NTIA Report 15-516

A Spectrum Sharing Case Study Leading to the Development of a Method for Identifying Interference Potential

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report series

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

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GLOSSARY OF TERMS

16QAM	16 quadrature-amplitude modulation
64QAM	64 quadrature-amplitude modulation
α	protection ratio
B	IF bandwidth before the demodulation of symbols or the baseband bandwidth
B_i	interferer's 3dB bandwidth (Hz)
B_r	receiver's 3dB bandwidth (Hz)
BER	bit error rate
COFDM	coded orthogonal frequency division multiplex
CW	continuous wave
DHS	Department of Homeland Security
DVB-T	Digital Video Broadcasting-Terrestrial
E_b	energy per bit
E_b/N_0	energy-per-bit-per-Hz-to-noise power ratio
E_s	energy per symbol
EMC	electromagnetic compatibility
Δf	frequency offset
f_i	interferer's center frequency
f_r	receiver's tuned frequency
FDR	frequency dependent rejection loss (dB)
FEC	forward error correction
FS	free-space loss model
FS–6	free-space loss model minus 6 dB along the slant range
G_t	gain of the transmitter antenna (dBi)
G_r	gain of the receiver antenna (dBi)
GOES	Geostationary Operational Environmental Satellites
$H(f)$	normalized receiver transfer function
h_r	receiver's antenna height (m)
h_t	transmitter's antenna height (m)
I	interfering signal strength (dB)
I_o	interference spectral density (W/Hz)
I/N	interference-to-noise ratio
IF	intermediate frequency
ITM	ITS Irregular Terrain Model
ITS	Institute for Telecommunication Sciences

LO	local oscillator
LOS	line-of-sight
L_p	free-space propagation loss
Loss	propagation loss between the transmitter and the receiver (dB)
LossT	total loss between the transmitter and the transmitter antenna (dB)
LossR	total loss between the receiver and the receiver antenna (dB)
LossP	loss due to the mismatch between the polarizations of the transmitter and the receiver (dB)
MIMO	multiple-in, multiple-out
N	noise (dB)
NF	noise figure (dB)
N_o	noise spectral density (W/Hz)
NOAA	National Oceanographic and Atmospheric Administration
NTIA	National Telecommunications and Information Administration
NWS	National Weather Service
OFR	off-frequency rejection
OTR	on-tune rejection
P_d	desired signal level (dB)
P_i	interfering signal level (dB)
$P_i(f)$	power spectral density of the interfering signal
P_{rec}	received signal power (dBm)
P_t	transmitted signal power (dBm)
QPSK	quadrature phase-shift keying
R	information or signaling rate (bps)
RF	radio frequency
S	desired signal
S/I	signal-to-interference ratio
S/N	signal-to-noise ratio
SDR	software-defined radio
SNR	signal-to-noise ratio
UFM	Undisturbed-Field Model
VSG	vector signal generator
VQiPS	Video Quality in Public Safety
VSS	Video Surveillance System

EXECUTIVE SUMMARY

The Institute for Telecommunication Sciences (ITS), the laboratory of the National Telecommunications and Information Administration (NTIA), was tasked by the Department of Homeland Security (DHS) to examine the potential of spectrally relocating a Federal agency's telecommunication services and to identify the possibility of sharing spectrum bands with services of other agencies. The specific systems involved were the National Oceanographic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellites (GOES) and receivers, NOAA's radiosondes, and the DHS's Video Surveillance System (VSS). NOAA's systems currently operate in the 1675–1695 MHz band. There is a proposal to move DHS's VSS frequency allocation from the 1755–1850 MHz band to the 1675–1695 MHz band. When a VSS (the potential entrant to the band) is deployed near NOAA's equipment (the incumbents), there will be a potential for interference.

To perform such an analysis, ITS developed a method to calculate the interference that could occur when Federal services must share a common frequency band. The primary objective is that the quality of the mission-critical communications for each service is maintained. A detailed electromagnetic compatibility (EMC) analysis is necessary to identify both the highest potential interference scenarios and those scenarios that have little to no effect.

Two primary interference mitigation techniques can be implemented to achieve electromagnetic compatibility: frequency offset (Δf) and separation distance. The Δf and separation distance necessary for a desired level of interference rejection can be calculated based on the frequency dependent rejection (*FDR*) between the interference source and the victim receiver. For all potential interference interactions, the Δf and the separation distance can be adjusted to arrive at a solution for operation on a non-interference basis. Based on this method, interference levels were calculated and Δf and separation distances were determined for acceptable operation of the VSS and the two NOAA systems.

Considering the interference from the VSS into the radiosonde, a separation distance of 4-36 km would be required to avoid interference for a Δf ranging from a 6 MHz offset to an on-tune condition, based on a required *FDR*. In the other direction, a similar level of interference from the radiosondes into the VSS receiver require protection distances from 30-90 km for a Δf of 6 MHz. Other deployment scenarios can have the potential of reducing the predicted separation distances and frequency offsets. A further refinement of this investigation would involve a statistical analysis with service probability considerations.

Interference from the GOES satellites into the VSS receiver is not a problem. The satellite's signal amplitude at ground level is very low while the VSS receiver has a very low gain antenna, which reduces the interference potential of the satellite's signal.

In the other direction (VSS into GOES), the satellite earth station receiver's antenna has an extremely high gain to receive the satellite's signal, making it very susceptible to interference from a nearby ground-based VSS transmitter. Due to the range of signals that the GOES satellites transmit in the 1675–1695 MHz band, the Δf and separation distance necessary for an acceptable level of interference rejection vary but are significant in all cases. Assuming that the VSS operates off the GOES antenna's main axis, for a separation distance of 0 km (co-located), the VSS must maintain a Δf of 10–22 MHz or greater, which places the VSS outside the frequency band in question. For the VSS to operate with a Δf of 0 MHz, the separation distance must be 10–50 km or greater.

It is not the intent of this report to make pronouncements on how to achieve coexistence within a shared band. The intent is to examine and illuminate the engineering questions that need to be answered so that those who are responsible for Federal services in a band may negotiate and cooperate with their colleagues who are responsible for other Federal services in the same band.

A SPECTRUM SHARING CASE STUDY LEADING TO THE DEVELOPMENT OF A METHOD FOR IDENTIFYING INTERFERENCE POTENTIAL

Christopher Behm, Nicholas DeMinco, Timothy Riley, Linh Vu[1]

This report details a method that was developed to identify all potential forms of interference that could occur with a proposed collocation of three Federal systems in the 1675–1695 MHz frequency band. The incumbents are the National Oceanographic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellites (GOES) and receivers and radiosonde systems. The entrant is the Department of Homeland Security's (DHS) Video Surveillance System (VSS). The primary objective is that the quality of the mission-critical communications for each service is maintained.

A detailed electromagnetic compatibility (EMC) analysis is used to identify both the highest potential interference scenarios and those scenarios that have little to no effect. Two primary interference mitigation techniques can be implemented to achieve electromagnetic compatibility: frequency offset (Δf) and separation distance. Based on the frequency dependent rejection (*FDR*) between the interference source and the victim receiver, the Δf and separation distance necessary for a desired level of interference rejection can be calculated. For all potential interference interactions, the Δf and the separation distance can be adjusted to arrive at a solution for operation on a non-interference basis. It is not the intent of this report to make pronouncements on how to achieve coexistence within a shared band. The intent is to examine and illuminate the engineering questions that need to be answered so that those who are responsible for Federal services in a band may negotiate and cooperate with their colleagues who are responsible for other Federal services in the same band.

Keywords: spectrum sharing; *FDR*; frequency dependent rejection; frequency offset; separation distance; electromagnetic compatibility; interference mitigation

1. INTRODUCTION

As part of the President's Spectrum Initiative to vacate 500 MHz of Federal spectrum to spur the innovation of new wireless services, Federal agencies have been instructed to examine the potential of spectrally relocating their telecommunication services and sharing spectrum bands with services of other agencies. The Institute for Telecommunication Sciences (ITS), the laboratory of the National Telecommunications and Information Administration (NTIA), was

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tasked to conduct such an evaluation. This report details the method developed to evaluate the feasibility of coexistence of Federal communications services.

This work was performed under the direction of the Department of Homeland Security (DHS) lead task group charged with examining an exit strategy for equipment assigned to operate in the 1755–1850 MHz band. It was proposed to relocate the frequency assignments of their services, which include a video surveillance system (VSS), to the 1675–1695 MHz band, which is currently occupied by satellite and radiosonde communications services that are central to the mission of the National Oceanographic and Atmospheric Administration (NOAA).

The generalized method described in this report can be used to evaluate interference when other Federal services may be required to relocate to already occupied bands. All of the services being evaluated are unique, not only from a mission standpoint but also from a physical perspective. The mission of communications in a band can vary widely and will form a basic set of subjective constraints for an interference analysis. Physically, the propagation mechanisms that affect communication signals are not consistent across all radio frequencies. The physical characteristics of the band comprise a set of subjective inputs to an interference analysis. The principles of interference analysis, which describe how to maintain reliable communications for all systems collocated in a band, will be similar across the spectrum.

This report will detail the multitude of ways that the NOAA and DHS communications systems could interact and the potential forms of interference that could occur with the proposed merging of Federal services in the 1675–1695 MHz band. The analysis determines if interference will affect the performance of each system. The primary objective is that the quality of the mission-critical communications for each agency is maintained. Through this analysis, the worst-case scenarios will be identified so that subsequent tests and evaluations of equipment entering the incumbent band will be clearly understood by all involved. A detailed electromagnetic compatibility (EMC) analysis is necessary to identify both the highest potential interference scenarios and those scenarios that have little to no effect.

Performing an EMC analysis such as this will allow evaluation of spectrum sharing and frequency reassignments. Regulatory agencies need to perform EMC analyses to address potential interference problems between users of the crowded electromagnetic spectrum.

2. EQUIPMENT DESCRIPTIONS

2.1 GOES-N/O/P Systems

The Geostationary Operational Environmental Satellite (GOES) systems have several components that occupy the 1675–1695 MHz band [1]. Of the three currently deployed GOES satellites (N/O/P), two are operational and one is parked in a central location for use as a spare when needed. The two operational satellites are positioned over the Atlantic (at 75°W longitude, referred to as GOES-East) and the Pacific (135.4°W longitude, referred to as GOES-West). Table 1 lists the important physical parameters that describe the GOES-N/O/P transmitters, receivers, and antenna subsystems.

Table 1. GOES-N/O/P communication parameters.

Link Designation	**SD**	**PDR**	**LRIT**[2]	**EMWIN**[3]	**MDL**	**DCPR**[4]	**CDA TLM**
Function Name	**Sensor Data**	**Processed Data Relay**	**Low Rate Information Transmission**	**Emergency Manager's Weather Information Network**	**Multiuse Data Link**	**Data Collection Platform Report**	**Command and Data Acquisition & Telemetry**
Frequency (MHz)	1676.0	1685.7	1691.0	1692.7	1681.478	1694.5, 1694.8 (1694.4474–26)[5]	1694.0
Modulation	UQPSK	BPSK	PCM/NRZ-L/BPSK	OQPSK	QPSK	8PSK	PCM/BiØ--L/PM
Symbol Rate (ksps)	TBD	TBD	293.0	35.94	TBD	i) 300 bps - the output symbol rate shall be 150 symbols per second ±0.025% ii) 1200 bps - the output symbol rate shall be 600 symbols per second[6]	TBD
Data Rate (kbps)	2660	2110	128.0	19.2	400	0.1/0.3/1.2	4000 bps operational 1000 bps contingency
Data format notes		GVAR		CCSDS coding		i) 200 FDMA channels @ 1500 Hz- 100 and 300 bps ii) 33 FDMA channels @ 3000 Hz - 1200 bps	
Rx Max *BER* (bps)	10^{-8}	10^{-6}	10^{-8}	10^{-8}	10^{-8}	10^{-6}	
Tx filter -3 dB	2.2 MHz	2.2 MHz	200 kHz	18 kHz	150 kHz	507 kHz	12 kHz
Tx Filter -20 dB	8.0 MHz	6.2 MHz	600 kHz	26 kHz	400 kHz	650 kHz	40 kHz
Tx Filter -60 dB	11.2 MHz	11.0 MHz	4.5 MHz	200 kHz	4.0 MHz	5.6 MHz	2.0 MHz
Tx Antenna EOC Gain (dBi)	14.5	14.5 (± 9°)	14.5 (± 9°)	14.5 (± 9°)	14.5	14.5 (± 9°)	-14.0

2 http://www.noaasis.noaa.gov/LRIT/pdf-files/3_LRIT_Receiver-specs.pdf
3 http://www.nws.noaa.gov/emwin/transition/EMWIN-OQPSK%20Specifications%20Final.doc
4 http://www.noaasis.noaa.gov/DCS/docs/DCPR_CS2_final_June09.pdf
5 http://www.noaasis.noaa.gov/DCS/docs/MIT-Lincoln_Lab_RRC_Pres.ppt
6 http://www.noaasis.noaa.gov/DCS/htmfiles/GOES_13-14_freq_offset.html

In all of the United States and its territories, there are 26 GOES earth stations owned and operated by the Federal Government. Appendix C lists the stations by name, location, and the antenna bearings (azimuth and elevation) for the two operational GOES satellites. Since the 1675-1695 MHz band only contains downlink channels, all of these sites are assumed to receive one or more channels from one or both of the operational satellites (GOES-West and GOES-East). Due to the extreme angles involved, some of the sites receive channels from only one satellite (at the sites in Hawaii and Alaska, GOES-East is below the horizon, and GOES-West is close to the horizon for the Puerto Rico site).

Due to differences in their individual requirements, not all sites monitor both satellites. Any site monitoring both satellites would need two antennas; physical constraints would require the antennas to be separated by some distance. However, this distance would be small enough compared to the overall distance to the satellites, that they could be considered co-located and still maintain reasonable accuracy regarding any geometric calculations.

Only interference involving these 26 sites will be considered in this report. Any privately owned and operated receiving sites are outside the scope of this report.

2.2 GOES-R Systems

The next generation GOES satellite (GOES-R) is scheduled to be launched in 2015. As a result, many of the design parameters (Table 2) have not been made available.

Table 2. GOES-R communication parameters.

Link Designation	DCPR #1	DCPR #2	GRB #1	GRB #2	HRIT/EMWIN	HK TLM
Function Name	**Data Collection Platform Report**		**GOES-R Re-Broadcast**		**High Rate Information Transmission/ Emergency Managers Weather Information Network**	**Command and Data Acquisition & Telemetry**
Frequency (MHz)	1679.7 to 1680.4		1686.6		1694.1	1693.0
Modulation	FDM	8PSK	QPSK	8PSK	BPSK	BPSK
Maximum Data Rate (kbps)	1.8/channel		17332	23480	927	64
Data format notes	933 channels @ 750 Hz steps*		DVB-S2			
Max BER (bps)	10^{-6}		10^{-10}		10^{-8}	10^{-7}
RF Selectivity -3 dB	27.0 MHz		27.0 MHz		27.0 MHz	27.0 MHz
RF Selectivity -20 dB	35.0 MHz		35.0 MHz		35.0 MHz	35.0 MHz
RF Selectivity -60 dB	50.0 MHz		50.0 MHz		50.0 MHz	50.0 MHz
IF Selectivity -3 dB	0.6/0.15 kHz		8.7 MHz	7.9 MHz	950 kHz	45.0 kHz
IF Selectivity -20 dB	1.2/0.3 kHz		10.9 MHz	9.8 MHz	1430 kHz	80.0 kHz

Link Designation	DCPR #1	DCPR #2	GRB #1	GRB #2	HRIT/EMWIN	HK TLM
IF Selectivity -60 dB	6.0/1.6 kHz		13.0 MHz	12.0 MHz	4000 kHz	350.0 kHz
Polarization	Linear		RHCP & LHCP		Linear	RHCP

Data for all of the transmitters was extracted from the Fast Track report [1] where available.

2.3 Radiosondes

A radiosonde is a measurement system that consists of a battery-powered instrument package attached to a balloon and a receiver that may use a motorized tracking antenna. The transmitter measures dry-bulb and wet-bulb temperatures and barometric pressure directly; wind speed and direction are calculated from either the tracking antenna’s orientation or an on-board GPS receiver. Data is generally correlated to the height above the ground and can be used to detect atmospheric boundary layers. Radiosondes are allowed to operate in the band 1675-1683 MHz.

Table 3. Radiosonde communication parameters.

Transmitter Function	Transmitter Parameter	Receiver Function	Receiver Parameter
Modulation	FSK	**Modulation**	FSK
Duty Cycle in Percent	100	**Duty Cycle in Percent**	100
Maximum Data Rate (bps)	9600	**Maximum Data Rate (bps)**	9600
Emission Spectrum 3 dB Bandwidth (kHz)	135	**Receiver IF Bandwidth (kHz)**	150
Relative Attenuation (dB) vs. Frequency Offset **3** **36** **48** **52** **56** **58**	Frequency Offset (kHz) 67.5 200 400 600 800 1000	**Receiver Selectivity (dB)** **3** **20** **60**	Receiver Frequency Offset (kHz) 75 270 600
Peak Power (dBm)	23.8	**Sensitivity (dBm)** **Noise Figure (dB)**	-115.7 6.5
Antenna Gain (dBi)	4.3	**Maximum Antenna Gain (dBi)**	28.0
Antenna Polarization	LHCP	**Antenna Polarization**	LHCP
		Interference Level (dBm) based on *I/N* = -6.0 dB	-121.7

Information on the radiosondes was supplied by DHS (the sponsor).

2.4 Video Surveillance Subsystem (VSS)

The VSS consists of a coded orthogonal frequency division multiplex (COFDM) transmitter, capable of transmitting a single video channel following the Digital Video Broadcasting-

Terrestrial (DVB-T) standard, and two audio channels, with 250 mW output power and a maximum bandwidth of 8 MHz. The matching receiver has two antenna input channels, allowing for a single transmit, dual receive, multiple-in, multiple-out (MIMO) antenna configuration. The receiver has a front panel received signal level bar graph display for each input channel and is able to display bit-error rate (*BER*) and signal-to-noise ratio (*SNR*) for each channel via an overlay at the video output. The system was supplied by the sponsor as a prototype unit that was specially re-programmed to operate in the target 1675-1695 MHz band.

Both devices support eight frequency channels within their operating band that can be selected by manual switches. Each device can be connected to a computer through a serial port for programming the various parameters (frequency, bandwidth, guard interval, mode, forward error correction (FEC) rate, polarity, etc.).

The purpose of the guard interval is to provide a space between successive symbols so that extraneous signals (due to propagation delays and multipath effects) do not corrupt the data stream. In DVB-T, four guard interval values are available, specified as fractions of a symbol period (1/32, 1/16, 1/8, and 1/4).

The VSS parameters relevant to the tests (Tables 8 and 9 in Section 5.2) came from information supplied by the sponsor. Additional information came from the operation manuals that accompanied the VSS hardware.

2.5 General Comments on Equipment and the Analysis

Appendix B contains a more detailed description of the published equipment specifications for each system; those specifications will be used in this analysis. The analysis starts with the collection of transmitter and receiver specifications for the systems that are proposed to occupy the 1675–1695 MHz band. The systems affected by this proposed relocation include NOAA's GOES-N/O/P and GOES-R satellites and receivers (incumbents), NOAA radiosondes (incumbents), and the VSS (the entrant). In the case of GOES-R, referenced parameters only refer to current design specifications and not actual equipment. The specification data, once compiled, helps identify what additional data will be necessary to continue the analysis. As with many calculations involving complex communications systems, some parameters will need to be estimated and/or measured. In cases where measurements and/or estimation are required, pertinent details will be given in this document.

NOAA uses a geographically distributed receiver system. When VSS systems operate in proximity to the NOAA GOES and radiosonde receiver system, there will be a potential for interference. The analysis will not be concerned with actual user patterns but will concentrate on examining potential interactions. This approach will insure to both the entrant and incumbent system users that all interference possibilities will be examined. It is assumed that some interference scenarios will be of low enough probability that more resources can focus on higher probability scenarios. Therefore, an electromagnetic compatibility (EMC) analysis will be used to evaluate the compatibility of all systems that are planned to occupy the band.

An apparent inconsistency should be noted. One main parameter used in the analysis was the maximum bandwidth of the VSS, which was stated to be 7.5 MHz in the sponsor-supplied specifications. When ITS received the actual hardware, it was found that the VSS could be set to utilize bandwidths of 6, 7, and 8 MHz, but not 7.5 MHz. As a result, the analysis uses 7.5 MHz, while the VSS was set to 8 MHz for testing. The difference between the analysis values for the two bandwidths will be no more than $10 \times \log(8.0/7.5)$, or 0.28 dB (assuming a uniform power spectral density, which is a close description of the VSS transmitter's output). This is much less than the 1 dB resolution of the attenuators used, the measurement equipment's noise figures, or the tested equipment's repeatability.

3. INTERFERENCE ANALYSIS APPROACH

Propagation loss is in part a result of the separation distance between an interference source (transmitter) and a victim (receiver) and is one mechanism for obtaining EMC between them. To evaluate this mechanism, the analyst needs to calculate the radio-wave propagation loss between the systems using an appropriate propagation model or models. Another EMC mechanism would be the frequency dependent rejection (*FDR*) between the interference source and the victim receiver. The *FDR* of a communication receiver is a figure of merit indicating how well a receiver is isolated from potential interference sources as a function of frequency. The victim receiver's ability to reject interference is a function of the following parameters of the interferer's transmitter:

- Operating frequency
- Emission bandwidth
- Transmitter power
- Modulation
- Antenna parameters

Characterizing the interference potential is also a function of the following parameters of the victim's receiver:

- Operating frequency
- Bandwidth
- Sensitivity
- Modulation
- Off-tune rejection
- On-tune rejection
- Frequency dependent rejection
- Antenna parameters

The antenna orientations of the interference source and victim receiver are important for calculating separation distances, as well as the relative positions of the source and receiver. Additional parameters for the receiver would include a signal-to-noise ratio for the required *BER* or similar performance metric.

The parameters necessary for an interference analysis are first gathered from the published specifications of each receiver and transmitter. Typical transmitter information includes:

- Transmitter power
- Operating frequency
- Modulation(s)
- Emission bandwidth with roll-off of the emission spectra at the band edges
- Antenna gain
- Antenna patterns
- Feed losses

Receiver information includes:

- Operating frequency
- Sensitivity
- Bandwidth with sufficient information to characterize rejection outside the receiver bandwidth
- Interference-to-desired signal ratio for desired performance
- Antenna parameters, including gain patterns

A required interference-to-noise ratio (*I/N*) or desired signal-to-interference signal ratio (*S/I*) are also needed to perform the interference analysis. This is where the type of modulation must be accounted for. In the absence of adequate interference interaction information between different modulations, the *I/N* will be set to -6.0 dB for general analysis of systems interference, and −10.0 dB where requirements are critical or there is a safety of life requirement. This is a simple but adequate approach, but more sophisticated procedures have been developed using an energy-per-bit-per-Hz-to-noise power ratio (E_b/N_0) for a required *BER* which could help to determine a more specific *I/N* criterion.

The analysis approach used here determines the *S/I*, the *I/N*, and the signal-to-noise ratio (*S/N)* based on the modulation type, the bandwidth, and the data rate. A digital system usually has a *BER* requirement for proper operation and this *BER* corresponds to a certain *S/N*. There are tables and graphs with this information [2], [3]. The required *BER* is sometimes associated with E_b/N_0, where N_0 is the noise per unit bandwidth, $N_0 \cdot = N/B$, and *B* is the IF bandwidth directly before demodulation. The relationship between required *S/N* and E_b/N_0 is:

$$\frac{E_b}{N_0} = \frac{B}{R} \times \frac{S}{N}$$

where *R* is the information or signaling rate in bits per second, and S is the signal power. The *BER* versus E_b/N_0 curves allow us to determine the E_b/N_0 values for a desired *BER* and calculate the *S/N* necessary to meet the required system performance.

3.1 Analysis Scenarios

After obtaining all the parameters of the systems involved, the analysis scenarios are created by deciding what interference interactions are going to take place. Table 4 describes all of the 28 potential interference interactions and Appendix B lists descriptions of the scenarios in detail. By knowing the deployment procedures for each of these systems, the analyst can set up a range of possible interference distances and antenna heights at which the different geometric scenarios of the systems can occur. Radio waves propagate differently over these different scenarios, because of the different distances and antenna height combinations involved. The basic phenomena that can occur over these scenarios that will affect these radio waves include refraction, diffraction, line-of-sight propagation, and troposcatter. The propagation models selected for each scenario result in the best prediction of radio-wave propagation loss between the candidate interference sources and the victim receivers with respect to distances and antenna heights.

Table 4. Potential interference scenarios for analysis.

Interference Scenario	Interference		Receiver	
	Source | Service	Antenna Height	Receiver | Service	Antenna Height
S01	VSS	2 m and greater	Radiosonde	5 m
S02	Radiosonde	1m to 33 km	VSS	2 m and greater
S03	GOES-N | SD	35,787 km	VSS	2 m and greater
S04	GOES-N | PDR	35,787 km	VSS	2 m and greater
S05	GOES-N | LRIT	35,787 km	VSS	2 m and greater
S06	GOES-N | EMWIN	35,787 km	VSS	2 m and greater
S07	GOES-N | MDL	35,787 km	VSS	2 m and greater
S08	GOES-N | DCPR	35,787 km	VSS	2 m and greater
S09	GOES-N | CDALM	35,787 km	VSS	2 m and greater
S10	GOES-R | GRB #1	35,787 km	VSS	2 m and greater
S11	GOES-R | GRB #2	35,787 km	VSS	2 m and greater
S12	GOES-R | HRIT	35,787 km	VSS	2 m and greater
S13	GOES-R | DCPR #1	35,787 km	VSS	2 m and greater
S14	GOES-R | DCPR #2	35,787 km	VSS	2 m and greater
S15	GOES-R | CDA TLM	35,787 km	VSS	2 m and greater
S16	VSS	2 m and greater	GOES-N | SD	20, 25, 33 m
S17	VSS	2 m and greater	GOES-N | PDR	20, 25, 33 m
S18	VSS	2 m and greater	GOES-N | LRIT	20, 25, 33 m
S19	VSS	2 m and greater	GOES-N | EMWIN	20, 25, 33 m
S20	VSS	2 m and greater	GOES-N | MDL	20, 25, 33 m
S21	VSS	2 m and greater	GOES-N | DCPR	20, 25, 33 m
S22	VSS	2 m and greater	GOES-N | CDA TLM	20, 25, 33 m
S23	VSS	2 m and greater	GOES-R | GRB #1	20, 25, 33 m
S24	VSS	2 m and greater	GOES-R | GRB #2	20, 25, 33 m
S25	VSS	2 m and greater	GOES-R | HRIT	20, 25, 33 m
S26	VSS	2 m and greater	GOES-R | DCPR #1	20, 25, 33 m
S27	VSS	2 m and greater	GOES-R | DCPR #2	20, 25, 33 m
S28	VSS	2 m and greater	GOES-R | CDA TLM	20, 25, 33 m

The scenarios can be ranked by evaluating their applicable technical parameters, as well as taking into consideration non-technical aspects of the systems, such as the type of information being transmitted (video, voice, still images, raw digital data), how the information will be used (subjective, task-based quality requirements), and information on the users themselves (deployment parameters such as position and density).

For a full analysis, considerations such as usage patterns, geographical deployment, and mission-critical and service priorities need to be taken into account; this information must be supplied by the potential victim. In considering the VSS, the quality requirements of the video (task-based video quality) were not addressed. *BER* can be used as an objective measure until more sophisticated metrics are developed. For the purposes of these tests, a subjective method based on perceived video failure was used.

This analysis has identified 28 scenarios. The number of necessary tests could be many multiples of 28, given the possibility of using up to four different propagation models (based on separation distance and antenna height) and taking into account multiple antenna configurations and modulation schemes. It is necessary to prioritize the scenarios and variants to reduce the number of tests to a manageable number.

Determining interference versus Δf and separation distance for the various scenarios (and variants) is the ultimate goal. Interference versus separation distance, given a fixed channel plan, will form the basis to develop exclusion zones. Interference versus Δf will aid in the development of channel plans.

3.2 Computation of the Received Interference Signal Levels

It is important to use the correct propagation model for different geometric scenarios to determine the signal strength of the interfering signal. Use of the wrong propagation model could result in either predicting interference when no interference is present or not predicting interference when interference is actually present. Basing subsequent interference mitigation techniques on inaccurate use of propagation models could result in either over- or under-compensation for calculated interference. This could result in an expensive mitigation solution or unexpected interference. An example of this is the use of free-space loss, which does not include all of the physical phenomena (such as the surface wave and the effects of the ground on the antenna performance) in the prediction of transmission loss. The propagation effects of diffraction and troposcatter are also not included in free-space loss. ITS has developed many specific radio-wave propagation models to meet the requirements for EMC analyses and other applications. These radio-wave propagation models have to be used in accordance with the range restrictions on input parameters.

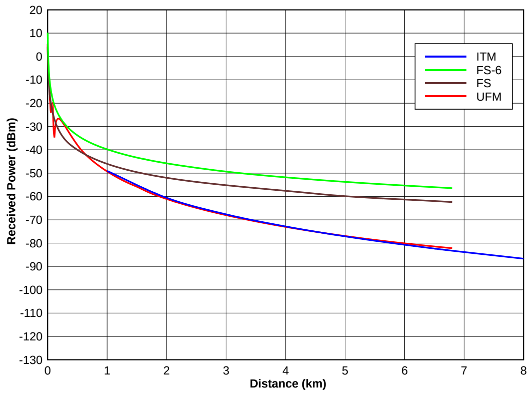
Four propagation models were used to determine the basic transmission loss and received signal levels: the Undisturbed-Field Model (UFM) [6], the ITS Irregular Terrain Model (ITM) [7], [8], a free-space loss model (FS), and a free-space loss model minus 6 dB along the slant range (FS-6) [9]. These models assume that the propagation takes place over a smooth spherical earth. The UTM, FS, and FS-6 models do not include the effects arising from terrain. The ITM model can take terrain effects into account in its point-to-point mode but, in this case, it was used in its area prediction mode, which uses a smooth spherical earth. The use of the idealized smooth spherical earth is a worst case for an interference analysis, since the loss is at a minimum compared to the case where terrain effects are present. The minimum propagation loss is what should be used to assure that the interference analysis provides the maximum possible interference signal-level prediction.

There are situations where a minimum propagation loss could occur with a terrain-covered earth when the interfering transmitter and victim receiver are at very different heights due to the actual terrain elevations and there is a clear path between the interfering transmitter and victim receiver.

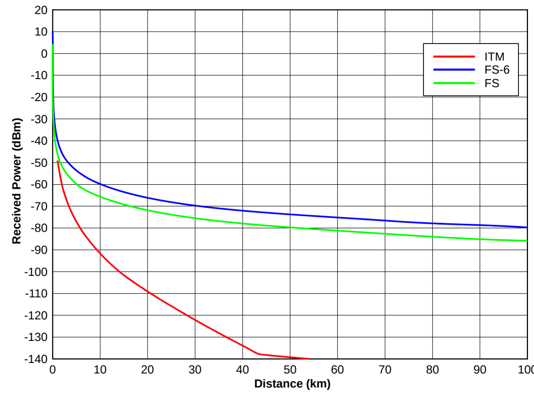
This could be examined further either statistically or when the specific geographic locations are known and the actual terrain can be determined and used as input.

The ITM is a good method for medium to long distances with antenna heights of up to 3,000 meters, and it includes line-of-sight, diffraction, and troposcatter phenomena over a spherical earth. The ITM model has been verified with measured data and other accurate models. It takes the presence of ground into account in addition to diffraction around a spherical earth. The ITM model also takes into account troposcatter propagation. The ITM model can also be used with input files of terrain for specific locations when the terrain files are available.

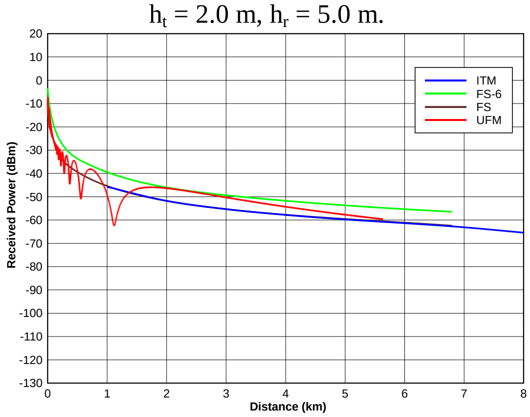
The UFM includes line-of-sight phenomena at medium and close-in distances less than 6.8 km, and for low antenna heights less than 10 meters [6]. It includes the direct and reflected waves as well as the surface wave. The surface wave is an important component of the total electromagnetic wave at close-in distances even at the higher frequencies. The distance of 6.8 km is used because at a frequency of 1800 MHz the Earth can be assumed flat out to a distance of 6.8 km [6]. The UFM will include all of the destructive and constructive interference behavior over a real smooth-earth environment, which will appear on a plot of received signal versus distance plot with many oscillations (Figures 1(a1) and 1(b1) for close-in distances). The UFM has been verified with measured data and other accurate propagation prediction techniques.



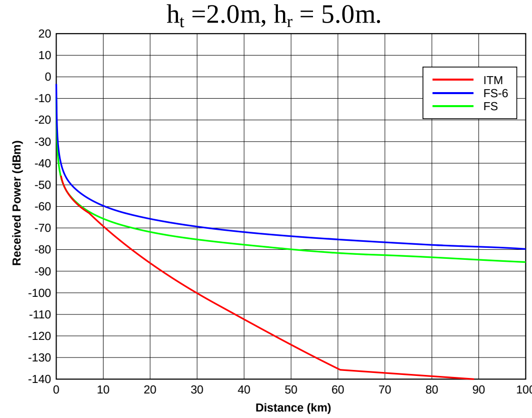
(a1) Low VSS antenna height, close distance, h_t = 2.0 m, h_r = 5.0 m.



(a2) Low VSS antenna height, far distance, h_t =2.0m, h_r = 5.0m.



(b1) High VSS antenna height, close distance, h_t = 20.0 m, h_r = 5.0 m.



(b2) High VSS antenna height, far distance, h_t = 20.0 m, h_r = 5.0 m.

Figure 1. Example plots of received power versus distance for the VSS to Radiosonde interference scenario S01 of Table 4.

The analysis technique can be best explained by going through an actual interference analysis example. The first interference interaction (denoted by S01 from Table 4) involves the interference from the VSS transmitter to the victim Radiosonde receiver. For long distances and both low and high antenna heights, Figures 1(a2) and 1(b2) don't show the constructive and destructive interference, since it doesn't occur at the longer distances. For the shorter distances of less than 6.8 km, the vertical and horizontal scale factors of Figures 1(a1) and 1(b1) make the constructive and destructive interference more discernible. Rather than trying to determine the exact received signal level at a specific distance, which may be difficult due to the occurrence of lobes in the received power versus distance curve, it is advisable to take the envelope of the maximum received signal level predicted by this model for a worst-case analysis. The height of the maximums (distance between the average value of received signal level and the maximum value of received signal level) can be as much as 6.0 dB over perfectly conducting ground. The maximum value of this excursion over average ground is about 4.0 to 5.0 dB.

The remaining two received signal prediction models are the FS and the FS-6. The FS-6 model results in an absolute maximum signal level that follows the minimum propagation loss predicted by the UFM. The FS-6 model is more suitable than FS model because it takes into account the maximum possible interference signal level due to interference phenomena predicted by the UFM. This is demonstrated by the plots in Figures 1(a1) and 1(b1) for the UFM. This phenomenon occurs in line-of-sight (LOS) scenarios. The FS model does not take into account any propagation phenomena other than the free-space loss. Decisions on whether to use the UFM or the FS-6 models are made based on which method would provide the best estimate of received signal level. An example of this is explained in the next paragraph and Figure 1(b1).

One must be careful in choosing the correct propagation model for EMC analysis. There are situations where the UFM should be used in preference to the two free-space models. Figure 1(b1) demonstrates that the predicted received interference signal level for the UFM is less than the received level predicted by the FS-6 model for distances greater than 3 km, and would be more accurate for distances above 3 km. However, for distances less than 3 km the UFM has lobes in the received power predictions, which are real, but are difficult to use as a general limit for maximum signal if the exact distance is not known. These lobes are bounded by the FS-6 model. In this case, the FS-6 model would be better to use for distances that are less than 3 km. The UFM is a more accurate model than the FS-6 model, so it would result in lesser separation distances for avoiding interference than the other free-space models for distances greater than 3 km and less than 6.8 km.

For distances less than 3 km the UFM (Figure 1(b1)) predicts the exact received signal level, but the FS 6 model follows the envelope of the varying signal level. In this case, it would be better to use the FS 6 model rather than be concerned about the actual locations of the peaks and nulls in the received signal level. The amount of frequency dependent rejection required would also be less for a fixed distance.

Figures 1(a2) and 1(b2) for the far distance scenarios demonstrate that the received signal level for the ITM model is much less than that for the two free-space models. This would allow much reduced separation distances and frequency dependent rejection for avoiding interference.

3.3 Noise Level Predictions for the Analysis

The noise level of the victim receiver in the analysis can be determined from the equation [10]:

$$Noise(dBm) = -174(dBm/Hz) + NF(dB) + 10\log(B_n(Hz))$$

where:

- NF is the receiver’s noise figure (dB)
- B_n is the receiver’s noise equivalent bandwidth in (Hz).

The received signal power from a desired transmitter is given by:

$$\begin{aligned} P_{rec}(dBm) = {} & P_t(dBm) + G_t(dBi) + G_r(dBi) \\ & - Loss(dB) - LossT(dB) - LossR(dB) - FDR(dB) \end{aligned}$$

where:

P_{rec}	is the received signal power from the desired transmitter or the interference source (dBm)
P_t	is the transmitted signal power from the desired transmitter or the interference source (dBm)
G_t	is the gain of the antenna at the desired transmitter or the interference source (dBi)
G_r	is the gain of the antenna at the receiver (dBi)
Loss	is the propagation loss between the desired transmitter (interference source) and the receiver (dB)
LossT	is the loss between the transmitter (interference source) and its antenna, including cable and feed losses (dB)
LossR	is the loss between the receiver and its antenna, including cable loss (dB)
FDR	is the frequency dependent rejection loss that is a result of the transmitter and receiver frequency differences, emission bandwidth of the transmitter, and filter characteristics of the receiver (dB).

3.4 Protection Ratio

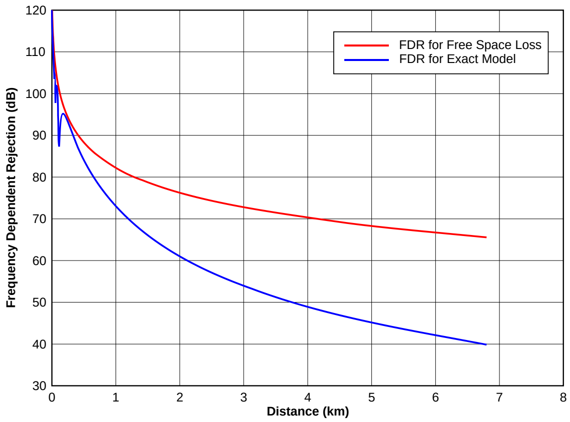
The interference protection ratio, α, is a value indicating the tolerance between the desired signal level, P_d, and the interfering signal level, P_i:

$$P_d - P_i \geq \alpha \ (dB)$$

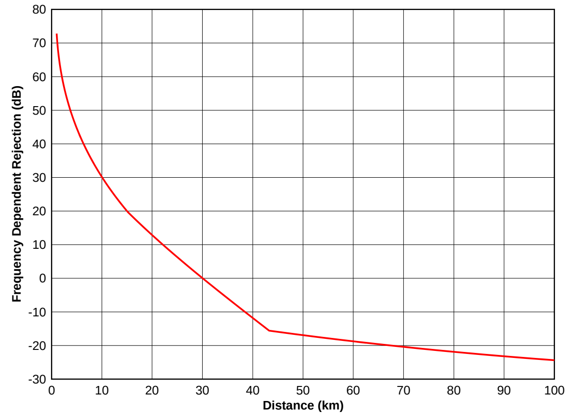
The protection ratio forms the basis of the interference criteria. In this analysis, the interference is based on the published maximum *BER* performance for GOES-N, an assumed maximum *BER* performance for GOES-R, and the minimum performance criteria for video quality as determined by the testing described in Section 5. Once these performance criteria are established, the protection ratio can be determined. The protection ratio determines the minimum separation distance between the interferer and the target.

3.5 Frequency-Dependent Rejection (*FDR*)

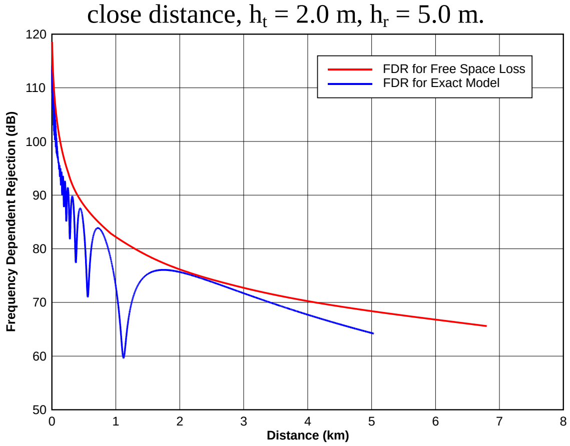
If analysis determines that a reasonable separation distance between the on-tune interference source and the victim receiver is not adequate to reduce the interfering signal to an acceptable level, then it is necessary to apply *FDR*. *FDR* (in dB) is the signal loss that is calculated from the transmitter and receiver center frequency offset (Δf), emission bandwidth of the transmitter, and filter characteristics of the receiver. *FDR* is the ability of a receiver to reject a specific interfering signal at a frequency offset from the receiver's center frequency. *FDR* defines the necessary frequency separation between the receiver and interferer to avoid interference [5]. It also can be used to determine the physical separation distance required, at a given Δf, to avoid interference. The plots of Figure 2 are examples taken from a single scenario for an entrant transmitter and incumbent receiver. The plots were calculated using the received interference signal power, and the *S/I*, *S/N*, and *I/N* ratios for the example scenario.



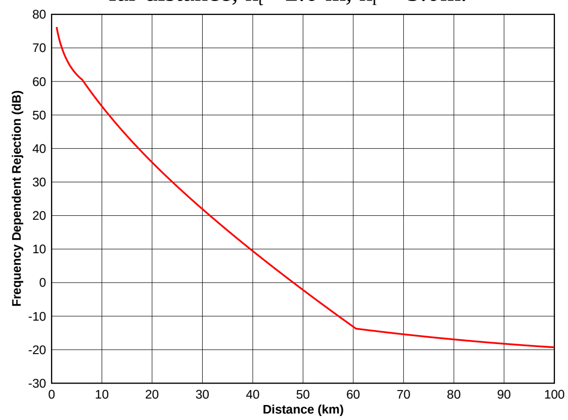
(a1) Low VSS antenna height, close distance, h_t = 2.0 m, h_r = 5.0 m.



(a2) Low VSS antenna height, far distance, h_t =2.0 m, h_r = 5.0m.



