: 20, Rx: 2.3−6, Az: 1.6	El: 2.25, Az: 1.9	El: 1.6, Az: 1.5
First Sidelobe Suppression (dB)	25	18.5	El: Tx: 20, Rx: ≥ 49, Az: Rx ≥ 35	25	El: 15, Az: 25
Polarization	Linear	Linear	Linear	Linear	Linear
Antenna type: N/A for all. *: Refer to Rec. ITU-R M.1460 for more information on these systems.					

(e) Rec. ITU-R M.1465-1

The antenna characteristics of the representative RLS radar systems operations in 3.1−3.7 GHz for conducting surface and air surveillance are provided in Rec. ITU-R M.1465-1; they are shown in Table 5-50. The land-based radars are usually for test operations to search and track airborne vehicles along extended flight paths, the shipborne radars are usually for air traffic control, and the airborne radars are for surveillance, target tracking and air traffic control.

Table 5-50. Antenna Characteristics of Representative RLS Radars in 3.1−3.7 GHz

Characteristics	Parametric Value				
System*	1	2	3	4	5
Platform	Land station	Land station	Ship	Ship	Aircraft
Type	Parabolic reflector	Parabolic reflector	Parabolic reflector	Phased array	Slotted array
G_{max} (dBi)	39	40	32	42	40
ϕ_{bw} (°)	1.72	El: 2.2, Az: 1.05	El: 4.4, Az: 1.75,	1.7	El: 6.0, Az: 1.2

			csc^2 to 30		
Polarization	Circular	Linear	Linear	Linear	N/A
*: Refer to Rec. ITU-R M.1465-1 for more information on these systems.					

(f) Rec. ITU-R M.1638

The antenna characteristics of the representative RLS radar systems operating in 5.25−5.85 GHz are provided in Rec. ITU-R M.1638; they are shown in Table 5-51. The land-based instrumentation radars provide highly accurate position data on space and aeronautical vehicles undergoing developmental and operational testing, the shipborne radars conduct sea and air surveillance for ship protection, and the airborne radars conduct land-mapping and imaging, environmental and land-use studies, and other related research activities.

Table 5-51. Antenna Characteristics of Representative RLS Radars in 5.25−5.85 GHz

Characteristics	Parametric Value			
System*	1	2	3	4
Platform	Land station	Ship	Aircraft	Aircraft
Function	Instrumentation	Search	Search	Research and Earth imaging
Type	Parabolic reflector, phased array,	Parabolic reflector, horn array	Slotted array	Horn
Radiation Pattern	Pencil	Csc^2, fan	Pencil	Fan
G_{max} (dBi)	38.3−54	28, 30	30−40	26
ϕ_{bw} (°)	0.4−2.5	El: 24.8, 28; Az: 2.6, 1.6	2−4	El: 28, Az: 3
Sidelobe Suppression (dB)	20−22	20, 25	25	22
Polarization	Linear, circular	Linear	Circular	Linear
*: Refer to Rec. ITU-R M.1638 for more information on these systems.				

(g) Rec. ITU-R M.628

The recommended requirements of the RLS radar transponder systems operating in 9.2−9.5 GHz for maritime search and rescue operations are provided in Rec. ITU-R M.628; they are

- vertical ϕ_{bw}: at least ±12.5° relative to transponder horizontal plane,
- azimuthal ϕ_{bw}: omnidirectional within ±2 dB, and
- polarization: horizontal (linear).

The transponders are installed onboard survival crafts.

(h) Rec. ITU-R M.1644

The antenna characteristics of the representative RLS radar systems operating in 13.75−14 GHz for surface and air surveillance of discrete approaching objects are provided in Rec. ITU-R M.1644; they are shown in Table 5-52.

Table 5-52. Antenna Characteristics of Representative RLS Radars in 13.75−14 GHz

Characteristics	Parametric Value			
System*	1	2	3	4
Platform & Operation	Land station	Ship, track	Ship, search	Aircraft
Type	Slotted array	Parabolic reflector	Slotted array	N/A
Radiation Pattern	Pencil	Pencil	Fan	N/A
G_{max} (dBi)	36	38.5	37.5	> 20
ϕ_{bw} (°)	El: 15, Az: 0.25	El: 1.2, Az: 2.4	El: 2.5, 10, Az: 2.2	N/A
Sidelobe Suppression (dB)	23	18.5	15.5	N/A
*: Refer to Rec. ITU-R M.1644 for more information on these systems.				

(i) Rec. ITU-R M.1730-1

The antenna characteristics of the representative RLS radar systems operating in 15.4−17.3 GHz for surface and air surveillance of discrete approaching objects are provided in Rec. ITU-R M.1730-1; they are shown in Table 5-53.

Table 5-53. Antenna Characteristics of Representative RLS Radars in 15.4−17.3 GHz

Characteristics	Parametric Value					
System*	1	2	3	4	5	6
Platform	Land station	Land station	Ship	Aircraft	Aircraft	Aircraft
Function	Surveillance	Surveillance, track	Surveillance, track	Search, track, mapping	Search, track, mapping	Search, track, mapping
Type	Parabolic reflector	Curved reflector	Phased array	Waveguide	Phased array	Phased array
Radiation Pattern	Pencil	Pencil	Pencil	Fan/pencil	Fan	Pencil
G_{max} (dBi)	37	43	43	25.6	38	35
ϕ_{bw} (°)	El: 1.1, Az: 3.5	El: 1.6, Az: 0.25	El: 1, Az: 1	El: 9.7, Az: 6.2	El: 2.5, Az: 2.2	El: 3.2, Az: 3.2
First Sidelobe Level	15 dBi @ 2.4°	23 dBi @ 1.6°	20 dBi @ 1.6°	10 dBi @ 31°	18 dBi @ 1.7°	3.5 dBi @ 1.2°
Polarization	Horizontal	Circular	RH circular	Linear vertical	Linear vertical	Linear
*: Refer to Rec. ITU-R M.1730-1 for more information on these systems.						

(j) Rec. ITU-R M.1640

The antenna characteristics of the representative RLS radar systems operating in 33.4−36 GHz for mapping, target identification, navigation, aim-point determination, and test range instrumentation are provided in Rec. ITU-R M.1640; they are shown in Table 5-54.

Table 5-54. Antenna Characteristics of Representative RLS Radars in 33.4−36 GHz

Characteristics	Parametric Value			
System*	1	2	3	4
Platform	Land station	Land station	Land station	Land station
Function	Imaging	Imaging	Metric	Seeker
Sensor type	Passive	Active	Active	Active
G_{max} (dBi)	35	30	51, 52	28.7
ϕ_{bw} (°)	0.5 × 3	0.75 × 10	0.25, 0.5	4.4
*: Refer to Rec. ITU-R M.1640 for more information on these systems.				

5.8.3 Radionavigation Service

RNS includes the maritime RNS (MRNS) and the aeronautical RNS (ARNS). These services will be discussed here.

NTIA does not provide the RNS antenna radiation performance standards for the federal systems. RTCM is developing the antenna standards for MRNS. RTCA provides the minimum antenna operational radiation performance standards for the ARNS airborne antennas. FAA does not provide the ARNS antenna performance standards in 14 CFR; however, it specifies the antenna performance requirements in its publication Technical Standard Order (TSO), which in turn refers to the standards in the RTCA publications.[135] [136] Otherwise, this sub-section contains antenna characteristics of the representative RNS radar systems in the frequency bands shown in Table 5-55; the information is from ITU-R.

Table 5-55. Summary of Representative RNS Radar Systems

Frequency Band (GHz)	Service, Platform	Antenna Characteristics		Source (Rec. ITU-R)
		Type	G_{max} (dBi)	
2.7−2.9	ARNS, land station	Parabolic reflector	32.8−34.3	M.1464-1
2.9−3.1	MRNS, ship	N/A	N/A	M.824-3[137]
5.25−5.85	ARNS, aircraft	Slotted array	34	M.1638
5.47−5.65	MRNS, ship	Slotted array	28−31	M.1313

135 http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title14/14tab_02.tpl, accessed Feb. 9, 2012.

136 *Technical Standard Order*, U.S., FAA, http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgtso.nsf/, accessed Feb. 9, 2012.

137 Rec. ITU-R M.824-3, *Technical Parameters of Radar Beacons (racons)* (2007).

8.85−9, 9.2−9.5	MRNS, ship	Slotted array	27−32	M.1313
		Yagi antenna for pleasure craft	21−27	
9.3−9.5	MRNS, ship	N/A	N/A	M.824-3
	ARNS, aircraft	N/A	0 minimum	
31.8−33.4	ARNS, aircraft	Parabolic reflector	41.1, 44	M.1466[138]

5.8.3.1 Maritime Radionavigation Service

This section contains one recommendation from ITU-R.

Rec. ITU-R M.824-3

For the MRNS radar beacon systems operating in 2.9−3.1 and 9.3−9.5 GHz, the recommended antenna characteristics in Rec. ITU-R M.824-3 are as follows:

- For a general purpose radar beacon:
  - platform: ship,
  - in the 3 GHz band, polarization should be suitable for responding to radars using either the horizontal or vertical polarizations, and
  - in the 9 GHz band, polarization should be suitable for responding to radars using the horizontal polarization.
- Characteristics for antenna gain and side-lobe suppression should be determined by the administrations.

5.8.3.2 Aeronautical Radionavigation Service

The ARNS antennas include the airborne antennas and land-based antennas. The picture of a land-based ARNS air traffic control radar beacon antenna is shown in Figure 5-7.[139]

Figure 5-7. Air Traffic Control Radar Beacon Antenna

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138 Rec. ITU-R M.1466, *Characteristics of, and Protection Criteria for Radars Operating in the Radionavigation Service in the Frequency Band 31.8-33.4 GHz* (2000).

139 http://www.answers.com/topic/air-traffic-control-radar-beacon-system-1, accessed Jan. 14, 2010.

The standards from RTCA and the recommendations and representative characteristics from ITU-R are discussed here.

(a) RTCA DO-195

For the airborne instrument landing system (ILS) localizer receiving equipment operating in 108–112 MHz, the minimum antenna operational radiation performance standards in RTCA DO-195 are as follows:[140]

- Radiation pattern: The horizontal component of the radiated signal in the forward and rearward directions shall not be down more than 10 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 113 MHz and mounted 10 inches above the ground plane.
- Gain variation: The difference between the maximum and minimum field strength of the horizontal component in the azimuth plane shall not exceed 20 dB.
- Polarization discrimination: The reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(b) RTCA DO-196

For the airborne VHF Omnidirectional Range receiving equipment operating in 108–117.95 MHz, the minimum antenna operational radiation performance standards in RTCA DO-196 are as follows:[141]

- Radiation pattern: The horizontal component of the radiated signal in the forward and rearward directions shall not be down more than 10 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 113 MHz and mounted 10 inches above the ground plane.
- Gain variation: The difference between the maximum and minimum field strength of the horizontal component in the azimuth plane shall not exceed 20 dB.
- Polarization discrimination: The reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(c) RTCA DO-253A

For the local area augmentation system of GPS operating in 108–117.975 MHz, the minimum airborne antenna operational radiation performance standards in RTCA DO-253A are as follows:[142]

- Antenna type: omnidirectional antenna.
- Horizontal gain:

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140 RTCA DO-195, *Minimum Operational Performance Standards for Airborne ILS Localizer Receiving Equipment Operating within the Radio Frequency Range of 108- 112 Megahertz* (1986).

141 RTCA DO-196, *Minimum Operational Performance Standards for Airborne VOR Receiving Equipment Operating within the Radio Frequency Range of 108- 117.95 Megahertz* (1986).

142 RTCA DO-253A, *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment*, §2.2.10.2, *Antenna Characteristics* (November 28, 2001).

  - The reception of the horizontally polarized component in the horizontal plane from the forward and rearward directions shall not be down more than 10 dB when compared to the maximum output response of a standard horizontal dipole antenna which is mounted 25.4 cm (10 inches) above the ground plane and resonant at 113 MHz.
  - The difference between the maximum and minimum reception of the horizontally polarized component from any direction in the horizontal plane shall not exceed 20 dB.
- Vertical gain:
  - When mounted on a 4×4 inch^2 (or larger) ground plane, the reception of the vertically polarized component in the horizontal azimuth plane shall not be down more than 6 dB when compared to a standard vertically polarized monopole antenna.
  - When mounted on a 4×4 inch^2 (or larger) ground plane, the difference between the maximum and minimum reception of the vertical polarized component from any direction in the horizontal azimuth plane shall not exceed 6 dB.

(d) RTCA DO-192

For the airborne ILS glide slope receiving equipment operating in 328.6–335.4 MHz, the minimum antenna operational radiation performance standards in RTCA DO-192 are as follows:[143]

- Radiation pattern: The horizontal component of the radiated signal in the forward direction shall not be down more than 15 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 332 MHz in free space.
- Polarization discrimination: The reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(e) RTCA DO-189

For the airborne Distance Measuring Equipment operating in 960–1215 MHz, the minimum antenna operational radiation performance standards in RTCA DO-189 are as follows:[144]

- Polarization: predominately vertically polarized.
- Field strength: The average field strength in the horizontal plane shall be equal to the field strength of a matched resonant ¼λ vertical antenna.
- Gain variation: The difference between the maximum and minimum field strengths in the horizontal plane shall not exceed 6 dB when the antenna is mounted at the center of the 1.2-meter (4-foot) diameter (or larger) flat circular ground plane.

143 RTCA DO-192, *Minimum Operational Performance Standards for Airborne ILS Glide Slope Receiving Equipment Operating within the Radio Frequency Range of 328.6-335.4 Megahertz* (1986).

144 RTCA DO-189, *Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating within the Radio Frequency Range of 960-1215 MHz* (1985).

(f) RTCA DO-181C

For the air traffic control radar beacon system and mode select airborne equipment operating in 1.03–1.09 GHz, the minimum antenna operational radiation performance standards in RTCA DO-181C are as follows:[145]

- Polarization: vertically polarized.
- Radiation pattern: The gain shall not be less than the gain of a matched ¼λ stub minus 3 dB over 90% of the coverage volume 0–360º in azimuth and 5–30º in elevation when installed at the center of a 1.2-meter (4-foot) diameter (or larger) circular ground plane.

(g) RTCA DO-185

For the traffic alert and collision avoidance system II transmitting in the 1.03 GHz band and receiving in 1.087–1.093 GHz, the minimum antenna operational radiation performance standards in RTCA DO-185 are as follows:[146]

- Polarization: vertically polarized.
- Radiation pattern: The gain shall not be less than the gain of a matched ¼λ stub minus 1 dB over 90% of the coverage volume 0–360º in azimuth and (-15)–20º in elevation when installed at the center of a 1.2-meter (4-foot) diameter (or larger) circular ground plane, which can be flat or cylindrical.

(h) RTCA DO-197A

For the active traffic alert and collision avoidance system I transmitting in the 1.03 GHz band and receiving in 1.087–1.093 GHz, the minimum antenna operational radiation performance standards in RTCA DO-197A are as follows:[147]

- Type: omnidirectional antenna or multiple beams to cover all azimuth directions.
- Polarization: vertically polarized.
- Radiation pattern: covering 360º in azimuth and at least (-10)–20º in elevation.

(i) RTCA DO-260A

For the Automatic Dependent Surveillance (ADS) system and Traffic Information Service (TIS) system operating at 1.09 GHz, the minimum antenna operational radiation performance standards in RTCA DO-260A are as follows:[148]

- Type: omnidirectional antenna.
- Polarization: vertically polarized.

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145 RTCA DO-181C, *Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment* (1983).

146 RTCA DO-185, *Minimum Operational Performance Standards for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment* (1990).

147 RTCA DO-197A, *Minimum Operational Performance Standards for an Active Traffic Alert and Collision Avoidance System I (Active TCAS I)* (1994).

148 RTCA DO-260A, *Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance - Broadcast (ADS-B) and Traffic Information Services - Broadcast (TIS-B)*, §2.2.13, *Antenna System* (April 10, 2003).

- Transmit radiation pattern: The gain shall not be less than the gain of a matched ¼λ stub minus 3 dB over 90% of a coverage volume from 0–360º in azimuth and 5–30º above the ground plane when installed at the center of 1.2 meters (4 feet) or larger flat circular ground plane.
- Receive radiation pattern: The gain should not be less than the gain of a matched ¼λ stub minus 1 dB over 90% of a coverage volume from 0–360º in azimuth and (-15)–(+20)º in elevation when installed at the center of 1.2 meters (4 feet) or larger circular ground plane, which can be either flat or cylindrical.

This standard is referred to in the FAA TSO-C166b for the extended squitter ADS-broadcast and TIS-broadcast equipment operating on 1090 MHz, and TSO-C166b is referred to in 14 CFR §91.227 for the ADS-broadcast out equipment performance requirements.[149] [150]

(j) Rec. ITU-R M.1464-1

The antenna characteristics of the representative ARNS radar systems in Rec. ITU-R M.1464-1, for the airport air traffic control systems operating in 2.7−2.9 GHz, are as follows:

- Platform: land station fixed and transportable.
- Type: parabolic reflector.
- Radiation pattern: Csc^2.
- G_{max}: 32.8−34.3 dBi.
- ϕ_{bw}: 4−5° elevation, 1.3−1.6° azimuth.
- First sidelobe level: 7.3−9.5 dBi.
- Polarization: linear and circular.

(k) Rec. ITU-R M.1638

The antenna characteristics of the representative ARNS airborne radar systems operating in 5.25−5.85 GHz, for weather avoidance, wind shear detection, and safety services, are provided in Rec. ITU-R M.1638; they are as follows:

- Type: slotted array.
- Radiation pattern: pencil beam.
- G_{max}: 34 dBi.
- ϕ_{bw}: 3.5°.
- Sidelobe suppression: 31 dB.
- Polarization: linear.

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149 FAA TSO-C166b, *Extended Squitter Automatic Dependent Surveillance - Broadcast (ADS-B) and Traffic Information Service - Broadcast (TIS-B) Equipment Operating on the Radio Frequency of 1090 Megahertz (MHz)* (December 2, 2009), http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgtso.nsf/0/e70544d62a001f87862576820057970f/$FILE/TSO-166b.pdf.

150 http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=d6c9ee5df86ab4132bba03a78525d969&rgn=div8&view=text&node=14:2.0.1.3.10.3.7.14&idno=14.

(l) Rec. ITU-R M.824-3

For the ARNS land-based general purpose radar beacon systems operating in 9.3−9.5 GHz, the recommended antenna characteristics in Rec. ITU-R M.824-3 are as follows:

- G_{max}: 0 dB minimum (it is not specified whether it is dBi or dBd).
- ϕ_{bw}: 360° azimuthal, 30° elevation.
- Polarization: horizontal.

(m) Rec. ITU-R M.1466

The antenna characteristics of the representative ARNS airborne radar systems operating in 31.8−33.4 GHz are provided in Rec. ITU-R M.1466; they are as follows:

- Type: parabolic reflector.
- G_{max}: 41.1 and 44, dBi.

The radars are used for ground mapping, weather avoidance, and calibration of airborne on-board navigation systems for accurate aerial delivery in adverse weather conditions.

5.9 Radiodetermination-Satellite Service

RDSS includes the radiolocation-satellite service (RLSS) and radionavigation-satellite service (RNSS). Satellite and earth station antenna characteristics for these services are presented here.

5.9.1 Radiolocation-Satellite Service

The Cospas-Sarsat International Satellite System, of which the U.S. is one of the founders, is the only operational RLSS system providing land, maritime and aeronautical search and rescue (SAR) services.[151] The Cospas-Sarsat system consists of GSO satellites (currently five satellites) and a LEO satellite constellation (currently four satellites). The land vehicles and persons, maritime ships and aeronautical crafts use beacons to transmit distress signals, which can be received by the satellites and relayed to the Cospas-Sarsat earth stations.

NTIA does not provide the RLSS antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains satellite and earth station antenna characteristics from Cospas-Sarsat system technical documents, and one recommended satellite antenna gain pattern from ITU-R.

(a) C/S T.011

A Cospas-Sarsat GSO satellite has a receiving antenna operating at 406.05 MHz and a transmitting antenna operating at 1544.5 MHz, performing the SAR repeater (SARR) function and the SAR processor (SARP) operation. Characteristics of the GSO satellite antennas are in the Cospas-Sarsat International Satellite System technical document C/S T.011.[152] In general, the satellite transmitting and receiving antennas have global beam coverage, and the polarizations

151 http://www.cospas-sarsat.org.

152 C/S T.011, *Description of the 406 MHz Payloads Used in the Cospas-Sarsat GEOSAR System*, Issue 1, Revision 6, (October 2010), http://www.cospas-sarsat.org/images/stories/SystemDocs/Current/t11oct28.10_completedoc.pdf.

are RHCP. Satellite antenna characteristics of the Cospas-Sarsat GSO systems are shown in Table 5-56.

Table 5-56. Cospas-Sarsat GSO Satellite Antenna Characteristics from C/S T.011

Satellite System	Satellite Antenna	Characteristics	Parametric Value
GOES	Transmit	G_{max}	12.3 dBi
		Transmission line loss	1.7 dB
		Net G_{max}	10.6 dBi
		Polarization	RHCP
	Receive	G_{max}	10 dBi
		Transmission line loss	1.9 dB
		Net G_{max}	8.1 dBi
		Polarization	RHCP
INSAT	Transmit	Coverage area	India, see Figure 5-8
		G_{max}	31.39 dBi
		Gain at edge of coverage	28.5 dBi[153]
		Polarization	Vertical
	Receive	Gain at edge of coverage	11 dBi
		Polarization	RHCP
Electro-L	Transmit	G_{max} including transmission line loss	12 dBi
		Polarization	LHCP
	Receive	G_{max} including transmission line loss	15 dBi
		Polarization	RHCP
MSG	Transmit:	Type	Electronically switched de-spun antenna
		Coverage	Global beam
		G_{max}	7.6 dBi
		Gain variation	• Typical 0.8 dB, • <1.6 dB peak-to-peak from column to column
		Polarization	Horizontal
	Receive	Type	Electronically switched de-spun antenna
		Coverage	Global beam
		G_{max}	5.6 dBi
		Gain within coverage area	3.1–4.5 dBi
		Gain variation	1.3 dB peak-to-peak in the south, 1.8 dB peak-to-peak in the north

153 There is discrepancy in the edge-of-coverage gain value in C/S T.011; the values 28.8 dBi and 28.5 dBi are given in the text and in the figure, respectively. Here it is assumed that the data provided from INSAT is correct.

		Cross-polarization discrimination within coverage area	(-9.0)–(-14.2) dB
		Polarization	RHCP

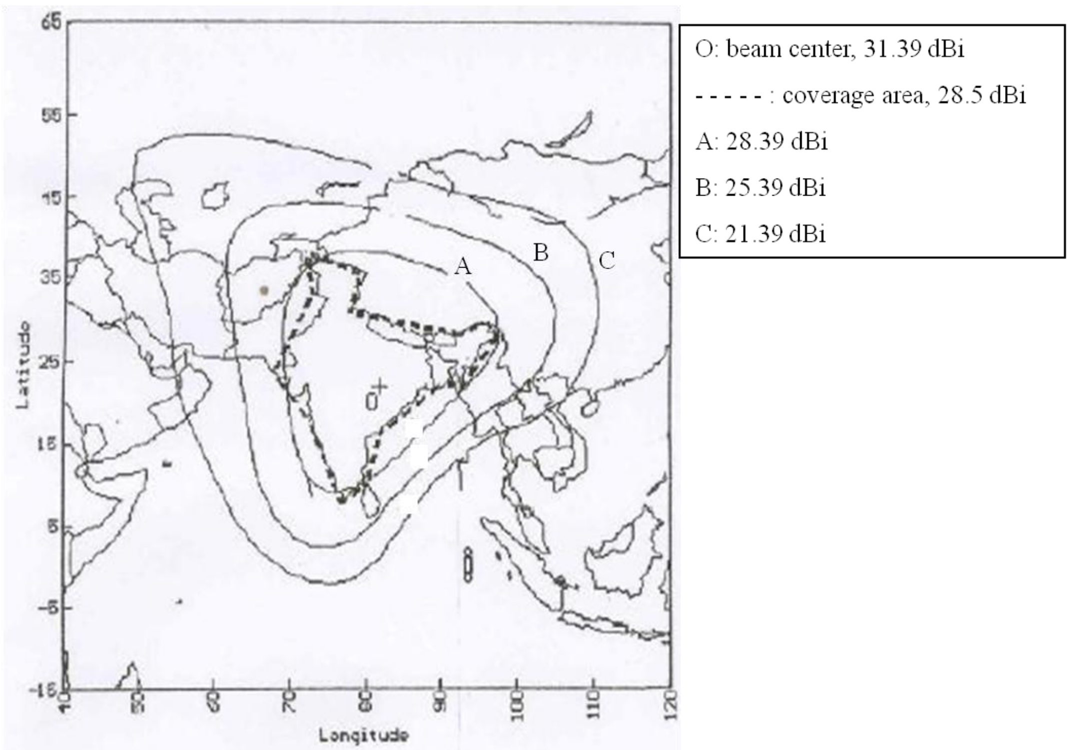


Figure 5-8. Sarsat INSAT Satellite Transmitting Antenna Coverage

(b) C/S T.003

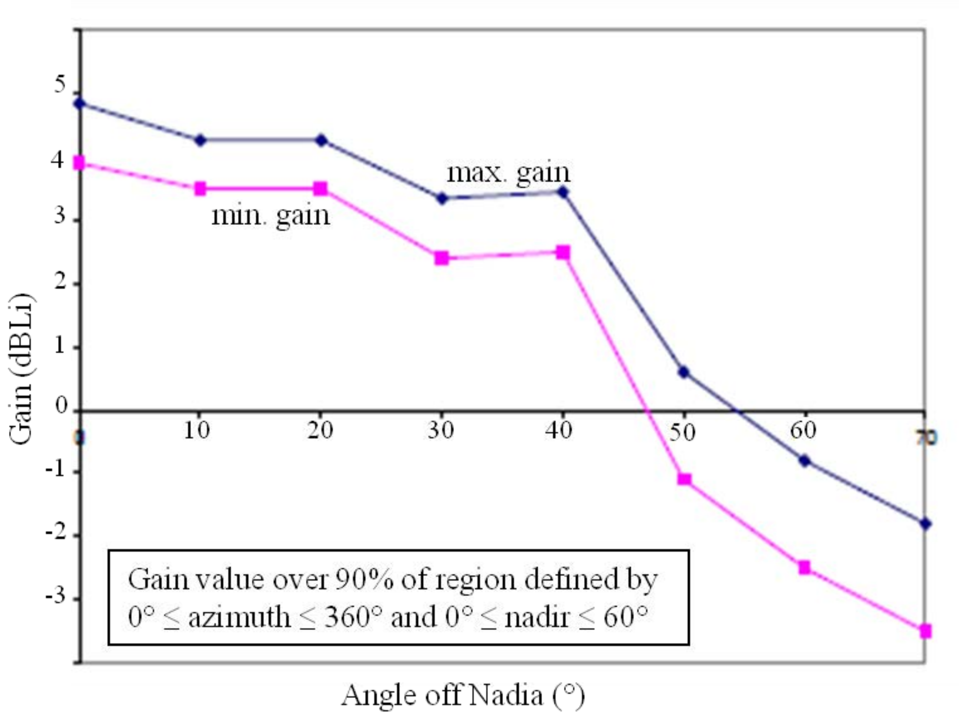
A Cospas LEO satellite has three antennas, and a Sarsat LEO satellite has four antennas. The gain patterns of the LEO satellite antennas in C/S T.003 are shown in Table 5-57 and Figure 5-9.[154]

Table 5-57. Cospas-Sarsat LEO Satellite Antenna Characteristics

Satellite	Antenna	Frequency (MHz)	Operation	Polari-zation	Satellite Antenna Gain Pattern
Cospas	Receive	406.05	SARP	LHCP	Figure 5-9(a)
	Transmit	1544.5	SARP	LHCP	Figure 5-9(b)
Sarsat-TIROS	Receive	406.05	SARR	RHCP	Figure 5-9(c)
	Receive	406.05	SARP	RHCP	Figure 5-9(d)

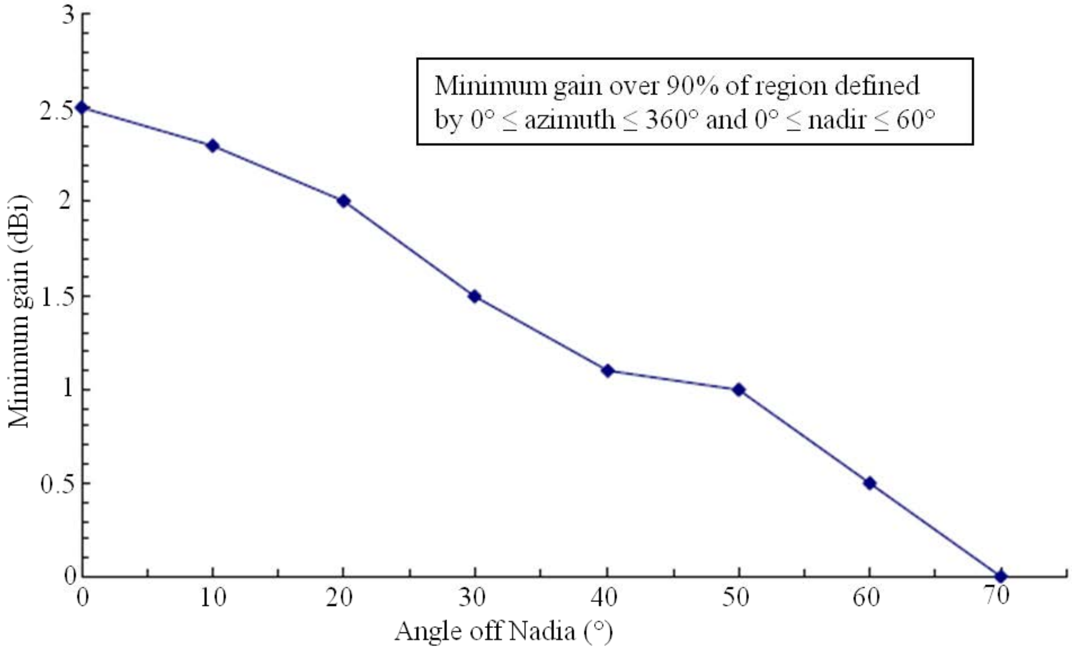
154 C/S T.003, *Description of the Payloads Used in the Cospas-Sarsat LEOSAR System*, Issue 34, Revision 21, (October 2010), http://www.cospas-sarsat.org/images/stories/SystemDocs/Current/T3OCT28.10completedocument.pdf.

	Transmit	1544.5	SARR	LHCP	Figure 5-9(e)
Sarsat-METOP	Receive	406.05	SARP & SARR	RHCP	Figure 5-9(f)
	Transmit	1544.5	SARR	LHCP	Figure 5-9(g)
Sarsat-NPOESS	Receive	403	SARP	RHCP	Figure 5-9(h)
	Transmit	1544.5	SARR	LHCP	Figure 5-9(i)

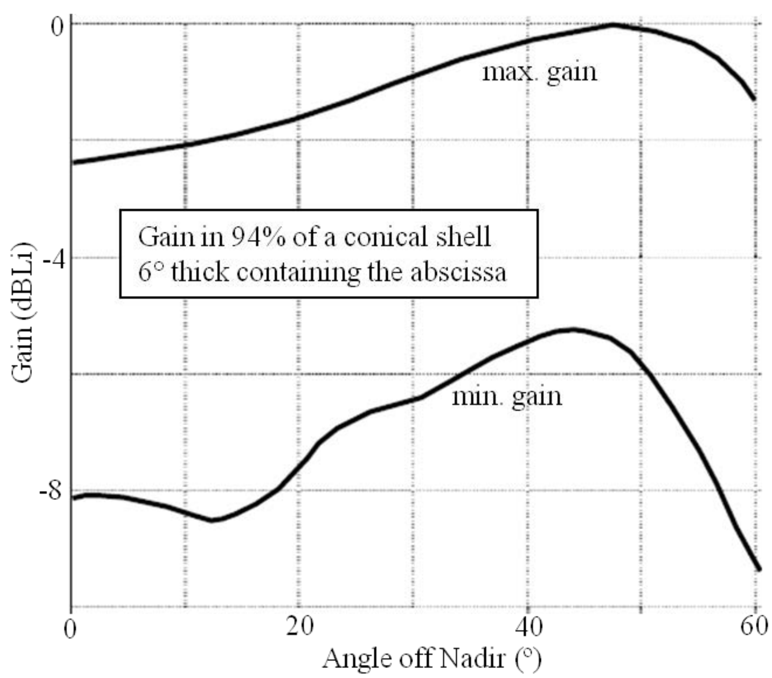


(a) Cospas 406.05 MHz Receiving Antenna

(Figure 5-9)

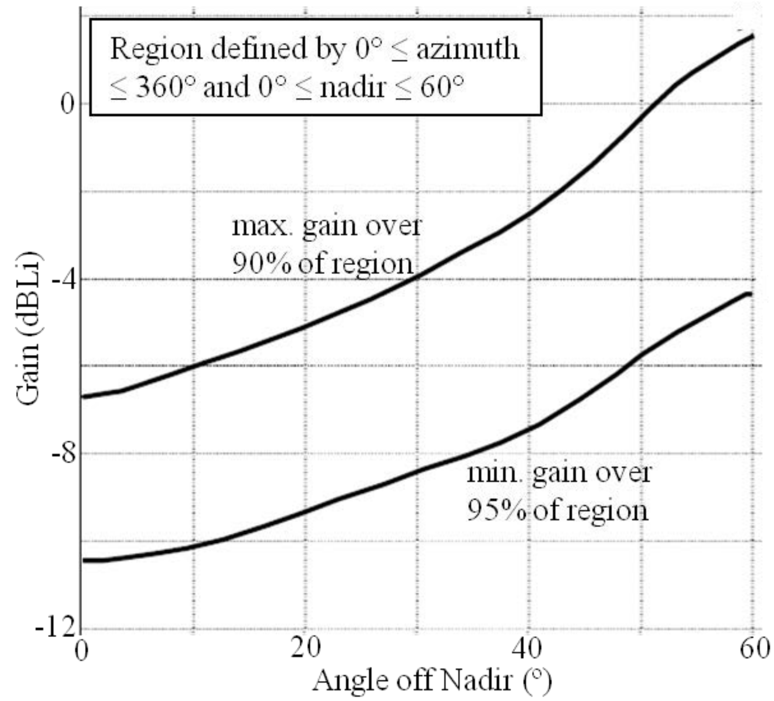


(b) Cospas 1544.5 MHz Transmitting Antenna

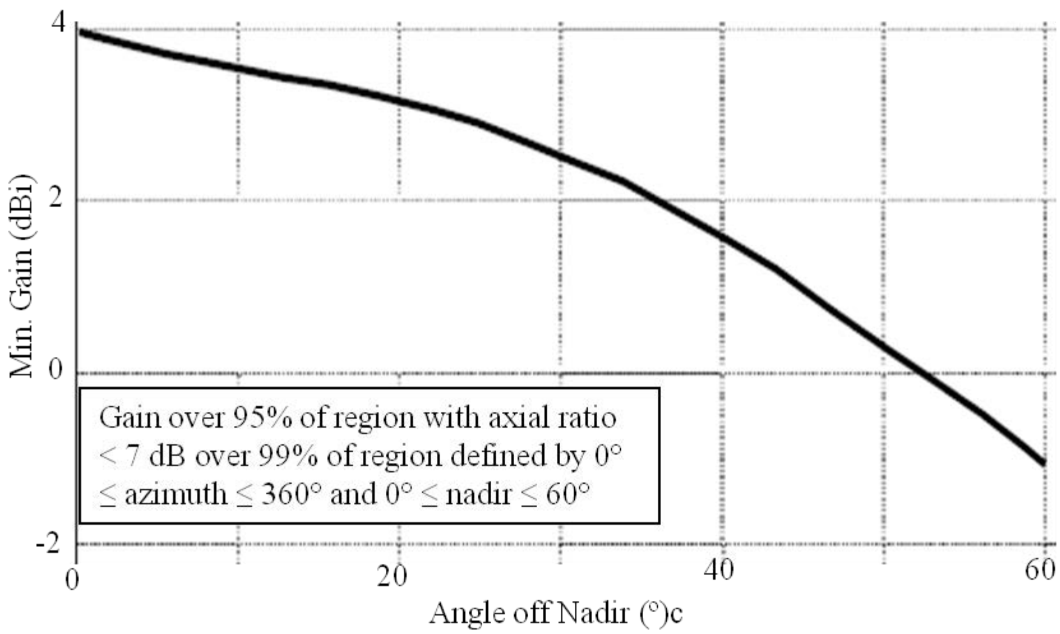


(c) Sarsat-TIROS 406.05 MHz SARR Receiving Antenna

(Figure 5-9)

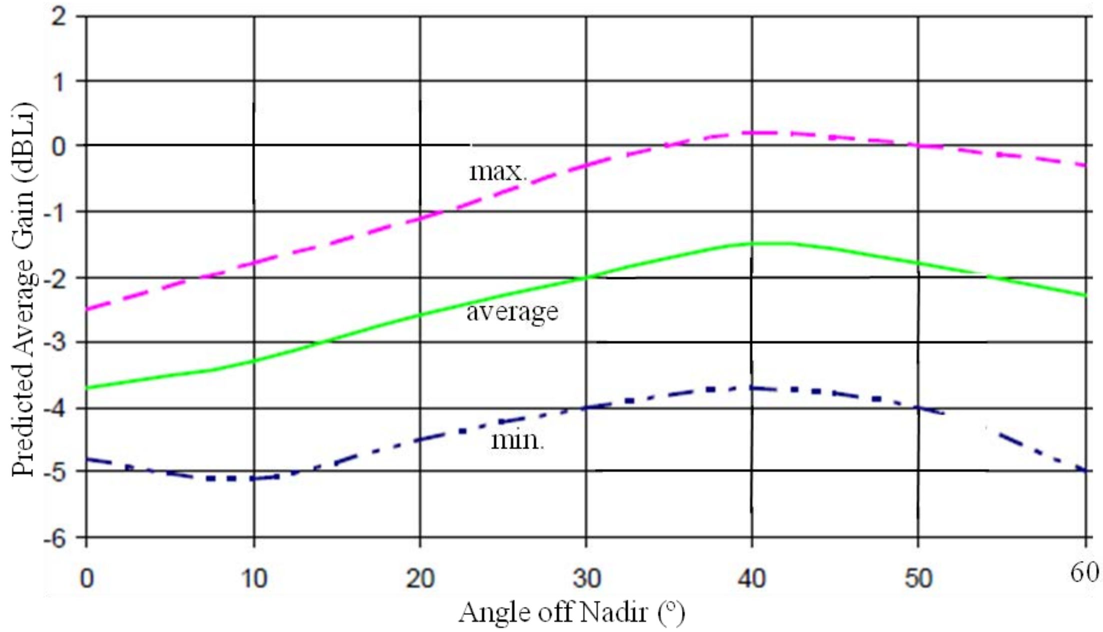


(d) Sarsat-TIROS 406.05 MHz SARP Receiving Antenna

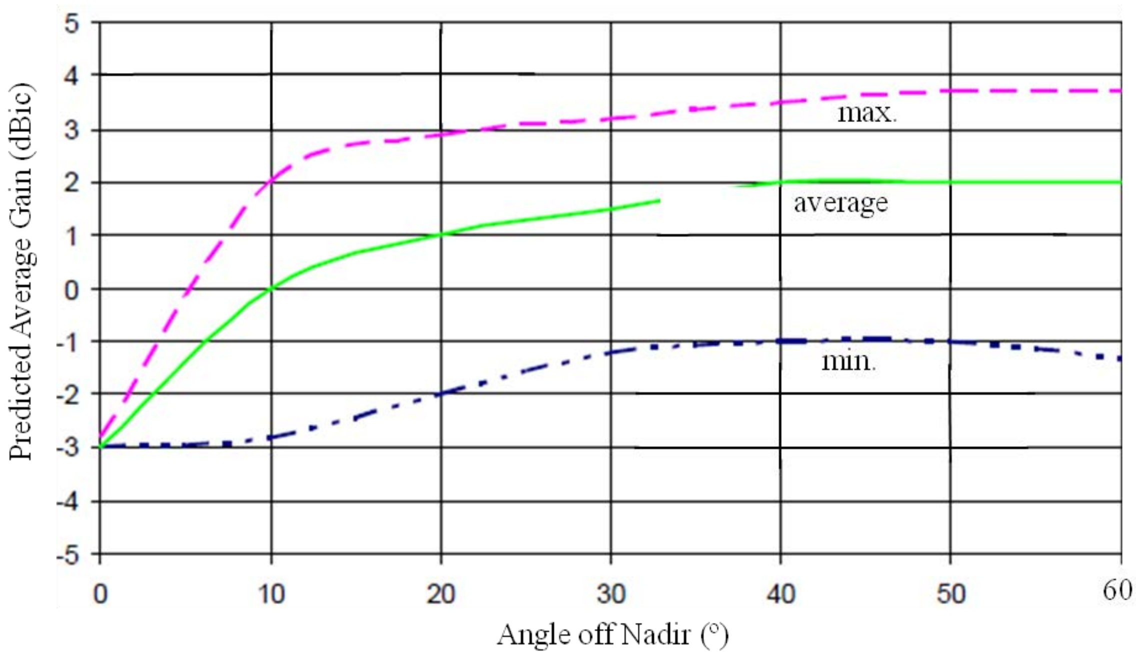


(e) Sarsat-TIROS 1544.5 MHz Transmitting Antenna

(Figure 5-9)

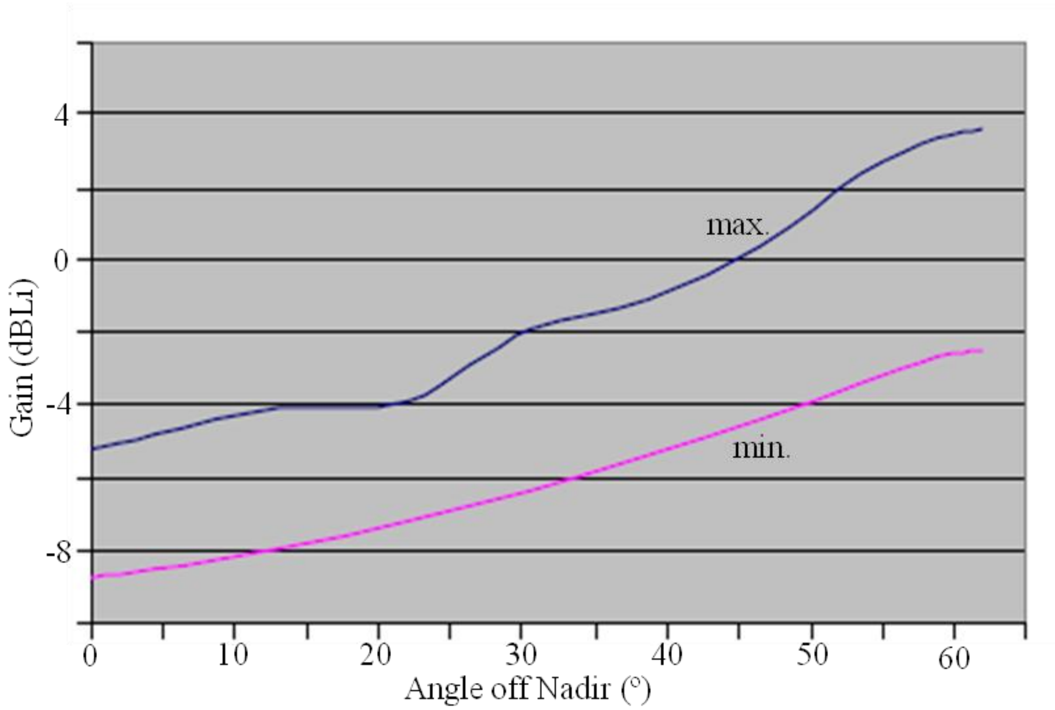


(f) Sarsat-METOP 406.05 MHz Receiving Antenna

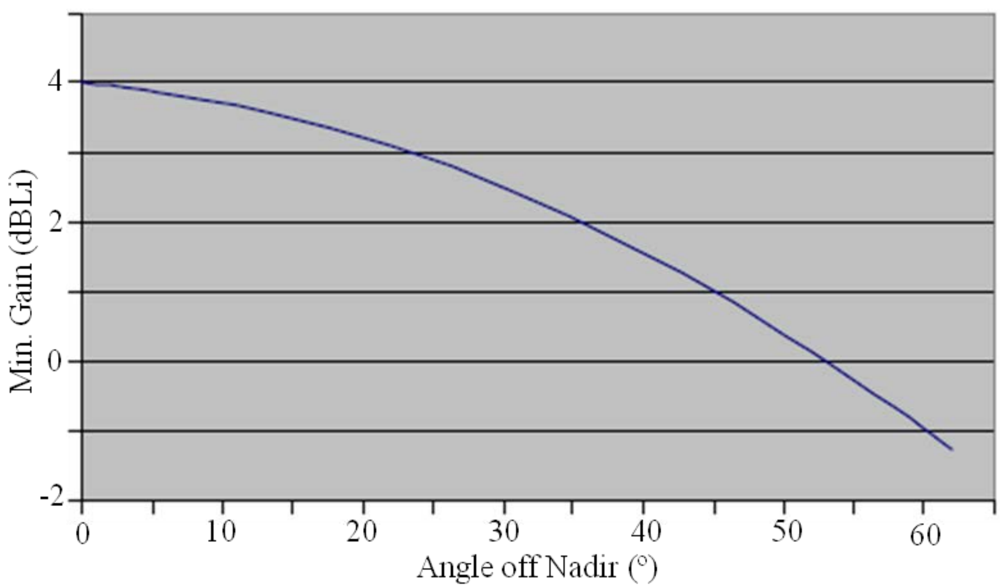


(g) Sarsat-METOP 1544.5 MHz Transmitting Antenna

(Figure 5-9)



(h) Sarsat-NPOESS 403 MHz Receiving Antenna



(i) Sarsat-NPOSS 1544.4 MHz Transmitting Antenna

Figure 5-9. Cospas-Sarsat LEO Satellite Antenna Gain Pattern

(e) C/S T.001

The Cospas-Sarsat distress beacon equipment operating at 406.05 MHz can be land-based (personal locator beacon, or PLB), shipborne (emergency position indicating radio beacon, or EPIRB), or airborne (emergency locator transmitters, or ELT). The beacons use monopole antennas to transmit distress signals; samples of beacons are shown in Figure 5-10.[155] The beacon antenna performance requirements in C/S T.001 for all azimuth angles and for elevation angle 5° < θ < 60° are as follows:[156]

- pattern: hemispherical,
- polarization: RHCP or linear, and
- Gain: -3 < G(dBi) < 4 over 90% of the angular range.

These specifications are referenced in Rec. ITU-R.M.633-4.[157]

Figure 5-10. Cospas-Sarsat Beacons

(f) Rec. ITU-R M.1478-1

For coordination studies against narrow band spurious emissions (harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, etc.) and out-of-band broadband emissions, the recommended Sarsat satellite SARP receiving antenna gain pattern in Rec. ITU-R M.1478-1 is shown in Table 5-58.[158]

Table 5-58. Recommended Sarsat Satellite SARP Receiving Antenna Gain Pattern

Nadir Satellite Angle (°)	Gain in RHCP (dBi)	Gain in LHCP (dBi)
62	3.85	-5.69
59	3.54	-6.23
54	2.62	-7.52
47	1.24	-9.39
39	-0.17	-11.39
31	-1.33	-13.12
22	-2.24	-14.52

155 http://www.sarsat.noaa.gov/emerbcns.html/, accessed Feb. 2, 2012.

156 C/S T.001, *Specification for Cospas-Sarsat 406 MHz Distress Beacons*, Issue 3, Revision 12, (October 2011), http://www.cospas-sarsat.org/images/stories/SystemDocs/Current/T1_27OCT_2011_completedocument.pdf.

157 Rec. ITU-R.M.633-4, *Transmission Characteristics of a Satellite Emergency Position-indicating Radio Beacon (Satellite EPIRB) System Operating through a Satellite System in the 406 MHz Band* (2010).

158 Rec. ITU-R M.1478-1, *Protection Criteria for Cospas-Sarsat Search and Rescue Instruments in the Band 406-406.1 MHz* (2004).

13	-3.08	-15.77
5	-3.80	-17.17
0	-3.96	-18.00

5.9.2 Radionavigation-Satellite Service

RNSS includes general RNSS, the aeronautical RNSS (ARNSS) and the maritime RNSS (MRNSS). There are two operating RNSS systems, i.e., GPS of the U.S. and the global navigation satellite system (GLONASS) of the Russian Federation; only GPS is discussed.

GPS is a constellation of 24 MEO satellites in circular 20200 km orbit. The GPS satellite antenna is a phased array; a picture of a GPS satellite is shown in Figure 5-11.[159] The GPS receivers can be land-based, shipborne or airborne; two GPS receivers are shown in Figure 5-12.[160] Generally, GPS antennas have hemispherical coverage; a sample hemispherical radiation pattern is shown in Figure 5-13, and a helical antenna can provide such a pattern.[161]

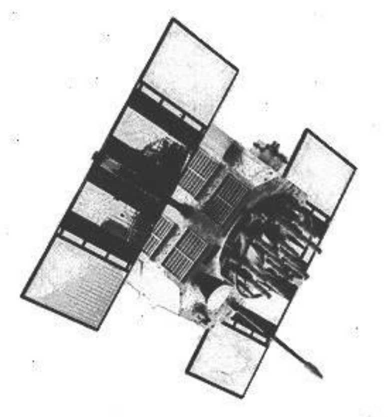


Figure 5-11. NAVSTAR GPS Satellite

(a) Land-Based Receiver **(b) Aeronautical Receiver**

Figure 5-12. GPS Receiver

159 http://ces.iisc.ernet.in/hpg/envis/Remote/section1611.htm, accessed Jan. 17, 2012.

160 http://www.garmin.com/us/, accessed Jan. 17, 2012.

161 http://www.gpssource.com/files/1526-TS-L1-Active-GPS-Antenna-01.pdf.

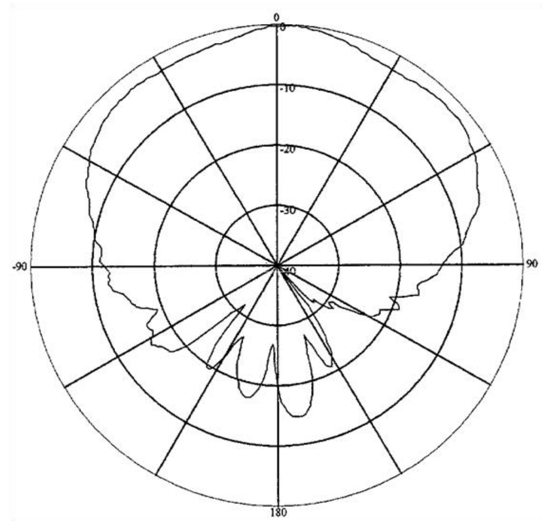


Figure 5-13. Sample of GPS Antenna Radiation Pattern

NTIA does not provide the RNSS antenna radiation performance standards for the federal systems. Specifications of ARNSS airborne antennas are mostly from the International Civil Aviation Organization (ICAO) and RTCA, and RTCM is developing the antenna standards for MRNSS. FAA does not provide the ARNSS antenna performance standards in 14 CFR; however, it specifies the antenna performance requirements in TSO, which in turn refers to the standards in the RTCA publications. This sub-section contains one airborne antenna radiation performance standard from RTCA and one recommended characteristics for the aeronautical GPS antennas from ITU-R.

(a) RTCA DO-228

For the global navigation satellite system (GNSS) airborne equipment operating in 1575.42 ± 10 MHz, the minimum airborne passive antenna operational radiation performance standards in RTCA DO-228 are as follows:[162]

- Polarization: nominally RHCP.
- Gain mask: Table 5-59, the gain mask is required for all azimuthal angles.

Table 5-59. ARNSS Airborne Passive Antenna Gain Requirement from RTCA DO-228

Elevation Angle θ	Lower Boundary of Gain Mask (dBic)	Upper Boundary of Gain Mask (dBic)
15º < θ	-2	7
10º < θ ≤ 15º	-3	7
5º < θ ≤ 10º	-4.5	7
0 < θ ≤ 5º	-7.5	-2

162 RTCA DO-228 & Change No. 1, *Minimum Operational Performance Standards for Global Navigation Satellite System (GNSS) Airborne Antenna Equipment*, §2.2 (January 11, 2000).

• dBic means it is circular polarization, which is required for the GNSS. • The antenna gain must not exceed an average gain loss of 4.5 dB at θ ≥ 30º when antenna is exposed to rain or an ice accumulation of 0.5 inch. • The antenna gain must not vary more than 1 dB over the full temperature range for which the antenna is specified.

This standard is referred to in the FAA TSO-C144a for the GNSS airborne passive antennas.[163] Both FAA TSO and RTCA use "passive antenna" for the antenna itself and "active antenna" for the combination of antenna and receiver.

(b) RTCA DO-301

For the global navigation satellite system (GNSS) airborne equipment operating in 1575.42 ± 10.23 MHz, the minimum airborne active antenna operational radiation performance standards in RTCA DO-301 are as follows:[164]

- Polarization: nominally RHCP.
- Gain mask: Table 5-59, the gain mask is required for all azimuthal angles.

Table 5-60. ARNSS Airborne Active Antenna Gain Requirement from RTCA DO-301

Lower Boundary of Gain Mask		Upper Boundary of Gain Mask	
Elevation Angle θ	**Gain Suppression (dB)**	**Elevation Angle θ**	**Gain Suppression (dB)**
75º < θ	2.5	75º < θ	0
30º < θ ≤ 75º	Linear from 2.5 to 3.73	10º < θ ≤ 75º	Linear from 0 to 0.5
20º < θ ≤ 30º	3.73	5º < θ ≤ 10º	0.5
10º < θ ≤ 20º	4	0º < θ ≤ 5º	2.75
5º < θ ≤ 10º	7	θ = 0º	5
0º < θ ≤ 5º	8.5		
θ = 0º	10		
• Passive antenna G_{max} ≥ -5.5 dBic at 1575.42 MHz and 5º elevation angle. • Passive antenna gain is expected to be no more than 4 dBic for elevation angle above 75º.			

This standard is referred to in the FAA TSO-C190 for the GNSS airborne active antennas.[165]

163 FAA TSO-C144a, *Passive Airborne Global Navigation Satellite System (GNSS) Antenna* (March 30, 2007), http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgtso.nsf/0/e0892eab64284184862572b50051f3bf/$FILE/C144a.pdf.

164 RTCA DO-301, *Minimum Operational Performance Standards for Global Navigation Satellite System (GNSS) Airborne Active Antenna Equipment for the L1 Frequency Band*, §2.2 (December 13, 2006).

165 FAA TSO-C190, *Active Airborne Global Navigation Satellite System (GNSS) Antenna* (March 30, 2007), http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgtso.nsf/0/196f61004d511c3e862572b50051f364/$FILE/TSO-C190.pdf.

(c) Rec. ITU-R M.1477

For coordination studies and interference analysis in 1559−1610 MHz, the recommended antenna characteristics of three types of aeronautical GPS receivers in Rec. ITU-R M.1477 are as follows:[166]

- Type 1, the airborne receiver meeting the requirements of the satellite-based augmentation system and providing category I precision approach operation: [167]
  - maximum antenna gain in upper hemisphere: 7 dBic,
  - minimum antenna gain towards satellite at 5° elevation: -4.5 dBic, and
  - assumed antenna gain in lower hemisphere: -10 dBic.
- Type 2, the airborne receiver meeting the requirements of the land-based augmentation system and providing category II/III precision approach operation:
  - maximum antenna gain in upper hemisphere: 7 dBic,
  - minimum antenna gain towards satellite at 5° elevation: -4.5 dBic, and
  - minimum antenna gain towards pseudolite: -21 dBic.[168]
- Type 3, the land-based receivers used in the satellite-based augmentation system to determine the ionospheric delay:
  - maximum antenna gain: 7 dBic, and
  - minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.

Land and ship station navigation receivers are similar to the type 1 receiver. Commercial land network receivers operating with a single frequency are similar to the type 1 receiver, and those operating with two frequencies are similar to the type 3 receiver.

5.10 Radio Astronomy Service

RAS uses telescopes or large paraboloidal antennas ($D/\lambda > 100$) for its observation operations.

NTIA does not provide the RAS antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains the following RAS antenna characteristics from ITU-R:

- from Rec. ITU-R RA.1631, recommended antenna reference radiation pattern for EMC analyses between NGSO space systems and RAS antennas sharing frequencies above 150 MHz;[169]

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166 Rec. ITU-R M.1477, *Technical and Performance Characteristics of Current and Planned Radionavigation-Satellite Service (Space-to-Earth) and Aeronautical Radionavigation Service Receivers to be Considered in Interference Studies in the Band 1559-1610 MHz* (2000).

167 Satellite-based augmentation system uses additional messages from the GPS satellites to augment GPS receivers' performance. Ground-based augmentation system uses additional messages from a terrestrial network to augment GPS receivers' performance.

168 Pseudolite, or pseudo-satellite, refers to a radio terminal which is not a satellite but provides radio services similar to satellites. In GPS, pseudolites are ground-based terminals functioning as local GPS alternatives.

169 Rec. ITU-R RA.1631, *Reference Radio Astronomy Antenna Pattern to be Used for Compatibility Analyses between Non-GSO Systems And Radio Astronomy Service Stations Based on the epfd Concept* (2003).

- from Rec. ITU-R SA.509-2, recommended earth station antenna sidelobe reference radiation pattern for EMC analyses in 1−30 GHz; and
- from Rec. ITU-R RA.1630, antenna parameters of some of the major land-based RAS systems.[170]

(a) Rec. ITU-R RA.1631

For coordination studies and interference assessment between the NGSO space systems and RAS antennas sharing frequencies above 150 MHz, the recommended RAS antenna reference radiation pattern in Rec. ITU-R RA.1631 is shown in Table 5-61. The sidelobe of the radiation pattern is the average sidelobe level for more accurate interference assessment because the interferers are the fast moving NGSO satellites. This pattern assumes antenna efficiency *e* = 100%.

Table 5-61. Recommended RAS Antenna Reference Radiation Pattern for EMC Analyses between NGSO Space Systems and RAS Systems above 150 MHz

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
G_1	$\phi_m \le \phi < \phi_r$
$29 - 25 \times \log(\phi)$	$\phi_r \le \phi < 10°$
$34 - 30 \times \log(\phi)$	$10° \le \phi < 34.1°$
-12	$34.1° \le \phi < 80°$
-7	$80° \le \phi < 120°$
-12	$120° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

$G_{max} = 10\times\log[(\pi D/\lambda)^2]$, dBi (100% aperture efficiency)

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_m = (20\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.

A more accurate representation of the mainbeam and the near sidelobe pattern may be adopted as follows:

$$G(\phi) = G_{max}[J_1(2\pi x)/(\pi x)]^2 \quad \text{(numerical ratio)} \quad 0 \le \phi \le \phi_n$$

$$= b[(\cos(2\pi x - 0.75\pi + 0.0953)/(\pi x)]^2 \quad \text{(numerical ratio)} \quad \phi_n \le \phi < 1°$$

where

$G_{max} = (\pi D/\lambda)^2$, numerical ratio, assume 100% aperture efficiency

$J_1()$: Bessel function of the first order

$b = 10^{3.2}\ \pi^2\ [(\pi D)/(360\lambda)]^2$

$x = \phi\pi D/(360\lambda)$

170 Rec. ITU-R RA.1630, *Technical and Operational Characteristics of Ground-Based Astronomy Systems for Use in Sharing Studies with Active Services between 10 THz and 1000 THz* (2003).

Rec. ITU-R RA.1631 also provides typical RAS antenna G_{max} values; these data are shown in Table 5-62.

Table 5-62. Typical G_{max} of RAS Antenna

Band (MHz)	G_{max} (dBi)	Band (GHz)	G_{max} (dBi)
150.05−153	44	4.99−5	74
322−328.6	51	10.6−10.7	81
406.1−410	53	14.47−14.5	84
608−614	56	15.35−15.4	84
1400−1427	63	22.21−22.5	87
1610.6−1613.8	64	23.6−24	88
1660−1670	65	31.3−31.7	90
2690−2700	69	42.5−43.5	93

(b) Rec. ITU-R SA.509-2

For coordination studies and interference assessment in 1−30 GHz, the recommended RAS earth station antenna sidelobe reference radiation pattern in Rec. ITU-R SA.509-2 is shown in Table 5-63.

Table 5-63. Recommended RAS Earth Station Antenna Sidelobe Reference Radiation Pattern for EMC Analyses in 1−30 GHz

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$1° \le \phi < 47.9°$
-10	$47.9° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. This pattern applies to $D/\lambda > 100$.	

(c) Rec. ITU-R RA.1630

The technical characteristics of the land-based RAS systems for coordination studies with radio services sharing in 10–1000 THz are provided in Rec. ITU-R RA.1630. Only optical device, either lens or optical reflector, are practical in this frequency range. Antenna parameters of some of the major land-based RAS systems are provided in Table 5-64.

Table 5-64. Antenna Parameters of Land-Based Optical RAS Systems in 10–1000 THz

Telescope	Location	Aperture Diameter (meter)	Focal Length (meter)	Focal Stop (f/)
Keck I, Keck II	Mauna Kea, HI, U.S.	10	17.5	1.75
Hobby-Eberly Telescope	Mt. Fowlkes, TX, U.S.	9.2	13.08	1.4
Subaru	Mauna Kea, HI, U.S.	8.3	15	1.8

Very Large Telescope	Cerro Paranal, Chile	8.2 x 4	14.8	1.8
Gemini North	Mauna Kea, HI, U.S.	8.0	129.6	16.2
Gemini South	Cerro Pachon, Chile	8.0	129.6	16.2
Multi-Mirror Telescope	Mt. Hopkins, AZ, U.S.	6.5	8.1	1.25
Magellan I	La Serena, Chile	6.5	8.1	1.25
Bolshoi Azimuthal Telescope	Zelenschuskaya, Russia	6.0	24	4.0
Hale	Palomar Mt., CA, U.S.	5.0	16.5	3.3
William Herschel Telescope	Roque de los Muchachos, La Palma, Canary Islands	4.2	10.5	2.5
Victor M. Blanco	Cerro Tololo, Chile	4.0	11.5	2.9
Mayall	Kitt Peak, AZ, U.S.	4.0	10.3	2.7
Anglo-Australian Telescope	Siding Springs, Australia	3.9	12.7	3.3
Focal stop: the ratio between the diameter of the aperture in the lens and the focal length of the lens.				

5.11 Remote Sensing Service

RSS includes Meteorological Aids Service (MetAids), Earth Exploration Satellite Service (EESS), Meteorological-satellite Service (MetSat), and Space Research Service (SRS). Antenna data for these services are presented here.

5.11.1 Meteorological Aids Service

The MetAids systems include radar, optical sensor, and remote sensing devices. Antenna data for these systems are presented here.

5.11.1.1 Meteorological Radar

MetAids wind profiler radars (WPR) are Doppler radars capable of measuring wind characteristics. They consist of at least 3 pencil-shaped beams, with one beam aimed vertically and the other two beams tilted 15° off zenith and opposite to each other. Some systems may have four tilted beams oriented with 90° of separation. For EMC analyses, the WPR mainbeam gain data is needed for interference between WPR and space systems, and the WPR sidelobe gain data is needed for interference between WPR and terrestrial radio systems.

This sub-section contains the following meteorological radar antenna radiation performance standards from NTIA:

- WPR operating at 449 MHz, and
- MetAids radar operating in the 2.7−2.9 GHz.

It also contains the following meteorological radar antenna characteristics from ITU-R:

- from Rec. ITU-R M.1226, recommended minimum requirements of WPR antennas and antenna characteristics of the representative WPR operating near 50 MHz;[171]
- from Rec. ITU-R M.1227, recommended minimum requirements of WPR antennas and antenna characteristics of the representative WPR operating near 1 GHz;[172]
- from Rec. ITU-R M.1464, antenna characteristics of the representative MetAids radar systems operating in 2.7−2.9 GHz; and
- from Rec. ITU-R M.1638, antenna characteristics of the representative MetAids radar systems operating in 5.25−5.85 GHz.

The ITU-R Recommendations provide characteristics of the representative MetAids radar systems; they are listed in Table 5-65.

Table 5-65. Summary of Representative MetAids Radar Systems

Frequency Band (MHz)	Platform	Antenna Characteristics		Source (Rec. ITU-R)
		Type	G_{max} (dBi)	
40−80	Land station	Phased array	30−34	M.1226
Near 1000	Land station	Phased array	25−32	M.1227-2
2700−2900	Land station	Parabolic reflector	38, 45.7	M.1464
5250−5850	Land station	Parabolic reflector	35−50	M.1638
	Ship		39	
	Aircraft		37.5	

(a) NTIA Manual Chapter 5

NTIA Manual, in Section 5.5, classifies WPR operating at 449 MHz as the Group E radar, and its antenna should meet the Criterion E requirements. Criterion E includes the antenna EIRP mask, and the antenna radiation pattern can be derived from the mask. The antenna EIRP mask and the derived sidelobe suppression data are shown in columns 2, 3, and 4 of Table 5-66.

Table 5-66. NTIA Wind Profile Radar Antenna Sidelobe Suppression Requirement at 449 MHz

Elevation Angle θ	Median EIRP (dBm)	Maximum EIRP (dBm)	Antenna Sidelobe Suppression (dB)
$\theta > 70°$	-	110	-
$60° < \theta \leq 70°$	83	95	15
$45° < \theta \leq 60°$	78	90	20
$5° < \theta \leq 45°$	73	85	25

171 Rec. ITU-R M.1226, *Technical and Operational Characteristics of Wind Profiler Radars in Bands in the Vicinity of 50 MHz* (1997).

172 Rec. ITU-R M.1227-2, *Technical and Operational Characteristics of Wind Profiler Radars in Bands in the Vicinity of 1000 MHz* (2001).

$\theta \leq 5°$	58	70	40

(b) NTIA Manual Chapter 5

NTIA Manual, in Section 5.5, classifies the MetAids radar operating in 2.7−2.9 GHz as the Group D radar, and its antenna should meet the Criterion D requirements. Referring to Table 5-41 in Section 5.8.1, the MetAids radar antenna radiation pattern is as follows:

- Antennas operated in 360°-rotation over the horizontal plane shall have a “median gain” of -10 dBi or less, as measured on an antenna test range, in the principal horizontal plane.
- For other antennas, sidelobe suppression below the mainbeam shall be
    - first three sidelobes: 17 dB, and
    - all other lobes: 26 dB.

(c) Rec. ITU-R M.1226

For WPR systems operating near 50 MHz, the recommended minimum antenna requirements and antenna characteristics of the representative WPR systems in Rec. ITU-R M.1226 are as follows:

- The minimum requirements in antenna sidelobe suppression are
    - $0° < \theta \leq 5°$ above horizon: median 40 dB, minimum 33 dB,
    - $5° < \theta \leq 45°$ above horizon: median 30 dB, minimum 23 dB, and
    - $\theta > 45°$ above horizon: median 23 dB, minimum 13 dB.[173]
- The antenna characteristics of representative WPR are
    - platform: land station,
    - type: phased array,
    - size: 2500−10000 meter^2,
    - G_{max}: 30−34 dBi,
    - ϕ_{bw}: 4−6°, and
    - beam tilt angle: 11−16°.

The 46.5 MHz WPR in Aberystwyth, UK is shown in Figure 5-14.[174]

Figure 5-14. 46.5 MHz Wind Profile Radar in UK

173 Rec. ITU-R M.1226 uses “0−5”, “5−45”, and “> 45” to specify the ranges of elevation angles.

174 http://mst.rl.ac.uk/nerc_mstr_tech_spec.html, accessed Jan. 17, 2012.

(d) Rec. ITU-R M.1227

For WPR systems operating near 1 GHz, the recommended minimum antenna requirements and antenna characteristics of the representative WPR systems in Rec. ITU-R M.1227 are as follows:

- The minimum requirements in antenna sidelobe suppression are
  - $0° < \theta \leq 5°$ above horizon: median 40 dB, minimum 28 dB,
  - $5° < \theta \leq 45°$ above horizon: median 25 dB, minimum 18 dB, and
  - $\theta > 45°$ above horizon: median 20 dB, minimum 13 dB.[175]
- The antenna characteristics of representative WPR are
  - platform: land station,
  - type: phased array,
  - size: 3−15 meter^2,
  - G_{max}: 25−32 dBi,
  - ϕ_{bw}: 4−12°, and
  - beam tilt angle: 12−25°.

The 915 MHz WPR developed by the U.S. Atmospheric Radiation Measurement Program is shown in Figure 5-15.[176]

Figure 5-15. 915 MHz Wind Profile Radar for U.S. Atmospheric Radiation Measurement

(e) Rec. ITU-R M.1464

The antenna characteristics of the representative MetAids radar systems operating in 2.7−2.9 GHz are provided in Rec. ITU-R M.1464; they are shown in Table 5-67.

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175 Rec. ITU-R M.1227 uses "0−5", "5−45", and "> 45" to specify the ranges of elevation angles.

176 http://www.arm.gov/instruments/rwp, accessed Jan. 17, 2012.

Table 5-67. Antenna Characteristics of Representative MetAids Radars in 2.7−2.9 GHz

Characteristics	Parametric Value	
System*	1	2
Platform	Land station	Land station
Type	Parabolic reflector	Parabolic reflector
Radiation Pattern	Pencil beam	Pencil beam
G_{max} (dBi)	38	45.7
ϕ_{bw} (°)	2	0.92
First Sidelobe Level (dBi)	15	20
Polarization	Linear	Linear
*: Refer to Rec. ITU-R M.1464 for more information on these systems.		

(f) Rec. ITU-R M.1638

The antenna characteristics of the representative MetAids radar systems operating in 5.25−5.85 GHz are provided in Rec. ITU-R M.1638; they are shown in Table 5-68.

Table 5-68. Antenna Characteristics of Representative MetAids Radars in 5.25−5.85 GHz

Characteristics	Parametric Value		
System*	1	2	3
Platform	Land station	Land station, ship	Aircraft
Type	Parabolic reflector	Parabolic reflector	Parabolic reflector
Radiation Pattern	Pencil	Conical	Fan
G_{max} (dBi)	35−50	39	37.5
ϕ_{bw} (°)	El: 0.5−12 Az: 0.5−12	El: 4.8 Az: 0.65	El: 4.1 Az: 1.1
Sidelobe Suppression (dB)	20−35	26	20
Polarization	Linear	Linear	Linear
*: Refer to Rec. ITU-R M.1638 for more information on these systems.			

5.11.1.2 Meteorological Remote Sensing Devices

NTIA does not provide the MetAids remote sensing device antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains antenna characteristics of the following typical MetAids remote sensing devices from ITU-R:

- radiosondes,
- dropsondes, and
- rocketsondes.

Antenna characteristics of the land stations communicating with these devices are not available.

The technical and operational characteristics of the representative MetAids remote sensing devices operating in the 403 MHz and 1680 MHz bands are provided in Rec. ITU-R RS.1165-2.[177]

(a) Radiosonde

Radiosonde is a device attached to a weather balloon to measure lower atmospheric conditions; a radiosonde is shown in Figure 5-16.[178] The antenna characteristics of the typical radiosondes in Rec. ITU-R RS.1165-2 are shown in Table 5-69.

Figure 5-16. Radiosonde

Table 5-69. Antenna Characteristics of Typical Radiosondes

<table>
<tr><th>Frequency Band</th><th>Antenna</th><th colspan="2">Characteristics & Parametric Value*</th></tr>
<tr><td rowspan="6">403 MHz</td><td rowspan="2">Transmit</td><td colspan="2">Platform: airborne with balloon</td></tr>
<tr><td colspan="2">$G_{max:}$ 2 dBi</td></tr>
<tr><td rowspan="4">Receive</td><td colspan="2">Platform: land based</td></tr>
<tr><td>System 1</td><td>Type: dipole, ground plane
Pattern: omnidirectional</td></tr>
<tr><td>System 2</td><td>Type: Kathrein
Horizontal gain: 2.15 dB
Vertical gain: -15 dB</td></tr>
<tr><td>System 3</td><td>Type: directional (dipole with array of six corner reflectors)
Horizontal gain: 8 dB</td></tr>
</table>

177 Rec. ITU-R RS.1165-2, *Technical Characteristics and Performance Criteria for Systems in the Meteorological Aids Service in the 403 MHz and 1 680 MHz Bands* (2006).

178 http://www.vaisala.com/en/defense/products/soundingequipment/Pages/RS92.aspx, accessed Jan. 17, 2012.

			Vertical gain: -3 dB
1.68 GHz	Transmit	Platform: airborne with balloon	
		G_{max}: 2 dBi G_{min}: < -10 dBi for analog transmission, -4 dBi for digital transmission	
	Receive	Platform: land based	
		System 1	Type: phased array G_{max}: 16 dBi ϕ_{bw}: Az: 20°, El: 15° Sidelobe suppression: > 20 dB in the direction of specular ground reflection on flat terrain when elevation > 14°
		System 2	Type: conical scan G_{max}: 28 dBi ϕ_{bw}: 8.8° Sidelobe suppression: 15 dB at ± 60° from boresight
		System 3	Type: modified conical scan G_{max}: 26 dBi ϕ_{bw}: 8° Sidelobe suppression: > 20 dB
*: Refer to Rec. ITU-R RS.1165-2 for more information on these systems.			

(b) Dropsonde

Dropsonde is essentially a radiosonde strapped to a parachute to be dropped from an aircraft into a tropical storm to more accurately measure the storm conditions. The antenna characteristics of the typical dropsondes in Rec. ITU-R RS.1165-2, for systems operating in the 403 MHz band, are shown in Table 5-70.

Table 5-70. Antenna Characteristics of Typical Dropsondes

Antenna	Characteristics	Parametric Value
Transmit	Platform	Parachute drop from aircraft
	Type	Vertical monopole
	Gain	2 dBi at horizon, -10 dBi at zenith and nadir
Receive	Platform	Onboard aircraft
	Type	Blade
	Radiation pattern	Omnidirectional

(c) Rocketsonde

Rocketsonde is essentially a dropsonde deployed by a rocket at altitude 250k feet (76.2 km) to measure upper atmospheric conditions; a rocketsonde is shown in Figure 5-17.[179] The

179 http://ams.confex.com/ams/pdfpapers/67306.pdf, accessed Jan. 17, 2012.

antenna characteristics of the typical rocketsondes in Rec. ITU-R RS.1165-2 are shown in Table 5-71.

Figure 5-17. Rocketsonde

Table 5-71. Antenna Characteristics of Typical Rocketsondes

Frequency Band	Antenna	Characteristics	Parametric Value
403 MHz	Transmit	Platform	Parachute drop from rocket
	Receive	Platform	Land based
		Type	Dipole, ground plane
		Radiation pattern	Omnidirectional
1.68 GHz	Transmit	Platform	Rocket launch then parachute drop
	Receive	Platform	Land based
		G_{max}	29 dBi
		ϕ_{bw}	5.4°
		Polarization	RHCP

5.11.1.3 Meteorological Optical Sensor

NTIA does not provide the MetAids lens antenna optical sensor performance standards for the federal systems. Otherwise, this sub-section contains antenna characteristics of the following representative MetAids lens antenna optical sensors from ITU-R:

- laser ceilometer,
- optical precipitation sensor,
- visibility sensor,
- sunshine sensor, and
- luminance sensor.

The technical and operational characteristics of the representative MetAids lens antenna optical sensors operating in 272−750 THz are provided in Rec. ITU-R RS.1744.[180]

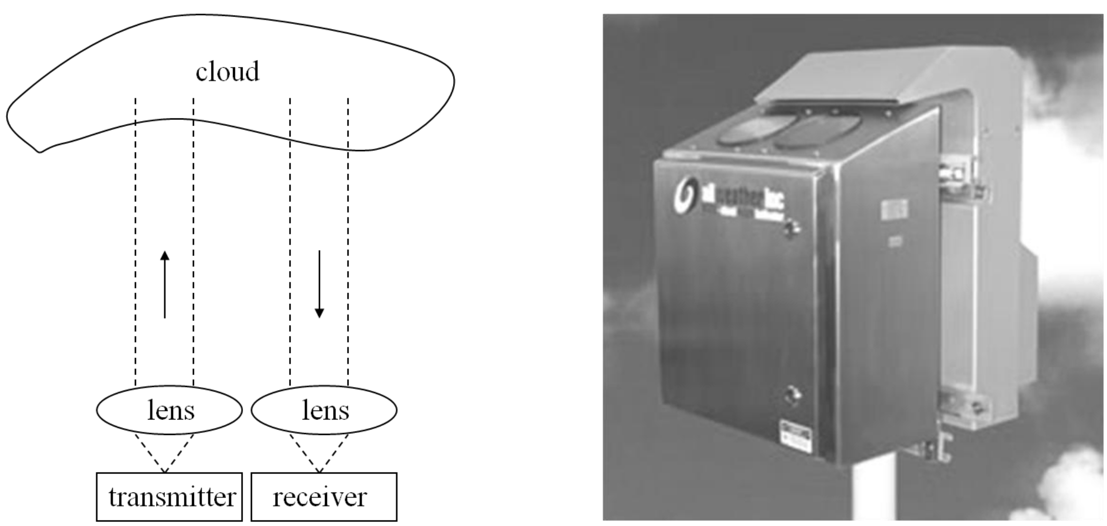
(a) Laser Ceilometer

Laser ceilometer is a light detection and ranging device to measure cloud levels in the atmosphere. Functional diagram and the picture of a ceilometer are shown in Figure 5-18.[181] The cloud height, h, is calculated from

$$P(h) = E\,\frac{c}{2}\,\frac{A}{h^2}\,\beta(h)\,e^{-\tau} \tag{5-14}$$

where

P(h): instantaneous power received from height h, in Watts;
E: effective pulse energy, compensated for optics attenuation, in Joule;
c: speed of light, in meters/second;
A: receiver aperture, in meter^2;
h: origination height of the backscattered return, in meters;
β(h): volume backscatter coefficient at height h, the portion of light that is reflected back towards the ceilometer, in (meter × steradian)$^{-1}$; and
τ: atmospheric transmittance that accounts for the transmitted and backscattered power by extinction at various heights between transceiver and height of backscatter; τ = 1 in a clear atmosphere.



(a) Functional Diagram **(b) Apparatus**

Figure 5-18. Laser Ceilometer

180 Rec. ITU-R RS.1744, *Technical and Operational Characteristics of Ground-Based Meteorological Aids Systems Operating in the Frequency Range 272-750 THz* (2006).

181 http://www.allweatherinc.com/meteorological/8339_ceilometer.html, accessed Jan. 17, 2012.

