An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands

U.S. Department of Commerce

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Acknowledgement

The National Telecommunications and Information Administration would like to thank the members of Policy and Plans Steering Group for their dedicated and cooperative work effort rallying to the President's call to seek opportunities to make spectrum available for wireless broadband. This complex task to assess the "Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz, and 4380-4400 MHz Bands" could not have been accomplished in the short timeframe available without having their valuable contributions in a timely fashion. While this report presents NTIA's technical analysis, the Department of Commerce, Department of Defense, Department of the Interior, and the National Aeronautics and Space Administration staff worked long hours to prepare and submit their own technical electromagnetic compatibility assessments, at times using different models or analysis techniques. The complex modern electromagnetic environment and the need to consider sharing of spectrum between diverse radio services and scenarios created significant challenges in the completion of the analyses. NTIA and agency engineers worked together to resolve differences in their approaches. These agencies provided critical components of the analyses and where their approaches differed, their inputs served to confirm results presented in this report. NTIA is grateful for their dedicated, thorough, and unselfish support.

Executive Summary

As a result of the evaluation contained in this report, the Department of Commerce recommends that 115 megahertz (MHz) of spectrum currently used by Federal agencies be made available for wireless broadband in the next five years. Reallocating this 115 megahertz of spectrum is one step toward freeing spectrum for wireless broadband that will help trigger the creation of innovative new businesses, provide cost-effective connections in rural areas, increase productivity, improve public safety, and allow for the development of mobile telemedicine, telework, distance learning, and other new applications that will transform Americans' lives.

Barely three months ago, President Obama set out the Administration's bold vision for spurring innovation by expanding the amount of spectrum available for wireless broadband access. The National Telecommunications and Information Administration (NTIA) has already taken two steps to implement that vision. In collaboration with the Federal Communications Commission (FCC), NTIA is releasing a Ten-Year Plan and Timetable to make 500 megahertz of Federal and non-Federal spectrum available for wireless broadband use. The Plan and Timetable (which is being released in parallel with this Report) identifies an initial list of candidate spectrum bands, outlines steps to determine additional candidate bands, sets out a process to assess and evaluate their feasibility, and to identify what actions are necessary to make that spectrum available for wireless broadband use within a decade. The Plan and Timetable identifies over 2200 megahertz of Federal and non-Federal spectrum that might provide opportunities for wireless broadband use.

In addition to the Plan and Timetable, at the request of the Office of Management and Budget, the National Economic Council and the Office of Science and Technology Policy, NTIA conducted the Fast Track Evaluation that is the subject of this Report. The purpose of this Fast Track Evaluation is to jump-start the effort to make 500 megahertz of spectrum available for wireless broadband use. Over the last several months, NTIA, working with other Federal agencies, has investigated four candidate bands of spectrum that could conceivably be made available for broadband use within five years, with the goal of making a recommendation about these bands by October 1, 2010.

The four candidate bands considered by NTIA in the Fast Track Evaluation are: (1) 1675-1710 MHz, (2) 3500-3650 MHz, (3) 4200-4220 MHz and 4380-4400 MHz, and (4) 1755-1780 MHz. The first three of these bands were selected based on NTIA's assessment of factors such as the number and types of assignments in the bands, as well as the geographic extent of operations within the bands. Based on those factors, these bands appeared to lend themselves to rapid decision-making and the possibility that wireless broadband systems could be accommodated within five years. NTIA selected the 1755-1780 MHz band for the Fast Track Evaluation because of the particular interest the wireless industry has in this band and because the National Broadband Plan recommended that this band be studied for possible pairing with the 2155-2180 MHz band. The selection of the candidate bands and the recommendations in this

Report take into account input received from the Policy and Plans Steering Group, a group of senior, policy-level Federal officials advising the NTIA Administrator on spectrum policy.

This Report recommends that various portions of the candidate bands totaling 115 megahertz be made available for geographic sharing with fixed and/or mobile wireless broadband use within five years. Specifically, NTIA recommends that 15 megahertz of the 1675-1710 MHz (specifically 1695-1710 MHz) spectrum could be made available for wireless broadband use within five years, contingent upon timely allocation of funds to redesign the Geostationary Operational Environmental Satellite-R satellite and other costs the National Oceanic and Atmospheric Administration (NOAA) and other Federal agencies will incur in connection with sharing this spectrum.