(b1) High VSS antenna height, close distance, h_t = 20.0 m, h_r = 5.0 m.



(b2) High VSS antenna height, far distance, h_t = 20.0 m, h_r = 5.0 m.

Figure 2. Example plots of *FDR* versus separation distance for the VSS to Radiosonde interference scenario S01 of Table 3.

FDR is a convenient way to define the discrimination of the communications circuit in terms of attenuation or rejection due to receiver selectivity [4]. Typically, the *FDR* is calculated from the transmitter spectral density $P_i(f)$ and the normalized receiver transfer function or receiver selectivity curve. *FDR* is given as the ratio of the total effective power at the receiver over the transmitted power.

$$FDR(\Delta f) = \frac{\int_0^\infty P_i(f)df}{\int_0^\infty P_i(f)\left|H(f+\Delta f)\right|^2 df}$$

where:

$P_i(f)$	is the power spectral density of the interfering signal
$H(f)$	is the normalized receiver transfer function
$\Delta f = f_i - f_r$	where f_i is the interferer's center frequency and f_r is the receiver's tuned frequency.

The above assumes that the channel transfer function is slowly varying relative to the product of the interferer spectral density and the receiver transfer function [5]. This is often not the case near the radio horizon.

When $\Delta f = 0$ then the *FDR* equals the on-tune rejection (*OTR*). When $\Delta f \neq 0$ then the off-frequency rejection (*OFR*), which is the additional rejection that occurs when the receiver is detuned relative to the interferer, can be found from the following:

$$OFR = FDR - OTR$$

The calculation of the *FDR* shows the importance of determining the IF filter bandwidth at the last stage before demodulation to characterize the interference potential accurately. In the case where the receiver bandwidth is less than the interferer bandwidth, *OTR* can be approximated from the following:

$$OTR \approx 10 \log\left(\frac{B_r}{B_i}\right) \quad B_r \leq B_i$$

where:

B_r is the receiver's 3dB bandwidth (Hz)
B_i is the interferer's 3dB bandwidth (Hz).

For this analysis, estimations of the integrals in the *FDR* equation will be used when possible.

The required *FDR* was calculated for the VSS to Radiosonde interferer/receiver pair as a function of separation distance (Figure 2). The *FDR* achieved as a function of the transmitter and receiver parameters mentioned previously and the frequency offset also was calculated (Figure 3). This results in the estimation of the potential interference rejection for this entrant transmitter into the incumbent receiver. The *FDR* was computed for all interactions of Table 4. Appendix A contains the plots of *FDR* versus Δf for all of the interactions of Table 4. The plots in Appendix A contain the total of on- and off-tune rejection that is equal to the *FDR*. These plots will determine the amount of frequency offset needed to attain compatibility and this can be used to trade off or reduce the required separation distance between the interferer and the victim receiver.

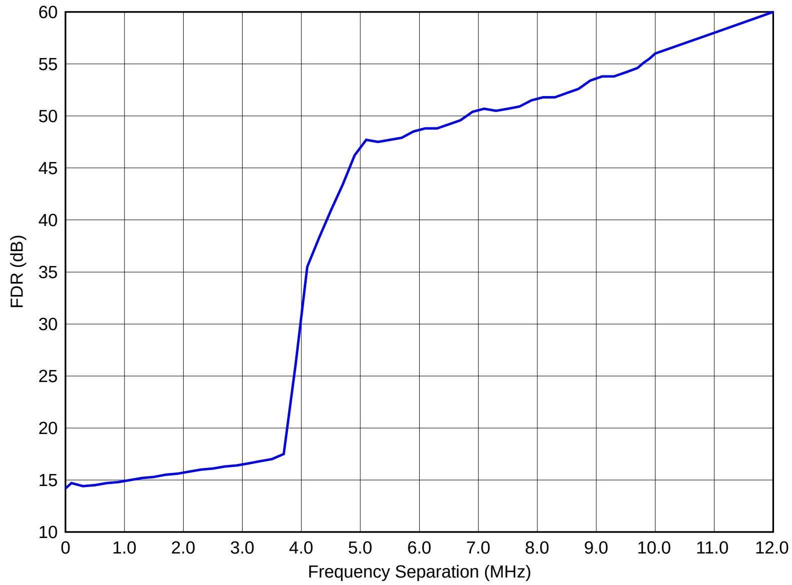


Figure 3. Example plot of *FDR* versus frequency offset for the VSS to Radiosonde Interference Scenario S01 of Table 4.

The *FDR* required to bring the interference signal level down to meet the *I/N* and *S/N* requirement is given by:

$$FDR(dB) = P_{rec}(dBm) - N(dBm) - I/N(dB)$$

$$\frac{S}{N} = \frac{E_b}{N_0} \times \frac{R}{B}$$

$$\frac{I}{N}(dB) = \frac{S}{N}(dB) - \frac{S}{I}(dB)$$

The S/N = 7.3 dB was computed from an E_b/N_o = 7.0 dB, a data rate R = 8.0 Mbps and a bandwidth B = 7.5 MHz [2]. The *BER* curves will allow for the calculation of the SNR at a given signal-to-interference (S/I) ratio. The E_b/N_o = 7.0 was obtained from the curves in [2] for a pre-correction *BER* of 10^{-3} and QPSK modulation with an S/I = 20 dB. The resultant I/N is -12.7 dB. The *FDR* computed from the equation is a function of distance since the received power P_r (dBm) is also a function of distance, so the plots in Figure 2 are a function of distance.

This analysis assumes that the radiosonde's receiver antenna is pointed directly at the VSS transmitter, which is worst case. In a more realistic situation, where the radiosonde's receiver antenna is not directly pointed at the VSS transmitter, then a reduction in interference level from the VSS into the radiosonde occurs and, as a result, the *FDR* versus distance decreases. In this case, the geometric orientation (elevation angle and distance) and the antenna patterns are taken into account. This is shown in the following four cases.

- Case 1 (Figure 4): the receiver was tracking a radiosonde near the horizon with the VSS transmitter antenna height at 2 meters and the radiosonde receiver antenna at its normal height of 5 meters.

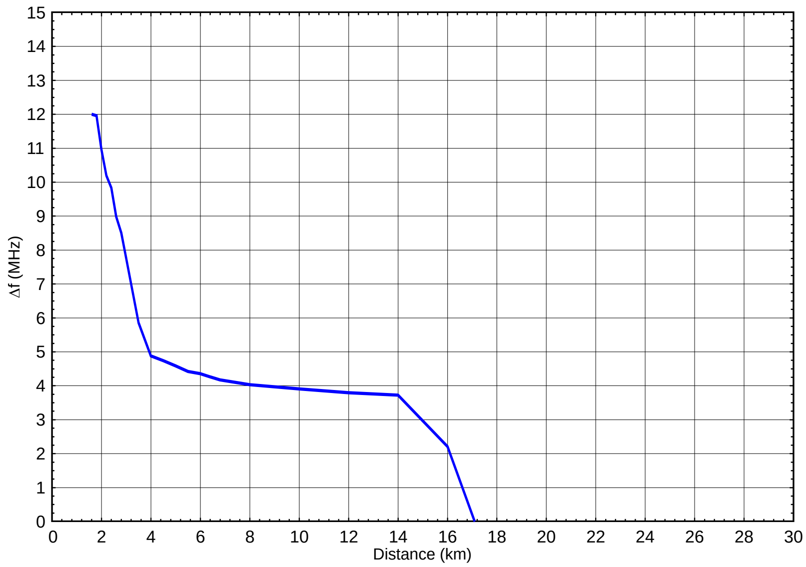


Figure 4. Frequency offset versus separation distance for tracking radiosonde near horizon with h_t = 2 m and h_r = 5 m – VSS transmitter interference into radiosonde receiver.

- Case 2 (Figure 5): the receiver was tracking a radiosonde near the horizon with the VSS transmitter antenna height at 20 meters and the radiosonde receiver antenna at its normal height of 5 meters.

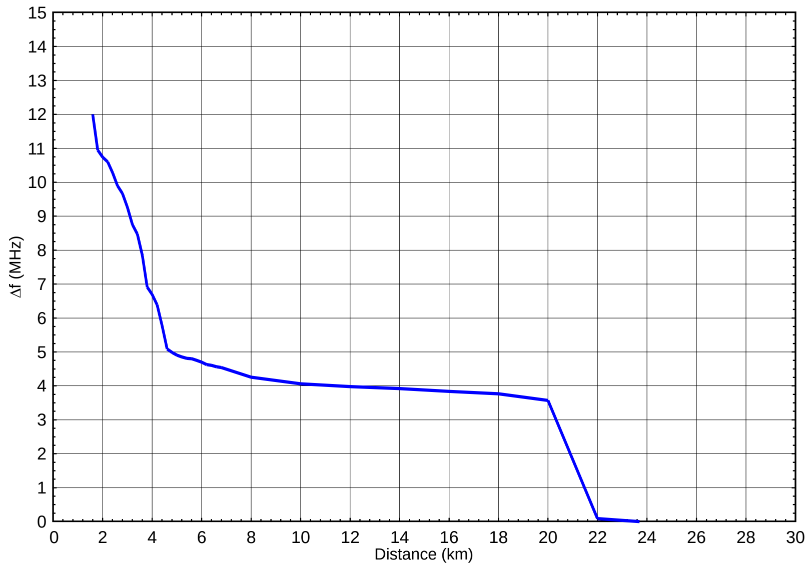


Figure 5. Frequency offset versus separation distance for tracking radiosonde near horizon with h_t = 20 m and h_r = 5 m – VSS transmitter interference into radiosonde receiver.

- Case 3 (Figure 6): the receiver was tracking a radiosonde at an elevation angle of 5 degrees above the horizon with the VSS transmitter antenna height at 2 meters and the radiosonde receiver antenna at its normal height of 5 meters.

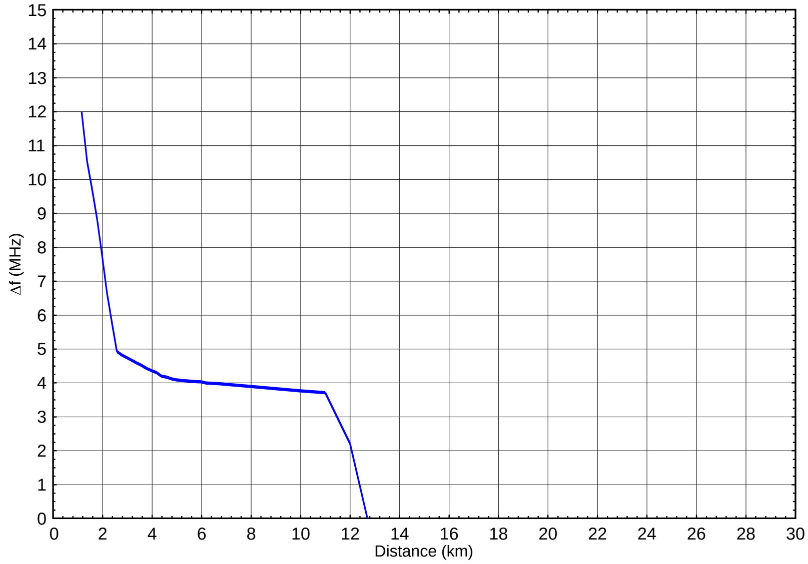


Figure 6. Frequency offset versus separation distance for 5° elevation angle with h_t = 2 m and h_r = 5 m – VSS transmitter interference into radiosonde receiver.

- Case 4 (Figure 7) the receiver was tracking a radiosonde at an elevation angle of 5 degrees above the horizon with the VSS transmitter antenna height at 20 meters and the radiosonde receiver antenna at its normal height of 5 meters.

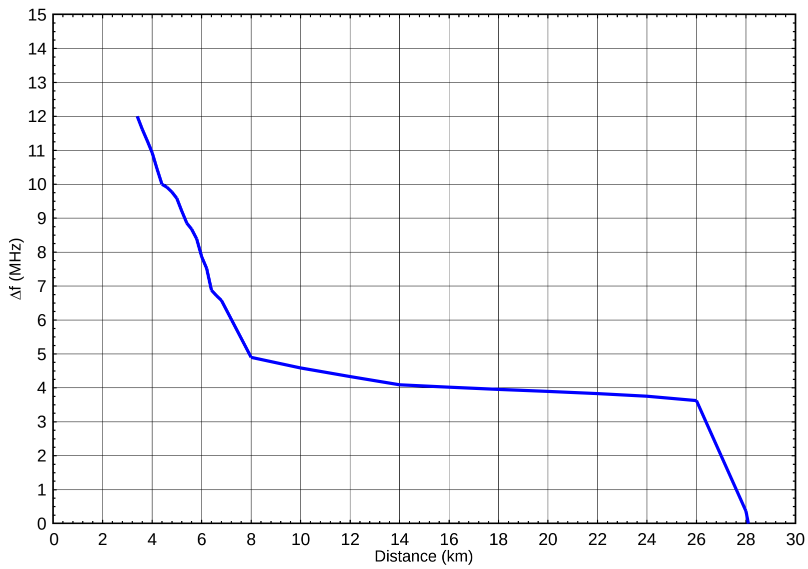
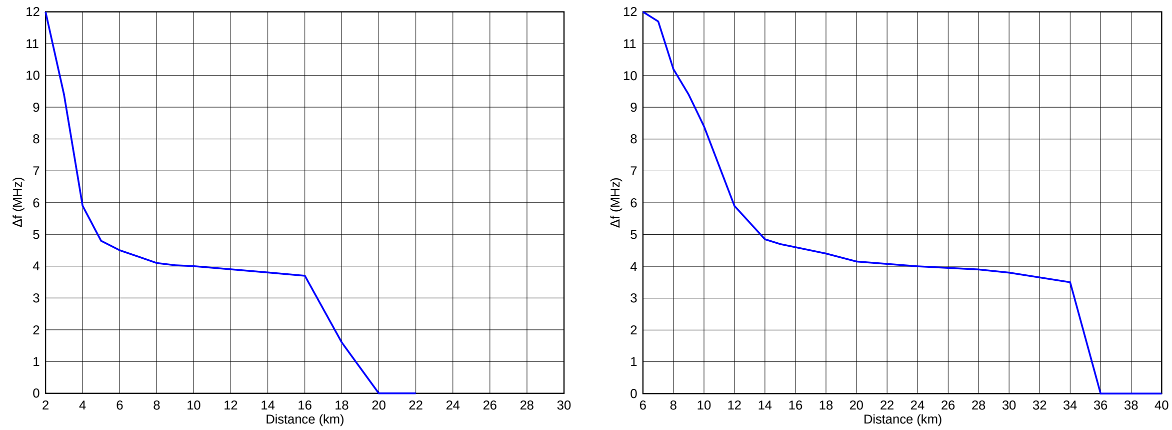


Figure 7. Frequency offset versus separation distance for 5° elevation angle with h_t = 20 m and h_r = 5 m – VSS transmitter interference into radiosonde receiver.

Figures 8(a) and 8(b) are examples of the frequency offset versus separation distance for the worst-case situation (on-boresight, with the radiosonde receiver pointed directly at the VSS transmitter). They were computed for the example entrant transmitter/incumbent receiver pair based on their parameters. For the entrant transmitter this would include the emission bandwidth with roll-off of the emission spectra at the band edges and beyond. For the incumbent receiver the information includes the receiver bandwidth with sufficient information for the receiver rejection characteristics outside of the receiver bandwidth.



(a) Low VSS antenna height, h_t = 2.0 m, h_r = 5.0 m. (b) High VSS antenna height, h_t = 20.0 m, h_r = 5.0 m.

Figure 8. Example plots of frequency offset versus separation distance for the VSS to Radiosonde Interference Scenario S01 of Table 4 (for *S/N* = 7.3 dB and *S/I* = 20 dB).

Compared to Figures 8(a) and 8(b), cases 1 through 4 (Figures 4 through 7) show that there is some reduction in interferer to victim-receiver separation distance. A statistical analysis could be performed that would determine the probability of interference and take into account the off-boresight cases in a stochastic representation.

3.6 The EMC Metric of Frequency Separation (*Δf*) Versus Separation Distance

From *S/N* and *S/I*, the *I/N* can be calculated which will allow a determination of *Δf* versus separation distance from the *FDR* curves (Figure 8). For a given separation distance between the entrant (interferer) and the incumbent (receiver), a certain *Δf* must be maintained between them. In this example, if the incumbent receiver is operating at a frequency that is 5 MHz away from the entrant interference source, the entrant transmitter (at a rooftop height of 20 meters) would have to be at least 13 km away from the incumbent receiver to avoid a harmful interference level. At greater distances, the frequency offset between the two systems can be less; at greater than 36 km, the two devices can operate on the same frequency, since Figure 8 shows that *Δf* is equal to zero at a 36 km separation. If the entrant interfering transmitter antenna were at a 2 meter height, it could operate at a frequency that is only 4.5 MHz from the incumbent receiver with a 6 km separation distance.

3.7 Applying Propagation Models to Scenarios

Table 5 groups the 28 interference scenarios into 20 propagation classes, based on antenna heights. For each class, the most appropriate radio-wave propagation loss model (ITM, UFM, FS, or FS-6) is shown first for separation distances of 6.8 km or less and then for greater separation distances. The fourth column lists the scenario applicable to that class.

Table 5. Propagation model loss analysis combinations for interference analysis applicable for all analysis scenarios.

Antenna Heights h_t/h_r (meters)	Separation Distances ≤ 6.8 km	Separation Distances > 6.8 km	Applicable Scenario
2/5	UFM	ITM	VSS to Radiosonde
20/5	FS-6	ITM	VSS to Radiosonde
2/33	UFM or FS-6	ITM	VSS to GOES-N or R RCVR
20/33	FS-6	ITM	VSS to GOES-N or R RCVR
1/2	UFM	ITM	Radiosonde to VSS
1/20	UFM	ITM	Radiosonde to VSS
100/2	FS-6	ITM	Radiosonde to VSS
100/20	FS-6	ITM	Radiosonde to VSS
1000/2	FS-6	FS-6	Radiosonde to VSS
1000/20	FS-6	FS-6	Radiosonde to VSS
3000/2	FS-6	FS-6	Radiosonde to VSS
3000/20	FS-6	FS-6	Radiosonde to VSS
10/2	UFM	ITM	Radiosonde to VSS
10/20	FS-6	ITM	Radiosonde to VSS
20,000/2	FS-6	FS	Radiosonde to VSS
20,000/20	FS-6	FS	Radiosonde to VSS
33,000/2	FS-6	FS	Radiosonde to VSS
33,000/20	FS-6	FS	Radiosonde to VSS
35,786,000/2	FS	FS	GOES-N to VSS GOES-R to VSS
35,786,000/20	FS	FS	GOES-N to VSS GOES-R to VSS

The antenna heights (in meters) are based on the following definitions:

1:	minimum radiosonde transmitter height
2:	average standing VSS height
5:	radiosonde receive antenna height
10:	intermediate value
20:	highest VSS rooftop height
33:	maximum satellite dish height
100, 1000, 3000:	valid ranges of the propagation models
20,000:	antenna height limit for groundwave model
33,000:	maximum radiosonde altitude
35,786,000:	satellite synchronous orbit

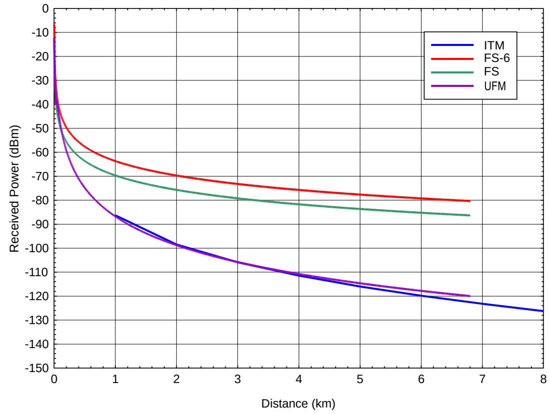
For the FS-6 model, the slant distance is the actual distance between the transmitter and the receiver as opposed to the distance along the smooth spherical earth. The minimum propagation loss should be used to assure that the interference analysis is on the safe side of the interference signal level prediction.

4. INTERACTION SCENARIO RESULTS

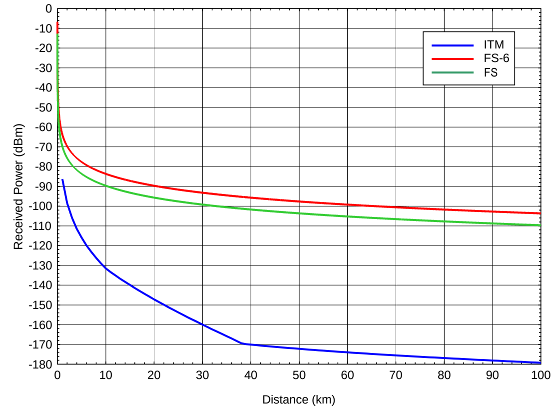
The previous section outlined the analysis approach with an example (scenario S01) that will be used to describe the analysis for other interactions contained in Table 4.

4.1 Scenario S02, Radiosonde Interference to VSS Victim Receiver

The effects of interference will be evaluated for the VSS's wideband mode, which can use one of three modulations (QPSK, 16QAM, and 64QAM), since the VSS is used primarily in this mode and the wide bandwidth represents a worst case situation. The first step is to calculate the interference power levels from the radiosonde into the VSS receiver. This computation was performed over all ranges of antenna heights and distances that both the radiosonde and the VSS would encounter during normal operation. The ranges were listed in Table 5 of the previous section. Plots of received interference power versus distance are illustrated in Figures 9-14.

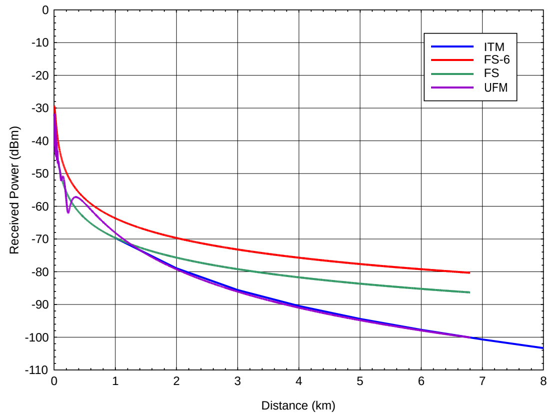


(a) Received power for scenario S02-15.1 for h_t = 1.0 m and h_r = 2.0 m – Radiosonde to VSS.

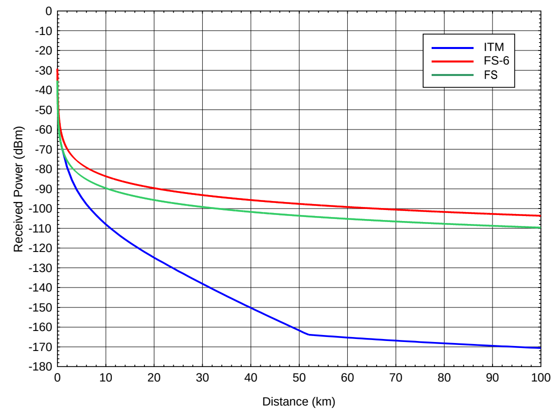


(b) Received power for scenario S02-15.1 for h_t = 1.0 m and h_r = 2.0 m – Radiosonde to VSS.

Figure 9. Near and far details of interference effects –
low transmitter antenna height – low receiver antenna height.

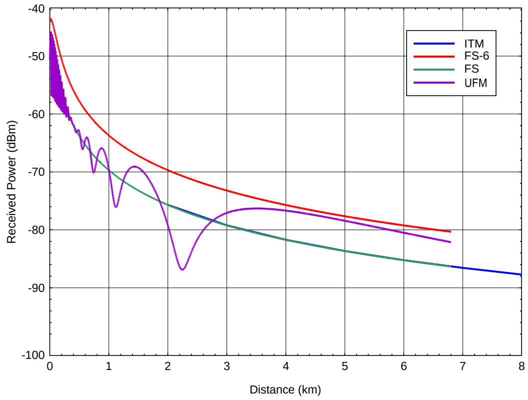


(a) Received power for scenario S02-15.1 for h_t = 1.0 m and h_r = 20.0 m – Radiosonde to VSS.

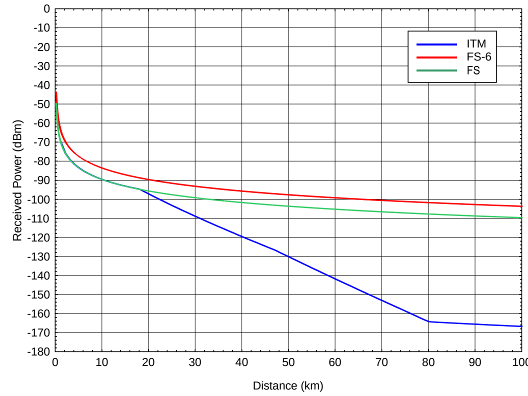


(b) Received power for scenario S02-15.1 for h_t = 1.0 m and h_r = 20.0 m – Radiosonde to VSS.

Figure 10. Near and far details of interference effects –
low transmitter antenna height – high receiver antenna height.

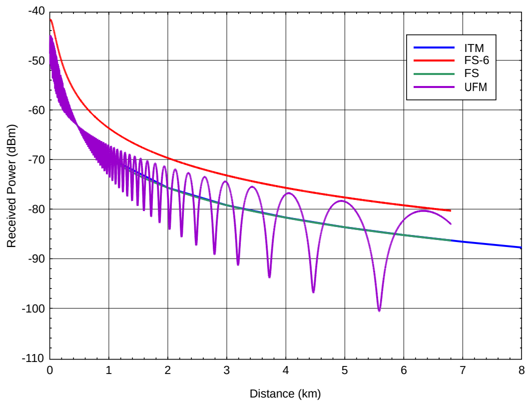


(a) Received power for scenario S02-15.1 for h_t = 100.0 m and h_r = 2.0 m – Radiosonde to VSS.

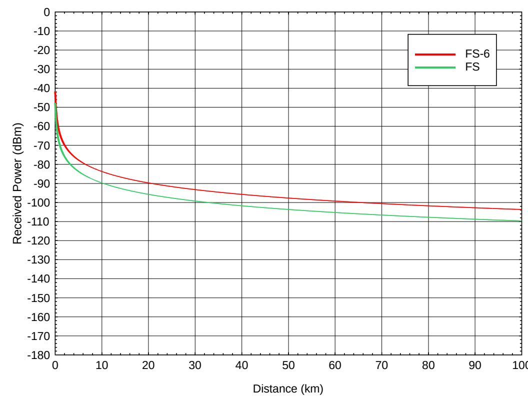


(b) Received power for scenario S02-15.1 for h_t = 100.0 m and h_r = 2.0 m – Radiosonde to VSS.

Figure 11. Near and far details of interference effects – high transmitter antenna height – low receiver antenna height.

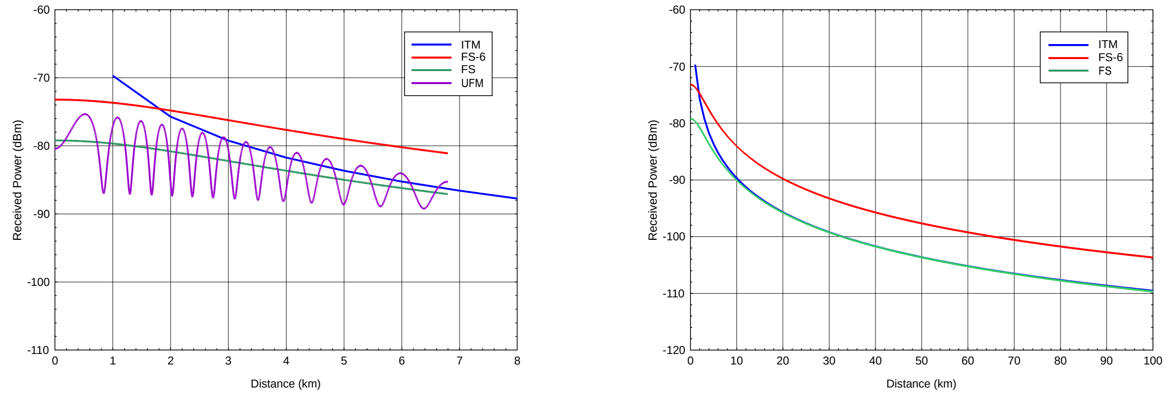


(a) Received power for scenario S02-15.1 for h_t = 100.0 m and h_r = 20.0 m – Radiosonde to VSS.



(b) Received power for scenario S02-15.1 for h_t = 100.0 m and h_r = 20.0 m – Radiosonde to VSS.

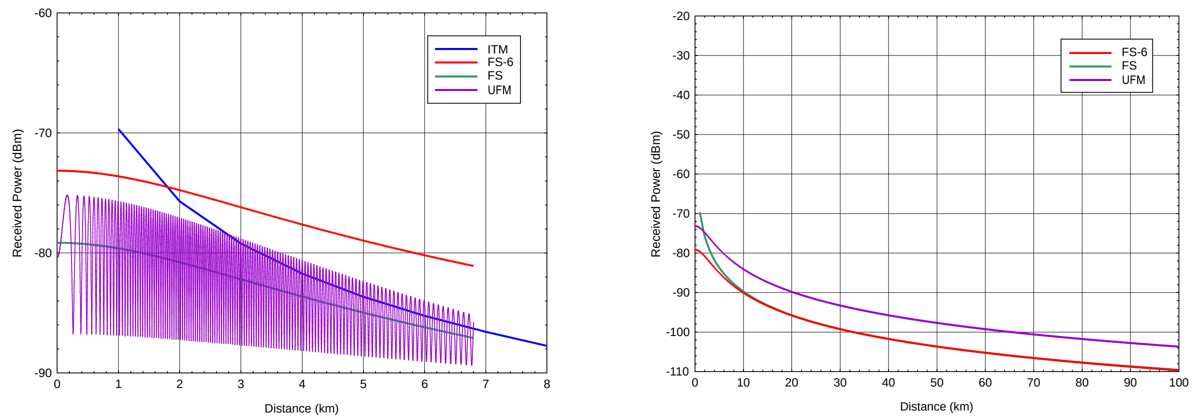
Figure 12. Near and far details of interference effects – high transmitter antenna height – high receiver antenna height.



(a) Received power for scenario S02-15.1 for h_t = 3000.0 m and h_r = 2.0 m – Radiosonde to VSS.

(b) Received power for scenario S02-15.1 for h_t = 3000.0 m and h_r = 2.0 m – Radiosonde to VSS.

Figure 13. Near and far details of interference effects – very high transmitter antenna height – low receiver antenna height.



(a) Received power for scenario S02-15.1 for h_t = 3000.0 m and h_r = 20.0 m – Radiosonde to VSS.

(b) Received power for scenario S02-15.1 for h_t = 3000.0 m and h_r = 20.0 m – Radiosonde to VSS.

Figure 14. Near and far details of interference effects – very high transmitter antenna height – high receiver antenna height.

The largest power level from the radiosonde interference source into the VSS receiver occurred for the scenario where the radiosonde transmitter was at a height of 100 meters and the VSS receiver was at a height of 20 meters. Curves were generated over two distance ranges to provide resolution at short distances and a greater dynamic range for long distances. These curves appear in Figures 12(a) and 12(b) respectively.

The VSS transmitter to VSS receiver separations used during normal operation range from 0.01 to 1 km, with the antenna heights both at 2.0 meters. Figure 15 is a computation of the received power versus the distance between the VSS transmitter and the VSS receiver with both antenna heights at 2 m.

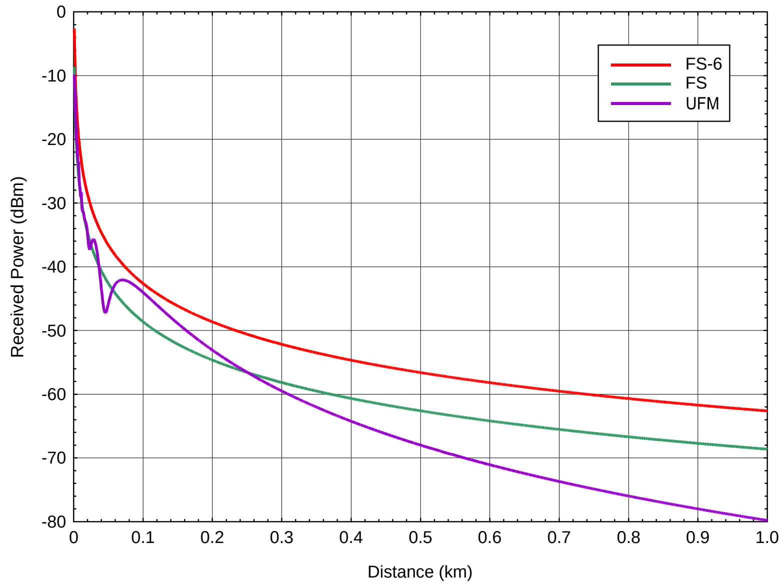


Figure 15. Received power for VSS to VSS with h_t = 2.0 m and h_r = 2.0m.

For incremental separation distances between the VSS transmitter and receiver, the allowed interference level was calculated for three *S/I* ratios of 20, 18, and 15 dB. For each VSS transmitter to VSS receiver separation distance, the allowed interference signal level was determined using the equation $I = S - S/I$, where *I*, *S*, and *S/I* are all in decibels for all three *S/I* ratios. Figures 12 and 15 can then be used to determine the separation distance between the radiosonde and VSS at which these interference levels are attained. These values can then be used to plot the radiosonde to VSS separation distance versus the VSS transmitter to VSS receiver separation distance for three different *S/I* ratios (Figure 16). These are on-tune plots (co-channel) and represent the situation for a strong desired and strong interference signal as long as the *S/I* ratios are maintained.

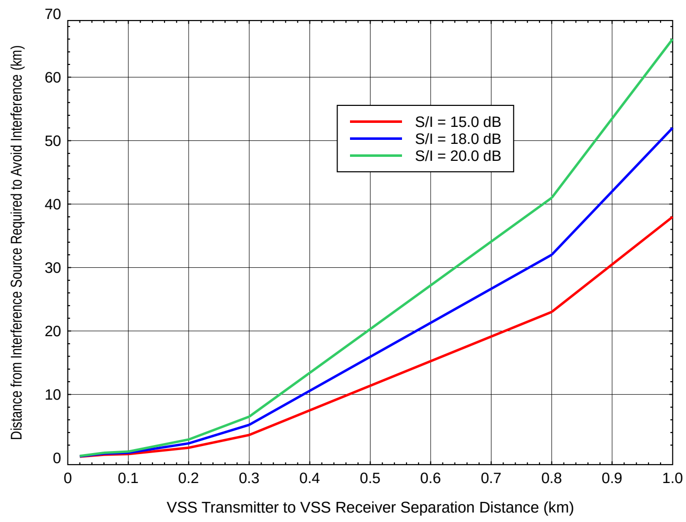


Figure 16. Distance from interference source required to avoid interference as a function of VSS transmitter to VSS receiver separation distance.

For situations where the signal is much weaker and near the noise level, the interference computation is performed using the minimum *S/N* in decibels, which is determined from the E_b/N_0 for a required *BER*. The *I/N* ratios required to maintain the *S/I* and *S/N* ratios are given by:

$$\frac{I}{N} = \frac{S}{N} - \frac{S}{I}$$

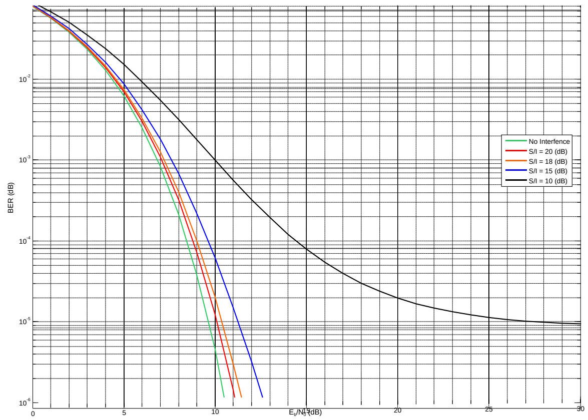
$$\frac{S}{N} = \frac{E_b}{N_0} \times \frac{R}{B}$$

$$= \frac{E_b}{N_0} + K \quad where\, K = \log \frac{R}{B}$$

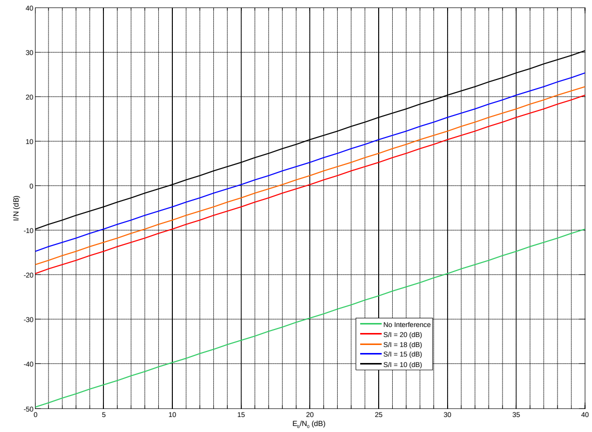
$$\frac{I}{N} = \frac{S}{N} - \frac{S}{I} = \frac{E_b}{N_0} + K - \frac{S}{I}$$

The E_b/N_0 required to obtain proper operation of the VSS was determined using the methods of Section 3.0 and computations of *BER* versus E_b/N_0 with *S/I* as a parameter shown in Figures 17(a1), 17(a2), and 17(a3) for each of the three modulations: QPSK, 16QAM, and 64QAM.

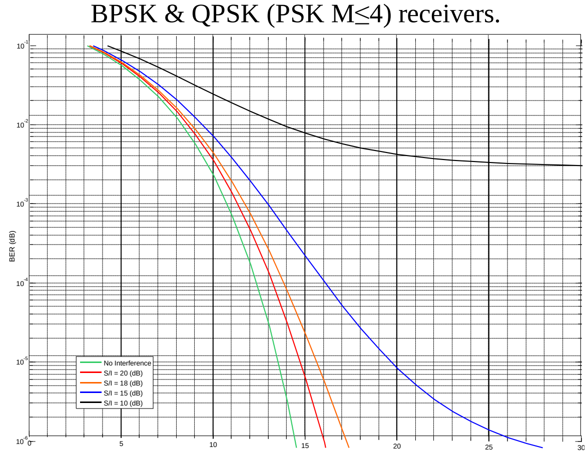
Figures 17(b1), 17(b2), and 17(b3) are plots of the *I/N* in dB as a function of E_b/N_0 with *S/I* as a parameter for each of the three modulations. It should be noted that based on the above definition of *I/N*, none of the variables (*S*, *N*, or *I*) are dependent on the type of modulation used or the *BER* to E_b/N_0 relationship. *I/N* only is dependent on the values of *R* and *B* which are the same for all three modulations. Therefore, the three plots are identical.



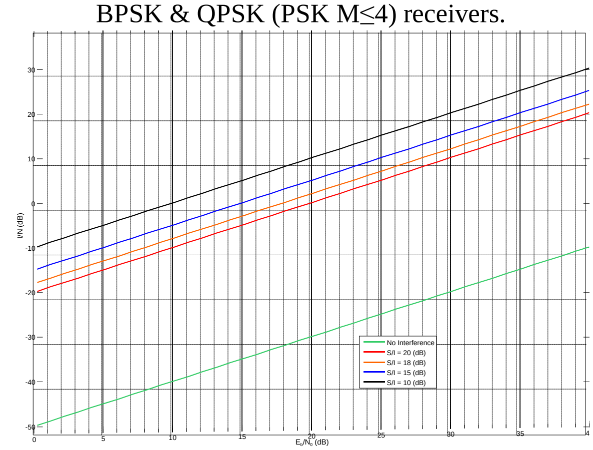
(a1) *BER* versus E_b/N_0 curves for scenario S02-15.3 for BPSK & QPSK (PSK M≤4) receivers.



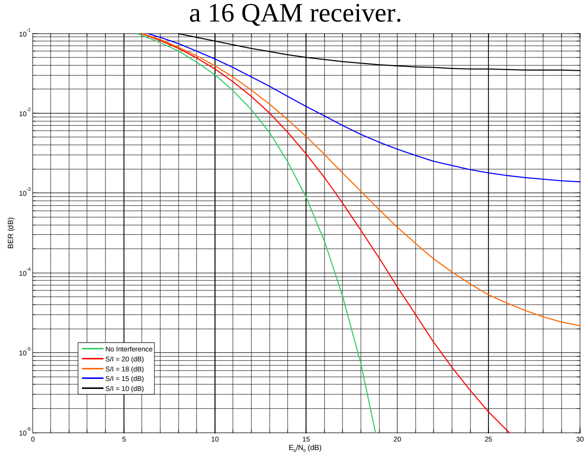
(b1) *I/N* vs. E_b/N_0 curves for scenario S02-15.3 for BPSK & QPSK (PSK M≤4) receivers.



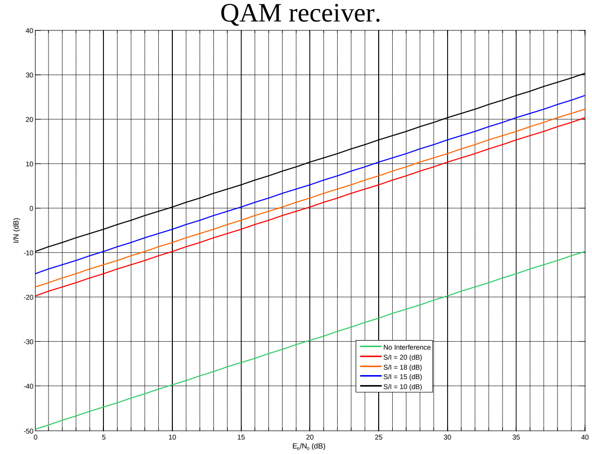
(a2) *BER* versus E_b/N_0 curves for scenario S02-15.4 for a 16 QAM receiver.



(b2) *I/N* vs. E_b/N_0 curves for scenario S02-15.4 for a 16 QAM receiver.



(a3) *BER* versus E_b/N_0 curves for scenario S02-15.5 for a 64 QAM receiver.



(b3) *I/N* vs. E_b/N_0 curves for scenario S02-15.5 for a 64 QAM receiver.

Figure 17. Victim VSS receiver with noise-like interferer (radiosonde and GOES satellites).

The required E_b/N_0, *S/N*, interference level (*I*), and signal level (*S*) for the 7.5 MHz bandwidth are listed in Tables 6(a), 6(b), and 6(c) for *S/I* ratios of 20, 18 and 15 dB. The plots with noise-like interference were calculated using the algorithms in [2]. The information regarding E_b/N_0 using CW noise was obtained from plots in [2]. From Tables 6(a), 6(b), and 6(c), it can be seen that there is a small difference between noise-like interference and CW interference.

Table 6(a). Required E_b/N_0 and S/N for a BER of 1.0×10^{-3} for noise-like and CW interference for S/I = 20 dB.

