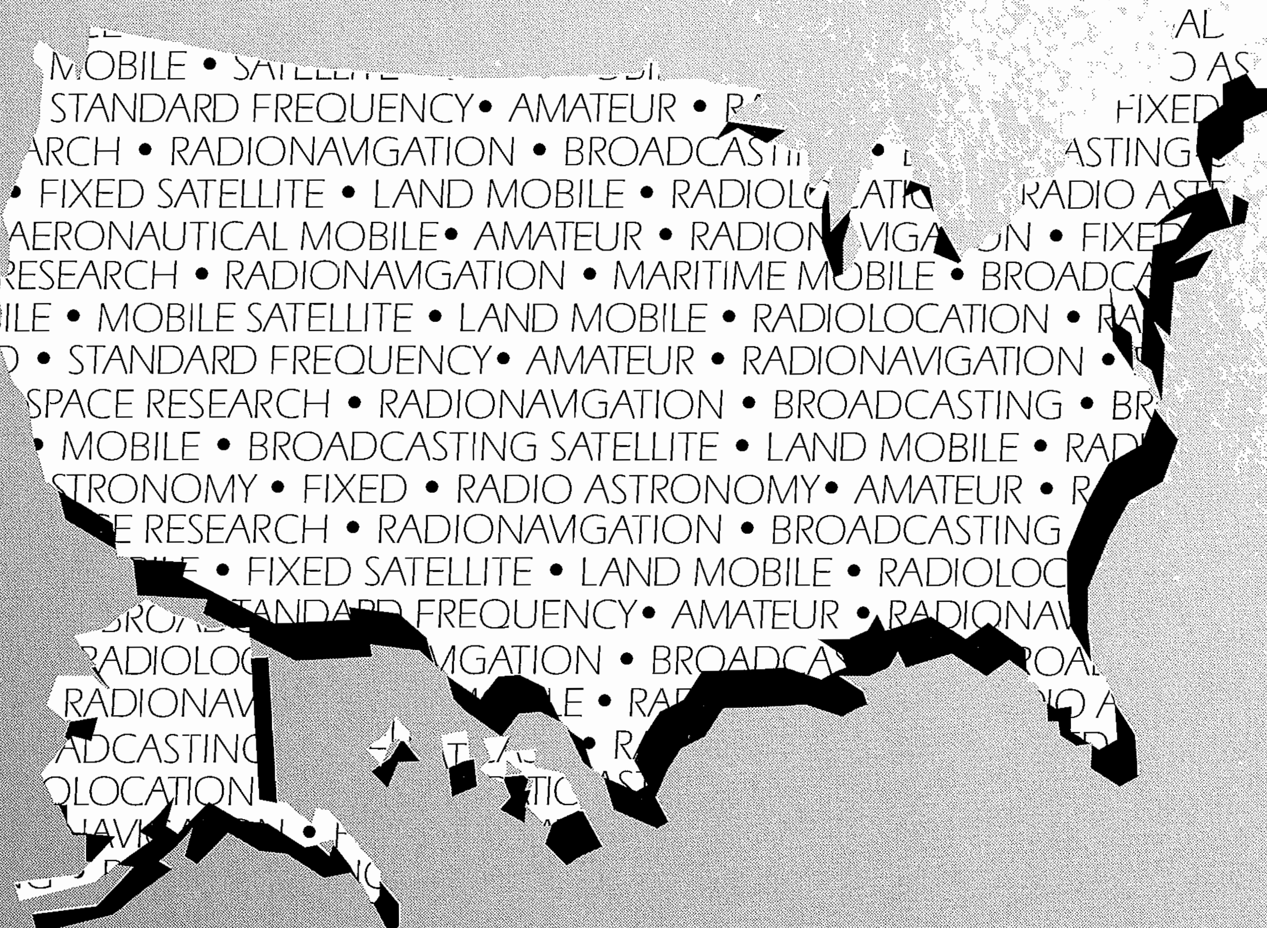
U.S. National Spectrum Requirements

Projections and Trends



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

NTIA Special Publication 94-31

U.S. NATIONAL SPECTRUM REQUIREMENTS: PROJECTIONS AND TRENDS

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

Larry Irving, Assistant Secretary
for Communications and Information, and
Administrator, National Telecommunications
and Information Administration

March 1995

PROJECT TEAM

Office of Spectrum Management

Associate Administrator
Richard D. Parlow

Director, Spectrum Plans and Policies
Robert J. Mayher

Manager, Strategic Spectrum Planning Program
W. Russell Slye

TEAM MEMBERS

Spectrum Plans and Policies
Joseph P. Camacho
Fredrick Matos
James T. Vorhies

Spectrum Engineering and Analysis Division
Robin H. Haines
Herbert K. Kobayashi
Richard J. Orsulak

Institute for Telecommunication Sciences
Robert J. Matheson

PROJECT CONTRIBUTORS

Office of Spectrum Management
David S. Anderson
Elizabeth H. Bertier
Dr. David J. Cohen
Ernesto A. Cerezo
Gordon A. Crandall III
Gerald F. Hurt
Janice M. Lawrence
Paul C. Roosa, Jr.
Robert R. Seach
William D. Speights

Office of International Affairs
Lawrence M. Palmer

Office of Policy Analysis and Development
Joseph L. Gattuso

Institute for Telecommunication Sciences
Kenneth C. Allen

Office of Telecommunications and Information Applications
Judith S. Sparrow

Office of Chief Counsel
Mindel M. DeLaTorre
Cheryl A. Kinsey
Wendy C. Chow

CONTENTS

List of Acronyms

The following acronyms are used in this report. Abbreviations for the names of commenters to our *Notice* are given in the Appendix.

AAC	Aeronautical Administrative Communications
AC/WPBX	Advanced Cordless/Wireless Private Branch Exchange
ACARS	Aircraft Communications, Addressing and Reporting System
ACSB	Amplitude Compandored Single Sideband
ACT	Air Combat Training
ACTS	Advanced Communications Technology Satellite
ADS	Automatic Dependent Surveillance
ALE	Automatic Link Establishment
AMCP	Aeronautical Mobile Communications Panel
AMSS	Aeronautical Mobile-Satellite Service
AMTS	Automated Maritime Telecommunications System
AOC	Aeronautical Operational Control
APC	Aeronautical Public Correspondence
ARES	Amateur Radio Emergency Service
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATDRSS	Advanced Tracking and Data Relay Satellite System
ATS	Air Traffic Services
ATV	Advanced Television
AUXBC	Auxiliary Broadcasting
AVM	Automatic Vehicle Monitoring
AWACS	Airborne Warning and Control System
BETRS	Basic Exchange Telecommunications Radio Service
BIB	Board for International Broadcasting
BMD	Ballistic Missile Defense
BMEWS	Ballistic Missile Early Warning System
BR	Radiocommunications Bureau
BSS	Broadcasting-Satellite Service
CAD	Computer-Aided Design
CARS	Cable Television Relay Service
CCCI or C^3I	Command, Control, Communications, and Intelligence
CD	Compact Disc
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CFR	Code of Federal Regulations

CITEL	Inter-American Telecommunications Commission
CONUS	Conterminous United States
CPU	Central Processing Unit
DAB	Digital Audio Broadcasting
DARS	Digital Audio Radio Service
DBF	Digital Beam Former
DBS	Direct Broadcast Satellite
DCP	Data Collection Platform
DEA	Drug Enforcement Administration
DEMS	Digital Electronic Message Service
DEW	Distant Early Warning
DGPS	Differential Global Positioning System
DME	Distance Measuring Equipment
DOT	Department of Transportation
DSC	Digital Selective Calling
DSCS	Defense Satellite Communications System
DTS	Digital Termination Service
E-TDMA	Extended Time Division Multiple Access
EIA	Electronic Industries Association
EMC	Electromagnetic Compatibility
ENG	Electronic News Gathering
EOS	Earth Observation Satellite
ER	Extended Range
ESMR	Enhanced Specialized Mobile Radio
FANS	Future Air Navigation System
FAS	Frequency Assignment Subcommittee
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FET	Field-Effect Transistor
FPLMTS	Future Public Land Mobile Telecommunications Systems
FRP	Federal Radionavigation Plan
FSS	Fixed-Satellite Service
GBR	Ground-Based Radar
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GSO	Geostationary Orbit
HDTV	High Definition Television
HEMT	High Electron Mobility Transistor
HF	High Frequency

HSD	Home Satellite Dish
IBOC	In-Band On-Channel
IC	Integrated Circuit
ICAO	International Civil Aviation Organization
ICR	Intercity Relay
ILS	Instrument Landing System
IMASS	Intelligent Multiple Access Spectrum Sharing
IMO	International Maritime Organization
IMPATT	Impact Avalanche and Transit Time
IMTS	Improved Mobile Telephone System
INMARSAT	International Maritime Satellite Organization
INTELSAT	International Telecommunications Satellite Organization
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific, and Medical
ITS	Intelligent Transportation System
ITS	Institute for Telecommunication Sciences
ITU	International Telecommunication Union
IVHS	Intelligent Vehicle Highway System
IXC	Interexchange Carrier
JSS	Joint Surveillance System
JTIDS	Joint Tactical Information Distribution System
LAN	Local Area Network
LEC	Local Exchange Carrier
LEO	Low-Earth Orbit
LF	Low Frequency
LMDS	Local Multipoint Distribution Service
LMS	Location and Monitoring Service
LMSS	Land Mobile-Satellite Service
LOS	Line-of-Sight
LPI	Low Probability of Intercept
MARS	Military Affiliate Radio System
MAS	Multiple Address Service
MDS	Multipoint Distribution Service
MES	Metal-Semiconductor
MLS	Microwave Landing System
MMDS	Multiband Multipoint Distribution Service
MMIC	Monolithic Microwave Integrated Circuit
MMSS	Maritime Mobile-Satellite Service
mmw	Millimeter Wave
MSS	Mobile-Satellite Service
MUF	Maximum Usable Frequency
NAS	National Airspace System

NASTD	National Association of State Telecommunications Directors
NAVSPASUR	Naval Space Surveillance System
NBDP	Narrow Band Direct Printing
NDB	Nondirectional Radiobeacon
NIST	National Institute of Standards and Technology
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rulemaking
NRSC	National Radio Systems Committee
NTDC	New Technology Directions Committee
NTIA	National Telecommunications and Information Administration
NTSC	National Television Systems Committee
NTU	New Threat Upgrade
NWS	National Weather Service
OR	Off-Route (aeronautical mobile and aeronautical mobile-satellite services)
OMB	Office of Management and Budget
OSCAR	Orbiting Satellite Carrying Amateur Radio
OTH	Over-the-Horizon
PAR	Precision Approach Radar
PCIA	Personal Communications Industry Association
PCP	Private Carrier Paging
PCS	Personal Communications Services
PDF	Probability Density Function
PLC	Power Line Carrier
PLMR	Private Land Mobile Radio
PRB	Private Radio Bureau
PSN	Public Switched Network
PSTN	Public Switched Telephone Network
PTS	Personal Telecommunications Services
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QPSK-C	Quadrature Phase Shift Keying Compatible
R	Route (aeronautical mobile and aeronautical mobile-satellite services)
R&O	Report and Order
RACES	Radio Amateur Civil Emergency Service
RACON	Radar Transponder Beacon
RAJPO	Range Joint Project Office
RBW	Reverse Band Working
RDSS	Radiodetermination-Satellite Service
RFE	Radio Free Europe
RL	Radio Liberty
RNP	Required Navigation Performance
ROTHR	Relocatable Over-the-Horizon Radar

SAM	Surface-to-Air Missile
SBR	Spaceborne Radars
SCADA	Supervisory Control and Data Acquisition
SDI	Strategic Defense Initiative
SHARES	Shared Resource Program
SHL	Studio-to-Headend Link
SIR	Shuttle Imaging Radars
SLBM	Submarine Launched Ballistic Missiles
SMR	Specialized Mobile Radio
SOLAS	Safety of Life at Sea
SSR	Secondary Surveillance Radar
SSTO	Single-Stage-to-Orbit
STL	Studio-to-Transmitter Link
TACAN	Tactical Air Navigation
TCAS	Traffic Alert and Collision Avoidance System
TCI	Telecommunications, Inc
TDMA	Time Division Multiple Access
TDRSS	Tracking and Data Relay Satellite System
TDWR	Terminal Doppler Weather Radar
TT&C	Tracking, Telemetry and Command
TVA	Tennessee Valley Authority
TVRO	Television Receive-Only
TWT	Traveling Wave Tube
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
USAF	United States Air Force
USAT	Ultra-Small Aperture Terminal
USIA	United States Information Agency
US&P	United States and Possessions
UTC	Universal Coordinated Time
UWB	Ultra-Wideband
VLBI	Very Long Baseline Interferometry
VOR	VHF Omnidirectional Range
VORAD	Vehicle On-Board Radar
VSAT	Very Small Aperture Terminal
VTS	Vessel Traffic Service
WARC	World Administrative Radio Conference
WRC	World Radiocommunication Conference

EXECUTIVE SUMMARY

INTRODUCTION

The availability of radio spectrum in the United States is critical to many telecommunications services, ranging from cellular telephones to air traffic control. Although spectrum is not a consumable resource, the use of a frequency at a given location usually excludes that frequency from being used by others in the same geographic area. This need for exclusive geographic use has led to current spectrum regulations that establish exclusivity in spectrum use by granting licenses for spectrum use, and the partitioning of the spectrum for shared use between radio services.

As the number of spectrum users increases, the amount of spectrum available for new and existing services decreases. Thus, to successfully plan for tomorrow's spectrum use, the spectrum management community must have an understanding of expected future spectrum requirements and spectrum availability, as well as the potential effects of new technology on the efficient use of the spectrum. A long-term spectrum plan can then be developed and used to guide modification of spectrum allocations, standards, and channeling plans for the best mix of radio services, economy, and spectrum efficiency.

The National Telecommunications and Information Administration (NTIA) is the primary Federal agency working toward the definition and development of the National Information Infrastructure (NII), commonly referred to as "the information superhighway." The NII will be a network linking people, businesses, schools, hospitals, communities and governments, allowing them to communicate and exchange information using voice, video and data with computers, telephones, radios, and other devices. The concept of the NII encompasses a wide range of telecommunications equipment, services, and transmission media. The technology encompassed by the NII includes, among other things, electronic cameras, computers, televisions, optical fiber transmission lines, microwave links, satellite systems, wireless networks, car telephones, pagers and facsimile machines. The NII will integrate and interconnect these physical components to provide a nation-wide information conduit, accessible by everyone. Although the NII is not a discrete telecommunication service, the increase in information flow, particularly to and from mobile users, will ultimately result in an increased requirement for radio spectrum to support the various mobile and fixed service interconnections.

Recently, commercial demand for access to some segments of the radio spectrum has exceeded spectrum availability in many major U.S. markets. Leading the demand for additional spectrum allocations are the various high-technology mobile systems, such as personal communications services (PCS), mobile-satellite systems interconnecting to the public switched telephone network (PSTN), enhanced public safety systems, and a variety of wireless data and voice systems. The continued growth of the telecommunications industry depends to a significant degree on the effective allocation of spectrum to meet additional radiocommunications requirements.

The Federal Government has unique requirements for spectrum use to support the many and varied missions of the Federal agencies. Most of the Federal spectrum use is in support of unique missions that are of direct benefit to U. S. citizens, such as Federal law enforcement, air traffic control, national defense, weather services, and environmental monitoring. Recognizing that continued economic growth in the telecommunications industry and other businesses is dependent on adequate spectrum to support new radiocommunications systems, the future use of the spectrum must be carefully planned so it can adequately support both commercial interests and the critical missions of the Federal Agencies.

To address the issue of spectrum planning, the Congress directed NTIA to prepare a long-term, strategic spectrum plan. The Congress also directed NTIA to meet biannually with the Federal Communications Commission (FCC) to discuss strategic spectrum planning and other key radio issues. The development of a realistic and dynamic spectrum plan requires periodic evaluation of spectrum requirements, analysis of spectrum availability, and preparation of spectrum planning options. Spectrum plans require periodic revisions because of the dynamics of spectrum management actions, fueled by new technologies and market demands.

NTIA's Strategic Spectrum Planning Program is divided into three phases: (1) Definition of long-term spectrum requirements, (2) spectrum availability and planning options, and (3) spectrum allocation implementation plans. As the first phase of this planning effort, NTIA issued a Notice of Inquiry (Notice) in June 1992, requesting comments from both the private sector and Federal agencies regarding future spectrum requirements. The Notice also requested information on future technology, technology trends, and international radio conference preparations. The purpose of this inquiry was to gather information for use in the long-term spectrum planning process. NTIA also conducted long-term spectrum studies to define critical radio service requirements. This report completes Phase 1 of the program. Phase 2, the spectrum availability report, is expected to be completed approximately one year from the date of this report.

This report describes a 10-year projection of spectrum requirements needed to support evolving radiocommunications requirements in the United States, based on the comments to our Inquiry, the NTIA studies, and other available literature. This report describes the present and projected uses of spectrum within the United States for all licensed radio services. Requirements for unlicensed radio services are not addressed. The projected spectrum requirements will need to be periodically re-evaluated as technology and needs change. The projected requirements not only serve as a key input to the long-term planning process, but are also intended to elicit comments concerning the validity of the requirements and the inter-relationship between the needs of the various radio services. This will ensure that evolving requirements will be balanced and will benefit from a broad range of discussions. It will be a significant challenge over the next few years to develop an efficient, effective and balanced long-term plan, and then a more significant challenge to make allocation or other spectrum management changes to satisfy the requirements.

The conclusions and recommendations contained in this report are those of NTIA. This report has been informally reviewed by the NTIA Interdepartment Radio Advisory Committee, the NTIA Spectrum Planning and Policy Advisory Committee and the Federal Communications Commission. Review of this report by these entities does not necessarily imply their endorsement of the conclusions or recommendations contained herein.

The following table lists the additional U.S. spectrum requirements for both Federal and non-Federal users. The additional spectrum requirements problem may be solved through technical, operational, or allocation changes that include Federal and non-Federal exclusive or shared spectrum, and will be discussed in the next report. The table is followed by a summary of spectrum requirements for radio services, spectrum sharing aspects, technology and technology trends, and comments regarding U.S. preparations for international radiocommunication conferences.

Summary of Additional U.S. Spectrum Requirements
(10-Year Projection)

Radio Services Discussed in Part I	Spectrum Requirements
Land Mobile a) Conventional dispatch, public safety, cellular, PCS, trunked mobile, and paging b) Intelligent Transportation System	a) 119 MHz Additional below 5 GHz b) 75 MHz below 10 GHz 10 MHz between 10 and 100 GHz
Aeronautical Mobile	30 kHz Additional (HF) for off-route (OR) and 108 kHz for route (R). 100 kHz Additional (HF) allocated to the Mobile Service.
Maritime Mobile	36-60 kHz Additional (HF)
Mobile-Satellite	60 MHz Additional
Fixed	Up To 250 MHz Reduction
Fixed-Satellite	200-400 MHz Additional (Feeder Links)
Broadcasting	1,900 kHz Additional (HF)
Broadcasting-Satellite	Present Spectrum Adequate
Radionavigation	Present Spectrum Adequate
Radiolocation	Present Spectrum Adequate
Radiodetermination-Satellite	Present Spectrum Adequate
Inter-Satellite	Present Spectrum Adequate
Space Operation	Present Spectrum Adequate
Space Services	Present Spectrum Adequate
Radio Astronomy	9.6 MHz Additional (see note)
Amateur and Amateur-Satellite	2,180 kHz Additional
Standard Frequency and Time Signal	Present Spectrum Adequate
Meteorological Aids	Present Spectrum Adequate

Note: The radio astronomy community also requested access to an additional 231 MHz, which could be obtained on a local, coordinated basis.

MOBILE AND MOBILE-SATELLITE SERVICES

LAND MOBILE SERVICES

The land mobile service encompasses all terrestrial mobile operations other than aeronautical and maritime mobile. Land mobile services, including public safety operations, are receiving high visibility in the United States. Numerous proceedings by NTIA and the FCC on land mobile issues, e.g., refarming, PCS spectrum allocations, and studies undertaken by NTIA indicate the importance of this radio service.

The land mobile services, including various public safety operations, are perhaps first among the radiocommunication services in need of additional spectrum within 10 years. This is largely due to the rapid growth in non-dispatch systems, such as cellular radiotelephones and pagers, and the projected growth of PCS and public safety operations. However, spectrum requirements are difficult to individually quantify for each of the service types since many users may show no preference in using services such as cellular or PCS as long as service offerings and costs are competitive.

An estimate of additional spectrum needed for the land mobile services was developed that included projected service needs, the effects of new technology, and the conversion rates of current systems to newer, more efficient technology. In the analysis of spectrum requirements, it was assumed that several of the mobile services are substitutes for each other (for example, cellular telephone, enhanced special mobile radio service and some PCS voice services may be similar). Therefore, since this commonality of telecommunications offerings tends to blur the distinctions between discrete services, the spectrum estimate for land mobile services is presented based on an aggregate user base, rather than on individual service offerings. The total spectrum requirement for these services is estimated to be an additional 119 MHz below 5 GHz.

> The land mobile services, including public safety operations, are perhaps first among the radiocommunications services in need of additional spectrum, due to the rapid growth in non-dispatch services.

The Intelligent Transportation System (ITS, formerly known as the Intelligent Vehicle Highway System or IVHS) is an emerging new development in the land mobile service. The ITS, being developed by the Department of Transportation, will employ various types of radiocommunications systems within different radio services aimed at providing for a safer and more efficient future transportation infrastructure. The next five years will see the research and development, evaluation, and operational testing of various ITS projects applying modern communications, location, and control technologies. The Department of Transportation and its advisory committee, the Intelligent Transportation Society of America (ITS AMERICA), have indicated that additional spectrum will be required. Current estimates for ITS spectrum requirements include both radiocommunications services and radar. Preliminary estimates for radiocommunications requirements are for access to 75 MHz below 10 GHz, and 10 MHz between 10 GHz and 100 GHz, as shown in the preceding table. ITS also has additional spectrum requirements for collision-avoidance radar systems, that can be accommodated in current radiolocation bands.

The total expected spectrum requirement for the land mobile services, including ITS, is 204 MHz of additional spectrum in the next 10 years. This is in addition to the recent FCC spectrum allocation of 140 MHz for licensed and unlicensed PCS services. The 10-year requirement for the land mobile services could vary significantly from the estimate because of possible variances in the application of new technology and the timing of conversion of existing systems to new technology.

AERONAUTICAL AND MARITIME MOBILE SERVICES

Two events are taking place within the aeronautical and maritime mobile communities that will help accommodate the expected growth in these services. The first is the implementation of satellite-based communications to fulfill future operational requirements. The second is the migration to more efficient technologies. The aeronautical community is considering implementation of either a reduction of channel bandwidth to 8.33 kHz, or a time-division multiple access system for future air-ground systems, and the maritime mobile community is planning to narrowband their VHF allocations to alleviate spectrum congestion. Further, much of the aeronautical voice traffic will be replaced by more efficient computer-to-computer data links that transmit aircraft flight information, such as estimated time of arrival, landing clearance, and weather information between ground and aircraft computers.

Requirements for an additional 30 kHz and 36-60 kHz have been identified for the aeronautical (OR) and maritime mobile services, respectively. There is also a requirement for an additional 108 kHz for the aeronautical mobile (R) service, and 100 kHz in the mobile service to support aircraft operations.

MOBILE-SATELLITE SERVICES

Expected demand for the mobile-satellite service (MSS) will require approximately 60 MHz of additional spectrum, particularly for MSS service to hand-held terminals. This requirement is in addition to the spectrum allocated in the United States today for MSS in the 1.5-1.6 and 2.4 GHz bands for service links for communications to the MSS subscriber equipment. MSS systems also require spectrum for communicating between the satellite and large earth stations to complete the communications path. The communications links to these large fixed earth stations are known as feeder links. Feeder links are considered to be a fixed-satellite service (FSS) application. Spectrum requirements for feeder links are discussed in the fixed-satellite section.

It is noted that of the 80 MHz of spectrum the FCC presently has in reserve for emerging technologies, 30 MHz is aligned with the 1992 World Administrative Radio Conference (WARC-92) worldwide MSS allocations and may become available in the future for MSS operations in the United States.

FIXED AND FIXED-SATELLITE SERVICES

FIXED SERVICE

The continuing replacement of microwave links by optical fiber is the most important factor affecting spectrum requirements for the fixed service. The use of microwave for general common carrier service has decreased substantially. As a result, the number of licenses in the 4 GHz band has decreased by 35 percent in the past five years. It is estimated that the 4 GHz band could accommodate the remaining users with 250 MHz less spectrum within 10 years.

The use of microwave links to connect rapidly growing cellular networks has caused growth in the 2 GHz, 6 GHz, and 11 GHz common carrier bands. However, the continued increase in the use of optical fiber and the capability of currently-installed copper wire to carry high bit-rate information may, in the long-term, cause the aggregate number of licenses in these bands to decrease.

> Fiber optic systems are growing rapidly, resulting in a decrease in the number of long-haul fixed microwave systems.

Following years of rapid growth, the use of microwave links by the cable TV relay service in the 13 GHz band has been relatively stable during the past two years. The number of licenses is expected to decrease in the next five years. However, private operational microwave is expected to grow three percent over the next 10 years, in applications where fiber is too expensive or is impractical to install.

In general, there is potential for growth in fixed microwave usage in frequency bands above 15 GHz. These bands are currently less used than the lower frequency fixed bands, and are suitable for short links connecting cellular and PCS cell sites. Many of the users in the 2 GHz band displaced by PCS applicants may be reaccommodated in these bands.

Although some common carrier bands are growing now, it is expected that the aggregate number of fixed service licenses in the 4 GHz, 6 GHz, and 11 GHz bands will decrease over the next 10 years. The 6 GHz band, although currently showing growth, is expected to decrease in the future.

The Federal Government's use of fixed microwave links is similar in many respects to that of the private sector. Federal use of these fixed systems shows a slow but steady growth. Improved spectral efficiency of new systems and conversion of existing systems to new technology will permit the current Federal fixed allocations to be adequate for the 10-year period. Any special spectrum needs, including systems having the high level of reliability, availability and security required by some Federal Agencies, will continue to be accommodated by the present allocations. This includes the expanded use of military transportable systems operating in the fixed service bands. Military use of spectrum supporting transportable fixed systems is necessary to maintain effective command and control capabilities. These systems are used in the United States for training and for communications in disaster relief operations.

If new large-scale fixed systems are built in support of PCS, they are expected to be established in the higher fixed bands. Excluding PCS-related systems, the total number of point-to-point microwave systems is expected to remain constant or decrease slowly.

FIXED-SATELLITE SERVICE

The conventional FSS should be adequately served by its present spectrum allocation for the near future. Satellites may continue to be the best choice for point-to-multipoint applications, while terrestrial systems (mainly optical fiber) would capture more of the point-to-point market. Spectrum made available by technological developments, such as video compression, may be absorbed by the requirements for additional video program distribution created by the falling cost of fiber optic equipment used for distribution. The FSS will also continue to provide a backup capability for systems using optical fiber, submarine cable, and terrestrial microwave.

Feeder links for geostationary MSS systems may be accommodated in bands currently allocated to the FSS. However, approximately 200-400 MHz of new FSS spectrum allocations may be required to accommodate non-geostationary MSS feeder links, because these feeder links cannot share in all cases with conventional FSS systems. Sharing with some types of terrestrial systems, however, appears feasible. MSS feeder links will require a total of more than 1 GHz of spectrum.

BROADCASTING AND BROADCASTING-SATELLITE SERVICES

The U.S. leadership in implementing digital signal processing and video compression technology in the broadcast services suggests that the United States will remain competitive internationally in providing digital audio broadcasting and high-definition television (HDTV) technology. Efforts to develop and implement digital audio radio for AM/FM radio broadcasting and HDTV for television broadcasting in their presently allocated frequency bands appear promising. No additional spectrum appears necessary for terrestrial AM, FM, and TV broadcasting. The eventual implementation of HDTV in the UHF-TV channels may free some, if not all, of the 72 MHz presently allocated to VHF television. Although this is not expected to occur within the next 10 years, considerable debate and competition can be expected between broadcasters and other potential users on how this spectrum should be used.

High-power, direct broadcast satellites (DBS) have come into operation in the broadcasting-satellite service (BSS) to provide television programming direct-to-the-home. The first U.S. DBS satellite has been launched and service has begun in most areas. The spectrum planned to support DBS and BSS-HDTV is sufficient and no additional spectrum appears to be necessary.

BSS (sound) systems are under development in the United States. These systems are expected to employ digital technology to broadcast compact disc (CD) quality programming to consumers' mobile or portable radios anywhere in the United States. The spectrum recently allocated for BSS-sound appears adequate for the foreseeable future.

High frequency broadcasters continue to express a strong need for increased spectrum allocations. Both Federal and non-Federal HF broadcasters identified their requirements as the spectrum shortfall resulting from the WARC-92. This shortfall amounted to approximately 1,900 kHz of internationally allocated spectrum.

RADIONAVIGATION

There is a trend toward the use of satellite-based technologies for both aeronautical and maritime radionavigation services. An example of this trend is the eventual replacement of LORAN-C by satellite-based navigation systems, such as the Global Positioning System (GPS). The GPS is expected to replace some radionavigation systems currently used in the aeronautical, maritime, and land transportation industries. For example, replacement of the VHF/UHF Instrument Landing System (ILS) by GPS-based systems is under consideration. The GPS is also considered by the International Civil Aviation Organization as a vital part of any future global, long-range, satellite-based navigation system. However, large-scale replacement of aircraft landing systems will take many years, and terrestrially-based systems may be needed as backup while confidence builds in satellite-based systems. In view of this future replacement, radionavigation spectrum allocations, including those for non-military radars, appear adequate for the next 10 years. However, they may be reduced as GPS-based systems replace current systems.

> Radionavigation applications based on the GPS may in the future replace systems serving land, maritime and aviation interests.

RADIOLOCATION

The primary use of the radiolocation service in the United States is for military radars. The concept-to-deployment cycle of a major new military radar system is typically 15-20 years. Once radars are deployed, they are usually used for at least 10 years. There is a trend toward keeping older radars operational for 20 years or more by modernizing the electronics and signal processing rather than funding a completely new design. Although there are radiolocation requirements for radar systems in the HF and VHF spectrum range, these systems are designed to share the spectrum with existing users, and new allocations may not be required.

Extensive research and development is being focused on ultra-wideband (impulse) radars. Although long-term spectrum requirements may evolve if these systems become operational, special arrangements will have to be developed regarding their allocation status because the necessary bandwidths would overlap numerous bands allocated to other services.

ITS collision-avoidance radars may require access to up to 220 MHz in the bands above 10 GHz. It is expected that these systems will be low-powered, and be accommodated in existing allocations.

Thus, taking into consideration the life cycles of existing operational radars, the trends, and the on-going research and development activity, the long-term radiolocation service spectrum requirements can be accommodated within the existing allocations.

OTHER SPACE SERVICES AND RADIO ASTRONOMY

Space communication services represent a wide variety of systems with differing spectrum requirements. Those services involved with tracking, telemetry and command (TT&C) functions and Federal launch facilities have adequate spectrum. Although there are recent developments in the space research and inter-satellite services, and the emerging commercial launch facilities, these will not require additional spectrum in the next 10 years.

Services primarily involved with the remote sensing of earth and space also have varied spectrum requirements. Present allocations for Earth-directed sensing systems appear adequate, but some flexibility in the spectrum management processes may be needed to accommodate unique space systems.

Radio astronomers are seeking access to approximately 239.6 MHz of additional spectrum (9.6 MHz allocated plus 230 MHz locally coordinated) through coordinated sharing and upgraded allocation status, whereas radar astronomers are adequately served for the foreseeable future.

OTHER RADIO SERVICES

AMATEUR SERVICE

The amateur and amateur-satellite service allocations have been based, in part, on the desirability of having a choice of relatively narrow frequency bands distributed throughout the spectrum with different propagation properties. Current amateur allocations start at 1800 kHz and, in narrow bands, extend to 250 GHz.

> The amateur community has expressed a desire for retention of current allocations, additional allocations, and alignment of some amateur bands internationally.

The amateur community commenters have suggested significant changes to the allocation table to accommodate expanded amateur operations. Amateurs generally express a desire for retention of the present amateur bands, additional spectrum, and for upgrading certain current amateur allocations. Many of the suggested allocation revisions are reasonable, and aggregate to about 2,180 kHz of additional spectrum. However, the requested co-primary sharing of amateur operation with radars in Federal radiolocation service bands is not feasible because of the potential loss of operational flexibility for military radar systems needed for national defense.

AMATEUR-SATELLITE SERVICE

The amateur-satellite service will soon have a new generation of amateur satellites in orbit that will use all frequency bands allocated to the amateur-satellite service from 29 MHz through 24 GHz. For this reason, the retention of current allocations, additional amateur-satellite allocations, and the upgrading of certain current allocations is desirable. Again, the suggested co-primary sharing of amateur operation with radars in Federal radiolocation service bands is not feasible because of the potential loss of operational flexibility for military radar systems.

STANDARD FREQUENCY AND TIME SIGNAL SERVICES

The frequency and time reference signals provided by these services (including the standard frequency and time signal-satellite service) are used in association with scientific research, and as standards for Universal Coordinated Time where precise time is required.

The HF and LF standard frequency and time signal services continue to fill important user needs. Mutual interference will likely continue to be a problem for users of HF services in some areas, but alternative sources are becoming more widely available and economically feasible. In the long term, it may become possible to replace some or all of the terrestrial HF and LF services with more reliable satellite-delivered services. Current spectrum allocations for this service are adequate for the next 10 years.

METEOROLOGICAL AIDS SERVICE

Reliance on the meteorological systems operating in the meteorological aids service is continually increasing due to the need for accurate weather predictions, as well for the investigation of worldwide climatological theories such as global warming. Accurate and timely prediction of severe weather helps to minimize loss of life, destruction of property, loss of agricultural production, etc. No additional spectrum appears necessary in the foreseeable future for the meteorological aids service.

SPECTRUM SHARING

The radio frequency spectrum is required to satisfy current and future needs for both the Federal and non-Federal radiocommunications service users. The spectrum is allocated to 40 radio services as defined in the FCC's Rules, and the Manual of Regulations and Procedures for Federal Radio Frequency Management (the NTIA Manual). With the increased use of frequency bands below 6 GHz, services that cannot find relief by moving to the higher bands must turn to sharing with other services, or to sharing between Federal and non-Federal users. Sharing opportunities for Federal and non-Federal users, particularly in the mobile, fixed, and space science services, should be increased.

NTIA has in the past recommended increased flexibility in spectrum allocations, and studying an interference-limited approach to licensing. Flexibility in spectrum use within a frequency band, along with the use of the most advanced automated frequency selection and assignment systems and the establishment of receiver standards to reduce interference effects, are key elements for increased spectrum efficiency. NTIA recognizes that the development of receiver standards has not always been accepted. However, it is becoming evident that more attention must be directed towards the electromagnetic environment surrounding radio systems. Manufacturers should be encouraged to design receivers that are more compatible with the existing environment and use the spectrum more efficiently. Finally, national spectrum allocations should also provide for flexibility of radio service use, including the use of electromagnetic compatibility techniques, to make the most efficient use of the spectrum.

> The military conducts training with radio systems and frequencies it expects to use in combat. Access to spectrum for tactical and training use must match operational requirements.

Recent downsizing of DOD operational units coupled with current demands for global mobility of our military forces, places greater demands on military spectrum planning than ever before. To exacerbate the problem, due to the result of recently enacted legislation, the military services may lose spectrum for which they have primary control. Future military spectrum planning should consider increased spectrum sharing between the military and other spectrum users in non-military frequency bands. Increased access to non-military bands on a synergistic or coordinated basis could increase the flexibility of military spectrum use in the United States.

Radio astronomy observatories require continued protection from interference. Airborne and satellite-based transmitters pose the greatest threat to radio astronomers, but the proliferation of low-powered devices and the advent of ultra-wideband systems are becoming a significant concern.

Co-channel sharing of the UHF television broadcast spectrum by other radio services in the same geographic area is not feasible. However, flexibility in the use of TV spectrum (i.e., ancillary services) may permit more efficient use of the spectrum.

Television receive-only (TVRO) systems are becoming widespread in the United States. Because TVRO systems are mostly unprotected, sharing TVRO with new terrestrial fixed systems has become difficult. Although the total number of fixed systems is decreasing in the 3.7-4 GHz band, if the band will be used for accommodation of some users displaced from the 2 GHz band, the establishment of new fixed links is likely to make TVRO use untenable in some areas.

TECHNOLOGIES

Semiconductor and information processing technologies, augmented by optical fiber and component development, drive important innovations in telecommunications. In particular, the microprocessor control of digitized information has spurred the development and implementation of techniques ranging from signal compression to scanning antenna arrays. Well within the next ten years, it will be possible for a portable transceiver to automatically optimize its performance by altering equipment parameters, such as bandwidth, modulation, and antenna pattern. Such versatility has significant implications for spectrum management in the future. The potential effects that the application of this technology will have on radiocommunications must be studied by the spectrum management community.

The move to spectrum above 10 GHz by the fixed and fixed-satellite services should pose few unanticipated problems despite the increased absorption of the signal because of rain and gaseous atmospheric constituents. Silicon and gallium arsenide appear to be the semiconductor materials that, when used in monolithic microwave integrated circuits, will help to extend radio use into higher frequencies. Experiments should determine if the low link-margin performance of small-aperture earth stations operating at 20 GHz and above is acceptable. Technological innovations provide for spectrum utilization well into the millimeter band.

Advances in digital modulation and microprocessor technology are resulting in spectrum conservation within existing narrowband channels, and the implementation of spectrum-efficient wideband systems. However, technical and regulatory problems will arise when spectrum is shared between ultra-wideband and multiple narrowband systems. Spectrum planning is increasingly aided by innovations in dynamic control of spectrum resources, most notably for frequency selection, bandwidth and transmitter power.

> A series of evolutionary technological breakthroughs has permitted the merging of radio and computer applications.

The alteration of an antenna's radiation pattern is becoming a practical tool for spectrum management. The greatest advances appear to be in electronically-phased arrays with real-time programmable capability. For spectrum sharing purposes, antennas capable of changing their center frequency and bandwidth, as well as radiation pattern, need to be further investigated for commercial applications.

More sophisticated propagation models that can handle fixed, mobile, and mobile-satellite systems are required for efficient spectrum management. In particular, the development of wideband models for point-to-point paths within buildings and through walls are a priority for cellular and personal communications system analysis.

U.S. PREPARATIONS FOR INTERNATIONAL RADIO CONFERENCES

Spectrum management has become globalized, and the United States is a critical part of this worldwide radio community. It is increasingly important that the United States develops a more coordinated and global view of radiocommunication services and spectrum allocation issues. To achieve this, the United States must maintain a continuous planning process that addresses advanced telecommunications technologies and worldwide services, and should re-evaluate the process by which domestic spectrum allocations are made, taking into consideration international markets for goods and services.

Many administrations are now in the process of privatizing previously government-owned and operated telecommunications systems. New systems and networks are being planned and established worldwide. Recognizing that these system developers may choose from multiple technologies, the United States must be competitive in international telecommunications markets, offering goods and services that meet common technical standards adopted by various administrations. To facilitate this, the United States must actively participate in international standards-setting activities, and maintain a progressive dialogue with regional administrations concerning spectrum and general telecommunications issues.

Current World Radiocommunication Conferences are held on a regular two-year cycle and may be somewhat narrower in scope than previous radio conferences. The two-year cycle adopted by the International Telecommunication Union (ITU) will make the ITU more responsive to an increasingly dynamic market and telecommunications environment. Furthermore, this new two-year cycle is expected to result in more efficient conference management; both domestically and within the ITU. However, the new two-year conference cycle will require a continuous planning process.

As part of this planning process, the IRAC recently established the Radio Conference Subcommittee (RCS) to develop recommended U.S. proposals and positions for ITU radio conferences. The RCS has established a close liaison with U.S. industry.

To improve the conference planning and preparation process, the head of the U.S. delegation should be appointed early in the two-year conference cycle in order to permit sufficient time to prepare for each conference. To facilitate the process by which the United States prepares for international radio conferences, NTIA will:

❑ Continue to work closely with the FCC, the Department of State, and the private sector to ensure that U.S. views are developed in a timely fashion to meet the new ITU conference schedule.

❑ Continue its efforts in the Inter-American Telecommunication Commission (CITEL) forum to provide a more effective mechanism for the development of recommendations and joint regional views on spectrum management issues and other matters that will be treated at ITU conferences.

CONCLUSION

This report projects U.S. spectrum requirements for a 10-year period based primarily on technical factors. The process of developing national requirements and forwarding these as U.S. requirements to international conferences requires additional consideration of technical, operational and regulatory factors. Among other factors in the planning process, we must also determine availability of spectrum, and prepare long-term spectrum plans, corresponding to phases 2 and 3 of the Strategic Spectrum Planning Program. These plans will include spectrum options and reallocation trade-offs needed to address future spectrum needs in a coordinated manner.

It has been said that long-range spectrum planning cannot be effectively accomplished. We recognize the many difficulties and problems with long-range planning, but must address the issues so we can make intelligent choices and address necessary changes in a realistic fashion. The alternative is to continue to address each spectrum requirement as it arises on a case-by-case basis, and often in a crisis-mode environment.

The projected spectrum requirements contained in this report are a key input to the long-range planning process. Further, our estimates of spectrum requirements are intended to foster dialogues between spectrum users and regulators, to ensure that spectrum is allocated to satisfy future requirements in a balanced and equatable fashion.

PART 1
REQUIREMENTS BY RADIO SERVICE

PART 1
REQUIREMENTS BY RADIO SERVICE

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency principally responsible for developing and articulating domestic and international telecommunications policy. NTIA acts as the principal advisor to the President on telecommunications policies pertaining to the Nation's economic and technological advancement and to the regulation of the telecommunications industry. Accordingly, NTIA conducts studies and makes recommendations regarding telecommunications policies and presents Executive Branch views on telecommunications matters to the Congress, the Federal Communications Commission (FCC), and the public.

NTIA is responsible for managing the Federal Government's use of the radio spectrum. Management of the spectrum for the private sector, including state and local governments, is the responsibility of the FCC. With the proliferation of radio-based technologies, the management and use of radio spectrum in the United States has lately become increasingly important, as reflected in current Federal legislation.[1] Congress found that telecommunications and information are vital to the public welfare, national security, and competitiveness of the United States, and that technological advances in the telecommunications and information fields make it imperative that the United States maintain effective national and international policies and programs capable of taking advantage of these continued advancements.[2]

The telecommunications service industry is an important factor in our national economy. More than 2000 companies and 875,000 employees make up the U.S. telecommunications service industry.[3] Operating revenues for 1994 are expected to exceed $180 billion in domestic services and an additional $12 billion in international services.[4] The expansion of telecommunications services is expected to continue, particularly with the introduction of personal communications services (PCS).

A large part of the telecommunications infrastructure depends on the use of the radio frequency spectrum. Shipments of spectrum-dependent equipment and systems are estimated to be in excess of $53

---

[1]The Omnibus Budget Reconciliation Act of 1993 requires transfer of Federally-controlled spectrum to the FCC, and provides other spectrum management guidance to both the FCC and NTIA. Omnibus Budget Reconciliation Act of 1993, Pub. L. No. 103-66, 107 Stat. 31 (1993) [hereinafter BUDGET ACT OF 1993]. The functions of NTIA were codified as a result of the National Telecommunications and Information Administration Organization Act. National Telecommunications and Information Administration Organization Act, P.L. 102-538, 106 Stat. 3533 (codified at 47 U.S.C. 901-904) [hereinafter NTIA ORGANIZATION ACT].

[2]NTIA ORGANIZATION ACT, *supra* note 1.

[3]INTERNATIONAL TRADE ADMINISTRATION, U.S. DEP'T OF COMMERCE, U.S. INDUSTRIAL OUTLOOK 1994 at 29-1 (1994). [hereinafter U.S. INDUSTRIAL OUTLOOK 1994].

[4]*Id.*

billion for 1994.[5] The cellular telephone industry alone is estimated to have approximately 19 million subscribers, with recent 12-month revenues of about $12.6 billion.[6] The spectrum is used in a variety of ways, from garage door openers to satellite-based intercontinental communications systems. Radiocommunication services, such as radio and television broadcasting, satellite systems, and the many kinds of mobile services, depend heavily on spectrum use. Aside from commercial use, the spectrum is also used to support the various missions of the Federal Government, including national defense.

NTIA is the primary Federal agency working toward the definition and development of the National Information Infrastructure (NII), commonly referred to as "the information superhighway." The NII will be a network linking people, businesses, schools, hospitals, communities and governments, allowing them to communicate and exchange information using voice, video and data with computers, telephones, radios, and other devices. The concept of the NII encompasses a wide range of telecommunications equipment, services, and transmission media. The technology encompassed by the NII includes, among other things, electronic cameras, scanners, computers, switches, televisions, optical fiber transmission lines, microwave links, car telephones, pagers and fax machines. The NII will integrate and interconnect these physical components to provide a nationwide information conduit, accessible by everyone. Although the NII is not a discrete telecommunication service, the increase in information flow, particularly to and from mobile users, will ultimately result in an increased requirement for radio spectrum to support the various mobile and fixed service interconnections. The role that wireless technology will play in the NII has not been specifically examined, and therefore unique spectrum requirements for NII have not been determined.

Recently, commercial demand for access to the radio spectrum has outstripped spectrum availability in many major U.S. markets. Leading the demand for additional spectrum allocations are the various high-technology mobile systems, such as cellular telephone, mobile-satellite systems interconnecting to the public switched telephone network (PSTN), a variety of wireless data and voice systems, and the emerging PCS. The further expansion of the telecommunications industry depends to a significant degree on the efficient allocation of spectrum to meet new, additional requirements.

The Federal Government also has large requirements for spectrum use to support the many and varied missions of the Federal agencies. Only a small percentage of Federal spectrum is used in support of administrative government functions; most is used to support unique missions of direct benefit to U.S. citizens. A partial list of missions supported by Federal spectrum uses includes national defense, protection of the President and foreign officials, assuring public safety of air and water transportation, Federal law enforcement, disaster relief, protection of national resources, ensuring the security of power generation and nuclear material, the health and well-being of our military veterans, and the efficient operation of our postal service.

---

[5] *Id.* at 30-6 to 30-22.

[6] CELLULAR TELECOMMUNICATIONS INDUSTRY ASSOCIATION, FAST FACTS (1994), at 1-2

Federal spectrum requirements, while not increasing as rapidly as commercial requirements, increase with population growth, and are often heaviest near centers of high population densities. Recognizing that continued economic growth in the telecommunications industry and other businesses is dependent on adequate spectrum to support new radiocommunications systems, the future use of the spectrum must be carefully planned so it can adequately support both commercial interests and the critical missions of the Federal agencies.

STRATEGIC SPECTRUM PLANNING

An NTIA spectrum policy report, published in 1991, recommended that NTIA and the FCC undertake a long-range spectrum planning effort that would forecast spectrum usage up to 15 years into the future.[7] NTIA implemented this recommendation in the form of a Fiscal Year 1992 Initiative to establish a strategic spectrum planning program, but limited the spectrum forecast to a ten-year period. With the approval of the Office of Management and Budget (OMB), Congress appropriated funds for NTIA's strategic spectrum planning effort. Congress tasked NTIA to provide strategic national spectrum planning to promote the effective and efficient use of the spectrum so that both near-term and long-term spectrum needs of the Federal Government and the private sector can be met. Strategic spectrum planning, in this context, involves identifying a limited number of spectrum-use issues that require the attention of national-level spectrum-use regulators, and developing a spectrum plan for implementation.

NTIA's Strategic Spectrum Planning Program is divided into three phases: the definition of long-term spectrum requirements, the development of spectrum availability and planning options, and the development of spectrum allocation implementation plans. This report completes Phase I of the program. Phase II, the spectrum availability report, is expected to be completed approximately one year from the date of this report.

At present, most spectrum planning is relatively short-term and generally reactive, occurring as a result of the requests of potential spectrum users. However, the efficient management and use of the electromagnetic spectrum requires a regulatory focus resulting from long-term planning if the spectrum resource is to adequately support national goals and objectives. Long-term planning can provide a framework upon which effective spectrum management is built, ensuring that spectrum is efficiently allocated for the constantly evolving radio spectrum needs. Spectrum planning also facilitates decision-making by providing a basis for the practical consideration and evaluation of several alternative courses of action. However, long-term spectrum planning must be sufficiently comprehensive to accommodate the national spectrum demands of both known and expected radiocommunications systems. These spectrum demands are generated by private sector economic incentives, nationwide demand for advanced telecommunications services, and growth in Federal Government telecommunications to support its ever-increasing public services.

---

[7]NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEP'T OF COMMERCE, NTIA SPECIAL PUBLICATION 91-23, U.S. SPECTRUM MANAGEMENT POLICY: AGENDA FOR THE FUTURE 178 (1991) [hereinafter NTIA SPECTRUM POLICY STUDY].

Spectrum planning results in revision of the National Table of Frequency Allocations, national positions regarding the agendas of international radio conferences, and revisions to spectrum regulations, policies, and standards. Recent spectrum legislation has emphasized the importance of national spectrum planning.[8] Future meetings required under that legislation between the Department of Commerce's Assistant Secretary for Communications and Information and the Chairman of the FCC will focus on spectrum planning and spectrum use efficiency.

Currently, some critical frequency bands are congested in several major U.S. markets, making spectrum planning a pressing issue for NTIA and the FCC. If further spectrum congestion is to be avoided, then spectrum use forecasting must be in the "tool box" of spectrum planners. Spectrum use forecasting is, at present, a new activity that strives to anticipate spectrum use requests by investigating telecommunications technology, spectrum use history, and other leading indicators. Although an imperfect science, spectrum use forecasting may become critical to the long-range accommodation of radiocommunication systems vital to the national economy, national defense, and the high quality of life expected in the United States.

Strategic spectrum planning requires a base of information that includes political, technical and economic information. As one avenue to acquire this data, NTIA issued a Notice of Inquiry[9] in June 1992, requesting comments from both the private sector and Federal Government agencies regarding future spectrum requirements for up to 15 years into the future. The Notice also requested information on technology and technology trends that may impact spectrum use in the future. Sixty-six private and public sector entities submitted comments on the inquiry; fourteen submitted reply comments.[10]

As stated in our Notice, NTIA believes that improved spectrum planning by both NTIA and the FCC can ease the transition from the current spectrum management system to one that relies more on market principles, by permitting modifications of existing spectrum allocations in a non-disruptive manner. In addition to making spectrum available for emerging, state-of-the-art commercial uses, spectrum planning also helps to ensure that adequate spectrum is available for a variety of non-commercial needs, e.g., public safety, state and local government, amateur radio, etc.

---

[8]BUDGET ACT OF 1993, *supra* note 1.

[9]*Current and Future Requirements for the Use of Radio Frequencies in the United States*, Notice of Inquiry and Request for Comments, Docket No. 920532-2132, 57 Fed. Reg. 25,010 (1992) [hereinafter *Notice*].

[10]Appendix A lists the commenters, along with their abbreviated names. The abbreviations are used herein for all citations to comments and reply comments. Commenters generally expressed support for a re-examination of policies regarding spectrum allocations and use. The IEEE stated that improvements in technology, frequency sharing strategies, and international radio conferences could ease future demands on the spectrum. IEEE—USA Comments at 6.

Based on the responses to the Notice, two independent studies,[11] and other information, NTIA in this report forecasts, in broad terms, future spectrum requirements for the major radio services. No distinctions are made between Federal and non-Federal spectrum requirements. Part I of this report contains chapters covering related groups of radio services. Each chapter contains a description of the radio services, and a discussion of the comments received in our inquiry, information contained in NTIA reports, or information gathered from other sources. Trends in spectrum usage for each radio service are also discussed, followed by an estimate of future spectrum requirements for that service. One chapter addresses spectrum sharing issues identified by the commenters. Additionally, based on the comments received and a study of the literature, Part II of this report describes significant technology and technology trends that may impact spectrum requirements,[12] and Part III briefly discusses comments received regarding U.S. preparations for international radio conferences.

---

[11]In support of this inquiry, NTIA undertook two studies: one addressing the future of the fixed service, ROBERT J. MATHESON & F. KENNETH STEELE, A PRELIMINARY LOOK AT SPECTRUM REQUIREMENTS FOR THE FIXED SERVICES (National Telecommunications and Information Administration, Institute for Telecommunication Sciences Staff Study, 1993), the other addressing the land mobile services, WILLIAM D. SPEIGHTS ET AL., NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, NTIA TECHNICAL MEMORANDUM 94-160, NATIONAL LAND MOBILE SPECTRUM REQUIREMENTS (1994). The mobile study was prepared by the Spectrum Engineering and Analysis Division of NTIA's Office of Spectrum Management.

[12]Technology may impact spectrum requirements either by producing new systems having new requirements, or by improving spectrum efficiency, thus reducing spectrum requirements.

CHAPTER 1

MOBILE AND MOBILE-SATELLITE SERVICES

INTRODUCTION

The mobile service is a "radiocommunication service between mobile and land stations, or between mobile stations."[13] This includes the conventional land, maritime, and aeronautical mobile services, common carriers such as cellular telephone and radio paging, and new applications like PCS and elements of the Intelligent Transportation System (ITS, formerly the Intelligent Vehicle Highway System, or IVHS).

Mobile and mobile-satellite services
- ❑ **land**
- ❑ **aeronautical**
- ❑ **maritime**

Mobile radiocommunication applications have been in use since the early part of this century, starting with ship–shore radiocommunications, although recent years have seen tremendous growth. This expansion has been stimulated both by technological advances and by increased demand for mobile services. Advancements in semiconductor technology allow for low–cost, lightweight, portable units and are, in part, responsible for the increase for land mobile services.

Mobile services are used by Federal, state and local government entities for many purposes, including such critical functions as law enforcement, public safety, natural resource conservation, transportation, and national defense. The private sector uses mobile services to satisfy the myriad of conventional communications requirements, including specialized needs such as electronic news gathering,[14] aeronautical public correspondence, and biomedical telemetry.

In the 1980's, mobile-satellite service technology advanced from initial concepts to practical system design and service demonstrations. Today, the competition to build global satellite networks is intense. Companies around the world have proposed to use satellites to deliver mobile services, which are expected

[13]NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, MANUAL OF REGULATIONS AND PROCEDURES FOR FEDERAL RADIO FREQUENCY MANAGEMENT § 6.1.1 at 6-10 (Jan. 1993) [hereinafter NTIA MANUAL]. A land station is a station in the mobile service not intended to be used while in motion (e.g., base, repeater, control).

[14]Spectrum requirements for electronic news gathering are discussed *infra* p. 76.

to generate large revenues. For communication service providers and users, satellite-based systems offer ubiquitous coverage of large geographical areas, the remotest of which may be uneconomical for coverage by terrestrial-based systems.

LAND MOBILE SERVICE

The land mobile service is a mobile service between fixed base stations (often with the use of repeaters) and stations capable of surface movement within the geographical limits of a country or continent (i.e., land mobile stations), or between land mobile stations.[15] These uses include mobile radiotelephony (such as cellular radiotelephone), radio paging, and dispatch-type communications. Additionally, new applications such as PCS and elements of ITS may also be licensed as land mobile services. Land mobile services are used by commercial firms, the public, and by Federal, state and local governments agencies.

One of the fastest growing segments of the mobile telecommunications industry is terrestrially-based radio services to mobile users in cars, in trucks and on foot.[16] Further, land mobile services and emerging technologies, such as PCS, are widely discussed and anticipated in the United States. For these reasons, NTIA undertook a study addressing current uses, technology trends, and spectrum requirements within the land mobile service.[17] Much of the information contained in the ensuing paragraphs is extracted from that study.

CURRENT USES OF THE LAND MOBILE SERVICE

PUBLIC USES

The general public has access to land mobile services by way of fully regulated service providers called common carriers. Common carriers are regulated by the FCC under Part 22 of the FCC Rules, and are subject to tariffs and regulations written by state public utility commissions. However, some common carrier services, such as cellular radio are now part of the Commercial Mobile Radio Service.[18] Recent legislation has amended the Communications Act of 1934 so that substantially similar services be treated with "regulatory parity". Other common carriers in the land mobile service include the conventional land mobile telephone system, and radio paging.

---

[15]*Id.* § 6.1.1 at 6-8.

[16]Motorola estimates the number of land mobile users in the United States will jump from over 33 million today to over 150 million by the year 2000. Motorola Comments at 5.

[17]SPEIGHTS ET AL., *supra* note 11.

[18]Commercial mobile services are those providing services for a profit, would be interconnection to the PSTN, and would be made available to the public.

LAND MOBILE TELEPHONE

In the mid 1960's, a mobile telephone system using analog FM, with such features as automatic frequency selection, direct dialing, and full duplex was introduced as the Improved Mobile Telephone System (IMTS). IMTS was designed to emulate the features found in the landline telephone networks. The service was field tested in Harrisburg, Pennsylvania, from 1962-1964, with commercial service offered beginning in 1965.

Conventional land mobile telephone systems have seen limited use since the inception of cellular systems. Many of the original IMTS frequencies are used in rural areas to interconnect to the local telephone service, where cellular service is not yet available.

CELLULAR TELEPHONE

The concept of cellular radiocommunications was developed by AT&T Bell Laboratories in 1947. It took, however, more than three and a half decades before the first cellular network began operating in October, 1983. As of March 1994, "1,529 cellular systems, employing nearly 40,000 people, [had] been activated in 734 markets across the United States."[19]

A cellular system is a mobile, two-way radio telephone system operating in the 824-849 MHz and 869-894 MHz bands that uses controlled, low-powered transmitters and divides the service area into small "cells". The radius of a cell, which ranges from 2 km to 32 km, is partly determined by the transmitter power of the base station, but also by careful use of terrain shielding, reduced antenna height, and directional antennas. Consequently, for a given number of frequencies per cell, the use of smaller cells allows a given frequency to be re-used in other nearby geographic areas, allowing more users to be served by a given set of frequencies.

Cellular telephony has experienced phenomenal growth since its inception in 1983. Public acceptance of cellular has grown at a rate faster than TV, cable TV, VCR's, and facsimile. Even during the recession in 1991, the number of subscribers grew at an annual rate of approximately 43 percent. This growth rate represented an additional 2.3 million new subscribers within a 12-month period. The Cellular Telecommunications Industry Association (CTIA) estimates that 17,000 subscribers are added each day. Cellular growth rate is attributed in part to the unique and appealing operational characteristics of the cellular system—mobility and instant communications. Other factors include the reduced size and decreasing prices of the mobile and portable equipment.

---

[19]Cellular Telecommunications Industry Association, 1993 Data Survey: Industry Success Story Continues, 2 (Mar. 2, 1994) (on file with NTIA).

RADIO PAGING

Radio paging, in existence since the 1950's, is one of the older forms of land-based mobile communications services. It is a one-way calling system operating within the 30 MHz, 150 MHz, 450 MHz and 930 MHz bands, which allows for ubiquitous communications access. It has evolved from the transmission of a simple tone signal or "beep" to its present orientation toward limited transmissions of alphanumeric messages. It is in this context of evolution that the radio paging industry provides various types of services and, consequently, has survived against challenges by newer types of mobile communications.

The rapid growth of the paging services is matched by the growth in retail pager distribution and new service offerings. Despite the recession in 1991, the paging industry sustained a record growth of an additional 1.9 million pagers in service compared to 1.8 million additional pagers in 1990. The U.S. paging industry reached a total of 19 million pagers in service with an estimated service revenue for 1993 of $3 billion. The paging industry experienced a 20 percent annual growth rate from 1990-1992.[20]

PRIVATE USES

The private land mobile radio (PLMR) services allow state and local governments, and commercial and non-profit organizations to use the electromagnetic spectrum for mobile and ancillary fixed radiocommunications[21] to assure the safety of life and property, and to improve productivity and efficiency. These communications are not intended for general public use. However, recent legislation has amended Section 332 of the Communications Act so that many private land mobile services would be classified as simply "commercial mobile services."[22]

The rules and regulations governing private radio are contained in Part 90 of the FCC Rules. The FCC has allocated portions of spectrum for the various PLMR services in the following bands: 25-50 MHz, 150-174 MHz, 220-222 MHz, 450-512 MHz, 806-824 MHz and 851-869 MHz (the "800 MHz" band), and 896-901 MHz and 935-940 MHz (the "900 MHz" band). Twenty PLMR services are grouped into broad categories such as public safety, industrial, and land transportation radio services. The different services are assigned different frequencies in accordance with Part 90. Channels are available for either conventional or trunked dispatch operations.

---

[20] SPEIGHTS ET AL., *supra* note 11, at 65.

[21] Spectrum requirements for private operational fixed services are discussed *infra* p. 75.

[22] BUDGET ACT OF 1993, *supra* note 1. Radio systems operated by industrial, land transportation, and public safety licensees, as well as a number of business systems, do not offer commercial for-profit land mobile services and therefore would not be classified as commercial mobile services under the recent legislative changes. These systems will continue to be regulated as private land mobile services.

Additionally, Part 90 authorizes one-way paging operations, called private carrier paging (PCP), the Location and Monitoring Service (LMS),[23] biomedical telemetry and operations within the specialized mobile radio (SMR) service.

The FCC has allocated spectrum within the 150 MHz, 460 MHz and 929 MHz bands for PCP's. Recently, the FCC agreed to open up PCP eligibility to non-Part 90 users, thus permitting services to individuals.

An SMR system is a radio system in which licensees provide land mobile communications services (other than radiolocation) on a commercial basis to eligible Part 90 entities.[24] It is a successful, multimillion dollar industry that has been in existence for two decades. SMR operators provide spectrally efficient, trunked private dispatch communications within the 800 MHz and 900 MHz bands.[25] Over 80 percent of the customers who subscribe to SMR services are in the construction, service, and transportation industries. There are over 1.5 million SMR units in operation, with industry sales in 1993 totaling $104 million. Enhanced SMR's (ESMR's) are the next generation of digital systems that provide a greater increase in capacity over the analog systems. These wide-area systems would be treated as commercial mobile systems, and hence, subject to the same "regulatory parity" as cellular systems.

Portable biomedical telemetry systems are used primarily to monitor the electrocardiogram of patients recovering from heart attacks. The systems allow ambulatory cardiac patients to move about within a hospital, while nurses monitor their heart functions from a central facility. The data is transmitted by a lightweight monitor, via radio, to a sensitive receiving system with antennas generally installed in the ceilings of the hospital corridors. Medical necessity requires that telemetry transmissions be continuous, real-time, and without any interruption or radio interference. Radio frequency spectrum currently available to support these biomedical telemetry applications includes the 174-216 MHz band on an unprotected, nonlicensed basis under FCC Part 15 Rules, and the 450-470 MHz band on a secondary basis, under FCC Part 90 Rules.

There are over 16 million PLMR transmitters, 12 million of which operate below 800 MHz. Between 1984 and 1991, the number of licensed transmitters grew at an annual rate of 10 percent per year.[26]

FEDERAL USES

The land mobile service is vital to the Federal Government in supporting the public service missions of the Federal agencies. Federal operations supported by the mobile services often represent nationwide or worldwide applications, as well as local service areas that can range in location from remote to urban areas.

---

[23]The Location and Monitoring Service is discussed beginning *infra* p. 19.

[24]Also included as eligible users are individuals and Federal agencies. *See* 47 C.F.R. § 90.603 (c).

[25]SMR's also provide interconnection to the local land lines.

[26]TIA MCD Comments at 3.

The Federal Government's requirements differ significantly from that of most of the non-Federal users because of the safety-of-life implications of many Federal services, the Federal need for nationwide coverage, missions that are mandated by Congress and the President, and operations that are not revenue-driven. Among these unique requirements or missions are: protection of the President and other high-level officials, both U.S. and foreign, providing for the national security; promoting public safety and efficiency in traveling via air, water and land; interdicting entry of illegal personnel and substances into the United States; establishing communications between disaster areas and relief forces; ensuring the swift search and rescue of human life; protecting the national forests, parks, and farmlands; bringing to justice perpetrators of Federal crimes; and ensuring the security of energy generation and distribution networks. In addition, Federal emergency response and public safety organizations conduct large scale exercises to prepare for and respond to a wide variety of emergencies and disasters, such as hurricanes, earthquakes, and chemical and nuclear power plant accidents.

The Federal Government non-tactical land mobile operations are accommodated in portions of the 30-50 MHz, 138-150.8 MHz,[27] 162-174 MHz, 220-222 MHz, and 406.1-420 MHz bands. These bands, specifically the 162-174 MHz and 406.1-420 MHz, are the most widely used by the Federal agencies. Currently, there are 48 Federal agencies authorized to operate in the 162-174 MHz band and 47 agencies in the 406.1-420 MHz band. The land mobile service is the dominant service used by the Federal agencies in these bands. Federal trunked mobile radiocommunications systems are accommodated primarily in the 406.1-420 MHz band.

A typical Federal non-tactical land mobile radio system uses a wide range of equipment in a variety of geographic environments supporting voice and data communications for non-tactical operations. The range of equipment includes base, repeater, vehicular, and hand-held stations. Federal land mobile radio systems are usually multi-purpose systems; for example, law enforcement, natural resource, medical, administrative, and utility functions may be supported by the same radio system or network. The radio systems, which are purchased from commercial vendors, are similar to those employed by non-Federal entities.

Federal land mobile service operations, other than radio paging, are usually two-way communications between a base and mobile station or between mobile stations. Federal users communicate in a dispatch/supervisory mode (one-to-many) or communicate in a one-to-one mode while other users monitor the channel and take action as appropriate. Typical messages from mobile sources are of relatively short duration. Typical channel hold times for Federal Government mobile communications are quite short, usually less than a minute. Under these circumstances, one or more channels can often be shared by several independent users. Although Federal agencies use common carrier services such as cellular telephones[28] and

---

[27]In addition, Department of Defense (DOD) aircraft use frequencies in the 138-144 MHz and 148-149.9 MHz bands to communicate with DOD ground forces in tactical scenarios.

[28]The Interagency Cellular Working Group estimates about 5000 cellular telephones in use by the Federal Government (exclusive of the DOD). Letter from R. Otis and C. E. Cape, Co-chairmen, Interagency Cellular Working Group, to David J. Cohen, NTIA (Mar. 3, 1993) (on file with NTIA).

radio pagers to augment communication needs, they do not serve as replacements for the agency's own land mobile systems.

The number of assignments in Federal land mobile bands has been steadily increasing over the last 20 years, particularly in the 138-150.8 MHz, 162-174 MHz, and 406.1-420 MHz bands, reflecting the increase of missions in support of the public. The number of assignments in the 30-50 MHz band has been increasing at an average rate of approximately 3 percent per year,[29] while the 138-150.8 MHz band growth rate is nearly 7 percent per year. The assignment growth rate in the 406.1-420 MHz band has been 12 percent per year over the last three years, while the 162-174 MHz band experienced an 8 percent per year increase over the same period.

TRENDS WITHIN THE LAND MOBILE SERVICE

Currently, significant effort is being focused on the land mobile services in order to increase their spectral efficiency and capacity, and to satisfy increasing user demand. The Federal and non-Federal sectors are undertaking parallel efforts to increase spectrum efficiency in the land mobile bands that are under their respective control. Two of the more important technology trends in the land mobile service are the migration to narrowbanding and to digital, multiple-access techniques.

NARROWBANDING

The FCC, recognizing the growing spectrum requirements of the PLMR services, has plans to "refarm" the PLMR bands below 512 MHz. On July 2, 1991, the FCC released a Notice of Inquiry (NOI)[30] to gather information on how to promote more efficient use of the frequency bands below 512 MHz allocated to the PLMR services. The NOI solicited comments on a wide range of technical and policy issues, with the overall goal of developing new rules to support future technologies relating to PLMR bands below 512 MHz. Over 120 comments and reply comments were received by the FCC, mainly from the private sector. Many of the commenters emphasized the urgency to increase spectrum efficiency through technical and policy changes.

Based on the received responses to the NOI, the FCC adopted on October 8, 1992, a Notice of Proposed Rulemaking (NPRM)[31] that contained a comprehensive set of proposals designed to increase channel capacity through narrowbanding,[32] promote efficient use of PLMR bands, and simplify current

[29]One reason for the slower growth in this band is that numerous assignments are used for wide-area operations.

[30]*Spectrum Efficiency in the Private Land Mobile Radio Bands in Use Prior to 1968*, Notice of Inquiry, PR Docket No. 91-170, 56 Fed. Reg. 31,097 (1991).

[31]*Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them*, Notice of Proposed Rule Making, PR Docket No. 92-235, 57 Fed. Reg. 54,034 (1992).

[32] In this refarming, the proposed channeling plan would eventually reduce channel spacing to 6.25 kHz or less.

policies governing the use of PLMR bands below 512 MHz. In addition, the FCC proposed to abolish Part 90 and create Part 88 of the FCC Rules.