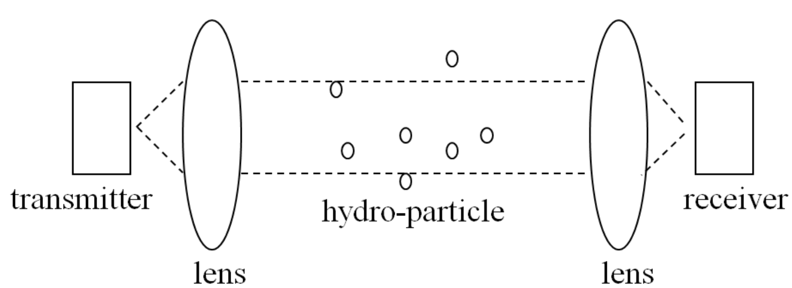
Lens antenna characteristics of representative ceilometers in Rec. ITU-R RS.1744 are shown in Table 5-72.

Table 5-72. Antenna of Representative Ceilometer

Characteristics		Parametric Value	
System*		1	2
Transmit	Optics system focal length	36.7 cm	35−40 cm
	Effective lens diameter	11.8 cm	6−15 cm
	Device of light source	Gallium Arsenide diode	Indium Gallium Arsenide diode
	Wavelength	904 nm	855/905/910 nm at 25°C
Receive	Surface diameter	0.8 mm	0.5 mm
	Reception lens effective diameter	11.8 cm	n/a
	Focal length	15.0 cm	n/a
	Lens transmittance	90% typical	96% typical
	Window transmittance	97% typical, clean	98% typical, clean
	Detector	Silicon avalanche photodiode	Silicon avalanche photodiode
Optical System	Lens distance, transmitter – receiver	30.1 cm	n/a
cm: centimeter, or 10^{-2} meter mm: mini-meter, or 10^{-3} meter nm: nano-meter, or 10^{-9} meter n/a: not available			
*: Refer to Rec. ITU-R RS.1744 for more information on these systems.			

(b) Optical Precipitation Sensor

Optical precipitation sensors are used to assess the occurrence and characteristics of precipitation. The functional diagram and picture of an optical precipitation sensor are shown in Figure 5-19.[182]



(a) Functional Diagram

182 http://www.geneq.com/catalog/en/pwsp.html, accessed Jan. 17, 2012.

(b) Apparatus

Figure 5-19. Optical Precipitation/Visibility Sensor

The lens antenna characteristics of the representative optical precipitation sensors in Rec. ITU-R RS.1744 are shown in Table 5-73.

Table 5-73. Antenna of Representative Optical Precipitation Sensor

Characteristics		**Parametric Value**	
System*		1	2
Transmit	Lens characteristics	175 mm/f3.5	n/a
	Device of light source	Infrared LED	*Diode*
	Wavelength	880 nm	870–920 nm
Receive	Lens characteristics	175 mm/f3.5	n/a
	Die size	2.75 mm^2	n/a
	Detector	PIN photodiode	Silicon photodiode
Optical System	Receiver field of view	100 mrad	100 mrad
	Optical path length	0.5 m	0.3–1.0 m
x mm/fy: focal length/focal ratio. Focal ratio is also termed focal stop or f-stop. mrad: mini-radian, or 10^{-3} radian. n/a: not available.			
*: Refer to Rec. ITU-R RS.1744 for more information on these systems.			

(c) Visibility Sensor

Visibility sensors are used to calculate the visibility level; the apparatus in Figure 5-19 has dual capability as a visibility sensor. The lens antenna characteristics of the representative visibility sensors in Rec. ITU-R RS.1744 are shown in Table 5-74.

Table 5-74. Antenna of Representative Visibility Sensor

Characteristics		Parametric Value	
System*		1	2
Transmit	Device of light source	Xenon flash lamp	Infrared LED
	Wavelength	400–1100 nm	400–1100 nm
Receive	Detector	PIN photodiode	Silicon photodiode
Optical System	Principal viewing direction	Horizontal	20° below horizon
	Receiver field of view	6° above the horizon	9 mrad
*: Refer to Rec. ITU-R RS.1744 for more information on these systems.			

(d) Sunshine Sensor

Sunshine sensors are passive sensor devices for measuring radiation from the sun; the picture of a sunshine sensor is shown in Figure 5-20.[183] The antenna characteristics of the representative sunshine sensor in Rec. ITU-R RS.1744 are as follows:

- sunshield type: pattern over multiple photodiodes,
- detector: photodiode, and
- photosynthetically active radiation (PAR) sensitivity range: 0–2500 μmol/(m^2s).

Figure 5-20. Sunshine Sensor

(e) Luminance Sensor

Luminance sensors are passive sensor devices to measure the background luminance of the atmosphere. The lens antenna characteristics of the representative luminance sensors in Rec. ITU-R RS.1744 are shown in Table 5-75.

183 http://www.dynamax.com/BF3.htm, accessed Jan. 17, 2012.

Table 5-75. Antenna of Representative Luminance Sensor

Characteristics	Parametric Value	
System*	1	2
Receiver field of view	87 mrad	105 mrad
Detector	Silicon photodiode	Silicon photodiode
Luminance Sensitivity Range	n/a	2–40000 cd/m^2
Luminance Measurement Resolution	n/a	1 cd/m^2
cd/m2: candela per square meter [184] n/a: not available		
*: Refer to Rec. ITU-R RS.1744 for more information on these systems.		

5.11.2 Meteorological Satellite Services and Earth Exploration-Satellite

NTIA does not provide the MetSat or EESS satellite antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains the following MetSat and EESS satellite antenna characteristics from ITU-R:

- from Rec. ITU-R SA.1627, telecommunication requirements and technical characteristics;[185] and
- from Rec. ITU-R S.1339-1, antenna reference radiation pattern.[186]

(a) Rec. ITU-R SA.1627

Telecommunication requirements and technical characteristics of MetSat and EESS service systems for data collection and platform location are provided in Rec. ITU-R SA.1627. The satellite can be in GSO or LEO. The satellite antennas are as follows:

- For LEO satellite: low-cost, low-gain antenna. Examples of gain values are
  - o Japanese marine observation satellite receiving antenna for data collection: gain from -6 dBi at the nadir to 2 dBi at the satellite horizon.
  - o Brazilian satellite receiving antenna for data collection: gain from -1 dBi at the nadir to 1 dBi at the satellite horizon.
- For GSO satellite:
  - o Paraboloid antenna, global-beam coverage.
  - o Semi isotropic (full horizon to zenith) antenna, more power required than the paraboloid antenna.
- The polarization is RHCP for both LEO and GSO systems.

(b) Rec. ITU-R S.1339-1

Lacking EESS satellite antenna reference radiation patterns, Rec. ITU-R S.1339-1 adopts the FSS satellite antenna reference radiation pattern in Rec. ITU-R S.672-4 to assess the

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184 One candela equals one lumen per steradian.

185 Rec. ITU-R SA.1627, *Telecommunication Requirements and Characteristics of EESS and Metsat Service Systems for Data Collection and Platform Location* (2003).

186 Rec. ITU-R S.1339-1, *Sharing between Spaceborne Passive Sensors of the Earth Exploration-satellite Service and Inter-satellite Links of Geostationary-satellite Networks in the Range 54.25 to 59.3 GHz* (1999).

interference between EESS spaceborne passive sensors and the ISS links of GSO space systems. The pattern is shown in Table 5-76.

Table 5-76. Recommended Satellite Antenna Reference Radiation Pattern for Assessing Interference between EESS Spaceborne Passive Sensors and ISS Links of GSO Space Systems

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^{\alpha}$	$0.5 < \phi/\phi_{bw} < a$
$G_{max} + L_n + 20 \times \log(z)$	$a \le \phi/\phi_{bw} < 1.58$
$G_{max} + L_n$	$1.58 \le \phi/\phi_{bw} < 3.16$
$x - 25 \times \log(\phi)$	$3.16 \le \phi/\phi_{bw} < y$
L_f	$y \le \phi/\phi_{bw} < 90/\phi_{bw}$
L_b	$90° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
L_n: near sidelobe level relative to G_{max} required by the system design, dB

$\alpha = 2$ for $L_n = -20, -25$
$= N/A$ for $L_n = -30$
$a = 1.29[1 - \log(z)]^{0.5}$ for $L_n = -20$
$= 1.29[1 - 0.8 \times \log(z)]^{0.5}$ for $L_n = -25$
$= N/A$ for $L_n = -30$

z = (major axis)/(minor axis)
$x = G_{max} + L_n + 25 \times \log(3.16 \times \phi_{bw})$, dBi
$y = 3.16 \times 10^{0.04(G_{max}+L_n-L_f)}$
L_f: far sidelobe level, $L_f = 0$ dBi
L_b: back lobe level, $L_b = \max[0, 15 + L_n + 0.25G_{max} + 5 \times \log(z)]$, dBi

5.11.3 Space Research Service

SRS uses large paraboloidal antennas or array antennas for its land-based observation operations, and antennas of sizes fitting to the space craft for its spaceborne operations.

NTIA does not provide the SRS antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains the following SRS antenna characteristics from ITU:

- from Rec. ITU-R SA.509-2, recommended earth station antenna sidelobe reference radiation pattern for EMC analyses in 1−30 GHz;[187]

187 Rec. ITU-R SA.509-2, *Space Research Earth Station and Radio Astronomy Reference Antenna Radiation Pattern for Use in Interference Calculations, Including Coordination Procedures* (1998).

- from Rec. ITU-R SA.1811, large-aperture earth station antenna reference radiation patterns for compatibility analyses in 31.8−32.3 and 37−38 GHz, one for single-entry and one for a large number of distributed interfering sources;[188]
- from Rec. ITU-R SA.1014-2, typical limitations on antenna surface accuracy and gain in the deep-space space-Earth telecommunication link, and antenna characteristics of representative antennas;[189] and
- from Rec. ITU-R SA.1742, technical and operational characteristics and reference radiation pattern of interplanetary and deep-space telescopes around 283 THz.[190]

(a) Rec. ITU-R SA.509-2

For coordination studies and interference assessment in 1−30 GHz, the recommended SRS earth station antenna sidelobe reference radiation pattern in Rec. ITU-R SA.509-2 is shown in Table 5-77.

Table 5-77. Recommended SRS Earth Station Antenna Sidelobe Reference Radiation Pattern for EMC Analyses in 1−30 GHz

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$1° \le \phi < 47.9°$
-10	$47.9° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. This pattern applies to $D/\lambda > 100$.	

(b) Rec. ITU-R SA.1811

For compatibility analyses in 31.8−32.3 and 37−38 GHz, the recommended SRS large-aperture earth station antenna reference radiation pattern in Rec. ITU-R SA.1811 is shown in Table 5-78.

Table 5-78. Recommended SRS Large-Aperture Earth Station Antenna Reference Radiation Pattern for Compatibility Analyses in 31.8−32.3 and 37−38 GHz

(a) For Single Interfering Source

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_1$
$G_{max} - G_1$	$\phi_1 < \phi \le \phi_2$
$G_{max} - G_1 - G_2 \times \log(\phi/\phi_2)$	$\phi_2 < \phi \le \phi_3$
G_3	$\phi_3 < \phi \le 80°$

188 Rec. ITU-R SA.1811, *Reference Antenna Patterns of Large-aperture Space Research Service Earth Stations to be Used for Compatibility Analyses Involving A Large Number of Distributed Interference Entries in the Bands 31.8-32.3 GHz and 37.0-38.0 GHz* (2007).

189 Rec. ITU-R SA.1014-2, *Telecommunication Requirements for Manned and Unmanned Deep-Space Research* (2011).

190 Rec. ITU-R SA.1742, *Technical and Operational Characteristics of Interplanetary and Deep-Space Systems Operating in the Space-to-Earth Direction around 283 THz* (2006).

$G_3 + 5$	$80° < \phi \leq 120°$
G_3	$120° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

ϕ_{bw}: HPBW, $\phi_{bw} = 69\ (\lambda/D)$, deg.

$\phi_1 = \phi_{bw} \times (G_1/12)^{0.5}$

$$\phi_2 = \phi_{bw} \times 10^{(G_1/G_2)} \times \left(\frac{G_2}{144}\right)^{0.5}$$

$$\phi_3 = \phi_2 \times 10^{\left(\frac{G_{max} - G_1 - G_3}{G_2}\right)}$$

$G_{max} = 10 \times \log[e_a\ (\pi D/\lambda)^2] - 4.343(4\pi h/\lambda)^2$, dBi

$G_1 = 17$ dBi

$G_2 = 27 + 10\ [\ \log(e_a) - \log(60h/\lambda)\ ]$, dBi

$G_3 = -10$ dBi.

D: aperture diameter

e_a: antenna efficiency excluding contribution from surface tolerance

h: root-mean-square surface tolerance, $\left(\frac{1}{60}\right) \leq \left(\frac{h}{\lambda}\right) \leq \left(\frac{1}{15}\right)$

(b) For Large Number of Distributed Interfering Sources

Gain Function (dBi)	**Angular Range**
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_4$
$G_{max} - G_4$	$\phi_4 < \phi \leq \phi_5$
$G_{max} - G_4 - G_5 \times \log((\phi/\phi_5)$	$\phi_5 < \phi \leq \phi_6$
G_6	$\phi_6 < \phi \leq 80°$
$G_6 + 5$	$80° < \phi \leq 120°$
G_6	$120° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

ϕ_{bw}: HPBW, $\phi_{bw} = 69\ (\lambda/D)$, deg.

$\phi_4 = \phi_{bw} \times (G_4/12)^{0.5}$

$$\phi_5 = \phi_{bw} \times 10^{[(G_4 - 3)/G_5]} \times \left(\frac{G_5}{144}\right)^{0.5}$$

$$\phi_6 = \phi_5 \times 10^{\left(\frac{G_{max} - G_4 - G_6}{G_5}\right)}$$

$G_{max} = 10 \times \log[e_a\ (\pi D/\lambda)^2] - 4.343(4\pi h/\lambda)^2$, dBi

$G_4 = 20$ dBi

$G_5 = 27 + 10\ [\ \log(e_a) - \log(60h/\lambda)\ ]$, dBi

$G_6 = -13$ dBi

D: aperture diameter

e_a: antenna efficiency excluding contribution from surface tolerance
h: root-mean-square surface tolerance, $\left(\frac{1}{60}\right) \le \left(\frac{h}{\lambda}\right) \le \left(\frac{1}{15}\right)$

(c) Rec. ITU-R SA.1014-2

The typical limitations on the antenna surface accuracy and gain in the deep-space SRS space-Earth telecommunication link are given in Rec. ITU-R SA.1014-2 and shown in Table 5-79, and the antenna characteristics of representative antennas are shown in Table 5-80.

Table 5-79. Typical Limitation on Deep-Space SRS Space-Earth Link Antenna

Antenna	Accuracy of Dish Surface	Pointing Accuracy	Max. G_{max}	Max. G_{max}*
3.7-meter Space Station Antenna	0.24 mm r.m.s.	0.15°	66 dBi at 100 GHz	55 dBi
70-meter Earth Station Antenna	0.53 mm r.m.s.	0.005°	83 dBi at 37 GHz	75 dBi
*: when ϕ_{bw} equals 2 times the pointing accuracy.				

Table 5-80. Characteristics of Representative Deep-Space SRS Space-Earth Link Antenna

Antenna	Link	Frequency (GHz)	G_{max} (dBi)	ϕ_{bw} (°)
70-meter Earth Station Dish Antenna	Earth-to-space	2.1	62	0.14
		7.2	72	0.04
		34.5	84	0.01
	Space-to-Earth	2.3	63	0.13
		8.45	74	0.03
		32	83.6	0.01
3.7-meter Satellite Dish Antenna	Earth-to-space	2.1	36	2.6
		7.2	48	0.64
		34.5	61	0.14
	Space-to-Earth	2.3	37	2.3
		8.45	48	0.64
		32	59.5	0.17

(d) Rec. ITU-R SA.1742

The interplanetary and deep-space systems plan to operate the space-Earth telecommunication links with telescopes around 283 THz. The technical and operational characteristics and reference radiation patterns of these telescopes are provided in Rec. ITU-R SA.1742. The typical parameters of the transmitting and receiving telescopes differ greatly from each other, resulting in different gain pattern for each telescope. The transmitting and receiving gain patterns are also different because the transmitting optics is usually fed by a Gaussian distributed beam while the receiving optics has a planar detector. The approximate envelope of the antenna gain patterns are shown in Table 5-81. It is recommended to use the following models for interference assessment: the diameter of the transmitting antenna should be 30 cm, and the receiving antenna should be 1, 4.2, or 10 meters.

Table 5-81. Antenna Gain Pattern of Planned Interplanetary and Deep-Space Systems Space-Earth Link Operating near 283 THz

(a) Antenna of Unobscured Circular Transmitting Aperture

Gain Function (dBi)	Angular Range
$G_{max} - 0.9 - 4.5 \times 10^{-4}(\phi D/\lambda)^{2.5}$	$0 \le \phi < \phi_{m1}$
G_1	$\phi_{m1} \le \phi < \phi_{r1}$
$G_{max} + 35 - 30 \times \log(\phi D/\lambda)$	$\phi_{r1} \le \phi < \phi_1$
-10	$\phi_1 \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
$\phi_{m1} = 0.75\phi_{r1}$, deg.
$\phi_{r1} = 5.83[180\lambda/(\pi^2 D)]$, deg.
ϕ_1: field of view limited by optical stops, deg.
D: aperture diameter
$G_{max} = 20\times\log(\pi D/\lambda)$, dBi
$G_1 = G_{max} - 25.8$, dBi

(b) Antenna of Obscured Circular Transmitting Aperture

Gain Function (dBi)	Angular Range
$G_{max} - 0.9 + 32 \times \log(1-\gamma^2) - (4 \times 10^{-4} + \gamma/2000)(\phi D/\lambda)^{2.5}$	$0 \le \phi < \phi_{m2}$
G_2	$\phi_{m2} \le \phi < \phi_{r2}$
$G_{max} + 40 + 15\gamma - 30 \times \log(\phi D/\lambda)$	$\phi_{r2} \le \phi < \phi_2$
-10	$\phi_2 \le \phi \le 180°$

$\phi_{m2} = (0.75 - 0.5\gamma)\phi_{r2}$, deg.
$\phi_{r2} = (5.77 - 2.9\gamma^2)[180\lambda/(\pi^2 D)]$, deg.
ϕ_2: field of view limited by optical stops, deg.
$G_2 = G_{max} + 2.17 + 15\gamma - 30 \times \log(5.77 - 2.9\gamma^2)$, dBi
γ: obscuration ratio, γ = (radius of secondary aperture)/(radius of primary aperture)

(c) Antenna of Unobscured Circular Receiving Aperture

Gain Function (dBi)	Angular Range
$G_{max} - 6 \times 10^{-4} \times (\phi D/\lambda)^{2.5}$	$0 \le \phi < \phi_{m3}$
G_3	$\phi_{m3} \le \phi < \phi_{r3}$
$G_{max} + 42 - 30 \times \log(\phi D/\lambda)$	$\phi_{r3} \le \phi < \phi_3$
-10	$\phi_3 \le \phi \le 180°$

$\phi_{m3} = 0.65\phi_{r3}$, deg.
$\phi_{r3} = 5.14[180\lambda/(\pi^2 D)]$, deg.
ϕ_3: field of view limited by optical stops, deg.
$G_3 = G_{max}$ - 17.5, dBi

(d) Antenna of Obscured Circular Receiving Aperture

Gain Function (dBi)	Angular Range
$G_{max} + 20 \times \log(1-\gamma^2) - (6 \times 10^{-4} + \gamma/3000)(\phi D/\lambda)^{2.5}$	$0 \leq \phi < \phi_{m4}$
G_4	$\phi_{m4} \leq \phi < \phi_{r4}$
$G_{max} + 44 + 8\gamma - 30 \times \log(\phi D/\lambda)$	$\phi_{r4} \leq \phi < \phi_4$
-10	$\phi_4 \leq \phi \leq 180°$
$\phi_{m4} = (0.62 - 0.3\gamma)\phi_{r4}$, deg. $\phi_{r4} = 5.14\ [180\lambda/(\pi^2 D)]$, deg. ϕ_4: field of view limited by optical stops, deg. $G_4 = G_{max} - 15.15 + 8\gamma$, dBi	

5.12 Space Applications Service

SA includes space operation service (SOS), Inter-Satellite Service (ISS), Data Relay Service (DRS), etc. These services will be discussed here.

NTIA does not provide the SA antenna radiation performance standards for the federal systems. Otherwise, this sub-section contains SOS and DRS antenna characteristics from ITU-R.

5.12.1 Space Operation Service

The main functions of SOS are maintenance telemetry, telecommand, tracking and radio frequency sensing for attitude control. Operational and technical parameters of SOS are provided in Rec. ITU-R SA.363-5.[191] Antennas with quasi-omnidirectional radiation patterns are mostly used to perform the SOS operations. The average gain of a quasi-omnidirectional antenna is around 0 dBi, and the minimum gain occasionally exceeds -6 dBi.[192] However, satellite structures greatly influence the radiation patterns. For instance for frequencies higher than 8 GHz, the antenna radiation pattern generally is not quasi-omnidirectional, but is restricted to certain aspect angles. When conducting link budget analyses, the antenna gain data should be the guaranteed value within the minimum required coverage area instead of the mainbeam gain value of (G_{max} - 3), dBi. In general, considerations for the antenna design are different in the following frequency ranges:

191 Rec. ITU-R SA.363-5, *Space Operation Systems* (1994).

192 Rec. ITU-R SA.1154, *Provisions to Protect the Space Research (SR), Space Operations (SO) and Earth Exploration Satellite Services (EES) and to Facilitate Sharing with the Mobile Service in the 2 025-2 110 MHz and 2 200-2 290 MHz Bands* (1995).

- f < 1 GHz: Radiation patterns are affected by the satellite structures, which may be an advantage for small satellites (less than 1 meter) and a disadvantage for larger ones.
- 1 ≤ f < 8 GHz: Radiation patterns are mainly defined by the characteristics and arrangement of the antennas.
- 8 ≤ f ≤ 30 GHz: Requirements on the radiation pattern entail stricter constraints on the design and manufacture of the antenna.[193]

5.12.2 Data Relay Service

The GSO DRS system provides telecommunication support between the earth stations and the manned/unmanned LEO satellites conducting space research operations. The antenna characteristics and reference radiation patterns of the U.S. DRS network in Rec. ITU-R SA.1414 are shown in Table 5-82.[194] Rec. ITU-R SA.1414 also provides technical data of three DRS networks from Russia, Europe and Japan.

Table 5-82. Antenna Characteristics of U.S. GSO DRS Network

(a) Satellite Antenna for GSO-Earth Link

Characteristics		Parametric Value
Platform		DRS
Type		Paraboloid
Diameter (meter)		2.2
Transmit	Frequency Range (GHz)	13.4–14.05
	G_{max} (dBi)	46.1
Receive	Frequency Range (GHz)	14.5–15.34
	G_{max} (dBi)	47
Radiation Pattern		Rec. ITU-R S.672
Polarization		Linear

(b) Earth Station Antenna for GSO-Earth Link

Characteristics		Parametric Value
Platform		Earth station
Type		Paraboloid
Diameter (meter)		18.3
Transmit	Frequency Range (GHz)	14.5–15.34
	G_{max} (dBi)	66.4
Receive	Frequency Range (GHz)	13.4–14.05
	G_{max} (dBi)	65.5
Radiation Pattern		RR Appendix 7*
Polarization		Linear
*: "RR Appendix S7" in Rec. ITU-R SA.1414 should be a misprint.		

193 Rec. ITU-R SA.363-5 uses "below 1", "1 to 8", and "8 to 30" to specify the frequency ranges.

194 Rec. ITU-R SA.1414, *Characteristics of Data Relay Satellite Systems* (1999).

(c) GSO Satellite Antenna for GSO-LEO Space Link

Characteristics		Parametric Value			
Platform		DRS			
Type		Phased array	Paraboloid		
Diameter (meter)		n/a	4.9		
Transmit	Frequency Range (GHz)	2–2.1	2.025–2.11	13.4–13.8	22.55–23.55
	G_{max} (dBi)	23	36.6	53.8	58.9
Receive	Frequency Range (GHz)	2.285–2.29	2.2–2.29	14.76–15.34	25.25–27.5
	G_{max} (dBi)	29	36	53.3	58
Radiation Pattern		N/A	Rec. ITU-R S.672		
Polarization		Circular			

(d) LEO Satellite Antenna for GSO-LEO Space Link

Characteristics		Parametric Value			
Platform		LEO satellite			
Type		Omnidirec-tional, arrays	Omnidirec-tional, arrays, paraboloid	Paraboloid	Paraboloid
Diameter (meters)		n/a	Paraboloid: ≤ 1.5	≤ 1.5	≤ 1.3
Transmit	Frequency Range (GHz)	2.285–2.29	2.2–2.29	14.76–15.34	25.25–27.5
	G_{max} (dBi)	≤ 15	≤ 27.3	≤ 43	≤ 47
Receive	Frequency Range (GHz)	2–2.1	2.025–2.11	13.4–13.8	22.55–23.55
	G_{max} (dBi)	≤ 15	≤ 27.3	≤ 44	≤ 47
Radiation Pattern		N/A	Rec. ITU-R S.672		
Polarization		Circular			

5.13 Summary

The rules, regulations, recommendations, and antenna characteristics presented in this section are summarily listed in Table 5-83 below for quick reference.

Table 5-83. Summary of Antenna Data in Section 5

(a) Fixed Service

System	Application	Frequency Bands	Table / Figure	Reference / Comments
P-P	Antenna standards, U.S. federal systems	406.1–420, 932–935, 941–944, 1710–15350 MHz	Table 5-1	NTIA Manual, §5.3.3
P-P	Antenna standard A, U.S. non-federal systems, for general applications	≥ 932.5 MHz	Table 5-2	47 CFR §101.115

P-P	Antenna standard B, U.S. non-federal systems, for operating in areas not subject to congestion	≥ 932.5 MHz	Table 5-2	47 CFR §101.115
P-P	Non-specific antenna standard, U.S. non-federal systems	≥ 932.5 MHz	Table 5-2	47 CFR §101.115
P-P	Cable TV relay system antenna standard, U.S. non-federal systems	12.7–13.25 17.7–19.7 GHz	Table 5-3	47 CFR §78.105
P-P	For coordination studies and interference assessment between FS systems and GSO/NGSO MSS system space-to-earth links	1–3 GHz	Table 5-4	RR Appendix 5, Annex 1
P-P	For deriving coordination area around earth station	100 MHz–105 GHz	Table 5-5	RR Appendix 7, Annex 6
P-P	For coordination studies and single-entry interference assessment between FS systems and between FS systems and space systems	100 MHz–70 GHz	Table 5-6	Rec. ITU-R F.699-7
P-P	For coordination studies and aggregate interference assessments between FS systems and between FS systems and space systems	1–70 GHz	Table 5-7	Rec. ITU-R F.1245
P-P	For statistical interference analysis between FS systems and between FS and space systems	1–70 GHz	Table 5-8	Rec. ITU-R F.1245
P-MP	For coordination studies and interference assessment between FS systems and GSO/NGSO MSS system space-to-Earth links	1–3 GHz	Table 5-9	RR Appendix 5
P-MP	For coordination studies and interference assessment between FS systems and between FS systems and space systems	1–70 GHz	Table 5-10	Rec. ITU-R F.1336-3, omnidirectional antennas
P-MP	For coordination studies and interference assessment between FS systems and between FS systems and space systems	1–70 GHz	Table 5-10	Rec. ITU-R F.1336-3, sectoral antennas
P-MP	For coordination studies and interference assessment between FS systems and between FS systems and space systems	1–3 GHz	Table 5-10	Rec. ITU-R F.1336-3, low-cost low-gain antenna with pencil-shaped beam
HAPS FS	General	General	Table 5-11	Rec. ITU-R F.1500

(b) Fixed-Satellite Service

System	Application	Frequency Bands	Table / Figure	Reference / Comments
GSO	Earth station antenna, U.S. non-federal systems, co-polarization, in GSO plane	General	Table 5-12	47 CFR §25.209
GSO	Earth station antenna, U.S. non-federal systems, co-polarization, not in GSO plane	General	Table 5-12(b)	47 CFR §25.209
GSO	Earth station antenna, U.S. non-federal systems, cross-polarization	General	Table 5-12(c)	47 CFR §25.209
NGSO	Earth station antenna, U.S. non-	General	Table	47 CFR §25.209

	federal systems, co-polarization		5-12(d)	
GSO	Earth station antenna, for establishing downlink *pfd* Limit of NGSO FSS System	3.7–4.2 GHz	Table 5-13	RR Article 22
GSO	Earth station antenna, for coordination studies involving GSO FSS network	General	Table 5-14	RR Appendix 8
GSO	Earth station antenna, as design objective and for coordination studies and interference assessment when allotments are implemented	6/4 and 13/10–11 GHz bands	Table 5-15	RR Appendix 30B, Allotment Plan
General	Earth station antenna, for coordination studies and interference assessment between FSS systems and between FSS systems and other systems	2–30 GHz	Table 5-16	Rec. ITU-R S.465-6
GSO	Earth station antenna, as design objective of new Systems	General	Table 5-17	Rec. ITU-R S.580-6
General	Earth station antenna, for coordination studies and interference assessment involving NGSO FSS systems	10.7–30 GHz	Table 5-18	Rec. ITU-R S.1428-1
General	Earth station antenna, cross-polarization, for coordination studies and interference assessment	2–30 GHz	Table 5-19	Rec. ITU-R S.731-1, used with caution if $D/\lambda < 50$ or if feed system causing high level spillover
General	Recommended FSS VSAT Earth Station Antenna Co- and Cross-Polarization Reference Radiation Patterns	2–30 GHz	Table 5-20	Rec. ITU-R S.728-1
GSO	Satellite antenna, as design objectives and for interference analysis when allotments are implemented	6/4 and 13/10–11 GHz bands	Table 5-21	RR Appendix 30B, Allotment Plan, $e > 0.55$
GSO	Satellite antenna, single-feed circular or elliptical beam, as design objective	General	Table 5-22	Rec. ITU-R S.672-4
GSO	Satellite antenna, multiple-feed circular or elliptical beam, as design objective	General	Table 5-23	Rec. ITU-R S.672-4
NGSO	Satellite antenna, as design objective and for coordination studies and interference assessment	< 30 GHz	Table 5-24	Rec. ITU-R S.1528

(c) Broadcasting Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
audio	AM radio transmitting array antenna, U.S. non-federal systems	AM band	Section 5.4.1.1	47 CFR §73.150 and §73.160, formulas
audio	HF AM radio transmitting antenna, as selection guideline	HF band	Table 5-25	Rec. ITU-R BS.80-3
audio	HF AM radio transmitting array antenna, for performance evaluation and system planning	HF band	Section 5.4.1.1	Rec. ITU-R BS.705-1, formulas
audio	HF AM radio	HF band	Figure 5-3	Rec. ITU-R BS.705-1

	receiving antenna, for performance evaluation and system planning			
audio	FM transmitting antenna for aural broadcast studio-to-transmitter-link or intercity-relay station, U.S. non-federal systems	17.7–19.7 GHz	Table 5-26	47 CFR §74.536
audio	VHF FM radio receiving antenna	30–88 MHz	Figure 5-4	ITU-R BS.599, not for planning of portable or mobile reception
video	TV broadcast auxiliary station, U.S. non-federal systems	1.9–1.97 GHz	Table 5-27	47 CFR Part 74
video	TV receiving antenna, for system planning	TV bands	Figure 5-5	Rec. ITU-R BT.419-3

(d) Broadcasting-Satellite Service

System	Application	Frequency Bands	Table / Figure	Reference / Comments
GSO	Earth station transmitting antenna for Region 2 Allotment Plan, feeder link	17.3–17.8 GHz	Table 5-28	RR Appendix 30A
GSO	Earth station antenna, for determining if coordination is required between GSO satellite networks	BSS bands	Table 5-29	RR Appendix 8
GSO	Earth station receiving antenna for Region 2 Allotment Plan	12.2–12.7 GHz	Table 5-30	RR Appendix 30
General	Earth station receiving antenna	11.7–12.75 GHz	Table 5-31	Rec. ITU-R BO.1213-1, $D/\lambda > 11$
General	Earth station receiving antenna, for interference assessment involving NGSO FSS satellites in BSS Allotment Plan bands	12.2–12.7, 17.3–17.8 GHz	Table 5-32	Rec. ITU-R BO.1443-2
General	Satellite transmitting antenna, Region 2 Allotment Plan	12.2–12.7 GHz	Table 5-33	RR Appendix 30
General	Satellite receiving antenna, Region 2 Allotment Plan	17.3–17.8 GHz	Table 5-34	RR Appendix 30A

(e) Mobile Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
LMS	Radiation performance standard for private radio service, U.S. non-federal systems	LMS band	Section 5.6.1	47 CFR Part 90
LMS	Radiation performance standard for personal radio service, U.S. non-federal systems	LMS band	Section 5.6.1	47 CFR Part 95
LMS HAPS	For interference protection of IMT-2000 stations operating in neighboring countries	LMS band	Table 5-35.	RR Resolution 221
LMS	For assessing interference from LMS systems to RDS systems	5 GHz	Table 5-36	ITU-R M.1652-1
MMS	Radiation performance standard, U.S. non-federal systems	MMS band	Section 5.6.2	47 CFR Part 80
AMS	Airborne transmitting and receiving	117.975–137	Section	RTCA DO-186B

	antenna, radiation performance standard	MHz	5.6.3	
AMS	Airborne transmitting antenna	1.452−1.525, 2.31−2.36 GHz	Section 5.6.3	Rec. ITU-R M.1459
AMS	Land-based receiving antenna for telemetry and telecommand operation	1.452–1.525, 2.31–2.36 GHz	Table 5-37	Rec. ITU-R M.1459

(f) Mobile-Satellite Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
LMSS	Earth station antenna	1–3 GHz	Table 5-38	Rec. ITU-R M.1091
MMSS	Ship antenna, for coordination studies and interference assessment between MSS and terrestrial or space services	1518–1660.5 MHz	Table 5-39	Rec. ITU-R M.694-1, for ship station antenna of 0.8−1.3 meter diameter
MMSS	INMARSAT standard-A shipborne antenna	MMSS band	Table 5-40	Rec. ITU-R M.694-1
AMSS	Airborne antenna, radiation performance standard as design objective and installation guideline	1.6/1.5 GHz band	Section 5.7.3	RTCA DO-210D

(g) Radiodetermination Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
RDS	Grouping of RDS radar and criteria of antenna radiation patterns	Operating bands	Table 5-41	NTIA Manual, § 5.5
RDS	Radar antenna	Operating bands	Table 5-42	Rec. ITU-R M.1851
RDS	For interference assessment from LMS systems to RDS system	5 GHz	Table 5-43	Rec. ITU-R M.1652
RDS	RDS radar for search, tracking, and surveillance, representative characteristics	1.215–1.4 GHz	Table 5-44	Rec. ITU-R M.1463-1
RLS	Land-based radar for space object recognition and tracking, representative characteristics	30–300 MHz	Table 5-46	Rec. ITU-R M. 1802-1
RLS	Land-based radar for detection, identification, and tracking of space objects, shipborne radar for surveillance, airborne radar for air traffic control, representative characteristics	420–450 MHz	Table 5-47	Rec. ITU-R M.1462
RLS	Military radar for air traffic control, naval surveillance, and land-based air defense, representative characteristics	2.7–2.9 GHz	Table 5-48	Rec. ITU-R M.1464-1
RLS	Radar for detecting airborne objects, representative characteristics	2.9–3.1 GHz	Table 5-49	Rec. ITU-R M.1460
RLS	Radar for surface and air surveillance, representative characteristics	3.1–3.7 GHz	Table 5-50	Rec. ITU-R M.1465-1
RLS	Land-based radar for providing position data of space and aeronautical vehicles, shipborne radar for conducting sea and air	5.25–5.85 GHz	Table 5-51	Rec. ITU-R M.1638

	surveillance, airborne radar for conducting land-mapping and imaging, representative characteristics			
RLS	Radar for surface and air surveillance of discrete approaching object, representative characteristics	13.75–14.0 GHz	Table 5-52	Rec. ITU-R M.1644
RLS	Radar for surface and air surveillance of discrete approaching object, representative characteristics	15.4−17.3 GHz	Table 5-53	Rec. ITU-R M.1730-1
RLS	Radar for mapping, target identification, navigation, aim-point determination, and test range instrumentation, representative characteristics	33.4–36.0 GHz	Table 5-54	Rec. ITU-R M.1640
ARNS	Airborne receiving antenna for ILS, minimum performance standard	108–112 MHz	Section 5.8.3	RTCA DO-195
ARNS	Airborne receiving antenna for VHF omnidirectional range equipment, minimum performance standard	108–117.95 MHz	Section 5.8.3	RTCA DO-196
ARNS	Airborne antenna for GPS local area augmentation system, minimum performance standard	108–117.975 MHz	Section 5.8.3	RTCA DO-253A
ARNS	Airborne receiving antenna for ILS glide slope equipment, minimum performance standard	328.6–335.4 MHz	Section 5.8.3	RTCA DO-192
ARNS	Airborne antenna for distance measuring equipment, minimum performance standard	960–1215 MHz	Section 5.8.3	RTCA DO-189
ARNS	Airborne antenna for air traffic control radar beacon system/mode select equipment, minimum performance standard	1.03–1.09 GHz	Section 5.8.3	RTCA DO-181
ARNS	Airborne antenna for traffic alert and collision avoidance system II, minimum performance standard	Transmit: 1.03 GHz, receive: 1.087–1.093 GHz	Section 5.8.3	RTCA DO-185
ARNS	Airborne antenna for active traffic alert and collision avoidance system I, minimum performance standard	Transmit: 1.03 GHz, receive: 1.087–1.093 GHz	Section 5.8.3	RTCA DO-197A
ARNS	Airborne antenna for automatic dependent surveillance system and traffic information service system, minimum performance standard	1.09 GHz	Section 5.8.3	RTCA DO-260A
ARNS	Radar for air traffic control at airport, representative characteristics	2.7–2.9 GHz	Section 5.8.3	Rec. ITU-R M.1464-1
ARNS, MRNS	Radar beacon system, recommended characteristics	2.9–3.1, 9.3–9.5 GHz	Section 5.8.3	Rec. ITU-R M.824-3
ARNS	Radar for airborne weather avoidance, wind shear detection, and safety services, representative characteristics	5.25–5.85 GHz	Section 5.8.3	Rec. ITU-R M.1638
ARNS	Radar for ground mapping, weather avoidance, and calibration of airborne on-board navigation system, representative characteristics	31.8–33.4 GHz	Section 5.8.3	Rec. ITU-R M.1466

(h) Radiodetermination-Satellite Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
RLSS	GSO satellite antenna characteristics	Transmit: 1544.5 MHz, receive: 406.05 MHz	Table 5-56	C/S T.011, Cospas-Sarsat SAR
RLSS	LEO satellite antenna characteristics	Transmit: 1544.5 MHz, receive: 406.05 MHz	Table 5-57, Figure 5-9	C/S T.003, Cospas-Sarsat SAR
RLSS	Sarsat satellite receiving antenna, for coordination against narrow band spurious emissions and out-of-band broadband emissions	Operating band	Table 5-58	Rec. ITU-R M.1478-1
ARNSS	Passive airborne antenna, minimum performance standards	1.597–1.605 GHz	Section 5.9.2 & Table 5-59	RTCA DO-228
ARNSS	Active airborne antenna, minimum performance standards	1575.42 ± 10.23 GHz	Section 5.9.2 & Table 5-59	RTCA DO-301
RNSS	Aeronautical GPS receiver, for coordination studies and interference analysis of aeronautical GPS receiver	Operating band	Section 5.9.2	Rec. ITU-R M.1477

(i) Radio Astronomy Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
RAS	For coordination studies and interference assessment between NGSO space systems and RAS antennas	> 150 MHz	Table 5-61	Rec. ITU-R RA.1631
RAS	Typical G_{max} values	> 150 MHz	Table 5-62	Rec. ITU-R RA.1631
RAS	Earth station antenna, for coordination studies and interference assessment	1−30 GHz	Table 5-63	Rec. ITU-R SA.509-2, sidelobe radiation pattern
RAS	Land-based systems, for coordination studies	10–1000 THz	Table 5-64	Rec. ITU-R RA.1630

(j) Remote Sensing Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
MetAids	Wind profiler radar, EIRP mask and antenna sidelobe suppression	449 MHz	Table 5-66	NTIA Manual §5.5
MetAids	Wind profiler radar, minimum requirements and representative characteristics	40−80 MHz	Section 5.11.1.1	Rec. ITU-R M.1226
MetAids	Wind profiler radar, minimum requirements and representative characteristics	Near 1 GHz	Section 5.11.1.1	Rec. ITU-R M.1227
MetAids	Radar, representative characteristics	2.7−2.9 GHz	Table 5-67	Rec. ITU-R M.1464
MetAids	Radar, representative characteristics	5.25−5.85 GHz	Table 5-68	Rec. ITU-R M.1638
MetAids	Radiosonde, representative characteristics	403, 1680 MHz	Table 5-69	Rec. ITU-R M.1165-2

MetAids	Dropsonde, representative characteristics	403 MHz	Table 5-70	Rec. ITU-R M.1165-2
MetAids	Rocketsonde, representative characteristics	Operating band	Table 5-71	Rec. ITU-R M.1165-2
MetAids	Laser ceilometer, representative characteristics	272−750 THz	Table 5-72	Rec. ITU-R RS.1744
MetAids	Optical precipitation sensor, representative characteristics	272−750 THz	Table 5-73	Rec. ITU-R RS.1744
MetAids	Visibility sensor, representative characteristics	272−750 THz	Table 5-74	Rec. ITU-R RS.1744
MetAids	Luminance sensor, representative characteristics	272−750 THz	Table 5-75	Rec. ITU-R RS.1744
EESS	Satellite antenna, for assessing interference between EESS spaceborne passive sensors and ISS links of GSO space systems	Operating band	Table 5-76	Rec. ITU-R S.1339-1
SRS	Land-based earth station antenna, for coordination studies and interference assessment	1−30 GHz	Table 5-77	Rec. ITU-R SA.509-2, sidelobe pattern
SRS	Land-based large-aperture earth station antenna, for compatibility analyses	31.8−32.3, 37−38 GHz	Table 5-78 (a)	Rec. ITU-R SA.1811
SRS	Land-based large-aperture earth station antenna, for compatibility analyses of large number of distributed interfering sources	31.8−32.3, 37−38 GHz	Table 5-78 (b)	Rec. ITU-R SA.1811
SRS	Deep space telecommunication link, typical limitation on surface accuracy and gain	Near 2, 8, 30 GHz	Table 5-79	Rec. ITU-R SA.1014-2
SRS	Deep space telecommunication link, representative characteristics	Near 2, 8, 30 GHz	Table 5-80	Rec. ITU-R SA.1014-2
SRS	Deep space space-Earth link, representative characteristics	283 THz	Table 5-81	Rec. ITU-R SA.1742

(k) Space Application Service

Service	Application	Frequency Bands	Table / Figure	Reference / Comments
DRS	Representative characteristics	Near 2, 15, 26 GHz	Table 5-82	Rec. ITU-R SA.1414

SECTION 6. RECOMMENDATIONS

6.1 Introduction

NTIA conducts the following EMC analysis tasks: system review for equipment approval, frequency assignment, and spectrum sharing analyses for the federal radio systems.

System review is the system certification process. Its EMC analyses require antenna radiation masks to approve antennas for installation.

Frequency assignment is the process of assessing radio interference between new radio systems and existing radio systems in order to determine the feasibility of providing frequency assignments to the new systems. Its EMC analyses require the antenna actual radiation patterns. However, antenna reference radiation patterns, which are developed from the actual radiation patterns and are agreed-upon by regulators and engineers, are usually used because the actual radiation patterns are usually not readily available.

Spectrum sharing analysis examines if a new radio system or a new radio service, whether federal or non-federal, may co-exist with the existing federal systems. Its EMC analyses require representative antenna radiation patterns that “represent” the federal radio operations in certain frequency bands.

6.1.1 Objective

NTIA provides authoritative antenna parameters in the NTIA Manual for itself and the federal agencies to conduct the EMC analysis tasks. However, NTIA only provides some antenna parameters for some radio services to conduct some of these tasks. As seen in Section 5, antenna parameters of many radio services are not available in the NTIA Manual. NTIA had on occasion used ad hoc antenna radiation patterns when the authoritative antenna parameters were not available, and the results had become contentious.

In order to provide the complete information, NTIA developed recommendations of antenna parameters for all of the radio services and all of the EMC analysis tasks for itself and the federal agencies. This information is presented in this section.

6.1.2 Methodology

The antenna parameters recommended for the EMC analysis tasks will be developed from the antenna parameters in Sections 4 and 5. The antenna parameters in Sections 4 and 5 are either widely used by NTIA and the federal agencies, or are from NTIA, FCC, ITU, and other authoritative institutions like ICAO. These parameters are for certain specific spectrum management tasks under certain conditions; for instance, the FS P-P system antenna radiation performance standards in Table 5-1 are for NTIA to conduct the system review task; or, the FSS earth station antenna radiation performance standards in Table 5-12 are for the non-federal FSS system operators to conduct EMC analyses in frequency assignment and spectrum sharing analyses.

For the system review task, antenna radiation masks will be adopted or developed. For the frequency assignment task, antenna reference radiation patterns will be adopted or developed.

The hierarchy of adoption is as follows: NTIA, FCC, RR, authoritative institutions, ITU-R recommendations, and other sources. When the radiation mask or pattern for a radio service is not available, it will be adopted or developed from other radio services with similar antenna usage.

The above hierarchy of adoption does not follow the instruction in the NTIA Manual which states that "[i]f spectrum standards are not specified in this chapter, the appropriate provisions of the ITU Radio Regulations normally shall apply. If spectrum standards are not specified in this chapter or in the ITU Radio Regulations, the appropriate criteria contained in current Recommendations of the ITU-R shall be used as guidelines."[195] However, any standard issued from the FCC becomes the industry standard in the U.S., and the equipment would be available commercially off the shelf (COTS). Therefore, it is more practical to select the FCC standards over the ITU standards or recommendations.

For the spectrum sharing analyses task, representative antenna radiation patterns for the federal frequency bands or non-federal frequency bands with significant federal presence will be developed. The radiation pattern for developing the representative radiation pattern is the reference radiation pattern for the frequency assignment task. The procedure to develop a representative antenna radiation pattern is as follows:

(1) For a radio service, obtain the list of frequency bands where federal agencies operate their radio systems. These bands are mostly in the federal bands, and they also can be in non-federal bands that federal agencies lease capacities from the commercial operators; this information is available in the Government Master File (GMF).[196]
(2) Retrieve frequency assignment records in a specific frequency band from the GMF.
(3) Develop the antenna G_{max} population profile, i.e., the distribution of the number of frequency assignments vs. G_{max} and its cumulative curve.
(4) Select the representative G_{max} value where the cumulative curve is closest to 75%, i.e., approximately 75% of the G_{max} population is less than or equal to the representative value. In the case when two G_{max} data have equal (or almost equal) spacing to the 75% threshold, the larger one is chosen such that more federal systems can be protected from interference.
(5) Develop the representative radiation pattern from the reference radiation pattern for the frequency assignment task and the representative G_{max} value.

In the following sub-sections, antenna parameters for the spectrum management tasks of system review, frequency assignment, and spectrum sharing analyses are developed for FS, FSS, MS, MSS, RDS, RDSS, RAS, RSS, and SA. Parameters for BS and BSS will not be developed because NTIA and the federal agencies do not conduct EMC analysis tasks for these radio services.

6.2 Fixed Service

Because most of the domestic antenna manufacturers use the unit "foot" to specify the FS antenna size, in this sub-section the main unit for specifying the antenna size will be in feet.

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195 *NTIA Manual*, Chapter 5.1.1.

196 GMF March 2009 CD ROM release.

6.2.1 System Review

NTIA provides P-P antenna gain suppression masks for system review; these were presented in Section 5.2.1. These masks are for the standard antennas. Some federal agencies are installing high performance and ultra-high performance antennas with lower sidelobes to reduce interference; this will be briefly discussed, but no recommendations will be developed.

6.2.1.1 Standard Antenna

6.2.1.1.1 Masks

The standard antenna gain suppression masks and their corresponding maximum HPBW data are shown in Table 6-1(a). These masks were developed from measurement data from antenna manufacturers. From the HPBW data, and assuming *e* = 0.55, the minimum G_{max} values and the minimum antenna sizes can be derived; this is presented in Table 6-1(b). The G_{max} data and antenna sizes are the nominal minimum values, and the masks are applicable to antennas of larger G_{max} values and antenna sizes.

Table 6-1. NTIA FS P-P System Antenna Gain Suppression Mask for System Review

(a) Mask

#	Frequency Band (MHz)	Max. ϕ_{bw} (º)	Min. Radiation Suppression to G_{max} (dB) Angle Off Mainbeam Axis (º)						
			5−10	10−15	15−20	20−30	30−100	100−140	140−180
1	406.1−420 [1]	80	n/a	n/a	n/a	n/a	10	10	10
2	(a) 932.5−935, 941.5−944 [2]	14	n/a	6	11	14	17	20	24
3	(b) 932.5−935, 941.5−944 [2]	20	n/a	n/a	6	10	13	15	20
4	(c) 1710−1850 [3]	10	n/a	14	16	18	23	24	30
5	(d) 1710−1850 [4]	8	5	18	20	20	25	28	36
6	2200−2400	8.5	4	12	16	16	24	25	30
7	4400−4990	4	13	20	23	24	29	31	31
8	7125−8500	2.5	19	23	28	30	34	35	43
9	14400−15350	1.5	21	26	31	35	37	41	48
10	21800–22075, 23000–23275	3.3	18	26	26	33	33	55	55

- These standards are not applicable to transportable antennas in tactical and training operations.
- n/a: not available.

1 Any secondary lobe.
2 Stations in this service must employ an antenna that meets the performance standard (a). Standard (b) may be employed in areas not subject to frequency congestion or subject to frequency coordination along the borders of the U.S. Note, however, the use of a high performance antenna may be required where interference problems can be resolved by the use of such antennas.
3 Standard (c) could be met, e.g., by a 1.2-meter (4-foot) diameter parabolic antenna.
4 Standard (d) is applicable to new stations in 1710–1850 MHz placed in service after January 1, 1985, except for those located on the military test ranges. These suppression levels could be met, e.g., by a 1.83-meter (6-foot) diameter parabolic antenna.

(b) Antenna Size

#	Frequency Range (MHz)	Max. HPBW (°)	Nominal G_{max} (dBi) *	Nominal Diameter (feet) *
1	406.1−420	80	6.2	2.1
2	(a) 932.5−935, 941.5−944	14	21.3	5.3
3	(b) 932.5−935, 941.5−944	20	18.2	3.7
4	(c) 1710−1850	10	24.2	4.0
5	(d) 1710−1850	8	26.2	5.0
6	2200−2400	8.5	25.7	3.7
7	4400−4990	4	32.2	3.9
8	7125−8500	2.5	36.3	3.9
9	14400−15350	1.5	40.7	3.2
10	21800–22075, 23000–23275	3.3	33.9	1.0
*: Values of G_{max} and antenna sizes are derived with Eqs. (4-5) and (4-6), the given HPBW data, frequency value at the lower edge of the band, and *e* = 0.55.				

Compared with the latest measurement data, some of the suppression masks have become outdated as antenna technologies have improved. Therefore, these masks are examined here by comparing them with the latest measurement data.

6.2.1.1.2 Evaluation

It is known that G_{max} and sidelobe level change at different rates. This can be seen in the Statgain and Rec. ITU-R F.699-7 formulas shown in Table 6-2. As G_{max} changes, the sidelobe level either remains the same for $D/\lambda > 100$, or changes half the magnitude of G_{max} (in dB) for $D/\lambda \leq 100$. This principle is used to evaluate the accuracy of the masks.

Table 6-2. Correlation of FS Antenna G_{max} and Reference Radiation Pattern Sidelobe Level

Range of G_{max} or D/λ	Statgain Formula		Rec. ITU-R F.699-7 Formula	
	Near Sidelobe (dBi)	Far Sidelobe (dBi)	Near Sidelobe (dBi)	Far Sidelobe (dBi)
G_{max} > 48 dBi or $D/\lambda > 100$	$29 - 25\times\log(\phi)$	-13	$32 - 25\times\log(\phi)$	-10
G_{max} < 48 dBi or $D/\lambda \leq 100$	$53 - (G_{max}/2) - 25\times\log(\phi)$	$11 - G_{max}/2$	$52 - 10\times\log(D/\lambda) - 25\times\log(\phi)$	$10 - 10\times\log(D/\lambda)$*
*: $G_{max} = k + 20\times\log(D/\lambda)$, where k is a constant. Therefore, $10\times\log(D/\lambda) = G_{max}/2$.				

First, the suppression masks are plotted in Figure 6-1 for visual examination. Since the sidelobe level is inversely correlated to the G_{max} value, the plateaus of the masks should also be inversely correlated to the G_{max} values. Moreover, the correlation should be consistent from one angular range to another. However, it can be seen in Figure 6-1 that there are cases where this correlation does not hold, e.g., referring to the mask numbers in Table 6-1(a),

(1) masks 4 and 5, in 1.71−1.85 GHz, are high in 30−100°;
(2) mask 6, in 2.2−2.4 GHz, is high in 20−30°;
(3) mask 7, in 4.4−4.99 GHz, is high in 140−180°; and
(4) mask 10, in 21.8−22.075 & 23−23.275 GHz, is high in 5−100°.

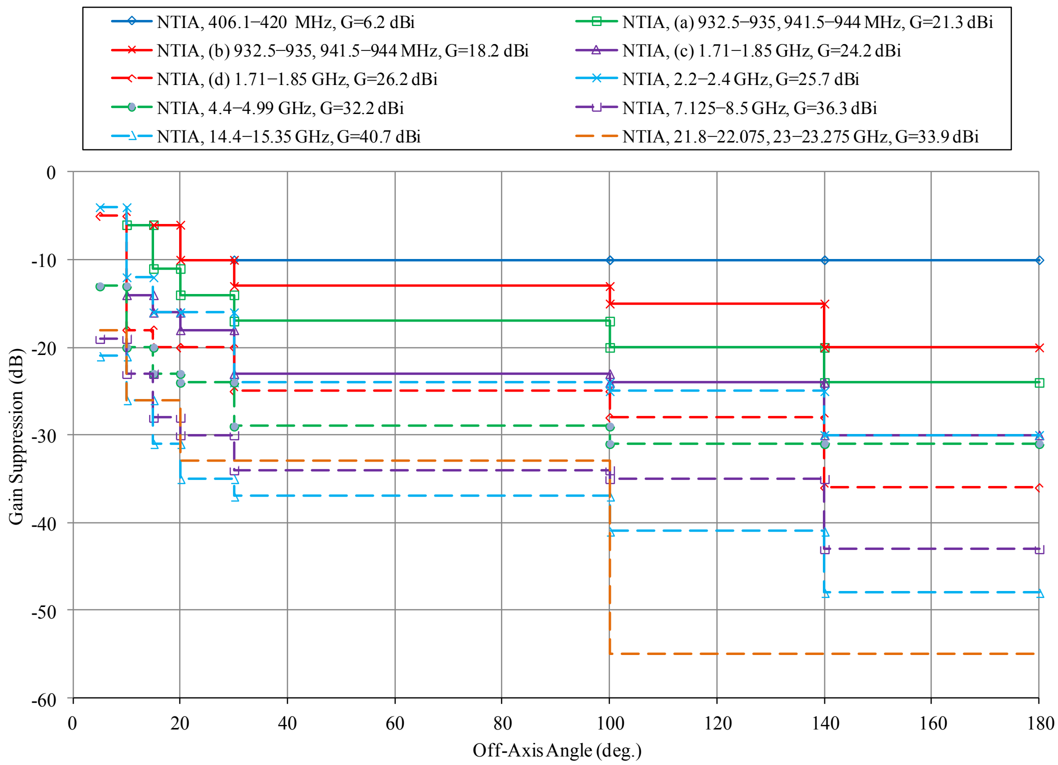


Figure 6-1. NTIA FS Antenna Gain Suppression Mask

Next, the first three cases are examined by comparing the masks with the measurement data from antenna manufacturers Commscope (Andrew Communications Systems), General Dynamics (Gabriel), and Radio Waves.[197] [198] [199] When feasible, new values for the masks will be recommended in order for the masks to have better match with measurement data. The fourth case, of mask 10, is not examined here because the small size of the antenna makes the comparison invalid.

197 http://www.commscope.com/andrew/eng/product/antennas/ter_microwave/index.html, accessed Jan. 17, 2012. The antenna manufacturer Andrew Communications Systems was acquired by Commscope.

198 http://www.gdsatcom.com/antennas.php, accessed Jan. 17, 2012. The antenna manufacturer Gabriel was acquired by General Dynamics.

199 http://www.radiowavesinc.com/cgi-bin/index.cgi/Products/, accessed Jan. 17, 2012.

(1) For masks 4 and 5 in 1.71−1.85 GHz, a comparison of the measurement data from Andrew versus the NTIA masks is shown in Figure 6-2. It appears that mask 4 can be lowered by 2 dB in 30−100° and lowered by 3 dB in 100−140°. It also appears that mask 5 can be lowered by 3 dB in 15−20°, lowered by 3 dB in 20−30°, lowered by 3 dB in 30−100°, and lowered by 2 dB in 100−140°.

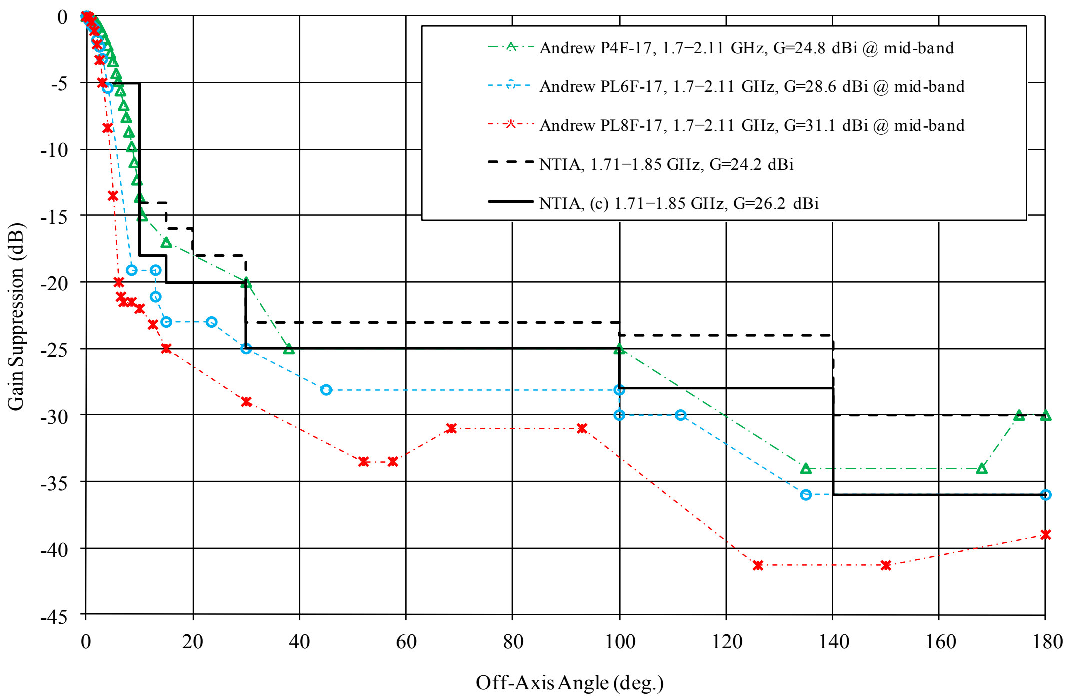
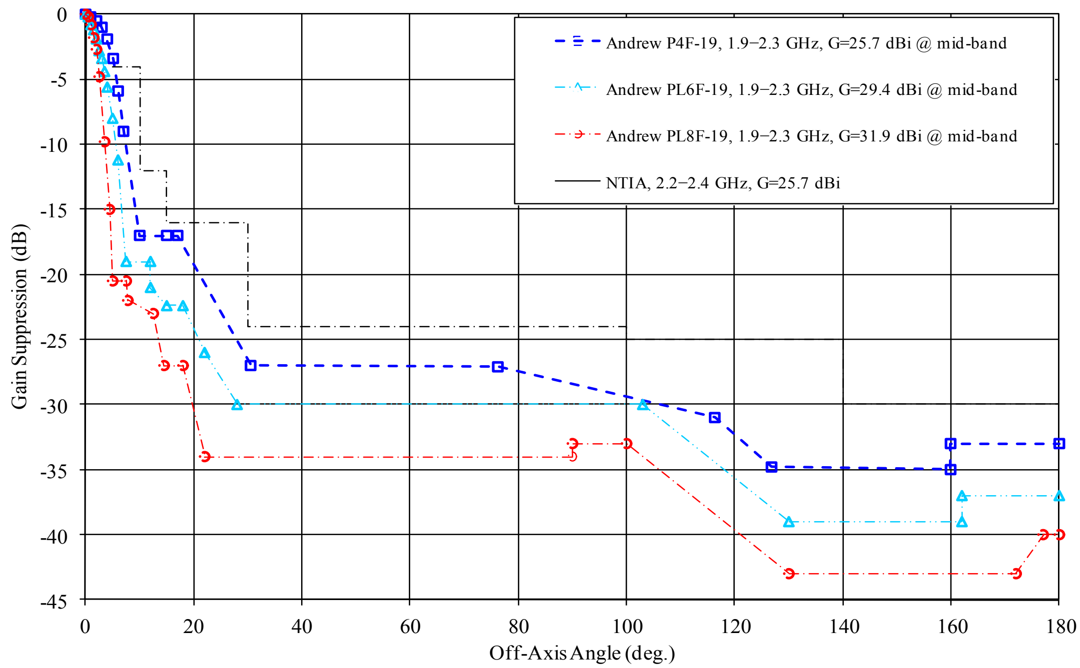
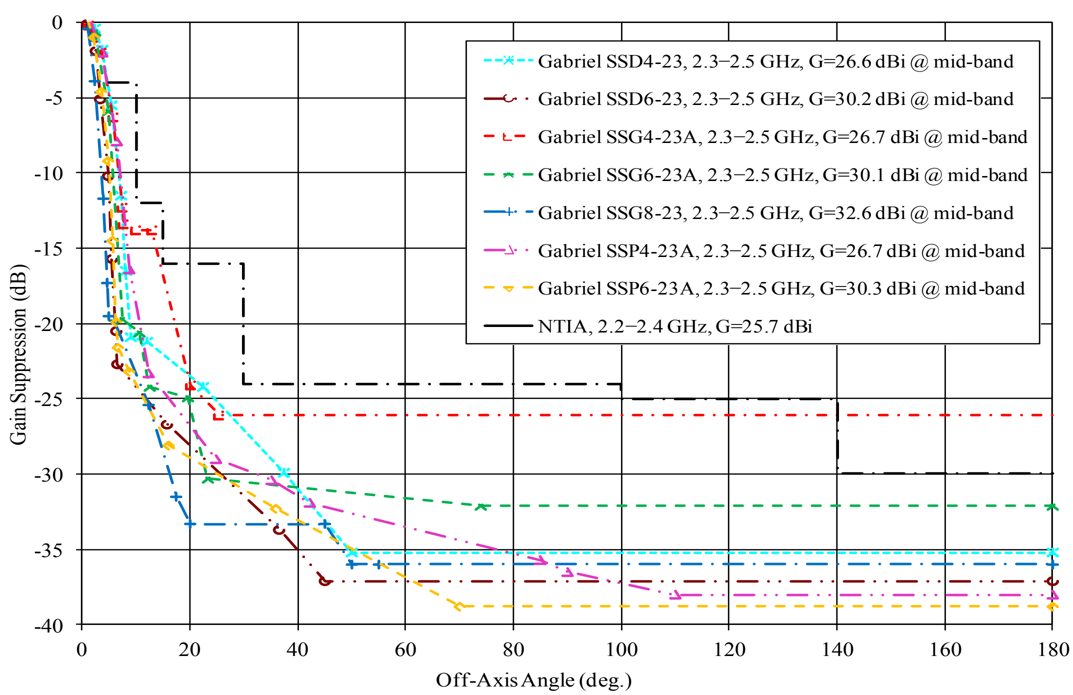


Figure 6-2. FS Antenna Measured Patterns versus NTIA Mask in 1.71-1.85 GHz

(2) For mask 6 in 2.2−2.4 GHz, a comparison of the measurement data from Andrew, Gabriel, and Radio Waves versus the NTIA mask is shown in Figure 6-3. It appears that the mask can be lowered by about 5 dB in 10−15°, lowered by about 1 dB in 15−20°, lowered by about 4 dB in 20−30°, lowered by about 3 dB in 30−100°, lowered by about 4 dB in 100−140°, and lowered by about 3 dB in 140−180°.

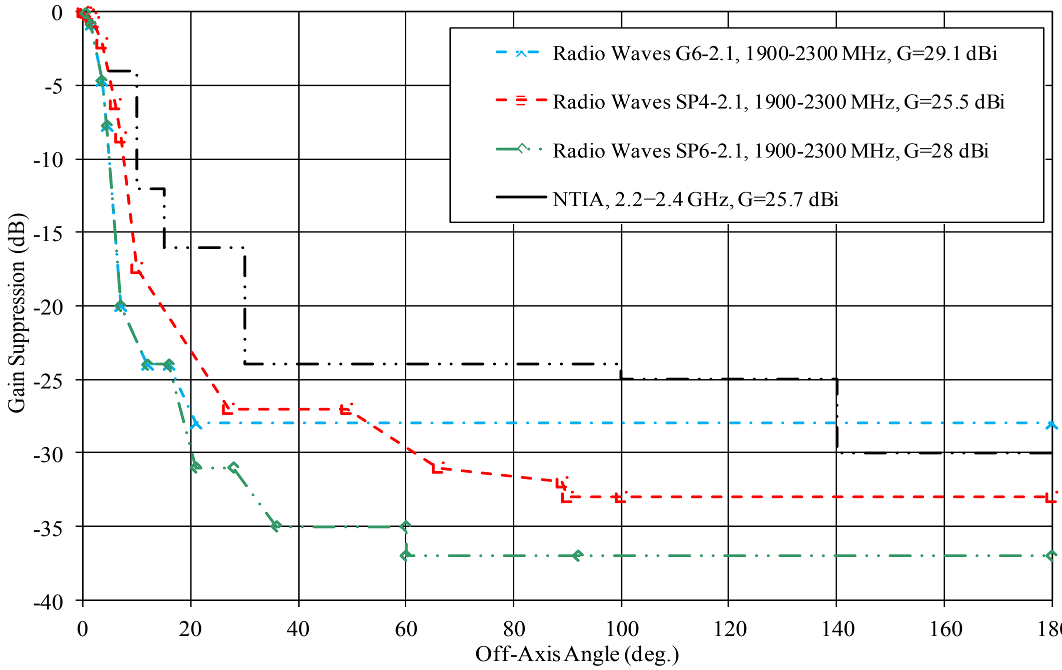


(a) Measured Patterns from Andrew



(b) Measured Patterns from Gabriel

(Figure 6-3)



(c) Measured Patterns from Radio Waves

Figure 6-3. FS Antenna Measured Patterns versus NTIA Mask in 2.2-2.4 GHz

(3) For mask 7 in 4.4−4.99 GHz, a comparison of the measurement data from Andrew and Radio Waves versus the NTIA mask is shown in Figure 6-4. It appears that the mask can be lowered by about 9 dB in 140−180° and lowered by about 2 dB in 20−30°.

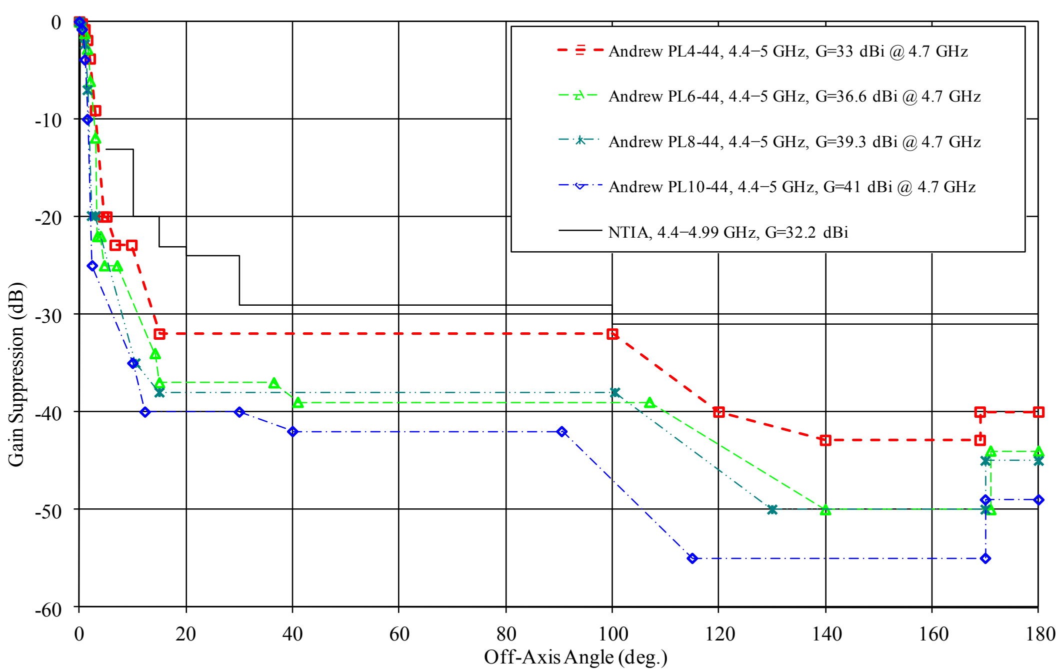
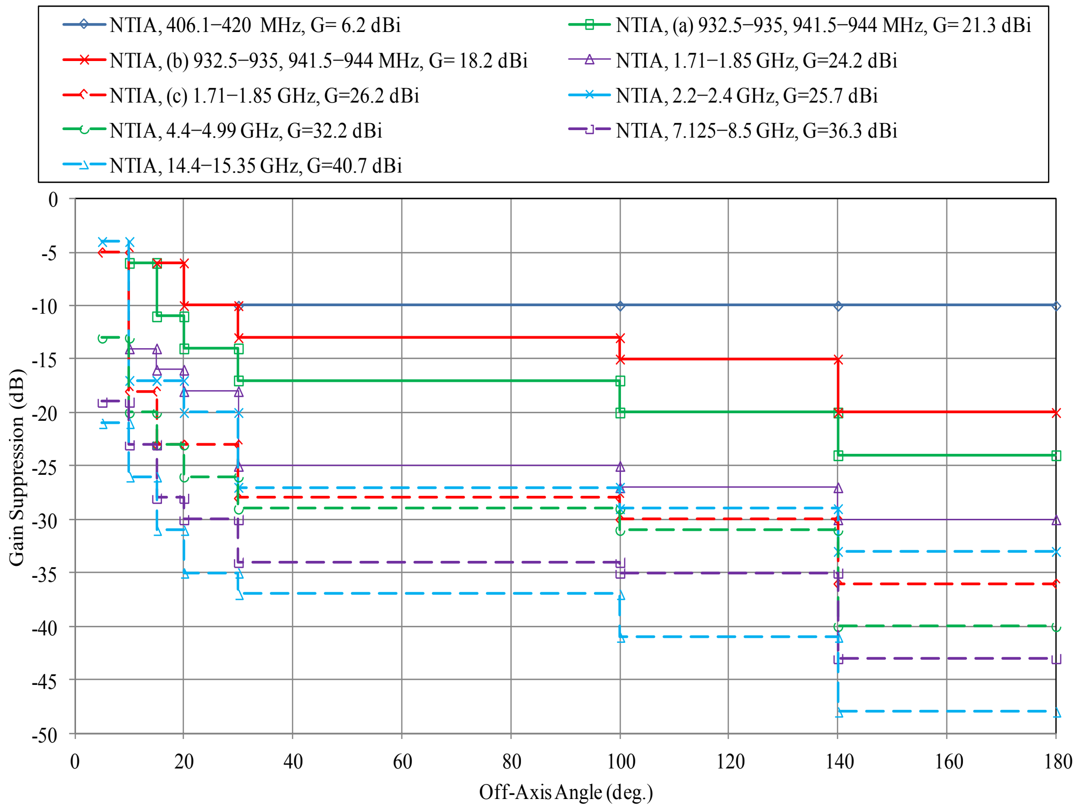


Figure 6-4. FS Antenna Measured Patterns versus NTIA Mask in 4.4-4.99 GHz

6.2.1.1.3 Recommendation

With the above evaluation, NTIA recommends that the current FS antenna radiation suppression suppression masks of Table 6-1(a) be modified to become Table 6-3; the recommended modifications are highlighted with shaded cells and bold font, and the outdated data are shown with strikethrough. The graphic representation of the proposed new masks, minus mask 10, is



shown in Figure 6-5. These recommended changes improve the correlation between G_{max} and the antenna sidelobe levels.

Table 6-3. Proposed Modification of the NTIA FS Antenna Suppression Mask

Frequency Band (MHz)	Max. ϕ_{bw} (°)	Min. Radiation Suppression to G_{max} (dB) Angle Off Mainbeam Axis (°)						
		5–10	10–15	15–20	20–30	30–100	100–140	140–180
406.1–420 [1]	80	n/a	n/a	n/a	n/a	10	10	10
(a) 932.5–935, 941.5–944 [2]	14	n/a	6	11	14	17	20	24
(b) 932.5–935, 941.5–944 [2]	20	n/a	n/a	6	10	13	15	20
(c) 1710–1850 [3]	10	n/a	14	16	18	~~23~~ **25**	~~24~~ **27**	30
(d) 1710–1850 [4]	8	5	18	~~20~~ **23**	~~20~~ **23**	~~25~~ **28**	~~28~~ **30**	36
2200–2400	8.5	4	~~12~~ **17**	~~16~~ **17**	~~16~~ **20**	~~24~~ **27**	~~25~~ **29**	~~30~~ **33**
4400–4990	4	13	20	23	~~24~~ **26**	29	31	~~31~~ **40**
7125–8500	2.5	19	23	28	30	34	35	43

14400–15350	1.5	21	26	31	35	37	41	48
21800–22075, 23000–23275	3.3	18	26	26	33	33	55	55

- These standards are not applicable to transportable antennas in tactical and training operations.
- n/a: not available.

1 Any secondary lobe.
2 Stations in this service must employ an antenna that meets the performance standard (a). Standard (b) may be employed in areas not subject to frequency congestion or subject to frequency coordination along the borders of the U.S. Note, however, the use of a high performance antenna may be required where interference problems can be resolved by the use of such antennas.
3 Standard (c) could be met, e.g., by a 1.2-meter (4-foot) diameter parabolic antenna.
4 Standard (d) is applicable to new stations in 1710–1850 MHz placed in service after January 1, 1985, except for those located on the military test ranges. These suppression levels could be met, e.g., by a 1.83-meter (6-foot) diameter parabolic antenna.