Modulation	**E_b/N_0 (dB) S/N (dB)**	***I* (dBm)**	***I/N* (dB)**	***S* (dBm)**	**E_b/N_0 (dB) S/N (dB)**	***I* (dBm)**	***I/N* (dB)**	***S* (dBm)**
	Noise Int.	**Noise Int.**	**Noise Int.**	**Noise Int.**	**CW Int.**	**CW Int.**	**CW Int.**	**CW Int.**
QPSK 7.5 MHz	7.0 7.28	-113.97	-12.72	-93.97	7.0 7.28	-113.97	-12.72	-93.97
16QAM 7.5 MHz	11.2 11.5	-109.5	-8.5	-89.5	11.2 11.5	-109.5	-8.5	-89.5
64QAM 7.5 MHz	16.6 16.9	-104.65	-3.1	-84.65	15.2 15.5	-105.75	-4.25	-85.75

Table 6(b). Required E_b/N_0 and S/N for a BER of 1.0×10^{-3} for noise-like and CW interference for S/I = 18 dB.

Modulation	**E_b/N_0 (dB) S/N (dB)**	***I* (dBm)**	***I/N* (dB)**	***S* (dBm)**	**E_b/N_0 (dB) S/N (dB)**	***I* (dBm)**	***I/N* (dB)**	***S* (dBm)**
	Noise Int.	**Noise Int.**	**Noise Int.**	**Noise Int.**	**CW Int.**	**CW Int.**	**CW Int.**	**CW Int.**
QPSK 7.5 MHz	7.1 7.38	-111.87	-10.62	-93.87	7.7 7.98	-111.27	-10.02	-93.27
16QAM 7.5 MHz	11.4 11.68	-107.57	-6.32	-89.57	11.5 11.78	-107.47	-6.22	-89.47
64QAM 7.5 MHz	18.0 18.28	-100.97	0.28	-82.97	16.0 16.28	-102.97	-1.72	-84.97

Table 6(c). Required E_b/N_0 and S/N for a BER of 1.0×10^{-3} for noise-like and CW interference for S/I = 15 dB.

Modulation	**E_b/N_0 (dB) S/N (dB)**	***I* (dBm)**	***I/N* (dB)**	***S* (dBm)**	**E_b/N_0 (dB) S/N (dB)**	***I* (dBm)**	***I/N* (dB)**	***S* (dBm)**
	Noise Int.	**Noise Int.**	**Noise Int.**	**Noise Int.**	**CW Int.**	**CW Int.**	**CW Int.**	**CW Int.**
QPSK 7.5 MHz	7.5 7.78	-108.47	-7.22	-93.47	8.2 8.48	-107.77	-6.52	-92.77
16QAM 7.5 MHz	12.9 13.18	-103.07	-1.82	-88.07	12.7 12.98	-103.27	-2.02	-88.97
64QAM 7.5 MHz	---- ----	----	----	----	16.8 17.08	-99.17	2.08	-84.17

Frequency dependent rejection between a transmitter and receiver depends on the operating center frequency and the in and out of band emission characteristics of the transmitter. It also depends on the center frequency and the in and out of band rejection characteristics of the receiver. Computation of frequency dependent rejection was covered in Section 3.5.

The *FDR* required to bring the interference signal down to a power level that would satisfy *I/N* and *S/N* ratios is:

$$FDR(dB) = P_{rec}(dBm) - \left(N(dBm) + I/N(dB)\right).$$

The plots of required *FDR* are plotted for each of the three modulations. Figure 18 is a plot of the *FDR* attainable between the radiosonde transmitter and the VSS receiver for the 7.5 MHz bandwidth. It is calculated based on the wanted signal's emission characteristics, the interference signal's emission characteristics, and the receiver's IF bandwidth characteristics.

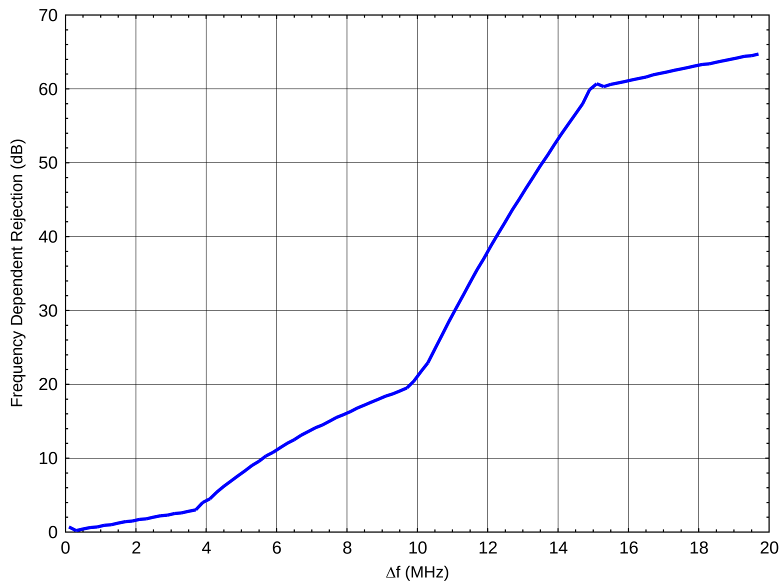
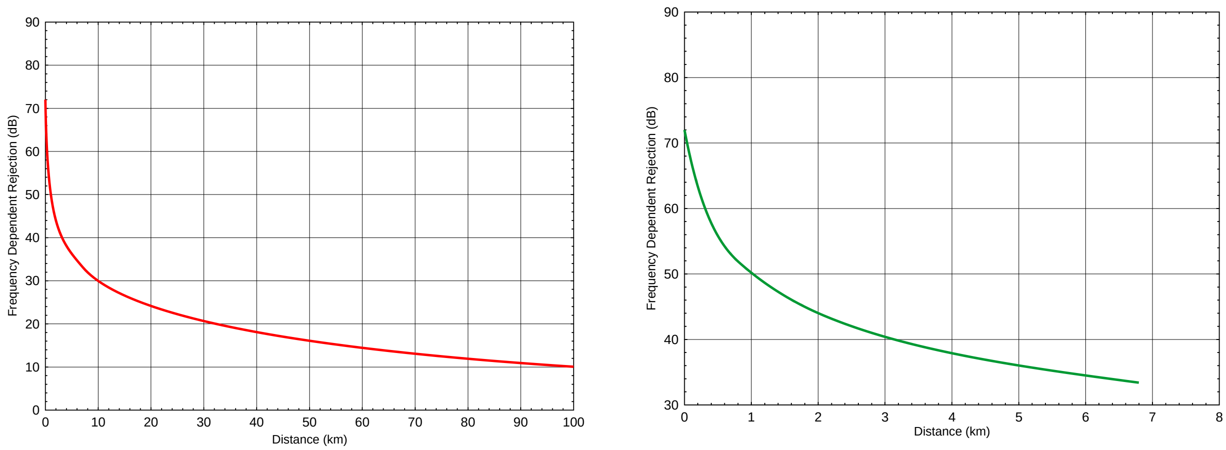


Figure 18. *FDR* versus *Δf* for the VSS transmitter to radiosonde receiver.

4.1.1 Scenario S02 (QPSK)

Figures 19(a) and 19(b) show the long and short distance range frequency dependent rejection, respectively, that is necessary to achieve electromagnetic compatibility for case S02 (QPSK) with a 7.5 MHz bandwidth and QPSK modulation.



(a) Long distance (b) Short distance

Figure 19. *FDR* for scenario S02-15.3
for h_t = 100 m and h_r = 20 m – radiosonde to VSS (QPSK).

Figure 20 shows the *Δf* in frequency versus radiosonde transmitter to VSS receiver separation required to provide electromagnetic compatibility with a 7.5 MHz bandwidth and QPSK modulation. Figure 20 was obtained by combining the *FDR* attainable for a 7.5 MHz bandwidth of Figure 18 with the required frequency dependent rejection of Figures 19(a) and 19(b).

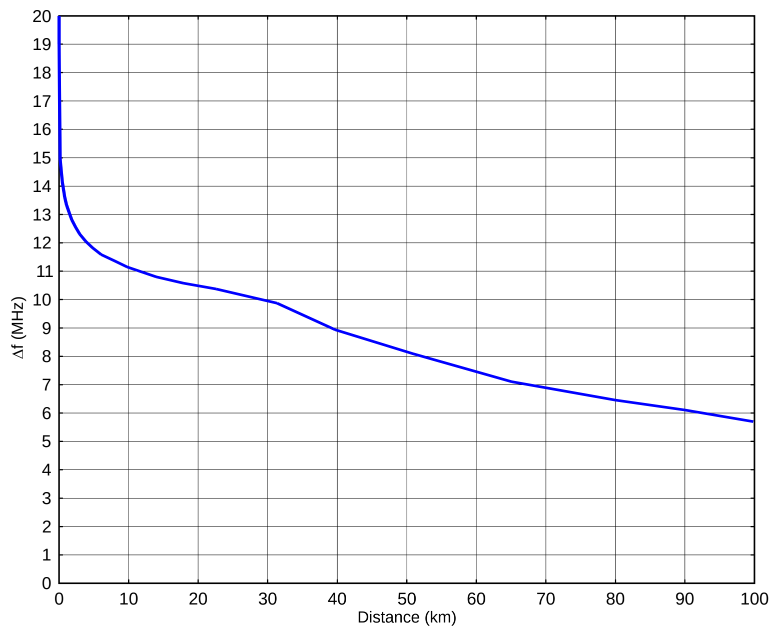
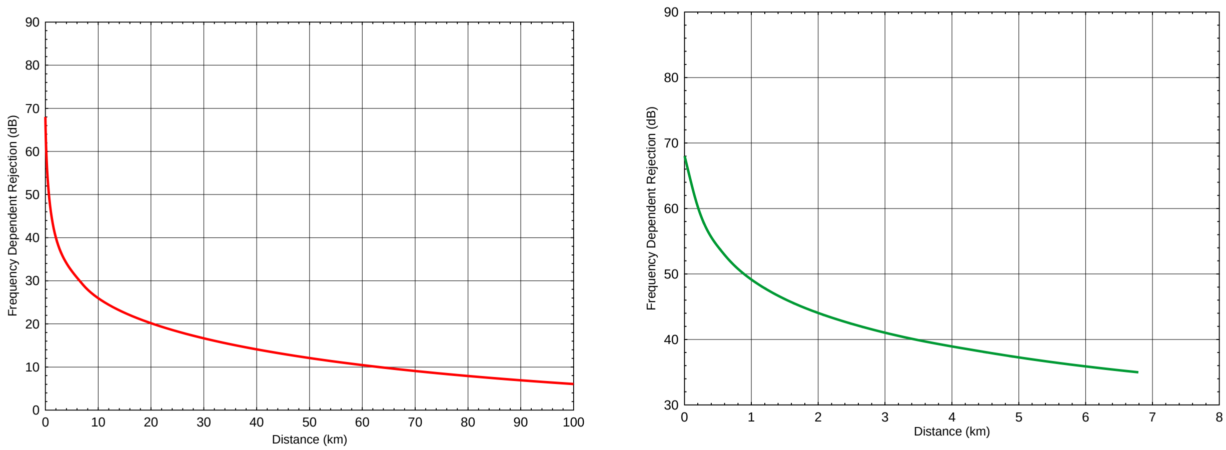


Figure 20. *Δf* versus separation distance for scenario S02-15.3
for h_t = 100 m and h_r = 20 m –radiosonde to VSS (QPSK).

4.1.2 Scenario S02 (16QAM)

Figures 21(a) and 21(b) show the long and short distance range frequency dependent rejection, respectively, that is necessary to achieve electromagnetic compatibility for case S02 (16QAM) with a 7.5 MHz bandwidth and 16QAM modulation.



(a) Long distance (b) Short distance

Figure 21. *FDR* for scenario S02-15.4
for h_t = 100 m and h_r = 20 m – radiosonde to VSS (16QAM).

Figure 22 shows the *Δf* in frequency versus radiosonde transmitter to VSS receiver separation required to provide electromagnetic compatibility with a 7.5 MHz bandwidth and 16QAM modulation. Figure 22 was obtained by combining the *FDR* attainable for a 7.5 MHz bandwidth of Figure 18 with the required frequency dependent rejection of Figures 21(a) and 21(b).

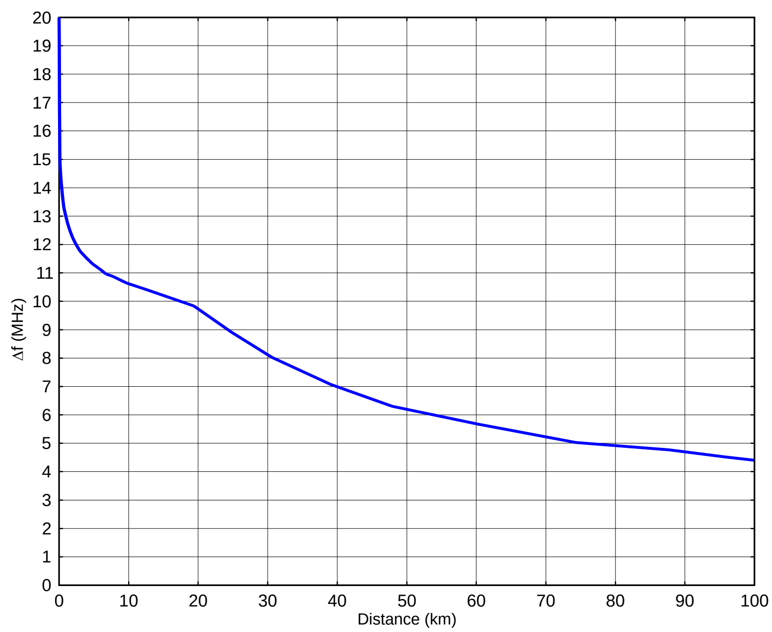
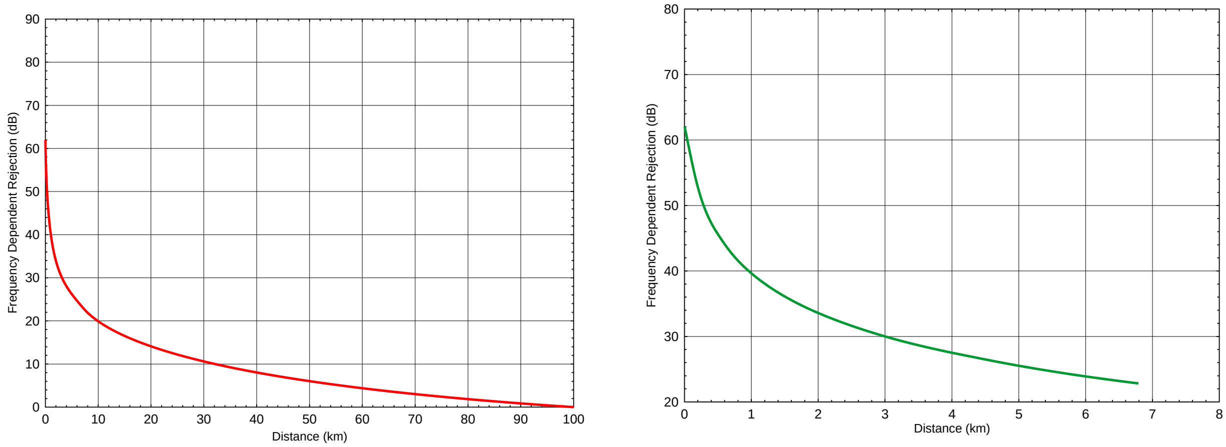


Figure 22. *Δf* versus separation distance for scenario S02-15.4
for h_t = 100 m and h_r = 20 m –radiosonde to VSS (16QAM).

4.1.3 Scenario S02 (64QAM)

Figures 23(a) and 23(b) show the long and short distance range required frequency dependent rejection, respectively, that is necessary to achieve electromagnetic compatibility for case S02 (64QAM) with a 7.5 MHz bandwidth and 64QAM modulation.



(a) Long Distance.

(b) Short Distance.

Figure 23. *FDR* for scenario S02-15.5
for h_t = 100 m and h_r = 20 m – radiosonde to VSS (64QAM).

Figure 24 shows the *Δf* in frequency versus radiosonde transmitter to VSS receiver separation required to provide electromagnetic compatibility with a 7.5 MHz bandwidth and 64QAM modulation. Figure 24 was obtained by combining the *FDR* attainable for a 7.5 MHz bandwidth of Figure 18 with the required frequency dependent rejection of Figures 23(a) and 23(b).

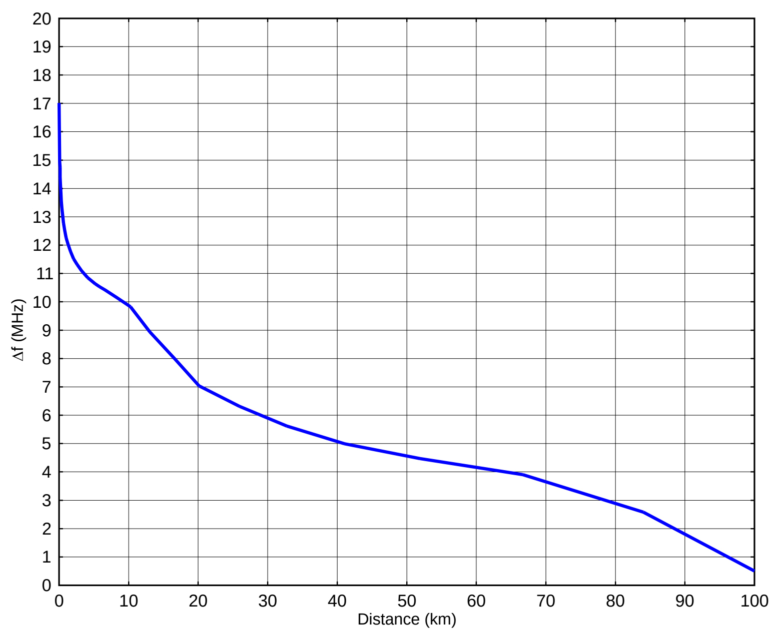


Figure 24. *Δf* versus separation distance for scenario S02-15.5
for h_t = 100 m and h_r = 20 m –radiosonde to VSS (64QAM).

4.1.4 Summary for Analysis of Results for Scenarios S02 (QPSK), S02 (16QAM), & S02 (64QAM)

Figures 20, 22, and 24 represent the amount in frequency separation that the victim receiver must be off-tuned from the interfering transmitter versus separation distance in order to avoid interference. Small amounts of off-tuning are required if the separation distance is large, and large amounts of off-tuning are required for small separation distances. For the 7.5 MHz bandwidth operation of the VSS, a separation distance of 10 km requires an approximate separation in frequency of 10 MHz to avoid interference.

4.2 Interactions for Scenarios S03 to S15, GOES-N and GOES-R Interference to VSS Victim Receiver

4.2.1 Computation of Interference Levels

Computations of the interference levels into the VSS receiver from the GOES-N and GOES-R satellite transmissions toward Earth were made to determine if this type of interference was an issue. The antenna gains of the VSS receiver (2.15 dBi) are very low in comparison to the antenna gains of the satellite receiver links (39.6 dBi for GOES-N and 47.2 dBi for GOES-R). The satellite links also have a low gain margin to conserve satellite power. As a result, the satellite signal levels, which are adequate for the design of the GOES-N and GOES-R links, do not cause interference into the low gain antennas on the VSS receivers.

The following equation calculates the received signal level from the GOES satellites into the VSS receiver. Free-space loss is used to compute the propagation loss from the satellites to the VSS receiver and is equal to 188 dB.

$$P_{rec}\left(dBm\right) = P_t\left(dBm\right) + G_t\left(dBi\right) + G_r\left(dBi\right) - L_p\left(dB\right)$$

where

- P_{rec} is the received interference power at the VSS receiver (dBm)
- P_t is the satellite transmitter power of the GOES satellite transmitter (dBm)
- G_t is the satellite transmitter antenna gain (dBi)
- G_r is the VSS receiver antenna gain (2.15 dBi)
- L_p is the free-space propagation loss from the satellite to the VSS receiver (188 dB).

Using the values in Table 6, the above equation produces the received signal level values contained in Table 7.

Table 7. Computation of received interference power from the GOES satellites into the VSS receiver.

Scenario	GOES Satellite Series	GOES Transmitter Function	P_t (dBm)	G_t (dBi)	P_r (dBm) Interferer	*I/N* (dB) Narrowband 1.25 MHz	*I/N* (dB) Wideband 7.5 MHz
S03	GOES-N	SD	36.9	15.6	-133.35	-24.35	-32.1
S04	GOES-N	PDR	44.5	15.6	-125.75	-16.75	-24.5
S05	GOES-N	LRIT-WEFAX	40.2	15.6	-130.05	-21.05	-28.8
S06	GOES-N	EMWIN	31.2	15.6	-139.05	-30.05	-37.8
S07	GOES-N	MDL	38.2	15.6	-132.05	-23.05	-30.08
S08	GOES-N	DCPR	38.0	15.6	-132.25	-23.25	-31.0
S09	GOES-N	CDA/TLM	34.5	15.6	-135.75	-26.75	-34.5
S10	GOES-R	GRB#1	46.0	17.3	-122.55	-13.6	-21.35
S11	GOES-R	GRB#2	46.0	17.3	-122.55	-13.6	-21.35
S12	GOES-R	HRIT	43.8	16.5	-125.55	-16.55	-24.30
S13	GOES-R	DCPR#1	37.0	16.5	-132.35	-23.35	-31.10
S14	GOES-R	DCPR#2	37.0	16.5	-132.35	-23.35	-31.10
S15	GOES-R	CDA/TLM	31.8	3.1	-150.95	-41.95	-49.70

4.2.2 Summary for the Interactions for Scenarios S03 to S15, GOES-N and GOES-R Interference to VSS Victim Receiver

All of the calculated interference levels in Table 7 are well below the noise levels for both the 1.25 MHz (-109.0 dBm) worst case and 7.5 MHz (-101.25 dBm) best case operating bandwidths of the VSS receiver. Interference from the GOES satellites into the VSS receiver antenna is therefore not a problem. The wide bandwidth of 7.5 MHz was assumed for this analysis, since VSSs run in wideband mode most of the time. No frequency dependent rejection is needed and as a result, no off-tuning of these systems is required to avoid this type of interference from the GOES satellites. The satellites maintain an almost constant separation distance from the VSS receivers of 35,786 km. The highest level of interference from GOES-N or GOES-R satellites is from the GOES-R Rebroadcast links (GRB#1 and GRB#2) at a signal level of -122.5 dBm, which results in a worst case *I/N* of -13.6 dB.

4.3 Interactions for Scenarios S16 to S28, VSS Interference to GOES-N and GOES-R Victim Receiver

The remainder of this section analyzes interference of the VSS transmitter into the GOES satellite earth station receivers (Scenarios S16 to S28). This is important since the sensitivity of the GOES receivers and the very large gains of the earth station satellite receiver antennas make the earth station satellite receiver very susceptible to interference from the VSS. The separation distance versus Δf relationships for all of these VSS transmitter to GOES receiver interactions have been calculated based on transmitter and receiver parameters, the received interference levels necessary to maintain compatibility, and the *FDR* to Δf and *FDR* to separation distance relationships.

Eight to twelve plots were generated for each scenario, based on interferer and victim antenna heights and antenna alignment. The scenarios specify two antenna heights for the VSS and two or three antenna heights for the GOES receiver. The relative alignment of the two antennas is important because it demonstrates the need to tailor the analysis for each potential deployment situation. In a worse case situation, the VSS would be located on the GOES antenna's axis, or boresight (on-axis). While an on-axis arrangement is improbable (but physically possible), a more likely scenario involves the VSS unit positioned on the ground (antenna height = 2 m) or on a rooftop (antenna height = 20 m) in the vicinity of the GOES receiver (off-axis).

Appendix C lists all 26 GOES receiver sites operated by the U.S. Government and their orientation towards the two GOES satellites. Not all sites receive signals from both satellites (due to local needs and the physical alignment with each satellite) and not all sites monitor all of the signals that GOES satellites transmit. In addition, the terrain around each GOES receiver site can vary greatly. This must be taken into account when calculating the separation distance.

Appendix D contains all of the separation distance versus Δf plots generated for the last 13 scenarios. The plots are laid out in the following manner: the first page for each scenario shows the plots for a VSS antenna height of 2 m, and the second page for a VSS antenna height of 20 m. The left-hand column of each page shows the results of the on-axis calculations, the right-hand column the results of the off-axis calculations. From top to bottom, the plots show the differences due to increasing GOES receiver antenna heights. Reading across (left-to-right), one can see the improvement (closer separation distances and smaller Δf) a more realistic configuration makes over the worst-case on-axis configuration.

Based on the Appendix D plots, an estimation of the required separation distance and Δf can be obtained and adjusted against each other to arrive at a solution for operation on a noninterference basis.

5. MEASUREMENTS

The primary goal of the test design was to define the environment that would result in detrimental interference to the VSS signal (Section 5.1). The tests also had to identify where, when, and if the VSS causes interference to the incumbent services in the band (Section 5.2). From an engineering perspective, the tests must verify and validate any assumptions made about the unknowns in the interference environment. Testing for such a complex problem meant that the number and range of potential test parameters had to be reduced to a manageable number. Analyzing all potential combinations of equipment settings, propagation channel conditions, and physical relationships between the various communication systems would be impractical. The following sections describe the measurements selected to form a manageable and meaningful set to test comprehensively the potential interference in this band.

5.1 Interference of the Radiosonde to the VSS

5.1.1 Actual Frequency Relationships Between the Radiosonde and the VSS

Figure 25 shows possible positions of the radiosonde (red line) and VSS signals (blue region) within the 1675–1695 MHz band. The radiosonde signal is limited to the 1675–1683 MHz range (gray region). Figures 25(a) and 25(b) are the extreme cases where the two signals are immediately adjacent to each other, with the radiosonde lying on the lower edge of the VSS signal; Figure 25(c) shows the singular case with the radiosonde lying on the upper edge of the VSS signal. Figures 25(d) and 25(e) are the extreme cases where the radiosonde and VSS signals are co-located. Figure 25(f) shows that the maximum frequency separation between the two signals is 16 MHz.

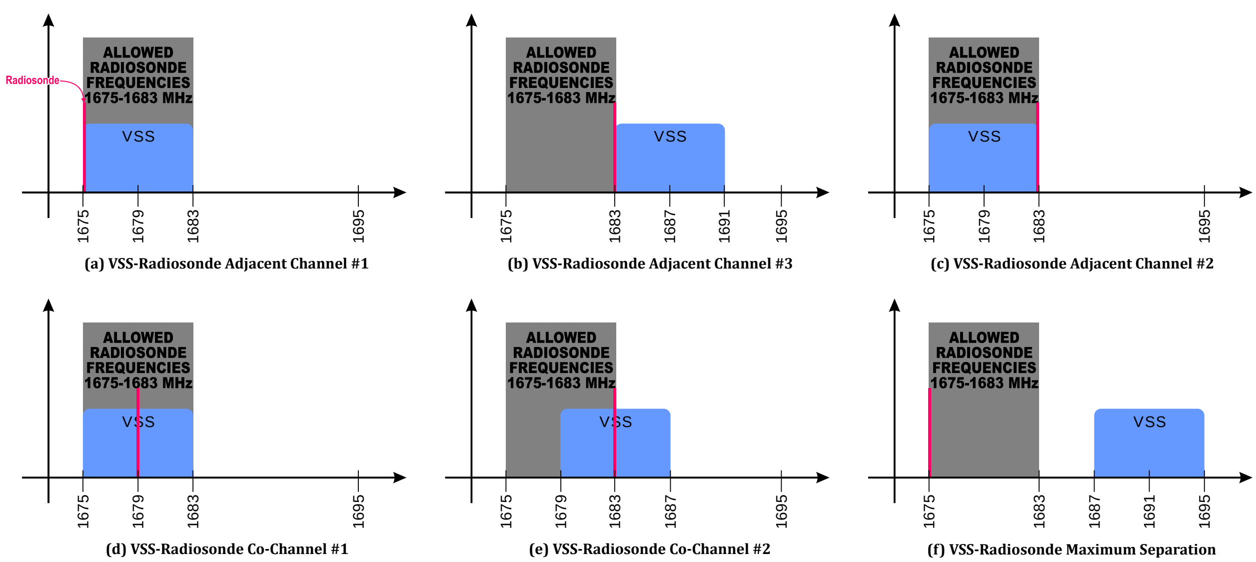


Figure 25. VSS-Radiosonde location extremes in the 1675–1695 MHz band.

5.1.2 VSS Configuration Space

The VSS COFDM transmitter can transmit in narrowband and wideband modes. In wideband mode, the device uses the DVB-T waveform. There are four parameters available to the user: FEC rate, guard interval, modulation, as well as a choice of three bandwidths (6, 7, and 8 MHz). Initial testing revealed that the choice of configuration parameters was limited by the selected bandwidth (for example, when the device is configured to transmit with a 6 MHz bandwidth, 64QAM is unavailable).

To obtain a detailed understanding of the VSS's failure-point and more thoroughly examine the interference environment, the configuration parameters were bracketed (i.e., ranges of VSS input parameters were selected such that the configurations would represent extremes in performance). The goal of selecting the appropriate configuration brackets is to reduce the number of required measurements without diminishing the significance of the results and assure that the most critical interference environments in a public safety setting are examined thoroughly. This process led to the creation of 20 potential configurations of the VSS as shown in Table 8.

Table 8. VSS configurations.

Configuration	**Bandwidth**		**FEC Rate**			**Guard Interval**		**Modulation**		
	6 MHz	**8 MHz**	**1/2**	**3/4**	**2/3**	**1/4**	**1/32**	**QPSK**	**16QAM**	**64QAM**
1	✓		✓				✓	✓		
2	✓			✓			✓	✓		
3	✓		✓			✓		✓		
4	✓			✓		✓		✓		
5		✓	✓				✓			✓
6		✓		✓			✓			✓
7		✓	✓			✓				✓
8		✓		✓		✓				✓
9		✓	✓				✓	✓		
10		✓		✓			✓	✓		
11		✓	✓			✓		✓		
12		✓		✓		✓		✓		
13		✓	✓				✓		✓	
14		✓		✓			✓		✓	
15		✓	✓			✓			✓	
16		✓		✓		✓			✓	
17	✓				✓		✓		✓	
18	✓				✓	✓			✓	
19		✓			✓		✓		✓	
20		✓			✓	✓			✓	

The remainder of the VSS parameters, such as Spectrum Inversion, and 4 kHz Offset (which are used to correct for transmission anomalies), were kept fixed for all configurations (Table 9). Preliminary tests showed that these parameters did not affect the VSS's sensitivity to interference.

Table 9. Non-critical VSS parameters.

Device	Parameter	Value
Transmitter	Spectrum Inversion	Inverted
	4 kHz Offset	None
	Video Input	NTSC
	MPEG Mode	MPEG2
	Horizontal Resolution	704
	Video Sharpness	Normal
Receiver	Down-converter LO	1050 MHz
	Down-converter LO Side	Low
	OFDM Polarity	Normal
	MPEG4 De-blocking Filter	Off
	Descrambling	Off
	LNB Power	Yes

Other parameters are used by the system's audio channel. Audio quality failure-points were not tested relative to the video quality failure-points because the video signal is more susceptible to interference than the audio signal and represents worst-case usage. As a result, the audio component was not taken into consideration in these tests and no specific audio content was sent between the VSS devices (save for ambient noise picked up by the microphones).

In addition, there are a number of "housekeeping" parameters used by both hardware and configuration software that do not affect the RF signal and are not addressed here.

Although the VSS transmitter can be adjusted to operate over a range of center frequencies, adjustment requires the device to be reprogrammed and the center frequency is not easily changed without the proper equipment. Consequently, the VSS was left to transmit at the pre-programmed frequency it was supplied with (1687 MHz) and the frequency of the simulated interference signals was varied instead.

5.1.3 Test Qualifiers

The test setup represents a communication circuit in a controlled interference environment. This concept is used to determine the interaction between the desired signal and the interferer. These interactions can be one-to-one, many-to-one, or one-to-many; the initial tests addressed a one-to-one interaction. Ideally, an objective measurement is used to determine the degree of performance degradation due to interference; for example, *BER*, receiver selectivity, or perhaps

FDR could be used as the receiver's figure of merit if such parameters could be measured. The most straightforward measurement to make is *BER* in the presence of interference. However, the interactions between modulation type, forward-error-correction methods, video codec, and the overall robustness of the underlying protocol (COFDM), make any correlation between *BER* and video quality complex. In situations where the communication content is primarily video, informal subjective measures are used. It is important that the test design use a simple video failure mode as a figure of merit for a particular interference environment.

What follows is a description of the tests that were conducted. Also included are tests that verified assumptions that were made to limit the search space. These tests were conducted in a laboratory environment only. Field tests should be performed when a target incumbent receiver is available. More significantly, field-testing the VSS is not possible without special exemptions for transmitting in the existing band; a VSS operating in the existing band can interfere with the active, mission-critical incumbents. In addition, field-testing that produces results that are not readily interpretable (because relevant propagation parameters cannot be controlled as well as in the lab and cannot be accurately measured) would not be a good use of time and resources. Field-testing should be limited to interference scenarios that exactly match actual, proposed deployments for assurance testing (validation and verification). Since the scenarios themselves are under evaluation, as much effort as possible went towards a thorough laboratory examination. This gives all potential users data that can be used to develop methods for peaceful coexistence.

5.1.4 Basic Test Setup

Figure 26 shows the basic test setup that was used to calibrate and test the VSS in a flat fading environment, which was simulated with variable and fixed attenuators. Flat fading occurs when the coherence bandwidth of the channel is greater than the bandwidth of the signal and, as a result, all frequency components of the signal will experience the same amount of fading. The fixed losses associated with the various circuit elements are shown in red text.

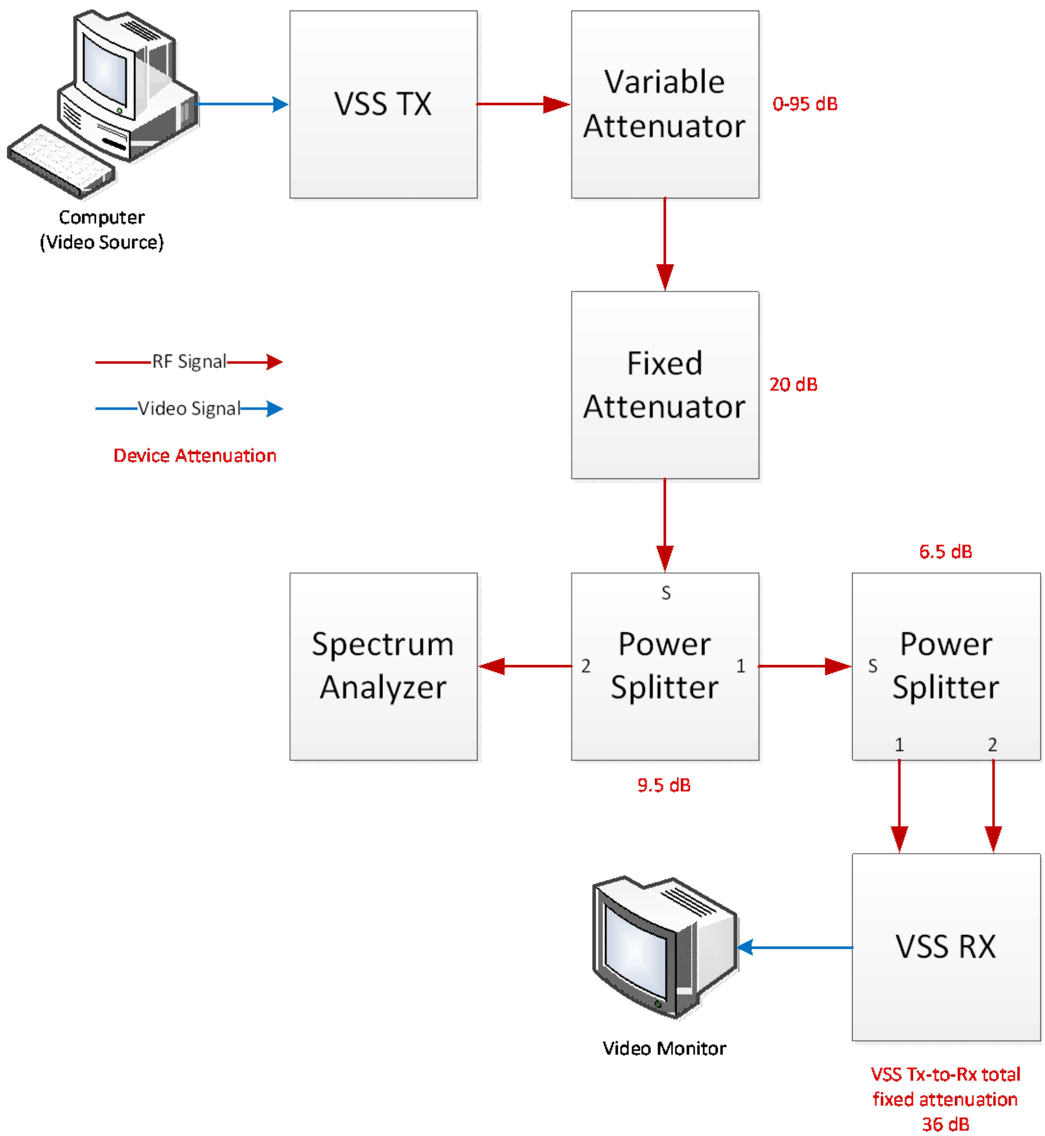


Figure 26. VSS baseline test setup.

Figure 27 shows the setup used to inject interference into the VSS propagation channel. Isolators were necessary in this setup to ensure that the signal generator was not exposed to input power levels beyond its designed limits. Note that the power splitter closest to the VSS transmitter was used as a power combiner.

These two tests served different purposes. The basic setup (Figure 26) was used to verify the proposed test design and to uncover any potential for equipment damage. The spectrum analyzer in both circuits confirmed that the intended interference environment was being created correctly. Since these tests were not designed to address the effects that receiver space diversity may have on the interference, the signal was fed to the dual inputs of the VSS receiver via a final power splitter.

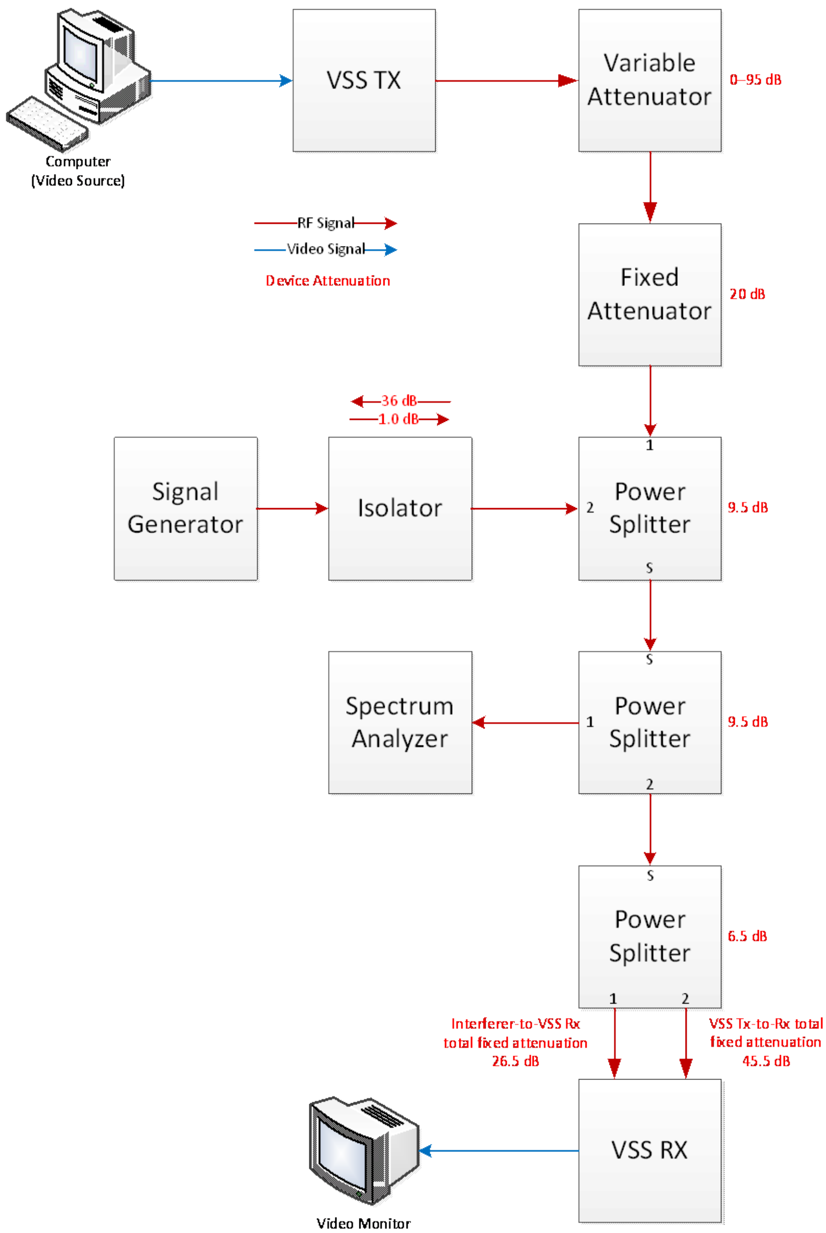


Figure 27. VSS interference injection test setup.

5.1.5 VSS Video Failure Mode

The video signal transmitted by the VSS originated from a desktop computer playing a 12 second long looped video clip (Figure 28). A surveillance video clip that shows an aerial view of a crowded parking lot from a helicopter was used in all tests. This clip was chosen because it reflected the intended use of the VSS (surveillance) and because of the high visual complexity of the scene. The clip satisfies the engineering requirement for a scene that has both high pixel-to-pixel dynamic range and motion that stresses the video codec and provides abrupt failure-points.

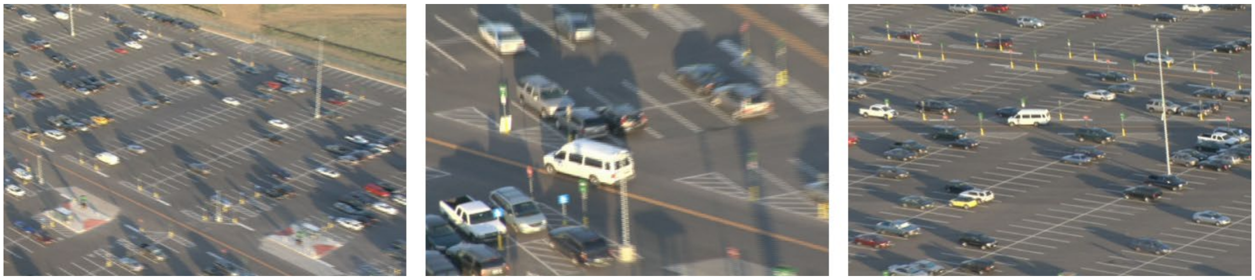


Figure 28. Sample frames from the video clip used for testing.

A series of preliminary tests determined that the VSS video link fails abruptly with a monotonically decreasing signal level. The video failure-point was consistently repeatable within a 1 dB value of attenuation. In this context, the video failure-point is defined as the last attenuation value (in 1 dB increments) that allows the video link to operate. Video failure is defined as the observed freeze of the video stream or the point at which the receiver is unable to decode the transmitted video. This consistent and well-defined failure mode was used as a performance metric to determine the lowest signal level of operation of the VSS.