In the fall of 1992, Congress requested that NTIA develop and implement a plan for Federal agencies to use wireless technologies that are at least as spectrum efficient and cost effective as readily available commercial mobile radio systems.[33] In response, NTIA began its efforts by analyzing the current Federal land mobile infrastructure with respect to spectrum efficiency and cost effectiveness.[34] NTIA has selected a 12.5 kHz channel width for rechanneling, which will double the number of basic channels available. Federal agencies have already begun procurement of these new radios for the 162-174 MHz and 406.1-420 MHz bands. The 138-150.8 MHz band is also to be rechannelized.

The resulting plan will ensure that Federal agencies use commercial or shared land mobile services where practical, use the most spectrally-efficient technologies available by halving the permissible channel widths;[35] and use the spectrum allocated to land mobile services more efficiently by restructuring provisions for its use.

Jointly sponsored by the Association of Public-Safety Communications Officials International, Inc. (APCO),[36] the National Association of State Telecommunications Directors (NASTD), [37] the Telecommunications Industry Association (TIA)[38] and agencies of the Federal Government (NTIA, National Communications System, National Security Agency), APCO Project 25 was formed to develop interoperability standards for the next generation public-safety mobile radio, including standards for trunked systems, mobile data systems, console interface, and encryption. The goals of Project 25 are "to develop standards for equipment which would ensure a graceful migration between techniques and intercommunications between the products of different manufacturers."[39] These systems will use 12.5 kHz channels, with a full range of digital data and vocoder features, including encryption. It is anticipated that the work being accomplished in Project 25 will have a profound effect on Federal and non-Federal public safety services.

---

[33]NTIA ORGANIZATION ACT, *supra* note 3.

[34]DAVID J. COHEN ET AL., NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, NTIA REPORT 93-300, LAND MOBILE SPECTRUM EFFICIENCY (1993).

[35]In addition, 12.5 kHz radios are expected to be adopted as the standard by Federal, state and local law enforcement agencies to ensure baseline interoperability. *Id.* at 12. If the FCC chooses a different channel width as a consequence of its refarming initiative, NTIA will evaluate the impact of this decision on Federal operations, spectrum-efficiency and cost considerations.

[36]APCO represents state, county and city police, fire, highway maintenance, emergency medical and local government functions. With a broad base international membership of over 9,500, it is the largest public safety telecommunications organization.

[37]NASTD members are the Directors of Telecommunications for 49 states who are responsible for the planning and implementation of critical state government and public safety telecommunications systems.

[38]TIA represents manufacturers and suppliers of telecommunications equipment. TIA also develops and produces technical standards for telecommunication systems.

[39]APCO Comments at 6.

DIGITAL

Although cellular radiotelephony represents a revolutionary advance in mobile communications technology, most systems transmit voice signals using standard analog FM within a 30 kHz channel bandwidth. Because of the limited capacity per channel offered by this technology, there is a need to venture into other technologies that can provide the solution to the current, limited capacity in the cellular industry. Most manufacturers in the cellular industry agree that digital technology offers greater capacity per channel and more features, such as improved voice transmission quality, improved security, and greater system accessibility than analog FM technology.[40] However, a dilemma within the cellular community has arisen as to what digital technology will be implemented for the U.S. cellular industry.[41]

In 1992, the cellular common carrier section of the TIA TR-45 committee developed a U.S. cellular industry standard, called the "IS 54", based on a digital, TDMA technology. Pioneers of TDMA have claimed a threefold increase in capacity per channel over conventional analog cellular systems for the first generation of the TDMA systems. The next generation of TDMA systems will further increase the capacity of a channel to six times over the standard analog systems. In February 1992, the CTIA endorsed TDMA as a standard.

Other digital systems employing different techniques such as code-division multiple-access (CDMA) or spread spectrum are being implemented. In early 1992, PacTel Cellular was the first cellular entity to commit to the CDMA format. During that time, the TIA's TR-45 committee voted to begin a standards-making process for spread spectrum, represented by CDMA technology. Preliminary analysis of CDMA systems project several advantages over TDMA, including the ability to share frequencies with other radio services and substantially greater capacity (e.g., 20 times as much as existing conventional analog systems). After three years of development, testing and demonstrations, TIA Subcommittee 45 adopted CDMA digital technology as an industry standard called IS-95. The progression toward a digital system is inevitable and will definitely bring about increased use of mobile, non-voice services such as facsimile, E-mail and others, over the cellular network system.

A trunked system supports a number of users on a group of channels, providing the spectrum efficiency benefits of channel sharing while minimizing blocking. When a user wishes to make a call, the system selects an available channel from the group and automatically tunes the user's transmitter to that channel while directing the appropriate receivers to switch to that channel also. Trunking improves spectrum efficiency by providing more user access for a given number of channels. Next-generation trunking systems

---

[40]Deployment of digital technology has been delayed for several reasons: improvements in existing analog technology; the recession, which has slowed the growth in usage, thereby reducing the pressure to expand system capacities; and the controversy over CDMA/TDMA.

[41]Narrowbanding is another technology within the cellular industry. Current conventional analog systems operate at 30 kHz channel bandwidth. A technology called narrowband-advanced mobile phone service (NAMPS), triples the capacity of a cellular voice channel by splitting the current channel into 10 kHz of channel bandwidth. In early 1992, several cellular entities urged TIA to adopt narrowband cellular technology as a standard. In November 1992, TIA released standards for narrowband analog mobile phone service (IS-88, IS-89, and IS-90).

will be even more efficient than current trunking systems. Nextel, formerly Fleet Call, has recently activated the first digital trunked mobile network in Los Angeles, Riverside, and parts of Orange and Ventura Counties in California.[42] This ESMR system incorporates innovative state-of-the-art technology, including digital speech coding and TDMA transmission, to create six voice channels using a single 25 kHz channel. ESMR's use low-power base stations, permitting geographic frequency reuse. Nextel estimates that these technologies can provide over 15 times the customer capacity as existing SMR systems.[43]

EMERGING USES

INTELLIGENT TRANSPORTATION SYSTEM

In the United States, there is growing interest in the development of an automated highway system that will provide for safer and better informed travelers, improved traffic control systems, systems aimed at increasing the efficiency of commercial vehicle and transit operations, and increase national productivity. Advanced technologies will be an integral element of a future transportation infrastructure. Probable configurations will both include mobile data links between vehicles and links between vehicles and the roadside infrastructure for automatic toll collection, route guidance, collision avoidance, etc. ITS is the general term applied to this broad application of modern communications, location, and control technologies to the needs of vehicle transportation. The next five years will see the research and development, evaluation, and operational testing of the following ITS projects and applications:

- ❑ Traveler Information Systems
- ❑ Route Guidance and Navigation Systems
- ❑ Transit Fleet Management Systems
- ❑ Fare Collection and Smart Cards
- ❑ Collision Avoidance Systems
- ❑ Transportation Demand Management Systems
- ❑ Traffic Control Systems
- ❑ Rural Applications
- ❑ Commercial Vehicle Applications
- ❑ Commercial Vehicle Network Systems
- ❑ Automated Highway Systems[44]

The Federal Government involvement in the ITS stems from the Intermodal Surface Transportation Efficiency Act of 1991, which designates the Department of Transportation (DOT) as the lead agency.[45] The

---

[42]Fleet Call Comments at 4. Nextel also plans to construct and operate these systems in other larger metropolitan areas in the country. Seth Malgieri, *Wall Street Smiling on ESMR's after Nextel-OneComm Merger*, RCR RADIO COMMUNICATIONS REPORT, Aug. 1, 1994, at 23, 23.

[43]Fleet Call Comments at 4.

[44]U.S. DEP'T OF TRANSPORTATION, IVHS STRATEGIC PLAN 48 (1992) [hereinafter IVHS STRATEGIC PLAN].

[45]See Intermodal Surface Transportation Efficiency Act of 1991, Pub L. No. 102-240. § 6052 (b), 105 Stat. 1914, 2189 (1991) (ISTEA). In this Act, Congress emphasized the importance of ITS systems and provided substantial funding to plan, develop, and deploy concepts and technologies for communications controls, navigation, and information systems to reduce highway congestion, improve highway safety, and render highway traffic more compatible with the environment. ISTEA authorized $660 million over a six-year period.

DOT recently completed a national strategic plan and has initiated efforts to develop a national ITS architecture by 1996.[46] In the coming years, the DOT will be working as partners with the Intelligent Transportation Society of America (ITS AMERICA, formerly IVHS AMERICA) and its members to help guide and advance the national ITS program.[47]

The DOT, recognizing that the many radiocommunication elements of ITS would be frequency-dependent, developed a radio frequency acquisition strategy for ITS. Its two aims are: first, to obtain specific dedicated frequencies suitable for supporting certain baseline ITS functions on a nationwide basis; and second, to maintain currently available spectrum and identify new opportunities for sharing communications capacity with emerging telecommunications technologies.[48]

The ITS will be supported by more than one radio service. Some ITS projects and programs are currently being defined, while other projects are in the testing and evaluation or operational stages. The radio service associated with these projects and programs depends on the use, and could be a combination of the mobile, radiolocation, radionavigation, radionavigation-satellite, fixed, and possibly broadcasting services in the near future. ITS could also employ Part 15 devices and PCS systems. Since most of the ITS systems and user functions are related to the mobile radio service, ITS is included in this chapter.

CURRENT USES

Current ITS-related systems operate from 100 MHz to 1 GHz. Most of the commenters to our Inquiry focused in this frequency range. Present FCC policy allows the use of the 902-928 MHz band for LMS functions.[49] One LMS system currently uses 904-912 MHz and employs pulse-ranging multilateration techniques.[50] In this system, a vehicle location unit installed in a vehicle communicates with a computer at a network control center through a network of transmission and receiving towers. Within a defined geographic area, a host of practical applications can be provided: monitoring the location of fleet vehicles, accurate tracking of stolen vehicles, and helping motorists in distress.

---

[46]DOT used the National Highway Traffic Safety Administration's IVHS Plan, NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION, IVHS PLAN (1992), and IVHS AMERICA's Strategic Plan, IVHS AMERICA, STRATEGIC PLAN FOR INTELLIGENT VEHICLE-HIGHWAY SYSTEMS IN THE UNITED STATES (1992), as inputs to develop the DOT plan, IVHS STRATEGIC PLAN, *supra* note 44, at 1.

[47]ITS AMERICA (formerly IVHS AMERICA) is a Federal Advisory Committee to DOT and is a non-profit educational and scientific organization whose purpose is to coordinate and promote the research and development of ITS in the United States. Membership ranges from federal, state, and local government to private industry and academia. IVHS AMERICA Comments at 1.

[48]IVHS STRATEGIC PLAN, *supra* note 44, at 51.

[49]LMS systems are used to locate and track vehicles using non-voice methods and to relay information to and from vehicles. In the 902-928 MHz band, LMS systems operate on Part 90 or secondary basis to Federal Government users and must also accept interference from industrial, scientific, and medical devices.

[50]Pacific Telesis Comments at 16.

Narrowband LMS systems also operate in the 904-912 MHz and 918-926 MHz bands. In one of these types of systems, a tag is affixed or placed in the vehicle to be located. The vehicle is interrogated by the LMS station as it passes nearby. The interrogating signal is either modulated with unit-specific information and reflected back to the station's receiver, or the tag transmits its own signal in response to the interrogation.[51] As with the system described above, status information or instructions can be transmitted to and from the unit being monitored or located.

One city has equipped a large number of its public buses with LORAN-C receivers and 800 MHz mobile radios for fleet monitoring to help provide greater on-time services. Bus locations are determined by the LORAN-C receivers and transmitted via the radio to a central dispatch center. Bus status information is provided to the public while simultaneously improving bus schedule adherence and labor productivity.[52] A major commercial bus company is presently using a vehicle on-board radar (VORAD) collision warning radar system on its 2,400 buses, which notifies drivers when vehicles or objects are in critical areas in front of or in the blind spots of the buses.[53] The forward-looking radar operates at 24.125 GHz; the blind spot radar at 10.525 GHz. In-vehicle navigational systems that provide information to the driver using both video displays and voice outputs to provide electronic maps, route guidance, and vehicle location are under operational testing. These include: ADVANCE (Chicago), FAST-TRAC (Detroit), and Pathfinder (California).[54] Further, U.S. car manufacturers will be offering a route guidance and navigation system as an option on some 1995 cars.

TRENDS

Today, ITS services such as the automatic vehicle monitoring, stolen vehicle recovery, and electronic toll and traffic management services are becoming readily available in the United States. Additionally, ITS products are increasingly available, including vehicular collision avoidance radar, in-vehicle computer-based navigation systems, and electronic road signs. The FCC is considering the creation of the Transportation Infrastructure Radio Service (TIRS) to regulate, as it pertains to ITS, new services and or spectrum as they are added to improve the nation's transportation system.

PERSONAL COMMUNICATIONS SERVICES

The increase in demand for mobile telecommunications has given rise to a wide array of new technologies and systems. This wide array of future alternative services spans a very large range of frequency

---

[51] This technology of reflecting energy back to a receiving unit is often described as "modulated backscatter." AMTECH Comments at 2.

[52] FEDERAL HIGHWAY ADMINISTRATION, U.S. DEP'T OF TRANSPORTATION, FHWA-SA-92-036, INTELLIGENT VEHICLE-HIGHWAY SYSTEM (IVHS) PROJECTS IN THE UNITED STATES 34 (1992) [hereinafter IVHS PROGRESS REPORT].

[53] FEDERAL HIGHWAY ADMINISTRATION, U.S. DEP'T OF TRANSPORTATION, IVHS PROGRAM PROGRESS REPORT 10 (1993).

[54] IVHS PROGRESS REPORT, *supra* note 52, at 17, 19, 21, 22.

allocations, expected data bandwidths, and assumptions regarding user mobility, location, and personal choice of potential service offerings.

Countries and businesses around the world have proposed new mobile applications that will deliver a wide variety of new (and old) services, including paging and messaging, telephone, facsimile, data communications, and even imaging and video. In the United States, these systems are often included in PCS. Many consider the international counterpart of PCS to be the Future Public Land Mobile Telecommunications Systems (FPLMTS).[55]

The term "PCS", as defined by the FCC, is a family of mobile or portable radiocommunications services which could provide services to individuals and businesses, and be integrated with a variety of competing networks. Emerging PCS will include some services that are not currently being offered to the public, and are conceptualized to provide a new combination of capabilities.

The FCC has recently allocated a total of 140 MHz of spectrum for 2 GHz PCS. The FCC adopted a modified plan that provides for three 30 MHz licenses (Blocks A, B, and C) and three 10 MHz licenses (Blocks D, E, and F), all of which are within the 1850-1990 MHz band. The FCC also maintained an allocation of spectrum at 1910-1930 MHz for unlicensed PCS devices and committed to examine in the near future allocation of additional spectrum for unlicensed PCS operations. Also, 80 MHz of spectrum will be placed in reserve. Figure 1-1 summarizes what the FCC has authorized for new PCS services in the 2 GHz band and, for comparison purposes, what WARC-92 has identified for FPLMTS and has allocated for mobile-satellite service uplinks and downlinks in these bands.

The PCS being developed today will have significant improvements over those services currently available. Among these emerging PCS are telepoint and advanced telepoint, personal telecommunications (e.g., Personal Communications Network or PCN and Enhanced Private Communications or EPC), advanced cordless, and wireless private branch exchange (PBX). The most significant trend of these emerging services appears to be toward person-to-person communications, vice telephone-to-telephone (i.e., universal personal communications). Future PCS would permit individuals to use the same identification number in several different environments. Some of the emerging PCS are briefly described below.

---

[55]The focus of WARC-92's attention to mobile services was on Future Public Land Mobile Telecommunications Systems (FPLMTS). WARC-92 did not formally allocate any frequencies for FPLMTS, but it did note that the 1885-2025 MHz and 2110-2200 MHz bands (a total of 230 MHz) are intended for use by FPLMTS. INTERNATIONAL TELECOMMUNICATION UNION, FINAL ACTS OF THE WORLD ADMINISTRATIVE RADIO CONFERENCE FOR DEALING WITH FREQUENCY ALLOCATIONS IN CERTAIN PARTS OF THE SPECTRUM (WARC-92) 59-60, 62 (1992) [hereinafter WARC-92 FINAL ACTS].

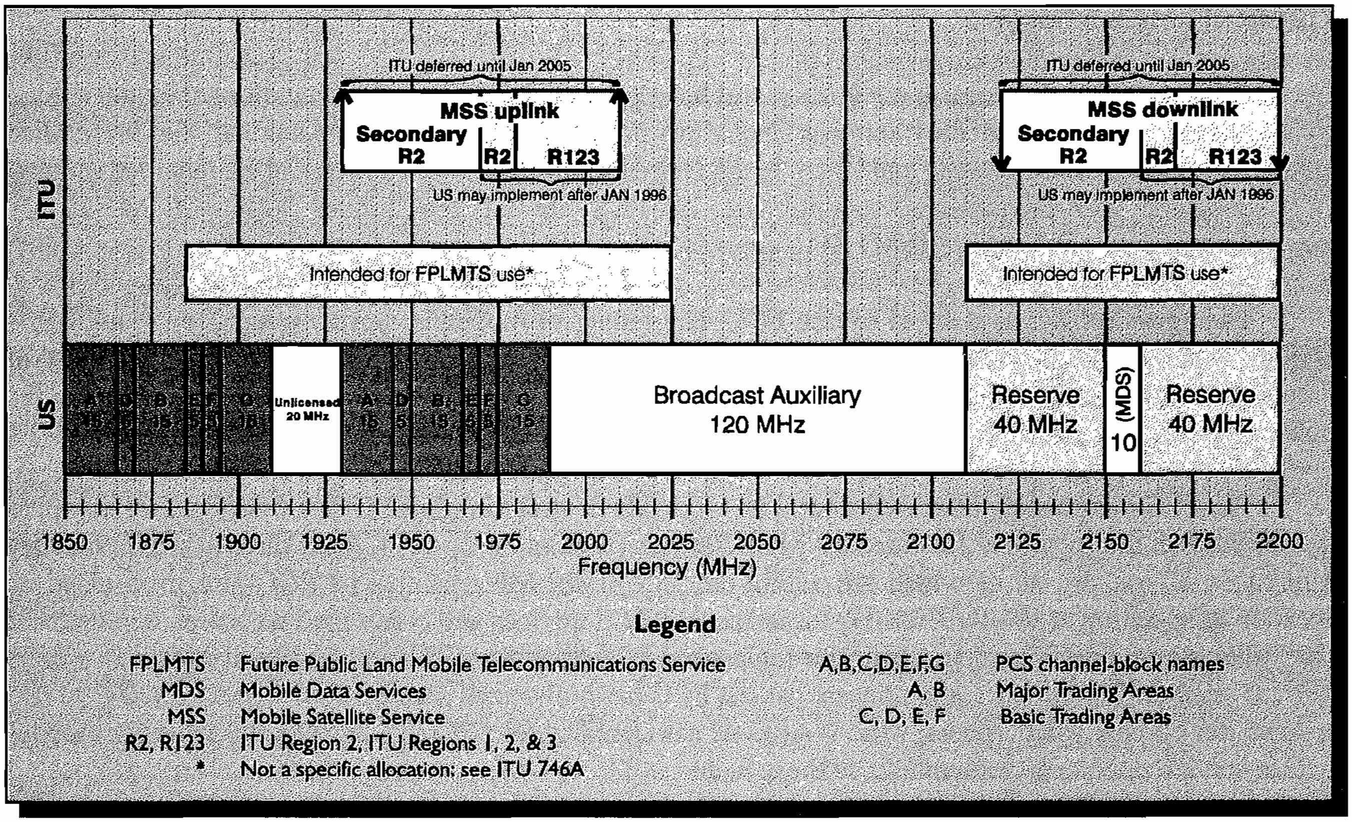


Figure 1-1. Emerging wireless technologies allocations.

SYSTEMS

TELEPOINT

Telepoint is a service that offers the ability to place calls from a pocket-sized telephone whenever the user is within range of a serving base station. It provides call origination only from a personal device into the PSTN. The coverage provided by a telepoint system is limited to discrete locations; hand-off between base stations is not provided. It provides medium-to high-quality voice and low-speed data communications. The handsets are relatively small, lightweight and low-cost.[56]

[56]It is not known how successful telepoint services will be in the United States. In the United Kingdom, telepoint services failed to attract many subscribers and the industry has recently decided to terminate telepoint services in the United Kingdom. However, telepoint services in Hong Kong are doing satisfactorily and has begun to make a profit, with a reported 70,000 plus subscribers, compared to the 9,000 subscribers in the United Kingdom.

ADVANCED TELEPOINT

Advanced telepoint is a service that allows a user to both place and receive calls from their personal device. Hand-off between base stations is possible, giving a limited amount of mobility during the call is envisioned. Like telepoint, advanced telepoint would provide high-quality voice and low-speed data communications but, probably faster than telepoint. When offered to closed user-groups, like residences or private businesses for example, such service would be described as Advanced Cordless/Wireless Private Branch Exchange (AC/WPBX). Hand-off between a private and public network would be possible, but not required.

PERSONAL TELECOMMUNICATIONS SERVICES

Personal Telecommunication Services (PTS) is a service that will bear a functional resemblance to cellular service from an end-user perspective. The main difference is that the size of a PTS cell will be much smaller than that of the cellular systems, thus permitting lower power transmitters than cellular and smaller, lighter handsets than cellular. PTS would provide high-quality voice and medium-speed data communications. It would also provide call origination and termination from a personal device to other devices or locations. The coverage provided by a PTS network will be ubiquitous within a defined service area, for example, local, wide-area or regional. Hand-off between base stations would be provided and hand-off between a private and public network would be possible, but not required.

ADVANCED CORDLESS/WIRELESS PRIVATE BRANCH EXCHANGE (AC/WPBX)

AC/WPBX is a service that will be offered to closed user-groups or used as part of an internal communications system. AC/WPBX would provide high-quality voice and medium-speed data communications. It would provide call origination and termination from a personal or shared device to the PSTN. Coverage would be limited to defined service areas, typically within buildings or neighborhoods. In addition, the coverage might be extended or integrated with a public network such as Advanced Telepoint, ESMR, Enhanced Cellular, or PTS. Hand-off between base stations would be provided and hand-off between a private and public network would be possible, but not required. Handsets are expected to be similar in size and weight to other PCS units.

DATA DEVICES

Data devices would provide non-voice communications between terminals. For example, these devices would send data messages in the form of electronic mail or facsimile through wireless local area networks (LAN's) and pagers. Some companies have already developed booksize PCS devices that reportedly combine a cellular phone, note pad, fax machine and personal computer. Generic names for such devices include Personal Digital Assistant and Information Appliance.

POTENTIAL USERS

COMMERCIAL

An unresolved issue is whether or not consumers who already have access to cellular phones, pagers, voice mail, and other wireless communications will pay for yet another technological alternative. Some analysts predict that PCS will generate revenues between $35 to $40 billion beyond current wireless revenue levels.[57]

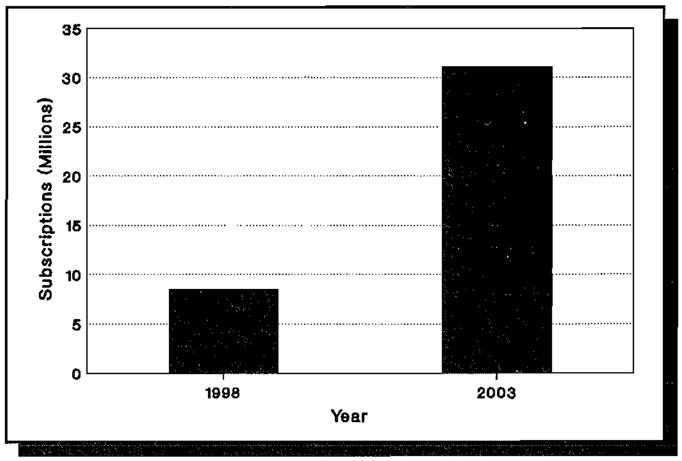


Figure 1-2. PCS market forecast.

A PCS market forecast for the years 1998 and 2003 is shown in Figure 1-2. Values in the figure for the emerging 2 GHz PCS were derived from a survey conducted by the Personal Communications Industry Association (PCIA)[58] in January, 1994. PCIA estimates that there will be 8.55 million subscriptions[59] for new 2 GHz PCS services in 1998. This estimate is based on a penetration of the population of 3.1 percent. In 2003, PCIA estimates that the number of subscriptions to new 2 GHz PCS will be 31.11 million, based on a penetration of the population of 10.4 percent. This represents a 264 percent increase from 1998 estimates. Assuming linear growth extrapolation, the number of subscriptions in 2004 could be approximately 35 million.

FEDERAL GOVERNMENT

Federal user requirements for emerging wireless services encompass a broad array of user needs in the civil and defense agencies. Emerging wireless services will enhance the performance and efficiency of the day-to-day operations of law enforcement, drug enforcement, health and human services, defense, and countless other activities. These services will also play a significant role in disaster relief and crisis situations. These requirements have been generally characterized as Digital, Ubiquitous, Interoperable, Transparent, and Secure (DUITS).

---

[57] ARTHUR D. LITTLE, WIRELESS/PERSONAL COMMUNICATIONS SERVICES IV (Conference, Washington, D.C., Mar. 10-11, 1992) (*in* Bell Atlantic Comments at 6).

[58] PERSONAL COMMUNICATIONS INDUSTRY ASSOCIATION, 1994 PCS MARKET DEMAND FORECAST (1994) [hereinafter PCIA MARKET FORECAST]. PCIA, formerly Telocator, is a national association representing the mobile communications industry, including paging, cellular, mobile telephone and PCS.

[59] The methodology used by PCIA tracks subscriptions to mobile services, not individual subscribers. Subscriptions will always be greater than subscribers because many individuals will subscribe to multiple services.

Federal use of emerging wireless services such as PCS services will supplement the Federal mobile service infrastructure. The Federal Wireless Users' Forum (FWUF) is reviewing Federal requirements for PCS and has suggested that Federal PCS requirements may be accommodated by one or more of the following spectrum approaches:[60]

- ❑ The use of commercial service by lease or subscription
- ❑ The use of PCS frequencies as a secondary Federal allocation to a primary non-Federal mobile application (e.g., a CDMA overlay)
- ❑ The use of leased commercial systems on Federal frequencies
- ❑ The use of Federal-owned systems on Federal frequencies
- ❑ The use of dynamic spectrum sharing (An example of this would be the dedicated use of some bands for commercial use with the option for government access in emergencies or national disasters.); or
- ❑ Unlicensed operations (e.g., wireless LAN's and wireless PBX's).

The Department of Veterans Affairs (VA) stated in its comments that PCS will have a major impact on two-way communications, possibly reducing or eliminating their requirements for conventional two-way radio, cellular, and radio paging systems.[61] Other Federal agencies have indicated that PCS may provide only limited spectrum relief or have little impact on land mobile users.[62]

The Department of Energy (DOE) has formulated a strategic planning program for its Information Resource Management into the 21st Century called IRM Vision 21. Since radiocommunication services are a critical element of the program, DOE used IRM Vision 21 as a basis for its response to the *Inquiry*. If DOE projections for the rapid development and deployment of PCS are accurate, PCS will soon be an important element of the mobile radio infrastructure. In particular, DOE offers these predictions for the future of PCS services:

> Emerging telecommunications technologies such as PCS promise effectiveness and efficiency throughout the Federal Government and the United States. PCS will also significantly change the telecommunications infrastructure within the Federal Government. DOE radiocommunication strategies [include the use of] terrestrial and satellite PCS network

---

[60]FWUF Comments at 2-3. FWUF is intended to represent Federal Government wireless telecommunication users. Participation by state and local government users, non-government users, as well as the wireless telecommunications industry is encouraged.

[61]VA Comments at 2.

[62]*See e.g.*, DOI Comments at 2; DOJ Comments at 2.

> systems, when and where feasible and practical, to augment and/or replace existing land mobile communication systems . . . . Terrestrial and satellite PCS networks and systems will be available in the mid to late 1990's. The Federal Government should consider the feasibility of obtaining a PCS version of the Federal Telecommunications System 2000 network . . . . [DOE] intends to evaluate PCS when available and envisions the potential use of wireless and PCS in the next 5 to 10 years, which will significantly change the telecommunications infrastructure throughout DOE.[63]

DEVELOPMENT OF SPECTRUM REQUIREMENTS FOR THE LAND MOBILE SERVICE

The fundamental dilemma facing the land mobile industry is whether there is currently enough spectrum to handle the anticipated demand and, if not, whether future technology will provide the necessary relief. It is clear that demand for land mobile services of all kinds is increasing. The driving force behind this demand can be attributed, in part, to the appealing nature of mobility and hence, instant communications. This is evidenced in Motorola's sales of portable units, which increased from 40 percent of all units sold in 1980 to 60 percent in 1991.[64] In addition, many users rely on land mobile communications to ensure the safe and efficient conduct of business. Hence, the use of land mobile radio is an occupational imperative.

Several commenters indicated that technology will provide only limited relief. TIA indicated that although there has been significant progress in technological advancement, the demand for land mobile spectrum may be pushed to the limits of practicality.[65] The Land Mobile Communication Council (LMCC) stated that growth in urban areas must be satisfied with techniques other than just technological advances, for example, more spectrum.[66] In contrast, however, Fleet Call believes that technology still has the ability to relieve spectrum congestion.[67] Most of the commenters to the *Inquiry* indicated that land mobile services need additional spectrum.

REQUIREMENTS

PUBLIC SAFETY REQUIREMENTS

There is growing concern not only by public safety users and manufacturers, but Congress as well, over the lack of spectrum dedicated for public safety use. A variety of factors, including increasing population density and higher crime rates, are placing ever-increasing demands on public safety agencies and, therefore,

---

[63]DOE Comments at 1-4.

[64]Motorola Comments at 9.

[65]TIA MCD Comments at 2.

[66]*See*, Comments of LMCC (filed Jan. 15, 1992) in *Spectrum Efficiency in the Private Land Mobile Radio Bands in Use Prior to 1968*, PR Docket No. 91-170.

[67]Fleet Call Comments at 2-3.

their communication systems.[68] APCO contends that in the interest of public safety, additional spectrum is needed. APCO contends that while new technology will alleviate some requirements, it cannot keep pace with ever-increasing demands. APCO urges NTIA to work with the FCC to find ways to allocate additional spectrum for vital public safety communications.[69]

In 1985, the FCC released an extensive study projecting public safety needs through the year 2000.[70] This study estimated that to meet the anticipated demand, additional public safety frequency allocations of between 12.5 MHz and 44.6 MHz would be needed in the 21 largest metropolitan areas by the year 2000, even assuming the use of advanced spectrum efficient technologies.[71] APCO noted that "so far, the FCC has allocated just 6 MHz nationwide in the 800 MHz band for public safety (and an additional 6 MHz in the UHF TV band for the especially congested Los Angeles area)."[72] APCO notes that future technologies now being developed suggest even greater spectrum needs. These include, for example, the ability to transmit maps, criminal records, mug shots, fingerprints, and even the use of video.[73]

The Omnibus Budget Reconciliation Act of 1993 requires that the FCC, by February 1995, complete a study of the current and future spectrum needs of public safety agencies through the year 2010 and develop a specific plan to satisfy those needs.[74] Because of similar wireless communications needs of both Federal public safety agencies and state and local public safety agencies, the FCC has asked NTIA for assistance regarding this study.[75] Additionally, NTIA, as part of the Land Mobile Efficiency Plan,[76] will investigate the common public safety spectrum needs of Federal, state, and local agencies and explore the potential for increased sharing of systems and spectrum resources.

APCO has provided input to the FCC regarding that study and has made the following suggestions for spectrum requirements:[77] allocate, as soon as possible, an additional 12 MHz in major markets and an additional 6 MHz nationwide for existing public safety communications services; and an allocation of 25 MHz

---

[68]APCO Comments at 2.

[69]*Id.* at 12.

[70]*Future Public Safety Telecommunications Requirements*, PR Docket 84-232, FCC 85-329 (August, 1985). APCO notes that this study made 1992 projection on the number of licensed radio stations that are 70 percent less than the actual number to date. APCO also notes that this study did not account for more recent public safety radio spectrum uses, such as mobile data terminals. APCO Comments at 3.

[71]*Id.* at 106 (Table 37).

[72]APCO Comments at 3.

[73]*Id.* at 5.

[74]BUDGET ACT OF 1993, *supra* note 1.

[75]Letter from Beverly Baker, Deputy Chief, Private Radio Bureau to Richard Parlow, Associate Administrator, Office of Spectrum Management, October 29, 1993 (on file with NTIA).

[76]COHEN ET AL., *supra* note 34, at 13.

[77]Association of Public-Safety Communications Officials–International, Inc., Public Safety Spectrum Needs Analysis and Recommendations at 18 (Aug. 1994) (unpublished manuscript, on file with NTIA) [hereinafter APCO].

by 2000 and another 50 MHz by 2010 to facilitate implementation of new public safety telecommunications technologies. These future systems will support an increasing number of voice, data, graphics and video services to include dispatch/telephone interconnect, transaction processing, facsimile, snapshot, decision support, slow video and full motion video.

The APCO analysis of spectrum requirements noted that the number of public safety licenses increased at a rate that approximately doubled the number of licenses in a 10-year period. We agree with APCO in this regard, and our analysis of dispatch spectrum requirements includes this factor when the additional dispatch spectrum requirements were evaluated.

BIOMEDICAL TELEMETRY REQUIREMENTS

The biomedical telemetry users view the currently allocated bands as increasingly subject to noise and radio interference and that these bands may become unavailable over the course of the next ten years, as a result of the FCC spectrum "refarming" efforts. Reflecting these concerns, the House-Senate Conference Report on Title VI states,

> "The Conferees note that advances in low power (e.g., below 5 mW) biomedical telemetry systems may greatly improve the quality and significantly decrease the cost of certain health care services. These systems are designed to operate in either the VHF or UHF bands. The Conferees believe that the NTIA and the FCC should carefully consider the needs of hospitals and other health care providers for interference-free radio spectrum in their respective allocation decisions made pursuant to this Act."[78]

Subsequent to enactment of Title VI, representatives from the biomedical telemetry industry[79] further clarified industry spectrum needs, specifically stating a need for an allocation of 12 MHz.

OTHER REQUIREMENTS

The Department of Justice indicated that the 162-174 MHz and 406-420 MHz bands are inadequate for many law enforcement purposes.[80] TIA indicated that land mobile services deserve a proprietary position in allocations of additional spectrum.[81] The LMCC supports efforts to make additional spectrum available for private land mobile use.[82]

---

[78] H.R. CONF. REP. NO. 213, 103rd Cong., 1st Sess., pt. 4, at 8 (1993).

[79] Hewlett-Packard Medical Products Group et al., *Spectrum Needs of the Biomedical Telemetry Industry* (no date) (on file with NTIA).

[80] DOJ Comments at 2.

[81] TIA MCD Comments at 9.

[82] LMCC Comments at 2.

The Coalition of Private Users of Emerging Multimedia Technologies (COPE) has filed a petition for rulemaking, requesting the FCC to allocate 75 MHz of spectrum, in aggregate, to establish a Private Land Mobile Advanced Communications Service.[83] The petition indicates that there is a need for spectrum for new services that will not and/or cannot be provided via carrier-based services such as PCS. The regulatory scheme adopted for PCS makes it impractical for private users to obtain and use their own PCS license for the new telecommunications technologies they need.[84] Further, the petition indicates that many of these services will require wide-band spectrum allocations for high-speed transmission of images and other specialized applications and existing PLMR allocations are insufficient to accommodate these new technologies.

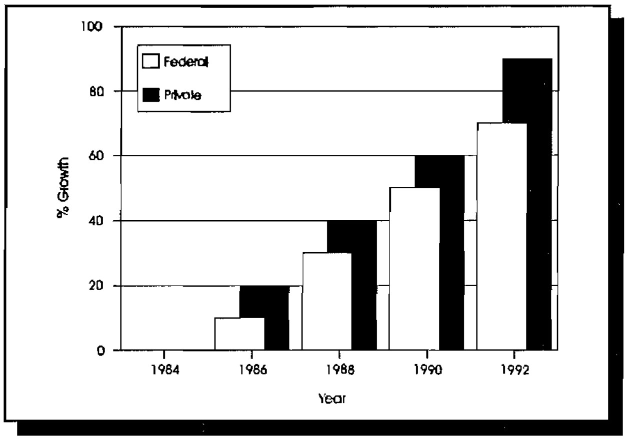


Figure 1-3. Growth of dispatch radio relative to 1984 levels.

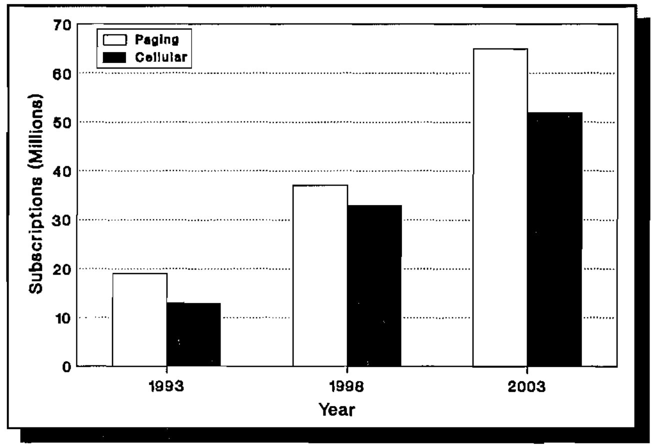


Figure 1-4. Paging and cellular forecasts.

GROWTH

In order to estimate future spectrum requirements, it is first necessary to estimate the growth of various land mobile services. Figure 1-3 presents historical data of growth trends for the Federal Government and PLMR services relative to 1984 levels of assignments or transmitters. Federal statistics include both conventional and trunked systems. Assuming linear growth, the number of conventional dispatch assignments and transmitters will nearly double in the next ten years. This represents a growth rate of two over the 10-year period. Figure 1-4 projects the number of cellular and paging subscriptions for selected years out to 2003. Historical data is combined with forecasts provided by PCIA. PCIA estimates that the number of paging subscriptions will increase by 94 percent from 1993 to 1998, and by 77 percent from 1998 to 2003.

---

[83]Coalition of Private Users of Emerging Multimedia Technologies, Petition for Rule Making, *Spectrum Allocations for Advanced Private Land Mobile Communications Services* (filed Dec. 23, 1993) [hereinafter COPE PETITION].

[84]*Id.* at 16-20.

Cellular subscriptions are expected to increase by 154 percent from 1993 to 1998, and 58 percent from 1998 to 2003.[85] Assuming linear trends, the growth factors for paging and cellular over the 10-year period are estimated to be approximately three and four, respectively.

Figure 1-5 identifies PLMR trunking growth in the 800 MHz and 900 MHz bands. Assuming linear growth, extrapolation indicates that the number of licensed trunking transmitters will nearly double over the next 10 years. This represents a growth factor of approximately two for the 10-year period for these uses. Figure 1-6 identifies SMR/ESMR growth for the following years: 1993, 1998, and 2003. PCIA estimates that the number of SMR/ESMR subscriptions will increase by a factor of six over a 10-year period.[86]

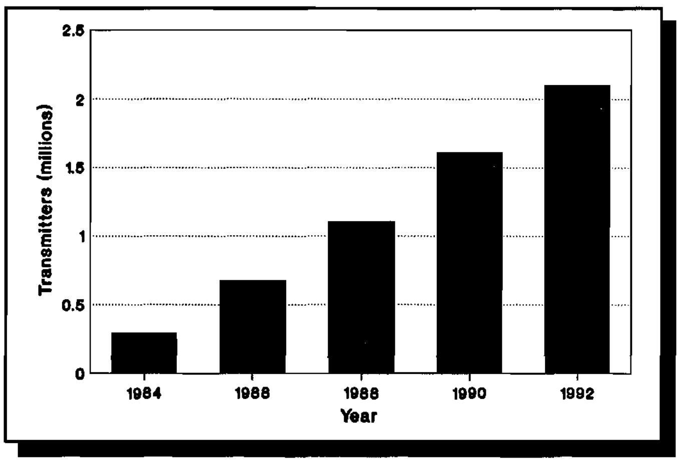


Figure 1-5. PLMR trunking growth.

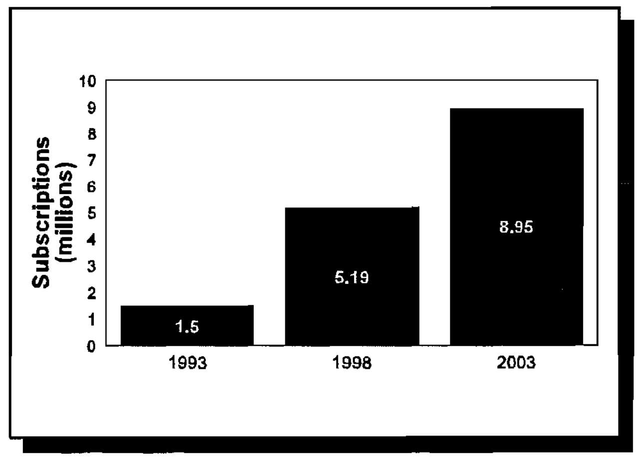


Figure 1-6. SMR/ESMR forecast.

SPECTRUM FORECASTING IN THE LAND MOBILE SERVICE

Spectrum forecasting, particularly in the land mobile services, is a difficult task because of the number of current initiatives, issues, and possible actions that could occur in the future. After reviewing the comments from the *Inquiry*, responses from many FCC proceedings on land mobile issues,[87] and the possible need for

---

[85]Others have made predictions on the number of cellular subscribers. Donaldson, Lufkin and Jenrette estimate the number of cellular subscribers (including PCN and ESMR's) are estimated to be between 56.6 million to 67.6 million in 2000. *See* DENNIS LEIBOWITZ ET AL., THE WIRELESS COMMUNICATIONS INDUSTRY, Table 4 (Winter 1994). Herschel Shosteck estimates the number of cellular subscribers (including PCS and ESMR's) in 2004 will be between 60-90 million. *See* HERCHEL SHOSTECK ASSOCIATES, CELLULAR MARKET FORECASTS, Figure 4-10 (1994).

[86]PCIA MARKET FORECAST, *supra* note 58.

[87]Because most of the comments received in our *Inquiry* contained only general information about spectrum requirements, NTIA obtained copies of comments to the FCC in response to its NOI's, NPRM's, Report and Orders, and other actions pertaining to the land mobile services.

additional public safety allocations, we conclude that additional spectrum will be necessary to accommodate increasing use of both Federal and non-Federal land mobile services.

An estimate of spectrum requirements for the next 10 years is developed using the data of Figures 1-3, 1-4, 1-5 and 1-6. In this estimate, assumptions are made regarding the growth of land mobile use, the effect of new technology on spectrum use, and the conversion rate of current systems to the new technology. Further, the approach taken results in spectrum requirements that do not necessarily assure complete satisfaction of all spectrum needs, but rather estimate the spectrum required to approximate the same level of spectrum availability as currently exists. Therefore, the spectrum requirements projected herein are intended to indicate the spectrum required to accommodate current and new users, so that in 10 years the level of spectrum availability will be approximately the same as today. That is, if the estimated requirements are accurate, and the additional spectrum is allocated, then the land mobile bands (including new spectrum) in the year 2004 would be no more congested than currently allocated bands are.

Several factors need to be addressed concerning the spectrum requirements. Most commercial land mobile users may not have a preference (as long as service rates are competitive) concerning the manner in which telecommunications services are provided (i.e., whether the means are via satellite, cellular telephone, or PCS). Further, some proposed communications systems have not been fully developed, and involve technological challenges that may require significant time to successfully implement. Additionally, it is likely that some future Federal communications will be satisfied through commercial facilities such as cellular telephone, PCS, and SMR's.[88] For these reasons, the requirements should be viewed as general telecommunication requirements and not necessarily as a requirement to support a specific service. A number of possible implementation regimes, technology complexities, and range of environments makes it difficult to develop a single spectrum requirement number.

> The requirements should be viewed as general telecommunication requirements and not necessarily as a requirement to support a specific service, since many of the functions or requirements being performed by a particular service may merge or even be replaced by another service.

It is assumed that technologies implemented today (narrowbanding, digital multiple-access techniques) will have some impact on the current spectrum infrastructure over the next 10 years. Federal plans to rechannelize the 162-174 MHz band require that all new equipment procured after 1995 be narrowband equipment, and by 2005, all equipment must be narrowband. The FCC's proposed refarming initiative would eventually require all equipment to operate in narrowband channels in the 2004-2012 time frame, depending on market areas. Also, dual-mode cellular telephone equipment will be able to access both analog and hybrid/digital systems. While the FCC's current refarming proposal requires a transition to 6.25 kHz or 5 kHz

[88]In some instances, Federal non-military and military land mobile communications cannot be satisfied through commercial facilities unless those facilities can provide secure communications when needed. The Federal Agencies also operate in remote areas in which the private sector may have no incentive to provide communication services. During emergencies, civil and Federal demand for spectrum increase simultaneously. Commercial facilities may not have adequate reserve capacity.

channels in major markets within 10 years, comments to the FCC from manufacturers indicate this would be difficult to accomplish.[89] For the purposes of this study, and recognizing that the FCC rulemaking is not complete, it is assumed that complete narrowbanding of non-Federal channels will be fully implemented for 12.5 kHz channels by the year 2004. Federal narrowbanding will be implemented at 12.5 kHz channels at different times for the various Federal mobile bands.

CALCULATION OF SPECTRUM REQUIREMENTS

Estimates of spectrum requirements are defined in Table 1-1. The projected 10-year spectrum requirement is for national (Federal and non-Federal) land mobile services, excluding requirements for special applications such as military tactical and training use. In predicting long-term requirements, various parameters such as the conversion of systems to more efficient ones (called the conversion factor) and the effect of introducing more efficient technologies (called the technology factor) have been assumed for this analysis.

Table 1-1 identifies five main types of land mobile operations: dispatch, non-dispatch, 2 GHz PCS, SMR/ESMR, and other emerging mobile services. Dispatch-type operations include the conventional and trunked land mobile radio systems such as those within the Federal and PLMR services providing primarily voice communications. These services combined have approximately 100 MHz of assignable spectrum for conventional use. Private sector trunking, excluding SMR systems, operates within the 806-824 MHz, 851-869 MHz, 896-901 MHz, and 935-940 MHz bands (19 MHz).[90] Although Federal trunking can be established in any band allocated for mobile operations, commercial equipment currently is being used primarily in the 406.1-420 MHz band (14 MHz). Since Federal trunking can be performed in any band allocated for mobile use (unlike the PLMR services that have dedicated trunking bands), this 14 MHz is included in the 100 MHz indicated for conventional use.

Non-dispatch operations include one-way calling systems such as radio paging (5 MHz) and new services such as the 900 MHz advanced messaging services (3 MHz).[91] Two-way operations include cellular radiotelephony which has 50 MHz in the 824-849 MHz and 869-894 MHz bands. SMR/ESMR systems operate within portions of the 800 MHz and 900 MHz bands (19 MHz). The emerging 2 GHz PCS includes licensed and unlicensed PCS devices, which total 140 MHz of spectrum.

---

[89]Comments of Motorola, Inc. (filed May 28, 1993) in *Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and the Policies Governing Them*, PR Docket No. 92-235.

[90]There are some channels in these bands used for conventional systems and are reflected as such in the amount of spectrum available for conventional dispatch use.

[91]*Amendment of the Commission's Rules to Establish New Narrowband Personal Communications Services*, First Report and Order, Gen. Docket No. 90-314, ET Docket No. 92-100 (1993).

TABLE 1-1
ESTIMATED 10-YEAR U.S. LAND MOBILE SPECTRUM REQUIREMENTS[a]

Service-type	Current Allocated Spectrum (MHz)	10-Year Growth Factor	Calculated Additional Spectrum Needed (MHz)	Technology Factor[b]	Conversion Factor[c]	Additional Spectrum Requirements (MHz)
Dispatch						
conventional	100	2x	100	.50	.65	18
trunked	19	2x	19	.33	.25	3
Non-dispatch						
one-way[d]	8	3x	16	.50	.25	7
two-way[e]	50	4x	150	.33	.50	33
2 GHz PCS[f]	140	--	0	--	--	0
SMR/ESMR	19	6x	95	.17	.50	8
Others[g]	--	--	135	--	--	135
					Total land mobile spectrum	204

a Tabulated spectrum values illustrate only the method by which the total spectrum required was derived; each individual service will not necessarily require the amount indicated. All values are rounded to the nearest whole number.

b Multiplier that accounts for increased spectrum efficiency from technologies such as narrowbanding and digital multiple-access techniques.

c Multiplier that represents the percent of current spectrum converted to more efficient use.

d One-way calling services include the current paging services plus other new services intended to receive informational transmissions, such as data and electronic-mail (i.e., advanced messaging).

e Two-way services include the conventional cellular telephone services intended to operate over a wide area, plus other new services that will operate over larger distances, primarily to vehicles providing data and graphics transmissions along with voice.

f PCS is defined by the FCC as "a family of mobile or portable radiocommunications services which could provide services to individuals and business, and be integrated with a variety of competing networks." The precise form of PCS is still evolving.

g Other radiocommunications services include ITS, and advanced private-dispatch operations such as transaction/decision processing, facsimile, snapshots, slow and full motion video, and remote file access. The requirements identified for ITS in this chapter exclude spectrum for collision avoidance radars.

Other emerging mobile uses include ITS, and advanced private dispatch operations such as transaction/decision processing, facsimile, snapshots, slow and full motion video, and remote file access. The concept of ITS is still evolving, but it is envisioned to provide traffic information over a wide area. The use of two-way telephony and unlicensed PCS may be a component of the ITS concept.

The methodology used to compute the Additional Spectrum Requirement is illustrated in the following discussion for the conventional dispatch operations. Other service requirements identified in Table 1-1 would follow in a similar manner.

DISPATCH OPERATIONS

The 100 MHz of spectrum allocated to Federal and non-Federal conventional dispatch operations is listed in Table 1-2 below.

TABLE 1-2
SPECTRUM ALLOCATED TO CONVENTIONAL DISPATCH OPERATIONS

Frequency Bands	Dispatch Spectrum	Allocation
25-50 MHz	19.4 MHz	Federal, non-Federal
138-150.8 MHz	8.7 MHz	Federal
150-174 MHz	19.8 MHz	Federal, non-Federal
220-222 MHz	2 MHz	Federal, non-Federal
406.1-420 MHz	13.9 MHz	Federal
450-512 MHz	28 MHz	non-Federal
800 MHz	8.4 MHz	non-Federal
Spectrum:	**100.2 MHz**	

As was stated previously, Federal land mobile assignments could double in the next ten years, as could the number of licensed PLMR transmitters. Therefore, it is assumed that twice as much spectrum would be needed to accommodate these assignments or transmitters in order not to exceed current spectrum congestion. This growth rate is reflected as a factor-of-two entry in the 10-year growth rate column of

Table 1-1. This would result in a requirement for an additional 100 MHz if the new spectrum were used in the same manner as the current spectrum allocation. This additional 100 MHz is indicated under the "Calculated Additional Spectrum Needed" column.

However, it is expected that the use of any new spectrum allocation would involve the application of newer, more efficient narrowband technologies that would provide for twice the users in the same spectrum space. This effect is reflected as a technology factor and is 0.5 for conventional dispatch operations. That is, the communication service that presently uses one unit of bandwidth will require one-half unit in the future because of technological advances (i.e., narrowbanding). Taking into account only the technology factor, the spectrum requirement is reduced to 50 MHz (100 MHz multiplied by 0.5).

If all users were to convert to newer technologies immediately upon adoption of a rulemaking, there would be little need for additional spectrum in the short term. However, there will be a time period when systems are in the process of being converted. The length of this time period is influenced by certain factors such as amortization of current systems, availability of new systems, and the need for frequency coordination among users in common geographical areas. The amount of current spectrum estimated to be converted to narrowband use is indicated by a conversion factor and is shown in Table 1-1.

In the case of dispatch operations, it is assumed that all systems achieve 12.5 kHz channel usage at the prescribed time, and that system conversion to narrow channels will be linear during the conversion period. The results of an analysis indicate that spectrum shortfalls will occur during the 10-year period, with a maximum shortfall of about 18 MHz during the 1997-1998 time frame. At the end of the 10-year period, however, only an additional 6 MHz will be needed. Using the maximum value of spectrum shortfall, an equivalent conversion factor of 0.65 was calculated.[92] If the non-Federal channels are narrowed to 6.25 kHz or 5 kHz, as proposed in the NPRM, it is expected that no additional spectrum would be required for this service (additional spectrum requirement equal to zero in Table 1-1).

For dispatch operations, it is estimated that 65 MHz (100 MHz multiplied by 0.65) of the currently allocated spectrum will be effectively converted to the new technology by the end of the 10-year period. However, not all of this 65 MHz can be applied to new requirements since the radiocommunications requirements of current systems still need to be satisfied in this spectrum. Thus, an amount of spectrum equal to the converted spectrum times the technology factor must be used to satisfy present users, and is not available to satisfy new requirements. For this case, this value would be 32.5 MHz (65 MHz multiplied by 0.5), where 0.5 is the technology factor.

In this analysis, the additional spectrum needed under current conditions (S_{add}) is equal to the current spectrum (S_{curr}) multiplied by the 10-year growth factor (F) less S_{curr}. If (R) is the future spectrum requirement, and only new systems were to use new technology (no conversion of existing systems), then S_{add}(T) additional spectrum would be needed, where (T) is the technology factor. However, as current

[92]This includes Federal conversion schedules which are in some cases longer than non-Federal schedules.

systems are converted to new technology, $S_{curr}(C)(1\text{-}T)$ spectrum becomes available for assignment to new systems, where C is the conversion factor. The requirement for additional spectrum (R) at the end of the 10-year period is therefore reduced by the amount $S_{curr}(C)(1\text{-}T)$. The equation for future spectrum requirement (R) is then equal to $S_{add}(T)\text{-}S_{curr}(C)(1\text{-}T)$, as shown below.

$$R = S_{add}T - [S_{curr}C(1 - T)]$$

Applying the equation to the conventional dispatch case, S_{curr} and S_{add} are both 100 MHz. Solving the equation for the required spectrum R, where the technology factor T is 0.5, and the conversion factor C is 0.65, results in approximately 18 MHz of additional spectrum required, as shown in Table 1-1.

For trunked dispatch operations, Figure 1-5 illustrates the growth that private sector trunking has experienced. As described earlier, this represents a growth factor of nearly two for the 10-year period. Therefore, it is assumed that twice as much spectrum will be needed to accommodate twice as many transmitters in order not to exceed current spectrum congestion. This would result in a requirement for an additional 19 MHz if the new spectrum were used in the same manner as the current spectrum allocation. It is further assumed that digital trunking systems will provide a three-to-one increase in capacity over current trunked systems[93] and that 25 percent of current trunked systems will convert to more efficient systems within 10 years. When these parameters are applied to the above equation, the estimated 10-year additional spectrum requirement is evaluated to be 3 MHz as shown in Table 1-1.

Spectrum requirements for dispatch operations are expected to be satisfied when the FCC refarming and the NTIA narrowband programs are complete. The additional dispatch spectrum required shown in Table 1-1 is a short-term requirement occurring only during a portion of the 10-year period of this forecast.

NON-DISPATCH OPERATIONS

For two-way non-dispatch operations, the current cellular radiotelephone systems are used as a model to formulate a basis for which the end result is derived. As implied by the growth curve in Figure 1-4, it may therefore take 4 times as much spectrum to satisfy the demand for cellular telephone services. Thus, the extrapolated spectrum requirement, assuming today's technology, would show an increase of 150 MHz that would be required so as not to exceed the same level of congestion for cellular-like services. Current digital systems provide a three-to-one increase in capacity. For planning purposes, a nominal three-to-one increase is assumed for this analysis. Therefore, only one-third of the spectrum (or 50 MHz) will be required to support the cellular demands. For the purposes of estimation, it is assumed that 50 percent of cellular systems will convert their current systems to much more spectrum-efficient systems over the 10-year period. Taking this into account, the estimated 10-year additional spectrum requirement is reduced to 33 MHz.

---

[93]Three-to-one and six-to-one TDMA systems have already been fielded. For estimation purposes, a nominal three-to-one increase is used here.

One-way calling services include the current paging systems plus other new advanced messaging services such as data messages, fax, voice paging, and wireless E-mail. As implied by the graph in Figure 1-4, it may take three times as much spectrum to satisfy the demand for non-dispatch, one-way services. The extrapolated spectrum requirement, assuming today's technology, would show an increase of 16 MHz that would be required so as not to exceed the same level of congestion. Assuming a technology factor of 0.5, which is supported by increases in data rates, and a conversion factor of 0.25, reduces the 10-year requirement to 7 MHz as indicated in Table 1-1.

PERSONAL COMMUNICATION SERVICES

The FCC has allocated a substantial amount of spectrum in the 2 GHz band for new PCS. The FCC allocated a total of 140 MHz at 1850-1990 MHz. Licensed PCS were allocated 120 MHz, while unlicensed PCS devices were allocated 20 MHz. It is assumed that the amount of PCS spectrum (140 MHz) that the FCC has allocated is sufficient for the 10-year period. Therefore, no additional spectrum will be required over the 10-year period.

SMR/ESMR

Figure 1-6 identifies the anticipated growth of SMR/ESMR's - it represents a growth of six-to-one over the 10-year period. The extrapolated spectrum requirement, assuming today's technology, would show an increase of 95 MHz of additional spectrum that would be needed. ESMR systems are expected to provide a six-to-one increase in capacity over SMR's.[94] Therefore, only one-sixth of the spectrum will be required. For estimation purposes, it is assumed that 50 percent of this spectrum will be used by more efficient systems within 10 years. Using the above equation, the estimated 10-year requirement is then reduced to 8 MHz.

OTHER LAND MOBILE SERVICES

Other service-types include ITS and advanced, private-dispatch operations.

In its Strategic Plan, IVHS AMERICA (now ITS AMERICA) recognized it must define RF spectrum needs and obtain appropriate spectrum allocations. In response to our *Inquiry*, IVHS AMERICA could not further identify in detail spectrum requirements necessary to implement the nationwide ITS infrastructure envisioned in its Strategic Plan. It also could not at that time identify whether the backbone ITS communications system that would support the ITS infrastructure would require dedicated ITS spectrum. Answers to these questions are being pursued through pilot projects, laboratory and field research, and testing.[95]

---

[94]The Motorola Integrated Radio System (MIRS) is a six-to-one TDMA system. This is the system that Nextel is using to establish its wide-area ESMR network.

[95]IVHS AMERICA Comments at 4.

Present ITS requirements are being accommodated within currently allocated spectrum in defined radio services, primarily in the 902-928 MHz band. Additional ITS functions, such as radar collision warning, will require spectrum in other bands. Further, certain ITS functions may be carried out in the context of new PCS services and in conjunction with wide-area broadcasting services.

The DOT and ITS AMERICA have indicated that access to additional spectrum will be required for ITS services. Although spectrum requirements for the ITS are still being defined, DOT has identified requirements in several frequency bands to support ITS functions.[96] Requirements for land mobile spectrum totaled 145.1 MHz, of which 100 kHz is presently authorized for ITS use. Sixty megahertz of this was for transitional use, and was subtracted to determine the long-term requirement. Noting the requirements are still being defined within the ITS community, we list 75 MHz below 10 GHz for short-range vehicle-to-roadside communications and toll collection, and 10 MHz between 10 GHz and 100 GHz for data links associated with collision avoidance radars. Eighty-five megahertz of spectrum for ITS (excluding spectrum for collision avoidance radar systems) has been included in the "other" category of Table 1-1.

COPE has filed a petition for rulemaking, requesting the FCC to allocate 75 MHz of spectrum, in aggregate, to establish a Private Land Mobile Advanced Communications Service.[97] The petition states that there is a need for additional spectrum for new services that will not and/or cannot be provided via common carrier-based services such as PCS. Further, the petition states that many of these services will require wide-band spectrum allocations for high speed transmission of images and other specialized applications, including public safety functions.

APCO, in comments to the FCC, stated that public safety services will require an additional 25 MHz by the year 2000, and another 50 MHz by 2010.[98] The APCO spectrum requirements are identical to the COPE petition in that 75 MHz was requested for advanced private land mobile applications. We have carefully reviewed these comments and agree that additional spectrum is needed for advanced wireless services such as transaction/decision processing, facsimile, snapshots, slow and full motion video, and remote file access for both public safety and industrial applications. Some of the requested spectrum is included in our assessment of general dispatch and two-way non-dispatch spectrum requirements. Our review indicates that approximately 50 MHz of additional spectrum is required to satisfy requirements for advanced private land mobile applications not previously addressed. It is expected that this 50 MHz would be shared between public safety and industrial uses, with public safety use primarily within urban areas, and industrial use primarily outside of these areas.

Having estimated that 85 MHz is needed for ITS and 50 MHz is necessary for advanced private operations, a total of 135 MHz is included as "Other" in Table 1-1.

---

[96] Jim Chadwick, DOT/MITRE Corp., IVHS Spectrum Requirements Summary, June 27, 1994.

[97] COPE PETITION, *supra* note 83, at 1.

[98] APCO, *supra* note 77, at 18.

A SECOND APPROACH TO SPECTRUM ESTIMATION

NTIA requested PCIA to estimate PCS requirements. The PCIA PCS Technical and Engineering Committee derived estimates of clear spectrum required to support PCS services (2 GHz PCS, cellular, ESMR) in the year 2003.[99] This report is an update of previous 1992 PCIA reports on spectrum.[100]

The methodology employed was a "bottom-up" approach, using estimated traffic loads for the services studied, considering the requirements of voice, data, imagery, and messaging as codified in the market demand research.[101] Implementation environments for low, medium, and high geographic densities of cells and population were considered. Included in the calculations were certain assumptions for cell spacing, grade of service, user busy hour traffic statistics, bearer channel bandwidths, and PCS infrastructure buildout. Based on an assumed number of 10 service providers per area, the report concludes that in the year 2003, the required spectrum for the PCS services of cellular, ESMR, and licensed 2 GHz PCS will be between 340 and 399 MHz.

NTIA agrees with the PCIA approach, but believes that urban in-building coverage would most likely be satisfied generally by either wireline or unlicensed wireless systems in the next 10-year period, and that spectrum efficiency is of such importance that cell reuse factors should be no more than seven. Using the PCIA model with a low/medium-density cell infrastructure and a cell reuse factor of seven, the PCIA model yields a spectrum requirement of approximately 216 MHz. This is compared with the NTIA estimation of 230 MHz for similar PCS-type licensed services determined by adding the "current allocated spectrum" and "additional spectrum requirements" column entries for licensed 2 GHz PCS, cellular (two-way non-dispatch), and SMR/ESMR services.

For paging services, a similar forecast was prepared by PCIA that included four paging applications: one-way, two-way, asymmetrical, two-way symmetrical, and high-speed voice. PCIA concluded that 35 MHz would be required to support these four services.[102] NTIA agrees, in general, with the forecasts for the first three paging services mentioned. Comments to our *Inquiry* did not provide sufficient data to conclude that high-speed voice paging will be a significant service within the 10-year period. Therefore, we cannot concur with the spectrum requirement for high-speed voice paging at this time.

---

[99]PCIA PCS TECHNICAL AND ENGINEERING COMMITTEE, TE/94-06-09/555, PCIA "2003" SPECTRUM ESTIMATE REPORT (Draft June 9, 1994) [hereinafter PCIA].

[100]TELOCATOR PCS TECHNICAL AND ENGINEERING COMMITTEE, TE/92-5-28/076, TELOCATOR SPECTRUM ESTIMATES FOR PCS REPORT (1992).

[101]PCIA MARKET FORECAST, *supra* note 58.

[102] PCIA, *supra* note 99.

ADDITIONAL SPECTRUM NEEDED

All services, when totaled, show a calculated value of 204 MHz of additional spectrum that may be needed for the land mobile services. It must be recognized that many of the values used in the derivation of spectrum requirements are estimates that vary over a range of values. To illustrate the effect on the estimated 10-year requirements and as an example, values such as growth rate, technology and conversion factors were increased or decreased by 10 percent. In the first case, the growth rates and technology factors were decreased by 10 percent, and the conversion factors were increased by 10 percent. Changing these values in concert will produce the greatest decrease in the estimated spectrum requirements. Thus, the estimated 10-year requirement is reduced nearly 43 MHz from 204 MHz to 161 MHz. Conversely, when growth rates and technology factors were increased by 10 percent, and conversion factors were decreased by 10 percent, the greatest increase in the estimated spectrum requirement is produced. Again, this yields a difference of nearly 43 MHz from the initial estimate of 204 MHz, resulting in a requirement of 247 MHz.

Clearly, such a variation illustrates the sensitivity of the end result on these input factors. If one or more of these parameters changes significantly, (which is not unexpected with today's technologies, service offerings, or demands) the overall spectrum requirement forecasted changes significantly. The fast pace of technology, the need to have instant communications, and world events make predictions beyond five years a speculative effort. Therefore, long-term planning, particularly in the land mobile services, should be re-evaluated on a continuing basis and adjusted, if necessary. By doing so, more current demands and technologies can be considered to provide a better estimate of requirements that will be needed to satisfy any demands.

The fast pace of technology, the need to have instant communications, and world events make predictions beyond five years a speculative effort. Therefore, long-term planning, particularly in the land mobile services, should be re-evaluated on a continuing basis and adjusted, if necessary.

Furthermore, recent spectrum legislation has required a transfer of at least 200 MHz of spectrum from the Federal Government to the private sector.[103] The 200 MHz will be used to satisfy some of the future land mobile service requirements.[104]

SPECTRUM REQUIREMENTS FOR THE LAND MOBILE SERVICE

In summary, assuming that the FCC rulemaking on refarming is completed, current cellular and SMR systems are partially replaced by much more efficient digital systems, and NTIA implements the narrowbanding of the Federal land mobile bands, there remains an estimated requirement of approximately

---

[103]BUDGET ACT OF 1993, *supra* note 1.

[104]The FCC will allocate and assign the frequencies made available from the transfer of 200 MHz of Federal spectrum. *Id.*, § 115.

204 MHz for land mobile use in the next 10 years. However, the variabilities associated with this particular analysis imply the requirement could range from 161 MHz to 247 MHz.

AERONAUTICAL MOBILE SERVICE

The aeronautical mobile service is "[a] mobile service between aeronautical stations and aircraft stations, or between aircraft stations, in which survival craft stations may participate."[105] The aeronautical mobile service supports voice and data communications between ground stations and aircraft or between aircraft including flight testing, telecommand, airdrome control, and route (R) and off-route (OR) services.[106] Many of the communications within this service are used for air traffic services (ATS) and aeronautical operational control (AOC) safety communications.

The aeronautical mobile service, including certain frequency bands and technical standards used for this service, are coordinated internationally through the International Civil Aviation Organization (ICAO) to ensure the worldwide interoperability of these services. Consequently, many of the regulations found in Part 87 of the FCC Rules and the NTIA Manual are based on ICAO standards.

Many aeronautical mobile communications are used by Federal and non-Federal agencies in identical ways and are accommodated in the 2-23 MHz (HF) and 118-137 MHz (VHF) bands. Additionally, the Federal Aviation Administration (FAA) provides air traffic control (ATC) services to military aircraft on allotted frequencies in the 225-400 MHz band.

The HF band includes 21 frequency ranges that are shared equally by Federal and non-Federal users for ATC and AOC functions. These bands, regulated by international agreement, have long provided the major means of communications with aircraft in transoceanic service.[107] Because HF signals propagate terrestrially over long distances, HF radio provides most communications with aircraft over ocean routes and in some developing countries. HF is not used over the United States, except in Alaska.

The VHF band provides the primary communications mode for ATS and AOC safety communications for all areas of the world where radio line-of-sight (LOS) services can be established in a practical manner.[108] This band is used by civil aviation authorities to provide ATS safety communications and by the airlines,

---

[105]NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-1. While an aeronautical station is usually located on land, it may, in certain instances, be located on board a ship or on a platform at sea. *Id.* at 6-2 (defining an aeronautical station).

[106]Off-route services are "intended for communications, including those related to flight coordination, primarily outside national or international civil air routes." Route services are for "communications relating to safety and regularity of flight, primarily along national or international civil air routes." *Id.* at 6-1 (defining the aeronautical mobile (OR) and aeronautical mobile (R) services).

[107]Because HF propagation is dependent on time of day, time of year, sunspot cycles, etc., it is common for airborne HF systems to have multiple frequencies assigned during flight.

[108]Though VHF radio is limited to LOS, modern aircraft fly at altitudes where LOS can exceed 400 km.

business aviation, and general aviation to provide AOC safety communications. Each communications frequency is re-used as often as possible due to the limited number of available frequencies. The FAA and Aeronautical Radio, Inc. (ARINC)[109] maintain an extensive network of VHF radio stations giving reliable coverage over the United States and off-shore areas.

CURRENT USES OF THE AERONAUTICAL MOBILE SERVICE

CIVIL AVIATION USES

The commercial airlines, private, and general aviation communities depend upon radiocommunications to foster the safe, economic, and efficient operation of aircraft, which includes ATS, AOC, aeronautical administrative communications (AAC), and aeronautical public correspondence (APC) services.

ATS communications include ATC, communications providing alphanumeric and graphical weather data, and communications intended to notify appropriate organizations regarding aircraft in need of search and rescue, and to aid and assist such organizations as required.