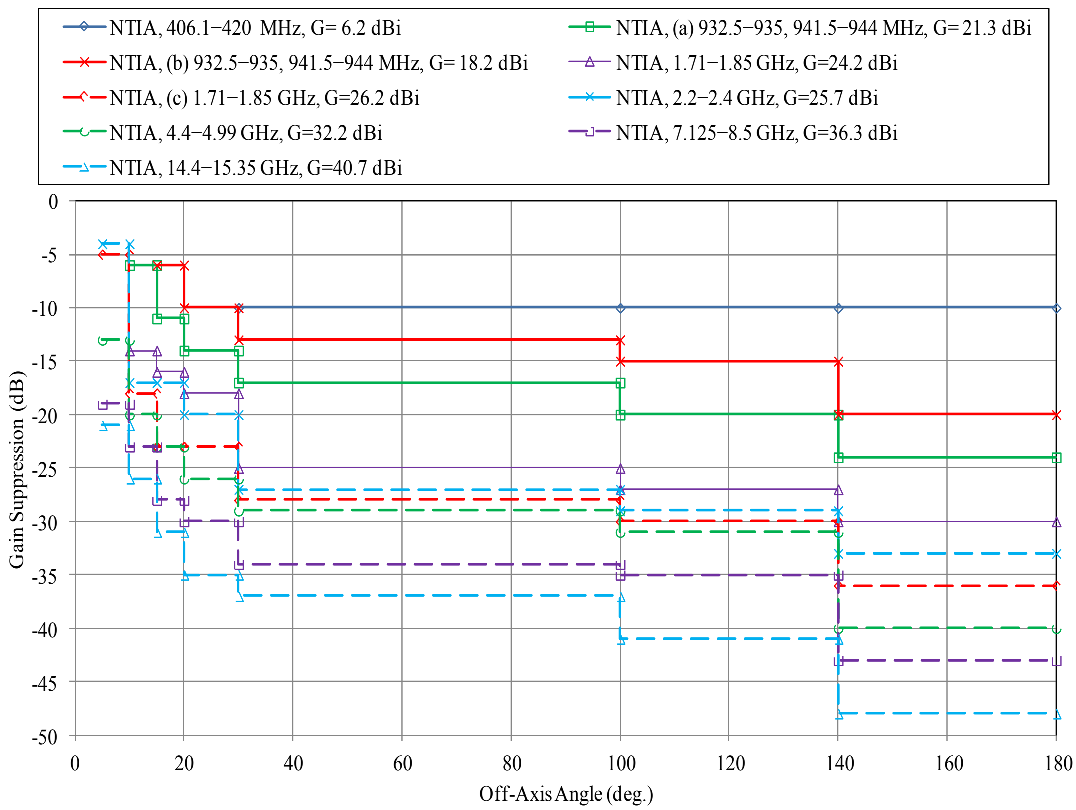
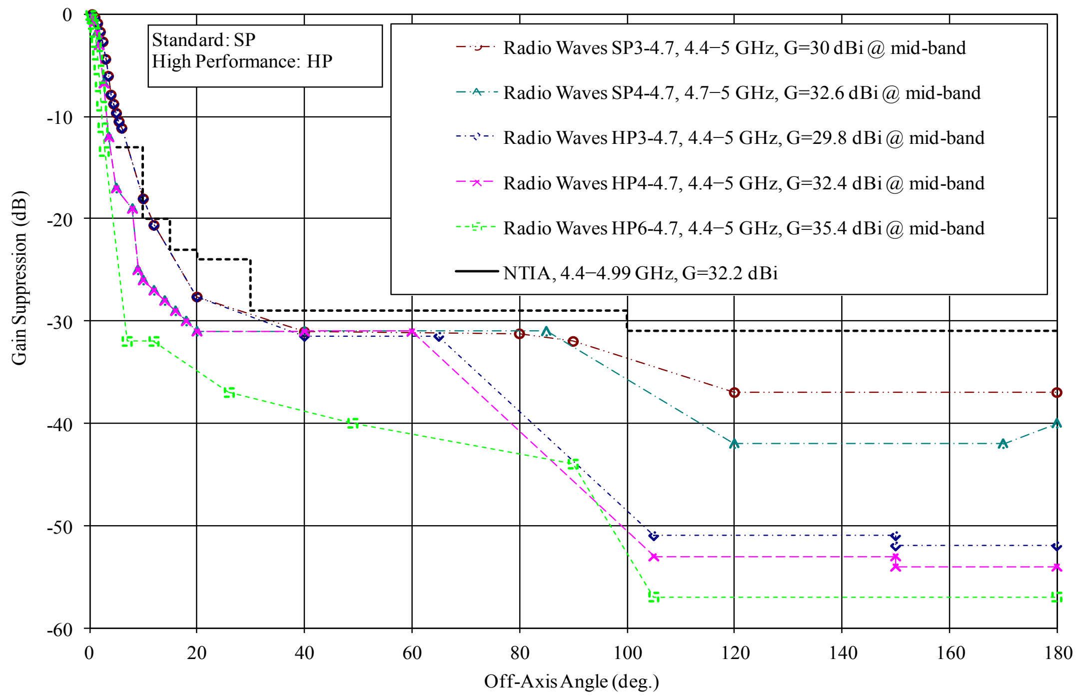


Figure 6-5. Graphic Representation of the Proposed Modification of the NTIA Suppression Masks

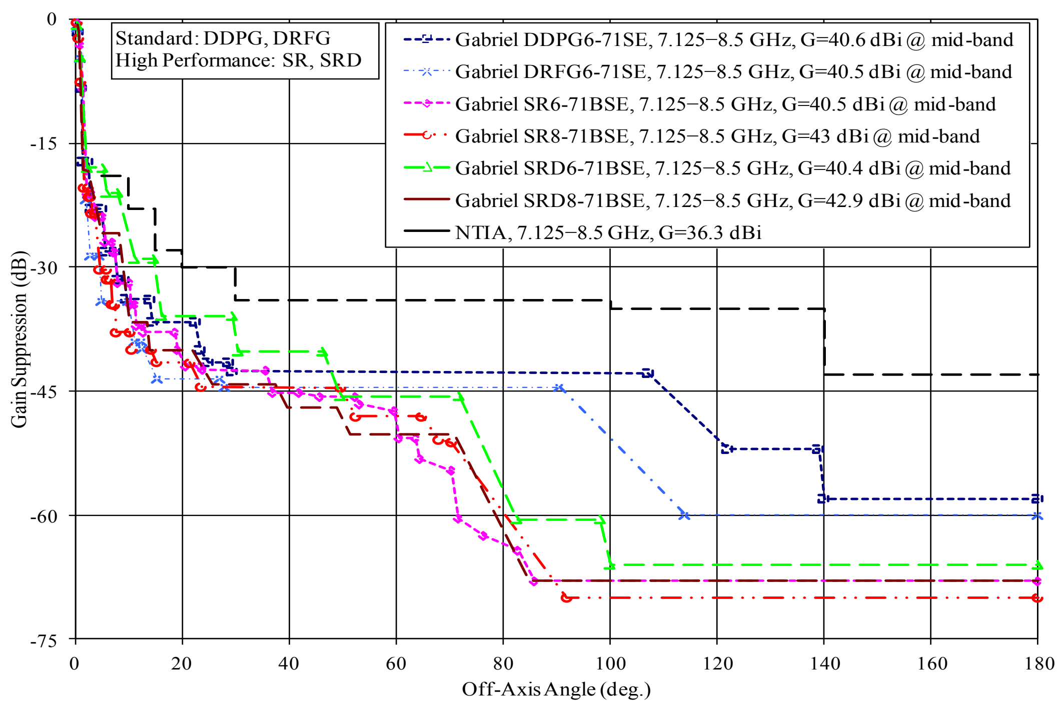
6.2.1.2 High Performance Antenna

As discussed in Section 3.7, dish antenna sidelobe radiation level can be reduced with better feeders and/or with modified reflector edge. Antennas with such improvement are called high-performance antennas.

Many manufacturers have developed high and ultra-high performance antennas, and they have become popular to some federal agencies. For comparison, the measurement data of the standard and high performance antennas from three manufacturers are shown in Figure 6-6; the numbers preceding the model names are the antenna diameters in feet. Also shown in Figure 6-6 are the standard antenna suppression masks.

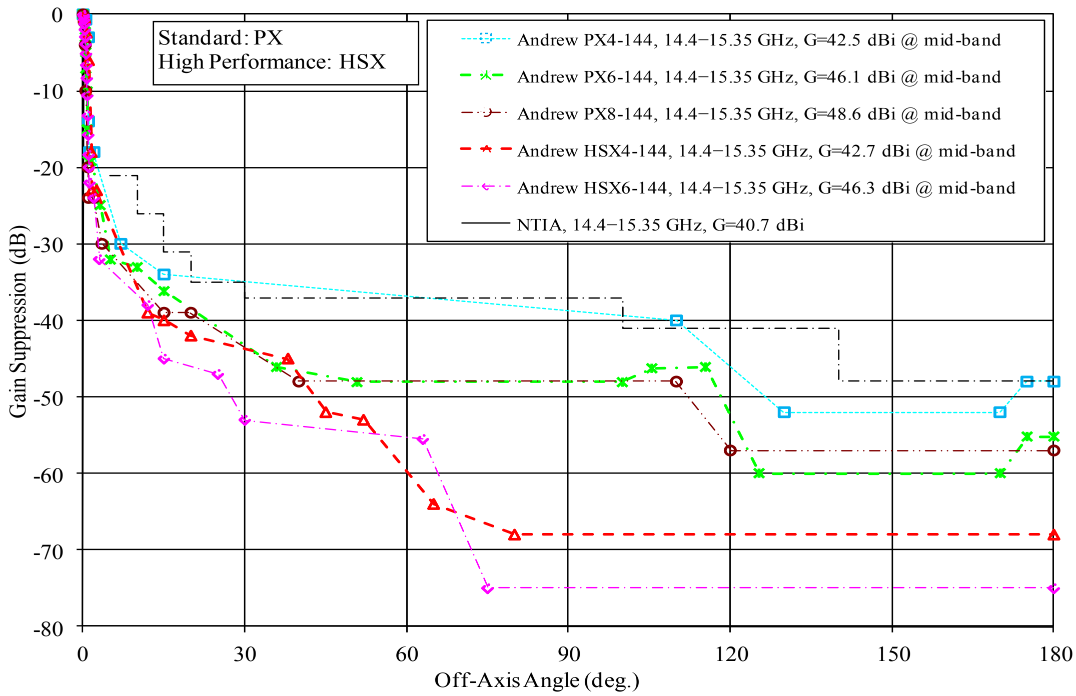


(a) Radio Waves Antenna in 4.4–4.99 GHz



(b) Gabriel Antennas in 7.125–8.5 GHz

(Figure 6-6)



(c) Andrew Antennas in 14.4–15.35 GHz

Figure 6-6. Comparison of NTIA FS Antenna Suppression Mask and Measured Standard and High Performance Antenna Performance Data

6.2.2 Frequency Assignment

Currently, NTIA and some federal agencies use *Spectrum XXI*, *iQ•link*, and *HTZ Warfare* to conduct most of the frequency assignment tasks for the FS systems. The default antenna radiation patterns in *Spectrum XXI* and *iQ•link* are the Wolfgain and Statgain antenna models in Sections 4.4.1 and 4.4.2. *iQ•link* also allows users to input antenna radiation patterns which may be the actual antenna radiation patterns from the antenna manufacturers. The default antenna radiation patterns in *HTZ Warfare* are from Recs. ITU-R F.699-7 and F.1245.

In practice, the actual radiation pattern should always be used in EMC analyses in frequency assignment when such a pattern is available. A reference radiation pattern should be used when the actual radiation pattern is not available. These two patterns are discussed here.

6.2.2.1 Actual Radiation Pattern

The actual antenna radiation patterns are available from the antenna manufacturers, and are usually available on their web sites, e.g., Ref. 197, 198, and 199.

Because the NTIA system review process uses the gain suppression masks as the certification criteria, the manufacturers usually provide the gain suppression patterns instead of the radiation patterns. The radiation patterns can be easily derived by adding the G_{max} values to the gain suppression patterns.

6.2.2.2 Reference Radiation Pattern

As stated in Section 4.4, a directional antenna is categorized as a low-gain antenna when its G_{max} < 10 dBi, and as a high-gain antenna when its $G_{max} \geq$ 10 dBi. In general, these two classes have different formulas for their reference radiation patterns. Here, all of the reference radiation patterns in Sections 4.4 and 5.2 are evaluated to develop suitable reference radiation patterns for NTIA and the federal agencies to conduct the frequency assignment task.

(a) Omnidirectional Antenna

Rec. ITU-R F.1336-3 provides an omnidirectional antenna reference radiation pattern for the P-MP system antennas. This pattern is adopted here as the omnidirectional antenna reference radiation pattern for EMC analyses in frequency assignment.

Table 6-4. Recommended FS Omnidirectional Antenna Reference Radiation Pattern for Frequency Assignment Task

Envelope Type	Gain Function (dBi)	Angular Range
Peak Sidelobe	$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \leq \lvert\theta\rvert < \theta_p$
	$G_{max} - 12 + 10 \times \log(k + 1)$	$\theta_p \leq \lvert\theta\rvert < \theta_{bw}$
	$G_{max} - 12 + 10 \times \log\{(\lvert\theta\rvert/\theta_{bw})^{-1.5} + k\}$	$\theta_{bw} \leq \lvert\theta\rvert \leq 90°$
Average Sidelobe	$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \leq \lvert\theta\rvert < \theta_{bw}$
	$G_{max} - 15 + 10 \times \log(k + 1)$	$\theta_{bw} \leq \lvert\theta\rvert < \theta_a$
	$G_{max} - 15 + 10 \times \log\{(\lvert\theta\rvert/\theta_{bw})^{-1.5} + k\}$	$\theta_a \leq \lvert\theta\rvert \leq 90°$

G_{max}: the maximum gain in the azimuth plane, dBi

θ: elevation angle relative to the angle of maximum gain, deg., $-90° \leq \theta \leq 90°$,

θ_{bw}: HPBW in the elevation plane, deg.

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

$$\theta_p = \theta_{bw}\sqrt{1 - \frac{\log(k+1)}{1.2}}$$

$$\theta_a = \theta_{bw}\sqrt{1.25 - \frac{\log(k+1)}{1.2}}$$

k: parameter that accounts for increased sidelobe levels above what would be expected for an antenna with improved sidelobe performance,

- k = 0.7 for typical antennas operating in $1 \leq f < 3$ GHz, and
- k = 0 for antennas with improved sidelobe performance operating in $1 \leq f < 3$ GHz or all antennas operating in $3 \leq f \leq 70$ GHz.*

If the antenna mainbeam is downward tilted, i.e., cone-shape instead flat, by electrical means, the radiation patterns above and below the horizontal plane are stretched and compressed, respectively. The formulas are still applicable with the following modifications.

Define

- β: downward tilt angle, the positive angle that the main beam axis is below the horizontal plane at the site of the antenna, deg., and
- θ_h: elevation angle measured from the horizontal plane at the site of the antenna, deg., $-90° \le \theta_h \le 90°$,

the formulas are applicable with θ replaced with θ_e of

$$\theta_e = \frac{90(\theta_h + \beta)}{90 + \beta} \qquad \text{for } \theta_h + \beta \ge 0$$

$$\theta_e = \frac{90(\theta_h + \beta)}{90 - \beta} \qquad \text{for } \theta_h + \beta < 0$$

(b) Low-Gain Antenna

Here, the candidates are the Wolfgain model in Section 4.4.1, the ECAC low-gain model in Section 4.4.3, and the low-gain reference radiation pattern in Rec. ITU-R F.699-7 in Section 5.2.1. For comparison, they are shown in Figure 6-7 together with the NTIA sidelobe mask for the 406.1−420 MHz band. The Wolfgain model and Rec. ITU-R F.699-7 pattern are developed with G_{max} = 6.2 dBi, which corresponds to ϕ_{bw} = 80° of the NTIA mask for the 406.1−420 MHz band. The ECAC model only has the sidelobe of -5 dBi which is for the average environment. It can be seen that both the Wolfgain model and the Rec. ITU-R F.699-7 pattern undercut the NTIA mask significantly. Therefore, the ECAC low-gain model is chosen to model a low-gain antenna.

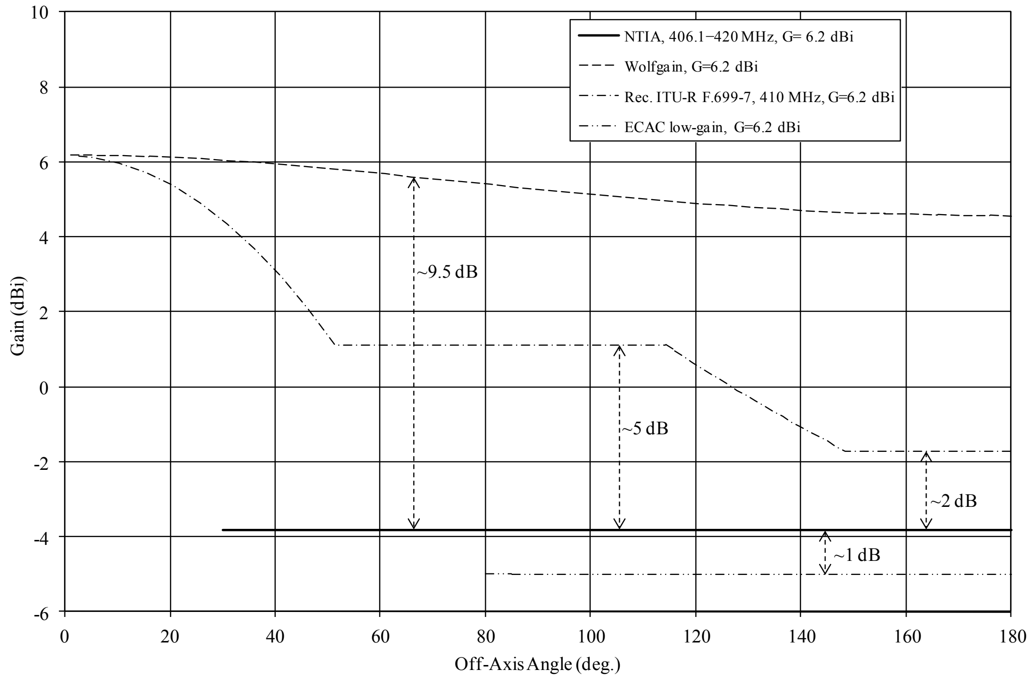


Figure 6-7. NTIA FS Antenna Radiation Mask versus Wolfgain Model and Rec. ITU-R F.699-7 Reference Radiation Pattern in the 400 MHz Band

The ECAC model specifies a region for the mainbeam without providing a formula for the mainbeam, and a region for the sidelobe with three possible sidelobe levels for three types of environments. First, a formula commonly used to describe the mainbeam is adopted. Research in the GMF shows that majority of the antennas in the 406.1−420 MHz band are Yagi, collinear, dipole array, corner reflector, and parabolic antennas, and the first four types have elliptical beams in general. Therefore, the mainbeam formula is modified for an elliptical beam. Then, the sidelobe level of -5 dBi for the average environment, as was used for the comparison shown in Figure 6-7, is adopted. This pattern is presented in Table 6-5.

Table 6-5. Recommended FS Low-Gain Antenna Reference Radiation Pattern for Frequency Assignment Task

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
Sidelobe and backlobe level of -5 dBi is chosen for the average site.

x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(c) High-Gain Antenna

Here, the candidates are the Statgain model and the high-gain reference radiation pattern in Rec. ITU-R F.699-7. Using

$$g = \frac{e\pi^2 D^2}{\lambda^2} \quad \text{(linear)} \qquad (6\text{-}1)$$

and $e = 0.55$, the Statgain formula is re-formatted and then compared with the reference radiation pattern in Rec. ITU-R F.699-7; this is shown in Table 6-6(a) with the difference shown in the rightmost column. It can be seen that the Statgain model is more stringent in the sidelobe by approximately 3 dB (except for the far sidelobe region of an antenna with $G_{max} < 22$ dBi); this is also illustrated in Figure 6-8. The Statgain is even more stringent if the value of e is higher. Since the Statgain model has been used in *Spectrum XXI* and *iQ•link* in EMC analyses, NTIA recommends that it continues to be used as the high-gain antenna reference radiation pattern; this pattern is presented in Table 6-6(b).

Table 6-6. Recommended FS High-Gain Antenna Reference Radiation Pattern for Frequency Assignment

(a) Comparison of Statgain Model and Radiation Pattern in Rec. ITU-R F.699-7

Category	Statgain (dBi)	Statgain Re-Formatted (dBi)	F.699-7 (dBi)	Statgain Lower Than F.699-7 by (dB) *
$G_{max} \geq 48$ dBi for Statgain, $f > 1$ GHz & $D/\lambda > 100$ for Rec. ITU-R F.699-7	$G_{max} - 4\times10^{-4} g_{max}\phi^2$	$G_{max} - 2.17\times10^{-3} \times (\phi D/\lambda)^2$	$G_{max} - 2.5\times10^{-3} \times (\phi D/\lambda)^2$	$-[0.33\times10^{-3} \times (\phi D/\lambda)^2]$
	$0.75G_{max} - 7$	$-1.5 + 15\times\log(D/\lambda)$	$2 + 15\times\log(D/\lambda)$	3.5
	$29 - 25\times\log(\phi)$	$29 - 25\times\log(\phi)$	$32 - 25\times\log(\phi)$	3
	-13	-13	-10	3
$22 \leq G_{max} < 48$ dBi for Statgain, $f > 1$ GHz & $D/\lambda < 100$ for Rec. ITU-R F.699-7	$G_{max} - 4\times10^{-4} g_{max}\phi^2$	$G_{max} - 2.17\times10^{-3} \times (\phi D/\lambda)^2$	$G_{max} - 2.5\times10^{-3} \times (\phi D/\lambda)^2$	$-[0.33\times10^{-3} \times (\phi D/\lambda)^2]$
	$0.75G_{max} - 7$	$-1.5 + 15\times\log(D/\lambda)$	$2 + 15\times\log(D/\lambda)$	3.5
	$53 - (G_{max}/2) - 25\times\log(\phi)$	$49.3 - 10\times\log(D/\lambda) - 25\times\log(\phi)$	$52 - 10\times\log(D/\lambda) - 25\times\log(\phi)$	2.7
	$11 - G_{max}/2$	$7.3 - 10\times\log(D/\lambda)$	$10 - 10\times\log(D/\lambda)$	2.7
$10 \leq G_{max} < 22$ dBi for Statgain, $f < 1$ GHz & $D/\lambda > 0.63$ for Rec. ITU-R F.699-7	$G_{max} - 4\times10^{-4} g_{max}\phi^2$	$G_{max} - 2.17\times10^{-3} \times (\phi D/\lambda)^2$	$G_{max} - 2.5\times10^{-3} \times (\phi D/\lambda)^2$	$-[0.33\times10^{-3} \times (\phi D/\lambda)^2]$
	$0.75G_{max} - 7$	$-1.5 + 15\times\log(D/\lambda)$	$2 + 15\times\log(D/\lambda)$	3.5
	$53 - (G_{max}/2) - 25\times\log(\phi)$	$49.3 - 10\times\log(D/\lambda) - 25\times\log(\phi)$	$52 - 10\times\log(D/\lambda) - 25\times\log(\phi)$	2.7
	0	0	$-2 - 5\times\log(D/\lambda)$	$-[2 + 5\times\log(D/\lambda)]$
Angular ranges not provided because the two patterns change courses at different angular locations;				

this is seen in Figure 6-8. g_{max}: numerical value of G_{max}. G_{max} = 47.3 dBi for D/λ = 100 and *e* = 0.55 G_{max} = 22 dBi for D/λ = 5.4 and *e* = 0.55 G_{max} = 10 dBi for D/λ = 1.36 and *e* = 0.55
*: The difference is illustrated in Figure 6-8.

(b) Statgain Model As the Recommended Reference Radiation Pattern

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 4 \times 10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(\text{dBi}) < 48$	$G_{max} - 4 \times 10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(\text{dBi}) < 22$	$G_{max} - 4 \times 10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

All angles in deg.

$$\phi_m = 50(0.25G_{max} + 7)^{0.5} / \left(10^{G_{max}/20}\right)$$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250 / \left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

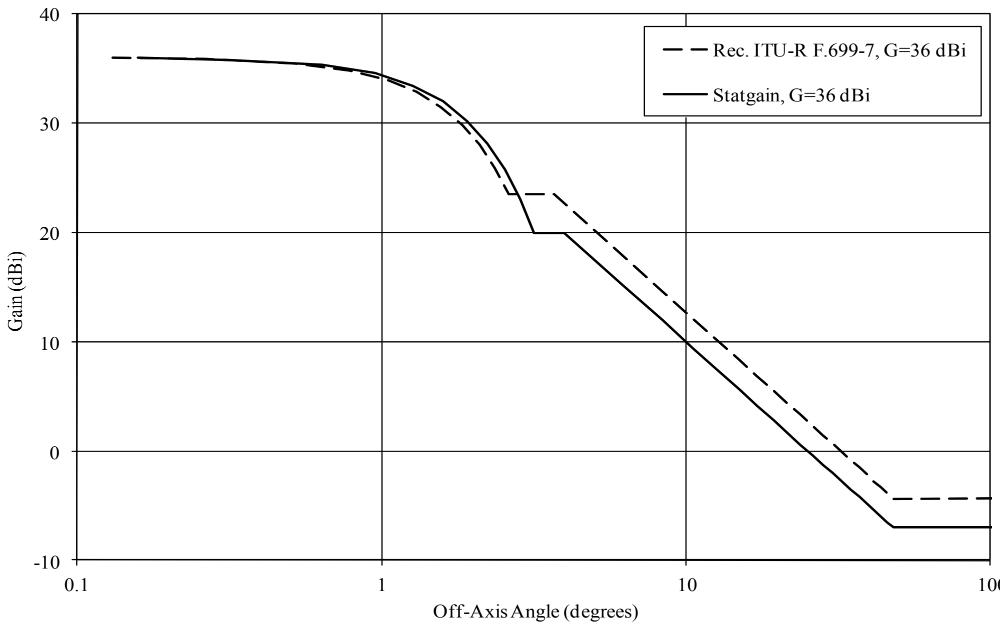


Figure 6-8. Statgain Model versus Reference Radiation Pattern in Rec. ITU-R F.699-7

6.2.3 Spectrum Sharing Analyses

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the FS service records in the GMF. The symbol of the station class is "FX". Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the receiving antenna G_{max} data population profile.
(3) Select a threshold G_{max} such that approximately 75% of the G_{max} population is equal to or smaller than the threshold value. This is the representative G_{max} value. Since the population profile spikes and dips irregularly, in some cases the final selection may not meet the 75% criterion closely.
(4) Develop a representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation pattern in Section 6.2.2.2.
(5) To ensure technical viability, compare the representative antenna radiation pattern with manufacturers' measurement data. If available, measurement data for G_{max} higher than, approximately equal to, and lower than the representative G_{max} will all be examined. Also, if available, measurement data of which G_{max} populations spike will be examined. Both the standard-performance and high-performance antennas will be examined. Since the measurement data are for system certification, they are likely to present the worst-case condition, i.e., the highest sidelobe level within the given angular ranges. Therefore, the extrapolated radiation patterns from the measurement data are likely to be higher than the representative radiation pattern, and caution must be taken not to make negative judgment about the representative radiation pattern.

The frequency bands being examined are

(1) 406.1−420 MHz,
(2) 932.5−935 and 941.5−944 MHz,

(3) 1.71−1.85 GHz,
(4) 2.2−2.4 GHz,
(5) 4.4−4.99 GHz,
(6) 7.125−8.5 GHz,
(7) 14.4−15.35 GHz,
(8) 21.2−23.6 GHz, and
(9) 25.25−27.5 GHz.

6.2.3.1 406.1−420 MHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-9. Most of these antennas are Yagi, collinear, dipole array, corner reflector, and parabolic antennas. The percentages of cumulative population are 59% and 93.6% for G_{max} = 9 dBi and 10 dBi, respectively, and the representative G_{max} is chosen to be 10 dBi to include the population spike at G_{max} = 10 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-7. Measurement data is not available for comparison with the representative radiation pattern.

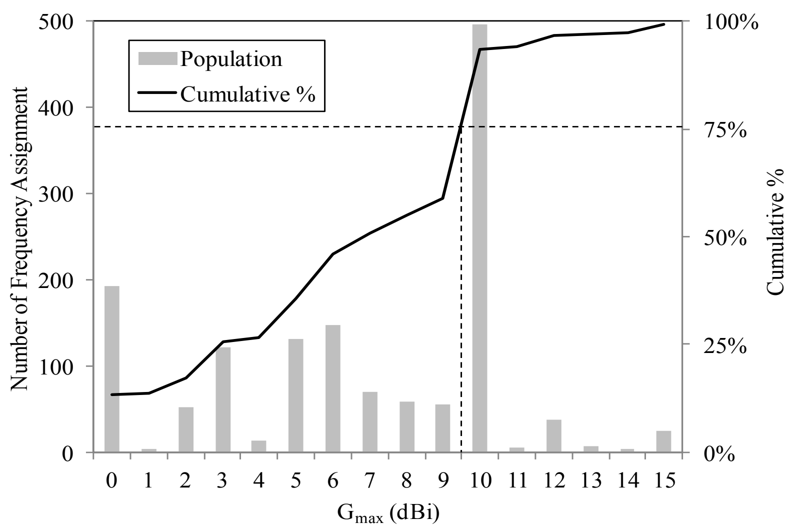


Figure 6-9. Population Profile of FS Receiving Antenna G_{max} Data in 406.1–420 MHz

Table 6-7. Representative FS Antenna Radiation Pattern in 406.1–420 MHz

Gain(θ) (dBi)	Angular Range
$10 - 0.004\times\phi^2$	$0 \le \phi \le 48.7°$
0.5	$48.7° < \phi \le 79.1°$
$48 - 25 \times \log(\phi)$	$79.1° < \phi \le 83.2°$
0	$83.2° < \phi \le 180°$
φ in deg.	

6.2.3.2 932.5−935 and 941.5−944 MHz

The population profile of the receiving antenna G_{max} data in these bands is shown in Figure 6-10. The representative G_{max} = 22 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-8. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-11.

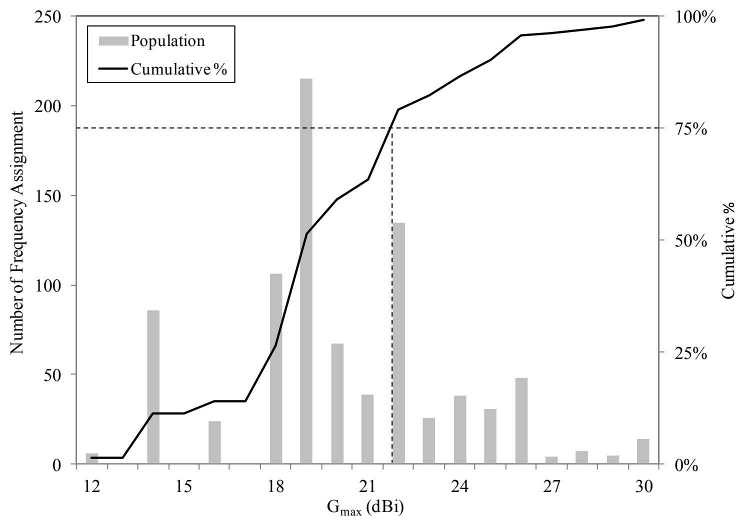


Figure 6-10. Population Profile of FS Receiving Antenna G_{max} Data in 932.5−935 and 941.5−944 MHz

Table 6-8. Representative FS Antenna Radiation Pattern in 932.5−935 and 941.5−944 MHz

Gain(θ) (dBi)	Angular Range
$22 - 0.06\times\phi^2$	$0 \le \phi \le 14°$
9.5	$14° < \phi \le 20°$
$42 - 25 \times \log(\phi)$	$20° < \phi \le 48°$
0	$48° < \phi \le 180°$
φ in deg.	

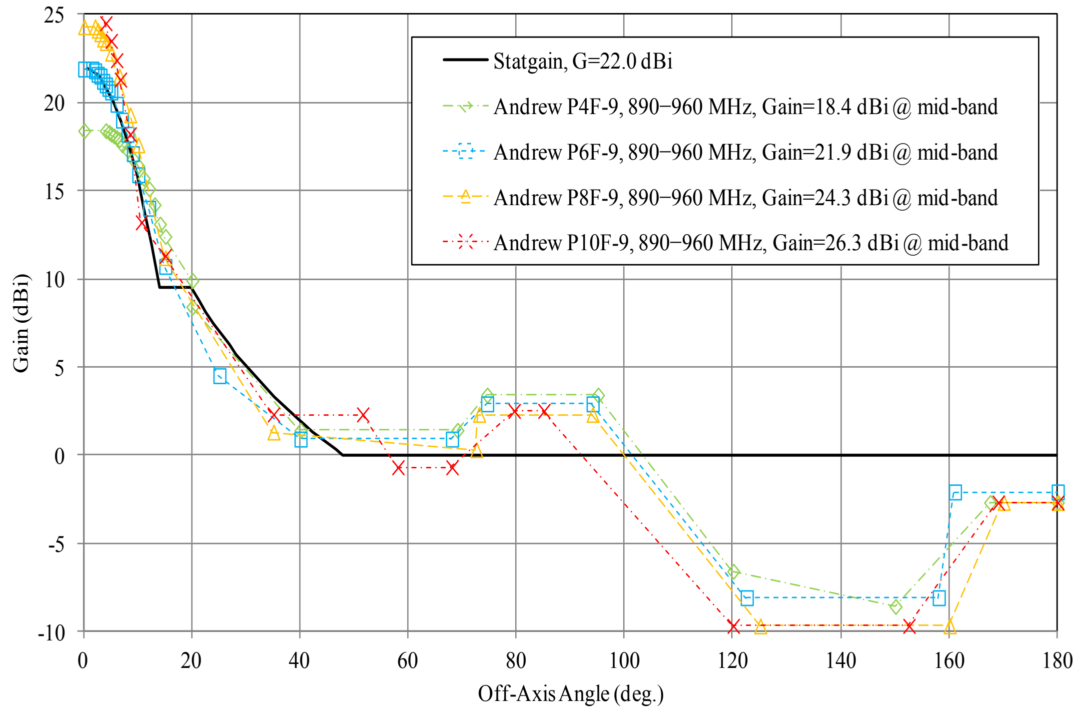


Figure 6-11. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 932.5−935 and 941.5−944 MHz

6.2.3.3 1.71−1.85 GHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-12. The representative G_{max} = 29 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-9. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-13.

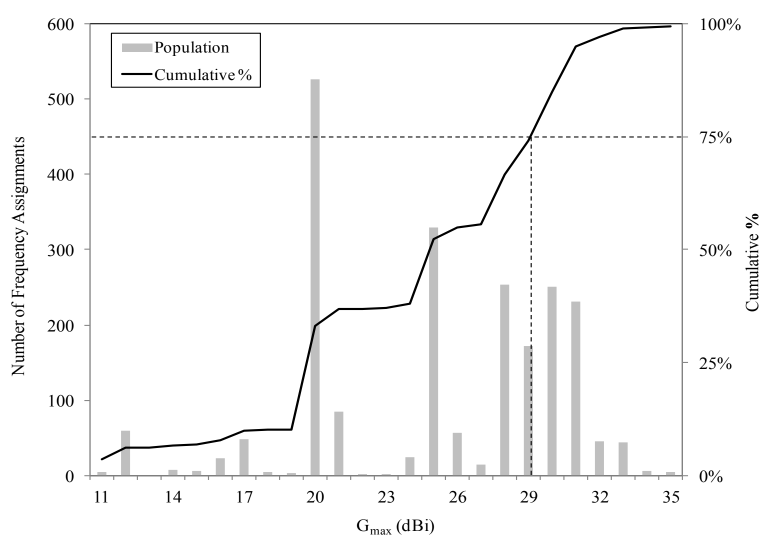


Figure 6-12. Population Profile of FS Receiving Antenna G_{max} Data in 1.71−1.85 GHz

Table 6-9. Representative FS Antenna Radiation Pattern in 1.71−1.85 GHz

Gain(θ) (dBi)	Angular Range
$29 - 0.32\times\phi^2$	$0 \le \phi \le 6.7°$
14.75	$6.7° < \phi \le 9°$
$38.5 - 25 \times \log(\phi)$	$9° < \phi \le 48°$
-3.5	$48° < \phi \le 180°$
φ in deg.	

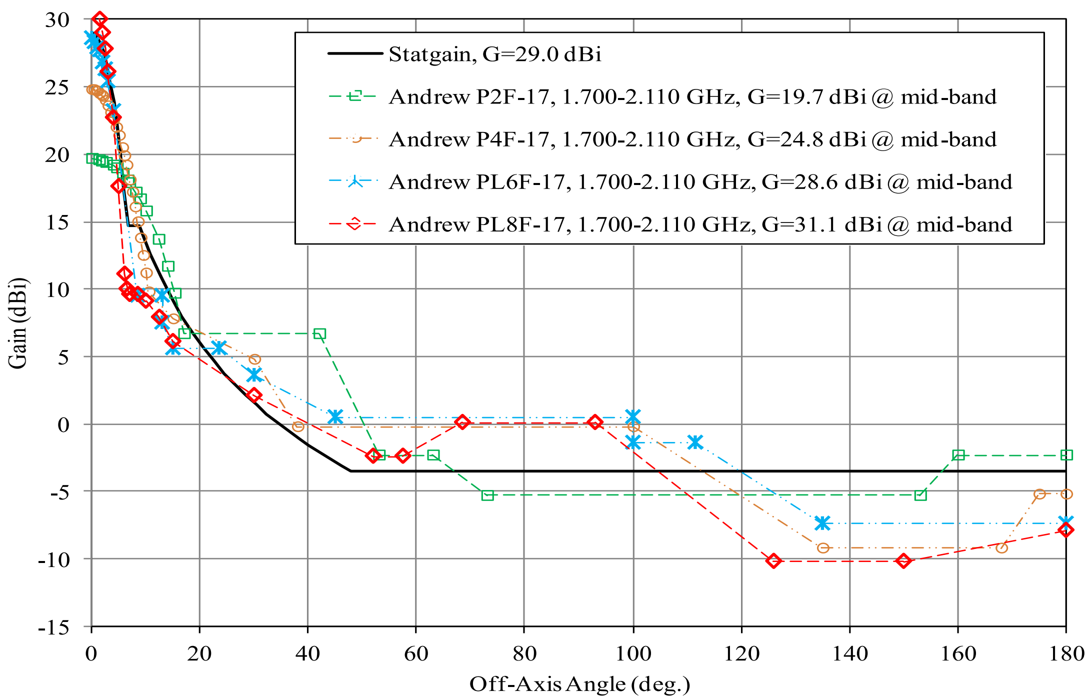


Figure 6-13. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 1.71−1.85 GHz

6.2.3.4 2.2−2.4 GHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-14. The representative G_{max} = 28 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-10. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-15.

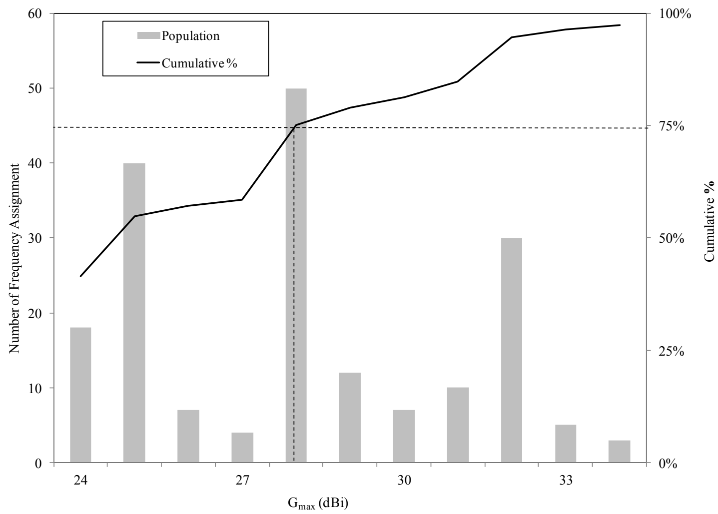


Figure 6-14. Population Profile of FS Receiving Antenna G_{max} Data in 2.2−2.4 GHz

Table 6-10. Representative FS Antenna Radiation Pattern in 2.2−2.4 GHz

Gain(θ) (dBi)	Angular Range
$28 - 0.25\times\phi^2$	$0 \le \phi \le 7.4°$
14	$7.4° < \phi \le 10°$
$39 - 25 \times \log(\phi)$	$10° < \phi \le 48°$
[illegible]	[illegible]

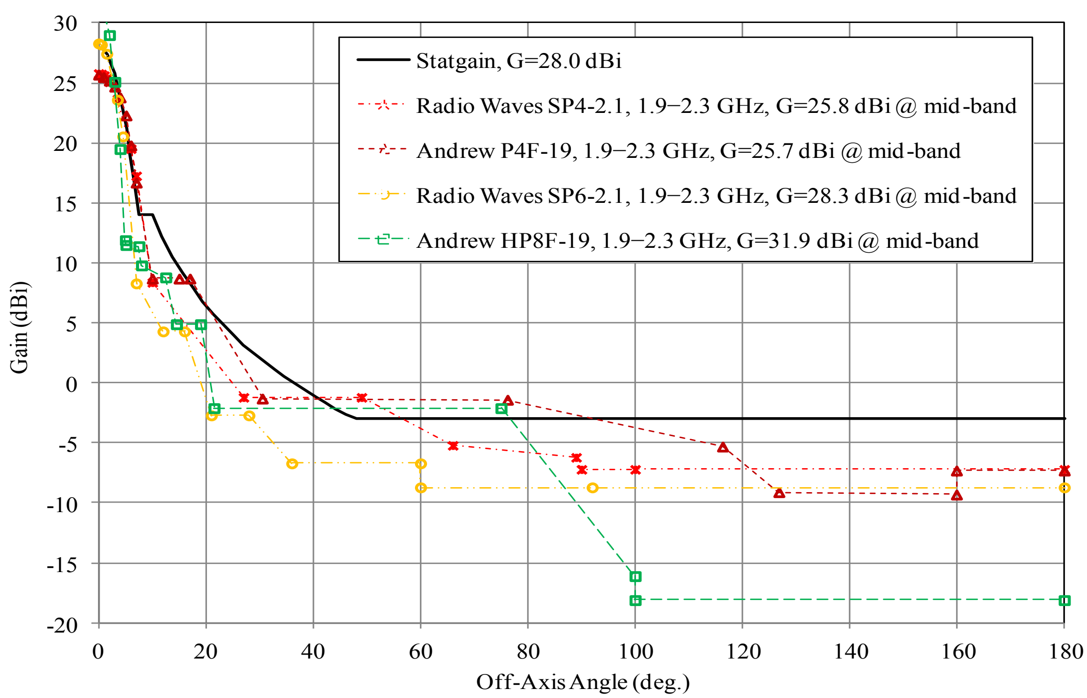


Figure 6-15. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 2.2−2.4 GHz

6.2.3.5 4.4−4.99 GHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-16. The representative G_{max} = 38 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-11. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-17.

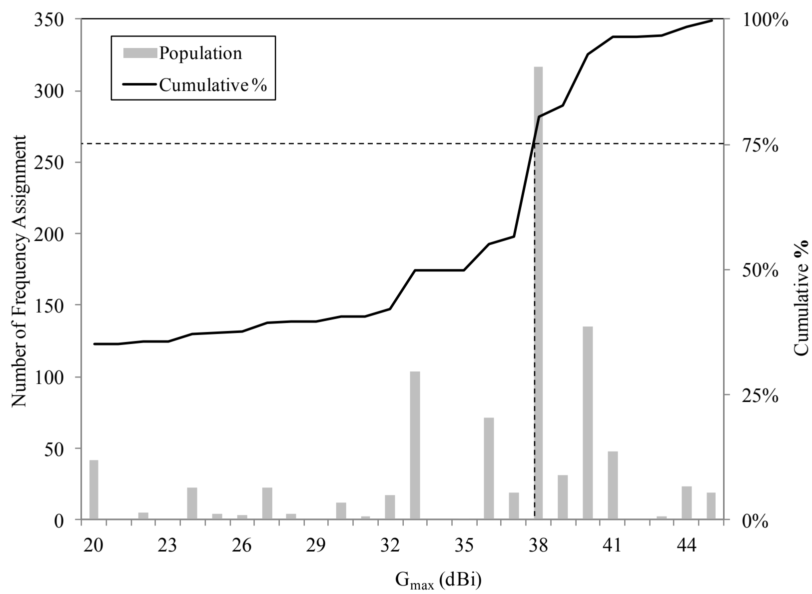


Figure 6-16. Population Profile of FS Receiving Antenna G_{max} Data in 4.4−4.99 GHz

Table 6-11. Representative FS Antenna Radiation Pattern in 4.4−4.99 GHz

Gain(θ) (dBi)	Angular Range
$38 - 2.52\times\phi^2$	$0 \le \phi \le 2.6°$
21.5	$2.6° < \phi \le 3.1°$
$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
-8	$48° < \phi \le 180°$
ϕ in deg.	

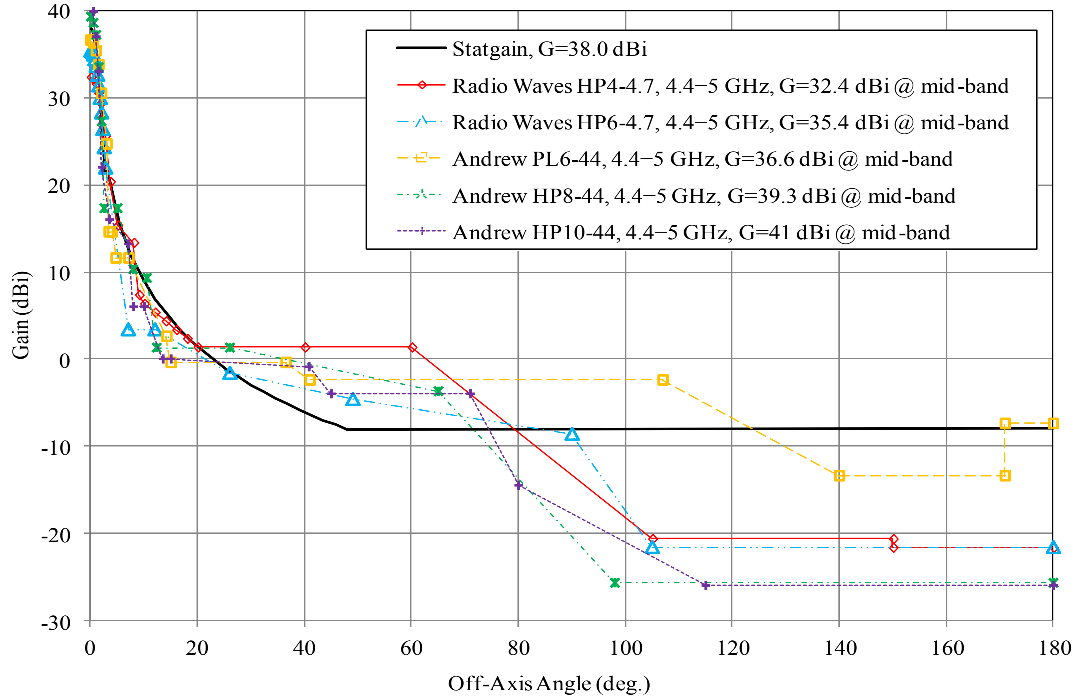


Figure 6-17. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 4.4−4.99 GHz

6.2.3.6 7.125−8.5 GHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-18. The representative G_{max} = 43 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-12. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-19.

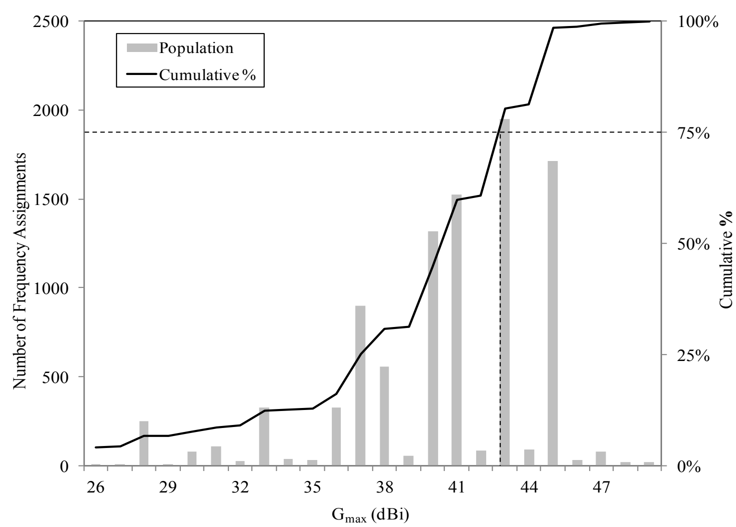


Figure 6-18. Population Profile of FS Receiving Antenna G_{max} Data in 7.125−8.5 GHz

Table 6-12. Representative FS Antenna Radiation Pattern in 7.125−8.5 GHz

Gain(θ) (dBi)	Angular Range
$43 - 7.98\times\phi^2$	$0 \le \phi \le 1.5°$
25.25	$1.5° < \phi \le 1.8°$
$31.5 - 25 \times \log(\phi)$	$1.8° < \phi \le 48°$
-10.5	$48° < \phi \le 180°$
ϕ in deg.	

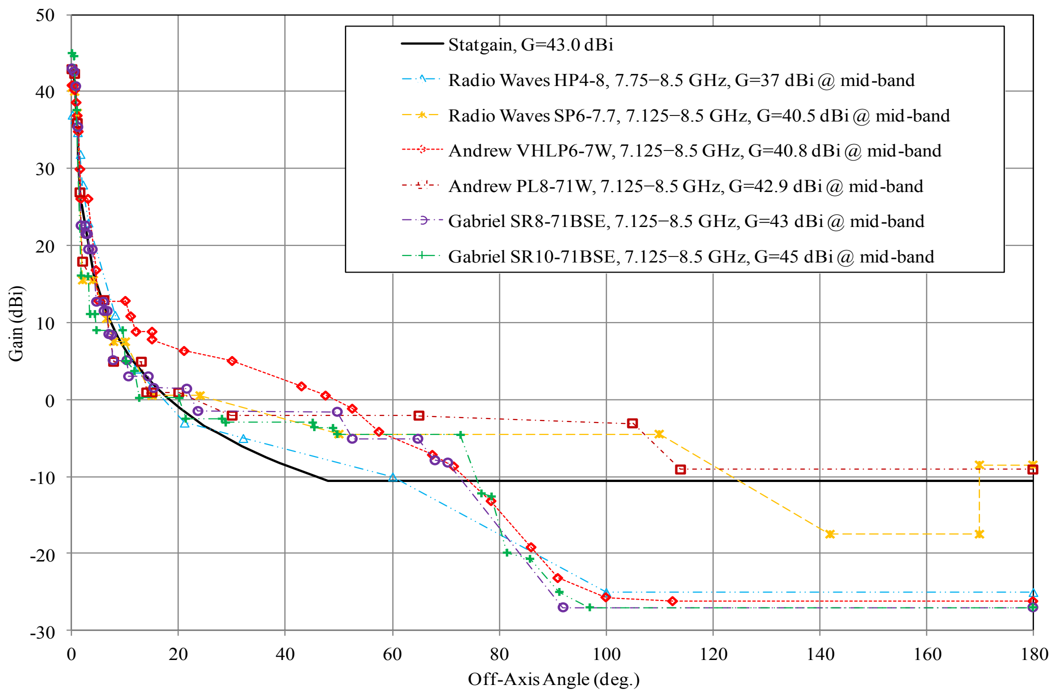


Figure 6-19. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 7.125−8.5 GHz

6.2.3.7 14.4−15.35 GHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-20. The representative G_{max} = 42 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-13. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-21.

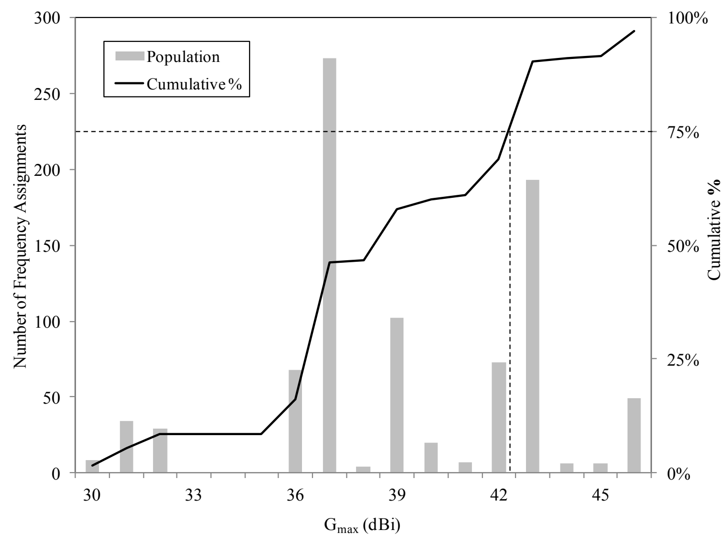


Figure 6-20. Population Profile of FS Receiving Antenna G_{max} Data in 14.4−15.35 GHz

Table 6-13. Representative FS Antenna Radiation Pattern in 14.4−15.35 GHz

Gain(θ) (dBi)	Angular Range
$42 - 6.34\times\phi^2$	$0 \leq \phi \leq 1.7°$
24.5	$1.7° < \phi \leq 2°$
$32 - 25 \times \log(\phi)$	$2° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$
ϕ in deg.	

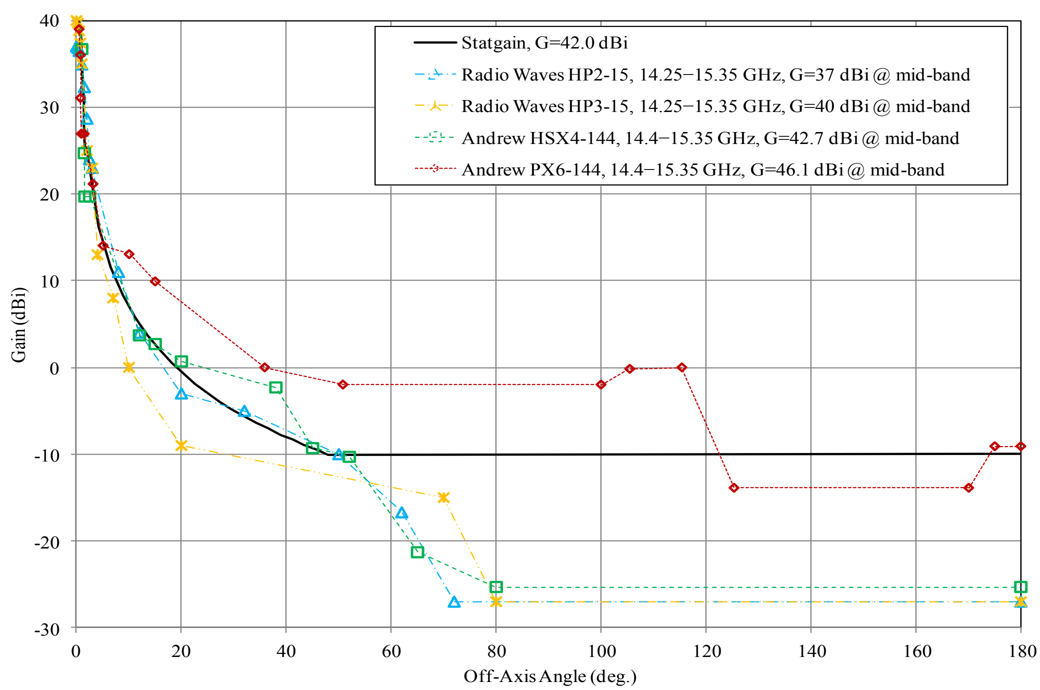


Figure 6-21. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 14.4−15.35 GHz

6.2.3.8 21.2−23.6 GHz

The population profile of the receiving antenna G_{max} data in this band is shown in Figure 6-22. The percentages of cumulative population are 70.1% and 80.5% for G_{max} = 39 dBi and 40 dBi, respectively, and the representative G_{max} is chosen to be 40 dBi to protect more federal systems. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-14. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-23.

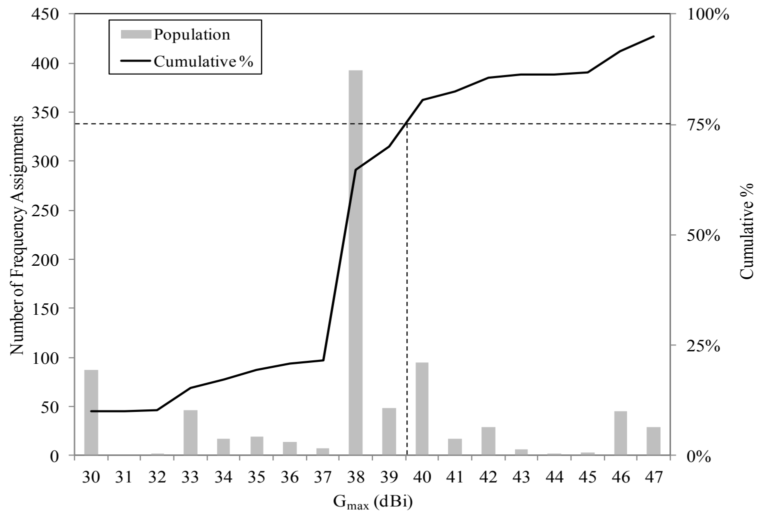


Figure 6-22. Population Profile of FS Receiving Antenna G_{max} Data in 21.2−23.6 GHz

Table 6-14. Representative FS Antenna Radiation Pattern in 21.2−23.6 GHz

Gain(θ) (dBi)	Angular Range
$40 - 4\phi^2$	$0 \leq \phi \leq 14°$
23	$14° < \phi \leq 20°$
$33 - 25 \times \log(\phi)$	$20° < \phi \leq 48°$
-9	$48° < \phi \leq 180°$
ϕ in deg.	

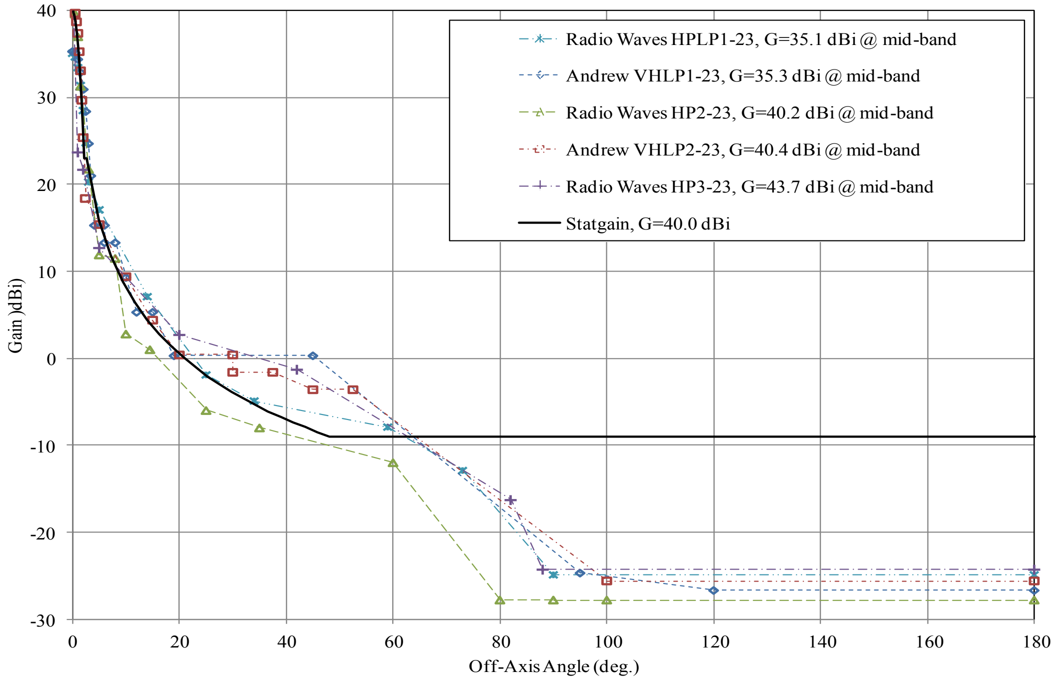


Figure 6-23. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 21.2−23.6 GHz

6.2.3.9 25.25−27.5 GHz

The receiving antenna G_{max} data count in this band is

- 30, 36 dBi: 29 frequency assignments,
- 38 dBi: 10 frequency assignments,
- 41 dBi: 162 frequency assignments (cumulative population % = 81%),
- 42 dBi: 31 frequency assignments,
- 44, 47 dBi: 16 frequency assignments.

The representative G_{max} = 41 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-15. Comparison of the representative radiation pattern and the measurement data is shown in Figure 6-24.

Table 6-15. Representative FS Antenna Radiation Pattern in 25.25−27.5 GHz

Gain(θ) (dBi)	Angular Range
$41 - 5.04\phi^2$	$0 \leq \phi \leq 14°$
23.75	$14° < \phi \leq 20°$
$32.5 - 25 \times \log(\phi)$	$20° < \phi \leq 48°$
-9.5	$48° < \phi \leq 180°$
ϕ in deg.	

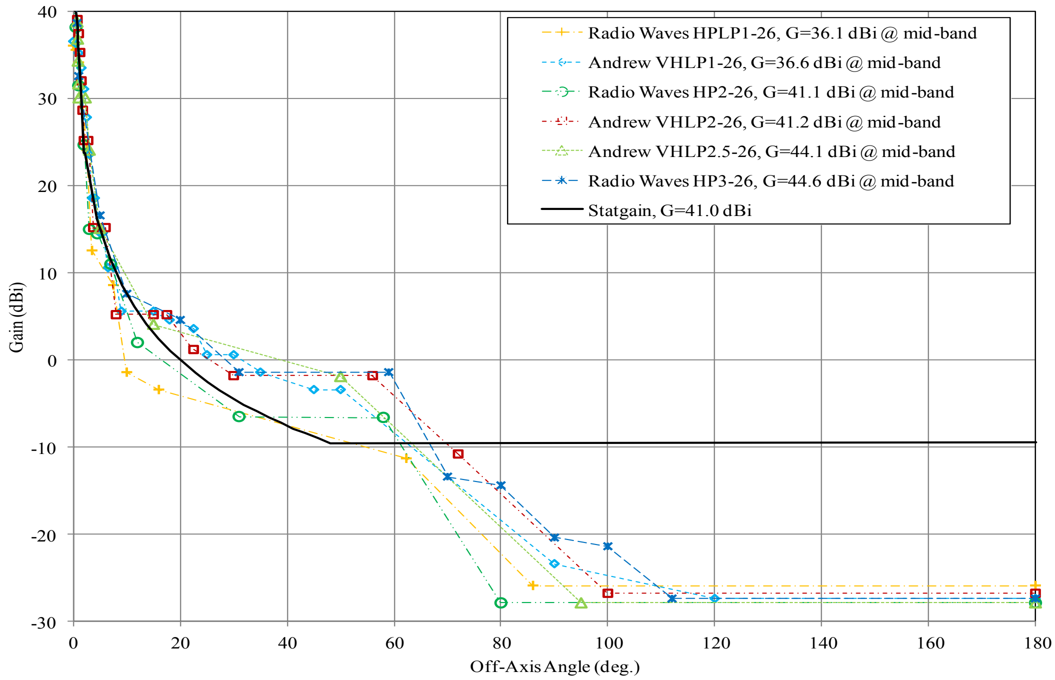


Figure 6-24. Comparison of Representative FS Antenna Radiation Pattern and Measurement Data in 25.25−27.5 GHz

6.3 Fixed-Satellite Service

The focus here is the earth station antenna radiation pattern. Satellite antenna radiation patterns are mostly shaped to cover the service areas as tightly as possible. These patterns are presented in gain contour maps that are available from the space system operators.

For FSS, the following earth station antenna radiation performance standards and reference radiation patterns will be developed:

- GSO system earth station antenna co-polarization radiation pattern,
- GSO system earth station antenna cross-polarization radiation pattern, and
- NGSO system earth station antenna co-polarization radiation pattern.

In satellite communications, the unit in length is almost always specified in the metric system. Therefore, in this sub-section the main unit for specifying the antenna size will be in meters.

6.3.1 System Review

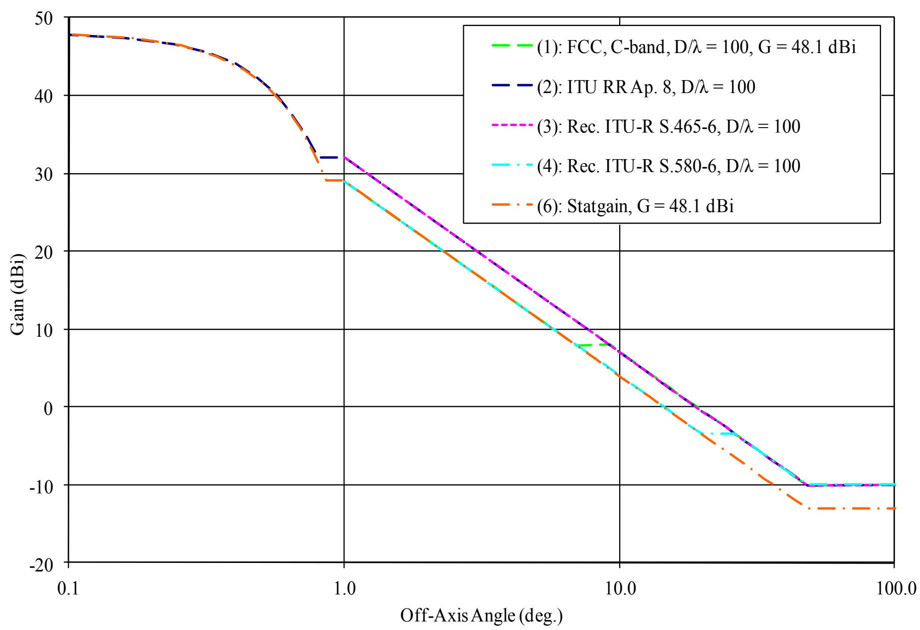
NTIA does not provide earth station antenna radiation performance standards for system review even though the federal agencies use FSS extensively in the federal bands and in the non-federal bands via leasing telecommunication capacities from non-government operators. However, since FSS is a popular medium to provide global telecommunications, and the earth station antenna radiation performance standard and recommended reference radiation patterns have been well established, it is easy to develop federal standards from the existing non-federal standards and recommendations.

6.3.1.1 GSO System Earth Station Antenna Co-Polarization Radiation Performance Standard

There are six GSO system earth station antenna co-polarization radiation patterns in Section 5.3.1. Excluding the radiation pattern for the Allotment Plan, the other five, plus the Statgain model, are evaluated in order to develop the earth station antenna co-polarization radiation performance standard; these are

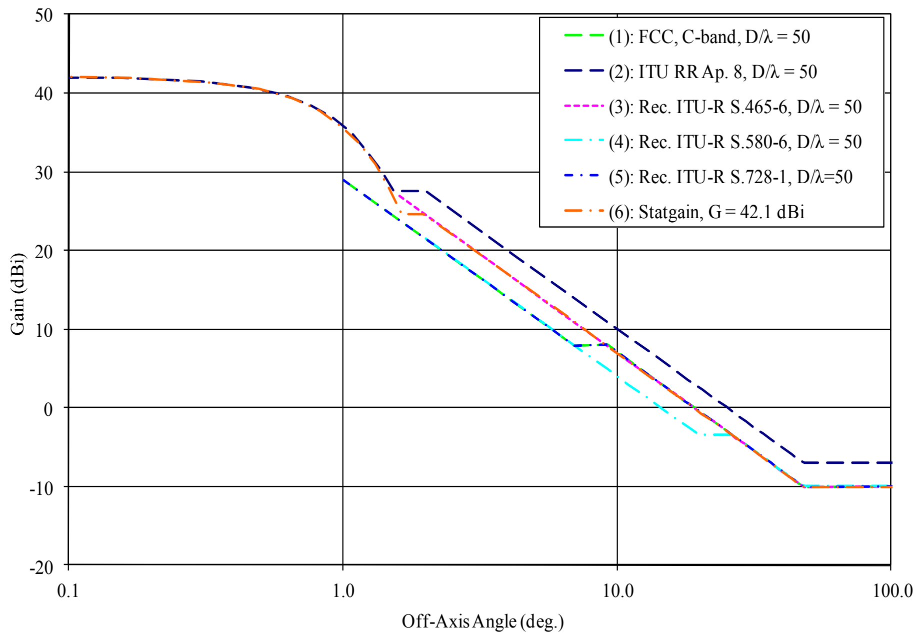
(1) from FCC, the earth station antenna radiation performance standard in Table 5-12(a) for U.S. non-federal systems;
(2) from RR Appendix 8, the earth station antenna reference radiation pattern in Table 5-14 for coordination studies involving GSO FSS networks;
(3) from Rec. ITU-R S.465-6, the recommended earth station antenna reference radiation pattern in Table 5-16 for coordination studies and interference assessment between FSS systems and between FSS systems and other radio systems in 2−30 GHz;
(4) from Rec. ITU-R S.580-6, the recommended FSS earth station antenna reference radiation patterns in Table 5-17 as design objective of new GSO FSS systems;
(5) from Rec. ITU-R S.728-1, the VSAT earth station antenna reference radiation pattern in Table 5-20 which is derived from the recommended earth station maximum permissible off-axis EIRP density level; and
(6) Statgain model in Table 4-1.

These patterns are plotted in Figure 6-25 for D/λ = 100 and D/λ = 50, where D/λ = 50 is the nominal threshold for VSAT. It can be seen that the sidelobe levels are within 3 dB of each other except for pattern (2) in Figure 6-25(b).



(a) $G_{max} \geq 48$ dBi or D/λ ≥ 100

(Figure 6-25)



(b) G_{max} < 48 dBi or D/λ < 100

Figure 6-25. Comparison of GSO FSS Earth Station Antenna Co-Polarization Radiation Patterns

Since there is an antenna sidelobe radiation performance standard from FCC for the non-federal systems, and it is comparable to the ITU-R recommendations, NTIA recommends that the earth station antenna co-polarization radiation standard combines

- the sidelobe radiation performance standard from FCC, and
- the mainbeam pattern from the ITU RR Appendix 8.

This recommended standard is presented in Table 6-16.

Table 6-16. Recommended GSO FSS Earth Station Antenna Co-Polarization Radiation Performance Standard

(a) In the GSO Plane and Not in the K_a or Conventional K_u Band

Category	Gain Function (dBi)	Angular Range
D/λ ≥ 68 (G_{max} ≥ 44.7 dBi for *e* = 0.65)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi \le \phi_m$
	G_1	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le 7°$
	8	$7° < \phi \le 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
	-10	$48° < \phi \le 180°$
D/λ < 68	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi \le \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le 7°$
	8	$7° < \phi \le 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$

	-10	$48° < \phi \le 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.
ϕ: angle off mainbeam axis, deg.
$G_1 = -1 + 15 \times \log(D/\lambda)$, dBi
$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.
$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.
ϕ_{r2} : intersection of $\{G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25 \times \log(\phi)\}$

The actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in $\phi_r < \phi \le 7°$.
- It may exceed the gain function in $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) In the GSO Plane and in the K_a and Conventional K_u Bands

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 68$ ($G_{max} \ge 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi \le \phi_m$
	G_1	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le 7°$
	8	$7° < \phi \le 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
	-10	$48° < \phi \le 85°$
	0	$85° < \phi \le 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi \le \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le 7°$
	8	$7° < \phi \le 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
	-10	$48° < \phi \le 85°$
	0	$85° < \phi \le 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.
ϕ: angle off mainbeam axis, deg.
$G_1 = -1 + 15 \times \log(D/\lambda)$, dBi
$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.
$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.
ϕ_{r2} : intersection of $\{G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25 \times \log(\phi)\}$

The actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in $\phi_r < \phi \le 7°$.
- It may exceed the gain function in $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(c) Not in the GSO Plane

Category	Gain Function (dBi)	Angular Range
Not K_a or conventional K_u band	32 - 25 × log(ϕ)	3° ≤ ϕ ≤ 48°
	-10	48° < ϕ ≤ 180°
K_a and conventional K_u bands	32 - 25 × log(ϕ)	3° ≤ ϕ ≤ 48°
	-10	48° < ϕ ≤ 85°
	0	85° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.		

6.3.1.2 GSO System Earth Station Antenna Cross-Polarization Radiation Performance Standard

There are three GSO system earth station antenna cross-polarization radiation patterns in Section 5.3.1; they are

(1) from FCC, the earth station antenna radiation performance standard in Table 5-12(c) for the non-federal systems;
(2) from Rec. ITU-R S.731-1, the recommended earth station antenna cross-polarization reference radiation pattern in Table 5-19 for coordination studies and interference assessments in 2−30 GHz; and
(3) from Rec. ITU-R S.728-1, the maximum permissible level of off-axis EIRP density from VSATs, in Table 5-20.

These three patterns are evaluated in order to develop the earth station antenna cross-polarization radiation performance standard. Patterns (1) and (3) are identical, hence patterns (1) and (2) are plotted in Figure 6-26 for comparison. It can be seen that the FCC pattern is much more stringent than the pattern from Rec. ITU-R S.731-1 in the near sidelobe region.

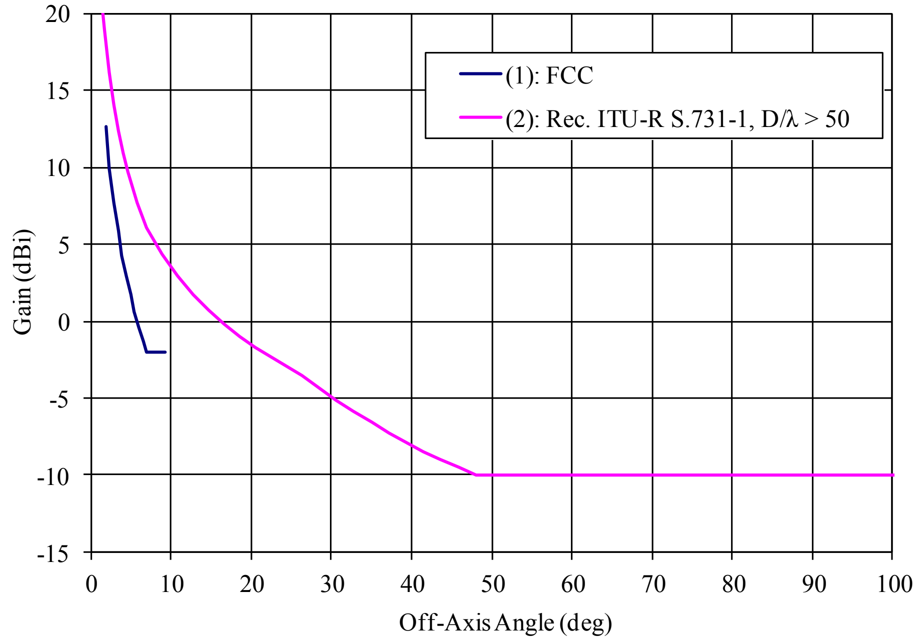


Figure 6-26. Comparison of FSS Earth Station Antenna Cross-Polarization Radiation Patterns

Since there is a radiation performance standard from FCC for the non-federal systems, and it is as stringent as or more stringent than the ITU-R recommendations, NTIA recommends that the earth station antenna cross-polarization radiation performance standard

- adopts the FCC standard, and then
- extends it to the ITU-R pattern where the FCC standard is not specified.

This recommended standard is presented in Table 6-17.

Table 6-17. Recommended GSO FSS Earth Station Antenna Cross-Polarization Sidelobe Radiation Performance Standard

Gain Function (dBi)	Angular Range
$19 - 25 \times \log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7 \times \log(\phi)$	$21.3° < \phi \le 26.3°$
$32 - 25 \times \log(\phi)$	$26.3° < \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.1.3 NGSO System Earth Station Antenna Co-Polarization Radiation Performance Standard

There are three NGSO system earth station antenna co-polarization radiation patterns in Section 5.3.1. These three patterns, plus the Statgain model, are evaluated in order to develop the NGSO earth station antenna co-polarization radiation performance standard; they are

(1) from FCC, the gateway antenna co-polarization radiation performance standard in Table 5-12(d) for the U.S. non-federal systems operating in 10.7–11.7, 12.75–13.15, 13.2125–13.25, 13.8–14.0, 14.4–14.5 GHz;
(2) from ITU RR Article 22, the earth station antenna reference radiation pattern in Table 5-13 for establishing the downlink *pfd* limit of the space systems operating in 3.7–4.2 GHz;
(3) from Rec. ITU-R S.1428-1, the recommended earth station antenna reference radiation pattern in Table 5-18 for coordination studies and interference assessments involving the NGSO FSS systems operating in 10.7−30 GHz; and
(4) Statgain model in Table 4-1.

These patterns are plotted in Figure 6-27 with a variety of D/λ values. Many patterns are very close to each other, and some are partially overlapping with each other, i.e.,

- patterns (1), (3.a), and (4), whose D/λ values are 100 or G_{max} are 48.1 dBi, are very close to each other, the three overlap from 1° to 10°, and patterns (1) and (4) overlap from 1° to 36°; and
- patterns (2.a) and (3.b), whose D/λ values are 60 and 50, respectively, are very close to each other.

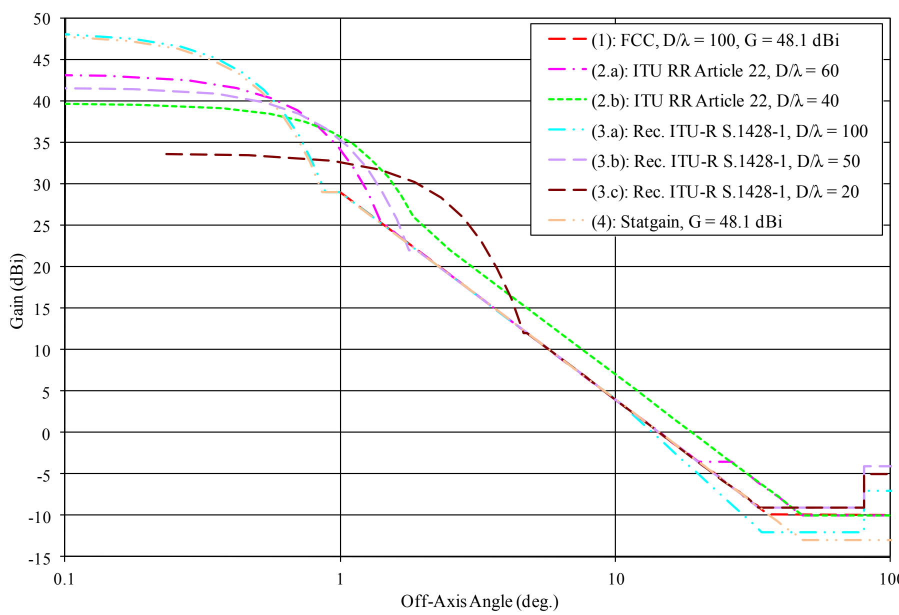


Figure 6-27. Comparison of NGSO FSS Earth Station Antenna Co-Polarization Radiation Patterns

Since there is an antenna sidelobe radiation performance standard from FCC for the non-federal systems, and it is comparable to the ITU-R recommendations, NTIA recommends that the earth station antenna co-polarization radiation performance standard combines

- the sidelobe radiation performance standard from FCC, and
- the mainbeam pattern from Rec. ITU-R S.1428-1.

This recommended standard is shown in Table 6-18.

Table 6-18. Recommended NGSO FSS Earth Station Antenna Co-Polarization Radiation Performance Standard

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}(dBi) < 48.1$ for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

6.3.2 Frequency Assignment

Because of the expense of manufacturing and launching satellites, a FSS system usually uses the whole allocated frequency band or bands as long as the solar panels are big enough to provide enough power to support the operation. Therefore, frequency assignment in FSS only involves coordination between space systems and between the space system and terrestrial systems.

The actual antenna radiation patterns, including both the earth station antennas and the satellite antennas, should always be used in EMC analyses for frequency assignment. The earth station antenna radiation patterns should be available from either the earth station operators or the antenna manufacturers, and the satellite antenna radiation patterns should be available from the space system operators.

When the actual radiation pattern is not available, the radiation performance standards in Section 6.3.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.3.1 do not specify the G_{max} value, and such data should be available in the GMF.

6.3.3 Spectrum Sharing Analyses

In spectrum sharing analyses between two space services or space systems, it is usually assumed that the space systems have the same Earth coverage, and the focus of the interference analysis is the earth station antenna radiation patterns. In spectrum sharing analyses between a space service or system and a terrestrial service or system, the interference analysis is between the earth station and the terrestrial station.

In the GMF, the FSS services cover the federal bands, lease services in the non-federal bands, and feeder links for other space services. The studies here cover the bands in which the federal systems have significant earth station population.

FSS uses different frequency bands for the uplink and downlink. When conducting spectrum sharing analyses in a band, it is necessary to identify if the band is for the uplink or downlink. In the uplink band, the earth stations are the transmitting stations, and are the interferers. In the downlink band, the earth stations are the receiving stations, and are the victims. These two cases will be analyzed separately.

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the FSS service records in the GMF. Since the GMF has only the station class information of the transmitting stations, the uplink band is processed with the station class symbol "TC" for the earth stations, and the downlink band is processed with the station class symbol "EC" for the space stations.
(2) Develop the earth station antenna G_{max} data population profile.
(3) Select the representative G_{max} value from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.3.2.

The frequency bands being examined are

(1) 3.6−4.2 GHz downlink,
(2) 5.85−6.425 GHz uplink,
(3) 7.25−7.75 GHz downlink,
(4) 7.9−8.4 GHz uplink,
(5) 10.7−12.2 GHz downlink,
(6) 14−14.5 GHz uplink,
(7) 20.2−21.2 GHz downlink,
(8) 30−31 GHz uplink,
(9) 43−45 GHz uplink, and
(10) 1.35−1.39 GHz downlink for NGSO system.

6.3.3.1 3.6−4.2 GHz Downlink

This band and its corresponding 5.85−6.425 GHz uplink band are allocated to the non-federal systems. However, federal agencies are heavy users of these bands by leasing the capacities from the commercial operators. Therefore, a representative antenna radiation pattern may be useful in spectrum sharing analyses.