NTIA also recommends reallocating 100 megahertz of the 3500-3650 MHz band (3550-3650 MHz) for wireless broadband use within five years, also contingent upon timely allocation of funds to support agency costs incurred in connection with sharing of this spectrum. As discussed more fully in this Report, there will be geographic limitations on the availability of these bands in order to make them available within the five years and to ensure that there is no loss of critical existing and planned Federal government capabilities.

In addition, NTIA recommends that the 4200-4220 MHz and 4380-4400 MHz bands be the subject of further review to confirm whether radio altimeters operate in these portions of the 4200-4400 MHz bands, and if so, are they impacted and to what extent. NTIA recognizes that due to the need for international regulatory action by the International Telecommunication Union and the International Civil Aviation Organization, these 40 megahertz of spectrum cannot be made available for broadband use in the United States before 2016. However, actions need to be taken now to start international processes to consider reallocating this spectrum for wireless broadband.

NTIA is currently unable to make a recommendation concerning the 1755-1780 MHz band because there was not sufficient time to complete the analysis of the band and to develop agreed-upon relocation transition plans by the October 1, 2010 deadline for this Report. The number of Federal users in the band, the diversity of Federal uses, and the need to find replacement spectrum for operations that would have to be relocated from the band if it were to be made available for wireless broadband precluded completion of the analysis by October 1, 2010. Because this band is harmonized internationally for mobile operations, wireless equipment already exists, and the band provides signal characteristics advantageous to mobile operations, it continues to be a priority for analysis, pursuant to the Ten-Year Plan and Timetable.

Making the spectrum available on an expedited basis requires that the incumbent agencies immediately commence detailed planning to share the spectrum with wireless broadband providers. The goal of the Fast Track Evaluation to make the spectrum available within five years cannot be met unless funds are allocated to the affected agencies for planning, cost estimation, and procurement preparation and sufficiently prior to the receipt of auction proceeds. The characteristics of the Federal systems in each of the candidate bands are described in detail in this Report. The 1675-1710 MHz band is currently allocated on a co-primary basis for Federal and non-Federal use for the meteorological aids service and the meteorological-satellite service (space-to-Earth). Specifically, this band is used for downlinks from geostationary and polar-orbiting weather satellites that are administered by NOAA. A number of Federal, state, and tribal government first-responder agencies, in support of their missions, directly access weather and other data provided by these satellites. The band is also used by thousands of non-Federal users, including public safety units, radio and television broadcast stations and universities. Furthermore, the NOAA satellites support an international network of weather and other environmental information. Foreign polar satellites also transmit signals to the United States in this band under international agreements. Also, NOAA operates radiosondes (weather balloons) in this band, along with a number of other Federal agencies.

The 3500-3650 MHz band is used by Department of Defense radar systems with installations on land, on ships and on aircraft. In general, the predominant use in the band by mobile radars is on ships and aircraft. Most of the aircraft and fixed, land-based systems are operated at military training areas and test ranges, recognizing that tactical necessities ultimately determine operational requirements. Functions performed by these systems include search for near-surface and high altitude airborne objects, sea surveillance, tracking of airborne objects, air traffic control, formation flight, and multi-purpose test range instrumentation.

The 4200-4400 MHz band is internationally reserved for radio altimeters. These devices are installed on government and civil aircraft. The altimeters operate continually during flight, wherever the aircraft may travel, to determine the altitude of the aircraft for visual display to the pilot and for use by an aircraft's Automatic Flight Control System. Because of the precision and accuracy of radio altimeters at altitudes of 1000 feet or less, they are used as a height controlling sensor in many aircraft automatic approach and landing systems and are essential for flight safety. Altimeters also support other aspects of low level flight outside of landing approaches, such as firefighting search and rescue operations, and military training. In many aircraft the radio altimeter is directly connected to the Ground Proximity Warning System which is designed to warn the pilot if the aircraft is flying too low or descending too quickly. Unmanned air vehicles, tactical weapons (missiles), and drone targets also employ radio altimeters.