AOC communications are used to initiate, continue, divert, or terminate a flight in the interest of the safety of the aircraft, and the regularity and efficiency of a flight. AOC functions operate via air-ground voice and data communications either through the cockpit crew or directly with airborne sensors or systems. In 1977, the Aircraft Communications, Addressing, and Reporting System (ACARS) was introduced. ACARS is an air-ground digital packet radio system operating in the VHF band, providing service over most of North America. ACARS has resulted in significant improvements in spectrum efficiency by removing routine communications from voice and replacing them with data messages. ARINC notes that "the system continues to grow, and ACARS now handles close to seven million messages a month with an availability at critical airports of 99 percent."[110]

Both AAC and APC are non-safety services and have priorities below ATS and AOC. AAC includes cabin provisioning and inventory, seat assignments, passenger travel arrangements, and baggage and parcel tracing. APC services include voice telephone service for passengers to connect with ground-based networks worldwide. These common carriers allow passengers onboard many commercial aircraft to place telephone calls while in flight. These systems operate in the 849-851 MHz (ground-air) and 894-896 MHz (air-ground)

[109]Aeronautical Radio, Inc. (ARINC) is the communications company of the air transport industry. It is owned by members of the civil aviation community and provides civil aviation with communications services, planning, and management on a not-for-profit basis. ARINC also sponsors technical forums where representatives of civil aviation meet to develop common solutions to communications and avionics related issues.

[110]ARINC Comments at 4. There are 39 airports in the United States that are defined as critical by ARINC. An ACARS customers at a critical airport will be able to access the ACARS system 99 percent of the time.

bands.[111] Although initial voice services were provided with 6 kHz-bandwidth Amplitude Compandored Single-Side Band (ACSB) circuits, improved services will be offered with digital technology and highly-efficient vocoders, including data and facsimile.

FEDERAL USES

The FAA provides air-ground communications support for enroute, terminal, and flight services[112] to end users such as the commercial airlines, general and private aviation, the military services and law enforcement agencies such as the Drug Enforcement Administration and the U.S. Customs Service. The Federal Government's use of aeronautical communications plays an important part of national defense. The FAA provides ATS to the military services on allotted frequencies in the 225-400 MHz band. The military services make extensive use of the 225-400 MHz band, which helps to avoid impacting national airspace air-ground communications.

Federal Government aeronautical mobile requirements are also accommodated in the HF and VHF portions of the radio spectrum and are used to provide aviation services to commercial airlines and general aviation. Over 90 percent of the Federal HF spectrum use is accounted for by the Air Force and Navy, while the FAA accounts for over 80 percent of the VHF spectrum use in its support to aeronautical mobile requirements of the flying public. DOD uses the HF band for a variety of functions, including but not limited to, tactical air-ground communications, command and control communications, and for communications supporting disaster relief operations. HF communications is the only communications means available between DOD aircraft transiting oceanic regions and many continental land masses lacking in other modes of communications. Some specific examples[113] of HF aeronautical mobile service spectrum include National Aeronautics and Space Administration (NASA) support of the space shuttle operations. The U.S. Air Force uses HF for global command and control stations, flight testing, tactical communications, data coordination and satellite recovery operations. The U.S. Navy utilizes HF aeronautical mobile spectrum for close air support, tactical support for anti-submarine warfare communications, and training. The Army uses the 30-88 MHz and 138-150.8 MHz bands for close air support training with ground troops via air-ground communications. The DOD has stated that the "30-88 MHz band is vital to tactical mobile communications."[114]

---

[111] WARC-92 allocated the 1670-1675 MHz band as a worldwide ground-to-air communications paired with 1800-1805 MHz for air-to-ground transmissions. WARC-92 FINAL ACTS, *supra* note 55, at 58 (International Footnote 740A). The United States will maintain its existing systems at 849-851 MHz and 894-896 MHz.

[112] Enroute services include the aircraft separation services, traffic advisories, and weather information to pilots enroute between airports, etc. Terminal communications include the radio communications in the airspace that immediately surrounds the airport and on the ground. Flight services include flight plan filing, preflight and in-flight weather briefings, enroute communications with pilots flying under visual flight rules, and assistance to pilots in distress.

[113] NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEP'T OF COMMERCE, NTIA TECHNICAL MEMORANDUM 89-141, SPECTRUM RESOURCE ASSESSMENT OF GOVERNMENT USE OF THE HF (3-30 MHZ) BAND, at 67-68 (June 1989) [hereinafter HF SPECTRUM RESOURCE ASSESSMENT].

[114] DOD Comments at 5.

Federal agencies make extensive use of the 225-400 MHz band for aeronautical mobile operations. This band is used primarily for military functions, including air-ground communications and ATC for military aircraft.[115] The FAA provides ATC functions for military aircraft essentially identical to the ATC communications in the VHF band. In fact, in most areas the FAA transmits ATC information simultaneously on VHF and UHF channels for military aircraft not VHF-equipped so that military aircraft remain aware of civilian aircraft, and vice versa. Military uses include, but are not limited to, coordination of in-flight refueling, vectoring of aircraft to targets, and large scale training exercises. Military ATC (i.e., ground control, approach control, training flights, combat, etc.) would typically use UHF exclusively.[116] The FAA, Air Force, Army and Navy account for nearly all of fixed and mobile spectrum use in this band.

There are aeronautical systems operating under the more general mobile service allocation. These systems operate above 1 GHz and generally provide non-voice communications referred to as telemetry, data, and video links. The main categories of mobile systems that involve aeronautical mobile operations are described below.

Air Combat Training (ACT) systems are more complex by nature of their operation, as both fixed and aeronautical mobile equipment are used. The military uses them at more than 21 sites across the United States to provide realistic tactical simulation and pilot training in a peacetime environment. Training is provided in air warfare operations and maneuvers without actually firing weapons. The systems provide real-time altitude, location, velocity, angle of attack, simulated weapon status, and other data on participating aircraft. A typical configuration for a system consists of a master control station, six or more remote tracking stations and up to 24 participating aircraft. Aircraft altitude of up to 35,000 feet is typical during exercises that may last for up to ten hours per day. Recent system upgrades provide for multiple control stations and up to 36 aircraft. These are tied together via radio links, nine or ten of which are required for each system. The 1760-1840 MHz frequency range supports this type of operation.

Air-ground video systems primarily provide real-time television displays from cameras on aircraft, typically flying at 10,000 to 15,000 feet. Some typical functions include video images of missile, drone, and remotely piloted vehicles testing, flight testing of new aircraft, and airborne monitoring of civil disturbances. The majority of operations are on the military test ranges. The most widely used bands for the air-ground video telemetry operations are the 1710-1850 MHz, 2200-2290 MHz, and 4400-4990 MHz bands.

The Federal Government uses various telemetry systems to support a variety of test flight and equipment development functions. The 1435-1525 MHz and 2360-2390 MHz bands support these functions at nine major military and NASA test ranges/centers and numerous smaller facilities. These bands are the

---

[115]An exception to this use is the 328.6-335.4 MHz band, which is exclusively reserved for instrument landing systems (glide paths) at airports worldwide.

[116]Although military ATC is part of the activity in the 225-400 MHz band, it is only a small part of the military tactical and strategic communications in this band. The major role for this band includes a wide variety of systems, including satellite links, air-to-air, vehicle-to-vehicle, and man-pack equipment designed to operate under battlefield conditions. These systems typically include frequency-hopping and spread-spectrum systems designed to be resistant to interception and jamming.

most important aeronautical flight test telemetry bands in the United States.[117] A number of complex and organizationally independent functions must be successfully coordinated to complete a mission. Examples of some of these are: range safety (e.g., flight termination capability and clearing the range of non-participants); chase aircraft; weather; measurement support (e.g., radar and recorders); target drone aircraft; nominal test system operation; and aeronautical telemetry support.

The DOD operates a variety of radio-based target scoring systems (airborne and seaborne) for training and weapons testing purposes. Because of the need to maintain a high level of combat readiness, these systems are tested on a regular basis. Currently, the airborne training activities are at recognized national test ranges. In recent years, the target scoring systems have become quite complex and provide multiple functions, such as: indicating whether a target was hit, how much of the target was destroyed, projectile velocity, and target tracking. The frequency bands supporting these systems are the 1710-1850 MHz, 2200-2290 MHz, and 4400-4990 MHz bands.

TRENDS WITHIN THE AERONAUTICAL MOBILE SERVICE

Several forums have completed studies and are now pursuing the development and implementation of system improvements providing increased spectrum utilization efficiency and functional capability in the 118-137 MHz VHF air-to-ground communications band. Internationally, the ICAO Aeronautical Mobile Communications Panel (AMCP) undertook this work, beginning in 1991, as a result of recommendations of the 1990 ICAO Communications/Meteorological/Operations (COM/MET/OPS) Divisional Meeting. In the United States, RTCA[118] Special Committee 172 (SC–172) was established in 1991 through recommendations by the FAA and ARINC, to undertake a compatible, parallel effort from a U.S. Government/industry perspective. Both forums have examined a number of present and future system improvements. As a result of these coordinated studies, a 25 kHz TDMA system (four independent voice and/or data link circuits on each RF channel) was recommended for the future (beyond 2004) VHF air-ground system. The future system will result in a substantial gain in system capacity, and provide system functional improvements, including data links. The AMCP had concluded that an 8.33 kHz double sideband amplitude modulation (DSB-AM) voice/25 kHz VHF digital link (VDL) carrier sensed multiple access (CSMA) system was the only practical solution which could be implemented within the shortest possible time scale and meet the anticipated near-term ATS and AOC requirements in those areas where frequency congestion exists. The implementation date of this system is expected in 1998.

Video compression reduces the bandwidth of an existing analog or digital channel by eliminating redundant information.[119] Compression, when applied to air-ground video, could significantly reduce future

---

[117]DOD Comments at 12.

[118]RTCA, Inc. is an association of aeronautical organizations of the United States from both government and industry. RTCA seeks sound technical solutions to problems involving the application of electronics and telecommunications to aeronautical problems.

[119]Compression is discussed *infra* pp. 87, 207.

spectrum requirements. Advances in digitized video compression and modulation technologies can place 10 or more video signals within the 6 MHz bandwidth normally occupied by a single analog video signal.[120]

SPECTRUM REQUIREMENTS FOR THE AERONAUTICAL MOBILE SERVICE

Aviation communication requirements are complicated by the need to maintain a common communications and radionavigation infrastructure throughout the world. ARINC notes that the aviation community plans very carefully and establishes reasonable transition periods before obsolescent systems are phased out, and that planning looks at least a decade ahead.[121]

ARINC contends that future demands may not be accommodated fully within the current allocations and that additional spectrum may be needed in the future.[122] Although the DOD did not elaborate on their use of aeronautical communications specifically, they did indicate that "for the next 10 to 20 years, DOD use of the current military spectrum will remain essentially as it exists today."[123]

In their initial comments to our *Inquiry,* the FAA indicated that current spectrum would be adequate.[124] However, the civil aviation community is pursuing a network-based HF data link system to help satisfy future ATS and AOC communication requirements in oceanic areas in a cost efficient and reliable manner. The FAA estimates that about 36 frequencies, totaling 108 kHz (6 families of 6 HF frequencies each), will be needed to establish an initial worldwide service.[125] The FAA expects that aeronautical mobile-satellite (R) services will provide a significant communications enhancement in oceanic areas. While there may be some future reductions in requirements for HF aeronautical mobile (R) voice services because of the continued implementation of the aeronautical mobile-satellite (R) service capability, such a reduction is not expected within the next 10 years.[126]

Many of the aeronautical communications requirements, including those for transoceanic flights and public correspondence, could be satisfied through satellite-based systems. The U.S. and international civil aviation communities have recommended a combination voice/data system to satisfy future VHF air-ground communication requirements. Furthermore, some of the aeronautical voice traffic will be supplemented by more efficient digital links. However, the continuing and unavoidable growth of air-ground voice and data

---

[120]Stewart D. Personick, *Towards Global Information Networking*, PROCEEDINGS OF THE IEEE (Nov. 1993).

[121]ARINC Comments at 2.

[122]*Id.* at 3.

[123]DOD Comments at 3.

[124]FAA Comments at 1-2.

[125]Letter from Gerald J. Markey, Director, Office of Spectrum Policy and Management, Federal Aviation Administration, to W. Russell Slye, Program Manager, Strategic Spectrum Planning Program, National Telecommunications and Information Administration (NTIA), Enclosure at 4 (Oct. 18, 1994) (on file with NTIA).

[126]*Id.*

circuit requirements is expected to maintain pressure on the FAA's frequency resources in this band despite the alleviatory effects of new technologies.

The United States Coast Guard (USCG) has indicated that 2 additional channels per band are needed for aeronautical mobile (OR) voice communications, particularly below 10 MHz.[127] There are 5 bands below 10 MHz allocated on a primary basis to the aeronautical mobile (OR) service: 3025-3155 kHz, 4700-4750 kHz, 5680-5730 kHz, 6685-6765 kHz, and 8965-9040 kHz. Therefore, 30 kHz of additional spectrum may be needed.

Further, the USCG indicated that additional HF spectrum would be needed for wideband mobile requirements such as imagery, etc.[128] NTIA finds that, as an initial estimate, 100 kHz of spectrum would be needed for such services.

In summary, we find that 108 kHz of additional HF aeronautical mobile (R) service spectrum will be needed over the 10-year period. There also appears to be a requirement over the 10-year period for 30 kHz of additional HF spectrum for aeronautical mobile (OR) uses, and a requirement for 100 kHz of additional HF mobile service spectrum used in support of aeronautical operations.

Maritime Mobile Service

The maritime mobile service is "a mobile service between coast stations and ship stations, or between ship stations, or between associated on-board communication stations."[129] In addition, emergency position-indicating radiobeacon and survival craft stations may also participate in this service.

The maritime community has been a pioneer in the use of wireless communications. As early as 1900, radios were being installed aboard ships to receive storm warnings transmitted from stations on shore. Today, the maritime mobile service provides a wide range of communication services to vessels operating in international waters, coastal areas, and inland lakes and waterways. These services provide a means of communications for the day-to-day activities of the maritime industry as well as providing a critical safety link for the protection of lives and property. Such uses include ordering ships' stores, ship command and control, inquiring about berthing facilities, making personal and business telephone calls, and changing schedules.

---

[127] Letter from Joe Hersey, United States Coast Guard, to W. Russell Slye, Program Manager, Strategic Spectrum Planning Program, NTIA (March 11, 1994) (on file with NTIA).

[128] *Id.* Since these requirements appear to be used in support of aeronautical mobile operations, NTIA has included them within the aeronautical mobile service.

[129] NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-9.

Because safety-of-life is a worldwide issue, compatibility among nations is a key concern. Therefore, many of the maritime standards are established by international agreements administered by the International Telecommunication Union (ITU) and the International Maritime Organization (IMO). The ITU and IMO regulations are the basis for many of the regulations in the NTIA Manual and in the FCC Part 80 Rules.

For most purposes, Federal and non-Federal users share the maritime frequencies and are accommodated in portions of the MF (300-3000 kHz), HF (3-30 MHz) and VHF (156-162 MHz) bands. Frequency bands below 30 MHz are used for a wide range of services.[130] Many of the channels are established and regulated by international agreement and are available for distress, urgency and safety, digital selective calling (DSC),[131] narrow-band direct-printing (NBDP),[132] facsimile, public correspondence, private communications, etc.

VHF channels in the 156-162 MHz band provide short-range ship-ship or ship-shore communications. Channels are made available according to the type of communication and the nature of the ship's operation. For example, channels are available for safety communications, distress and calling, control of ship movement, environmental, etc. Also, channels are available for public correspondence and private communications. Although not used extensively, data communications are also available on various channels, subject to special arrangement among interested and affected administrations. Many of these frequencies are specified on an international basis.[133]

The 216-220 MHz band is allocated to the Federal and non-Federal users for the maritime mobile service on a shared, primary, co-equal basis. Channels are made available within the 216-220 MHz band for a system called the Automated Maritime Telecommunications System (AMTS).

CURRENT USES OF THE MARITIME MOBILE SERVICE

PRIVATE USES

Private entities that use maritime communications include commercial and non-commercial vessels, the U.S. Merchant Marine, international commercial traffic vessels, and port operators. National maritime mobile service allocations are administered by the FCC. Channels are available in the MF, HF and VHF bands according to the type of communication intended as described above.

---

[130] These frequencies support long distance communications and are therefore suitable for ocean-going vessels. The use of these frequencies for long distances is dependent on ionospheric conditions and subject to interference and radio noise. Therefore, a set of frequencies may be needed over the course of a day to maintain acceptable communications.

[131] Digital selective calling is a synchronous system developed to establish contact with a station or group of stations automatically by means of radio.

[132] Narrow-band direct-printing (NBDP) is a form of telegraphy for the transmission and receipt of data communications.

[133] Appendix 18 of the ITU Radio Regulations describes the function for each of the channels used in the maritime mobile services. INTERNATIONAL TELECOMMUNICATION UNION, RADIO REGULATIONS app. 18 (1990) [hereinafter ITU RADIO REGULATIONS].

Commercial transport vessels are ships that are used primarily in commerce for transporting persons or goods to or from any harbor or port or between places within a harbor or port area. Commercial vessels are also engaged in the construction, change in construction, servicing, maintenance, repair, loading, unloading, movement, piloting, or salvaging of any other ship or vessel.[134]

Non-commercial communications are used by recreational boaters and by vessels not intending to make a profit while in operation. Channels are available in the MF, HF and VHF bands according to the type of communications intended.

AMTS is an automatic, integrated, and interconnected communications system serving ship stations within the 216-220 MHz band. AMTS provides full-duplex voice and data public correspondence service to the maritime community similar to that provided by landline telephone systems on specific frequencies allotted to the AMTS. Calls may be placed to, from, or between vessels on a direct-dial basis without operator intervention. Currently, there is only one AMTS in operation, with service being provided by Waterway Communications System, Inc. (WATERCOM), a corporation set up by a number of barge and towing operators. The system of 55 base stations (100-115 km spacing) tracks ship locations so that incoming calls are routed through the nearest base station. This system operates along the Mississippi, Illinois and Ohio Rivers, providing service primarily to the tug and towboat industry from New Orleans to Minneapolis/St. Paul, Chicago and Pittsburgh, and along the Gulf Intracoastal Waterway from the Texas/Mexican border to the Florida panhandle.

Although not originally set up as a maritime service, cellular telephone is becoming the service-of-choice, especially for small boat owners not required by law to carry a VHF maritime mobile radio.[135] The USCG permits certain fishing vessels required to carry radio equipment for safety purposes to equip themselves with a cellular telephone in lieu of other radio equipment.[136] In the Gulf of Mexico, Petrocom operates an offshore cellular telephone service that provides voice and data services to vessels. In many areas, dialing "* CG" on a cellular telephone will immediately connect to the USCG. While this has the great advantage of providing emergency help to many boaters who would not have purchased a marine radio, it has the disadvantage of not allowing other nearby boats to hear a distress call and respond more promptly.[137] Cellular telephone has a more limited range than either of the other services (16 vs. 80 km). In addition, cellular telephone service tends to follow highways, rather than rivers or coastlines. Nevertheless, cellular telephone service is rapidly expanding and should be expected to play a greater role in coastal and inland maritime mobile services.

---

[134]47 C.F.R. § 80.5 (1993).

[135]Cellular telephony is also discussed *supra* p. 11

[136]46 C.F.R. § 28.245 (1993).

[137]Some entities feel that although cellular service is becoming increasingly popular for marine communications because it is much cheaper than marine radios and has automatic interconnect, the issues of safety through cellular telephony is a concern. *See, e.g.*, Reply Comments of Marine Telephone Company at 3 & Mobile Marine Radio at 3 (filed June 1, 1993) in *Amendment of the Commission's Rules Governing Maritime Communications*, Notice of Proposed Rule Making and Notice of Inquiry, PR Docket No. 92-257, 7 FCC Rcd 7863, (1992) [hereinafter MARITIME NOI].

FEDERAL USES

Federal maritime mobile communications support the operation, movement and safety of shipping on navigable waters of the United States and on the surrounding seas. The USCG has major responsibilities for maritime safety and navigation. Federal use of maritime mobile allocations must be in compliance with international and domestic regulations to ensure interoperability with all shipping and to maintain the integrity of maritime distress and safety communications.

The USCG relies on HF for command and control communications with cutters, aircraft, and shore facilities for purposes including search and rescue, off-shore enforcement of laws and treaties (including drug enforcement). Because of the USCG's expanding role in drug enforcement, a significant increase in the use of HF systems for air-ground and ship-shore circuits has taken place in the last decade. The USCG also relies on the HF band for such communications as distress and safety, broadcast of maritime safety information, emergency medical assistance communications, receipt of vessel position reports for safety purposes, and receipt of weather observation reports.

The Navy also has HF communication systems that transmit between shore stations and ships, and ship-ship in the maritime mobile bands. They support hydrographic surveys, communications with jumbo tankers, weapon system testing, and secure tactical voice systems. Constant communications with individual ships and naval forces at sea is required. Therefore, the Navy has a large investment and heavy reliance on HF communication equipment at shore installations and shipboard. HF transmissions will continue to be very important for fleet-wide communications. The Department of Interior uses HF for its U.S. Geological Survey organization. These systems support marine geology exploration and mapping tasks. The Department of Commerce has HF maritime mobile systems to support ships and boats used by the National Marine Fisheries Service and for communication links between major fishery centers and research vessels of the National Oceanic and Atmospheric Administration (NOAA) Corps fleet.

The USCG also relies on VHF channels for ship-ship and ship-shore communications on a regular basis. The only exclusive Federal Government allocation for the maritime mobile service in the bands between 30-3000 MHz is at 157.0375-157.1875 MHz. This band consists of six 25 kHz channels. Five channels are used to support the National VHF-FM Distress and Safety System operated by the USCG. The remaining channel is used by Federal agencies as a working frequency for their maritime operations.

Maritime mobile service use in the Federal Government fixed and mobile bands between 30-3000 MHz primarily supports Federal agency requirements to interface with civil land and aeronautical mobile service operations.

TRENDS WITHIN THE MARITIME MOBILE SERVICE

In November 1992, the FCC issued an NOI/NPRM, with the intent of reviewing present requirements and future trends concerning maritime communications.[138] The information sought will assist in formulating rules and regulatory policies for the maritime services that will increase safety, promote flexibility, reduce congestion, and remove unnecessary impediments to the economic well-being of the maritime industry. An issue of particular importance addressed in the Maritime NOI is the use of narrowband channels (i.e., splitting the current 25 kHz VHF voice channels into 12.5 kHz channels).

To address the congestion problem in the VHF maritime band, the ITU Radiocommunications Sector Study Group 8 will be considering the use of narrowband channels during the 1995 time frame. The United States has submitted a draft report and recommendations to the study group on the subject suggesting the use of 12.5 kHz spacing using narrowband FM techniques.

Commenters to the Maritime NOI indicated that voice telephony services, data communications, including facsimile, Electronic-Mail, video technology and position location will likely be future telecommunications requirements.[139] Many of the commenters supported narrowbanding of the VHF band in order to provide the spectrum for these services.[140]

SPECTRUM REQUIREMENTS FOR THE MARITIME MOBILE SERVICE

The maritime mobile services provide a means of communications for the day-to-day activities of a multi-billion dollar industry as well as providing the critical safety link for the protection of life and property at sea.

The USCG indicated that "HF remains a needed, affordable and reliable communications medium for the foreseeable future."[141] Furthermore, the USCG stated that WARC-87 did not provide adequate spectrum for maritime requirements in the 4 and 8 MHz bands and, consequently, a severe shortfall (of spectrum) exists

---

[138] *Id.*

[139] *See* Comments of Global Maritime Communications Systems, Inc. at 1 (filed May 27, 1993), Ross Engineering Company at 1 (filed May 27, 1993), SEA, Inc. at 2 (filed May 26, 1993), National Marine Electronics Association at 4 (filed May 31, 1993), KFS World Communications, Inc. at 3 (filed June 1, 1993) in MARITIME NOI, *supra* note 137.

[140] *See* Comments of Global Maritime Communications Systems, Inc. at 3 (filed May 27, 1993), Ross Engineering Company at 3 (filed May 27, 1993), The Ohio River Company at 3 (filed June 1, 1993), National Marine Electronics Association at 8 (filed May 31, 1993), Mobile Marine Radio, Inc. at 4 (filed June 1, 1993) in MARITIME NOI, *supra* note 137.

[141] USCG Comments at 2.

below 10 MHz.[142] The USCG further clarified this point by indicating that 6-10 additional channels per band below 10 MHz would be needed for maritime mobile voice requirements.[143] This would imply, for the 4 MHz and 8 MHz bands (with 3 kHz voice channels), that 18-30 kHz would be required per band, or 36-60 kHz total.

The Coast Guard indicated that it is essential for the maritime VHF band to be maintained for exclusive maritime use since it is vital to maritime safety and maritime interoperability on a worldwide basis.[144] Many of the commenters to the Maritime NOI indicated that narrowbanding the VHF band will allow for the expansion of increasing services. It is anticipated that any additional VHF maritime mobile spectrum requirements needed over the next 10-year period can be satisfied through the implementation of new technologies (such as VHF narrowbanding), and the increased use of land-based services.

In summary, NTIA estimates that 36-60 kHz of additional spectrum will be needed to satisfy HF maritime mobile requirements. No additional MF and VHF spectrum (provided VHF narrowbanding as discussed above is achieved) will be required for the maritime mobile services over the 10-year period.

MOBILE-SATELLITE SERVICES

The mobile-satellite service (MSS) is a "radiocommunication service between mobile earth stations and one or more space stations, or between space stations, or between mobile earth stations by means of one or more space stations."[145] MSS services meet the needs of many industries worldwide. They are ideal for international applications where rapidly-deployable mobile communications between countries are needed. Mobile-satellite communications to and from ships and aircraft greatly aid their safe operation. The use of land mobile-satellite terminals in times of emergencies to establish immediate communications is now being recognized as necessary.[146]

---

[142]*Id.* at 1. A 1989 NTIA report stated that U.S. requirements (at WARC-87) were not completely satisfied for additional NBDP, DSC, radiotelephone, and coast and ship wideband spectrum, especially in the 4 MHz and 8 MHz bands, due to other countries' interests in the fixed service. This report also states that there is a continuing requirement for maritime use of the 4 MHz and 8 MHz shared bands. HF SPECTRUM RESOURCE ASSESSMENT, *supra* note 113, at 22.

[143]HERSEY, *supra* note 127.

[144]USCG Comments at 2.

[145]NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-10.

[146]Mobile-satellite communications are rapidly becoming necessary for U.S. military operations. Vice Admiral Tuttle (Retired), former Director of Space and Electroni(Warfare, Office of Chief of Naval Operations, said the next time the Navy or Marines deploy to a war zone such as Somalia, they will bring with them commercial (INMARSAT) MSS terminals, thus creating an "infrastructure for peacekeeping". COMM. DAILY, Nov. 12, 1993, at 2.

In the United States, MSS meets the needs of the transportation industry by providing communications links for systems that are able to track and monitor cargo, including hazardous materials.[147] Public safety needs, such as supporting fire fighting, search and rescue, and communications during disasters can also be met with MSS.

The FCC has authorized the operation of the first domestic mobile-satellite system, which will use portions of the 1500/1600 MHz band. This system will be operated by the American Mobile Satellite Corporation (AMSC). AMSC plans to offer services to not only cellular telephone consumers who do not have access to complete coverage from terrestrial cellular systems, but also to the maritime and aeronautical communities. AMSC's first satellite is due for launch in 1995; the satellite is to be placed in geostationary orbit in position to serve North America.

CURRENT USES OF THE MOBILE-SATELLITE SERVICE

AERONAUTICAL MOBILE-SATELLITE SERVICE

The International Maritime Satellite Organization (INMARSAT) is using geostationary satellites to provide voice and digital data circuits for transoceanic aircraft on an experimental basis, giving much more reliable and inclusive coverage than current HF radio circuits. This experimental program includes Automatic Dependent Surveillance (ADS), an important new air traffic control procedure based on the periodic reporting from aircraft of on-board navigation data. The initial use of ADS is being planned for oceanic areas. The aeronautical mobile-satellite service (AMSS) could also replace many HF links over land areas. ARINC stated that "In time, communications currently handled by HF radio will be transferred to satellite communications."[148]

Several commenters indicated that satellite-based services will play a greater role in future air mobile services. The aeronautical mobile-satellite (R) service (AMS(R)S) has the capability to provide air-ground communication service to areas that are not served by present air-ground facilities.[149]

MARITIME MOBILE-SATELLITE SERVICE

INMARSAT is providing much-improved communications to larger ocean-going ships, which will tend to replace the use of long-range HF communications. INMARSAT provides distress, safety and general communication services. This system is currently used by approximately 17,000 ships throughout the world,

---

[147] A system used by commercial trucking companies makes use of fixed-satellite transponders in the 11/14 GHz band.

[148] ARINC Comments at 5.

[149] FAA Comments at 3.

including extensive operations within inland waterways for ship-shore communications. The number of users is expected to reach 40,000 within the next 10 years. Its use for distress and safety communications is part of the Global Maritime Distress and Safety System (GMDSS). This international application is tied to and required by international treaty resulting from the Safety of Life at Sea (SOLAS) Convention.

The size and cost of current INMARSAT shipboard installations currently limits its use by smaller vessels. However, future mobile-satellite service (provided particularly by low-Earth-orbiting satellites) would be expected to provide service to smaller vessels, including those in polar regions. Commercial and non-commercial maritime users can be anticipated to increasingly use MSS as availability improves and costs are reduced.[150] The USCG stated that satellite communications through the INMARSAT system are now coming into wide-spread use within the maritime service.[151]

LAND MOBILE-SATELLITE SERVICE

The land mobile-satellite service (LMSS) is expected to be a crucial component of future personal mobile communications systems. One such system being studied by the ITU Radiocommunications Bureau is the FPLMTS. The objective of FPLMTS is to provide pervasive mobile communications by the year 2000. It is recognized that in low-traffic areas, or in areas where FPLMTS has not been implemented, communications could be provided by mobile-satellite systems as an integral part of the FPLMTS.

Other LMSS services include remote news-gathering, remote monitoring of pipelines, wells and environmental sensors, and delivery of health and emergency services to rural locations. Federal, state, and local government agencies have a need for intermittent-use of LMSS terminals when other communications systems may be unavailable. For many industries, such as interstate trucking, MSS may be used instead of terrestrially-delivered communications services. MSS has clear opportunities for providing service to remote areas in which cellular or PCS investment is not economical.[152]

Mobile-satellite services are expected to grow rapidly, including many applications for Federal agencies. For example, mobile-satellite communications is a current and growing requirement of U.S. military Command, Control, Communications and Intelligence (C^3I).[153] Many Federal agencies are currently using INMARSAT services to satisfy a variety of telecommunications needs. Based on DOE's extensive land mobile service use and operations throughout the United States, DOE is planning to use mobile-satellite services for navigation, identification, location, and tracking of vehicles transporting nuclear materials.[154] The

---

[150]Pacific Telesis Comments at 6.

[151]USCG Comments at 2.

[152]Bell Atlantic Comments at 8.

[153]DOD Comments at 6.

[154]DOE Comments at 5.

newly-allocated MSS systems, including low-Earth-orbiting (LEO) satellites, will be incorporated into the array of commercial communication resources available to the military.[155]

The spectrum requirements expressed for MSS to date are primarily for voice services, along with a growing amount of data. However, it is likely that graphic and video data will also be transmitted over MSS systems. For example, APCO[156] envisions the use of MSS systems to transmit medical diagnostic images from ambulances to hospitals during emergencies in rural locations. These types of applications require much higher bandwidths than typical (message) data applications and have not been incorporated in the estimates given in this section.

USE OF NON-GEOSTATIONARY SYSTEMS FOR MOBILE-SATELLITE SERVICES

In the late 1980's, proposals were advanced to use non-geostationary (non-GSO) satellites[157] for commercial MSS purposes. Two types of commercial Non-GSO systems have emerged: small, inexpensive data-only satellite systems using frequencies below 1 GHz, and large, high-capacity systems operating above 1 GHz.

The smaller capacity systems are presently authorized to operate in lower frequency bands (137 MHz, 149 MHz and 400 MHz). The first of these systems is now operating experimentally in the United States and in some other nations. A large market targeted by these systems in the United States is for automobile theft recovery, distress alerting, water level monitoring, agricultural uses and environmental monitoring activities. Three domestic companies have applied to operate Non-GSO systems operating below 1 GHz.

Large-scale Non-GSO systems propose to offer voice, data, and location services to hand-held terminals similar to cellular telephones. These systems could begin operating within a few years. Five domestic companies have applied to operate Non-GSO systems above 1 GHz.

DEVELOPMENT OF SPECTRUM REQUIREMENTS FOR THE MOBILE-SATELLITE SERVICE

MSS systems provide coverage to large areas of the Earth. Spacecraft weight and antenna technology presently limit the amount of frequency reuse possible in and between MSS systems. For example, operation of a geostationary MSS system over the North Atlantic may preclude the use of the same frequency set in

---

[155]DOD Comments at 6.

[156]Letter from Steven H. Proctor, Association of Public Safety Communications Officials International, Inc., to Joe Camacho, National Telecommunications and Information Administration (no date, received Oct. 1994) (on file with NTIA).

[157]Geostationary satellites orbit approximately 35,800 kilometers above the equator so that the satellite appears stationary with respect to a point on the Earth. In non-geostationary orbits, which are generally closer to the Earth, the satellite does not appear stationary with respect to a point on Earth. Satellites in some highly elliptical non-GSO orbits exhibit characteristics of GSO satellites at times during an orbit.

most parts of the United States. Thus, the amount of spectrum required to support a given number of MSS users is large in comparison to the same number of users that can be served by highly developed terrestrial systems. However, the advantage of MSS is that traffic can be accommodated originating anywhere within the large coverage areas of the MSS satellite. Many countries are implementing MSS systems today, and these foreign systems may well impact the use of MSS spectrum available in the United States.

Comsat stated that an estimated 200 MHz is required for GSO MSS systems, worldwide, in the future. Spectrum projections out to the year 2010, made in 1991, showed a large increase in spectrum needed to serve the potential MSS market.[158] In Comsat's view, this 200 MHz does not include spectrum needed for voice service to hand-held devices as envisioned by FPLMTS and the prospective Big Non-GSO MSS systems.[159]

MSS systems providing service to hand-held devices are further constrained in the amount of frequency reuse that can presently be achieved. Fundamentally, the lack of high-gain satellite antenna discrimination is a limiting factor in the spectrum efficiency achievable with these systems. For example, present designs of big Non-GSO's generate at most a few hundred voice channels per megahertz over the United States. However, the MSS Non-GSO above 1 GHz applicants have been cautious in stating spectrum requirements beyond those in their initial FCC applications. The initial licenses would be limited to a maximum of 33 MHz.[160]

Non-GSO MSS systems below 1 GHz use considerably less spectrum than the Non-GSO systems using frequencies above 1 GHz because they are used for low data rate transmissions only. These systems should be capable of supporting large numbers of users in a few megahertz.

Several Federal MSS systems support U.S. military operations on a worldwide basis. These include GSO and non-GSO systems. Non-GSO systems can be in various higher orbits (medium orbit, intermediate orbit, or elliptical orbit). Federal systems operate in the 225-400 MHz, 7/8 GHz, 20/30 GHz and 20/44 GHz portions of the spectrum[161]. Beyond the use of Federally-operated MSS systems to support military operations, it is anticipated that the growing demand for MSS by Federal agencies will be met by commercial MSS providers.

---

[158]Comsat Comments at 2.

[159]AMSC also filed comments but did not quantify future MSS requirements. AMSC referred to the work of the ITU Radiocommunications Sector in preparation for WARC-92. The CCIR's Joint Interim Working Party Report to WARC-92 indicates that by the year 2010, 328.2 MHz will be needed for MSS. AMSC Comments at 8.

[160]The FCC has recently adopted an Report and Order that would provide approximately 5 MHz initially for bi-directional TDMA systems (e.g., IRIDIUM) and up to 25 MHz for the other applicants, holding approximately 3 MHz in reserve. *Amendment of the Commission's Rules to Establish Rules and Policies Pertaining to a Mobile Satellite Service in the 1610-1626.5/2483.5-2500 MHz Frequency Bands*, Report and Order, CC Docket No. 92-166 (released Oct. 14, 1994) [hereinafter MOBILE SATELLITE REPORT AND ORDER].

[161]With advancing technology, it is becoming more feasible to use satellites operating in frequency bands above 3 GHz for mobile applications.

Internationally, several frequency bands are allocated to commercial MSS. Additionally, there are several bands allocated to MSS on an ITU Regional basis. Currently in the United States only a subset of the worldwide allocated bands are available for commercial MSS systems; the 1525-1559, 1610-1626.5, 1626.5-1660.5 and 2483.5-2500 MHz bands and the 137-138, 148-150.05, 399.9-400.5, and the 400.15-401 MHz bands. AMSC stated that "even the substantial additional MSS allocations made at the 1992 WARC cannot be expected to alleviate the severe shortage of spectrum that constrains the development of MSS in the United States"[162] AMSC further stated that additional spectrum is urgently needed because the international coordination process has indicated that the United States is unlikely to gain access to a sufficient amount of the presently allocated spectrum to fully develop AMSC's currently planned system.[163]

The MSS industry perceives a shortage of MSS spectrum even taking into account the bands allocated at WARC-92. Many of the newly allocated bands are shared with other services and will not be available entirely to MSS. Further, MSS spectrum used by other countries, such as Mexico and Canada, cannot also be used by a U.S. system. More than 30 MSS systems around the world are in various stages of planning for the 28 MHz of spectrum presently authorized to AMSC in the United States.[164] Of the newly-allocated bands, only the 1525-1530, 1610-1626.5, and 2483.5-2500 MHz bands are readily available in the United States.[165] For commercial Non-GSO systems operating on frequencies below 1 GHz, there is approximately 4 MHz, shared among a number of radio services, that is currently available.

SPECTRUM REQUIREMENTS FOR MSS

There are several factors that will determine whether additional spectrum is needed for MSS in the United States. The first is the extent to which MSS voice and data services using hand-held devices can successfully compete with terrestrially-delivered services.[166] A high level of acceptance of such MSS services would likely cause the present spectrum available for large-scale MSS (Non-GSO's and future GSO systems) to be inadequate. A second factor is the availability of the MSS spectrum allocated at WARC-92. The implementation of worldwide MSS systems will require at least the spectrum allocated at WARC-92 to account for the non-uniform implementation of MSS allocations within and between various administrations.[167] The third factor is that the spectrum efficiency of MSS systems is limited by the size of

[162]AMSC Comments at 11.

[163]AMSC Comments at 2. Further, AMSC applied to the FCC for authority to operate in the maritime mobile satellite portion of the lower portion of the 1500-1600 MHz band. This would provide up to an additional 35 MHz for the U.S. system. COMM. DAILY, Nov. 4, 1993, at 6. However, it is not likely, given the present use of these frequencies by INMARSAT, that a substantial amount will be available for a U.S. system.

[164]AMSC Comments at 6.

[165]Comsat states that only 60 MHz allocated at WARC-93 is suitable for MSS use on a worldwide basis. Comsat Comments at 3.

[166]Additionally, it is not known how many of the potential MSS providers will actually be financially able to establish mobile-satellite systems.

[167]However, while spectrum used by other countries for MSS might not be usable for MSS in the United States, other uses may be possible.

the space and terrestrial antennas employed. Improvements in MSS system efficiency will result primarily from larger spacecraft antennas that increase frequency reuse potential. There are plans to use very large antennas, generating many beams over an area the size of the continental United States, in future MSS systems.

It is assumed that the principal growth in MSS services in the United States over the next 10 years will be from the introduction of low-cost "personal" satellite-delivered telecommunications services. Existing MSS services will also experience growth during the next 10 years; new services will be primarily a voice-oriented service that supplements terrestrial cellular radiotelephone service. This MSS service is characterized by being able to use hand-held earth stations and will require new technologies to be employed, such as non-GSO satellite systems, in order to be offered.

An estimate of additional spectrum needed to accommodate this service in the next 10 years requires several assumptions to be made regarding this new, untried market. First, it is assumed that the service offerings will be dual-mode, in that the customer will automatically receive the lowest-cost option available, either MSS or terrestrial cellular-like service, including PCS services. We further assume that about three percent of cellular subscribers will use MSS offerings.

The estimate of additional spectrum for MSS is calculated as equal to the product of the number of subscribers, the number of channels per subscriber, the bandwidth per channel, and the reuse factor.[168] It is estimated that the cellular and cellular-like subscriber base will be in excess of 80 million by 2004.[169] An additional 0.9 million data-only and conventional MSS subscribers is estimated to use MSS services by 2004. This results in a total MSS user base of 3.3 million.[170]

With a first-generation MSS reuse factor of 0.67, the current 99 MHz of MSS spectrum will accommodate 1.48 million subscribers, leaving 1.82 million to be accommodated in additional, as yet un-allocated MSS spectrum. Assuming a second-generation reuse factor of 0.33, then approximately 60 MHz of additional MSS spectrum will be needed by 2004. It would be preferable for international compatibility and spectrum efficiency that this spectrum come from the bands allocated internationally at WARC-92 (1980-2010 MHz and 2170-2200 MHz).

For non-GSO MSS systems below 1 GHz, industry has recently estimated that an additional 7 MHz is required by the year 2000.[171] However, it is envisioned that this spectrum will be shared with terrestrial use.

---

[168]Reuse is taken to be the amount of effective spectrum that can be available, taking into account the design of domestic MSS systems. First-generation MSS systems will have limited reuse capability, corresponding to multiplying the allocated spectrum by an average reuse factor of 0.67. Second-generation MSS systems will have at least double the reuse. For the purposes of this analysis, the average reuse factor is taken to be 0.33 for additional spectrum requirements.

[169]See *supra* note 99, at 5, where the total for PCS and cellular subscribers is 83.3 million in 2003.

[170]See *supra* note 99 where PCIA estimates 4.11 million satellite subscribers by 2003.

[171]Contribution to Report of Task Group 8/3 CPM '95, U.S. TG 8/3-22, *Assessment of Spectrum Requirements for MSS Below 1 GHz* (Oct. 18, 1994) (U.S. input document to ITU-R Task Group 8/3) (on file with NTIA).

An additional amount of spectrum, estimated to be on the order of 60 MHz, is needed to be available to meet U.S. mobile-satellite traffic requirements by the year 2004. This additional spectrum is needed to serve the several million new MSS subscribers envisioned for the period beginning around the year 2000. The principal service is expected to be as a supplement to terrestrial cellular and PCS in order to provide voice communications into areas where terrestrial systems will not operate. Additional spectrum also needs to be available for non-GSO MSS operating below 1 GHz. This requirement is on the order of a few Megahertz but can be shared with terrestrial systems. However, because of rapidly evolving nature of MSS technology and the uncertainty of market demand, this spectrum requirement should be monitored closely and modified accordingly in the future.

REQUIREMENTS FOR MSS FEEDER LINKS

MSS systems typically use frequencies in bands above 3 GHz for links between the satellite and large earth stations. Mobile-satellite feeder links are included as part of the fixed-satellite service (FSS) and thus use bands allocated to the FSS. Feeder links complete the path from the mobile earth station to a large fixed earth station that connects to the PSTN. Feeder links are also used to control the satellite transponder. The amount of spectrum required for feeder links is large, using today's technology which employs a single feederlink beam antenna on the satellite. It is estimated that given the efficient reuse of service link spectrum that between 10 and 20 times as much feeder link as service link spectrum could be needed. Future systems may be able to reduce the amount of spectrum required by introducing reuse of the feeder link frequencies and possibly by using compression techniques involving satellite on-board signal processing.

Since large earth stations are used for the feeder links for GSO MSS systems, feeder links can be shared with other satellite and terrestrial services in existing FSS bands. Therefore, no additional spectrum is needed to be dedicated to GSO MSS feeder links. For non-GSO systems, sharing is more difficult. One likely approach is to use FSS bands in the reverse direction for non-GSO feeder links. In such bands there may be limited sharing opportunities for terrestrial services. The amount of spectrum required for non-GSO feeder links, assuming that 50 MHz of service link spectrum were used for such systems, could be 500 to 1000 MHz. This spectrum requirement should be satisfied in the existing FSS bands for the most part. Domestic and international efforts are underway to identify bands and sharing possibilities for MSS feeder links within existing FSS bands.[172] Some bands not presently allocated to the FSS are also being considered for non-GSO feeder links. Several non-GSO MSS applicants have requested spectrum for uplinks which would not be shared with other FSS systems[173]. Several other non-GSO systems have requested spectrum in the 20/30 GHz bands. The subject of MSS feeder links is on the agenda for the 1995 ITU World Radiocommunication Conference (WRC).

[172]Candidate frequency bands include FSS bands below 15 GHz, in the reverse direction, and the 20/30 GHz FSS bands.

[173]MOBILE SATELLITE REPORT AND ORDER, *supra* note 160, at 63.

Recent studies indicate that in some cases multiple MSS system feederlinks can share the same spectrum.[174] Both forward band working (FBW) and reverse band working (RBW) of FSS Bands have been advocated by MSS industry representatives to accommodate the feeder link spectrum requirements within the current FSS allocations. If RBW provides better sharing prospects than FBW, the candidate FSS bands may have to be reallocated at a future WRC. Comments to the FCC indicated that spectrum needed for non-GSO feederlinks could be from 200 to 400 MHz, depending on the amount of intrasystem sharing possible.[175]

Preliminary analysis indicates that GSO MSS feeder links may be able to share compatibly with the FSS and that additional spectrum may not be required. For non-GSO feeder links, the emphasis has been on using RBW as a promising means for sharing with some FSS bands. However, industry has indicated that spectrum not shared with FSS for feederlink uplinks on the order of 200-400 MHz is needed for initial U.S. systems. This spectrum would, however, be shared with terrestrial systems. Studies are now being conducted that will provide more insight into spectrum requirements and sharing possibilities. The amount of spectrum needed for feederlinks in the United States depends on the number of Non-GSO systems implemented, the spectrum available for MSS service links (that is from the mobile to the satellite) and the amount of intra-MSS system reuse.

---

[174]Contribution to Report of Task Group 4/5, U.S. TG 4/5-19, *Summary and Discussion of Three Analyses and Computer Simulations to Assess Sharing Potential Between Multiple NGSO Feeder Link Analysis* (Oct. 19, 1994) (U.S. input document to ITU-R Task Group 4/5) (on file with NTIA).

[175]Radiocommunication Study Groups, International Telecommunication Union, Document 8-3/TEMP/53(Rev.1)-E, Element of CPM Report Non-GSO MSS Feederlink Spectrum Requirements (Nov. 24, 1994).

CHAPTER 2

FIXED AND FIXED-SATELLITE SERVICES

INTRODUCTION

The fixed and fixed-satellite services provide communications between two or more fixed locations. The fixed-satellite service involves one or more satellites as intermediate relay points; the fixed services utilize only terrestrial stations.

The use of radio systems for point-to-point communications has gone through several phases, including the use of HF radio after World War I for long-range circuits, especially transoceanic circuits and other routes which were not well served by the early wired telephone and telegraph networks. The next important phase of point-to-point radiocommunications began after World War II, when extensive point-to-point microwave networks were installed by the telephone companies. These microwave networks typically had more than a thousand times the information-carrying capacity of HF radio links, which allowed microwave to carry TV programs and large numbers of long-distance telephone calls. Unfortunately, each microwave link only had a short range (50-80 kilometers) and many links had to be connected in series to achieve transcontinental range.

The development of communication satellites in the 1970's allowed wideband single-hop relay of information across a continent or an ocean. Satellites greatly improved transoceanic communications of many types, and provided improved distribution of television signals across the United States. The half-second transit-time delay for geosynchronous satellites was objectionable to telephone users, however, and satellite-based voice circuits did not gain wide acceptance. Optical fiber became a greatly-improved alternative to copper wires in the early 1980's, and it has become the technology of choice for most new high-traffic capacity communications between fixed points installed in the 1990's.

This chapter describes the present state of fixed radiocommunications and estimates future requirements for radio spectrum supporting these services. Section II describes the (terrestrial) fixed service; Section III describes the fixed-satellite service.

FIXED SERVICES

The fixed service is defined as "a radiocommunication service between specified fixed points."[176] This includes those services in which a stationary transmitter communicates with one or more intended stationary receivers.[177] Fixed services include operations in frequency bands ranging from below HF (3 MHz) to millimeter-wavelength (above 30 GHz). They can be divided into several very different groups, according to frequency. The lowest range is the HF band (3-30 MHz). HF signals are not restricted to line-of-sight, but can travel for thousands of kilometers, providing a long-range but highly variable narrowband service. At VHF and UHF frequencies (30-1000 MHz), narrowband fixed services are provided over short ranges (up to 60 km), often sharing frequencies in mobile bands but using directional antennas. These services also include the rapidly growing point-to-multipoint multiple address service (MAS). The last group of fixed services uses microwave frequencies (above 1 GHz). Point-to-point microwave systems (often simply called "microwave systems") provide wideband communications over line-of-sight paths. Tropospheric scatter systems provide point-to-point service over paths up to 200 km, using highly directional antennas and high-power transmitters. Point-to-multipoint microwave services are used over line-of-sight paths, often with an omnidirectional master antenna and directional node antennas. These microwave fixed services have been described in a recent NTIA staff study,[178] hereinafter called the Fixed Study.

The fixed services will be grouped within seven categories: HF services, VHF/UHF services, and five categories of microwave services. The microwave categories include common carrier, private, auxiliary broadcasting, cable relay, and Federal Government. These five microwave categories represent the licensing categories established by the FCC or NTIA. Within each of these five categories, there are functionally similar uses which cross the category boundaries. For example, the supervisory control and data acquisition (SCADA) functions within private operations are similar to SCADA uses within the Federal Government. Similarly, video signals are carried by stations belonging to all five categories, using virtually identical technology.

---

[176]NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-6.

[177]Fixed service systems include point-to-point operations (a single transmitter and a single receiver). Fixed services also include point-to-multipoint operations (a single transmitter and many receivers), including multiple address service (MAS) operations (two-way transfer of data between a master station and multiple slave stations). The fixed service differs from the broadcasting service, in that the broadcasting service is one-way and does not have specifically identified receivers. Fixed services differ from the mobile services because the fixed service transmitters and receivers are stationary (i.e., fixed), though fixed service stations may be transported between sites.

[178]MATHESON & STEELE, *supra* note 11. This study considered 33 radio bands between 406 MHz and 30 GHz that are allocated to the fixed services on a primary basis. The opinions expressed in the study are those of the authors and do not necessarily reflect NTIA policies or planning.

CURRENT USES OF THE FIXED SERVICE

HIGH FREQUENCY SERVICES

Since HF signals are reflected back to Earth by the ionosphere, they can travel long distances, including transoceanic routes. HF communication users must consider the constantly-changing nature of the ionosphere, high levels of ambient noise, severe crowding and interference, and the need for relatively large antennas. Nevertheless, because of the long-range capability using inexpensive equipment, HF is uniquely valuable for many long-range fixed applications. USCG said that no other portion of the spectrum can "do it all" like HF.[179]

The DOD and many other Federal agencies use HF fixed to support priority communications after hurricanes, earthquakes, or other natural disasters have disrupted the existing communications infrastructure. DOD uses HF for command and control communications. In addition, HF communications are often the only way to communicate with developing nations via radio links. The recent development of HF automatic link establishment (ALE) technology has given HF systems improved performance. An ALE system continually monitors the propagation between all stations in the network over a range of HF frequencies. This allows the best frequency to be automatically selected for each message, substantially improving performance and reliability over conventional HF systems. Many Federal agencies have joined the Shared Resource Program (SHARES), which uses HF voice network assets and ALE technology, during emergency conditions.[180]

Private industry and Federal agencies use many fixed HF links to offices in foreign countries, partly as backup for sometimes unreliable foreign communications services. The main Federal users are DOD and the Department of State, which maintain many HF links to overseas bases, embassies, and offices.

VHF AND UHF FIXED SERVICES

Fixed services are permitted in the mobile bands in the 30-1000 MHz range, though often as a secondary service or only in a limited geographical area. These fixed services include voice circuits (often serving as low traffic backbone between mobile radio sites), supervisory control and data acquisition circuits (SCADA) for control and monitoring of utilities, hydrologic and transportation systems, to replace wired telephone connections in remote areas,[181] and to send audio program material from radio studios to radio transmitter sites. Most VHF/UHF fixed services share frequencies (sometimes on a secondary basis) within the VHF and UHF mobile bands—using directional antennas, but otherwise similar technology to the mobile systems. Recently, several bands have been allocated especially for fixed services around 900 MHz. These bands provide for MAS, where a master site can provide two-way data connections to a number of slave

---

[179]USCG Comments at 1.
[180]Federal participation involves 38 agencies with almost 1000 sites.
[181]An example of this is the Basic Exchange Telecommunications Radio Service (BETRS).

sites. This rapidly growing technology is being used for a wide range of services, from verifying checks written at stores to reading residential electric meters.

COMMON CARRIER FIXED SERVICES

These microwave services are licensed by the FCC's Common Carrier Bureau under Part 21 of the FCC Rules. They include fixed radio stations operated mainly for the use of the public, i.e., for the use of parties other than the owner of the station. The telephone companies—local exchange carriers (LEC's) and long distance or interexchange carriers (IXC's)—and cellular telephone companies are the major users.

The telephone companies built networks of point-to-point analog microwave links in the 1950-1970 period in the 4-GHz and 6-GHz bands and short-range links in the 11-GHz band. The original analog circuits carried coast-to-coast TV coverage, as well as long-distance telephone circuits and computer data. Most of the early analog channels have been converted to digital systems in recent years. Narrowband channels in the 2-GHz bands have recently proven ideal to provide a backbone network for rapidly-expanding cellular telephone systems. The 2-GHz links are also used by telephone companies to bring services into smaller towns in remote areas, where the lower equipment costs and the modest bandwidth requirements of a small town make an excellent fit.

Public operations also include a series of "distribution" services. These include the multipoint distribution service (MDS, 2 GHz), the multiband multipoint distribution service (MMDS, 2.5 GHz), digital electronic message service (DEMS, 10.5 GHz) or digital termination service (DTS), and a recently proposed local multipoint distribution service (LMDS) operating at 28 GHz. These distribution services are intended to provide one-way or two-way services for digital messages, but they have been used mainly to distribute TV signals. They feature a "star" topology, i.e., a master station (with an omnidirectional antenna) communicating with multiple slave stations (using directional antennas aimed at the master station). The same bands and services can often be used by private operators.

MDS and MMDS are used as "wireless cable" in rural areas where the subscriber density is too small to support cable TV and in urban areas where they compete with cable. LMDS is planned for crowded urban locations, where multiple short-range master stations would be used.

PRIVATE FIXED SERVICES

These microwave services are licensed by the FCC's Wireless Radio Bureau under Part 94 of the FCC Rules.[182] They include services that are operated by organizations mainly to carry signals for their own purposes. Major users include private companies, utilities, transportation providers, and state and local governments.

---

[182] 47 C.F.R. § 94 (1993).

Private companies use microwave to support corporate data and voice circuits serving several local sites. These links are installed to get improved economy or performance compared to the LEC, or to provide backup circuits independent of the LEC central office.

State and local governments use microwave to interconnect various government office complexes. In addition, many cities interconnect police and fire stations with a microwave system backbone, serving as a back-up in case a major disaster destroys normal telephone communications. State government functions use private microwave as backbone to connect remote mobile radio relay sites. These sites provide statewide mobile radio service to state highway patrol, natural resource management, and highway maintenance personnel.

Transportation and utility companies use private microwave for SCADA, which includes monitoring and control applications for pipelines, electrical power lines, railroads, dams and locks, irrigation projects, etc. In many SCADA applications, the data rate is quite low, although high reliability and quick response may be needed. SCADA applications often follow a solitary power line or pipeline through remote areas, where few alternative telecommunication services are available. State and local governments also use SCADA to control water, gas, and electric distribution, traffic signals, etc.

AUXILIARY BROADCASTING SERVICES

Auxiliary Broadcasting (AUXBC) functions are described in Part 74 of the FCC rules; they include applications that support the TV and AM/FM broadcasting industry. Although TV signals are broadcast to the consumer with a 6-MHz-wide signal in the NTSC[183] format, AUXBC video links utilize an analog frequency-modulated point-to-point microwave channel with 17-25 MHz bandwidth. Electronic news gathering (ENG) uses transportable microwave links, usually carried in small vans with telescoping antenna towers, to provide "live" coverage of a local news event or a major sports event. ENG's will typically move several times a day to cover different local news stories, using ENG frequencies that are often coordinated and shared between local TV stations on a tightly scheduled basis.

Fixed AUXBC video applications include studio-to-transmitter links (STL's) and intercity relays (ICR's),[184] which carry program material and control circuits between the studio, transmitter sites, and other locations. A large TV station might use 10-15 AUXBC links, including several remotely controlled rooftop ICR's that can be pointed to receive signals from distant ENG's or used with a local camera to provide pictures of weather or traffic conditions.

[183]The National Television Systems Committee (NTSC) modulation format is used for TV broadcast signals in the United States and many other countries.

[184]ICR is a broadcast industry term that includes FCC designations for TV relay stations, TV microwave booster station, and audio ICR.

AUXBC audio links are used by AM and FM stations for temporary live coverage of particular events, as well as for studio-to-transmitter links. Audio STL services are also provided by specially equalized analog or special digital telephone lines.

CABLE RELAY SERVICE

The cable relay service (CARS)[185] is described in Part 78 of the FCC rules; it supports the cable TV industry. CARS and AUXBC use electronic news gathering in identical ways to provide temporary real-time coverage of news events outside the studio. CARS uses studio-to-cable headend links (SHL's) to transmit TV program material from a distribution hub to individual cable headend sites, where the signal is transferred to cable. SHL's can transport individual TV channels (similar to the STL's used by AUXBC services) or they can transmit blocks of up to 42 contiguous NTSC channels from a central distribution hub to multiple cable headend sites.

FEDERAL GOVERNMENT FIXED SERVICES

The Federal Government uses fixed services for a wide variety of functions, in accordance with the regulations found in the NTIA Manual. Many functions (including SCADA, back-up communications for high-priority functions, backbone connection to remote radio sites, etc.) are similar to corresponding civilian functions. Other Federal functions, e.g., military and air traffic control, do not have non-Federal counterparts.

Federal civilian agencies like the Department of Interior and Department of Agriculture use microwave networks to support mobile radiocommunication sites in Federally-controlled remote areas like National Forests and National Parks. These networks are used for natural resource management, firefighting, law enforcement, tourist information, environmental and wildlife control, search and rescue, and general administrative communications. The Departments of Justice and Treasury maintain extensive urban and wide-area radio nets to support national law enforcement and security. The FAA uses a nationwide microwave network to monitor and control the national airways, bringing air traffic information from remote radar sites and navigation sensors, and providing two-way voice and data communications between air traffic controllers and aircraft. USCG provides monitoring and control of maritime traffic in major U.S. harbor areas, using microwave communications to interconnect multiple local vessel traffic service (VTS) radar and radiocommunications sites.

Federal power agencies, such as the Tennessee Valley Authority (TVA), Bonneville Power Administration, the Army Corps of Engineers, etc. make extensive use of microwave SCADA networks to monitor and control the operation of electrical distribution networks, irrigation, flood control, river navigation and lock systems, navigation projects, gas and oil pipelines, and other systems. DOE, for example, has 2.4 million kilometers of telecommunications circuits for SCADA applications.[186]

---

[185]The cable television relay service was originally called the "community antenna relay service," hence the "CARS" acronym.

[186]DOE Comments at 6.

Military test and training ranges use extensive fixed microwave systems to support range safety and security; to relay telemetry data received from airborne, mobile, and stationary platforms to central control sites; for closed circuit TV for safety, security, and performance evaluation; to provide radar tracking and air traffic control information, and to observe other test and training results; and to support a wide range of logistics and administrative support activities on these ranges. The need for extensive communication backbones on some ranges includes the relay to central monitoring sites of real-time updates on the status and exact location of thousands of individual vehicles and soldiers during realistic exercises that cover hundreds of square kilometers of test range.

Military operations and training make extensive use of transportable fixed and fixed-satellite microwave terminals, designed to be transported to an overseas combat or support area, rapidly set up and configured into a communications network, and used for critical operational C^3I communications for the duration of the mission. These capabilities are also used domestically to support training and to provide support of disaster relief and similar missions..

Numerous Federal agencies use the fixed service to communicate with a wide range of sensors that keep track of weather, stream flow, geophysical, agricultural, and pollution phenomena. Microwave is also used to provide more economical communications between nearby offices, as well as providing high-reliability backup in case of LEC failures.

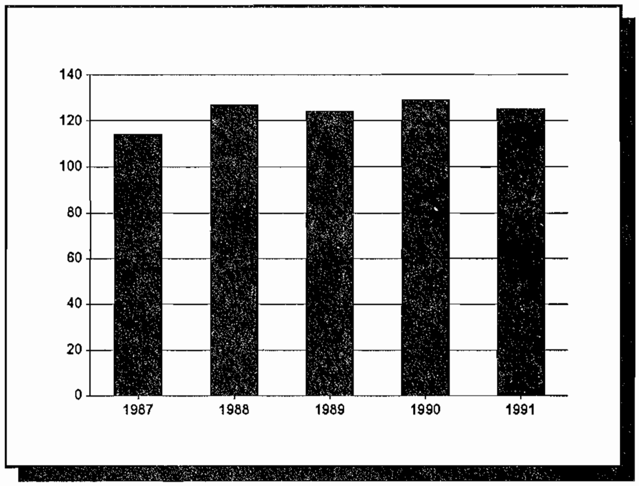


Figure 2-1. Number (in thousands) of fixed licensed frequencies in the non-Government bands above 1 GHz, excluding the 13 GHz band.

TRENDS

GENERAL MARKET TRENDS

Although the telecommunications industry as a whole is growing rapidly, the fixed microwave industry is not. Figure 2-1 shows the number of fixed licenses in the non-Government microwave bands above 1 GHz, not counting the 13-GHz CARS band (which is shown separately in Figure 2-7).[187] Some reasons for the observed performance of the microwave industry will be examined in this section, with obvious application to predicting future fixed service spectrum requirements.

[187] Data on non-Federal fixed service licenses used throughout this section was obtained from Comsearch, under contract to the Department of Commerce. The data gives the number of licenses on December 31 of the respective years. This data is extracted from MATHESON & STEELE, *supra* note 11.

In contrast to the stable, or slightly declining number of microwave licenses, fiber optic systems are growing very rapidly. Figure 2-2 shows the cumulative kilometers of fiber installed by U.S. LEC's and IXC's for the 1987-1992 period.[188] The NTIA Fixed Study[189] calculated that the amount of new communications capacity (in terms of DS-3 kilometers)[190] added in optical fiber in 1991 was about 23 times the capacity added with microwave systems.

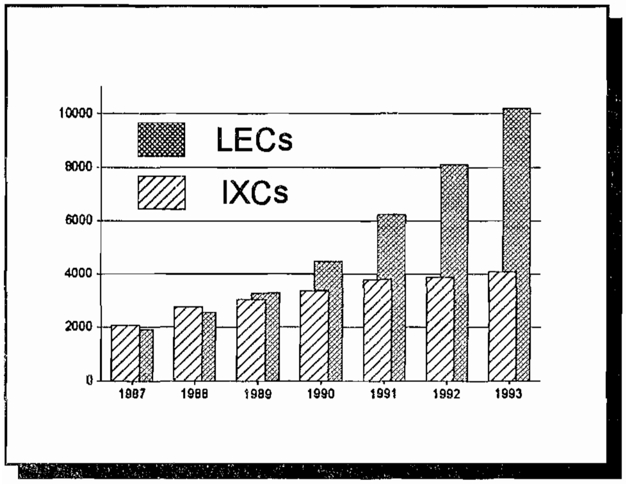


Figure 2-2. Cumulative fiber kilometers (in thousands) deployed by LEC and IXC service providers.

The initial rapid growth in optical fiber systems was produced by the IXC's, whose long-distance networks are now mostly based on fiber. The next wave of fiber growth was by the LEC's, who installed fiber to interconnect central offices, major customers, and neighborhood interface sites. About two years ago, cable TV companies began replacing microwave and coaxial cable with optical fiber networks capable of supplying advanced two-way digital services. Independent fiber providers are currently building fiber systems in dense business and industrial areas. The proposed mergers between cable TV and local telephone companies represent still another possible route to a great expansion of local telephone/TV/data service based on optical fiber.

The rapid expansion of optical fiber systems by multiple vendors is expected to bring a competitive environment for optical fiber services throughout urban areas, although it is not yet clear which of the rapidly-changing business alliances will provide the services. Cellular telephone companies, future PCS providers, cable TV companies, the LEC and non-LEC telephone companies, etc. are all expected to play a role.

Many commenters recognized a strong and continuing trend toward the replacement of long-haul microwave with fiber.[191] Motorola asked that the migration to fiber be encouraged, so that spectrum could be freed up for new mobile services.[192] Comsat suggested that a shrinkage of the fixed services in the shared 4-GHz and 6-GHz bands would allow greater growth of fixed-satellite services in those bands.[193] SBCA

---

[188] JONATHAN M. KRAUSHAAR, FED. COMM. COMMISSION, FIBER DEPLOYMENT UPDATE—END OF YEAR 1992 (1993).

[189] MATHESON & STEELE, *supra* note 11, at 7.

[190] A DS-3 link is equivalent to one TV channel, twenty-eight T1 circuits, 762 voice channels, or 45 Mb/s.

[191] Pacific Telesis Comments at 7-11; Motorola Comments at 11-13; Digital Microwave Comments at 3; Harris Comments at 2-10; Comsat Comments at 9; AT&T Comments, Exhibit B at 5.

[192] Motorola Comments at 13.

[193] Comsat Comments at 9.

wanted to put a freeze on any new fixed assignments in the 4-GHz band, leaving the band more available for television receive-only (TVRO) sites.[194]

FIBER OPTIC VS MICROWAVE TRADEOFFS

A single optical fiber can carry 2400 Mb/s of data (48 DS-3 circuits); the maximum capacity of a commercial microwave channel is 135 Mb/s (three DS-3 circuits). Thus, fiber provides much greater capacity than microwave, and this capacity can be increased arbitrarily by simply adding more fibers. Typically, 25-35 individual fibers are installed in a fiber cable.[195]

Because the relatively high cost of right-of-way and cable burial, the cost is the same for a cable with one fiber or many fibers. The cost per fiber decreases as more fibers are included in the cable. Thus, fiber tends to be more expensive than microwave for a low-traffic circuit and less expensive than microwave for a high-traffic circuit. The case study in Table 2-1 shows the relative cost of a specific 130-km circuit requiring three microwave hops or one fiber repeater site.[196] This table expands a figure in the cited paper to include a larger number of DS-3 links. The relative costs show why microwave is often chosen for routes with less dense traffic and fiber is selected for denser routes. Difficult terrain or a difficult landowner can make it more time-consuming and expensive to install fiber. Microwave circuits can usually be installed much more rapidly than fiber.

The high cost of a fiber optic link is partly due to the cost of optical components, with individual optical repeaters, laser modulators, optical switches, etc. often costing $25,000 to $50,000 apiece. This cost could decrease by 90 percent with economies of scale and improved technology. The cost of placing fiber in the ground will remain an important factor, however, even if component costs decrease.

There is a risk that buried fiber will be accidently damaged. One industry rule-of-thumb points toward one fiber cut/year/500 km of fiber. Alcatel says that typical fiber breaks require 6-12 hours to locate and repair.[197] Since the risk of outages are too great for some applications, many fiber networks are beginning to use self-healing ring architectures where the ring must be broken in two places before a segment becomes isolated. Microwave links are also used to back up some fiber circuits.

[194] SBCA Comments at 3.

[195] KRAUSHAAR, *supra* note 188.

[196] *Proactively Surviving "Fiber Fever"*, Dave Wand, U.S. West Communications, National Wireless/Radio Engineers Conference, Denver, Colo. (June 3, 1992).

[197] Alcatel Comments, Comments of Technical Staff at 10.

TABLE 2-1
RELATIVE COSTS OF MICROWAVE AND FIBER OPTICS OPTIONS

Number of DS-3 Links	Construction Cost per DS-3 Link ($1000's)	
	Microwave	Fiber Optics
1	1890	4410
2	945	2205
3	630	1470
6	450	735
12	260	367
24	203	195
36	183	138
60	168	88
96	160	67

Although fiber has substantial advantages for many applications, AT&T has suggested several situations where microwaves are likely to remain preferable over fiber.[198] AT&T's list includes circumstances where the circuit needs only a traffic capacity of one DS-3 or less, crosses inaccessible terrain, is needed for disaster recovery, is used as backup for disaster avoidance, is used for rapid deployment, or is used to provide temporary service.

The above list implies that fiber optics have taken over many of the long-haul, high-density markets, but have left several important niche markets to microwaves. Some of these niche markets may remain quite active in future years. Several commenters stated that low traffic density, inaccessible terrain, or cost would prevent complete replacement of microwave with fiber.[199] DOD stated that an increased percentage of fixed communications traffic would be shifted to fiber, but that transportable links would continue to need microwave frequencies.[200]

[198]AT&T Comments at 4.