Although it is beyond the scope of these tests, it must be mentioned that that video stream exhibited performance hysteresis. That is, when this measurement was conducted in the opposite direction (monotonically increasing signal level), the 1 dB point before the video stream recovered from failure was not the same as the failure-point. This is because the underlying complexity of initiating a video stream is greater than that when it fails. It was observed also that the recovery point was less repeatable than the failure-point; the recovery point could vary from 3 to 6 dB between tests.

5.1.6 VSS Configuration Baseline Tests

The baseline tests were conducted to assure that the concept of VSS configuration bracketing was valid. For these tests, all of the 20 configurations in Table 8 were examined. Using the basic circuit configuration (Figure 26), a variable attenuator was used to represent a simple flat-fading channel to determine the operational failure-point of the VSS. The results in Table 10 were then used to gauge the performance variability of the VSS for each of the 20 configurations.

Table 10. Results from VSS baseline tests.

Configuration Number	Transmitter	Receiver				VSS Measured Power at Failure (dBm)
	Video Bit Rate (Mb/sec)	Input Lev. A (dBm)	Input Lev. B (dBm)	SNR A (dB)	SNR B (dB)	
1	3.502	-91	-96	7.7	-	-98.2
2	5.7159	-92	-98	7	-	-98.6
3	2.7271	-90	-95	0	6.8	-98.7
4	4.5536	-90	-96	7.3	-	-98.7
5	12.3576	-87	-92	9.7	-	-96.1
6	18.9993					

Configuration Number	Transmitter	Receiver				VSS Measured Power at Failure (dBm)
	Video Bit Rate (Mb/sec)	Input Lev. A (dBm)	Input Lev. B (dBm)	SNR A (dB)	SNR B (dB)	
7	10.033	-84	-89	12	-	-95.5
8	15.5124					
9	4.978	-117	-117	4	-	-103.2
10	7.9298	-102	-117	5.8	0	-101.8
11	3.9448	-117	-117	1	0.7	-103.7
12	6.3801	-99	-112	4.4	3.9	-102.7
13	16.7854	-89	-96	12.1	11.2	-98.4
14	25.6411					
15	13.686	-88	-93	10.3	9.6	-98.7
16	20.9919					
17	16.7854	-83	-88	11.8	10.4	-93.8
18	13.686	-82	-87	12.4	11.3	-90.9
19	22.6892	-85	-91	13.1	14.2	-91.2
20	18.5566	-83	-88	13.1	11.6	-90.8

The four receiver columns of Table 10 (input level A and B, SNR A and B) are values generated by the VSS receiver and displayed on the output video monitor. The methods by which they are measured or calculated is unknown. Although the same signal is fed into both of the receiver's inputs (through a splitter), the reported input levels are rarely the same and the difference is inconsistent. Similarly, the reported SNRs do not correspond with each other. Consequently, these values are not used in the analysis and are included here just for the sake of completeness.

These preliminary tests demonstrated that four of the proposed configurations (6, 8, 14, and 16) could not be tested because the receiver would not link to the transmitted signal. These four configurations involved an FEC of 3/4 with both 16QAM and 64QAM modulations; an FEC of 3/4 with QPSK modulation was not a problem. This appears to be a limitation in the VSS design.

It was decided to concentrate further testing on three (5, 9, and 13) of the remaining configurations because they represented the performance extremes for the VSS (FEC = 1/2 and Guard Interval = 1/32 for each of the three modulations).

5.1.7 Interference Testing

Figures 29, 30, and 31 display the VSS receiver power at the failure-point versus the interferer center frequency offset. In each graph, the dotted line indicates the average VSS failure-point power in the absence of interference.

Using the test setup shown in Figure 27, interference at five different power levels was injected into the VSS transmission path at varying frequency offsets relative to the VSS's center frequency. The VSS's failure-point was then determined and the various signal powers were measured. The interfering signal (supplied by the signal generator) was a simulated radiosonde signal, 150 kHz wide, driven by a base-band random sequence. The interference-free failure-point was also measured for each test. When the failure-point could not be identified without changing the test configuration then no data was recorded. This assures that all plotted points were measured with a consistent test configuration.

In the case of configuration 13, the graphs of the VSS failure-points (Figures 31(a) and 31 (b)) are compared to a plot of the theoretical calculation of *FDR* (Figure 31(c)). It is apparent that there is a significant change in slope at the band edge (4 MHz) in both plots. However, there are unique features in each plot. There is an inflection point between 4.5 and 5 MHz in the measurements that does not appear in the calculated values, while two points at 10 and 15 MHz that exist in the calculated values are not reflected in the measurements. The overall total rejection is comparable between the plots over the range of offset frequencies. The calculated values take 16 MHz from the band edge to achieve approximately 60 dB of rejection, while the measurements achieve the same rejection range over 1 MHz from the band edge. As can be seen from Figure 31(b), there is no significant improvement in interference rejection once the interferer (radiosonde in this case) is outside of the victim's bandwidth.

Since the failure-point is a performance-based measure, it includes several error-mitigation techniques, such as FEC and packet re-transmission. The calculated data in Figure 31(c) does not take these methods into account. It is assumed that the difference in interference rejection behavior between the calculated and measured data is due to the presence of error-correction methods used in the VSS.

An examination of the measured data shows that actual equipment achieves interference rejection in a significantly shorter offset range than the calculated *FDR* would indicate. Some of this difference can be attributed to interference and error reduction techniques (such as FEC, retransmission requests, scrambling, and interleaving) that are not taken into account in the *FDR* calculations Therefore, the *FDR* values reflect a more conservative estimation of interference rejection with increasing frequency offset than what actual fielded equipment presumably will experience.

It is best to base planning decisions on conservative estimates of interference. However, due to the mission-critical nature of these communication systems, it would be prudent to perform additional measurements of the interference potential before the VSS is deployed in the shared band. This would involve measuring the interference rejection potential with different bandwidths, FEC levels, guard intervals, etc. This could be easily accomplished since the test methodologies have already been established, as described in Sections 5.1.4 and 5.1.6.

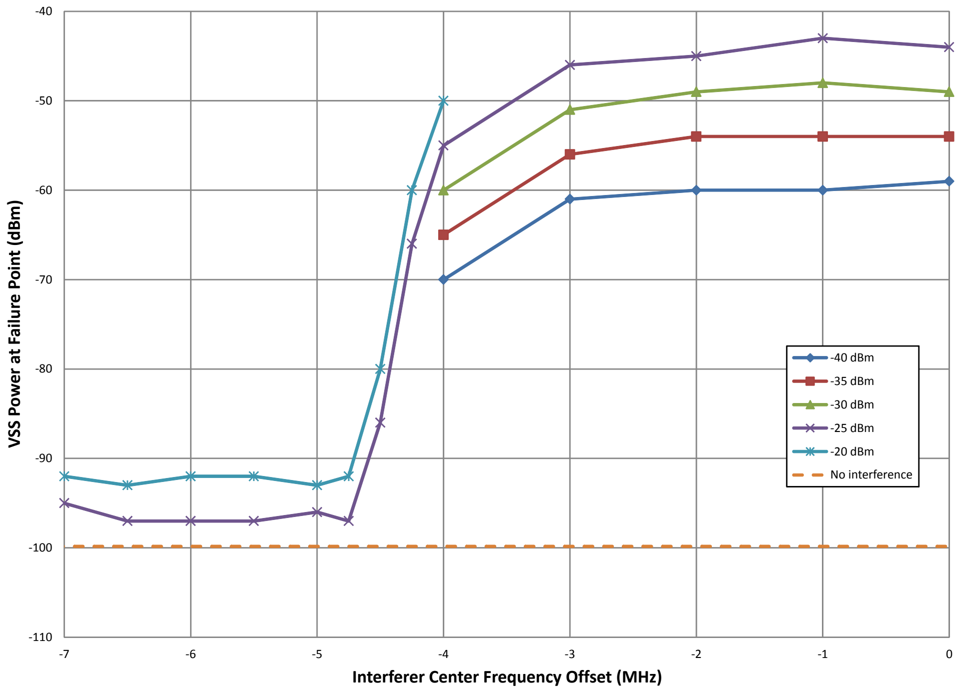


Figure 29. VSS failure-points with a simulated radiosonde interferer – configuration 5.

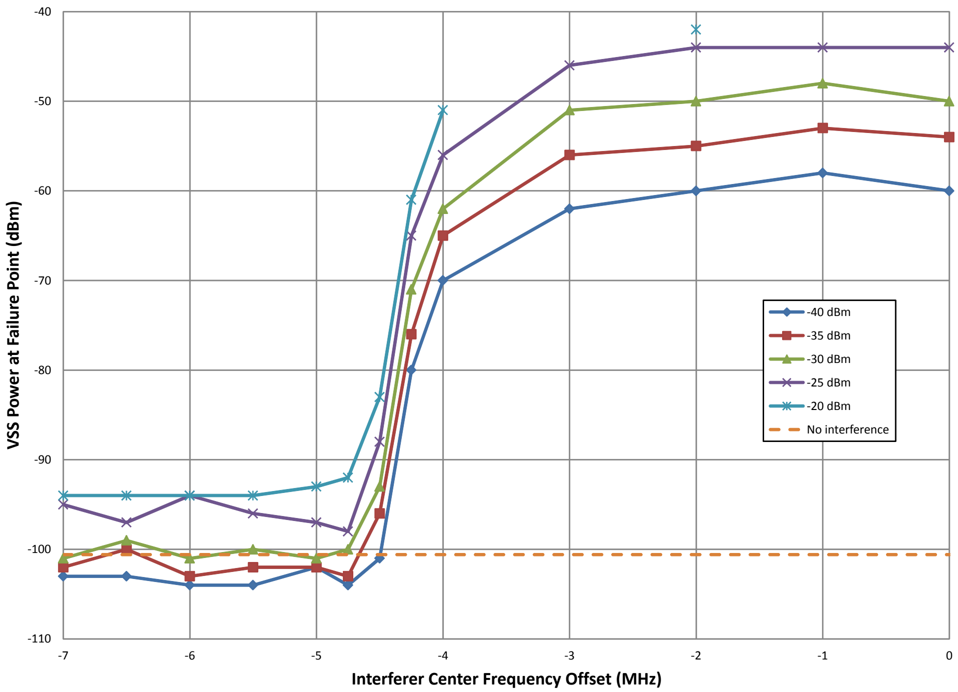


Figure 30. VSS failure-points with a simulated radiosonde interferer – configuration 9.

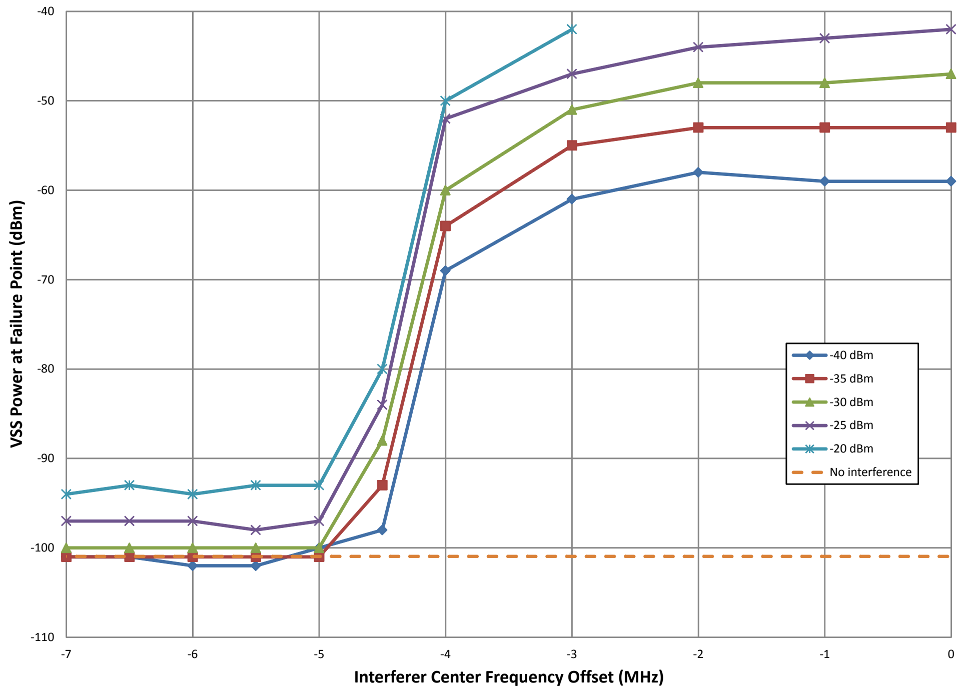


Figure 31(a). VSS failure-points with a simulated radiosonde interferer – configuration 13.

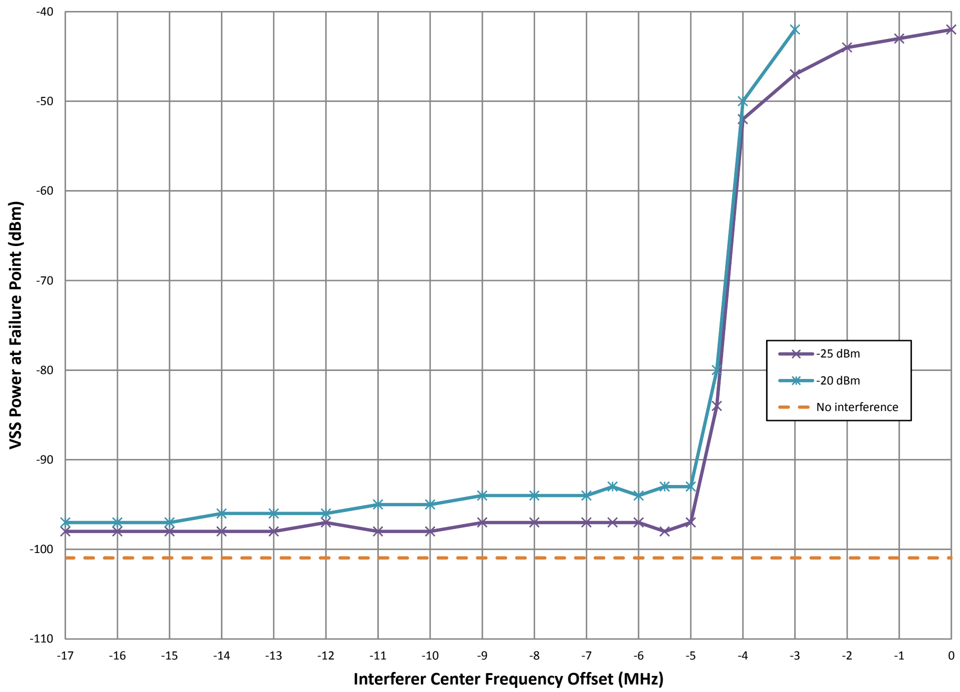


Figure 31(b). VSS failure-points with a simulated radiosonde interferer – configuration 13 (large frequency separation).

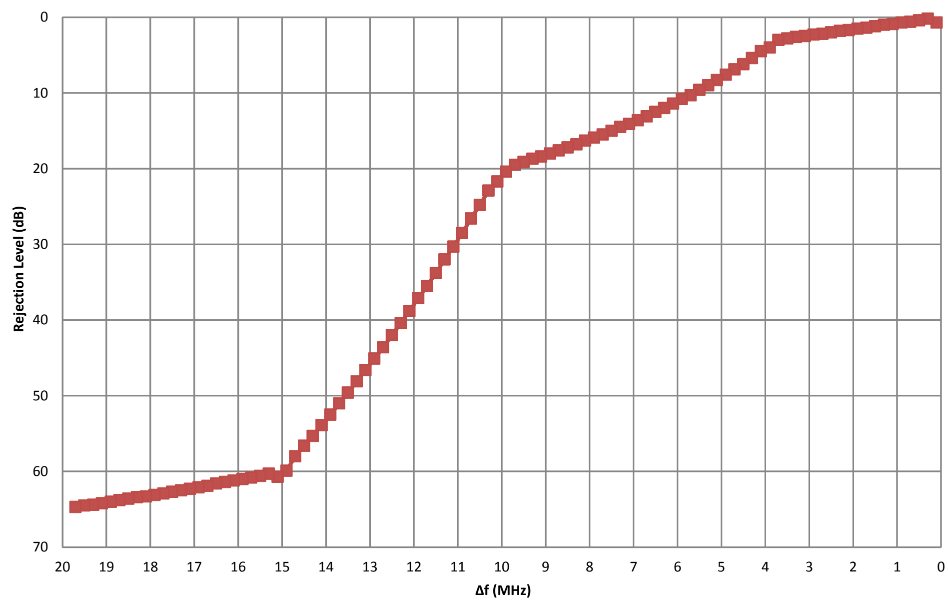


Figure 31(c). Calculated *FDR* for scenario S02 (radiosonde to VSS interference).

5.1.8 Narrowband vs. Wideband Interference Comparison

The characteristics of narrowband and wideband interference are quite different. Typically, it is assumed that wideband interference represents the worst-case scenario since it occupies the victim's entire receiver passband. To simplify the interference calculation, wideband interference is used since it is easier to describe. To perform a similar interference calculation using a narrowband interferer, the actual demodulation technique must be modeled. Since there is no consistency of demodulation techniques between receivers, generalizing the effects of narrowband interference is impossible.

In the analysis described in an earlier section, broadband interference was assumed to be the worst-case situation. In light of the difficulty in calculating the effect of narrowband interference, tests were performed to verify that this assumption was valid.

The three graphs below (Figures 32, 33, and 34) show the *S/I* power at the VSS failure-point versus the interference bandwidth for two levels of interference power that are 10 dB apart, for each of the three modulations used by the VSS. A co-channel interference situation (the center frequencies of the VSS and the interferer are identical) was used, which represents the most extreme interference case. The VSS was configured for its widest possible bandwidth (8 MHz), making it most susceptible to interference.

When the bandwidth of the interferer is less than half of the victim's (VSS) bandwidth, then there appears to be a complex relationship between the two signals. For very narrow interferer bandwidths, the *S/I* value approaches that of a broadband interferer, in which case a broadband-based interference estimate would be adequate. When the interferer bandwidth is between ¼ and

½ of the VSS bandwidth, then the victim receiver appears to be less susceptible to the interferer than to a broader-band interferer. Once the interferer's bandwidth is greater than half of the victim receiver's bandwidth, then the effect of interference is essentially constant (to within the accuracy of the measurement equipment).

These measurements indicate that broadband interference is the worst-case situation. In a spectrum-sharing scenario where the interferer bandwidth is approximately ¼ to ½ of the victim receiver's bandwidth, these graphs indicate that an assumption based on broadband interference will over-estimate the effect of interference. In such a case, further measurements would be valuable to determine the level of interference rejection more accurately.

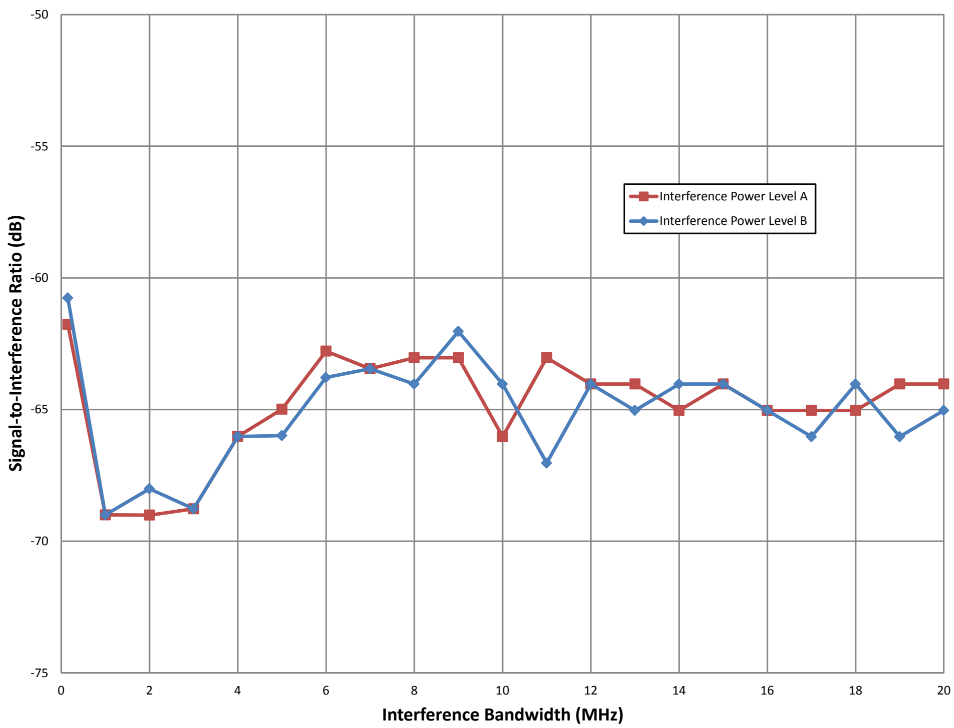


Figure 32. Signal-to-interference ratio versus interference bandwidth – QPSK.

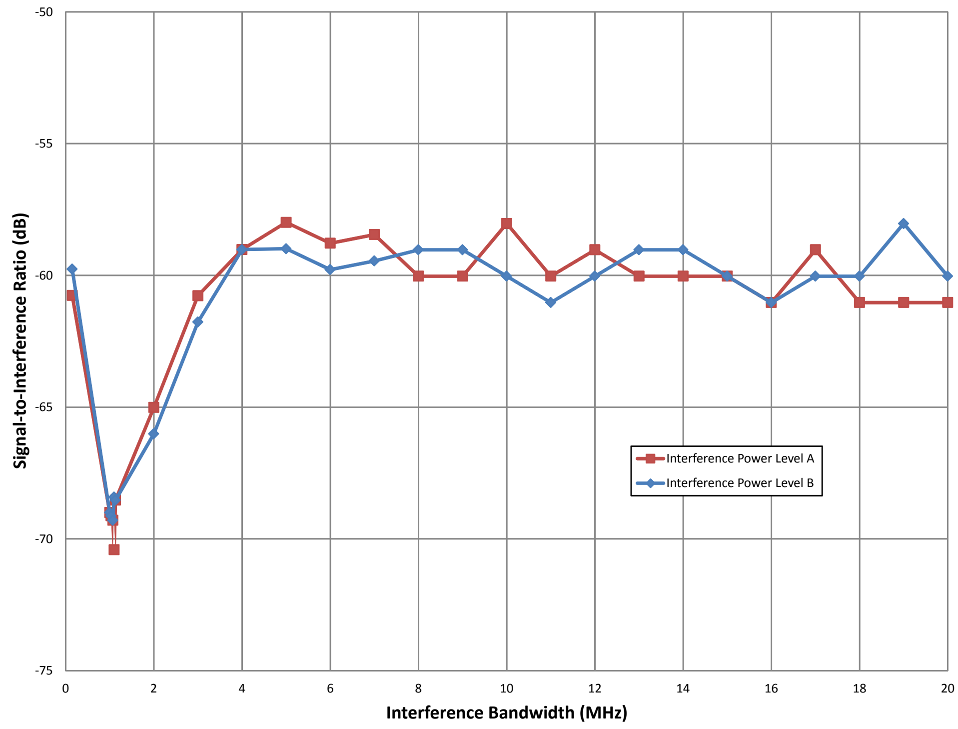


Figure 33. Signal-to-interference ratio versus interference bandwidth - 16QAM.

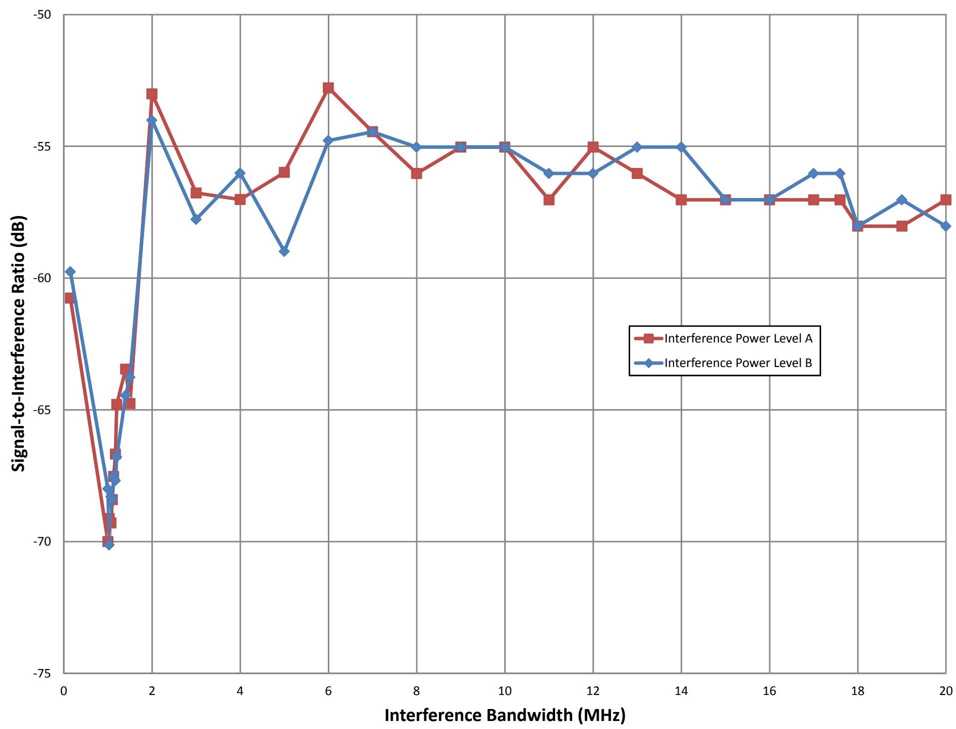


Figure 34. Signal-to-interference ratio versus interference bandwidth - 64QAM.

5.2 Interference of the VSS to the GOES

5.2.1 Considerations for GOES Receiver Testing

From an engineering perspective, an objective measure of service performance would involve evaluating metrics such as *BER* and throughput. Data streams would be tested in various interference environments to determine the degree to which the stream has been degraded. This assumes that all evaluated data streams have similar parametric characteristics and are used in a similar manner.

In the case of the GOES systems, the data “stream” is not monolithic. It actually consists of an aggregate of multiple data services, seven of which are wholly or partially within the 1675–1695 MHz band for the GOES-N/O/P case (Figures 35–37). Each of these has distinct user characteristics (Table 11). For instance, the telemetry channel (CDA Telem) requires high-priority, real-time data access, while a channel such as LRIT is used to download archived, low-rate meteorological information that could be perceived to be a lower priority. All channels have different downstream processing methods that require different levels of signal quality and time availability. A single data stream quality metric cannot cover all of the possible GOES data use scenarios.

Figure 35 shows the GOES RF signal received by an off-the-shelf five-foot diameter dish with an integral pre-amplifier installed at ITS’s site in Boulder. Figure 36 shows the GOES IF signal received, amplified, filtered, and down-converted at NOAA’s receiver located 400 meters (one-quarter mile) from ITS’s site.

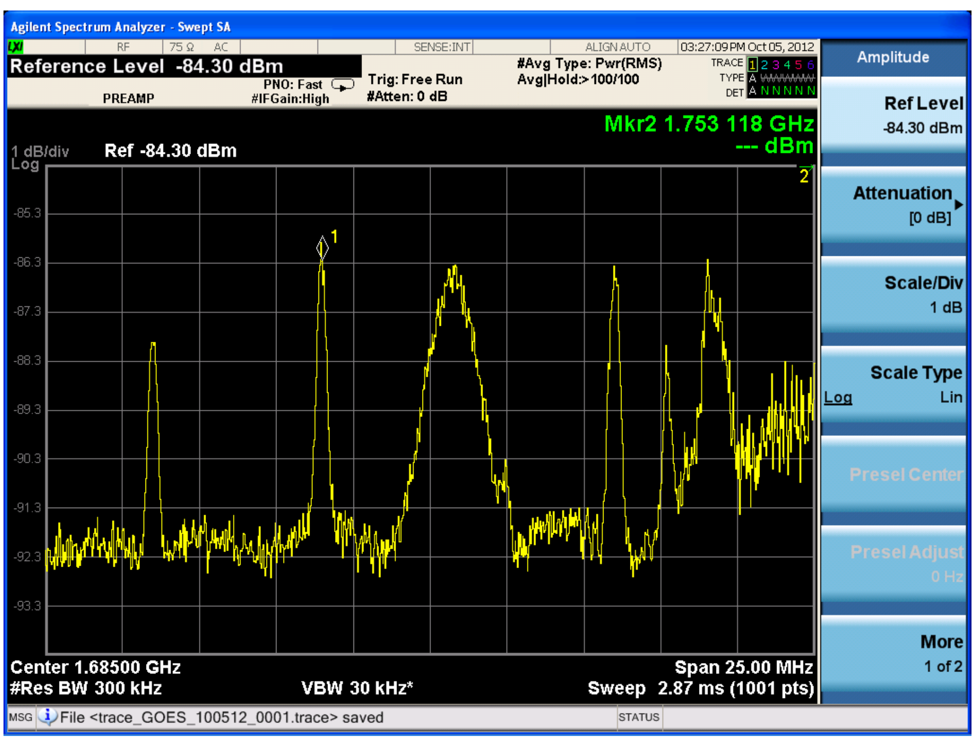


Figure 35. GOES RF signals.

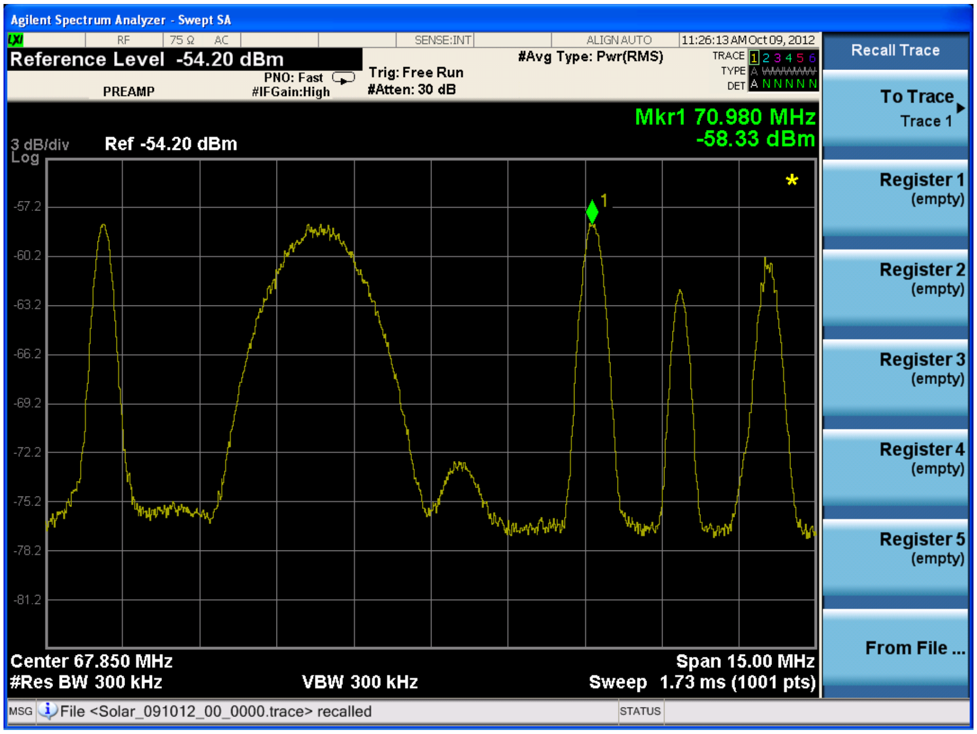


Figure 36. GOES IF signals received at the Boulder site.

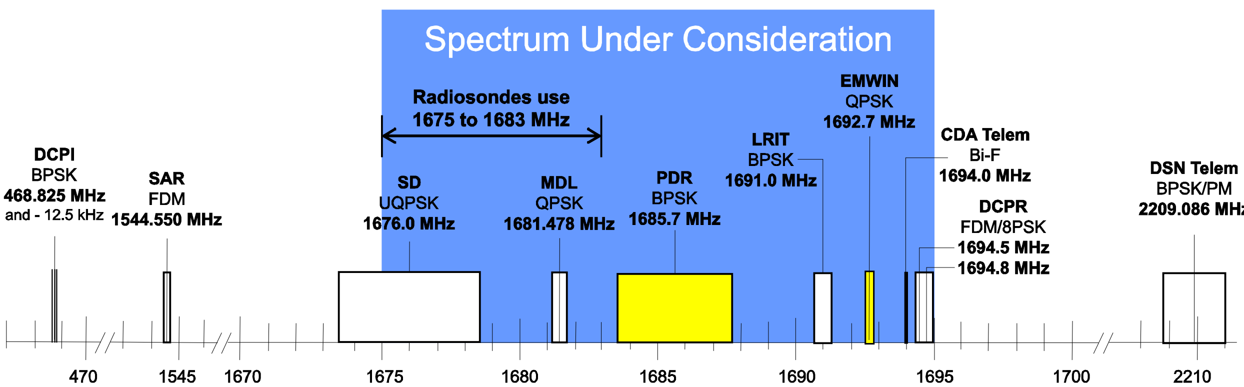


Figure 37. GOES-N/O/P frequency plan (downlinks).

Table 11. Characteristics of GOES-N/O/P channels in the 1675–1695 MHz band.

Link Designation	SD	MDL	PDR	LRIT	EMWIN	CDA Telem	DCPR
Function Name	**Sensor Data**	**Multiuse Data Link**	**Processed Data Relay**	**Low Rate Information Transmission**	**Emergency Managers Weather Information Network**	**Command and Data Acquisition & Telemetry**	**Data Collection Platform Report**
Frequency (MHz)	1676.0	1681.478	1685.7	1691.0	1692.7	1694.0	1694.5, 1694.8 (1694.4474 – 26)
Modulation	UQPSK	QPSK	BPSK	PCM/NRZ-L/ BPSK	OQPSK	PCM/BiØ-L/PM	8PSK

Link Designation	SD	MDL	PDR	LRIT	EMWIN	CDA Telem	DCPR
Symbol Rate (ksps)	TBD	TBD	TBD	293.0	35.94	TBD	i) 300 bps certification the output symbol rate shall be 150 symbols per second ±0.025% ii) 1200 bps certification the output symbol rate shall be 600 symbols per second
Data Rate (kbps)	2660	400	2110	128.0	19.2	4000 bps operational 1000 bps contingency	0.1/0.3/1.2
Data format notes			GVAR		CCSDS coding		i) 200 FDMA channels @ 1500 Hz- 100 and 300 bps ii) 33 FDMA channels @ 3000 Hz - 1200 bps
Rx Max BER (bps)	10^{-8}	10^{-8}	10^{-6}	10^{-8}	10^{-8}		10^{-6}
Tx filter -3 dB	2.2 MHz	150 kHz	2.2 MHz	200 kHz	18 kHz	12 kHz	507 kHz
Tx Filter -20 dB	8.0 MHz	400 kHz	6.2 MHz	600 kHz	26 kHz	40 kHz	650 kHz
Tx Filter -60 dB	11.2 MHz	4.0 MHz	11.0 MHz	4.5 MHz	200 kHz	2.0 MHz	5.6 MHz
Tx Antenna EOC Gain (dBi)	14.5	14.5	14.5 (± 9°)	14.5 (± 9°)	14.5 (± 9°)	-14.0	14.5 (± 9°)

To design an effective suite of tests to cover each data use scenario, the required data throughput, reliability, and integrity need to be determined. Conversations with staff at the NOAA/NWS Space Weather Prediction Center in Boulder have led to an understanding of how the aggregate RF signal is received, demodulated, and pre-processed before each service is distributed to various Federal users. However, once the data services are distributed locally and nationally, it is not known how they are further processed. Without actual specifications of minimum performance requirements for each service, the results of the tests will be based on assumed performance requirements.

Because the GOES N/O/P is a live, mission-critical system, in-situ testing is not possible; laboratory testing is the only option. Several alternative test procedures were considered:

- *Playback simulation*. This involves recording a portion of an actual GOES signal and playing it back in the presence of varying degrees of interference while measuring the level of data degradation. The problem with this method is the difficulty in accurately recording an RF signal for a long-enough period. Such a recording would contain propagation channel effects that would be difficult to remove.
- *Software-defined radio (SDR) simulation*. This involves simulating one or more of the GOES data services with an SDR. This allows for full control of the data content and

measurement of the data quality. Problems with this method include the need to replicate the entire signal, including the data protocol, error correction schemes, equalization, etc.

- *Live signal interference test*. This involves injecting a live signal into a controlled interference environment. The live signal would come from an earth station with similar characteristics to the incumbent receiver. Problems with this method include the inability to match the signal-to-noise ratio of an actual earth station and the fact that the dynamic characteristics of the propagation channel cannot be removed.
- *Replication of an actual GOES earth station in the laboratory*. This involves the acquisition of the actual hardware used in an earth station. It allows for the testing in a controlled interference environment. Problems with this method include replicating the RF front-end equipment used by the actual earth station; configuration of the equipment to match that of an earth station; and difficulty in receiving comparable RF levels and SNR values.

All of these potential methods share a common drawback: although throughput can be measured easily, *BER* cannot be measured in a receive-only configuration without a priori knowledge of the signal. The lack of a quality metric such as *BER* makes the determination of a service failure-point impossible. The GOES service failure-point would be equivalent to the VSS video failure-point at which the required data throughput, reliability, and integrity are considered inadequate. Without determining a GOES service failure-point, the effect of interference cannot be determined.

5.2.2 Test Plan

Given the time constraints the project had to meet, the fourth method (replica of a GOES earth station) was chosen. However, all GOES earth stations are not identically configured. Different sites use different modems, depending on the signals being received. The RF front-end at the Boulder site is a custom design, using custom-built filters. Replicating any RF front-end, much less one that would be representative of all GOES earth stations (see Appendix C) would be extremely impractical. So it was decided to try measuring the system's parameters at the IF level. One major drawback to this approach is that the contribution of the RF electronics to the system's *FDR* is missing.

5.2.3 Test Setup

The satellite modems that were tested are general-use modems with a wide range of configurable settings. They also have limitations in various areas, notably the types of modulations and data rates they can handle. This also points out the inequality among the various GOES earth stations. Some stations do not monitor all of the downlink signals in the 1675–1695 MHz band. For example, the Boulder site does not monitor the raw sensor data (SD) and therefore does not need an additional modem that can handle the modulation and data rate of the SD signal. To minimize the amount of testing required, the two extreme signals, in terms of modulation and data rate, that the on-hand modems could handle, were tested. These are Processed Data Relay (PDR) and Emergency Managers Weather Information Network (EMWIN), shown highlighted in Table 11. In the case of the PDR signal, the modem's maximum data rate of 512 kbps was less than that required (2110 kbps). To exercise the extremes, we settled for the 512 kbps data rate.

Besides the parameters shown in Table 11, the modems can be configured to use a number of other functions that may or may not affect the received signal quality. These include Viterbi FEC, FEC rate, different types of automatic power modes, data framing, data scrambling, and clocking source (embedded, internal, or external). Of these, only FEC and data scrambling were tested to see if they made a difference on the received data quality.

The modems can display the *BER* and E_b/N_0 of the received signal. These values were recorded during the measurements when required, although an outboard *BER* measuring setup was developed in case better accuracy was required.

Since the tests were to be performed at the IF level, the VSS signal needed to be down-converted. This was accomplished by using a component mixer/down-converter and a vector signal generator (VSG) operating as a local oscillator (LO). The modems' output center frequency (IF) could be reconfigured and varied between 104 and 176 MHz; it was set to the midpoint of 140 MHz. The modems' frequency was left fixed for convenience sake since it was easier to change the LO's frequency for off-frequency testing.

The resultant test setup is shown in Figure 38. It was determined that the VSS's RF output was not affected by the presence (or lack) of an input video signal. Consequently, the tests were performed with no input video signal.

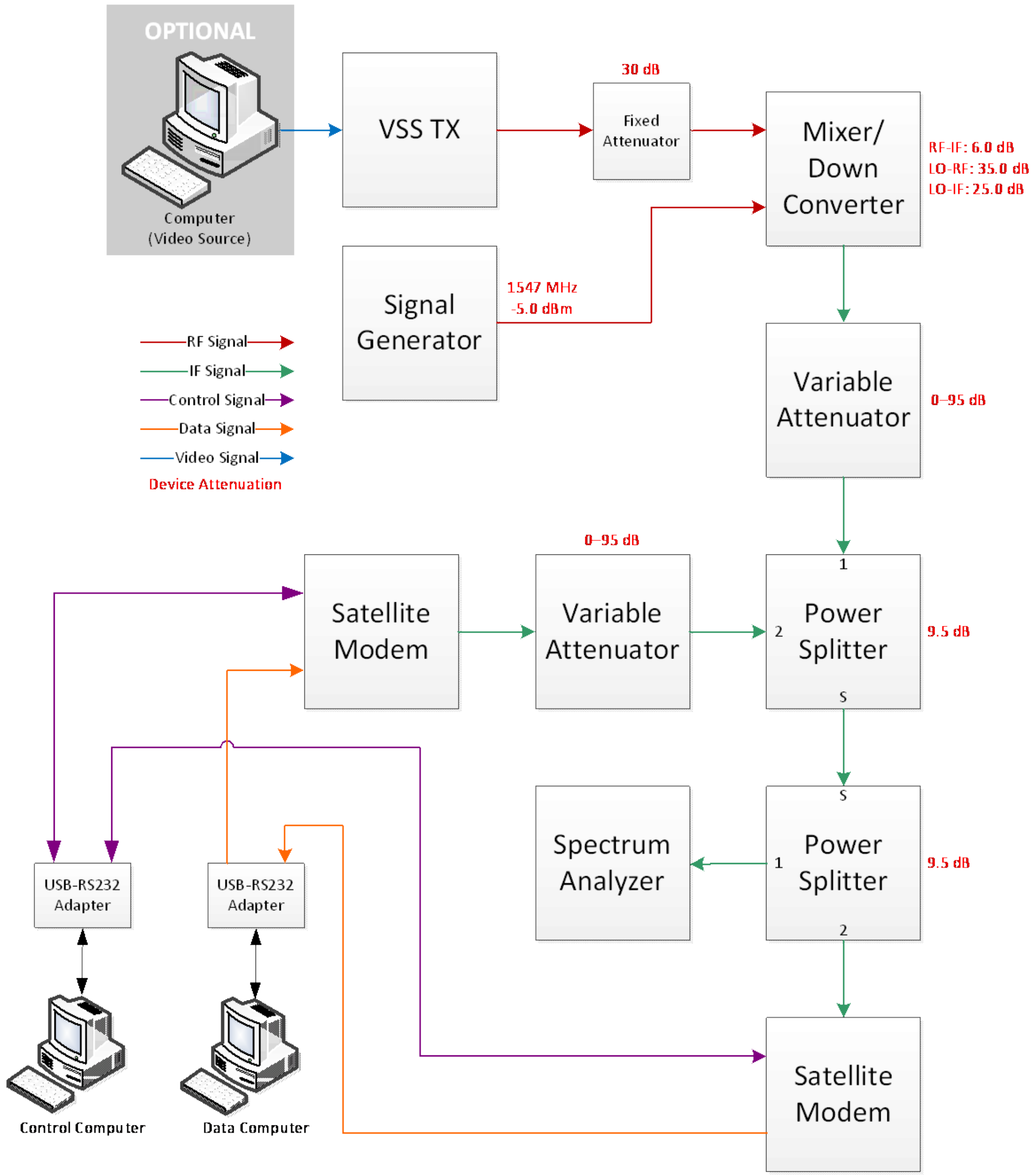


Figure 38. Test setup - VSS interference injection into GOES.