The GMF has 3 service records with earth station receiving antenna data in this band, all with G_{max} = 55 dBi. Should this be the representative G_{max} value, the dish antenna size would be 18 meters. However, it will be seen in Section 6.3.3.2 where the corresponding uplink band is analyzed, the antenna size for its representative G_{max} value is only 4 meters. In general, a FSS earth station antenna is used for both transmitting and receiving. Since the number of G_{max} data in Section 6.3.3.2 is much larger than the number of G_{max} data here, the representative G_{max} value in this band should be derived by frequency scaling the representative G_{max} value in Section 6.3.3.2. Therefore, the representative G_{max} = 42 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-19.

Table 6-19. Representative FSS Earth Station Antenna Radiation Patterns in 3.6−4.2 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$42 - 2.5 \times 10^{-3}(49.3\times\phi)^2$	$0° \le \phi \le 1.77°$
$29 - 25 \times \log(\phi)$	$1.77° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 4 meters, e = 0.65, f = 3.7 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
$19 - 25 \times \log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7 \times \log(\phi)$	$21.3° < \phi \le 26.3°$
$32 - 25 \times \log(\phi)$	$26.3° < \phi \le 48°$
-10	$48° < \phi \le 180°$

• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.

6.3.3.2 5.85−6.425 GHz Uplink

This band is the corresponding uplink band to the 3.6−4.2 GHz downlink band.

The earth station transmitting antenna G_{max} data count in this band is

- 42, 44 dBi: 24 frequency assignments,
- 45 dBi: 121 frequency assignments,
- 46 dBi: 16 frequency assignments (cumulative population % = 65%),
- 47 dBi: 55 frequency assignments (cumulative population % = 87%),
- 48 dBi: 2 frequency assignments,
- 49 dBi: 9 frequency assignments,
- 51–59 dBi: 21 frequency assignments.

The representative G_{max} = 46 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-20.

Table 6-20. Representative FSS Earth Station Antenna Radiation Patterns in 5.85−6.425 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$46 - 2.5 \times 10^{-3}(79\times\phi)^2$	$0° \leq \phi \leq 1.05°$
27.4	$1.05° < \phi \leq 1.16°$
$29 - 25\times\log(\phi)$	$1.16° < \phi \leq 7°$
8	$7° < \phi \leq 9.2°$
$32 - 25\times\log(\phi)$	$9.2° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 4 meters, *e* = 0.65, *f* = 5.9 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
-10	$48° < \phi \leq 180°$
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
19 - 25×log(ϕ)	x° ≤ ϕ ≤ 7°
-2	7° < ϕ ≤ 21.3°
20.2 - 16.7×log(ϕ)	21.3° < ϕ ≤ 26.3°
32 - 25×log(ϕ)	26.3°< ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.3 7.25−7.75 GHz Downlink

This is a downlink band, and its corresponding uplink band is in 7.9−8.4 GHz.

The population profile of the earth station receiving antenna G_{max} data in this band is shown in Figure 6-28. The representative G_{max} = 57 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-21.

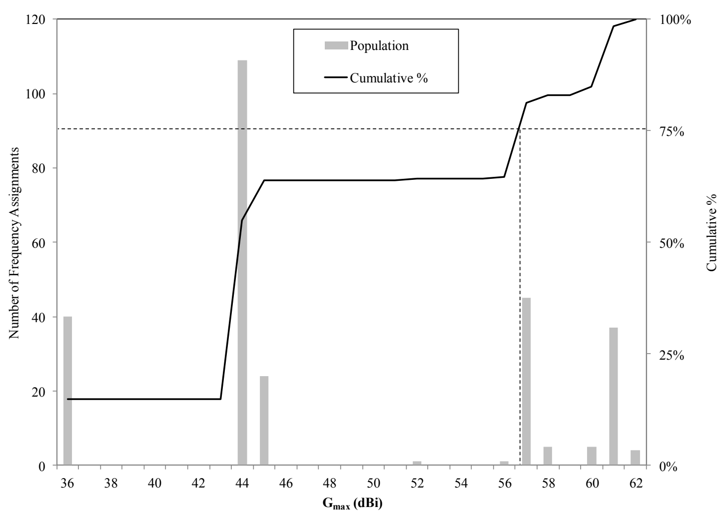


Figure 6-28. Population Profile of FSS Earth Station Receiving Antenna G_{max} Data in 7.25−7.75 GHz

Table 6-21. Representative FSS Earth Station Antenna Radiation Patterns in 7.25−7.75 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$57 - 2.5 \times 10^{-3}(280\times\phi)^2$	0° ≤ ϕ ≤ 0.33°
35.7	0.33° < ϕ ≤ 0.54°
29 - 25×log(ϕ)	0.54° < ϕ ≤ 7°

8	7° < ϕ ≤ 9.2°
32 - 25×log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 11 meters, *e* = 0.65, *f* = 7.64 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
32 - 25 × log(ϕ)	3° ≤ ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
19 - 25×log(ϕ)	x° ≤ ϕ ≤ 7°
-2	7° < ϕ ≤ 21.3°
20.2 - 16.7×log(ϕ)	21.3° < ϕ ≤ 26.3°
32 - 25×log(ϕ)	26.3°< ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.4 7.9−8.4 GHz Uplink

This band is the corresponding uplink band to the 7.25−7.75 GHz downlink band.

The population profile of the earth station transmitting antenna G_{max} data in this band is shown in Figure 6-29. The representative G_{max} = 57 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-22.

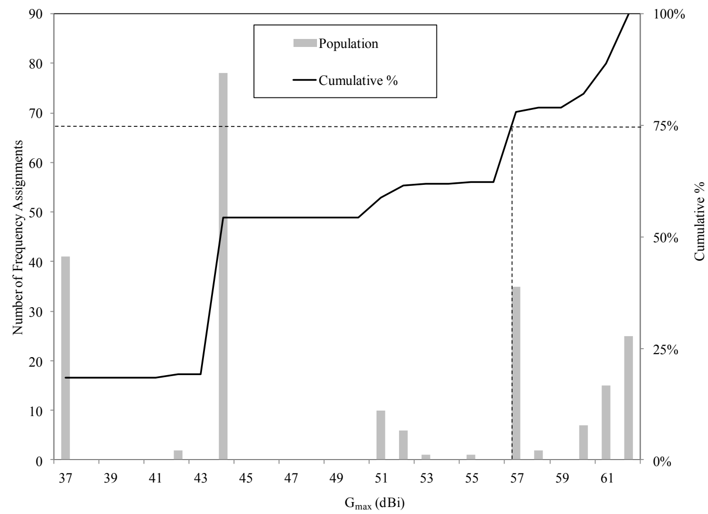


Figure 6-29. Population Profile of FSS Earth Station Transmitting Antenna G_{max} Data in 7.9−8.4 GHz

Table 6-22. Representative FSS Earth Station Antenna Radiation Patterns in 7.9−8.4 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$57 - 2.5 \times 10^{-3}(280\times\phi)^2$	$0° \le \phi \le 0.33°$
35.7	$0.33° < \phi \le 0.54°$
$29 - 25\times\log(\phi)$	$0.54° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 10.5 meters, *e* = 0.65, *f* = 8 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
$19 - 25\times\log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7\times\log(\phi)$	$21.3° < \phi \le 26.3°$

32 - 25×log(ϕ)	26.3°< ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.5 10.7−12.2 GHz Downlink

This band and its corresponding 14−14.5 GHz uplink band are allocated to non-federal systems. Federal agencies are heavy users of these bands by leasing the capacities from the commercial operators.

The earth station receiving antenna G_{max} data count in this band is

- 45 dBi: 1 frequency assignment,
- 48 dBi: 1 frequency assignment,
- 52 dBi: 2 frequency assignments (cumulative population % = 67%),
- 53 dBi: 1 frequency assignment (cumulative population % = 83%),
- 55 dBi: 1 frequency assignment.

The representative G_{max} value is chosen to be 53 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-23.

Table 6-23. Representative FSS Earth Station Antenna Radiation Patterns in 10.7−12.2 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$53 - 2.5 \times 10^{-3}(176\times\phi)^2$	0° ≤ ϕ ≤ 0.51°
32.7	0.51° < ϕ ≤ 0.71°
29 - 25×log(ϕ)	0.71° < ϕ ≤ 7°
8	7° < ϕ ≤ 9.2°
32 - 25×log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 85°
0	85° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 4.8 meters, *e* = 0.65, *f* = 11 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
32 - 25 × log(ϕ)	3° ≤ ϕ ≤ 48°
-10	48° < ϕ ≤ 85°
0	85° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial	

interference path.

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
19 - 25×log(ϕ)	x° ≤ ϕ ≤ 7°
-2	7° < ϕ ≤ 21.3°
20.2 - 16.7×log(ϕ)	21.3° < ϕ ≤ 26.3°
32 - 25×log(ϕ)	26.3°< ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.6 14−14.5 GHz Uplink

This band is the corresponding uplink band to the 10.7−12.2 GHz downlink band.

The population profile of the earth station transmitting antenna G_{max} data in this band is shown in Figure 6-30. The representative G_{max} = 54 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-24.

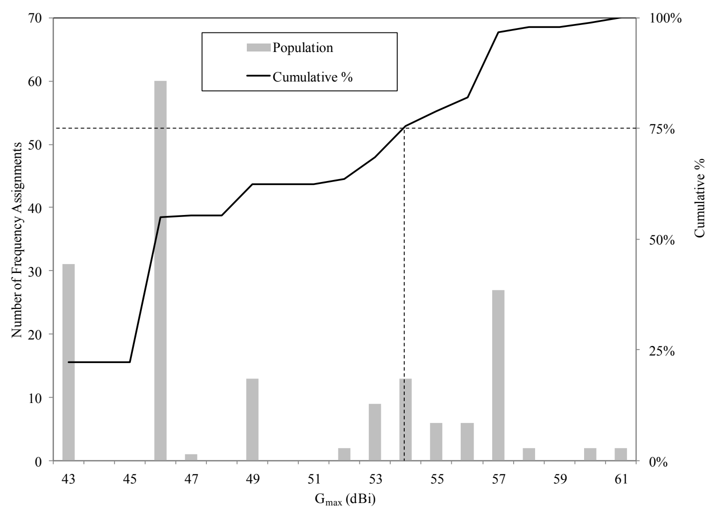


Figure 6-30. Population Profile of FSS Earth Station Transmitting Antenna G_{max} Data in 14−14.5 GHz

Table 6-24. Representative FSS Earth Station Antenna Radiation Patterns in 14−14.5 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$54 - 2.5 \times 10^{-3}(197\times\phi)^2$	0° ≤ ϕ ≤ 0.46°
33.4	0.46° < ϕ ≤ 0.66°

29 - 25×log(ϕ)	0.66° < ϕ ≤ 7°
8	7° < ϕ ≤ 9.2°
32 - 25×log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 85°
0	85° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 4.2 meters, *e* = 0.65, *f* = 14.1 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
32 - 25 × log(ϕ)	3° ≤ ϕ ≤ 48°
-10	48° < ϕ ≤ 85°
0	85° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
19 - 25×log(ϕ)	x° ≤ ϕ ≤ 7°
-2	7° < ϕ ≤ 21.3°
20.2 - 16.7×log(ϕ)	21.3° < ϕ ≤ 26.3°
32 - 25×log(ϕ)	26.3°< ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.7 20.2−21.2 GHz Downlink

This is mainly a downlink band, and its corresponding uplink bands are in 30−31 GHz and 43−45 GHz.

The earth station receiving antenna G_{max} data count in this band is

- 41 dBi: 1 frequency assignment,
- 48 dBi: 50 frequency assignments (cumulative population % = 50%),
- 52 dBi: 50 frequency assignments (cumulative population % = 100%).

The representative G_{max} value is chosen to be 52 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-25.

Table 6-25. Representative FSS Earth Station Antenna Radiation Patterns in 20.2−21.2 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$52 - 2.5 \times 10^{-3}(157.2\times\phi)^2$	$0° \le \phi \le 0.57°$
31.9	$0.57° < \phi \le 0.76°$
$29 - 25\times\log(\phi)$	$0.76° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 85°$
0	$85° < \phi \le 180°$

- ϕ: angle off mainbeam axis, deg.
- This pattern is developed with D = 2.3 meters, *e* = 0.65, *f* = 20.5 GHz.

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
-10	$48° < \phi \le 85°$
0	$85° < \phi \le 180°$

- ϕ: angle off mainbeam axis, deg.
- This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
$19 - 25\times\log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7\times\log(\phi)$	$21.3° < \phi \le 26.3°$
$32 - 25\times\log(\phi)$	$26.3° < \phi \le 48°$
-10	$48° < \phi \le 180°$

- ϕ: angle off mainbeam axis, deg.
- x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.

6.3.3.8 30−31 GHz Uplink

This band is the corresponding uplink band to the 20.2−21.2 GHz downlink band. There are no GMF service records in this band. However, the usage of the 20.2−21.2 GHz downlink band implies that the 30−31 GHz uplink band should be equally used by the federal systems.

Assuming that the same antennas are used both in the uplink and downlink, the earth station transmitting antenna G_{max} value can be calculated by frequency scaling the earth station receiving antenna G_{max} value. Therefore, the representative G_{max} = 55.5 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-26.

Table 6-26. Representative FSS Earth Station Antenna Radiation Patterns in 30−31 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$55.5 - 2.5 \times 10^{-3}(233.8\times\phi)^2$	$0° \le \phi \le 0.39°$
34.5	$0.39° < \phi \le 0.6°$
$29 - 25\times\log(\phi)$	$0.6° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 85°$
0	$85° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 2.3 meters, e = 0.65, f = 30.5 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
-10	$48° < \phi \le 85°$
0	$85° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
$19 - 25\times\log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7\times\log(\phi)$	$21.3° < \phi \le 26.3°$
$32 - 25\times\log(\phi)$	$26.3° < \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.9 43−45 GHz Uplink

This band is the corresponding uplink band to the 20.2−21.2 GHz downlink band.

The GMF has only one service record in this band, with the earth station transmitting antenna G_{max} = 42 dBi. The representative G_{max} = 42 dBi, and the representative antenna radiation patterns for spectrum sharing analyses are provided in Table 6-27.

Table 6-27. Representative FSS Earth Station Antenna Radiation Patterns in 43−45 GHz

(a) Co-Polarization Pattern in the GSO Plane

Gain Function (dBi)	Angular Range
$42 - 2.5 \times 10^{-3}(49.9\times\phi)^2$	$0° \le \phi \le 1.75°$
$29 - 25\times\log(\phi)$	$1.75° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This pattern is developed with D = 0.34 meter, *e* = 0.65, *f* = 44 GHz.	

(b) Co-Polarization Pattern Not in the GSO Plane

Gain Function (dBi)	Angular Range
$32 - 25 \times \log(\phi)$	$3° \le \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.	

(c) Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
$19 - 25\times\log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7\times\log(\phi)$	$21.3° < \phi \le 26.3°$
$32 - 25\times\log(\phi)$	$26.3° < \phi \le 48°$
-10	$48° < \phi \le 180°$
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.	

6.3.3.10 1.35−1.39 GHz Downlink for NGSO System

The GMF contains 3 service records in this band, all with the earth station receiving antenna G_{max} = 17 dBi. The representative G_{max} = 17 dBi. This G_{max} value, approximately corresponding to $D/\lambda = 3$, is much less than the G_{max} range of the radiation pattern in Section 6.3.1. However, Table 5-38 in Section 5.7.1 provides a LMSS earth station antenna reference radiation pattern for circular-beam antennas of $12 \le G_{max}(dBi) \le 18$ operating in 1−3 GHz. This antenna reference radiation pattern is recommended for developing the representative antenna radiation pattern for spectrum sharing analyses here. The representative antenna radiation pattern is provided in Table 6-28.

Table 6-28. Representative NGSO FSS Earth Station Antenna Sidelobe Radiation Pattern in 1.35−1.39 GHz

Gain Function (dBi)	Angular Range
$17 - 12 \times (\phi/23.1)^2$	$0° < \phi \leq 24.1°$
4	$24.1° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$

- ϕ: angle off mainbeam axis, deg.
- Mainbeam and first sidelobe are added to complete the pattern. This will be discussed in Section 6.7.1.1.

6.4 Broadcasting Service

The federal agencies do not operate domestic BS systems, and NTIA does not conduct EMC analysis tasks involving BS systems. Therefore, there is no need to establish the BS antenna radiation performance standard for the federal systems.

6.5 Broadcasting-Satellite Service

The federal agencies do not operate BSS system, and NTIA does not conduct EMC analysis tasks involving BSS systems. Therefore, there is no need to establish the BSS antenna radiation performance standard for the federal systems.

6.6 Mobile Service

A MS system consists of base stations and mobile stations. The antennas of these two classes of stations are different, and they will be analyzed separately. Antennas for the LMS, MMS, and AMS will be discussed separately.

NTIA does not provide the MS antenna radiation performance standards even though the federal agencies have extensive usage of MS. FCC provides LMS and MMS antenna radiation performance standards, and RTCA provides AMS antenna radiation performance standards, which basically are the international standards. These standards will be used to develop the federal MS antenna radiation performance standards.

6.6.1 Land Mobile Service

Most of the LMS systems use omnidirectional antennas, e.g., whip or dipole array antennas, in their base stations and mobile stations. A very small percentage of the stations use directional antennas, e.g., Yagi antennas.

6.6.1.1 System Review

Based on the discussion in Section 5.6.1 pertaining to the LMS antenna performance standards from 47 CFR and the recommended antenna radiation pattern from Rec. ITU-R M.1652-1, the following standards may be used as the LMS antenna performance standards for the federal systems.

(a) Omnidirectional Antenna

The FS P-MP system omnidirectional antenna peak-sidelobe reference radiation pattern in Rec. ITU-R F.1336-3, with improved sidelobe performance, can be used as the LMS base station omnidirectional antenna vertical radiation performance standard. The vertical radiation pattern in Rec. ITU-R M.1652 can be used as the LMS mobile station omnidirectional antenna vertical radiation performance standard. In combination, it is written as:

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \qquad \text{dBi} \qquad (6\text{-}2)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10\times\log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + k \}$, dBi

θ: elevation angle off peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$\theta_{bw} = 107.6 \times 10^{-0.1 G_{max}}$, deg.,

k = 0 for base station antennas,

0.5 for mobile station antennas.

(b) Directional Antenna

It is more practical to use elliptical-beam antennas so as not to waste the EM power into the sky. The azimuth beam sizes depend on the intended coverage areas.

The FS antenna radiation performance standards in Section 6.2.2.2, modified for the elliptical beam, can be adopted as the LMS directional antenna radiation performance standards. The standards are provided in Table 6-29.

Table 6-29. LMS Directional Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(\text{dBi}) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(\text{dBi}) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

6.6.1.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 6.6.1.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.6.1.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.6.1.3 Spectrum Sharing Analyses

In the GMF, only the transmitting antennas have the antenna class information indicating they are for base stations, mobile stations, or repeaters. Hence, the transmitting antennas will be used to develop the representative antenna radiation patterns.

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the LMS service records in the GMF. The symbols of the station classes are "FB" for base station, "FBR" for base station and repeater, "ML" for mobile station, "MLR" for mobile station and repeater, "MLP" for portable mobile station, and "MLPR" for portable mobile station and repeater. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the base station antenna G_{max} data population profile.
(3) Select the threshold G_{max} value such that approximately 75% of the G_{max} population is equal to or smaller than the threshold value. This is the representative G_{max} value. Since the population profile spikes and dips irregularly, the final selection may not meet the 75% criterion closely in some cases.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.6.1.2.
(5) Repeat Steps (2–4) for the mobile station antennas.

The G_{max} data of several adjacent MS and LMS bands have similar population profiles, leading to the same representative G_{max} value and radiation pattern. These bands will be examined together.

The frequency bands being examined are

(1) 498–505 and 525–535 kHz,
(2) 1.605–1.615 and 1.705–1.8 MHz,
(3) 2–3.4 MHz range containing the following bands:
   - 2–2.065 MHz,
   - 2.107–2.17 MHz,
   - 2.1735–2.1905 MHz,
   - 2.194–2.495 MHz,
   - 2.505–2.85 MHz,
   - 3.155–3.4 MHz,
(4) 4.438–8.1 MHz range containing the following bands:
   - 4.438–4.65 MHz,
   - 4.75–4.995 MHz,
   - 5.73–5.9 MHz,
   - 6.765–7 MHz,
   - 7.4–8.1 MHz,
(5) 23.35–24.89 MHz,
(6) 25.33–25.55 and 26.48–26.95 MHz,
(7) 27.54–28 MHz,
(8) 29.89–75.4 MHz range containing the following bands:

- 29.89–29.92 MHz,
- 30–30.56 MHz,
- 32–33 MHz,
- 34–35 MHz,
- 36–37 MHz,
- 38–39 MHz,
- 40–42 MHz,
- 46.6–47 MHz,
- 49.6–50 MHz,
- 74.6–74.8 MHz,
- 75.2–75.4 MHz,

(9) 138–144, 148–149.9, and 150.05–150.8 MHz,
(10) 162.0125–173.2 and 173.4–174 MHz,
(11) 220–420 MHz range containing the following bands:

- 220–222 MHz,
- 225–328.6 MHz,
- 335.4–399.9 MHz,
- 406.1–420 MHz,

(12) 1.755–1.85 GHz,
(13) 2.2–2.3 and 2.36–2.395 GHz, and
(14) 21.2–23.6 GHz.

6.6.1.3.1 496–535 kHz

This frequency range contains the 498–505 and 525–535 kHz MS bands. The GMF only has service records in 498–505 kHz, but the result should be applicable to 525–535 kHz.

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 15 frequency assignments,
- 2 dBi: 5 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}3)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off peak gain plane, in deg.

(b) Mobile Station Antenna

Lacking the mobile station transmitting antenna service records, the receiving antenna service records, which should be for the mobile stations, are used to derive the mobile station antenna G_{max} data. The mobile station receiving antenna G_{max} data count is

- 0 dBi: 16 frequency assignments,
- 2 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \le 99.4° \qquad (6\text{-}4)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.2 1.605–1.8 MHz

This frequency range contains the 1.605–1.615 and 1.705–1.8 MHz MS bands. The GMF only has service records in 1.605–1.615 MHz, but the result should be applicable to 1.705–1.8 MHz.

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 17 frequency assignments,
- 1 dBi: 2 frequency assignments (cumulative population % = 76%),
- 2 dBi: 5 frequency assignments,
- 3 dBi: 1 frequency assignment.

The representative G_{max} = 1 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 1 - 12(\theta/85.5)^2 \quad \text{dBi for } |\theta| \le 78.9° \qquad (6\text{-}5)$$
$$= -11 + 10\times\log\{ [\max(|\theta|/85.5, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 78.9°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The GMF does not have service records containing the mobile station transmitting antenna data in these bands. Hence, the receiving antenna service records, which should be for the mobile stations, are used to derive the mobile station antenna G_{max} data. The mobile station receiving antenna service records all have G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \le 99.4° \qquad (6\text{-}6)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.3 2–3.4 MHz

This frequency range contains the following MS bands:

- 2–2.065 MHz,
- 2.107–2.17 MHz,
- 2.1735–2.1905 MHz,

- 2.194–2.495 MHz,
- 2.505–2.85 MHz,
- 3.155–3.4 MHz.

The GMF does not have service records in 2.1735–2.1905 MHz, but the results derived from the other bands should be applicable in this band.

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 58 frequency assignments,
- 1, 2 dBi: 12 frequency assignments,
- 3 dBi: 164 frequency assignments (cumulative population % = 87%),
- 4 dBi: 9 frequency assignments,
- 5 dBi: 22 frequency assignments,
- 6–12 dBi: 4 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= 3 - 12(\theta/53.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \qquad (6\text{-}7)\\
&= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} && \text{dBi} \quad \text{for} \quad |\theta| > 49.8°
\end{aligned}
$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The mobile station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 124 frequency assignments,
- 1 dBi: 4 frequency assignments,
- 2 dBi: 38 frequency assignments,
- 3 dBi: 196 frequency assignments (cumulative population % = 88%),
- 4 dBi: 10 frequency assignments,
- 5 dBi: 21 frequency assignments,
- 6–12 dBi: 19 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= 3 - 12(\theta/53.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \qquad (6\text{-}8)\\
&= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} + 0.5 \} && \text{dBi} \quad \text{for} \quad |\theta| > 49.8°
\end{aligned}
$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.4 4.438–8.1 MHz

This frequency range contains the following MS bands:

- 4.438–4.65 MHz,
- 4.75–4.995 MHz,
- 5.73–5.9 MHz,
- 6.765–7 MHz,
- 7.4–8.1 MHz.

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 120 frequency assignments,
- 1 dBi: 5 frequency assignments,
- 2 dBi: 17 frequency assignments (cumulative population % = 72.1%),
- 3 dBi: 14 frequency assignments (cumulative population % = 79.2%),
- 4 dBi: 10 frequency assignments,
- 5 dBi: 21 frequency assignments,
- 6–12 dBi: 10 frequency assignments.

The representative G_{max} = 2 dBi. The representative antenna vertical radiation pattern for spectrum sharing studies is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}9)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The population profile of the mobile station transmitting antenna G_{max} data in these bands is shown in Figure 6-31. The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}10)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

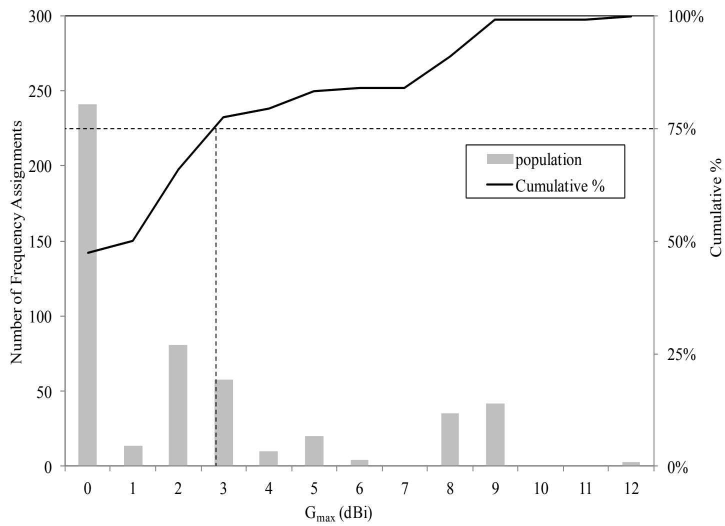


Figure 6-31. Population Profile of LMS Mobile Station Transmitting Antenna G_{max} Data in 4.438−8.1 MHz

6.6.1.3.5 23.35–24.89 MHz

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in this band is

- 0, 1 dBi: 7 frequency assignments,
- 2 dBi: 1 frequency assignment,
- 3 dBi: 14 frequency assignments (cumulative population % = 85%),
- 6 dBi: 4 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}11)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The mobile station transmitting antenna G_{max} data count in this band is

- 0, 1, 2 dBi: 19 frequency assignments,
- 3 dBi: 14 frequency assignments,
- 6 dBi: 5 frequency assignments (cumulative population % = 63%),
- 9 dBi: 21 frequency assignments (cumulative population % = 98%),
- 13 dBi: 1 frequency assignment.

The representative G_{max} = 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 25° \qquad (6\text{-}12)$$

$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.6 25.33–26.95 MHz

This frequency range contains the 25.33–25.55 and 26.48–26.95 MHz MS bands.

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 34 frequency assignments (cumulative population % = 89%),
- 2, 3 dBi: 4 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}13)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The mobile station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 49 frequency assignments (cumulative population % = 79%),
- 2, 3 dBi: 13 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}14)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.7 27.54–28 MHz

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in this band is

- 0 dBi: 8 frequency assignments,
- 2 dBi: 1 frequency assignment,
- 3 dBi: 16 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}15)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The mobile station transmitting antenna G_{max} data count in this band is

- 0 dBi: 14 frequency assignments,
- 2 dBi: 4 frequency assignments,
- 3 dBi: 19 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}16)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.8 29.89–75.4 MHz

This frequency range contains the following MS bands:

- 29.89–29.92 MHz,
- 30–30.56 MHz,
- 32–33 MHz,
- 34–35 MHz,
- 36–37 MHz,
- 38–39 MHz,
- 40–42 MHz,
- 46.6–47 MHz,
- 49.6–50 MHz,
- 74.6–74.8 MHz,
- 75.2–75.4 MHz.

(a) Base Station Antenna

The base station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 109 frequency assignments,
- 1 dBi: 6 frequency assignments,
- 2 dBi: 52 frequency assignments (cumulative population % = 82%),
- 3 dBi: 20 frequency assignments,
- 5–8 dBi: 17 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}17)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The mobile station transmitting antenna G_{max} data count in these bands is

- 0 dBi: 451 frequency assignments,
- 1 dBi: 12 frequency assignments,
- 2 dBi: 221 frequency assignments (cumulative population % = 85%),
- 3 dBi: 91 frequency assignments,
- 5–7 dBi: 29 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}18)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.9 138–150.08 MHz

This frequency range contains the following MS bands:

- 138–144 MHz,
- 148–149.9 MHz,
- 150.05–150.8 MHz.

(a) Base Station Antenna

The population profile of the base station transmitting antenna G_{max} data in these bands is shown in Figure 6-32. The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}19)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

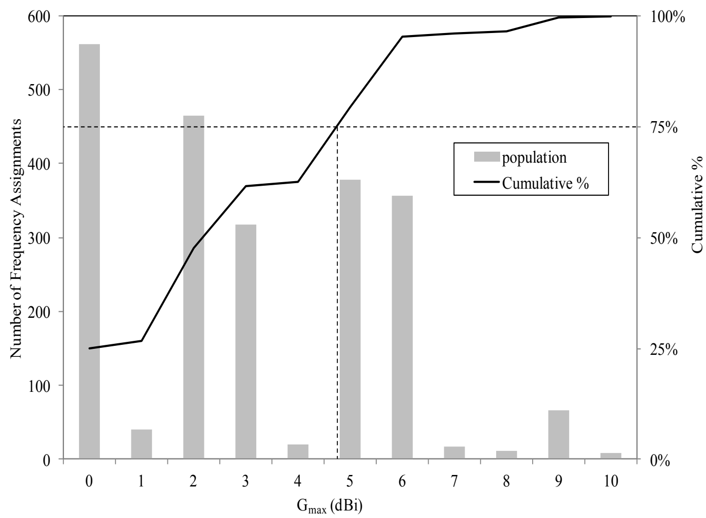


Figure 6-32. Population Profile of LMS Base Station Transmitting Antenna G_{max} Data in 138–150.08 MHz

(b) Mobile Station Antenna

The population profile of the mobile station transmitting antenna G_{max} data in these bands is shown in Figure 6-33. The percentages of cumulative population are 70.8% and 80.5% for G_{max} = 2 dBi and 3 dBi, respectively, and the representative G_{max} is chosen to be 3 dBi to protect more federal systems. The representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}20)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

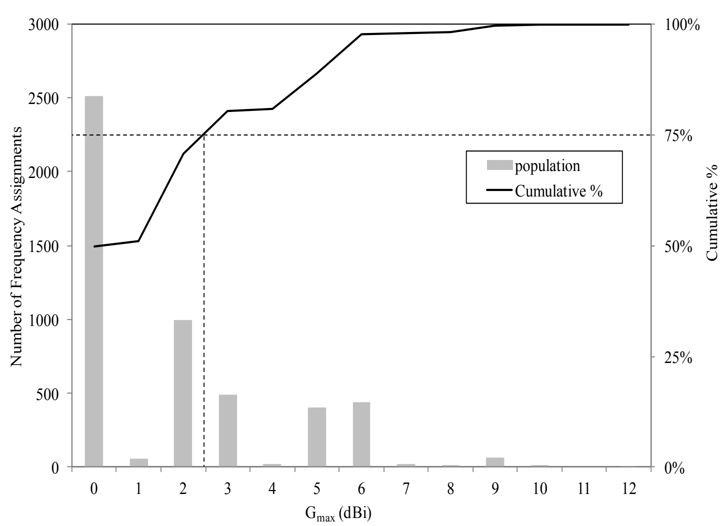


Figure 6-33. Population Profile of LMS Mobile Station Transmitting Antenna G_{max} Data in 138–150.08 MHz

6.6.1.3.10 162–174 MHz

This frequency range contains the 162.0125–173.2 and 173.4–174 MHz MS bands.

(a) Base Station Antenna

The population profile of the base station transmitting antenna G_{max} data in these bands is shown in Figure 6-34. The percentages of cumulative population are 53% and 95.2% for G_{max} = 5 dBi and 6 dBi, respectively, and the representative G_{max} is chosen to be 6 dBi to protect more federal systems. The representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}21)$$
$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

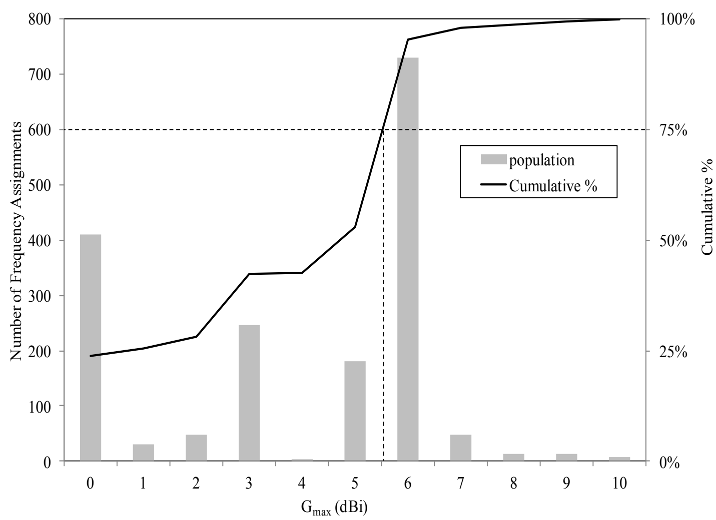


Figure 6-34. Population Profile of LMS Base Station Transmitting Antenna G_{max} Data in 162–174 MHz

(b) Mobile Station Antenna

The population profile of the mobile station transmitting antenna G_{max} data in these bands is shown in Figure 6-35. The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}22)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

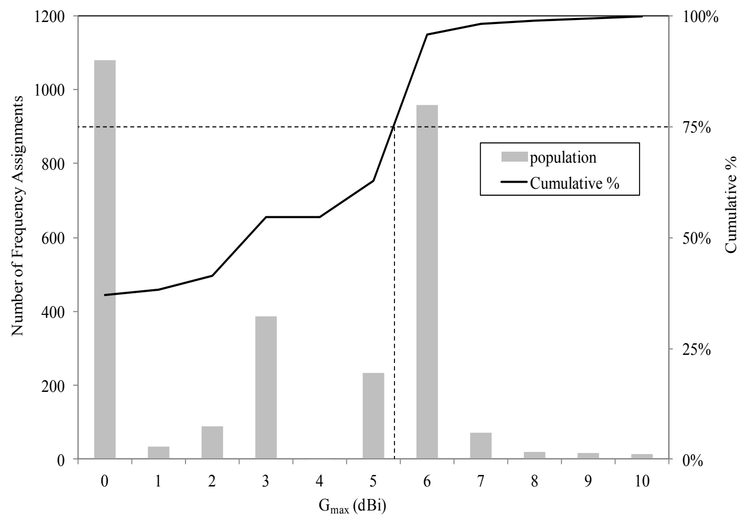


Figure 6-35. Population Profile of LMS Mobile Station Transmitting Antenna G_{max} Data in 162–174 MHz

6.6.1.3.11 220–420 MHz

This frequency range contains the following MS bands:

- MS:
  - 225–328.6 MHz,
  - 335.4–399.9 MHz,
  - 406.1–420 MHz,
- LMS: 220–222 MHz.

(a) Base Station Antenna

The population profile of the base station transmitting antenna G_{max} data in these bands is shown in Figure 6-36. The percentages of cumulative population are 69.8% and 79% for G_{max} = 5 dBi and 6 dBi, respectively, and the representative G_{max} is chosen to be 6 dBi to protect more federal systems. The representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 25° \qquad (6\text{-}23)$$
$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

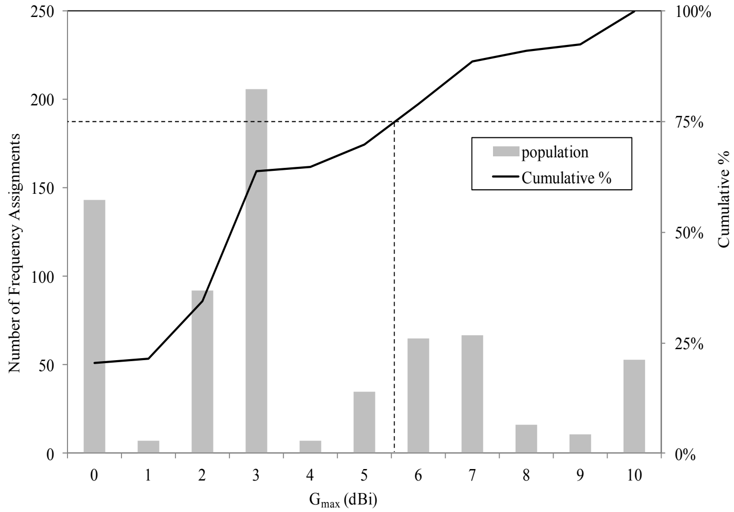


Figure 6-36. Population Profile of LMS Base Station Transmitting Antenna G_{max} Data in 220–420 MHz

(b) Mobile Station Antenna

The population profile of the mobile station transmitting antenna G_{max} data in these bands is shown in Figure 6-37. The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \qquad (6\text{-}24)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg

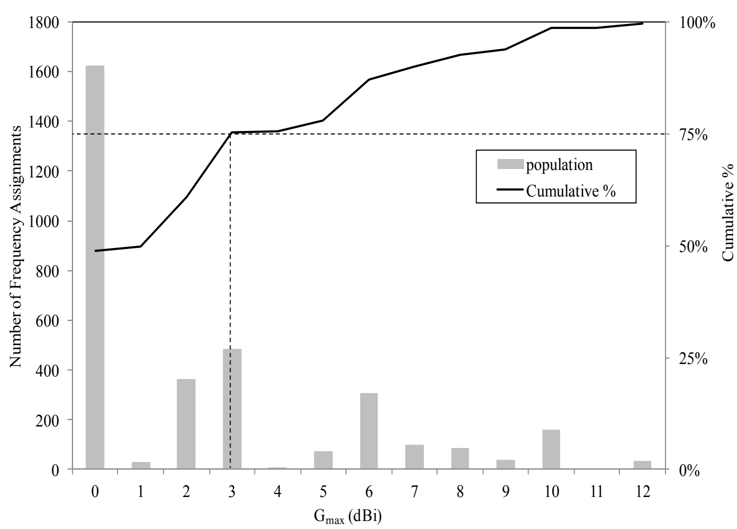


Figure 6-37. Population Profile of LMS Mobile Station Transmitting Antenna G_{max} Data in 220–420 MHz

6.6.1.3.12 1.755–1.85 GHz

(a) Base Station Antenna

There are 2 base station transmitting antenna service records in this band, with both G_{max} = 2 dBi. The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}25)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Antenna

The mobile station transmitting antenna G_{max} data count in this band is

- 0 dBi: 10 frequency assignments,
- 2 dBi: 13 frequency assignments,
- 3 dBi: 29 frequency assignments (cumulative population % = 86%),
- 9 dBi: 4 frequency assignments,
- 12 dBi (directional): 2 frequency assignments,
- 20, 28 dBi (directional): 2 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \qquad (6\text{-}26)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.1.3.13 2.2–2.395 GHz

This frequency range contains the 2.2–2.3 and 2.36–2.395 GHz MS bands. The GMF has only the mobile station antenna data in these bands. The numbers of the omnidirectional and directional antenna data are comparable, thus both types will be analyzed.

(a) Mobile Station Omnidirectional Antenna

The mobile station omnidirectional transmitting antenna G_{max} data count in these bands is

- 0 dBi: 2 frequency assignments,
- 2 dBi: 17 frequency assignments (cumulative population % = 76%),
- 3 dBi: 6 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}27)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Mobile Station Directional Antenna

The mobile station directional transmitting antenna G_{max} data count in these bands is

- 12 dBi (corner reflector antenna): 5 frequency assignments,
- 14 dBi (patch antenna): 7 frequency assignments.

The representative G_{max} = 14 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-30.

Table 6-30. Representative LMS Mobile Station Directional Antenna Radiation Pattern in 2.2−2.395 GHz

Gain(ϕ) (dBi)	Angular Range (deg.)
$14 - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
3.5	$\phi_m < \phi \le 49.9°$
$46 - 25 \times \log(\phi)$	$49.9° < \phi \le 69.2°$
0	$69.2° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. ϕ_m : intersection of $\{14 - 12(\phi/\phi_{bw})^2\}$ and 3.5	

6.6.1.3.14 21.2–23.6 GHz

The GMF has only mobile station antenna data in this band.

The mobile station transmitting antenna G_{max} data count is

- 0, 3 dBi: 3 frequency assignments,
- 12 dBi (cylindrical array): 2 frequency assignments,
- 13 dBi (log periodic antenna): 11 frequency assignments (cumulative population % = 70%),
- 26 dBi (parabolic antenna): 1 frequency assignment (cumulative population % = 74%),
- 33 dBi (parabolic antenna): 3 frequency assignments,
- 36, 38 dBi (parabolic antenna): 3 frequency assignments.

The representative G_{max} is chosen to be 13 dBi instead of 26 dBi, which is closer to the threshold of 75%, because the combination of 12 dBi and 13 dBi accounts for the largest portion of the population, and because of the big gap between 13 dBi and 26 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-31.

Table 6-31. Representative LMS Mobile Station Directional Antenna Radiation Pattern in 21.2−23.6 GHz

Gain (ϕ) (dBi)	Angular Range (deg.)
$13 - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
2.75	$\phi_m < \phi \leq 56°$
$46.5 - 25 \times \log(\phi)$	$56° < \phi \leq 72.4°$
0	$72.4° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. ϕ_m : intersection of $\{13 - 12(\phi/\phi_{bw})^2\}$ and 2.75	

6.6.2 Maritime Mobile Service

MMS systems use both omnidirectional and directional antennas at the coast stations, and mostly omnidirectional antennas onboard ships.

6.6.2.1 System Review

NTIA does not provide the MMS antenna radiation performance standards for system review. Because the LMS base station and the MMS coast station perform similar functionalities, the LMS base station antenna radiation performance standards in Section 6.6.1.1 are recommended as the MMS coast station antenna radiation performance standards. These standards are provided below.

(a) Coast Station Omnidirectional Antenna

The recommended MMS coast station omnidirectional antenna vertical radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (6\text{-}28)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10\times\log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.,

(b) Coast Station Directional Antenna

The recommended MMS coast station directional antenna radiation performance standards are provided in Table 6-32.

Table 6-32. MMS Coast Station Directional Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \ge 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le \phi_{b1}$
	-13	$\phi_{b1} < \phi \le 180°$
$22 \le G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \le 180°$
$10 \le G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \le \phi_{b3}$
	0	$\phi_{b3} < \phi \le 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

(c) Shipborne Omnidirectional Antenna

When an antenna is installed on a ship, its radiation pattern is heavily influenced by the ship structure and the antenna installation. Lacking any viable data, the recommended LMS omnidirectional antenna vertical radiation performance standard in Section 6.6.1.1 is used as the MMS shipborne omnidirectional antenna vertical radiation performance standard; it is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \qquad \text{dBi} \qquad (6\text{-}29)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + 0.5 \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

RTCM is currently developing the MMS shipborne antenna radiation performance standards. Its result, when established, will be examined to determine if the federal standards should be amended.

6.6.2.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 6.6.2.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.6.2.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.6.2.3 Spectrum Sharing Analyses

In the GMF, only the transmitting antennas have the station class information indicating they are coast stations, ship stations, or repeaters. Since in general the antennas are for both transmitting and receiving, the transmitting antennas will be used to obtain the representative antenna G_{max} value and the radiation patterns.

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the MMS service records in the GMF. The station classes are “FC” for coast stations, “FCB” for broadcasting coast stations, “FCD” for telecommand coast stations, “MS” for ship stations, “MSD” for ship telecommand stations, and “MSP” for portable ship stations. Only the frequency bands in which the federal government is the primary user are searched.

(2) Develop the costal station antenna G_{max} data population profile.

(3) Select the threshold G_{max} value such that approximately 75% of the G_{max} population is equal to or smaller than the threshold value. This is the representative G_{max} value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.6.2.2.
(5) Repeat Steps (2–4) for the shipborne antennas. Only the ship stations whose locations are in the 50 States, D.C., U.S. Commonwealths and Possessions, and within the U.S. coastal waters are processed.

The G_{max} data of several adjacent MS and MMS bands have similar population profiles, leading to the same representative antenna G_{max} value and radiation pattern. These bands will be examined together.

The frequency bands being examined are

(1) 20.05–59, 61–90, and 110–190 kHz,
(2) 415–535 kHz range containing the following bands:
    - 415–495 kHz,
    - 496–505 kHz,
    - 505–525 kHz.
    - 525–535 kHz,
(3) 2.065–2.107, 2.17–2.1735, and 2.1905–2.194 MHz,
(4) 2–3.4 MHz range containing the following bands:
    - 2–2.065 MHz,
    - 2.107–2.17 MHz,
    - 2.1735–2.1905 MHz,
    - 2.194–2.495 MHz,
    - 2.505–2.85 MHz,
    - 3.155–3.4 MHz,
(5) 4–5.9 MHz range containing the following bands:
    - 4.438–4.65 MHz,
    - 4.75–4.995 MHz,
    - 5.73–5.9 MHz,
    - 4–4.438 MHz,
(6) 6.765–7, 7.4–8.1, 8.1–8.815 MHz,
(7) 12.23–19.8 MHz range containing the following bands:
    - 12.23−13.2 MHz,
    - 16.36−17.41 MHz,
    - 18.78−18.9 MHz,
    - 19.68−19.8 MHz,
(8) 23.35–28 MHz range containing the following bands:
    - 23.35–24.89 MHz,
    - 25.07–25.21 MHz,
    - 25.33–25.55 MHz,
    - 26.1–26.175 MHz,
    - 26.48–26.95 MHz,
    - 27.54–28 MHz,

(9) 138–174 MHz range containing the following bands:
  - 138–144 MHz,
  - 148–149.9 MHz,
  - 150.05–150.8 MHz,
  - 157.0375–157.1875 MHz,
  - 162.0125–173.2 MHz, and
  - 173.4–174 MHz.

6.6.2.3.1 20–190 kHz

This frequency range contains the following MMS bands:

- 20.05–59 kHz,
- 61–90 kHz,
- 110–190 kHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 11 frequency assignments (cumulative population % = 85%),
- 2 dBi: 1 frequency assignment,
- 4 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}30)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The GMF does not have shipborne transmitting antenna service records in these bands. However, it has 4 receiving antenna service records, which should be shipborne, with all the G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and this is an omnidirectional antenna; the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}31)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.2 415–535 kHz

This frequency range contains the following MS bands:

- MS:
  - o 496–505 kHz,

    - 525–535 kHz,
- MMS:
    - 415–495 kHz,
    - 505–525 kHz.

The GMF has 2 service records in the 415–495 kHz band, and the transmission is from Newport News, Virginia to coastal Virginia. The result should be applicable to all bands.

(a) Coast Station Antenna

Both coast station transmitting antennas are omnidirectional, with both G_{max} = 2 dBi. The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}32)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

Both shipborne receiving antennas are omnidirectional, with both G_{max} = 2 dBi. The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}33)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.3 2.065–2.194 MHz

This frequency range contains the following MMS bands:

- 2.065–2.107 MHz,
- 2.17–2.1735 MHz,
- 2.1905–2.194 MHz.

The GMF has five MMS service records in the 2.065–2.107 MHz band, and they are from coast stations to ships and aircrafts over coastal water. The result should be applicable to all the bands in this frequency range.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 4 frequency assignments (cumulative population % = 80%),
- 2 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \le 99.4° \qquad (6\text{-}34)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The shipborne receiving antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 3 frequency assignments (cumulative population % = 75%),
- 3 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \le 99.4° \qquad (6\text{-}35)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.4 2–3.4 MHz

This frequency range contains the following MS bands:

- 2–2.065 MHz,
- 2.107–2.17 MHz,
- 2.1735–2.1905 MHz,
- 2.194–2.495 MHz,
- 2.505–2.85 MHz,
- 3.155–3.4 MHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 84 frequency assignments,
- 1 dBi: 11 frequency assignments,
- 2 dBi: 28 frequency assignments (cumulative population % = 73.6%),
- 3 dBi: 6 frequency assignments (cumulative population % = 77.3%),
- 4 dBi: 9 frequency assignments,
- 5–10 dBi: 29 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi for } |\theta| \le 62.7° \qquad (6\text{-}36)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The shipborne transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 146 frequency assignments (cumulative population % = 76%),
- 1−4 dBi: 22 frequency assignments,
- 5 dBi: 21 frequency assignments,
- 6−10 dBi: 4 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}37)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.5 4–5.9 MHz

This frequency range contains the following MS bands:

- MS:
  - 4.438–4.65 MHz,
  - 4.75–4.995 MHz,
  - 5.73–5.9 MHz,
- MMS: 4–4.438 MHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 65 frequency assignments,
- 1 dBi: 8 frequency assignments (cumulative population % = 61%),
- 2 dBi: 32 frequency assignments (cumulative population % = 88%),
- 3–6 dBi: 14 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}38)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The shipborne transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 32 frequency assignments,
- 1 dBi: 27 frequency assignments (cumulative population % = 74.7%),
- 2 dBi: 13 frequency assignments,
- 3–6 dBi: 7 frequency assignments.

The representative G_{max} = 1 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 1 - 12(\theta/85.5)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 78.9° \qquad (6\text{-}39)$$
$$= -11 + 10\times\log\{ [\max(|\theta|/85.5, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 78.9°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.6 6.765–8.815 MHz

This frequency range contains the following MS bands:

- MS:
    - 6.765–7 MHz,
    - 7.4–8.1MHz ,
- MMS: 8.1–8.815 MHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 108 frequency assignments,
- 1 dBi: 5 frequency assignments,
- 2 dBi: 42 frequency assignments (cumulative population % = 77.5%),
- 3 dBi: 7 frequency assignments,
- 4–12 dBi: 38 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}40)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

Only the stations whose localities are in the U.S. and labeled as “coastal water” are processed. The shipborne transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 77 frequency assignments,
- 1 dBi: 19 frequency assignments,
- 2 dBi: 14 frequency assignments (cumulative population % = 75.3%),
- 3 dBi: 4 frequency assignments,
- 5 dBi: 21 frequency assignments,
- 6, 12 dBi: 11 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}41)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.7 12.23–19.8 MHz

This frequency range contains the following MMS bands:

- 12.23−13.2 MHz,
- 16.36−17.41 MHz,
- 18.78−18.9 MHz,
- 19.68−19.8 MHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 40 frequency assignments,
- 1 dBi: 9 frequency assignments (cumulative population % = 62%),
- 2 dBi: 20 frequency assignments (cumulative population % = 87.3%),
- 3 dBi: 3 frequency assignments,
- 4 dBi: 3 frequency assignments,
- 5, 6, 14 dBi: 4 frequency assignments.

The representative G_{max} is chosen to be 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}42)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The shipborne transmitting antennas are all omnidirectional in these bands, and the G_{max} data count is

- 0 dBi: 20 frequency assignments,
- 1 dBi: 41 frequency assignments (cumulative population % = 75.3%),

- 2 dBi: 14 frequency assignments,
- 3–14 dBi: 6 frequency assignments.

The representative G_{max} = 1 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 1 - 12(\theta/85.5)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 78.9° \qquad (6\text{-}43)$$
$$= -11 + 10\times\log\{ [\max(|\theta|/85.5, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 78.9°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.8 23.35–28 MHz

This frequency range contains the following MS bands:

- MS:
  - 23.35–24.89 MHz,
  - 25.33–25.55 MHz,
  - 26.48–26.95 MHz,
  - 27.54–28 MHz,
- MMS:
  - 25.07–25.21 MHz,
  - 26.1–26.175 MHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 86 frequency assignments (cumulative population % = 77%),
- 1 dBi: 2 frequency assignments,
- 2 dBi: 17 frequency assignments,
- 3−6 dBi: 7 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}44)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The shipborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 49 frequency assignments (cumulative population % = 64.5%),
- 1 dBi: 7 frequency assignments (cumulative population % = 86.8%),
- 2 dBi: 4 frequency assignments,
- 3, 6 dBi: 6 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \leq 99.4° \qquad (6\text{-}45)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} + 0.5 \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.2.3.9 138–174 MHz

This frequency range contains the following MS bands:

- MS:
    - 138–144 MHz,
    - 148–149.9 MHz,
    - 150.05–150.8 MHz,
    - 162.0125–173.2 MHz,
    - 173.4–174 MHz,
- MMS: 157.0375–157.1875 MHz.

(a) Coast Station Antenna

The coast station transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0–2 dBi: 68 frequency assignments,
- 3 dBi: 52 frequency assignments,
- 4 dBi: 1 frequency assignment,
- 5 dBi: 15 frequency assignments (cumulative population % = 73.5%),
- 6 dBi: 44 frequency assignments,
- 7–12 dBi: 5 frequency assignments.

The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi for } |\theta| \leq 31.4° \qquad (6\text{-}46)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Shipborne Antenna

The shipborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0–1 dBi: 270 frequency assignments,
- 2 dBi: 108 frequency assignments,
- 3 dBi: 160 frequency assignments,
- 4 dBi: 2 frequency assignments (cumulative population % = 74.8%),
- 5dBi: 54 frequency assignments,

- 6 dBi: 118 frequency assignments,
- 7–12 dBi: 10 frequency assignments.

The representative G_{max} = 4 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 4 - 12(\theta/42.8)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 39.6° \qquad (6\text{-}47)$$
$$= -8 + 10\times\log\{ [\max(|\theta|/42.8, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 39.6°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.6.3 Aeronautical Mobile Service

Federal AMS systems use mostly omnidirectional antennas in their land stations and aircraft stations for in-flight operations. Directional antennas are mostly used at the airport land stations for take-off and landing operations.

6.6.3.1 System Review

NTIA does not provide the AMS antenna radiation performance standards for system review. These standards can be developed as follows.

(a) Land-Based Omnidirectional Antenna

Because the LMS base station and the AMS land station perform similar functionalities, the LMS base station antenna radiation performance standards in Section 6.6.1.1 are recommended as the AMS land-based antenna radiation performance standards.

The AMS land-based omnidirectional antenna performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (6\text{-}48)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10\times\log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

(b) Land-Based Directional Antenna

In Section 5.6.3, Rec. ITU-R M.1459 provides a recommended reference radiation pattern for the AMS land-based directional antennas which is shown in Table 5-37. However, as discussed in Section 5.6.3, this reference radiation pattern is really the combination of two reference radiation patterns of different antenna sizes, and is not a realistic radiation pattern.

Hence, the LMS antenna radiation performance standards in Section 6.6.1.1 are recommended as the AMS land-based directional antenna radiation performance standards; these standards are shown in Table 6-33.

Table 6-33. AMS Land-Based Directional Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(b) High-Gain Antenna

Category	Gain(φ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

(c) Airborne Antenna

One of the factors for selecting an airborne antenna is aerodynamics. Therefore, antenna radiation performance standards should not be established for the purpose of system review.

6.6.3.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

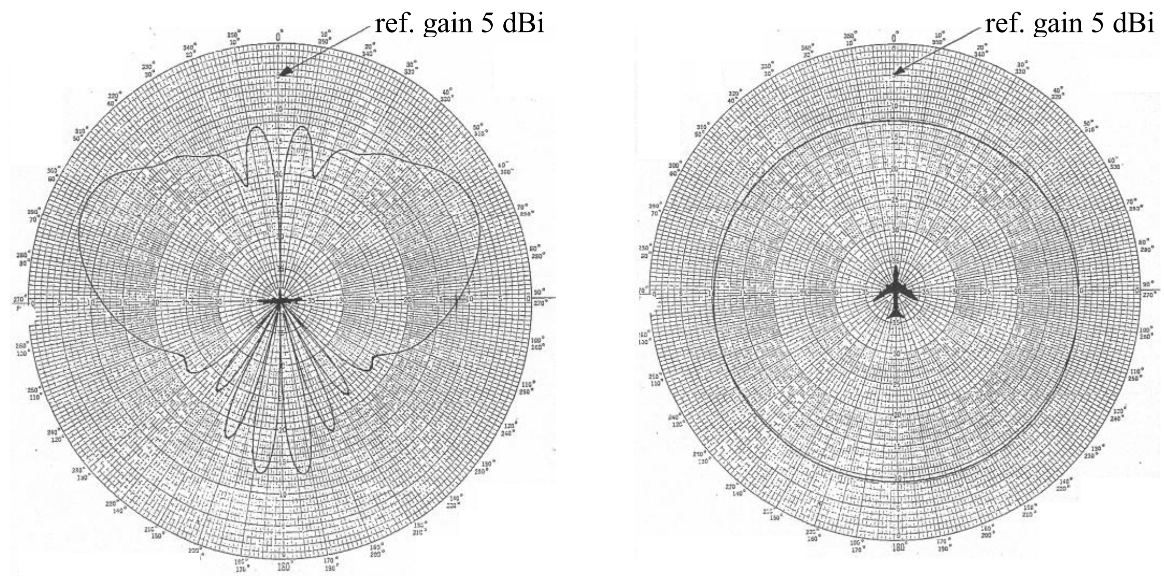
For the land-based antenna, when the actual antenna radiation patterns are not available, the radiation performance standards in Section 6.6.3.1 may be used as the reference radiation patterns. The radiation performance standards in Section 6.6.3.1 do not specify the G_{max} value; however, such data should be available in the GMF.

The airborne antenna radiation pattern is heavily influenced by the aircraft structure and antenna installation; thus, it is impossible to develop a general radiation pattern.

For the airborne omnidirectional antenna, Section 5.6.3 contains the recommended airborne omnidirectional antenna technical characteristics from Rec. ITU-R M.1459 for the telemetry and telecommand operations in the 1.452−1.525 and 2.31−2.36 GHz bands, which recommends that the power gain follows the rule:

$$P_1(G \leq G_1) = [1 - \exp(-3.46\ G_1)]^{1.25} \qquad (6\text{-}49)$$

where P_1 is the probability that a given gain value, G_1, may not exceed. However, this cannot be used to develop a radiation pattern. Here, using the worst-case scenario for frequency assignment, the reference radiation pattern has three-dimensional uniformity, with gain values equal G_{max} in all directions. The measured airborne omnidirectional antenna radiation pattern, shown in Figure 6-38, justifies the worst-case scenario. The G_{max} data should be available in the GMF.



(a) Front View **(b) Top View**

Figure 6-38. Measured Airborne Antenna Radiation Patterns

For the airborne directional antenna, a reference radiation pattern applicable for all cases cannot be developed because of the complexities and variations of the aircraft structure.

6.6.3.3 Spectrum Sharing Analyses

In the GMF, only the transmitting stations have the station class information indicating they are land stations or aircraft stations. The representative antenna radiation patterns will be developed from the transmitting station antenna G_{max} data and the reference radiation patterns in Section 6.6.3.2.

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the AMS service records in the GMF. The land station classes are “FA” for AMS stations, “FG” for AMS(OR) stations, “FD” for AMS(R) stations, and “FAD” for telecommand AMS stations. The aircraft station classes are “MA” for aircrafts, “MAD” for telecommand aircrafts, and “MAP” for portable aircrafts. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the land-based transmitting antenna G_{max} data population profile.
(3) Select a threshold G_{max} value such that approximately 75% of the G_{max} population is equal to or smaller than the threshold value. This is the representative G_{max} value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.6.3.2.
(5) Repeat steps (2–4) for the airborne antennas.

The G_{max} data of several adjacent MS and AMS bands have similar population profiles, leading to the same representative G_{max} value and antenna radiation pattern. These bands will be presented in one group.

The frequency bands being examined are

(1) 2−3.5 MHz range containing the following bands:
- 2–2.065 MHz,
- 2.107–2.17 MHz,
- 2.1735–2.1905 MHz,
- 2.194–2.495 MHz,
- 2.505–2.85 MHz,
- 2.85–3.155 MHz,
- 3.155–3.4 MHz,
- 3.4–3.5 MHz,

(2) 4.438−5.73 MHz range containing the following bands:
- 4.438–4.65 MHz,
- 4.75–4.995 MHz,
- 4.65–4.75 MHz,
- 5.45–5.73 MHz,

(3) 5.73−8.1MHz range containing the following bands:
- 5.73–5.9 MHz,
- 6.525–6.765 MHz,
- 6.765–7 MHz,
- 7.4–8 MHz,

(4) 8.815−18.03 MHz range containing the following bands:
- 8.815−9.04 MHz,
- 11.175−11.4 MHz,
- 13.2−13.36 MHz,
- 15.01−15.6 MHz,
- 17.9−18.03 MHz,

(5) 21.924−22 and 23.2−23.35 MHz,

(6) 23.35−30.56 MHz range containing the following bands:
- 23.35−24.89 MHz,
- 25.33−25.55 MHz,
- 26.48−26.95 MHz,
- 27.54−28 MHz,
- 29.89−29.91 MHz,
- 30−30.56 MHz,

(7) 32−50 MHz range containing the following bands:
- 32−33 MHz,
- 34−35 MHz,
- 36−37 MHz,
- 38−39 MHz,
- 40−42 MHz,
- 46.6−47 MHz,
- 49.6−50 MHz,

(8) 117.975−137 MHz

(9) 138−144, 148−149.9, and 150.05−150.8 MHz,

(10) 162.0125−173.2 and 173.4−174 MHz,
(11) 225−328.6, 335.4−399.9. and 406.1−420 MHz,
(12) 1.35−1.525 GHz,
(13) 1.755−1.85 GHz, and
(14) 4.4−4.94 GHz.

6.6.3.3.1 2−3.5 MHz

This frequency range contains the following MS bands:

- MS:
  - 2–2.065 MHz,
  - 2.107–2.17 MHz,
  - 2.1735–2.1905 MHz,
  - 2.194–2.495 MHz,
  - 2.505–2.85 MHz,
  - 3.155–3.4 MHz,
- AMS:
  - 2.85–3.155 MHz,
  - 3.4–3.5 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 65 frequency assignments,
- 1 dBi: 4 frequency assignments,
- 2 dBi: 14 frequency assignments (cumulative population % = 64.9%),
- 3 dBi: 20 frequency assignments (cumulative population % = 80.5%),
- 4 dBi: 9 frequency assignments,
- 5–12 dBi: 12 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$\begin{aligned} G(\theta) &= 3 - 12(\theta/53.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \\ &= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} && \text{dBi} \quad \text{for} \quad |\theta| > 49.8° \end{aligned} \tag{6-50}$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 28 frequency assignments (cumulative population % = 74%),
- 2−6 dBi: 8 frequency assignments,
- 12 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi. The radiation pattern is uniform, with G = G_{max} = 0 dBi in all directions.

6.6.3.3.2 4.438−5.73 MHz

This frequency range contains the following MS bands:

- MS:
  - 4.438–4.65 MHz,
  - 4.75–4.995 MHz,
- AMS:
  - 4.65–4.75 MHz,
  - 5.45–5.73 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0, 1 dBi: 59 frequency assignments,
- 2 dBi: 29 frequency assignments,
- 3 dBi: 44 frequency assignments (cumulative population % = 74.6%),
- 4 dBi: 16 frequency assignments,
- 5–12 dBi: 29 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \qquad (6\text{-}51)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9,\ 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 31 frequency assignments,
- 2 dBi: 6 frequency assignments (cumulative population % = 40%),
- 3 dBi: 50 frequency assignments (cumulative population % = 94.5%),
- 6, 12 dBi: 5 frequency assignments.

The representative G_{max} = 3 dBi. The radiation pattern is uniform, with G = G_{max} = 3 dBi in all directions.

6.6.3.3.3 5.73−8.1MHz

This frequency range contains the following MS bands:

- MS:
  - 5.73–5.9 MHz,
  - 6.765–7 MHz,

    - 7.4–8 MHz,
- AMS: 6.525–6.765 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0, 1 dBi: 95 frequency assignments,
- 2 dBi: 35 frequency assignments,
- 3 dBi: 27 frequency assignments (cumulative population % = 73.7%),
- 4 dBi: 10 frequency assignments (cumulative population % = 78.4%),
- 5 dBi: 4 frequency assignments,
- 6 dBi: 27 frequency assignments,
- 8–14 dBi: 15 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 49.8° \qquad (6\text{-}52)$$
$$= -9 + 10\times\log\{\,[\max(|\theta|/53.9,\ 1)]^{-1.5}\,\} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are mostly omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 223 frequency assignments (cumulative population % = 82%),
- 1, 2 dBi: 9 frequency assignments,
- 3 dBi: 27 frequency assignments,
- 4−6 dBi: 10 frequency assignments,
- 12 dBi: 2 frequency assignments.

The representative G_{max} = 0 dBi. The radiation pattern is uniform, with G = G_{max} = 0 dBi in all directions.

6.6.3.3.4 8.815−18.03 MHz

This frequency range contains the following AMS bands:

- 8.815−9.04 MHz,
- 11.175−11.4 MHz,
- 13.2−13.36 MHz,
- 15.01−15.6 MHz,
- 17.9−18.03 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0, 1 dBi: 157 frequency assignments,
- 2 dBi: 54 frequency assignments (cumulative population % = 65.5%),
- 3 dBi: 58 frequency assignments (cumulative population % = 83.5%),
- 4 dBi: 4 frequency assignments,
- 5−12 dBi: 49 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}53)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 92 frequency assignments,
- 2 dBi: 4 frequency assignments,
- 3 dBi: 147 frequency assignments (cumulative population % = 85.6%),
- 5−12 dBi: 41 frequency assignments.

The representative G_{max} = 3 dBi. The radiation pattern is uniform, with G = G_{max} = 3 dBi in all directions.

6.6.3.3.5 21.924−23.35 MHz

This frequency range contains the 21.924−22 MHz band for AMS(R) and 23.2−23.35 MHz band for AMS(OR). The GMF only contains service records in the 23.2−23.35 MHz band, but the result should be applicable to the other band.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in the 23.2−23.35 MHz band, and the antenna G_{max} data count is

- 0 dBi: 27 frequency assignments,
- 1 dBi: 2 frequency assignments (cumulative population % = 69%),
- 2 dBi: 6 frequency assignments (cumulative population % = 83.3%),
- 3 dBi: 2 frequency assignments,
- 9 dBi: 5 frequency assignments.

The representative G_{max} = 1 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 1 - 12(\theta/85.5)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 78.9° \qquad (6\text{-}54)$$
$$= -11 + 10\times\log\{ [\max(|\theta|/85.5, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 78.9°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in the 23.2−23.35 MHz, and the antenna G_{max} data count is

- 0 dBi: 7 frequency assignments,
- 3 dBi: 6 frequency assignments (cumulative population % = 86.7%),
- 6 dBi: 1 frequency assignment,
- 9 dBi: 1 frequency assignment.

The representative G_{max} = 3 dBi. The radiation pattern is uniform, with G = G_{max} = 3 dBi in all directions.

6.6.3.3.6 23.35−30.56 MHz

This frequency range contains the following MS bands:

- 23.35−24.89 MHz,
- 25.33−25.55 MHz,
- 26.48−26.95 MHz,
- 27.54−28 MHz,
- 29.89−29.91 MHz,
- 30−30.56 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 54 frequency assignments,
- 1 dBi: 4 frequency assignments,
- 2 dBi: 6 frequency assignments (cumulative population % = 71.9%),
- 3 dBi: 16 frequency assignments,
- 4–12 dBi: 9 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= 2 - 12(\theta/67.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}55)\\
&= -10 + 10\times\log\{\, [\max(|\theta|/67.9,\, 1)]^{-1.5} \,\} && \text{dBi} \quad \text{for} \quad |\theta| > 62.7°
\end{aligned}
$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 62 frequency assignments (cumulative population % = 82%),
- 1 dBi: 5 frequency assignments,
- 2−5 dBi: 9 frequency assignments.

The representative G_{max} = 0 dBi. The radiation pattern is uniform, with G = G_{max} = 0 dBi in all directions.

6.6.3.3.7 32−50 MHz

This frequency range contains the following MS bands:

- 32−33 MHz,
- 34−35 MHz,
- 36−37 MHz,
- 38−39 MHz,
- 40−42 MHz,
- 46.6−47 MHz,
- 49.6−50 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 196 frequency assignments (cumulative population % = 74%),
- 1 dBi: 16 frequency assignments,
- 2 dBi: 34 frequency assignments,
- 3 dBi: 9 frequency assignments,
- 5 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}56)$$
$$= -12 + 10\times\log\{\ [\max(|\theta|/107.6,\ 1)]^{-1.5}\ \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 290 frequency assignments,
- 1 dBi: 21 frequency assignments (cumulative population % = 76%),
- 2 dBi: 61 frequency assignments,
- 3 dBi: 34 frequency assignments,
- 5, 10 dBi: 3 frequency assignments.

The representative G_{max} = 1 dBi. The radiation pattern is uniform, with G = G_{max} = 1 dBi in all directions.

6.6.3.3.8 117.975−137 MHz

This is an AMS band.

(a) Land-Based Antenna

The land-based transmitting antennas are mostly omnidirectional in this band, and the antenna G_{max} data count is

- 0 dBi: 3579 frequency assignments (cumulative population % = 84%),
- 1 dBi: 19 frequency assignments,
- 2 dBi: 465 frequency assignments,
- 3 dBi: 107 frequency assignments,
- 4−20 dBi: 87 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for conducting spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}57)$$
$$= -12 + 10\times\log\{\,[\max(|\theta|/107.6,\,1)]^{-1.5}\,\} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 165 frequency assignments,
- 1 dBi: 9 frequency assignments (cumulative population % = 63%),
- 2 dBi: 57 frequency assignments (cumulative population % = 83.7%),
- 3 dBi: 36 frequency assignments,
- 4−6 dBi: 9 frequency assignments.

The representative G_{max} = 2 dBi. The radiation pattern is uniform, with $G = G_{max}$ = 2 dBi in all directions.

6.6.3.3.9 138−150.8 MHz

This frequency range contains the following MS bands:

- 138−144 MHz,
- 148−149.9 MHz,
- 150.05−150.8 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 346 frequency assignments,
- 1 dBi: 39 frequency assignments,
- 2 dBi: 292 frequency assignments (cumulative population % = 80.7%),

- 3 dBi: 113 frequency assignments,
- 4−9 dBi: 49 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}58)$$
$$= -10 + 10\times\log\{\, [\max(|\theta|/67.9,\ 1)]^{-1.5} \,\} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 561 frequency assignments,
- 1 dBi: 49 frequency assignments,
- 2 dBi: 301 frequency assignments (cumulative population % = 79.9%),
- 3 dBi: 125 frequency assignments,
- 4−9 dBi: 104 frequency assignments.

The representative G_{max} = 2 dBi. The radiation pattern is uniform, with G = G_{max} = 2 dBi in all directions.

6.6.3.3.10 162.0125−174 MHz

This frequency range contains the 162.0125−173.2 and 173.4−174 MHz MS bands.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 25 frequency assignments,
- 2−5 dBi: 7 frequency assignments,
- 6 dBi: 70 frequency assignments (cumulative population % = 98.1%),
- 7, 8 dBi: 2 frequency assignments.

The representative G_{max} = 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}59)$$
$$= -6 + 10\times\log\{\, [\max(|\theta|/27,\ 1)]^{-1.5} \,\} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 63 frequency assignments,

- 1−5 dBi: 13 frequency assignments,
- 6 dBi: 159 frequency assignments (cumulative population % = 96.3%),
- 7−9 dBi: 9 frequency assignments.

The representative G_{max} = 6 dBi. The radiation pattern is uniform, with G = G_{max} = 6 dBi in all directions.

6.6.3.3.11 225−420 MHz Range

This frequency range contains the following MS bands:

- 225−328.6 MHz,
- 335.4−399.9 MHz,
- 406.1−420 MHz.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 3572 frequency assignments,
- 1 dBi: 104 frequency assignments,
- 2 dBi: 1458 frequency assignments (cumulative population % = 78.9%),
- 3 dBi: 877 frequency assignments,
- 4−24 dBi: 496 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$\begin{aligned} G(\theta) &= 2 - 12(\theta/67.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \\ &= -10 + 10\times\log\{\,[\max(|\theta|/67.9,\,1)]^{-1.5}\,\} && \text{dBi} \quad \text{for} \quad |\theta| > 62.7° \end{aligned} \tag{6-60}$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 1211 frequency assignments,
- 1 dBi: 105 frequency assignments,
- 2 dBi: 1928 frequency assignments (cumulative population % = 72.1%),
- 3 dBi: 884 frequency assignments,
- 4-10 dBi: 352 frequency assignments,
- 11-19 dBi: 17 frequency assignments,
- 30 dBi: 1 frequency assignment.

The representative G_{max} = 2 dBi. The radiation pattern is uniform, with G = G_{max} = 2 dBi in all directions.

6.6.3.3.12 1.35−1.525 GHz

This is a MS band.

(a) Land-Based Antenna

The land-based transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 2 frequency assignments,
- 2 dBi: 6 frequency assignments,
- 3 dBi: 8 frequency assignments,
- 6 dBi: 1 frequency assignment,
- 7 dBi: 16 frequency assignments (cumulative population % = 94.3%),
- 8 dBi: 2 frequency assignments.

The representative G_{max} = 7 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 7 - 12(\theta/21.5)^2 \quad \text{dBi for } |\theta| \le 19.8° \qquad (6\text{-}61)$$
$$= -5 + 10\times\log\{ [\max(|\theta|/21.5, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 19.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Airborne Antenna

The airborne transmitting antennas are all omnidirectional in these bands, and the antenna G_{max} data count is

- 0 dBi: 2 frequency assignments,
- 2 dBi: 6 frequency assignments,
- 3 dBi: 8 frequency assignments,
- 6 dBi: 1 frequency assignment,
- 7 dBi: 15 frequency assignments (cumulative population % = 94.1%),
- 8 dBi: 2 frequency assignments.

The representative G_{max} = 7 dBi. The radiation pattern is uniform, with $G = G_{max}$ = 7 dBi in all directions.

6.6.3.3.13 1.755−1.85 GHz

This is a MS band. The airborne antennas in this band use both the omnidirectional and the directional antennas.

(a) Land-Based Antenna

The land-based transmitting antennas are mostly omnidirectional in this band, and the population profile of the antenna G_{max} data is shown in Figure 6-39. The representative G_{max} = 8 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 8 - 12(\theta/17)^2 \quad \text{dBi for } |\theta| \le 15.8° \qquad (6\text{-}62)$$
$$= -4 + 10\times\log\{ [\max(|\theta|/17, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 15.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

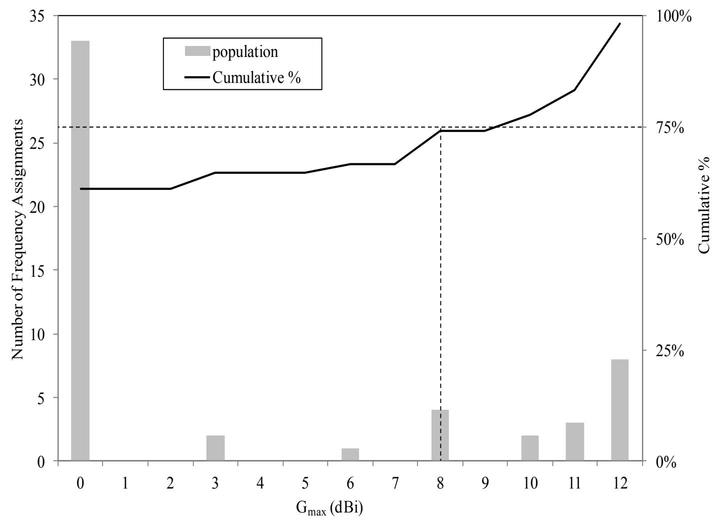


Figure 6-39. Population Profile of AMS Land-Based Transmitting Antenna G_{max} Data in 1.755−1.85 GHz

(b) Airborne Antenna

The GMF contains a comparable amount of omnidirectional and directional airborne transmitting antenna service records in this band, and both are analyzed.

(b.1) Airborne Omnidirectional Antenna

The population profile of the airborne omnidirectional transmitting antennas G_{max} data in this band is shown in Figure 6-40. The representative G_{max} = 3 dBi. The radiation pattern is uniform, with $G = G_{max}$ = 3 dBi in all directions.

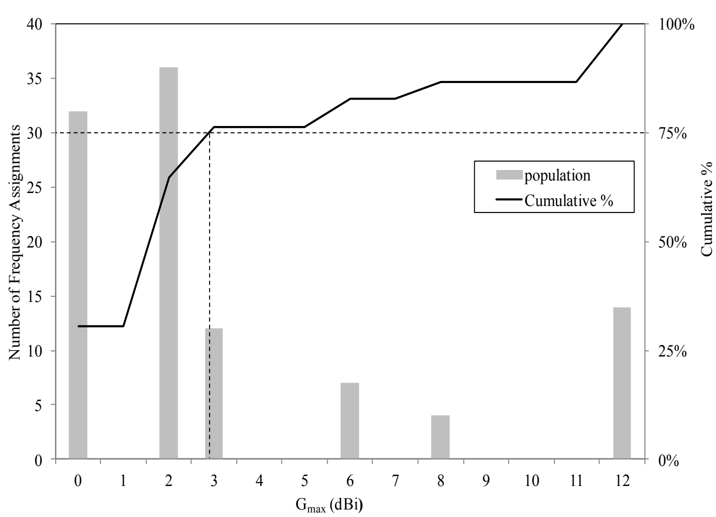


Figure 6-40. Population Profile of AMS Airborne Transmitting Omnidirectional Antenna G_{max} Data in 1.755−1.85 GHz

(b.2) Airborne Directional Antenna

The population profile of the airborne directional transmitting antenna G_{max} data in this band is shown in Figure 6-41. The representative G_{max} = 32 dBi. A representative antenna radiation pattern is not available, and there is no recommendation of the gain value for spectrum sharing analyses.

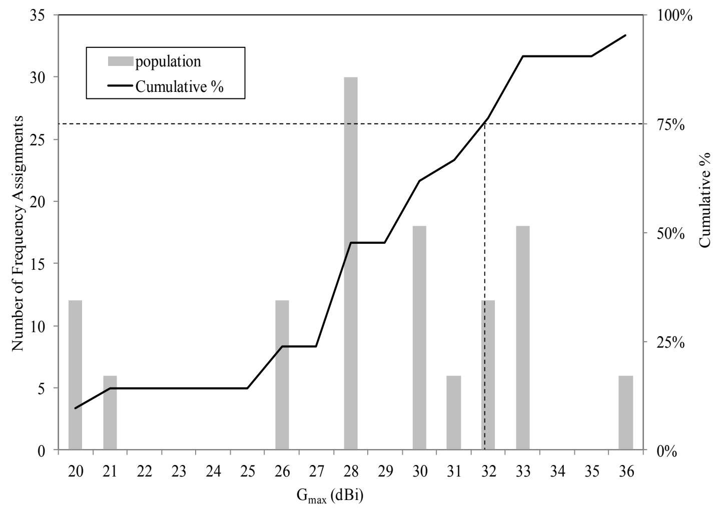


Figure 6-41. Population Profile of AMS Airborne Transmitting Directional Antenna G_{max} Data in 1.755−1.85 GHz

6.6.3.3.14 4.4−4.94 GHz

This is a MS band. The airborne antennas use both the omnidirectional and the directional antenna service records in this band.