[199]AAR Comments at 9; Southwestern Bell Comments at 7; DOI Comments at 4. *See also* Comments of the Utilities Telecommunications Council at 54-61 (filed June 5, 1992) in *Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies*, ET Docket 92-9.

[200]DOD Comments at 7-8.

FIXED USE OF HIGHER FREQUENCY BANDS (ABOVE 15 GHZ)

Another major change affecting the use of fixed services is the increasing use of higher frequencies. Although most of the bands below 10 GHz have exhibited growth rates of less than 2 percent a year, the 18-GHz and 23-GHz microwave bands are growing at the rate of 20-30 percent a year, as shown in Figure 2-3.[201] The very high apparent growth rate of the 18-GHz band in 1992 is mostly caused by a change in rules that allowed this band to transport television signals to private cable networks (similar to the use of the 13-GHz CARS band). The past use of higher frequencies (greater than 15-GHz) was limited by the high cost of electronic components and by poor performance over long paths. Continued technical development has recently provided much-improved complex gallium arsenide (GaAs) monolithic microwave integrated circuits (MMIC's) capable of operating as high as 30 GHz.

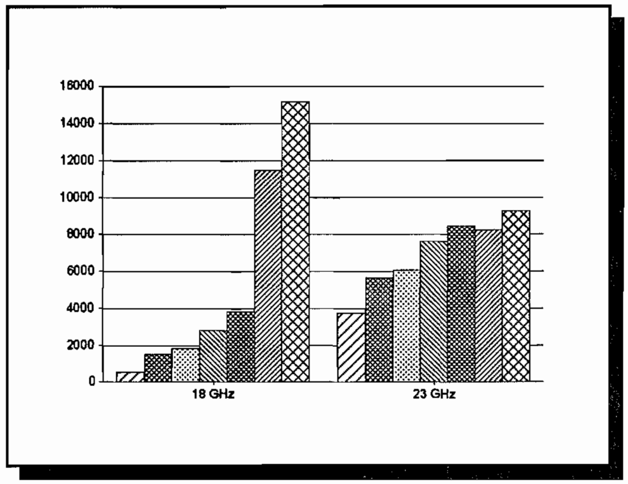


Figure 2-3. Number of licensed frequencies in the 18-GHz and 23-GHz bands, 1987-1993.

The smaller antennas typically used at higher frequencies can be integrated into a compact radio/antenna package and set into a window, avoiding the expense of a separate rooftop antenna. These systems may have an operational range of only 20 to 30 kilometers, but this is acceptable for short-range bypass of the LEC—one of the major uses for the new higher frequency microwave units. Frequencies above 23 GHz are not yet extensively used, and licenses in higher bands are limited mostly to experimental uses. Recently, a number of systems have been built for the 38 GHz band, mainly for use with PCS in Europe.

Since fiber has taken most of the new capacity in the long-haul and heavy traffic uses, the majority of new microwave systems have been short-range, low-capacity systems. Although a modern 23 GHz radio operates in a 50 MHz bandwidth, it provides a maximum capacity of only a single DS-3 link.[202] The 23 GHz radio uses simple QPSK modulation, and provides only about one fourth the capacity per MHz as 6 GHz radios using 64-QAM modulation.

In frequency bands well below 15 GHz, there is a movement toward higher frequencies. The FCC has undertaken a series of rulemakings that reallocated 220 MHz of fixed frequency bands near 2 GHz from fixed

[201]*See* MATHESON & STEELE, *supra* note 11, at 79, 81. Some of the original graphs have been updated by adding licensed frequency counts from 1992 and 1993. Comsearch, under contract to NTIA, supplied the additional data.

[202]Digital Microwave Comments at 4.

microwave to various PCS applications.[203] The existing 2 GHz microwave links are permitted to move into several migration bands higher in frequency (4 GHz, 6 GHz, 10.5 GHz, and 11 GHz). The process will also provide narrower channelization in the destination bands to more efficiently handle the low-capacity links commonly in use at 2 GHz.

Many commenters believe that microwave will remain attractive for short links, particularly in the 18-GHz, 23-GHz and higher frequency microwave bands.[204] Alcatel, however, states that there is a growing demand for high-reliability microwave links, which cannot be met using frequencies above 10 GHz because of weather-related outages. Alcatel suggests reallocation of the 3.6-3.7 GHz band to meet a possible future need for fixed services spectrum.[205] AT&T states that there will be a continued need for some long-range microwave links, though new services will tend to use shorter paths.[206]

FEDERAL GOVERNMENT FACTORS

In general, the role of radiocommunications in the Federal Government is expected to continue growing, as it will in U.S. industry and business. However, recent policies often require Federal agencies to procure telecommunications service from commercial suppliers, instead of building and operating their own networks.[207] Some Federal fixed radio networks are expected to be discontinued or consolidated with other networks over the next 20 years, slowly decreasing Federal use of fixed services. Since many commercial telecommunication suppliers use fiber networks, there will be a net replacement of fixed radio services with fiber.

At first glance, the military use of microwave might be expected to decrease because of the anticipated military downsizing, as well as the increased use of fiber optics. Many future military communications services will be implemented with fiber or furnished by commercial networks using fiber. However, much of the military use of "fixed" is for transportable stations that are used to rapidly extend wideband communications to any part of the globe. These stations cannot be replaced by fiber. The reduction in permanent overseas bases will tend to increase the amount of temporary communications needed when U.S. forces are deployed overseas. In addition, modern military doctrine depends on a highly mobile force with increased use of C^3I as a "force-multiplier." This includes increased use of high-resolution digital imaging data for reconnaissance purposes. DOD stated that the need for transportable fixed stations is expected to increase. However, the existing spectrum for transportable fixed systems is expected to be adequate until the year 2000.[208]

---

[203] *Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies*, Third Report and Order and Memorandum Opinion and Order, ET Docket No. 92-9, 8 FCC Rcd 6589 (1993).

[204] *See, e.g.*, Digital Microwave Comments at 3.

[205] Alcatel Comments, Comments of Technical Staff at 1-2.

[206] AT&T Comments, Exhibit B at 7.

[207] *See, e.g.*, COHEN ET AL., *supra* note 34, at 60-64.

[208] DOD Comments at 6-8.

DEVELOPMENT OF SPECTRUM REQUIREMENTS FOR THE FIXED SERVICES

SPECTRUM REQUIREMENTS FOR HF FIXED SERVICES

The HF bands have been very crowded, because HF has been the only technology that could provide very long range coverage with a minimum investment in infrastructure. In the past, HF circuits operated by government, industry, and private and common carriers provided the great majority of long range fixed circuits, including most of the transoceanic circuits. All HF services remain extremely crowded today, with strong competition between services for spectrum and a substantial backlog of demand to absorb any frequencies that become available.

However, the availability of alternative technologies may bring a decrease in HF crowding. Communication satellites and greatly improved optical fiber undersea cables have taken over the majority of overseas circuits. Inexpensive VSAT terminals[209] and improved wired telecommunications infrastructure in many foreign countries are also reducing the past heavy dependency on HF circuits. Although HF fixed use may decrease, it will remain very important for emergency use within the United States and for backup communications between the United States and foreign countries. ALE techniques have recently made HF communications more reliable and useful.

SPECTRUM REQUIREMENTS FOR VHF AND UHF FIXED SERVICES

Fixed services in the VHF and UHF bands (30-1000 MHz) are generally not expected to grow rapidly, though some bands may. In many of these bands, the fixed services share frequencies with the mobile services, though the fixed stations may usually have to meet additional restrictions. The number of fixed assignments in the 406-420 MHz Federal mobile radio band, for example, declined slightly between 1986 and 1992, though the number of mobile stations doubled. On the other hand, the number of MAS stations is growing in some newly-allocated bands near 900 MHz.[210]

SPECTRUM REQUIREMENTS FOR COMMON CARRIERS.

The common carriers were the first to begin switching from microwaves to optical fiber. Figure 2-4 shows seven years of license data from the four most-heavily used common carrier bands.[211] This figure reflects two distinct trends. First, the number of licenses used for general common carrier purposes shows a decrease from the highs of the late 1980's in the 4 GHz, 6 GHz, and 11 GHz bands, probably caused by the replacement of microwave with optical fiber, a trend that is expected to continue. The decrease is especially

---

[209] *See infra* p. 87 for a discussion of very small aperture terminal (VSAT) technology.

[210] MATHESON & STEELE, *supra* note 11, at 22-31.

[211] *Id.* at 43, 55, 59, 69.

noticeable in the 4 GHz band, where the presence of numerous TVRO stations has discouraged the licensing of new fixed stations.

The second trend is a recent increase in the use of microwave links to connect new cellular base stations. This trend was first evident in the 2 GHz band, but recently it can be seen in the 6 GHz and 11 GHz bands. Although this is a strong trend now, we expect this trend to become less important in a few years. Fiber and wideband copper are becoming more available in the urban areas where many future additional cellular sites will be established. Simultaneously, the cellular network is changing to carry denser traffic between more closely space sites—conditions that tend to favor fiber. Even if the number of licenses continues to increase in the 6 GHz and 11 GHz bands, this does not necessarily imply increased crowding, since many of these new licenses will be using the newly-created narrowband channels.

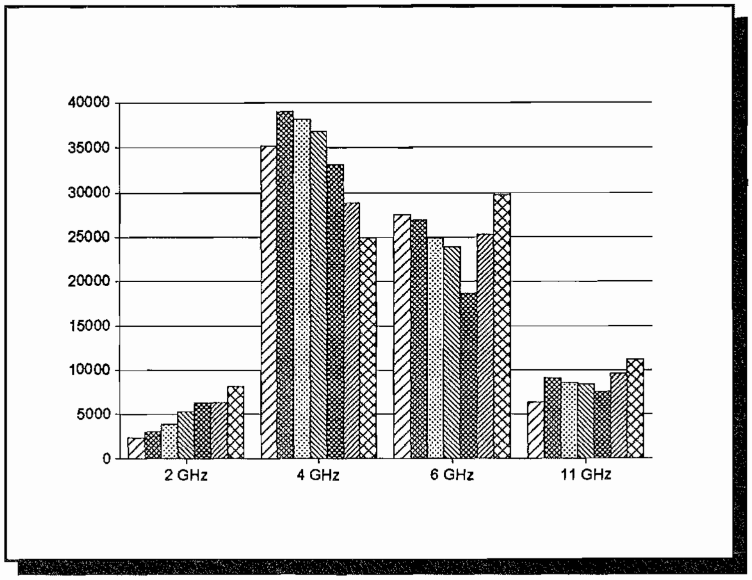


Figure 2-4. Number of licensed frequencies in the 2 GHz, 4 GHz, 6 GHz, and 11 GHz common carrier bands, 1987-1993.

Since the 2 GHz bands will be vacated for new PCS applications, it is expected that this growth will stop. Harris suggested that it may be a long time before PCS needs the 2 GHz bands in rural areas[212] and that major portions of the 2 GHz bands should be left to point-to-point microwave in the rural areas. Harris also suggested that it would be very helpful to allow some of the displaced 2 GHz microwave systems to use some of the Federal 1710-1850 MHz band. One carrier stated that some of its microwave assignments "can, over time, be released to other services."[213]

Although the number of licenses in some common carrier bands is still growing, it is expected that the aggregate number of common carrier licenses in the 2 GHz, 4 GHz, 6 GHz, and 11 GHz bands will decrease over the next five years. Moreover, the remaining users (including the new cellular users) will carry comparatively less traffic, since the routes with the heaviest traffic will tend to be replaced with fiber first. The cellular telephone services will continue to add microwave links in support of new cellular networks and to relocate links from the 2 GHz bands, but will use an increasing percentage of fiber.

[212]Harris Comments at 2-10.

[213]Bell Atlantic Comments at 16-19.

The FCC has recently reallocated most common carrier and private microwave bands to make them equally accessible to common carrier and private use.[214] Previously, these bands were allocated for specialized use, with certain bands intended for wideband common carrier use and other bands intended for private use with an assortment of narrower bandwidths. The recent reallocation provides a complete assortment of bandwidths in most bands. This gives private carriers access to wideband channels and provides many more narrowband channels (suitable for cellular backbone) to the common carriers. Since all of these microwave bands are now allocated almost identically, the reallocation should also eventually erase the distinctive features that now make some bands crowded and others relatively empty. Therefore, in the future, growth of a particular service might not occur within frequency bands that have traditionally been associated with that service.

These trends are expected to continue over the next ten years, with the major uncertainty being whether support services for cellular telephone and PCS will use microwave or fiber. At the end of 10 years, it is expected that only 30 to 50 percent of the present total number of assignments will be active in the common carrier service.

SPECTRUM REQUIREMENTS FOR PRIVATE OPERATIONAL SERVICES

The private operational services include a number of niche markets, including SCADA, remote operations, and short-range LEC bypass. These services are not particularly subject to competition from fiber, and private operational services have been growing steadily. Growth is slow (less than 5 percent) or negative for frequencies below 10 GHz (Figure 2-5)[215] and quite rapid (20 to 30 percent) for frequencies above 10 GHz (see Figure 2-3). Digital Microwave Corporation believes that the 18 GHz and 23 GHz bands will exhibit considerable growth, that higher capacity 16-QAM and 64-QAM modulation[216] may be needed, along with spectrum in the 26 GHz, 29 GHz, and 38 GHz bands.[217] On the other hand, Alcatel believes that attenuation due to rain and water vapor will curtail effective use of the microwave bands above 10 GHz when high reliability is needed.[218]

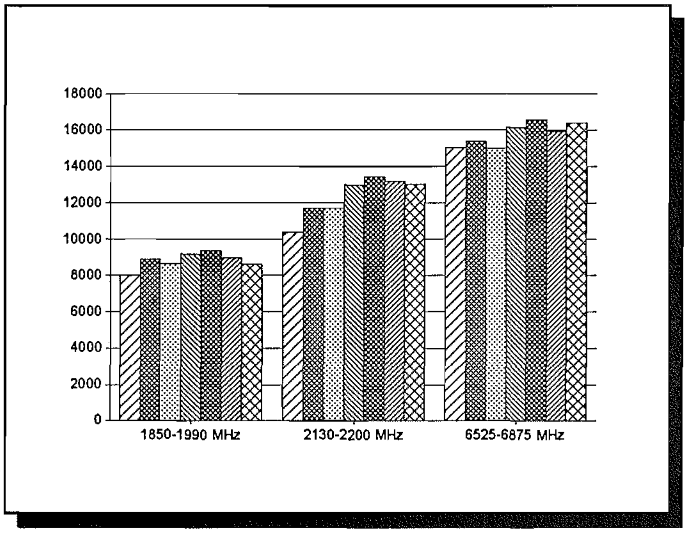


Figure 2-5. Number of licenses in selected private microwave bands, 1987-1993.

---

[214]FCC 93-350, second report and order, adopted July 15, 1993.

[215]*Id.* at 39, 45, 61.

[216]*See infra* p. 204 for a discussion of quadrature amplitude modulation (QAM).

[217]Digital Microwave Comments at 3.

[218]Alcatel Comments at 1.

As several commenters noted, SCADA systems often require higher reliability than that obtainable with a single fiber route and require relatively low data rates—situations where fiber is not competitive. SCADA is often located in areas where fiber is not practical or economical to install[219]. UTC said that a much more complex regulatory and structural environment (open power distribution systems with multiple independent producers, automatic switching and load management, and tightened environmental controls) will double or triple the spectrum requirements for SCADA in the next five to ten years.[220]

The situation for LEC bypass is a little less clear. Although several commenters said that short-range bypass of the LEC was a probable growth area for higher frequency microwave,[221] it should also be noted that fiber is likely to be available less expensively in a competitive urban environment.

It is expected that there will be slow and steady growth in the private microwave services, amounting to a three percent growth rate, averaged over the next five years.[222] Over the next 10 years, it is difficult to predict the degree to which fiber will displace microwave LEC by-pass in urban areas and SCADA in rural areas. Much of the growth in these services will be in the 18 GHz and 23 GHz bands, with less growth in the bands designated as migration bands from the 2 GHz bands. No additional frequency allocations will be needed, because most bands (including empty bands above 23 GHz) still have adequate room for growth.

Spectrum Requirements for AUXBC Services

AUXBC is currently growing at a moderate rate (Figure 2-6),[223] but the industry is undergoing rapid changes, and it is not clear what will be the final outcome. The AUXBC bands are already crowded and will become more so, mostly because of the need to simultaneously transport NTSC[224] and HDTV signals and the increasing use of ENG

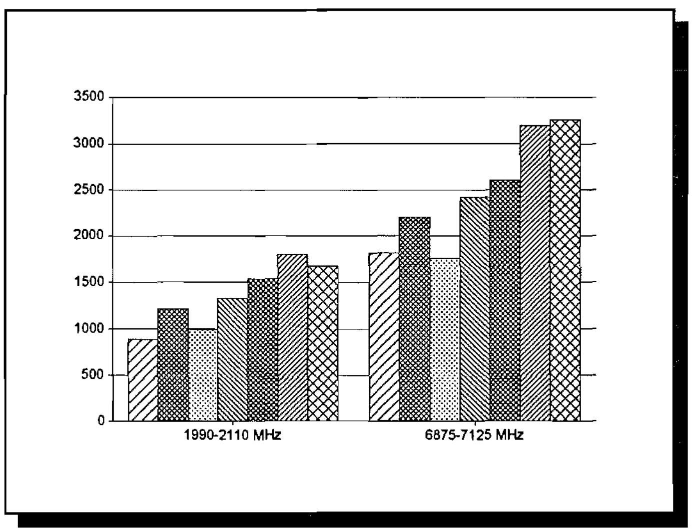


Figure 2-6. Number of licenses in selected AUXBC frequency bands, 1987-1993.

219AAR Comments at 8-10; Utilities Telecommunications Council *supra* note 199.

220UTC Comments at 9.

221AT&T Comments at 4; Digital Microwave Comments at 3; Alcatel Comments at 1.

222MATHESON & STEELE, *supra* note 11, at 123.

223*Id.* at 41, 63.

224The National Television Systems Committee (NTSC) signal format is the standard for television in the United States and numerous other countries.

for local news coverage.[225] To meet this crowding, digital signal compression will be used to squeeze in some additional ENG and STL links. In addition, many STL and ICR microwave links will be replaced with optical fiber. Nevertheless, broadcasters believe that crowding will be too great in the top 30 markets and intend to ask the FCC to reverse an earlier decision against providing more AUXBC spectrum.[226]

NAB believes that the deployment of digital audio broadcasting (DAB) will require additional audio STL's, causing serious crowding in major metropolitan areas, and perhaps requiring an additional 5-8 MHz of spectrum for audio STL's.[227]

SPECTRUM REQUIREMENTS FOR CABLE RELAY SERVICES

CARS is replacing many microwave links with fiber. Beginning in 1992, many cable systems began converting their coaxial cable trunks and feeders to fiber to obtain a larger number of channels with improved quality. Recently, more ambitious plans to provide a broad mix of two-way services have added to the need for networks of fiber or fiber and coaxial cable.[228] These rapidly-changing plans include various partnerships between LEC's, cable companies, electrical utilities, and providers of PCS and cellular to provide analog TV, digital TV, telephone, data, TV-on-demand, electrical power management, etc. Irrespective of who the providers of these services are, or exactly what technologies are finally used, it is clear that CARS will be affected by the rapid and significant changes that are likely in this service.

The existing CARS microwave distribution architecture, based on one-way SHL's in the 13 GHz band, is not suited to the new two-way services which the cable companies would like to offer. Therefore, plans to provide two-way services on cable may require the switch to fiber. Figure 2-7[229] shows the number of licenses in the 13 GHz CARS band. This band was packed with more than 109,000 SHL assignments and was still growing rapidly in 1991. The growth stopped

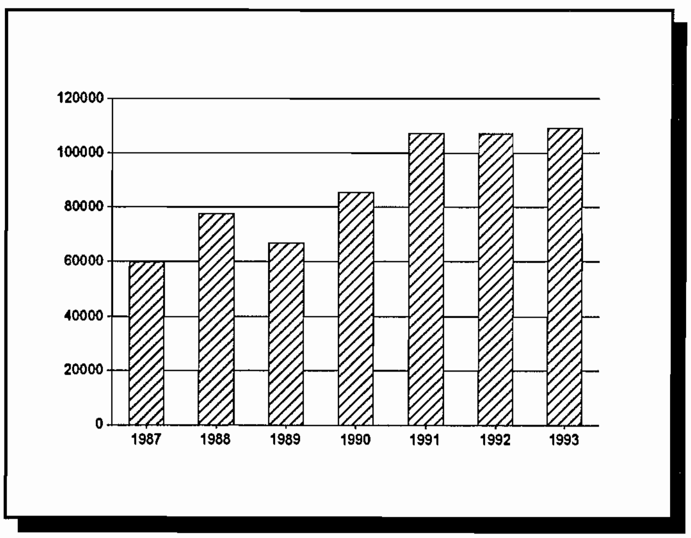


Figure 2-7. Number of licensed frequencies in the 13 GHz CARS band, 1987-1993.

225NAB Comments at 4.

226MSTV Comments at 10.

227NPR Comments at 9.

228Craig J. Brunet, *Hybridizing the Local Loop*, IEEE SPECTRUM, June 1994, at 28-32.

229MATHESON & STEELE, *supra* note 11, at 73.

abruptly in 1992 as cable companies began to switch to fiber. Even if all cable companies do not choose to offer a broad range of 2-way services, most will still convert to fiber networks.

The fiber networks owned by the cable companies could remove microwave stations from more bands than the 13 GHz CARS band. They could become another general-purpose local fiber carrier, offering broad competition to the LEC's and greatly increasing the accessibility to fiber and wideband communications. This could provide substantial competition to microwave for LEC bypass and future cellular and PCS network connectivity.

The use of the 13 GHz CARS band is expected to experience a rapid decrease in a few years, after many SHL's networks are replaced with fiber. Cable companies will use more ENG to meet the programming demands of 500-channel systems with a larger number of viewers. There may be considerable opportunity to exploit vacated CARS channels for ENG and STL.

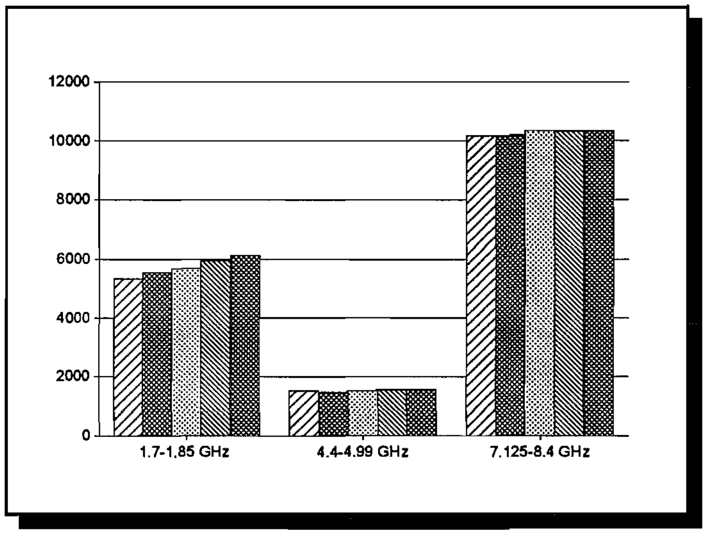


Figure 2-8. Number of assignments in selected Government bands, 1987-1991.

Spectrum Requirements for Federal Government Services

The use of microwave bands by the Federal Government will follow many of the same trends followed by similar non-Federal services. There are, however, several factors unique to Federal use. Figure 2-8[230] shows the number of Federal assignments in several of the frequency bands used by the Federal Government for fixed services.

Since HF provides long-range communications with a minimum of infrastructure, Federal use of fixed HF systems will continue to be highly important for emergency and military communications throughout the foreseeable future. However, commercial switched systems and fixed-satellite technology will meet an increasing share of fixed communications needs. Many Federal civilian agencies plan to use HF for communications restoration after natural disasters. The VA, for example, plans to acquire additional HF sites to provide communications in emergency and national disaster situations.[231]

The use of telecommunications between fixed geographical locations is expected to continue to grow within the Federal Government, as is it within the society as a whole. However, a smaller percentage of this traffic will be carried by microwave links. Fixed microwave is used to connect Federal offices within the same

[230]*Id.* at 37, 57, 65.

[231]VA Comments at 3.

city for general traffic, often with links to Federal centers in nearby cities. Some agencies also have extensive nationwide nets, but these are more often used to support SCADA or mobile radio operations. Although these general-purpose communications links will continue to have advantages in specific situations, their number will decrease slowly under the competitive pressure of widely available optical fiber in a competitive telecommunications environment.

Fixed networks used to support military test and training ranges will probably be slowly converted to fiber—partly to reduce the cost of maintaining old analog microwave links and partly to increase bandwidth to monitor more complex tests and training exercises. The conversion of existing microwave links to fiber is paced partly by the funds available for the conversion. The replaced microwave links will often continue to be used for backup and for lower priority purposes.

Federal SCADA applications and the use of microwave backbone to support mobile radio nets are expected to slowly decrease over the long run, although temporary increases are presently indicated in support of particular programs. DOE will be using microwave links to replace many of its 3,000 power line carrier (PLC) systems over the next 10 years.[232] The FAA is adding up to 300 additional low-density microwave links in the 1710-1850 MHz band.[233] The Coast Guard is adding more VTS sites to more closely monitor active harbor areas. Fiber and microwave will be used to tie together radar and communications sites.

SCADA and mobile backbone applications are not easily replaced with fiber because of cost and reliability considerations, but fiber will become continually cheaper and more available, even in rural locations. The use of microwave to support SCADA and mobile agency communications nets is expected to decrease, gradually being replaced with VSAT links, fiber, or commercial services purchased under the FTS 2000 program.

In summary, we expect Federal use of the fixed microwave services to remain at present levels. Although a higher portion of Federal fixed communications will be carried on commercial systems and Federal fiber optic systems, this trend will be partly balanced by continued growth of communication-related functions performed by the Federal Government. The extensive use of transportable systems by the military will continue, and these systems cannot be replaced by fiber systems.

SPECTRUM REQUIREMENTS FOR THE FIXED SERVICE

Optical fiber is expected to continue to take market share away from microwave for many point-to-point systems. Especially for the high traffic density markets, such as dense urban common carrier and urban CARS SHL's, the use of fiber is often very advantageous. We believe that some parts of certain microwave bands could reasonably be converted to other uses within the next 10 years. The following bands may have sufficient spare capacity, that they should be considered for reallocation at a future date.

[232]DOE Comments at 6.

[233]FAA Comments at 4.

3.7-4.2 GHz Common Carrier Band

The number of common carrier links is rapidly decreasing in this band, and it is expected that 50 percent of the fixed service allocation could be converted to other uses within 10 years. A major limitation on the reallocation of this band is the large number of home satellite dishes (TVRO's) receiving television signals from geosynchronous satellites. A new user may find it difficult to operate compatibly with the existing TVRO's and will tend to choose another band. *The common carrier fixed service in this band could reasonably be expected to operate with 50 percent (250 MHz) less spectrum by 2004. Any other use, however, should be compatible with TVRO operation.*

12.7-13.25 GHz CARS Band

It is believed that the number of licenses in this band will begin to decrease rapidly as the Cable TV industry changes from microwave distribution of TV programming to optical fiber distribution systems. The use of this band will vary greatly from city to city. In many cities, most cable program material will be transported by fiber; in other cities it will be mostly by microwave. Where microwave is used, however, a large block of spectrum will be needed to fill a 500-channel cable system. In fact, as the total bandwidth in fiber-based cable systems increases, the 550 MHz allocated in this band may be insufficient to handle the required fiber bandwidth. *At some future time, it may no longer be in the public interest to allocate this large band to the fixed service if it is used heavily in only a few cities. At that time 50 percent of the band (275 MHz) could be reallocated for other purposes.*

The net reduction in fixed service requirements identified above suggests that a significant amount of currently allocated spectrum may not be required in the future. By the year 2004, as much as 250 MHz could be made available, under certain conditions, for use by other services.

Fixed-Satellite Service

The space age opened new opportunities for radiocommunications between widely-separated locations. Instead of HF systems with limited bandwidth or a large number of short-range microwave relays, satellites could link distant locations from a vantage point high above the Earth. By the mid-60's, launch vehicles were delivering communications satellites to locations in the geostationary satellite orbit, about 35,800 kilometers above the equator. In this orbit, the satellites circle the Earth at the same rate as the Earth rotates, making them appear nearly stationary from the Earth's surface.

Today, geostationary communications satellites continue to play a major role in telecommunications. From the geostationary orbit, satellite antennas can illuminate a small area (using "spot beams"), a country, or a larger region encompassing many countries. Thus, satellites can theoretically compete with point-to-point microwave and non-radio media (e.g., optical fiber) in providing communications between fixed points.

The fixed-satellite service primarily involves communications between fixed earth stations via satellite, i.e., uplinks and downlinks, although the service can also include certain inter-satellite links and feeder links.[234] The fixed-satellite service can include communications to multiple, specified fixed locations, but not broadcasting functions.[235] While current U.S. systems operating in the fixed-satellite service use geostationary satellites exclusively, one commenter has suggested the use of non-geostationary satellites to reduce the time delay.[236]

The fixed-satellite service basically involves four frequency bands: 4/6 GHz, 7/8 GHz (for military systems), 11/14 GHz, and 20/30 GHz. Although numerous bands above 30 GHz are allocated to the fixed-satellite service, only one is presently used.[237] Microwave frequencies and "stationary" satellites allow the use of high-gain, directional antennas, much like the fixed service.[238] This reduces the power requirements for the satellite transmitters.

CURRENT USES

The fixed-satellite service includes international, domestic, and military systems. Though they often carry the same type of traffic, each group has its own set of users. International and domestic systems operate at 4/6 GHz and 11/14 GHz while military systems use 7/8 GHz and frequencies near 20 GHz and 45 GHz. This section describes each of these applications, as well as the use of the fixed-satellite service for inter-satellite links, feeder links, and power control beacons.

[234]NTIA defines the fixed-satellite service as "[a] radiocommunication service between earth stations at given positions when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases this service includes satellite-to-satellite links, which may also be effected in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radiocommunication services. NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-6. A feeder link is "[a] radio link from an earth station at a given location to a space station, or vice versa, conveying information for a space radiocommunication service other than for the fixed-satellite service. The given location may be at a specified fixed point, or at any fixed point within specified areas." *Id.*

[235]Broadcasting involves signals "intended for direct reception by the general public." *See id.* § 6.1.1, at 6-3 (defining the broadcasting and broadcasting-satellite services). Although the fixed-satellite service is not used for broadcasting, it *is* used for point-to-multipoint distribution of television programming to broadcasters and cable providers. Public reception of these signals was not the original intent.

[236]NASA Comments at 15. LEO satellites can occupy much lower orbits than geostationary satellites. The resulting reduction in time delay is critical for certain real-time two-way communications (e.g., computer communications).

[237]The DOD MILSTAR system operates at 20/44 GHz.

[238]Although some earth stations in the fixed-satellite service are transportable, *see, e.g.*, DOD Comments at 7, the users can still erect directional antennas, though they may be smaller than the antennas used at truly fixed sites. The use of satellites in low-Earth orbit for the fixed-satellite service would require satellite tracking or less directional antennas, changing the nature of the service.

INTERNATIONAL SYSTEMS

In the mid-1960's, satellites began offering a reliable new alternative to submarine cable for intercontinental telephony, along with the promise of intercontinental television transmission. Until recently, the history of international fixed-satellite service satellites was the history of INTELSAT. More recently, private "separate systems" have begun providing an alternative.

International systems in the fixed-satellite service use frequencies at both 4/6 GHz and 11/14 GHz. In the United States, part of the 4/6 GHz spectrum has been reserved for "International inter-Continental" systems.[239]

INTELSAT

Created in 1964, the International Telecommunications Satellite Organization (INTELSAT) owns and operates the primary global satellite system. The INTELSAT system provides international voice, data, and video services as well as domestic services for many smaller countries.

The INTELSAT system began with the launch of the "Early Bird" satellite (INTELSAT I) on April 6, 1965 and achieved worldwide coverage with the completion of the INTELSAT III system four years later. Since then, the INTELSAT system has progressed thorough several generations of satellites. The first satellite of the INTELSAT VII series was launched on October 22, 1993 to an orbital location over the Pacific Ocean.[240]

SEPARATE SYSTEMS

Under Article XIV of the INTELSAT Agreement, members may establish international public telecommunication services separate from INTELSAT. These "separate systems" must be technically compatible with existing and planned components of the INTELSAT space segment and must not cause "significant economic harm" to the INTELSAT system.[241]

In June 1988, Pan American Satellite (PanAmSat) launched its PAS-1 satellite into geostationary orbit over the Atlantic Ocean. The first private international satellite, PAS-1 provides services to customers in the Americas and Europe. Although television programming accounts for most of PanAmSat's business, PAS-1

---

[239] Footnote US245, which specifies this limitation, applies to the 3600-3700 MHz and 4500-4800 MHz bands (space-to-Earth) and the 5850-5925 MHz band (Earth-to-space). NTIA MANUAL, *supra* note 13 § 4.1.3, at 4-69, -70, -72, -110.

[240] Philip Chien, *INTELSAT 701 and Spot 3 Launched, Landsat 6 Lost*, VIA SATELLITE, Dec. 1993, at 63.

[241] INT'L RADIO CONSULTATIVE COMMITTEE, INT'L TELECOMMUNICATION UNION, HANDBOOK ON SATELLITE COMMUNICATIONS § 6.2.1.2(ii) (1988) (summarizing the provisions of Article XIV d of the INTELSAT Agreement).

also provides data services to businesses as well as voice services.[242] PanAmSat launched its second satellite, PAS-2, into orbit over the Pacific ocean region in July 1994.[243]

PanAmSat's plans for a global satellite network suffered a setback with a launch failure that destroyed PAS-3 in early December 1994. A replacement for the satellite, which was intended to provide service to Latin America, is under construction but will not be launched for at least a year.[244] PAS-4, covering the Indian Ocean, is scheduled for launch by the end of 1994.[245] The completed network of satellites will provide global coverage that will reach 98 percent of the world's population.[246]

Another separate systems provider, Columbia Communications Corporation leases 4/6 GHz capacity on NASA's Tracking and Data Relay Satellite System (TDRSS) satellites located over the Atlantic and Pacific Oceans. Columbia plans to eventually launch two satellites of its own.[247]

DOMESTIC SYSTEMS

While INTELSAT and PanAmSat provide international satellite communications, about 30 privately-owned 4/6 GHz and 11/14 GHz satellites provide U.S. domestic services.[248] While the number of domestic satellite owners and operators was higher in the 80's, the limitations of the market in the 90's have reduced the competitors to four: Hughes Communications, AT&T Skynet, GE Americom, and GTE Spacenet.[249]

Domestic 4/6 GHz satellites fall into three categories based on the markets they serve. "Cable" satellites distribute television programming to cable headends and, opportunistically, to homes equipped with backyard TVRO "dishes."[250] "Broadcast" satellites distribute network programming to affiliates and syndicated programming to affiliates and independent stations. The third category of 4/6 GHz satellites is

---

[242]Daniel J. Marcus, *PanAmSat's Global Satellite System*, VIA SATELLITE, Oct. 1993, at 26.

[243]PanAmSat, BROADCASTING & CABLE, July 18, 1994, at 5 (magazine advertisement).

[244]*PanAmSat Loses Atlantic Satellite in $214 Million Launch Failure*, COMM. DAILY, Dec. 5, 1994 at 1 [hereinafter *PanAmSat Loses Satellite*].

[245]COMM. DAILY, Dec. 6, 1994 at 9.

[246]MARCUS, *supra* note 242, at 26-28.

[247]Columbia's renewable lease with NASA expires at the end of 1997. Theresa Foley, *Is It Time to Change the Rules of the Game?*, VIA SATELLITE, Dec. 1994 at 18. TDRSS is discussed *infra* p. 146.

[248]The use of privately-owned domestic satellites is not limited to the private sector. The FAA, for example, uses satellites to link remote air-to-ground communications sites to central air traffic control facilities in Alaska. The FAA plans to use a similar capability as a backup for terrestrial services in the CONUS. MARKEY, *supra* note 125, Enclosure at 6.

[249]John McNiff, *Domestic Satellite Operators*, VIA SATELLITE, Nov. 1993 at 26. Recently, the distinction between international and domestic U.S. satellites has blurred as Hughes Galaxy has sought FCC permission to use its domestic satellites for international traffic. *See PanAmSat Loses Satellite*, *supra* note 244. Columbia, meanwhile, is seeking to offer domestic services, at least temporarily, to help offset a 4/6 GHz transponder shortfall. FOLEY, *supra* note 247, at 18.

[250]Direct broadcast satellite (DBS) systems, a new competitor to the TVRO systems, are discussed *infra* p. 101.

generally used for point-to-point transmission (as opposed to the point-to-multipoint operation of the other categories) of video and data signals.[251]

Satellites operating in the 11/14 GHz band are generally used for private networks, such as those operated by businesses and academia. A typical use of 11/14 GHz satellites is for data networks, carrying voice, facsimile, and compressed video signals in addition to business data. Educational video is another common application.[252] Satellite networks in the 11/14 GHz band can use smaller earth station antennas than 4/6 GHz systems and are subject to less interference.[253]

MILITARY SYSTEMS

U.S. military communications satellites, having both international and domestic applications but serving a very different user, constitute a third group of FSS satellites. Since the success of the armed forces depend upon their mobility, many of their requirements for communications between fixed points involve transportable systems.[254] The fixed-satellite service accommodates many of these requirements because military units cannot quickly or economically connect temporarily fixed locations with wires.[255]

Unlike commercial systems in the fixed-satellite service, military systems primarily use Federal frequency allocations in the 7-8 GHz range.[256] Recently launched or planned systems use frequencies near 20 GHz, 30 GHz, and 44 GHz.[257] In addition to satellites in these bands, DOD also uses commercial satellites to satisfy some of its requirements.[258]

Since the late 1960's the Defense Satellite Communications System (DSCS) has provided satellite communications for the armed forces. The first of the current generation of satellites, DSCS III, was launched in 1982. Although DSCS III replace DSCS II in January 1994, two DSCS II satellites still provide reserve

[251]Grace Leone, *U.S. Transponder Supply*, VIA SATELLITE, April 1993 at 24, 24-25.

[252]*Id.*

[253]Unlike the satellite systems in the 4/6 GHz band, the 11/14 GHz domestic fixed-satellite service systems generally do not share frequency bands with the terrestrial fixed service. The 11/14 GHz systems therefore experience less interference. They also operate under fewer sharing constraints, such as those that limit the power flux density of emissions from the satellites.

[254]DOD Comments at 7.

[255]*Id.*

[256]The government fixed-satellite service allocations in the 7/8 GHz band are located at 7900-8400 MHz (Earth-to-space) and 7250-7750 MHz (space-to-Earth). NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-73 to 4-75.

[257]The frequency bands 20.2-21.2 GHz (space-to-Earth), 30-31 GHz (Earth-to-space), and 43.5-45.5 GHz (Earth-to-space) are allocated to the fixed-satellite service for government use in the United States, although the latter band is not allocated to this service internationally. *Id.* § 4.1.3, at 4-88, -92, -95. The MILSTAR system operates at 20/44 GHz. The planned Joint Defense Broadcast System operates at 20/30 GHz.

[258]DOD Comments at 7. The Department of Defense used commercial satellites to meet part of its communications requirements during Operation Desert Storm. *Id.*

capabilities. DOD launched the first MILSTAR satellite on February 7, 1994. This system will provide tactical communications in the fixed-satellite service using the 20 GHz and 44 GHz bands.

DOD expects its use of the fixed-satellite service to increase. Data and imaging communications, which require large amounts of bandwidth, will continue to strain communications systems. Commercial systems currently take on some of the burden and the need for additional spectrum is not anticipated before the turn of the century. After that, however, spectrum requirements are expected to increase as data and imaging take on a critical and increasing role in military communications.[259]

OTHER FIXED-SATELLITE SERVICE LINKS

Under the U.S. and international definitions, the fixed-satellite service can include some feeder links and inter-satellite links.[260] Spectrum requirements for feeder links are discussed in the chapters covering the services they support.[261] *We expect that 200-400 MHz of additional FSS spectrum will be required for feeder links supporting initial non-geostationary MSS systems. We believe that sharing between these feeder links and terrestrial systems will be feasible.*[262]

None of the current fixed-satellite service allocations provide for space-to-space (inter-satellite) links, although they can be accommodated in other services.[263] Any future requirements for inter-satellite links in the fixed-satellite service would thus require changes to allocations. No such requirements have been identified.

The fixed-satellite service is also used for satellite power control. Because satellite links at 20-30 GHz are subject to significant rain attenuation,[264] they can be unreliable. To meet requirements for uplink availability and performance, earth stations monitor a power control beacon on the satellite, which indicates the level of rain attenuation.[265] Acting on a U.S. proposal, WARC-92 allocated the 27.5-30 GHz band for space-to-Earth links for this purpose on a secondary basis (except for the bottom and top 1 MHz, in which the allocation is primary).[266] No requirements beyond this allocation have been identified.

---

[259]*Id.* at 6-8.

[260]*See supra* note 234.

[261]Feeder links for the mobile-satellite service are discussed *supra* p. 59. Feeder links for the broadcasting satellite service are discussed *infra* p. 103.

[262]*See* discussion *supra* p. 60.

[263]*See infra* p. 146 for a discussion of inter-satellite links.

[264]The effects of rain on satellite links are discussed *infra* p. 195.

[265]U.S. DEP'T OF STATE, PUB. 9903, UNITED STATES PROPOSALS FOR THE 1992 WORLD ADMINISTRATIVE RADIO CONFERENCE FOR DEALING WITH FREQUENCY ALLOCATIONS IN CERTAIN PARTS OF THE SPECTRUM 8 (1991) [hereinafter U.S. PROPOSALS FOR WARC-92].

[266]WARC-92 FINAL ACTS, *supra* note 55, at 85, 87.

TRENDS

The fixed-satellite service competes with point-to-point microwave and non-radio media (wire and optical fiber) for telecommunications traffic between fixed points. As all three have matured, each has captured its own niche in the market. Users (or industries) will generally choose the most economical medium that meets their requirements for availability, capacity, and reliability.

The first satellite communications between fixed points involved international voice (telephony) and television signals. More recently, voice communications has largely returned to terrestrial telecommunications systems and has been replaced by increasingly sophisticated video and data communications. This section discusses trends in the fixed-satellite service including voice communications, video and data communications, VSAT's, and proposed multi-service satellite systems.

VOICE COMMUNICATIONS

The history of two-way voice telecommunications goes back to the invention of the telephone in the last century. Wire continued as the primary medium for telephone until the 1950's, when microwave links began to carry long-distance calls. With the development of the INTELSAT system in the 1960's, satellites proved more reliable than submarine cable for intercontinental telephone calls. The time delay caused by the distances involved with geostationary satellites, however, made telephone conversations cumbersome. Telephone links via satellite became undesirable when a reliable terrestrial medium was available.

Today, telephony has come full circle, as optical fiber has largely replaced both microwave links and satellite links, once again physically connecting the users. Indeed, most voice applications of the fixed-satellite service in the United States have been replaced by optical fiber.[267] The fixed-satellite service, however, may continue to provide a backup capability for voice communications.[268]

VIDEO AND DATA COMMUNICATIONS

While their use for voice communications has decreased, satellites have proven cost effective and reliable for video and data signals, which often involve transmission of the same signal to numerous sites.[269] Since satellites link multiple, geographically dispersed locations as easily as they link two locations, they are more economical than multiple terrestrial links.

[267]Pacific Telesis Comments at 11.

[268]Southwestern Bell Comments at 7.

[269]Pacific Telesis Comments at 11. Point-to-multipoint service is in many ways similar to broadcasting. Broadcasting, however, involves signals intended for direct reception by the general public.

The largest application of domestic and international satellites is video communications, mainly involving programming for cable providers and television broadcasters. Other video communications links are used for distance learning and teleconferencing.

The growth of digital video communications will bring greatly improved efficiency through video compression. Digital video signals are compressed by removing redundant information from the signal, dramatically decreasing the bandwidth required for transmission. Satellite transponders that carry a single analog video signal are able to accommodate several compressed signals. The satellite industry is already using video compression for broadcast and cable television and for educational networks.[270] Although this could reduce spectrum requirements for video transmission, some argue that the demand will rise along with the capacity as compression makes satellite communications more economical.[271] One commenter believes that video compression will lead to the growth of "new services . . . , such as HDTV, direct to the home applications, and growth in the distance learning market — just to name a few."[272]

Private satellite data communications began in 1975 as Dow Jones transmitted facsimiles of *The Wall Street Journal* from Massachusetts to Florida for sale to that state's retirees.[273] With the Information Age in full swing, the United States now has tens of thousands of data terminals using satellite communications.[274] Users exchanging modest amounts of data between two sites often find public switched services to be the best suited medium.[275] For higher data rates or multiple dispersed sites, however, the choice is more complicated and satellite networks offer a competitive option.

TELEPORTS AND VSAT SYSTEMS

In the 1980's satellite service providers began assembling earth stations on properties conveniently located near urban areas. These "teleports," numbering in the dozens in the United States, serve as high-tech telecommunications hubs.[276] While most began as small operations, "[t]oday's teleport typically includes ten to 20 antennas ranging in size from 3.5 to 11 meters, with an occasional dish for international communications."[277] Teleports connect terrestrial telecommunications (microwave and optical fiber) with satellite uplinks, providing access to space telecommunications. Although most teleport traffic is cable and

---

[270] Karen JP Howes, *Teleports*, VIA SATELLITE, Aug. 1993, at 26, 33-34.

[271] "If we're going to have quadruple the amount of satellite use, then in my mind, we'll have quadruple the amount of business;" Bob Doty, Jr., Director of Operations, Upsouth, quoted in Howes, *Teleports*, *supra* note 270, at 34.

[272] AT&T Comments, Exhibit C, at 3-4.

[273] Chuck Emmert, *VSAT Hardware*, VIA SATELLITE, Feb. 1993, at 26, 26-27.

[274] *Id.* at 27.

[275] Perhaps the most familiar example is two computers exchanging data using telephone lines and modems.

[276] Howes, *Teleports*, *supra* note 270, at 27. According to the industry, a teleport is "an access facility to satellite or other long-haul telecommunications media incorporating a distribution network serving the greater regional community and often associated with a related real estate or other economic development;" Boeke, *Teleports in the United States*, VIA SATELLITE, Aug. 1992, at 24.

[277] Howes, *Teleports*, *supra* note 270, at 27.

broadcast television programming,[278] teleports also provide data communications and communications in other space services.[279]

The use of VSAT technology is moving the fixed-satellite service back into crowded urban areas.[280] VSAT systems use 11/14 GHz frequencies and higher power satellite transmitters, allowing antennas on the order of a meter or less in diameter.[281] Low-cost private networks based on VSAT systems serve diverse applications, including data, voice, and video communications.[282] The largest providers of VSAT networks are Hughes Network Systems, GTE Spacenet, AT&T Tridom, and Scientific Atlanta.[283]

A typical VSAT network consists of a hub (a central location with a host computer) and multiple VSAT's connected to remote computer terminals.[284] If the remote terminals need to communicate with each other, they do so through the hub. A teleport may serve as the hub of several VSAT networks.[285] Recently, VSAT systems have been evolving from "hub" to "mesh" architecture, allowing user terminals to communicate with each other without going through the hub.[286]

The major users of VSAT systems are the retail and automotive industries.[287] VSAT systems have been competitive with private line networks for users requiring an on-line (as opposed to a dial-up) network. Satellite advocates claim that VSAT networks offer better throughput, response time, and system availability than private line networks.[288] In the past few years, VSAT's have been replacing dial-up networks as users recognize the need for an on-line system and choose VSAT's over private line networks.[289]

While the growth of VSAT networks is expected to continue, the future growth of teleports is less certain. VSAT networks will proliferate because they are economical and because they can operate in a crowded urban environment.[290] At the same time, the increased use of VSAT systems could slow the growth

---

[278]Karen JP Howes, *Programmers — Customers or Competitors?*, VIA SATELLITE, Aug. 1993, at 28.

[279]Some teleport operators are providing maritime services; *see* Howes, *Teleports*, *supra* note 270, at 30.

[280]Comsat Comments at 10.

[281]Because of the shorter wavelength, 11/14 GHz earth station antennas are smaller than 4/6 GHz antennas having the same gain. Increased satellite transmitter power further reduces the required antenna diameter, since less antenna gain is needed to meet performance criteria. Although they are less susceptible to terrestrial interference than systems in the 4/6 GHz band, 11/14 GHz systems are more susceptible to rain attenuation, *see infra* p. 195.

[282]NASA Comments at 15.

[283]EMMERT, *supra* note 273, at 29.

[284]*Id.* at 27. This typical "star" configuration constitutes a point-to-multipoint system.

[285]Howes, *Teleports*, *supra* note 270, at 27.

[286]NASA Comments at 15.

[287]EMMERT, *supra* note 273, at 29.

[288]*Id.* at 28.

[289]*Id.* at 29.

[290]NASA Comments at 15; Comsat Comments at 10.

of teleports, especially if network architecture becomes more flexible (i.e., if private networks can easily be configured without the use of a hub), if VSAT data capacity increases, and if costs decline.[291] The anticipated growth of VSAT networks and the requirements for higher data rates lead some to project additional spectrum requirements for the fixed-satellite service by the end of the century.[292] Data compression, however, could reduce or eliminate these requirements.[293]

ADVANCED SATELLITE TECHNOLOGY

NASA's Advanced Communications Technology Satellite (ACTS) is a major development for the fixed-satellite service. The purpose of the ACTS satellite, launched on September 12, 1993, is to verify new fixed-satellite service technologies and techniques.[294] According to NASA, it will serve as a prototype of future multi-function, multi-service satellites, demonstrating, in part, the space segment of an integrated services digital network (ISDN).[295]

The ACTS satellite features on-board baseband processing of signals, providing satellite-based routing and switching. This eliminates the need to route traffic through an intermediate earth station. The ACTS satellite features electronically hopping high-gain antenna beams permitting smaller and cheaper earth stations. ACTS has a steerable antenna for flexible coverage throughout the Western Hemisphere. ACTS' microwave switch matrix will allow higher data rates and volume.[296]

A major facet of the ACTS technology is the development of new earth stations. One such earth station is the T-1 VSAT, which provides voice, data, and video communications through a standard 64 kbps telephony interface and also a 1.544 Mbps "T-1" interface. In conjunction with other interfaces, the T-1 VSAT will accommodate ISDN and packet switching. Recent earth station developments include high data rate terminals for supercomputing networks and HDTV applications as well as earth stations using ultra-small aperture terminal (USAT) technology in the 11/14 GHz band.[297]

NASA believes the continued viability of the fixed-satellite service depends on its compatibility with ISDN. Standards for ISDN, particularly standards for network delay, must be realistic and not preclude fixed-satellite service systems. With the development of compressed voice terminals and aeronautical communications, NASA sees the ACTS system as a prototype of a satellite operating in both the fixed- and mobile-satellite services. NASA further sees the use of fixed-satellite service systems in ISDN as bringing

---

[291]NASA Comments at 16.

[292]*See* Comsat Comments at 11; NASA Comments at 15.

[293]NASA Comments at 15. VSAT systems require very little bandwidth compared to video systems.

[294]*Id.* at 4.

[295]*Id.* See *infra* p. 147 for a discussion of the proposed general-satellite service, which could accommodate such a system.

[296]*Id.* at 15-16.

[297]*Id.* at 16.

about greater homogeneity between satellite and terrestrial systems, including similar bandwidth requirements.[298]

SPECTRUM REQUIREMENTS FOR THE FIXED-SATELLITE SERVICE

Future spectrum requirements for the fixed-satellite service (excluding feeder links supporting other space services) will depend on the overall market for communications between fixed points, the portion of that market for which satellites are the medium of choice, and the efficiency (in terms of bandwidth requirements) with which satellites can provide services. For some applications using optical fiber or terrestrial microwave, the fixed-satellite service will continue to provide a backup capability.[299]

Several factors will affect the market share of satellite communications as compared with terrestrial media. As terrestrial switched digital services become more available and economical, they will put increasing competitive pressure on VSAT systems.[300] International carriers' increasing investment in fiber optic cable—which has a much smaller time delay than satellite systems—will negatively affect the demand for international voice and data satellite services.[301] Improvements in launch vehicle reliability may enhance the growth of the satellite industry.[302] In general, while terrestrial systems (mainly optical fiber) will likely capture the point-to-point market, satellite communications may still be the best choice for point-to-multipoint applications.[303]

The main source of increased efficiency will be video compression. This technology will permit a dramatic increase in the amount of programming that can be carried by a single transponder. However, as discussed earlier, the spectrum requirements for video distribution may not decrease since the demand may increase significantly as the cost of distributing programming to affiliates and cable headends drops.[304] Another source of increased efficiency will be the use of spot beams, orthogonal polarizations, and reverse band working to allow frequency reuse.

---

[298]*Id.*

[299]Southwestern Bell Comments at 7.

[300]Pacific Telesis Comments at 11.

[301]*Id.* Comsat, however, believes that the overall use of the fixed-satellite service will increase along with the growth of fiber systems, though not as quickly for dense traffic routes. Comsat Comments at 11.

[302]*See* Comsat Comments at 11.

[303]Howes, *Teleports*, *supra* note 270, at 33.

[304]*See supra* p. 87.

While commenters representing international and military users suggested a possible need for additional spectrum after the turn of the century,[305] *other commenters believe that the spectrum allocated to the fixed-satellite service will be adequate in the short term.*[306] *We believe that the currently allocated spectrum will be adequate to meet requirements for the fixed-satellite service, except for feeder links supporting other space services. We estimate a requirement for 200-400 MHz of additional FSS spectrum for feeder links supporting non-geostationary satellites in the mobile-satellite service.*[307]

[305]Comsat, which provides INTELSAT access for U.S. users, believes that WARC-92's reallocation of the 13.75-14 GHz band to the fixed-satellite service will satisfy short-term demands. However, they suggest that "additional spectrum could be needed by the turn of the century." Comsat Comments at 11; *but see* Pacific Telesis comments at 11 (stating that optical fiber will have an advantage for international telecommunications and that spectrum allocations will be adequate). Also, the U.S. Department of Defense expects to need additional spectrum to support data and imagery requirements early in the next century. DOD Comments at 8.

[306]Pacific Telesis Comments at 11; DOD Comments at 8.

[307]*See supra* p. 60.

CHAPTER 3

BROADCASTING AND BROADCASTING-SATELLITE SERVICES

INTRODUCTION

Of all the functions performed by radiocommunications, none is more familiar to the general public than broadcasting. Indeed , to the layman, the term "radio" is synonymous with audio broadcasting. Radio and television broadcasts provide entertainment, information, and educational services to nearly every household in America. Both forms of broadcasting are accommodated primarily in the broadcasting, and more recently the broadcasting-satellite services.[308]

While broadcasting is among the most familiar services, it is also among the most rapidly changing. New services, including high definition television (HDTV), digital audio broadcasting, and new direct broadcast satellite (DBS) services will augment, and in some cases compete with, existing AM and FM radio, VHF and UHF television, and TVRO.

The results of WARC-92 will have considerable influence on the broadcasting services for many years to come. Additional radio spectrum was allocated for broadcast systems, including satellite systems to provide HDTV and audio broadcasting with compact disc (CD) sound quality.[309] Also, an additional 790 kHz of HF spectrum was allocated for broadcasting, including a new band between 18,900 and 19,020 kHz that will be available in the year 2007.[310]

---

[308]The broadcasting service is "[a] radiocommunication service in which the transmissions are intended for direct reception by the general public. This service may include sound transmissions, television transmissions or other types of transmissions." NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-3. The broadcasting-satellite service is "[a] radiocommunication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. In the broadcasting-satellite service, the term 'direct reception' shall encompass both individual reception and community reception." *Id. See infra* p. 100 for a discussion of TVRO systems operating in the fixed-satellite service.

[309]WARC-92 FINAL ACTS, *supra* note 55, at 65, 76.

[310]*Id.* at 28 (International Footnote 529B).

BROADCASTING SERVICE

The application of the broadcasting service in the United States is used to serve both international and domestic audiences. International audiences are served by Federal and non-Federal international broadcasting stations.[311] Domestic U.S. audiences are served by commercial over-the-air radio and television systems which continue to be the major source of local news, sports, public affairs, etc.[312]

INTERNATIONAL AUDIENCES

International broadcasting by its very nature requires the generation of signals that are intended to be transmitted across international borders. Consequently, transmission of these signals is subject to the ITU Radio Regulations. For decades, governments have made increasing use of the electromagnetic spectrum to conduct public diplomacy by broadcasting speech and music throughout the world. These broadcasts are made directly to receivers used by individuals throughout the world.

NON-FEDERAL INTERNATIONAL BROADCASTING STATIONS

The FCC issues authorizations for non-Federal international broadcasting stations in eight frequency bands between 5950-26100 kHz.[313] These stations operate in the United States and Possessions (US&P) and broadcast overseas on various frequencies depending on the time of day and season of the year. The licensee is required to provide an international broadcast service that will promote international goodwill, understanding, and cooperation. Approximately 15 non-Federal broadcasters providing commercial or sponsored programming are licensed by the FCC. It is estimated that there are 600 million shortwave receivers throughout the world.[314]

U.S. HF BROADCAST FREQUENCY ALLOCATIONS
5950-6200 kHz
9500-9900 kHz
11650-12050 kHz
13600-13800 kHz
15100-15600 kHz
17550-17900 kHz
21450-21850 kHz
25670-26100 kHz

[311] International broadcasting stations are defined as broadcasting stations, employing frequencies allocated to the broadcasting service between 5950 kHz and 26,100 kHz, whose transmissions are intended to be received directly by the general public in foreign countries. NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-8. *See also* 47 C.F.R. § 73.701(a) (1993).

[312] For a further discussion of localism, *see* NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEP'T OF COMMERCE, NTIA SPECIAL PUBLICATION 93-290, GLOBALIZATION OF THE MASS MEDIA, 215-228 (January 1993).

[313] *See* 47 C.F.R. § 73.701(a) (1993).

[314] Jacobs Comments at 4.

FEDERAL INTERNATIONAL BROADCASTING STATIONS

The Voice of America (VOA) of the United States Information Agency (USIA) is the Federal agency that is assigned the mission of preparing and broadcasting radio programs related to U.S. interests and activities.[315] The VOA transmits audio programs to audiences in English and 43 other languages throughout the world.[316] VOA's transmissions originate in the studio complex at VOA headquarters in Washington, DC. Unlike the non-Federal international broadcaster, VOA uses two terrestrially-based radio broadcasting technologies in the United States to reach its international audiences: HF and AM radio.[317]

VOA has three HF transmitting stations in the United States located at Greenville, North Carolina; Bethany, Ohio; and Delano, California. VOA is the only U.S. Federal foreign broadcast service that operates from the United States. Radio Free Europe (RFE) and Radio Liberty (RL), funded by Congress through the Board for International Broadcasting (BIB), serve as surrogate stations for the countries to which they broadcast: Eastern European countries (for RFE) and the former Soviet Union (for RL).[318]

VOA Operations	
Transmitters	112
Number of Relays	18
Programming	1300 hrs/week
Transmitter/Broadcast	3
Broadcast Languages	English and 43 others

DOMESTIC AUDIENCES

In the United States, domestic audiences are served by AM, FM, and TV broadcast stations employing analog radio transmissions designed for direct reception. The U.S. domestic broadcasting structure is a complex, interconnected web of over-the-air radio and television stations, intertwined with cable and satellite delivery media carrying programming by numerous competing sources. U.S. households are well

[315]The VOA Charter stipulates that the VOA will serve as a consistently reliable and authoritative source of news and that its news will be accurate, objective and comprehensive; represent America, not any single segment of American society, and will therefore present a balanced and comprehensive projection of significant American thought and institutions; present the policies of the United States clearly and effectively, and will also present responsible discussion and opinion on these policies. Foreign Relations Authorization Act, Fiscal Year, 1977, 22 U.S.C. § 2689 (1976).

[316]Though this section covers international broadcasting stations, it is relevant to note that VOA also transmits television programs via UHF television (TV Marti) from the United States to Cuba.

[317]AM broadcasting operations performed by VOA use frequencies in the band 535-1705 kHz. Marathon, Florida is the only site in the United States for VOA AM broadcasting operations. It is primarily designed to serve a more local audience with groundwave signals alone, as compared to its HF broadcast operations. The Marathon station transmits on 1180 kHz.

[318]Surrogate broadcasting provides alternative sources of accurate news and information to countries where the local media cannot or does not carry out this function because of authoritarian control. Programming of surrogate stations concentrates on news about the target country itself and strongly promotes the concepts of democracy and free enterprise. Programming of the VOA is broader in scope. Even though VOA programming includes the concepts of democracy and free enterprise, it puts relatively more emphasis on news and information about general international developments, about the United States, and U.S. policy than does the surrogate programming. *See* THE REPORT OF THE PRESIDENT'S TASK FORCE ON U.S. GOVERNMENT INTERNATIONAL BROADCASTING 32 (1991).

served with 99 percent owning a radio (5.6 radios average) and 98 percent owning television sets (average of 2.1 sets).[319] Over one-third of the TV households can receive 7-10 TV channels and over another third can receive 11-14 TV channels.[320] However, more than 61 percent of U.S. TV households subscribe to cable television[321] and over 70 percent of U.S. television households own VCR's. [322] Planned service include improved terrestrial and satellite broadcast systems.

AM BROADCAST STATIONS

AM broadcast stations are licensed by the FCC for operation on a channel in the 535-1705 kHz AM broadcast band. This band consists of 117 carrier frequencies beginning at 540 kHz and progresses in 10 kHz steps to 1700 kHz.[323] The modulation of the radio carrier wave is amplitude modulation; hence, the AM reference. Depending on the broadcast station class, maximum operating power ranges from .25 kilowatts to 50 kilowatts.[324] Propagation in the AM broadcast band involves both the ground wave and skywave modes. The ground wave and skywave modes of AM broadcasting stations serve local and distant audiences, respectively. A disadvantage in AM broadcasting is its limited audio fidelity, relative to FM.[325] There are over 4900 AM broadcast stations operating in the US&P.[326]

The potential exists for an enhancement to the U.S. AM broadcast operations with the introduction of digital audio broadcasting technology, where the audio fidelity is expected at or near CD-quality. Various terrestrial digital audio broadcasting technologies are being developed worldwide. In the United States, two different terrestrial digital audio broadcasting technologies are being considered but only the "in-band" technology can be implemented in the AM broadcast band.[327] This is a promising new service that must consider technical and marketplace forces to succeed. Under the auspices of the Electronic Industries Association (EIA) and the National Radio Systems Committee (NRSC), efforts are presently underway to evaluate and recommend an in-band on-channel (IBOC) system for AM broadcast operations.

---

[319]BUREAU OF THE CENSUS, U.S. DEP'T OF COMMERCE, STATISTICAL ABSTRACT OF THE UNITED STATES 561 (1993).

[320]THE WORLD ALMANAC AND BOOK OF FACTS 305 (1993).

[321]U.S. INDUSTRIAL OUTLOOK 1994, *supra* note 3, at 31-6.

[322]*Id.* at 36-16.

[323]47 C.F.R. § 73.14 (1993).

[324]47 C.F.R. § 73.21 (1993).

[325]This signal inferiority results from several factors. First, the amplitude modulation of the AM broadcasting signal is more vulnerable to atmospheric interference and noise; second, man-made radio noise, such as ignition systems and power lines, emit radio waves that interfere with AM broadcast reception; third, while AM stations occupy 10 kHz channels, FM channels are 200 kHz wide, permitting the broadcast of high fidelity stereo programming; fourth, the widespread practice of "processing" or boosting the higher frequencies of the broadcast signal by AM operators has created excess interference; fifth, radio manufacturers produce inexpensive AM radios with limited frequency response and reduced bandwidth capability.

[326]FEDERAL COMMUNICATIONS COMMISSION, MIMEO NO. 51785, BROADCAST STATION TOTALS AS OF DECEMBER 31, 1994 (1994) [hereinafter BROADCAST STATION TOTALS].

[327]The other is an "out-of-band" technology that would operate outside the existing broadcasting allocation and would require additional broadcast spectrum allocation. The "in-band" technology is commonly referred to as "in-band on-channel" (IBOC) where the digital signal is transmitted with the analog AM broadcast signal on a non-interfering basis.

FM BROADCAST STATIONS

FM broadcast stations are authorized for operation on 100 allocated channels, each 200-kHz wide, extending consecutively from Channel 201 on 88.1 MHz to Channel 300 on 107.9 MHz.[328] Depending on its FM station class, the maximum effective radiated power authorized ranges from 6 kilowatts to 100 kilowatts.[329] Over 6700 licensed commercial and noncommercial educational FM stations are supported in this band: 5109 FM commercial stations and 1733 FM educational stations.[330] Better audio fidelity is a distinct advantage of FM radio over AM radio broadcasting; however, FM radio does not normally have the extensive service coverage areas that AM radio broadcasting enjoys.

As with the AM broadcast stations, IBOC technology represents a potential enhancement to FM broadcast operations. Two IBOC proponents with a total of three FM IBOC systems are presently being evaluated under the auspices of the EIA and NRSC.

TELEVISION BROADCAST STATIONS

Throughout the US&P, commercial and educational television broadcast stations comprise the broadcast television industry. These stations operate on 6-MHz wide channels in the VHF and UHF frequency bands.[331] Allotment of channels to specific communities is made by the FCC, and the channel assignments are designated as commercial or educational. The spectrum occupied by television broadcast comprises 72 MHz in the VHF band and 336 MHz in the UHF band. There are over 1500 television stations operating in the US&P.[332]

Numerical Designations of TV Channels

CHANNELS	FREQUENCY MHz	BAND
2-4	54-72	VHF
5-6	76-88	
7-13	174-216	
14-69	470-806	UHF

Advances in microelectronics, digital signal processing, and video compression technology have recently brought advanced television (ATV) technologies close to commercial application in the United States.[333] Digital HDTV is an ATV technology and would provide improved picture (high resolution, better

[328] 47 C.F.R. § 73.201 (1993).

[329] 47 C.F.R. § 73.211 (1993).

[330] BROADCAST STATION TOTALS, *supra* note 326.

[331] 47 C.F.R. § 73.603(a) (1993).

[332] BROADCAST STATION TOTALS, *supra* note 326.

[333] ATV is generally defined as any television technology that provides improved audio and video quality or enhances the existing National Television Systems Committee (NTSC) television broadcast system. REFERENCE DATA FOR ENGINEERS: RADIO, ELECTRONICS, COMPUTER, AND COMMUNICATIONS 35-43 (Van Valkenburg, ed. 1993).

color, and wider screen) as well as improved sound (at or near CD) quality.[334] The FCC, through a rulemaking proceeding, proposed to provide an ATV channel for each television broadcast station and require simulcasting on both the NTSC and ATV channels.[335]

SUMMARY OF COMMENTS

Despite the development of satellite program delivery systems, commenters indicated that there continues to be a long-term shortfall of allocated HF frequencies for international broadcasting operations.[336] Both Herald Broadcasting and the National Association of Shortwave Broadcasters (NASB) urged that the difference between the amount of spectrum recommended by the Industry Advisory Committee and what was provided by WARC-92 should be used as a basis for future planning by the United States.[337] This shortfall amounted to approximately 1,655 kHz. VOA indicated that less than half of the VOA's HF frequency requirements were included in the U.S. proposals to WARC-92.[338] VOA identified its unsatisfied spectrum requirement as the shortfall from what it identified in its requirements process to what was allocated by WARC-92.[339] This was calculated to be approximately 1,810 kHz. These two requirements contain common spectrum and cannot be added directly. Considering the overlapping requirements, the total additional spectrum requirement is approximately 1,900 kHz. There are a number of radio services still competing for allocations in the limited HF spectrum. These include, in addition to international broadcast operations, the fixed, mobile, and amateur services.

The National Association of Broadcasters (NAB) indicated that most broadcasters in the United States favored a terrestrial IBOC technology and that there appears to be significant progress being made

---

[334]The FCC in 1987 established an Advisory Committee on Advanced Television Service (ACATS) to recommend a new television standard for the United States. Industry responded with over 20 systems that were eventually reduced to a smaller field of feasible proponents after a thorough review. These early systems were either analog or hybrid analog and digital approaches. The FCC in early 1990 stated its desire for a simulcast HDTV system and four digital HDTV systems were identified. The competing systems were officially tested and extensively analyzed during 1992 that led to an ACATS recommendation that a digital HDTV system be adopted for the United States. It was also recommended that the competing systems should either be improved and retested, or somehow combined. In mid-1993, the four digital HDTV proponents joined in a "Grand Alliance" that began a collaborative effort with the ACATS to create the best possible HDTV system for the United States. On April 14, 1994, a System Specification of the Grand Alliance HDTV System was published to form the basis of the proposed digital HDTV standard. Further, the prototype hardware was expected to be delivered around March 1995 to the Advanced Television Test Center for verification of the performance of the proposed Grand Alliance HDTV system standard.