5.2.4 Test Procedure

The following tests were performed for the two GOES signals (PDR and EMWIN).

5.2.4.1 Calibration Test

An initial test was performed to determine if the RF output level of the VSS would have any effect on the measured values. A 30 dB fixed attenuator was inserted between the VSS's output and the mixer's RF input to avoid overloading (and possibly damaging) the test components and the satellite modems. This test resulted in the plots shown in Figures 39 and 40. Values were measured for two signal-to-interference ratios (15 and 20 dB). The modems were configured to operate with QPSK modulation and the maximum 512 kbps data rate.

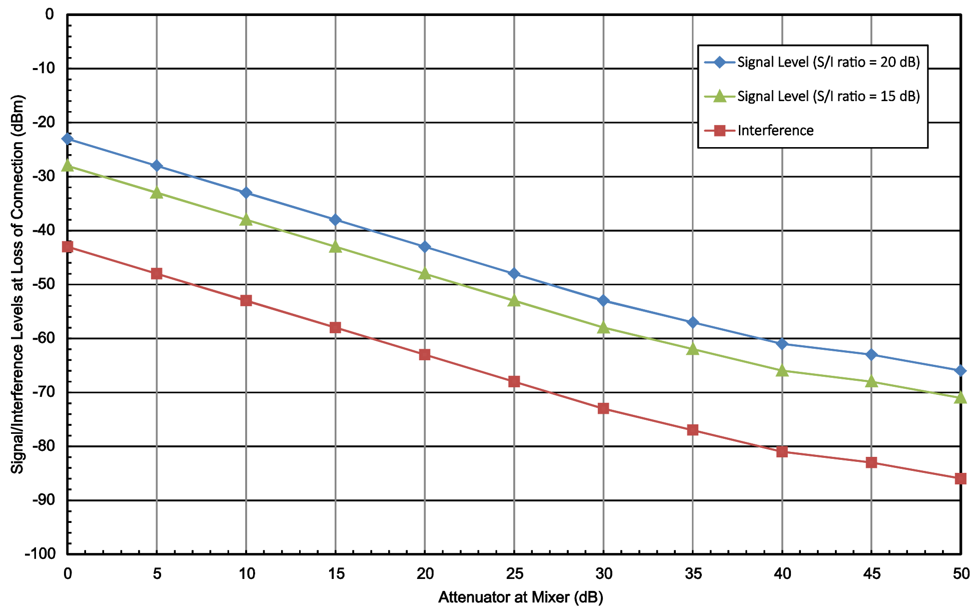


Figure 39. Results of calibration test – fixed attenuator at VSS output = 20 dB.

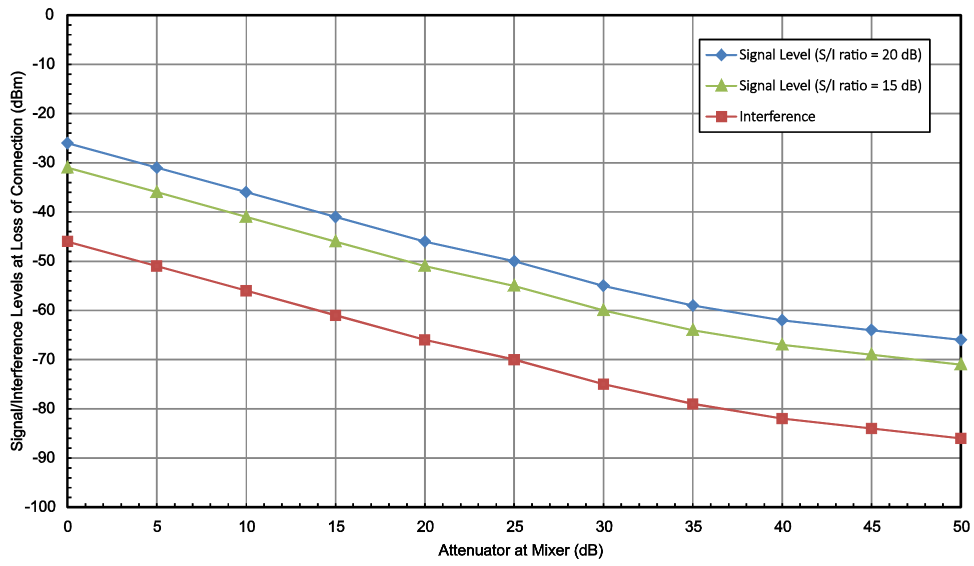


Figure 40. Results of calibration test – fixed attenuator at VSS output = 30 dB.

As can be seen, there is, at the most, a couple of dB difference between the two plots, but the difference is not significant.

5.2.4.2 Test 1 – A Procedure to Demonstrate the Baseline Failure Point

1. With the satellite modems connected back to back through the variable attenuator, start out with the attenuator adjusted such that data is transferred without errors.
2. Increase the attenuation in 1 dB steps until the signal is too weak for the two modems to maintain a connection. The results of this test are shown in Table 12.

Table 12. Results from GOES baseline tests.

Signal	Viterbi FEC	Scrambling	Attenuator Value (dB)
EMWIN	1/2	ON	61
	1/2	OFF	58
	7/8	ON	58
PDR	1/2	OFF	52
	1/2	ON	52
	OFF	OFF	55
	OFF	ON	55

5.2.4.3 Test 2 – Coincident Signal Interference

1. Set up the test configuration as shown in Figure 38.
2. Set the LO frequency to 1547.0 MHz so that the down-converted VSS signal is centered at 140 MHz.
3. With the RF output of the vector signal generator OFF, adjust the variable attenuator at the output of the transmitting modem such that the receiving modem starts reporting errors, then lower the attenuator by 1 dB (so that the receiving modem reports no errors but the signal is immediately preceding the failure point). The results of this test are shown in Table 13.

Table 13. Results from Test 2, Step 3.

Signal	Viterbi FEC	Scrambling	Attenuator Value (dB)
EMWIN	1/2	ON	40
	1/2	OFF	39
	7/8	ON	36
PDR	1/2	OFF	31
	1/2	ON	31
	OFF	OFF	33
	OFF	ON	33

4. Set the attenuator at the output of the down converter to max (95 dB), turn the RF output of the vector signal generator ON, then decrease the attenuation in 1 dB steps, recording

both *BER*s and the E_b/N_0 at each step, until the modems can no longer connect to each other. The results of this test are shown in Figures 41 through 45.

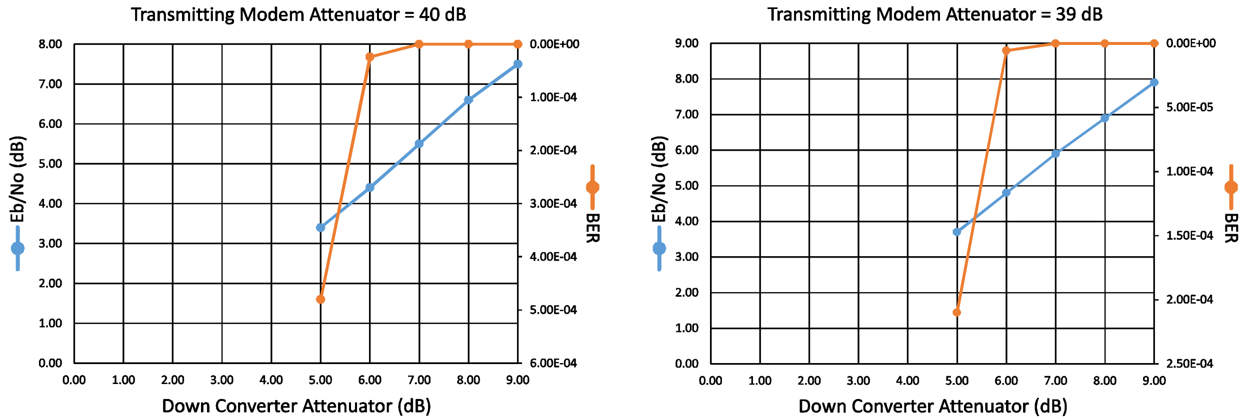


Figure 41. Results of Test 2, Step 4 – EMWIN, FEC = 1/2, Scrambling = ON.

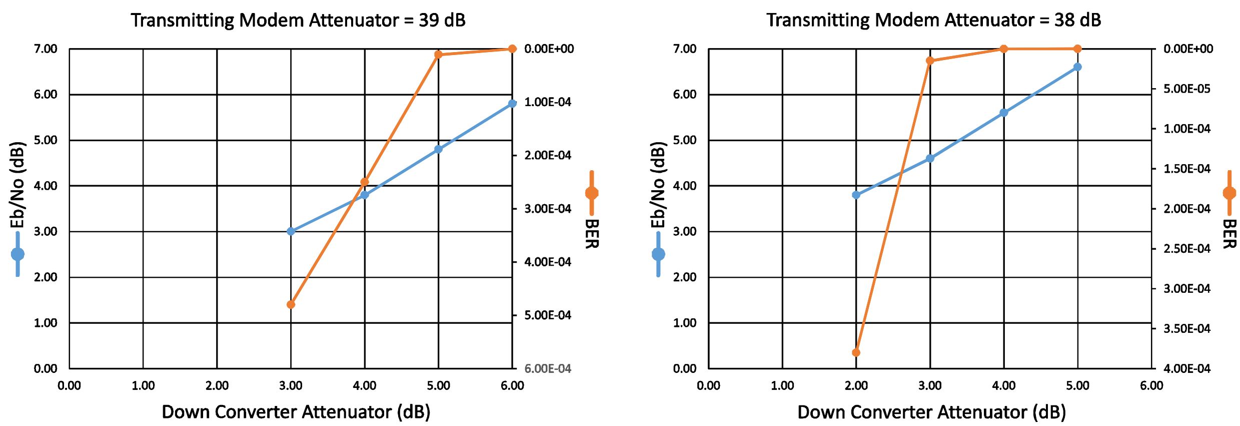


Figure 42. Results of Test 2, Step 4 – EMWIN, FEC = 1/2, Scrambling = OFF.

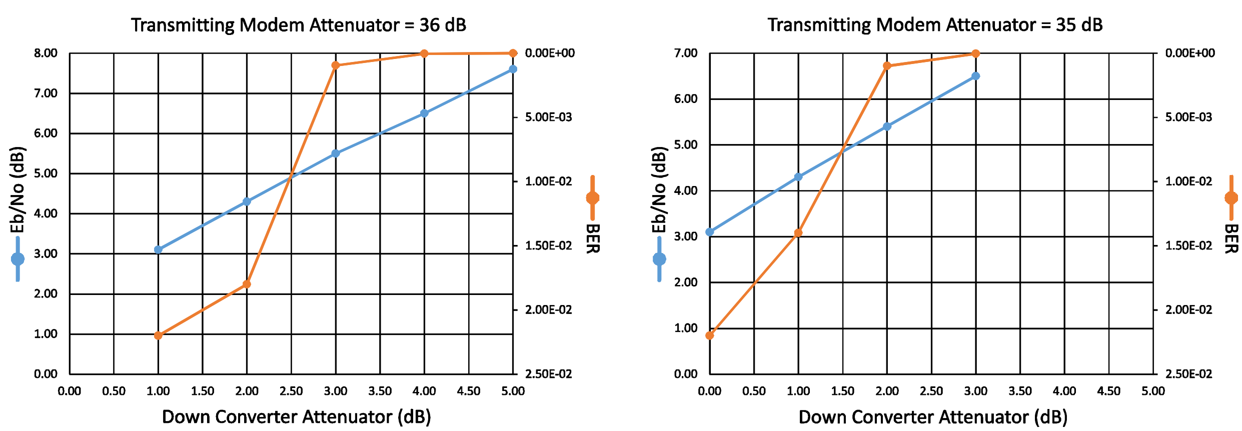


Figure 43. Results of Test 2, Step 4 – EMWIN, FEC = 7/8, Scrambling = ON.

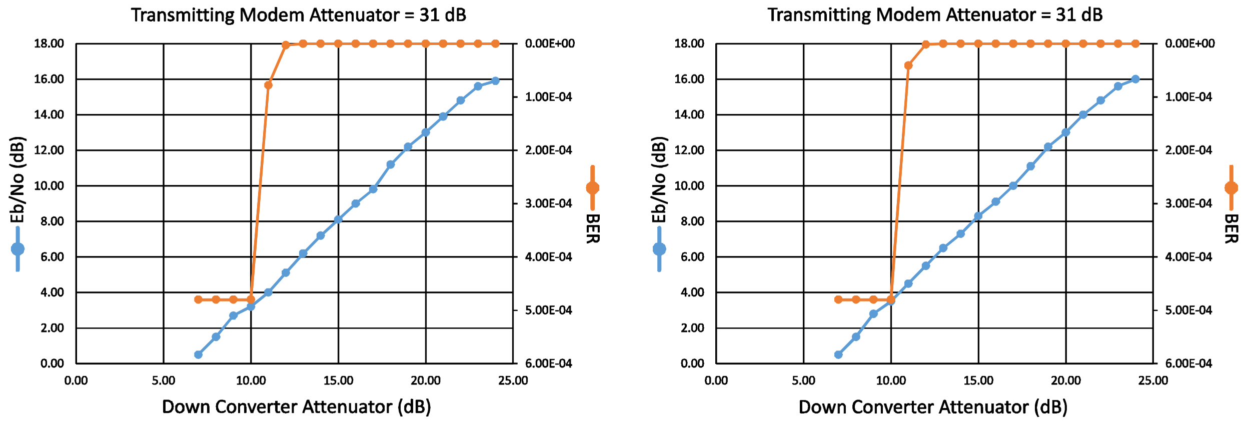


Figure 44. Results of Test 2, Step 4 – PDR, FEC = 1/2,
Scrambling = OFF (left), ON (right).

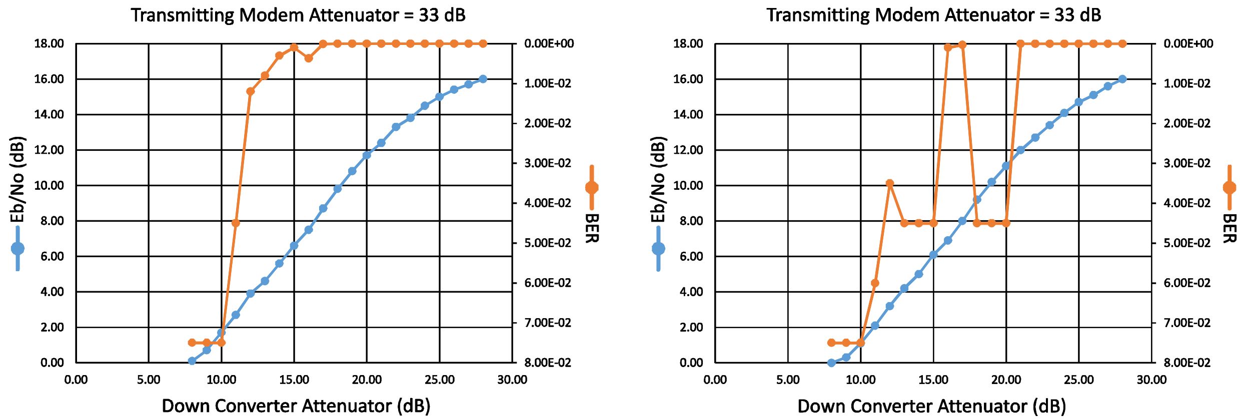


Figure 45. Results of Test2, Step 4 – PDR, FEC = OFF,
Scrambling = OFF (left), ON (right).

5.2.4.4 Test 3 – Out-of-Band Interference

1. Repeat Test 2 while changing the center frequency of the down-converted VSS signal (by changing the LO frequency). Start out with the down-converted VSS at 140 MHz, and then decrease the frequency by 0.5 MHz steps until the interfering signal no longer has any effect on the modems (i.e., change the LO frequency from 1547.0 MHz to 1546.5 MHz and so on).
2. Repeat a single test, but *increase* the LO (raising the VSS's frequency) in a similar manner to prove that the offset interference effect is symmetrical.

We could not discern any effect of the VSS on the satellite modem's failure point until we reached an *I/N* of 25 dB and further increasing the *I/N* to 35 dB changed the failure point only by 1 dB.

5.2.5 VSS to GOES Interference Test Conclusions

Test 1 showed that for EMWIN, data scrambling can improve the satellite modem's performance by 3 dB, but increasing the FEC from 1/2 to 7/8 reverses that improvement. For PDR, data scrambling has no effect, but simply turning FEC on can cause a 3 dB improvement. This could be significant in an interfering environment. However, it is unknown how any deployed modems are configured. One would assume that the modems would be optimally configured, considering the low signal levels that are received at the earth stations (which are only 4–5 dB above the noise floor), but this should be looked into if interference becomes a problem. Note that, depending on the modulation selected, the modems will limit the levels of FEC available, which accounts for the difference in settings between the two signals.

Test 2 was a proof-of-concept to confirm the validity of the test design, and to confirm that the modems performed as intended. It shows that the E_b/N_0 and *BER* reported by the receiving modem vary relatively smoothly (within the measurement's ranges) as interference is gradually increased, except in the last case (PDR, FEC = OFF, Scrambling = ON) where the presumed loss of synchronization results in large variations of *BER*.

The failure of Test 3 showed the limits of trying to measure the *FDR* of a device at IF. This test was performed in lieu of having access to a complete GOES receiver system. Without the RF front end, the total system *FDR* cannot be measured. We had hoped to gain some qualitative insight into the total system *FDR* by measuring the IF portion. We learned that the IF section's contribution to the total system *FDR* is negligible.

The purpose of testing interference into the satellite modems was to try to validate the assumptions made during the analysis stage. The fact that testing the modems at IF did not produce usable results did not disprove those assumptions. The assumptions were already confirmed by the results of the tests described in Section 5.1 (Interference of the Radiosonde to the VSS). What was confirmed was that the entire system (RF, IF, and the down-stream processing gain) needs to be tested as a single entity to obtain an accurate understanding of *FDR* behavior.

6. CONCLUSIONS

6.1 The Interference Between the Incumbent and Entrant Systems

It is not the intent of this report to make pronouncements on how to achieve coexistence within a shared band. The intent is to examine and illuminate the engineering questions that need to be answered so that those who are responsible for Federal services in a band may negotiate and cooperate with their colleagues who are responsible for other Federal services in the same band.

Four classes of interaction were examined: VSS-to-radiosonde, radiosonde-to-VSS, GOES-to-VSS, and VSS-to-GOES. Of these interactions, interference from the GOES-N/O/P and GOES-R satellites into the VSS receiver was determined not to be a problem. The interfering signal levels from the satellites into the VSS receiver are so low because the levels of the satellite's signals are very low and the VSS receiver has a very low gain antenna.

On the other hand, interference from the VSS transmitter into the GOES earth stations can be a significant problem given the fact that the GOES receiver antennas have extremely high gains to receive the satellite signals. As a result, Δf versus separation distance plots for all VSS-into-GOES interactions were calculated (Appendix D) and can be used to plan the deployment of VSS devices near GOES earth stations.

Interference from the radiosondes into the VSS receiver is best described by Figures 20, 22, and 24 in Section 4, which define the Δf needed versus radiosonde-to-VSS separation distance. These figures provide protection distance and off-tuning information for compatible operation for coexistence in the 1675–1695 MHz band. The analysis and measurement data included in this report can be used to create a coexistence plan by specifying protection distances and frequency arrangements compatible with the findings.

Interference from the VSS transmitter into the radiosonde receiver resulted in plots such as Figure 8, which specify the Δf versus the separation distance between the VSS transmitter and the radiosonde receiver. Figure 8 is a worst-case scenario where the VSS transmitter antenna and the radiosonde receiver antenna are pointed directly at each other. This is not always the case, but is possible. Figures 4 through 7 plot Δf versus separation distance for other cases where the antennas of each system are not pointing directly at each other. Further investigation of this interaction between the VSS transmitter and the radiosonde receiver would involve a statistical analysis with probability considerations.

All of the interference scenarios have been analyzed to determine the calculated *FDR*. In the absence of additional corroborating information from testing, these graphs can form the basis for the development of a detailed sharing plan. A clear understanding of the *FDR* for these scenarios forms an engineering basis for establishing protection zones and frequency plans. The required *S/I* values still need to be determined for the equipment used for each service; this may not be possible until the users determine their minimum data performance requirements. Determining these performance requirements will require an understanding of how the data is both acquired and used.

Defining the problem and the search space for this proposed shared communication service band is complete at this point. Tests based on the methods given here have been verified and can now be applied to other receivers for validation or the raw analysis data can be used to move forward to develop frequency channel plans and protection zones.

6.2 The Importance of Using the Correct Propagation-Loss Prediction Model

It is critical to an EMC analysis of any digital communication system that the correct propagation-loss prediction models are used and that the specific digital receiver modulation is accurately modeled. The correct propagation model must be used in specific geometric scenarios to determine the signal strength of the interfering signal. A suitably selected propagation model will accurately represent the effects of input parameters such as frequency, antenna heights, antenna characteristics, and communication distance on predicted signal strength. Failure to account for the implicit range of input parameters in the selection of a propagation model will produce erroneous results. Consequently, the use of a model outside its designed range will lead to inevitable misinterpretation of the interference potential. Based on such misinterpretation, interference mitigation techniques could be proposed that either over- or under-compensate. This could result in either an unnecessarily expensive mitigation solution or unexpected interference, both of which could be catastrophic to mission critical communication systems.

An example of potential misinterpretation is incorrect use of the free-space loss model. Principally, this model does not include physical phenomena such as the surface wave, the effects of ground on the antenna performance, and the propagation effects of diffraction and troposcatter in the prediction of transmission loss. In applying the free-space model to an interference scenario, the analyst must be vigilantly aware of these limitations. Use of the correct propagation model provides cost savings by eliminating ineffective mitigation techniques from consideration and assuring that interference is effectively estimated.

This report shows where and why the correct propagation model is used in all 28 of the interference scenarios. Using the correct propagation models allows for the accurate and appropriate levels of interference to be identified, thus eliminating misinterpretation of the results. In this fashion, this complex analysis has been streamlined and simplified. This is possible because many of the radio-wave propagation models used in this investigation have been developed at ITS.

6.3 The Method for Identifying Interference Potential

Although the method described here was developed for a specific frequency band, it could be used for any pair of systems sharing any frequency band. This document can act as a template for determining the Δf and separation distances necessary to achieve a required level of interference rejection for potential interference scenarios (such as those listed in Appendix B). The best way to illustrate how to use this document is through a generalized example.

To begin with, all of the potential interference scenarios must be defined. Then the operating parameters for both devices under consideration must be identified; for instance, transmitter and receiver filter characteristics, the receiver noise figure, the calculated receiver sensitivity, and the calculated acceptable interference level at the receiver. Using these parameters, the following steps can be performed to determine the *FDR*, Δf, and separation distances necessary to maintain required performance levels:

1. Once the acceptable *BER* of the victim system is determined, the *BER* versus E_b/N_0 plot (e.g. Figure 17 in Section 4.1) is used to determine the E_b/N_0 for a given *S/I*. An *S/I* of 20 dB is a generally accepted value.

2. Using these E_b/N_0 and *S/I* values, *I/N* is determined from the *I/N* versus E_b/N_0 plot (e.g. Figure 17 in Section 4.1).

3. For a given distance between the interfering transmitter and the victim receiver, the received interference power is derived from the received interference power versus distance plot (e.g. Figure 1 in Section 3.2).

4. Using the interference power and *I/N* values, the *FDR* can be derived from the *FDR* versus distance plot (e.g. Figure 2 in Section 3.5). If the *I/N* differs from that used to generate an existing plot, then the *FDR* equation in Section 3.5 can be used to scale the *FDR*.

5. The *FDR* can be used to determine either the Δf or the separation distance from the *FDR* versus Δf plot (e.g. Figure 3 in Section 3.5) and the *FDR* versus separation distance plot (e.g. Figure 2 in Section 3.5). Those two relationships can be combined into a Δf versus separation distance plot (e.g. Figure 4 in Section 3.5).

6.4 Miscellaneous Conclusions

The interference effects on digital communication systems have been addressed by taking into account the specific digital modulation of the incumbent receiver. Consideration of the digital modulation permits specific *S/I* and *I/N* ratios based on E_b/N_0 to provide a more precise determination of interference thresholds.

It has been shown that broadband and narrowband interference are similar enough that the broadband interference assumptions used in the calculations do not affect the predictions of the effect of interference.

It was determined that the video failure method described in this report can be used as a surrogate for objective measures since it appears to correlate well with assumptions made regarding video behavior in the presence of interference.

7. REFERENCES

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ACKNOWLEDGEMENTS

ITS was tasked to conduct an exit evaluation to evaluate the feasibility of coexistence of Federal communications services. This work was performed under the funding and direction of the DHS lead task group charged with examining an exit strategy for the 1755–1850 MHz band.

APPENDIX A. FREQUENCY DEPENDENT REJECTION VERSUS OFFSET FREQUENCY CURVES FOR ALL SCENARIOS

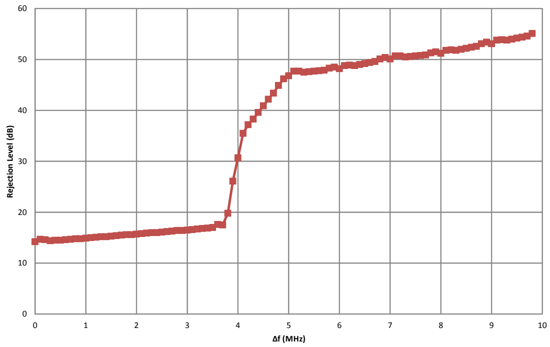


Figure A-1. Frequency dependent rejection versus offset frequency – scenario S01.

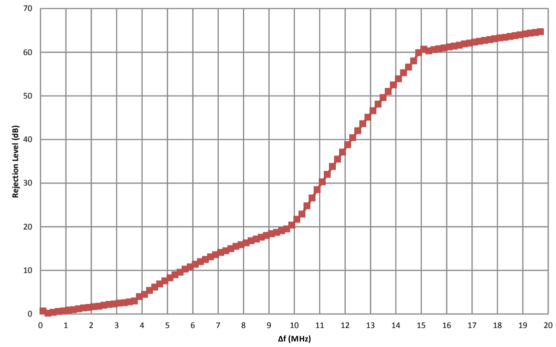


Figure A-2. Frequency dependent rejection versus offset frequency – scenario S02.

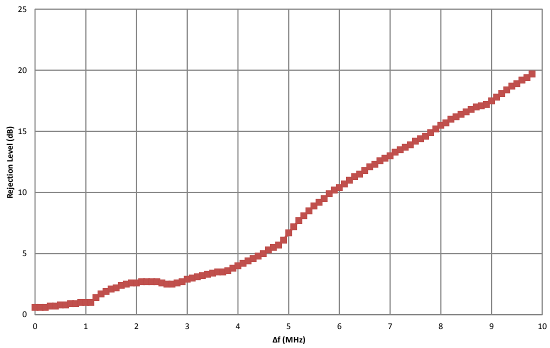


Figure A-3. Frequency dependent rejection versus offset frequency – scenario S03.

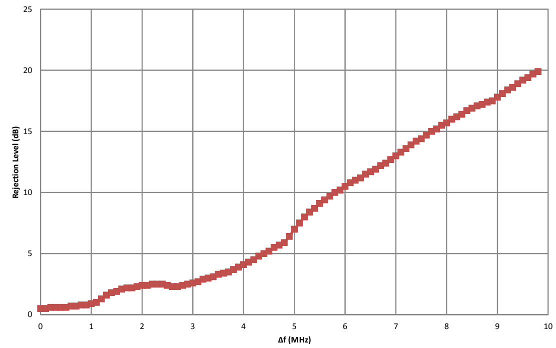


Figure A-4. Frequency dependent rejection versus offset frequency – scenario S04.

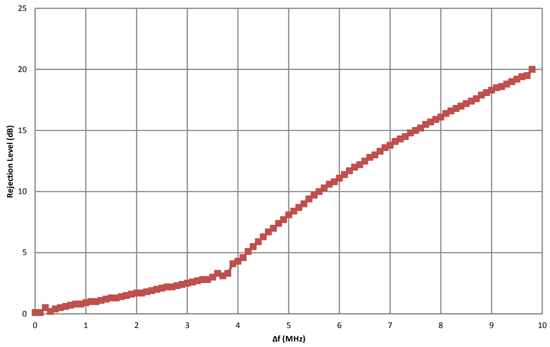


Figure A-5. Frequency dependent rejection versus offset frequency – scenario S05.

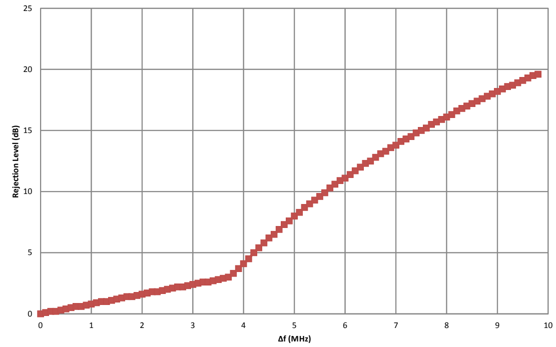


Figure A-6. Frequency dependent rejection versus offset frequency – scenario S06.

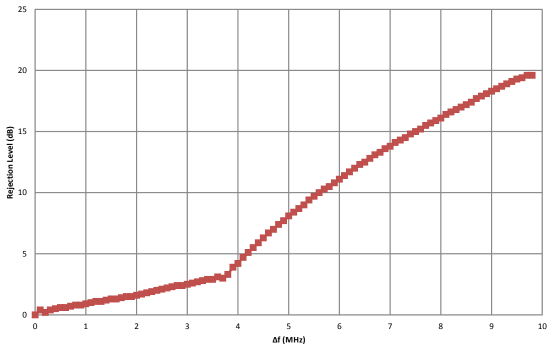


Figure A-7. Frequency dependent rejection versus offset frequency – scenario S07.

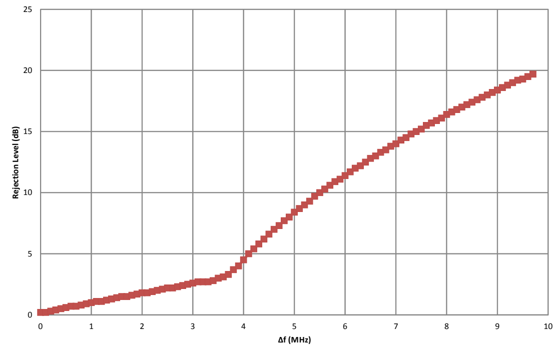


Figure A-8. Frequency dependent rejection versus offset frequency – scenario S08.

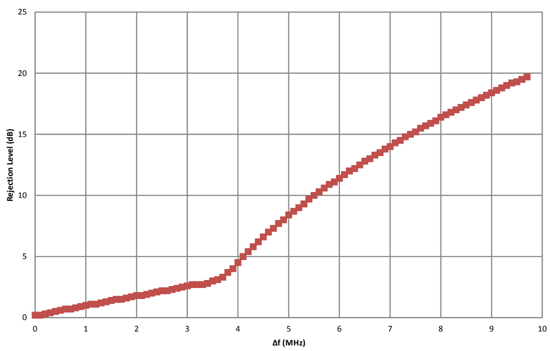


Figure A-9. Frequency dependent rejection versus offset frequency – scenario S09.

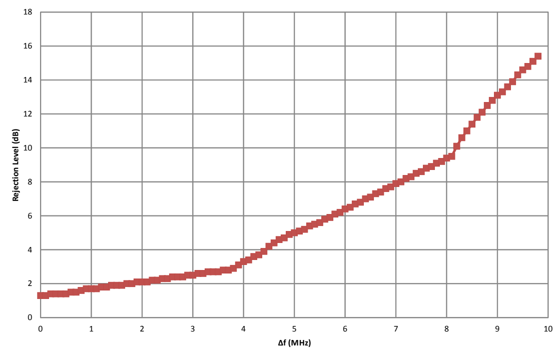


Figure A-10. Frequency dependent rejection versus offset frequency – scenario S10.

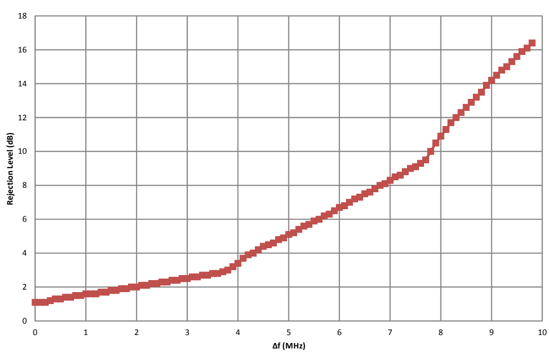


Figure A-11. Frequency dependent rejection versus offset frequency – scenario S11.

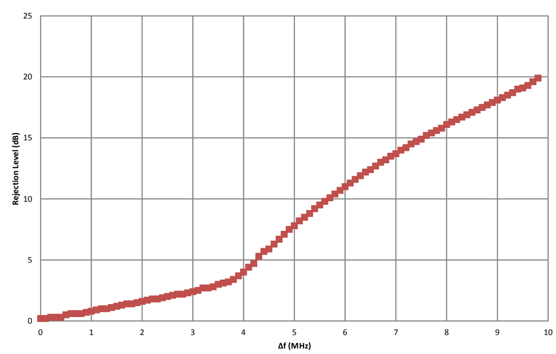


Figure A-12. Frequency dependent rejection versus offset frequency – scenario S12.

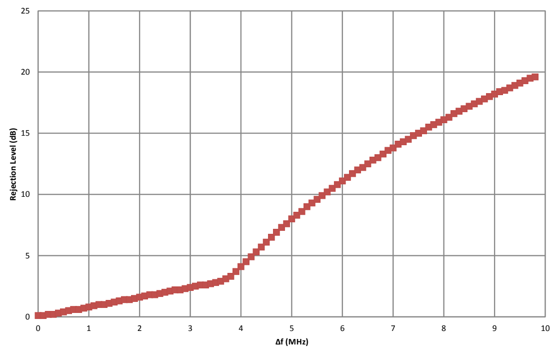


Figure A-13. Frequency dependent rejection versus offset frequency – scenario S13.

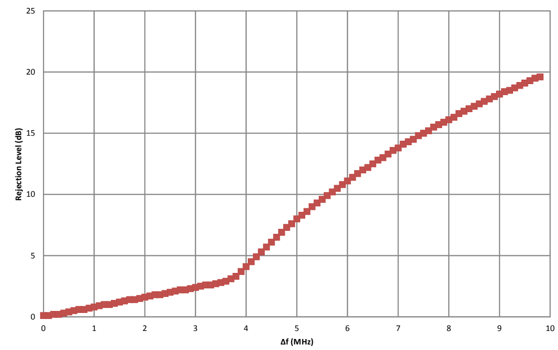


Figure A-14. Frequency dependent rejection versus offset frequency – scenario S14.

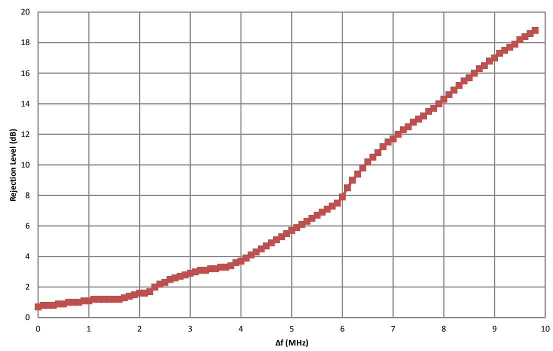


Figure A-15. Frequency dependent rejection versus offset frequency – scenario S15.

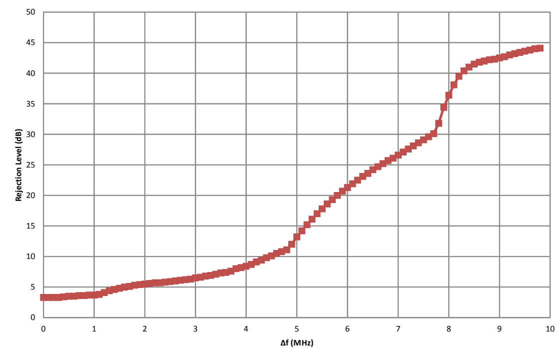


Figure A-16. Frequency dependent rejection versus offset frequency – scenario S16.

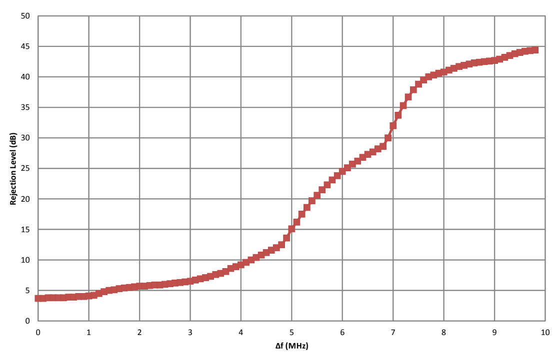


Figure A-17. Frequency dependent rejection versus offset frequency – scenario S17.

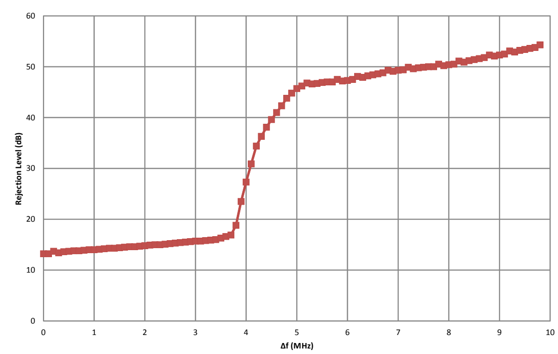
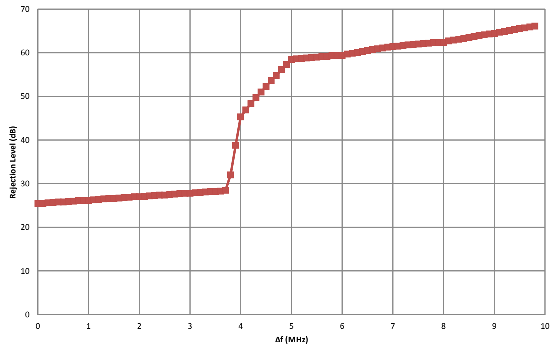


Figure A-18. Frequency dependent rejection versus offset frequency – scenario S18.



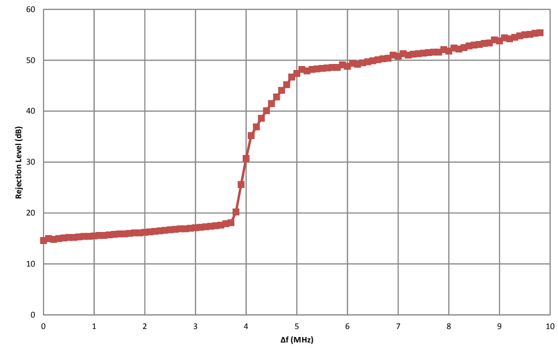
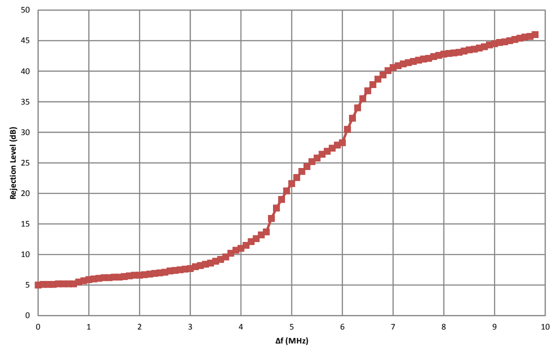


Figure A-19. Frequency dependent rejection versus offset frequency – scenario S19.

Figure A-20. Frequency dependent rejection versus offset frequency – scenario S20.



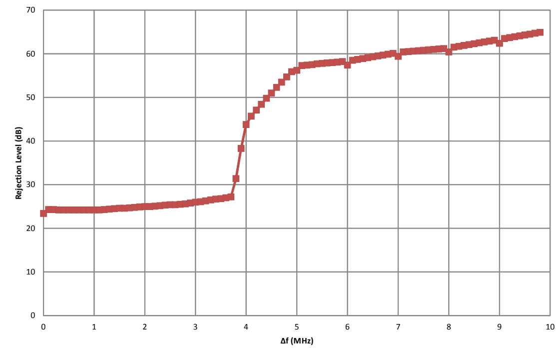
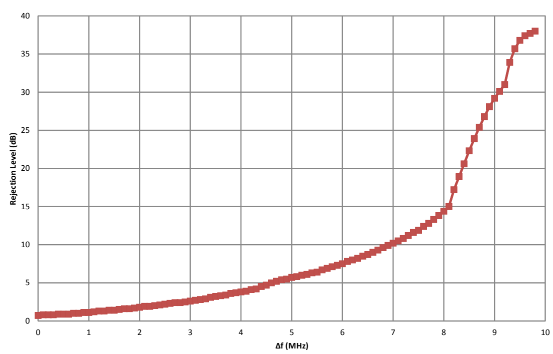


Figure A-21. Frequency dependent rejection versus offset frequency – scenario S21.

Figure A-22. Frequency dependent rejection versus offset frequency – scenario S22.



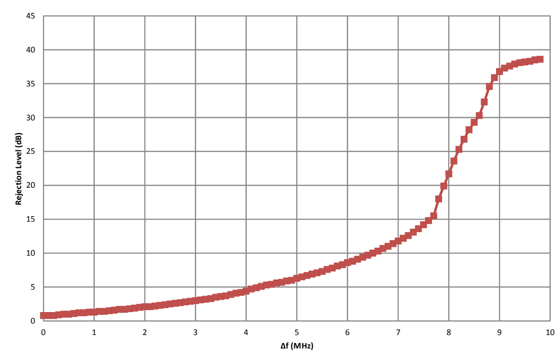


Figure A-23. Frequency dependent rejection versus offset frequency – scenario S23.

Figure A-24. Frequency dependent rejection versus offset frequency – scenario S24.

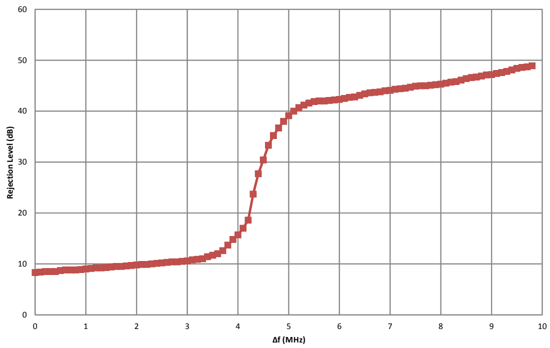


Figure A-25. Frequency dependent rejection versus offset frequency – scenario S25.