(a) Land-Based Antenna

The land-based transmitting antennas are mostly directional in this band, and the antenna G_{max} data count is

- 3 dBi: 1 frequency assignment,
- 29 dBi: 2 frequency assignments,
- 36 dBi: 4 frequency assignments (cumulative population % = 78%), and
- 40 dBi: 2 frequency assignments.

The representative G_{max} = 36 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-34.

Table 6-34. Representative AMS Land-Based Antenna Radiation Pattern in 4.4−4.94 GHz

Gain (dBi)	Angular Range
$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.15\times\phi_{bw}$
20	$1.15\times\phi_{bw} < \phi \leq 4°$
$35 - 25 \times \log(\phi)$	$4° < \phi \leq 48°$
-7	$48° < \phi \leq 180°$

Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.

(b) Airborne Antenna

The GMF has a comparable amount of airborne omnidirectional and directional transmitting antenna service records in this band, and both will be analyzed.

(b.1) Airborne Omnidirectional Antenna

The airborne omnidirectional transmitting antenna G_{max} data count in this band is

- 0−2 dBi: 11 frequency assignments,
- 3 dBi: 31 frequency assignments (cumulative population % = 90%),
- 5, 6 dBi: 3 frequency assignments, and
- 12 dBi: 2 frequency assignments.

The representative G_{max} = 3 dBi. The radiation pattern is uniform, with G = G_{max} = 3 dBi in all directions.

(b.2) Airborne Directional Antenna

The airborne directional transmitting antenna G_{max} data count in this band is

- 13−16 dBi: 4 frequency assignments,
- 19, 20 dBi: 2 frequency assignments,
- 26−30 dBi: 2 frequency assignments,
- 32, 33 dBi: 4 frequency assignments,
- 36 dBi: 2 frequency assignments (cumulative population % = 70%), and
- 38, 39 dBi: 6 frequency assignments.

The representative G_{max} = 36 dBi. A representative antenna radiation pattern is not available, and there is no recommendation of the gain value for spectrum sharing analyses.

6.7 Mobile-Satellite Service

The primary MSS bands for the federal agencies are

- 240−270 MHz downlink and 290−320 MHz uplink,
- 1.525−1.559 GHz downlink and 1.61−1.6605 GHz uplink,
- 7.25−7.3 GHz downlink and 7.9−8.025 GHz uplink,
- 20.2−21.2 GHz downlink and 30−31 GHz uplink,
- 39.5−40.5 GHz downlink and 43.5−47 GHz uplink, and
- others.

Sometimes the 43.5−47 GHz band is used as the corresponding uplink band to the 20.2−21.2 GHz downlink band. In the uplink band, the earth stations are the transmitting stations, and are the potential interferers.

In EMC analyses between two MSS systems or between a MSS system and another space system, it is usually assumed that the space systems have the same Earth coverage. For instance in the GMF, the G_{max} values of the LMSS satellite antennas, whose symbols are “EU”, are 17, 18, and 20 dBi, with 18 dBi being the super majority. These data indicate global coverage. Therefore, the EMC analyses involve only the earth station antenna radiation patterns, but not the satellite antenna radiation patterns. In EMC analyses between a space system and a terrestrial system, the EMC analyses are between the earth station and the terrestrial station. In both cases, the EMC analyses require only the MSS earth station antenna radiation patterns. Therefore in this sub-section, only the earth station antennas are discussed.

6.7.1 Land Mobile-Satellite Service

6.7.1.1 System Review

NTIA does not provide the LMSS earth station antenna radiation performance standards for system review. However, these can be developed from the ITU-R Recommendations.

There is only one set of LMSS earth station antenna reference radiation patterns in Section 5.7.1; it is from Rec. ITU-R M.1091 and is applicable for omnidirectional, low- and medium-gain antennas operating in the 1−3 GHz range. These radiation patterns are recommended for the LMSS earth station omnidirectional, low- and medium-gain antenna radiation performance standards.

(a) Omnidirectional Antenna

The recommended omnidirectional antenna radiation performance standards are provided in Table 6-35.

Table 6-35. LMSS Earth Station Omnidirectional Antenna Radiation Performance Standards

(a) Vehicle-Mounted Near-Omnidirectional Antenna

Gain Function (dBi)	Angular Range
≤ 5	$-20° \leq \theta$
≤ 0	$\theta < -20°$
θ: elevation angle, deg.	

(b) Vehicle-Mounted Vertical Array Antenna with Toroidal Beams and $7 \leq G_{max}(dBi) \leq 13$

Gain Function (dBi)	Angular Range
$G_{max} - 10$	$45° < (\theta - \theta_o)$
$G_{max} - 0.3 \times [(\theta - \theta_o)/10]^{2.3}$	$20° \leq (\theta - \theta_o) \leq 45°$
$G_{max} - 12 \times [(\theta - \theta_o)/\theta_{bw})]^2$	$-20° < (\theta - \theta_o) < 20°$
$G_{max} - 0.3 \times [(\theta_o - \theta)/10]^{2.3}$	$-50° \leq (\theta - \theta_o) \leq -20°$
$G_{max} - 13$	$(\theta - \theta_o) < -50°$
Mainbeam is added to complete the pattern. θ: elevation angle, deg. θ_o: mainbeam elevation angle, deg. θ_{bw}: HPBW, deg.	

(b) Low- and Medium-Gain Antennas

The recommended low- and medium-gain antenna radiation performance standards are provided in Table 6-36.

Table 6-36. LMSS Earth Station Low- and Medium-Gain Antenna Radiation Performance Standards

(a) Vehicle-Mounted Tracking Antenna with Fan-Beams and Operating in Low Elevation Angle

Gain Function (dBi)	Angular Range
≤ 4	$0° \leq \theta \leq 60°$, $[30°+k(\theta)] \leq \lvert\varphi-\varphi_0\rvert \leq 180°$
(θ, φ): elevation and azimuth angles, deg. (θ_o, φ_o): mainbeam elevation and azimuth angles, deg. $k(\theta) = 0.33°$ for $G_{max} = 11-15$, dBi $k(\theta)$ is TBD for $G_{max} = 9-11$, dBi	

(b) Transportable or Vehicle-Mounted Antenna with Circular Beams and $G_{max} \leq 18$ dBi

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° \leq \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
-5	$90° \leq \phi$
Mainbeam and first sidelobe are added to complete the pattern. In Rec. ITU-R M.1091, this radiation pattern is valid for $12 \leq G_{max}$(dBi) ≤ 18. The lower bound is removed to be consistent with the classification in Section 4.4. ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg. x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.	

(c) High-Gain Antenna

Section 5.7.1 does not contain any high-gain antenna reference radiation patterns. Since the earth station high-gain antennas should be similar for all the space telecommunication services, the FSS earth station antenna co-polarization radiation performance standards in Section 6.3.1.1 can be used as the LMSS earth station high-gain antenna radiation performance standards; these standards are shown in Table 6-37.

Table 6-37. LMSS Earth Station High-Gain Antenna Radiation Performance Standards

(a) GSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_m$
	G_1	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15 \times \log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25 \times \log(\phi)\}$

An actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) NGSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}(dBi) < 48.1$ for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20 \times \log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15 \times \log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi $G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi $\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg. $\phi_{rb} = (95\lambda/D)$, deg.

6.7.1.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 6.7.1.1 may be used as the reference radiation patterns. The radiation performance standards in Section 6.7.1.1 do not specify the G_{max} values; however, such data should be available in the GMF.

6.7.1.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the LMSS service records in the GMF. For the uplink, the symbol of the earth station class is “TU”; for the downlink, the symbol of the space station class is “EU”. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile.
(3) Select a representative G_{max} from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.7.1.2.

In the GMF, some of the earth station localities are given specifically, e.g., Los Alamos, New Mexico. Some are non-specific, i.e., “USA” for the continental U.S., “US” for the 50 states and D.C., and “USP” for the 50 states, D.C., Puerto Rico, and the Territories and Possessions. The non-specific ones are the mobile stations whose localities can be anywhere within the specified region.

The frequency bands being examined are

(1) 240−270 MHz downlink,
(2) 290−320 MHz uplink,
(3) 1.525−1.559 GHz downlink and 1.61−1.6605 GHz uplink,
(4) 7.25−7.3 GHz downlink and 7.9−8.025 GHz uplink, and
(5) 39.5−40.5 GHz downlink and 43.5−47 GHz uplink.

6.7.1.3.1 240−270 MHz Downlink

The LMSS earth station receiving antenna G_{max} data count in this band is

- 6 dBi: 6 frequency assignments in Guam and Hawaii,
- 11 dBi: 318 frequency assignments in “US”.

The representative G_{max} = 11 dBi, and the antenna is a low-gain directional antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-38.

Table 6-38. Representative LMSS Earth Station Antenna Radiation Pattern in 240−270 MHz

Gain Function (dBi)	Angular Range
$11 - 12 \times (\phi/46.2)^2$	$0° \leq \phi \leq 35.2°$
4	$35.2° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
-5	$90° \leq \phi$
Directional antenna. ϕ: angle off mainbeam axis, deg. The pattern in Section 6.7.1.1 is applicable for $12 \leq G_{max}$(dBi) ≤ 18. It is used here because it is the only pattern for directional antennas.	

6.7.1.3.2 290−320 MHz Uplink

This is the corresponding uplink band for the 240−270 MHz downlink band.

The earth station transmitting antenna G_{max} data count in this band is

- 2 dBi: 2 frequency assignments in Guam,
- 3 dBi: 2 frequency assignments in Hawaii,
- 6 dBi: 2 frequency assignments in Guam and Hawaii,
- 11 dBi: 302 frequency assignments in “US”, and
- 19 dBi: 9 frequency assignments in Guam and Hawaii.

The representative G_{max} = 11 dBi, and the antenna is a low-gain directional antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-39.

Table 6-39. Representative LMSS Earth Station Antenna Radiation Pattern in 290−320 MHz

Gain Function (dBi)	Angular Range
$11 - 12 \times (\phi/46.2)^2$	$0° \leq \phi \leq 35.2°$
4	$35.2° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
-5	$90° \leq \phi$
Directional antenna. ϕ: angle off mainbeam axis, deg. The pattern in Section 6.7.1.1 is applicable for $12 \leq G_{max}$(dBi) ≤ 18. It is used here because it is the only pattern for directional antennas.	

6.7.1.3.3 1.525−1.559 GHz Downlink and 1.61−1.6605 GHz Uplink

The GMF does not have any service records in the 1.525−1.559 GHz downlink band. However, because of the vicinity of this band to its corresponding uplink band, the representative G_{max} value and antenna radiation pattern of the uplink band are applicable to the downlink band.

The earth station transmitting antenna G_{max} data count in 1.61−1.6605 GHz is

- 10 dBi: 1 frequency assignment in Nevada, 24 frequency assignments in "USP",
- 19 dBi: 6 frequency assignments at New Mexico, Texas, and New York,
- 23 dBi: 4 frequency assignments in "USA", and
- 24 dBi: 3 frequency assignments in "USP".

Because of the mobility factor, the representative G_{max} value is chosen with the earth station localities as "USA" and "USP". The representative G_{max} is chosen to be 10 dBi, and the antenna is a low-gain directional antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-40.

Table 6-40. Representative LMSS Earth Station Antenna Radiation Pattern in 1.525−1.559 and 1.61−1.6605 GHz

Gain Function (dBi)	Angular Range
$10 - 12\ (\phi/51.8)^2$	$0° \le \phi \le 36.6°$
4	$36.6° < \phi \le 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
-5	$90° \le \phi$
Directional antenna. ϕ: angle off mainbeam axis, deg. The pattern in Section 6.7.1.1 is applicable for $12 \le G_{max}$(dBi) ≤ 18. It is used here because it is the only pattern for directional antennas.	

6.7.1.3.4 7.25−7.3 GHz Downlink and 7.9−8.025 GHz Uplink

The GMF has one service record in each of these bands. The earth stations are in Colorado, and both the transmitting and receiving antenna G_{max} = 42 dBi. The representative G_{max} = 42 dBi, and the antenna is a high-gain directional antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-41.

Table 6-41. Representative LMSS Earth Station Antenna Radiation Pattern in 7.25−7.3 and 7.9−8.025 GHz

Gain Function (dBi)	Angular Range
$42 - 2.5 \times 10^{-3}(49.7 \times \phi)^2$	$0° \le \phi \le 2.6°$
$29 - 25 \times \log(\phi)$	$2.6° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.96 meters, *e* = 0.65, *f* = 7.6 GHz.

6.7.1.3.5 39.5−40.5 GHz Downlink and 43.5−47 GHz Uplink

The GMF does not have service records in the 39.5−40.5 GHz downlink band. However, because of the vicinity of this band to its corresponding uplink band, the representative antenna G_{max} value and radiation pattern of the uplink band are applicable to the downlink band.

The GMF has 2 earth station transmitting antenna service records in 43.5−47 GHz, with both G_{max} = 57 dBi. The representative G_{max} = 57 dBi, and the antenna is a high-gain directional antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-42.

Table 6-42. Representative LMSS Earth Station Antenna Radiation Pattern in 39.5−40.5 and 43.5−47 GHz

Gain Function (dBi)	Angular Range
$57 - 2.5 \times 10^{-3}(279 \times \phi)^2$	$0° \leq \phi \leq 0.33°$
35.7	$0.33° < \phi \leq 0.54°$
$29 - 25 \times \log(\phi)$	$0.54° < \phi \leq 7°$
8	$7° < \phi \leq 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.86 meters, *e* = 0.65, *f* = 45 GHz.	

6.7.2 Maritime Mobile-Satellite Service

The MMSS earth stations are either ship earth stations or coast earth stations. The antennas are mostly directional antennas.

6.7.2.1 System Review

NTIA does not provide the LMSS earth station antenna radiation performance standards for system review. However, these can be developed from the ITU-R Recommendations.

(a) Shipborne Directional Antenna

There is only one MMSS shipborne directional antenna reference radiation pattern in Section 5.7.2.1. Therefore, NTIA recommends that this radiation pattern in Rec. ITU-R M.694-1 be used as the MMSS shipborne directional antenna radiation performance standard. This standard is provided in Table 6-43.

Table 6-43. MMSS Shipborne Directional Antenna Radiation Performance Standard

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$

$2 + 15 \times \log(D/\lambda)$	$\phi_m \leq \phi < (100\lambda/D)°$
$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < \phi_1$
0	$\phi_1 \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $\phi_m = 20(\lambda/D)[G_{max} - 2 - 15 \times \log(D/\lambda)]^{0.5}$, deg. $\phi_1 = 120\ (\lambda/D)^{0.4}$, deg.	

(b) Coast Earth Station Antenna

Section 0 does not have coast earth station antenna reference radiation patterns. However, the MMSS coast station antenna should be similar to a FSS earth station antenna. Therefore, the FSS earth station antenna radiation performance standards in Section 6.3.1.1 are used as the MMSS coast earth station antenna radiation performance standards. These standards are provided in Table 6-44.

Table 6-44. GSO MMSS Coast Earth Station Antenna Radiation Performance Standards

(a) GSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_m$
	G_1	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda = 68$ is the threshold when the G_1 plateau disappears. ϕ: angle off mainbeam axis, deg . $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg. ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$		
An actual radiation pattern shall meet the following conditions: • It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$. • It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.		

(b) NGSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20 \times \log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15 \times \log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20 \times \log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25 \times \log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

6.7.2.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 6.7.2.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.7.2.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.7.2.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the MMSS service records in the GMF. For the uplink, the symbol of the earth station class is "TG" for the ship earth station and "TI" for the coast earth station; for the downlink, the symbol of the space station class is "EG". Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile. For the ship earth stations, only those whose locations are denoted "US" or any locations within the 50 states are

processed, the ship earth station locations whose locations are oceans, e.g., “PAC” for Pacific or “LANT” for Atlantic, or foreign territories are not processed.
(3) Select a representative G_{max} from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna radiation performance standards in Section 6.7.2.2.

Similar to the LMSS case, the earth station localities can be specific or non-specific. The non-specific ones, i.e., “US”, USA”, and “USP”, are the mobile stations whose localities can be anywhere within the specified region.

The frequency bands being examined are

(1) 240−270 MHz downlink,
(2) 290−320 MHz uplink,
(3) 1.525−1.559 GHz downlink and 1.61−1.6605 GHz uplink,
(4) 20.2−21.2 GHz downlink,
(5) 30−31 GHz uplink, and
(6) 39.5−40.5 GHz downlink and 43.5−47 GHz uplink.

6.7.2.3.1 240−270 MHz Downlink

The earth station receiving antenna G_{max} data count in this band is

- 2 dBi: 1 frequency assignment in Guam,
- 11 dBi: 318 frequency assignments in “US”,
- 12 dBi: 4 frequency assignments in Maryland,
- 16 dBi: 2 frequency assignments in Virginia,
- 17 dBi: 8 frequency assignments in Florida and Virginia,
- 18 dBi: 1 frequency assignment in Maryland,
- 19 dBi: 36 frequency assignments in Guam and Hawaii.

The representative antenna is a shipborne antenna, and the representative G_{max} = 11 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-45.

Table 6-45. Representative MMSS Earth Station Antenna Radiation Pattern in 240−270 MHz

Gain Function (dBi)	Angular Range
$11 - 2.5 \times 10^{-3}(1.46\phi)^2$	$0° \leq \phi < 35.1°$
4.5	$35.1° \leq \phi < 68.6°$
$50.4 - 25 \times \log(\phi)$	$68.6° \leq \phi < 103.2°$
0	$103.2° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.75 meters, *e* = 0.6 (for shipborne antenna), *f* = 250 MHz.	

6.7.2.3.2 290−320 MHz Uplink

This is the corresponding uplink band for the 240−270 MHz downlink band.

The earth station transmitting antenna G_{max} data count in this band is

- 2 dBi: 2 frequency assignments of shipborne antennas in Guam,
- 3 dBi:
  - 1 frequency assignment of coast station antennas in Guam,
  - 2 frequency assignments of shipborne antennas in Guam,
- 11 dBi: 302 frequency assignments of shipborne antennas in "US",
- 12 dBi: 9 frequency assignments of coast station antennas in Maryland,
- 14 dBi: 2 frequency assignments of coast station antennas in California,
- 16 dBi: 1 frequency assignment of coast station antenna in Virginia,
- 17 dBi: 3 frequency assignments of coast station antennas in Virginia,
- 19 dBi:
  - 5 frequency assignments of coast station antennas in Guam and Hawaii,
  - 11 frequency assignments of shipborne antennas in Guam and Hawaii.

The representative antenna is a shipborne antenna, and the representative G_{max} = 11 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-46.

Table 6-46. Representative MMSS Earth Station Antenna Radiation Pattern in 290−320 MHz

Gain Function (dBi)	Angular Range
$11 - 2.5 \times 10^{-3}(1.46\phi)^2$	$0° \leq \phi < 35°$
4.5	$35° \leq \phi < 68.5°$
$50.4 - 25 \times \log(\phi)$	$68.5° \leq \phi < 103.1°$
0	$103.1° \leq \phi \leq 180°$
φ: angle off mainbeam axis, deg. This pattern is developed with D = 1.46 meters, *e* = 0.6, *f* = 300 MHz.	

6.7.2.3.3 1.525−1.559 GHz Downlink and 1.61−1.6605 GHz Uplink

The GMF does not have service records in the 1.525−1.559 GHz downlink band. However, because of the close proximity of this band to its corresponding uplink band, the representative antenna G_{max} value and the radiation pattern of the uplink band are applicable to the downlink band.

The earth station transmitting antenna G_{max} data count in the 1.61−1.6605 GHz band is

- 19 dBi: 1 frequency assignment of shipborne antenna in Midway,
- 21 dBi: 18 frequency assignments of shipborne antennas in "US" (cumulative population % = 83%),
- 24 dBi: 4 frequency assignments of shipborne antennas in "USP".

The representative antenna is a shipborne antenna, and the representative G_{max} = 21 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-47.

Table 6-47. Representative MMSS Earth Station Antenna Radiation Pattern in 1.525−1.559 and 1.61−1.6605 GHz

Gain Function (dBi)	Angular Range
$21 - 2.5 \times 10^{-3}(4.62\phi)^2$	$0° \le \phi < 13°$
12	$13° \le \phi < 21.7°$
$45.4 - 25 \times \log(\phi)$	$21.7° \le \phi < 65.1°$
0	$103.1° \le \phi \le 180°$
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 0.85 meters, e = 0.6, f = 1.63 GHz.	

6.7.2.3.4 20.2−21.2 GHz Downlink

The earth station receiving antenna service records all have G_{max} = 48 dBi in this band, and the localities are in California, Florida, Guam, Hawaii, and Virginia. The representative G_{max} = 48 dBi, and this is a coast station antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-48.

Table 6-48. Representative MMSS Earth Station Antenna Radiation Pattern in 20.2−21.2 GHz

Gain Function (dBi)	Angular Range
$48 - 2.5 \times 10^{-3}(99.4\phi)^2$	$0° \le \phi \le 0.88°$
29	$0.88° < \phi \le 1°$
$29 - 25 \times \log(\phi)$	$1° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.44 meters, e = 0.65, f = 20.7 GHz.	

6.7.2.3.5 30−31 GHz Uplink

This is the corresponding uplink band for the 20.2−21.2 GHz downlink band.

The GMF does not have service records in this band with the earth station operating in the continental U.S. and Alaska. It has 2 coast station transmitting antenna service records, with both G_{max} = 70 dBi and localities in Hawaii. However, this G_{max} value is incompatible with the representative G_{max} value in the corresponding downlink band.

A more logical representative G_{max} value can be derived by frequency scaling G_{max} = 48 dBi of the 20.2−21.2 GHz band, and the resulting G_{max} = 51.4 dBi. Therefore, the representative antenna is a coast station antenna, and the representative G_{max} = 51.4 dBi. The representative antenna radiation pattern for spectrum sharing analyses in the U.S. is provided in Table 6-49.

Table 6-49. Representative MMSS Earth Station Antenna Radiation Pattern in 30−31 GHz

Gain Function (dBi)	Angular Range
$51.4 - 2.5 \times 10^{-3}(146.4\phi)^2$	$0° \le \phi \le 0.61°$
31.5	$0.61° < \phi \le 0.8°$
$29 - 25 \times \log(\phi)$	$0.8° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.44 meters, e = 0.65, f = 30.5 GHz.	

6.7.2.3.6 39.5−40.5 GHz Downlink and 43.5−47 GHz Uplink

The GMF does not have any service records in the 39.5−40.5 GHz downlink band. However, because of the close proximity of this band to its corresponding uplink band, the representative antenna G_{max} value and the radiation pattern of the uplink band should be applicable to the downlink band.

The earth station transmitting antenna G_{max} data count in the 43.5−47 GHz band is

- 49 dBi: 1 frequency assignment in California,
- 55 dBi: total 25 frequency assignments in California, Florida, Guam, Hawaii, Maine, Virginia, and Washington (cumulative population % = 69%),
- 56 dBi: 10 frequency assignments of coast station antennas in California.

The representative G_{max} = 55 dBi, and this is a coast station antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-50.

Table 6-50. Representative MMSS Earth Station Antenna Radiation Pattern in 39.5−40.5 and 43.5−47 GHz

Gain Function (dBi)	Angular Range
$55 - 2.5 \times 10^{-3}(222\phi)^2$	$0° \le \phi \le 0.41°$
34.2	$0.41° < \phi \le 0.62°$
$29 - 25 \times \log(\phi)$	$0.62° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.48 meters, e = 0.65, f = 45 GHz.	

6.7.3 Aeronautical Mobile-Satellite Service

The AMSS earth stations are either aircraft earth stations or land-based aeronautical earth stations.

6.7.3.1 System Review

NTIA does not provide the AMSS earth station antenna radiation performance standards for system review. However, this can be developed from the RTCA documents and ITU-R Recommendations.

(a) Airborne Antenna

NTIA recommends that the AMSS airborne antenna radiation performance standards in RTCA DO-210D be used as the AMSS airborne antenna performance standard. These standards are as follows:

- Polarization: RHCP.
- For antenna of $12 \le G(dBic) \le 17$ within the coverage volume:
  - o the coverage volume shall comprise not less than 75% of the solid angle above 5º elevation (to the horizon during normal cruise attitude),
  - o $G > 0$ dBic outside the coverage volume.
- For antenna of $6 \le G(dBic) \le 12$ within the coverage volume:
  - o the coverage volume shall comprise not less than 85% of the solid angle above 5º elevation,
  - o the coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith in straight and level flight, $G > 4$ dBic within this cone,
  - o $G > 0$ dBic for 99% of the solid angle above 5º elevation,
  - o to the maximum extent possible, $G > 6$ dBic for 100% of the solid angle above 5º elevation.
- For antenna of $0 \le G(dBic) \le 5$ within the coverage volume:
  - o the coverage volume shall comprise no less than 85% of the solid angle above 5º elevation,
  - o the coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith (in normal cruise attitude) in straight and level flight, $G > -2$ dBic within this cone,
  - o $G > -5$ dBic outside the coverage volume.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

(b) Land-Based Antenna

Section 5.7.3 does not contain the land-based antenna reference radiation pattern. However, the AMSS land-based antenna is similar to a FSS earth station antenna. Therefore, the FSS earth station antenna radiation performance standards in Section 6.3.1.1 are recommended for the AMSS land-based antenna radiation performance standards. These standards are provided in Table 6-51.

Table 6-51. AMSS Land-Based Antenna Radiation Performance Standards

(a) GSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_m$
	G_1	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15 \times \log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25 \times \log(\phi)\}$

An actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) NGSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}(dBi) < 48.1$ for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

6.7.3.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 6.7.3.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.7.3.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.7.3.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the AMSS service records in the GMF. For the uplink, the symbol of the earth station class is "TB" for the land earth station and "TJ" for the aircraft earth station; for the downlink, the symbol of the space station class is "EJ". Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile. Only the aircraft earth stations and land earth stations whose locations are denoted "US" or any locations within the 50 states are processed, the aircraft locations whose locations are denoted oceans, e.g., "PAC" for Pacific or "LANT" for Atlantic, or foreign territories are not processed.
(3) Select a representative G_{max} from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna radiation performance standards in Section 6.7.3.2.

Similar to the LMSS case, the earth station localities can be specific or non-specific. The non-specific ones, i.e., "US", USA", and "USP", are the mobile stations whose localities can be anywhere within the specified region.

The frequency bands being examined are

(1) 240−270 MHz downlink,
(2) 290−320 MHz uplink,
(3) 20.2−21.2 GHz downlink,
(4) 30−31 GHz uplink, and
(5) 39.5−40.5 GHz downlink and 43.5−47 GHz uplink.

6.7.3.3.1 240−270 MHz Downlink

The earth station receiving antenna G_{max} data count in this band is

- 2 dBi: 1 frequency assignment in Guam,
- 11 dBi: 321 frequency assignments in "USP",
- 12 dBi: 1 frequency assignment in Nebraska,
- 14 dBi: 1 frequency assignment in Hawaii,
- 16 dBi: 3 frequency assignments in Texas and Virginia,
- 17 dBi: 8 frequency assignments in Florida and Virginia,
- 19 dBi: 36 frequency assignments in Guam and Hawaii.

The representative G_{max} = 11 dBi, and this is an airborne antenna. The representative antenna radiation characteristics for spectrum sharing analyses are as follows:

- Polarization: RHCP.
- The coverage volume shall comprise not less than 85% of the solid angle above 5º elevation.
- $6 \leq G(dBic) \leq 11$ within the coverage volume.
- The coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith in straight and level flight, G > 4 dBic within this cone.
- G > 0 dBic for 99% of the solid angle above 5º elevation.
- To the maximum extent possible, G > 6 dBic for 100% of the solid angle above 5º elevation.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

6.7.3.3.2 290−320 MHz Uplink

This is the corresponding uplink for the 240−270 MHz downlink band.

The earth station transmitting antenna G_{max} data count in this band is

- 2 dBi: 2 frequency assignments of airborne antennas in Guam,
- 3 dBi: 2 frequency assignments of airborne antennas in Guam, 1 frequency assignment of land-based antennas in Guam,
- 11 dBi: 2 frequency assignments of land-based antennas in "USA", 306 frequency assignments of airborne antennas in "USP",
- 12 dBi: 2 frequency assignments of land-based antenna in Nebraska and Texas,
- 16 dBi: 1 frequency assignment of land-based antenna in Texas, 1 frequency assignment of airborne antenna in Virginia,
- 17 dBi: 3 frequency assignments of land-based antennas in Virginia,
- 20 dBi: 1 frequency assignment of land-based antenna in Wyoming,
- 14 dBi: 1 frequency assignment of airborne antenna in Hawaii, and
- 19 dBi: 11 frequency assignments of airborne antennas in Guam and Hawaii, 4 frequency assignments of land-based antennas in Guam and Hawaii.

The representative G_{max} = 11 dBi, and this is an airborne antenna. The representative antenna radiation characteristics for spectrum sharing analyses are as follows:

- Polarization: RHCP.
- The coverage volume shall comprise not less than 85% of the solid angle above 5º elevation.
- $6 \leq G(dBic) \leq 11$ within the coverage volume.
- The coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith in straight and level flight, G > 4 dBic within this cone.
- G > 0 dBic for 99% of the solid angle above 5º elevation.
- To the maximum extent possible, G > 6 dBic for 100% of the solid angle above 5º elevation.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

6.7.3.3.3 20.2−21.2 GHz Downlink

The earth station receiving antenna service records all have G_{max} = 48 dBi in this band, and the localities are California, Florida, Guam, Hawaii, and Virginia. These are all GSO systems. The representative G_{max} = 48 dBi, and this is a land-based antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-52.

Table 6-52. Representative AMSS Earth Station Antenna Radiation Pattern in 20.2−21.2 GHz

Gain Function (dBi)	Angular Range
$48 - 2.5 \times 10^{-3}(99.4\phi)^2$	$0° \leq \phi \leq 0.88°$
29	$0.88° < \phi \leq 1°$
$29 - 25 \times \log(\phi)$	$1° < \phi \leq 7°$
8	$7° < \phi \leq 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$
φ: angle off mainbeam axis, deg. This pattern is developed with D = 1.44 meters, e = 0.65, f = 20.7 GHz.	

6.7.3.3.4 30−31 GHz Uplink

This is the corresponding uplink band for the 20.2−21.2 GHz downlink band.

The GMF does not have service records in the 30−31 GHz band. The representative antenna G_{max} value can be obtained by frequency scaling the representative G_{max} value of the 20.2−21.2 GHz band. The representative G_{max} = 51.4 dBi, and this is a land-based earth station antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-53.

Table 6-53. Representative AMSS Earth Station Antenna Radiation Pattern in 30−31 GHz

Gain Function (dBi)	Angular Range
$51.4 - 2.5 \times 10^{-3}(146.4\phi)^2$	$0° \leq \phi \leq 0.61°$

34.5	0.61° < ϕ ≤ 0.8°
29 - 25 × log(ϕ)	0.8° < ϕ ≤ 7°
8	7° < ϕ ≤ 9.2°
32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.44 meters, *e* = 0.65, *f* = 30.5 GHz.	

6.7.3.3.5 39.5−40.5 GHz Downlink and 43.5−47 GHz Uplink

The GMF does not have service records in the 39.5−40.5 GHz downlink band. However, because of the close proximity of this band to its corresponding uplink band, the representative antenna G_{max} value and radiation pattern of the uplink band should be applicable to the downlink band.

The AMSS earth station transmitting antenna G_{max} data count in the 43.5−47 GHz band is

- 49 dBi: 1 frequency assignment in California,
- 55 dBi: total 22 frequency assignments in California, Guam, Hawaii, Maine, Virginia, Washington (cumulative population % = 67%),
- 56 dBi: 10 frequency assignments of land-based antennas in California.

The representative G_{max} = 55 dBi, and this is a GSO system land-based earth station antenna. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-54.

Table 6-54. Representative AMSS Earth Station Antenna Radiation Pattern in 39.5−40.5 GHz and 43.5−47 GHz

Gain Function (dBi)	Angular Range
$55 - 2.5 \times 10^{-3}(222\phi)^2$	0° ≤ ϕ ≤ 0.41°
34.2	0.41° < ϕ ≤ 0.62°
29 - 25 × log(ϕ)	0.62° < ϕ ≤ 7°
8	7° < ϕ ≤ 9.2°
32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. This pattern is developed with D = 1.48 meters, e = 0.65, *f* = 45 GHz.	

6.8 Radiodetermination Service

As shown in Section 5.8.1, NTIA classifies five groups of RDS radars for performance specification, and each group is associated with an antenna radiation performance standard criterion. These five groups and the corresponding five criteria are listed in Table 6-55.

Table 6-55. NTIA RDS Radars Antenna Radiation Performance Standards

(a) Types

Group	Types of Radar	Criterion
A	• Non-pulsed radar of 40 watts or less rated average power, • Pulsed radar of 1 kW or less rated peak power, • Radar with operating frequency above 40 GHz, • Man-portable radar, • Man-transportable radar, • RNS radar in 9.3–9.5 GHz band, • Expendable, non-recoverable radar on missiles.	A
B	Radar with rated peak power of more than 1 kW but not more than 100 kW and operating between 2.9 GHz and 40 GHz	B
C	All radars not included in Group A, B, or D.	C
D	All fixed radars in 2.7–2.9 GHz band.	D
E	Wind Profiler Radar operating on 449 MHz	E

(b) Criteria

<table>
<tr><th>Criterion</th><th colspan="2">Description</th></tr>
<tr><td>A</td><td colspan="2">Presently exempt.</td></tr>
<tr><td>B</td><td colspan="2">Currently no requirement is specified.</td></tr>
<tr><td>C, D</td><td colspan="2">Antennas operated in 360°-rotation over the horizontal plane shall have a “median gain” of -10 dBi or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, sidelobe suppression below the mainbeam shall be:
• first three sidelobes: 17 dB,
• all other lobes: 26 dB.</td></tr>
<tr><td rowspan="7">E</td><td>Antenna Radiation Profile (dB)</td><td>Elevation Angle θ</td></tr>
<tr><td>x</td><td>$70^\circ \le \theta$</td></tr>
<tr><td>x - 15</td><td>$60^\circ \le \theta < 70^\circ$</td></tr>
<tr><td>x - 20</td><td>$45^\circ \le \theta < 60^\circ$</td></tr>
<tr><td>x - 25</td><td>$5^\circ \le \theta < 45^\circ$</td></tr>
<tr><td>x - 40</td><td>$\theta < 5^\circ$</td></tr>
<tr><td colspan="2">• Radiation profile derived from EIRP profile requirement.
• Symbol “<” is used instead of “≤” for the angular range in the NTIA Manual.</td></tr>
<tr><td colspan="3">For antennas operated in 360°-rotation over the horizontal plane, the EMC analysis must cover all directions. Thus the allowable radar antenna radiation pattern may be usefully specified by its “median gain” relative to an isotropic radiator.</td></tr>
</table>

6.8.1 Radiolocation Service

6.8.1.1 System Review

The antenna radiation performance standards in Table 6-55 are suitable for system review.

6.8.1.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment. The antenna radiation pattern should be available from either the system operators or the antenna manufacturers.

When the actual radiation pattern is not available, a reference radiation pattern needs to be used. However, Table 6-55 does not provide the necessary reference radiation pattern. Therefore, two types of reference radiation patterns are developed here. These radiation patterns do not specify the G_{max} value; however, such data should be available in the GMF.

(a) Omnidirectional Antenna

The LMS base station omnidirectional antenna radiation performance standard in Section 6.6.1.1 can be adopted as the RLS omnidirectional antenna vertical reference radiation pattern for EMC analyses in frequency assignment; it is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (6\text{-}63)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

(b) Directional Antenna

The FS antenna radiation performance standard in Section 6.2.2.2, modified for the elliptical beam, is recommended for the RLS directional antenna reference radiation pattern for EMC analyses in frequency assignment. This is provided in Table 6-56.

Table 6-56. RLS Directional Antenna Reference Radiation Pattern for Frequency Assignment

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. G_{max} usually given, or can be calculated from: • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi, • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5.	

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10 \times \log\{e \times [41253/(\phi_{bw1} \times \phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3 G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

(c) Cosecant-Square Antenna

Section of Pattern			Gain(θ) (dBi)	Angular Range
Azimuthal Plane			Table 6-56 (a) or (b) with φ replacing ϕ	$0 \leq \lvert\varphi\rvert \leq 180°$
Elevation Plane	Lower plane		Table 6-56 (a) or (b) with θ replacing ϕ	$-180° \leq \theta \leq 0°$
	Upper plane	Circular	$G_{max} - 12(\theta/\theta_{bw})^2$	$0 \leq \theta \leq \frac{\theta_{bw}}{2}$

		Cosecant-Square	$(G_{max}-3)+20\times\log\left(\frac{\csc(\theta)}{\csc\left(\frac{\theta_{bw}}{2}\right)}\right)$	$\frac{\theta_{bw}}{2}\le\theta\le\theta_m$
		Sidelobe	-55	$\theta_m\le\theta\le 180^{o}$

This pattern was discussed in Section 5.8.1 and Table 5-42.
It is assumed that

- the cosecant-square pattern is in the upper elevation plane,
- the mainbeam axis does not have elevation, and
- the break point from the circular pattern to the cosecant-square pattern is at the half-power point.

G_{max}: on-axis gain, dBi
θ, φ: elevation and azimuth angle off mainbeam axis
θ_{bw} and φ_{bw}, the half power beamwidth in the θ and φ planes, need not be the same.
θ_m: angle where cosecant-square pattern reaches sidelobe level
Sidelobe level is tentative.

- The break point from the circular pattern to the cosecant-square pattern is a design parameter. In general, the half power point is chosen to be the break point in a model.
- Usually, a land-based radar operates the cosecant-square antenna with an elevation angle of $\theta_{bw}/2$. Then, all the θ should be replaced with $(\theta - \theta_{bw}/2)$.
- A radar may operate its cosecant-square antenna in the inverse mode, e.g., airborne radar monitoring its lower air space. Then, all the θ should be replaced with $-\theta$.

6.8.1.3 Spectrum Sharing Analyses

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the federal RLS service records in the GMF. The station classes are “LR” for the land station, “MR” for the mobile station, and “MRP” for the portable station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the antenna G_{max} data population profile.
(3) Select a representative G_{max} from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.8.1.2.

Because the receiving antenna may not be the transmitting antenna, the transmitting and receiving antenna representative G_{max} values and radiation patterns are processed separately.

The frequency bands being examined are

(1) 1.705–1.8 MHz,
(2) 216–217 MHz,
(3) 420–450 MHz,
(4) 902–928 MHz,
(5) 1.215–1.3 GHz,

(6) 1.35–1.39 GHz,
(7) 2.9–3.65 GHz,
(8) 5.25–5.6 GHz,
(9) 5.65–5.925 GHz,
(10) 8.5–9 GHz,
(11) 9.5–10.55 GHz,
(12) 13.4–14 GHz,
(13) 15.7–17.3 GHz,
(14) 24.05–24.25 GHz, and
(15) 33.4–36 GHz.

6.8.1.3.1 1.705–1.8 MHz

The GMF contains only the omnidirectional antenna records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 7 frequency assignments (cumulative population % = 57%),
- 2 dBi: 6 frequency assignments (cumulative population % = 100%).

The representative G_{max} is chosen to be 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}64)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Omnidirectional Receiving Antenna

There are 8 omnidirectional receiving antenna service records in this band, all with G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 99.4° \qquad (6\text{-}65)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.8.1.3.2 216–217 MHz

The GMF contains only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 30 dBi: 1 frequency assignment,
- 31 dBi: 2 frequency assignments,
- 33 dBi: 1 frequency assignment (cumulative population % = 80%),

- 40 dBi: 1 frequency assignment.

The representative G_{max} = 33 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-57.

Table 6-57. Representative RLS Directional Transmitting Antenna Radiation Pattern in 216–217 MHz

Gain (dBi)	Angular Range
$33 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.13\times\phi_{bw}$
17.75	$1.13\times\phi_{bw} < \phi \leq 5.6°$
$36.5 - 25 \times \log(\phi)$	$5.6° < \phi \leq 48°$
-5.5	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 26 dBi: 44 frequency assignments (cumulative population % = 71%),
- 34 dBi: 18 frequency assignments.

The representative G_{max} = 26 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-58.

Table 6-58. Representative RLS Directional Receiving Antenna Radiation Pattern in 216–217 MHz

Gain (dBi)	Angular Range
$26 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.06\times\phi_{bw}$
12.5	$1.06\times\phi_{bw} < \phi \leq 12.5°$
$40 - 25 \times \log(\phi)$	$12.5° < \phi \leq 48°$
-2	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.3 420–450 MHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count is

- 0 dBi: 66 frequency assignments,

- 2, 3 dBi: 37 frequency assignments,
- 4 dBi: 55 frequency assignments,
- 5 dBi: 4 frequency assignments (cumulative population % = 64.3%),
- 6 dBi: 54 frequency assignments (cumulative population % = 85.7%),
- 7 dBi: 2 frequency assignments,
- 11, 12 dBi: 34 frequency assignments.

The representative G_{max} is chosen to be 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}66)$$
$$= -6 + 10 \times \log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 18, 21 dBi: 7 frequency assignments,
- 32 dBi: 6 frequency assignments,
- 35 dBi: 1 frequency assignment,
- 38 dBi: 1 frequency assignment (cumulative population % = 75%),
- 41−43 dBi: 5 frequency assignments.

The representative G_{max} = 38 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-59.

Table 6-59. Representative RLS Directional Transmitting Antenna Radiation Pattern in 420−450 MHz

Gain (dBi)	Angular Range
$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17 \times \phi_{bw}$
21.5	$1.17 \times \phi_{bw} < \phi \le 3.1°$
$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
-8	$48° < \phi \le 180°$
Elliptical beam. φ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 66 frequency assignments,
- 1 dBi: 1 frequency assignment,
- 2 dBi: 13 frequency assignments,
- 3 dBi: 10 frequency assignments (cumulative population % = 70.3%),

- 4 dBi: 18 frequency assignments,
- 5 dBi: 9 frequency assignments,
- 6 dBi: 11 frequency assignments.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}67)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 18 dBi: 1 frequency assignment,
- 21 dBi: 1 frequency assignment,
- 32 dBi: 1 frequency assignment (cumulative population % = 75%),
- 42 dBi: 1 frequency assignment.

The representative G_{max} = 32 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-60.

Table 6-60. Representative RLS Directional Receiving Antenna Radiation Pattern in 420–450 MHz

Gain (dBi)	Angular Range
$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.12\times\phi_{bw}$
17	$1.12\times\phi_{bw} < \phi \leq 6.3°$
$37 - 25 \times \log(\phi)$	$6.3° < \phi \leq 48°$
-5	$48° < \phi \leq 180°$
Elliptical beam. φ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.4 902–928 MHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 2 frequency assignments,
- 2 dBi: 17 frequency assignments,
- 3 dBi: 13 frequency assignments,
- 4 dBi: 1 frequency assignment,

- 5 dBi: 3 frequency assignments (cumulative population % = 72.2%),
- 6 dBi: 10 frequency assignments.

The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}68)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-42. The representative G_{max} = 28 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-61.

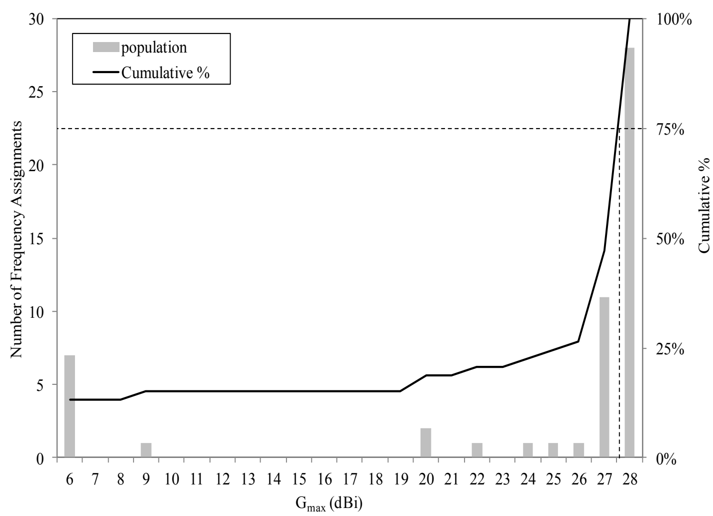


Figure 6-42. Population Profile of RLS Directional transmitting Antenna G_{max} Data in 902−928 MHz

Table 6-61. Representative RLS Directional Transmitting Antenna Radiation Pattern in 902–928 MHz

Gain (dBi)	Angular Range
$28 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.08\times\phi_{bw}$
14	$1.08\times\phi_{bw} < \phi \le 10°$
$39 - 25 \times \log(\phi)$	$10° < \phi \le 48°$
-3	$48° < \phi \le 180°$
Elliptical beam. φ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 1 frequency assignment,
- 2 dBi: 17 frequency assignments,
- 3 dBi: 2 frequency assignments,
- 5 dBi: 3 frequency assignments (cumulative population % = 14%),
- 6 dBi: 137 frequency assignments (cumulative population % = 100%).

The representative G_{max} = 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}69)$$
$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 21 dBi: 1 frequency assignment,
- 26 dBi: 1 frequency assignment,
- 27 dBi: 10 frequency assignments (cumulative population % = 75%),
- 28 dBi: 4 frequency assignments.

The representative G_{max} = 27 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-62.

Table 6-62. Representative RLS Directional Receiving Antenna Radiation Pattern in 902–928 MHz

Gain (dBi)	Angular Range
$27 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.07\times\phi_{bw}$
13.25	$1.07\times\phi_{bw} < \phi \le 11.2°$
$39.5 - 25 \times \log(\phi)$	$11.2° < \phi \le 48°$
-2.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.5 1.215–1.3 GHz

The GMF contains only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-43. The percentages of cumulative population are 71% and 79.7% at G_{max} =

34 and 35 dBi, respectively. The representative G_{max} = 34 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-63.

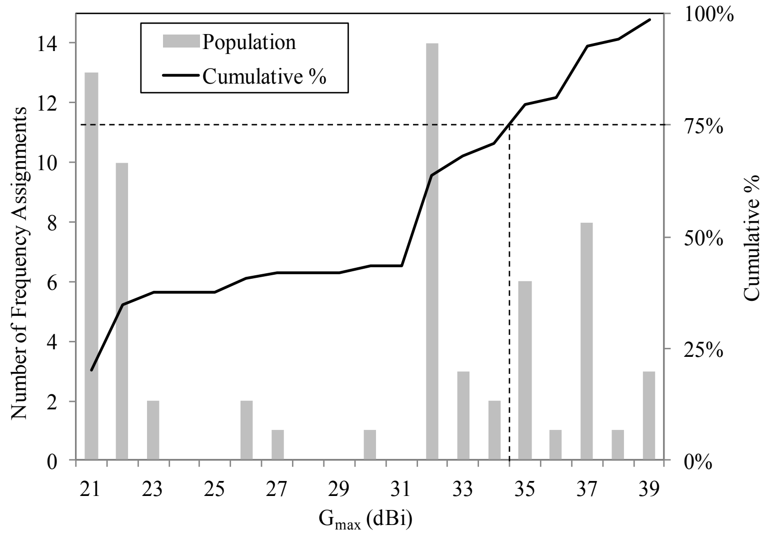


Figure 6-43. Population Profile of RLS Directional Transmitting Antenna G_{max} Data in 1.215−1.3 GHz

Table 6-63. Representative RLS Directional Transmitting Antenna Radiation Pattern in 1.215−1.3 GHz

Gain (dBi)	Angular Range
$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.14\times\phi_{bw}$
18.5	$1.14\times\phi_{bw} < \phi \leq 5°$
$36 - 25 \times \log(\phi)$	$5° < \phi \leq 48°$
-6	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 21 dBi: 11 frequency assignments,
- 22 dBi: 8 frequency assignments (cumulative population % = 79%),
- 27 dBi: 1 frequency assignment,
- 33 dBi: 1 frequency assignment, and
- 37 dBi: 3 frequency assignments.

The representative G_{max} = 22 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-64.

Table 6-64. Representative RLS Directional Receiving Antenna Radiation Pattern in 1.215−1.3 GHz

Gain (dBi)	Angular Range
$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
9.5	$1.02\times\phi_{bw} < \phi \le 19.9°$
$42 - 25 \times \log(\phi)$	$19.9° < \phi \le 48°$
0	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.6 1.35–1.39 GHz

The GMF contains only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 21 dBi: 6 frequency assignments,
- 22 dBi: 5 frequency assignments,
- 32 dBi: 1 frequency assignment (cumulative population % = 55%),
- 37 dBi: 9 frequency assignments (cumulative population % = 95%),
- 39 dBi: 1 frequency assignment.

The representative G_{max} is chosen to be 37 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-65.

Table 6-65. Representative RLS Directional Transmitting Antenna Radiation Pattern in 1.35–1.39 GHz

Gain (dBi)	Angular Range
$37 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.16\times\phi_{bw}$
20.75	$1.16\times\phi_{bw} < \phi \le 3.5°$
$34.5 - 25 \times \log(\phi)$	$3.5° < \phi \le 48°$
-7.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 21 dBi: 4 frequency assignments,
- 22 dBi: 3 frequency assignments (cumulative population % = 64%),
- 37 dBi: 4 frequency assignments.

The representative G_{max} = 22 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-66.

Table 6-66. Representative RLS Directional Receiving Antenna Radiation Pattern in 1.35–1.39 GHz

Gain (dBi)	Angular Range
$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
9.5	$1.02\times\phi_{bw} < \phi \le 19.9°$
$42 - 25 \times \log(\phi)$	$19.9° < \phi \le 48°$
0	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.7 2.9–3.65 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 1 dBi: 5 frequency assignments,
- 3 dBi: 2 frequency assignments,
- 4 dBi: 2 frequency assignments (cumulative population % = 75%),
- 9 dBi: 2 frequency assignments,
- 10 dBi: 1 frequency assignment.

The representative G_{max} = 4 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 4 - 12(\theta/42.8)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 39.6° \qquad (6\text{-}70)$$
$$= -8 + 10\times\log\{ [\max(|\theta|/42.8, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 39.6°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-44. Because there is no data count at G_{max} = 41 dBi, the representative G_{max} is chosen to be 40 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-67.

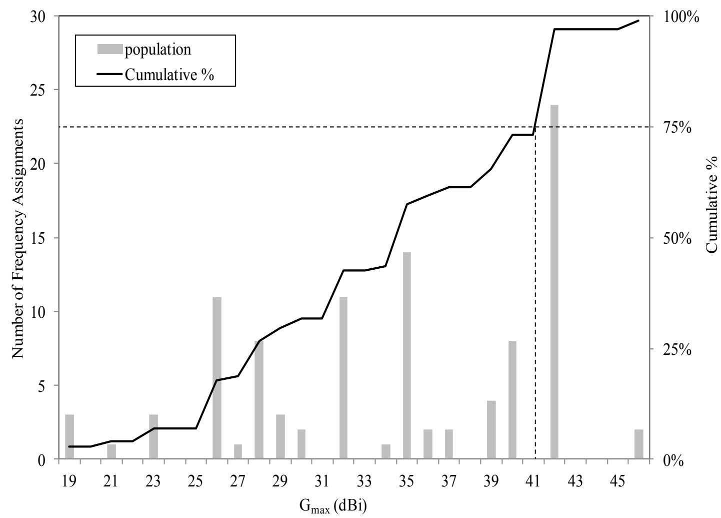


Figure 6-44. Population Profile of RLS Directional Transmitting Antenna G_{max} Data in 2.9−3.65 GHz

Table 6-67. Representative RLS Directional Transmitting Antenna Radiation Pattern in 2.9−3.65 GHz

Gain (dBi)	Angular Range
$40 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.19 \times \phi_{bw}$
23	$1.19 \times \phi_{bw} < \phi \leq 2.5°$
$33 - 25 \times \log(\phi)$	$2.5° < \phi \leq 48°$
-9	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 1 frequency assignment,
- 1 dBi: 3 frequency assignments,
- 2 dBi: 3 frequency assignments (cumulative population % = 70%),
- 3 dBi: 1 frequency assignments (cumulative population % = 80%),
- 9 dBi: 2 frequency assignments.

The representative G_{max} is chosen to be 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}71)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The population profile of the directional receiving antenna G_{max} data in this band is shown in Figure 6-45. Because there are no data counts at G_{max} = 37, 38, 39 dBi, the representative G_{max} is chosen to be 36 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-68.

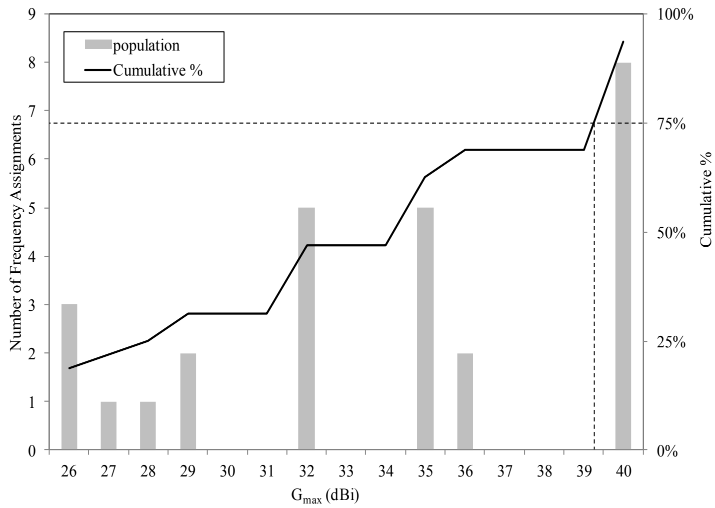


Figure 6-45. Population Profile of RLS Directional Receiving Antenna G_{max} Data in 2.9−3.65 GHz

Table 6-68. Representative RLS Directional Receiving Antenna Radiation Pattern in 2.9−3.65 GHz

Gain (dBi)	Angular Range
$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
20	$1.15\times\phi_{bw} < \phi \le 4°$
$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
-7	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.8 5.25–5.6 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0–2 dBi: 9 frequency assignments,

- 3 dBi: 3 frequency assignments,
- 4 dBi: 3 frequency assignments,
- 5 dBi: 1 frequency assignment (cumulative population % = 50%),
- 6 dBi: 16 frequency assignments (cumulative population % = 100%).

The representative G_{max} is chosen to be 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}72)$$
$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-46. The representative G_{max} = 43 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-69.

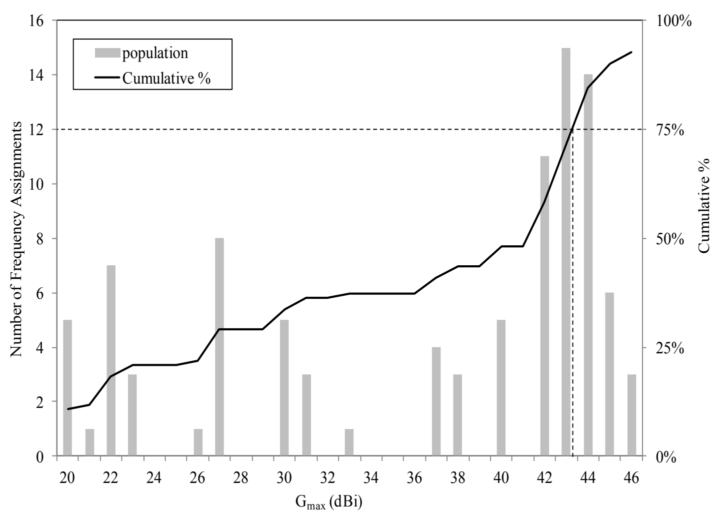


Figure 6-46. Population Profile of RLS Directional Transmitting Antenna G_{max} Data in 5.25−5.6 GHz

Table 6-69. Representative RLS Directional Transmitting Antenna Radiation Pattern in 5.25−5.6 GHz

Gain (dBi)	Angular Range
$43 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.22\times\phi_{bw}$
25.25	$1.22\times\phi_{bw} < \phi \le 1.8°$
31.5 - 25 × log (ϕ)	1.8° < ϕ ≤ 48°
-10.5	48° < ϕ ≤ 180°
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg.	

ϕ_{bw}: HPBW in the direction of interest, deg.

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0–2 dBi: 9 frequency assignments,
- 3 dBi: 3 frequency assignments,
- 4 dBi: 3 frequency assignments (cumulative population % = 41.7%),
- 6 dBi: 21 frequency assignments (cumulative population % = 100%).

The representative G_{max} = 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}73)$$
$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The population profile of the directional receiving antenna G_{max} data in this band is shown in Figure 6-47. The representative G_{max} = 43 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-70.

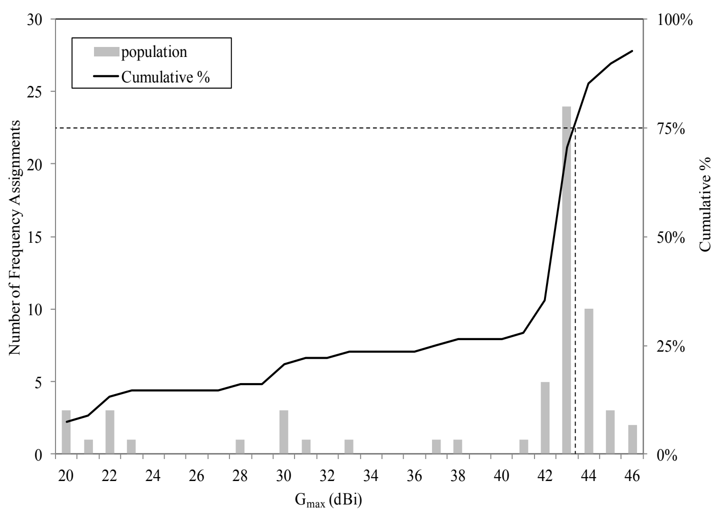


Figure 6-47. Population Profile of RLS Directional Receiving Antenna G_{max} Data in 5.25−5.6 GHz

Table 6-70. Representative RLS Directional Receiving Antenna Radiation Pattern in 5.25−5.6 GHz

Gain (dBi)	Angular Range
$43 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.22\times\phi_{bw}$

25.25	$1.22\times\phi_{bw} < \phi \le 1.8°$
31.5 - 25 × log (ϕ)	$1.8° < \phi \le 48°$
-10.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.9 5.65–5.925 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0–2 dBi: 6 frequency assignments,
- 3 dBi: 11 frequency assignments,
- 4 dBi: 14 frequency assignments,
- 5 dBi: 13 frequency assignments (cumulative population % = 73.3%),
- 6 dBi: 16 frequency assignments.

The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}74)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-48. The percentages of cumulative population are 74.4% and 76% at G_{max} = 45 and 46 dBi, respectively. The representative G_{max} = 45 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-71.

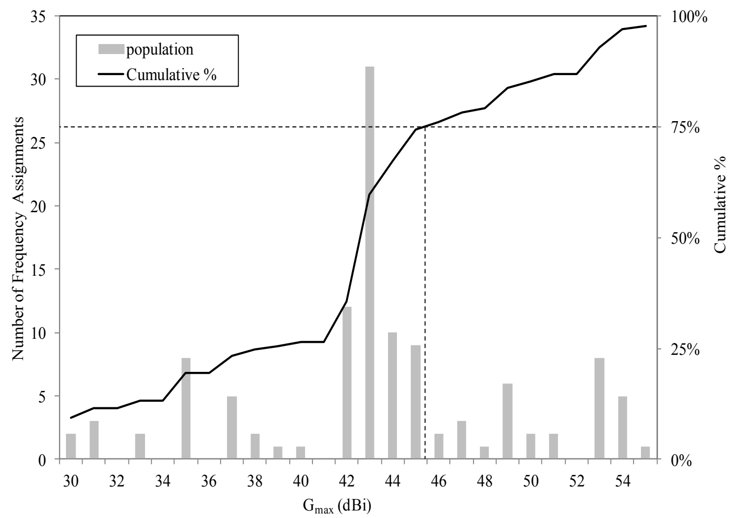


Figure 6-48. Population Profile of RLS Directional Transmitting Antenna G_{max} Data in 5.65−5.925 GHz

Table 6-71. Representative RLS Directional Transmitting Antenna Radiation Pattern in 5.65−5.925 GHz

Gain (dBi)	Angular Range
$45 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.23\times\phi_{bw}$
26.75	$1.23\times\phi_{bw} < \phi \le 1.4°$
$30.5 - 25 \times \log(\phi)$	$1.4° < \phi \le 48°$
-11.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 1–2 dBi: 3 frequency assignments,
- 3 dBi: 13 frequency assignments,
- 4 dBi: 11 frequency assignments,
- 5 dBi: 2 frequency assignments (cumulative population % = 50%),
- 6 dBi: 29 frequency assignments (cumulative population % = 100%).

The representative G_{max} is chosen to be 6 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 6 - 12(\theta/27)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 25° \qquad (6\text{-}75)$$

$$= -6 + 10\times\log\{ [\max(|\theta|/27, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 25°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The population profile of the directional receiving antenna G_{max} data in this band is shown in Figure 6-49. The representative G_{max} = 45 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-72.

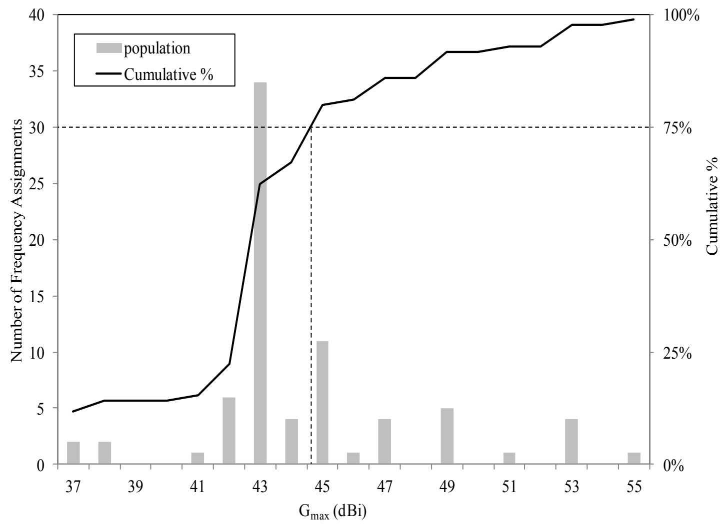


Figure 6-49. Population Profile of RLS Directional Receiving Antenna G_{max} Data in 5.65−5.925 GHz

Table 6-72. Representative RLS Directional Receiving Antenna Radiation Pattern in 5.65−5.925 GHz

Gain (dBi)	Angular Range
$45 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.23\times\phi_{bw}$
26.75	$1.23\times\phi_{bw} < \phi \le 1.4°$
$30.5 - 25 \times \log(\phi)$	$1.4° < \phi \le 48°$
-11.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.10 8.5–9 GHz

The GMF contains only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 20, 22 dBi: 9 frequency assignments,
- 27, 29, 30 dBi: 6 frequency assignments,
- 31 dBi: 117 frequency assignments (cumulative population % = 81%),
- 33, 34 dBi: 15 frequency assignments,

- 37–44 dBi: 16 frequency assignments.

The representative G_{max} = 31 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-73.

Table 6-73. Representative RLS Directional Transmitting Antenna Radiation Pattern in e 8.5−9 GHz

Gain (dBi)	Angular Range
$31 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.11\times\phi_{bw}$
16.25	$1.11\times\phi_{bw} < \phi \le 7°$
$37.5 - 25 \times \log(\phi)$	$7° < \phi \le 48°$
-4.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 27 dBi: 2 frequency assignments,
- 31 dBi: 118 frequency assignments (cumulative population % = 95%),
- 34–42 dBi: 6 frequency assignments.

The representative G_{max} = 31 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-74.

Table 6-74. Representative RLS Directional Receiving Antenna Radiation Pattern in 8.5−9 GHz

Gain (dBi)	Angular Range
$31 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.11\times\phi_{bw}$
16.25	$1.11\times\phi_{bw} < \phi \le 7°$
$37.5 - 25 \times \log(\phi)$	$7° < \phi \le 48°$
-4.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.11 9.5–10.55 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna service records all have G_{max} = 2 dBi in this band. The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}76)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-50. The representative G_{max} = 36 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-75.

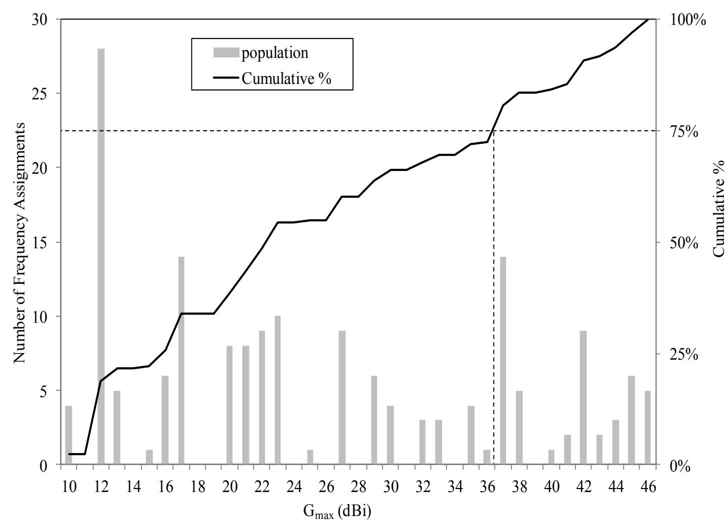


Figure 6-50. Population Profile of RLS Directional Transmitting Antenna G_{max} Data in 9.5–10.55 GHz

Table 6-75. Representative RLS Directional Transmitting Antenna Radiation Pattern in 9.5–10.55 GHz

Gain (dBi)	Angular Range
$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.15\times\phi_{bw}$
20	$1.15\times\phi_{bw} < \phi \leq 4°$
$35 - 25 \times \log(\phi)$	$4° < \phi \leq 48°$
-7	$48° < \phi \leq 180°$
Elliptical beam. φ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna service records all have G_{max} = 2 dBi in this band. The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}77)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The population profile of the directional receiving antenna G_{max} data in this band is shown in Figure 6-51. The representative G_{max} = 36 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-76.

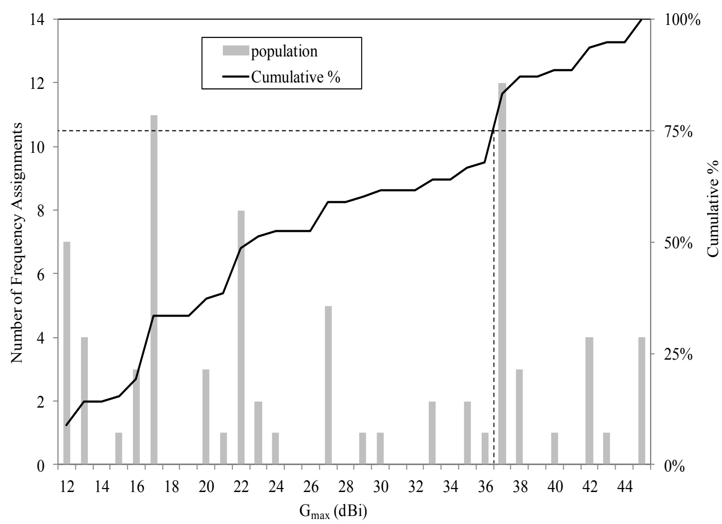


Figure 6-51. Population Profile of RLS Directional Receiving Antenna G_{max} Data in 9.5–10.55 GHz

Table 6-76. Representative RLS Directional Receiving Antenna Radiation Pattern in 9.5–10.55 GHz

Gain (dBi)	Angular Range
$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
20	$1.15\times\phi_{bw} < \phi \le 4°$
$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
-7	$48° < \phi \le 180°$
Elliptical beam. φ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.12 13.4–14 GHz

The GMF contains only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 27 dBi: 1 frequency assignment,
- 34 dBi: 1 frequency assignment,
- 38 dBi: 3 frequency assignments (cumulative population % = 71%),
- 43 dBi: 2 frequency assignments.

The representative G_{max} = 38 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-77.

Table 6-77. Representative RLS Directional Receiving Antenna Radiation Pattern in 13.4–14 GHz

Gain (dBi)	Angular Range
$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
-8	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 27 dBi: 1 frequency assignment,
- 34 dBi: 1 frequency assignment.

The representative G_{max} is chosen to be 34 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-78.

Table 6-78. Representative RLS Directional Receiving Antenna Radiation Pattern in 13.4–14 GHz

Gain (dBi)	Angular Range
$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.14\times\phi_{bw}$
18.5	$1.14\times\phi_{bw} < \phi \le 5°$
$36 - 25 \times \log(\phi)$	$5° < \phi \le 48°$
-6	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.13 15.7–17.3 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 2 frequency assignments (cumulative population % = 67%),
- 2 dBi: 1 frequency assignment.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}78)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-52. The representative G_{max} = 43 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-79.

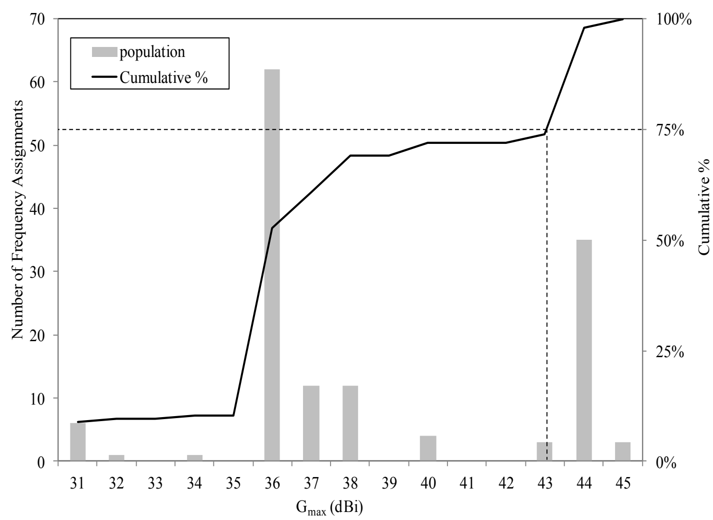


Figure 6-52. Population Profile of RLS Directional Transmitting Antenna G_{max} Data in 15.7–17.3 GHz

Table 6-79. Representative RLS Directional Transmitting Antenna Radiation Pattern in 15.7–17.3 GHz

Gain (dBi)	Angular Range
$43 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.22\times\phi_{bw}$
25.25	$1.22\times\phi_{bw} < \phi \le 1.8°$
$31.5 - 25 \times \log(\phi)$	$1.8° < \phi \le 48°$
-10.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

There is one omnidirectional receiving antenna service record in this band, with G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}79)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 22, 25 dBi: 4 frequency assignments,
- 31, 32 dBi: 4 frequency assignments,
- 36 dBi: 63 frequency assignments (cumulative population % = 74.7%),
- 37 dBi: 8 frequency assignments,
- 38 dBi: 10 frequency assignments,
- 40, 44, 45 dBi: 6 frequency assignments.

The representative G_{max} = 36 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-80.

Table 6-80. Representative RLS Directional Receiving Antenna Radiation Pattern in 15.7–17.3 GHz

Gain (dBi)	Angular Range
$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
20	$1.15\times\phi_{bw} < \phi \le 4°$
$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
-7	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg.	

ϕ_{bw}: HPBW in the direction of interest, deg.

6.8.1.3.14 24.05–24.25 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 1 frequency assignment,
- 2 dBi: 3 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}80)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 10, 12 dBi: 3 frequency assignments,
- 19, 20 dBi: 2 frequency assignments,
- 22, 23 dBi: 52 frequency assignments,
- 28 dBi: 15 frequency assignments,
- 29 dBi: 4 frequency assignments (cumulative population % = 73.8%),
- 30 dBi: 25 frequency assignments,
- > 30 dBi: 2 frequency assignments.

The representative G_{max} = 29 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-81.

Table 6-81. Representative RLS Directional Transmitting Antenna Radiation Pattern in 24.05–24.25 GHz

Gain (dBi)	Angular Range
$29 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.09\times\phi_{bw}$
14.75	$1.09\times\phi_{bw} < \phi \leq 8.9°$
$38.5 - 25 \times \log(\phi)$	$8.9° < \phi \leq 48°$
-3.5	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 1 frequency assignment,
- 2 dBi: 1 frequency assignment.

The representative G_{max} is chosen to be 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}81)$$
$$= -10 + 10 \times \log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 10 dBi: 1 frequency assignment,
- 23 dBi: 8 frequency assignments,
- 28 dBi: 1 frequency assignment (cumulative population % = 34%),
- 30 dBi: 18 frequency assignments (cumulative population % = 97%),
- 52 dBi: 1 frequency assignment.

The representative G_{max} = 30 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-82.

Table 6-82. Representative RLS Directional Receiving Antenna Radiation Pattern in 24.05–24.25 GHz

Gain (dBi)	Angular Range
$30 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.1 \times \phi_{bw}$
15.5	$1.1 \times \phi_{bw} < \phi \le 7.9°$
$38 - 25 \times \log(\phi)$	$7.9° < \phi \le 48°$
-4	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.1.3.15 33.4–36 GHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

There is one omnidirectional transmitting antenna service record in this band, with G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}82)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 12, 15 dBi: 5 frequency assignments,
- 21, 23, 29 dBi: 13 frequency assignments,
- 32 dBi: 153 frequency assignments (cumulative population % = 83%),
- 33, 37, 38 dBi: 5 frequency assignments,
- 41 dBi: 23 frequency assignments,
- 50, 54, 57, 58 dBi: 5 frequency assignments.

The representative G_{max} = 32 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-83.

Table 6-83. Representative RLS Directional Transmitting Antenna Radiation Pattern in 33.4–36 GHz

Gain (dBi)	Angular Range
$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.12\times\phi_{bw}$
17	$1.12\times\phi_{bw} < \phi \le 6.3°$
$37 - 25 \times \log(\phi)$	$6.3° < \phi \le 48°$
-5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

There is one omnidirectional receiving antenna service record in this band, with G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}83)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 15, 23, 29 dBi: 7 frequency assignments,
- 32 dBi: 148 frequency assignments (cumulative population % = 88%),

- 38 dBi: 1 frequency assignment,
- 41 dBi: 16 frequency assignments,
- 50, 57, 58 dBi: 4 frequency assignments.

The representative G_{max} = 32 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-84.

Table 6-84. Representative RLS Directional Receiving Antenna Radiation Pattern in 33.4–36 GHz

Gain (dBi)	Angular Range
$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.12\times\phi_{bw}$
17	$1.12\times\phi_{bw} < \phi \leq 6.3°$
$37 - 25 \times \log(\phi)$	$6.3° < \phi \leq 48°$
-5	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.2 Maritime Radionavigation Service

6.8.2.1 System Review

The antenna radiation performance standards in Table 6-55 are suitable for system review.

6.8.2.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation pattern is not available, a reference radiation pattern should be used. The standards in Table 6-55 do not provide sufficient information for EMC analyses in frequency assignment; therefore, the RLS base station antenna reference radiation patterns in Section 6.8.1.2 are recommended for the MRNS beacon service antennas. These are as follows:

(a) Beacon Service Omnidirectional Antenna

The omnidirectional antenna vertical radiation pattern is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (6\text{-}84)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

(b) Directional Antenna

The directional antenna radiation patterns are provided in Table 6-85.

Table 6-85. MRNS Directional Antenna Reference Radiation Patterns

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
G_{max} - $12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. G_{max} usually given, or can be calculated from: • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5	

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \ge 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le \phi_{b1}$
	-13	$\phi_{b1} < \phi \le 180°$
$22 \le G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \le 180°$
$10 \le G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \le \phi_{b3}$
	0	$\phi_{b3} < \phi \le 180°$
Elliptical beam. All angles in deg. G_{max} usually given, or can be calculated from • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi, • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes ϕ: angle off mainbeam axis in the direction of interest ϕ_{bw}: HPBW in the direction of interest ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$		

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$
$$\phi_{r2} = \phi_{r3} = 250 / \left(10^{G_{max}/20}\right)$$
$$\phi_{b1} = \phi_{b2} = 48°$$
$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

These radiation patterns do not specify the G_{max} values; however, such data should be available in the GMF.

6.8.2.3 Spectrum Sharing Analyses

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the MRNS service records in the GMF. The symbol of the station class is "NL" for the land station, "NLC" for the radar beacon, and "NLM" for the marine radio beacon. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the transmitting antenna G_{max} data population profile.
(3) Select a representative G_{max} from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.8.2.2.

The GMF contains only the MRNS transmitting antenna service records. Thus, only the transmitting antenna representative G_{max} data and reference radiation pattern are discussed here.

The frequency bands being examined are

(1) 2.9–3.1 GHz,
(2) 9.2–9.3 GHz, and
(3) 9.3–9.5 GHz.

6.8.2.3.1 2.9–3.1 GHz

The GMF contains only beacon service records in this band. The beacon antenna G_{max} data count in this band is

- 4 dBi: 72 frequency assignments,
- 5 dBi: 1 frequency assignments (cumulative population % = 71%),
- 6 dBi: 26 frequency assignments,
- 7 dBi: 4 frequency assignments.

The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}85)$$
$$= -7 + 10 \times \log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.8.2.3.2 9.2–9.3 GHz

The GMF has only one service record in this band, and its land-based transmitting antenna G_{max} = 38 dBi. The representative G_{max} = 38 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-86.

Table 6-86. Representative MRNS Antenna Radiation Pattern in 9.2−9.3 GHz

Gain (dBi)	Angular Range
$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
-8	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.2.3.3 9.3–9.5 GHz

This is a general-purpose RNS band. The GMF contains only the beacon service records in this band.

(a) Omnidirectional Antenna

The beacon antenna G_{max} data count in this band is

- 4 dBi: 67 frequency assignments,
- 5 dBi: 4 frequency assignments (cumulative population % = 68%),
- 6 dBi: 26 frequency assignments,
- 7 dBi: 8 frequency assignments.

The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}86)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Antenna

There is only one directional beacon antenna service record in this band, with G_{max} = 29 dBi. The representative G_{max} = 29 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-87.