[335]*Advanced Television Systems and Their Impact Upon the Existing Television Broadcast Service,* Notice of Proposed Rulemaking, MM Docket No. 87-268, FCC Rcd 7024 (1991); *Advanced Television Systems and Their Impact Upon the Existing Television Broadcast Service,* Second Report and Order/Further Notice of Proposed Rulemaking, MM Docket No. 87-268, FCC Rcd 3340 (1992); *Advanced Television Systems and Their Impact Upon the Existing Television Broadcast Service,* Second Further Notice of Proposed Rulemaking, MM Docket No. 87-268, FCC Rcd 5376 (1992).

[336]VOA Comments at 7; NASB Comments at 2; Herald Broadcasting Comments at 2; Jacobs Comments at 10.

[337]Herald Broadcasting Comments at 2; NASB Comments at 3.

[338]VOA Comments at 6.

[339]*Id.* at 1.

towards this end with recent demonstrations of prototypes in the AM and FM broadcast bands.[340] The NAB also noted that should IBOC digital audio broadcasting not achieve technological success and not succeed in adequate U.S. market penetration, an additional 54 MHz of spectrum would be required to implement "out-of-band" digital audio broadcasting.[341] General Motors recognized the promise and uncertainties of in-band digital audio broadcasting technologies and indicated that the United States should be prepared to introduce a competitive digital audio broadcasting service should in-band digital audio broadcasting prove to be unsatisfactory.[342]

The NAB indicated that no new additional spectrum would be required to implement ATV since ATV channels would use spectrum provided from existing UHF TV channels as envisioned in the pending FCC ATV rulemaking proceeding.[343] Members of NTIA's Spectrum Planning and Policy Advisory Committee noted that there is an uncertainty regarding whether or not ATV can be fully accommodated in the UHF TV band noting that the FCC draft ATV Table of Allotments includes the use of VHF channels for 17 ATV allotments.[344]

TRENDS IN TERRESTRIAL BROADCASTING SYSTEMS

Developments in digital coding, modulation, and compression have made the transmission of digital audio commonplace and digital video feasible. These technologies are gradually making their way into the conventional broadcasting scene as digital audio and ATV. The potential exists for an enhancement to AM and FM broadcast stations where the sound quality can equal or nearly equal that of CD-technology. Also, HDTV is being developed in the United States, Europe, and Japan as a means of providing greatly improved picture quality to television viewers. The U.S. development of a successful HDTV system will provide the basis for revolutionary new video services to many homes, industry, scientific, and medical customers, as well as affecting billions of dollars of international trade. The U.S. capability in digital signal processing and video compression technology is creating the first digital HDTV standard that could displace existing Japanese and European analog technology.[345] The implementation of HDTV may be difficult and expensive for broadcasters, but it appears essential for broadcasters to find a way to upgrade their facilities to provide HDTV to consumers and remain competitive with the virtually certain introduction of HDTV by cable, VCR's, and DBS. International broadcast stations will experience improved spectrum efficiency with the

---

[340]NAB Comments at 5-6.

[341]*Id.* at 6.

[342]GM Comments at 2-3.

[343]NAB Comments at 3.

[344]Letter from Julian L. Shepard and A. James Ebel, Spectrum Planning and Policy Advisory Committee, to Richard Parlow, Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administration, Enclosure at 3-5 (Aug. 19, 1994) (on file with NTIA).

[345]*Japan Backs U.S. Design for High-Definition TV*, WASH. POST, Feb. 23, 1994, at A1, A22; *EC Abandons Bid to Develop an HDTV Standard*, INT'L HERALD TRIBUNE, Feb. 21, 1993, at 20.

planned single-sideband implementation and with satellite-sound broadcasting potentially representing a supplemental delivery system to international audiences.

SPECTRUM REQUIREMENTS FOR THE BROADCASTING SERVICE

From the comments received and information collected, we believe that no additional spectrum is required for terrestrial AM, FM, and TV broadcast services. Efforts to develop and implement IBOC digital audio broadcasting technology in the AM and FM broadcast bands appears promising and, if successful, no additional spectrum would be required. The FCC plan to facilitate development and implementation of ATV does not appear to require additional spectrum. Eventually, the spectrum vacated by the transition from the VHF channels to UHF channels will free up some, if not all, of the 72 MHz of VHF TV spectrum. Federal and non-Federal broadcasters expressed their requirements for additional HF spectrum as the shortfall resulting from WARC-92. The aggregate U.S. requirement for additional HF broadcasting spectrum was calculated to be approximately 1,900 kHz, since these separate requirements were not mutually exclusive. However, strong competition for the limited and very congested HF spectrum continues from the maritime, fixed, mobile, aeronautical and amateur services.

BROADCASTING-SATELLITE SERVICE SYSTEMS

In the 1970's and 1980's, satellites became a chief means of long distance radiocommunication and facilitated worldwide TV program distribution in real time and, in some cases, with delays as required due to time zone differences. In rural areas not serviced by terrestrial TV broadcast stations and cable TV systems, FSS satellite signals made possible direct reception of TV from satellites by TVRO receivers equipped with parabolic antennas with diameters between 2 and 5 meters. For almost two decades, TV program delivery by satellites was done in the 4/6 GHz and 11/14 GHz FSS bands.[346]

	Uplink (GHz)	Downlink (GHz)
DBS	17.3-17.8	12.2-12.7
BSS-HDTV	24.75-25.25	17.3-17.8
BSS-Sound	Undecided	2.31-2.36

Developments in advanced radiocommunications technologies and the offer of improved radio-based services paved the way for direct TV and audio broadcasts from satellites. Today, three technologies have been aggressively developed for the BSS: the direct broadcast service (DBS), BSS-HDTV, and BSS-Sound.

346 Initially, the frequency bands allocated to the FSS carried the bulk of television programming while BSS bands remained virtually unused. The ITU established and defined the BSS and FSS as two distinct radio services. Specific frequency bands were allocated to the BSS and FSS around 1971.

The frequencies for the DBS uplink, sometimes referred to as feeder link (Earth-to-space direction), are allocated in the FSS.[347] Downlink DBS frequencies are allocated in the BSS.

DIRECT BROADCAST SATELLITE

With the launching of the first U.S. DBS in late 1993 and its operation in mid-1994, another means for the delivery of conventional television programming directly to the consumer was achieved. This application marked the first U.S. broadcasting use of 12.2-12.7 GHz for the BSS. A few companies were expected to begin service in 1994 and others have active plans to launch DBS service. DBS systems are commercially used in Europe and in Japan.

Relative to FSS satellites that deliver television programming, U.S. DBS satellite systems use higher-powered transponders. TV receiver antennas are dishes approximately 0.5 meter in diameter, and incorporate new, state-of-the-art delivery technology. Their use of advanced satellite antennas make efficient use of available satellite power and frequency spectrum with their spot beam-type of antennas. DBS receiver hardware is small, inexpensive, and easy to install.

BROADCASTING-SATELLITE SERVICE—HDTV

Some HDTV proponents began to develop satellite systems and pushed for new international allocations for satellite-delivered HDTV at the 1988 and 1992 WARC's. Initially, many believed more allocations were necessary due to the large transmission bandwidths required by analog HDTV technology, and that it would not be accommodated into the channels planned for the BSS.[348] The U.S. proposal for a single worldwide BSS-HDTV allocation at the WARC-92 was not supported; however, the conference adopted two BSS-HDTV allocations: Region 2 at 17.3-17.8 GHz; and Regions 1 and 3 at 21.4-22.0 GHz. These new allocations will become effective April 1, 2007.[349]

BROADCASTING-SATELLITE SERVICE—SOUND (BSS-SOUND)

Another technology that is aggressively being developed is the broadcast satellite delivery of high-quality audio programming (BSS-Sound). BSS-Sound generally refers to the delivery of music, sports, news, etc., directly to consumers' radio via satellite. WARC-92 adopted three different allocations for

---

[347]WARC-92 allocated the 24.75-25.25 GHz to the FSS (Earth-to-space direction) for feeder links to support wideband HDTV, thereby displacing the radionavigation allocation. WARC-92 FINAL ACTS, *supra* note 55, at 26-27.

[348]Analog examples include the MUSE-E (multiple sub-Nyquist sampling encoding) system developed in Japan, the HDBMAC (a high-definition version of a particular multiplexed analog components format) system in the United States, and the HDMAC system in Europe.

[349]*Id.* at 76-77, 81.

BSS-Sound: 1452-1492 MHz, 2310-2360 MHz, and 2535-2655 MHz.[350] The FCC has allocated the spectrum 2310-2360 MHz based on the international allocation adopted for the United States by the WARC-92 for a Digital Audio Radio Service (DARS).[351]

Presently, there are no operational BSS-Sound systems in the United States; however, systems are now under development that will employ digital technology to broadcast CD-quality programming to consumers. Consumers will receive radio programming via their mobile or portable radios and be able to receive the program signals across the United States. Such services will not be compatible with existing analog AM and FM radios and require consumers to purchase new radios to enjoy this new broadcast service. The DARS, as envisioned, will be provided via satellites for wide area coverage and be supplemented, as needed, by terrestrial stations for local services or to fill in areas where the satellite signal is marginal.

TRENDS IN SATELLITE BROADCASTING SYSTEMS

Satellite broadcasting systems appear to be helping the United States move into a dual approach in providing television and radio programming services to the U.S. consumer. DBS will help bring direct-to-the-home television programming and possibly HDTV in the very near future. BSS-Sound will help bring additional audio listening choices to the American consumer.

SUMMARY OF COMMENTS

Commenters believed that the spectrum allocated for DBS at 12.2-12.7 GHz is adequate[352] and that it is unlikely that the requirements of the DBS will ever saturate this band.[353] The NAB pointed out that while DBS systems are now being developed by several proponents, public acceptance and demand for this technology will not be known for some time.[354] Hubbard believes, despite the WARC-92 actions, that a single worldwide allocation for the DBS should have been made instead of being split into two separate bands.[355] Further, Hubbard believes that technology will make it possible to accommodate HDTV by DBS at 12.2-12.7 GHz and that the bands at 17.3-17.8 GHz should be regarded as "expansion" bands should the

[350]Mexico and Canada are planning to use 1452-1492 MHz for their BSS-Sound systems. Close frequency coordination will be needed to ensure compatible operations along U.S. borders.

[351]*New Digital Audio Radio Services*, 60 Fed. Reg. 8309 (1995) (to be codified at 47 C.F.R. § 2). "DARS" is an all-inclusive term that encompasses both terrestrial DAB and digital audio provided by satellite.

[352]NAB Comments at 3.

[353]Hubbard Comments at 6.

[354]NAB Comments at 3.

[355]The BSS is currently allocated in the 12 GHz and 17 GHz bands. It should be noted that the 12 GHz band contains three segments that "overlap" each other without a common single worldwide allocation (11.7-12.5 GHz for Region 1, 12.2-12.7 GHz for Region 2, and 12.5-12.75 GHz for Region 3).

12 GHz band become saturated.[356] Satellite CD Radio, Inc. stated that the 2310-2360 MHz band will be sufficient to allow for competitive entry by the four DARS proponents.[357] The NASB does not believe that satellite-based broadcasting will represent a replacement for HF broadcasting any time in the foreseeable future. However, they believe it could supplement HF broadcasting.[358]

SPECTRUM REQUIREMENTS FOR THE BROADCASTING-SATELLITE SERVICE

From the comments received and information reviewed, we believe that no additional spectrum is required for the DBS, BSS-HDTV, and BSS-Sound in the foreseeable future. We expect future requirements for BSS feeder links to be accommodated in existing FSS bands and that the currently allocated spectrum to be adequate.

[356]Hubbard Comments at 5-6.

[357]SCDR Comments at 3.

[358]NASB Comments at 5.

CHAPTER 4

RADIODETERMINATION AND RADIODETERMINATION-SATELLITE SERVICES

INTRODUCTION

Radiodetermination is defined as: "[t]he determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation properties of radio waves."[359] The radiodetermination service has two parts: the radionavigation service, and the radiolocation service. These services are defined herein and are treated as distinct services in subsequent sections of this report when considering their requirements for long-range spectrum planning. The radiodetermination-satellite service is the space counterpart to the terrestrial service.

The radionavigation service is defined as "[r]adiodetermination used for the purpose of navigation, including obstruction warning."[360] The radionavigation service is a safety service, which is defined as "[a]ny radiocommunication service used permanently or temporarily for the safeguarding of human life and property."[361] There are no allocations to the safety service per se, however, the radionavigation service and certain other radio services are categorized as safety services because of their use for safeguarding human life and property.

The radiolocation service is defined as "[a] radiodetermination service used for the purpose of radiolocation."[362] Furthermore, radiolocation is defined as "[r]adiodetermination used for purposes other than those of radionavigation."[363] Examples of radiolocation systems are military radar systems used for defense purposes; and a privately operated continuous wave (CW) radar system using the 1705-1800 kHz band to precisely position a ship to drill an oil well in a large body of water.

---

[359] NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-12.

[360] *Id.*

[361] *Id.* at 6-14.

[362] *Id.* at 6-13.

[363] *Id.* at 6-12.

RADIONAVIGATION SERVICE

The radionavigation service provides a number of vital functions such as aeronautical, maritime, land, and space navigation. The frequency bands allocated to the radionavigation service can be used by either the maritime or aeronautical radionavigation services, while other bands are allocated specifically to the maritime radionavigation or aeronautical radionavigation services. A total of 62 frequency bands are allocated to these three services.

The Federal Government provides radionavigation services for the safe transportation of people and goods, and to encourage the flow of commerce. DOD also develops and uses its own radionavigation services for national defense purposes. The radionavigation service in the United States is jointly planned by DOD and DOT with input from the user community. Every two years, DOD and DOT jointly issue major navigation policy statements and a strategic radionavigation plan published in the Federal Radionavigation Plan (FRP).[364] The FRP presents the major goal of DOD and DOT in radionavigation planning, which is the selection of a mix of common-use civilian/military systems which meets diverse user requirements. The user community and its requirements vary widely, e.g., from single-engine aircraft to large commercial airliners; from small pleasure boats to large ocean-going-vessels, and military ships and aircraft. There are numerous user requirements, but the most significant ones are accuracy, reliability, and cost.

Two organizations in DOT provide radionavigation services: the USCG, and the FAA. The USCG has the statutory responsibility to provide for safe and efficient maritime navigation; the FAA has the statutory responsibility for aeronautical navigation. Some modern navigation services are used by both maritime and aviation, so there is some overlapping interest. The FAA has the responsibility for the development and implementation of aeronautical radionavigation systems for safe and efficient air navigation, as well as control of all civil and military aviation within the National Airspace System (NAS), and for international airspace under the control of the United States.

DOD develops and operates some its own navigation systems. A number of these systems are used by both military and civilian users. Furthermore, DOD ensures that military ships and aircraft have the necessary civilian and military navigational capabilities.

Many radionavigation services require international standardization to provide for the orderly flow of ships and aircraft across borders. Equipment and operating standards are established in the ITU that primarily deals with radio spectrum matters, in the International Maritime Organization (IMO) for maritime systems, and in the ICAO for aviation systems. The ITU, IMO, and ICAO are specialized treaty organizations of the United Nations, with some overlapping spectrum-related interests. Although the IMO and ICAO consider some radio spectrum matters, their main emphasis is in the standardization and interoperability of

---

[364] U.S. DEP'T OF TRANSPORTATION & U.S. DEP'T OF DEFENSE, DOT-VNTSC-RSPA-92-2/DOD-4650.5, 1992 FEDERAL RADIONAVIGATION PLAN (1993) [hereinafter FEDERAL RADIONAVIGATION PLAN].

equipment and standardizing operating procedures. The United States participates in these organizations to plan and provide for the international standardization of navigation for U.S. ships and aircraft.

CURRENT RADIONAVIGATION USES

This section presents a brief description of the major radionavigation systems currently operating, and their long-term spectrum requirements.

OMEGA

The Omega system is a worldwide CW radionavigation system used for both maritime and enroute aeronautical navigation. The Omega system operates in the 9-14 kHz VLF band on four discrete frequencies There are eight transmitters in the United States along with about 16,200 civil aviation users, 6,900 civil maritime, and 1,000 DOD users. The number of Omega users is expected to decline steadily for the next 10 years down to 800 civil aviation, 1,200 civil maritime, and no DOD users.[365]

The long-term projection of the FRP is that the existing Omega transmitters will continue in operation through 2005,[366] and thus the corresponding spectrum requirements for the Omega system will continue through at least 2005. Although the number of U.S. users may decline to essentially zero sometime beyond 2005, the United States may continue to operate Omega systems for a period of time to provide navigation for foreign ships and aircraft as required by international treaty obligations.

LORAN-C

LORAN-C operates on 100 kHz and is a maritime and aeronautical radionavigation system operated by the USCG. It is a long-range radionavigation system that possesses an inherent high degree of accuracy at ranges up to 1,900 kilometers. LORAN-C was originally developed for military use, but was selected for civil maritime use because of its high accuracy and relatively inexpensive receiving equipment.

LORAN-C has been designated by the FAA as a supplementary system in the NAS. The FAA will incorporate LORAN-C in the NAS by approving non-precision approaches at selected airports that have adequate LORAN-C coverage.[367]

The FRP estimates for LORAN-C for 1994 are 180,000 civil aviation users, 530,000 civil maritime users, and 29,300 civil land users. The FRP long-range projection shows 33 percent growth from 180,000

[365] *Id.* at 3-17.

[366] *Id.*

[367] *Id.* at 3-9.

to 230,000 civil aviation users from 1994 to 2005; a slight increase in the civil maritime users from 530,000 to 550,000; and a decline in the civil land users from 29,300 to 24,000.[368]

The USCG operates 27 LORAN-C transmitters with some joint U.S. and Canadian operations. The 27 transmitters are projected to continue operation through 2005, and there are more current and projected users of LORAN-C than any other service.[369] Thus, the corresponding long-range spectrum requirements in the 90-110 kHz band will continue for at least the next 10 years.

AERONAUTICAL RADIOBEACONS

Aeronautical nondirectional radiobeacons (NDB) operate in the 190-535 kHz part of the spectrum and serve the civilian aircraft and DOD user community with low-cost navigational aids. They are used for transition from enroute to precision terminal approach facilities and as non-precision approach aids in many airports. The NDB's also provide weather information to pilots; and in Alaska, the NDB's are used for enroute navigation. The FAA operates over 700 NDB's; the military operates about 200; and there are 800 privately operated NDB's. There are about 180,000 civil aviation users of these beacons, and about 10,000 military users.[370]

The FRP mid-range projections indicate that the number of NDB's will remain about the same for the next five years. Over the long term, the FRP projects a decline of over 50 percent by 2005 to 300 FAA beacons, 400 private, and 20 DOD beacons. Furthermore, during the next 10 years, the FAA expenditures will be limited to replacement of older NDB's and an occasional relocation. Although there is a projected over-50 percent decline in the number of beacons, the numbers of civil aviation users is projected to increase from today's 180,000 to 210,000.[371]

Since the number of beacons is projected to decline by over 50 percent, the spectrum requirement is expected to decline a corresponding amount.

MARITIME RADIOBEACONS

Maritime radiobeacons provide a backup to more sophisticated radionavigation systems and are the primary low-cost, medium accuracy system for ships equipped with only minimal radionavigation equipment. The beacons are used for direction finding.

---

[368] *Id.* at 3-21.

[369] *Id.*

[370] *Id.* at 3-36.

[371] *Id.*

Approximately 150 marine radiobeacons are operated by the USCG in the 190-535 kHz band serving an estimated 500,000 users. The number of beacons is projected to decline down to 50 by 2005, although the number of users is projected to remain large at 290,000.[372]

Since the number of maritime radiobeacons is projected by the FRP to decline by 67 percent from 150 to 50, the corresponding long-range spectrum requirements are expected to be reduced.

On the other hand, the Institute for Telecommunication Sciences, a unit of NTIA (NTIA/ITS), conducted a study of the use of various methods to provide the differential Global Positioning System (DGPS) signal to make the satellite-based GPS systems more accurate.[373] The NTIA/ITS recommended the use of "Coast Guard-like" beacons to provide the signal.[374]

If the Department of Transportation decides to implement the recommended national system of beacons to provide the differential GPS signal, there may not be an increase in spectrum requirements as the beacons may be accommodated in the existing spectrum allocations. However, the concept of nationwide deployment of such beacons may require additional study to determine if additional spectrum is necessary.

VOR, DME, AND TACAN

The VHF Omnidirectional Range (VOR) provides azimuth readings to aircraft. A collocated Distance Measuring Equipment (DME) System (VOR/DME) provides the distance from the aircraft to the DME transmitter. The VOR system operates in the 108-118 MHz band, and the DME and its military version, tactical air navigation (TACAN), operates in the 960-1215 MHz band.

VOR/DME is the primary radionavigation aid in the NAS, and it is the internationally designated standard short-distance radionavigation aid for air carrier, business aviation, and general aviation instrument flight operations. Its use is an integral part of the air traffic control procedures.

The FAA operated 962 VOR/DME facilities in 1992, and the long-range projection is 1,020 in 1993 through 2000, followed by a projected decline down to 800 in 2005. The FRP estimates that there were 196,000 users in 1992, and the projected number of users is expected to peak at 204,000 in 2000, and decline slightly to 198,000 in 2005.[375] The VOR/DME is projected to remain a short-range aviation navigation system through the year 2010.[376] The FAA has indicated that beyond the year 2010, the need for air-ground voice

---

[372]*Id.*

[373]R.O. DEBOLT ET AL., NTIA SPECIAL PUBLICATION 94-30, A NATIONAL APPROACH TO AUGMENTED GPS SERVICES xiv (1994). This report is discussed at length beginning *infra* p. 115.

[374]Although it is a part of NTIA, the Institute for Telecommunication Sciences conducts contractual technical studies whose results and recommendations are entirely separate and distinct from the NTIA telecommunications policy making process.

[375]*Id.* at 3-21.

[376]*Id.* at 1-9.

and data communications is expected to require the use of spare capacity in the adjacent VOR navigation band as the requirement for VOR's may decrease.[377]

At some sites, the DME function is provided by the TACAN system which also provides azimuth guidance to military users. These facilities are called VORTAC stations. The DOD operated 85 facilities in 1992 and had 12,500 users. The DOD requirement will diminish when aircraft are properly integrated with the satellite-based GPS, and when GPS is certified to meet Required Navigation Performance (RNP) for national and international controlled airspace. The GPS certification is expected in the year 2000.[378] The DOD has indicated that their "... use of TACAN will continue as a backup to GPS even if GPS is certified to meet the RNP and all aircraft are fitted."[379]

Extensive use is projected for the VOR/DME systems for at least the next 10 years, and the corresponding long-range spectrum requirements are expected to continue. The GPS may eventually supplant the VOR/DME and TACAN systems, but this is not expected for at least 10 years until the GPS is certified as an approved sole means navigation system within the NAS. (For additional information, see the sub-section on GPS.)

JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM

The Joint Tactical Information Distribution System (JTIDS) is a military system used by United States and NATO forces that provides both communications and navigation functions. JTIDS has been an on-going program for over 20 years, reaching operational status in 1981. The JTIDS is deployed on aircraft and ships of all three military Departments. Man-transportable versions are also used. Operations are expected well into the next century.

JTIDS operates on 51 frequencies in the 960-1215 MHz band under the provisions of Footnote US224.[380] The 960-1215 MHz band is also used by air traffic control radar beacon system (ATCRBS), Mode S, the Traffic Alert and Collision Avoidance System (TCAS), DME and TACAN systems. JTIDS operation is allowed on the condition that no harmful interference will be caused to current or future users authorized to operate in the band. An extensive test program was initiated to assure that JTIDS, employing spread spectrum modulation (frequency hopping and phase coding) techniques, can operate compatibly with other navigation systems operating in the band. The issues involving the 960-1215 MHz

---

[377] MARKEY, *supra* note 125, Enclosure at 8.

[378] FEDERAL RADIONAVIGATION PLAN, *supra* note 364, at 1-9.

[379] Memorandum from Nelson V. Pollack, Air Force Member, Interdepartment Radio Advisory Committee (IRAC), to Chairman, IRAC at 5 (Oct. 7, 1994) (on file with NTIA).

[380] "Government systems utilizing spread spectrum techniques for terrestrial communications, navigation and identification may be authorized to operate in the band 960-1215 MHz on the condition that harmful interference will not be caused to the aeronautical radionavigation service. These systems will be handled on a case-by-case basis. Such systems shall be subject to a review at the national level for operational requirements and electromagnetic compatibility prior to development, procurement or modification." NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-116.

band will not be resolved until compatibility testing with the Precision DME and MODE-S systems are completed in 1996. (MODE-S is discussed under the Air Traffic Control Beacon System sub-section.)

The JTIDS is expected to operate well into the next century, and thus, the long-range spectrum requirements for its operation in the 960-1215 MHz band are expected to continue.

INSTRUMENT LANDING SYSTEM

The Instrument Landing System (ILS) provides aircraft with precision vertical and lateral navigation guidance information during approach and landing. The ILS consists of a localizer operating in the 108-112 MHz band, and a glideslope operating in the 328.6-335.4 MHz band, and associated marker beacons operating at 75 MHz. Federal regulations require U.S. air carrier aircraft to be equipped with ILS avionics. ILS is also extensively used by general aviation and military aircraft. ILS is the ICAO standard landing system, and is used extensively worldwide.

There were 974 ILS sites in the United States in 1992, and the FRP projected growth peak is 1,094 in 2000-2003, with a slight decline to 1,020 projected in 2005. The FRP estimates the number of ILS users in 1992 as 131,000, and it projects about a 15 percent decline to 110,000 in 2005.[381]

There were 165 DOD ILS facilities in 1992, and the FRP projects a substantial decline down to 40 in 2005. The DOD had 10,500 users in 1992, and the long-range projection is a decline down to 1000 in 2005.

The FRP points out that even though the present 50 kHz frequency spacing in the 108-118 MHz band has nearly doubled the number of usable ILS channels, frequency congestion in some areas of the United States has limited the number of ILS requirements can be satisfied. The FAA has estimated, that by the year 2000, approximately 100 requirements for ILS's in high density areas of the United States will not be implemented because of ILS frequency congestion.[382]

MICROWAVE LANDING SYSTEM

The Microwave Landing System (MLS) was a joint development of DOT, DOD, and NASA under FAA management. Its purpose was to provide a civil/military, Federal/non-federal standardized airport approach and landing system with improved performance. The MLS operates in the 5000-5150 MHz band with associated DME in the 960-1215 MHz band.

---

[381] FEDERAL RADIONAVIGATION PLAN, *supra* note 364, at 3-28; *FAA Won't Delegate New Landing System*, WASH. POST, June 3, 1994, at F1 [hereinafter MLS ARTICLE].

[382] MARKEY, *supra* note 125, Enclosure at 8.

In 1978, the ICAO selected the MLS as the international standard precision approach system, with implementation targeted for 1998. The MLS was expected to gradually replace the ILS in national and international civil aviation.[383] Furthermore, the ICAO scheduled the MLS to be deployed at all international airports by early 1998.[384] The MLS has a number of advantages over the ILS because the MLS signals are minimally affected by surrounding terrain, structures, and weather; and MLS signals can be used to support curved approaches.

The FAA indicated that approximately 464 MLS systems were planned for procurement through 2000, and procurement of an additional 786 were planned after 1999. The DOD had planned to procure up to 405 MLS's through the FAA.[385] The FRP projects MLS operations beyond the year 2025.[386]

In June 1994, the FAA announced the cancellation of the MLS contracts, indicating that it will focus on buying "off-the-shelf" technology to lower costs.[387] The FAA later indicated that it canceled only MLS research and development contracts supporting certain landing categories, indicating that it will purchase the needed equipment on the open market.[388]

The Air Force has indicated that although the FAA has canceled further MLS development, "... DOD still plans on using the MLS and has begun installation of both air and ground based equipment."[389]

In conclusion, there are a number key aeronautical radionavigation activities in the 5000-5150 MHz band:

- ❑ Although the FAA has canceled MLS research and development contracts, the FAA will use off-the-shelf equipment.
- ❑ The DOD plans on using the MLS.
- ❑ The MLS has also been adopted by the ICAO as the future precision approach system. These MLS activities will require spectrum support in the 5000-5150 MHz band for at least 10 years.

---

[383] *Id.*

[384] Philip J. Klass, *Europe Seeks to Fill MLS "Gap" Left by U.S.*, AVIATION WEEK AND SPACE TECHNOLOGY, Sept. 12, 1994, at 65.

[385] FEDERAL AVIATION ADMINISTRATION, U.S. DEP'T OF TRANSPORTATION, AVIATION SYSTEM CAPITAL INVESTMENT PLAN 2-4-4 to 2-4-5 (1991).

[386] FEDERAL RADIONAVIGATION PLAN, *supra* note 364, at 3-29.

[387] MLS ARTICLE, *supra* note 381, at F1.

[388] MARKEY, *supra* note 125, Enclosure at 2.

[389] POLLACK, *supra* note 379, Enclosure at 9.

AIR ROUTE SURVEILLANCE RADAR

The FAA and the Air Force jointly operate the Joint Surveillance System (JSS) for air defense and air traffic control. Thus the JSS operates in both the radiolocation service and the aeronautical radionavigation service. The newest upgrade to the JSS is the Air Route Surveillance Radar (ARSR-4) radar located at the periphery of the United States, and which provides long range surveillance for air traffic control centers to monitor enroute aircraft. The JSS is also used by air traffic controllers to guide aircraft to smaller airports that do not have their own radar systems. In addition to the JSS, the FAA maintains an extensive network of radars supporting the FAA's air traffic surveillance requirements.

The long-term air traffic surveillance requirements and the availability of large frequency bandwidth make the 1215-1400 MHz band very attractive for air traffic control radars. Both the newer ARSR-4 and the older ARSR radars operate in the 1215-1400 MHz band, with radionavigation services confined to the 1240-1370 MHz band, with the older radars limited to 1350 MHz. The ARSR-4 radars are new and are expected to operate for more than 20 years, and the older upgraded radars could also operate for at least 10 years. Thus, long-term spectrum requirements for long-range air traffic control radars within the 1215-1370 MHz band can be expected for at least 10 years.

AIRPORT SURVEILLANCE RADAR

The FAA operates airport surveillance radars (also called terminal radars) at over 250 airports for management and control of the aircraft as they approach the airport for landing.

All of the ASR radars operate in the 2700-2900 MHz band. They are the mainstay of air traffic management around major airports, and spectrum requirements are expected to continue for more than 10 years. This spectrum is currently shared with meteorological radars and a variety of DOD radars. The FAA is in the early stages of procuring a new ASR-11 system to replace the older ASR-7's and ASR-8's.[390]

AIR TRAFFIC CONTROL RADAR BEACON SYSTEM AND MODE-S

The Air Traffic Control Radar Beacon System (ATCRBS) operates on 1030 and 1090 MHz at stand-alone sites or in conjunction with the long-range air traffic control and airport control radars to provide identification and other flight information about the aircraft so that it can be tracked and managed by air traffic controllers. The ATCRBS is called a secondary surveillance radar (SSR), and consists of a ground-based interrogator and an airborne transponder. The present system interrogates all transponders in its surveillance area and displays target information on a radar screen.

The MODE-S system, also on 1030 and 1090 MHz, will replace the ATCRBS to provide more accurate position information and to minimize interference. MODE-S is a discrete address beacon system that

---

[390]MARKEY, *supra* note 125, Enclosure at 10.

selectively interrogates only those aircraft in the antenna beamwidth. The MODE-S also provides the means for a digital data-link that will be used to exchange information between the aircraft and various air traffic control functions and weather data bases. The military also operates these systems for air-to-air surveillance.

Spectrum requirements for the ATCRBS and MODE-S on 1030 and 1090 MHz are expected to continue for more than 10 years.

TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM

As of December 31, 1993, the Traffic Alert and Collision Avoidance System (TCAS) is required for installation aboard aircraft with a capacity of 30 or more passengers. The TCAS operates on 1030 and 1090 MHz.

TCAS is a family of airborne devices that operate independently of the ground-based ATC system. Three different TCAS control levels have evolved. TCAS I is intended for commuter and general aviation aircraft; and it provides proximity warning only, assisting the pilot in visually acquiring intruder aircraft. TCAS II is intended for commercial airliners and business aircraft; it provides traffic and resolution advisories (recommended escape maneuvers) in a vertical direction. TCAS III, still under development, will provide traffic and resolution advisories in the horizontal as well as vertical direction. The system obtains information from the signals of beacon transponders carried by aircraft for ATC purposes. The level of protection provided depends on the type of transponder carried by the target aircraft. TCAS provides no protection against aircraft that do not have an operating transponder. Major airlines are installing TCAS II systems and plan to install thousands of systems.

The TCAS is a new system with widespread deployment expected, and spectrum requirements can be expected for more than 10 years.

AIRBORNE WEATHER NAVIGATION RADARS

All commercial aircraft and many private business aircraft use radars to avoid serious weather during their flights. Most of these radars operate in the 9300-9500 MHz band, and usage is expected for at least 10 years as no immediate replacement system has been identified. Thus, spectrum requirements are expected to continue in the 9300-9500 MHz band for at least 10 years.

The long-term spectrum requirements for weather radar navigation use of the 5350-5470 MHz, 8750-8850 MHz, 13.25-13.4 GHz, and 15.4-15.7 GHz bands are not expected to change in the next 10 years.

AIRBORNE RADAR ALTIMETERS

Many aircraft use radar altimeters during flight to determine height above the Earth. Most of the radar altimeters operate in the 4200-4400 MHz band reserved exclusively for this function by international agreement. Because of the capability to achieve increased precision and accuracy at altitudes of 1,000 ft. or less, they are used as a height controlling function in aircraft automatic approach and landing systems. In many aircraft, radio altimeters are also directly coupled to Ground Proximity Warning Systems (GPWS) designed to give warning when an aircraft falls dangerously below its desired descent path. Frequency modulated CW altimeters are used in practically all civil aircraft, including many general aviation aircraft. For higher altitude measurement, pulsed type radio altimeters are in extensive use. Some Federal Government agencies operate these pulsed systems at 1600 and 1630 MHz.

In response to a 1987 Mobile WARC Question, the ICAO studied the issue and concluded that the whole 4200 to 4400 MHz band currently allocated for radio altimeters is required up to at least the year 2015.[391] The International Radio Consultative Committee (CCIR) also conducted a study of the altimeter use of the 4200-4400 MHz band, and made a similar conclusion.[392]

In conclusion, there are long-term spectrum requirements for altimeters in the 4200-4400 and 1600-1630 MHz bands.

PRECISION APPROACH RADAR

The 9000-9200 MHz band is used extensively by the military for Precision Approach Radars (PAR's). Newer technologies may eventually be developed that would supplant the PAR's. However, the PAR's can be expected to be used for at least the next 10 years, and thus, long-range spectrum requirements will continue.

The FAA has indicated that it is investigating the use of this band for other aeronautical functions.[393]

GLOBAL POSITIONING SYSTEM

The Global Positioning System (GPS) is a DOD-developed, worldwide, satellite-based radionavigation system operating in the 1215-1240 MHz and 1559-1610 MHz bands. It will be the DOD's primary radionavigation system well into the next century. Twenty-four GPS satellites are available. The GPS is proposed to be used extensively worldwide by the civilian community. As an international system, it is expected to be a principal part of a Global Navigation Satellite System (GNSS). Other possible satellites for GNSS may include the Russian Global Navigation Satellite System (GLONASS) and some geostationary satellites.

---

[391] INTERNATIONAL CIVIL AVIATION ORGANIZATION, REPORT COM/MET/OPS/90, REPORT OF THE COMMUNICATIONS, METEOROLOGY, AND OPERATIONS DIVISIONAL MEETING, Appendix A to Agenda Item 1 (1990).

[392] INT'L RADIO CONSULTATIVE COMMITTEE, INT'L TELECOMMUNICATION UNION, REPORT 1186, USE OF THE FREQUENCY BAND 4,200 TO 4,400 MHZ BY RADIO ALTIMETERS (1990).

[393] MARKEY, *supra* note 125, Enclosure at 10.

The GPS was officially integrated into the U.S. National Airspace System on February 17, 1994. The FAA indicated that the action paves the way for satellites to eventually become the sole means navigation system in U.S. airspace.[394] In its comments, DOD noted that radionavigation systems often perform "safety-of-life" services, and are thus less amenable to sharing. DOD indicated that navigation systems, such as the GPS, LORAN-C, and TACAN, provide somewhat competitive functions. DOD also pointed out a current trend to satellite-based navigation systems. Moreover, DOD expects that GPS will replace such systems as Omega, LORAN-C, and perhaps VOR/DME. TACAN will be replaced by GPS for airborne use, but will probably remain in use aboard Naval and USCG ships.[395]

The FRP has developed projections for the future use of the GPS system. In 2005, the FRP projects 38,000 DOD users, 500,000 civilian aviation users, 2,500,000 civilian users on land, and 180,000 civilian maritime users. The largest projected growth of GPS usage is in the civilian land sector. Automobile usage of GPS is a major component of the large land use projection.[396]

Differential GPS (DGPS) improves the accuracy of the basic GPS. The DGPS process uses differences between the known surveyed location of the DGPS station and the derived location from the DGPS signal received at that location. A "delta" differential correction factor is then calculated which is transmitted to users over a separate radio link. DGPS is necessary for some civil applications such as very accurate position location requirements; for example, off-shore oil drilling. In these position location activities, the GPS is actually providing a radiolocation service that may be supplanting CW radiolocation systems operating in the MF band. Examples of radionavigation applications are trans-oceanic navigation, and precision landing approach for aircraft.

There are two types of differential signals: wide area, and local area. The wide area DGPS could achieve improved accuracies over large areas, e.g., for aeronautical navigation purposes. Local differential signal areas could be used, for example, by a ship looking for the exact location to drill for oil. Various methods are being considered for delivering the differential signal. A geostationary satellite could be used for the wide area differential correction signal; an FM broadcasting sub-carrier could be used for the local area differential correction signal in those cases where integrity, continuity, and availability are not important factors.

The NTIA/ITS conducted a study under contract to the Department of Transportation (DOT) to analyze various methods of providing the differential GPS signal. The study was conducted by the DOT, with the support and assistance of the DOD and the Department of Commerce. Radionavigation beacons operating in frequency bands below 500 kHz similar to maritime radio beacons were recommended for national deployment for the addition of the differential signals.[397]

---

[394]*Satnav Sanctioned*, AVIATION WEEK AND SPACE TECHNOLOGY, Feb. 21, 1994, at 31.

[395]DOD Comments at 9.

[396]FEDERAL RADIONAVIGATION PLAN, *supra* note 364, at 3-31.

[397]DEBOLT ET AL., *supra* note 373, at x.

Various architectures and security concerns were analyzed in the study, and it was determined that either of the two preferred architectures will meet aviation user requirements for all phases of flight user requirements, marine user requirements for all modes of operation, and most land user needs including ITS, railroad and survey applications. However, neither architecture will satisfy highway collision avoidance because of the high degree of accuracy (1 meter) required nationwide.[398]

The NTIA/ITS study recommended that the FAA should continue to implement its Wide Area Augmentation System and local area differential GPS programs as currently planned and the DOT, in coordination and cooperation with the Department of Commerce, should plan, install, and maintain and expanded LF/MF beacon system modeled after the USCG system."[399]

The large growth projections together with the general trend away from other navigation systems to the GPS indicate that spectrum requirements for GPS in the 1215-1240 MHz and 1559-1610 MHz bands will continue well into the next century.

GLONASS

The Russian GLONASS navigation satellite system provides navigation services similar to the GPS. The FAA has a planned research effort to examine the combined use of both GPS and GLONASS for a navigation system which meets the required navigation performance within the NAS.[400] Research to date indicates that opportunities exist to develop receiver avionics to take advantage of the GPS and GLONASS radionavigation signals to improve the navigation performance over that available from a single system.[401]

The GLONASS operates within the 1215-1260 MHz and 1559-1626.5 MHz bands. The present GLONASS system occupies approximately 24 MHz. The Russian Federation, in discussions with the United States, has indicated that the GLONASS frequency usage will be modified so that by the year 2005, only about 17 MHz will be occupied below 1610 MHz. The United States is playing a key role in ensuring that the GLONASS system will be able to be used, in conjunction with GPS, as a viable global navigation satellite system (GNSS) for international use. This involves ensuring that GLONASS utilizes aeronautical radionavigation radio spectrum which is suitably protected worldwide as well as limiting spurious emissions from MSS mobile earth stations using adjacent frequencies.[402]

---

[398] *Id.* at xiv.

[399] *Id.* at xv.

[400] FEDERAL RADIONAVIGATION PLAN, *supra* note 364, at 4-6.

[401] *Id.* at 4-12.

[402] MARKEY, *supra* note 125, Enclosure at 12.

Shipborne Navigation Radars

Ships with large displacements are required to be equipped with a radionavigation radar system that enables them to navigate in coastal areas and near docks. The 2900-3100, 5460-5650, and 9300-9500 MHz bands are allocated for this purpose. The 9300-9500 MHz band is the most frequently used band because radars using it can provide a very high resolution. Furthermore, the 9300-9500 MHz radars use interference-rejection circuitry to eliminate harmful interference even though several radars may be operating on or near the same frequency in the same geographical area.

The requirement for maritime radionavigation radars is contained in the IMO Safety of Life At Sea (SOLAS) treaty. The radars will continue operating well into the next century; thus, long-range spectrum requirements are expected to continue.

Radar Transponder Beacons

Radar Transponder Beacons (RACON's) are short-range navigation devices that provide target images on a ship's maritime navigation radar operating in the 9300-9500 MHz band. RACON's are used to identify specific locations such as hazards. Although most RACON's are operated by the USCG, private users are permitted to operate RACON's. The USCG expects to have 110 frequency agile RACON's operating by 1994.[403]

RACON's provide important navigation information that is difficult to provide by other means, and spectrum requirements for RACON's in the 9300-9500 MHz band can be expected for at least the next 10 years.

Vessel Traffic Systems

The USCG operates vessel traffic systems (VTS) around harbors and coastal areas with large amount of ship traffic. There are eight VTS locations including New York, Puget Sound, Houston, and San Francisco. The radars serve port management and vessel control functions by providing "video pictures" of ship activity at various locations that are then transmitted to a central port control facility. The VTS radars operate in the 9300-9500 MHz band. The usage and corresponding spectrum requirements are expected to continue for at least the next 10 years.

Other Research Activities

Although the FAA and other agencies conduct a great deal of research to improve the performance of existing systems, research into entirely new concepts is also being conducted. The Air Force and the FAA have jointly sponsored research into systems, such as head-up displays and synthetic vision systems, which

---

[403]FEDERAL RADIONAVIGATION PLAN, *supra* note 364, at 3-38.

will supplement existing navigation systems. Many of these systems operate in frequency bands around 30 and 90 GHz. One area of research is high resolution systems for landing applications.

Hughes Aircraft is conducting research into a terminal landing aids radar operating in the 34-35 GHz band.[404] Although these bands are not allocated to the radionavigation service, they are near bands that are. If the research progresses towards development or production, then the systems would have to operate in properly allocated bands.

RELATED ISSUES

The FAA indicated that its mission can be accomplished within the allocated spectrum, and that no additional spectrum is needed.[405]

In addition to filing comments on our *Inquiry*, the FAA provided its spectrum management concerns in a 1989 correspondence to NTIA.[406] The FAA commented on three specific areas:

- ❏ because of the increased use in the 2700-2900 MHz band for terminal radars, the FAA plans to expand into the 2900-3100 MHz band for aeronautical radionavigation use;
- ❏ radionavigation needs to be protected from encroachment by the broadcast service; and
- ❏ the 5150-5250 MHz band must be protected from encroachment by non-aeronautical services.[407]

TRENDS

The are several major trends in radionavigation that are technology-driven. There is a major trend towards increased use of the GPS satellite-based system for many navigation applications. The GPS is expected to be used for even more applications in the future as the more accurate DGPS becomes available

---

[404]Letter from Michael Tom, Senior Scientist, Radar Systems Group, Hughes Aircraft Co., to Fred Matos, National Telecommunications and Information Administration (Jan. 14, 1994) (on file with NTIA).

[405]FAA Comments.

[406]Letter from Arnold Aquilano, Federal Aviation Administration, to Honorable Janice Obuchowski, Administrator, National Telecommunications and Information Administration (Apr. 2, 1990) (on file with NTIA).

[407]The FAA subsequently provided more information on its activities, stating that "[t]he 5150–5250 MHz band, which is allocated worldwide for the aeronautical radionavigation service, must be protected from encroachment by non-aeronautical services to satisfy spectrum requirements for the pressing needs of a modern, global, and compatible all-weather radionavigation system. These requirements include spectrum for automatic dependent surveillance, digital links to transmit differential corrections for satellite navigation systems, expansion of the Doppler weather radar program, and ground surface movement and control." The FAA indicated that it has applied to NTIA for spectrum certification for systems for these purposes using the band. Letter from Don Willis, Federal Aviation Administration, to Fred Matos, National Telecommunications and Information Administration (Oct. 31, 1991) (on file with NTIA).

throughout the United States. Conversely, a decline in the number of Omega users indicates a trend away from some of the older technologies.

The increased use of GPS is expected to promote long-term reduced use of traditional radionavigation systems. There will be a period of testing and transition when both GPS and the replaced system will need to be used simultaneously. Gradually, systems such as LORAN-C, ILS, and VOR will be replaced by GPS-bases systems. Spectrum for current systems will need to be retained on a case-by-case basis until GPS has been accepted as the sole source of location information for a given function.

DEVELOPMENT OF SPECTRUM REQUIREMENTS

There are numerous aeronautical and maritime radionavigation systems currently operating providing service to hundreds of thousands of users. There are tens of thousands of radionavigation systems deployed on ships, aircraft, and other mobile platforms. These systems will continue to have spectrum requirements for at least 10 years.

Improved radionavigation systems have been and are being developed using new technologies, emphasizing the satellite-based technologies. Although some of these new systems are expected to supplant many of the older systems, the transition may take at least 10 years.

SPECTRUM REQUIREMENTS FOR THE RADIONAVIGATION SERVICE

The long-term spectrum requirements for the radionavigation service are generally driven by requirements to support specific radionavigation systems. Although there are trends towards more accurate and reliable satellite-based technologies, the spectrum requirements for both aeronautical and maritime radionavigation services for at least the next 10 years can be satisfied within the existing allocated bands.

RADIOLOCATION SERVICE

The radiolocation service is used by pulsed and CW radar systems for a number of vital functions. The specific functions are: determining precise location, search or surveillance, target tracking, weapons control, ground mapping and target identification, or combinations of these functions. The radars can be fixed or operating on ships, aircraft, missiles or land vehicles, or on space platforms.

By far, the largest user of radar systems in the radiolocation service is the DOD for its national defense mission. Other radiolocation service users are the USCG, Customs Service, FAA, NASA, and the private sector.

Unlike some other radio services that can use alternatives such as commercial resources or non-spectrum techniques, the radiolocation service, especially radars, has few, if any, alternatives to the use of the radio spectrum. Thus, the important mission of the radiolocation service must be achieved using the spectrum.

RADIOLOCATION FREQUENCY BANDS

There are 55 frequency bands allocated to the radiolocation service in the United States. Table 4-1 presents the broad categories of the spectrum, and why geophysical and mechanical limitations make one region of the spectrum preferable to another for a particular radar application. These limitations are the reasons why operational compromises are necessary for multi-function radars.

TABLE 4-1
RADAR OPERATIONS AND LIMITATIONS

70-90 and 10-130 kHz (LF)	Allocations provided but no radiolocation usage or applications identified.
300-3000 kHz (MF)	Used by CW radiolocation systems for accurate position locations. High noise levels are characteristic.
3-30 MHz (HF)	Very long range surveillance possible via ionospheric waves. Very large antennas necessary for good resolution. High noise levels. No primary frequency allocations; only a small secondary allocation at 3230-3400 kHz.
30-300 MHz (VHF)	Long range surveillance possible. Large antennas required for good angular resolution. Few frequency allocations except for a narrow band at 216-225 MHz.
300-3000 MHz (UHF)	Good for long range surveillance and tracking. Narrow bands allocated to radiolocation below 1 GHz. Large antennas required, especially below 1 GHz.
3-30 GHz (SHF)	Low external noise. Above 8 GHz, small antenna sizes provide good performance leading to various airborne and missile-borne applications. Weather effects begin above 10 GHz.
30-300 GHz (EHF)	Weather and atmospheric effects seriously effect range performance. Good performance obtainable with very small antennas.

CURRENT USES

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 30-300 KHZ BAND (LF)

The FCC has made frequencies available to the civil radiolocation service in the 70-90 and 110-130 kHz bands under Part 90.103. However, no radiolocation service activities were identified in the 70-90 and 110-130 kHz bands, and no comments were received in response to our *Inquiry* concerning radiolocation requirements in these bands.

The FCC provides radiodetermination frequencies on a number of channels in the 285-325 kHz band for ship stations for the purpose of cable repair. No comments were received concerning spectrum requirements for this activity.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 300-3000 KHZ (MF) BAND

The radiolocation systems using the MF band are CW "lane-counting" types using the precise phase differences of several signals for determining accurate position locations. A typical application is the determination of the precise position of an oil-drilling ship in the Gulf of Mexico. Such MF radar systems have been operating for over 30 years. The private sector and the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) are the main users of CW radar systems in the MF band.

The 1605-1705 kHz band was reallocated to the broadcasting service on an exclusive basis by WARC-79. A two-part ITU regional conference subsequently planned the band for Region 2, and AM broadcasting should begin in the next few years. Sharing is virtually impossible because broadcasting signals could disturb the necessary phase precision of the CW radar systems; conversely, the possible harmful interference that the radiolocation signals can have on the broadcasting signals. The radiolocation allocation is secondary to broadcasting in the 1605-1700 kHz band, and it is expected that the radiolocation systems' use of the 1605-1705 kHz band will substantially decline because of interference problems.[408]

Some of the systems operating in the 1615-1700 kHz band also require a transmitted signal at the second harmonic, in the 3210-3400 kHz band. As the usage of the 1615-1700 kHz band will decline with the inception of broadcasting, use of the 3230-3400 kHz band should also decline.

According to a navigation industry executive, the MF systems operating in this band can provide a position accuracy of 5-10 meters, and the GPS system must use a DGPS for better accuracy. The DGPS can provide an accuracy from 2-3 meters. The inception of the GPS and DGPS has resulted in a 50-percent decline in MF radiolocation service usage over the past five years.[409]

There are a large number of assignments in the 1705-1800 and 1900-2000 kHz bands, and operations can be expected at least for the next five years. Many of the systems currently operating in the 1705-1800 and 1900-2000 kHz bands will most likely continue to operate over the next five years. However, long-range spectrum requirements for the radiolocation service in the 1705-1800, 1900-2000, and 3230-3400 kHz band are expected to decrease over the next five years as activities are shifted to GPS. The requirements beyond

---

[408]NTIA conducted an extensive analysis of the 1605-2000 kHz band in 1984-1985. *See* R.E. THOMPSON ET AL., NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, NTIA REPORT 85-175, SPECTRUM RESOURCE ASSESSMENT OF THE 1605-2000 KHZ BAND (1985).

[409]Telephone Interview with Pat Matthews, Vice President - Operations, Offshore Navigation, Inc. (Oct. 21, 1993).

five years are unclear, but nevertheless, are expected to decrease even more because of the increased use of GPS.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 3-30 MHZ BAND (HF)

Although some of the very earliest radars used the HF (3-30 MHz) band for radar, the band was not used extensively for operational radars until about the 1970's. Prior to the 1970's, HF radars were primarily used for research and experimentation. One of the main reasons for the lack of extensive activity in HF radars in the post World War II era was the shortage of spectrum allocations, as there are no primary or large allocations made to the radiolocation service in the HF bands.[410] Secondly, the radar R & D during that period emphasized the UHF and microwave frequency bands.

The HF bands are highly congested with many users and numerous radio services. Furthermore, skywave propagation frequently permits signals to propagate for long distances, even intercontinentally, which may be desirable for some radio services such as broadcasting, but present sharing and compatibility problems to others such as fixed service communications users. In order to avoid interference, HF over-the-horizon (OTH) radars usually choose transmitting frequencies dynamically by monitoring for other signals and avoiding frequencies that are in use.

OTH radars use signals reflected from the ionosphere to detect targets at long ranges, up to 5,000 km. One of the main uses is the detection of aircraft, although the detection of ships and sea conditions are also applications. Some HF radars also use ground wave signals, although the useful range is much less.

Some future civilian applications of OTH radars could be air traffic control, monitoring ships at sea, interdiction of drug trafficking, and oceanographic applications such as monitoring of sea states and wind patterns over oceans. For example, there are northern Pacific air routes where aircraft must navigate on their own for a large part of the flight, and an OTH radar could fill the void.[411]

The Navy operates a HF radar in Whitehall, VA in the 5-30 MHz band, and has also developed and deployed the Relocatable Over-the-Horizon Radar (ROTHR). The ROTHR will be land-based, and will provide early warning of naval and airborne threats.[412]

---

[410]The only radiolocation service allocation in the 3-30 MHz band is in the 3230-3400 kHz band discussed *supra* p. 122.

[411]M. Westlake, *Research and Innovation: Beyond the Horizon*, FAR EASTERN ECONOMIC REVIEW, Jan. 31, 1991, at 54; J. M. Headrick, *Looking Over the Horizon*, IEEE SPECTRUM, July 1990, at 36-39; IEEE JOURNAL ON OCEANOGRAPHIC ENGINEERING, April 1986, *passim*.

[412]D. Hughes, *Navy Installs ROTHR System in Alaska to Protect Battle Groups in Pacific*, AVIATION WEEK AND SPACE TECHNOLOGY, Nov. 27, 1989, at 69-80.

NTIA recently certified that spectrum was available for the Navy Mirage OTH radar system for development in California.[413] Following development and testing, the Mirage will enter production followed by deployment aboard Navy ships worldwide. The Mirage operates in the 5-40 MHz band using surface wave and near-horizon propagation to provide OTH target acquisition, identification, and tracking information.[414]

Although there are no appropriate allocations, the HF spectrum is used for radiolocation. Furthermore, there are military requirements for HF radar spectrum, and there are a number of civilian applications. However, there are many other users and extensive unsatisfied requirements for HF spectrum, and future allocations to the radiolocation service in the HF spectrum are unlikely. Thus, future HF radar systems must be carefully designed with a dynamic channel occupancy analyzer to minimize harmful interference to other systems.

Radiolocation Usage and Requirements in the 30-300 MHz Band (VHF)

The use of the VHF band for radiolocation systems is limited because the allocations are narrow. Furthermore, high performance is difficult to achieve because very large antennas are required for good angular resolution.

Footnote NG148 provides that the frequencies 154.585, 159.480, 160.725, and 160.785 may be authorized to maritime mobile stations for offshore radiolocation and associated telecommand operations.[415] The FCC has developed rules and regulations in section 80.375 concerning these applications. No comments were received on the use of these frequencies for the radiolocation service.

Footnote US239 provides for protection of the Navy's Space Surveillance (SPASUR) system operating in the southern part of the United States in the frequency band 216.88-217.08 MHz.[416] The Navy has modernized its SPASUR system, and has operated since 1965. The NAVSPASUR system provides data on satellites and other space objects as they pass over the continental United States. The system uses three transmitter sites and five receiver sites positioned on a great circle in the southern part of the United States. It is a bistatic system, locating objects by triangulation.[417]

The DOD indicated in its comments that it is conducting advanced research in radiolocation in the 137-225 MHz band.[418] Furthermore, DOD indicated that the VHF or UHF spectrum is needed for

---

[413]National Telecommunications and Information Administration, IRAC Doc. 28039/1-1.14.10/6.14, Certification of Spectrum Support, Mirage Systems Over-the-Horizon Radar (Nov. 25, 1992).

[414]Memorandum from M. Grunden, to the Secretary, Spectrum Planning Subcommittee (SPS-9113) (May 6, 1992).

[415]NTIA Manual, *supra* note 13, § 4.1.3 at 4-171.

[416]*Id.* § 4.1.3 at 4-116.

[417]A.R. Francoeur, *Naval Space Surveillance System (NAVSPASUR) Solid State Transmitter Modernization*, IEEE National Radar Conference, Institute of Electrical and Electronics Engineers, at 147 (1989).

[418]DOD Comments at 9.

development of radiolocation systems for the detection of, and defense against, aircraft employing low-observable (stealth) technology. DOD also indicated that it had a critical need for radars in the VHF or UHF region for foliage penetration since the physics of penetration through foliage requires such wavelengths.[419]

The only allocations to the radiolocation service in the VHF band are to a few discrete frequencies in the 154-161 MHz part of the spectrum and the secondary allocation in the 216-225 MHz band. In the near future, 5-10 years, new radiolocation service allocations are unlikely even though new radar spectrum requirements may develop as a result of the DOD advanced research activities. If developed, such VHF radars would be without primary allocation status, and would have to be designed to minimize interference, or used outside the United States.

Radiolocation Usage and Requirements in the 420-450 MHz Band

The 420-450 MHz band is excellent for long-range search and surveillance and, to a lesser extent, target tracking. The large antennas required for good angular resolution generally limit operations to land or ship-based installations.

The Air Force Ballistic Missile Early Warning System (BMEWS) has been the backbone of the U.S. missile defense system for over 30 years. The BMEWS radars are located in Clear, Alaska; Flyingdales, UK; and Thule and Sonderstrom AFB, Greenland, and are used for search and tracking. The radars operate in the 420-450 MHz band, and they have been modernized over the years. Technical improvements on the BMEWS radars may continue over the next 5-10 years. Spectrum requirements will continue over the next 10 years for the BMEWS. In the future, the BMEWS spectrum requirements for the 420-450 MHz band may be reduced if spaceborne radars can perform the early warning function.

The Air Force Pave Paws, or AN/FPS-115, radars are used for detection and tracking of submarine launched ballistic missiles (SLBM), and for satellite tracking. Four phased array radars were installed between 1982 and 1987 in the United States. Other elements of the Pave Paws system are the Perimeter Acquisition Radar which was developed in the 1960's and 1970's as a Safeguard anti-ballistic missile (ABM) radar and the AN/FPS-85 SPACETRACK radar.

The AN/FPS-115 Pave Paws radars and the Perimeter Acquisition Radar use the 420-450 MHz band, and are expected to operate for the next 10 years. The older AN/FPS-85 may be phased out. Some modernization may occur to these radars, and the spectrum requirements will likely continue.

The shipborne AN/SPS-40(V) is an older radar used by the Navy and USCG for air search and surveillance of air targets at long-ranges. The AN/SPS-40(V) radar has been modernized, and it can be expected to be used for the next 10 years.

---

[419]*Id.* at 10.

The frequency 449 MHz is allocated for use by wind profiler radars to measure the atmosphere near the surface of the Earth. The radars measure wind speed and direction as a function of time and altitude, information that is useful to aviation. NOAA is planning a network to cover the United States.[420]

The DOD indicated in its comments on our *Inquiry* that "[A]dvanced research in radiolocation is being performed in the bands ... 400-500; 390-940 ...MHz."[421] As discussed in the VHF sub-section, DOD has long-range spectrum requirements for UHF radars for anti-stealth and foliage penetration radars. When considering all of the classified and unclassified current and planned systems, it can be concluded that the military agencies are expected to continue their extensive use of the 420-450 MHz band for long-range search and surveillance radars for at least the next 10 years.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 902-928 MHZ BAND

The 902-928 MHz band allocation is shared by Federal and non-Federal users. Both military and non-Federal radiolocation services use the band, sharing with the fixed service, the amateur service, Part 15 devices, and ISM.

The Navy operates the AN/SPS-49(V) as a shipborne air search radar onboard a variety of ships including all aircraft carriers and the AEGIS Ticonderoga class cruisers. The AN/SPS-49(V) is a modern all-solid state radar, and since a large number have been deployed in the fleet, it is likely that operations will continue through the next 10 years. Thus, the 902-928 MHz band will be a spectrum requirement for this radar over the next 10 years.

As noted above, DOD indicated in its comments that "Advanced research in radiolocation is being performed in the bands ...390-940... MHz."[422]

The Air Force has indicated that it "... uses the 902-928 MHz band to track missiles at test ranges, a capability that is important because it provides real-time tracking capability of manned and unmanned vehicles in test and training areas."[423]

The predominant radiolocation activity in the 902-928 MHz band is non-Federal LMS operations, licensed by the FCC. Whereas there were very few assignments in 1980, there are now over 6,800 frequency assignments. The adoption of final rules and standards by the FCC in 1994 should provide for more LMS growth in the band. There are two basic LMS systems:

---

[420]MARKEY, *supra* note 125, Enclosure at 13.

[421]DOC Comments at 9.

[422]*Id.*

[423]POLLACK, *supra* note 379, Enclosure at 6.

- multi-lateration used to locate vehicles, including stolen ones, that have a special transponder onboard;

- passive transponders on vehicles and accessed by toll booths, to automatically charge vehicles for use of the tunnel, toll road, etc.

These systems were in operation under interim rules under Part 90 for about 15 years. The FCC issued a NPRM on automatic vehicle monitoring in April 1993 to finalize the rules that had been used on an interim basis since 1974. The NPRM was issued in response to a petition for rule making filed by an operator of LMS systems. The new rules would create a more stable environment in which LMS systems operate.[424]

The subsequent Report and Order renamed the AVM service by defining and establishing a new service, the location and monitoring service (LMS), defined as "[t]he use of non-voice signaling methods to locate or monitor mobile radio units. LMS systems may transmit and receive voice and non-voice status and instructional messages related to such units."[425] This definition expands the service to encompass the location of all objects, animate and inanimate, and to permit licensees to provide service on a private carrier basis to individuals, the Federal Government, and those entities eligible under Part 90.

The FCC expects that in the coming years, LMS systems will play an integral role in the development and implementation of the variety of radio advanced transportation-related services known as Intelligent Vehicle Highway Systems (IVHS) or Intelligent Transportation Systems (ITS). The ITS is a collection of advanced radio technologies that promise to improve the efficiency and safety of our nation's highways, reduce harmful automobile emissions, promote more efficient energy use, and increase national productivity.[426]

The FCC is proposing to permit operation of non-Federal profiler radars in the 902-928 MHz band, specifically at 915 MHz. Similar to systems operating at 449 MHz, these wind profilers are sensitive Doppler radars that measure wind speed and direction at a variety of altitudes to collect atmospheric data usable in aviation to detect severe wind conditions. In meteorology, the radars improve weather forecasts and warn of severe weather conditions, and in environmental studies to analyze movement of air masses and pollutants. The FCC issued a NPRM to solicit comments on accommodating wind profiler radar systems at 915 MHz, in response to a proposal by the Radian Corporation.[427] NOAA and the National Science Foundation currently operate wind profiling radars on 915 MHz.

---

[424] *Amendment of Part 90 of the Commission's Rules to Adopt Regulations for Automatic Vehicle Monitoring Systems*, Notice of Proposed Rulemaking, PR Doc. 93-61 (1993).

[425] *Amendment of Part 90 of the Commission's Rules to Adopt Regulations for Automatic Vehicle Monitoring Systems*, Report and Order, PR Docket No.93-61 (FCC 95-41) (released February 6, 1995), at 55.

[426] *Id.* at 4.

[427] *Amendment of Section 2.106 of the Commission's Rule to Allocate Spectrum for Wind Profiler Radar Systems*, Notice of Proposed Rule Making and Notice of Inquiry, ET Docket No. 93-59, at 1 (1994).

The Navy requirements for shipborne search radars should continue for at least the next 10 years; the LMS systems are expected to proliferate; thus, there are radiolocation service spectrum requirements for the 902-928 MHz band for at least the next 10 years.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 1215-1400 MHZ BAND [428]

The 1215-1400 MHz band is excellent for radars used for long-range search, surveillance, and tracking, and it is used extensively for these purposes.

The JSS is a joint Air Force/FAA system used for air defense and air traffic control. The JSS ARSR-4 is a 3-dimensional radar system using the 1215-1400 MHz band. The radar development began in 1984, and it is a major new system; 40 are expected to be deployed on the periphery of the United States; operations and spectrum requirements are expected well into the 21st century.[429] The Air Force has indicated that the ARSR-4 must retain access to the 1215-1400 MHz band in order to support national air defense surveillance and air traffic control missions.[430]

The Air Force AN/FPS-117(V) radars and the aerostat version, the L-88, operate in the 1215-1400 MHz band. Thirteen AN/FPS-117's will be deployed to replace the Distant Early Warning (DEW) air defense system. The Customs Service is deploying four of the aerostat L-88 radars in the Caribbean and southwestern U.S. border in a $51 million contract.[431] In addition, the FAA operates AN/FPS-117 radar at Murphy Dome, Alaska.

The Air Force is now responsible for the L-88 radars. These radars are currently being replaced by the new L-88A radars. While the L-88 is electrically identical to the FPS-117, the two radars are not similar in operation. The L-88A frequencies are crystal-controlled, while the FPS-117 is more easily tuned and has the ability to frequency hop.[432] Since the AN/FPS-117 and L-88 are new radars, and the mission requirements will most likely continue, operations in the 1215-1400 band can be expected for at least the next 10 years.

The AN/TPS-59 radar is a joint Air Force and Marine Corps sponsored system operating in the 1215-1400 MHz band. It will most likely remain in operation through the next 10 years, requiring spectrum in the 1215-1400 MHz band.

---

[428]The radiolocation service is allocated on a primary basis in the 1215-1300 MHz and 1350-1400 MHz bands, and on a secondary basis in the 1300-1350 MHz band.

[429]For additional technical and operational details see R.J. LAY ET AL, ARSR-4: UNIQUE SOLUTIONS TO LONG-RECOGNIZED RADAR PROBLEMS, IEEE 1990 INTERNATIONAL RADAR CONFERENCE, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, at 6-11 (1990).

[430]POLLACK, *supra* note 379, Enclosure at 6.

[431]RADAR FORECAST, REPORT ON FPS-117(V), FORECAST INTERNATIONAL/DMS 1-7 (June 1993).

[432]POLLACK, *supra* note 379, Enclosure at 7.

The AN/TPS-63 is a transportable radar system used by the Marine Corps for detection of small, low-flying aircraft. It operates in the 1250-1350 MHz band. Improvements have been made to this radar since 1987. The radar is expected to be used at least for the next five years, and if it is modernized, it may be used for 10 years. An aerostat version of the AN/TPA-63 is also in use. Spectrum requirements in the 1250-1350 MHz band will continue for at least five and perhaps 10 years or more.

The Air Force operates the Cobra Dane radar (AN/FPS-108) in the Aleutian Islands for space track support and for inter-continental ballistic missile (ICBM) early warning. It was deployed in 1977. The Cobra Dane operates in the 1215-1400 MHz band using a 29m phased array antenna.[433] Spectrum requirements will likely continue for the next five years.

There are numerous radar systems currently operating in the 1215-1400 MHz band, many of which are relatively new, and whose operations can be expected for at least the next 10 years. The total of the investments made into the JSS, L-88, AN/TPS-59, AN/TPS-63, and Cobra Dane (AN/FPS-108) are over $1 billion. Without being specific, the DOD indicated in its comments that "[A]dvanced research in radio location is being performed in the bands ... 1215-1400...MHz."[434]

In conclusion, the relatively new radars and their important missions indicate that substantial spectrum requirements for the radiolocation service in portions of the 1215-1400 MHz band will remain for at least the next 10 years.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 2-4 GHZ FREQUENCY RANGE

The 2-4 GHz frequency range has a number of bands allocated to the radiolocation service. The radiolocation service is allocated on a primary or secondary basis in the lower part, 2300-2450 MHz, and to five bands in the upper part, 2700-3700 MHz. NTIA has recently transferred the 2390-2400 MHz and 2402-2417 MHz bands to the FCC.

Although the DOD indicated that advanced radiolocation research was taking place in the 2300-2550 MHz band,[435] no other information on this activity was provided by commenters nor were any activities identified by NTIA.

Adequate spectrum space is available in the 2700-3700 MHz bands, and good radar performance and angular resolution can be obtained by radars in this band with reasonably sized antennas. The external noise level is low, enabling long-range air search and surveillance radars to operate in the band. The good angular resolution and narrow antenna beams make the band attractive for military radars for the ability to reduce hostile jamming. The band can be used for multi-function radars for medium-range aircraft detection and

---

[433] ASPECTS OF MODERN RADAR 25-26 (E. Brookner ed. 1988) [hereinafter BROOKNER].

[434] DOD Comments at 9.

[435] *Id.*

tracking.[436] The overall good radar performance and the reasonable-sized antennas make the band very attractive for transportable military radars used for air search and surveillance.

The Air Force uses the 2900-3100 MHz band for a transportable land-based three-dimensional air search and surveillance radar system. Overall, the Air Force investment is approximately over $1 billion.

The Air Force Airborne Warning and Control System (AWACS) radar is used for specialized surveillance and identification and control. The radar operates in part of the 2-4 GHz part of the spectrum, but the operating frequency band is classified. Through 1991, a total of 68 AWACS have been produced of which 34 are operated by the Air Force. The estimated cost per aircraft is $112 million.

The Army uses the 2900-3100 MHz band for a major transportable radar used to provide accurate information on artillery and/or rockets.[437] Through 1992, an estimated 134 radars have been produced at a cost of $10 million each for a total of $1.34 billion invested.[438] The radar is expected to be in use for at least the next five years, and it may see use through the next 10 years.