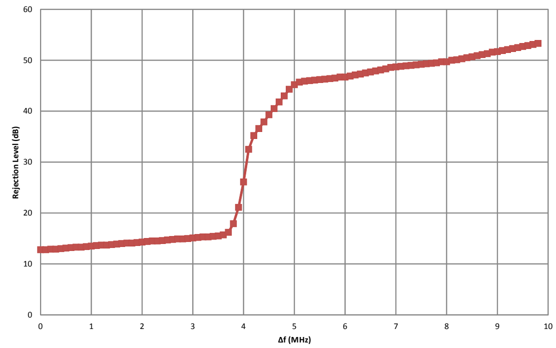


Figure A-26 Frequency dependent rejection versus offset frequency – scenario S26

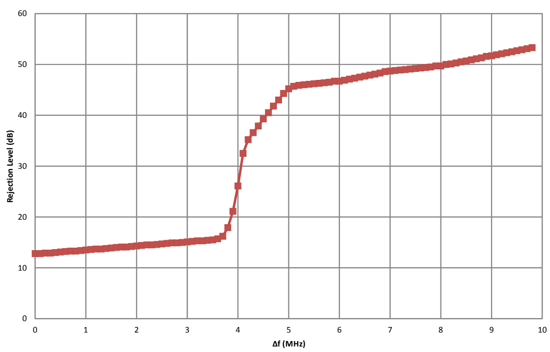


Figure A-27. Frequency dependent rejection versus offset frequency – scenario S27.

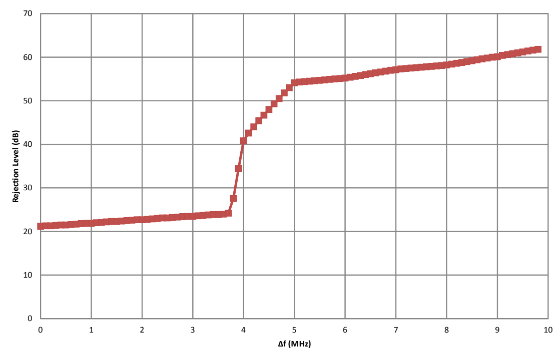


Figure A-28. Frequency dependent rejection versus offset frequency – scenario S28.

APPENDIX B. SCENARIOS

The VSS provided by DHS operates on three discrete channels: 1679, 1687, and 1695 MHz and can be re-programmed to operate on other frequencies within the 1675-1695 MHz band. For the purposes of determining worst-case interference levels in the following scenarios, the VSS will operate in a co-channel configuration, independent of bandwidth. During actual testing, the VSS channel closest to the paired transceiver frequency will be used.

<table>
<tr><td colspan="4">Scenario: S01</td></tr>
<tr><td colspan="2">Transmitter: VSS</td><td colspan="2">Receiver: Radiosonde</td></tr>
<tr><td colspan="2">h_t = 2m and greater</td><td colspan="2">h_r =5m</td></tr>
<tr><td colspan="2">P_t = 24 dBm</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = linear</td><td colspan="2">Polarization = LHCP</td></tr>
<tr><td colspan="2">G_t = 2.15 dBi</td><td colspan="2">G_r = 7 dBi (wide angle, close to ground)
= 28 dBi (otherwise)</td></tr>
<tr><td colspan="2">Cable loss = 0 dB</td><td colspan="2">Cable loss = 0 dB</td></tr>
<tr><td colspan="2">f = 1676, 1678, 1680, 1682 MHz</td><td colspan="2">f = 1676, 1678, 1680, 1682 MHz</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
33
34
36
37
39
41
43
45
46
48
50
51
53
54
55</td><td>3.75
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19</td><td>3
20
60
66
72
78</td><td>0.075
0.270
0.600
1.200
2.400
4.800</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 7.5 MHz</td><td colspan="2">3dB receiver bandwidth = 0.150 MHz</td></tr>
<tr><td colspan="2" rowspan="5"></td><td colspan="2">Noise Figure = 6.5 dB</td></tr>
<tr><td colspan="2">Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz)
= -174 dBm/Hz + 6.5 dB + 10log(0.150×10^6)
= -115.74 dBm</td></tr>
<tr><td colspan="2">I/N = -6 dB</td></tr>
<tr><td colspan="2">I = -121.74 dBm</td></tr>
<tr><td colspan="2">Tuning range = 1668.4 to 1700 MHz</td></tr>
</table>

Scenario: S02			
Transmitter: Radiosonde		Receiver: VSS	
h_t = 1 to 33,000m		h_r = 2m and greater	
P_t = 23.8 dBm			
Polarization = LHCP		Polarization = linear	
G_t = 4.3 dBi		G_r = 2.15 dBi	
Cable loss = 0 dB		Cable loss = 0.5 dB	
f = 1676, 1678, 1680, 1682 MHz		f = 1676, 1678, 1680, 1682 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3	0.0675	3	3.751
36	0.2000	20	10.000
48	0.4000	60	≥15.000
52	0.6000		
56	0.8000		
58	1.0000		
3dB emission bandwidth = 0.135 MHz		3dB receiver bandwidth = 7.502 MHz	
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021×10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S03			
Transmitter: GOES-N Sensor Data (SD)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 6.9 dBW			
Polarization = linear (N-S) 3 dB vertical beamwidth = 32° 3 dB horizontal beamwidth = 32°		Polarization = linear	
G_t = 15.6 dBi (-6 dBi @ 60°)		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1676.0 MHz		f = 1676.0 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 60	1.1 4.0 5.6	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 2.2 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -70 dB 2nd harmonic = -60 dB 3rd harmonic = -60 dB Higher harmonics = -80 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021×10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S04			
Transmitter: GOES-N Processed Data Relay (PDR)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 14.5 dBW (28.0 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 32° 3 dB horizontal beamwidth = 32°		Polarization = linear	
G_t = 15.6 dBi (-6 dBi @ 60°)		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1685.7 MHz		f = 1685.7 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 60	1.1 3.1 5.5	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 2.2 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -75 dB 2nd harmonic = -67 dB 3rd harmonic = -67 dB Higher harmonics = -80 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

<table>
<tr><td colspan="4">Scenario: S05</td></tr>
<tr><td colspan="2">Transmitter: GOES-N Low Rate Info Transponder (LRIT) WEFAX</td><td colspan="2">Receiver: VSS</td></tr>
<tr><td colspan="2">h_t = 35,786 Km</td><td colspan="2">h_r = 2m and greater</td></tr>
<tr><td colspan="2">P_t = 10.2 dBW (10.4 W)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = linear (N-S)
3 dB vertical beamwidth = 32°
3 dB horizontal beamwidth = 32°</td><td colspan="2">Polarization = linear</td></tr>
<tr><td colspan="2">G_t = 15.6 dBi (-6 dBi @ 60°)</td><td colspan="2">G_r = 2.15 dBi</td></tr>
<tr><td colspan="2"></td><td colspan="2">Cable loss = 0.5 dB</td></tr>
<tr><td colspan="2">f = 1691.0 MHz</td><td colspan="2">f = 1691.0 MHz</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
60</td><td>0.10
0.30
2.25</td><td>3
20
60</td><td>3.751
10.000
≥15.000</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 0.2 MHz</td><td colspan="2">3dB receiver bandwidth = 7.502 MHz</td></tr>
<tr><td colspan="2">Spurious emissions = -75 dB
2nd harmonic = -63 dB
3rd harmonic = -63 dB
Higher harmonics = -80 dB</td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="5"></td><td colspan="2">Noise Figure = 4.0 dB</td></tr>
<tr><td colspan="2">Receiver sensitivity:
-89 dBm @ QPSK
-83 dBm @ 16QAM
-77 dBm @ 64QAM
Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz)
= -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6)
= -101.25 dBm</td></tr>
<tr><td colspan="2">I/N = -6 or -10 dB</td></tr>
<tr><td colspan="2">I = -107.25 or -111.25 dBm</td></tr>
<tr><td colspan="2">Tuning range = 1675 to 1695 MHz</td></tr>
</table>

Scenario: S06			
Transmitter: GOES-N Emergency Management Weather Info Network (EMWIN)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 1.2 dBW (1.3 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 32° 3 dB horizontal beamwidth = 32°		Polarization = linear	
G_t = 15.6 dBi (-6 dBi @ 60°)		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1692.7 MHz		f = 1692.7 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 60	0.009 0.013 0.100	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 0.018 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -65 dB 2nd harmonic = -69 dB 3rd harmonic = -69 dB Higher harmonics = -80 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S07			
Transmitter: GOES-N Multiuse Data Link (MDL)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 8.2 dBW (6.7 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 32° 3 dB horizontal beamwidth = 32°		Polarization = linear	
G_t = 15.6 dBi (-6 dBi @ 60°)		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1681.478 MHz		f = 1681.478 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 60	0.075 0.200 2.000	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 0.150 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -70 dB 2nd harmonic = -60 dB 3rd harmonic = -60 dB Higher harmonics = -80 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S08			
Transmitter: GOES-N Data Collection Platform Report (DCPR)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 8.0 dBW (6.3 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 32° 3 dB horizontal beamwidth = 32°		Polarization = linear	
G_t = 15.6 dBi (-6 dBi @ 60°)		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1694.5 and 1694.8 MHz		f = 1694.5 and 1694.8 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 60	0.254 0.325 2.800	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 0.507 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -65 dB 2nd harmonic = -61 dB 3rd harmonic = -61 dB Higher harmonics = -80 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

<table>
<tr><td colspan="4">Scenario: S09</td></tr>
<tr><td colspan="2">Transmitter: GOES-N Command and Data Acquisition (CDA) Telemetry</td><td colspan="2">Receiver: VSS</td></tr>
<tr><td colspan="2">h_t = 35,786 Km</td><td colspan="2">h_r = 2m and greater</td></tr>
<tr><td colspan="2">P_t = 4.5 dBW (2.8 W)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = RHCP
3 dB vertical beamwidth = 56°
3 dB horizontal beamwidth = 56°</td><td colspan="2">Polarization = linear</td></tr>
<tr><td colspan="2">G_t = 0 dBi (-1.5 dBi @ 122°)</td><td colspan="2">G_r = 2.15 dBi</td></tr>
<tr><td colspan="2"></td><td colspan="2">Cable loss = 0.5 dB</td></tr>
<tr><td colspan="2">f = 1694.0 MHz</td><td colspan="2">f = 1694.0 MHz</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
60</td><td>0.006
0.020
1.000</td><td>3
20
60</td><td>3.751
10.000
≥15.000</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 0.012 MHz</td><td colspan="2">3dB receiver bandwidth = 7.502 MHz</td></tr>
<tr><td colspan="2">Spurious emissions = -65 dB
2^{nd} harmonic = -65 dB
3^{rd} harmonic = -65 dB
Higher harmonics = -80 dB</td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="5"></td><td colspan="2">Noise Figure = 4.0 dB</td></tr>
<tr><td colspan="2">Receiver sensitivity:
-89 dBm @ QPSK
-83 dBm @ 16QAM
-77 dBm @ 64QAM
Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz)
= -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6)
= -101.25 dBm</td></tr>
<tr><td colspan="2">I/N = -6 or -10 dB</td></tr>
<tr><td colspan="2">I = -107.25 or -111.25 dBm</td></tr>
<tr><td colspan="2">Tuning range = 1675 to 1695 MHz</td></tr>
</table>

<table>
<tr><td colspan="4">Scenario: S10</td></tr>
<tr><td colspan="2">Transmitter: GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) QPSK</td><td colspan="2">Receiver: VSS</td></tr>
<tr><td colspan="2">h_t = 35,786 Km</td><td colspan="2">h_r = 2m and greater</td></tr>
<tr><td colspan="2">P_t = 16.0 dBW (40 W)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = RHCP and LHCP
3 dB vertical beamwidth = 26°
3 dB horizontal beamwidth = 26°</td><td colspan="2">Polarization = linear</td></tr>
<tr><td colspan="2">G_t = 17.3 dBi</td><td colspan="2">G_r = 2.15 dBi</td></tr>
<tr><td colspan="2"></td><td colspan="2">Cable loss = 0.5 dB</td></tr>
<tr><td colspan="2">f = 1686.6 MHz</td><td colspan="2">f = 1686.6 MHz</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
40
60</td><td>4.35
5.45
6.10
54.00</td><td>3
20
60</td><td>3.751
10.000
≥15.000</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 8.7 MHz</td><td colspan="2">3dB receiver bandwidth = 7.502 MHz</td></tr>
<tr><td colspan="2">Spurious emissions = -60 dB
2nd harmonic = -60 dB
3rd harmonic = -60 dB
Higher harmonics = -60 dB</td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="5"></td><td colspan="2">Noise Figure = 4.0 dB</td></tr>
<tr><td colspan="2">Receiver sensitivity:
-89 dBm @ QPSK
-83 dBm @ 16QAM
-77 dBm @ 64QAM
Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz)
= -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6)
= -101.25 dBm</td></tr>
<tr><td colspan="2">I/N = -6 or -10 dB</td></tr>
<tr><td colspan="2">I = -107.25 or -111.25 dBm</td></tr>
<tr><td colspan="2">Tuning range = 1675 to 1695 MHz</td></tr>
</table>

<table>
<tr><td colspan="4">Scenario: S11</td></tr>
<tr><td colspan="2">Transmitter: GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) 8PSK</td><td colspan="2">Receiver: VSS</td></tr>
<tr><td colspan="2">h_t = 35,786 Km</td><td colspan="2">h_r = 2m and greater</td></tr>
<tr><td colspan="2">P_t = 16.0 dBW (40 W)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = RHCP and LHCP
3 dB vertical beamwidth = 26°
3 dB horizontal beamwidth = 26°</td><td colspan="2">Polarization = linear</td></tr>
<tr><td colspan="2">G_t = 17.3 dBi</td><td colspan="2">G_r = 2.15 dBi</td></tr>
<tr><td colspan="2"></td><td colspan="2">Cable loss = 0.5 dB</td></tr>
<tr><td colspan="2">f = 1686.6 MHz</td><td colspan="2">f = 1686.6 MHz</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
40
60</td><td>3.95
4.90
5.40
50.00</td><td>3
20
60</td><td>3.751
10.000
≥15.000</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 7.90 MHz</td><td colspan="2">3dB receiver bandwidth = 7.502 MHz</td></tr>
<tr><td colspan="2">Spurious emissions = -60 dB
2nd harmonic = -60 dB
3rd harmonic = -60 dB
Higher harmonics = -60 dB</td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="5"></td><td colspan="2">Noise Figure = 4.0 dB</td></tr>
<tr><td colspan="2">Receiver sensitivity:
-89 dBm @ QPSK
-83 dBm @ 16QAM
-77 dBm @ 64QAM
Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz)
= -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6)
= -101.25 dBm</td></tr>
<tr><td colspan="2">I/N = -6 or -10 dB</td></tr>
<tr><td colspan="2">I = -107.25 or -111.25 dBm</td></tr>
<tr><td colspan="2">Tuning range = 1675 to 1695 MHz</td></tr>
</table>

Scenario: S12			
Transmitter: GOES-R High Resolution Information Transponder (HRIT, EMWIN)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 13.8 dBW (24.0 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 26° 3 dB horizontal beamwidth = 26°		Polarization = linear	
G_t = 16.5 dBi		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1694.1 MHz		f = 1694.1 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 40 60	0.475 0.715 0.750 1.250	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 0.950 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -60 dB 2^{nd} harmonic = -60 dB 3^{rd} harmonic = -60 dB Higher harmonics = -60 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S13			
Transmitter: GOES-R Data Collection Platform Report (DCPR #1)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 7.0 dBW (5.0 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 26° 3 dB horizontal beamwidth = 26°		Polarization = linear	
G_t = 16.5 dBi		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1679.9 MHz		f = 1679.9 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 40 60	0.2000 0.2010 0.20125 2.0000	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 0.400 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -60 dB 2^{nd} harmonic = -60 dB 3^{rd} harmonic = -60 dB Higher harmonics = -60 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S14			
Transmitter: GOES-R Data Collection Platform Report (DCPR #2)		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 7.0 dBW (5.0 W)			
Polarization = linear (N-S) 3 dB vertical beamwidth = 26° 3 dB horizontal beamwidth = 26°		Polarization = linear	
G_t = 16.5 dBi		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1680.2 MHz		f = 1680.2 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 40 60	0.2000 0.2010 0.20125 2.0000	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth = 0.400 MHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -60 dB 2^{nd} harmonic = -60 dB 3^{rd} harmonic = -60 dB Higher harmonics = -60 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S15			
Transmitter: GOES-R Command and Data Acquisition (CDA) Telemetry		Receiver: VSS	
h_t = 35,786 Km		h_r = 2m and greater	
P_t = 1.8 dBW (1.5 W)			
Polarization = RHCP 3 dB vertical beamwidth = 160° 3 dB horizontal beamwidth = 160°		Polarization = linear	
G_t = 3.1 dBi		G_r = 2.15 dBi	
		Cable loss = 0.5 dB	
f = 1693.0 MHz		f = 1693.0 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 40 60	22 or 2.2 40 or 4.0 42.5 or 4.25 125.0	3 20 60	3.751 10.000 ≥15.000
3dB emission bandwidth =44 or 4.4 kHz		3dB receiver bandwidth = 7.502 MHz	
Spurious emissions = -60 dB 2^{nd} harmonic = -60 dB 3^{rd} harmonic = -60 dB Higher harmonics = -60 dB			
		Noise Figure = 4.0 dB	
		Receiver sensitivity: -89 dBm @ QPSK -83 dBm @ 16QAM -77 dBm @ 64QAM Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 4.0 dB + 10log(7.5021x10^6) = -101.25 dBm	
		I/N = -6 or -10 dB	
		I = -107.25 or -111.25 dBm	
		Tuning range = 1675 to 1695 MHz	

Scenario: S16			
Transmitter: VSS		Receiver: GOES-N Sensor Data (SD)	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = linear	
G_t = 2.15 dBi		G_r = 39.6 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1676.0 MHz		f = 1676.0 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3	3.75	3	1.1
20	4	20	4.0
33	5	60	5.6
34	6		
36	7		
37	8		
39	9		
41	10		
43	11		
45	12		
46	13		
48	14		
50	15		
51	16		
53	17		
54	18		
55	19		
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 2.2 MHz	
		Noise Figure = 2.85 dB	
		Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 2.85 dB + 10log(2.2x10^6) = -107.73 dBm	
		I/N = -6 dB	
		I = -113.73 dBm	

Scenario: S17			
Transmitter: VSS		Receiver: GOES-N Processed Data Relay (PDR)	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = linear	
G_t = 2.15 dBi		G_r = 39.6 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1685.7 MHz		f = 1685.7 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 60	1.1 3.1 5.5
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 2.2 MHz	
		Noise Figure = 2.85 dB	
		Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 2.85 dB + 10log($2.2x10^6$) = -107.73 dBm	
		I/N = -6 dB	
		I = -113.73 dBm	

Scenario: S18			
Transmitter: VSS		Receiver: GOES-N Low Rate Info Transponder (LRIT WEFAX)	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = linear	
G_t = 2.15 dBi		G_r = 39.6 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1691.0 MHz		f = 1691.0 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3	3.75	3	0.10
20	4	20	0.30
33	5	60	2.25
34	6		
36	7		
37	8		
39	9		
41	10		
43	11		
45	12		
46	13		
48	14		
50	15		
51	16		
53	17		
54	18		
55	19		
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 0.2 MHz	
		Noise Figure = 2.85 dB	
		Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 2.85 dB + 10log($0.20x10^6$) = -118.14 dBm	
		I/N = -6 dB	
		I = -124.14 dBm	

<table>
<tr><td colspan="4">Scenario: S19</td></tr>
<tr><td colspan="2">Transmitter: VSS</td><td colspan="2">Receiver: GOES-N Emergency Management Weather Information Network (EMWIN)</td></tr>
<tr><td colspan="2">h_t = 2m and greater</td><td colspan="2">h_r =20, 25, 33m</td></tr>
<tr><td colspan="2">P_t = 24 dBm</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = linear</td><td colspan="2">Polarization = linear</td></tr>
<tr><td colspan="2">G_t = 2.15 dBi</td><td colspan="2">G_r = 39.6 dBi</td></tr>
<tr><td colspan="2">Cable loss = 0 dB</td><td colspan="2">Cable loss = 0 dB</td></tr>
<tr><td colspan="2">f = 1692.7 MHz</td><td colspan="2">f = 1692.7 MHz</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
33
34
36
37
39
41
43
45
46
48
50
51
53
54
55</td><td>3.75
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19</td><td>3
20
60</td><td>0.009
0.013
0.100</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 7.5 MHz</td><td colspan="2">3dB receiver bandwidth = 0.018 MHz</td></tr>
<tr><td colspan="2" rowspan="5"></td><td colspan="2">Noise Figure = 2.85 dB</td></tr>
<tr><td colspan="2">Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz)
= -174 dBm/Hz + 2.85 dB + 10log(0.018×10^6)
= -128.6 dBm</td></tr>
<tr><td colspan="2">I/N = -6 dB</td></tr>
<tr><td colspan="2">I = -134.6 dBm</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Scenario: S20			
Transmitter: VSS		Receiver: GOES-N Multiuse Data Link (MDL)	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = linear	
G_t = 2.15 dBi		G_r = 39.6 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1681.478 MHz		f = 1681.478 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 60	0.075 0.200 2.000
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 0.150 MHz	
		Noise Figure = 2.85 dB	
		Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 2.85 dB + 10log(0.150x10^6) = -119.39 dBm	
		I/N = -6 dB	
		I = -125.39 dBm	

Scenario: S21			
Transmitter: VSS		Receiver: GOES-N Data Collection Platform Report (DCPR)	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = linear	
G_t = 2.15 dBi		G_r = 39.6 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1694.5 and 1694.8 MHz		f = 1694.5 and 1694.8 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 60 80 92 NOTE: use slope of -20 to -60 to get to -80 dB, then use 40 dB/decade.	0.750 2.250 5.040 6.435 12.890
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 1.50 MHz	
		Noise Figure = 2.85 dB	
		Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 2.85 dB + 10log(1.50×10^6) = -109.39 dBm	
		I/N = -6 dB	
		I = -115.39 dBm	

Scenario: S22			
Transmitter: VSS		Receiver: GOES-N Command and Data Acquisition (CDA) Telemetry	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = RHCP	
G_t = 2.15 dBi		G_r = 39.6 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1693.0 MHz		f = 1693.0 MHz	
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3	3.75	3	0.006
20	4	20	0.020
33	5	60	1.000
34	6		
36	7		
37	8		
39	9		
41	10		
43	11		
45	12		
46	13		
48	14		
50	15		
51	16		
53	17		
54	18		
55	19		
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 0.012 MHz	
		Noise Figure = 2.85 dB	
		Sensitivity = -174 dBm/Hz + NF (dB) + 10logBW(Hz) = -174 dBm/Hz + 2.85 dB + 10log(0.012×10^6) = -130.36 dBm	
		I/N = -6 dB	
		I = -136.36 dBm	

Scenario: S23			
Transmitter: VSS		Receiver: GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) QPSK	
h_t = 2m and greater		h_r =9m	
P_t = 24 dBm			
Polarization = linear		Polarization = RHCP and LHCP 3 dB vertical beamwidth = 0.66° 3 dB horizontal beamwidth = 0.66°	
G_t = 2.15 dBi		G_r = 47.2 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1686.6 MHz		f = 1686.6 MHz	
		16.4 m dish	*BER* = $1x10^{-10}$
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 60	4.35 5.45 6.50
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 8.7 MHz	
		Noise Figure = 1.45 dB	
		Max bitrate = 17.332Mbps	N Temp = 115°K
		Sensitivity = -103.15 dBm	
		I/N = -6 dB	
		I = -109.15 dBm	

Scenario: S24			
Transmitter: VSS		Receiver: GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) 8PSK	
h_t = 2m and greater		h_r =9m	
P_t = 24 dBm			
Polarization = linear		Polarization = RHCP and LHCP 3 dB vertical beamwidth = 0.66° 3 dB horizontal beamwidth = 0.66°	
G_t = 2.15 dBi		G_r = 47.2 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1686.6 MHz		f = 1686.6 MHz	
		16.4 m dish	*BER* = $1x10^{-10}$
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 60	3.95 4.90 6.00
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 7.9 MHz	
		Noise Figure = 1.45 dB	
		Max bitrate = 23.480 Mbps	N Temp = 115°K
		Sensitivity = -103.57 dBm	
		I/N = -6 dB	
		I = -109.57 dBm	

Scenario: S25			
Transmitter: VSS		Receiver: GOES-R High Resolution Information Transponder (HRIT, EMWIN)	
h_t = 2m and greater		h_r =20, 25, 33m	
P_t = 24 dBm			
Polarization = linear		Polarization = linear (N-S) 3 dB vertical beamwidth = 0.66° 3 dB horizontal beamwidth = 0.66°	
G_t = 2.15 dBi		G_r = 47.2 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1694.1 MHz		f = 1694.1 MHz	
		16.4 m dish	*BER* = $1x10^{-8}$
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3	3.75	3	0.475
20	4	20	0.715
33	5	60	2.000
34	6		
36	7		
37	8		
39	9		
41	10		
43	11		
45	12		
46	13		
48	14		
50	15		
51	16		
53	17		
54	18		
55	19		
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 0.95 MHz	
		Noise Figure = 1.45 dB	
		Max bitrate = 927 Kbps	N Temp = 115°K
		Sensitivity = -112.77 dBm	
		I/N = -6 dB	
		I = -118.77 dBm	

Scenario: S26			
Transmitter: VSS		Receiver: GOES-R Data Collection Platform Report (DCPR #1)	
h_t = 2m and greater		h_r =9m	
P_t = 24 dBm			
Polarization = linear		Polarization = RHCP 3 dB vertical beamwidth = 0.66° 3 dB horizontal beamwidth = 0.66°	
G_t = 2.15 dBi		G_r = 47.2 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1679.9 MHz		f = 1679.9 MHz	
		16.4 m dish	*BER* = $1x10^{-6}$
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 40 60	0.20000 0.20100 0.20125 2.0000
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 0.4 MHz	
		Noise Figure = 1.45 dB	
		Max bitrate = 1.8 Kbps	N Temp = 115°K
		Sensitivity = -116.53 dBm	
		I/N = -6 dB	
		I = -122.53 dBm	

<table>
<tr><td colspan="4">Scenario: S27</td></tr>
<tr><td colspan="2">Transmitter: VSS</td><td colspan="2">Receiver: GOES-R Data Collection Platform Report (DCPR #2)</td></tr>
<tr><td colspan="2">h_t = 2m and greater</td><td colspan="2">h_r =9m</td></tr>
<tr><td colspan="2">P_t = 24 dBm</td><td colspan="2"></td></tr>
<tr><td colspan="2">Polarization = linear</td><td colspan="2">Polarization = RHCP
3 dB vertical beamwidth = 0.66°
3 dB horizontal beamwidth = 0.66°</td></tr>
<tr><td colspan="2">G_t = 2.15 dBi</td><td colspan="2">G_r = 47.2 dBi</td></tr>
<tr><td colspan="2">Cable loss = 0 dB</td><td colspan="2">Cable loss = 0 dB</td></tr>
<tr><td colspan="2">f = 1680.2 MHz</td><td colspan="2">f = 1680.2 MHz</td></tr>
<tr><td colspan="2"></td><td>16.4 m dish</td><td>BER = $1x10^{-6}$</td></tr>
<tr><td colspan="2">Filter characteristics</td><td colspan="2">Filter characteristics</td></tr>
<tr><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td><td>Attenuation (dB)</td><td>Frequency offset (MHz)</td></tr>
<tr><td>3
20
33
34
36
37
39
41
43
45
46
48
50
51
53
54
55</td><td>3.75
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19</td><td>3
20
40
60</td><td>0.2000
0.2010
0.20125
2.0000</td></tr>
<tr><td colspan="2">3dB emission bandwidth = 7.5 MHz</td><td colspan="2">3dB receiver bandwidth = 0.4 MHz</td></tr>
<tr><td colspan="2" rowspan="6"></td><td colspan="2">Noise Figure = 1.45 dB</td></tr>
<tr><td>Max bitrate = 45 Kbps</td><td>N Temp = 115°K</td></tr>
<tr><td colspan="2">Sensitivity = -116.53 dBm</td></tr>
<tr><td colspan="2">I/N = -6 dB</td></tr>
<tr><td colspan="2">I = -122.53 dBm</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Scenario: S28			
Transmitter: VSS		Receiver: GOES-R Command and Data Acquisition (CDA) Telemetry	
h_t = 2m and greater		h_r =9m	
P_t = 24 dBm			
Polarization = linear		Polarization = RHCP 3 dB vertical beamwidth = 0.66° 3 dB horizontal beamwidth = 0.66°	
G_t = 2.15 dBi		G_r = 47.2 dBi	
Cable loss = 0 dB		Cable loss = 0 dB	
f = 1693.0 MHz		f = 1693.0 MHz	
		16.4 m dish	*BER* = $1x10^{-7}$
Filter characteristics		Filter characteristics	
Attenuation (dB)	Frequency offset (MHz)	Attenuation (dB)	Frequency offset (MHz)
3 20 33 34 36 37 39 41 43 45 46 48 50 51 53 54 55	3.75 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	3 20 60	0.0225 0.0400 0.1750
3dB emission bandwidth = 7.5 MHz		3dB receiver bandwidth = 0.045 MHz	
		Noise Figure = 1.45 dB	
		Max bitrate = 64 Kbps	N Temp = 115°K
		Sensitivity = -126.02 dBm	
		I/N = -6 dB	
		I = -132.02 dBm	

APPENDIX C. GOES EARTH STATION LOCATIONS AND ALIGNMENTS

In all of the United States and its territories, there are 26 Geostationary Operational Environmental Satellite (GOES) earth stations owned and operated by the Federal Government. This Appendix lists the stations by name, location, and the antenna bearings (azimuth and elevation) for the two operational GOES satellites. Since the 1675–1695 MHz band only contains downlink channels, all of these sites receive one or more channels from one or both of the operational satellites (GOES-West and GOES-East). Due to the extreme angles involved, some of the sites receive channels from only one satellite (at the sites in Hawaii and Alaska, GOES-East is below the horizon, and GOES-West is close to the horizon for the Puerto Rico site).

Due to their extremely differing positions, each site requires a separate antenna for each satellite, so not all sites monitor both satellites. Any site monitoring both satellites would need two antennas; physical constraints would require the antennas to be separated by some distance. However, this distance would be small enough compared to the overall distance to the satellites, that they could be considered co-located and still maintain reasonable accuracy regarding any geometric calculations.

Location	Latitude	Longitude	GOES-E (75°W)		GOES-W (135.4°W)		Antenna Height (m)
			Elevation	Azimuth	Elevation	Azimuth	
Wallops Island, VA	37°56'45"N 37.9458°	075°27'45"W 75.4625°	46.000	179.300	14.900	250.116	20.0
Fairbanks, AK	64°48'14"N 64.8039°	147°52'34"W 147.8761°	-	-	16.170	165.822	33.0
Suitland, MD	38°49'00"N 38.8167°	076°51'00"W 76.8500°	45.010	177.050	15.917	248.724	33.0
Boulder, CO	40°00'54"N 40.0150°	105°16'14"W 105.2706°	34.218	137.746	34.543	221.587	9.0
Sioux Falls, SD	43°44'06"N 43.7350°	096°37'32"W 96.6256°	35.091	150.168	26.743	228.878	33.0
Boise, ID	46°36'53"N 46.6147°	116°15'08"W 116.2522°	23.098	129.646	33.317	205.034	33.0
Knoxville, TN	35°57'58"N 35.9661°	083°55'13"W 83.9203°	47.192	165.037	22.534	244.628	33.0
Guaynabo, PR	18°25'44"N 18.4289°	066°06'85"W 66.1000°	66.088	206.352	11.448	263.045	33.0
Greenbelt, MD	39°05'00"N 39.0833°	076°46'00"W 76.7667°	44.715	177.199	15.753	248.675	33.0
Huntsville ,AL	34°38'42"N 34.6450°	086°40'29"W 86.6747°	47.852	160.025	25.306	243.158	33.0
Cincinnati, OH	39°06'08"N 39.1022°	084°30'36"W 84.5100°	43.659	165.125	21.498	242.521	20.0
Rock Island, IL	41°31'04"N 41.5178°	090°33'46"W 90.5628°	39.458	157.210	24.404	235.941	25.0
St. Louis, MO	38°35'26"N 38.5906°	090°12'25"W 90.2069°	42.567	156.453	25.870	237.860	20.0
Vicksburg, MS	32°21'23"N 32.3564°	090°51'29"W 90.8581°	48.612	152.041	29.774	241.125	20.0
Sacramento, CA	38°34'59"N 38.5831°	121°29'39"W 121.4942°	18.971	125.371	32.905	197.804	20.0
Omaha, NB	41°15'32"N 41.2589°	095°55'20"W 95.9222°	37.734	149.898	28.032	230.920	20.0
Elmendorf AFB, AK	61°08'59"N 61.1497°	149°28'12"W 149.4700°	-	-	19.668	163.584	33.0
Hickam AFB, HI	21°19'07"N 21.3186°	157°55'21"W 157.9225°	-	-	53.994	130.686	33.0
Norfolk, VA	36°53'59"N 36.8997°	076°17'59"W 76.2997°	47.182	177.836	16.199	249.945	33.0
Monterey, CA	36°36'00"N 36.6000°	121°54'00"W 121.9000°	25.418	119.159	45.336	201.321	33.0
Stennis Space Center, MS	30°23'59"N 30.3997°	089°35'59"W 89.5997°	51.137	152.763	29.728	243.480	33.0
Twenty Nine Palms, CA	34°17'46"N 34.2961°	116°09'44"W 116.1622°	31.013	122.802	45.332	211.194	33.0
Camp Pendleton, CA	33°18'04"N 33.3011°	117°21'19"W 117.3553°	30.672	121.057	46.861	210.085	33.0
Yuma, AZ	32°39'24"N 32.6567°	114°36'22"W 114.6061°	33.169	123.109	46.086	214.566	33.0
Bogue Field, NC	34°41'26"N 34.6906°	077°01'47"W 77.0297°	51.939	176.242	18.265	251.347	33.0
Beaufort, SC	32°28'50"N 32.4806°	080°43'09"W 80.7192°	51.697	169.436	21.412	248.886	33.0

APPENDIX D. FREQUENCY SEPARATION VS. SEPARATION DISTANCE CURVES FOR VSS-INTO-GOES SCENARIOS

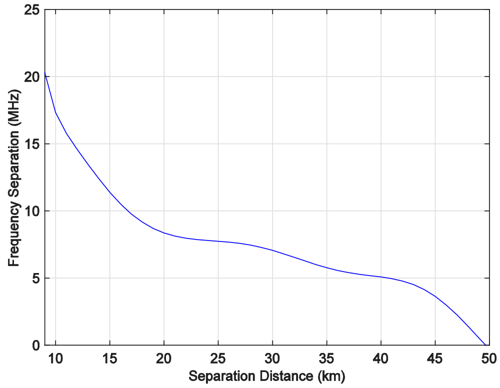
Plots of the frequency separation versus separation distance required for minimum performance were generated for scenarios of VSS interference to GOES-N and GOES-R victim receivers (Scenarios 16 through 28) for varying antenna heights.

VSS heights of 2 m (ground location) and 20 m (roof-top location) were used, as well as GOES heights of 20 m, 25 m, and 33 m (Scenarios 16– 22), or GOES heights of 9 m and 21 m (Scenarios 23–28).

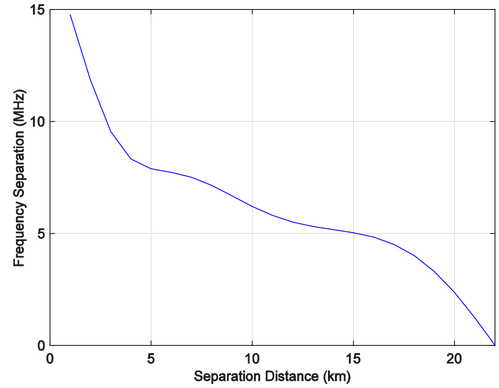
In each figure, the left-hand column was calculated by assuming that the antennas of the interfering source (VSS) and the victim receiver (GOES) were pointed at each other for maximum interference transfer.

The plots in the right-hand column were calculated by assuming that both antennas have directional characteristics and the scenario geometry was taken into account; this assumption factors in the off-axis gains of both antennas. Separate antennas were used for GOES-N/O/P and GOES-R.

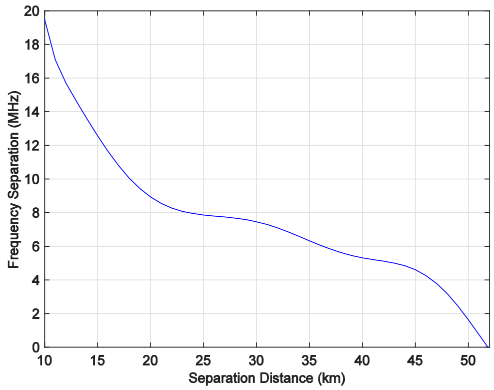
The plot ranges cover the most critical portions of the frequency-distance relationships and extend out to where the required frequency separation drops to zero.



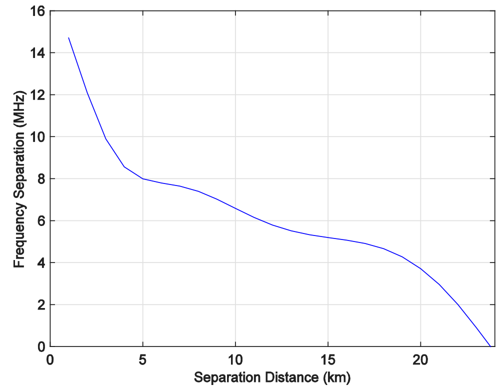
(a) GOES antenna height = 20 m antennas on axis.



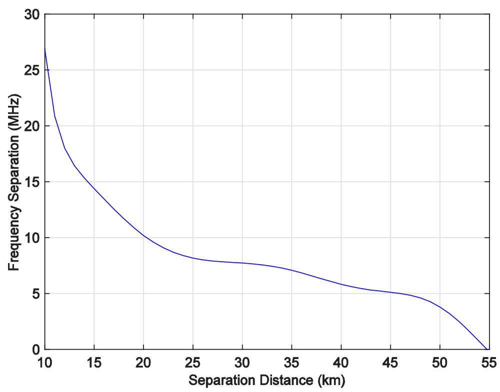
(b) GOES antenna height = 20 m antennas off axis.



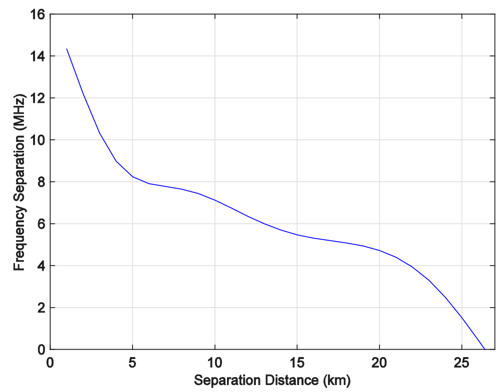
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

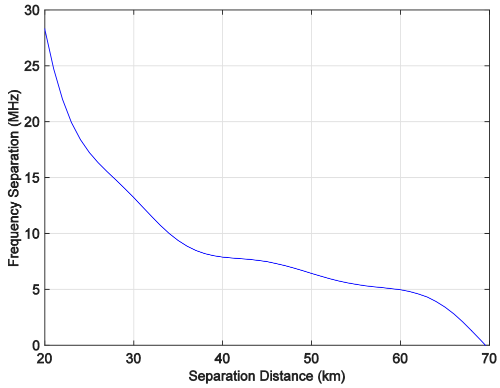


(e) GOES antenna height = 33 m antennas on axis.

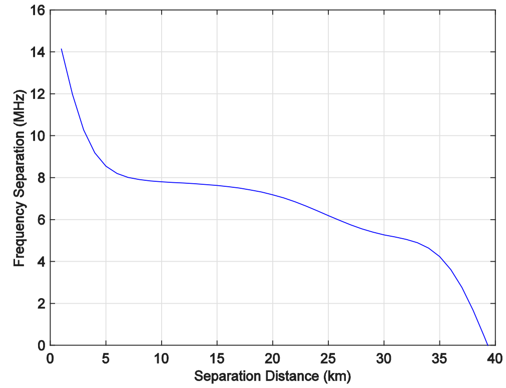


(f) GOES antenna height = 33 m antennas off axis.

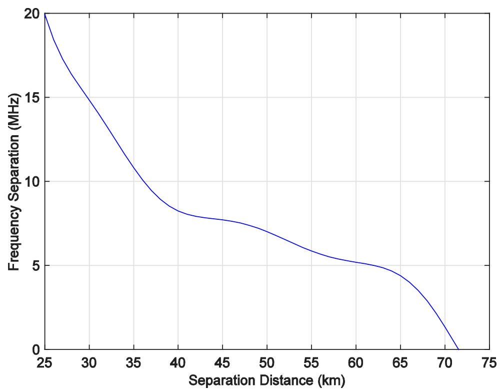
Figure D-1. Frequency separation versus separation distance curves for scenario 16 – VSS transmitter into GOES-N Sensor Data (SD) for VSS antenna height = 2 m.



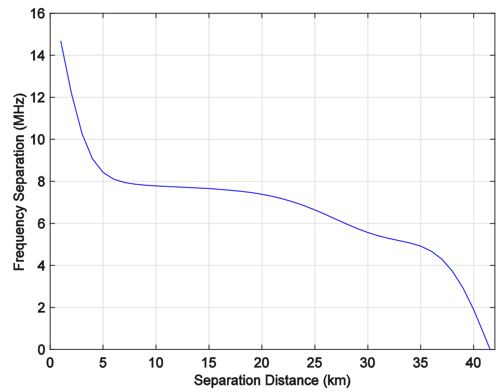
(a) GOES antenna height = 20 m antennas on axis.



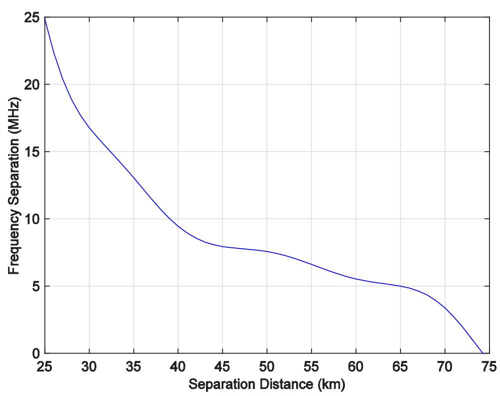
(b) GOES antenna height = 20 m antennas off axis.



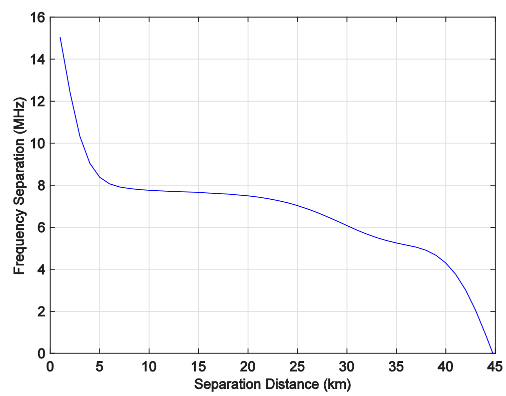
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

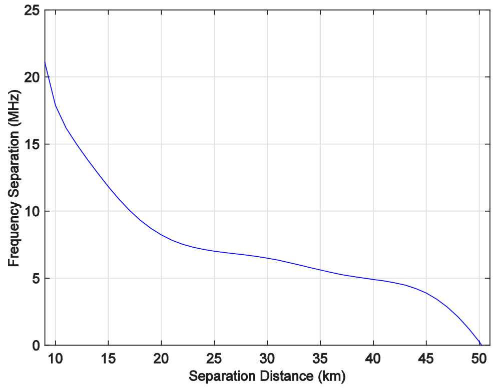


(e) GOES antenna height = 33 m antennas on axis.