Table 6-87. Representative MRNS Directional Beacon Antenna Radiation Pattern in 9.3−9.5 GHz

Gain (dBi)	Angular Range
$29 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.09\times\phi_{bw}$
14.75	$1.09\times\phi_{bw} < \phi \le 8.9°$
$38.5 - 25 \times \log(\phi)$	$8.9° < \phi \le 48°$
-3.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3 Aeronautical Radionavigation Service

6.8.3.1 System Review

While the RDS radar antenna radiation performance standards in Table 6-55 are the federal standards for the general RDS systems, the ARNS antenna radiation performance standards from RTCA are developed for the ARNS operations, and should be the more accurate standards. Therefore, NTIA recommends that the antenna radiation performance standards from RTCA be used as the federal ARNS antenna radiation performance standards. They are as follows:

(a) The minimum operational radiation performance standards of the ARNS airborne receiving antenna for the ILS (instrument landing system) localizer equipment operating in the 108–112 MHz band are

- radiation pattern: the horizontal component of the radiated signal in the forward and rearward directions shall not be down more than 10 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 113 MHz and mounted 10 inches above the ground plane,
- gain variation: the difference between the maximum and minimum field strength of the horizontal component in the azimuth plane shall not exceed 20 dB,
- polarization discrimination: the reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(b) The minimum operational radiation performance standards of the ARNS airborne receiving antenna for the VHF omnidirectional range equipment operating in the 108–117.95 MHz band are

- radiation pattern: the horizontal component of the radiated signal in the forward and rearward directions shall not be down more than 10 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 113 MHz and mounted 10 inches above the ground plane,
- gain variation: the difference between the maximum and minimum field strength of the horizontal component in the azimuth plane shall not exceed 20 dB,

- polarization discrimination: the reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(c) The minimum operational radiation performance standards of the ARNS airborne antenna for the GPS local area augmentation system operating in the 108–117.975 MHz band are

- antenna type: omnidirectional antenna,
- horizontal gain:
    - the reception of the horizontally polarized component in the horizontal plane from the forward and rearward directions shall not be down more than 10 dB when compared to the maximum output response of a standard horizontal dipole antenna that is mounted 25.4 cm (10 inches) above the ground plane and resonant at 113 MHz,
    - the difference between the maximum and minimum reception of the horizontally polarized component from any direction in the horizontal plane shall not exceed 20 dB,
- vertical gain:
    - when mounted on a 4×4 $inch^2$ (or larger) ground plane, the reception of the vertically polarized component in the horizontal azimuth plane shall not be down more than 6 dB when compared to a standard vertically polarized monopole antenna,
    - when mounted on a 4×4 $inch^2$ (or larger) ground plane, the difference between the maximum and minimum reception of the vertical polarized component from any direction in the horizontal azimuth plane shall not exceed 6 dB.

(d) The minimum operational radiation performance standards of the ARNS airborne receiving antenna for the ILS glide slope equipment operating in the 328.6–335.4 MHz band are

- radiation pattern: the horizontal component of the radiated signal in the forward direction shall not be down more than 15 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 332 MHz in free space,
- polarization discrimination: the reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(e) The minimum operational radiation performance standards of the ARNS airborne antenna for the distance measuring equipment operating in the 960–1215 MHz band are

- polarization: predominately vertically polarized,
- radiation pattern: the average field strength in the horizontal plane shall be equal to the field strength of a matched resonant ¼λ vertical antenna,
- gain variation: the difference between the maximum and minimum field strengths in the horizontal plane shall not exceed 6 dB when the antenna is mounted at the center of the 1.2-meter (4-foot) diameter (or larger) flat circular ground plane.

(f) The minimum operational radiation performance standards of the ARNS airborne antenna for the air traffic control radar beacon system/mode select equipment operating in the 1030–1090 MHz band are

- polarization: vertically polarized,
- radiation pattern: the gain shall not be less than the gain of a matched ¼λ stub minus 3 dB over 90% of the coverage volume 0–360º in azimuth and 5–30º in elevation when installed at the center of a 1.2-meter (4-foot) diameter (or larger) circular ground plane.

(g) The minimum operational radiation performance standards of the ARNS airborne antenna for the traffic alert and collision avoidance system II transmitting in the 1030 MHz band and receiving in the 1087–1093 MHz band are

- polarization: vertically polarized,
- radiation pattern: the gain shall not be less than the gain of a matched ¼λ stub minus 1 dB over 90% of the coverage volume 0–360º in azimuth and (-15)–20º in elevation when installed at the center of a 1.2-meter (4-foot) diameter (or larger) circular ground plane, which can be flat or cylindrical.

(h) The minimum operational radiation performance standards of the ARNS airborne antenna for the active traffic alert and collision avoidance system I transmitting in the 1030 MHz band and receiving in the 1087–1093 MHz band are

- type: omnidirectional antenna or multiple beams to cover all azimuth directions,
- polarization: vertically polarized,
- radiation pattern: covering 360º in azimuth and at least (-10)–20º in elevation.

(i) The minimum operational radiation performance standards of the ARNS airborne antenna for the automatic dependent surveillance system and traffic information service system operating at 1090 MHz are

- type: omnidirectional antenna,
- polarization: vertically polarized,
- transmit radiation pattern: the gain shall not be less than the gain of a matched ¼λ stub minus 3 dB over 90% of a coverage volume from 0–360º in azimuth and 5–30º above the ground plane when installed at the center of 1.2 meters (4 feet) or larger flat circular ground plane,
- receive radiation pattern: the gain should not be less than the gain of a matched ¼λ stub minus 1 dB over 90% of a coverage volume from 0–360º in azimuth and (-15)–(+20)º in elevation when installed at the center of 1.2 meters (4 feet) or larger circular ground plane, which can be either flat or cylindrical.

6.8.3.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation pattern is not available, a reference radiation pattern should be used. The standards in Section 6.8.3.1 do not provide sufficient information for EMC analyses in frequency assignment; therefore, the RLS base station antenna reference radiation patterns in Section 6.8.1.2 are recommended for the ARNS antennas. They are as follows:

(a) Omnidirectional Antenna

The omnidirectional antenna vertical radiation pattern is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \qquad \text{dBi} \qquad (6\text{-}87)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$\theta_{bw} = 107.6 \times 10^{-0.1 G_{max}}$, deg.

(b) Directional Antenna

The directional antenna radiation patterns are provided in Table 6-88.

Table 6-88. ARNS Directional Antenna Reference Radiation Patterns

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5.

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \ge 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le \phi_{b1}$
	-13	$\phi_{b1} < \phi \le 180°$
$22 \le G_{max}(\text{dBi}) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$

	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \le 180°$
$10 \le G_{max}(\text{dBi}) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \le \phi_{b3}$
	0	$\phi_{b3} < \phi \le 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest

ϕ_{bw}: HPBW in the direction of interest

ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$

$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$

$\phi_{b1} = \phi_{b2} = 48°$

$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$

These radiation patterns do not specify the G_{max} value; however, such data should be available in the GMF.

6.8.3.3 Spectrum Sharing Analyses

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the ARNS service records in the GMF. The symbol of the station class is “AL” for the land station, “ALA” for the marker beacon, “ALB” for the radio beacon, “ALC” for the radar beacon, “ALG” for the glide path, “ALL” for the localizer, “ALO” for the omnidirectional range, “ALR” for the radio range, “ALS” for the surveillance radar, “ALTM” for the land test maintenance, “ALTO” for the land test operation, “AM” for the mobile station, and “AMA” for the altimeter. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the antenna G_{max} data population profile.
(3) Select a representative G_{max} from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} and the antenna reference radiation patterns in Section 6.8.3.2.

Because the receiving antenna may not be the transmitting antenna, the transmitting and receiving antenna service records are processed separately.

The frequency bands being examined are

(1) 190–435 kHz range containing the following bands:
   - 190–285 kHz,
   - 325–405 kHz,
   - 405–415 kHz,
   - 415–435 kHz.

(2) 510–535 kHz, 1.715–1.725 MHz, and 1.74–1.75 MHz,
(3) 74.8–75.2 MHz,
(4) 108–117.975 MHz,
(5) 328.6–335.4 MHz,
(6) 960–1215 MHz,
(7) 1.24–1.37 and 2.7–2.9 GHz,
(8) 4.2–4.4 GHz,
(9) 5–5.25 GHz,
(10) 9–9.2 GHz,
(11) 9.3–9.5 GHz,
(12) 13.25–13.4 GHz, and
(13) 15.4–15.7 GHz.

6.8.3.3.1 190–435 kHz

This frequency range contains the following RNS bands:

- RNS: 405–415 kHz,
- ARNS:
  - 190–285 kHz,
  - 325–405 kHz,
  - 415–435 kHz.

The GMF contains only the omnidirectional antenna service records in these bands.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in these bands is

- 0 dBi: 57 frequency assignments (cumulative population % = 73%),
- 1 dBi: 6 frequency assignments,
- 2 dBi: 9 frequency assignments,
- 3 dBi: 6 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}88)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in these bands is

- 0 dBi: 43 frequency assignments,
- 2 dBi: 1 frequency assignment,
- 3 dBi: 2 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \leq 99.4° \qquad (6\text{-}89)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.8.3.3.2 510–535 kHz and 1.705–1.75 MHz

This frequency range contains the following ARNS bands:

- 510–535 kHz,
- 1.715–1.725 MHz,
- 1.74–1.75 MHz.

The GMF contains only the omnidirectional antenna service records in these bands.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in these bands is

- 0 dBi: 6 frequency assignments,
- 2 dBi: 27 frequency assignments (cumulative population % = 100%).

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi for } |\theta| \leq 62.7° \qquad (6\text{-}90)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in these bands is

- 0 dBi: 30 frequency assignments,
- 2 dBi: 4 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi for } |\theta| \leq 99.4° \qquad (6\text{-}91)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi for } |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.8.3.3.3 74.8–75.2 MHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 2 frequency assignments,
- 3 dBi: 1 frequency assignment
- 7 dBi: 3 frequency assignments.

The representative G_{max} = 7 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= 7 - 12(\theta/21.5)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 19.8° \qquad (6\text{-}92)\\
&= -5 + 10\times\log\{\,[\max(|\theta|/21.5,\ 1)]^{-1.5}\,\} && \text{dBi} \quad \text{for} \quad |\theta| > 19.8°
\end{aligned}
$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 5 dBi: 1 frequency assignment,
- 6 dBi: 1 frequency assignment,
- 7 dBi: 12 frequency assignments.

The representative G_{max} = 7 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-89.

Table 6-89. Representative ARNS Directional Antenna Radiation Pattern in 74.8−75.2 MHz

Gain Function (dBi)	Angular Range
$7 - 12(\phi/\phi_{bw})^2$	$0 \le \phi < \phi_{bw}$
-5	$\phi_{bw} \le \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Receiving Antenna

There are 3 receiving antenna service records in this band, all are omnidirectional antennas, all with G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= -12(\theta/107.6)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}93)\\
&= -12 + 10\times\log\{\,[\max(|\theta|/107.6,\ 1)]^{-1.5}\,\} && \text{dBi} \quad \text{for} \quad |\theta| > 99.4°
\end{aligned}
$$

where θ is the elevation angle off the peak gain plane, in deg.

6.8.3.3.4 108–117.975 MHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The population profile of the omnidirectional transmitting antenna G_{max} data in this band is shown in Figure 6-53. The representative G_{max} = 5 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 5 - 12(\theta/34)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 31.4° \qquad (6\text{-}94)$$
$$= -7 + 10\times\log\{ [\max(|\theta|/34, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 31.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

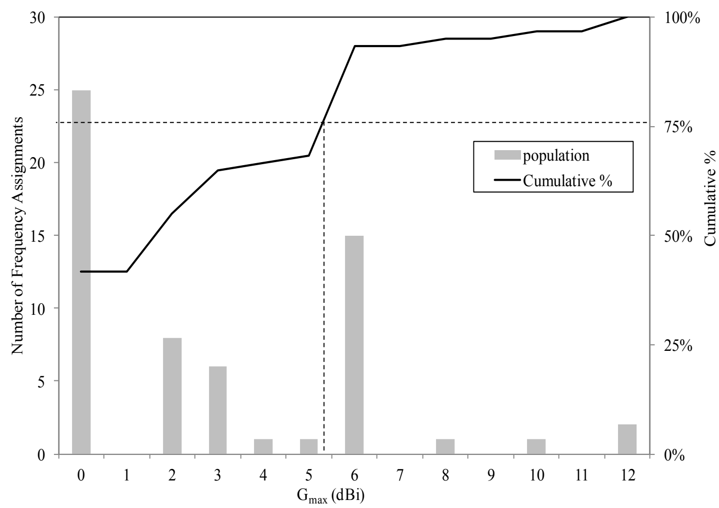


Figure 6-53. Population Profile of ARNS Omnidirectional Transmitting Antenna G_{max} Data in 108−117.975 MHz

(b) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-54. The percentages of cumulative population are 50% and 100% for G_{max} = 26 dBi and 28 dBi, respectively, and the representative G_{max} is chosen to be 28 dBi to protect more federal systems. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-90.

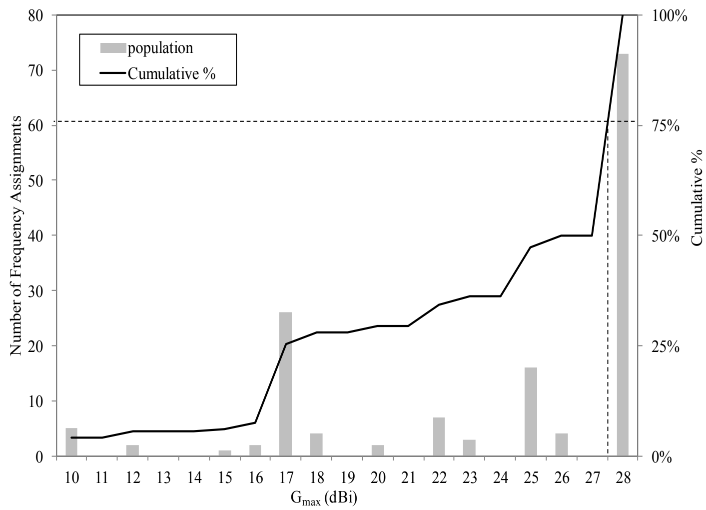


Figure 6-54. Population Profile of ARNS Directional Transmitting Antenna G_{max} Data in 108−117.975 MHz

Table 6-90. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 108−117.975 MHz

Gain (dBi)	Angular Range
$28 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.08\times\phi_{bw}$
14	$1.08\times\phi_{bw} < \phi \le 10°$
$39 - 25 \times \log(\phi)$	$10° < \phi \le 48°$
-3	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 16 frequency assignments (cumulative population % = 67%),
- 2 dBi: 5 frequency assignments (cumulative population % = 88%),
- 3 dBi: 3 frequency assignments.

The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = -12(\theta/107.6)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 99.4° \qquad (6\text{-}95)$$
$$= -12 + 10\times\log\{ [\max(|\theta|/107.6, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 99.4°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

There are 2 directional receiving antenna service records in this band, with both G_{max} = 25 dBi. The representative G_{max} = 25 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-91.

Table 6-91. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 108−117.975 MHz

Gain (dBi)	Angular Range
$25 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.05\times\phi_{bw}$
11.75	$1.05\times\phi_{bw} < \phi \le 14.1°$
$40.5 - 25 \times \log(\phi)$	$14.1° < \phi \le 48°$
-1.5	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.5 328.6–335.4 MHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 3 frequency assignments,
- 3, 4 dBi: 8 frequency assignments,
- 5, 6 dBi: 6 frequency assignments,
- 8 dBi: 1 frequency assignment (cumulative population % = 45%),
- 10 dBi: 22 frequency assignments (cumulative population % = 100%).

The representative G_{max} = 10 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 10 - 12(\theta/10.8)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 9.9° \qquad (6\text{-}96)$$
$$= -2 + 10\times\log\{ [\max(|\theta|/10.8, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 9.9°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 10 dBi: 6 frequency assignments,
- 12, 13 dBi: 17 frequency assignments,
- 15 dBi: 2 frequency assignments,
- 16 dBi: 82 frequency assignments (cumulative population % = 97.3%),

- 17, 19, 20 dBi: 3 frequency assignments.

The representative G_{max} = 16 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-92.

Table 6-92. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 328.6–335.4 MHz

Gain (dBi)	Angular Range
$16 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 0.96\times\phi_{bw}$
5	$0.96\times\phi_{bw} < \phi \leq 39.6°$
$45 - 25 \times \log(\phi)$	$39.6° < \phi \leq 63.1°$
0	$63.1° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(c) Receiving Antenna

The GMF contains only the omnidirectional antenna service records.

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 8 frequency assignments,
- 1 dBi: 1 frequency assignment,
- 2 dBi: 1 frequency assignment (cumulative population % = 77%),
- 3 dBi: 2 frequency assignments,
- 10 dBi: 1 frequency assignment.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 62.7° \qquad (6\text{-}97)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

6.8.3.3.6 960–1215 MHz

The GMF contains both the omnidirectional and directional antenna service records in this band.

(a) Omnidirectional Transmitting Antenna

The population profile of the omnidirectional transmitting antenna G_{max} data in this band is shown in Figure 6-55. The representative G_{max} = 4 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 4 - 12(\theta/42.8)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 39.6° \qquad (6\text{-}98)$$

$$= -8 + 10\times\log\{ [\max(|\theta|/42.8, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 39.6°$$

where θ is the elevation angle off the peak gain plane, in deg.

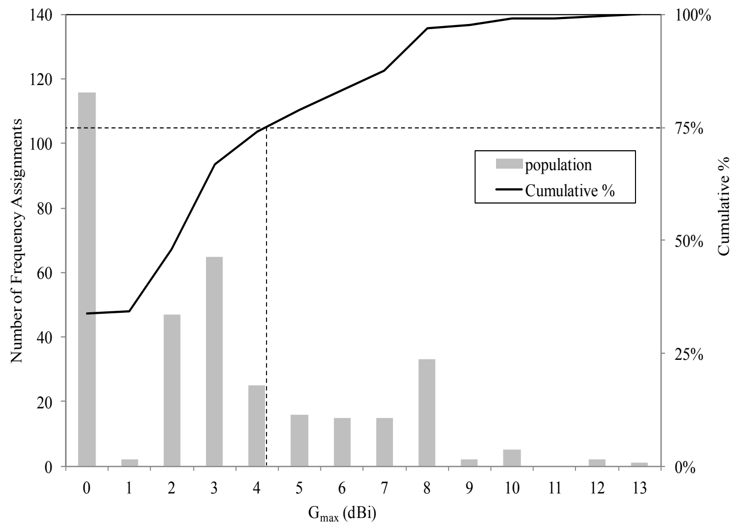


Figure 6-55. Population Profile of ARNS Omnidirectional Transmitting Antenna G_{max} Data in 960−1215 MHz

(b) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 3 dBi: 49 frequency assignments,
- 4–11 dBi: 25 frequency assignments,
- 12 dBi: 187 frequency assignments,
- 13 dBi: 73 frequency assignments,
- 14 dBi: 6 frequency assignments,
- 15 dBi: 280 frequency assignments (cumulative population % = 87.6%),
- 16–23 dBi: 47 frequency assignments,
- 27 dBi: 39 frequency assignments,
- 28, 34 dBi: 2 frequency assignments.

The representative G_{max} = 15 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-93.

Table 6-93. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 960−1215 MHz

Gain (dBi)	Angular Range
$15 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.95\times\phi_{bw}$
4.25	$0.95\times\phi_{bw} < \phi \le 44.5°$
$45.5 - 25 \times \log(\phi)$	$44.5° < \phi \le 66.1°$
0	$66.1° < \phi \le 180°$
Elliptical beam.	

ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.

(c) Omnidirectional Receiving Antenna

The omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 14 frequency assignments,
- 2 dBi: 36 frequency assignments (cumulative population % = 50%),
- 3 dBi: 44 frequency assignments (cumulative population % = 94%),
- 4, 5 dBi: 5 frequency assignments,
- 11 dBi: 1 frequency assignment.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 3 - 12(\theta/53.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \leq 49.8° \qquad (6\text{-}99)$$
$$= -9 + 10\times\log\{ [\max(|\theta|/53.9, 1)]^{-1.5} \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 49.8°$$

where θ is the elevation angle off the peak gain plane, in deg.

(d) Directional Receiving Antenna

The population profile of the directional receiving antenna G_{max} data in this band is shown in Figure 6-56. The figure shows two disconnected clusters at 19–22 dBi and 26–28 dBi. The percentages of cumulative population are 61.4% and 95.4% at G_{max} = 21 and 27 dBi, respectively, and are 63.9% and 64.4% at G_{max} = 22 and 26 dBi, respectively. Choosing the cluster at 19–22 dBi to find the representative G_{max}, the representative G_{max} is chosen to be 22 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-94.

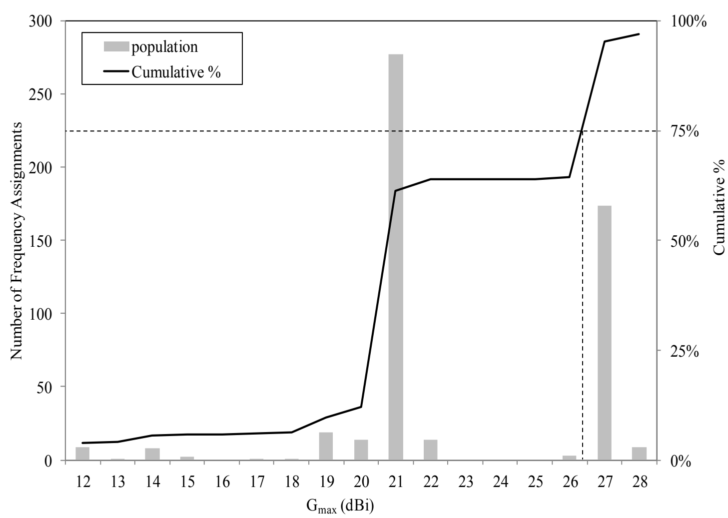


Figure 6-56. Population Profile of ARNS Directional Receiving Antenna G_{max} Data in 960−1215 MHz

Table 6-94. Representative ARNS Directional Receiving Antenna Radiation Pattern in 960−1215 MHz

Gain (dBi)	Angular Range
$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.02 \times \phi_{bw}$
9.5	$1.02 \times \phi_{bw} < \phi \leq 19.9°$
$42 - 25 \times \log(\phi)$	$19.9° < \phi \leq 48°$
0	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.7 1.24–2.9 GHz

This frequency range contains the 1.24–1.37 and 2.7–2.9 GHz ARNS bands. The GMF has only the directional antenna service records in these bands.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 21, 22, 27 dBi: 4 frequency assignments,
- 32, 33 dBi: 5 frequency assignments,
- 34 dBi: 155 frequency assignments (cumulative population % = 91.6%),
- 35, 39 dBi: 15 frequency assignments.

The representative G_{max} = 34 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-95.

Table 6-95. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 1.24–2.9 GHz

Gain (dBi)	Angular Range
$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.14 \times \phi_{bw}$
18.5	$1.14 \times \phi_{bw} < \phi \leq 5°$
$36 - 25 \times \log(\phi)$	$5° < \phi \leq 48°$
-6	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 14, 27, 30 dBi: 3 frequency assignments,
- 31 dBi: 18 frequency assignments,

- 32, 33 dBi: 3 frequency assignments,
- 34 dBi: 55 frequency assignments (cumulative population % = 96%),
- 35 dBi: 3 frequency assignments.

The representative G_{max} = 34 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-96.

Table 6-96. Representative ARNS Directional Receiving Antenna Radiation Pattern in 1.24–2.9 GHz

Gain (dBi)	Angular Range
$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.14 \times \phi_{bw}$
18.5	$1.14 \times \phi_{bw} < \phi \le 5°$
$36 - 25 \times \log(\phi)$	$5° < \phi \le 48°$
-6	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.8 4.2–4.4 GHz

The GMF contains only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 8 dBi: 2 frequency assignments,
- 9 dBi: 8 frequency assignments,
- 10 dBi: 12 frequency assignments (cumulative population % = 62.9%),
- 11 dBi: 9 frequency assignments (cumulative population % = 88.6%),
- 12, 13, 18 dBi: 3 frequency assignments,
- 35 dBi: 1 frequency assignment.

The representative G_{max} = 10 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-97.

Table 6-97. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 4.2–4.4 GHz

Gain (dBi)	Angular Range
$10 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.89 \times \phi_{bw}$
0.5	$0.89 \times \phi_{bw} < \phi \le 79.1°$
$48 - 25 \times \log(\phi)$	$79.1° < \phi \le 83.2°$
0	$83.2° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 8 dBi: 2 frequency assignments,
- 9 dBi: 6 frequency assignments,
- 10 dBi: 8 frequency assignments (cumulative population % = 76%),
- 11 dBi: 3 frequency assignments,
- 13, 18 dBi: 2 frequency assignments.

The representative G_{max} = 10 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-98.

Table 6-98. Representative ARNS Directional Receiving Antenna Radiation Pattern in 4.2–4.4 GHz

Gain (dBi)	Angular Range
$10 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.89\times\phi_{bw}$
0.5	$0.89\times\phi_{bw} < \phi \le 79.1°$
$48 - 25 \times \log(\phi)$	$79.1° < \phi \le 83.2°$
0	$83.2° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.9 5–5.25 GHz

The GMF has only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

There are 28 directional transmitting antenna service records in this band, all with G_{max} = 22 dBi. The representative G_{max} = 22 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-99.

Table 6-99. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 5–5.25 GHz

Gain (dBi)	Angular Range
$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
9.5	$1.02\times\phi_{bw} < \phi \le 19.86°$
$42 - 25 \times \log(\phi)$	$19.86° < \phi \le 48°$
0	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

There is only 1 directional receiving antenna service record in this band, with G_{max} = 22 dBi. The representative G_{max} = 22 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-10000.

Table 6-100. Representative ARNS Directional Receiving Antenna Radiation Pattern in 5–5.25 GHz

Gain (dBi)	Angular Range
$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
9.5	$1.02\times\phi_{bw} < \phi \le 19.9°$
$42 - 25 \times \log(\phi)$	$19.9° < \phi \le 48°$
0	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.10 9–9.2 GHz

The GMF has only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-57. The representative G_{max} = 40 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-101.

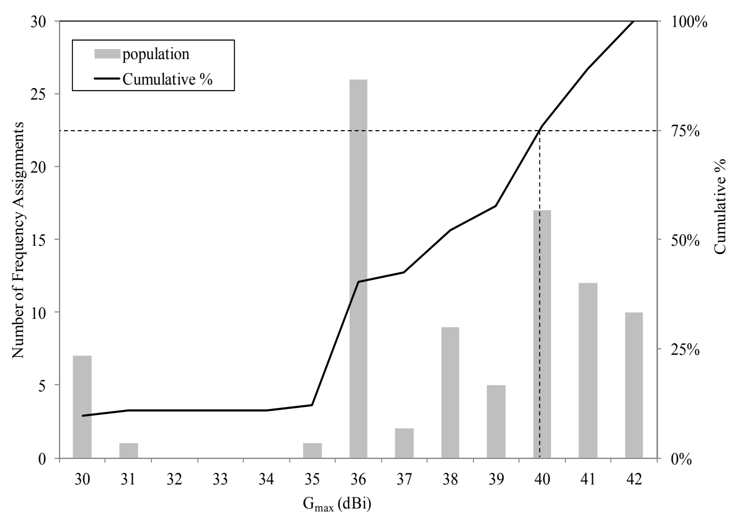


Figure 6-57. Population Profile of ARNS Directional Transmitting Antenna G_{max} Data in 9–9.2 GHz

Table 6-101. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 9–9.2 GHz

Gain (dBi)	Angular Range
$40 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.19\times\phi_{bw}$
23	$1.19\times\phi_{bw} < \phi \le 2.5°$
$33 - 25 \times \log(\phi)$	$2.5° < \phi \le 48°$
-9	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The population profile of the directional receiving antenna G_{max} data in this band is shown in Figure 6-58. The representative G_{max} = 38 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-102.

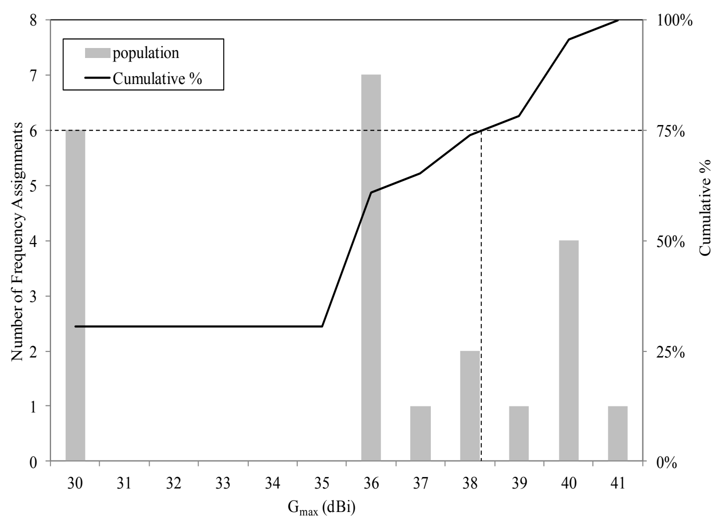


Figure 6-58. Population Profile of ARNS Directional Receiving Antenna G_{max} Data in 9–9.2 GHz

Table 6-102. Representative ARNS Directional Receiving Antenna Radiation Pattern in 9–9.2 GHz

Gain (dBi)	Angular Range
$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
-8	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.11 9.3–9.5 GHz

The GMF has only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The population profile of the directional transmitting antenna G_{max} data in this band is shown in Figure 6-59. The representative G_{max} = 32 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-103.

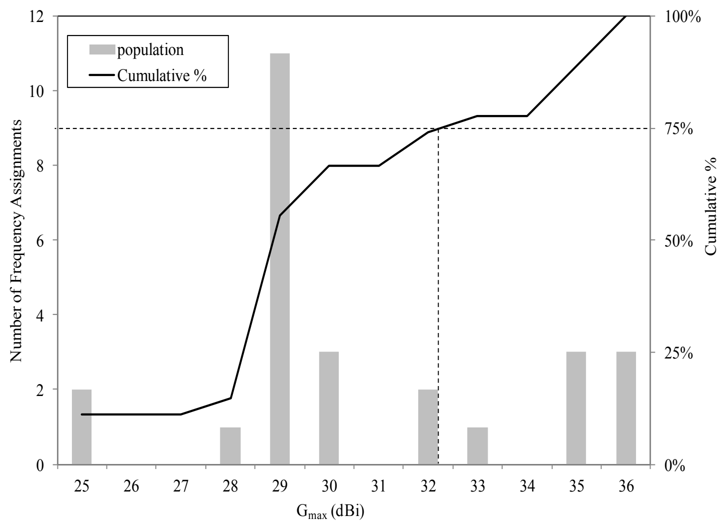


Figure 6-59. Population Profile of ARNS Directional Transmitting Antenna G_{max} Data in 9.3–9.5 GHz

Table 6-103. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 9.3–9.5 GHz

Gain (dBi)	Angular Range
$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.12\times\phi_{bw}$
17	$1.12\times\phi_{bw} < \phi \leq 6.3°$
$37 - 25 \times \log(\phi)$	$6.3° < \phi \leq 48°$
-5	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 17, 25 dBi: 2 frequency assignments,
- 29 dBi: 8 frequency assignments,

- 30 dBi: 1 frequency assignment,
- 33 dBi: 1 frequency assignment (cumulative population % = 75%),
- 35 dBi: 3 frequency assignments,
- 38 dBi: 1 frequency assignment.

The representative G_{max} = 33 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-104.

Table 6-104. Representative ARNS Directional Receiving Antenna Radiation Pattern in 9.3–9.5 GHz

Gain (dBi)	Angular Range
$33 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.13 \times \phi_{bw}$
17.75	$1.13 \times \phi_{bw} < \phi \leq 5.6°$
$36.5 - 25 \times \log(\phi)$	$5.6° < \phi \leq 48°$
-5.5	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.12 13.25–13.4 GHz

The GMF has only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

There is only 1 directional transmitting antenna service record in this band, with G_{max} = 26 dBi. The representative G_{max} = 26 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-105.

Table 6-105. Representative ARNS Directional Transmitting Antenna Radiation Pattern in 13.25–13.4 GHz

Gain (dBi)	Angular Range
$26 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.06 \times \phi_{bw}$
12.5	$1.06 \times \phi_{bw} < \phi \leq 12.5°$
$40 - 25 \times \log(\phi)$	$12.5° < \phi \leq 48°$
-2	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

There is only 1 directional receiving antenna service record in this band, with G_{max} = 26 dBi. The representative G_{max} = 26 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-106.

Table 6-106. Representative ARNS Directional Receiving Antenna Radiation Pattern in 13.25–13.4 GHz

Gain (dBi)	Angular Range
$26 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.06\times\phi_{bw}$
12.5	$1.06\times\phi_{bw} < \phi \leq 12.5°$
$40 - 25 \times \log(\phi)$	$12.5° < \phi \leq 48°$
-2	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.8.3.3.13 15.4–15.7 GHz

The GMF has only the directional antenna service records in this band.

(a) Directional Transmitting Antenna

The directional transmitting antenna G_{max} data count in this band is

- 5 dBi: 1 frequency assignment,
- 19 dBi: 3 frequency assignments,
- 31 dBi: 2 frequency assignments (cumulative population % = 60%),
- 32 dBi: 4 frequency assignments.

The representative G_{max} = 31 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-107.

Table 6-107. Representative ARNS Directional Receiving Antenna Radiation Pattern in 15.4–15.7 GHz

Gain (dBi)	Angular Range
$31 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.11\times\phi_{bw}$
16.25	$1.11\times\phi_{bw} < \phi \leq 7°$
$37.5 - 25 \times \log(\phi)$	$7° < \phi \leq 48°$
-4.5	$48° < \phi \leq 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(b) Directional Receiving Antenna

The directional receiving antenna G_{max} data count in this band is

- 5 dBi: 1 frequency assignment,
- 8 dBi: 2 frequency assignments (cumulative population % = 75%),
- 31 dBi: 1 frequency assignments.

The representative G_{max} = 8 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-108.

Table 6-108. Representative ARNS Directional Receiving Antenna Radiation Pattern in 15.4–15.7 GHz

Gain Function (dBi)	Angular Range
$8 - 12(\phi/\phi_{bw})^2$	$0 \le \phi < 1.04\times\phi_{bw}$
-5	$1.04\times\phi_{bw} \le \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.9 Radiodetermination-Satellite Service

Only the earth station antenna radiation pattern is discussed. RDSS earth station antenna radiation pattern is usually specified in terms of a single value for a given angular range, but not an equation that is a function of the off mainbeam axis angle.

6.9.1 Radiolocation-Satellite Service

6.9.1.1 System Review

NTIA does not provide the RLSS earth station antenna performance standards for system review. The Cospas-Sarsat technical manual provides authoritative specifications for their operations, thus its antenna performance requirements are recommended as the antenna performance standards for system review. These standards are as follows.

The distress beacon equipments use monopole antennas for distress signal transmission. The beacon antenna radiation performance standards within the elevation angle $5° < \theta < 60°$ are

- pattern: hemispherical,
- polarization: RHCP or linear,
- gain: $-3 < G(dBi) < 4$, over 90% of the angular range, and
- gain variation in azimuth: < 3 dB.

6.9.1.2 Frequency Assignment

The actual beacon antenna radiation data should always be used in EMC analyses for frequency assignment. The radiation data should be available from either the system operators or the antenna manufacturers.

When the actual radiation data are not available, the radiation pattern in Section 6.9.1.1 may be used as the reference radiation pattern.

6.9.1.3 Spectrum Sharing Analyses

The GMF does not have RLSS service records. When it is necessary to conduct spectrum sharing analyses, the beacon antenna radiation pattern in Section 6.9.1.2 may be used for the representative antenna radiation pattern.

6.9.2 Radionavigation-Satellite Service

6.9.2.1 System Review

NTIA does not provide the RNSS earth station antenna performance standards for system review. RTCA DO-228 provides the ARNSS airborne antenna radiation performance requirements, and Rec. ITU-R M.1477 provides recommendations for the GPS antenna characteristics. Their combined characteristics can be used as the RNSS antenna radiation performance standards for system review. These are as follows.

There are three types of RNSS GPS receivers:

- Type 1 receiver: meeting the requirements of the satellite-based augmentation system.
- Type 2 receiver: meeting the requirements of the land-based augmentation system.
- Type 3 receiver: used in the satellite-based augmentation system to determine the ionospheric delay.

(a) Land-Based RNSS and MRNSS

The land-based RNSS receivers and shipborne MRNSS receivers are either type 1 or type 3 receivers. The GPS antenna radiation performance standard, from Rec. ITU-R M.1477, is

- Maximum antenna gain in upper hemisphere: 7 dBic.
- Minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.

(b) ARNSS

The ARNSS airborne system meeting the requirements of the satellite-based augmentation system and providing category I precision approach operation is the type 1 receiver. The airborne antenna radiation performance standard, from RTCA DO-228, is shown in Table 6-109.

Table 6-109. ARNSS Airborne Antenna Radiation Performance Standard

Min. Gain (dBic)	Max. Gain (dBic)	Elevation Angle θ
-2	7	$\theta > 15°$
-3	7	$10° < \theta \leq 15°$
-4.5	7	$5° < \theta \leq 10°$
-7.5	-2	$0 < \theta \leq 5°$
dBic means it is circular polarization, which is required for GNSS.		

The ARNSS airborne system meeting the requirements of the land-based augmentation system and providing category II/III precision approach operation is the type 2 receiver. The airborne antenna radiation performance standard, from Rec. ITU-R M.1477, is

- Maximum antenna gain in upper hemisphere: 7 dBic.
- Minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.
- Minimum antenna gain towards pseudolite: -21 dBic.

The ARNSS land-based system used in the satellite-based augmentation system to determine the ionospheric delay is the type 3 receiver. The land-based antenna radiation performance standard, from Rec. ITU-R M.1477, is

- Maximum antenna gain: 7 dBic.
- Minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.

6.9.2.2 Frequency Assignment

The actual antenna radiation data should always be used in EMC analyses for frequency assignment. The antenna radiation data should be available from either the system operators or the antenna manufacturers.

When the actual radiation data are not available, a reference radiation pattern should be used. The radiation performance standard in Section 6.9.2.1 can be used to develop the reference radiation pattern for EMC analyses in frequency assignment; this reference radiation pattern is provided in Table 6-110. This reference radiation pattern does not specify the G value, and such data may be available in the GMF. If the G data are not available in the GMF, the value G = 0 dBic may be used.

Table 6-110. RNSS Antenna Reference Radiation Pattern for Frequency Assignment

Gain (dBic)	Elevation Angle θ
G	$\theta > 15^o$
G - 1	$10^o < \theta \leq 15^o$
G - 2.5	$5^o < \theta \leq 10^o$
-4.5	$0^o < \theta \leq 5^o$
-10	lower hemisphere *
G is not the peak gain value G_{max}, it is the lowest gain value within the conical range of $\theta > 15^o$. $-2 < G(\text{dBic}) \leq 7$. * : Gain = -10 dBic in lower hemisphere applies to ARNSS.	

6.9.2.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the RNSS service records in the GMF. The symbol of the station class is “EN” for the RNSS space station, “TN” for the RNSS earth station, “UM” for the RNSS mobile earth station, “EO” for the ARNSS space station, “TO” for the ARNSS earth station, “TZ” for the ARNSS mobile earth station, “EQ” for the MRNSS space station, “TQ” for the MRNSS earth station, “TX” for the MRNSS mobile earth station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G data population profile.
(3) Select a representative G from the population profile such that approximately 75% of the G population is equal to or smaller than the representative value.

(4) Develop the representative antenna radiation pattern from the representative G value and the antenna reference radiation pattern in Table 6-110.

The frequency bands being examined are

(1) 149.9−150.05 MHz,
(2) 1.164−1.24 GHz, and
(3) 1.559−1.61 GHz.

6.9.2.3.1 149.9−150.05 MHz

The RNSS service records in the GMF are of MRNSS in this band. All of the services are downlink services from NGSO satellites. There are two groups of receiving earth stations.

(a) Coastal-Water Area

In the first group, the earth station localities are the oceans, with all shipborne antenna G = 5 dBi. The representative G = 5 dBic, and the representative antenna radiation pattern for spectrum sharing analyses in the coastal-water areas is provided in Table 6-111.

Table 6-111. Representative MRNSS Coastal-Water Area Shipborne Antenna Radiation Pattern in 149.9–150.05 MHz

Gain (dBic)	Elevation Angle θ
5	θ > 15º
4	10º < θ ≤ 15º
2.5	5º < θ ≤ 10º
-4.5	0º < θ ≤ 5º

(b) USP Area

The second group has two service records, the earth station localities are “USP,” with both shipborne antenna G = 12 dBi. However, this gain value exceeds the data range of -2 < G(dBic) ≤ 7 specified in Table 6-110. To develop the representative antenna radiation pattern for spectrum sharing analyses, the G value for θ > 15º shall be 12 dBic, and the G value for θ ≤ 15º shall be 0 dBic. The representative G = 12 dBic, and the representative antenna radiation pattern for spectrum sharing analyses in the USP area is provided in Table 6-112.

Table 6-112. Representative MRNSS USP Area Shipborne Antenna Radiation Pattern in 149.9–150.05 MHz

Gain (dBic)	Elevation Angle θ
12	θ > 15º
-1	10º < θ ≤ 15º
-2.5	5º < θ ≤ 10º
-4.5	0º < θ ≤ 5º

6.9.2.3.2 1.164−1.24 GHz

The RNSS service records in the GMF are of ARNSS in this band. The GMF has two ARNSS service records. These services are downlink services from NGSO satellites.

(a) Coastal-Water Area

The earth station locality of the first service record is the ocean, and the antenna G = 0 dBic. The representative G = 0 dBic, and the representative antenna radiation pattern for spectrum sharing analyses in the coastal-water areas is provided in Table 6-113.

Table 6-113. Representative ARNSS Coastal-Water Area Airborne Antenna Radiation Pattern in 1.164–1.24 GHz

Minimum Gain (dBic)	Elevation Angle θ
0	$\theta > 15^o$
-1	$10^o < \theta \leq 15^o$
-2.5	$5^o < \theta \leq 10^o$
-4.5	$0^o < \theta \leq 5^o$
-10	lower hemisphere

(b) USP Area

The earth station locality of the second service record is "USP", and the antenna G_{max} = 47 dBi. This is a 20-meter dish antenna, thus it is a land-based antenna instead of an airborne antenna. The antenna radiation pattern for spectrum sharing analyses can be adopted from the AMSS NGSO system earth station antenna radiation performance standard in Section 6.7.3.1. The representative G_{max} = 47 dBi, and the representative antenna radiation pattern for spectrum sharing analyses in the USP area is provided in Table 6-114.

Table 6-114. Representative ARNSS USP Area Land-Based Earth Station Antenna Radiation Pattern in 1.164–1.24 GHz

Gain Function (dBi)	Angular Range
$47 - 2.5 \times 10^{-3} (92\times\phi)^2$	$0° \leq \phi < 0.93°$
28.7	$0.93° \leq \phi < 1.03°$
$29 - 25 \times \log(\phi)$	$1.03° \leq \phi < 36°$
-10	$36° \leq \phi \leq 180°$
φ: angle off mainbeam axis, deg. $D/\lambda = 92$ for f = 1.2 GHz, G_{max} = 47 dBi, and e = 0.65.	

6.9.2.3.3 1.559−1.61 GHz

The RNSS service records in the GMF are of ARNSS in this band. The GMF has three ARNSS service records. All services are downlink services from NGSO satellites.

The earth station localities are “USP” and the oceans, and the antenna G_{max} = 47 dBi. This is a 16-meter dish antenna, thus it is a land-based antenna instead of an airborne antenna. The representative G_{max} = 47 dBi, and the representative antenna radiation pattern, adopted from the AMSS NGSO system earth station antenna radiation performance standard in Section 6.7.3.1, for spectrum sharing analyses is provided in Table 6-115.

Table 6-115. Representative ARNSS Land-Based Earth Station Antenna Radiation Pattern in 1.559–1.61 GHz

Gain Function (dBi)	Angular Range ϕ
$47 - 2.5 \times 10^{-3} (92.27 \times \phi)^2$	$0° \leq \phi < 0.93°$
28.7	$0.93° \leq \phi < 1.03°$
$29 - 25 \times \log(\phi)$	$1.03° \leq \phi < 36°$
-10	$36° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 92.27 for f = 1.6 GHz, G_{max} = 47 dBi, and e = 0.65.	

6.10 Radio Astronomy Service

Because RAS systems are passive, i.e., reception only, their service records are not collected in the GMF.

6.10.1 System Review

NTIA does not provide the antenna radiation performance standards for the RAS antennas. Due to the unique feature of the RAS operations, RAS antennas are designed with unique specifications, thus general antenna radiation performance standards are not needed.

6.10.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment. The antenna radiation pattern should be available from either the system operator or the antenna manufacturer.

When the actual radiation pattern is not available, the reference radiation patterns from ITU-R for coordination studies and interference assessment can be used in EMC analyses for frequency assignment. The radiation pattern in Rec. ITU-R SA.509-2 for coordination studies with the terrestrial radio systems is shown in Table 6-116, and the radiation pattern in Rec. ITU-R RA.1631 for coordination studies with the space radio systems is shown in Table 6-117. The radiation pattern does not specify the G_{max} value; however, such data should be available from the system operators.

Table 6-116. RAS Antenna Sidelobe Reference Radiation Pattern for Coordination Studies with Terrestrial Radio Systems

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
G_1	$\phi_m \leq \phi < \phi_r$

$32 - 25 \times \log(\phi)$	$\phi_r \leq \phi < 47.9°$
-10	$47.9° \leq \phi \leq 180°$

This pattern applies to $D/\lambda > 100$.
ϕ: angle off mainbeam axis, deg.
$G_1 = 2 + 15 \times \log(D/\lambda)$, dBi
$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.
$\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.

Original pattern from 1° to 180°.
Mainbeam and first plateau added to complete the radiation pattern.

Table 6-117. RAS Antenna Reference Radiation Pattern for Coordination Studies with Space Radio Systems

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
G_1	$\phi_m \leq \phi < \phi_r$
$29 - 25 \times \log(\phi)$	$\phi_r \leq \phi < 10°$
$34 - 30 \times \log(\phi)$	$10° \leq \phi < 34.1°$
-12	$34.1° \leq \phi < 80°$
-7	$80° \leq \phi < 120°$
-12	$120° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.
$G_1 = -1 + 15 \times \log(D/\lambda)$, dBi
$\phi_m = (20\lambda/D)(G_{max} - G_1)^{0.5}$, deg.
$\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.

6.10.3 Spectrum Sharing Analyses

Because of the special features of the RAS operations, the National Radio Quiet Zone is established around RAS facilities for the protection of RAS observations.[200] [201] [202] Other radio services intending to share frequencies with RAS in the Radio Quiet Zone must consult the Rules and Regulations from NTIA and FCC.

When the radiation patterns are needed for spectrum sharing analyses, the reference radiation patterns in Table 6-116 and Table 6-117 can be used. The radiation pattern does not specify the G_{max} value, and such data should be available from the system operators.

200 http://www.gb.nrao.edu/nrqz/nrqz.html, accessed Nov. 21, 2011

201 NTIA Manual, Chapter 8, *Procedures and Principles for the Assignment and Coordination of Frequencies*, §8.3.9

202 CFR 47, Part 1, *Practice and Procedure*, §1.924

6.11 Remote Sensing Service

6.11.1 Meteorological Aids Service

The MetAids service encompasses the meteorological radar, precipitation gauge, and radiosonde system.

6.11.1.1 System Review

(a) Meteorological Radar

NTIA does not provide the meteorological radar antenna performance standards. The meteorological radar antenna should have similar performance as the RLS antenna; therefore, the RLS antenna performance standards in Section 6.8.1.1 can be adopted here. These standards are provided in Table 6-118.

Table 6-118. Meteorological Radar Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. G_{max} usually given, or can be calculated from • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5	

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range
$G_{max} \ge 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_M$
	$0.75 \times G_{max} - 7$	$\phi_M < \phi \le \phi_{R1}$
	$29 - 25 \times \log(\phi)$	$\phi_{R1} < \phi \le \phi_{B1}$
	-13	$\phi_{B1} < \phi \le 180°$
$22 \le G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_M$
	$0.75 \times G_{max} - 7$	$\phi_M < \phi \le \phi_{R2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{R2} < \phi \le \phi_{B2}$
	$11 - G_{max}/2$	$\phi_{B2} < \phi \le 180°$
$10 \le G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_M$
	$0.75 \times G_{max} - 7$	$\phi_M < \phi \le \phi_{R3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{R3} < \phi \le \phi_{B3}$
	0	$\phi_{B3} < \phi \le 180°$
Elliptical beam. All angles in deg.		

G_{max} usually given, or can be calculated from • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes ϕ: angle off mainbeam axis in the direction of interest ϕ_{bw}: HPBW in the direction of interest ϕ_M : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$ $\phi_{R1} = 27.466\times10^{-0.3G_{max}/10}$ $\phi_{R2} = \phi_{R3} = 250/\left(10^{G_{max}/20}\right)$ $\phi_{B1} = \phi_{B2} = 48°$ $\phi_{B3} = 131.8257\times10^{-G_{max}/50}$

(b) Wind Profile Radar

NTIA provides a wind profile radar antenna radiation sidelobe suppression standard. This is shown in Table 6-119.

Table 6-119. WPR Antenna Radiation Sidelobe Suppression Standard

Elevation Angle θ	Antenna Sidelobe Suppression (dB)
$\theta > 70°$	-
$60° < \theta \leq 70°$	15
$45° < \theta \leq 60°$	20
$5° < \theta \leq 45°$	25
$\theta \leq 5°$	40

(c) Radiosonde

The radiosonde airborne transmitting units use omnidirectional antennas, and the land-based receiving units use either omnidirectional or directional antennas. NTIA does not provide the radiosonde antenna radiation performance standards, nor does ITU-R provide recommendations for the radiosonde antenna reference radiation patterns.

For the radiosonde antenna, the RLS mobile station antenna radiation performance standards in Section 6.8.1.1 are recommended for the radiosonde antenna radiation performance standards. The airborne omnidirectional transmitting antenna and the land-based station omnidirectional receiving antenna vertical radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (6\text{-}100)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + 0.5 \}$, dBi θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}\text{, deg.}$$

The land-based station directional receiving antenna radiation performance standards are provided in Table 6-120.

Table 6-120. Radiosonde Land-Based Station Directional Receiving Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range
$G_{max} \ge 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_M$
	$0.75 \times G_{max} - 7$	$\phi_M < \phi \le \phi_{R1}$
	$29 - 25 \times \log(\phi)$	$\phi_{R1} < \phi \le \phi_{B1}$
	-13	$\phi_{B1} < \phi \le 180°$
$22 \le G_{max}(\text{dBi}) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_M$
	$0.75 \times G_{max} - 7$	$\phi_M < \phi \le \phi_{R2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{R2} < \phi \le \phi_{B2}$
	$11 - G_{max}/2$	$\phi_{B2} < \phi \le 180°$
$10 \le G_{max}(\text{dBi}) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_M$
	$0.75 \times G_{max} - 7$	$\phi_M < \phi \le \phi_{R3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{R3} < \phi \le \phi_{B3}$
	0	$\phi_{B3} < \phi \le 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest

ϕ_{bw}: HPBW in the direction of interest
ϕ_M : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$
$\phi_{R1} = 27.466 \times 10^{-0.3\,G_{max}/10}$
$\phi_{R2} = \phi_{R3} = 250 / \left(10^{G_{max}/20}\right)$
$\phi_{B1} = \phi_{B2} = 48°$
$\phi_{B3} = 131.8257 \times 10^{-G_{max}/50}$

(d) Precipitation Gauge

NTIA does not provide the precipitation gauge antenna radiation performance standards, nor does ITU-R provide recommendations for the precipitation gauge antenna reference radiation patterns. Lacking necessary information, this standard will not be developed here. This standard will be developed when necessary information becomes available.

6.11.1.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers. When the actual radiation pattern is not available, the radiation performance standards in Section 6.11.1.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.11.1.1 do not specify the G_{max} value; however, such data should be available in the GMF.

For the radiosonde airborne antenna, because it is operated while being airborne, the G_{max} value should be used instead of the radiation pattern of Eq. (6-100) for the worst case scenario.

6.11.1.3 Spectrum Sharing Analyses

The procedure to develop the representative antenna radiation pattern is as follows:

(1) Retrieve the MetAids service records in the GMF. The symbol of the station class is "SA" for the MetAids mobile station, "SAR" for the radiosonde, "SM" for the MetAids base station, "SMB" for the radar beacon precipitation gauge, "SMD" for meteorological radar, and "SMRG" for the radiosonde land-based station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the antenna G_{max} data population profile.
(3) Select a representative G_{max} value from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Except for the precipitation gauge, develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation pattern in Section 6.11.1.2.

For the radiosonde airborne antenna, because it is operated while being airborne, the representative antenna radiation pattern must be used with caution. The spectrum sharing analyses should either use the representative G_{max} values for the worst case scenario, or build statistical models that take into account the radiosonde flight heights and antenna orientations.

The frequency bands being examined are

(1) 400.15−406 MHz,
(2) 1.675−1.7 GHz,
(3) 2.7−2.9 GHz, and
(4) 5.6−5.65 GHz.

6.11.1.3.1 400.15−406 MHz for Radiosonde System and Precipitation Gauge

(a) Radiosonde Airborne Omnidirectional Transmitting Antenna

The radiosonde airborne omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 8 frequency assignments,
- 1 dBi: 1 frequency assignment,
- 2 dBi: 22 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= 2 - 12(\theta/67.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \\
&= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} && \text{dBi} \quad \text{for} \quad |\theta| > 62.7°
\end{aligned}
\qquad (6\text{-}101)
$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Radiosonde Land-Based Station Omnidirectional Receiving Antenna

The radiosonde land-based station omnidirectional receiving antenna G_{max} data count in this band is

- 0 dBi: 12 frequency assignments,
- 1 dBi: 1 frequency assignment,
- 2 dBi: 13 frequency assignments (cumulative population % = 81%),
- 3−6 dBi: 5 frequency assignments,
- 10 dBi: 1 frequency assignment.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$
\begin{aligned}
G(\theta) &= 2 - 12(\theta/67.9)^2 && \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \\
&= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} && \text{dBi} \quad \text{for} \quad |\theta| > 62.7°
\end{aligned}
\qquad (6\text{-}101)
$$

where θ is the elevation angle off the peak gain plane, in deg.

(c) Radiosonde Land-Based Station Directional Receiving Antenna

The radiosonde land-based station directional receiving antenna G_{max} data count in this band is

- 10 dBi: 1 frequency assignment,
- 12 dBi: 2 frequency assignments,
- 15 dBi: 6 frequency assignments.

The representative G_{max} = 15 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-121.

Table 6-121. Representative Radiosonde Land-Based Station Directional Antenna Radiation Pattern in 400.15−406 MHz

Gain (dBi)	Angular Range
$15 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.95\times\phi_{bw}$
4.25	$0.95\times\phi_{bw} < \phi \le 44.5°$
$45.5 - 25 \times \log(\phi)$	$44.5° < \phi \le 66.1°$
0	$66.1° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

(d) Precipitation Gauge

The precipitation gauge antenna G_{max} data count in this band is

- 0 dBi: 1 frequency assignment,
- 1 dBi: 2 frequency assignments.

The representative G_{max} = 1 dBi. There is no representative radiation pattern.

6.11.1.3.2 1.675−1.7 GHz for Radiosonde System

(a) Airborne Omnidirectional Transmitting Antenna

The radiosonde airborne omnidirectional transmitting antenna G_{max} data count in this band is

- 0 dBi: 1 frequency assignment,
- 2 dBi: 12 frequency assignments.

The representative G_{max} = 2 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is

$$G(\theta) = 2 - 12(\theta/67.9)^2 \quad \text{dBi} \quad \text{for} \quad |\theta| \le 62.7° \qquad (6\text{-}101)$$
$$= -10 + 10\times\log\{ [\max(|\theta|/67.9, 1)]^{-1.5} + 0.5 \} \quad \text{dBi} \quad \text{for} \quad |\theta| > 62.7°$$

where θ is the elevation angle off the peak gain plane, in deg.

(b) Land-Based Station Directional Receiving Antenna

The radiosonde land-based station directional receiving antenna G_{max} data count in this band is

- 27 dBi: 2 frequency assignments,
- 30 dBi: 3 frequency assignments (cumulative population % = 63%),
- 31 dBi: 3 frequency assignments.

The representative G_{max} = 30 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-122.

Table 6-122. Representative Radiosonde Land-Based Station Directional Receiving Antenna Radiation Pattern in 1.675−1.7 GHz

Gain (dBi)	Angular Range
$30 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.1\times\phi_{bw}$
15.5	$1.1\times\phi_{bw} < \phi \le 7.9°$
$38 - 25 \times \log(\phi)$	$7.9° < \phi \le 48°$
-4	$48° < \phi \le 180°$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.	

6.11.1.3.3 2.7−2.9 GHz for Meteorological Radar

The meteorological radar transmitting antenna G_{max} data count in this band is

- 40 dBi: 1 frequency assignment,
- 45 dBi: 5 frequency assignments,
- 46 dBi: 160 frequency assignments.

The representative G_{max} = 46 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-123.

Table 6-123. Representative Meteorological Radar Antenna Radiation Pattern in 2.7−2.9 GHz

Gain(ϕ) (dBi)	Angular Range
$46 - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le 1.24\times\phi_{bw}$
27.4	$1.24\times\phi_{bw} < \phi \le 1.25°$
$30 - 25 \times \log(\phi)$	$1.25° < \phi \le 48°$
-12	$48° < \phi \le 180°$
Elliptical beam. ϕ_{bw}: HPBW in the direction of interest, deg. ϕ: angle off mainbeam axis in the direction of interest, deg.	

6.11.1.3.4 5.6−5.65 GHz for Meteorological Radar

The meteorological radar antenna G_{max} data count in this band is

- 39−41 dBi: 4 frequency assignments,
- 43−45 dBi: 6 frequency assignments,
- 50 dBi: 46 frequency assignments.

The representative G_{max} = 50 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-124.

Table 6-124. Representative Meteorological Radar Antenna Radiation Pattern in 5.6−5.65 GHz

Gain(ϕ) (dBi)	Angular Range
$50 - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le 1.27\times\phi_{bw}$
30.5	$1.27\times\phi_{bw} < \phi \le 0.87°$
$29 - 25 \times \log(\phi)$	$0.87° < \phi \le 48°$
-13	$48° < \phi \le 180°$

Elliptical beam.
G_{max} can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ_{bw}: HPBW in the direction of interest, deg.
ϕ: angle off mainbeam axis in the direction of interest, deg.

6.11.2 Meteorological Satellite Services

Only the earth station antennas are discussed here.

The earth station antennas can be omnidirectional antennas, low-gain antennas with semi isotropic (full horizon to zenith) radiation pattern, medium-gain antennas of $10 \le G_{max}(dBi) < 22$, or high-gain antennas. All four classes of antennas are used in the GSO and NGSO systems. An omnidirectional or low-gain antenna in a GSO system should be a mobile unit, and a medium- or high-gain antenna in a NGSO system should have a satellite-tracking sub-system.

6.11.2.1 System Review

NTIA does not provide the MetSat earth station antenna radiation performance standards, nor does ITU-R provide recommendations for the MetSat earth station antenna reference radiation patterns.

For omnidirectional, low- and medium-gain antennas, the LMSS earth station omnidirectional, low- and medium-gain antenna radiation performance standards in Section 6.7.1.1 are recommended for the MetSat earth station antennas. These are shown in Table 6-125 and Table 6-126.

(a) Omnidirectional Antenna

Table 6-125. MetSat Earth Station Omnidirectional, Low- and Medium-Gain Antenna Vertical Radiation Performance Standards

(a) Omnidirectional Antenna

Gain Function (dBi)	Angular Range
≤ 5	$-20° \leq \theta \leq 20°$
≤ 0	$\theta < -20°$ & $\theta > 20°$
θ: elevation angle, deg.	

(b) Vertical Array Antenna with Toroidal Beam and $7 \leq G_{max}(dBi) \leq 13$

Gain Function (dBi)	Angular Range
$G_{max} - 10$	$45° \leq (\theta - \theta_o)$
$G_{max} - 0.3 \times [(\theta - \theta_o)/10]^{2.3}$	$20° \leq (\theta - \theta_o) \leq 45°$
$G_{max} - 12 \times [(\theta - \theta_o)/\theta_{bw})]^2$	$20° < \mid \theta - \theta_o \mid$
$G_{max} - 0.3 \times [(\theta_o - \theta)/10]^{2.3}$	$20° \leq (\theta_o - \theta) \leq 50°$
$G_{max} - 13$	$50° \leq (\theta_o - \theta)$
θ: elevation angle, deg. θ_o: mainbeam elevation angle, deg. θ_{bw}: HPBW, deg.	

(b) Low- and Medium-Gain Antenna

Table 6-126. MetSat Earth Station Low- and Medium-Gain Antenna Radiation Performance Standards

(a) Vehicle-Mounted Tracking Antenna with Fan-Beam and Operating in Low Elevation Angle

Gain Function (dBi)	Angular Range
≤ 4	$0° \leq \theta \leq 60°$, $[30°+k(\theta)] \leq \lvert\varphi - \varphi_0\rvert \leq 180°$
(θ, φ): elevation and azimuth angles, deg. (θ_o, φ_o): mainbeam elevation and azimuth angles, deg. k(θ) = 0.33° for G_{max} = 11−15, dBi k(θ) is TBD for G_{max} = 9−11, dBi	

(b) Transportable or Vehicle-Mounted Antenna with Circular Beam and $G_{max} \leq 18$ dBi

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$

ϕ: angle off mainbeam axis, deg.
ϕ_{bw}: HPBW, deg.
x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.

(c) High-Gain Antenna

For high-gain antennas, the FSS earth station antenna radiation performance standards in Section 6.3.1 are recommended for the MetSat earth station high-gain antennas. These are provided in Table 6-127.

Table 6-127. MetSat Earth Station High-Gain Antenna Radiation Performance Standards

(a) GSO System

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_m$
	G_1	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda = 68$ is the threshold when the G_1 plateau disappears. ϕ: angle off mainbeam axis, deg. $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg. ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$		
An actual radiation pattern shall meet the following conditions: • It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$. • It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.		

(b) NGSO System

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

$20 < D/\lambda < 100$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
$(34.1 < G_{max}(dBi) < 48.1$ for $e = 0.65)$	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$D/\lambda < 20$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{rc}$
	$29 - 25 \times \log(\phi)$	$\phi_{rc} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

Pattern for $D/\lambda < 20$ is added to extend the high-gain pattern to $G_{max} = 22$ dBi.

ϕ_{rc} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$, deg.

6.11.2.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standard in Section 6.11.2.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.11.2.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.11.2.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the MetSat service records in the GMF. The symbol of the station class is “EM” for the space station and “TM” for the earth station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile.
(3) Select a representative G_{max} value from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.11.2.2.

The frequency bands being examined are

(1) 137−138 MHz downlink,
(2) 401−403 MHz uplink,
(3) 460−470 MHz downlink, and
(4) 1.675−1.71 GHz downlink.

6.11.2.3.1 137−138 MHz Downlink

The GMF has only NGSO system service records in this band, and the earth stations use both the omnidirectional and directional antennas.

(a) Omnidirectional Antenna

The earth station omnidirectional antennas in this band all have G_{max} = 0 dBi. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is provided in Table 6-128.

Table 6-128. Representative MetSat Earth Station Omnidirectional Antenna Vertical Radiation Pattern in 137−138 MHz

Gain Function (dBi)	Angular Range
≤ 0	$-20° \leq \theta$
≤ 0	$\theta < -20°$
θ: elevation angle, deg. G_{max} = 0 dBi	

(b) Directional Antenna

The earth station directional antenna G_{max} data count in this band is

- 16 dBi: 2 frequency assignments,
- 22 dBi: 2 frequency assignments,
- 27 dBi: 4 frequency assignments.

The representative G_{max} = 27 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-129.

Table 6-129. Representative MetSat NGSO System Earth Station Directional Antenna Radiation Pattern in 137−138 MHz

Gain Function (dBi)	Angular Range
$27 - 2.5 \times 10^{-3} (8.84 \times \phi)^2$	$0° \leq \phi < x°$
$29 - 25 \times \log(\phi)$	$x° \leq \phi < 36°$
-10	$36° \leq \phi \leq 180°$
φ: angle off mainbeam axis, deg. D/λ = 8.84 for *f* = 137 MHz, G_{max} = 27 dBi, and *e* = 0.65 $x : \{27 - 2.5\times10^{-3}(8.84\times x)^2\} = \{29 - 25\times\log(x)\}$	

6.11.2.3.2 401−403 MHz Uplink

The GMF has both GSO and NGSO system service records in this band, and the earth stations use both the omnidirectional and directional antennas.

(a) Omnidirectional Antenna

The earth station omnidirectional antennas are used by both GSO and NGSO systems in this band, and the antenna G_{max} data count is

- 0 dBi: 8 frequency assignments,
- 2 dBi: 2 frequency assignments,
- 3 dBi: 4 frequency assignments (cumulative population % = 64%),
- 4 dBi: 7 frequency assignments,
- 5 dBi: 1 frequency assignment.

The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is provided in Table 6-130.

Table 6-130. Representative MetSat Earth Station Omnidirectional Antenna Vertical Radiation Pattern in 401−403 MHz

Gain Function (dBi)	Angular Range
≤ 3	$-20° \leq \theta$
≤ 0	$\theta < -20°$
θ: elevation angle, deg. G_{max} = 3 dBi	

(b) Directional Antenna

The earth station directional antennas are used by both GSO and NGSO systems in this band, and the antenna G_{max} data count is

- 3–6 dBi: 185 frequency assignments,
- 7–10 dBi: 971 frequency assignments,
- 11 dBi: 3034 frequency assignments (cumulative population % = 70.7%),
- 12 dBi: 565 frequency assignments (cumulative population % = 80.2%),
- 13 dBi: 1072 frequency assignments,
- 14, 15 dBi: 96 frequency assignments,
- 26, 61, 68 dBi: 4 frequency assignments.

The representative G_{max} = 11 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-131.

Table 6-131. Representative MetSat Earth Station Directional Antenna Radiation Pattern in 401−403 MHz

Gain Function (dBi)	Angular Range
$11 - 12 \times (\phi/46.2)^2$	$0° \leq \phi \leq 35.2°$

4	35.2° < $\phi \le$ 40°
44 - 25 × log(ϕ)	40° < $\phi \le$ 90°
-5	90° < ϕ
ϕ: angle off mainbeam axis, deg. This radiation pattern is valid for 12 ≤ G_{max}(dBi) ≤ 18, and is applied here by extrapolation.	

6.11.2.3.3 460−470 MHz Downlink

The GMF has only GSO system service records in this band, and the earth stations use both the omnidirectional and directional antennas.

(a) Omnidirectional Antenna

The earth station omnidirectional antennas all have G_{max} = 0 dBi in this band. The representative G_{max} = 0 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is provided in Table 6-132.

Table 6-132. Representative MetSat Earth Station Omnidirectional Antenna Vertical Radiation Pattern in 460−470 MHz

Gain Function (dBi)	Angular Range
≤ 0	-20° ≤ θ
≤ 0	θ < -20°
θ: elevation angle, deg. G_{max} = 0 dBi	

(b) Directional Antenna

The earth station directional antennas all have G_{max} = 6 dBi in this band. The representative G_{max} = 6 dBi. The directional antenna radiation pattern for G_{max} = 6 dBi is not available in Section 6.11.2.1. To develop an antenna radiation pattern for spectrum sharing analyses, the FS low-gain antenna reference radiation pattern in Section 6.2.2.2 is applied here, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-133.

Table 6-133. Representative MetSat Earth Station Directional Antenna Radiation Pattern in 460−470 MHz

Gain Function (dBi)	Angular Range
$6 - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{6 - 12(\phi/\phi_{bw})^2\}$ and -5	

6.11.2.3.4 1.675−1.71 GHz Downlink

The GMF has both GSO and NGSO system service records in this band.

(a) Omnidirectional Antenna

The NGSO system earth stations use only the omnidirectional antennas in the in this band, and all of the 182 G_{max} data are 3 dBi. The representative G_{max} = 3 dBi, and the representative antenna vertical radiation pattern for spectrum sharing analyses is provided in Table 6-134.

Table 6-134. Representative MetSat Earth Station Omnidirectional Antenna Vertical Radiation Pattern in 1.675−1.71 GHz

Gain Function (dBi)	Angular Range
≤ 3	$-20° \leq \theta$
≤ 0	$\theta < -20°$
θ: elevation angle, deg. G_{max} = 3 dBi	

(b) Directional Antenna

The GSO system earth stations use only the directional antennas in this band, and the antenna G_{max} data count is

- 36 dBi: 2 frequency assignments,
- 41 dBi: 1 frequency assignment,
- 43 dBi: 1 frequency assignment,
- 47 dBi: 4 frequency assignments,
- 48 dBi: 41 frequency assignments.

The representative G_{max} = 48 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-135.

Table 6-135. Representative MetSat Earth Station Directional Antenna Radiation Pattern in 1.675−1.71 GHz

Gain Function (dBi)	Angular Range
$48 - 2.5 \times 10^{-3}(99.17\times\phi)^2$	$0° \leq \phi \leq 0.9°$
28.9	$0.9° < \phi \leq 1°$
$29 - 25 \times \log(\phi)$	$1° < \phi \leq 7°$
8	$7° < \phi \leq 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 99.17 for f = 1.7 GHz, G_{max} = 48 dBi, and e = 0.65	

6.11.3 Earth Exploration-Satellite Service

Only the earth station antenna is discussed here.

The earth station antennas can be low-gain and high-gain antennas, and both classes are used in the GSO and NGSO systems. A low-gain antenna in a GSO system should be a mobile unit, and a high-gain antenna in a NGSO system should have satellite-tracking sub-system.

6.11.3.1 System Review

NTIA does not provide the EESS earth station antenna radiation performance standards, nor does ITU-R provide recommendation for the EESS earth station antenna reference radiation patterns.

The EESS and MetSat systems perform the similar task of using satellites to collect information about the Earth's surface. Therefore, it is assumed that the EESS and MetSat systems earth station antennas have the same radiation performances, and the MetSat earth station antenna radiation performance standards in Section 6.11.2.1 may be used as the EESS earth station radiation performance standards. These standards are provided in Table 6-136.

Table 6-136. EESS Earth Station Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \le x°$
4	$x° < \phi \le 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \le 90°$
-5	$90° < \phi$
Circular Beam, $12 \le G_{max}(dBi) \le 18$ ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg. x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.	

(b) GSO System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 68$ ($G_{max} \ge 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi \le \phi_m$
	G_1	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le 7°$
	8	$7° < \phi \le 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
	-10	$48° < \phi \le 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi \le \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le 7°$
	8	$7° < \phi \le 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$

	-10	$48° < \phi \leq 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$

An actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(c) NGSO System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}(dBi) < 48.1$ for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$D/\lambda < 20$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{rc}$
	$29 - 25 \times \log(\phi)$	$\phi_{rc} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

Pattern for $D/\lambda < 20$ is added to extend the high-gain pattern to $G_{max} = 22$ dBi.

ϕ_{rc} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$, deg.

6.11.3.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standard in Section 6.11.3.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.11.3.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.11.3.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the EESS service records in the GMF. The symbol of the station class is “EW” for the space station and “TW” for the earth station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile.
(3) Select a representative G_{max} value from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.11.3.2.

The frequency bands being examined are

(1) 401−403 MHz uplink,
(2) 2.025−2.11 GHz,
(3) 2.2−2.29 GHz downlink,
(4) 8.025−8.4 GHz downlink, and
(5) 25.5−27 GHz downlink.

6.11.3.3.1 401−403 MHz Uplink

The GMF has both the GSO and NGSO system service records in this band, and the earth stations use only directional antennas.

(a) GSO System

The GSO system earth station transmitting antenna G_{max} data count in this band is

- 6 dBi: 1 frequency assignment,
- 13 dBi: 3 frequency assignments.

The representative G_{max} = 13 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-137.

Table 6-137. Representative EESS GSO System Earth Station Antenna Radiation Pattern in 401−403 MHz

Gain Function (dBi)	Angular Range
$13 - 12 \times (\phi/36.7)^2$	$0° \le \phi \le 31.7°$
4	$31.7° < \phi \le 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \le 90°$
-5	$90° < \phi$
ϕ: angle off mainbeam axis, deg.	

(b) NGSO System

The NGSO system earth station directional antenna G_{max} data count in this band is

- 4 dBi: 8 frequency assignments,
- 6 dBi: 15 frequency assignments.

The representative G_{max} = 6 dBi, and this is a low-gain antenna. The directional antenna radiation pattern for G_{max} = 6 dBi is not available in Section 6.11.3.1. To develop a radiation pattern for spectrum sharing analyses, the FS low-gain antenna reference radiation pattern in Section 6.2.2.2 is applied here, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-138.

Table 6-138. Representative EESS NGSO System Earth Station Antenna Radiation Pattern in 401−403 MHz

Gain Function (dBi)	Angular Range
$6 - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{6 - 12(\phi/\phi_{bw})^2\}$ and -5	

6.11.3.3.2 2.025−2.11 GHz

The GMF has both the NGSO and GSO system service records in this band. The uplink transmissions use both the NGSO and GSO systems, and the downlink transmissions use only the GSO systems.

(a) GSO System Uplink

The GSO system uplink earth station antenna G_{max} data count in this band is

- 47 dBi: 1 frequency assignment,
- 50 dBi: 10 frequency assignments,
- 51 dBi: 1 frequency assignment,
- 54 dBi: 1 frequency assignment,

- 56 dBi: 1 frequency assignment.

The representative G_{max} = 50 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-139.

Table 6-139. Representative EESS GSO System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$50 - 2.5 \times 10^{-3} (124.9\times\phi)^2$	$0° \le \phi \le 0.7°$
30.4	$0.7° < \phi \le 0.9°$
$29 - 25 \times \log(\phi)$	$0.9° < \phi \le 36°$
-10	$36° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 124.9 for f = 2.06 GHz, G_{max} = 50 dBi, and e = 0.65	

(b) GSO System Downlink

The GSO system downlink earth station antenna G_{max} data count in this band is

- 21 dBi: 1 frequency assignment,
- 26 dBi: 21 frequency assignments,
- 34, 35 dBi: 2 frequency assignments,
- 39 dBi: 2 frequency assignments,
- 53 dBi: 1 frequency assignment.

The representative G_{max} = 26 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-140.

Table 6-140. Representative EESS GSO System Downlink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$26 - 2.5 \times 10^{-3}(7.88\times\phi)^2$	$0° \le \phi \le x°$
$29 - 25 \times \log(\phi)$	$x° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 7.88 for f = 2.06 GHz, G_{max} = 26 dBi, and e = 0.65 x: $\{26 - 2.5\times10^{-3}(7.88\times x)^2\} = \{29 - 25\times\log(x)\}$	

(c) NGSO System Uplink

Both the low- and high-gain antennas are used in the uplink service in this band.

(c.1) Low-Gain Antenna

The NGSO system uplink earth station low-gain antenna G_{max} data in this band are all 6 dBi. The representative antenna G_{max} = 6 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-141.

Table 6-141. Representative EESS NGSO System Uplink Earth Station Low-Gain Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$6 - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. φ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{6 - 12(\phi/\phi_{bw})^2\}$ and -5.	

(c.2) High-Gain Antenna

The population profile of the NGSO system uplink earth station high-gain antenna G_{max} data in this band is shown in Figure 6-60. Since there is no data count at G_{max} = 47 dBi, the representative G_{max} is chosen to be 46 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-142.

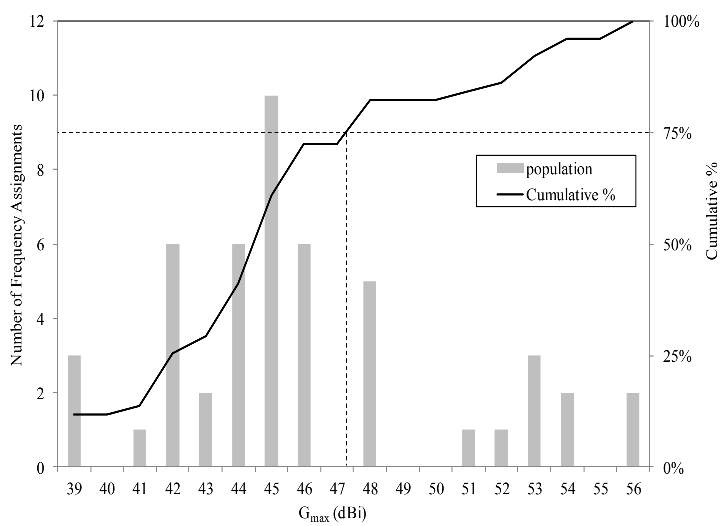


Figure 6-60. Population Profile of EESS NGSO System Uplink Earth Station High-Gain Antenna G_{max} Data in 2.025−2.11 GHz

Table 6-142. Representative EESS NGSO System Uplink Earth Station High-Gain Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$46 - 2.5 \times 10^{-3} (78.78\times\phi)^2$	$0° \leq \phi \leq 1.05°$
27.4	$1.05° < \phi \leq 1.16°$
$29 - 25 \times \log(\phi)$	$1.16° < \phi \leq 36°$
-10	$36° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 82.2 for f = 2.06 GHz, G_{max} = 46 dBi, and e = 0.65	

6.11.3.3.3 2.2−2.29 GHz Downlink

The GMF has only the NGSO system service records in this band.

The population profile of the earth station antenna G_{max} data in this band is shown in Figure 6-61. The representative G_{max} = 46 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-143.

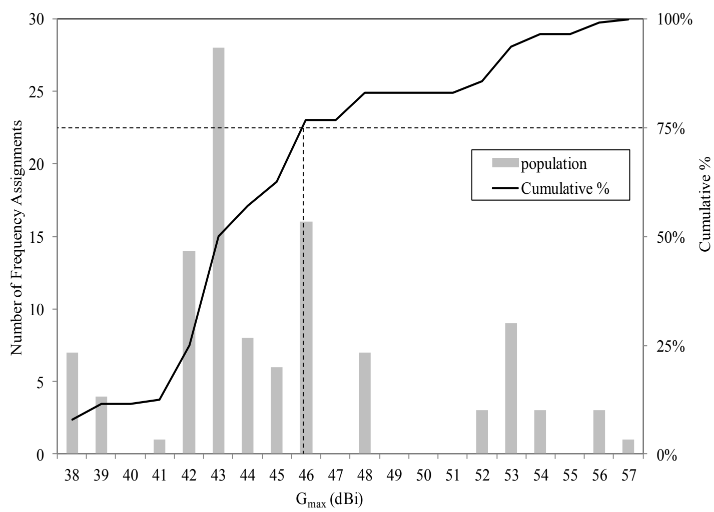


Figure 6-61. Population Profile of EESS Earth Station Antenna G_{max} Data in 2.2−2.29 GHz

Table 6-143. Representative EESS Earth Station Antenna Radiation Pattern in 2.2−2.29 GHz

Gain Function (dBi)	Angular Range
$46 - 2.5 \times 10^{-3} (78.78\times\phi)^2$	$0° \leq \phi \leq 1.05°$
27.4	$1.05° < \phi \leq 1.16°$
$29 - 25 \times \log(\phi)$	$1.16° < \phi \leq 36°$
-10	$36° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 82.2 for f = 2.25 GHz, G_{max} = 46 dBi, and e = 0.65	

6.11.3.3.4 8.025−8.4 GHz Downlink

The GMF has only the NGSO system service records in this band.