Cobra Judy, or the AN/SPQ-11, is a shipborne phased array radar designed to detect and track ICBM's launched by Russia in their west-to-east missile range. It collects data for SALT treaty verification. The Cobra Judy operates in this band, and a 9-GHz band capability was added in FY85. The spectrum requirements for Cobra Judy are expected to continue for at least the next five years.

The Navy uses the 2900-3100 MHz band for shipborne radars used for long-range air surveillance using a combination of mechanical and electronic scanning. The radars are deployed onboard a variety of ships, with the total estimated cost over $1.9 billion.[439] The Navy continues to modernize the radars, and operations and spectrum requirements will likely continue for the next 10 years.

The AN/SPY-1(V) is part of the Navy shipborne AEGIS weapon system, and considered the Navy's premier fleet air defense system. The AN/SPY-1(V) is a 3-D phased array air defense radar used on guided missile cruisers and destroyers. Through 1992, a total of 35 systems have been produced at a cost of approximately $20 million each for a total of $700 million.[440] The AN/SPY-1(V) operates in the 3100-3500 MHz band. Operations and spectrum requirements are likely to extend for at least 10 years.

The Navy has an extensive investment in the 3.5-3.7 GHz band. Navy air traffic control radars are deployed worldwide. The radars utilize 15 or more channels throughout the 3.5-3.7 GHz band for optimum

---

[436]RADAR HANDBOOK 1-13, 1-16 (M.I. Skolnik ed. 1970).

[437]BROOKNER, *supra* note 433, at 38.

[438]RADAR FORECAST, REPORT ON TPQ-37(V), FORECAST INTERNATIONAL/DMS 1-5 (Aug. 1993).

[439]RADAR FORECAST, REPORT ON SPS-48(V), FORECAST INTERNATIONAL/DMS 1-5 (Apr. 1993).

[440]RADAR FORECAST, REPORT ON SPY-1(V), FORECAST INTERNATIONAL/DMS 1-8 (Apr. 1993). For further information, see Chapter 3, "The AEGIS System," by J. Sensi, Jr., in BROOKNER, *supra* note 433, at 239-53.

operation. The requirement for operation of these radars will continue throughout the 10-year planning period.[441]

NTIA conducted an analysis of the radiolocation service bands in 1987. One of its recommendations was: "Since there is no use of the aeronautical radionavigation service in the 3500-3600 MHz band, consideration should be given to making this band an exclusive radiolocation band."[442]

The DOD comments indicated that it is performing advanced research in radiolocation in the 2300-2550 MHz and the 2700-3700 MHz bands.[443] The DOD indicated that frequencies between 1 and 10 GHz may be needed for spaceborne radar, but operational deployment is not expected until after the year 2000.[444]

A review of radar R & D in the 2700-3700 MHz band did not identify any major new radar systems being developed for the band. However, the general trend is towards modernizing existing radars as new technology becomes available, although revolutionary trends sometimes result from the new technologies.

The important national security missions carried out by the many classified and unclassified military radars operating in the 2-4 GHz frequency range indicates that spectrum requirements will be needed for at least the next 10 years.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 4-8 GHZ FREQUENCY RANGE

The 5250-5925 MHz frequency range is allocated to the radiolocation service on a primary or secondary basis in six bands. These bands have some physical limitations that reduce their usefulness for long-range air search and surveillance. On the other hand, these bands are used extensively for test range instrumentation radars to track missiles and other targets.

The upper band, 5850-5925 MHz, is allocated to the fixed-satellite service (Earth-to-space) on a primary basis, and is shared with the radiolocation service, also allocated on a primary basis. Footnote US245 limits the satellite activities in the United States to international intercontinental systems and such activities are subject to case-by-case electromagnetic compatibility analysis.[445]

The 5400-5900 MHz band has been a mainstay for test range instrumentation radars since the early days of the space age. The AN/FPS-16 and its transportable or mobile version, the AN/MPS-25, provided

---

[441]Memorandum from Bruce Swearington, Navy Member, Interdepartment Radio Advisory Committee (IRAC), to Executive Secretary, IRAC (Oct. 12, 1994) (on file with NTIA).

[442]R.E. THOMPSON ET AL., NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, NTIA TECHNICAL NOTE 87-6C, SPECTRUM RESOURCE ASSESSMENT OF THE RADIOLOCATION BANDS FROM 1605 KHZ TO ABOVE 17.7 GHZ, at 2-6 (1987).

[443]DOD Comments at 9.

[444]*Id.* at 10.

[445]NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-106.

service for many years on the Eastern Test Range, the Western Test Range, White Sands Missile Range NM, Wallops Island, VA, on tracking ships and other test ranges.

Although test range radars remain in use, there is an emerging trend towards use of the new Range Applications Joint Program Office (RAJPO) system. Accurate locating of platforms such as missiles is accomplished via a GPS receiver on the platform and an air-to-ground data link. Use of the RAJPO system may lessen the future spectrum requirements for test range instrumentation radars.

The RAJPO data link operates in the bands 1350-1400 MHz and 1427-1435 MHz. It is scheduled to be used at 18 different test and training ranges throughout the United States. The Air Force has stated that this system is critical to ensuring the safety of personnel during test and training systems operation. Radar tacking of aircraft, etc., will still be required at test and training areas." [446]

The AN/SPG-55(V) radar is a Navy fire control radar used with the Terrier and the Standard SM-1 and SM-2 ER (extended range) missiles. The New Threat Upgrade (NTU) program provided for some improvements, but the radars will likely leave service throughout the 1990's.[447]

The Navy uses the shipborne AN/SPS-67(V) radar for surface search and navigation, and it is the Navy's primary surface search radar. Operations and spectrum requirements in the 5350-5850 MHz band will likely continue for the next 10 years.

The Navy uses the bands for a surface search and navigation radar. An estimated 133 units have been produced through 1992, and deployment is on a variety of ships, including guided missile cruisers and destroyers.[448] The radar has been deployed on newer ships, and operations, and spectrum requirements in the 5450-5825 MHz band can be expected for at least the next 10 years.

The Army's Patriot surface-to-air-missile (SAM) defense system includes the AN/MPQ-53 5-GHz band radar incorporating several phased array antennas. The multi-function radar provides search, surveillance, tracking, and missile guidance.

The DOD indicated that it was performing advanced research in radiolocation in the 5255-5925 MHz band.[449]

In summary, the 5250-5925 MHz band is used extensively for test range instrumentation radars, a spectrum requirement that is likely to continue for at least 10 years. The Navy shipboard search and surveillance radars are likely to continue in operation, through upgrades, for the next 10 years.

---

[446]POLLACK, *supra* note 379, Enclosure at 6.

[447]RADAR FORECAST, REPORT ON SPG-55(V), FORECAST INTERNATIONAL/DMS 1-3 (Jan. 1993).

[448]RADAR FORECAST, REPORT ON SPS-55(V), FORECAST INTERNATIONAL/DMS 1-3 (June 1993).

[449]DOD Comments at 9.

Taking all classified and unclassified systems into consideration, the radiolocation spectrum requirements are expected to continue for at least 10 years.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 8-10.55 GHZ BANDS

Good radar performance is achieved in the 8-10.55 GHz band with small antennas permitting numerous mobile applications on aircraft, missiles, ships, tanks, and other vehicles. Small hand-held radar systems are also used extensively. The band is well suited for short range search. The frequency band allocations are wide, permitting the use of narrow pulses with wide emission bandwidth to achieve good target resolution.

The 8.5-10.55 GHz frequency range is allocated in eight bands, some of which are as large as 500 MHz. Over 2 GHz of spectrum is available for radar usage. Some of the bands are used extensively for radionavigation by the private sector. For example, the 9300-9500 MHz band is used by both aircraft weather navigation radars, and by shipborne navigation radars. Since the FCC uses fleet licenses for ships and aircraft, an accurate count is not available. However, since almost all commercial aircraft and larger ships employ such radars, there must be at least 5,000-10,000 installed navigation radars.

The Army and Marine Corps use the band for transportable ground-based radars for weapon locating. A total of 382 units have been produced at a cost of $6.5 million each for a total cost of nearly $2.5 billion.[450] Units have been modernized with new technology, and operations are likely to continue for the next 10 years.

The Navy uses the band for a radar for a fire control system on frigates and small ships. Approximately 94 units of two different models have been produced at a cost of $8.5 million each for a total of about $800 million.[451] Operations will likely continue for at least the next 10 years, and spectrum requirements continue.

The Army's Ground Based Radar (GBR-X) is a new radar evolving out of the Upper Tier Theater Missile Defense Program which is part of the Ballistic Missile Defense (BMD) program, known as the Strategic Defense Initiative (SDI) prior to May 1993.[452] The GBR-X, also referred to as the GBR-T and formerly referred to as the Terminal Imaging Radar, is a transportable radar operating in the 8.55-10 GHz bands. The radar will search and track enemy tactical ballistic missiles, cruise missiles, and other air-breathing threats. It will have fire control capability against such threats.[453]

The GBR Theater Missile Defense Radar requires spectrum in the 8.55-10 GHz band, and with adequate funding will likely require spectrum for at least the next 10 years and beyond. Additional

---

[450] RADAR FORECAST, REPORT ON TPQ-36(V), FORECAST INTERNATIONAL/DMS 1-6 (June 1993).

[451] RADAR FORECAST, REPORT ON TPQ-37(V), FORECAST INTERNATIONAL/DMS 1-6 (Apr. 1993).

[452] RADAR FORECAST, REPORT ON SDI GROUND BASED RADARS, FORECAST INTERNATIONAL/DMS 1-7 (Sept. 1993).

[453] *Id.*

information is needed on the National Missile Defense radar and the guided missile interceptor radar to adequately develop their future spectrum requirements.

"Speed gun" radars used by state and local police to measure the speed of autos frequently use 10.525 GHz. FCC license records indicate 2,895 licenses in the 10.5-10.55 GHz band attributed to the many state and local law enforcement agencies that operate such radars for traffic control. This number is probably extremely low since law enforcement agencies are no longer required to obtain a separate license to operate a speed gun. The authority to operate such devices is covered under their normal "two-way" license, regardless of what frequencies that license specifies. (See discussion of "blanket" licenses under the sub-section "The 24.05-24.25 GHz Band.")

The Hughes Aircraft Co. is conducting R & D into a passenger bus warning system called FORWARN at 10.5 GHz. This activity is considered to be part of the ITS activities. Furthermore, 20 MHz of spectrum was identified as a requirement for an ITS lateral collision avoidance radar above 10 GHz.[454] Another 200 MHz was identified as needed by ITS for longitudinal collision avoidance radars operating in bands above 20 GHz.[455]

Military land-based radars also use the 8.5-10.55 GHz bands for search and surveillance. New radars are being developed that use the bands, and given a typical life cycle of 15-20 years between concept and deployment, spectrum requirements should continue for at least 20 years.

New technologies and military requirements are leading towards multi-function systems capable of simultaneously supporting communications, navigation, and identification functions as well as missile guidance, radar, and electronic warfare functions. Hughes indicates that while much of the multifunction nature of the waveforms will be a result of faster processors and enhanced algorithms, the multiplicity of compound waveforms to support the multiple functions implies that instantaneous bandwidth will be much wider, on the order of 50-60 percent in the 8.5-10.55 GHz bands. Hughes expects to see such multifunction systems in the 10-25 year time frame.[456]

In summary, the 8.5-10.55 GHz bands are prime bands for military weapons control radars installed onboard aircraft, and spectrum requirements for such activities should continue well beyond 10 years.

RADIOLOCATION USAGE AND REQUIREMENTS IN THE 10.55-30 GHZ BANDS

The major application of radars in the 10.55-30 GHz radiolocation bands is on mobile platforms such as fighter aircraft, military unmanned aerial vehicles (UAV's), etc., where physical limitations require small

---

[454]Carl Kain, Remarks at the Federal Wireless Users Forum (Oct. 6, 1994).

[455]*Id.*

[456]Letter from Michael Tom, Senior Scientist, Radar Systems Group, Hughes Aircraft, to Fred Matos, National Telecommunications and Information Administration (Jan. 14, 1994) (on file with NTIA).

antennas. Good performance can be obtained over short ranges, but precipitation attenuation can limit the useful range.

There are three frequency bands between the 10.55-30 GHz band that are allocated to the radiolocation service. Some of these bands have a large number of frequency assignments. The DOD stated that advanced research in radiolocation is being conducted in the 8.5-10.7 GHz bands.[457]

THE 13.4-14.0 GHZ BAND

The 13.4-14.0 GHz band has over 300 assignments most of which are to Federal agencies. The Navy has about 86 percent of the assignments, most of which are to one system. The USCG also uses a weapons control system on a number of ships for protection against anti-ship missiles.

Although the Navy radars are 15-20 years old, continued operations are expected for at least the next five years. No other systems are being developed, and they may operate more than 10 years into the future. Thus, radiolocation spectrum requirements are needed for at least the next 10 years.

THE 15.7-17.7 GHZ BANDS.

The 15.7-17.7 GHz portion of the spectrum is divided into five frequency bands allocated to the radiolocation service. The 15.7-16.6 GHz band is the most used of the five bands.

Military uses of the 15.7-17.7 GHz bands include radars employed for guided weapons systems, combat surveillance, mortar locating, airborne weapons control radars, and unmanned air vehicles.

A segment of the 15.7-17.1 GHz band, 15.7-16.2 GHz, has been approved for use by the FAA for their Airport Surface Detection Equipment (ASDE) on a coequal basis with military radars subject to prior coordination with the military. This usage was accomplished with the addition of Government Footnote G59 to the allocation table.

The FAA operates older ASDE systems in the 23.6-24.4 GHz band dating back to 1969-70. There were 15 systems at one time but only eight systems are currently operating. The FAA is slowly phasing out these systems, and replacing them with systems operating in the 15.7-16.2 GHz band. As the management and control of aircraft on runways is a very important safety issue, ASDE is expected to continue in operation for at least the next 10 years. Thus, spectrum requirements for ASDE in the 15.7-16.2 GHz band are expected to continue.

In summary, there are substantial long-term spectrum requirements for the radiolocation service in the 15.7-17.7 GHz bands to support the military and FAA activities.

---

[457]DOD Comments at 9.

THE 24.05-24.25 GHZ BAND

The 24.05-24.25 GHz band is used extensively for automobile traffic speed measuring (speed guns) operating in the radiolocation service. Under Part 90.19, the FCC uses a "blanket" authority to license speed gun operations regardless of whether the radar operates in the 10.5-10.55 or 24.05-24.25 GHz bands. Federal policy for authorization of speed guns is similar, therefore, there may be thousands of authorized Federal and non-Federal speed gun users in the 24.05-24.25 GHz band. These activities are expected to continue for at least the next 10 years, and thus, the corresponding radiolocation spectrum requirements will continue.

The FAA operates older ASDE systems in the 23.6-24.4 GHz, but it is phasing them out and replacing them with systems in the 15.7-16.2 GHz band. The 24.05-24.25 GHz band is available for other radiolocation operations.

RADIOLOCATION USAGE AND REQUIREMENTS ABOVE 30 GHZ

The 30-300 GHz or EHF part of the spectrum is designated the millimeter wave (mmw) region. Advances in solid state and signal processing technologies in recent years have made the millimeter wave part of the spectrum more attractive for a number of applications. Small diameter antennas are possible offering some advantages such as narrow beamwidths. The narrow antenna beamwidth leads to other operational advantages such as increased immunity to interference and improved resolution.

The mmw radars have a number of attractive military applications: surveillance and target identification and acquisition, tracking and fire control, seekers and terminal guidance on missiles, instrumentation and measurements and ground mapping.

One of the major disadvantages to operations at millimeter waves is the increased atmospheric attenuation, particularly from water vapor and oxygen. The atmospheric attenuation characteristics in the 10-300 GHz range vary widely and influence the choice of frequency bands. However, there are troughs or atmospheric "windows" of lower attenuation around 35, 90, 140, and 240 GHz, coinciding with some radiolocation service band allocations.

There is extensive R&D on radiolocation service radars, and to a lesser extent, on radionavigation service radars, at millimeter waves. Although the activities are primarily research rather than development, the research results may eventually lead to the development and extensive production of equipment at some time in the future, and spectrum will be needed for equipment at the operational stage.

The DOD has indicated that it is performing advanced research in radiolocation in the 33-36 GHz, 42-46 GHz, 59-62 GHz, and 92-100 GHz bands.[458] Open literature searches of recent research activities revealed that the military agencies are also sponsoring radiolocation research in the 140 GHz, 215 GHz, and

[458] *Id.*

225 GHz bands. Furthermore, the DOD indicated that it is funding research at 215 GHz and 225 GHz, but both frequencies are in bands that are not allocated to the radiolocation service.[459]

In summary, there is a great deal of DOD-sponsored radar R&D taking place in the millimeter wave bands. The R&D applications stress ground mapping, including precise resolution and target identification. Some of the radar R&D will most likely evolve into the production and deployment of radar systems.

General Motors has conducted research into the use of automotive radar systems in the 76-77 GHz band, and has petitioned the FCC to amend their rules to permit such a service. GM indicated that the band has been proposed in Europe for radar and road guidance systems.[460] The FCC subsequently proposed to amend its rules to limit non-licensed Part 15 use of the 76.0-77.0 GHz band to vehicular radar systems.[461]

In conclusion, radiolocation long-term spectrum requirements may evolve in the 33.4-36 GHz, 59-64 GHz, 92-95 GHz, 95-100 GHz, and 134-142 GHz bands.

RADIOLOCATION USAGE AND REQUIREMENTS ABOVE 300 GHZ

Although frequencies above 300 GHz are not allocated at the present time, research is taking place, and allocations may have to be considered in the future. A majority of the research in the 300-3000 GHz (3 THz) band emphasizes components such as oscillators, mixers, amplifiers, etc. As currently envisioned, the main applications are radio astronomy and remote sensing. The remote sensing application leads to radiolocation service applications. Long-range spectrum requirements for the radiolocation service above 300 GHz may evolve as the R & D continues.

LONG-RANGE SPECTRUM REQUIREMENTS FOR ULTRA-WIDEBAND AND SYNTHETIC APERTURE RADARS

Although ultra-wideband (UWB) radars date back to the early 1960's, there has been a strong interest in UWB in recent years, particularly for potential military applications. UWB radars are characterized by very wide bandwidth and the commensurate fine range resolution. There are military applications such as the imaging of typical tactical targets where resolutions on the order of 30 cm are desired. Other potential military applications include counter-stealth capabilities, low probability of intercept (LPI), and the detection of relocatable targets in camouflage and foliage.

---

[459]It is suggested that the DOD and the military agencies review their research taking place in non-radiolocation bands. If the requirements are strong enough, then the United States could advocate allocation changes in a future ITU radio conference.

[460]Petition for Rule Making by General Motors Research Corporation, RM-8308 (Oct. 13, 1993).

[461]*Revision of Parts 2, 15, 21, 74, 78, and 94 of the Commission's Rules to Stimulate Economic Growth by Permitting Use of Radio Frequencies above 40 GHz for Access to the National Information Infrastructure and for Other Communications Applications,* Notice of Proposed Rulemaking, ET Docket 94-124, at 10 (1994).

UWB radars can be generally categorized into impulse radars and non-impulse radars. The non-impulse radars are generally extrapolations and extensions of conventional radar systems. An impulse radar is defined as a radar with a waveform of a single-cycle sine wave that has a bandwidth of approximately 100 percent, or approximately equal to the numerical value of its center frequency.[462]

The DOD recognizes that there is no possibility of exclusive or even sufficient properly allocated shared spectrum for UWB radars, and thus, spectrum sharing is required. DOD also recognizes that support for these systems must be based on demonstrated electromagnetic compatibility. Furthermore, DOD asks that flexibility should be allowed to permit their operation in bands where such compatibility can be shown.[463]

There has been extensive research and experimentation on UWB radars over the past five years. The results indicate that the UWB radars are useful for certain applications. It is possible that one or more of these systems may move forward to a production phase within the next five years. The wide emission bandwidth of UWB radars transcend many bands, including passive bands, that are used by many services. Although spectrum requirements are apparent, spectrum allocations to accommodate UWB systems are virtually impossible to obtain.

The Navy and NASA are experimenting with synthetic aperture radar (SAR) systems which operate in several radiolocation bands simultaneously and may be able to accomplish many of the applications of UWB radars while operating within allocated radiolocation bands.

RADIOLOCATION SERVICE REQUIREMENTS FOR MULTI-BAND RADAR SYSTEMS

Radar target identification is valuable in applications such as remote earth sensing and for military uses. Research has been conducted on radars that operate simultaneously in two or more bands to determine if the data provides more accurate target identification. The following provides brief descriptions of some of the recent research.

---

[462]Skolnik points out that a conventional radar might have a wide absolute bandwidth and still be narrowband in the relative sense. For example, a short-pulse 10-GHz band radar with 500 MHz bandwidth is "narrowband" in that its bandwidth is small compared to its center frequency (5 percent). However, a 500 MHz bandwidth radar at UHF (500 MHz) has a wide relative bandwidth of 100 percent. The definition of "impulse" is evolving, as research has been conducted on a wideband radar that transmitted two cycles of a sine wave. *See* M.I. SKOLNIK, NAVAL RESEARCH LABORATORY, NRL MEMORANDUM REPORT 6755, AN INTRODUCTION TO IMPULSE RADAR 1 (1990).

[463]DOD Comments at 10. Radio astronomers are concerned with the potential for interference due to UWB radar systems. Coordination between radio observatories and users of UWB devices will be necessary to minimize the risk of interference. Memorandum from Andrew Clegg, National Science Foundation, to Russell Slye, National Telecommunications and Information Administration (Oct. 13, 1994) (on file with NTIA).

The MIT Lincoln Laboratory has conducted research and experiments on target identification in foliage using radars operating simultaneously at UHF, in the 1215-1400 MHz band, and in the 5 GHz band, fully polarimetrically.[464] The system was an airborne synthetic-aperture-radar (SAR).[465]

NASA has a established a tri-band radar at the Jet Propulsion Laboratory (JPL) for research. The radar is the airborne synthetic aperture radar (AIRSAR) operating at 410-450 MHz with a 40 MHz chirp bandwidth; 1220-1260 MHz with a 40 MHz chirp bandwidth; and 5270-5310 MHz also with a 40 MHz chirp bandwidth.[466]

The ARPA and Navy have funded research into a tri-band radar for target identification. The radar was a polarimetric SAR using the 8-10 GHz, 1215-1400 MHz, and 5 GHz frequency bands. The radar could change transmit and receive polarization on a pulse-to-pulse basis. The system provided very high image quality.[467]

In summary, the overall mission requirement for improved and very accurate target information is the driving force behind the increased interest in tri-band radars. This application is for an airborne radar "mapping" the ground and identifying targets. Spectrum requirements will likely be accommodated within existing allocated bands.

RADIOLOCATION SERVICE SPECTRUM REQUIREMENTS FOR SPACEBORNE RADARS

Spaceborne radars (SBR's) can provide wide area surveillance of the Earth for commercial, law enforcement, and military applications including national defense and the detection of drug smuggling traffic. Satellite radars have two major advantages over surface or airborne radars: an essentially unrestricted line-of-sight view to any point on Earth, and an extremely large field of view. The disadvantage is that their location is always known, and a given satellite is within the view of a jammer for substantial periods of time.

In their comments, DOD stated that "there is a known and documented requirement for deployment and operation of a DOD spaceborne radar system." Furthermore, the DOD indicated that basic research is presently underway to determine optimum frequencies, modulation, and other parameters.[468]

---

[464]Polarmetric radars process the polarization of the return signal to determine the type of target as electromagnetic waves are scattered by the object, their polarization changes. The changes are processed and compared with the characteristics of known objects.

[465]J. Fleischman et al., *Summary of Results from a Foliage Penetration Experiment with a Three-Frequency Polarmetric SAR*, SURVEILLANCE TECHNOLOGIES II, Apr. 1992, at 151-60.

[466]Letter from James N. Scott, NASA Representative to IRAC Spectrum Planning Subcommittee (SPS), to Arthur Gray, Secretary, Spectrum Planning Subcommittee, SPS-9414 (Feb. 9, 1993).

[467]R. SULLIVAN ET AL., ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN, RESULTS FROM ERIM/NADC POLARIMETRIC X/L/C BAND SAR 3 (undated).

[468]DOD Comments at 9.

The DOD further indicated that while the specific spectrum requirements for a spaceborne radar are not yet available, it believes that frequencies between 1 and 10 GHz will be needed. Operational deployment is not expected until after the year 2000.[469]

The Naval Electronic System Command funded research into spaceborne radar in 1985-1986 to identify the optimum radar architecture for air surveillance. After an extensive study weighing various advantages and disadvantages, Brookner and Mahoney concluded that "[t]he choice of frequency for a satellite air surveillance radar quickly can be narrowed to a choice between the 1215-1400 MHz and 3 GHz bands."[470]

Rockwell International has conducted research into spaceborne radars for various applications in the radiolocation service and other services. One application where substantial future commercial growth is expected is SAR image interpretation. Rockwell indicates that requirements for higher resolutions, e.g., about one meter, will provide the impetus to go to frequencies in the 8.55-10 GHz range where bandwidth in the hundreds of Megahertz will be needed. Rockwell also indicates that the associated space-to-Earth communications radar data link requirement will likewise run to hundreds of MHz.[471]

Many of the SAR space applications are for imaging radars for remote Earth sensing. Although not a radiolocation service per se, remote sensing could lead to military applications. NASA has used three Shuttle Imaging Radars (SIR-A, SIR-B, and SIR-C). All three operate in the 1215-1400 MHz band, and the SIR-C also operates in the 5-GHz band. A future system, the X-SAR, will operate at 9.6 GHz.[472]

The Earth Observation Satellite (EOS), a joint U.S., Japanese, and European effort will use the 5.3 and 9.6-GHz bands in 1997.[473] The only SBR system identified to be using the 3-GHz band is the Soviet ALMAZ SAR system launched in 1991.[474]

The existence of radiolocation stations onboard spacecraft is recognized in International Footnote 713 that has been incorporated into the National Table of Frequency Allocations:

---

[469]*Id.* at 10.

[470]E. Brookner and T.F. Mahoney, *Derivation of a Satellite Radar Architecture for Air Surveillance*, MICROWAVE JOURNAL, Feb. 1986, at 173-91.

[471]Letter from Dr. Charles E. Weir, Principal Scientist, Space Systems Division, Rockwell International, to Fred Matos, National Telecommunications and Information Administration, Nov. 15, 1993 (on file with NTIA).

[472]J.C. CURLANDER & R.N. MCDONOUGH, SYNTHETIC APERTURE RADAR SYSTEMS AND SIGNAL PROCESSING 39 (1991).

[473]BROOKNER, *supra* note 433, at 84.

[474]CURLANDER & MCDONOUGH, *supra* note 472, at 12.

"In the bands 1215-1300, 3100-3300, 5250-5350, 8550-8650, 9500-9800 MHz, and 13.4-14.0 GHz, radiolocation stations installed on spacecraft may also be employed for the earth exploration-satellite and space research services on a secondary basis."[475]

Technology trends and available bandwidth appear to be focusing on 8.55-10 GHz for space-based radar systems. Based on the information received from industry, space-based radar systems may proliferate in the future although there may be other applications in addition to the radiolocation service.

The Air Force has received Congressional budget approval for the Alarm early-warning satellite.[476] The Alarm is believed to use radars onboard low-Earth orbiting satellites, and will transmit its collected data via communications satellites to ground control stations. Spectrum requirements for the Alarm system will be needed as the system becomes more clearly defined.

TRENDS

The review of ongoing R & D, interviewing experts, analyses of existing and planned operations, and the DOD comments reveal numerous trends:

- ☐ The DOD has increased requirements for more accurate radar ground mapping and accurate target classification.
- ☐ A large number of research projects are taking place in the bands above 30 GHz, even up to 225 GHz and into the terahertz range.
- ☐ A number of on-going research projects are using tri-band radars (radars operating simultaneously in three bands) for more accurate target classification;
- ☐ Experts concluded that most of the radars that will need spectrum 10 years from now are in operation now.[477] (This is based on the experts' conclusions that radars using new technologies have a 15-20 year life cycle between concept and deployment.)

---

[475] NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-147.

[476] John D. Morrocco and David A. Fulghum, *Conferees Spare Programs by Spreading Cuts*, AVIATION WEEK AND SPACE TECHNOLOGY, Oct. 3, 1994, at 30.

[477] The radar experts interviewed were Dr. Merrill Skolnik, Superintendent, Radar Division, U.S. Navy; Mr. Robert T. Hill, Consultant and former Navy Radar Scientist; Dr. David Barton, Senior Radar Scientist, ANRO Co.; and Dr. Eli Brookner, Senior Radar Scientist, Raytheon Corp. The 15-20 year radar concept-to-deployment cycle is essentially supported by Norman Augustine, President, Martin Marietta Corp. Augustine indicated that it takes 14 years from major program inception to operational capability. *See* ELECTRONIC INDUSTRIES ASSOCIATION, EIA TEN-YEAR FORECAST OF DEFENSE ELECTRONIC OPPORTUNITIES (FY'S 1993-2002), 28TH ANNUAL REPORT 520 (1992).

- Rather than buying new radars, some agencies like the Navy are modernizing existing radars with new electronics and signal processing technologies. (The operating bands remain the same.)

- Future battlefields will employ a large number of sensors, robots, and UAV's that will use many radars, with many operating in the millimeter-wave bands.

- Spaceborne radars are receiving greater interest.

- Advanced Research Projects Agency (ARPA) and the military agencies are funding many ultra-wideband and impulse radar projects. Some of these systems operate in the lower bands with very wide bandwidth, e.g., a 1 GHz bandwidth at a center frequency of 1 GHz. No spectrum allocations can be provided for these systems, and the proof of compatibility rests with the system developer.

SPECTRUM REQUIREMENTS FOR THE RADIOLOCATION SERVICE

A review of the R & D indicated that the future spectrum needs of the radiolocation service can be accommodated within existing allocations. Those new systems developed in heavily used bands where there are no allocations must use engineering and operating techniques to minimize the interference potential.

With the following exceptions, the radiolocation service long-term spectrum requirements can be accommodated within the existing allocations:

- *Although there are spectrum requirements in the HF and VHF spectrum range, the bands are congested with many users and allocations for the radiolocation service are unlikely.*

- *Although long-term spectrum requirements may evolve for ultra-wideband systems, if the R & D grows into operational systems, spectrum allocations are unlikely because of the very wide emission bandwidth.*

RADIODETERMINATION-SATELLITE SERVICE

The radiodetermination-satellite service (RDSS) is defined as "[A] radiocommunication service for the purpose of radiodetermination involving the use of one or more space stations."[478] The RDSS can provide both radionavigation and radiolocation services, and its long-term spectrum requirements are considered separately from that of the radionavigation-satellite service.

[478] NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-12

There has been considerable private sector interest in developing and operating a radiodetermination satellite or a radiodetermination-satellite type of service that could provide position locating services. A typical application would be from the long-haul trucking industry, where the headquarters or central control facility could easily determine the precise location of its trucks.

Although not a true RDSS system or service, one approach uses another radionavigation service to determine position which is then communicated to a central location. A remote unit calculates its position from a separate navigation system such as GPS or LORAN-C, and then transmits its location via a communications satellite system operating in either the fixed-satellite or mobile-satellite services. One example of this pseudo-RDSS system is the Qualcomm Company use of LORAN-C and a communications satellite to provide positioning and locating services to long-haul trucking companies. A true RDSS system would be a self-contained navigation and satellite system using the frequency bands allocated to the RDSS.

True RDSS systems use the timing provided by radio signals transmitted by multiple satellites and a participating vehicle (or remote ground station) to a central control point. In a supplementary service, using appropriate radio frequency spectrum, the positions can be communicated to the vehicle or remote station for navigation and/or locating.

Following the proposals of the United States and other nations, the ITU allocated frequency bands to the RDSS at the 1987 Mobile WARC and at WARC-92. The U.S. proposals advocating RDSS allocations resulted from industry requirements. One system that was never fully implemented was developed by the GEOSTAR Corporation. While GEOSTAR operated a satellite messaging system in the radiodetermination satellite service using two satellites for a few years, the positioning capability was never implemented.

The relatively low cost of GPS receivers has reduced the impetus for separate RDSS satellites. Thus, no additional RDSS spectrum requirements are anticipated for at least the next 10 years.

CHAPTER 5

OTHER SPACE SERVICES AND RADIO ASTRONOMY

INTRODUCTION

During the past several decades, space radiocommunications have greatly expanded the scientific and telecommunications capabilities of our nation and world. The space services today provide communications between fixed and mobile users on the Earth, much as do the terrestrial fixed and mobile services. They provide communications to allow spaceborne platforms to disseminate information to, and collect information from, the Earth's surface. They also provide the ability to look outward into space, and back toward the Earth from space, to further our scientific knowledge.

Many of the space services are closely related to terrestrial services. For example, the mobile- and fixed-satellite services are similar to the terrestrial mobile and fixed services and often compete in the same markets. For this reason, they, along with the broadcasting-, radiodetermination-, amateur-, and standard frequency and time signal-satellite services are discussed in the same chapters as the corresponding terrestrial services.[479]

This chapter discusses spectrum requirements for space services not included in the above list, mainly because they do not have closely related terrestrial counterparts. These include the inter-satellite service and the proposed general-satellite service, which are related to satellite communications; the space operation service; and the services related to space sciences. The latter group includes the space research service, the earth exploration-satellite service, and the meteorological-satellite service. While they do not involve space *services*, radio astronomy and radar astronomy are covered in this chapter because they are space *sciences*.

[479]The mobile-satellite service is discussed *supra* p. 52, the fixed-satellite service *supra* p. 80, the broadcasting-satellite service *supra* p. 100, the radiodetermination-satellite service *supra* p. 142, the amateur-satellite service *infra* p. 163, and the standard frequency and time signal-satellite service *infra* p. 169.

SATELLITE COMMUNICATIONS SERVICES

A major function of the space services is to provide communications between widely separated points on the Earth. While the bulk of these communications fall to the mobile-, fixed-, and broadcasting-satellite services, two other services may see significant use in the future. The inter-satellite service provides communications between satellites. If established, the general-satellite service would combine the functions of several existing satellite services, providing greater flexibility for multi-function systems.

INTER-SATELLITE SERVICE

Although most satellite communications involves links between satellites and the Earth, satellites and other spacecraft must often communicate among themselves. Communications links that involve more than one satellite require inter-satellite links. Non-geostationary U.S. satellites and other spacecraft in low Earth orbit generally relay their signals to the ground through geostationary data relay satellites. Manned space missions involving multiple spacecraft or extra-vehicular activities also require "inter-satellite" radiocommunications links.

While the inter-satellite service can support these communications links,[480] they are usually accommodated in other services. Data relay satellites, which serve satellites and spacecraft in low-Earth orbit, operate in the space research, space operation, and earth exploration-satellite services. They will, however, use inter-satellite service allocations in the future. The fixed-satellite service can accommodate links between satellites operating in that service.[481]

TRENDS

The Tracking and Data Relay Satellite System (TDRSS) provides communications between low Earth orbit satellites and Earth. TDRSS uses the 2025-2110 MHz and 2200-2300 MHz bands and the 13.4-14 GHz and 14.5-15.35 GHz bands, all allocated to the space research service. The proposed Advanced TDRSS (ATDRSS) system will use frequencies in the inter-satellite service near 23 GHz as well as those in the space research and fixed-satellite (for feeder links) services.

[480]The inter-satellite service is defined as "[a] radiocommunication service providing links between artificial satellites;" WARC-92 FINAL ACTS, *supra* note 55, at 21. Prior to WARC-92, the ITU definition, incorporated in NTIA regulations, specified "artificial *earth* satellites." NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-8. The U.S. proposed the change so that the service would include links between data relay satellites and either deep space spacecraft and spacecraft orbiting other celestial bodies. U.S. PROPOSALS FOR WARC-92, *supra* note 265, at 12. The service is allocated on a primary basis in several frequency bands above 20 GHz. The 5000-5250 MHz and 15.4-15.7 GHz frequency bands are also allocated to the inter-satellite service to support aeronautical operations. NTIA MANUAL, *supra* note 13, § 4.1.3 at 4-156 (International Footnote 797).

[481]*Supra* note 234.

Non-GSO satellites in the mobile-satellite service could be major users of inter-satellite links in the future. Systems operating above 1 GHz may require inter-satellite links in addition to planned feeder links.[482] Plans for the Iridium system, for example, call for inter-satellite links in the 22.55-23.55 GHz band. Under an agreement with NASA, the FCC will accommodate future inter-satellite links for mobile-satellite systems in the 24.45-24.75 GHz band, which was designated for such systems at WARC-92.[483]

Inter-satellite links are unique in that they do not involve propagation through the Earth's atmosphere. Therefore, the atmospheric properties that preclude communications between the Earth and space at many frequencies above 10 GHz benefit the inter-satellite service in that they allow communications effectively insulated from terrestrial interference. Extending this reasoning, DOD remarked in its comments that laser communications would be ideal for inter-satellite links.[484]

SPECTRUM REQUIREMENTS FOR THE INTER-SATELLITE SERVICE

Those who commented on the inter-satellite service expressed a belief that allocations are generally adequate.[485] Although NASA requested, however, that the 22.55-23.55 GHz band be extended to 23.6 GHz, NTIA must first address the sharing potential between the inter-satellite service and the other services allocated in this band.[486]

Despite the advantages of using higher frequencies for inter-satellite links, NASA contends that lower frequencies are required for communications with an omni-directional antenna if a satellite becomes unstable. Because of these requirements, NASA says the 2025-2110 MHz and 2200-2290 MHz bands will be needed indefinitely for inter-satellite communications in the space research service. NASA believes, however, that these bands must not be allocated to the inter-satellite service, because the defined uses would be too broad.[487]

GENERAL-SATELLITE SERVICE

At WARC-92, the United States proposed the creation of a new radiocommunication service to accommodate multi-function satellite systems, specifically those combining fixed, mobile and point-to-

---

[482]*See* discussion of spectrum requirements for MSS feeder links *supra* p. 59. Spectrum requirements for inter-satellite links would presumably be similar to those for feeder links.

[483]NASA Comments at 23-24.

[484]DOD Comments at 15.

[485]NASA Comments at 5.

[486]*Id.* at 2. The 23.55-23.6 GHz band is currently allocated worldwide to the fixed and mobile services. NTIA MANUAL, *supra* note 13, § 4.1.3 at 4-89.

[487]NASA Comments at 24.

multipoint functions.[488] Under the proposal, the primary fixed-satellite service and secondary mobile-satellite service allocations in the 19.7-20.2 GHz (space-to-Earth) and 29.5-30.0 GHz (Earth-to-space) bands would have been replaced by primary general-satellite service allocations.[489]

WARC-92 did not establish a general-satellite service. Instead, it upgraded the mobile-satellite service allocations to primary status in the 20.1-20.2 GHz and 29.9-30 GHz bands and to primary status in Region 2 only in the 19.7-20.1 GHz and 29.5-29.9 GHz bands. The mobile-satellite service allocations remained secondary in the latter bands in Regions 1 and 3.[490] A new footnote to the ITU frequency allocation table recognizes "networks which are both in the fixed-satellite service and in the mobile-satellite service" as including point-to-point and point-to-multipoint links between fixed and mobile earth stations.[491] The conference recommended further study of the general-satellite service concept as well as its inclusion on the agenda of the next competent WARC.[492]

Though the establishment of this service may raise a sharing issue nationally between the various satellite services, and internationally between the proposed service and the fixed and mobile services in the 19.7-20.2 GHz band, it does not involve a requirement for any additional spectrum in the near future.

SPACE OPERATION SERVICE

In addition to the communications related to the spacecraft's mission, satellites and other spacecraft also require communications specifically for their operation. These functions include receiving commands from the ground and replying with information on the spacecraft's condition. NTIA defines the space operation service as "[a] radiocommunication service concerned exclusively with the operation of spacecraft,

---

[488] U.S. PROPOSALS FOR WARC-92, *supra* note 265, at 8. The proposal defined the general-satellite service as "[a] radiocommunication service using satellites for fixed and/or mobile applications." *Id.* at 12.

[489] *Id.* at 56, 61.

[490] WARC-92 FINAL ACTS, *supra* note 55, at 79, 87.

[491] *Id.* at 80 (International Footnote 873B).

[492] *Id.* at 262-63 (Recommendation 719).

in particular space tracking, space telemetry and space telecommand."[493] These operations are called TT&C.[494]

Different TT&C communications are required for the various phases of a spacecraft's mission. This section describes both long-term, in-orbit TT&C and the short-term TT&C communications required for launch, satellite positioning, and spacecraft reentry.

IN-ORBIT TT&C

TT&C communications for a spacecraft normally occur in the same frequency band used by the spacecraft for communications related to its mission.[495] For example, spacecraft operating in the fixed-satellite service will generally multiplex the TT&C with the communications in fixed-satellite service bands. This practice results in considerable cost savings and improved reliability as the same equipment, including redundant systems, can be used for both functions.[496]

In some cases, however, TT&C links in a separate band are necessary. NASA's data relay satellites, although they combine TT&C with the feeder links, require backup TT&C links at 2 GHz. The 2 GHz backup links are crucial because they provide all-weather communications to an omni-directional satellite antenna. These TT&C links also allow direct communications between LEO satellites and earth stations for emergencies and contingencies.[497]

WARC-92 allocated the 2025-2110 MHz (Earth-to-space and space-to-space) and 2200-2290 MHz (space-to-Earth and space-to-space) bands to the space research, space operation, and earth-exploration

[493] NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-15. Space tracking is defined as the "[d]etermination of the orbit, velocity or instantaneous position of an object in space by means of radiodetermination, excluding primary radar, for the purpose of following the movement of the object." *Id.* Space telemetry is "[t]he use of telemetry for the transmission from a space station of results of measurements made in a spacecraft, including those relating to the functioning of spacecraft." *Id.* Space telecommand is "[t]he use of radiocommunication for the transmission of signals to a space station to initiate, modify or terminate functions of equipment on a space object, including the space station." *Id.* Interestingly, since the definition of space telemetry includes the results of measurements, some communications related to the spacecraft's mission can be accommodated in the space operation service. In its comments, NASA suggested renaming the space operation service to "something like the Space Command and Control Service" to better describe its function. NASA Comments at 25.

[494] While TT&C as used herein means tracking, telemetry, and command (a variation on the "telecommand" in the definition of the space operation service), the use of the acronym within the space communications community is not consistent. *See, e.g.,* NASA Comments at 5 (telemetry, tracking, and command); *id.* at 24 (tracking, telecommand, and control); *id.* at 25 (tracking, telemetry, and control); IEEE STANDARD DICTIONARY OF ELECTRICAL AND ELECTRONICS TERMS 1260 (Jay Frank ed., 1988) [hereinafter IEEE DICTIONARY] (telemetry, tracking, and control). Fortunately, all use the same acronym and all refer to essentially the same functions.

[495] NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-15 (defining the space operation service).

[496] NASA Comments at 24-25.

[497] *Id.* at 25.

satellite services on a primary basis.[498] NTIA adopted the new allocations for Federal Government use in the 2200-2290 MHz band in the National Table of Frequency Allocations. Federal use of the 2025-2110 MHz band continues under footnote allocations.[499]

Despite the desire that the 2 GHz allocations be upgraded to primary status in the National Table of Frequency Allocations,[500] commenters did not indicate the need for new allocations for in-orbit TT&C.

LAUNCH AND REENTRY TT&C

Various types of launch vehicles are used to deliver payloads into space. The original and most common is the multi-stage expendable launch vehicle, which is still used to orbit many payloads. In the early 1980's, the United States began launching the Space Transportation System or "Space Shuttle," which could carry a crew and be used for repeated flights. More recently, the Pegasus launch vehicle, released from an aircraft at high altitude instead of being launched from the ground, introduced economical dedicated launches of small payloads.[501] Development continues on a variety of suborbital, orbital, reentry, and reusable single-stage-to-orbit (SSTO) vehicles to support both Federal and commercial operations.[502]

TT&C requirements during launch, satellite positioning, and reentry (if applicable) are very different from those for in-orbit spacecraft. During launch, a radar system is needed to determine the position of the spacecraft. A flight termination command system is necessary if a launch vehicle must be destroyed. Third, telemetry is needed to determine the condition of the spacecraft. Communications required during satellite positioning are much like in-orbit TT&C except that they are needed for a relatively short time. Manned spacecraft have additional communications requirements, including voice and video channels.[503] Aeronautical communications, in addition to telemetry and position determination, are critical for reusable vehicles, because the reentry phase includes flight within the atmosphere. The precision of position determination has significant impact on the landing accuracy of ballistically reentering vehicles. For example, an uncertainty of one mile in altitude could cause the vehicle to miss the landing site by ten miles.[504]

---

[498] WARC-92 FINAL ACTS, *supra* note 55, at 62-63.

[499] NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-69 to -70.

[500] NASA Comments at 2.

[501] Small satellites can also be economically launched as secondary payloads on larger launch vehicles. However, they are then subject to the orbital specifications of the primary payload. *See* Orly König, *OSC's Pegasus System—The First Air-Launched Booster*, VIA SATELLITE, Feb. 1994, at 124.

[502] Facsimile from Ruben Van Mitchell, Office of Commercial Space Transportation, U.S. Dep't of Transportation, to Robin H. Haines, Office of Spectrum Management, National Telecommunications and Information Administration (Nov. 17, 1993) (on file with NTIA). *See also* U.S. INDUSTRIAL OUTLOOK 1994, *supra* note 3, at 20-12 to -15.

[503] MISSION OPERATIONS AND DATA SYSTEMS DIRECTORATE, NAT'L AERONAUTICS AND SPACE ADMIN., MISSION REQUIREMENTS AND DATA SYSTEMS SUPPORT FORECAST 92-95 (Feb./Mar. 1994).

[504] MITCHELL, *supra* note 502.

FEDERAL GOVERNMENT LAUNCH FACILITIES

NASA and the Air Force launch government payloads, including military satellites, weather satellites, data relay satellites, and scientific payloads, among others. NASA and the Air Force have launch sites at several locations in the U.S. and tracking stations worldwide. In its comments, NASA indicated that allocations for government launch telemetry, radar tracking, and flight termination are adequate.[505]

COMMERCIAL LAUNCH FACILITIES

Communication satellites dominate in the total number of commercial satellites launched in the past decade. Navigational satellite constellations, particularly in the United States, represent a rapidly growing use of new satellite technology. Small size payloads in low-Earth orbit, designed for data messaging and location service, are another example of new satellite technology meeting the needs of the commercial sector. While communications satellites are the most profitable of the commercial satellites, significant efforts are devoted to establishing new commercial satellite uses such as microgravity and remote sensing.[506]

Until the mid 1980's, NASA provided launch services for both government and commercial payloads. Since 1990, however, commercial payloads have greatly relied on commercial launch vehicles.[507] Although current launch vehicles utilize Federal Government launch sites and tracking stations, the private sector has begun to develop plans for new commercial launch sites. States such as Florida, Alaska, New Mexico and California recently received Federal funding to examine the feasibility of developing commercial spaceport facilities. For example, over the past several years, Hawaiian state officials have worked with the Department of Transportation's Office of Commercial Space Transportation (OCST) to address issues pertinent to spaceport development. Sites such as these will still have to support launch vehicle communication requirements that have long been associated with federal sites.[508]

To accommodate the telemetry requirements of commercial launch vehicles, the FCC and NTIA allocated six frequencies in the 2310-2390 MHz band.[509] WARC-92, however, reallocated the 2310-2360 MHz band for satellite sound broadcasting in the United States and India, essentially reducing the number of commercial launch telemetry frequencies in the United States from six to three.[510]

---

[505]NASA Comments.

[506]MITCHELL, *supra* note 502.

[507]*Id.* Shuttle-sized payloads and those with foreign policy implications may still be launched on the STS.

[508]*Id.* OCST promotes and licenses commercial launch vehicles. *Id.*

[509]NTIA MANUAL, *supra* note 13, § 4.1.3 at 4-120 (Footnote US276). The six frequencies are 2312.5 MHz, 2332.5 MHz, 2352.5 MHz, 2364.5 MHz, 2370.5 MHz, and 2382.5 MHz. NASA still maintains that existing government communications facilities and frequency bands should support commercial launches. NASA Comments at 26.

[510]WARC-92 FINAL ACTS, *supra* note 55, at 65. The reallocation leaves only 2364.5 MHz, 2370.5 MHz, and 2382.5 MHz available for commercial launch telemetry. The other three channels are available on only a secondary basis and are not protected from interference.

OCST sees a growing need for communications for commercial launch vehicles. According to OCST, "the industry is now evolving toward new vehicles, toward reentry vehicles that have a whole host of additional spectrum requirements, and toward commercial spaceports"[511] If the demand for commercial launches is sufficient, spaceports or possibly even commercial airports could be used for launch and reentry of certain vehicles. Communications requirements, and thus spectrum requirements, for these developments have yet to be determined.[512]

According to OCST, the allocations for commercial launch telemetry seem to be adequate for the present. However, they have expressed concern that "there may not be adequate frequency allocations in the longer term . . . to support the needs of a growing industry."[513] At issue is the impact the WARC-92 reallocation will have on the range operations of commercial space launches. Further, it is not fully clear what effects the limited number of frequencies will have on the industry.[514]

OCST has taken the initial steps to address the issue of frequency allocation for commercial launches. OCST maintains that the size of the late 1990's commercial user base will consist of an average annual launch rate of 8 (compared to 14 and 17 for NASA and DOD, respectively). Efforts to model long-term commercial launch rates is one of many approaches OCST plans to employ to aid in determining spectrum requirements. The concern still remains, however, that the available spectrum may be inadequate for requirements beyond the next decade. If the commercial launch industry does experience tremendous growth, the available frequencies could soon prove insufficient for its needs.[515]

SERVICES RELATED TO SPACE SCIENCES

The final space services discussed are those related to space sciences.[516] Included are the space research, earth-exploration satellite and meteorological-satellite services. The remote sensing aspects of these services are discussed in a separate section. Radio astronomy and radar astronomy, although they are terrestrial functions, are also included because of their similarities with the space services.

Initially, the U.S. space program was a scientific program run by the Federal Government. However, many activities once classified as research have commercial applications, such as biochemical crystallizations

---

[511] Carl Rappaport, Office of Commercial Space Transportation, U.S. Dep't of Transportation, Remarks at the NTIA Strategic Spectrum Planning Seminar (Mar. 3, 1993).

[512] MITCHELL, *supra* note 502.

[513] RAPPAPORT, *supra* note 511.

[514] MITCHELL, *supra* note 502. For purposes of frequency sharing, future commercial space operations may well have to be limited to minimum power, range and use of select bands. To further reduce interference, particularly during down-range or orbital operation, special modulation technique and launch scheduling constraints may be required. *Id.*

[515] *Id.*

[516] The space sciences are not limited to research activities. Remote sensing, for example, is becoming increasingly commercial.

and lunar mining for fusionable materials. NASA contends that U.S. commercial space development at 2 GHz is disadvantaged compared to that of other countries because of a lack of allocations for commercial activities. NASA believes the space science bands should be shared between Federal and non-Federal users.[517]

SPACE RESEARCH SERVICE

NTIA defines the space research service as "[a] radiocommunication service in which spacecraft or other objects in space are used for scientific or technological research purposes."[518] The space research service includes Earth-to-space and space-to-Earth links, both near-Earth and deep space,[519] space-to-space links, and active and passive remote sensing.

Because most of its space activities are research-oriented, NASA has historically used the space research service for the bulk of its radiocommunications. However, NASA now believes that it should be using other radio services since many of its research activities lead directly to commercial activities. The experimental connotation of the space research service is no longer applicable to much of NASA's work. Further, NASA believes that space research bands should be allocated for both Federal and non-Federal users.[520]

NASA believes that current allocations for the space research service (not including active and passive remote sensing) are generally adequate in location and bandwidth. However, the status of some allocations may be inadequate.[521] NASA's concerns regarding several frequency bands allocated to the space research service are discussed here.

WARC-92 allocated the 410-420 MHz band to the space research service on a secondary basis for space-to-space links within five kilometers of an orbiting, manned space vehicle.[522] The United States has adopted the secondary allocation for use by Federal Agencies.[523] Potential U.S. uses of this allocation include

[517]NASA Comments at 10-11. WARC-92 also acknowledged the need for 100 MHz worldwide at 2 GHz. *Id.* at 11; *cf.* WARC-92 FINAL ACTS, *supra* note 55, at 62-63.

[518]NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-12. NASA suggested a modification of the definition to indicate that TT&C is most often performed in the mission band. NASA Comments at 25.

[519]Deep space is defined as "[s]pace at distances from the Earth equal to or greater than 2×10^6 kilometers." NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-4. Distances nearer the Earth are described as "near-Earth." NASA believes that "local communications around non-terrestrial bodies do not require regulation." Rather, guidelines for these communications can be developed in the Space Frequency Coordination Group, a consortium of spectrum managers from the space agencies of various nations. NASA Comments at 19.

[520]NASA Comments at 3, 6.

[521]*Id.* at 6.

[522]WARC-92 FINAL ACTS, *supra* note 55, at 18. The distance limitation is stated in RR651A.

[523]NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-56.

the Space Station Freedom and the Space Shuttle. NASA, however, wants the allocation to have primary status.[524]

Some of NASA's concerns about the 2025-2110 MHz and 2200-2290 MHz bands were discussed earlier in conjunction with the inter-satellite service.[525] NASA believes the U.S. space program needs to maintain access to the 2 GHz space research bands because of their all-weather capability, because they allow the use of omnidirectional antennas that provide contingency communications for unstable satellites, and because planned data relay satellites will use the 2 GHz band indefinitely.[526]

Deep space communications for U.S. satellites are provided at 2110-2120 MHz (Earth-to-space) and at 2290-2300 MHz (space-to-Earth). NASA states that keeping deep space frequencies free from interference is critical because much of the data obtained from deep space probes is based on measurements that are not repeatable and because the frequencies will be used in the future for manned deep space missions.[527] WARC-92 allocated the 2110-2120 MHz band to the space research service internationally on a primary basis for deep space Earth-to-space links.[528] NASA believes the National Table of Frequency Allocations should contain this allocation for both Federal and non-Federal users.[529]

The 12.75-13.25 GHz and 16.6-17.1 GHz frequency bands are also allocated to the space research service for deep space Earth-to-space links.[530] NASA wants these allocations to not be limited to deep space communications.[531]

EARTH EXPLORATION-SATELLITE SERVICE

Systems operating in the earth exploration-satellite service are used to obtain "information relating to the characteristics of the Earth and its natural phenomena . . . from active sensors or passive sensors on earth satellites."[532] The service is also used to collect similar information from terrestrial or airborne

---

[524] NASA Comments at 2, 6.

[525] *See supra* p. 147.

[526] NASA Comments at 6.

[527] *Id.*

[528] WARC-92 FINAL ACTS, *supra* note 55, at 62.

[529] NASA Comments at 2. Although this band is close to the bands proposed for PCS, NASA does not believe deep space uplinks will cause significant interference to PCS. The deep space transmissions will occur only at Goldstone, California; Vandenburg, California; Cape Canaveral, Florida; and at the Jet Propulsion Laboratory at the California Institute of Technology. Of these four sites, only the Goldstone station will have high power emissions (400 kW transmitted power and 63 dBi mainbeam antenna gain) and its antenna will be limited to 5° minimum mainbeam elevation. Telephone Interview with David P. Struba, IRAC Representative, NASA (Oct. 19, 1994).

[530] The former band is allocated under Footnote US251.

[531] NASA Comments at 2.

[532] NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-4 (defining the earth exploration-satellite service).

platforms, to interrogate platforms, and to relay the information collected to earth stations. Like the space research service, the earth exploration-satellite service includes Earth-to-space, space-to-Earth, and space-to-space links as well as active and passive remote sensing. While the sensors in the space research service are directed into space, those in the earth exploration-satellite service are directed toward the Earth. Again, the remote sensing applications of the service are discussed later in this chapter.

According to NASA, the current number and location of allocations are generally adequate.[533] Concerns about remote sensing are discussed below. Concerns about links near 2 GHz were discussed earlier.[534]

METEOROLOGICAL-SATELLITE SERVICE

The meteorological-satellite service is "[a]n earth exploration-satellite service for meteorological purposes."[535] The service is used to support weather satellites operated by NOAA and DOD. Most of the allocations are used to send meteorological data from geostationary and polar-orbiting satellites to earth stations. A few of the allocations, however, are used for Earth-to-space links.[536]

Commenters believe that, for the present, allocations for the meteorological-satellite service are adequate.[537] However, NOAA believes that increased data rate requirements from polar satellites will make about 100 MHz of additional spectrum necessary.[538] We believe these requirements can be accommodated in existing frequency bands at 7 and 8 GHz.[539]

REMOTE SENSING

Active and passive remote sensing make up a significant portion of the activities in the space research and earth exploration-satellite services.[540] In the space research service, active sensors are used to measure such things as solar winds and lunar soil content while passive sensors are used for Very Long Baseline

---

[533]NASA Comments at 5.

[534]*See supra* pp. 147, 154.

[535]NTIA MANUAL, *supra* note 13, § 6.1.1, at 6-9 to -10.

[536]*See, e.g., id.*, § 4.1.3 at 4-79 (showing the 8175-8215 MHz band allocated in the Earth-to-space direction).

[537]NASA Comments at 5; NOAA Comments at 3.

[538]NOAA Comments at 3.

[539]The 7450-7550 MHz band is allocated to the meteorological-satellite service on a primary basis for Federal Government use. NTIA MANUAL, *supra* note 13, § 4.1.3 at 4-78. The 8025-8400 GHz band is likewise allocated to the earth exploration-satellite service, which includes the meteorological-satellite service. *Id.* at 4-78 to -79.

[540]Radio astronomy and radar astronomy, which are terrestrial forms of remote sensing, are discussed beginning *infra* p. 157.

Interferometry (VLBI) in bands also allocated to the radio astronomy service. In the earth exploration-satellite service, remote sensing devices are directed toward the Earth instead of into space.[541]

Commenters expect an increase in the use of remote sensing from satellites because of increasing environmental concerns.[542] While this does not necessarily translate into a requirement for new allocations, NASA would like to see some secondary allocations upgraded to primary status as well as certain other changes. The desired changes for specific frequency bands are discussed below.[543]

At one time, NASA thought it was appropriate to allocate the same frequency bands for both the space research and earth exploration-satellite services. Now, however, NASA believes it may be more appropriate to have separate bands for earth sensing and space sensing from satellites.[544] NASA believes that allocation of the same bands for the space research and earth exploration-satellite services may be inappropriate and confusing to users and regulators. NASA therefore favors deleting some space research service allocations in bands to which the earth exploration-satellite service is also allocated.[545] In some cases, more study is needed to determine which allocations should be deleted.[546] As with some other space services, NASA believes frequency bands allocated for remote sensing should be shared by Federal and non-Federal users.[547]

Under International Footnote 713, the 1215-1300 MHz, 3100-3300 MHz, 5250-5350 MHz, 9500-9800 MHz, and 13.4-14 GHz radiolocation bands may also be used in the space research and earth exploration-satellite services for radiolocation (active sensors) on a secondary basis.[548] The 17.2-17.3 GHz radiolocation band is also allocated to the space research and earth exploration-satellite services for active sensors on a secondary basis.[549] NASA requests that these bands be available for active sensors on a primary basis.[550]

---

[541]NASA Comments at 19.

[542]*Id.* at 21.

[543]Other applications of Earth-directed remote sensing are not related to environmental concerns. The U.S. Department of Energy has remote sensing requirements related to nuclear explosion detection and proliferation detection. While not requesting additional allocations, the Department of Energy is seeking flexibility in the management of allocations to allow operation of these systems outside of the bands allocated to the earth exploration-satellite service. Letter from Lawrence Wasson, IRAC Representative, U.S. Dep't of Energy, to W. Russell Slye, Program Manager, Strategic Spectrum Planning Program, National Telecommunications and Information Administration (undated, received Oct. 6, 1994) (on file with NTIA).

[544]NASA Comments at 5.

[545]*Id.* at 19.

[546]*Id.* This is true partly because specific frequencies for active and passive sensing of certain celestial bodies are still to be identified. *Id.*

[547]*Id.* at 21.

[548]NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-146. International Footnote 713 also includes the 8550-8650 MHz band, which is not mentioned in the NASA comments.

[549]*Id.* § 4.1.3 at 4-86.

[550]NASA Comments at 2.

The 13.25-13.40 GHz band is allocated, nationally and internationally, to aeronautical radionavigation for Doppler navigation aids. The band is also allocated, on a secondary basis, to the space research service for Earth-to-space links.[551] Instead of the secondary allocation to the space research service, NASA favors a primary allocation to the earth exploration-satellite service for active sensors.[552] The 24.05-24.25 GHz radiolocation band has a secondary allocation to the earth exploration-satellite service for active sensors.[553] NASA requests that this allocation be raised to primary status.[554]

RADIO ASTRONOMY AND RADAR ASTRONOMY

Two additional radiocommunications functions are included in this chapter. Radio astronomy and radar astronomy, while they are terrestrial rather than space systems, have many similarities with space systems. They are the terrestrial counterparts of the active and passive remote sensing accommodated in the space research service. The users of radio astronomy and radar astronomy are also the users of the space services.

Some radio astronomy observations are currently being made at frequencies beyond the 300 GHz upper limit of the U.S. allocation tables. In fact, radio astronomers have identified spectral lines of great importance at frequencies beyond 800 GHz.[555] Simultaneously, research and development continues on active systems such as radiolocation devices that also use frequencies above 300 GHz.[556] To minimize the potential for interference to radio astronomical observations by active devices at frequencies above 300 GHz, the National Science Foundation believes the extension of the allocation tables beyond the current limit should be considered.[557]

RADIO ASTRONOMY

DESCRIPTION

NTIA defines radio astronomy as "[a]stronomy based on the reception of radio waves of cosmic origin."[558] The service is unique in that it involves only passive systems. Since the signals received emanate from natural sources, the radio astronomers have no control over the power, the frequency, or other

---

[551]NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-160 (International Footnotes 851 and 852).

[552]NASA Comments at 2.

[553]NTIA MANUAL, *supra* note 13, § 4.1.3, at 4-90.

[554]NASA Comments at 2.

[555]INT'L RADIO CONSULTATIVE COMMITTEE, INT'L TELECOMMUNICATION UNION, RECOMMENDATION 314-7, PROTECTION FOR FREQUENCIES USED FOR RADIOASTRONOMICAL MEASUREMENTS (1990) [hereinafter RADIO ASTRONOMY FREQUENCIES].

[556]*See supra* p. 137.

[557]CLEGG, *supra* note 463.

[558]NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-12.

characteristics of the emissions. Radio astronomers employ radio telescopes, highly sensitive receivers with large, high-gain antennas, to pick up the weak signals from space.

Because the desired signals are so weak and the receivers are so sensitive, radio telescopes are highly susceptible to interference.[559] Radio observatories are usually built in remote locations with surrounding terrain that provides natural shielding from interference sources. Nonetheless, effective spectrum management is critical to protect the radio telescopes from harmful interference. Major sources of interference are spurious, harmonic, and adjacent band emissions from satellites, large numbers of nonlicensed devices, and ultrawideband devices.[560]

Radio astronomers are interested in two distinct types of cosmic signals: wideband continuum emissions and narrowband spectral line emissions. Continuum emissions, both thermal and non-thermal, extend continuously over most of the radio frequency spectrum.[561] Thermal emissions generally increase in intensity with increasing frequency, while the intensity of non-thermal emissions generally decreases with increasing frequency.

Spectral line emissions result from changes in the energy states of individual cosmic atoms and molecules.[562] Spectrum planning for observation of these emissions is difficult because the Doppler effect causes a shift of the apparent frequency of the emissions as a function of the relative velocity of the source.[563]

SPECTRUM REQUIREMENTS FOR RADIO ASTRONOMY

Radio astronomers have no control over the signals they are receiving. The spectrum requirements for radio astronomy are therefore based on physical phenomena rather than expected growth, as is the case for most other services.

Using terrestrial radio telescopes, radio astronomers can observe cosmic phenomena at frequencies ranging from 15 MHz to over 800 GHz.[564] To meet the needs of radio astronomy, frequencies at regular

---

[559]NSF gives the typical power flux density (PFD) of the emissions studied (in the 1-10 GHz frequency range) as -250 dBW/m²/Hz, though signals with a PFD below -300 dBW/m²/Hz have been studied. In contrast, the PFD of satellite emissions are typically -150 dBW/m²/Hz to -200 dBW/m²/Hz. This means the power of the satellite emissions is 50-150 dB greater than the desired signal. *See* NSF Comments at 4.

[560]NSF Comments at 4-5.

[561]INT'L RADIO CONSULTATIVE COMMITTEE, INT'L TELECOMMUNICATION UNION, REPORT 852-2, CHARACTERISTICS OF THE RADIO ASTRONOMY SERVICE AND PREFERRED FREQUENCY BANDS (1990). Thermal emissions come from "hot ionized and neutral gas . . . solid bodies, and the universal microwave background," while non-thermal emissions are "mainly synchrotron radiation from relativistic electrons spiraling in a magnetic field, but including gyro-synchrotron and electron-cyclotron maser emissions, as well as plasma emissions resulting from the scattering of plasma waves." *Id.*, § 2.1.

[562]*Id.* § 2.3.

[563]*See* NSF Comments at 17-20.

[564]Occasionally, observations at frequencies as low as 1.5 MHz are possible. NSF Comments at 5.

intervals across this range must be protected from interference in the vicinity of the radio observatories. The basic plan of spectrum management for radio astronomy is to protect small bands across the range for continuum observations, while choosing those bands so they contain the spectral lines of greatest interest.

Ideally, allocations with a bandwidth equal to five percent of the center frequency would be available at one octave intervals above 1 MHz for continuum observations. Minimally, the bandwidth of the allocations should be one percent of the center frequency. Between 1 MHz and 1 GHz, the allocations should be spaced every half-octave.[565]

The National Science Foundation expressed concern that it had no protected frequencies for observations between 74.6 MHz and 406.1 MHz. They suggest radio astronomy allocations in the bands shown in Table 5-1 to remedy this problem.[566] The total spectrum involved is 9.55 MHz.

TABLE 5-1
NEW ALLOCATIONS REQUESTED FOR CONTINUUM OBSERVATIONS

Frequency Band	Bandwidth
150.05-153 MHz	2.95 MHz
322-328.6 MHz	6.6 MHz
Total Spectrum Requested:	9.55 MHz

Several other radio astronomy bands have less than the minimum one percent bandwidth. NSF recommends increasing the bandwidths of the eight frequency bands shown in Table 5-2.[567] The total spectrum required to increase these bandwidths is about 169 MHz.

Astronomers have identified over 550 spectral lines. The International Astronomical Union maintains a list of the frequencies it considers most important for spectral line observations.[568] The frequency bands listed in Table 5-3 are those identified by the National Science Foundation as necessary to extend protection

[565] *Id.* at 13-14.

[566] *Id.* at 13. Because they use the band extensively, the Department of Defense believes that radio astronomy of the 322-328.6 MHz band could have only secondary status and would require local coordination. POLLACK, *supra* note 379, at 7.

[567] NSF Comments at 14. The Department of Defense believes some of these bands may be difficult to coordinate in some areas. For example, expansion of the 4990-5000 MHz band would limit use of existing troposcatter systems and airborne data links in this spectrum. POLLACK, *supra* note 379, at 7.

[568] NSF Comments at 17-18. The list is included in Recommendation 314 of the CCIR. *See* RADIO ASTRONOMY FREQUENCIES, *supra* note 555.

TABLE 5-2
INCREASED BANDWIDTH REQUESTED FOR CONTINUUM OBSERVATIONS

Frequency Band	Current Bandwidth	One Percent Bandwidth	Additional Spectrum Requested
13.36-13.41 MHz	50 kHz	134 kHz	84 kHz
25.55-25.67 MHz	120 kHz	256 kHz	136 kHz
406.1-410 MHz	3.9 MHz	4.1 MHz	200 kHz
608-614 MHz	6.0 MHz	6.1 MHz	100 kHz
2690-2700 MHz	10 MHz	27 MHz	17 MHz
4990-5000 MHz	10 MHz	50 MHz	40 MHz
10.6-10.7 GHz	100 MHz	107 MHz	7 MHz
15.35-15.4 GHz	50 MHz	154 MHz	104 MHz
		Total Spectrum Requested:	169 MHz

of the most important spectral lines to more highly redshifted (lower) frequencies or to afford protection to important spectral lines that are not currently within a band allocated exclusively to passive services.[569] The total additional spectrum requested in these bands is 62.3 MHz.

Above 20 GHz, radio astronomy allocations are still adequate, since this spectrum is not in as great demand and subject to the same allocation pressures as spectrum below 20 GHz. Preservation of these allocations is important to the radio astronomers.[570]

The total of the spectrum requirements shown in the three tables is about 241 MHz. Spectrum requirements for radio astronomy are somewhat different from those of most other services in that they are not dictated by predicted traffic requirements and, in the case of spectral lines, involve very specific frequencies. Spectrum requirements are 9.6 MHz of additional allocations, and access to an additional 231 MHz by local coordination.