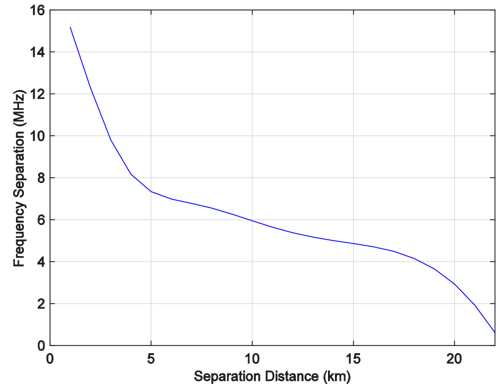


(f) GOES antenna height = 33 m antennas off axis.

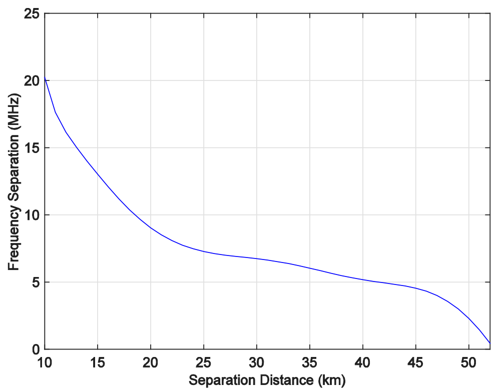
Figure D-2. Frequency separation versus separation distance curves for scenario 16 – VSS transmitter into GOES-N Sensor Data (SD) for VSS antenna height = 20 m.



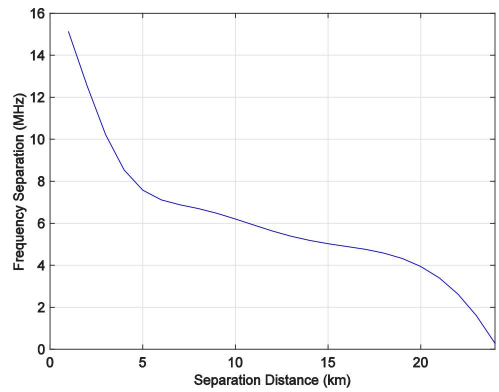
(a) GOES antenna height = 20 m antennas on axis.



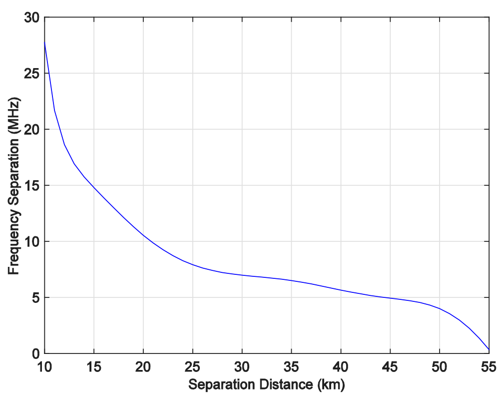
(b) GOES antenna height = 20 m antennas off axis.



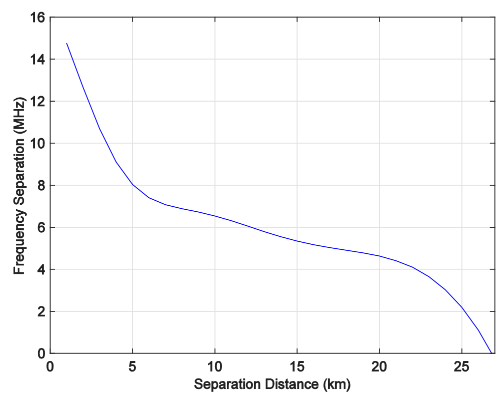
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

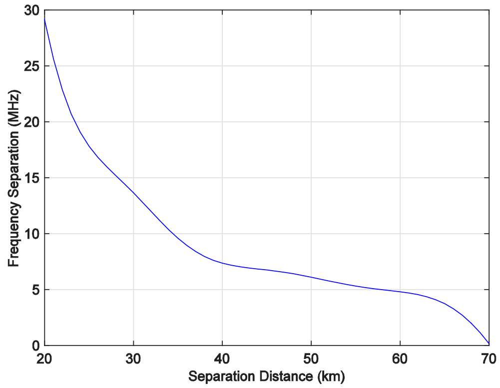


(e) GOES antenna height = 33 m antennas on axis.

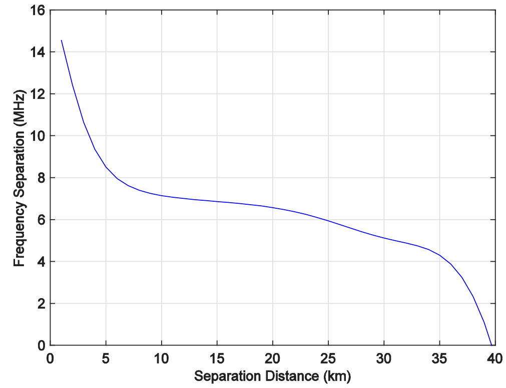


(f) GOES antenna height = 33 m antennas off axis.

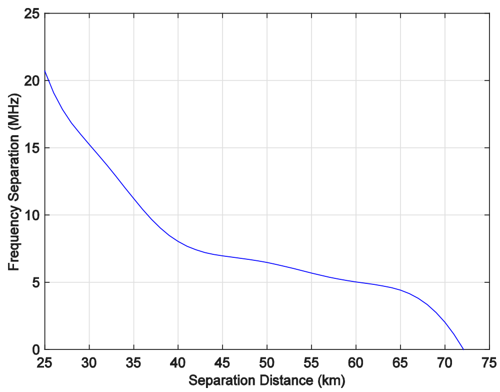
Figure D-3. Frequency separation versus separation distance curves for scenario 17 – VSS transmitter into GOES-N Processed Data Relay (PDR) for VSS antenna height = 2 m.



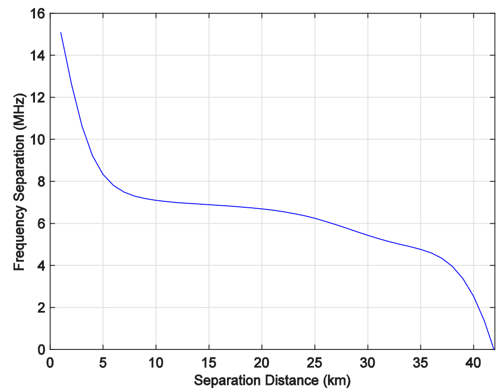
(a) GOES antenna height = 20 m
antennas on axis.



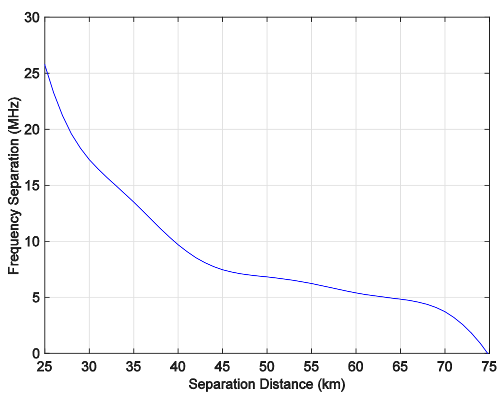
(b) GOES antenna height = 20 m
antennas off axis.



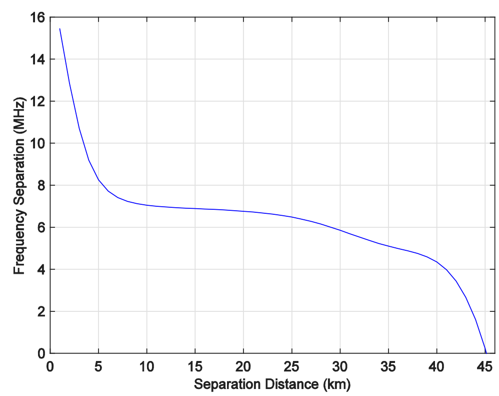
(c) GOES antenna height = 25 m
antennas on axis.



(d) GOES antenna height = 25 m
antennas off axis.

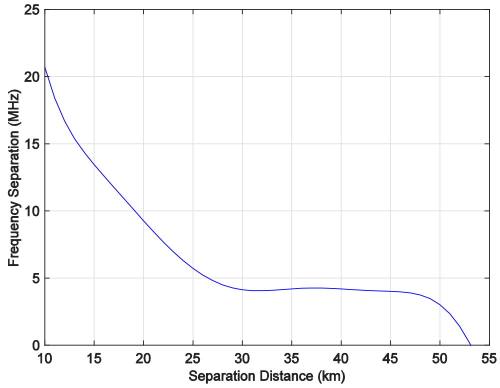


(e) GOES antenna height = 33 m
antennas on axis.

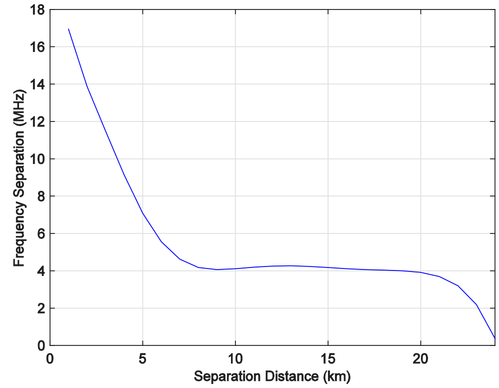


(f) GOES antenna height = 33 m
antennas off axis.

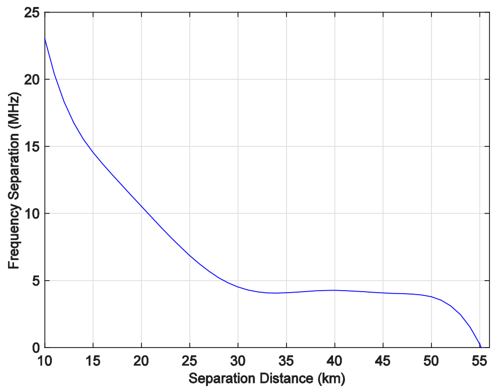
Figure D-4. Frequency separation versus separation distance curves for scenario 17 – VSS transmitter into GOES-N Processed Data Relay (PDR) for VSS antenna height = 20 m.



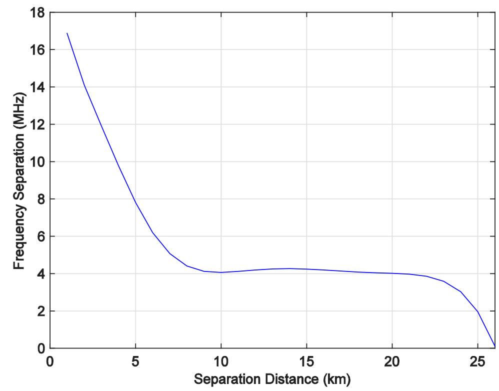
(a) GOES antenna height = 20 m antennas on axis.



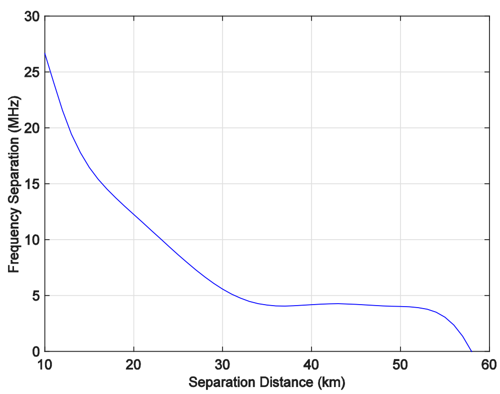
(b) GOES antenna height = 20 m antennas off axis.



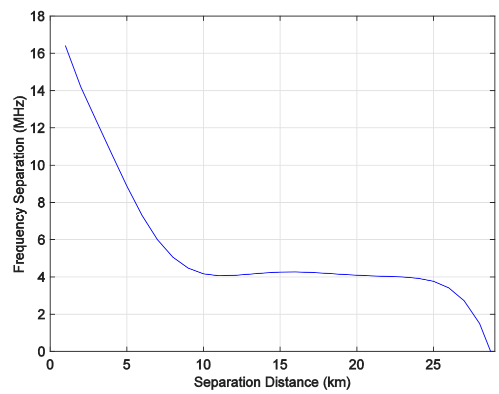
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

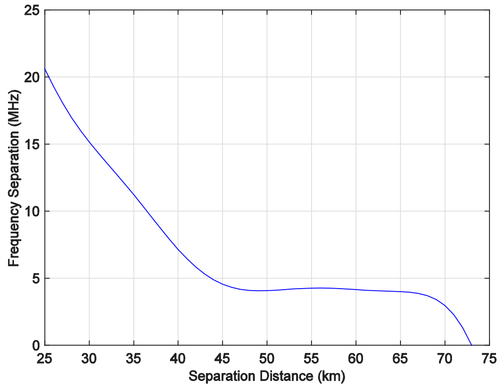


(e) GOES antenna height = 33 m antennas on axis.

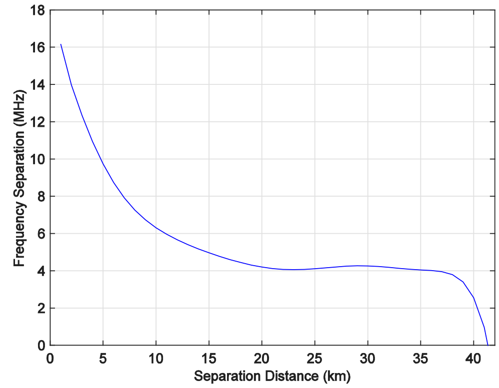


(f) GOES antenna height = 33 m antennas off axis.

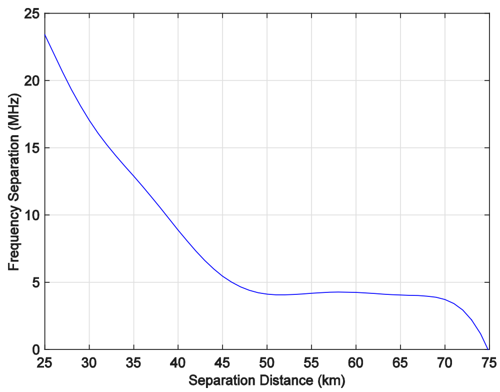
Figure D-5. Frequency separation versus separation distance curves for scenario 18 – VSS transmitter into GOES-N Low Rate Info Transponder (LRIT WEFAX) for VSS antenna height = 2 m.



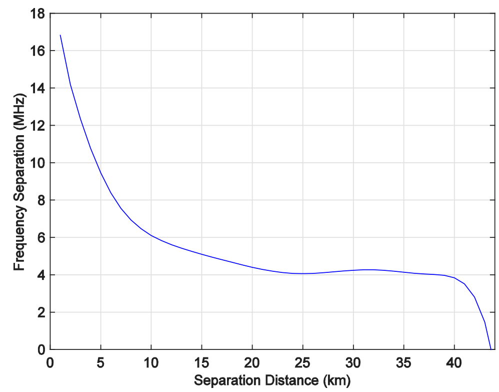
(a) GOES antenna height = 20 m
antennas on axis.



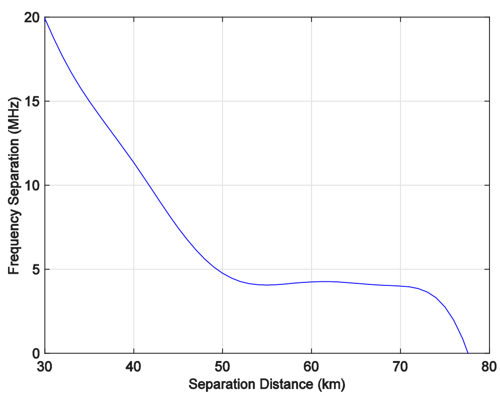
(b) GOES antenna height = 20 m
antennas off axis.



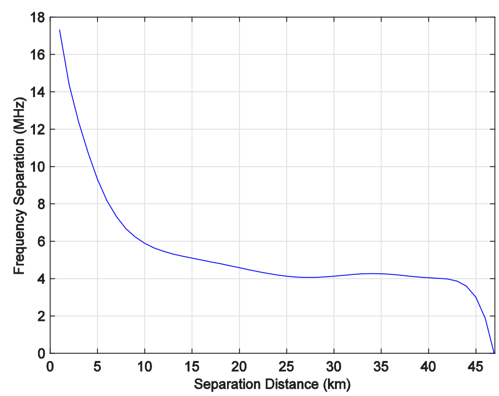
(c) GOES antenna height = 25 m
antennas on axis.



(d) GOES antenna height = 25 m
antennas off axis.

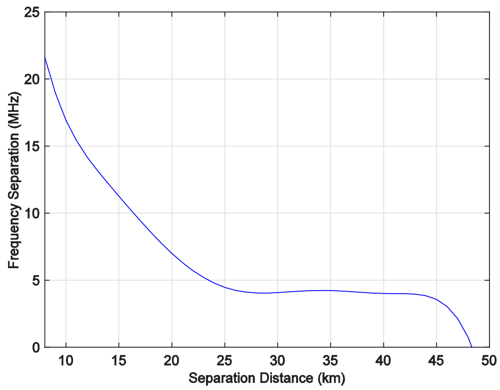


(e) GOES antenna height = 33 m
antennas on axis.

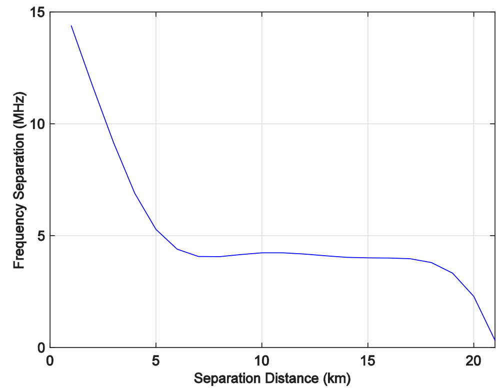


(f) GOES antenna height = 33 m
antennas off axis.

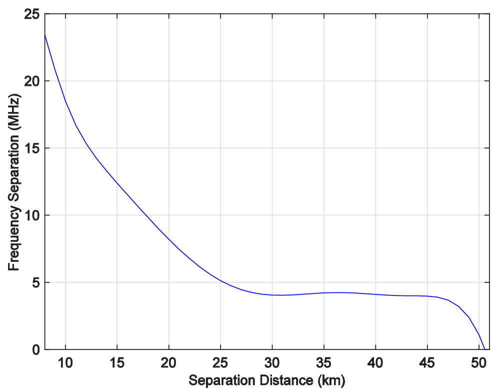
Figure D-6. Frequency separation versus separation distance curves for scenario 18 – VSS transmitter into GOES-N Low Rate Info Transponder (LRIT WEFAX) for VSS antenna height = 20 m.



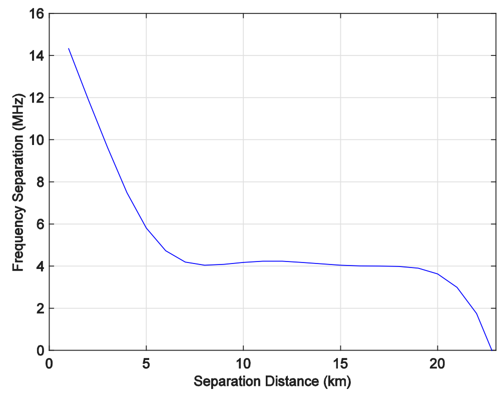
(a) GOES antenna height = 20 m antennas on axis.



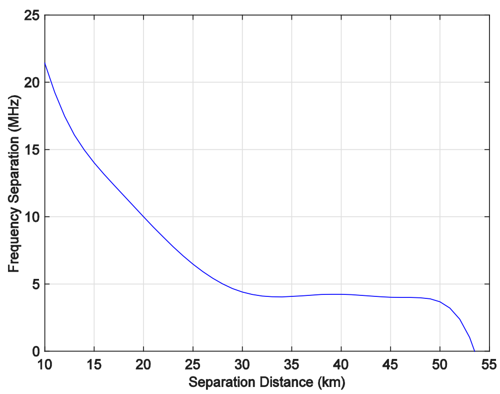
(b) GOES antenna height = 20 m antennas off axis.



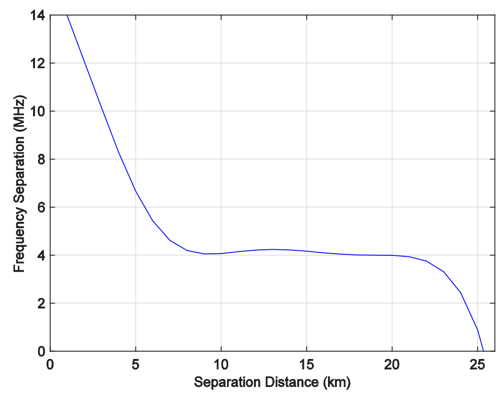
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

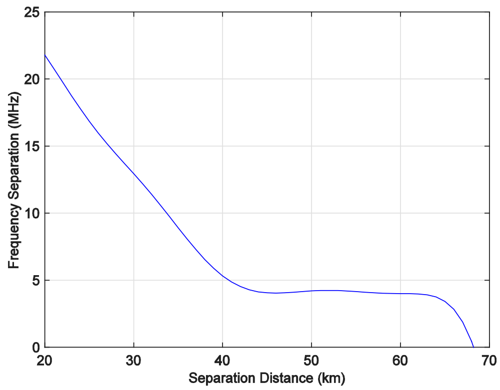


(e) GOES antenna height = 33 m antennas on axis.

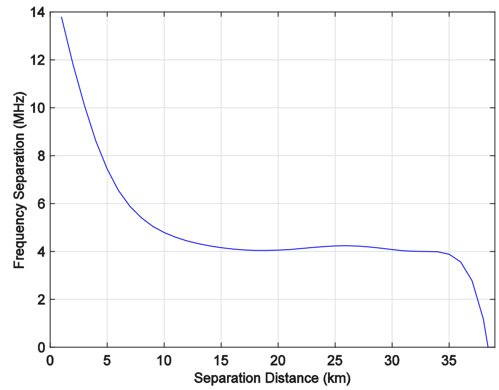


(f) GOES antenna height = 33 m antennas off axis.

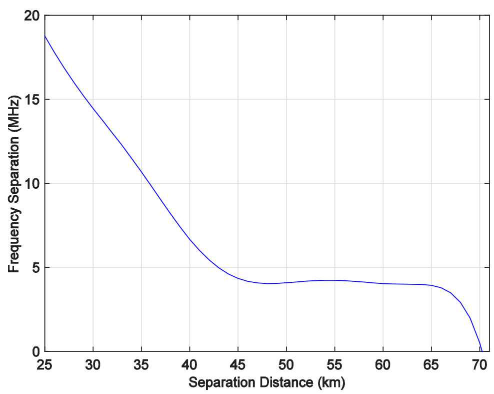
Figure D-7. Frequency separation versus separation distance curves for scenario 19 – VSS transmitter into GOES-N Emergency Management Weather Information Network (EMWIN) for VSS antenna height = 2 m.



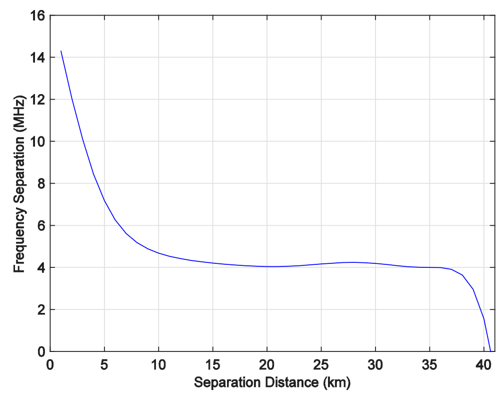
(a) GOES antenna height = 20 m
antennas on axis.



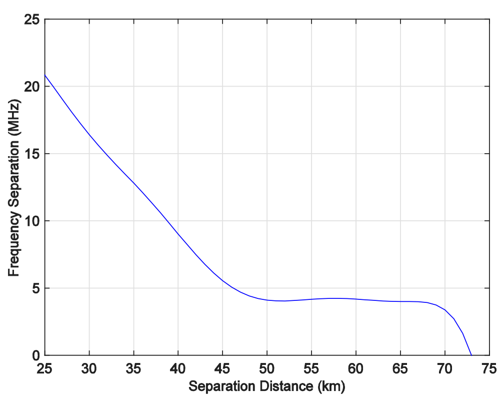
(b) GOES antenna height = 20 m
antennas off axis.



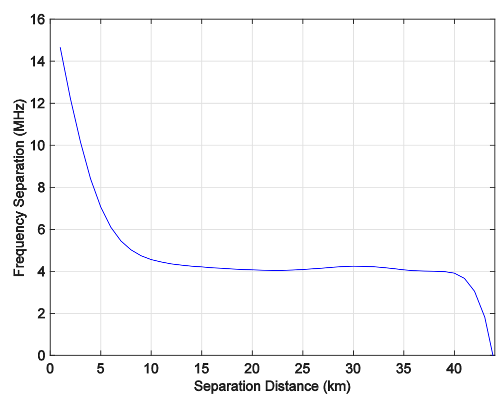
(c) GOES antenna height = 25 m
antennas on axis.



(d) GOES antenna height = 25 m
antennas off axis.

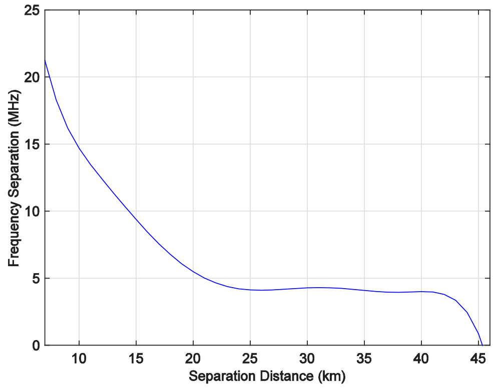


(e) GOES antenna height = 33 m
antennas on axis.

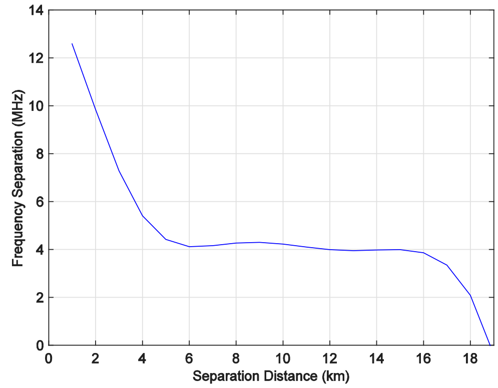


(f) GOES antenna height = 33 m
antennas off axis.

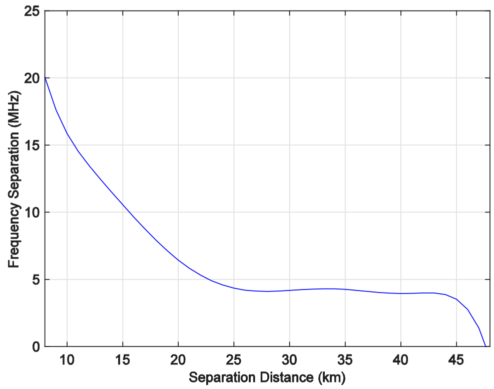
Figure D-8. Frequency separation versus separation distance curves for scenario 19 – VSS transmitter into GOES-N Emergency Management Weather Information Network (EMWIN)
for VSS antenna height = 20 m.



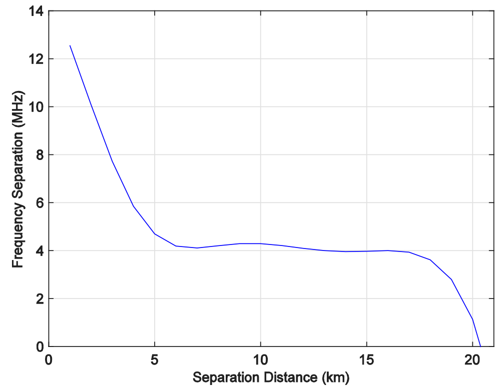
(a) GOES antenna height = 20 m antennas on axis.



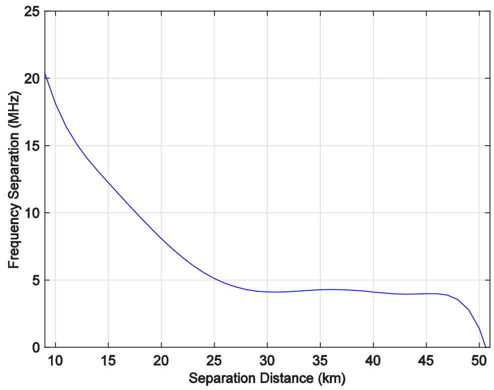
(b) GOES antenna height = 20 m antennas off axis.



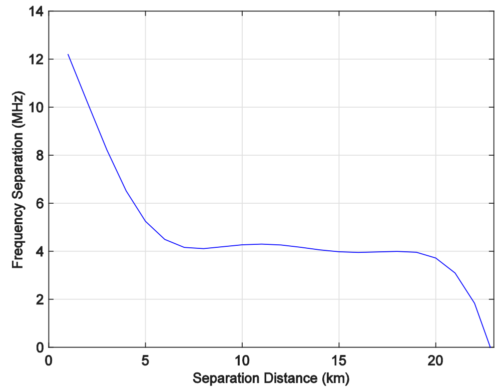
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

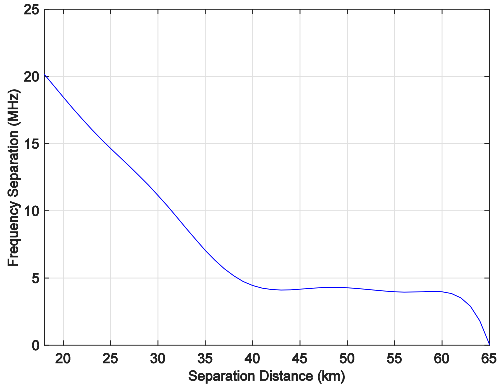


(e) GOES antenna height = 33 m antennas on axis.

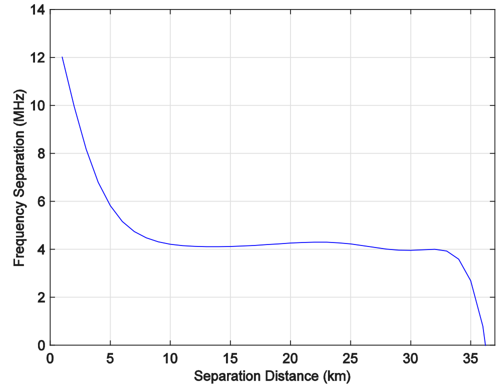


(f) GOES antenna height = 33 m antennas off axis.

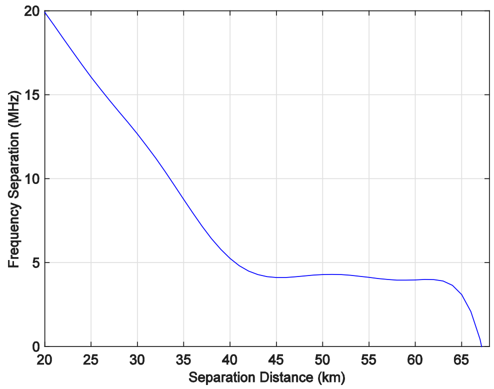
Figure D-9. Frequency separation versus separation distance curves for scenario 20 – VSS transmitter into GOES-N Multiuse Data Link (MDL) for VSS antenna height = 2 m.



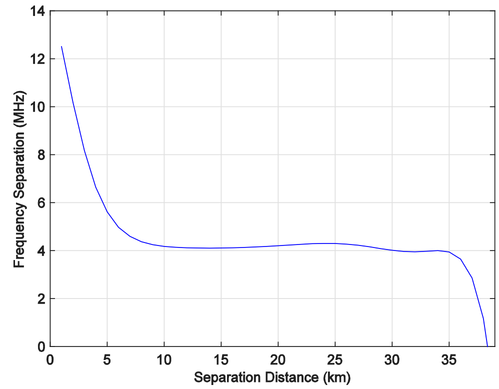
(a) GOES antenna height = 20 m
antennas on axis.



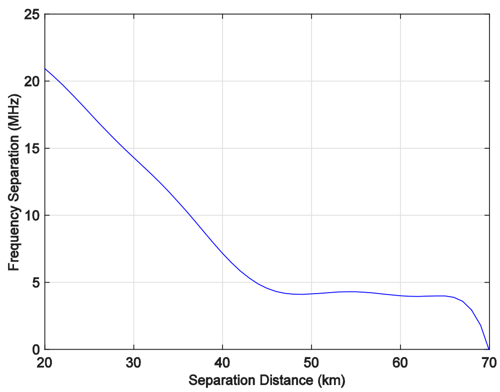
(b) GOES antenna height = 20 m
antennas off axis.



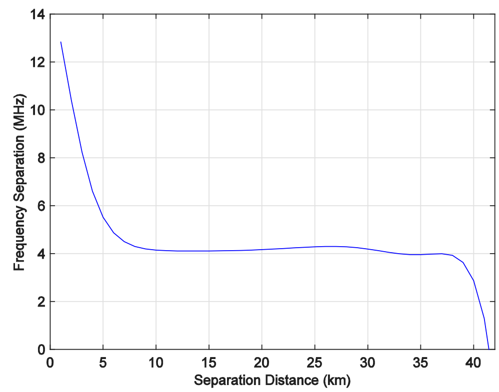
(c) GOES antenna height = 25 m
antennas on axis.



(d) GOES antenna height = 25 m
antennas off axis.

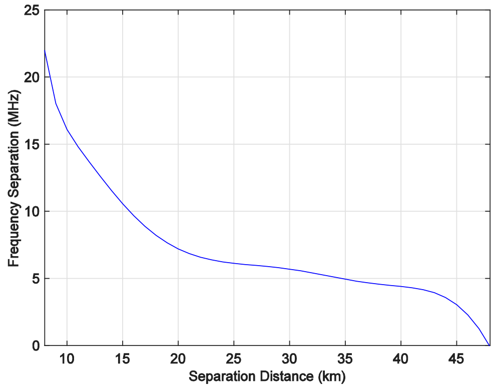


(e) GOES antenna height = 33 m
antennas on axis.

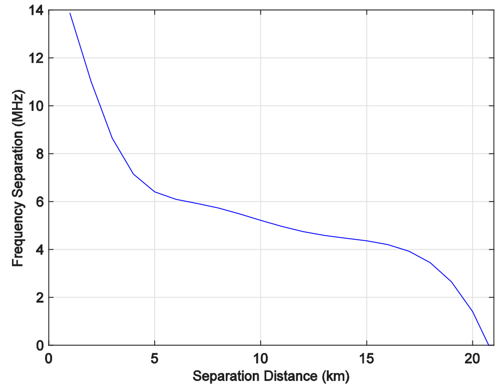


(f) GOES antenna height = 33 m
antennas off axis.

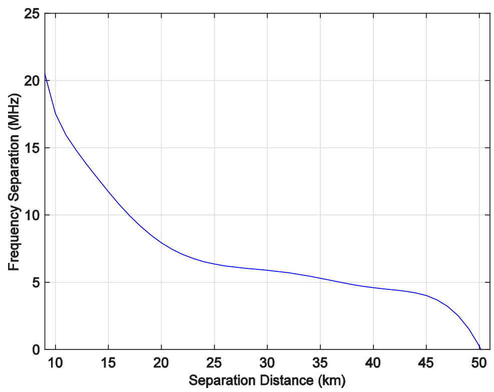
Figure D-10. Frequency separation versus separation distance curves for scenario 20 – VSS transmitter into GOES-N Multiuse Data Link (MDL) for VSS antenna height = 20 m.



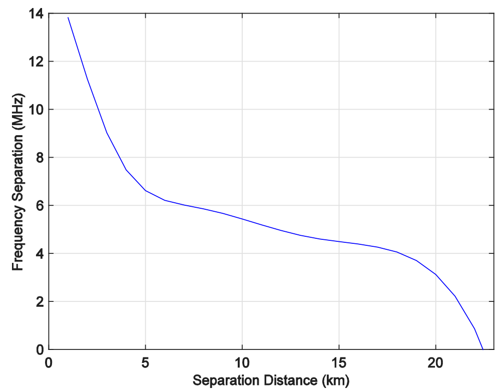
(a) GOES antenna height = 20 m antennas on axis.



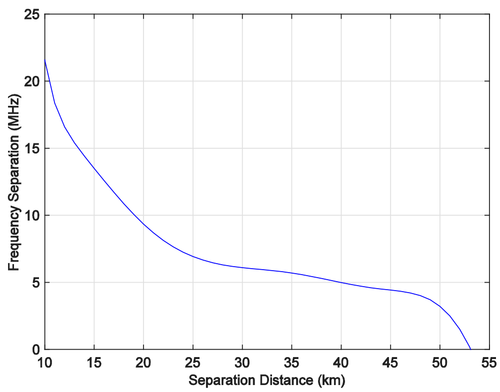
(b) GOES antenna height = 20 m antennas off axis.



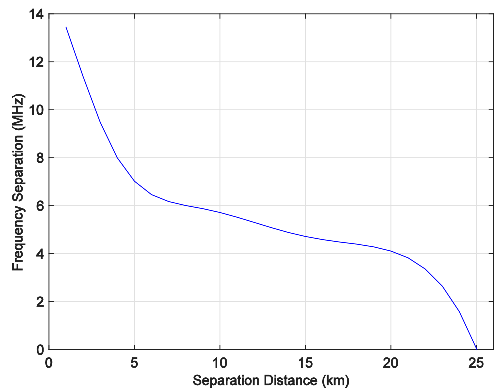
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

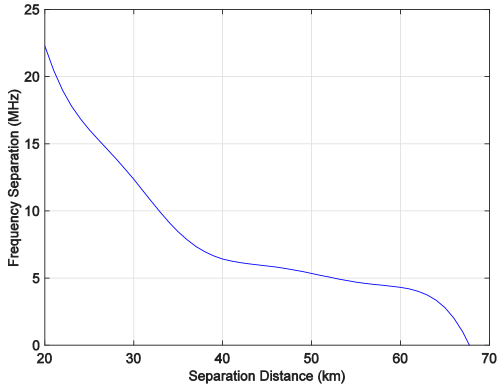


(e) GOES antenna height = 33 m antennas on axis.

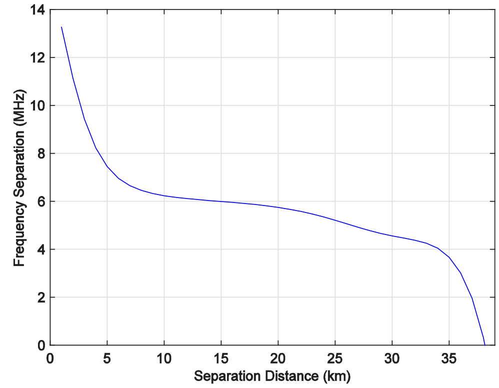


(f) GOES antenna height = 33 m antennas off axis.

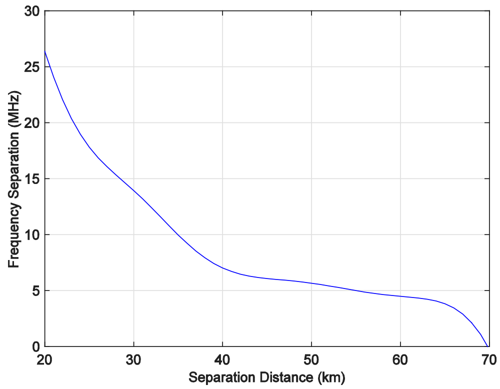
Figure D-11. Frequency separation versus separation distance curves for scenario 21 – VSS transmitter into GOES-N Data Collection Platform Report (DCPR) for VSS antenna height = 2 m.



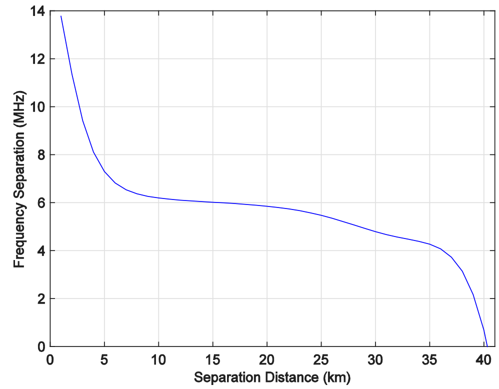
(a) GOES antenna height = 20 m antennas on axis.



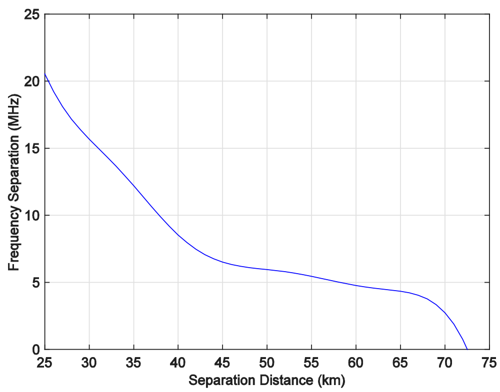
(b) GOES antenna height = 20 m antennas off axis.



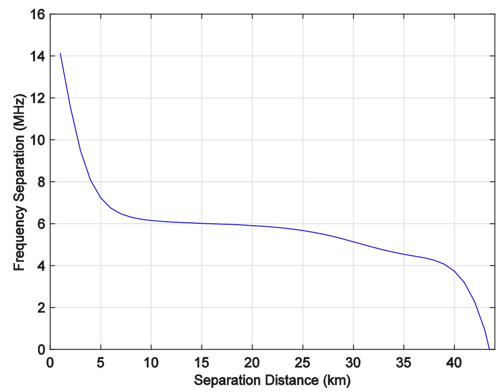
(c) GOES antenna height = 25 m antennas on axis.



(d) GOES antenna height = 25 m antennas off axis.

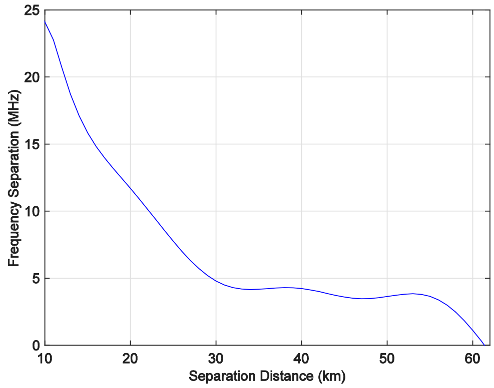


(e) GOES antenna height = 33 m antennas on axis.