The earth station antenna G_{max} data count in this band is

- 42 dBi: 1 frequency assignment,
- 44 dBi: 48 frequency assignments,
- 45 dBi: 4 frequency assignments,
- 46 dBi: 6 frequency assignments (cumulative population % = 73.8%),
- 54 dBi: 1 frequency assignment (cumulative population % = 75%),
- 56 dBi: 3 frequency assignments,
- 57, 58, 59 dBi: 17 frequency assignments.

There are two disconnected clusters at 42–46 dBi and 54–59 dBi. Even though the percentage of cumulative population is 75% at Gmax = 54 dBi, the cluster at 42–46 dBi is chosen to find the representative Gmax, and the representative Gmax is chosen to be 46 dBi. The representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-144.

Table 6-144. Representative EESS Earth Station Antenna Radiation Pattern in 8.025−8.4 GHz

Gain Function (dBi)	Angular Range
$46 - 2.5 \times 10^{-3} (82.2\times\phi)^2$	$0° \le \phi \le 1.05°$
27.4	$1.05° < \phi \le 1.16°$
$29 - 25 \times \log(\phi)$	$1.16° < \phi \le 36°$
-10	$36° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 82.2$ for $f = 8.2$ GHz, $G_{max} = 46$ dBi, and $e = 0.65$	

6.11.3.3.5 25.5−27 GHz Downlink

The GMF has only the NGSO system service records in this band.

All of the earth station antenna G_{max} data in this band are 58 dBi. The representative G_{max} = 58 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-145.

Table 6-145. Representative EESS Earth Station Antenna Radiation Pattern in 25.5−27 GHz

Gain Function (dBi)	Angular Range
$58 - 2.5 \times 10^{-3} (313.6\times\phi)^2$	$0° \le \phi \le 0.3°$
36.4	$0.3° < \phi \le 0.5°$

$29 - 25 \times \log(\phi)$	$0.5° < \phi \leq 36°$
-10	$36° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 313.6$ for $f = 8.2$ GHz, $G_{max} = 58$ dBi, and $e = 0.65$	

6.11.4 Space Research Service

Only the earth station antenna is discussed here. The earth station antenna can be either low-gain or high-gain, and both types are used in the GSO systems, NGSO systems, and deep space systems.

6.11.4.1 System Review

NTIA does not provide the SRS earth station antenna radiation performance standards for system review. ITU-R provides two recommendations of the SRS earth station large-aperture antenna reference radiation pattern for coordination studies and interference assessment in Recs. ITU-R SA.509-2 and SA.1811, and these radiation patterns are recommended for the SRS earth station antenna radiation performance standard. The original recommendation for the below-30 GHz case has only the sidelobe radiation pattern, and is only for $D/\lambda \geq 100$. It is extended by adopting the FSS earth station antenna reference radiation pattern in RR Appendix 8. These standards are provided in Table 6-146.

Table 6-146. SRS Earth Station Large-Aperture Antenna Radiation Standards

(a) Below 30 GHz

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48$ dBi)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_m$
	G_1	$\phi_m < \phi \leq \phi_r$
	$32 - 25 \times \log(\phi)$	$\phi_r < \phi \leq 47.9°$
	-10	$47.9° < \phi \leq 180°$
$D/\lambda < 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < (100\lambda/D)°$
	$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < 47.9°$
	$10 - 10 \times \log(D/\lambda)$	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = 2 + 15 \times \log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.		
47.9° is the value in the ITU-R recommendation for the SRS, while that data is 48° in RR Appendix 8 for the FSS.		

(b) Above 30 GHz

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_1$
$G_{max} - G_1$	$\phi_1 < \phi \leq \phi_2$
$G_{max} - G_1 - G_2 \times \log(\phi/\phi_2)$	$\phi_2 < \phi \leq \phi_3$
G_3	$\phi_3 < \phi \leq 80°$
$G_3 + 5$	$80° < \phi \leq 120°$
G_3	$120° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

ϕ_{bw}: HPBW, $\phi_{bw} = 69\ (\lambda/D)$, deg.

$\phi_1 = \phi_{bw} \times (G_1/12)^{0.5}$

$$\phi_2 = \phi_{bw} \times 10^{(G_1/G_2)} \times \left(\frac{G_2}{144}\right)^{0.5}$$

$$\phi_3 = \phi_2 \times 10^{\left(\frac{G_{max} - G_1 - G_3}{G_2}\right)}$$

$G_{max} = 10 \times \log[e_a\ (\pi D/\lambda)^2] - 4.343(4\pi h/\lambda)^2$, dBi

$G_1 = 17$ dBi

$G_2 = 27 + 10\ [\ \log(e_a) - \log(60h/\lambda)\ ]$, dBi

$G_3 = -10$ dBi

D: aperture diameter,

e_a: antenna efficiency excluding contribution from surface tolerance,

h: root-mean-square surface tolerance, $\left(\frac{1}{60}\right) \leq \left(\frac{h}{\lambda}\right) \leq \left(\frac{1}{15}\right)$

6.11.4.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standard in Section 6.11.4.1 may be used as the reference radiation patterns. In addition, ITU-R has an antenna reference radiation pattern for the coordination studies and interference assessment for large number of distributed interfering sources above 30 GHz. This pattern is provided in Table 6-147. These radiation patterns do not specify the G_{max} value; however, such data should be available in the GMF.

Table 6-147. SRS Earth Station Large-Aperture Antenna Reference Radiation Pattern against Large Number of Distributed Interfering Sources above 30 GHz

Gain Function (dBi)	Angular Range
G_{max} - 12 × $(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_4$
G_{max} - G_4	$\phi_4 < \phi \le \phi_5$
G_{max} - G_4 - G_5 × log((ϕ/ϕ_5)	$\phi_5 < \phi \le \phi_6$
G_6	$\phi_6 < \phi \le 80°$
G_6 + 5	$80° < \phi \le 120°$
G_6	$120° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
ϕ_{bw}: HPBW, ϕ_{bw} = 69 (λ/D), deg.
$\phi_4 = \phi_{bw} \times (G_4/12)^{0.5}$

$$\phi_5 = \phi_{bw} \times 10^{[(G_4-3)/G_5]} \times \left(\frac{G_5}{144}\right)^{0.5}$$

$$\phi_6 = \phi_5 \times 10^{\left(\frac{G_{max}-G_4-G_6}{G_5}\right)}$$

$G_{max} = 10 \times \log[e_a (\pi D/\lambda)^2] - 4.343(4\pi h/\lambda)^2$, dBi
G_4 = 20 dBi
$G_5 = 27 + 10 [\log(e_a) - \log(60h/\lambda)]$, dBi
G_6 = -13 dBi
D: aperture diameter
e_a: antenna efficiency excluding contribution from surface tolerance
h: root-mean-square surface tolerance, $\left(\frac{1}{60}\right) \le \left(\frac{h}{\lambda}\right) \le \left(\frac{1}{15}\right)$

6.11.4.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the SRS service records in the GMF. The symbol of the station class is “EH” for the space station and “TH” for the earth station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile.
(3) Select a representative G_{max} value from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.11.4.2.

The frequency bands being examined are

(1) 2.025−2.11 GHz,

(2) 2.2−2.3 GHz,
(3) 7.145−7.235 GHz,
(4) 8.4−8.5 GHz,
(5) 13.25−13.75 GHz,
(6) 14.8−15.4 GHz,
(7) 25.5−27 GHz,
(8) 31.3−32.3 GHz, and
(9) 34.2−34.7 GHz.

6.11.4.3.1 2.025−2.11 GHz

(a) Deep-Space System Uplink

Here the deep-space systems include the lunar-orbiting systems. The deep-space system uplink earth station antenna G_{max} data count in this band is

- 47 dBi: 1 frequency assignment,
- 50 dBi: 1 frequency assignment,
- 52 dBi: 2 frequency assignments,
- 53 dBi: 2 frequency assignments,
- 54 dBi: 2 frequency assignments,
- 56 dBi: 7 frequency assignments (cumulative population % = 83%),
- 63 dBi: 1 frequency assignment,
- 70 dBi: 2 frequency assignments.

The representative G_{max} = 56 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-148.

Table 6-148. Representative SRS Deep-Space System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$56 - 2.5 \times 10^{-3} (249.1\times\phi)^2$	$0° \leq \phi \leq 0.3°$
37.9	$0.3° < \phi \leq 0.6°$
$32 - 25 \times \log(\phi)$	$0.6° < \phi \leq 47.9°$
-10	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 249.1 for f = 2.06 GHz, G_{max} = 56 dBi, and e = 0.65	

(b) GSO System Uplink

There are three GSO system uplink service records in this band, with all earth station antenna G_{max} = 45 dBi. The representative G_{max} = 45 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-149.

Table 6-149. Representative SRS GSO System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$45 - 2.5 \times 10^{-3} (70.2\times\phi)^2$	$0° \leq \phi \leq 1.1°$
29.7	$1.1° < \phi \leq 1.4°$
$33.5 - 25 \times \log(\phi)$	$1.4° < \phi \leq 47.9°$
-8.5	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 70.2 for f = 2.06 GHz, G_{max} = 45 dBi, and e = 0.65	

(c) GSO System Downlink

The GSO system downlink earth station antenna G_{max} data count in this band is

- 21 dBi: 3 frequency assignments,
- 26 dBi: 7 frequency assignments,
- 34 dBi: 7 frequency assignments,
- 35 dBi: 7 frequency assignments (cumulative population % = 59%),
- 39 dBi: 14 frequency assignments (cumulative population % = 93%),
- 53 dBi: 3 frequency assignments.

The representative G_{max} = 35 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-150.

Table 6-150. Representative SRS GSO System Downlink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$35 - 2.5 \times 10^{-3} (22\times\phi)^2$	$0° \leq \phi \leq 3.2°$
22.2	$3.2° < \phi \leq 4.5°$
$38.5 - 25 \times \log(\phi)$	$4.5° < \phi \leq 47.9°$
-3.5	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 22 for f = 2.06 GHz, G_{max} = 39 dBi, and e = 0.65	

(d) NGSO System Uplink

The population profile of the NGSO system uplink earth station antenna G_{max} data in this band is shown in Figure 6-62. The representative G_{max} = 51 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-151.

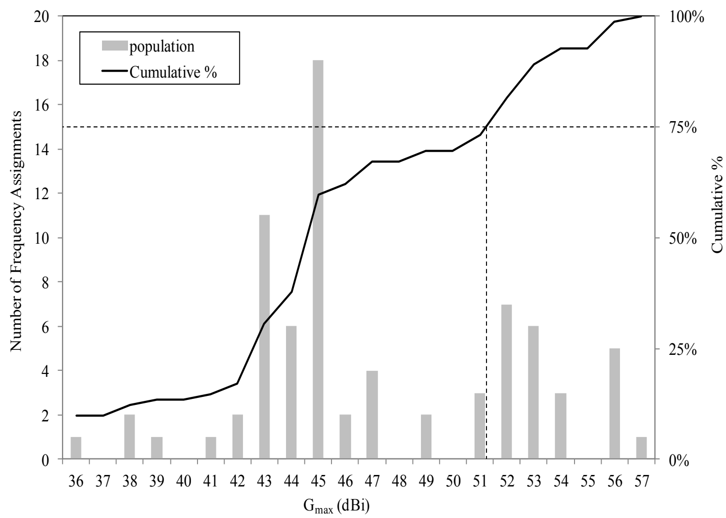


Figure 6-62. Population Profile of SRS NGSO System Uplink Earth Station Antenna G_{max} Data in 2.025−2.11 GHz

Table 6-151. Representative SRS NGSO System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$51 - 2.5 \times 10^{-3} (140.1\times\phi)^2$	$0° \le \phi \le 0.6°$
34.2	$0.6° < \phi \le 0.8°$
$32 - 25 \times \log(\phi)$	$0.8° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 140.1$ for $f = 2.06$ GHz, $G_{max} = 51$ dBi, and $e = 0.65$	

6.11.4.3.2 2.2−2.3 GHz

(a) Deep-Space System Downlink

Here the deep-space systems include the lunar-orbiting systems. The deep-space system downlink earth station antenna G_{max} data count in this band is

- 48, 50 dBi: 6 frequency assignments,
- 52, 54, 55 dBi: 7 frequency assignments,
- 56 dBi: 5 frequency assignments,
- 57 dBi: 9 frequency assignments (cumulative population % = 79%),
- 63, 66 dBi: 7 frequency assignments.

The representative G_{max} = 57 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-152.

Table 6-152. Representative SRS Deep-Space System Downlink Earth Station Antenna Radiation Pattern in 2.2−2.3 GHz

Gain Function (dBi)	**Angular Range**
$57 - 2.5 \times 10^{-3} (279.5\times\phi)^2$	$0° \leq \phi \leq 0.3°$
38.7	$0.3° < \phi \leq 0.5°$
$32 - 25 \times \log(\phi)$	$0.5° < \phi \leq 47.9°$
-10	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 279.5$ for $f = 2.25$ GHz, $G_{max} = 57$ dBi, and $e = 0.65$	

(b) GSO System Uplink

There are three GSO system uplink service records data in this band, with all the earth station antenna $G_{max} = 45$ dBi. The representative $G_{max} = 45$ dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-153.

Table 6-153. Representative SRS GSO System Uplink Earth Station Antenna Radiation Pattern in 2.2−2.3 GHz

Gain Function (dBi)	**Angular Range**
$45 - 2.5 \times 10^{-3} (70.2\times\phi)^2$	$0° \leq \phi \leq 1.1°$
29.7	$1.1° < \phi \leq 1.4°$
$33.5 - 25 \times \log(\phi)$	$1.4° < \phi \leq 47.9°$
-8.5	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 70.2$ for $f = 2.25$ GHz, $G_{max} = 45$ dBi, and $e = 0.65$	

(c) NGSO System Downlink

The population profile of the NGSO system downlink earth station antenna G_{max} data in this band is shown in Figure 6-63. The representative $G_{max} = 50$ dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-154.

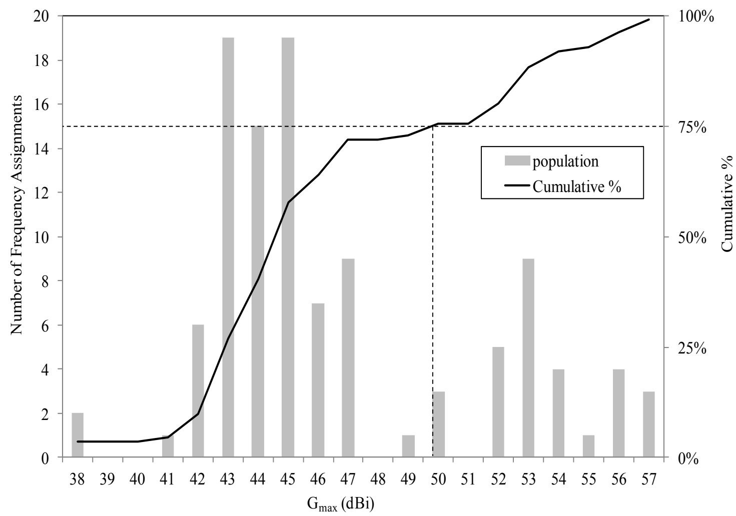


Figure 6-63. Population Profile of SRS NGSO System Downlink Earth Station Antenna G_{max} Data in 2.2−2.3 GHz

Table 6-154. Representative SRS NGSO System Downlink Earth Station Antenna Radiation Pattern in 2.2−2.3 GHz

Gain Function (dBi)	Angular Range
$50 - 2.5 \times 10^{-3} (124.9\times\phi)^2$	$0° \le \phi \le 0.7°$
33.4	$0.7° < \phi \le 0.9°$
$32 - 25 \times \log(\phi)$	$0.9° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 124.9$ for $f = 2.25$ GHz, $G_{max} = 50$ dBi, and $e = 0.65$	

6.11.4.3.3 7.145−7.235 GHz

(a) Deep-Space System Uplink

Here the deep-space systems include the Mars-orbiting systems. The deep-space system uplink earth station antenna G_{max} data count in this band is

- 67 dBi: 37 frequency assignments,
- 68 dBi: 10 frequency assignments,
- 72 dBi: 1 frequency assignment (cumulative population % = 74%),
- 73 dBi: 14 frequency assignments,
- 74 dBi: 3 frequency assignments.

The representative G_{max} = 72 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-155.

Table 6-155. Representative SRS Deep-Space System Uplink Earth Station Antenna Radiation Pattern in 7.145−7.235 GHz

Gain Function (dBi)	Angular Range
$72 - 2.5 \times 10^{-3} (1572\times\phi)^2$	$0° \leq \phi \leq 0.06°$
49.9	$0.06° < \phi \leq 0.19°$
$32 - 25 \times \log(\phi)$	$0.19° < \phi \leq 47.9°$
-10	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 1572$ for $f = 7.2$ GHz, $G_{max} = 72$ dBi, and $e = 0.65$	

(b) NGSO System Uplink

There are two NGSO system uplink service records in this band, and the earth station antenna G_{max} values are 55 and 68 dBi. The representative G_{max} is chosen to be 68 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-156.

Table 6-156. Representative SRS NGSO System Uplink Earth Station Antenna Radiation Pattern in 7.145−7.235 GHz

Gain Function (dBi)	Angular Range
$68 - 2.5 \times 10^{-3} (222\times\phi)^2$	$0° \leq \phi \leq 0.1°$
46.9	$0.1° < \phi \leq 0.25°$
$32 - 25 \times \log(\phi)$	$0.25° < \phi \leq 47.9°$
-10	$47.9° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 992$ for $f = 7.2$ GHz, $G_{max} = 68$ dBi, and $e = 0.65$	

6.11.4.3.4 8.4−8.5 GHz

The GMF has only the downlink service records in this band.

(a) Deep-Space System Downlink

The deep-space downlink earth station antenna G_{max} data count in this band is

- 43, 56, 63, 66 dBi: 4 frequency assignments,
- 67 dBi: 16 frequency assignments,
- 68 dBi: 34 frequency assignments (cumulative population % = 77%),
- 72, 73, 74 dBi: 16 frequency assignments.

The representative G_{max} = 68 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-157.

Table 6-157. Representative SRS Deep-Space System Downlink Earth Station Antenna Radiation Pattern in 8.4−8.5 GHz

Gain Function (dBi)	Angular Range
$68 - 2.5 \times 10^{-3} (992\times\phi)^2$	$0° \le \phi \le 0.1°$
46.9	$0.1° < \phi \le 0.25°$
$32 - 25 \times \log(\phi)$	$0.25° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 992 for f = 8.45 GHz, G_{max} = 68 dBi, and e = 0.65	

(b) NGSO System Downlink

The NGSO system downlink earth station antenna G_{max} data count in this band is

- 55 dBi: 2 frequency assignments,
- 60 dBi: 1 frequency assignment (cumulative population % = 60%),
- 68 dBi: 2 frequency assignments.

The representative G_{max} = 60 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-158.

Table 6-158. Representative SRS NGSO System Downlink Earth Station Antenna Radiation Pattern in 8.4−8.5 GHz

Gain Function (dBi)	Angular Range
$60 - 2.5 \times 10^{-3} (394.8\times\phi)^2$	$0° \le \phi \le 0.22°$
40.9	$0.22° < \phi \le 0.44°$
$32 - 25 \times \log(\phi)$	$0.44° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 394.8 for f = 8.45 GHz, G_{max} = 60 dBi, and e = 0.65	

6.11.4.3.5 13.25−13.75 GHz

The GMF has only the GSO system downlink service records in this band.

The GSO system downlink earth station antenna G_{max} data count in this band is

- 30 dBi: 10 frequency assignments,
- 47 dBi: 7 frequency assignments.

The representative G_{max} = 30 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-159.

Table 6-159. Representative SRS GSO System Downlink Earth Station Antenna Radiation Pattern in 13.25−13.75 GHz

Gain Function (dBi)	Angular Range
$30 - 2.5 \times 10^{-3} (12.5\times\phi)^2$	$0° \le \phi \le 5.4°$
18.4	$5.4° < \phi \le 8°$
$41 - 25 \times \log(\phi)$	$8° < \phi \le 47.9°$
-1	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 12.5 for f = 13.5 GHz, G_{max} = 30 dBi, and e = 0.65	

6.11.4.3.6 14.8−15.4 GHz

The GMF has only the uplink service records in this band.

(a) GSO System Uplink

There are three GSO system uplink service records in this band, with all earth station antenna G_{max} = 60 dBi. The representative G_{max} = 60 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-160.

Table 6-160. Representative SRS GSO System Uplink Earth Station Antenna Radiation Pattern in 14.8−15.4 GHz

Gain Function (dBi)	Angular Range
$60 - 2.5 \times 10^{-3} (394.8\times\phi)^2$	$0° \le \phi \le 0.22°$
40.9	$0.22° < \phi \le 0.44°$
$32 - 25 \times \log(\phi)$	$0.44° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 394.8 for f = 15 GHz, G_{max} = 60 dBi, and e = 0.65	

(b) NGSO System Uplink

There is only one NGSO system uplink service records in this band, with the earth station antenna G_{max} = 62 dBi. The representative G_{max} = 62 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-161.

Table 6-161. Representative SRS NGSO System Uplink Earth Station Antenna Radiation Pattern in 14.8−15.4 GHz

Gain Function (dBi)	Angular Range
$62 - 2.5 \times 10^{-3} (497\times\phi)^2$	$0° \le \phi \le 0.18°$
42.4	$0.18° < \phi \le 0.38°$
$32 - 25 \times \log(\phi)$	$0.38° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg.	

$D/\lambda = 497$ for $f = 15$ GHz, $G_{max} = 62$ dBi, and $e = 0.65$

6.11.4.3.7 25.5−27 GHz

The GMF has only the downlink service records.

(a) Moon-Orbiting System Downlink

There is only one moon-orbiting system downlink service record in this band, with the earth station antenna $G_{max} = 70$ dBi. The representative $G_{max} = 70$ dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-162.

Table 6-162. Representative SRS Moon-Orbiting System Downlink Earth Station Antenna Radiation Pattern in 25.5−27 GHz

Gain Function (dBi)	Angular Range
$70 - 2.5 \times 10^{-3} (1248\times\phi)^2$	$0° \le \phi \le 0.07°$
48.4	$0.07° < \phi \le 0.22°$
$32 - 25 \times \log(\phi)$	$0.22° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 1248$ for $f = 26$ GHz, $G_{max} = 70$ dBi, and $e = 0.65$	

(b) NGSO System Downlink

There is only one NGSO system service records in this band, with the earth station antenna $G_{max} = 71$ dBi. The representative $G_{max} = 71$ dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-163.

Table 6-163. Representative SRS NGSO System Downlink Earth Station Antenna Radiation Pattern in 25.5−27 GHz

Gain Function (dBi)	Angular Range
$71 - 2.5 \times 10^{-3} (1401\times\phi)^2$	$0° \le \phi \le 0.06°$
49.2	$0.06° < \phi \le 0.21°$
$32 - 25 \times \log(\phi)$	$0.21° < \phi \le 47.9°$
-10	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 1401$ for $f = 26$ GHz, $G_{max} = 71$ dBi, and $e = 0.65$	

6.11.4.3.8 31.3−32.3 GHz

(a) Deep-Space System Downlink

The deep-space system downlink earth station antennas G_{max} data count in this band is

- 77 dBi: 1 frequency assignment,

- 78 dBi: 2 frequency assignments,
- 79 dBi: 2 frequency assignments.

The representative G_{max} = 78 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-164.

Table 6-164. Representative SRS Deep-Space System Downlink Earth Station Antenna Radiation Pattern in 31.3−32.3 GHz

Gain Function (dBi)	Angular Range
$78 - 12 \times (\phi/0.022)^2$	$0 \le \phi \le 0.026°$
61	$0.026° < \phi \le 0.047°$
$61 - 23.4 \times \log(\phi/0.047)$	$0.047° < \phi \le 51.7°$
-10	$51.7° < \phi \le 80°$
-5	$80° < \phi \le 120°$
-10	$120° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. e_a= 0.65 h/λ = 1/40	

(b) NGSO System Downlink

There are two NGSO system service records in this band, with both earth station antenna G_{max} = 68 dBi. The representative antenna G_{max} = 68 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-165.

Table 6-165. Representative SRS NGSO System Downlink Earth Station Antenna Radiation Pattern in 31.3−32.3 GHz

Gain Function (dBi)	Angular Range
$68 - 12 \times (\phi/0.07)^2$	$0 \le \phi \le 0.083°$
51	$0.083° < \phi \le 0.15°$
$51 - 23.4 \times \log(\phi/0.15)$	$0.15° < \phi \le 61°$
-10	$61° < \phi \le 80°$
-5	$80° < \phi \le 120°$
-10	$120° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. e_a= 0.65 h/λ = 1/40	

6.11.4.3.9 34.2−34.7 GHz

The GMF has only the uplink service records in this band.

There is only one deep-space system uplink service record in this band, with the earth station antenna G_{max} = 78 dBi. The representative G_{max} = 78 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-166.

Table 6-166. Representative SRS Deep-Space System Uplink Earth Station Antenna Radiation Pattern in 34.2−34.7 GHz

Gain Function (dBi)	Angular Range
$78 - 12 \times (\phi/0.022)^2$	$0 \leq \phi \leq 0.026°$
61	$0.026° < \phi \leq 0.047°$
$61 - 23.4 \times \log(\phi/0.047)$	$0.047° < \phi \leq 51.7°$
-10	$51.7° < \phi \leq 80°$
-5	$80° < \phi \leq 120°$
-10	$120° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. e_a= 0.65 h/λ = 1/40	

6.12 Space Application Service

6.12.1 Space Operation Service

6.12.1.1 System Review

NTIA does not provide the SOS earth station antenna radiation performance standards, nor does ITU-R have recommendations for the SOS earth station antenna reference radiation patterns. Here, it is assumed that the SOS earth station antenna has similar radiation performance as the FSS earth station antenna; therefore, the FSS earth station antenna radiation performance standard in Section 6.3.1 is recommended for the SOS earth station antenna radiation performance standard. Furthermore, the standard for the GSO system is extended to the moon-orbiting system and the deep-space system. The low-gain antenna radiation performance standard is not available in Section 6.3.1, and the LMSS low-gain antenna radiation performance standards in Section 6.7.1.1 are applied here. These standards are shown in Table 6-167.

Table 6-167. SOS Earth Station Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
Circular Beam, $12 \leq G_{max}(dBi) \leq 18$ ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg.	

x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.

(b) GSO and Higher Orbit System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_m$
	G_1	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq 7°$
	8	$7° < \phi \leq 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$

An actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(c) NGSO System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{ma}$
	G_{1a}	$\phi_{ma} < \phi \leq \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{mb}$
	G_{1b}	$\phi_{mb} < \phi \leq \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$
$D/\lambda < 20$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi \leq \phi_{rc}$
	$29 - 25 \times \log(\phi)$	$\phi_{rc} < \phi \leq 36°$
	-10	$36° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi $\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg. $\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg. $G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi $G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi $\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg. $\phi_{rb} = (95\lambda/D)$, deg.
Pattern for $D/\lambda < 20$ is added to extend the high-gain pattern to $G_{max} = 22$ dBi. ϕ_{rc} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$, deg.

6.12.1.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 6.12.1.1 may be used as the reference radiation patterns. The radiation patterns in Section 6.12.1.1 do not specify the G_{max} value; however, such data should be available in the GMF.

6.12.1.3 Spectrum Sharing Analyses

The procedure to develop the representative earth station antenna radiation pattern is as follows:

(1) Retrieve the SOS service records in the GMF. The symbol of the station class is “ET” for the space station and “TT” for the earth station. Only the frequency bands in which the federal government is the primary user are searched.
(2) Develop the earth station antenna G_{max} data population profile.
(3) Select a representative G_{max} value from the population profile such that approximately 75% of the G_{max} population is equal to or smaller than the representative value.
(4) Develop the representative antenna radiation pattern from the representative G_{max} value and the antenna reference radiation patterns in Section 6.12.1.2.

The frequency bands being examined are

(1) 148−149.9 MHz,
(2) 401−402 MHz,
(3) 2.025−2.11 GHz, and
(4) 2.2−2.29 GHz.

6.12.1.3.1 148−149.9 MHz

The GMF has only one GSO system uplink service record in this band, with the earth station antenna G_{max} = 12 dBi. The representative G_{max} = 12 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-168.

Table 6-168. Representative SOS GSO System Uplink Earth Station Antenna Radiation Pattern in 148−149.9 MHz

Gain Function (dBi)	Angular Range
$12 - 12 \times (\phi/41.2)^2$	$0° \leq \phi \leq 33.7°$
4	$33.7° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
ϕ: angle off mainbeam axis, deg.	

6.12.1.3.2 401−402 MHz

The GMF contains only one NGSO system downlink service record in this band, with the earth station antenna G_{max} = 16 dBi. The representative G_{max} = 16 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-169.

Table 6-169. Representative SOS NGSO System Downlink Earth Station Antenna Radiation Pattern in 401−402 MHz

Gain Function (dBi)	Angular Range
$16 - 12 \times (\phi/26)^2$	$0° \leq \phi \leq 26°$
4	$26° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
ϕ: angle off mainbeam axis, deg.	

6.12.1.3.3 2.025−2.11 GHz

(a) Deep-Space System Uplink

There are four deep-space system uplink service records in this band, with the earth station antenna G_{max} = 52, 53, 56, and 62 dBi. The representative G_{max} is chosen to be 56 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-170.

Table 6-170. Representative SOS Deep-Space System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$56 - 2.5 \times 10^{-3} (249\times\phi)^2$	$0° \leq \phi \leq 0.37°$
34.9	$0.37° < \phi \leq 0.58°$
$29 - 25 \times \log(\phi)$	$0.58° < \phi \leq 7°$
8	$7° < \phi \leq 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
-10	$48° < \phi \leq 180°$

ϕ: angle off mainbeam axis, deg. D/λ = 249 for *f* = 2.06 GHz, G_{max} = 56 dBi, and *e* = 0.65

(b) GSO System Uplink

The GSO system uplink earth station antenna G_{max} data count in this band is

- 39 dBi: 24 frequency assignments,
- 53 dBi: 7 frequency assignments.

The representative G_{max} = 39 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-171.

Table 6-171. Representative SOS GSO System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$39 - 2.5 \times 10^{-3} (35.2\times\phi)^2$	$0° \le \phi \le 2.55°$
$29 - 25 \times \log(\phi)$	$2.55° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. D/λ = 35.2 for *f* = 2.06 GHz, G_{max} = 39 dBi, and *e* = 0.65	

(c) GSO System Downlink

The GSO system downlink earth station antenna G_{max} data count in this band is

- 21 dBi: 6 frequency assignments,
- 26 dBi: 21 frequency assignments,
- 34 dBi: 9 frequency assignments,
- 35 dBi: 8 frequency assignments (cumulative population % = 72%),
- 39 dBi: 14 frequency assignments (cumulative population % = 95%),
- 53 dBi: 3 frequency assignments.

Since the uplink and downlink antenna sizes should be compatible in this band, the representative G_{max} is chosen to be 39 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-172.

Table 6-172. Representative SOS GSO System Downlink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain Function (dBi)	Angular Range
$39 - 2.5 \times 10^{-3} (35.2\times\phi)^2$	$0° \le \phi \le 2.55°$
$29 - 25 \times \log(\phi)$	$2.55° < \phi \le 7°$
8	$7° < \phi \le 9.2°$

32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. D/λ = 35.2 for *f* = 2.06 GHz, G_{max} = 39 dBi, and *e* = 0.65	

(d) NGSO System Uplink

The NGSO system uplink earth station antenna G_{max} data count in this band is

- 16 dBi: 1 frequency assignment,
- 38 dBi: 1 frequency assignment,
- 44 dBi: 2 frequency assignments,
- 47 dBi: 1 frequency assignment (cumulative population % = 71%),
- 49 dBi: 1 frequency assignment,
- 52 dBi: 1 frequency assignment.

The representative G_{max} = 47 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-173.

Table 6-173. Representative SOS NGSO System Uplink Earth Station Antenna Radiation Pattern in 2.025−2.11 GHz

Gain (dBic)	Angular Range
$47 - 2.5 \times 10^{-3} (92\times\phi)^2$	0° ≤ ϕ ≤ 0.93°
28.7	0.93° < ϕ ≤ 1.03°
29 - 25 × log(ϕ)	1.03° < ϕ ≤ 36°
-10	36° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. D/λ = 92 for *f* = 2.06 GHz, G_{max} = 47 dBic, and *e* = 0.65	

6.12.1.3.4 2.2−2.29 GHz

(a) Deep-Space System Downlink

There are four deep-space system uplink earth station antenna G_{max} data in this band, and their G_{max} values are 52, 53, 57, and 63 dBi. The representative G_{max} = 57 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-174.

Table 6-174. Representative SOS Deep-Space System Downlink Earth Station Antenna Radiation Pattern in 2.2−2.29 GHz

Gain Function (dBi)	Angular Range
$57 - 2.5 \times 10^{-3} (279.4\times\phi)^2$	0° ≤ ϕ ≤ 0.33°
35.7	0.33° < ϕ ≤ 0.54°
29 - 25 × log(ϕ)	0.54° < ϕ ≤ 7°
8	7° < ϕ ≤ 9.2°

32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. D/λ = 279.4 for *f* = 2.25 GHz, G_{max} = 57 dBi, and *e* = 0.65	

(b) GSO System Uplink

The GSO system uplink earth station antenna G_{max} data count in this band is

- 21, 26 dBi: 16 frequency assignments,
- 34 dBi: 17 frequency assignments,
- 35 dBi: 14 frequency assignments (cumulative population % = 65%),
- 39 dBi: 14 frequency assignments (cumulative population % = 86%),
- 46, 53, 65 dBi: 9 frequency assignments.

The representative G_{max} = 35 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-175.

Table 6-175. Representative SOS GSO System Uplink Earth Station Antenna Radiation Pattern in 2.2−2.29 GHz

Gain Function (dBi)	Angular Range
$35 - 2.5 \times 10^{-3} (22.2\times\phi)^2$	0° ≤ ϕ ≤ 4.18°
29 - 25 × log(ϕ)	4.18° < ϕ ≤ 7°
8	7° <ϕ ≤ 9.2°
32 - 25 × log(ϕ)	9.2° < ϕ ≤ 48°
-10	48° < ϕ ≤ 180°
ϕ: angle off mainbeam axis, deg. D/λ = 22.2 for *f* = 2.25 GHz, G_{max} = 35 dBi, and *e* = 0.65	

(c) GSO System Downlink

The GSO system downlink earth station antenna G_{max} data count in this band is

- 22, 27 dBi: 4 frequency assignments,
- 42 dBi: 81 frequency assignments,
- 43 dBi: 11 frequency assignments,
- 44 dBi: 3 frequency assignments (cumulative population % = 71%),
- 47 dBi: 35 frequency assignments,
- 50, 52, 55, 56 dBi: 5 frequency assignments.

The representative antenna G_{max} = 44 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-176.

Table 6-176. Representative SOS GSO System Downlink Earth Station Antenna Radiation Pattern in 2.2−2.29 GHz

Gain Function (dBi)	Angular Range
$44 - 2.5 \times 10^{-3} (62.55\times\phi)^2$	$0° \le \phi \le 1.37°$
$29 - 25 \times \log(\phi)$	$1.37° < \phi \le 7°$
8	$7° < \phi \le 9.2°$
$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 62.55$ for $f = 2.25$ GHz, $G_{max} = 44$ dBi, and $e = 0.65$	

(d) NGSO System Downlink

The NGSO system downlink earth station antenna G_{max} data count in this band is

- 16 dBi: 3 frequency assignments,
- 36, 38 dBi: 4 frequency assignments,
- 42 dBi: 25 frequency assignments (cumulative population % = 82%),
- 43, 44 dBi: 5 frequency assignments,
- 47, 49 dBi: 2 frequency assignments.

The representative G_{max} = 42 dBi, and the representative antenna radiation pattern for spectrum sharing analyses is provided in Table 6-177.

Table 6-177. Representative SOS NGSO System Downlink Earth Station Antenna Radiation Pattern in 2.2−2.29 GHz

Gain (dBic)	Angular Range
$42 - 2.5 \times 10^{-3} (51.75\times\phi)^2$	$0° \le \phi \le 1.71°$
22.4	$1.71° < \phi \le 1.84°$
$29 - 25 \times \log(\phi)$	$1.84° < \phi \le 36°$
-10	$36° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $D/\lambda = 51.75$ for $f = 2.25$ GHz, $G_{max} = 42$ dBic, and $e = 0.65$	

6.12.2 Data Relay Service

The DRS system provides telecommunication support between the earth stations and the LEO satellites conducting space research operations. The GMF does not provide a separate category for this service.

SECTION 7. SUMMARY OF RECOMMENDATIONS

7.1 Introduction

The recommended antenna models from Section 6 for system review, frequency assignment, and spectrum sharing analyses are summarized here.

7.2 Fixed Service (FS)

7.2.1 System Review

The FS antenna radiation performance standards for system review are provided in Table 7-1.

Table 7-1. FS Antenna Suppression Masks for System Review

Frequency Band (MHz)	Max. ϕ_{bw} (°)	Min. Radiation Suppression to G_{max} (dB) Angle Off Mainbeam Axis (°)						
		5−10	**10−15**	**15−20**	**20−30**	**30−100**	**100−140**	**140−180**
406.1−420	80	n/a	n/a	n/a	n/a	10	10	10
(a) 932.5−935, 941.5−944	14	n/a	6	11	14	17	20	24
(b) 932.5−935, 941.5−944	20	n/a	n/a	6	10	13	15	20
1710−1850	10	n/a	14	16	18	25	27	30
(c) 1710−1850	8	5	18	23	23	28	30	36
2200−2400	8.5	4	17	17	20	27	29	33
4400−4990	4	13	20	23	26	29	31	40
7125−8500	2.5	19	23	28	30	34	35	43
14400−15350	1.5	21	26	31	35	37	41	48

- These standards are not applicable to transportable antennas in tactical and training operations.
- n/a: not available.
- (a) is required except in areas not subject to frequency congestion or in areas subject to frequency coordination along the U.S. borders where (b) is applicable.
- (c) is applicable to new stations in service after January 1, 1985 except for those located on the military test ranges.

7.2.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. Because the NTIA system review process uses the gain suppression masks as the certification criteria, the manufacturers generally provide the gain suppression patterns instead of the radiation patterns. The radiation patterns can be easily derived by adding the G_{max} values to the gain suppression patterns.

When the actual radiation pattern is not available, a reference radiation pattern should be used. The FS low- and high-gain antenna reference radiation patterns for EMC analyses in frequency assignment are provided in Table 7-2.

Table 7-2. FS Antenna Reference Radiation Patterns for Frequency Assignment

(a) Omnidirectional Antenna

Envelope Type	Gain Function (dBi)	Angular Range
Peak Sidelobe	$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \leq \lvert\theta\rvert < \theta_p$
	$G_{max} - 12 + 10 \times \log(k + 1)$	$\theta_p \leq \lvert\theta\rvert < \theta_{bw}$
	$G_{max} - 12 + 10 \times \log\{(\lvert\theta\rvert/\theta_{bw})^{-1.5} + k\}$	$\theta_{bw} \leq \lvert\theta\rvert \leq 90°$
Average Sidelobe	$G_{max} - 12(\theta/\theta_{bw})^2$	$0° \leq \lvert\theta\rvert < \theta_{bw}$
	$G_{max} - 15 + 10 \times \log(k + 1)$	$\theta_{bw} \leq \lvert\theta\rvert < \theta_a$
	$G_{max} - 15 + 10 \times \log\{(\lvert\theta\rvert/\theta_{bw})^{-1.5} + k\}$	$\theta_a \leq \lvert\theta\rvert \leq 90°$

G_{max}: the maximum gain in the azimuth plane, dBi

θ: elevation angle relative to the angle of maximum gain, deg., $-90° \leq \theta \leq 90°$,

θ_{bw}: HPBW in the elevation plane, deg.

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

$$\theta_p = \theta_{bw}\sqrt{1 - \frac{\log(k+1)}{1.2}}$$

$$\theta_a = \theta_{bw}\sqrt{1.25 - \frac{\log(k+1)}{1.2}}$$

k: parameter that accounts for increased sidelobe levels above what would be expected for an antenna with improved sidelobe performance,

- k = 0.7 for typical antennas operating in the $1 \leq f < 3$ GHz range, and
- k = 0 for antennas with improved sidelobe performance operating in the $1 \leq f < 3$ GHz range or all antennas operating in the $3 \leq f \leq 70$ GHz range.*

If the antenna mainbeam is downward tilted, i.e., cone-shape instead flat, by electrical means, the radiation patterns above and below the horizontal plane are stretched and compressed, respectively. The formulas are still applicable with the following modifications.

Define

- β: downward tilt angle, the positive angle that the main beam axis is below the horizontal plane at the site of the antenna, deg., and
- θ_h: elevation angle measured from the horizontal plane at the site of the antenna, deg., $-90° \leq \theta_h \leq 90°$,

the formulas are applicable with θ replaced with θ_e of

$$\theta_e = \frac{90(\theta_h + \beta)}{90 + \beta} \qquad \text{for } \theta_h + \beta \geq 0$$

$$\theta_e = \frac{90(\theta_h + \beta)}{90 - \beta} \qquad \text{for } \theta_h + \beta < 0$$

(b) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(c) High-Gain Antenna

Category	Gain(φ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 4\times10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(\text{dBi}) < 48$	$G_{max} - 4\times10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(\text{dBi}) < 22$	$G_{max} - 4\times10^{-4}\left(10^{G_{max}/10}\right)\phi^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$

	0	$\phi_{b3} < \phi \leq 180°$

All angles in deg.

ϕ: angle off mainbeam

$$\phi_m = 50(0.25G_{max} + 7)^{0.5} / \left(10^{G_{max}/20}\right)$$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250 / \left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

7.2.3 Spectrum Sharing Analyses

The representative FS antenna radiation patterns for spectrum sharing analyses are provided in Table 7-3.

Table 7-3. Representative FS Antenna Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Representative Antenna Reference Radiation Pattern		
	G_{max} (dBi)	Gain(θ) (dBi)	Angular Range
406.1−420 MHz	10	$10 - 0.004\times\phi^2$	$0 \leq \phi \leq 48.7°$
		0.5	$48.7° < \phi \leq 79.1°$
		$48 - 25 \times \log(\phi)$	$79.1° < \phi \leq 83.2°$
		0	$83.2° < \phi \leq 180°$
932.5−935 & 941.5−944 MHz	22	$22 - 0.06\times\phi^2$	$0 \leq \phi \leq 14°$
		9.5	$14° < \phi \leq 20°$
		$42 - 25 \times \log(\phi)$	$20° < \phi \leq 48°$
		0	$48° < \phi \leq 180°$
1.71−1.85 GHz	29	$29 - 0.32\times\phi^2$	$0 \leq \phi \leq 6.7°$
		14.75	$6.7° < \phi \leq 9°$
		$38.5 - 25 \times \log(\phi)$	$9° < \phi \leq 48°$
		-3.5	$48° < \phi \leq 180°$
2.2−2.4 GHz	28	$28 - 0.25\times\phi^2$	$0 \leq \phi \leq 7.4°$
		14	$7.4° < \phi \leq 10°$
		$39 - 25 \times \log(\phi)$	$10° < \phi \leq 48°$
		-3	$48° < \phi \leq 180°$
4.4−4.99 GHz	38	$38 - 2.52\times\phi^2$	$0 \leq \phi \leq 2.6°$
		21.5	$2.6° < \phi \leq 3.1°$
		$34 - 25 \times \log(\phi)$	$3.1° < \phi \leq 48°$
		-8	$48° < \phi \leq 180°$
7.125−8.5 GHz	43	$43 - 7.98\times\phi^2$	$0 \leq \phi \leq 1.5°$
		25.25	$1.5° < \phi \leq 1.8°$
		$31.5 - 25 \times \log(\phi)$	$1.8° < \phi \leq 48°$

		-10.5	$48° < \phi \leq 180°$
14.4−15.35 GHz	42	$42 - 6.34 \times \phi^2$	$0 \leq \phi \leq 1.7°$
		24.5	$1.7° < \phi \leq 2°$
		$32 - 25 \times \log(\phi)$	$2° < \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
21.2−23.6 GHz	40	$40 - 4\phi^2$	$0 \leq \phi \leq 14°$
		23	$14° < \phi \leq 20°$
		$33 - 25 \times \log(\phi)$	$20° < \phi \leq 48°$
		-9	$48° < \phi \leq 180°$
25.25−27.5 GHz	41	$41 - 5.04\phi^2$	$0 \leq \phi \leq 14°$
		23.75	$14° < \phi \leq 20°$
		$32.5 - 25 \times \log(\phi)$	$20° < \phi \leq 48°$
		-9.5	$48° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg.			

7.3 Fixed-Satellite Service (FSS)

Only earth station antenna characteristics are discussed here.

7.3.1 System Review

The FSS earth station antenna radiation performance standards for system review are provided in Table 7-4.

Table 7-4. FSS Earth Station Antenna Radiation Performance Standards

(a) GSO System Co-Polarization Standards in the GSO Plane and not in the K_a or Conventional K_u Band

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for *e* = 0.65)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda = 68$ is the threshold when the G_1 plateau disappears. ϕ: angle off mainbeam axis, deg. $G_1 = -1 + 15 \times \log(D/\lambda)$, dBi		

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg. ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$
The actual radiation pattern shall meet the following conditions: • It may not exceed the gain function in the range $\phi_r \le \phi < 7°$. • It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) GSO System Co-Polarization Standards in the GSO Plane and in the K_a and Conventional K_u Bands

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 68$ ($G_{max} \ge 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \le \phi < 7°$
	8	$7° \le \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \le \phi < 48°$
	-10	$48° \le \phi < 85°$
	0	$85° \le \phi \le 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \le \phi < 7°$
	8	$7° \le \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \le \phi < 48°$
	-10	$48° \le \phi < 85°$
	0	$85° \le \phi \le 180°$
$D/\lambda = 68$ is the threshold when the G_1 plateau disappears. ϕ: angle off mainbeam axis, deg. $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg. ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$		
The actual radiation pattern shall meet the following conditions: • It may not exceed the gain function in the range $\phi_r \le \phi < 7°$. • It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.		

(c) GSO System Co-Polarization Standard not in the GSO Plane

Category	Gain Function (dBi)	Angular Range
Not K_a or conventional K_u band	$32 – 25 \times \log(\phi)$	$3° \le \phi \le 48°$
	-10	$48° < \phi \le 180°$
K_a and	$32 – 25 \times \log(\phi)$	$3° \le \phi \le 48°$

conventional K_u bands	-10	$48° < \phi \le 85°$
	0	$85° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.

(d) GSO System Cross-Polarization Pattern

Gain Function (dBi)	Angular Range
$19 - 25 \times \log(\phi)$	$x° \le \phi \le 7°$
-2	$7° < \phi \le 21.3°$
$20.2 - 16.7 \times \log(\phi)$	$21.3° < \phi \le 26.3°$
$32 - 25 \times \log(\phi)$	$26.3° < \phi \le 48°$
-10	$48° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.

(e) NGSO System Co-Polarization Pattern

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 100$ ($G_{max} \ge 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \le \phi < \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \le \phi < \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

7.3.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Table 7-4 may be used as the reference radiation pattern. The radiation pattern in Table 7-4 does not specify the G_{max} value, and such data should be available in the GMF.

7.3.3 Spectrum Sharing Analyses

The representative FSS earth station antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-5.

Table 7-5. Representative FSS Earth Station Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

(a) GSO System Co-Polarization Radiation Pattern in the GSO Plane

Frequency Band, Transmission Direction	G_{max} (dBi)	Gain Function (dBi)	Angular Range
3.6−4.2 GHz, Downlink	42	$42 - 2.5 \times 10^{-3}(49.3\times\phi)^2$	$0° \le \phi \le 1.77°$
		$29 - 25 \times \log(\phi)$	$1.77° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
5.85−6.425 GHz, Uplink	46	$46 - 2.5 \times 10^{-3}(79\times\phi)^2$	$0° \le \phi \le 1.05°$
		27.4	$1.05° < \phi \le 1.16°$
		$29 - 25\times\log(\phi)$	$1.16° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
7.25−7.75 GHz, Downlink; 7.9−8.4 GHz, Uplink	57	$57 - 2.5 \times 10^{-3}(280\times\phi)^2$	$0° \le \phi \le 0.33°$
		35.7	$0.33° < \phi \le 0.54°$
		$29 - 25\times\log(\phi)$	$0.54° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
10.7−12.2 GHz, Downlink	53	$53 - 2.5 \times 10^{-3}(176\times\phi)^2$	$0° \le \phi \le 0.51°$
		32.7	$0.51° < \phi \le 0.71°$
		$29 - 25\times\log(\phi)$	$0.71° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 85°$
		0	$85° < \phi \le 180°$
14−14.5 GHz, Uplink	54	$54 - 2.5 \times 10^{-3}(197\times\phi)^2$	$0° \le \phi \le 0.46°$
		33.4	$0.46° < \phi \le 0.66°$
		$29 - 25\times\log(\phi)$	$0.66° < \phi \le 7°$

		8	$7° < \phi \leq 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 85°$
		0	$85° < \phi \leq 180°$
20.2−21.2 GHz, Downlink	52	$52 - 2.5 \times 10^{-3}(157.2\times\phi)^2$	$0° \leq \phi \leq 0.57°$
		31.9	$0.57° < \phi \leq 0.76°$
		$29 - 25\times\log(\phi)$	$0.76° < \phi \leq 7°$
		8	$7° < \phi \leq 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 85°$
		0	$85° < \phi \leq 180°$
30−31 GHz, Uplink	55.5	$55.5 - 2.5 \times 10^{-3}(233.8\times\phi)^2$	$0° \leq \phi \leq 0.39°$
		34.5	$0.39° < \phi \leq 0.6°$
		$29 - 25\times\log(\phi)$	$0.6° < \phi \leq 7°$
		8	$7° < \phi \leq 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 85°$
		0	$85° < \phi \leq 180°$
43−45 GHz, Uplink	42	$42 - 2.5 \times 10^{-3}(49.9\times\phi)^2$	$0° \leq \phi \leq 1.75°$
		$29 - 25\times\log(\phi)$	$1.75° < \phi \leq 7°$
		8	$7° < \phi \leq 9.2°$
		$32 - 25\times\log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg.			

(b) GSO System Co-Polarization Radiation Pattern Not in the GSO Plane

Frequency Band	G_{max} (dBi)	Gain Function (dBi)	Angular Range
3.6−4.2 GHz	42	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
5.85−6.425 GHz	46	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
7.25−7.75 GHz; 7.9−8.4 GHz	57	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
10.7−12.2 GHz	53	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 85°$
		0	$85° < \phi \leq 180°$
14−14.5 GHz	54	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 85°$
		0	$85° < \phi \leq 180°$
20.2−21.2 GHz	52	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 85°$

		0	$85° < \phi \leq 180°$
30−31 GHz	55.5	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 85°$
		0	$85° < \phi \leq 180°$
43−45 GHz	42	$32 - 25 \times \log(\phi)$	$3° \leq \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
• ϕ: angle off mainbeam axis, deg. • This also applies to the plane of horizon including any out-of-plane potential terrestrial interference path.			

(c) GSO System Cross-Polarization Radiation Pattern

Frequency Band	Gain Function (dBi)	Angular Range
3.6−4.2 GHz, 5.85−6.425 GHz, 7.25−7.75 GHz, 7.9−8.4 GHz, 10.7−12.2 GHz, 14−14.5 GHz, 20.2−21.2 GHz, 30−31 GHz, 43−45 GHz,	$19 - 25 \times \log(\phi)$	$x° \leq \phi \leq 7°$
	-2	$7° < \phi \leq 21.3°$
	$20.2 - 16.7 \times \log(\phi)$	$21.3° < \phi \leq 26.3°$
	$32 - 25 \times \log(\phi)$	$26.3° < \phi \leq 48°$
	-10	$48° < \phi \leq 180°$
• ϕ: angle off mainbeam axis, deg. • x = 1.8 when in the GSO plane. x = 3 when not in GSO plane, or in the plane of horizon including any out-of-plane potential terrestrial interference path.		

(d) NGSO System Sidelobe Radiation Pattern

Frequency Band, Transmission Direction	G_{max} (dBi)	Gain Function (dBi)	Angular Range
1.35−1.39 GHz, Downlink	17	$17 - 12 \times (\phi/23.1)^2$	$0° < \phi \leq 24.1°$
		4	$24.1° < \phi \leq 40°$
		$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
		-5	$90° < \phi$
• ϕ: angle off mainbeam axis, deg. • Radiation pattern for G_{max} = 17 dBi is not covered in Table 7-4(e). This pattern is from Section 7.7.1 of the LMSS low- and medium-gain earth station antenna.			

7.4 Broadcasting Service (BS)

The federal agencies do not operate BS systems. There is no need to establish the BS antenna radiation performance standard.

7.5 Broadcasting-Satellite Service (BSS)

The federal agencies do not operate BSS systems. There is no need to establish the BSS antenna radiation performance standard.

7.6 Mobile Service (MS)

7.6.1 Land Mobile Service (LMS)

7.6.1.1 System Review

(a) Omnidirectional antenna

The LMS omnidirectional antenna vertical radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (7\text{-}1)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10\times\log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + k \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.,

k = 0 for base station antennas,
0.5 for mobile station antennas.

(b) Directional antenna

The LMS directional antenna radiation performance standards are provided in Table 7-6.

Table 7-6. LMS Directional Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5.

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10 \times \log\{e \times [41253/(\phi_{bw1} \times \phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

7.6.1.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Section 7.6.1.1 may be used as the reference radiation pattern. The radiation pattern in Section 7.6.1.1 does not specify the G_{max} value, and such data should be available in the GMF.

7.6.1.3 Spectrum Sharing Analyses

The representative LMS antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-7.

Table 7-7. Representative LMS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Station Type	G_{max} (dBi)	Gain Function (dBi)	Angular Range
498–505, 525–535 kHz	Base stations	0	$-12(\theta/107.6)^2$	$\|\theta\| \leq 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5}\}$	$\|\theta\| > 99.4°$
	Mobile stations	0	$-12(\theta/107.6)^2$	$\|\theta\| \leq 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 99.4°$
1.605–1.615, 1.705–1.8 MHz	Base station	1	$1 - 12(\theta/85.5)^2$	$\|\theta\| \leq 78.9°$
			$-11 + 10\times\log\{[\max(\|\theta\|/85.5, 1)]^{-1.5}\}$	$\|\theta\| > 78.9°$
	Mobile station	0	$-12(\theta/107.6)^2$	$\|\theta\| \leq 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 99.4°$
2–2.065, 2.107–2.17, 2.1735–2.1905, 2.194–2.495, 2.505–2.85, 3.155–3.4 MHz	Base stations	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Mobile stations	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 49.8°$
4.438–4.65, 4.75–4.995, 5.73–5.9, 6.765–7, 7.4–8.1 MHz	Base station	2	$2 - 12(\theta/67.9)^2$	$\|\theta\| \leq 62.7°$
			$-10 + 10\times\log\{[\max(\|\theta\|/67.9, 1)]^{-1.5}\}$	$\|\theta\| > 62.7°$
	Mobile station	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 49.8°$
23.35–24.89 MHz	Base station	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Mobile station	6	$6 - 12(\theta/27)^2$	$\|\theta\| \leq 25°$
			$-6 + 10\times\log\{[\max(\|\theta\|/27, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 25°$
25.33–25.55, 26.48–26.95 MHz	Base stations	0	$-12(\theta/107.6)^2$	$\|\theta\| \leq 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5}\}$	$\|\theta\| > 99.4°$
	Mobile stations	0	$-12(\theta/107.6)^2$	$\|\theta\| \leq 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 99.4°$
27.54–28 MHz	Base stations	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Mobile stations	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 49.8°$

29.89–29.92, 30–30.56, 32–33, 34–35, 36–37, 38–39, 40–42, 46.6–47, 49.6–50, 74.6–74.8, 75.2–75.4 MHz	Base stations	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \leq 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Mobile stations	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \leq 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 62.7°$
138–144, 148–149.9, 150.05–150.8 MHz	Base station	5	$5 - 12(\theta/34)^2$	$\lvert\theta\rvert \leq 31.4°$
			$-7 + 10\times\log\{[\max(\lvert\theta\rvert/34, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 31.4°$
	Mobile station	3	$3 - 12(\theta/53.9)^2$	$\lvert\theta\rvert \leq 49.8°$
			$-9 + 10\times\log\{[\max(\lvert\theta\rvert/53.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 49.8°$
162.0125–173.2, 173.4–174 MHz	Base station	6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \leq 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
	Mobile station	5	$5 - 12(\theta/34)^2$	$\lvert\theta\rvert \leq 31.4°$
			$-7 + 10\times\log\{[\max(\lvert\theta\rvert/34, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 31.4°$
220–222, 225–328.6, 335.4–399.9, 406.1–420 MHz	Base station	6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \leq 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
	Mobile station	3	$3 - 12(\theta/53.9)^2$	$\lvert\theta\rvert \leq 49.8°$
			$-9 + 10\times\log\{[\max(\lvert\theta\rvert/53.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 49.8°$
1.755–1.85 GHz	Base station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \leq 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Mobile station	3	$3 - 12(\theta/53.9)^2$	$\lvert\theta\rvert \leq 49.8°$
			$-9 + 10\times\log\{[\max(\lvert\theta\rvert/53.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 49.8°$
2.2–2.3, 2.36–2.395 GHz	Mobile station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \leq 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 62.7°$
	Mobile station	14*	$14 - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
			3.5	$\phi_m < \phi \leq 49.9°$
			$46 - 25 \times \log(\phi)$	$49.9° < \phi \leq 69.2°$
			0	$69.2° < \phi \leq 180°$
			ϕ_{bw}: HPBW in the direction of interest, deg. ϕ_m : intersection of $\{14 - 12(\phi/\phi_{bw})^2\}$ and 3.5	
21.2–23.6 GHz	Mobile station	13*	$13 - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_n$
			2.75	$\phi_n < \phi \leq 56°$
			$46.5 - 25 \times \log(\phi)$	$56° < \phi \leq 72.4°$
			0	$72.4° < \phi \leq 180°$
			ϕ_{bw}: HPBW in the direction of interest, deg.	

			ϕ_n : intersection of $\{13 - 12(\phi/\phi_{bw})^2\}$ and 2.75
θ: of omnidirectional antenna, elevation angle off the peak gain plane, in deg.			
* : directional antenna with elliptical beam ϕ: of directional antenna, angle off mainbeam axis in the direction of interest, deg.			

7.6.2 Maritime Mobile Service (MMS)

7.6.2.1 System Review

(a) Coast Station Omnidirectional Antenna

The MMS coast station omnidirectional antenna vertical radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \qquad \text{dBi} \qquad (7\text{-}2)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10\times\log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$\theta_{bw} = 107.6 \times 10^{-0.1 G_{max}}$, deg.

(b) Coast Station Directional Antenna

The MMS coast station directional antenna radiation performance standards are provided in Table 7-8.

Table 7-8. MMS Coast Station Directional Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. G_{max} usually given, or can be calculated from: • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5	

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(\text{dBi}) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(\text{dBi}) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10 \times \log\{e \times [41253/(\phi_{bw1} \times \phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$

$\phi_{r2} = \phi_{r3} = 250 / \left(10^{G_{max}/20}\right)$

$\phi_{b1} = \phi_{b2} = 48°$

$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$

(c) Shipborne Omnidirectional Antenna

The MMS shipborne omnidirectional antenna radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (7\text{-}3)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi
$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + 0.5 \}$, dBi
θ: elevation angle off the peak gain plane, deg.
θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

7.6.2.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Section 7.6.2.1 may be used as the reference radiation pattern. The radiation pattern in Section 7.6.2.1 does not specify the G_{max} value, and such data should be available in the GMF.

7.6.2.3 Spectrum Sharing Analyses

The representative MMS antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-9.

Table 7-9. Representative MMS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Station Type	G_{max} (dBi)	Gain Function (dBi)	Angular Range
20.05–59, 61–90, 110–190 kHz	Coast station	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
	Ship	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 99.4°$
415–495, 496–535 kHz	Coast station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Ship	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 62.7°$
2.065–2.107, 2.17–2.1735, 2.1905–2.194 MHz	Coast station	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
	Ship	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 99.4°$
2–2.065, 2.107–2.17, 2.1735–2.1905, 2.194–2.495, 2.505–2.85, 3.155–3.4 MHz	Coast station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Ship	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 99.4°$
4–4.65, 4.75–4.995, 5.73–5.9 MHz	Coast station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Ship	1	$1 - 12(\theta/85.5)^2$	$\lvert\theta\rvert \le 78.9°$
			$-11 + 10\times\log\{[\max(\lvert\theta\rvert/85.5, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 78.9°$
6.765–7, 7.4–8.815 MHz	Coast station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Ship	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$

			$-10 + 10\times\log\{[\max(\|\theta\|/67.9, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 62.7°$
12.23−13.2, 16.36−17.41, 18.78−18.9, 19.68−19.8 MHz	Coast station	2	$2 - 12(\theta/67.9)^2$	$\|\theta\| \le 62.7°$
			$-10 + 10\times\log\{[\max(\|\theta\|/67.9, 1)]^{-1.5}\}$	$\|\theta\| > 62.7°$
	Ship	1	$1 - 12(\theta/85.5)^2$	$\|\theta\| \le 78.9°$
			$-11 + 10\times\log\{[\max(\|\theta\|/85.5, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 78.9°$
23.35–24.89, 25.07–25.21, 25.33–25.55, 26.1–26.175, 26.48–26.95, 27.54–28 MHz	Coast station	0	$-12(\theta/107.6)^2$	$\|\theta\| \le 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5}\}$	$\|\theta\| > 99.4°$
	Ship	0	$-12(\theta/107.6)^2$	$\|\theta\| \le 99.4°$
			$-12 + 10\times\log\{[\max(\|\theta\|/107.6, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 99.4°$
138–144, 148–149.9, 150.05–150.8, 157.0375–157.1875, 162.0125–173.2, 173.4–174 MHz	Coast station	5	$5 - 12(\theta/34)^2$	$\|\theta\| \le 31.4°$
			$-7 + 10\times\log\{[\max(\|\theta\|/34, 1)]^{-1.5}\}$	$\|\theta\| > 31.4°$
	Ship	4	$4 - 12(\theta/42.8)^2$	$\|\theta\| \le 39.6°$
			$-8 + 10\times\log\{[\max(\|\theta\|/42.8, 1)]^{-1.5} + 0.5\}$	$\|\theta\| > 39.6°$
All are omnidirectional antennas. θ: elevation angle off the peak gain plane, deg.				

7.6.3 Aeronautical Mobile Service (AMS)

7.6.3.1 System Review

(a) Land-Based Omnidirectional Antenna

The AMS land-based omnidirectional antenna vertical radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (7\text{-}4)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10\times\log\{[\max(|\theta|/\theta_{bw}, 1)]^{-1.5}\}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1 G_{max}}$, deg.

(b) Land-Based Directional Antenna

The AMS land-based directional antenna radiation performance standards are provided in Table 7-10.

Table 7-10. AMS Land-Based Directional Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	**Angular Range**
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5.

(b) High-Gain Antenna

Category	**Gain(ϕ) (dBi)**	**Angular Range (deg.)**
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(dBi) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(dBi) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

(c) Airborne Antenna

The AMS airborne antenna radiation performance standard is

$$P_1(G \leq G_1) = [1 - \exp(-3.46\, G_1)]^{1.25} \quad (7\text{-}5)$$

where P_1 is the probability that a given gain, G_1, may not exceed.

7.6.3.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Section 7.6.3.1 may be used as the reference radiation pattern. The radiation pattern in Section 7.6.3.1 does not specify the G_{max} value, and such data should be available in the GMF.

7.6.3.3 Spectrum Sharing Analyses

The representative AMS antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-11.

Table 7-11. Representative AMS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Station Type	G_{max} (dBi)	Gain Function (dBi)	Angular Range
2–2.065, 2.107–2.17, 2.1735–2.1905, 2.194–2.495, 2.505–3.5 MHz	Land station	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Aircraft	0	0	All
4.438–4.995, 5.45–5.73 MHz	Land station	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Aircraft	3	3	All
5.73–5.9, 6.525–7, 7.4–8 MHz	Land station	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Aircraft	0	0	All
8.815−9.04, 11.175−11.4, 13.2−13.36, 15.01−15.6, 17.9−18.03 MHz	Land station	3	$3 - 12(\theta/53.9)^2$	$\|\theta\| \leq 49.8°$
			$-9 + 10\times\log\{[\max(\|\theta\|/53.9, 1)]^{-1.5}\}$	$\|\theta\| > 49.8°$
	Aircraft	3	3	All
21.924−22, 23.2−23.35 MHz	Land station	1	$1 - 12(\theta/85.5)^2$	$\|\theta\| \leq 78.9°$
			$-11 + 10\times\log\{[\max(\|\theta\|/85.5, 1)]^{-1.5}\}$	$\|\theta\| > 78.9°$
	Aircraft	3	3	All
23.35−24.89,	Land	2	$2 - 12(\theta/67.9)^2$	$\|\theta\| \leq 62.7°$

25.33−25.55, 26.48−26.95, 27.54−28, 29.89−29.91, 30−30.56 MHz	station		$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Aircraft	0	0	All
32−33, 34−35, 36−37, 38−39, 40−42, 46.6−47, 49.6−50 MHz	Land station	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
	Aircraft	1	1	All
117.975-137 MHz	Land station	0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
	Aircraft	2	2	All
138−144, 148−149.9, 150.05−150.8 MHz	Land station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Aircraft	2	2	All
162.0125−173.2, 173.4−174 MHz	Land station	6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \le 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
	Aircraft	6	6	All
225−328.6, 335.4−399.9, 406.1−420 MHz	Land station	2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Aircraft	2	2	All
1.35-1.525 GHz	Land station	7	$7 - 12(\theta/21.5)^2$	$\lvert\theta\rvert \le 19.8°$
			$-5 + 10\times\log\{[\max(\lvert\theta\rvert/21.5, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 19.8°$
	Aircraft	7	7	All
1.755-1.85 GHz	Land station	8	$8 - 12(\theta/17)^2$	$\lvert\theta\rvert \le 15.8°$
			$-4 + 10\times\log\{[\max(\lvert\theta\rvert/17, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 15.8°$
	Aircraft	3	3	All
		32 *	N/A	
4.4-4.94 GHz	Land station	36 #	$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
			20	$1.15\times\phi_{bw} < \phi \le 4°$
			$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
			-7	$48° < \phi \le 180°$
	Aircraft	3	3	All
		36 *	N/A	

θ: of omnidirectional antenna, elevation angle off the peak gain plane, deg.

*: airborne directional antenna

N/A: not available. Airborne antenna radiation pattern is heavily influenced by the aircraft structure, thus a representative radiation pattern for general application cannot be developed.

#: land-based directional antenna with elliptical beam

ϕ: of directional antenna, angle off mainbeam axis in the direction of interest, deg.

ϕ_{bw} : HPBW

7.7 Mobile-Satellite Service (MSS)

Only the earth station antenna characteristics are discussed here.

7.7.1 Land Mobile-Satellite Service (LMSS)

7.7.1.1 System Review

The LMSS earth station antenna radiation performance standards for system review are provided in Table 7-12, Table 7-13, and Table 7-14.

Table 7-12. LMSS Earth Station Omnidirectional Antenna Radiation Performance Standards

(a) Vehicle-Mounted Near-Omnidirectional Antenna

Gain Function (dBi)	Angular Range
≤ 5	$-20° \leq \theta \leq 20°$
≤ 0	$\theta < -20°$ & $\theta > 20°$
θ: elevation angle, deg.	

(b) Vehicle-Mounted Vertical Array Antenna with Toroidal Beams and $7 \leq G_{max}$(dBi) ≤ 13

Gain Function (dBi)	Angular Range
$G_{max} - 10$	$45° \leq (\theta - \theta_o)$
$G_{max} - 0.3 \times [(\theta - \theta_o)/10]^{2.3}$	$20° \leq (\theta - \theta_o) \leq 45°$
$G_{max} - 12 \times [(\theta - \theta_o)/\theta_{bw})]^2$	$20° < \| \theta - \theta_o \|$
$G_{max} - 0.3 \times [(\theta_o - \theta)/10]^{2.3}$	$20° \leq (\theta_o - \theta) \leq 50°$
$G_{max} - 13$	$50° \leq (\theta_o - \theta)$
θ: elevation angle, deg. θ_o: mainbeam elevation angle, deg. θ_{bw}: HPBW, deg.	

Table 7-13. LMSS Earth Station Low- and Medium-Gain Antenna Radiation Performance Standards

(a) Vehicle-Mounted Tracking Antenna with Fan-Beams and Operating in Low Elevation Angle

Gain Function (dBi)	Angular Range
≤ 4	$0° \leq \theta \leq 60°$, $[30°+k(\theta)] \leq \|\varphi-\varphi_0\| \leq 180°$
(θ, φ): elevation and azimuth angles, deg. (θ_o, φ_o): mainbeam elevation and azimuth angles, deg. $k(\theta) = 0.33°$ for G_{max} = 11−15, dBi $k(\theta)$ is TBD for G_{max} = 9−11, dBi	

(b) Transportable or Vehicle-Mounted Antenna with Circular Beams and $G_{max} \leq 18$ dBi

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg. x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.	

Table 7-14. LMSS Earth Station High-Gain Antenna Radiation Performance Standards

(a) GSO System

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg. ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$		
An actual antenna radiation pattern shall meet the following conditions: • It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$. • It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.		

(b) NGSO System

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \leq \phi < \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} \leq \phi < 36°$

	-10	$36° \leq \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \leq \phi < \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $G_{ma} = 20 \times \log(D/\lambda) + 8.4$, dBi $G_{1a} = -1 + 15 \times \log(D/\lambda)$, dBi $\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg. $\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg. $G_{mb} = 20 \times \log(D/\lambda) + 7.7$, dBi $G_{1b} = 29 - 25 \times \log(95\lambda/D)$, dBi $\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg. $\phi_{rb} = (95\lambda/D)$, deg.		

7.7.1.2 Frequency Assignment

The actual earth station antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Section 7.7.1.1 may be used as the reference radiation pattern. The radiation pattern in Section 7.7.1.1 does not specify the G_{max} value, and such data should be available in the GMF.

7.7.1.3 Spectrum Sharing Analyses

The representative LMSS earth station antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-15.

Table 7-15. Representative LMSS Earth Station Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band, Transmission Direction	G_{max} (dBi)	Gain Function (dBi)	Angular Range
240−270 MHz, Downlink; 290−320 MHz, Uplink	11 *	$11 - 12 \times (\phi/46.2)^2$	$0° \leq \phi \leq 35.2°$
		4	$35.2° < \phi \leq 40°$
		$44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
		-5	$90° \leq \phi$
1.525−1.559 GHz, Downlink; 1.61−1.6605 GHz, Uplink	10 *	$10 - 12 \ (\phi/51.8)^2$	$0° \leq \phi \leq 36.6°$
		4	$36.6° < \phi \leq 40°$
		$44 - 25 \times \log(\phi)$	$40° < \phi < 90°$
		-5	$90° \leq \phi$

7.25−7.3 GHz, Downlink; 7.9−8.025 GHz, Uplink	42	$42 - 2.5 \times 10^{-3}(49.7 \times \phi)^2$	$0° \leq \phi \leq 2.6°$
		$29 - 25 \times \log(\phi)$	$2.6° < \phi \leq 7°$
		8	$7° < \phi \leq 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
39.5−40.5 GHz, Downlink; 43.5−47 GHz, Uplink	57	$57 - 2.5 \times 10^{-3}(279 \times \phi)^2$	$0° \leq \phi \leq 0.33°$
		35.7	$0.33° < \phi \leq 0.54°$
		$29 - 25 \times \log(\phi)$	$0.54° < \phi \leq 7°$
		8	$7° < \phi \leq 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. * : low-gain directional antenna.			

7.7.2 Maritime Mobile-Satellite Service (MMSS)

7.7.2.1 System Review

The MMSS earth station antenna radiation performance standards for system review are provided in Table 7-16 and Table 7-17.

Table 7-16. MMSS Shipborne Directional Antenna Radiation Performance Standard

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
$2 + 15 \times \log(D/\lambda)$	$\phi_m \leq \phi < (100\lambda/D)°$
$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \leq \phi < \phi_1$
0	$\phi_1 \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $\phi_m = 20(\lambda/D)[G_{max} - 2 - 15 \times \log(D/\lambda)]^{0.5}$, deg. $\phi_1 = 120 (\lambda/D)^{0.4}$, deg.	

Table 7-17. MMSS Coast Station Earth Station Antenna Radiation Performance Standards

(a) GSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$

$D/\lambda < 68$	G_{max} - 2.5 × $10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	29 - 25 × log(ϕ)	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	32 - 25 × log(ϕ)	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$

An actual antenna radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) NGSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	G_{ma} - 2.5 × 10^{-3} $(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \leq \phi < \phi_{ra}$
	29 - 25 × log(ϕ)	$\phi_{ra} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	G_{mb} - 2.5 × 10^{-3} $(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \leq \phi < \phi_{rb}$
	29 - 25 × log(ϕ)	$\phi_{rb} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

7.7.2.2 Frequency Assignment

The actual earth station antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Section 7.7.2.1 may be used as the reference radiation pattern. The radiation pattern in Section 7.7.2.1 does not specify the G_{max} value, and such data should be available in the GMF.

7.7.2.3 Spectrum Sharing Analyses

The representative MMSS earth station antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-18.

Table 7-18. Representative MMSS Earth Station Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band, Transmission Direction	Station Type, G_{max} (dBi)	Gain Function (dBi)	Angular Range
240−270 MHz, Downlink;290−320 MHz, Uplink	Ship, 11	$11 - 2.5 \times 10^{-3}(1.46\phi)^2$	$0° \le \phi < 35.1°$
		4.5	$35.1° \le \phi < 68.6°$
		$50.4 - 25 \times \log(\phi)$	$68.6° \le \phi < 103.2°$
		0	$103.2° \le \phi \le 180°$
1.525−1.559 GHz, Downlink;1.61−1.6605 GHz, Uplink	Ship, 21	$21 - 2.5 \times 10^{-3}(4.62\phi)^2$	$0° \le \phi < 13°$
		12	$13° \le \phi < 21.7°$
		$45.4 - 25 \times \log(\phi)$	$21.7° \le \phi < 65.1°$
		0	$103.1° \le \phi \le 180°$
20.2−21.2 GHz, Downlink	Coast station, 48	$48 - 2.5 \times 10^{-3}(99.4\phi)^2$	$0° \le \phi \le 0.88°$
		29	$0.88° < \phi \le 1°$
		$29 - 25 \times \log(\phi)$	$1° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
30−31 GHz, Uplink	Coast station, 51.4	$51.4 - 2.5 \times 10^{-3}(146.4\phi)^2$	$0° \le \phi \le 0.61°$
		31.5	$0.61° < \phi \le 0.8°$
		$29 - 25 \times \log(\phi)$	$0.8° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
39.5−40.5 GHz, Downlink;43.5−47 GHz, Uplink	Coast station, 55	$55 - 2.5 \times 10^{-3}(222\phi)^2$	$0° \le \phi \le 0.41°$
		34.2	$0.41° < \phi \le 0.62°$
		$29 - 25 \times \log(\phi)$	$0.62° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg.			

7.7.3 Aeronautical Mobile-Satellite Service (AMSS)

7.7.3.1 System Review

The AMSS earth station antenna radiation performance standards for system review are as follows.

(a) Airborne Antenna

The AMSS airborne antenna radiation performance standards for system review are

(a.1) For Antenna of 12 ≤ G(dBic) ≤ 17 within Coverage Volume

- Polarization: RHCP.
- The coverage volume shall comprise not less than 75% of the solid angle above 5º elevation (to the horizon during normal cruise attitude).
- G > 0 dBic outside the coverage volume.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

(a.2) For Antenna of 6 ≤ G(dBic) ≤ 12 within Coverage Volume

- Polarization: RHCP.
- The coverage volume shall comprise not less than 85% of the solid angle above 5º elevation.
- The coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith in straight and level flight, G > 4 dBic within this cone.
- G > 0 dBic for 99% of the solid angle above 5º elevation.
- To the maximum extent possible, G > 6 dBic for 100% of the solid angle above 5º elevation.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

(a.3) For Antenna of 0 ≤ G(dBic) ≤ 5 within Coverage Volume

- Polarization: RHCP.
- The coverage volume shall comprise no less than 85% of the solid angle above 5º elevation.
- The coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith (in normal cruise attitude) in straight and level flight, G > -2 dBic within this cone.
- G > -5 dBic outside the coverage volume.
- The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.

(b) Land-Based Earth Station Antennas

The AMSS land-based earth station antenna radiation performance standards for system review are provided in Table 7-19.

Table 7-19. AMSS Land-Based Earth Station Antenna Radiation Performance Standards

(a) GSO System

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15 \times \log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25 \times \log(\phi)\}$

An actual antenna radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) NGSO System

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \leq \phi < \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}(\text{dBi}) < 48.1$ for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \leq \phi < \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20 \times \log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15 \times \log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20 \times \log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

7.7.3.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, a reference radiation pattern should be used, and the radiation performance standard in Section 7.7.3.1 may be used as the reference radiation pattern. The radiation pattern in Section 7.7.3.1does not specify the G_{max} value, and such data should be available in the GMF.

7.7.3.3 Spectrum Sharing Analyses

The representative AMSS earth station antenna reference radiation patterns for spectrum sharing analyses are provided in Table 7-20.