[569]NSF Comments at 18-19; Electronic mail from Andrew Clegg, National Science Foundation, to Robin H. Haines, National Telecommunications and Information Administration (Oct. 31, 1994) (printed copy on file with NTIA) (clarifying the need for the frequency bands).

[570]NSF Comments at 6.

TABLE 5-3
NEW ALLOCATIONS REQUESTED FOR SPECTRAL LINE OBSERVATIONS

Additional Allocation	Bandwidth of Allocation
1370-1400 MHz	30 MHz
1606.8-1610.6 MHz	3.8 MHz
1659.8-1660 MHz	200 kHz
1714.8-1722.2 MHz	7.4 MHz
4813.6-4834.5 MHz	20.9 MHz
Total Spectrum Requested:	62.3 MHz

RADAR ASTRONOMY

Unlike radio astronomy, radar astronomy involves transmission of radio signals as well as reception. Radar astronomy does not have its own service. Instead, it is conducted in radiolocation bands, in cooperation with other users of the bands.

The NASA radar at Goldstone, California is used for locating and examining celestial bodies such as planets, moons, and asteroids. The data obtained is used, among other things, for the determination of landing site locations for interplanetary spacecraft. The radar operates in radiolocation bands at 2320 MHz and 8510 MHz. The sensitivity of the receiver is the same as that for the deep space network.[571] The National Science Foundation's radio telescope at Arecibo, Puerto Rico includes a radar operating at 2380 MHz. This radar is used for activities such as planetary mapping and imaging, investigation of asteroids, and tracking of space debris. NSF coordinates the operation of this radar with military users of the frequency band.[572]

According to commenters, spectrum requirements for radar astronomy are adequately met at the present time, and "it is expected that they will be accommodated with relatively little effort in the foreseeable future." [573]

---

[571]NASA Comments at 18.

[572]Letter from Tomas Gergely, Electromagnetic Spectrum Manager, National Science Foundation, to William Gamble, Chairman, Interdepartment Radio Advisory Committee (IRAC Doc. 28393) (Aug. 6, 1993) (on file with NTIA).

[573]NSF Comments at 3.

SUMMARY OF REQUIREMENTS

Requirements for new and expanded frequency bands for radio astronomy total approximately 240 MHz. These requirements represent the top priorities for radio astronomers, who seek additional spectrum to better study cosmic phenomena. Allocation changes for any of these frequency bands will probably involve sharing arrangements as opposed to relocating existing users.

Although they represent a wide variety of systems and expect vigorous growth, the space services discussed in this chapter had few significant requirements for additional frequency spectrum. Those mentioned include:

- ❑ a requirement from NASA for a 50 MHz extension of the 22.55-23.55 GHz inter-satellite service band to 23.6 GHz,
- ❑ uncertain future requirements for spectrum to support commercial launch vehicles, and
- ❑ status upgrades and other regulatory changes for numerous space research and earth exploration-satellite bands, including bands used for remote sensing.

Some of these requirements, such as those for the inter-satellite service and for remote sensing, may be satisfied through spectrum sharing with minimal impact on existing users of the bands.

CHAPTER 6

OTHER RADIO SERVICES

AMATEUR AND AMATEUR-SATELLITE SERVICES

The amateur service is defined internationally as "A Radiocommunications service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest."[574] Radio amateurs are trained and experienced in electronics, propagation theory, and communications techniques.[575] Amateurs also respond swiftly and effectively to calls for communications assistance when normal channels are lost. The amateur service has significantly contributed to the development of radio technology. Amateur operators continue to fulfill certain public service radiocommunications requirements, and increase their skills relating to emergency communications. During natural disasters such as hurricanes, floods, and other events, amateur radio communications have been particularly effective, and in many cases have been the sole means of communicating from the scene of a disaster.

The amateur-satellite service was formally created as a result of the 1971 World Administrative Radio Conference for Space Services. At that Conference and the 1979 WARC, both primary and secondary frequency allocations were granted to the service. Many of the secondary allocations are provided as a result of international Radio Regulation 664.

Amateur, or "ham" radio operators, have provided a unique service to the public while enjoying a popular, technical hobby. Many innovative uses of radio systems have been developed by amateurs for use

---

[574] ITU RADIO REGULATIONS, *supra* note 133, art. 1, § 3.34.

[575] Within the United States, the purpose of the amateur service is to provide to the public a voluntary, non-commercial radio service, particularly with respect to providing emergency communications; contribute to the advancement of the art; advance technical and communications skills; expand the national pool of trained radio operators and technicians; and enhance international goodwill through amateur radio communications. 47 C.F.R. § 97.1.

in the amateur bands, such as packet-switched systems and amateur television. It is estimated that there are in excess of 632,000 amateur radio operators in the United States, and over 2.4 million worldwide.[576]

CURRENT USES OF THE AMATEUR SERVICE

Amateur allocations have been based, in part, on the desirability of having a choice of relatively narrow frequency bands with different propagation properties distributed throughout the spectrum. As propagation conditions change in the medium and high-frequency bands, amateur operators can follow the changing maximum usable frequency (MUF) and still be able to communicate. Higher frequency bands have other propagation properties useful for different amateur activities, such as amateur-satellite and short-range land mobile applications. Current amateur allocations start at 1800 kHz and, in narrow bands, extend to 250 GHz.

Amateurs use the HF bands for medium to long-distance communications. The 160 meter band (1.8 MHz) provides good groundwave coverage and is relatively free of propagation anomalies. The higher HF bands have increasing dependance on ionospheric refraction to provide long-distance communications. Time-of-day and sunspot activity are important factors in the ability of the HF bands to support communications beyond the range of groundwave coverage. A good selection of frequencies spread throughout the HF bands is critical to maintaining reliable communications. Amateurs use voice and data communications in the HF bands, operating from base and mobile stations.

Frequencies above 30 MHz provide generally short-range terrestrial communications, and support the use of amateur satellite communications. In the bands above 54 MHz, amateurs rely heavily on a system of radio repeaters to increase the range of amateur communications. However, amateurs are always experimenting with point-to-point systems to push the state-of-the-art in antenna design and solid-state equipment, and to investigate the properties of signal propagation at the higher frequencies. Amateurs use Morse code, voice, packet-switched data, television, and satellite communications in the various frequency bands.

In addition to recreational use, amateurs use the amateur bands to provide public services in a variety of ways. The American Radio Relay League sponsored National Traffic System provides a nationwide network that carries thousands of messages monthly. This system is available in the event that regional or local disasters degrade the public communications systems. The DOD works closely with the amateur community in its Military Affiliate Radio System (MARS) network. Local amateur radio clubs provide

[576]ARRL Comments at 5. Comments of American Radio Relay League, Inc. to NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEP'T OF COMMERCE, NTIA SPECIAL PUBLICATION 94-27, PRELIMINARY SPECTRUM REALLOCATION REPORT (1994) at 10 (updating the current number of licensed U.S. amateurs).

communications support for community events, and are a source of trained radio operators to complement state and local communications personnel through the ARES and RACES programs.[577]

TRENDS

Amateurs have historically been on the leading edge of radio technology. As new solid-state devices become available, amateurs will use them in radio systems to push the upper limits of practical spectrum usage. It is expected that the current analog systems employing single-sideband, FM voice, and television modulation will be overtaken by digital techniques. The number of amateur radio operators is increasing at a current annual rate of 7.5 percent in the United States,[578] and about 7 percent worldwide.[579] Growth in the amateur service will require increased use of higher frequencies, and necessitate the use of radio repeaters to overcome the limitations imposed by the propagation characteristics of the higher frequency bands.

Some of the frequency bands shared by amateur operations are becoming heavily used. For example, the 902-928 MHz band will become more used with the increased use of LMS systems and possibly by Federal and non-Federal wind profiler radars. Radiolocation bands, which have been shared with amateurs for years, will become more valuable to military users as new radar systems are deployed and pressure for the bands to be used for non-government purposes increases.

The amateur-satellite service will soon have a new generation of amateur satellites in orbit using all frequency bands allocated to the amateur-satellite service from 29 MHz through 24 GHz.[580] The Phase 3D OSCAR (Orbiting Satellite Carrying Amateur Radio) satellite is scheduled to be launched in late 1995. This satellite is designed to be an improvement over current OSCAR satellites in terms of link performance and capabilities. The OSCAR 3D satellite will facilitate the use of gateway earth stations, so that an amateur operator with a hand-held radio will be able to reliably communicate with other amateurs over a distance of several thousand kilometers.

DEVELOPMENT OF SPECTRUM REQUIREMENTS

Future spectrum requirements for the amateur and the amateur-satellite services were contained in responses to the Notice provided by the American Radio Relay League (ARRL) and the Radio Amateur Satellite Corporation (AMSAT). The commenters have requested a significant revision of the allocation table to accommodate expanded amateur operations. Table 6-1 lists ARRL's and AMSAT's requested future spectrum allocations for these services.

---

[577] The Amateur Radio Emergency Service (ARES) and the Radio Amateur Civil Emergency Service (RACES) provide local and regional communications support to state and local governments on a coordinated basis.

[578] This figure represents growth for 1993.

[579] ARRL Comments at 5.

[580] ARRL Comments at 21.

It should be noted that the frequency ranges 2390-2400 MHz and 2402-2417 MHz, allocated to the amateur service on a secondary basis to Federal Government radiolocation, have been made available for immediate reallocation to the FCC. The range 2300-2310 MHz, also allocated to the amateur service on a secondary basis, may be reallocated to the FCC within two years.

TABLE 6-1
ARRL AND AMSAT REQUESTED AMATEUR AND AMATEUR-SATELLITE FUTURE SPECTRUM ALLOCATIONS

Frequency Band	Requested Amateur Allocations	Notes
160-190 kHz	New Allocation (Shared)	(a, b)
1800-1900 kHz	Retain	
1900-2000 kHz	Retain	
3500-4000 kHz	Retain, but Add 300 kHz Worldwide	(a, c)
5000 kHz	New Allocation (Shared)	(a, d)
6900-7200 kHz	New Allocation: Exclusive, Worldwide	(a, e)
10100-10350 kHz	New Allocation: Primary, Worldwide	(a, f)
14000-14250 kHz	Retain	
14250-14400 kHz	New Allocation	(a, g)
18068-18318 kHz	New Allocation: Exclusive, Worldwide	(a, h)
21000-21450 kHz	Retain	
24740-24990 kHz	New Allocation: Exclusive, Worldwide	(a, i)
28.0-29.7 MHz	Retain	
29.7-30.0 MHz	New Allocation	(a, j)
Between 30-50 MHz	New Allocation	(a, k)
50-54 MHz	Retain; Extend into Region 1	(a, l)
144-146 MHz	Retain; Delete RR 605, 606	(a, m)
146-148 MHz	Retain; Extend into Region 1	(a)
Part of 216-220 MHz	New Allocation	(n)
222-225 MHz	Retain	
420-430 MHz	Retain	

Frequency Band	Requested Amateur Allocations	Notes
430-440 MHz	Revised Allocation: Exclusive, Worldwide	(a, o)
440-450 MHz	Retain	
902-903 MHz	Revised Allocation (Upgrade to Primary)	(p)
903-928 MHz	Retain	(p)
1240-1260 MHz	Retain	
1260-1300 MHz	Revised Allocation (Upgrade to Primary)	(a, q)
2300-2310 MHz	Retain	
2390-2400 MHz	New Allocation (Add Amateur-Satellite, Upgrade to Primary)	(a, r)
2400-2402 MHz	New Allocation (Add Amateur-Satellite, Upgrade to Primary)	(a)
2402-2450 MHz	Revised Allocation (Upgrade to Primary)	(s)
3300-3400 MHz	Retain	
3400-3402 MHz	Revised Allocation (Upgrade Amateur-Satellite to Primary)	(a)
3402-3420 MHz	Revised Allocation (Upgrade to Primary)	(a, t)
3420-3500 MHz	Retain	
5650-5668 MHz	Retain	(s)
5668-5670 MHz	Revised Allocation (Upgrade Amateur and Amateur-Satellite to Primary)	(a)
5670-5848 MHz	Retain	(u)
5848-5850 MHz	Revised Allocation (Upgrade Amateur and Amateur-Satellite to Primary)	(a)
5850-5925 MHz	Retain	
10.00-10.45 GHz	Retain	
10.45-10.50 GHz	Revised Allocation (Upgrade Amateur and Amateur-Satellite to Primary)	(a)
All above 24 GHz	Retain	(v)

Notes:
[a]Allocation must also be approved at competent World Radiocommunication Conferences

[b]New allocation would be secondary to the fixed and maritime mobile services nationally. Additionally, must share with the broadcasting service in ITU Region 1, and aeronautical radionavigation in ITU Region 3.
[c]The requirement is for any common, worldwide *exclusive* 300 kHz allocation within the 3500-4000 kHz band.
[d]Requirement is for about 50 kHz near 5 MHz, on a shared basis. Particularly desirable for communications during solar cycle minima when maximum usable frequencies are below 3.5 MHz.
[e]The requirement is for 300 kHz aligned worldwide to reduce sharing with high frequency broadcasting in the 7100-7300 kHz band; 6900-7200 kHz was requested.
[f]A modification of the present 10100-10150 kHz allocation, requiring elimination or downgrading of the fixed service internationally.
[g]The requirement is for an additional 50 kHz primary, exclusive, worldwide.
[h]The requirement is for an additional 150 kHz to the present 18068-18168 kHz allocation.
[i]The requirement is for an additional 150 kHz to the present 24890-24990 kHz band allocation.
[j]The requirement is for amateur-satellite (space-to-Earth)
[k]The requirement is for a number (e.g., five) of narrow bands of frequencies between 30 and 50 MHz.
[l]A 2 MHz allocation in ITU Region 1 is requested, with at least 500 kHz being exclusive.
[m]The deletion of RR 605 & 606 is requested. These footnotes allow operation other than amateur in certain countries.
[n]Amateurs requested access to a portion of the 216-220 MHz band. The ARRL petitioned the Commission for additional access. The Commission (ET Docket No. 93-40, RM-7747) has proposed to allocate the 219-220 MHz band for amateur use.
[o]Requested for amateur television, voice and data communications, and Earth-moon-Earth communications.
[p]This band presently used by LMS systems, which have priority over amateur operations. The proposed LMS systems would also have priority. Non-government primary allocation is for ISM operations on 915 MHz $\pm$ 13 MHz.
[q]Additionally, the removal of the directional Earth-to-space indicators is requested to increase the flexibility of amateur satellite use.
[r]Expand the amateur-satellite allocation by 10 MHz in the 2390-2400 MHz band.
[s]Retain amateur-satellite allocation in accordance with RR 664.
[t]Amateur-satellite allocations in the 3400-3410 MHz band are to be expanded to ITU Region 1.
[u]Retain amateur-satellite allocation in accordance with RR 808.
[v]Retain all current amateur and amateur-satellite allocations above 24 GHz.

SPECTRUM REQUIREMENTS FOR THE AMATEUR SERVICES

In general, we believe that current amateur and amateur-satellite allocations should be retained. Amateur requests for international reallocations would be appropriate issues for FCC private sector advisory committees addressing U.S. preparations for future World Radiocommunication Conferences (WRC's). Additional allocations at 160-190 kHz, and near 5 MHz will require technical studies to determine the availability of these bands to support amateur use.

The expansion and upgrading of amateur allocations in the 10 MHz, 14 MHz, 18 MHz and 24 MHz bands are acceptable, but will depend on future decrease of requirements for the aeronautical mobile (R) or the fixed services internationally. The alignment of the amateur 3.5 and 7 MHz bands worldwide will require the inclusion of these issues in U.S. preparations for future WRC's.[581]

As noted, FCC rulemaking is in progress for amateur access to the 219-220 MHz band. The request for additional narrow spectrum allocations between 30 and 50 MHz for propagation experimentation (e.g., five, 50 kHz slots) will need to be studied for technical compatibility. Spectrum requirements for the amateur service total 2,180 kHz.

However, any sharing of military radiolocation spectrum (e.g., 430-440 MHz) with the amateur services on a co-primary basis in current Federal radiolocation bands is not feasible because of the potential loss of operational flexibility for military radar systems. Further, the expansion of use in the 902-928 MHz band by Federal and non-Federal users, including the operation of wind profiling radars, may make this band untenable for amateur operations in the future.

STANDARD FREQUENCY AND TIME SIGNAL SERVICES

The standard frequency and time signal service is "[a] radiocommunication service for scientific, technical and other purposes, providing the transmission of specified frequencies, time signals, or both, of stated high precision, intended for general reception."[582] The standard frequency and time signal-satellite service is "a radiocommunications service using space stations on earth satellites for the same purpose as those of the standard frequency and time signal service. This service may also include feeder links necessary for its operation."[583]

The reference signals provided by these services are used in association with scientific research, and as standards for Universal Coordinated Time (UTC) where precise time is required. Reflecting the widespread need for precise and accurate frequency and time information in a great variety of applications, standard time and frequency reference signals are distributed by a variety of techniques. Most users are served, directly or indirectly, by one of a variety of radio broadcasts available in the United States. These include not only the dedicated time and frequency broadcasts from radio stations WWV, WWVB (Ft. Collins, Colorado), and WWVH (Hawaii) operated by the Department of Commerce's National Institute of Standards and Technology (NIST) but also the broadcasts from other radio services, such as electronic navigation aids, which have proven to be highly useful for time and frequency applications.[584]

---

[581]The alignment of the 7 MHz band is consistent with proposals made by the United States at WARC-92.

[582]NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-14.

[583]*Id.*

[584]NIST Comments at 1.

Terrestrial as well as satellite-based transmissions are used for dissemination of additional frequency and time information. The Omega, LORAN-C, and GPS navigation broadcasts are examples of systems that are widely used for time and frequency standards, although they are primarily intended for a different purpose. Time and frequency reference signals are also distributed by dial-up telephone services, such as NIST's Automated Computer Time Service, by telecommunication networks, and by other more special-purpose links.

The various time and frequency dissemination methods and services mentioned above have varying spectrum requirements. In the United States, the only services that operate in frequency bands specifically allocated for time and frequency include the NIST broadcasts from WWV and WWVH in the 2-30 MHz band, and from WWVB in the low frequency (LF) band. Dissemination via the NOAA Geostationary Operational Environmental Satellite (GOES) time-code service is a shared use of spectrum near 469 MHz allocated to the meteorological-satellite service. The Omega, LORAN-C, and GPS broadcasts for time and frequency applications makes use of the existing allocations in the radiodetermination services. Increasing use is also being made of the fixed-satellite service spectrum by exchanging time and frequency signals simultaneously through communication satellite channels to accomplish point-to-point time comparisons at the highest possible accuracy levels of near one nanosecond. Other techniques, such as the dial-up service offered by NIST, do not require direct use of the spectrum.

Current Uses of the Standard Frequency and Time Signal Services

Current Use at 20 kHz

This allocation was formerly used by radio station WWVL, providing very-low-frequency standard frequency and time signal service operated from Ft. Collins, Colorado. Although this service was discontinued in 1972, primarily due to financial reasons and the impact of the Omega Navigation System coming into operation, the capability to broadcast on 20 kHz still exists at NIST.

Current Use at 60 kHz

Use of this frequency for standard frequency and time signal dissemination is allowed by Radio Regulation 447. NIST's WWVB low-frequency service has used this allocation in the United States since 1963. Approximately 1000 entities from government, private industry, universities, science, and the military have been identified as current users. Primary applications for WWVB are in scientific data monitoring, electric power system operations, standards laboratories, communication system calibrations, and military applications.

Current Use at 2.5 MHz, 5.0 MHz, 10.0 MHz, 15.0 MHz, 20.0 MHz, and 25.0 MHz

These are the primary allocations used by many high-frequency services, including WWV and WWVH in the United States. All these allocations have been in use at one time or another by WWV and/or WWVH. Currently, the first five allocations are used by WWV and the first four by WWVH. The WWV service has operated since 1923 and WWVH has served the Pacific Ocean area since 1948. Radio stations WWV, WWVH, and other similar services serve users numbering well into the tens of thousands and provide the main access to time signals accurate to about 1 millisecond and frequency references accurate to about 1 x 10^{-7}. HF standard frequency signals transmitted by WWV and WWVH are used by many communicators, including amateur radio operators. Additional information regarding HF propagation is also transmitted by these stations. U.S. standard frequency and time signal systems are allocated 90 kHz in the National Table of Frequency Allocations.

Current Use at 400.1 MHz

This space-to-Earth satellite allocation was made by the 1971 WARC. The allocation was originally intended for use as a satellite-based replacement for some terrestrial HF time and frequency services. However, no administration has implemented a service using this allocation.

Current Use at 4202 MHz and 6427 MHz

Radio Regulation 791 allows the use of this uplink/downlink pair of frequencies for time and frequency transfer on a shared basis subject to completion of suitable agreements under Article 14 of the Radio Regulations. Although two-way exchange of timing signals simultaneously through communication satellites, for which this allocation was intended, has become rather widely used in the time and frequency community for the highest accuracy time transfers, it has not proven necessary to use this specific allocation. Under present conditions, there are no plans to use these specific 4202/6427 MHz allocations within the United States.

Current Use at 13.4-14.0 GHz and 20.2-21.2 GHz

These two uplink/downlink bands are allocated on a secondary basis for satellite-based time transfers at the highest possible accuracy levels. The relatively large bandwidth should support time transfers at higher accuracy and precision than can presently be achieved by any other method or system. However, to date there has been no activity within the United States involving these frequencies for time and frequency transfer.

Current Use at 25.25-27.0 GHz and 30.0-31.3 GHz

This is a second uplink/downlink allocation intended for development of future, higher accuracy time transfer techniques that would take advantage of the relatively large bandwidth provided. As in the previous case there has been no U.S. or international activity as yet to make use of this allocation pair for time and frequency applications.

TRENDS

The HF and LF services, such as WWV, WWVH, and WWVB, continue to fill important user needs for accuracies that are adequate for most applications. Mutual interference will likely continue to be a problem for use of HF services in some areas, but alternative sources are becoming more widely available and economically feasible. In the long term, it may become possible to replace some or all of the terrestrial HF and LF services with more reliable satellite-delivered services.

However, only limited efforts in this direction have been attempted to date, most notably in the form of the NIST time code service from the NOAA GOES satellite system, and the similar service from the INSAT satellite system in the Indian subcontinent region. The future of the GOES system is somewhat uncertain at this time and cannot be considered as a permanent replacement for any of the existing services.[585] Preliminary planning by NIST for future satellite services could affect the long-term need for HF and LF allocations, but for at least the next 10 years no impact on the need for the current allocations is foreseen.

While the continuing need for current HF and LF spectrum during the next 10 years or so is clear, the situation concerning spectrum for satellite-based time and frequency distribution is more uncertain. Recently, there has been a strong trend toward increased reliance on satellite-delivered time and frequency signals for applications requiring timing accuracies of better than 1 millisecond. As many modern time and frequency applications develop requirements for sub-millisecond timing accuracies that can no longer be satisfied by the traditional HF and LF broadcast services, more users are tending to make use of the GPS satellite system. Today's most demanding applications must rely on GPS, or in some cases, the two-way exchange of signals through communication satellites. During the next few years it is also possible that additional high-accuracy time and frequency dissemination alternatives may become available through the use of emerging digital synchronized telecommunication networks and perhaps from the INMARSAT system.

SPECTRUM REQUIREMENTS FOR THE STANDARD FREQUENCY AND TIME SIGNAL SERVICES

In summary, we believe that spectrum currently allocated to and used by the standard frequency and time signal services needs to be retained and seems adequate for future use and expansion of time and frequency standards for the foreseeable future.[586] *Further, it would seem that as long as the GPS signals continue to be available to the civilian sector at current accuracy levels and assuming sufficient availability of economical communication-satellite channels for the most demanding needs, there may be little need for*

[585] *Id.* at 3.

[586] *Id.*

specific dedicated satellite frequency allocations for the time and frequency services. On the other hand, if future developments restrict time and frequency providers from efficiently making use of spectrum assigned to other services, then the availability of dedicated space-service spectrum becomes essential. Therefore, spectrum planners should consider the standard frequency and time signal-satellite allocations for alternate uses that can share with the radio services currently allocated in these bands, while not eliminating future use of the bands by the standard frequency and time-signal services.

METEOROLOGICAL AIDS SERVICE

The meteorological aids service is "a radiocommunications service used for meteorological, including hydrological, observations and exploration."[587] In the United States, the National Weather Service (NWS) of the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) is charged with the observing and reporting of weather, issuing forecasts, and warning of weather and flood conditions affecting national safety, welfare and the economy. The equipment employed in the meteorological aids service (e.g., weather radars, radiosondes, and rocketsondes) provide many of these observations and continue to provide critical data used in around-the-clock weather forecasting services, flood warning, and meteorological research studies.[588] The collected data is shared among various Federal agencies, state and local governments, academic research programs, private weather-forecasting firms, etc. Because of national and agency-specific meteorological functions and requirements, the Federal Government is the largest user of meteorological aids equipment in the frequency bands depicted.

U.S. FREQUENCY BANDS ALLOCATED TO THE METEOROLOGICAL AIDS SERVICE

Frequency Band	Operations
153 - 154 MHz	Radiosondes
400.15 - 401 MHz	Radiosondes
401 - 402 MHz	Radiosondes
402 - 403 MHz	Radiosondes
403 - 406 MHz	Radiosondes
1668.4 - 1670 MHz	Radiosondes
1670 - 1690 MHz	Radiosondes
1690 - 1700 MHz	Radiosondes
2700 - 2900 MHz	Weather Radars
5600 - 5650 MHz	Weather Radars
9300 - 9500 MHz	Weather Radars
35200 - 36000 MHz	Weather Radars

---

587 *See* NTIA MANUAL, *supra* note 13, § 6.1.1 at 6-9.

588 In the course of a 24-hour-per-day, year-round operation, the National Meteorological Center (NMC) receives approximately 50,000 surface observation reports daily from land stations, 3,000 reports from ships, 4,100 upper air observations, and 3000-4000 reports from aircraft. OFFICE OF THE FEDERAL COORDINATOR FOR METEOROLOGY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEP'T OF COMMERCE, FCM P1-1992, FEDERAL PLAN FOR METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH A-4 (1992).

FEDERAL USES

Of the 13 Federal Agencies that engage in meteorological activities, 10 own and operate meteorological aids equipment. These include the Departments of Commerce, Agriculture, Energy, Treasury, as well as the United States Army, Navy, Air Force, the FAA, NASA, and NSF. Over the next two decades, major emphasis in the research community will be on climate and global changes and the operational meteorological community will have responsibilities in providing most of the observations.[589]

Radiosondes and their associated tracking and receiving stations are used in the meteorological aids service for the determination of atmospheric conditions.[590] The NWS operates approximately 93 radiosonde stations in the US&P as well as a large number of cooperative stations throughout the Western Hemisphere. Rocketsondes also provide atmospheric readings and are the only means of obtaining adequate data from 25-60 kilometers into the atmosphere for stratospheric monitoring and global warming assessments.[591] Both provide accurate readings and are used often to calibrate meteorological satellite readings. The three largest users of these systems are the NWS, the Army, and the Department of Energy.

NOAA currently collects water level data using the Next Generation Water Level Measurement System. This data is collected primarily via the existing GOES Data Collection Platform (DCP) network operating near 402 MHz. Additionally, NOAA operates a network of DCP's aboard ships of opportunity to collect sea surface and subsurface temperatures, with the data being transmitted back via GOES or other meteorological satellites operated by cooperating nations.

The NWS, USAF and FAA are the Federal Agencies having the largest number of ground weather radars. Both the NWS and the FAA operate weather radars in the frequency bands 2700-2900 MHz and 5400-5600 MHz. In addition to these two bands, the USAF also operates weather radars in the 9300-9400 MHz band. The newest weather radar is the WSR-88D, commonly referred to as the Next Generation Radar (NEXRAD), and is the second-generation Doppler, meteorological radar replacing the non-Doppler meteorological radars of the NWS and USAF operating in the 2700-2900 MHz band. The introduction of the NEXRAD radar presented a problem in those areas where the band is heavily used. Consequently, the NEXRAD radar was accommodated in an adjacent band, 2900-3000 MHz, to provide frequency supportability. The United States adopted Footnote US316 to the allocation table that allocated

---

[589] *Id.* at 108.

[590] A radiosonde is generally a balloon-borne meteorological instrument consisting of sensors coupled to a radio transmitter and assembled in a light-weight box used to measure the ambient temperature, relative humidity, and barometric pressure of the air through which it rises. Wind velocity and direction are determined due to the changes of its position and direction.

[591] *See* OFFICE OF THE FEDERAL COORDINATOR FOR METEOROLOGY, NAT'L OCEANIC AND ATMOSPHERIC ADMIN., U.S. DEP'T OF COMMERCE, FCM-R13-1990, FEDERAL METEOROLOGICAL REQUIREMENTS 2000 at 96 (1990).

the band 2900-3000 MHz on a primary basis to the meteorological aids service.[592] The FAA used technology developed during the NEXRAD program to develop its Terminal Doppler Weather Radar (TDWR). The TDWR operates on a single channel in the 5600-5650 MHz band and serves the immediate vicinity of airport terminal areas to provide warning of wind shear and other weather conditions hazardous to aviation.[593]

Unattended remote sensors, while requiring large capital investments, offer low cost per sounding. Large numbers of these can be deployed in networks to obtain needed observations with the frequency, accuracy, and vertical resolution needed to predict severe weather. Of all the promising technologies currently available, wind profiler Doppler radars are the most advanced.[594] Propagation characteristics of the atmosphere require that the wind profilers operate in the range 50-1000 MHz. Currently, there are three frequency ranges of particular interest: around 50 MHz, 200-500 MHz, and 1000 MHz, each of which best accommodates a particular application. Most of wind profiler operations to date have been conducted at research facilities for experimental purposes. The concern with wind profilers is the selection of appropriate frequencies for long-term operation, both nationally and internationally. Nationally, the majority of effort has focused around the 200-500 MHz range since NOAA plans to establish a national network. Within this range, the frequency 449 MHz has been authorized for Federal wind profilers. Internationally, papers concerning wind profiler operations have been presented in various scientific fora such as the ITU's Radiocommunication Sector (formerly the CCIR). As a result, the ITU established ITU-R Task Group 8/2 to identify suitable frequency bands for wind profilers.

NON-FEDERAL USES

Non-Federal usage of the meteorological aids bands is in the 400.15-406 MHz and 9300-9500 MHz bands; however, many licensees also use the 5350-5600 MHz band on a non-interference basis. State and local governments primarily use the 400.15-406 MHz band for hydrologic data collection, fire weather forecasting, and water runoff predictions, with the data sent back and collected via the GOES satellite. Many colleges and universities perform research in the areas of carbon monoxide studies and global atmospheric assessments. Many meteorological weather radars operate in the 5350-5600 MHz and 9300-9500 MHz bands

[592] Footnote US316 further states that operations in this service are limited to Government NEXRAD systems where accommodation in the 2700-2900 MHz band is not technically practical and are subject to coordination with existing authorized stations. NTIA MANUAL, *supra* note 13, § 4.1.3 at 4-112.

[593] NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, DOC. SPS-7861/2, NTIA PRELIMINARY ASSESSMENT OF FEDERAL AVIATION ADMINISTRATION (FAA) TERMINAL DOPPLER WEATHER RADAR, STAGE 4, at 1-2 (Mar. 7, 1988).

[594] Wind profilers can measure wind speed and direction, vertical velocity, intensity of turbulence, and key precipitation parameters with resolutions between 100 and 1000 meters from about 200 meters to 18 or more kilometers above the surface. The Wind Profiler is a vertically oriented ground-based pulsed radar that utilizes scattering from irregularities in the index of refraction in the atmosphere to measure wind parameters in three dimensions. By transmitting pulses on sequential beams (e.g., east, north, and vertical) and processing the return signal, profiles of the wind can be obtained faster and cheaper than by radiosondes. Range gate and Doppler radar principles are applied to deduce the wind parameters from signals received from each of the beam positions. By integrating the backscatter signal pulses at one beam position over a suitably long period of time (i.e., 2 minutes), it is possible to operate with very low signal-to-noise ratios (e.g., -25 to -30 dB).

and are owned and operated by state and local governments, private weather forecasting businesses, utility companies, Cable television companies, broadcast stations, college/universities, etc.[595]

SUMMARY OF COMMENTS

NOAA noted that weather radars and radiosondes are "traditional" methods for the collection of weather observations where spectrum has been set aside for in the United States and throughout the world. Meteorological and hydrologic data collection via the GOES data collection platforms will continue unabated into the foreseeable future.[596] The FAA in their comments noted that the NEXRAD radars have added to the congestion in the 2700-2900 MHz bands in many geographic areas of the United States.[597] Further, the FAA noted that they plan to implement the full NEXRAD system in the 2900-3000 MHz and 3500-3700 MHz bands when frequencies become unavailable in the 2700-2900 MHz band.[598] NOAA stated that both the NEXRAD and the wind profiler required the allocation of new spectrum to support them. In both cases, the impact is minor: the NEXRAD requires shared access to an adjacent radar band in those few areas where its primary band is crowded and the wind profiler can be accommodated in 2 MHz in the upper end of a 30 MHz wide military radar band. NOAA further noted that in both cases, NTIA and NOAA have worked carefully to protect systems operating in these shared bands.[599]

SPECTRUM REQUIREMENTS FOR THE METEOROLOGICAL AIDS SERVICE

Meteorological aids equipment will continue to provide necessary meteorological observations in support of Federal agencies' plans and programs, and to support meteorological research initiatives through the year 2000 and beyond. Their importance in providing for national safety, welfare, and the economy is well documented. As new meteorological aids systems are fielded, attempts to provide for frequency supportability via sharing techniques will be made. We believe the spectrum allocated for the meteorological aids service appears adequate for the foreseeable future.

---

[595]The 5350-5600 MHz band is allocated to the aeronautical radionavigation, radiolocation, and radionavigation services. The meteorological radars operate on a non-conformance basis.

[596]NOAA Comments at 2.

[597]FAA Comments at 5.

[598]*Id.*

[599]NOAA Comments at 3.

CHAPTER 7

SPECTRUM SHARING

THE NATIONAL SPECTRUM RESOURCE

In the United States, NTIA and the FCC jointly manage the use of the radio spectrum. The Federal Government uses the spectrum to support missions that include national defense, energy production and distribution, federal law enforcement, protection of national forests and natural resources, space exploration, and other vital government services. Management of spectrum use by Federal agencies is the responsibility of NTIA. The FCC manages spectrum use of the private sector, which includes broadcast entertainment, commercial, industrial, personal uses, and state and local government uses. Although spectrum users have brought higher portions of the spectrum into use through the years, the majority of use still remains below about 20 GHz. This spectrum is a national resource, and must be used to satisfy all demands, current and future, for radiocommunications services for both public and Federal use.

As a basic plan for usage, the radio spectrum is *allocated* to various radio services in blocks of frequencies. The concept of the block allocation system is that a band of contiguous frequencies is dedicated to one or more radio services, depending on the technical and operational characteristics of the service(s). A block so dedicated is said to be allocated to the radio service(s) associated with that block. Further, within a block the radio services may have a hierarchial structure that grants rights or imposes limitations on the services relative to other services in the same block. The assemblage of these spectrum blocks, along with associated footnotes, is called the *National Table of Frequency Allocations*,[600] and is used for general spectrum planning. The Table also further separates those allocation blocks that are managed by NTIA from those managed by the FCC.

In many cases, an allocation block will be shared by two or more radio services, each with its own allocation status.[601] An investigation of the block allocation system was undertaken as part of the NTIA Spectrum Policy Study.[602] One of the conclusions from that study stated that "[a]lthough the basic structure

[600]NTIA MANUAL, *supra* note 13, § 4.1.2.

[601]Allocation status is shown in the Table as either primary, permitted, or secondary. Services or uses may be allocated under other bases, such as non-interference, by footnotes to the Table.

[602]NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEP'T OF COMMERCE, NTIA SPECIAL PUBLICATION 91-23, U.S. SPECTRUM MANAGEMENT POLICY: AGENDA FOR THE FUTURE 55 (1991) [hereinafter SPECTRUM POLICY STUDY].

of the block allocation system should be retained, NTIA and the FCC should seek to modify it in the next decade to increase flexibility."[603] The NTIA Spectrum Policy Study promoted flexibility in allocations, stating that "to the extent that the block allocation system can be modified to permit additional flexibility, users, their customers, and the economy as a whole, will benefit. More rational suballocations will permit users greater opportunities to harness unused spectrum for similar functions. Greater technical flexibility would permit manufacturers to focus on the best standards for their products to meet user needs. And greater user flexibility would permit more private ordering of desirable spectrum uses."[604]

There are 40 allocated radio services defined in the Code of Federal Regulations.[605] A listing of these services is shown in Table 7-1 below.

TABLE 7-1
RADIO SERVICES

Aeronautical Fixed	Maritime Mobile
Aeronautical Mobile	Maritime Mobile-Satellite
Aeronautical Mobile (R)	Maritime Radionavigation
Aeronautical Mobile (OR)	Maritime Radionavigation-Satellite
Aeronautical Mobile-Satellite	Meteorological Aids
Aeronautical Mobile-satellite (R)	Meteorological-Satellite
Aeronautical Mobile-Satellite (OR)	Mobile
Aeronautical Multicom	Mobile-Satellite
Aeronautical Radionavigation	Port Operations
Aeronautical Radionavigation-Satellite	Radio Astronomy
Amateur	Radiodetermination
Amateur-Satellite	Radiodetermination-Satellite
Broadcasting	Radiolocation
Broadcasting-Satellite	Radionavigation
Earth Exploration-Satellite	Radionavigation-Satellite
Fixed	Ship Movement
Fixed-Satellite	Space Operation
Inter-Satellite	Space Research
Land Mobile	Standard Frequency and Time Signal
Land Mobile-Satellite	Standard Frequency and Time Signal-Satellite

Flexibility in allocating spectrum would allow additional radio services to share a frequency band according to criteria other than the block allocation. If additional services could be engineered into a band without causing or receiving interference, then the efficiency of that frequency band would increase.

[603] *Id.* at 5.

[604] *Id.* at 84.

[605] *See* 47 C.F.R. § 2.1. Three other services are defined, i.e., the radiocommunications service, safety service, and special service, but are not contained as allocated radio services in the National Table of Frequency Allocations.

Examples of sharing methods are geographical (i.e., distance separation between users), time sharing, class of service (e.g., sharing between fixed and mobile services), and class of user (e.g., military/civil sharing).

One method for increased flexibility in spectrum allocation includes the use of electromagnetic compatibility (EMC) techniques to assess the interference potential between existing systems and new systems to be "engineered in." Some engineering firms support using EMC methods to manage spectrum. EMC techniques allow users to share the spectrum-space among several different radio services. The key for successful use of EMC techniques is for spectrum managers and users to agree to interference criteria that are acceptable to all affected services.[606]

With the current capability of personal computers, complex frequency assignment algorithms, using terrain data bases, can now be automated. Commercial software is available for certain radio services, and the Federal Government is developing a system for automation of its frequency selection and assignment procedures. These personal computer-based systems can be used by frequency managers for efficient selection of frequency and radio system parameters.

PERFORMANCE GUIDELINES AND EXCLUSIVITY

In the Notice, we asked three questions concerning spectrum sharing. First, we requested comments on standards or performance guidelines regarding sharing between different classes of users (e.g., Federal, non-Federal) to promote sharing and improve spectrum efficiency.

Although there were no specific comments relating to performance guidelines submitted,[607] some observations can be made. It was noted that sharing between Federal and non-Federal users would be facilitated if the FCC would adopt transmitter and receiver standards, such as used by Federal Government agencies.[608] Although the FCC does not currently set receiver standards, homogeneity of systems and practices within frequency bands would be very desirable if increased sharing between Federal and non-Federal users is to be successful. In particular, in shared fixed service bands, three system parameters are of interest. First, receiver standards should be set to optimize the channel bandwidth.[609] Second, a common channelling plan for Federal and non-Federal users would lead to increased spectrum efficiency and reduced costs for equipment.[610] Third, a more accurate and comprehensive data base of antenna characteristics used

---

[606]SPECTRUM POLICY STUDY, *supra* note 7, 602 at 82-83.

[607]Southwestern Bell Comments at 28. Southwestern Bell believes that technical standards should be defined in such a way as to encourage future technological evolution in the provisioning of new telecommunications services.

[608]DOJ Comments at 6.

[609]DOD Comments at 15. DOD states that "As a spectrum sharing issue, receivers built to a higher, FCC-mandated performance criteria will facilitate the measures that will be required to attain optimum frequency and spatial sharing." *Id.*

[610]Alcatel Comments at 11.

in fixed bands would aid in the analysis of frequency selection for new systems proposed for insertion in a crowded electromagnetic environment.

Generally, interference is a function of transmitter and receiver standards, including the related antenna standards. Frequency/distance separation criteria are dependent on these two main sets of standards. Spectrum efficiency is enhanced when any of these items is optimized. When the bandwidth of a receiver significantly exceeds the necessary bandwidth of the transmitted signal it is to receive, the receiver is susceptible to receiving non-desired signals, and may account for approximately 50 percent of the interference potential of radio systems. For this reason, system performance guidelines must also include receiver standards.

We also asked questions regarding the requirements for worldwide allocations, and the necessity for exclusivity of these allocations in the United States. Several requirements for worldwide allocations were indicated by the comments and by the nature of the radio services. Many frequencies or frequency bands are designated for international and worldwide use. Examples include distress frequencies, radionavigation services, some amateur service bands, HF bands, and various satellite radio services.

Generally, the need for exclusivity is embodied in the need for worldwide allocations, especially for safety services, since commenters have noted that frequency sharing between safety-related services, such as air traffic control and certain radionavigation services, and other services is not currently practicable.[611] However, there may be some exceptions. For example, it is planned that air traffic control information will be carried over the same mobile-satellite trunked system as public correspondence, but with over-riding priority and preemption for the safety information. It may also be possible for certain land mobile and international maritime mobile operations to share a common band if the dissimilar users are geographically separated.[612] Similarly, certain amateur-satellite bands may be aligned worldwide and yet not require exclusive allocations by individual administrations.

There is also a requirement for national exclusivity for some radio services without concomitant worldwide allocations. One example of this is the exclusive United States national radio astronomy allocation in the 608-614 MHz band, with footnote allocations in ITU Regions 1 and 3 on a secondary basis. Another example is in the amateur service where this service has an exclusive allocation in the 3900-4000 kHz band not aligned internationally with ITU Regions 1 and 3.

---

[611]ARINC Comments at 8. ARINC states that aviation safety communications are vital to the safety of life and property in the air, and rely on channel discipline. Such discipline would not be possible in many interservice sharing situations. *Id.*

[612]*Amendment of the Commission's Rules Concerning Maritime Communications*, Notice of Proposed Rule Making and Notice of Inquiry, PR Docket No. 92-257, 7 FCC Rcd 7863 (1992).

FEDERAL/NON-FEDERAL SHARING

Many frequency bands have co-equal allocations for both Federal and non-Federal users. Above about 40 GHz, all bands are generally co-equally shared, except for radio services such as broadcasting and amateur, which are allocated for non-Federal use. Below 40 GHz, shared terrestrial service allocations are still abundant, but diminish until in the portion of the allocation table below about 6 GHz most bands are managed either by NTIA for Federal Government use, or the FCC for private sector use.

With the increased use of frequency bands below 6 GHz, services that cannot find relief in the higher bands must turn to sharing with other services, or to sharing between Federal and non-Federal users, to be accommodated.[613] The need for sharing seems to be most acute for the mobile and fixed services. However, Federal and non-Federal sharing has been occurring in the 21-23 GHz band for some time. One commenter believes additional sharing may be possible in the 1710-1850 MHz, 3.6-3.7 GHz, and 4.5-4.8 GHz bands.[614] Some planning for the use of shared bands has taken place. One commenter noted that sharing between the fixed, mobile, and the fixed-satellite services, as was arranged in the 17.7-19.7 GHz band, is a good example of judicious planning.[615]

One area of government and private-sector sharing that deserves immediate attention is that of sharing between different radio services in certain space service bands. While certain space service bands support critical government activities and are not viable sharing options, other bands support TT&C functions, and orbital payload downlinks including environmental sensing information. The expected commercialization of many former government scientific activities would make this sharing highly practical.[616]

One private sector commenter stated that "A significant, but largely untapped, source of sharing is between state and local government public safety agencies and the Federal Government."[617] The concept of government/private sharing of public safety channels is also endorsed by at least one Federal agency.[618] Further, NTIA's Institute for Telecommunication Sciences is closely observing an attempt to establish a shared Federal/state government trunked land mobile system for the State of Colorado.

Although sharing between Federal and non-Federal users is increasing, there is no comprehensive, integrated program for future spectrum sharing. Significant regulatory barriers exist that impede frequency

---

[613]DOE Comments at 11. "The demands on the future use of the spectrum resources in the United States, already the highest user in the world, require additional sharing between Government and non-Government entities . . . ." *Id.*

[614]IEEE—USA Comments at 3.

[615]Harris Comments at 5.

[616]NASA Comments at 3. Examples of commercial science include biochemical manufacturing, crystallizations in space, and outer space mining activities. *Id.*

[617]APCO Comments at 9.

[618]DOE Comments at 12. DOE states that trunked mobile systems is one area in which band sharing is both feasible and practical, particularly to facilitate mutual aid ventures between Federal, state and local governments. *Id.*

band sharing between Federal and non-Federal users. It was stated that a more effective spectrum management approach would include developing innovative programs to encourage the sharing of government spectrum by the private sector, and government use of commercial services in order to help alleviate the shortage of spectrum.[619] Two commenters have suggested that NTIA establish a spectrum sharing committee to promote and coordinate spectrum sharing among spectrum user groups.[620]

The NTIA Organization Act required NTIA to submit a plan to Congress addressing improvement in the spectral efficiency of the Federal mobile services.[621] Specifically, Congress required Federal land mobile systems to be as spectrum-efficient and as cost-effective as commercial systems. In response, NTIA prepared the Land Mobile Spectrum Efficiency report[622] containing an analysis of the current Federal land mobile infrastructure with respect to spectrum efficiency and cost effectiveness.

The report included a summary of Federal land mobile requirements and technologies, and a plan to re-channelize Federal land mobile bands to narrower bandwidths. Further, NTIA established the framework for implementing procedures for increased Federal use of commercial radiocommunication service offerings.

OTHER SHARING ISSUES

Although the Notice requested comments regarding performance guidelines and standards for increased sharing, a number of commenters provided additional thoughts on inter-service sharing. While the following is not meant to be a complete evaluation of sharing issues, it reflects the main comments regarding the probability of success in certain inter-service sharing situations.

MOBILE

In the search for additional spectrum, the concept of mobiles sharing spectrum allocated to other user classes is being intensely studied. Three distinct categories of mobile systems can be considered in the context for sharing. The first is the classic vehicular or hand-held unit, with transmitter power ranging from one to over one hundred Watts, operating in simplex or half-duplex, or in a demand-access mode such as trunking. Platforms can be on land, at sea, or airborne. The second category is the transportable system, such as electronic news gathering, using high-gain antennas and transmitting for a limited time from any one location. The third category is broadly termed "wireless systems" and include low-power PCS, wireless PBX's, and wireless radio local area networks.

---

[619]InterDigital Comments at 3.

[620]DOD Comments at 18 (suggesting a spectrum sharing users group under the IRAC); InterDigital Reply Comments at 5 (suggesting a spectrum sharing panel).

[621]NTIA ORGANIZATION ACT, *supra* note 1.

[622]COHEN ET AL., *supra* note 34.

Sharing between the mobile service and the space services in the 2025-2110 MHz and 2200-2290 MHz bands is considered to be a tenuous situation.[623] However, low-density mobile systems, such as electronic news gathering systems, have been sharing successfully with the space services in the 2025-2110 MHz band. Similarly, sharing between mobile systems and LEO mobile-satellite systems in the 148-149.9 MHz range, concerned parties have agreed to. Low-density mobiles, along with stations in the fixed and fixed-satellite services can also share in limited degrees with other space systems, such as passive sensors in the earth exploration-satellite service. The degree of sharing increases with the frequency bands above 20 GHz.[624]

The advent of PCS may provide opportunities for frequency sharing between PCS systems and other systems, such as the fixed service and possibly analog cellular systems. It has been stated that the use of wide-band CDMA could be overlaid on existing fixed or cellular systems without any degradation to transmission quality.[625]

RADIO ASTRONOMY

The radio astronomy service is characterized by a relatively small number of sites using very sensitive receivers and high-gain antennas. Further, certain observations can be made only on given frequencies or bands, since natural phenomena govern the existence of the extra-terrestrial transmissions and their spectral positions. Radio astronomers cannot be relocated to other frequencies, but given the small number of sites nationally, sharing the allocated radio astronomy bands is possible under certain conditions. For example, radio astronomy and other passive services can equally share any passive frequency band, since by definition no emissions are allowed in these bands.[626] However, line-of-sight sharing between radio astronomy stations and stations in the active services is not possible due to the high sensitivity of the radio astronomy receivers and the extremely low-level signals to be detected.[627] NSF states that geographical sharing between the radio astronomy service and some active services is possible if the separation distances are large enough, but sharing with the mobile service is possible only under other special circumstances.[628]

The fixed service, however, is a particularly good candidate for sharing and is best able among other services to share with radio astronomy.[629] This sharing is feasible, in part, due to the predictability of the fixed service. Consequently, the activities of the service can be coordinated, usually based on geographical

[623]NASA Comments at 13.

[624]*Id.* at 21.

[625]SCS Comments at 7. *But see* GTE Comments at 2, 9 (stating that "stealth-like" sharing is not technically feasible for high capacity applications like PCS); Apple Comments at 5 (stating that fixed service users could not be assured the mobile, unlicensed PCS systems would not cause them interference).

[626]For example, the 4990-5000 MHz band is allocated as a passive band for radio astronomy and space research.

[627]NSF Comments at 6.

[628]*Id.* at 6-7.

[629]CORF Comments at 4.

separation, or occasionally on some other arrangement. Geographical sharing is also possible with the fixed-satellite service in the frequency bands limited to Earth-to-space transmissions. It is not possible, however, for radio astronomy to share a band with unlicensed devices because of their unpredictable and ubiquitous nature.[630] Other active services, such as aeronautical mobile, fixed- and mobile-satellite downlinks, and radionavigation-satellite services have potential for causing interference to radio astronomy stations. Of particular concern to the radio astronomers is the emergence of ultra-wideband systems, also known as "impulse" systems. These systems may have operational bandwidths up to several hundred megahertz, and traverse some radio astronomy bands. These systems could cause a rise in the level of background noise, or corrupt received data. However, it was stated that impulse radios can share spectrum with conventional radio transmissions (including spread spectrum) without interfering with them or being interfered with by them.[631]

TELEVISION BROADCASTING

Sharing the UHF television broadcast spectrum with other services, particularly mobile, has been an issue for many years. It was noted in the comments that in most cases, this sharing was in fact a local reallocation of the broadcast spectrum to the mobile service.[632] One commenter stated that broadcast television is allocated spectrum that could be used for land mobile applications. Lack of selectivity in TV receivers eliminates 2-4 times the channel width from other use. Stricter television receiver standards could make hundreds of channels available for land mobile use.[633] Since broadcast receivers are pervasive in our society, co-channel sharing with television services is very difficult, and indeed probably not feasible. The introduction of advanced television systems, with the requirement for additional use of currently allocated UHF television channels, would make the local reallocation technique less viable. However, with the advent of digital modulation, ancillary services carried by the UHF television transmissions appears to be technically feasible.

AMATEUR

The amateur service operates in many of its bands on a secondary basis. Several amateur bands are shared successfully with Federal (military) radiolocation. The sharing is successful primarily because the peacetime use of military radars does not affect amateur operation in large areas of the United States. However, there are significant coordination areas surrounding some radars in the 420-450 MHz band.[634] Amateur operations also share spectrum with industrial, scientific, and medical (ISM) and LMS systems. Interference to amateur communications is accepted in these bands on the basis that some useful operation is better than exclusion from the band. Amateur operation in the 7100-7300 kHz band, while primary in the

---

[630] NSF Comments at 10

[631] Pulson Comments at 5.

[632] MSTV Comments at 11.

[633] POLLACK, *supra* note 379, Attachment at 2.

[634] AMSAT Comments at 3.

United States, suffers interference from international broadcasters operating on a primary basis in Regions 1 and 3. Amateurs have requested an alignment of the band internationally, but broadcasters are also requesting more HF broadcasting spectrum.

TELEVISION RECEIVE ONLY

The deregulation of private satellite dishes in the early 1980's has led to a burgeoning industry termed "home satellite dish" (HSD). The success of this industry is dependent on the sharing between the fixed service in the 3.7-4.2 GHz band and the downlinks of the fixed-satellite service that carry television and video programming for residential HSD consumers. Techniques have been worked out to prevent most of the interference to HSD systems from fixed links. However, the HSD systems are not licensed, thus not protected. Additional systems introduced into the band will increase the probability of interference.

If the 3.7-4.2 GHz band is to be used for the accommodation of fixed service users moved from the 2 GHz bands, then the sharing problem may be severe in many areas. Microwave users would prefer to use other bands, as they do not want to interfere with even the non-licensed television receive-only (TVRO) systems.[635] The HSD industry will be further impacted by the advent of digital satellite transmissions, which will be more vulnerable to interference from fixed links than the present analog satellite signals. Sharing between these users, while now affordable and practicable, may in the future be impossible.[636]

MILITARY AND CIVIL SHARING

Recent downsizing of DOD components, coupled with current demands for global mobility of our military forces, places greater demands on military spectrum planning than ever before. To exacerbate the problem, there is a potential for the military services to lose some spectrum for which they have primary control due to spectrum legislation. An aid to military spectrum planning may be found in increased spectrum sharing between the military and other spectrum users in non-military frequency bands. Exclusive military frequency bands may not be required for those systems that are used only for training in the United States, and are deployed elsewhere. Increased access to non-military bands on a coordinated basis for this type of training would increase the flexibility of military spectrum use in the United States. However, certain military spectrum requirements prevent spectrum sharing in some instances.

A significant amount of sharing currently exists. The Army uses many frequencies in the 30-88 MHz for tactical and training purposes on a coordinated basis with private sector users. The Navy shares the 928-941 MHz band with private sector land mobile operations, on a non-interference basis. Further, the military gained access to the 420-450 MHz band for radiolocation use on a shared basis. The DOD often

---

[635] Alcatel Comments at 6.

[636] SBCA Comments at 20.

leases satellite time from commercial providers, using Federally-owned earth stations. The USAF has stated that if DOD should be granted the same protected status as other users of commercial satellite services, the DOD's satellite communications ability would be greatly enhanced, and commercial use could increase.[637]

However, additional sharing is expected to be required for the military to maintain its radiocommunications infrastructure in view of the possible loss of frequencies to the private sector. Military-civil sharing is generally of two forms; long-term and short-term. One form of a long-term sharing arrangement is the military/amateur sharing in certain radiolocation bands. A form of short-term sharing is the coordination of certain frequencies for military tests and training exercises. Examples of this are Army tactical exercises using frequencies in the 30-88 MHz band coordinated with the FCC, and certain JTIDS testing requiring military coordination with the FAA. The DOD has suggested coordinated sharing with the radio astronomy service as one way to have available spectrum for tactical and training purposes.[638]

CONCLUSIONS

- ❑ *National spectrum allocations should provide for flexibility of radio service use, including the use of EMC techniques, to make the most efficient use of the spectrum.*

- ❑ *Spectrum managers should use the most advanced frequency assignment techniques, including automated systems using terrain data, to ensure the spectrum-space is efficiently utilized.*

- ❑ *Federal and non-Federal users should increase sharing opportunities, particularly in the mobile, fixed, and space science services. Barriers to Federal/non-Federal sharing should be identified and reduced by NTIA and FCC cooperative actions.*

- ❑ *Receiver standards should be implemented nationally for those services where improved receiver characteristics would increase spectrum efficiency.*

- ❑ *Radio and radar astronomy observatories should continue to be protected from interference on a regulatory and coordinated basis.*

- ❑ *Co-channel sharing of the UHF television spectrum in the same geographic area with other radio services appears not to be feasible. However, flexibility in the use of TV spectrum (e.g., ancillary services) should be studied.*

- ❑ *Although mostly unprotected, TVRO systems are becoming widespread. Sharing TVRO with terrestrial systems may become more difficult with the advent of digital television.*

---

[637]POLLACK, *supra* note 379, Attachment at 5.

[638]DOD Comments at 5.

- ❏ *The amateur 7 MHz band should be aligned with a 300 kHz bandwidth internationally, since sharing with broadcasting has not proved to be satisfactory.*

- ❏ *To use the radiocommunications resources effectively, the military services must train with the equipment and the frequencies that will be used in combat.*[639] *Therefore, similar spectrum resources must be available in the United States for training as will be available in areas of potential combat. Since exclusive spectrum for training may not be required in all cases, military access to additional spectrum by sharing with other government agencies or the private sector, either on a synergistic or coordinated basis, will be of paramount importance for national defense purposes.*

---

[639]DOD Comments at 4.

PART 2

TECHNOLOGIES AFFECTING SPECTRUM REQUIREMENTS

PART 2
TECHNOLOGIES AFFECTING SPECTRUM REQUIREMENTS

In the responses to NTIA's *Inquiry*, few comments were submitted on the impact of technology on spectrum management.[640] Nearly all comments were on particular technologies affecting their own requirements. Implicit in most comments was the sense that technology, in the aggregate, is not solving the problems of spectrum scarcity. Commenters noted that the aggregate needs of existing and new services are increasing at a rate such that, despite the infusion of new technology that increases spectrum efficiency, additional spectrum allocations for these services are still being requested. Nonetheless, the application of new technology to telecommunications systems has reduced spectrum needs, and continues to hold the promise of satisfying certain radiocommunications demands without additional spectrum. The reduction of spectrum needs is typified by the trend toward optical fiber replacing radio links; the trend of digital modulation replacing analog modulation makes spectrum use more efficient.

The New Technology Directions Committee (NTDC) of the IEEE Technical Activities Board is a group whose views on future trends proposed several technological challenges, and merit serious consideration. Of the seven "grand challenges" facing electrotechnology in 1993 evinced by the NTDC, at least four involve radiocommunications,[641] and thereby have spectrum management implications.

These challenges are familiar ones ranging from instant global communications for all to attaining a cheap, clean, and safe source of energy. The communication-related systems that would meet or support these challenges have familiar acronyms, *e.g.*, ISDN - integrated services digital network, HDTV - high definition television, and CDMA - code division multiple access, many of which were proven experimentally feasible decades ago.[642] As with large-scale machine computation, application of these systems became practical with the introduction of high-speed analog-to-digital conversion, embedded micro-processors, and the rapid advance of solid-state electronics.

These challenges, along with other applications of technologies, are examined in this Part. Emphasis is placed on technology's ability to offer improved spectrum efficiency while permitting expanded service offerings, and the resultant impact on spectrum management.

---

[640]Only Pacific Telesis Group commented explicitly on technologies.

[641]T.E. Bell, *Technology Directions 1993*, IEEE SPECTRUM, Jan. 1993, at 81.

[642]CDMA and other spread spectrum systems, for example, were developed with vacuum tube technology. R.A. Scholtz, *The Origins of Spread-Spectrum Communications*, IEEE TRANSACTIONS ON COMMUNICATIONS, May 1982, at 822.

CHAPTER 8

TECHNOLOGIES THAT EXTEND THE USABLE SPECTRUM TO HIGHER FREQUENCIES

INTRODUCTION

During the past decades, the Federal Government has always kept some level of activity in the band above 20 GHz, mainly in the area of military R&D for high-resolution radiolocation and short-range radiocommunications. The national laboratories have been mandated to transfer this technology to the public sector where possible. Among the civilian federal agencies, there is the NSF-supported National Radio Astronomy Observatory that develops passive receiving systems operating well into the millimeter wavelengths.[643] NASA has recently launched the ACTS satellite that has the capability for testing ISDN and other new technologies at 20 GHz and 30 GHz.[644]

From the commercial sector, additional impetus to utilize the higher frequencies may come from wideband spread spectrum and other advanced megahertz-wide systems because they may face opposition to band sharing from the present users of the more congested lower bands.

Today, despite the fact that radio began at microwave frequencies over 100 years ago,[645] the spectrum above 20 GHz is still relatively underutilized. The general reasons for this condition, as found in scientific literature and echoed in the comments to our *Inquiry*, are

- ❑ limitations on use because of the effect of atmospheric constituents on radio waves at higher frequencies,

- ❑ the limitations of devices and manufacturing processes to operate at higher frequencies, and

---

[643]NSF Comments at 22-23.

[644]NASA Comments at 35-36.

[645]Brian Santo, *Making Waves at 100*, IEEE SPECTRUM, May 1988, at 58, 60; K.L. Smith, *Victorian Microwaves*, WIRELESS WORLD, Sept. 1979, at 93, 93-95.

- the need to develop supporting signal processing technology for digital wideband communications and other applications.[646]

THE IMPACT OF ATMOSPHERIC CONSTITUENTS ON RADIO PROPAGATION

Beginning at about 10 GHz, absorption, scattering and refraction by atmospheric gases and hydrometeors (the various forms of precipitated water vapor such as rain, fog, sleet and snow) become the important limiting factors for electromagnetic wave propagation.[647] Figure 8-1 shows the specific attenuation in dB/km as a function of frequency for atmospheric gases (oxygen and water vapor) and liquid hydrometeors (rain, drizzle and fog).[648]

ATMOSPHERIC GASES

The atmospheric gases assume importance for telecommunications starting at frequencies greater than 30 GHz, with attenuation generally increasing with frequency (Figure 8-1). This high attenuation appears ideal for short distance line-of-sight communication (*e.g.,* cellular radio), but rain which is even higher in attenuation (see Figure 8-1) and less predictable, would be a major consideration. For the space services operating outside of the atmosphere, negligible path losses and the narrow beamwidths and wide bandwidths possible in the higher, uncrowded frequencies are attractive at 100 GHz and above.[649]

Molecular absorption at particular frequencies (shown as peaks in Figure 8-1) are of interest to spectrum management for special applications, such as space operations. Satellite-to-satellite links operating in these bands would be relatively free of interference from co-channel terrestrial stations limited by the atmosphere.

---

[646] *See, e.g.,* Pacific Telesis Comments at 19; Alcatel Comments at 11.

[647] E.J. DUTTON & F.K. STEELE, NTIA REPORT 82-107, BIBLIOGRAPHY AND SYNOPSIS OF LITERATURE CONCERNED WITH MICROWAVE AND MILLIMETER WAVE PROPAGATION EFFECTS (1982); S.J. Roome, *Bibliography on Propagation Factors Affecting Microwave Links Operating the 10 GHz to 30 GHz Frequency Range*, IEEE PROCEEDINGS, Feb. 1986, Part H at 50, 50-56.

[648] Figure 8-1 is based on INTERNATIONAL RADIO CONSULTATIVE COMMITTEE, INT'L TELECOMMUNICATION UNION, REPORT 719-3, ATTENUATION BY ATMOSPHERIC GASES § 1, Figure 1 (1990).

[649] K. Krishen, *Future Trends in Antennas and Propagation for the US Space Program,* IEEE ANTENNAS & PROPAGATION MAGAZINE, Feb. 1994, at 32.

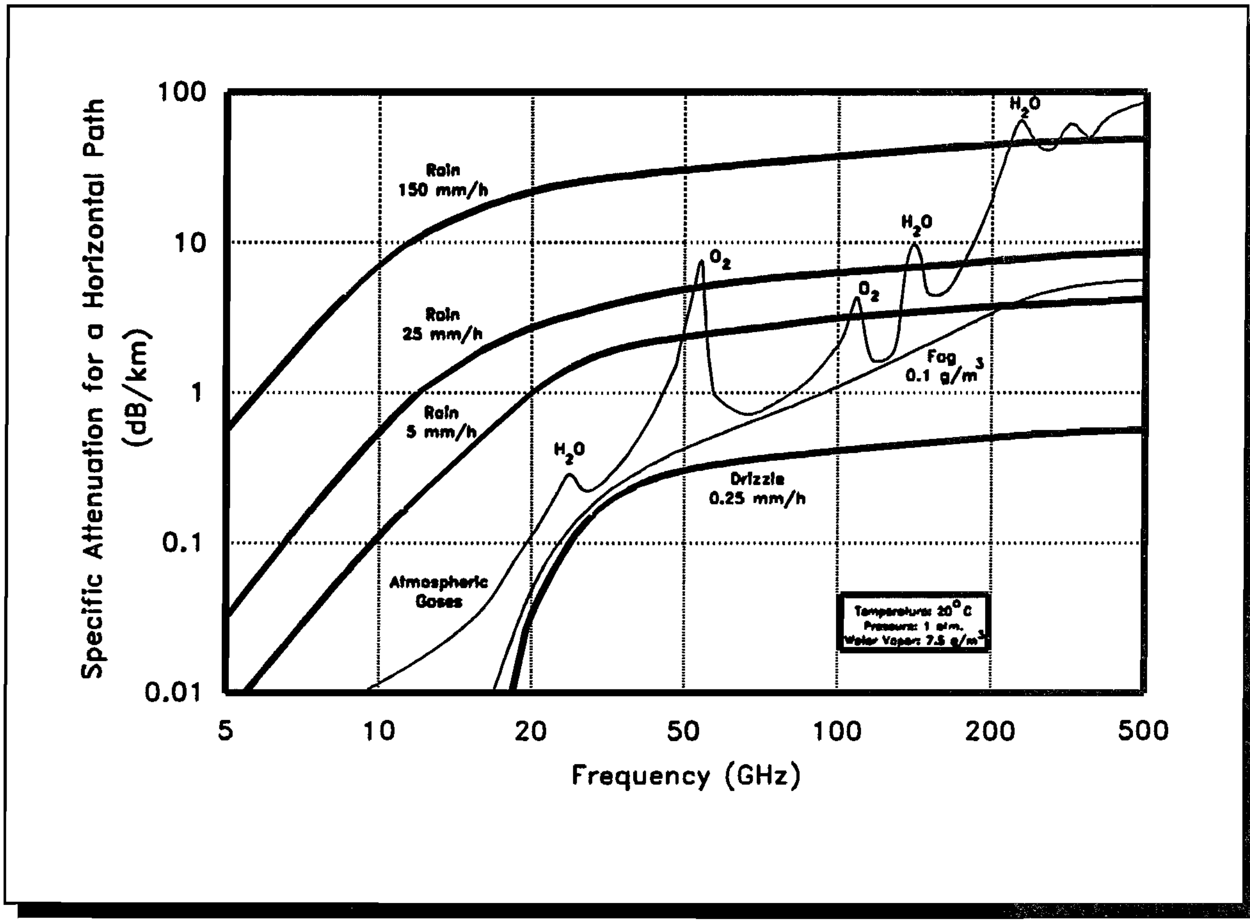


Figure 8-1. Attenuation Due to Atmospheric Gases and Liquid Hydrometeors

HYDROMETEORS

Hydrometeors in the form of raindrops are the largest natural objects most frequently encountered in the lower atmosphere, with the larger drops more numerous in the heavier rainfalls.[650] Consequently, high attenuation is correlated with high rainfall and is significant even below 20 GHz. With the worldwide adoption of the 20-30 GHz band for the fixed-satellite service, raindrop absorption presents a continuing problem for countries with high rainfall rates. Propagation experiments between NASA's ACTS satellite and these countries will aid in gauging the long-term reliability of the higher frequencies.[651]

[650] H.K. KOBAYASHI, ATMOSPHERIC SCIENCES LABORATORY, WHITE SANDS MISSILE RANGE, TECHNICAL REPORT ASL-TR-0049, ATMOSPHERIC EFFECTS ON MILLIMETER RADIO WAVES 13, 15 (1989).

[651] National Aeronautics and Space Administration, *ACTS Propagation Experiments Preparations Are Under Way*, ACTS QUARTERLY, Feb. 1993, at 14.

A spectrum management consideration in the near-future will be the appearance of hundreds, perhaps thousands, of transportable VSAT's with antenna diameters less than one meter using the 20-30 GHz radio links. Compared to terminals with larger antennas, the VSAT's are more susceptible to scintillation and fades because of the small aperture area of their antennas. The relationship among microwave scintillation, clear-air and rain, and antenna aperture smoothing is being actively explored by European researchers.[652]

U.S. investigators are looking at rain-induced fading itself, with low-margin earth stations in mind, and have compared a theoretical fade-rate model with 20-GHz Earth-satellite link data.[653] Recently, conventional radio-link methods (*e.g.*, diversity reception and forward error-correction) as well as selection of appropriate modulations (TDMA, FDMA, and single-channel) were investigated for their effectiveness in VSAT fade control.[654] Further consideration of VSAT's and spectrum management will be taken up later in this chapter and the next one.

The smaller size of drops in fog or clouds compared to rain allows for simpler analysis enabling good agreement between the fog curve in Figure 8-1 and measurements by others.[655] Moist clouds are similar to elevated fog and would have a curve congruent to the fog curve in Figure 1.[656] Fog or moist cloud attenuation is generally less than for atmospheric absorption.