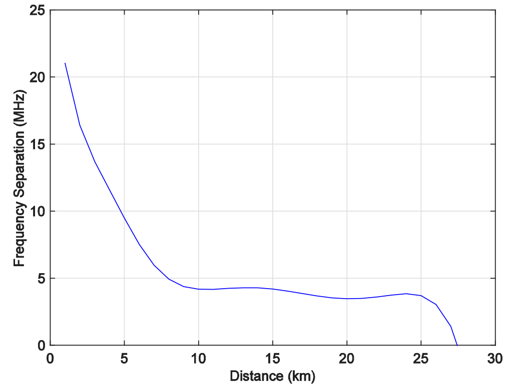


(f) GOES antenna height = 33 m antennas off axis.

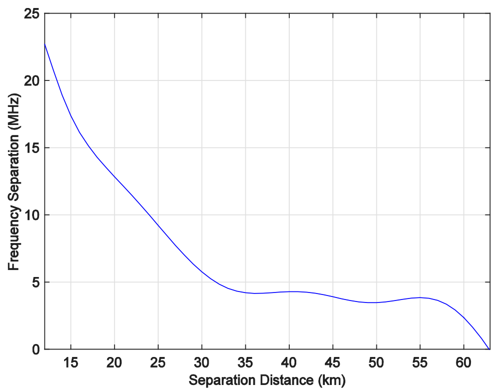
Figure D-12. Frequency separation versus separation distance curves for scenario 21 – VSS transmitter into GOES-N Data Collection Platform Report (DCPR) for VSS antenna height = 20 m.



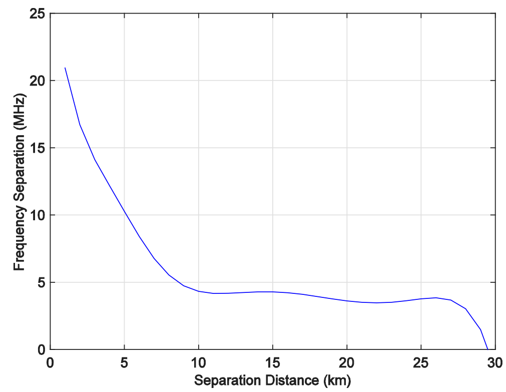
(a) GOES antenna height = 20 m
antennas on axis.



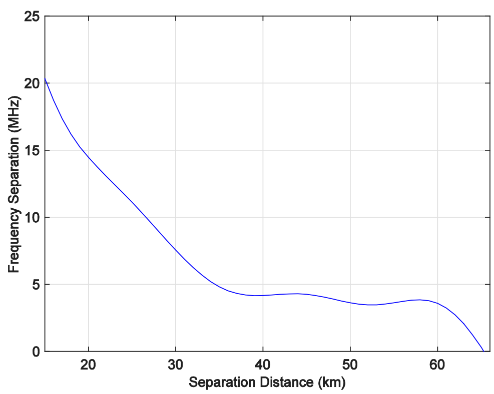
(b) GOES antenna height = 20 m
antennas off axis.



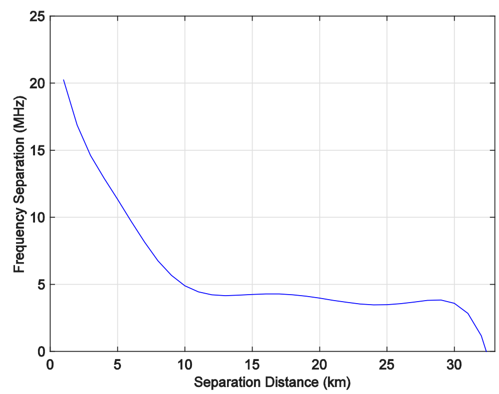
(c) GOES antenna height = 25 m
antennas on axis.



(d) GOES antenna height = 25 m
antennas off axis.

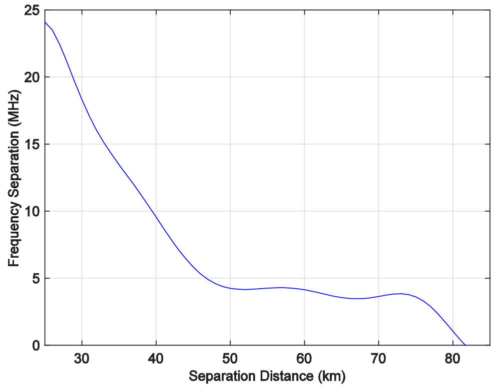


(e) GOES antenna height = 33 m
antennas on axis.

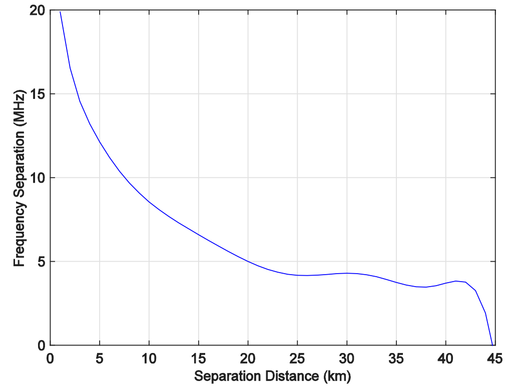


(f) GOES antenna height = 33 m
antennas off axis.

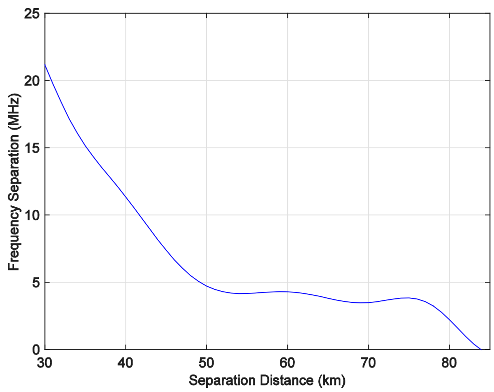
Figure D-13. Frequency separation versus separation distance curves for scenario 22 – VSS transmitter into GOES-N Command and Data Acquisition (CDA) Telemetry for VSS antenna height = 2 m.



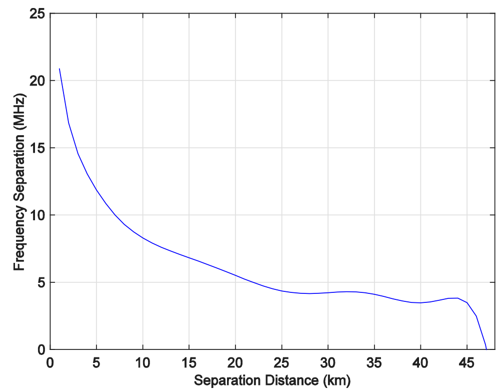
(a) GOES antenna height = 20 m
antennas on axis.



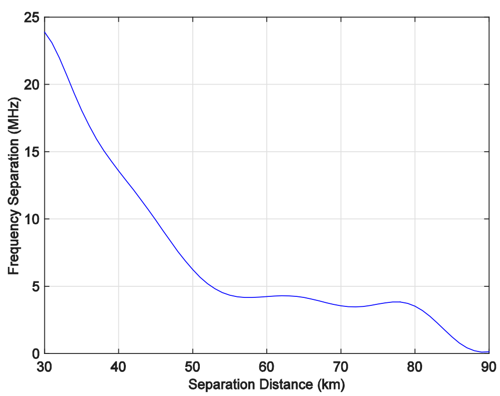
(b) GOES antenna height = 20 m
antennas off axis.



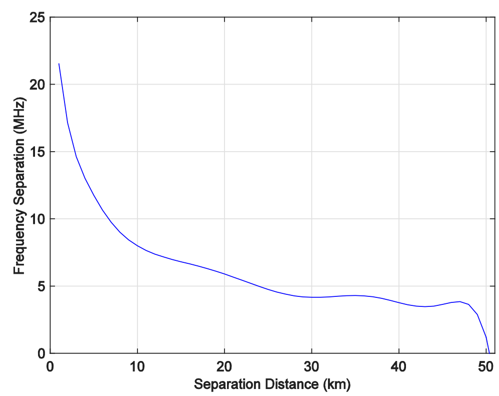
(c) GOES antenna height = 25 m
antennas on axis.



(d) GOES antenna height = 25 m
antennas off axis.

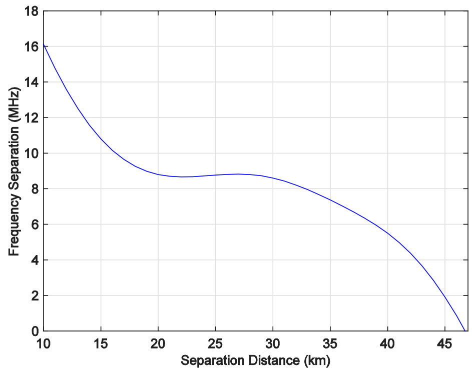


(e) GOES antenna height = 33 m
antennas on axis.

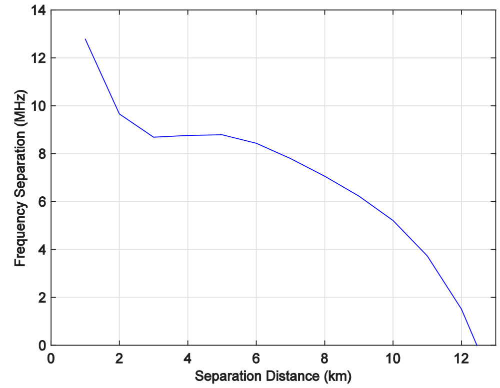


(f) GOES antenna height = 33 m
antennas off axis.

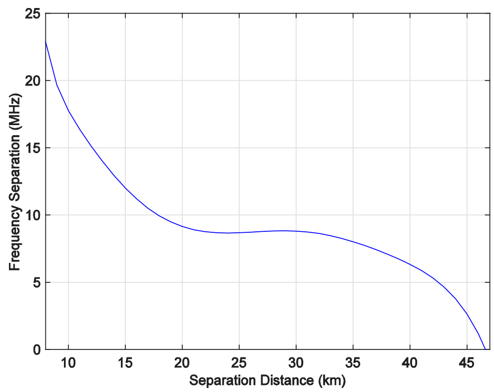
Figure D-14. Frequency separation versus separation distance curves for scenario 22 – VSS transmitter into GOES-N Command and Data Acquisition (CDA) Telemetry for VSS antenna height = 20 m.



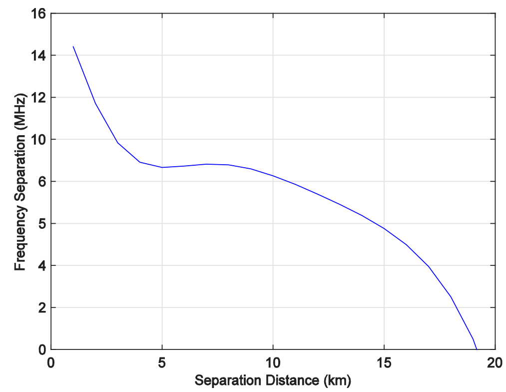
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

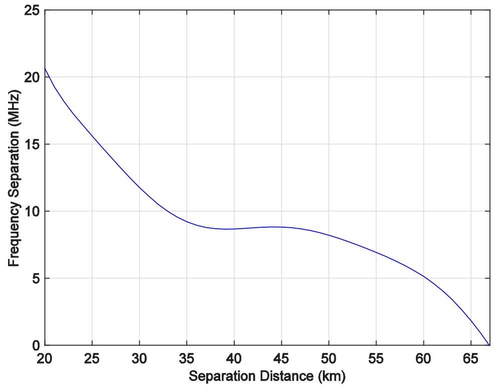


(c) GOES antenna height = 21 m
antennas on axis.

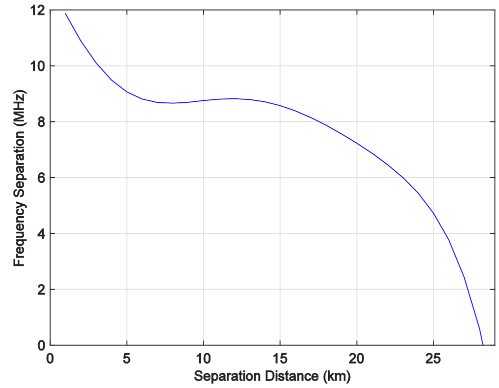


(d) GOES antenna height = 21 m
antennas off axis.

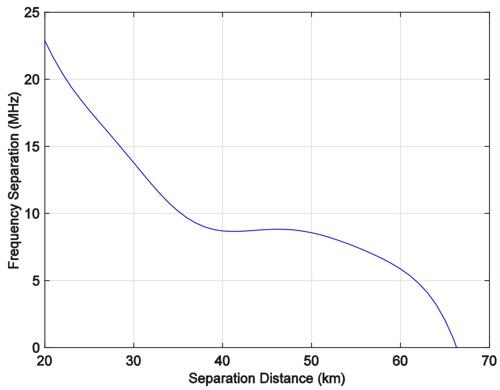
Figure D-15. Frequency separation versus separation distance curves for scenario 23 – VSS transmitter into GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) QPSK for VSS antenna height = 2 m.



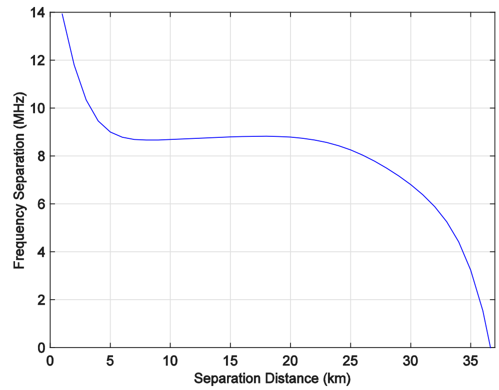
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

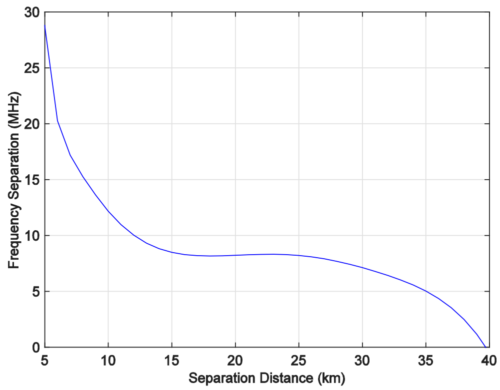


(c) GOES antenna height = 21 m
antennas on axis.

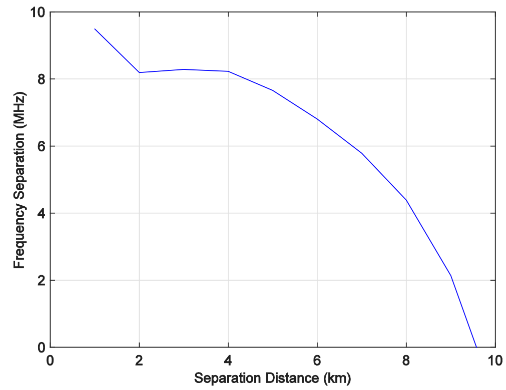


(d) GOES antenna height = 21 m
antennas off axis.

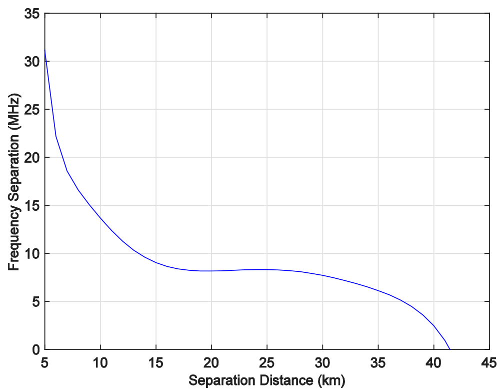
Figure D-16. Frequency separation versus separation distance curves for scenario 23 – VSS transmitter into GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) QPSK for VSS antenna height = 20 m.



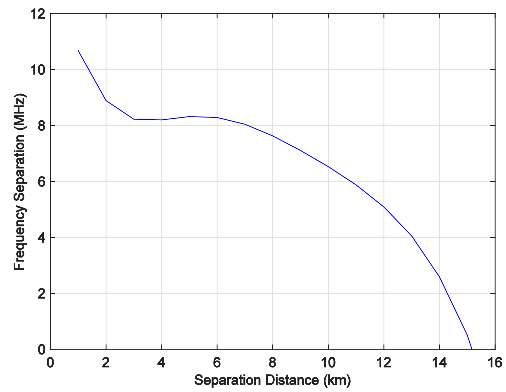
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

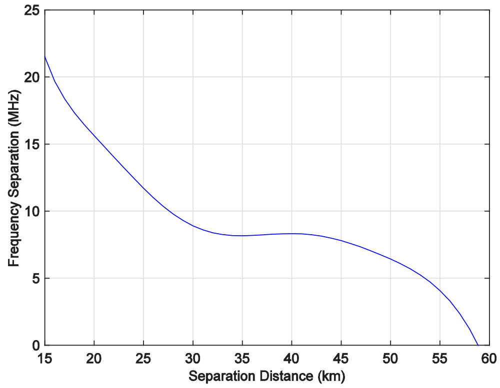


(c) GOES antenna height = 21 m
antennas on axis.

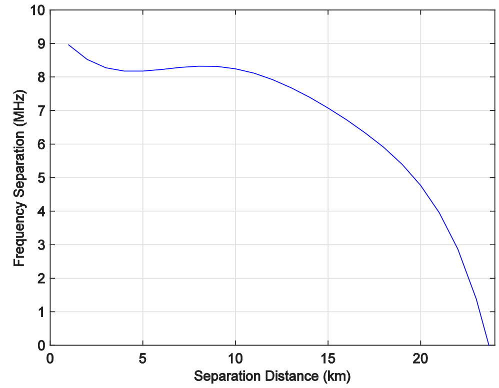


(d) GOES antenna height = 21 m
antennas off axis.

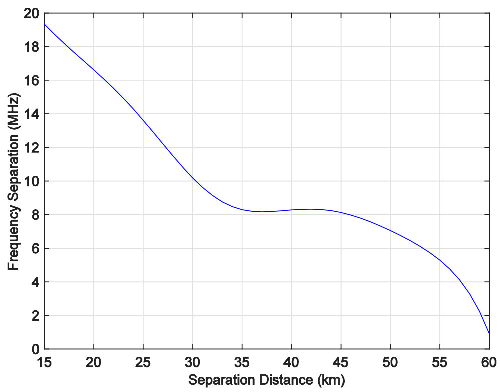
Figure D-17. Frequency separation versus separation distance curves for scenario 24 – VSS transmitter into GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) 8PSK for VSS antenna height = 2 m.



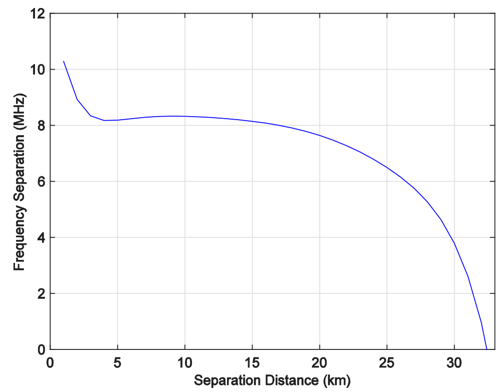
(a) GOES antenna height = 9 m antennas on axis.



(b) GOES antenna height = 9 m antennas off axis.

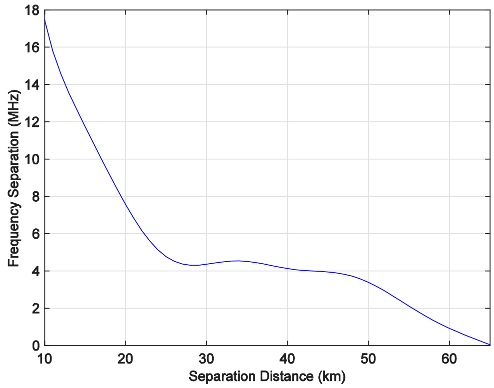


(c) GOES antenna height = 21 m antennas on axis.

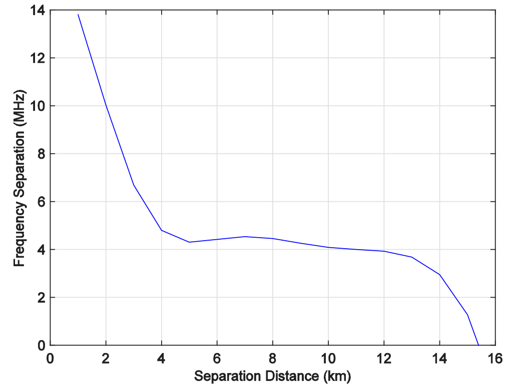


(d) GOES antenna height = 21 m antennas off axis.

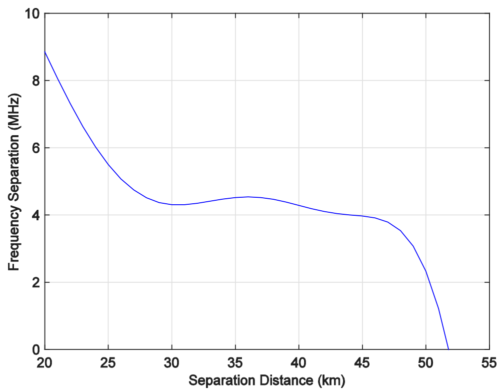
Figure D-18. Frequency separation versus separation distance curves for scenario 24 – VSS transmitter into GOES-R Rebroadcast Data Transponder (GRB1 and GRB2) 8PSK for VSS antenna height = 20 m.



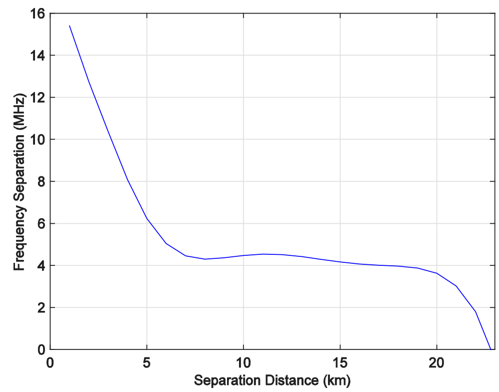
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

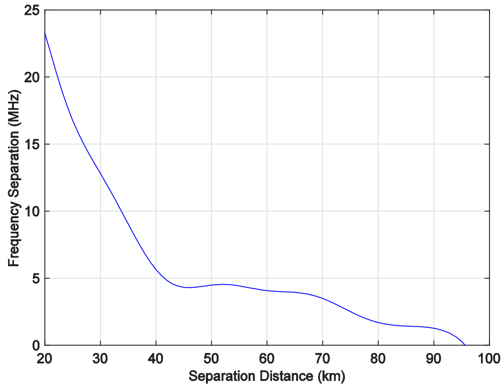


(c) GOES antenna height = 21 m
antennas on axis.

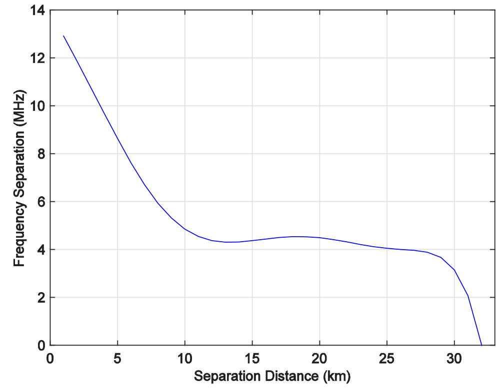


(d) GOES antenna height = 21 m
antennas off axis.

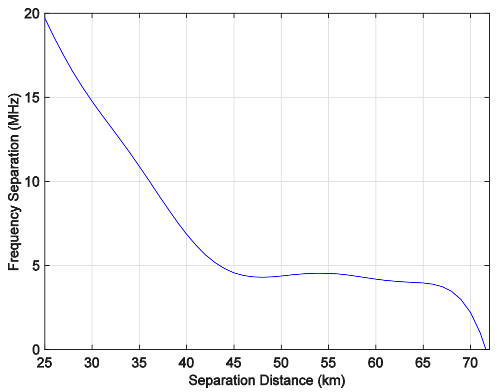
Figure D-19. Frequency separation versus separation distance curves for scenario 25 – VSS transmitter into GOES-R High Resolution Information Transponder (HRIT, EMWIN) for VSS antenna height = 2 m.



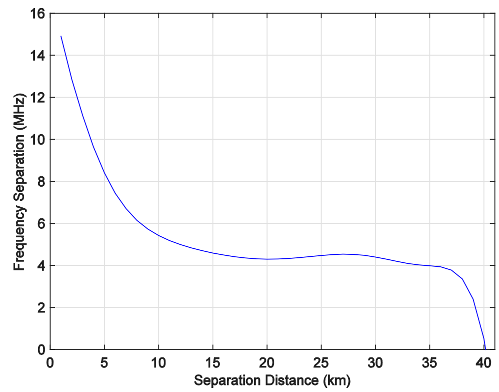
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

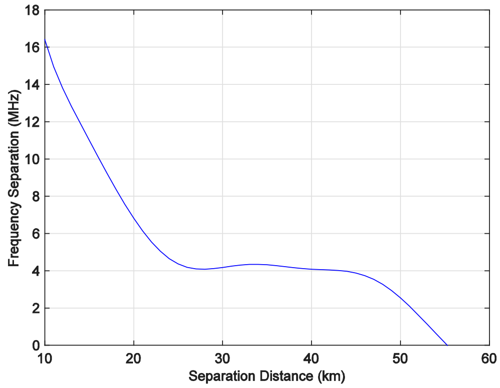


(c) GOES antenna height = 21 m
antennas on axis.

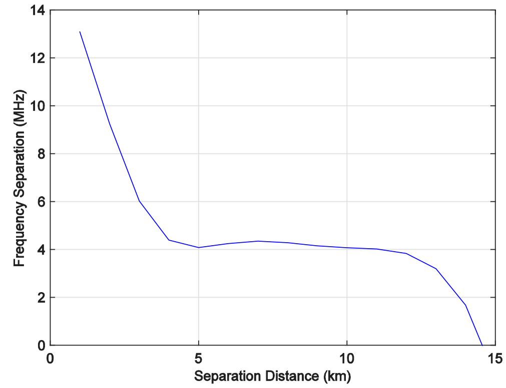


(d) GOES antenna height = 21 m
antennas off axis.

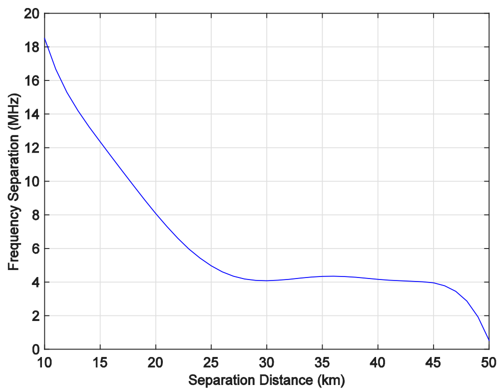
Figure D-20. Frequency separation versus separation distance curves for scenario 25 – VSS transmitter into GOES-R High Resolution Information Transponder (HRIT, EMWIN) for VSS antenna height = 20 m.



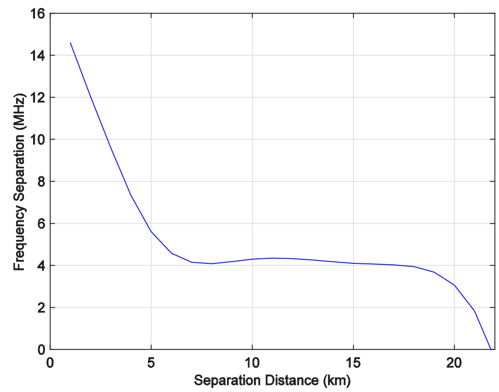
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

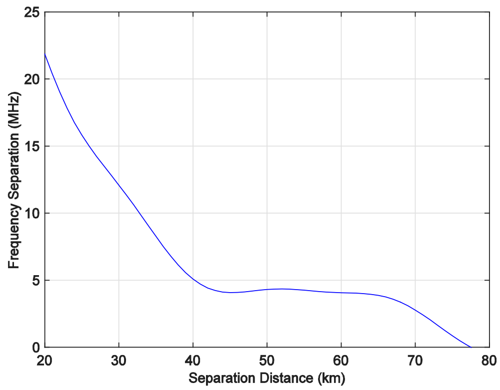


(c) GOES antenna height = 21 m
antennas on axis.

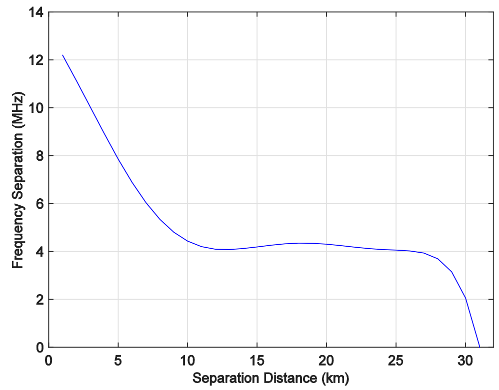


(d) GOES antenna height = 21 m
antennas off axis.

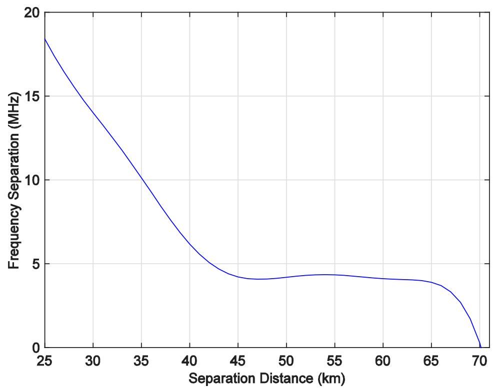
Figure D-21. Frequency separation versus separation distance curves for scenario 26 – VSS transmitter into GOES-R Data Collection Platform Report (DCPR #1) for VSS antenna height = 2 m.



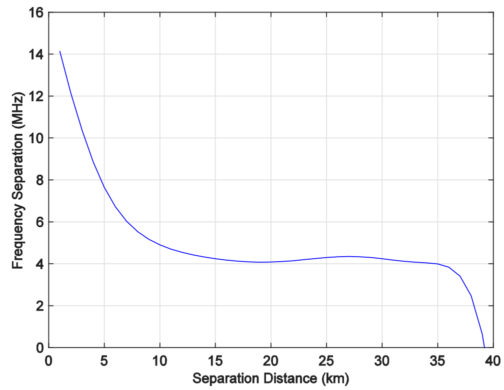
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

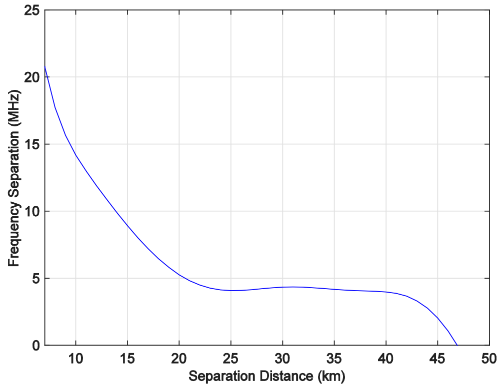


(c) GOES antenna height = 21 m
antennas on axis.

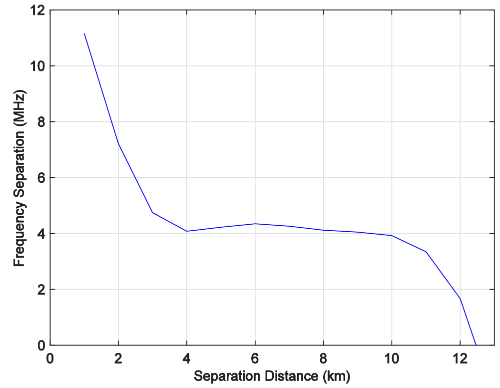


(d) GOES antenna height = 21 m
antennas off axis.

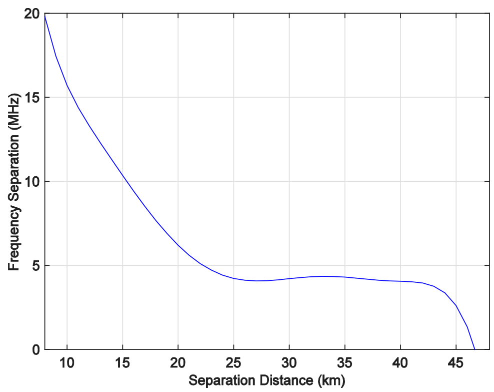
Figure D-22. Frequency separation versus separation distance curves for scenario 26 – VSS transmitter into GOES-R Data Collection Platform Report (DCPR #1) for VSS antenna height = 20 m.



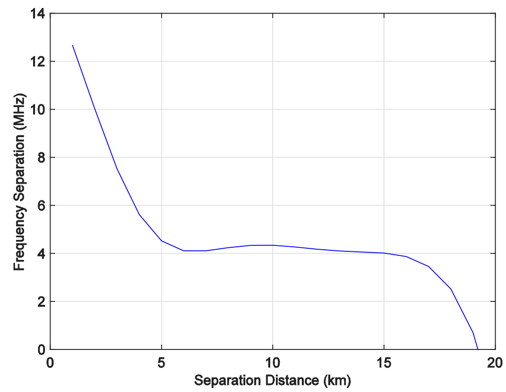
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

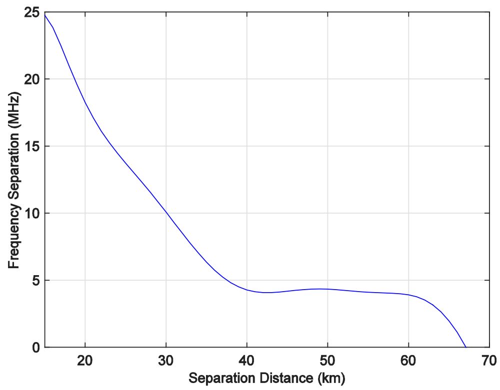


(c) GOES antenna height = 21 m
antennas on axis.

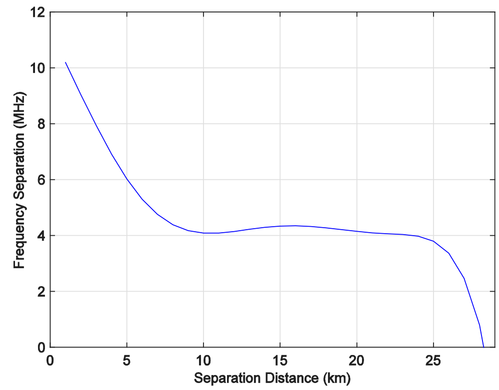


(d) GOES antenna height = 21 m
antennas off axis.

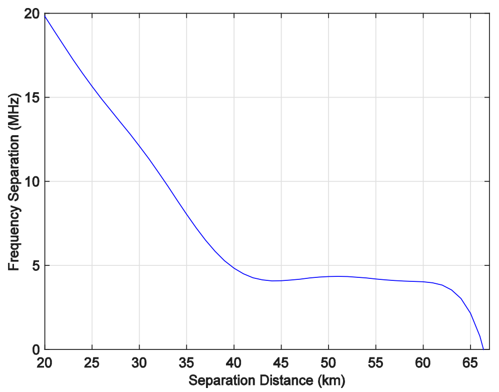
Figure D-23. Frequency separation versus separation distance curves for scenario 27 – VSS transmitter into GOES-R Data Collection Platform Report (DCPR #2) for VSS antenna height = 2 m.



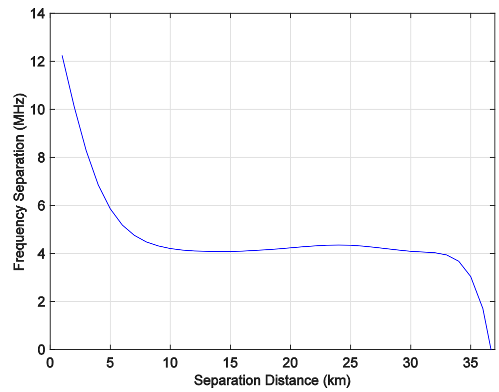
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

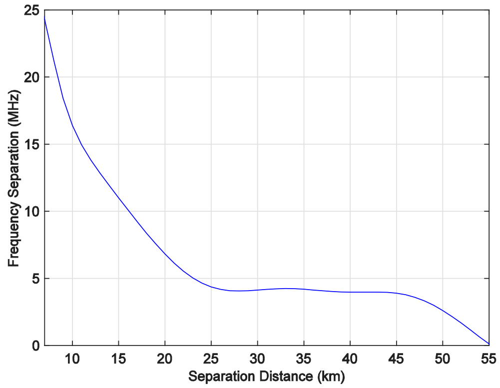


(c) GOES antenna height = 21 m
antennas on axis.

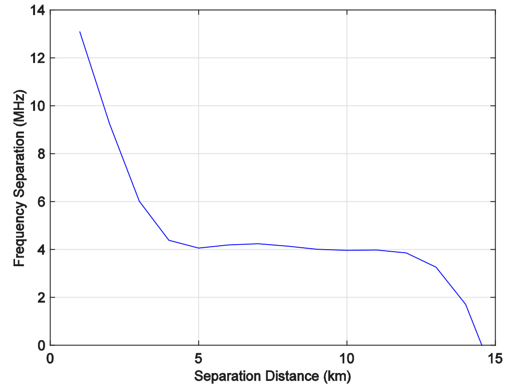


(d) GOES antenna height = 21 m
antennas off axis.

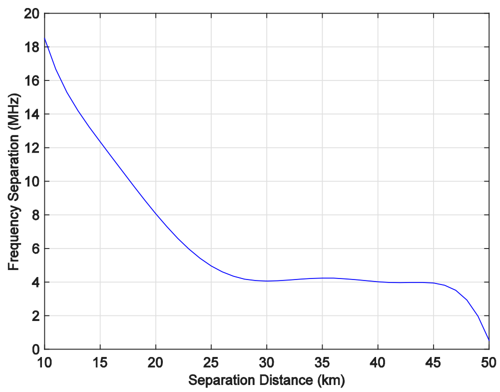
Figure D-24. Frequency separation versus separation distance curves for scenario 27 – VSS transmitter into GOES-R Data Collection Platform Report (DCPR #2) for VSS antenna height = 20 m.



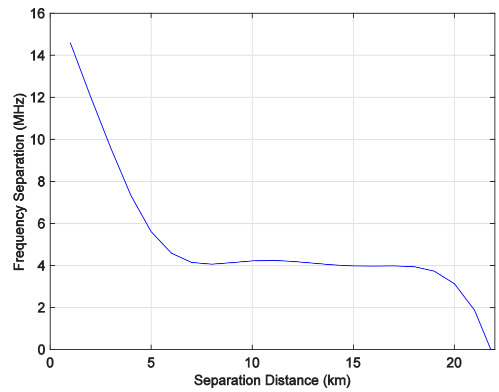
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.

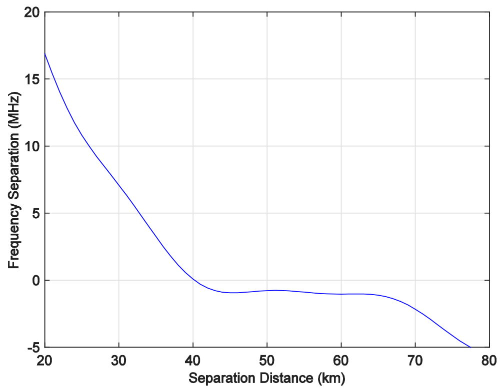


(c) GOES antenna height = 21 m
antennas on axis.

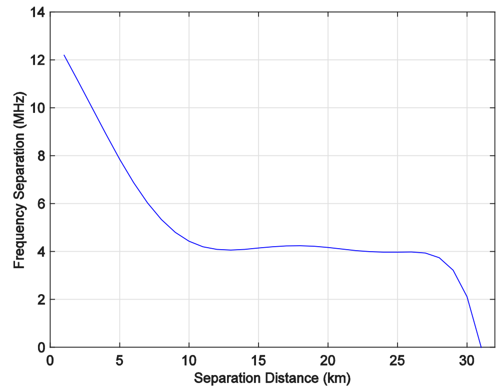


(d) GOES antenna height = 21 m
antennas off axis.

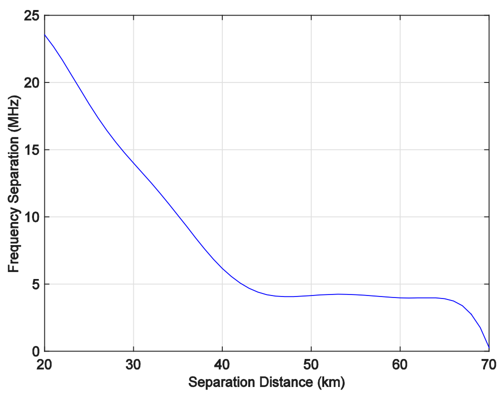
Figure D-25. Frequency separation versus separation distance curves for scenario 28 – VSS transmitter into GOES-R Command and Data Acquisition (CDA) Telemetry for VSS antenna height = 2 m.



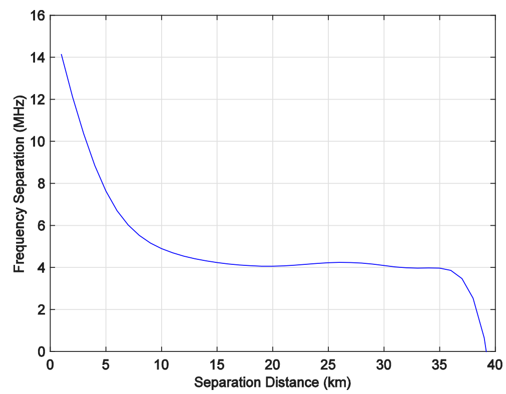
(a) GOES antenna height = 9 m
antennas on axis.



(b) GOES antenna height = 9 m
antennas off axis.



(c) GOES antenna height = 21 m
antennas on axis.



(d) GOES antenna height = 21 m
antennas off axis.

Figure D-26. Frequency separation versus separation distance curves for scenario 28 – VSS transmitter into GOES-R Command and Data Acquisition (CDA) Telemetry for VSS antenna height = 20 m.

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15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report details a method that was developed to identify all potential forms of interference that could occur with a proposed collocation of three Federal systems in the 1675–1695 MHz frequency band. The incumbents are the National Oceanographic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellites (GOES) receivers and radiosonde systems. The entrant is the Department of Homeland Security's (DHS) Video Surveillance System (VSS). The primary objective is that the quality of the mission-critical communications for each service is maintained.

A detailed electromagnetic compatibility (EMC) analysis is used to identify both the highest potential interference scenarios and those scenarios that have little to no effect. Two primary interference mitigation techniques can be implemented to achieve electromagnetic compatibility: frequency offset (Δf) and separation distance. Based on the frequency dependent rejection (*FDR*) between the interference source and the victim receiver, the Δf and separation distance necessary for a desired level of interference rejection can be calculated. For all potential interference interactions, the Δf nd the separation distance can be adjusted to arrive at a solution for operation on a non-interference basis. It is not the intent of this report to make pronouncements on how to achieve coexistence within a shared band. It is intended to examine and illuminate the engineering questions that need to be answered so that those who are responsible for Federal services in a band may negotiate and cooperate with their colleagues who are responsible for other Federal services in the same band.

16. Key Words (Alphabetical order, separated by semicolons)
spectrum sharing; *FDR*; frequency dependent rejection; frequency offset; separation distance; electromagnetic compatibility; interference mitigation

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