Table 7-20. Representative AMSS Earth Station Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

<table>
<tr><th>Frequency Band, Transmission Direction</th><th>Station Type, G_{max} (dBi)</th><th>Gain Function (dBi)</th><th>Angular Range</th></tr>
<tr><td>240−270 MHz, Downlink;
290−320 MHz, Uplink</td><td>Aircraft,
11</td><td colspan="2">• Polarization: RHCP.
• The coverage volume shall comprise not less than 85% of the solid angle above 5º elevation.
• $6 \leq G(dBic) \leq 11$ within the coverage volume.
• The coverage volume may include a volume corresponding to a cone of 20º half-angle at the aircraft zenith in straight and level flight, G > 4 dBic within this cone.
• G > 0 dBic for 99% of the solid angle above 5º elevation.
• To the maximum extent possible, G > 6 dBic for 100% of the solid angle above 5º elevation.
• The coverage volume takes into account the effects from the mounting surface, beam-pointing error, radome or any protective surface.</td></tr>
<tr><td rowspan="6">20.2−21.2 GHz,
Downlink</td><td rowspan="6">Land station,
48</td><td>$48 - 2.5 \times 10^{-3}(99.4\phi)^2$</td><td>$0° \leq \phi \leq 0.88°$</td></tr>
<tr><td>29</td><td>$0.88° < \phi \leq 1°$</td></tr>
<tr><td>$29 - 25 \times \log(\phi)$</td><td>$1° < \phi \leq 7°$</td></tr>
<tr><td>8</td><td>$7° < \phi \leq 9.2°$</td></tr>
<tr><td>$32 - 25 \times \log(\phi)$</td><td>$9.2° < \phi \leq 48°$</td></tr>
<tr><td>-10</td><td>$48° < \phi \leq 180°$</td></tr>
</table>

30−31 GHz, Uplink	Land station, 51.4	$51.4 - 2.5 \times 10^{-3}(146.4\phi)^2$	$0° \le \phi \le 0.61°$
		34.5	$0.61° < \phi \le 0.8°$
		$29 - 25 \times \log(\phi)$	$0.8° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
39.5−40.5 GHz, Downlink; 43.5−47 GHz, Uplink	Land station, 55	$55 - 2.5 \times 10^{-3}(222\phi)^2$	$0° \le \phi \le 0.41°$
		34.2	$0.41° < \phi \le 0.62°$
		$29 - 25 \times \log(\phi)$	$0.62° < \phi \le 7°$
		8	$7° < \phi \le 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
		-10	$48° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg.			

7.8 Radiodetermination Service (RDS)

7.8.1 Radiolocation Service (RLS)

7.8.1.1 System Review

The RLS antenna radiation performance standards for system review are provided in Table 7-21.

Table 7-21. RLS Antenna Radiation Performance Standards

(a) Types

Group	Types of Radar	Criterion
A	• Non-pulsed radar of 40 watts or less rated average power, • Pulsed radar of 1 kW or less rated peak power, • Radar with operating frequency above 40 GHz, • Man-portable radar, • Man-transportable radar, • RNS radar in 9.3–9.5 GHz band, • Expendable, non-recoverable radar on missiles.	A
B	Radar with rated peak power of more than 1 kW but not more than 100 kW and operating between 2.9 GHz and 40 GHz	B
C	All radars not included in Group A, B, or D.	C
D	All fixed radars in 2.7–2.9 GHz band.	D
E	Wind Profiler Radar operating on 449 MHz.	E

(b) Criteria

Criterion	Description
A	Presently exempt.
B	Currently no requirement is specified.

C, D	Antennas operated in 360°-rotation over the horizontal plane shall have a “median gain” of -10 dBi or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, sidelobe suppression below the mainbeam shall be: • first three sidelobes: 17 dB, • all other lobes: 26 dB.	
E	Antenna Radiation Profile (dB)	Elevation Angle θ
	x	$70° \le \theta$
	x - 15	$60° \le \theta < 70°$
	x - 20	$45° \le \theta < 60°$
	x - 25	$5° \le \theta < 45°$
	x - 40	$\theta < 5°$
	• Radiation profile derived from EIRP profile requirement. • Symbol “<” is used instead of “≤” for the angular range in the NTIA Manual.	
For antennas operated in 360°-rotation over the horizontal plane, the EMC analysis must cover all directions. Thus the allowable radar antenna radiation pattern may be usefully specified by its “median gain” relative to an isotropic radiator.		

7.8.1.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment. The antenna radiation pattern should be available from either the system operators or the antenna manufacturers. When the actual radiation pattern is not available, a reference radiation pattern should be used. These reference radiation patterns are shown below. These patterns do not specify the G_{max} value, and such data should be available in the GMF.

(a) Omnidirectional Antenna

The RLS omnidirectional antenna vertical reference radiation pattern for EMC analyses in frequency assignment is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (7\text{-}6)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1 G_{max}}$, deg.

(b) Directional Antenna

The RLS directional antenna reference radiation patterns for EMC analyses in frequency assignment are provided in Table 7-22.

Table 7-22. RLS Directional Antenna Reference Radiation Patterns for Frequency Assignment

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Elliptical beam. G_{max} usually given, or can be calculated from: • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg. ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5	

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \ge 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \le \phi_{b1}$
	-13	$\phi_{b1} < \phi \le 180°$
$22 \le G_{max}(\text{dBi}) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \le \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \le 180°$
$10 \le G_{max}(\text{dBi}) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \le \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \le \phi_{b3}$
	0	$\phi_{b3} < \phi \le 180°$
Elliptical beam. All angles in deg. G_{max} usually given, or can be calculated from • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes ϕ: angle off mainbeam axis in the direction of interest ϕ_{bw}: HPBW in the direction of interest ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$ $\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$ $\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$ $\phi_{b1} = \phi_{b2} = 48°$		

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

7.8.1.3 Spectrum Sharing Analyses

The representative RLS antenna radiation patterns for spectrum sharing analyses are provided in Table 7-23.

Table 7-23. Representative RLS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Antenna Function	Antenna Type & G_{max} (dBi)	Gain Function (dBi)	Angular Range
1.705–1.8 MHz	Transmit	Omni., 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
216–217 MHz	Transmit	Dir., 33	$33 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.13\times\phi_{bw}$
			17.75	$1.13\times\phi_{bw} < \phi \le 5.6°$
			$36.5 - 25 \times \log(\phi)$	$5.6° < \phi \le 48°$
			-5.5	$48° < \phi \le 180°$
	Receive	Dir., 26	$26 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.06\times\phi_{bw}$
			12.5	$1.06\times\phi_{bw} < \phi \le 12.5°$
			$40 - 25 \times \log(\phi)$	$12.5° < \phi \le 48°$
			-2	$48° < \phi \le 180°$
420–450 MHz	Transmit	Omni., 6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \le 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
		Dir., 38	$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
			21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
			$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
			-8	$48° < \phi \le 180°$
	Receive	Omni., 3	$3 - 12(\theta/53.9)^2$	$\lvert\theta\rvert \le 49.8°$
			$-9 + 10\times\log\{[\max(\lvert\theta\rvert/53.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 49.8°$
		Dir., 32	$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.12\times\phi_{bw}$
			17	$1.12\times\phi_{bw} < \phi \le 6.3°$
			$37 - 25 \times \log(\phi)$	$6.3° < \phi \le 48°$
			-5	$48° < \phi \le 180°$
902–928 MHz	Transmit	Omni., 5	$5 - 12(\theta/34)^2$	$\lvert\theta\rvert \le 31.4°$
			$-7 + 10\times\log\{[\max(\lvert\theta\rvert/34, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 31.4°$
		Dir., 28	$28 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.08\times\phi_{bw}$
			14	$1.08\times\phi_{bw} < \phi \le 10°$
			$39 - 25 \times \log(\phi)$	$10° < \phi \le 48°$
			-3	$48° < \phi \le 180°$
	Receive	Omni., 6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \le 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$

		Dir., 27	$27 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.07\times\phi_{bw}$
			13.25	$1.07\times\phi_{bw} < \phi \le 11.2°$
			$39.5 - 25 \times \log(\phi)$	$11.2° < \phi \le 48°$
			-2.5	$48° < \phi \le 180°$
1.215–1.3 GHz	Transmit	Dir., 34	$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.14\times\phi_{bw}$
			18.5	$1.14\times\phi_{bw} < \phi \le 5°$
			$36 - 25 \times \log(\phi)$	$5° < \phi \le 48°$
			-6	$48° < \phi \le 180°$
	Receive	Dir., 22	$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
			9.5	$1.02\times\phi_{bw} < \phi \le 19.9°$
			$42 - 25 \times \log(\phi)$	$19.9° < \phi \le 48°$
			0	$48° < \phi \le 180°$
1.35–1.39 GHz	Transmit	Dir., 37	$37 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.16\times\phi_{bw}$
			20.75	$1.16\times\phi_{bw} < \phi \le 3.5°$
			$34.5 - 25 \times \log(\phi)$	$3.5° < \phi \le 48°$
			-7.5	$48° < \phi \le 180°$
	Receive	Dir., 22	$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
			9.5	$1.02\times\phi_{bw} < \phi \le 19.9°$
			$42 - 25 \times \log(\phi)$	$19.9° < \phi \le 48°$
			0	$48° < \phi \le 180°$
2.9–3.65 GHz	Transmit	Omni., 4	$4 - 12(\theta/42.8)^2$	$\lvert\theta\rvert \le 39.6°$
			$-8 + 10\times\log\{[\max(\lvert\theta\rvert/42.8, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 39.6°$
		Dir., 40	$40 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.19\times\phi_{bw}$
			23	$1.19\times\phi_{bw} < \phi \le 2.5°$
			$33 - 25 \times \log(\phi)$	$2.5° < \phi \le 48°$
			-9	$48° < \phi \le 180°$
	Receive	Omni., 3	$3 - 12(\theta/53.9)^2$	$\lvert\theta\rvert \le 49.8°$
			$-9 + 10\times\log\{[\max(\lvert\theta\rvert/53.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 49.8°$
		Dir., 36	$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
			20	$1.15\times\phi_{bw} < \phi \le 4°$
			$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
			-7	$48° < \phi \le 180°$
5.25–5.6 GHz	Transmit	Omni., 6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \le 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
		Dir., 43	$43 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.22\times\phi_{bw}$
			25.25	$1.22\times\phi_{bw} < \phi \le 1.8°$
			$31.5 - 25 \times \log(\phi)$	$1.8° < \phi \le 48°$
			-10.5	$48° < \phi \le 180°$
	Receive	Omni., 6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \le 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
		Dir., 43	$43 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.22\times\phi_{bw}$
			25.25	$1.22\times\phi_{bw} < \phi \le 1.8°$
			$31.5 - 25 \times \log(\phi)$	$1.8° < \phi \le 48°$
			-10.5	$48° < \phi \le 180°$
5.65–5.925	Transmit	Omni., 5	$5 - 12(\theta/34)^2$	$\lvert\theta\rvert \le 31.4°$

GHz			$-7 + 10\times\log\{[\max(\lvert\theta\rvert/34, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 31.4°$
		Dir., 45	$45 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.23\times\phi_{bw}$
			26.75	$1.23\times\phi_{bw} < \phi \le 1.4°$
			$30.5 - 25 \times \log(\phi)$	$1.4° < \phi \le 48°$
			-11.5	$48° < \phi \le 180°$
	Receive	Omni., 6	$6 - 12(\theta/27)^2$	$\lvert\theta\rvert \le 25°$
			$-6 + 10\times\log\{[\max(\lvert\theta\rvert/27, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 25°$
		Dir., 45	$45 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.23\times\phi_{bw}$
			26.75	$1.23\times\phi_{bw} < \phi \le 1.4°$
			$30.5 - 25 \times \log(\phi)$	$1.4° < \phi \le 48°$
			-11.5	$48° < \phi \le 180°$
8.5–9 GHz	Transmit & Receive	Dir., 31	$31 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.11\times\phi_{bw}$
			16.25	$1.11\times\phi_{bw} < \phi \le 7°$
			$37.5 - 25 \times \log(\phi)$	$7° < \phi \le 48°$
			-4.5	$48° < \phi \le 180°$
9.5–10.55 GHz	Transmit & receive	Omni., 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
		Dir., 36	$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
			20	$1.15\times\phi_{bw} < \phi \le 4°$
			$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
			-7	$48° < \phi \le 180°$
13.4–14 GHz	Transmit	Dir., 38	$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
			21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
			$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
			-8	$48° < \phi \le 180°$
	Receive	Dir., 34	$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.14\times\phi_{bw}$
			18.5	$1.14\times\phi_{bw} < \phi \le 5°$
			$36 - 25 \times \log(\phi)$	$5° < \phi \le 48°$
			-6	$48° < \phi \le 180°$
15.7–17.3 GHz	Transmit	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
		Dir., 43	$43 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.22\times\phi_{bw}$
			25.25	$1.22\times\phi_{bw} < \phi \le 1.8°$
			$31.5 - 25 \times \log(\phi)$	$1.8° < \phi \le 48°$
			-10.5	$48° < \phi \le 180°$
	Receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
		Dir., 36	$36 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.15\times\phi_{bw}$
			20	$1.15\times\phi_{bw} < \phi \le 4°$
			$35 - 25 \times \log(\phi)$	$4° < \phi \le 48°$
			-7	$48° < \phi \le 180°$
24.05–24.25 GHz	Transmit	Omni., 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
		Dir., 29	$29 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.09\times\phi_{bw}$
			14.75	$1.09\times\phi_{bw} < \phi \le 8.9°$

			$38.5 - 25 \times \log(\phi)$	$8.9° < \phi \le 48°$
			-3.5	$48° < \phi \le 180°$
	Receive	Omni., 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
		Dir., 30	$30 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.1\times\phi_{bw}$
			15.5	$1.1\times\phi_{bw} < \phi \le 7.9°$
			$38 - 25 \times \log(\phi)$	$7.9° < \phi \le 48°$
			-4	$48° < \phi \le 180°$
33.4–36 GHz	Transmit	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
		Dir., 32	$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.12\times\phi_{bw}$
			17	$1.12\times\phi_{bw} < \phi \le 6.3°$
			$37 - 25 \times \log(\phi)$	$6.3° < \phi \le 48°$
			-5	$48° < \phi \le 180°$
	Receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \le 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
		Dir., 32	$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.12\times\phi_{bw}$
			17	$1.12\times\phi_{bw} < \phi \le 6.3°$
			$37 - 25 \times \log(\phi)$	$6.3° < \phi \le 48°$
			-5	$48° < \phi \le 180°$
Omni.: Omnidirectional antenna. θ: for omnidirectional antenna, elevation angle off the peak gain plane, in deg.				
Dir.: Directional antenna. All directional antennas have elliptical beam. ϕ: for directional antenna, angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.				

7.8.2 Maritime Radionavigation Service (MRNS)

7.8.2.1 System Review

The MRNS antenna radiation performance standards for system review are provided in Table 7-24.

Table 7-24. MRNS Antenna Radiation Performance Standards

(a) Types

Group	Types of Radar	Criterion
A	• Non-pulsed radar of 40 watts or less rated average power, • Pulsed radar of 1 kW or less rated peak power, • Radar with operating frequency above 40 GHz, • Man-portable radar, • Man-transportable radar, • RNS radar in 9.3–9.5 GHz band, • Expendable, non-recoverable radar on missiles.	A
B	Radar with rated peak power of more than 1 kW but not more than 100 kW and operating between 2.9 GHz and 40 GHz	B

C	All radars not included in Group A, B, or D.	C
D	All fixed radars in 2.7–2.9 GHz band.	D
E	Wind Profiler Radar operating on 449 MHz.	E

(b) Criteria

Criterion	Description	
A	Presently exempt.	
B	Currently no requirement is specified.	
C, D	Antennas operated in 360°-rotation over the horizontal plane shall have a “median gain” of -10 dBi or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, sidelobe suppression below the mainbeam shall be: • first three sidelobes: 17 dB, • all other lobes: 26 dB.	
E	Antenna Radiation Profile (dB)	Elevation Angle θ
	x	$70° \le \theta$
	x - 15	$60° \le \theta < 70°$
	x - 20	$45° \le \theta < 60°$
	x - 25	$5° \le \theta < 45°$
	x - 40	$\theta < 5°$
	• Radiation profile derived from EIRP profile requirement. • Symbol “<” is used instead of “≤” for the angular range in the NTIA Manual.	
For antennas operated in 360°-rotation over the horizontal plane, the EMC analysis must cover all directions. Thus the allowable radar antenna radiation pattern may be usefully specified by its “median gain” relative to an isotropic radiator.		

7.8.2.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment. The antenna radiation pattern should be available from either the system operators or the antenna manufacturers. When the actual radiation pattern is not available, a reference radiation pattern should be used. These reference radiation patterns are shown below. These patterns do not specify the G_{max} value, and such data should be available in the GMF.

(a) Omnidirectional Antenna

The MRNS beacon service omnidirectional antenna vertical reference radiation pattern for EMC analyses in frequency assignment is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)), \quad \text{dBi} \qquad (7\text{-}7)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}, \text{ deg.}$$

(b) Directional Antenna

The MRNS directional antenna reference radiation patterns for EMC analyses in frequency assignment are provided in Table 7-25.

Table 7-25. MRNS Directional Antenna Reference Radiation Patterns for Frequency Assignment

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}$(dBi) < 48	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}$(dBi) < 22	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest

ϕ_{bw}: HPBW in the direction of interest ϕ_m : intersection of {G_{max} - $12(\phi/\phi_{bw})^2$} and (0.75 × G_{max} - 7) $\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$ $\phi_{r2} = \phi_{r3} = 250 / \left(10^{G_{max}/20}\right)$ $\phi_{b1} = \phi_{b2} = 48°$ $\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$

7.8.2.3 Spectrum Sharing Analyses

The representative MRNS antenna radiation patterns for spectrum sharing analyses are provided in Table 7-26.

Table 7-26. Representative MRNS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Antenna Type & G_{max} (dBi)	Gain (dBi)	Angular Range
2.9–3.1 GHz	Omni., 5	$5 - 12(\theta/34)^2$	$\|\theta\| \le 31.4°$
		$-7 + 10\times\log\{[\max(\|\theta\|/34, 1)]^{-1.5}\}$	$\|\theta\| > 31.4°$
9.2–9.3 GHz	Dir., 38	$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
		21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
		$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
		-8	$48° < \phi \le 180°$
9.3–9.5 GHz	Omni., 5	$5 - 12(\theta/34)^2$	$\|\theta\| \le 31.4°$
		$-7 + 10\times\log\{[\max(\|\theta\|/34, 1)]^{-1.5}\}$	$\|\theta\| > 31.4°$
	Dir., 29	$29 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.09\times\phi_{bw}$
		14.75	$1.09\times\phi_{bw} < \phi \le 8.9°$
		$38.5 - 25 \times \log(\phi)$	$8.9° < \phi \le 48°$
		-3.5	$48° < \phi \le 180°$
Omni.: Omnidirectional antenna. θ: for omnidirectional antenna, elevation angle off the peak gain plane, in deg. Dir.: Directional antenna. All directional antennas have elliptical beam. ϕ: for directional antenna, angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.			

7.8.3 Aeronautical Radionavigation Service (ARNS)

7.8.3.1 System Review

The ARNS antenna radiation performance standard for system review is as follows.

(a) The minimum operational radiation performance standards of the ARNS airborne receiving antenna for the ILS (instrument landing system) localizer equipment operating in the 108–112 MHz band are

- radiation pattern: the horizontal component of the radiated signal in the forward and rearward directions shall not be down more than 10 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 113 MHz and mounted 10 inches above the ground plane,
- gain variation: the difference between the maximum and minimum field strength of the horizontal component in the azimuth plane shall not exceed 20 dB,
- polarization discrimination: the reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(b) The minimum operational radiation performance standards of the ARNS airborne receiving antenna for the VHF omnidirectional range equipment operating in the 108–117.95 MHz band are

- radiation pattern: the horizontal component of the radiated signal in the forward and rearward directions shall not be down more than 10 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 113 MHz and mounted 10 inches above the ground plane,
- gain variation: the difference between the maximum and minimum field strength of the horizontal component in the azimuth plane shall not exceed 20 dB,
- polarization discrimination: the reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(c) The minimum operational radiation performance standards of the ARNS airborne antenna for the GPS local area augmentation system operating in the 108–117.975 MHz band are

- antenna type: omnidirectional antenna,
- horizontal gain:
  - o the reception of the horizontally polarized component in the horizontal plane from the forward and rearward directions shall not be down more than 10 dB when compared to the maximum output response of a standard horizontal dipole antenna that is mounted 25.4 cm (10 inches) above the ground plane and resonant at 113 MHz,
  - o the difference between the maximum and minimum reception of the horizontally polarized component from any direction in the horizontal plane shall not exceed 20 dB,
- vertical gain:

- when mounted on a 4×4 inch^2 (or larger) ground plane, the reception of the vertically polarized component in the horizontal azimuth plane shall not be down more than 6 dB when compared to a standard vertically polarized monopole antenna,
- when mounted on a 4×4 inch^2 (or larger) ground plane, the difference between the maximum and minimum reception of the vertical polarized component from any direction in the horizontal azimuth plane shall not exceed 6 dB.

(d) The minimum operational radiation performance standards of the ARNS airborne receiving antenna for the ILS glide slope equipment operating in the 328.6–335.4 MHz band are

- radiation pattern: the horizontal component of the radiated signal in the forward direction shall not be down more than 15 dB when compared to the maximum radiation from a standard horizontal dipole antenna resonant at 332 MHz in free space,
- polarization discrimination: the reception of vertically polarized signals from any horizontal direction with respect to the antenna shall be at least 10 dB below the reception of horizontally polarized signals from the same direction.

(e) The minimum operational radiation performance standards of the ARNS airborne antenna for the distance measuring equipment operating in the 960–1215 MHz band are

- polarization: predominately vertically polarized,
- radiation pattern: the average field strength in the horizontal plane shall be equal to the field strength of a matched resonant ¼λ vertical antenna,
- gain variation: the difference between the maximum and minimum field strengths in the horizontal plane shall not exceed 6 dB when the antenna is mounted at the center of the 1.2-meter (4-foot) diameter (or larger) flat circular ground plane.

(f) The minimum operational radiation performance standards of the ARNS airborne antenna for the air traffic control radar beacon system/mode select equipment operating in the 1030–1090 MHz band are

- polarization: vertically polarized,
- radiation pattern: the gain shall not be less than the gain of a matched ¼λ stub minus 3 dB over 90% of the coverage volume 0–360º in azimuth and 5–30º in elevation when installed at the center of a 1.2-meter (4-foot) diameter (or larger) circular ground plane.

(g) The minimum operational radiation performance standards of the ARNS airborne antenna for the traffic alert and collision avoidance system II transmitting in the 1030 MHz band and receiving in the 1087–1093 MHz band are

- polarization: vertically polarized,
- radiation pattern: the gain shall not be less than the gain of a matched ¼λ stub minus 1 dB over 90% of the coverage volume 0–360º in azimuth and (-15)–20º in elevation when installed at the center of a 1.2-meter (4-foot) diameter (or larger) circular ground plane, which can be flat or cylindrical.

(h) The minimum operational radiation performance standards of the ARNS airborne antenna for the active traffic alert and collision avoidance system I transmitting in the 1030 MHz band and receiving in the 1087–1093 MHz band are

- type: omnidirectional antenna or multiple beams to cover all azimuth directions,
- polarization: vertically polarized,
- radiation pattern: covering 360º in azimuth and at least (-10)–20º in elevation.

(i) The minimum operational radiation performance standards of the ARNS airborne antenna for the automatic dependent surveillance system and traffic information service system operating at 1090 MHz are

- type: omnidirectional antenna,
- polarization: vertically polarized,
- transmit radiation pattern: the gain shall not be less than the gain of a matched ¼λ stub minus 3 dB over 90% of a coverage volume from 0–360º in azimuth and 5–30º above the ground plane when installed at the center of 1.2 meters (4 feet) or larger flat circular ground plane,
- receive radiation pattern: the gain should not be less than the gain of a matched ¼λ stub minus 1 dB over 90% of a coverage volume from 0–360º in azimuth and (-15)–(+20)º in elevation when installed at the center of 1.2 meters (4 feet) or larger circular ground plane, which can be either flat or cylindrical.

7.8.3.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment. The antenna radiation pattern should be available from either the system operators or the antenna manufacturers. When the actual radiation pattern is not available, a reference radiation pattern should be used. These reference radiation patterns are shown below. These patterns do not specify the G_{max} value, and such data should be available in the GMF.

(a) Omnidirectional Antenna

The ARNS omnidirectional antenna vertical reference radiation pattern for EMC analyses in frequency assignment is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \quad \text{dBi} \qquad (7\text{-}8)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

(b) Directional Antenna

The ARNS directional antenna reference radiation patterns for EMC analyses in frequency assignment are provided in Table 7-27.

Table 7-27. ARNS Directional Antenna Reference Radiation Patterns for Frequency Assignment

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from:

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}$(dBi) < 48	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}$(dBi) < 22	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3\,G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

7.8.3.3 Spectrum Sharing Analyses

The representative ARNS antenna radiation patterns for spectrum sharing analyses are provided in Table 7-28.

Table 7-28. Representative ARNS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Antenna Function	Antenna Type & G_{max} (dBi)	Gain Function (dBi)	Angular Range
190–285, 325–405, 405–415, 415–435 kHz	Transmit & receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \leq 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
510–535, 1715–1725, 174–175 kHz	Transmit	Omni., 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \leq 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
	Receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \leq 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
74.8–75.2 MHz	Transmit	Omni., 7	$7 - 12(\theta/21.5)^2$	$\lvert\theta\rvert \leq 19.8°$
			$-5 + 10\times\log\{[\max(\lvert\theta\rvert/21.5, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 19.8°$
		Dir., 7	$7 - 12(\phi/\phi_{bw})^2$	$0 \leq \phi < \phi_{bw}$
			-5	$\phi_{bw} \leq \phi \leq 180°$
	Receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \leq 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
108–117.975 MHz	Transmit	Omni., 5	$5 - 12(\theta/34)^2$	$\lvert\theta\rvert \leq 31.4°$
			$-7 + 10\times\log\{[\max(\lvert\theta\rvert/34, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 31.4°$
		Dir., 28	$28 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.08\times\phi_{bw}$
			14	$1.08\times\phi_{bw} < \phi \leq 10°$
			$39 - 25 \times \log(\phi)$	$10° < \phi \leq 48°$
			-3	$48° < \phi \leq 180°$
	Receive	Omni., 0	$-12(\theta/107.6)^2$	$\lvert\theta\rvert \leq 99.4°$
			$-12 + 10\times\log\{[\max(\lvert\theta\rvert/107.6, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 99.4°$
		Dir., 25	$25 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 1.05\times\phi_{bw}$
			11.75	$1.05\times\phi_{bw} < \phi \leq 14.1°$
			$40.5 - 25 \times \log(\phi)$	$14.1° < \phi \leq 48°$
			-1.5	$48° < \phi \leq 180°$
328.6–335.4 MHz	Transmit	Omni., 10	$10 - 12(\theta/10.8)^2$	$\lvert\theta\rvert \leq 9.9°$
			$-2 + 10\times\log\{[\max(\lvert\theta\rvert/10.8, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 9.9°$
		Dir., 16	$16 - 12 \times (\phi/\phi_{bw})^2$	$0 \leq \phi \leq 0.96\times\phi_{bw}$
			5	$0.96\times\phi_{bw} < \phi \leq 39.6°$
			$45 - 25 \times \log(\phi)$	$39.6° < \phi \leq 63.1°$
			0	$63.1° < \phi \leq 180°$
	Receive	Omni., 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \leq 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5}\}$	$\lvert\theta\rvert > 62.7°$
960–1215	Transmit	Omni.,	$4 - 12(\theta/42.8)^2$	$\lvert\theta\rvert \leq 39.6°$

MHz		4	$-8 + 10\times\log\{[\max(\lvert\theta\rvert/42.8,\ 1)]^{-1.5}\}$	$\lvert\theta\rvert > 39.6°$
		Dir., 15	$15 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.95\times\phi_{bw}$
			4.25	$0.95\times\phi_{bw} < \phi \le 44.5°$
			$45.5 - 25 \times \log(\phi)$	$44.5° < \phi \le 66.1°$
			0	$66.1° < \phi \le 180°$
	Receive	Omni., 3	$3 - 12(\theta/53.9)^2$	$\lvert\theta\rvert \le 49.8°$
			$-9 + 10\times\log\{[\max(\lvert\theta\rvert/53.9,\ 1)]^{-1.5}\}$	$\lvert\theta\rvert > 49.8°$
		Dir., 22	$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
			9.5	$1.02\times\phi_{bw} < \phi \le 19.9°$
			$42 - 25 \times \log(\phi)$	$19.9° < \phi \le 48°$
			0	$48° < \phi \le 180°$
1.24–1.37, 2.7–2.9 GHz	Transmit & receive	Dir., 34	$34 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.14\times\phi_{bw}$
			18.5	$1.14\times\phi_{bw} < \phi \le 5°$
			$36 - 25 \times \log(\phi)$	$5° < \phi \le 48°$
			-6	$48° < \phi \le 180°$
4.2–4.4 GHz	Transmit & receive	Dir., 10	$10 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.89\times\phi_{bw}$
			0.5	$0.89\times\phi_{bw} < \phi \le 79.1°$
			$48 - 25 \times \log(\phi)$	$79.1° < \phi \le 83.2°$
			0	$83.2° < \phi \le 180°$
5–5.25 GHz	Transmit & receive	Dir., 22	$22 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.02\times\phi_{bw}$
			9.5	$1.02\times\phi_{bw} < \phi \le 19.86°$
			$42 - 25 \times \log(\phi)$	$19.86° < \phi \le 48°$
			0	$48° < \phi \le 180°$
9–9.2 GHz	Transmit	Dir., 40	$40 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.19\times\phi_{bw}$
			23	$1.19\times\phi_{bw} < \phi \le 2.5°$
			$33 - 25 \times \log(\phi)$	$2.5° < \phi \le 48°$
			-9	$48° < \phi \le 180°$
	Receive	Dir., 38	$38 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.17\times\phi_{bw}$
			21.5	$1.17\times\phi_{bw} < \phi \le 3.1°$
			$34 - 25 \times \log(\phi)$	$3.1° < \phi \le 48°$
			-8	$48° < \phi \le 180°$
9.3–9.5 GHz	Transmit	Dir., 32	$32 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.12\times\phi_{bw}$
			17	$1.12\times\phi_{bw} < \phi \le 6.3°$
			$37 - 25 \times \log(\phi)$	$6.3° < \phi \le 48°$
			-5	$48° < \phi \le 180°$
	Receive	Dir., 33	$33 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.13\times\phi_{bw}$
			17.75	$1.13\times\phi_{bw} < \phi \le 5.6°$
			$36.5 - 25 \times \log(\phi)$	$5.6° < \phi \le 48°$
			-5.5	$48° < \phi \le 180°$
13.25–13.4 GHz	Transmit & receive	Dir., 26	$26 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.06\times\phi_{bw}$
			12.5	$1.06\times\phi_{bw} < \phi \le 12.5°$
			$40 - 25 \times \log(\phi)$	$12.5° < \phi \le 48°$
			-2	$48° < \phi \le 180°$
15.4–15.7 GHz	Transmit	Dir., 31	$31 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.11\times\phi_{bw}$
			16.25	$1.11\times\phi_{bw} < \phi \le 7°$

			$37.5 - 25 \times \log(\phi)$	$7° < \phi \leq 48°$
			-4.5	$48° < \phi \leq 180°$
	Receive	Dir., 8	$8 - 12(\phi/\phi_{bw})^2$	$0 \leq \phi < 1.04 \times \phi_{bw}$
			-5	$1.04 \times \phi_{bw} \leq \phi \leq 180°$
Omni.: Omnidirectional antenna. θ: for omnidirectional antenna, elevation angle off the peak gain plane, in deg.				
Dir.: Directional antenna. All directional antennas have elliptical beam. ϕ: for directional antenna, angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg.				

7.9 Radiodetermination-Satellite Service (RDSS)

7.9.1 Radiolocation-Satellite Service (RLSS)

7.9.1.1 System Review

The distress beacon equipments use monopole antennas for distress signal transmission. The beacon antenna radiation performance standard within the elevation angle $5° < \theta < 60°$ is

- pattern: hemispherical,
- polarization: RHCP or linear,
- gain: $-3 < G(dBi) < 4$, over 90% of the angular range, and
  gain variation in azimuth: < 3 dB.

7.9.1.2 Frequency Assignment

The actual beacon antenna radiation data should always be used in EMC analyses for frequency assignment. The radiation data should be available from either the system operators or the antenna manufacturers. When the actual radiation data are not available, the radiation pattern in Section 7.9.1.1 may be used.

7.9.1.3 Spectrum Sharing Analyses

The GMF does not have any RLSS service records. When it is necessary to conduct spectrum sharing analyses, the beacon antenna radiation pattern in Section 7.9.1.1 may be used as the representative radiation pattern.

7.9.2 Radionavigation-Satellite Service (RNSS)

7.9.2.1 System Review

There are three types of RNSS GPS receivers:

- Type 1 receiver: meeting the requirements of the satellite-based augmentation system.
- Type 2 receiver: meeting the requirements of the land-based augmentation system.
- Type 3 receiver: used in the satellite-based augmentation system to determine the ionospheric delay.

(a) Land-Based RNSS and Maritime RNSS (MRNSS)

The land-based RNSS receivers and shipborne MRNSS receivers are either type 1 or type 3 receivers. The GPS antenna radiation performance standard is

- Maximum antenna gain in upper hemisphere: 7 dBic.
- Minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.

(b) Aeronautical RNSS (ARNSS)

The ARNSS airborne system meeting the requirements of the satellite-based augmentation system and providing category I precision approach operation is the type 1 receiver. The airborne antenna radiation performance standard is provided in Table 7-29.

Table 7-29. ARNSS Airborne Antenna Radiation Performance Standard

Min. Gain (dBic)	Max. Gain (dBic)	Elevation Angle θ
-2	7	$\theta > 15^o$
-3	7	$10^o < \theta \leq 15^o$
-4.5	7	$5^o < \theta \leq 10^o$
-7.5	-2	$0 < \theta \leq 5^o$
dBic means it is circular polarization, which is required for the GNSS.		

The ARNSS airborne system meeting the requirements of the land-based augmentation system and providing category II/III precision approach operation is the type 2 receiver. The airborne antenna radiation performance standard is

- Maximum antenna gain in upper hemisphere: 7 dBic.
- Minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.
- Minimum antenna gain towards pseudolite: -21 dBic.

The ARNSS land-based system used in the satellite-based augmentation system to determine the ionospheric delay is the type 3 receiver. The land-based earth station antenna radiation performance standard is

- Maximum antenna gain: 7 dBic.
- Minimum antenna gain towards satellite at 5° elevation: -4.5 dBic.

7.9.2.2 Frequency Assignment

The actual antenna radiation data should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer.

When the actual radiation data are not available, a reference radiation pattern should be used. The radiation performance standards in Section 7.9.2.1 can be used to develop the reference radiation pattern for EMC analyses in frequency assignment; this reference radiation pattern is provided in Table 7-30. This radiation pattern does not specify the G value, and such data may be available in the GMF. Should the G data not available in the GMF, the value G = 0 dBic may be used.

Table 7-30. RNSS Earth Station Antenna Reference Radiation Pattern for Frequency Assignment

Gain (dBic)	Elevation Angle θ
G	$\theta > 15^{o}$
G - 1	$10^{o} < \theta \leq 15^{o}$
G - 2.5	$5^{o} < \theta \leq 10^{o}$
-4.5	$0^{o} < \theta \leq 5^{o}$
-10	lower hemisphere *
G is not the peak gain value G_{max}, it is the lowest gain value within the conical range of $\theta > 15^{o}$. $-2 < G(dBic) \leq 7$. *: Gain = -10 dBic in lower hemisphere applies to ARNSS.	

7.9.2.3 Spectrum Sharing Analyses

The representative RNSS antenna radiation patterns for conducting spectrum sharing analyses are provided in Table 7-31.

Table 7-31. Representative RNSS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Radio Service, Operating Area	G (dBic) or G_{max} (dBi)	Gain Function (dBic or dBi)	Angular Range
149.9−150.05 MHz	MRNSS, coastal-water	5 dBic	5	$\theta > 15^{o}$
			4	$10^{o} < \theta \leq 15^{o}$
			2.5	$5^{o} < \theta \leq 10^{o}$
			-4.5	$0^{o} < \theta \leq 5^{o}$
	MRNSS, USP	12 dBic *	12	$\theta > 15^{o}$
			-1	$10^{o} < \theta \leq 15^{o}$
			-2.5	$5^{o} < \theta \leq 10^{o}$
			-4.5	$0^{o} < \theta \leq 5^{o}$
1.164−1.24 GHz	ARNSS, coastal-water	0 dBic	0	$\theta > 15^{o}$
			-1	$10^{o} < \theta \leq 15^{o}$
			-2.5	$5^{o} < \theta \leq 10^{o}$
			-4.5	$0^{o} < \theta \leq 5^{o}$
			-10	lower hemisphere
	ARNSS, USP	47 dBi	$47 - 2.5 \times 10^{-3} (92\times\phi)^{2}$	$0° \leq \phi < 0.93°$
			28.7	$0.93° \leq \phi < 1.03°$
			$29 - 25 \times \log(\phi)$	$1.03° \leq \phi < 36°$
			-10	$36° \leq \phi \leq 180°$
1.559−1.61	ARNSS,	47 dBi	$47 - 2.5 \times 10^{-3} (92.27\times\phi)^{2}$	$0° \leq \phi < 0.93°$

GHz	USP		28.7	$0.93° \leq \phi < 1.03°$
			$29 - 25 \times \log(\phi)$	$1.03° \leq \phi < 36°$
			-10	$36° \leq \phi \leq 180°$

G (dBic): for GPS receiver
θ: elevation angle
*: G value exceeds range specified in Table 7-30. To develop the representative radiation pattern, G value for $\theta > 15°$ is 12 dBic, and G value for $\theta \leq 15°$ is 0 dBic.

G_{max} (dBi): for land-based earth station antenna.
ϕ: angle off mainbeam axis, deg.
Antenna radiation pattern from Table 7-19 of AMSS NGSO system earth station antenna radiation pattern.

7.10 Radio Astronomy (RAS)

7.10.1 System Review

NTIA does not provide the antenna radiation performance standards for the RAS antennas. Due to the unique feature of this service, every RAS antenna is designed with its unique specifications, thus a general antenna radiation performance standard is not needed.

7.10.2 Frequency Assignment

The actual antenna radiation pattern should always be used in EMC analyses for frequency assignment, and it is usually available from the manufacturer. When the actual radiation pattern is not available, the reference radiation patterns from Recs. ITU-R SA.509-2 and RA.1631 can be used as the reference radiation patterns; these patterns are shown in Table 7-32. The radiation pattern in Table 7-32 does not specify the G_{max} value, and such data should be available from the system operators.

Table 7-32. RAS Antenna Reference Radiation Patterns for Frequency Assignment

(a) Coordination Studies with Terrestrial Radio Systems

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
G_1	$\phi_m \leq \phi < \phi_r$
$32 - 25 \times \log(\phi)$	$\phi_r \leq \phi < 47.9°$
-10	$47.9° \leq \phi \leq 180°$

This pattern applies to $D/\lambda > 100$.
ϕ: angle off mainbeam axis, deg.
$G_1 = 2 + 15\times\log(D/\lambda)$, dBi
$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.
$\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.

(b) Coordination Studies with Space Radio Systems

Gain Function (dBi)	Angular Range
$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
G_1	$\phi_m \leq \phi < \phi_r$
$29 - 25 \times \log(\phi)$	$\phi_r \leq \phi < 10°$
$34 - 30 \times \log(\phi)$	$10° \leq \phi < 34.1°$
-12	$34.1° \leq \phi < 80°$
-7	$80° \leq \phi < 120°$
-12	$120° \leq \phi \leq 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = -1 + 15\times \log(D/\lambda)$, dBi $\phi_m = (20\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.	

7.10.3 Spectrum Sharing Analyses

Because of the special features of the RAS operations, the National Radio Quiet Zone is established around RAS facilities for the protection of RAS observations. Other radio services intending to share frequencies with RAS in the Radio Quiet Zone must consult the Rules and Regulations from NTIA Manual §8.3.9 and FCC 47 CFR §1.924.

When the radiation patterns are needed for spectrum sharing analyses, the reference radiation patterns in Table 7-32 can be used. The radiation pattern in Table 7-32 does not specify the G_{max} value, and such data should be available from the system operators.

7.11 Remote Sensing Service (RSS)

7.11.1 Meteorological Aids Service (MetAids)

The MetAids service uses the MetAids mobile system, meteorological radar, precipitation gauge, and radiosonde system.

7.11.1.1 System Review

(a) Meteorological Radar

NTIA does not provide the meteorological radar antenna performance standards. The meteorological radar antenna should have similar performance as the RLS antenna, therefore the RLS antenna performance standards in Section 7.8.1.2 are recommended here. The standards are provided in Table 7-33.

Table 7-33. Meteorological Radar Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$

Elliptical beam.
G_{max} usually given, or can be calculated from

- $G_{max} = 10 \times \log\{e \times [41253/(\phi_{bw1} \times \phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.

ϕ: angle off mainbeam axis in the direction of interest, deg.
ϕ_{bw}: HPBW in the direction of interest, deg.
x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5.

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}(\text{dBi}) < 48$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}(\text{dBi}) < 22$	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10 \times \log\{e \times [41253/(\phi_{bw1} \times \phi_{bw2})]\}$, dBi
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3 G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

(b) Wind Profile Radar

NTIA provides a wind profile radar antenna radiation sidelobe suppression standard, this is provided in Table 7-34.

Table 7-34. WPR Antenna Radiation Sidelobe Suppression Standard

Elevation Angle θ	Antenna Sidelobe Suppression (dB)
$\theta > 70°$	-
$60° < \theta \leq 70°$	15
$45° < \theta \leq 60°$	20
$5° < \theta \leq 45°$	25
$\theta \leq 5°$	40

(c) Radiosonde

The radiosonde airborne transmitting units use omnidirectional antennas, and the land-based receiving units use either omnidirectional or directional antennas. NTIA does not provide the radiosonde antenna radiation performance standards, nor does ITU-R provide radiosonde antenna reference radiation patterns.

For the radiosonde antenna, the RLS antenna radiation performance standard in Section 7.8.1.2 may be adopted as the radiosonde antenna radiation performance standard. The airborne omnidirectional transmitting antenna and the land-based omnidirectional receiving antenna vertical radiation performance standard is

$$G(\theta) = \max(G_a(\theta), G_b(\theta)) \qquad \text{dBi} \qquad (7\text{-}9)$$

where

$G_a(\theta) = G_{max} - 12(\theta/\theta_{bw})^2$, dBi

$G_b(\theta) = G_{max} - 12 + 10 \times \log\{ [\max(|\theta|/\theta_{bw}, 1)]^{-1.5} + 0.5 \}$, dBi

θ: elevation angle off the peak gain plane, deg.

θ_{bw}: HPBW in the vertical plane,

$\theta_{bw} = 107.6 \times 10^{-0.1\,G_{max}}$, deg.

The land-based directional receiving antenna radiation performance standards are provided in Table 7-35.

Table 7-35. Radiosonde Land-Based Directional Receiving Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12(\phi/\phi_{bw})^2$	$0 < \phi/\phi_{bw} < x$
-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$
Elliptical beam. G_{max} usually given, or can be calculated from • $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi, • ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes, deg.	

ϕ: angle off mainbeam axis in the direction of interest, deg. ϕ_{bw}: HPBW in the direction of interest, deg. x: intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and -5.

(b) High-Gain Antenna

Category	Gain(ϕ) (dBi)	Angular Range (deg.)
$G_{max} \geq 48$ dBi	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} < \phi \leq \phi_{b1}$
	-13	$\phi_{b1} < \phi \leq 180°$
$22 \leq G_{max}$(dBi) < 48	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r2}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r2} < \phi \leq \phi_{b2}$
	$11 - G_{max}/2$	$\phi_{b2} < \phi \leq 180°$
$10 \leq G_{max}$(dBi) < 22	$G_{max} - 12(\phi/\phi_{bw})^2$	$0 \leq \phi \leq \phi_m$
	$0.75 \times G_{max} - 7$	$\phi_m < \phi \leq \phi_{r3}$
	$53 - (G_{max}/2) - 25 \times \log(\phi)$	$\phi_{r3} < \phi \leq \phi_{b3}$
	0	$\phi_{b3} < \phi \leq 180°$

Elliptical beam.
All angles in deg.
G_{max} usually given, or can be calculated from

- $G_{max} = 10\times\log\{e\times[41253/(\phi_{bw1}\times\phi_{bw2})]\}$, dBi,
- ϕ_{bw1}, ϕ_{bw2}: HPBW of major and minor axes

ϕ: angle off mainbeam axis in the direction of interest
ϕ_{bw}: HPBW in the direction of interest
ϕ_m : intersection of $\{G_{max} - 12(\phi/\phi_{bw})^2\}$ and $(0.75 \times G_{max} - 7)$

$$\phi_{r1} = 27.466 \times 10^{-0.3G_{max}/10}$$

$$\phi_{r2} = \phi_{r3} = 250/\left(10^{G_{max}/20}\right)$$

$$\phi_{b1} = \phi_{b2} = 48°$$

$$\phi_{b3} = 131.8257 \times 10^{-G_{max}/50}$$

(d) Precipitation Gauge

NTIA does not provide the precipitation gauge antenna radiation performance standards, nor does ITU-R provide precipitation gauge antenna reference radiation patterns. Lacking proper information, this standard will not be developed here.

7.11.1.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers. When the actual radiation pattern is not available, the radiation performance standard in Section 7.11.1.1 may be used as the reference radiation patterns. The radiation patterns in Section 7.11.1.1 do not specify the G_{max} value, and such data should be available in the GMF.

For the radiosonde airborne antenna, because it is operated while being airborne, the G_{max} value should be used instead of the radiation pattern of Eq. (7-9) for the worst case scenario.

7.11.1.3 Spectrum Sharing Analyses

The representative MetAids antenna radiation patterns for conducting spectrum sharing analyses are provided in Table 7-36.

Table 7-36. Representative MetAids Antenna Reference Radiation Pattern for Spectrum Sharing Analyses

Frequency Band	System, Station Type	Antenna Type, Function, G_{max} (dBi)	Gain Function	Angular Range
400.15−406 MHz	Radiosonde, airborne *	Omni-, transmit, 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 62.7°$
	Radiosonde, land station	Omni-, receive, 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 62.7°$
		Directional, receive, 15	$15 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 0.95\times\phi_{bw}$
			4.25	$0.95\times\phi_{bw} < \phi \le 44.5°$
			$45.5 - 25 \times \log(\phi)$	$44.5° < \phi \le 66.1°$
			0	$66.1° < \phi \le 180°$
	Precipitation gauge	Receive, 1	none	
1.675−1.7 GHz	Radiosonde, airborne *	Omni-, transmit, 2	$2 - 12(\theta/67.9)^2$	$\lvert\theta\rvert \le 62.7°$
			$-10 + 10\times\log\{[\max(\lvert\theta\rvert/67.9, 1)]^{-1.5} + 0.5\}$	$\lvert\theta\rvert > 62.7°$
	Radiosonde, land station	Directional, receive, 30	$30 - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le 1.1\times\phi_{bw}$
			15.5	$1.1\times\phi_{bw} < \phi \le 7.9°$
			$38 - 25 \times \log(\phi)$	$7.9° < \phi \le 48°$
			-4	$48° < \phi \le 180°$
2.7−2.9 GHz	Meteoro-logical radar	Directional, transmit & receive, 46	$46 - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le 1.24\times\phi_{bw}$
			27.4	$1.24\times\phi_{bw} < \phi \le 1.25°$
			$30 - 25 \times \log(\phi)$	$1.25° < \phi \le 48°$
			-12	$48° < \phi \le 180°$
5.6−5.65 GHz	Meteoro-logical radar	Directional, transmit & receive, 50	$50 - 12(\phi/\phi_{bw})^2$	$0 \le \phi \le 1.27\times\phi_{bw}$
			30.5	$1.27\times\phi_{bw} < \phi \le 0.87°$
			$29 - 25 \times \log(\phi)$	$0.87° < \phi \le 48°$
			-13	$48° < \phi \le 180°$

θ: elevation angle, for omnidirectional antennas *: The representative antenna radiation pattern of the radiosonde airborne antenna must be used with caution because it is operated while being airborne. The spectrum sharing analyses should either use the representative G_{max} values for the worst case scenario, or build statistical models that take into account the radiosonde flight heights and antenna orientations.
ϕ: angle off mainbeam axis, deg., for directional antennas Directional antennas have elliptical beams. ϕ_{bw}: HPBW in the direction of interest

7.11.2 Meteorological Satellite Service (MetSat)

7.11.2.1 System Review

NTIA does not provide the MetSat earth station antenna radiation performance standards, nor does ITU-R provide recommendations for the MetSat earth station antenna reference radiation patterns.

For omnidirectional, low- and medium-gain antennas, the LMSS earth station antenna radiation performance standards in Section 7.7.1.1 are recommended for the MetSat earth station antennas. They are provided in Table 7-37 and Table 7-38.

(a) Omnidirectional Antenna

Table 7-37. MetSat Earth Station Omnidirectional, Low- and Medium-Gain Antenna Vertical Radiation Performance Standards

(a) Omnidirectional Antenna

Gain Function (dBi)	Angular Range
≤ 5	-20° ≤ θ ≤ 20°
≤ 0	θ < -20° & θ > 20°
θ: elevation angle, deg.	

(b) Vertical Array Antenna with Toroidal Beams and 7 ≤ G_{max}(dBi) ≤ 13

Gain Function (dBi)	Angular Range
G_{max} - 10	45° ≤ (θ - θ_o)
$G_{max} - 0.3 \times [(\theta - \theta_o)/10]^{2.3}$	20° ≤ (θ - θ_o) ≤ 45°
$G_{max} - 12 \times [(\theta - \theta_o)/\theta_{bw})]^2$	20° < | θ - θ_o |
$G_{max} - 0.3 \times [(\theta_o - \theta)/10]^{2.3}$	20° ≤ (θ_o - θ) ≤ 50°
G_{max} - 13	50° ≤ (θ_o - θ)
θ: elevation angle, deg. θ_o: mainbeam elevation angle, deg. θ_{bw}: HPBW, deg.	

(b) Low- and Medium-Gain Antenna

Table 7-38. MetSat Earth Station Low- and Medium-Gain Antenna Radiation Performance Standards

(a) Vehicle-Mounted Tracking Antenna with Fan-Beams and Operating in Low Elevation Angle

Gain Function (dBi)	Angular Range
≤ 4	$0° \leq \theta \leq 60°$, $[30°+k(\theta)] \leq \lvert\varphi-\varphi_0\rvert \leq 180°$
(θ, φ): elevation and azimuth angles, deg. (θ_o, φ_o): mainbeam elevation and azimuth angles, deg. $k(\theta) = 0.33°$ for $G_{max} = 11-15$, dBi $k(\theta)$ is TBD for $G_{max} = 9-11$, dBi	

(b) Transportable or Vehicle-Mounted Antenna with Circular Beams and $G_{max} \leq 18$ dBi

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg. x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.	

(c) High-Gain Antenna

For high-gain antennas, the FSS earth station antenna radiation performance standards in Section 7.3.1 are recommended for the MetSat earth station high-gain antenna. These are provided in Table 7-39.

Table 7-39. MetSat Earth Station High-Gain Antenna Radiation Performance Standards

(a) GSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$

	$32 - 25 \times \log(\phi)$	$9.2° \le \phi < 48°$
	-10	$48° \le \phi \le 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$

An actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \le \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(b) NGSO Systems

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 100$, ($G_{max} \ge 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \le \phi < \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$
$20 < D/\lambda < 100$, ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \le \phi < \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$
$D/\lambda < 20$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{rc}$
	$29 - 25 \times \log(\phi)$	$\phi_{rc} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

Pattern for $D/\lambda < 20$ is added to extend the high-gain pattern to $G_{max} = 22$ dBi.

ϕ_{rc} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$, deg.

7.11.2.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 7.11.2.1 may be used as the reference radiation patterns. The radiation patterns in Section 7.11.2.1 do not specify the G_{max} value, and such data should be available in the GMF.

7.11.2.3 Spectrum Sharing Analyses

The representative MetSat antenna radiation patterns for conducting spectrum sharing analyses are provided in Table 7-40.

Table 7-40. Representative MetSat Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band, Link Direction	Antenna Type, G_{max} (dBi)	Gain Function (dBi)	Angular Range
137−138 MHz, Downlink	Omni-, 0	≤ 0	$-20° \leq \theta$
		≤ 0	$\theta < -20°$
	Directional, 27	$27 - 2.5 \times 10^{-3} (8.84\times\phi)^2$	$0° \leq \phi < x°$
		$29 - 25 \times \log(\phi)$	$x° \leq \phi < 36°$
		-10	$36° \leq \phi \leq 180°$
401−403 MHz, Uplink	Omni-, 3	≤ 3	$-20° \leq \theta$
		≤ 0	$\theta < -20°$
	Directional, 11	$11 - 12 \times (\phi/46.2)^2$	$0° \leq \phi \leq 35.2°$
		4	$35.2° < \phi \leq 40°$
		$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
		-5	$90° < \phi$
460−470 MHz, Downlink	Omni-, 0	≤ 0	$-20° \leq \theta$
		≤ 0	$\theta < -20°$
	Directional, 6 *	$6 - 12(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} < x$
		-5	$x \leq \phi/\phi_{bw} \leq 180/\phi_{bw}$
1.675−1.71 GHz, Downlink	Omni-, 3	≤ 3	$-20° \leq \theta$
		≤ 0	$\theta < -20°$
	Directional, 48	$48 - 2.5 \times 10^{-3}(99.17\times\phi)^2$	$0° \leq \phi \leq 0.9°$
		28.9	$0.9° < \phi \leq 1°$
		$29 - 25 \times \log(\phi)$	$1° < \phi \leq 7°$
		8	$7° < \phi \leq 9.2°$
		$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
		-10	$48° < \phi \leq 180°$

θ: elevation angle, for omnidirectional antennas

ϕ: angle off mainbeam axis, deg., for directional antennas *: G_{max} value below the minimum specification of Table 7-38. FS low-gain antenna radiation pattern in Table 7-2 is used here. ϕ_{bw}: HPBW in the direction of interest

7.11.3 Earth Exploration-Satellite Service (EESS)

7.11.3.1 System Review

NTIA does not provide the EESS earth station antenna radiation performance standards, nor does ITU-R have recommendations for the EESS earth station antenna reference radiation patterns.

The EESS and MetSat systems perform a similar task of using satellites to collect information about the Earth's surface. Therefore, the EESS and MetSat systems earth station antennas should have similar radiation performance, and the MetSat earth station antenna radiation performance standards in Section 7.11.2.1 are recommended for the EESS earth station radiation performance standard. These standards are provided in Table 7-41.

Table 7-41. EESS Earth Station Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
Circular Beam, $12 \leq G_{max}(dBi) \leq 18$ ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg. x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.	

(b) GSO System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$

	-10	$48° \le \phi \le 180°$

$D/\lambda = 68$ is the threshold when the G_1 plateau disappears.

ϕ: angle off mainbeam axis, deg.

$G_1 = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg.

$\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg.

ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$

An actual radiation pattern shall meet the following conditions:

- It may not exceed the gain function in the range $\phi_r \le \phi < 7°$.
- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(c) NGSO System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 100$, ($G_{max} \ge 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \le \phi < \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$
$20 < D/\lambda < 100$, ($34.1 < G_{max}$(dBi) < 48.1 for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \le \phi < \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$
$D/\lambda < 20$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \le \phi < \phi_{rc}$
	$29 - 25 \times \log(\phi)$	$\phi_{rc} \le \phi < 36°$
	-10	$36° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

Pattern for $D/\lambda < 20$ is added to extend the high-gain pattern to $G_{max} = 22$ dBi.

ϕ_{rc} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$, deg.

7.11.3.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers. When the actual radiation patterns are not available, the radiation performance standard in Section 7.11.3.1 may be used. The radiation patterns in Section 7.11.3.1 do not specify the G_{max} value, and such data should be available in the GMF.

7.11.3.3 Spectrum Sharing Analyses

The representative EESS earth station antenna radiation patterns for conducting spectrum sharing analyses are provided in Table 7-42.

Table 7-42. Representative EESS Earth Station Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Space System, Link Direction	G_{max} (dBi)	Gain Function (dBi)	Angular Range
401−403 MHz	GSO system, uplink	13	$13 - 12 \times (\phi/36.7)^2$	$0° \le \phi \le 31.7°$
			4	$31.7° < \phi \le 40°$
			$44 - 25 \times \log(\phi)$	$40° < \phi \le 90°$
			-5	$90° < \phi$
	NGSO system, uplink	6 *	$6 - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
			-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
2.025−2.11 GHz	GSO system, uplink	50	$50 - 2.5 \times 10^{-3} (124.9\times\phi)^2$	$0° \le \phi \le 0.7°$
			30.4	$0.7° < \phi \le 0.9°$
			$29 - 25 \times \log(\phi)$	$0.9° < \phi \le 36°$
			-10	$36° < \phi \le 180°$
	GSO system, downlink	26	$26 - 2.5 \times 10^{-3}(7.88\times\phi)^2$	$0° \le \phi \le x°$
			$29 - 25 \times \log(\phi)$	$x° < \phi \le 7°$
			8	$7° < \phi \le 9.2°$
			$32 - 25 \times \log(\phi)$	$9.2° < \phi \le 48°$
			-10	$48° < \phi \le 180°$
	NGSO system, uplink	6 *	$6 - 12(\phi/\phi_{bw})^2$	$0 \le \phi/\phi_{bw} < x$
			-5	$x \le \phi/\phi_{bw} \le 180/\phi_{bw}$
		46	$46 - 2.5 \times 10^{-3} (78.78\times\phi)^2$	$0° \le \phi \le 1.05°$
			27.4	$1.05° < \phi \le 1.16°$
			$29 - 25 \times \log(\phi)$	$1.16° < \phi \le 36°$
			-10	$36° < \phi \le 180°$
2.2−2.29 GHz	NGSO system, downlink	46	$46 - 2.5 \times 10^{-3} (78.78\times\phi)^2$	$0° \le \phi \le 1.05°$
			27.4	$1.05° < \phi \le 1.16°$
			$29 - 25 \times \log(\phi)$	$1.16° < \phi \le 36°$
			-10	$36° < \phi \le 180°$

8.025−8.4 GHz	NGSO System, downlink	46	$46 - 2.5 \times 10^{-3} (82.2\times\phi)^2$	$0° \le \phi \le 1.05°$
			27.4	$1.05° < \phi \le 1.16°$
			$29 - 25 \times \log(\phi)$	$1.16° < \phi \le 36°$
			-10	$36° < \phi \le 180°$
25.5−27 GHz	NGSO System, downlink	58	$58 - 2.5 \times 10^{-3} (313.6\times\phi)^2$	$0° \le \phi \le 0.3°$
			36.4	$0.3° < \phi \le 0.5°$
			$29 - 25 \times \log(\phi)$	$0.5° < \phi \le 36°$
			-10	$36° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. *: G_{max} value below the minimum specification of Table 7-38. FS low-gain antenna elliptical beam radiation pattern in Table 7-2 is used here. ϕ_{bw}: HPBW in the direction of interest				

7.11.4 Space Research Service (SRS)

7.11.4.1 System Review

NTIA does not provide the SRS earth station antenna radiation performance standards for system review. ITU-R provides three recommendations for the SRS earth station large-aperture antenna reference radiation patterns for coordination studies and interference assessments, and these radiation patterns are recommended for the SRS earth station antenna radiation performance standards. These standards are provided in Table 7-43. Here standard (a) is an extension of the original recommendation by adding the mainbeam pattern and by adding a new pattern for $D/\lambda < 100$.

Table 7-43. SRS Earth Station Large-Aperture Antenna Radiation Standards

(a) Below 30 GHz

Category	Gain Function (dBi)	Angular Range
$D/\lambda \ge 100$ ($G_{max} \ge 48$ dBi)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < \phi_r$
	$32 - 25 \times \log(\phi)$	$\phi_r \le \phi < 47.9°$
	-10	$47.9° \le \phi \le 180°$
$D/\lambda < 100$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \le \phi < \phi_m$
	G_1	$\phi_m \le \phi < (100\lambda/D)°$
	$52 - 10 \times \log(D/\lambda) - 25 \times \log(\phi)$	$(100\lambda/D)° \le \phi < 47.9°$
	$10 - 10 \times \log(D/\lambda)$	$47.9° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg. $G_1 = 2 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_r = 15.85(D/\lambda)^{-0.6}$, deg.		
This is the FSS earth station antenna reference radiation pattern in RR Appendix 8 except that the second plateau starts at 47.9° instead of 48°.		

(b) Above 30 GHz

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_1$
$G_{max} - G_1$	$\phi_1 < \phi \le \phi_2$
$G_{max} - G_1 - G_2 \times \log(\phi/\phi_2)$	$\phi_2 < \phi \le \phi_3$
G_3	$\phi_3 < \phi \le 80°$
$G_3 + 5$	$80° < \phi \le 120°$
G_3	$120° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg.

ϕ_{bw}: HPBW, $\phi_{bw} = 69\ (\lambda/D)$, deg.

$\phi_1 = \phi_{bw} \times (G_1/12)^{0.5}$

$$\phi_2 = \phi_{bw} \times 10^{(G_1/G_2)} \times \left(\frac{G_2}{144}\right)^{0.5}$$

$$\phi_3 = \phi_2 \times 10^{\left(\frac{G_{max} - G_1 - G_3}{G_2}\right)}$$

$G_{max} = 10 \times \log[e_a\ (\pi D/\lambda)^2] - 4.343(4\pi h/\lambda)^2$, dBi

$G_1 = 17$ dBi

$G_2 = 27 + 10\ [\ \log(e_a) - \log(60h/\lambda)\ ]$, dBi

$G_3 = -10$ dBi

D: aperture diameter

e_a: antenna efficiency excluding contribution from surface tolerance

h: root-mean-square surface tolerance, $\left(\frac{1}{60}\right) \le \left(\frac{h}{\lambda}\right) \le \left(\frac{1}{15}\right)$

7.11.4.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 7.11.4.1 may be used as the reference radiation patterns. In addition, ITU-R has an antenna reference radiation pattern for the coordination studies and interference assessment for a large number of distributed interfering sources above 30 GHz; this pattern is provided in Table 7-44. These radiation patterns do not specify the G_{max} value, and such data should be available in the GMF.

Table 7-44. SRS Earth Station Large-Aperture Antenna Reference Radiation Pattern against Large Number of Distributed Interfering Sources above 30 GHz

Gain Function (dBi)	Angular Range
G_{max} - 12 × $(\phi/\phi_{bw})^2$	$0 \le \phi \le \phi_4$
G_{max} - G_4	$\phi_4 < \phi \le \phi_5$
G_{max} - G_4 - G_5 × log((ϕ/ϕ_5)	$\phi_5 < \phi \le \phi_6$
G_6	$\phi_6 < \phi \le 80°$
$G_6 + 5$	$80° < \phi \le 120°$
G_6	$120° < \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
ϕ_{bw}: HPBW, $\phi_{bw} = 69\ (\lambda/D)$, deg.
$\phi_4 = \phi_{bw} \times (G_4/12)^{0.5}$

$$\phi_5 = \phi_{bw} \times 10^{[(G_4-3)/G_5]} \times \left(\frac{G_5}{144}\right)^{0.5}$$

$$\phi_6 = \phi_5 \times 10^{\left(\frac{G_{max}-G_4-G_6}{G_5}\right)}$$

$G_{max} = 10 \times \log[e_a\ (\pi D/\lambda)^2] - 4.343(4\pi h/\lambda)^2$, dBi
$G_4 = 20$ dBi
$G_5 = 27 + 10\ [\ \log(e_a) - \log(60h/\lambda)\ ]$, dBi
$G_6 = -13$ dBi
D: aperture diameter,
e_a: antenna efficiency excluding contribution from surface tolerance,
h: root-mean-square surface tolerance, $\left(\frac{1}{60}\right) \le \left(\frac{h}{\lambda}\right) \le \left(\frac{1}{15}\right)$

7.11.4.3 Spectrum Sharing Analyses

The representative SRS antenna radiation patterns for conducting spectrum sharing analyses are provided in Table 7-45.

Table 7-45. Representative SRS Earth Station Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Space System, Link Direction	G_{max} (dBi)	Gain Function (dBi)	Angular Range
2.025−2.11 GHz	Deep-space and lunar-orbiting systems, uplink	56	$56 - 2.5 \times 10^{-3}\ (249.1\times\phi)^2$	$0° \le \phi \le 0.3°$
			37.9	$0.3° < \phi \le 0.6°$
			$32 - 25 \times \log(\phi)$	$0.6° < \phi \le 47.9°$
			-10	$47.9° < \phi \le 180°$
	GSO system, uplink	45	$45 - 2.5 \times 10^{-3}\ (70.2\times\phi)^2$	$0° \le \phi \le 1.1°$
			29.7	$1.1° < \phi \le 1.4°$

			33.5 - 25 × log(ϕ)	1.4° < ϕ ≤ 47.9°
			-8.5	47.9° < ϕ ≤ 180°
	GSO system, downlink	35	35 - 2.5 × 10^{-3} $(22×ϕ)^2$	0° ≤ ϕ ≤ 3.2°
			22.2	3.2° < ϕ ≤ 4.5°
			38.5 - 25 × log(ϕ)	4.5° < ϕ ≤ 47.9°
			-3.5	47.9° < ϕ ≤ 180°
	NGSO system, uplink	51	51 - 2.5 × 10^{-3} $(140.1×ϕ)^2$	0° ≤ ϕ ≤ 0.6°
			34.2	0.6° < ϕ ≤ 0.8°
			32 - 25 × log(ϕ)	0.8° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
2.2−2.3 GHz	Deep-space system, downlink	57	57 - 2.5 × 10^{-3} $(279.5×ϕ)^2$	0° ≤ ϕ ≤ 0.3°
			38.7	0.3° < ϕ ≤ 0.5°
			32 - 25 × log(ϕ)	0.5° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
	GSO system, uplink	45	45 - 2.5 × 10^{-3} $(70.2×ϕ)^2$	0° ≤ ϕ ≤ 1.1°
			29.7	1.1° < ϕ ≤ 1.4°
			33.5 - 25 × log(ϕ)	1.4° < ϕ ≤ 47.9°
			-8.5	47.9°< ϕ ≤ 180°
	NGSO system, Downlink	50	50 - 2.5 × 10^{-3} $(124.9×ϕ)^2$	0° ≤ ϕ ≤ 0.7°
			33.4	0.7° < ϕ ≤ 0.9°
			32 - 25 × log(ϕ)	0.9° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
7.145−7.235 GHz	Deep-space and mars-orbiting systems, uplink	72	72 - 2.5 × 10^{-3} $(1572×ϕ)^2$	0° ≤ ϕ ≤ 0.06°
			49.9	0.06° < ϕ ≤ 0.19°
			32 - 25 × log(ϕ)	0.19° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
	NGSO system, uplink	68	68 - 2.5 × 10^{-3} $(222×ϕ)^2$	0° ≤ ϕ ≤ 0.1°
			46.9	0.1° < ϕ ≤ 0.25°
			32 - 25 × log(ϕ)	0.25° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
8.4−8.5 GHz	Deep-space system, downlink	68	68 - 2.5 × 10^{-3} $(992×ϕ)^2$	0° ≤ ϕ ≤ 0.1°
			46.9	0.1° < ϕ ≤ 0.25°
			32 - 25 × log(ϕ)	0.25° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
	NGSO System, downlink	60	60 - 2.5 × 10^{-3} $(394.8×ϕ)^2$	0° ≤ ϕ ≤ 0.22°
			40.9	0.22° < ϕ ≤ 0.44°
			32 - 25 × log(ϕ)	0.44° < ϕ ≤ 47.9°
			-10	47.9° < ϕ ≤ 180°
13.25−13.75 GHz	GSO system, downlink	30	30 - 2.5 × 10^{-3} $(12.5×ϕ)^2$	0° ≤ ϕ ≤ 5.4°
			18.4	5.4° < ϕ ≤ 8°
			41 - 25 × log(ϕ)	8° < ϕ ≤ 47.9°
			-1	47.9° < ϕ ≤ 180°

14.8−15.4 GHz	GSO system, uplink	60	$60 - 2.5 \times 10^{-3} (394.8\times\phi)^2$	$0° \le \phi \le 0.22°$
			40.9	$0.22° < \phi \le 0.44°$
			$32 - 25 \times \log(\phi)$	$0.44° < \phi \le 47.9°$
			-10	$47.9° < \phi \le 180°$
	NGSO system, uplink	62	$62 - 2.5 \times 10^{-3} (497\times\phi)^2$	$0° \le \phi \le 0.18°$
			42.4	$0.18° < \phi \le 0.38°$
			$32 - 25 \times \log(\phi)$	$0.38° < \phi \le 47.9°$
			-10	$47.9° < \phi \le 180°$
25.5−27 GHz	Moon-orbiting system, downlink	70	$70 - 2.5 \times 10^{-3} (1248\times\phi)^2$	$0° \le \phi \le 0.07°$
			48.4	$0.07° < \phi \le 0.22°$
			$32 - 25 \times \log(\phi)$	$0.22° < \phi \le 47.9°$
			-10	$47.9° < \phi \le 180°$
	NGSO system, downlink	71	$71 - 2.5 \times 10^{-3} (1401\times\phi)^2$	$0° \le \phi \le 0.06°$
			49.2	$0.06° < \phi \le 0.21°$
			$32 - 25 \times \log(\phi)$	$0.21° < \phi \le 47.9°$
			-10	$47.9° < \phi \le 180°$
31.3−32.3 GHz	Deep-space system, downlink	78	$78 - 12 \times (\phi/0.022)^2$	$0 \le \phi \le 0.026°$
			61	$0.026° < \phi \le 0.047°$
			$61 - 23.4 \times \log(\phi/0.047)$	$0.047° < \phi \le 51.7°$
			-10	$51.7° < \phi \le 80°$
			-5	$80° < \phi \le 120°$
			-10	$120° < \phi \le 180°$
	NGSO system, downlink	68	$68 - 12 \times (\phi/0.07)^2$	$0 \le \phi \le 0.083°$
			51	$0.083° < \phi \le 0.15°$
			$51 - 23.4 \times \log(\phi/0.15)$	$0.15° < \phi \le 61°$
			-10	$61° < \phi \le 80°$
			-5	$80° < \phi \le 120°$
			-10	$120° < \phi \le 180°$
34.2−34.7 GHz	Deep-space system, uplink	78	$78 - 12 \times (\phi/0.022)^2$	$0 \le \phi \le 0.026°$
			61	$0.026° < \phi \le 0.047°$
			$61 - 23.4 \times \log(\phi/0.047)$	$0.047° < \phi \le 51.7°$
			-10	$51.7° < \phi \le 80°$
			-5	$80° < \phi \le 120°$
			-10	$120° < \phi \le 180°$
ϕ: angle off mainbeam axis, deg.				

7.12 Space Application Service (SAS)

7.12.1 Space Operation Service (SOS)

7.12.1.1 System Review

NTIA does not provide the SOS earth station antenna radiation performance standards, nor does ITU-R have recommendations for a SOS earth station antenna reference radiation patterns. The SOS earth station antenna is assumed to have similar radiation performance as the FSS earth station antenna; therefore, the FSS earth station antenna radiation performance standard in Section 7.3.1 is recommended for the SOS earth station antenna radiation performance standard. Furthermore, the standard for the GSO system is extended to moon-orbiting systems and deep-space systems. The low-gain antenna radiation performance standard is not available in Section 7.3.1, and the LMSS low-gain antenna radiation performance standards in Section 7.7.1.1 are recommended here. These standards are provided in Table 7-46.

Table 7-46. SOS Earth Station Antenna Radiation Performance Standards

(a) Low-Gain Antenna

Gain Function (dBi)	Angular Range
$G_{max} - 12 \times (\phi/\phi_{bw})^2$	$0° < \phi \leq x°$
4	$x° < \phi \leq 40°$
$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
-5	$90° < \phi$
Circular Beam, $12 \leq G_{max}(dBi) \leq 18$ ϕ: angle off mainbeam axis, deg. ϕ_{bw}: HPBW, deg. x: $\{G_{max} - 12\times(x/\phi_{bw})^2\} = 4$, deg.	

(b) GSO and Higher Orbit System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 68$ ($G_{max} \geq 44.7$ dBi for $e = 0.65$)	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_m$
	G_1	$\phi_m \leq \phi < \phi_{r1}$
	$29 - 25 \times \log(\phi)$	$\phi_{r1} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda < 68$	$G_{max} - 2.5 \times 10^{-3}(\phi D/\lambda)^2$	$0° \leq \phi < \phi_{r2}$
	$29 - 25 \times \log(\phi)$	$\phi_{r2} \leq \phi < 7°$
	8	$7° \leq \phi < 9.2°$
	$32 - 25 \times \log(\phi)$	$9.2° \leq \phi < 48°$
	-10	$48° \leq \phi \leq 180°$
$D/\lambda = 68$ is the threshold when the G_1 plateau disappears. ϕ: angle off mainbeam axis, deg. $G_1 = -1 + 15\times\log(D/\lambda)$, dBi $\phi_m = 20(\lambda/D)(G_{max} - G_1)^{0.5}$, deg. $\phi_{r1} = 15.85(D/\lambda)^{-0.6}$, deg. ϕ_{r2} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$		
An actual radiation pattern shall meet the following conditions: • It may not exceed the gain function in the range $\phi_r \leq \phi < 7°$.		

- It may exceed the gain function in the range $\phi > 7°$ by no more than 10% with individual sidelobe not exceeding the gain function by more than 3 dB.

(c) NGSO System High-Gain Antenna

Category	Gain Function (dBi)	Angular Range
$D/\lambda \geq 100$ ($G_{max} \geq 48.1$ dBi for $e = 0.65$)	$G_{ma} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{ma}$
	G_{1a}	$\phi_{ma} \leq \phi < \phi_{ra}$
	$29 - 25 \times \log(\phi)$	$\phi_{ra} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$
$20 < D/\lambda < 100$ ($34.1 < G_{max}(dBi) < 48.1$ for $e = 0.65$)	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{mb}$
	G_{1b}	$\phi_{mb} \leq \phi < \phi_{rb}$
	$29 - 25 \times \log(\phi)$	$\phi_{rb} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$
$D/\lambda < 20$	$G_{mb} - 2.5 \times 10^{-3} (\phi D/\lambda)^2$	$0° \leq \phi < \phi_{rc}$
	$29 - 25 \times \log(\phi)$	$\phi_{rc} \leq \phi < 36°$
	-10	$36° \leq \phi \leq 180°$

ϕ: angle off mainbeam axis, deg.

$G_{ma} = 20\times\log(D/\lambda) + 8.4$, dBi

$G_{1a} = -1 + 15\times\log(D/\lambda)$, dBi

$\phi_{ma} = 20(\lambda/D)(G_{ma} - G_{1a})^{0.5}$, deg.

$\phi_{ra} = 15.85(D/\lambda)^{-0.6}$, deg.

$G_{mb} = 20\times\log(D/\lambda) + 7.7$, dBi

$G_{1b} = 29 - 25\times\log(95\lambda/D)$, dBi

$\phi_{mb} = 20(\lambda/D)(G_{mb} - G_{1b})^{0.5}$, deg.

$\phi_{rb} = (95\lambda/D)$, deg.

Pattern for $D/\lambda < 20$ is added to extend the high-gain pattern to $G_{max} = 22$ dBi.

ϕ_{rc} : intersection of $\{G_{max} - 2.5\times10^{-3}(\phi D/\lambda)^2\}$ and $\{29 - 25\times\log(\phi)\}$, deg.

7.12.1.2 Frequency Assignment

The actual antenna radiation patterns should always be used in EMC analyses for frequency assignment. The antenna radiation patterns should be available from either the system operators or the antenna manufacturers.

When the actual radiation patterns are not available, the radiation performance standards in Section 7.12.1.1 may be used. The radiation patterns in Section 7.12.1.1 do not specify the G_{max} value, and such data should be available in the GMF.

7.12.1.3 Spectrum Sharing Analyses

The representative SOS antenna radiation patterns for conducting spectrum sharing analyses are provided in Table 7-47.

Table 7-47. Representative SOS Antenna Reference Radiation Patterns for Spectrum Sharing Analyses

Frequency Band	Space System, Link Direction	G_{max} (dBi)	Gain Function (dBi)	Angular Range
148−149.9 MHz	GSO system, uplink	12	$12 - 12 \times (\phi/41.2)^2$	$0° \leq \phi \leq 33.7°$
			4	$33.7° < \phi \leq 40°$
			$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
			-5	$90° < \phi$
401−402 MHz	NGSO system, downlink	16	$16 - 12 \times (\phi/26)^2$	$0° \leq \phi \leq 26°$
			4	$26° < \phi \leq 40°$
			$44 - 25 \times \log(\phi)$	$40° < \phi \leq 90°$
			-5	$90° < \phi$
2.025−2.11 GHz	Deep-space system, uplink	56	$56 - 2.5 \times 10^{-3} (249\times\phi)^2$	$0° \leq \phi \leq 0.37°$
			34.9	$0.37° < \phi \leq 0.58°$
			$29 - 25 \times \log(\phi)$	$0.58° < \phi \leq 7°$
			8	$7° < \phi \leq 9.2°$
			$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
			-10	$48° < \phi \leq 180°$
	GSO system, Uplink & downlink	39	$39 - 2.5 \times 10^{-3} (35.2\times\phi)^2$	$0° \leq \phi \leq 2.55°$
			$29 - 25 \times \log(\phi)$	$2.55° < \phi \leq 7°$
			8	$7° < \phi \leq 9.2°$
			$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
			-10	$48° < \phi \leq 180°$
	NGSO system, uplink	47	$47 - 2.5 \times 10^{-3} (92\times\phi)^2$	$0° \leq \phi \leq 0.93°$
			28.7	$0.93° < \phi \leq 1.03°$
			$29 - 25 \times \log(\phi)$	$1.03° < \phi \leq 36°$
			-10	$36° < \phi \leq 180°$
2.2−2.29 GHz	Deep-space system, downlink	57	$57 - 2.5 \times 10^{-3} (279.4\times\phi)^2$	$0° \leq \phi \leq 0.33°$
			35.7	$0.33° < \phi \leq 0.54°$
			$29 - 25 \times \log(\phi)$	$0.54° < \phi \leq 7°$
			8	$7° < \phi \leq 9.2°$
			$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
			-10	$48° < \phi \leq 180°$
	GSO system, uplink	35	$35 - 2.5 \times 10^{-3} (22.2\times\phi)^2$	$0° \leq \phi \leq 4.18°$
			$29 - 25 \times \log(\phi)$	$4.18° < \phi \leq 7°$
			8	$7° < \phi \leq 9.2°$
			$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$
			-10	$48° < \phi \leq 180°$
	GSO system, downlink	44	$44 - 2.5 \times 10^{-3} (62.55\times\phi)^2$	$0° \leq \phi \leq 1.37°$
			$29 - 25 \times \log(\phi)$	$1.37° < \phi \leq 7°$
			8	$7° < \phi \leq 9.2°$
			$32 - 25 \times \log(\phi)$	$9.2° < \phi \leq 48°$

			-10	$48° < \phi \leq 180°$
	NGSO system, downlink	42	$42 - 2.5 \times 10^{-3} (51.75\times\phi)^2$	$0° \leq \phi \leq 1.71°$
			22.4	$1.71° < \phi \leq 1.84°$
			$29 - 25 \times \log(\phi)$	$1.84° < \phi \leq 36°$
			-10	$36° < \phi \leq 180°$
ϕ: angle off mainbeam axis, deg.				

7.12.2 Data Relay Service (DRS)

The DRS system provides telecommunication support between the earth stations and the LEO satellites conducting space research operations. The GMF does not provide a separate category for this service.