Millimeter-wave attenuation by falling snowflakes appears to be about the same as for rain for comparable values of equivalent rain rate. But since snowfall rates are usually less than 10 mm/h (a moderate rainfall), the effect is less severe than for rain in most cases.[657]

A spectrum management consideration in the near future is the effect of high-altitude cirrus clouds, commonly found in Earth-satellite paths, which depolarize radio waves at frequencies above 10 GHz.

---

[652]J. Haddon & E. Vilar, *Scattering Induced Microwave Scintillations from Clear Air and Rain on Earth Space Paths and the Influence of Antenna Aperture*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, May 1986, at 646; D. Vanhenacker et al., *The Effects of Atmospheric Turbulence on Broadband Communication Channels Above 10 GHz*, SUPERCOM '92, IEEE CONFERENCE ON COMMUNICATIONS, 1992, at 1064.

[653]D.G. Sweeney & C.W. Bostian, *The Dynamics of Rain-Induced Fades*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, Mar. 1992, at 275.

[654]J.C. Cardoso et al., *Microscale Diversity in Satellite Communications*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, June 1993, at 801; M.J. Willis, *Fade counter-measures applied to transmissions at 20/30 GHz*, IEE ELECTRONICS & COMMUNICATION JOURNAL, Apr. 1991, at 88.

[655]H.J. Liebe et al., *Millimeter-Wave Attenuation and Delay Rates Due to Fog/Cloud Conditions*, IEEE TRANS. ON ANTENNAS & PROPAGATION, Dec. 1989, at 1617; T. Oguchi, *Electromagnetic Wave Propagation and Scattering in Rain and Other Hydrometeors*, PROCEEDINGS OF THE IEEE, Sept. 1983, at 1029.

[656]K.C. ALLEN, NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, NTIA REPORT 83-132, ATTENUATION OF MILLIMETER WAVES ON EARTH-SPACE PATHS BY RAIN CLOUDS 4 (1983). For a moist cumulus rain cloud, $\alpha = 12.9 wf^2/(14000 + f^2)$, where $\alpha =$ specific attenuation (dB/km/g/m) at 2° C, w = liquid water content (g/m^3), and f = frequency (GHz).

[657]D. Chakraborty et al., *The Ka-Band Propagation Measurements Campaign at JPL*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Feb. 1993, at 7. The table also lists the effect and remedy for other hydrometeors, depolarization, scintillation, and excess noise emission.

Reflections from the flat, horizontally-oriented surfaces of the crystals making up these clouds cause abrupt phase reversals of a radio signal,[658] thus degrading the performance of dual-polarization (frequency-reuse) systems. More importantly, digital systems in general are seriously affected because they are more sensitive to abrupt phase changes and reversals than analog systems.

Melting falling snow and ice are difficult to study in the field; nevertheless, knowledge of their effect is important in high-latitude countries along low-elevation radio paths. Towards this end, a theoretical approach using field data and observation has been developed by Canadian researchers.[659]

TECHNOLOGIES THAT EXTEND THE USABLE SPECTRUM

The extension of microwave techniques to millimeter wavelengths poses equipment design problems as severe as those associated with the move from the shortwave to the microwave band earlier in this century. Presently, system development has less problems between 30 to 100 GHz, where old techniques can be extended with some success. New devices and methods come into play mostly above 100 GHz.

PASSIVE COMPONENTS

The insertion loss of rectangular and circular waveguides, ferrite devices (phase shifters, isolators, etc.), and other standard microwave components become excessively high above 150 GHz because of size reduction and material losses. For example, a standard rectangular waveguide with a cutoff frequency of 100 GHz (at the basic TE_{10} mode) has an inside width of only about 1 mm, clearly making it a costly item difficult to interconnect mechanically and to maintain electrically pure. Also, magnetic and insulating properties undergo changes with reduction in size.

The dielectric line in the form of the microstrip, on the other hand, works well with solid state devices and is an important part of integrated circuit (IC) technology. The microstrip line is easily formed by printed circuit methods and integrated with solid state devices. But difficulty introduced by conflicting analyses has slowed extension to higher frequencies.[660] Nevertheless, technology has progressed to the point where

---

[658]D.P. Haworth et al., *Relationship Between Electricity and Microwave Radio Propagation*, NATURE, 1977, at 703; Yasuyuki Maekawa et al., *Ice Depolarizations on K_a Band (20 GHz) Satellite-to-ground Path and Correlation With Radar Observations*, RADIO SCIENCE, May-June 1993, at 249.

[659]M.M. Khardly & A.S. Choi, *A Simplified Approach to the Evaluation of EM Wave Propagation Characteristics in Rain and Melting Snow*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, Feb. 1988, at 282.

[660]M. Kachmar, *NSF Workshop on EM Readies Its Report*, MICROWAVES & RF, May 1986, at 35-40. Difficulty in modeling the non-symmetrical electromagnetic field of a microstrip line may also be a factor. *See* A.J. BADEN FULLER, MICROWAVES 268-271 (1979).

commercial computer-aided-design software has been used to model IC's for field-effect-transistor antenna elements of microstrip arrays.[661]

The microstrip transmission line works well in integrated circuits up to about 100 GHz where radiation losses due to its inherent low Q can be tolerated. But other line components, such as the H-guide and groove guide, show more promise for integrated circuits at higher frequencies.[662]

With respect to spectrum management, the integration of dielectric line components and solid state active devices introduces flexibility in specifying and changing the parameters of a radio system. Two examples of a change in a system parameter are the bandwidth of a receiver stage and the radiating pattern and gain of an antenna. The action in the latter case could be effected by differentially altering the phase of active devices located at the antenna element of a phase array. A conventional antenna array usually has only one active source per array. An analogous situation exists for active filters that determine a receiver's bandpass characteristics. Moreover, microprocessor control for each active element would add real-time response to spectrum management capability.

ACTIVE DEVICES

The dominant role of silicon technology in low-cost integrated circuitry presently extends to about 2.5 GHz, and with improved fabrication may go above 10 GHz.[663] Presently, gallium-arsenide devices are extending monolithic microwave integrated circuit (MMIC) technology to higher frequencies despite the higher cost of the starting up material.[664] Meanwhile, a low-cost silicon MMIC with cutoff frequency approaching 20 GHz has been proposed for wireless systems.[665] At least for the next decade, silicon and galium-arsenide are the semiconductor materials on which MMIC technology is being extending into the higher frequencies.

Upgraded microwave power devices appear to be adequate as power sources for most millimeter wave applications at least to 300 GHz. Sources can be divided into vacuum tube and solid state devices, with the former being the primary means of generating power greater than about 20 W. Slow-wave devices (klystrons, magnetrons and traveling wave tubes) have a mature technology compared to the gyrotrons and the newer fast-wave devices for power applications. However, the requirement for scaling down by a factor inversely proportional to frequency, imposes limits on the amount of power that can be handled by a

---

[661] A. Boulouard et al., *Microstrip Antenna Modeling*, MICROWAVE & RF, Jan. 1993, at 44-45.

[662] P. BHARTIA & I.J. BAHL, MILLIMETER WAVE ENGINEERING AND APPLICATIONS 341 (1984).

[663] NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, U.S. DEP'T OF COMMERCE, NISTIR 4583, MEASUREMENTS FOR COMPETITIVENESS IN ELECTRONICS 160 (1993); J.S. Mayo, *Materials for Information and Communication*, SCIENTIFIC AMERICAN, Oct. 1986, at 59-65.

[664] NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, *supra* note 663 at 161 (1993); C. Huang, *MMIC's Move Into New Marketplaces*, MICROWAVE & RF, Sept. 1992, at 136.

[665] S. Rynas, *Silicon MMICs Add Low-Cost Power to Wireless Systems*, MICROWAVE & RF, May 1992, at 199.

miniaturized device; hence, power generation at higher frequencies may depend on more efficient designs such as the fast-wave devices. Presently, traveling wave tubes for satellite broadcasting at 12 GHz are commercially available at 100-W continuous wave output,[666] and the capability to go into the EHF range has been demonstrated experimentally.

The trend toward more efficient high-power satellite transmitters at higher frequencies is enabling earth stations to function with smaller, more portable antennas; but proliferation of these VSAT-like stations may pose spectrum management problems in the future. For any given frequency, a VSAT antenna is subject to greater interference than a larger antenna because of its poorer directional discrimination.

For low power generation, such as in receiver circuits, improved versions of solid-state devices appear adequate for the millimeter band at least to the year 2000. Specific examples are the impact avalanche and transit time (IMPATT) diode, a variation of the avalanche oscillator, which can operate across the band at pulsed power of 20 W or better, and the transferred electron oscillator (familiarly called the GUNN diode), with somewhat less output and a more restricted frequency range.

Millimeter receiver circuits still largely depend on solid state technology. The familiar gallium arsenide (GaAs) field-effect transistor (FET), improved by better production techniques, can perform well into the lower millimeter band. Better-designed Schottky-barrier diodes are still usable as detectors and mixers. Research to increase receiver sensitivity by cooling circuits to reduce the intrinsic temperature noise is being carried out on Schottky diodes and Josephson junctions.[667] In digital circuitry, reduced bit-error-rates were reported for cooled GaAs metal-semiconductor (MES) FET's at 38 GHz.[668]

Some of the latest advances in broadband millimeter wave technology have been in low-noise high electron mobility transistor (HEMT) technology. At Comsat Laboratories, Clarksville, MD, a HEMT amplifier successfully generated a broadband (60 GHz) signal for an optical phase shifter designed to control transmission line phase variations.[669] In another report, a HEMT GaAs MMIC amplifier with a gain greater than 10 dB from 14 to 44 GHz had a noise figure of only 4 dB at 35 GHz.[670] MMIC technology also brings in the microprocessor control of millimeter components and devices. The subsequent control of telecommunication systems at all levels of complexity is the next step in the management of the spectrum.

---

[666] J. Browne, *Tubes Continue the Chase for Power, Gain and Bandwidth*, MICROWAVES & RF, Mar. 1990, at 152; W.R. House, *Electron Tubes Serving Ku-Band Space Communications*, VIA SATELLITE, Feb. 1991, at 42-43 (discussing the advantages of improved TWT's); J. Auboin & W.R. House, *DBS Satellite Tubes*, VIA SATELLITE, July 1993, at 48 (stating that overall efficiency of high-power tubes was increased from 40-45 percent to 62 percent in early 1992).

[667] Pacific Telesis Comments at 20. Semiconductor cryogenics may eventually be practical for at least base (fixed) stations.

[668] *Cryogenic Test Characterizes GaAs MESFET Noise Performance*, MICROWAVES & RF, Mar. 1993, at 62.

[669] *Id.*

[670] Jack Browne, *HEMT Devices Fuel 26-40 GHz GaAs MMIC Amplifier*, MICROWAVES & RF, Mar. 1993, at 149.

Optical components and devices are attractive supplements to solid-state electronic circuitry because of their extremely wideband characteristics. Although usually associated with fiber optic transmission lines, they are also being integrated with electronic components and devices. Some quasi-optical components developed for the millimeter wavelengths are beam waveguides, attenuators, and polarization rotators. In small scale systems, optical switches have had definite success due to their high throughput, high-speed response, and immunity to electromagnetic interference. Incorporation into large-scale systems, such as those in commercial telephone central offices, will require careful analysis at all system levels.[671]

The technology of components and devices extending into the millimeter band (30-300 GHz) appears to satisfy spectrum needs at least to the year 2000. The uncrowded conditions in these higher frequencies have furthered the development of broadband systems using solid-state as well as optical techniques.

SUMMARY OF TECHNOLOGIES THAT EXTEND THE USABLE SPECTRUM TO HIGHER FREQUENCIES

The salient points of this chapter are summarized as follows:

- *Communication links requiring long-term reliability, such as those in the fixed-satellite service, will be most affected by greater rain attenuation at higher frequencies. The fixed and mobile-satellite service links will also be affected by rain in horizontal and low-elevation angle paths.*

- *The performance of dual-polarization and digital systems of the satellite services can be degraded by the ice-crystal clouds commonly found in Earth-satellite paths. These clouds depolarize radio waves at frequencies above 10 GHz.*

- *Above 30 GHz, the relatively high attenuation of radiowaves by atmospheric gases has spectrum-saving implications, such as a smaller cell size for PCS applications. But the effect of rain, a more severe and unpredictable factor, will need to be considered also.*

- *The absorption of radiowaves by atmospheric gases at certain frequencies can be used to isolate space and terrestrial radio systems. For example, a satellite-to-satellite link could operate co-channel with a point-to-point terrestrial link at these frequencies.*

- *Above 20 GHz, the small antenna apertures of VSAT's are more susceptible to the effects of the atmosphere than the larger antenna apertures in current use. Notably, digital transmissions are affected by scintillation and fade.*

---

[671] S.F. Su et al., *A Review on Classification of Optical Switching Systems*, IEEE COMMUNICATIONS MAGAZINE, May 1986, at 50.

- ❑ *During the next several years, silicon and gallium-arsenide will compete as semiconductor materials for the extension of MMIC and wireless technology into the higher frequencies.*

- ❑ *Improved microwave tube and solid state power devices appear to adequately serve spectrum needs at higher frequencies, at least to the year 2000. The trend toward smaller dishes for VSAT's and other earth stations is due, in large part, to the development of efficient high-power transmitters for Earth-orbiting satellites.*

- ❑ *The integration of solid-state and optical components and devices with MMIC technology appears to be meeting the spectrum needs of low power systems through progress in such important applications as wideband digital MMIC. In the future, microprocessor control of large-scale MMIC systems will add real-time response to spectrum management capabilities, such as the alteration of receiver passband characteristics.*

CHAPTER 9

MODULATION AND MICROPROCESSOR-BASED TECHNOLOGIES

INTRODUCTION

Advances in semiconductor technology are major forces behind innovations in radiocommunications. New types of modulation, new uses for microprocessors, and other digital applications have, in turn, led to spectrally efficient radio systems.[672]

The distinction between modulation and microprocessor-based technologies is blurring with the trend to all-digital systems and microminiaturization of electronic devices and components. This is most apparent in the wideband systems conceived in the vacuum-tube era (*e.g.*, spread spectrum), whose commercial realization came only with digitization and integrated circuitry. Microprocessors are a necessity rather than an adjunct for digital systems. For instance, central processing units (CPU's) control the spreading and despreading of a coded bit stream, a function that is not usually required in simpler modulation schemes.[673]

Spectrum-efficient technologies useful for mobile communications were reviewed in a recent NTIA report.[674] Many of the same technologies mentioned in that report are discussed herein. The first, *Modulation Technologies*, begins with narrowband methods and ends with ultra-wideband techniques. Then, under *Microprocessor-Based Technologies*, the focus will be on topics in the NOI comments, starting from baseband processing and ending with whole systems.

From the sprectrum management viewpoint, the sharing of spectrum between wideband and narrowband systems in the decade ahead is probably the most serious issue identified in this chapter.

---

[672]Kenneth Crisler & Allen Davidson, *Impact of 90's Technology on Spectrum Management*, IEEE INTERNATIONAL SYMPOSIUM OF ELECTROMAGNETIC COMPATIBILITY, Aug. 1993, at 401. Improvements in semiconductor technology is traced to spectrum efficiency, primarily in land mobile radio.

[673]Kazuo Tsubouchi, *Application of Spread Spectrum Communication and Its Devices*, ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1, May 1992, at 62. This article discusses spreading and despreading techniques and devices.

[674]COHEN ET AL., *supra* note 34.

MODULATION TECHNOLOGIES

NARROWBAND DIGITAL TECHNOLOGY

Large gains in spectrum efficiency are possible by digital speech within the limits of a conventional 25-kHz channel. One example is the application of quadrature phase-shift keying compatible (QPSK-C) modulation to reduce the bandwidth requirements by one-half.[675]

The Enhanced Specialized Mobile Radio (ESMR) system recently fielded in several metropolitan areas shows promise as a very efficient spectrum saver.[676] A TDMA transmission will create six digitized voice channels in place of a single 25 kHz channel. Within a multiple low-power base station configuration, approximately six times the customer capacity of existing systems is claimed by the proponents of the ESMR system.

HIGH-LEVEL DIGITAL MODULATION TECHNOLOGY

The demand for more information transmittal can be technically translated into more bits per second within a prescribed bandwidth. For the fixed service where the challenge of spectral efficiency and cost has been great, quadrature amplitude modulation (QAM) is the apparent choice over other alternatives with 256 QAM level commercially available now.[677]

The lack of higher-power linear amplifiers is limiting the move to 512 QAM and above for terrestrial fixed service since forward error correction and other techniques to overcome non-linearity are now optimized for 256 QAM.[678] This is a common problem for all high-level digital modulation requiring linearity across megahertz-wide channels. In satellite broadcasting, digital compression allows several TV signals in place of one analog channel; however, distortion may result when more than one carrier is processed by a satellite multiplexer. Improved traveling wave tubes and feed-forward, feed-back, and predistortion linearizers are promising solutions to high-level linear amplifiers, at least up to 20 GHz.[679]

---

[675]Timothy G. Twohig, *How digital radio affects trunked radio systems*, MOBILE RADIO TECHNOLOGY, July 1992, at 26.

[676]Fleet Call Comments at 4.

[677]Alcatel Comments at 12. Alcatel considers the development of 256QAM to be optimal at the present time with little room for improvement. *See also* B. Manz, *Digital Radio Advances to the Next Plateau*, MICROWAVES & RF, Dec. 1988, at 59 (comparing high-level and low-level QAM and other modulations).

[678]Alcatel Comment at 12; MANZ, *supra* note 677 at 63.

[679]MANZ, *supra* note 677 at 74-75.

SPREAD SPECTRUM AND MULTIPLE-ACCESS MODULATION

Spread spectrum (CDMA) modulation spreads a signal across a band that is considerably wider than the information bandwidth. This results in a signal having a low-power spectral density in any narrow portion of the band.[680] Nevertheless, commenters in NTIA's *Inquiry* are concerned about such a wide signal sharing spectrum with non-CDMA spectrum users.[681] One developer of TDMA systems comments that a spectrum saving of up to 20 times, as claimed by spread spectrum proponents, needs validation, and the feasibility of sharing with non-CDMA systems awaits further field testing.[682] One commenter indicated that the optimum bandwidth of 8 kb/s coded voice traffic ranges from 1 to 3 MHz, so wider-range CDMA would not be able to accommodate more users on a per megahertz basis.[683]

Developers of spread spectrum equipment are also among the commenters.[684] One typical CDMA system soon to be field demonstrated is designed to locate land mobile radio vehicles in a band shared with other LMS systems.[685] Aside from the signal-to-noise advantage of high processing gain,[686] CDMA has good rejection of unwanted signals and a high degree of security.[687]

Other multiple access systems conserve spectrum within the bandwidth limits imposed on narrowband modulation and require no spectrum sharing to be implemented. From the comments to the NOI and the open literature, digital TDMA appears to be a favorite replacement for time-honored analog FM modulation in mobile radio.[688] Frequency division multiple access (FDMA) is also a contender in the mobile and mobile-satellite service.

---

[680]For a digital data rate of 1 kb/s, the information bandwidth would be about twice this rate or 2 kHz. Spreading the signal over 1 MHz (a typical low value for existing spread-spectrum systems) yields a ratio of 500:1.

[681]*E.g.*, Motorola Comments at 28; NSF Comments at 23-24.

[682]Motorola Comments at 28.

[683]GTE Comments, Attachment A at 9-10.

[684]*See, e.g.*, SCS Comments at 2; Pinpoint Comments at 2.

[685]Pinpoint Comments at 1-4. For another commercially developed burst-signal CDMA vehicle tracking system, see B. Xenakis & A. Evans, *Vehicle Locator Uses Spread-Spectrum Technology*, RF DESIGN, Oct. 1992, at 58-65.

[686]P.M. Schumacher, *Understand the Basics of Spread-Spectrum Communications*, MICROWAVES & RF, May 1993, at 149. "The number of CDMA users of a communication channel . . . is directly related to the process gain" wherein, process gain is defined as the channel capacity divided by information volume. *Id.*

[687]E. Worthman, *The Spreading of Spectrum*, COMMUNICATIONS, Jan. 1991, at 29.

[688]*See, e.g.*, Fleet Call Comments at 4; Motorola Comments at 7; Ericsson Comments at 3. The merits of TDMA versus CDMA for next-generation mobile communications (including cellular and PC systems) was reviewed in Gen Marubayashi, *Recent Research and Development Activities on Spread Spectrum Communication Systems*, ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1, May 1992, at 54.

ULTRA-WIDEBAND TECHNOLOGY

Ultra-wideband radar and radio systems transmit one to a few extremely short duration pulses of a nanosecond or slightly longer. These pulses require a bandwidth of 50-100 percent or more of the center frequency and may span across bands allocated to several services.[689] By contrast, conventional radio has a bandwidth of 10 percent or less. Two recent examples of ultra-wideband systems are a synthetic aperture radar operating at the relatively low frequency band of 20-90 MHz useful for ground and foliage penetration,[690] and a commercial communications radio that transmits a single non-sinusoidal nanosecond pulse with a bandwidth of 1 GHz (see Figure 9-1, where peak energy is at f_c).[691]

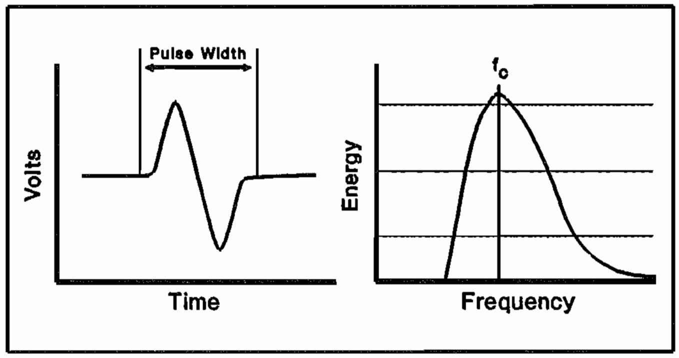


Figure 9-1. A Gaussian monocycle in the time and frequency domain

By spreading signal energy broadly across the spectrum, as in wideband spread spectrum emission, impulse radio has the same advantages of extremely high processing gain and relative immunity to fading. The implementation of pseudorandom coding (also common in spread spectrum applications) can add the desirable features of easy encoding and near-orthogonal discrimination of transmitted signals.[692]

However, at frequencies below several gigahertz, the ultra-wide bandwidth (on the order of a gigahertz) requires sharing the spectrum with many services using narrow and wideband systems. At this time, field tests against conventional narrowband and other new technology wideband systems would help to assess the spectrum sharing capabilities of ultra-wideband radar and radio. Also, tutorials published in widely-read professional journals can help spectrum managers understand this relatively little-known technology.[693]

---

[689]DOD comments at 10; Pulson Comments, Exhibit C at 3.

[690]Bruce D. Nordwall, *Swedish-Developed Radar to Penetrate Foliage, Ground*, AVIATION WEEK & SPACE TECHNOLOGY, Jan. 18, 1993, at 52.

[691]Pulson Comments, Exhibit C at 3. The pulse is termed a Gaussian monocycle because it is the first derivative of the Gaussian function as opposed to one gated cycle of a sine wave.

[692]Pulson Comments at 4, 5. A Modulating signal is made to change the pulse repetition interval in proportion to its strength.

[693]D. Lamensdorf & L. Susman, *Baseband-Pulse-Antenna Techniques*, IEEE ANTENNAS AND PROPAGATION MAGAZINE, Feb. 1994, at 20. According to the authors and others, frequency-domain methods commonly used for narrow-band analysis are "questionable for an instantaneous wide-band excitation. Time-domain and/or wide-band analyses can provide more insight and more effective terminology." *Id.* at 29.

MICROPROCESSOR-BASED TECHNOLOGIES

DIGITAL COMPRESSION

Digital compression is a technique to reduce the bandwidth of an existing analog or digital channel by eliminating redundant information. It has significant implications for spectrum management because the technique works within the requirements of existing bandwidths. Compression is done on raw digitized information within a piece of equipment, and output can be to many types of digital processing equipment.

Comments to our *Inquiry* on compression technology came from several sources. Most were favorable, but none saw it as a panacea for spectrum sharing. In fact, a few cautioned that it would not lessen the demand for spectrum.[694] Compression removes audio or visual information that is redundant or irrelevant to the user's perception of quality reception. In digital audio broadcasting, as much as 80 percent of the raw data may be removed and still maintain a CD-quality performance.[695]

The greatest savings in spectrum is in digital video compression. Generally, the raw digitized data (bits or pixels) are partitioned into blocks which are periodically tested for redundancy; then bits are kept or discarded as necessary. Using video compression, one satellite transponder is said to carry up to 18 conventional TV channels, and requires only a bandwidth of 2 MHz to send a high-quality full-motion NTSC TV signal.[696]

DIGITAL TRUNKING TECHNOLOGY

Trunking, a concept borrowed from the wire telephony, maximizes the use of radio channels or trunks by assigning a call to an idle channel within a dedicated block of channels. The spectrum efficiency afforded by trunking techniques applied to the land mobile service was reported recently in a NTIA publication.[697] There is general agreement among the Notice commenters that mobile assignments not critical to safety or emergency service would benefit from trunking.[698]

---

[694] *See, e.g.*, SBCA Comments at 15-16; GTE Comments, Attachment 5 at 2.

[695] IEEE—USA Comments at 2.

[696] J.D. Lakin, *Dueling Digital Video Compression Products*, VIA SATELLITE, Nov. 1991, at 60.

[697] SPEIGHTS ET AL., *supra* note 11.

[698] *See, e.g.*, DOD Comments at 14. Trunking "is an excellent example of the application of technology to substantially raise the overall efficiency of spectral use." *Id.* at 14.

Spectrum efficiency can be enhanced by digitizing trunked radio systems. For a trunked channel, this enables control and voice information to be sent simultaneously. In one example, half of the channel capacity of 9.6 kbps is required for voice information leaving the rest for control signaling, error correction, and other functions.[699]

Also important from the spectrum management viewpoint is the flexibility afforded by digital trunking in accommodating voice and data traffic on a real-time basis. A typical example is a recently introduced high-capacity trunking system that can control a mix of mobile radios, portable sets, and fixed console positions through two computers and a network of radio repeaters.[700] This system reportedly can handle up to 50 repeater sites, and existing trunking systems.

CELLULAR AND PCS TECHNOLOGY

Comments to the *Inquiry* on mobile cellular and portable PCS technology were mainly focused on ways to facilitate band sharing among a mix of wideband and narrowband systems, and also with the fixed and mobile-satellite service. A favorite topic of commenters was the dynamic control of spectrum resources, *e.g.*, transmitter power, channel and frequency switching, and antenna directionality. Two important topics brought up were the control of transmitter power and the lack of data on channel characteristics.

The comments received on controlling power include one on mobile operations near fixed microwave receivers which will be discussed in detail later.[701] In anticipating the overlaying of fixed and mobile channels, developers of cellular CDMA equipment have added power control to their mobile sets.[702] In one "open-loop" design, the mobile set adjusts its transmitted power only according to the received signal strength.[703] A more complex design features a closed loop for adjusting a mobile unit's power to the minimum for acceptable signal quality within a cell, and an open loop for smoothing the transition from cell to cell.[704]

One of the more pressing technical problems facing the cellular and PCS sector is the lack of information on the channel characteristics required for delivering high-traffic continuous service approaching

---

[699]TWOHIG, *supra* note 675, at 26-27.

[700]Paul Nauman & Steve Norwood, *A New Dimension in Trunking*, GLOBAL COMMUNICATIONS, Nov.-Dec. 1992, at 25.

[701]Southwestern Bell Comments at 22, 23.

[702]The near-far problem within an all spread-spectrum system is also an area of active research. *See, e.g.*, Yu-Dong Yao et al., *Near/Far Effects on Packet Radio Networks With Direct-Sequence Spread-Spectrum Signaling*, IEEE PACIFIC RIM CONFERENCE ON COMMUNICATIONS, COMPUTERS & SIGNAL PROCESSING, June 1-2, 1989, at 122.

[703]SCS Comments, Appendix C at 4-5. This design developed for PCS devices is called an "adaptive power control" (APC). In addition, SCS has patented a notch filter for excluding a spread spectrum signal from designated narrowband frequencies.

[704]K.S. Gilhousen, *Mobile Power Control for CDMA*, COMMUNICATIONS MAGAZINE, Jan. 1992, at 36. The closed loop signal-to-noise ratio (SNR) received at a cell is monitored and a power command sent every 1.25 msec (800 b/s) to the mobile unit. The developer QUALCOM states that with a ±24 dB dynamic range and a 800 b/s bit stream, the loop can keep up with the fast multipath changes induced by conventional Rayleigh fades. A coarser open loop control adjusts for different cell sizes and cell-to-cell handoffs.

wire-telephone quality.[705] The transmission environment encountered by users in motion when passing into and around large obstructions is a demanding one. High propagation loss, multipath from many directions, and the fluctuations caused by motion of the user are but a few characteristics that determine such factors as the choice of modulation (narrowband or wideband), location of fixed antennas (utility pole or mast), and type of service (video, voice, or data). Some trends and challenges brought out in a review of wireless communication were as follows:[706]

- ❑ The need for PCS propagation models that account for antenna patterns and wave polarization. The bandwidths investigated should be at least a few megahertz in order to match the needs of wideband systems.

- ❑ Emphasis is required on the development of adaptive antennas, antenna-diversity techniques and algorithms for real-time control in a changing environment.

- ❑ The need for better experimental data on the health-risk of cellular and PC devices in close proximity to humans.

EXAMPLES OF DYNAMIC CONTROL OF SPECTRUM RESOURCES

Upgrading the ALE radios used on HF frequencies should lead to substantial spectrum savings according to commenters.[707] The present ALE radios have spectrum-efficient selective calling and frequency selection features. By adding chirp capability, frequency channels may become even more efficiently selected[708] and the idle time on a channel reduced. Chirp is the periodic linear sweeping of the HF band for a fixed point-to-point HF link to establish the maximum usable frequency (MUF) for the path. Other dynamic control systems use different methods to monitor the HF path.[709]

The Intelligent Multiple Access Spectrum Sharing (IMASS) is an example of an active avoidance technique which reclaims underutilized frequencies assigned to fixed microwave services for use by new

---

[705] J. Shapira, *Channel Characteristics For Land Cellular Radio, and Their Systems Implications*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Aug. 1992, at 7.

[706] Theodore S. Rappaport, *Wireless Personal Communications: Trends and Challenges*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Oct. 1991, at 27.

[707] DOD Comments at 14; DOJ Comments at 5.

[708] DOJ Comments at 5. Chirp is the periodic linear sweeping of the HF band for a fixed point-to-point HF link to establish the maximum usable frequency (MUF) for the path.

[709] *See, e.g.*, A.P. Clark & S. Hariharan, *Efficient Estimators for an HF Radio Link*, IEEE TRANSACTIONS ON COMMUNICATIONS, Aug. 1990, at 1173; D. Mark Haines & Bert Weijers, *Embedded HF Channel Probes/Sounders*, IEEE PROCEEDINGS OF MILCOM'85, Oct. 20-23, 1985, at 12.1.1.

mobile services on a shared basis.[710] This "active avoidance" technique employs a special receiver to scan the microwave channels in an area of fixed microwave systems. Actual measurements are made to determine the amount of RF isolation between mobile and fixed radios, and any available channels are temporarily assigned to low-power mobile networks. IMASS is designed to accept only certain FDMA, TDMA, and narrowband CDMA protocols. On the basis of current information, broadband overlay service (wideband CDMA and impulse radio) is not generally recommended for operation in high-concentration fixed microwave areas.[711]

SUMMARY OF MODULATION & MICROPROCESSOR-BASED TECHNOLOGIES

The salient points of this chapter are summarized as follows:

- ❑ *Savings in spectrum is still possible within the limits of a conventional narrowband channel by digitization and compression techniques. This trend is expected to continue during the next decade.*
- ❑ *Efficient use of the spectrum is obtainable by digital trunking, high-level digital modulation, and multiple access systems. This trend will increase during the forseeable future.*
- ❑ *Extremely wideband systems spanning several megahertz or more need to be extensively field tested with narrowband systems to show whether overlaying is feasible and band sharing possilble.*
- ❑ *Flexible control of transmitter power in mobile sets is a spectrum management tool under active development, especially in cellular CDMA equipment. The cellular and PCS sector needs more information on the channel characteristics required for delivering quality high-traffic continuous service to their customers.*
- ❑ *Spectrum efficiency is aided by the microprocessor control of spectrum resources, such as transmitter power, frequency selection, and receiver bandwidth. This trend will probably spread to all telecommunications services in the next decade.*

---

[710] Southwestern Bell Comments at 16.

[711] Southwestern Bell Comments at 23.

CHAPTER 10

ANTENNA AND PROPAGATION TECHNOLOGIES

ANTENNA TECHNOLOGY

Antenna design, long thought of as a static area of engineering research, has undergone accelerated growth in recent times through the use of computer-aided design (CAD). Antennas can now be designed as self-optimizing systems that respond to changes imposed by man and nature, rather than simply acting as passive couplers between the external environment and electronic equipment.

According to several comments to our *Inquiry*, an antenna's ability (or inability) to alter its radiation pattern is probably its most important characteristic from a spectrum management viewpoint.[712]

With the trend toward higher frequencies (hence antennas of smaller physical size), adaptive antenna designs are becoming easier to implement, since antennas will interact less in an unpredictable way with their immediate environment. Progress in simple applications is reaching a point where no clear distinction can be made between the antenna and its surroundings; for example, slot antennas can be designed flush with the surfaces of personal communicator cases (Figure 10-1).

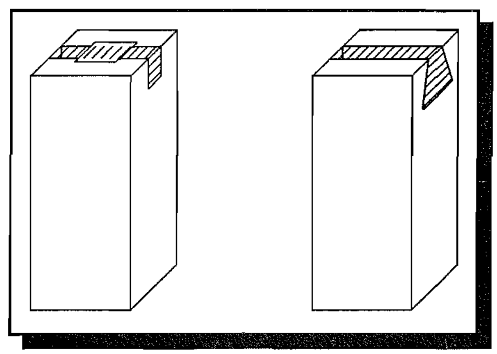


Figure 10-1. Personal communicators with slot antennas

In the future, the space-time alteration of an antenna's radiation pattern, both in transmission and reception, will become a powerful tool for spectrum management. The emphasis of this

[712]IEEE—USA Comments at 1, 2. The *Technologies* part of the comments was prepared by the IEEE Antennas & Propagation Society. Some advanced antenna technologies mentioned were electronic beam steering (as opposed to mechanical motion), distributed power sources in each array element rather than one source for the array, and shaped-beam patterns permitting frequency reuse (*i.e.*, orthogonal polarity isolation). NASA Comments at 38. Antennas are mentioned by NASA with respect to beam-hoppers for the ACTS satellite and phased-array antennas for mobile earth stations.

section is on electronically controlled antennas where most of the new technological work is being done, and ends with developments in extending the bandwidth of antennas to accommodate emerging wideband systems.

ELECTRONICALLY-CONTROLLED ANTENNAS AND ARRAYS

The greatest activity in antenna technology appears to be in arrays, especially electronically-steered phased arrays.[713] This trend is readily seen in the sophisticated conformal designs developed for aircraft and land vehicles communicating with satellites moving in non-synchronous orbits.[714] An array is defined as a group of identical elements activated to produce (or receive) a prescribed overall field pattern.[715]

Several comments stressed the importance of developing arrays that can maximize or minimize gain in different directions in real time.[716] The following discussion on emerging array technology generally supports the view of the commenters.

ADAPTIVE ANTENNA ARRAYS

The topic of adaptive arrays goes back at least 30 years.[717] Today, after a long period of development, adaptive arrays are meeting the requirements of the burgeoning mobile-satellite services. An adaptive array is defined as a collection of antenna elements, each connected in a feedback loop to a weighting and summing network. The network algorithms automatically reduce the effect of an unwanted signal or enhance a desired one. These algorithms still occupy much of the research effort in adaptive arrays, but work is being done on hardware as well.[718]

SCANNING PHASED ARRAYS

A phased array generally has one control element for each array element making the cost relatively high compared to other beamforming techniques.[719] The phased array appears to have an advantage over the

---

[713]James R. James, *What's New in Antennas?*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Feb. 1990, at 6, 11.

[714]*See, e.g.*, Wataru Chujo et al., *Conformal Array Antenna for Mobile Satellite Communications*, ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1, Aug. 1992, at 97. A conformal array is one that is aerodynamically shaped to fit on a moving body.

[715]IEEE DICTIONARY, *supra* note 494, at 53.

[716]IEEE—USA Comments at 1-2; SBCA Comments at 19; Bell Atlantic Comments at 9-10; GTE Comments, Attachment A at 9; NASA Comments at 38; Pacific Telesis Comments at 25.

[717]Irving S. Reed, *Brief History of Adaptive Arrays*, PROCEEDINGS MILCOM '85, Oct. 20-23, 1985, at 28.1.1.

[718]*See, e.g.*, J.P. Daniel et al., *Research on Planar Antennas and Arrays: "Structures Rayonnantes"*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Feb. 1993, at 14 (discussing integration of planar arrays and MMIC design).

[719]P.S. Hall & S.J. Vetterlein, *Review of Radio Frequency Beamforming Techniques For Scanned and Multiple Beam Antennas*, IEE PROCEEDINGS-H, Oct. 1990, at 293, 301.

mechanically steered reflector antenna due to its ability to beamshape electronically. This is generally true if the performance specifications are modest, as in INMARSAT applications.[720]

Accurate electronic control at each antenna element is the key to reconfiguring the radiation pattern of an array. The next-generation communication satellites are designed with steerable phased arrays having beamforming networks digitally switched by phase-shifters and attenuators.[721] Phase and amplitude controls have reached a level where MMIC chips have switching accuracies better than 5° and 0.5 dB across a 8 percent bandwidth.

The implementation of phase-only control for telecommunications and EMC is significant.[722] Since phase is easier to control electronically than amplitude (where power is handled), circuit miniaturization is greatly simplified, notably for multi-element arrays. The ability of one antenna to produce two or more radiation patterns (*e.g.,* cosecant and pencil-beam) on demand and in prescribed directions has obvious application in the mobile and satellite services. For example, an earth station could avoid interference from an orbiting satellite by switching from an omnidirectional to a cardioid pattern when the satellite is in view.

MULTIPLE-BEAM ANTENNAS

Historically, multiple-beam antennas and scanning phased arrays have been competing approaches to pattern forming. A multiple-beam antenna differs in requiring one port for each beam and a reflector or lens aperture. With good isolation between ports, the multiple-beam antenna (being based on time-proven design) is probably a better choice when the requirement is only for a few independently switchable beams, as with the ACTS space platform and most Earth-based systems. But tens of beams are planned for future satellites, and the added weight and volume of hardware required for a multiple-beam antenna makes the active phased array a very viable alternative.[723]

Presently, the most sophisticated designs in beamformers combine a scanning reflector with a phased-array feed in a hybrid arrangement. Broad, instantaneously tunable bandwidths, and good control of amplitude and phase of the aperture illumination, have recently been reported in the literature.[724] But there

---

[720] P.V. Brennan, *Low Cost Phased Array Antenna for Land-Mobile Satcom Applications*, IEE PROCEEDINGS-H, April 1991, at 131. This low-cost design is an example of a high-gain electronically steerable array that may replace conventional low-gain vehicular whip antennas.

[721] M.T. Moore & P. Miller, *Microwave IC Control Components for Phased-Array Antennas*, IEE ELECTRONICS & COMMUNICATION ENGINEERING JOURNAL, June 1992, at 123.

[722] Ovidio M. Bucci et al., *Reconfigurable Arrays by Phase-Only Control*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, July 1991, at 919. This paper points to the possible attainment of practical phase-only control in a few years.

[723] *Future Directions of Satellite Communications Applications and Technologies*, J.W. Bagwell, Institute for Electrical, Aerospace, and Electronic Engineers & George Washington University, National Telesystem Conference, Washington, D.C. (May 19-20, 1993).

[724] Richard M. Davis et al., *A Scanning Reflector Using an Off-Axis Space-Fed Phased-Array Feed*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, March 1991, at 391.

are still problems common to most hybrid antennas, *e.g.*, the dynamic control of aperture amplitude. However, these appear tractable in the near future.

BROADBAND ANTENNAS

In the 1950's, it was shown that an antenna could be relatively frequency independent (*i.e.*, broadband) if its shape could be specified by smoothly changing physical dimensions.[725] This led to the invention of broadband angle-dependent antennas such as the omnidirectional spiral and cone antennas, and the directional multi-wire log-periodic and planar-dipole arrays. These appear satisfactory for the relatively wide bandwidth requirements of spread spectrum and multiple access systems.

In the near future, mechanically-steerable log periodic and dipole arrays may successfully compete with electronically steerable phased arrays for tracking LEO satellites. Low-cost rotatable Yagi arrays have been developed for mobile satellite use.[726] But Yagis are inherently narrowband and may not be suitable for the wideband requirements of some proposed systems. Instead, mechanically steerable wideband wire antennas may be a better choice until electronically steerable phased arrays are developed for widespread use.

For a bandwidth ratio of three-to-one or more, conventional antennas, such as discones and spiral cones, can meet an omnidirectional criterion for signal magnitude. For the additional control of phase across the band needed for digital systems, the conical antenna appears to be a more suitable choice.[727]

Directive antennas, on the other hand, have the problems of poor compatibility with the feedline, high cross-polarization, and poor control of beamwidth when operated over a wide band. One solution uses microwave components combined in a novel way.[728] Since this design is based on conventional microwave technology, extension to 18 GHz and beyond requires close attention to construction techniques and dielectric characteristics.

---

[725] V.H. Rumsey, *Frequency Independent Antennas*, IRE (IEEE) NATIONAL CONVENTION RECORD, PART 1, 1957, at 114. A broadband antenna is taken to have a highest-to-lowest operating frequency ratio of at least two to one.

[726] *See, e.g.*, John Huang & Arthur C. Densmore, *Microstrip Yagi Array Antenna for Mobile Satellite Vehicle Application*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, July 1991, at 1924; John Huang, *Microstrip Yagi for mobile satellite service*, ELECTRONICS WORLD, Feb. 1992, at 171.

[727] R.H.T. Bates & G.A. Burrell, *Towards Faithful Radio Transmission of Very Wide Bandwidth Signals*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, Nov. 1972, at 684. A phase-corrected conical monopole is proposed as a solution to the design of an omnidirectional antenna focussed in the vertical plane. James G. Maloney & Glen S. Smith, *Optimization of a Conical Antenna for Pulse Radiation: An Efficient Design Using Resistive Loading*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, July 1993, at 940.

[728] Albert K.Y. Lai et al., *A Novel Antenna for Ultra-Wide-Band Applications*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, July 1992, at 755. This design employs a wideband slotline transmission guide opening into bowtie antenna whose arms are folded into a horn with a rolled edge.

The self-complementary antenna holds some promise as a directive wideband radiator. Consisting of two complementary parts fed at a common point, this antenna type has a constant input impedance over a wide band and can be ideally designed for any desirable radiation pattern.[729] However, its phase characteristics need more study before the antenna can find acceptance as a distortion-free short-pulse emitter.

PROPAGATION TECHNOLOGY

Only about a dozen comments to our *Inquiry* explicitly addressed propagation technology.[730] Implicit in these replies was the need for radio systems to attain a real-time response to changing propagation conditions. This section is presented from a spectrum management viewpoint with this need in mind.

Propagation technology is directed at producing better models to explain and predict the behavior of radio waves in the natural and manmade environment. Models are often semiempirical because of the difficulty in describing the environment. In recent years, these models have been improved with numerical computation afforded by the availability of fast computers. Propagation models will be discussed in terms of three broad frequency bands: 10 kHz to 30 MHz, 30 MHz to 10 GHz, and above 10 GHz. Propagation is mainly affected by the ground and ionosphere in the first band and by the atmosphere in the last band. From a spectrum management standpoint, the least affected middle band is the most important because most spectrum usage is occurring in the 30 MHz to 10 GHz region and this will probably continue to be the case past the year 2000.

PROPAGATION BETWEEN 10 KHZ AND 30 MHZ

Radio waves propagate primarily along the Earth's surface in the lower part of this band. A refined empirical expression based on ground permittivity is the accepted surface-wave model today and probably into the near future.[731]

In the upper parts of the band, the dominating sky-wave propagation between two points on Earth depends on the launch angle, frequency and ionosphere. Since the angle and frequency can be controlled, knowledge of the spatial and temporal distribution of electrons making up the ionosphere is central to predicting sky-wave propagation. The short-term prediction needed by adaptive radio systems is aided by providing better input data to accepted models such as the Ionosperic Communications Analysis and

[729] Yasuto Mushiake, *Self-Complementary Antennas*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Dec. 1992, at 23.

[730] *See, e.g.*, IEEE—USA Comments at 2 (pertaining to indoor communication); DOE Comments at 9, 10 (multipath, channel coherence, and other specifics); SBCA Comments at 11 (wide coherent bandwidths).

[731] P. Knight & J.A.W. Robson, *Empirical Formula For Groundwave Field-Strength Calculation*, ELECTRONICS LETTERS, Aug. 30, 1984, at 740; INTERNATIONAL RADIO CONSULTATIVE COMMITTEE, INTERNATIONAL TELECOMMUNICATION UNION, RECOMMENDATION 368-7, GROUNDWAVE PROPAGATION CURVES FOR FREQUENCIES BETWEEN 10 KHZ & 30 MHZ, at 48 (1992).

Prediction (IONCAP) program,[732] as well as programs specifically designed for shorter-term prediction, such as PROPHET.[733]

The direct monitoring of the short-term behavior of ionospheric propagation paths is accomplished by special ionosondings or by channel "probes" embedded in the signal itself.[734] The monitoring data become inputs not only to propagation models, but can be used directly by efficient users of HF channels, such as the ALE system.[735]

PROPAGATION BETWEEN 30 MHZ AND 10 GHZ

Generally, as the frequency increases from 30 MHz to 10 GHz, the ionosphere appears more transparent to radio waves. The properties of optic waves (such as reflection, refraction, and diffraction) assume importance at these frequencies, and topographic features affect propagation.

TERRESTRIAL RADIO MODELS

The demands of the fixed and mobile services have created a need for better terrestrial propagation models for the VHF and SHF bands. NTIA and others have several models available for use in analyzing point-to-point paths.[736] But, models that relate more directly to spectrum management need to be developed.

The past few decades has seen the development of a number of prediction models for VHF-UHF land mobile communication. However, the large number of mobile models currently in contention indicates the difficulties of characterizing a typical mobile channel.[737] In recognizing the problem, the Scientific Committee

---

[732]M.H. Reilly et al., *Updated climatological model predictions of ionospheric and HF propagation parameters*, RADIO SCIENCE, July-Aug. 1991, at 1017.

[733]R.B. Rose, *PROPHET, an emerging HF technology, in* EFFECT OF THE IONOSPHERE ON RADIOWAVE SYSTEMS (J. Goodman ed., 1981).

[734]*See, e.g.*, J.W. Wright, *Ionogram inversion for a tilted ionosphere*, RADIO SCIENCE, Nov.-Dec. 1990, at 1175; D.M Haines & B. Weijers, *Embedded HF Channel Probes/Sounders*, PROCEEDINGS OF THE IEEE MILCOM'85 CONFERENCE, Oct. 20-23, 1985, at 12.1.5.

[735]DOD Comments at 14; DOJ Comments at 5.

[736]NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, U.S. DEP'T OF COMMERCE, MICROCOMPUTER SPECTRUM ANALYSIS MODELS (MSAM), NTIS ORDER NO. PB 94-501145 (1994). The MSAM package contains other programs useful for spectrum management. INTERNATIONAL TELECOMMUNICATION UNION, CATALOGUE OF SOFTWARE FOR RADIO SPECTRUM MANAGEMENT (1993).

[737]G.Y. Delise et al., *Propagation Loss Prediction: A Comparative Study with Application to the Mobile Radio Channel*, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, May 1985, at 86. In comparing mobile models, the authors state that there is general agreement among methods, but note that there is no one complete model; however, existing ones can be complemented by the addition of missing parameters.

of the International Union of Radio Science for Telecommunication is forming a task force whose objective is to seek such a characterization.[738]

For spectrum management, the requirements go past the need to simply characterize a channel. The rising complexity of allocation problems in terrestrial communications demand more intensive processing of a wider range of input data for proper scenario representation than can be handled by the present models. Fixed, mobile, and mobile-satellite systems will have to be considered together in many cases.

The beginnings of the sophisticated processing needed for spectrum management can be seen in a recently developed polarimetric model.[739] Here, the probability density function (PDF) and field strength delay spectrum are derived for a multipath signal over a 3-D representation of the terrain, and further processed to yield a 2-D receiver field strength PDF. The model's developers point out that the multi-dimensional approach allows better coordination between mobile and fixed systems in local-to-large area coverage and evaluates the spectrum-efficient use of frequency, modulation, coding, and dual-polarization.

PROPAGATION INTO AND WITHIN BUILDINGS

The advent of cellular and PCS devices requires detailed information on radio propagation through the external walls and within a building.[740] For the simpler problem of penetration through the external walls, particularly from 100 MHz to 1 GHz, several sources of information are available for system planning and spectrum management.[741]

By contrast, the problems of path loss and time dispersion of propagation within a building are more complex, but a large body of measurements for narrowband propagation for the upper UHF band is presently available.[742] For the near future in the UHF band, the potential advent of wideband modulation for

---

[738] Joseph Shapira, *Toward a Generalized Characterization of the Mobile Channel*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Aug. 1992, at 16.

[739] Manfred Lebherz et al., *A Versatile Wave Propagation Model for the VHF/UHF Range Considering Three-Dimensional Terrain*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, Oct. 1992, at 1121.

[740] *See* DOJ Comments at 5; IEEE—USA Comments at 2.

[741] *See, e.g.*, HERBERT K. KOBAYASHI & GARY PATRICK, NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION, NTIA TECHNICAL MEMORANDUM 92-155, PRELIMINARY BUILDING ATTENUATION MODEL (1992) (featuring a literature review and application graphs); Raymond C.V. Macario, *How Building Penetration Loss Varies With Frequency*, IEEE VEHICULAR TECHNOLOGY SOCIETY NEWS, Nov. 1993, at 26 (encompassing the 30-3000 MHz band); Wolfhard J. Vogel & Geoffrey W. Torrence, *Propagation Measurements for Satellite Radio Reception Inside Buildings*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, July 1993, at 954 (featuring original measurements from 700-1800 MHz.

[742] D. Molkdar, *Review on radio propagation into and within buildings*, IEE PROCEEDINGS-H, Feb. 1991, at 61; J. Lafortune & M. Lecours, *Measurement and Modeling of Propagation Losses in a Building at 900 MHz*, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, May 1990, at 101-108; S.Y. Seidel & T.S. Rappaport, *914 MHz Path Loss Prediction Models for Indoor Wireless Communications in Multifloored Buildings*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, Feb. 1992, at 207; D.M.J. Devasirvatham, *Time Delay Spread and Signal Level Measurements of 850 MHz Radio Waves in Building Environments*, IEEE TRANSACTIONS ON ANTENNAS & PROPAGATION, Nov. 1986, at 1300.

PCS devices requires better propagation data.[743] For the more distant future, a review of wireless personal communication indicated that propagation modeling for higher bands may be satisfied by scaling data from the work done so far for the UHF band,[744] but scaling alone cannot account for scattering from surfaces that appear rough at higher frequencies. A diffuse-scattering model of rms time delay (which affects high data rate digital signals) is available, but the model would need validation by field measurements.[745]

PROPAGATION ABOVE 10 GHZ

Atmospheric factors that affect propagation at frequencies above 10 GHz were discussed in Chapter 8. Here, the propagation models themselves will be discussed with regard to Earth-space and terrestrial paths.

Most Earth-space propagation models span from about the upper VHF to lower SHF (200 MHz to 20 GHz) reflecting the current needs of the satellite services. At the gigahertz frequencies, the models depend heavily on the data and models describing the effects of atmospheric constituents.

The Earth-space models have been extended into the SHF, but are better substantiated below 30 GHz.[746] Propagation experiments of ISDN transmissions at 20/30 GHz between Earth and the ACTS satellite are scheduled this year.[747] These are vital in determining the reliability of wideband digital transmission at higher frequencies where atmospheric scintillation and ice cloud depolarization take effect.[748] As described in Chapter 8, Earth-based VSAT's are especially susceptible to these effects. The deployment of thousands of highly mobile VSAT's in the near future may cause interference problems of importance to spectrum management.

---

[743] Homayoun Hashemi, *The Indoor Radio Propagation Channel*, PROCEEDINGS OF THE IEEE, July 1993, at 943. The author alludes to the heuristic nature of the models he has reviewed in his recommendations for future work.

[744] Theodore S. Rappaport, *Wireless Personal Communications: Trends and Challenges*, IEEE ANTENNAS & PROPAGATION MAGAZINE, Oct. 1991, at 19.

[745] Peter F. Driessen, *Development of a Propagation Model in the 20-60 GHz Band for Wireless Indoor Communications*, IEEE PACIFIC RIM CONFERENCE ON COMMUNICATIONS, COMPUTERS AND SIGNAL PROCESSING, May 9-10, 1991, at 59.

[746] *See, e.g.*, Evan J. Dutton et al, *An Improved Model for Earth-space Microwave Attenuation Distribution Prediction*, RADIO SCIENCE, Nov.-Dec. 1982, at 1360 (presenting a model developed by ITS requiring specific meteorological inputs); INTERNATIONAL RADIO CONSULTATIVE COMMITTEE, INTERNATIONAL TELECOMMUNICATION UNION, HANDBOOK ON SATELLITE COMMUNICATIONS, ANNEX I PROPAGATION 551 (1988) (showing a widely-used model incorporating global climatological data).

[747] S.K. Johnson, *ISDN Experimenters Meet*, ACTS QUARTERLY, May 1993, at 12.

[748] D. Vanhoenacker et al., *The Effects of Atmospheric Turbulence on Broadband Communication Channels Above 10 GHz*, SUPERCOM'92, IEEE CONFERENCE ON COMMUNICATIONS, 1992, at 1064; L.J. Ippolito, *Propagation Considerations for Emerging Satellite Communications Applications*, PROCEEDINGS OF THE IEEE, June 1993, at 923; W.L. Stutzman, *Prolog to The Special Section on Propagation Effects on Satellite Communication Links*, PROCEEDINGS OF THE IEEE, June 1993, at 830.

Fixed point-to-point propagation have been treated extensively in CCIR publications and other sources dealing with system studies and spectrum management.[749] These nearly always include information on rain conditions, the most significant factor at gigahertz frequencies.

The trend toward using short-haul common carrier links at higher uncrowded frequencies raises the question as to whether the long-haul microwave models are still applicable at higher frequencies. A study at 19 and 23 GHz addressed this question by determining that models used successfully below 10 GHz are overly optimistic and should be replaced by a model having better rain rate statistics.[750]

An atmospheric propagation model taking into account dry-air, water vapor, and suspended-particle conditions at gigahertz frequencies has been developed by NTIA's Institute for Telecommunication Sciences.[751] System designers and spectrum managers will find the PC-software version of the model useful in assessing propagation under "clear-air" conditions.

SUMMARY OF ANTENNA AND PROPAGATION TECHNOLOGIES

The salient points of this chapter are summarized as follows:

- ❑ *The space-time alteration of an antenna's radiation pattern will be a powerful tool for spectrum management in the future. This will probably be achieved most completely by electronically steered phased arrays. Multiple-beam antennas and their hybrids will still be in general use in the coming decade.*

- ❑ *Antennas capable of changing their center frequency and bandwidth on demand would be useful for spectrum management purposes. However, the difficulty of controlling phase over a wide frequency range contributes to the lag in work done in this area.*

- ❑ *The complex assignment problems of terrestrial communication require more sophisticated propagation models than those presently available. Models that can handle fixed, mobile, and mobile-satellite systems simultaneously are necessary.*

---

[749]*See, e.g.*, INTERNATIONAL RADIO CONSULTATIVE COMMITTEE, INTERNATIONAL TELECOMMUNICATIONS UNION, RPN SERIES, PROPAGATION IN NON-IONIZED MEDIA, RECOMMENDATIONS 214 (1992).

[750]J.W. Rush, *Microwave Path Availability at 19 and 23 GHz*, MICROWAVE JOURNAL, Aug. 1992, at 165.

[751]*Progress in Atmospheric Propagation Modeling at Frequencies Below 1000 GHz*, Hans J. Liebe et al., 1992 Battlefield Atmospherics Conference, El Paso, Tex. (Dec. 1992); Hans J. Liebe, *An Atmospheric Millimeter-Wave Propagation Model*, INTERNATIONAL JOURNAL INFRARED & MILLIMETER WAVES, 1989, at 631 (presenting a detailed model for non-precipitation conditions available in IBM PC-compatible software).

- ❑ *The proliferation of low-margin VSAT's and other small earth stations linked to satellites operating above 10 GHz may give rise to interference problems in the near future. More data and better modeling are needed to predict the enhanced effect of rain absorption and fast-acting phenomena (such as scintillation and depolarization) on small aperture, low data rate terminals.*

- ❑ *More measurements and models for propagation inside and through the walls of buildings are needed for the spectrum management of cellular and PCS systems. The propagation of wideband digital signals is especially in need of characterization.*

PART 3

INTERNATIONAL COORDINATION

PART 3
U.S. PREPARATIONS FOR INTERNATIONAL CONFERENCES

Any study of U.S. spectrum requirements must also address international spectrum issues. The ITU is the focal point for development of international radio regulations and spectrum allocations. The rapid development of radio-based technologies and the internationalization of telecommunications development have dramatically increased the importance of the ITU decision-making processes.

To a significant degree, spectrum allocation decisions made at international conferences affect national spectrum allocations. The international dimension of spectrum management can be critical to the successful establishment of certain types of telecommunications systems, particularly satellite-based systems. Therefore, the adoption of U.S. proposals at international radio conferences is vital to certain segments of the U.S. telecommunications industry.

It must be recognized that spectrum management has become globalized, and the United States is a critical part of this worldwide community. With this view, it is increasingly important that the United States develops a more coordinated and global view of radiocommunications services and spectrum allocation issues. To achieve this, the United States must maintain a continuous planning process that addresses advanced telecommunications technologies and services worldwide, and must re-evaluate the process by which domestic spectrum allocations are made, considering international markets for goods and services.

Many administrations are now in the process of privatizing previously government-owned and operated telecommunications systems. New systems and networks are being planned and established worldwide. Recognizing that these system developers may choose from multiple technologies, the United States must be competitive in the international telecommunications markets, offering goods and services that meet common technical standards adopted by the various administrations. To facilitate this, the United States must actively participate in international standards-setting activities, and maintain a progressive dialog with regional administrations concerning spectrum and general telecommunications issues.

The changing international order, made evident at the 1992 World Administrative Radio Conference (WARC-92), has created new alliances and centers of cooperation resulting in many common proposals from groups of administrations that tend to vote together as a bloc on major issues, *e.g.*, the European Conference of Postal and Telecommunications Administrations (CEPT). The expansion of existing groups and the creation of others will significantly influence the ITU processes such as World Radiocommunication Conferences (WRC's), Radiocommunication Study Group meetings, and others.

In recognition of these factors, and with the understanding that future WRC's will be held at two year intervals, a number of questions were asked in the *Inquiry* regarding the development of U.S. positions for international radio conferences. This Part reviews and discusses comments received on these issues.

CHAPTER 11

U.S. PREPARATIONS FOR INTERNATIONAL CONFERENCES

INTERNATIONAL CONFERENCE SCHEDULE

NTIA requested comments regarding the appropriateness of the two-year cycle. Several comments were received regarding the frequency of ITU world radio conferences. Some commenters supported a regular conference schedule since it will reduce the substantial lag in introducing innovative services or technologies that may potentially be successful in the marketplace.[752] The disadvantage, as noted by another, was that a 2-year conference cycle would require continuous preparatory work.[753]

At the 1989 Nice Plenipotentiary, a High Level Committee was established to carry out an in-depth review of the structure and functioning of the ITU. From the result of this Committee's recommendations and the Final Acts adopted at the 1992 Additional Plenipotentiary Conference, the ITU Constitution (Article 13) initiated a work program based upon the convening of WRC's on a biannual basis.

We believe that the more frequent and focussed WRC's will result in more efficient conference management, domestically and within the ITU. Further, we believe that the changes adopted by the ITU were necessary to make the ITU more responsive to an increasingly dynamic market and telecommunications environment.

APPOINTING A PERMANENT U.S. DELEGATION HEAD

The topic of appointing the chair of the delegation as early as possible, at least one year in advance, has been raised in past reviews of the U.S. international conference preparatory process. Early appointment would provide more continuity for preparations, but each conference delegation usually has a different head.

[752] NSF Comments at 24. *See also* NASA Comments at 45.

[753] *See* Bell Atlantic Comments at 8 (showing a preference for a 4-year cycle).

It has also been suggested that the United States should consider appointing a chair "at-large" who would serve as chair of the delegation for an interval that covers two or more conferences. In light of a more intense conference schedule, NTIA requested comments on the advantages and disadvantages of such an approach.

Some support for the selection of a permanent U.S. delegation head was indicated in the comments. Reasons given were based on the fact that the delegation chair responsibilities require a familiarity with spectrum management, and the political workings of the ITU,[754] all facilitated by a permanent delegation head. Other commenters did not object to a fixed U.S. delegation head, but more importantly supported the early selection of a qualified candidate. It was noted that strong leadership and negotiating ability are critical and continuity is less important because it is inherent in a delegation of professionals.[755] There was a recommendation that a personnel pool be created of former FCC Commissioners and Presidential appointees to serve as U.S. delegation heads at the WRC's.[756] Similarly, the formation of a core group of experts was recommended, including both government and industry, with emphasis on accommodating existing users in radio services that are being displaced as a result of new or enlarged allocations to other radio services.[757] However, there is a possibility that instituting a permanent delegation head will become a disadvantage since the most qualified candidates will not be considered, as the Government's remuneration is thought by many to be inadequate.[758]

WRC's differ in their scope and degree of complexity. The most appropriate U.S. WRC delegation head will, therefore, depend upon the agenda of the conference. While *not* establishing a permanent delegation head for all WRC's provides more flexibility to the U.S. delegation, NTIA recognizes the problem regarding the time-consuming and political nature of certain appointments.

We believe that the head of the U.S. delegation should be appointed early in the two-year conference cycle in order to permit sufficient time to prepare for the conference.

CONFERENCE PREPARATORY EFFORT

NTIA requested comments on whether the ITU schedule for submitting proposals eight months before a conference be rigidly adhered to in order to maximize the possibility of acceptance of the proposals. We also asked what are the pros and cons regarding early submission of proposals. Further, should the United States have a cut-off date after which no new proposals would be accepted for consideration in order to improve the preparatory process?

---

[754]NSF Comments at 25. *But see* NASA Comments at 45 (giving advantages and disadvantages of having a permanent chair).

[755]IEEE—USA Comments at 5.

[756]Harris Comments at 8.

[757]Motorola Comments at 31.

[758]Hubbard Comments at 7; Digital Microwave Comments at 7.

With regard to the length of preparation for radio conferences, commenters noted that eight months for preparatory work may be excessive; a four- to six-month process[759] may be more appropriate, particularly since the 1992 Additional Plenipotentiary Conference adopted 4 months before a conference as the time element when proposals should be sent to the ITU.[760] Some commenters supported a deadline for U.S. proposals while another suggested that conference positions should only be adopted after consultations with other countries.[761] International broadcasters and others recommended improved access to the IRAC process by the commercial sector.[762] Harris suggested that the FCC should maintain the Industry Advisory Committees permanently.

With WRC's every two years, we believe that the U.S. preparatory process will become more systematic and more efficient. NTIA will continue to work closely with the FCC and the private sector to ensure that U.S. views are developed in a timely fashion to meet the new ITU conference schedule. In a more general approach, NTIA's Openness program has been established to provide improved public access to the Federal Government's spectrum planning process.

PROMOTING U.S. INTERESTS

NTIA also requested comments regarding how various U.S. commercial interests, which are sometimes competing with one another, can be addressed during the preparatory process in a manner that is fair and equitable to all concerned. Further, NTIA asked how to reconcile competing Federal and non-Federal spectrum requirements. Finally, NTIA requested information on how to best present U.S. proposals to ITU WRC's, given their international nature, in order to promote U.S. commercial and government interests.

Many respondents noted the effective European cooperation in countering U.S. positions at WARC-92. In their comments, NASA encouraged the Federal Government to increase its awareness of European long-term plans and frequency requirements, and to improve ties with the Europeans by using areas of common interest to develop a more substantive dialogue.[763] A large number of the respondents support more cooperation with the Organization of American States' InterAmerican Telecommunications Commission (CITEL) in all areas of telecommunications.

The U.S. Government continues to improve its working relationship with regional telecommunication organizations. Efforts have been taken to explore radio matters with the European Radiocommunications

[759]IEEE—USA Comments at 5.

[760]Convention of the Additional Plenipotentiary Conference, Dec. 22,1992, Int'l Telecommunication Union, art. 30.

[761]Bell Atlantic Comments at 17. *See also* NASA Comments at 43; NSF Comments at 24-25; AT&T Comments at 8.

[762]*See* IEEE—USA Comments at 5. *See also* AT&T Comments at 7.

[763]NASA Comments at 43.

Office of CEPT. These efforts will continue. Of more critical importance is the efforts that NTIA has undertaken to improve U.S relations and assistance to CITEL.

NTIA will continue its efforts in the CITEL forum to have that organization provide a more effective mechanism for the development of recommendations and joint regional views on spectrum management issues and matters that will be treated at ITU conferences.

APPENDIX
LIST OF COMMENTERS

The following organizations have provided either comments, reply comments, or both, to our *Inquiry*. Citations of these comments and reply comments use the short forms shown. Copies of these documents are available through NTIA's Openness Program.

AAR	Association of American Railroads
AMSAT	Radio Amateur Satellite Corporation
AMSC	AMSC Subsidiary Corporation
AMTECH	AMTECH Corporation
Alcatel	Alcatel Network Systems, Inc.
APCO	Association of Public-Safety Communications Officials–International, Inc. (formerly Associated Public-Safety Communications Officers, Inc.)
Apple	Apple Computer, Inc.
APTS & PBS	Association of America's Public Television Stations and Public Broadcasting Service (joint comments)
ARINC	Aeronautical Radio, Inc.
ARRL	American Radio Relay League, Inc.
AT&T	American Telephone and Telegraph Company
Bell Atlantic	Bell Atlantic Companies
Comsat	Communications Satellite Corporation
CORF	National Academy of Sciences–National Research Council, Committee on Radio Frequencies
Digital Microwave	Digital Microwave Corporation
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOJ	U.S. Department of Justice
EDS	EDS Corporation
Ericsson	Ericsson Corporation
FAA	U.S. Department of Transportation, Federal Aviation Administration
FCCA	Forestry-Conservation Communications Association
Fleet Call	Fleet Call, Inc.
FWUF	Federal Wireless Users' Forum

GM	General Motors Research Corporation
GTE	GTE Service Corporation
Harris	Harris Corporation–Farinon Division
Herald Broadcasting	Herald Broadcasting
Hubbard	Hubbard Broadcasting, Inc.
IEEE–USA	Institute of Electrical and Electronics Engineers–United States Activities
InterDigital	InterDigital Communications Corporation
IVHS AMERICA	Intelligent Vehicle-Highway Society of America
Jacobs	George Jacobs & Associates, Inc.
Kansas City Water	City of Kansas City, Missouri; Water and Pollution Control Department
LMCC	Land Mobile Communications Council
LQSS	Loral Qualcomm Satellite Services, Inc.
LVVWD	Las Vegas Valley Water District
Motorola	Motorola, Inc.
MSTV	Association for Maximum Service Television, Inc.
MWD	Metropolitan Water District of Southern California
NAB	National Association of Broadcasters
NASA	National Aeronautics and Space Administration
NASB	National Association of Shortwave Broadcasters
NCS	National Communications System
NIST	National Institute of Standards and Technology
NOAA	U.S. Department of Commerce, National Oceanic and Atmospheric Administration
NPR	National Public Radio
NSF	National Science Foundation
NYNEX	NYNEX Corporation
OCST	U.S. Department of Transportation, Office of Commercial Space Transportation
Pacific Telesis	Pacific Telesis Group
PAS	Pan American Satellite
Pinpoint	Pinpoint Communications, Inc.
Protocol	Protocol Systems, Inc.
Pulson	Pulson Communications Corporation
Rose	Rose Communications, Inc.

Southwestern Bell	Southwestern Bell Corporation
SBCA	Satellite Broadcasting and Communications Association
SCDR	Satellite CD Radio, Inc.
SCS	SCS Mobilecom, Inc.
SDCWA	San Diego County Water Authority
TIA MCD	Telecommunications Industry Association, Mobile Communications Division
Treasury	U.S. Department of the Treasury
TRW	TRW, Inc.
USCG	U.S. Department of Transportation, U.S. Coast Guard
USDA	U.S. Department of Agriculture
UTC	Utilities Telecommunications Council
VA	U.S. Department of Veterans Affairs
VOA	U.S. Information Agency, Voice of America

*U.S. GOVERNMENT PRINTING OFFICE:1995-386-551/22002