Nationally, the 1755-1780 MHz sub-band of the 1755-1850 MHz band is allocated on an exclusive basis to the Federal Government for fixed and mobile services. The majority of operations within the 1755-1780 MHz band also operate in the 1755-1850 MHz band. Many of these operations have recently consolidated their operations in the 1755-1850 MHz band, having yielded the 1710-1755 MHz band to the wireless industry between 2007 and 2014 for the Advanced Wireless Service. The 1755-1780 MHz band supports a variety of Federal functions: (1) conventional fixed microwave communications systems; (2) military tactical radio relay systems; (3) air combat training systems; (4) precision guided munitions; (5) high-resolution video data links, and other law enforcement video surveillance applications; (6) tracking, telemetry, and command for Federal Government space systems; (7) data links for short-range unmanned aerial vehicles; (8) land mobile robotic video functions (e.g., explosive ordnance and hazardous material investigations and disposals); and (9) control links for various power, land, water, and electric power management systems. The radio systems supporting these functions are deployed across the United States.

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Abbreviations and Acronyms

ACTS	Air Combat Training System
ADCS	Advanced Data Collection System
AMD	Aviation Management Directorate
APM	Advanced Propagation Model
ARGOS	Advanced Research and Global Observation Satellite
ATC	Air Traffic Control
AVHRR	Advanced Very High Resolution Radiometer
AWS	Advanced Wireless Service
AWS-3	Advanced Wireless Service-3
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
CDA	Command and Data Acquisition
CDAS	Climate Data Assimilation System
CSEA	Commercial Spectrum Enhancement Act
CTS	Combat Training System
DCP	Data Collection Platform
DCPR	Data Collection Platform Report
DCS	Data Collection System
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DRGS	Direct Readout Ground Stations
DWTS	Digital Wideband Transmission System
EDDN	Emergency Data Distribution Network
EMWIN	Emergency Managers Weather Information Network
EOD	Explosive Ordnance Disposal
EROS	Earth Resources Observation and Science
EUMETSAT	European Organization for the Exploitation of Meteorological-Satellites
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FCDAS	Fairbanks Command and Data Acquisition Station
FDD	Frequency Division Duplex
FDR	Frequency Dependent Rejection
FS	Forest Service
GOES	Geostationary Operational Environmental Satellite
GOES-N	Geostationary Operational Environmental Satellite-N Series
GOES-R	Geostationary Operational Environmental Satellite-R Series
GRB	GOES-Rebroadcast
GSFC	Goddard Space Flight Center
GVAR	GOES Variable

HRIT	High Rate Information Transmission
HRPT	High Resolution Picture Transmission
I/N	Interference to Noise Ratio
I_T	Interference Threshold
ICAO	International Civil Aviation Organization
ISR	Intelligence Surveillance and Reconnaissance
ITM	Irregular Terrain Model
ITU-R	International Telecommunication Union-Radiocommunication Sector
JPSS	Joint Polar Satellite System
LAC	Local Area Coverage
LRIT	Low Rate Information Transmission
LTE	Long Term Evolution
MDL	Multi-use Data Link
MetAids	Meteorological Aids
MetSat	Meteorological-Satellite
MHz	Megahertz
MSE/HCLOS	Mobile Subscriber Equipment / High Capacity Line of Sight
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NEC	National Economic Council
NESDIS	National Environmental Satellite, Data, and Information Service
NIFC	National Interagency Fire Center
NOAA	National Oceanic and Atmospheric Administration
NSOF	NOAA Satellite Operations Facility
NTIA	National Telecommunications and Information Administration
NWS	National Weather Service
OFR	Off Frequency Rejection
OTR	On Tune Rejection
PCS	Personal Communications Service
PDR	Process Data Relay
PGM	Precision Guided Munitions
POES	Polar-Orbiting Environmental Satellites
RAWS	Remote Automated Weather Station
RCS	Radar Cross Section
RPA	Remotely Piloted Aircraft
RR	Radio Regulations
SEM	Space Environment Monitor
SIDS	Small Island Developing States
SKE	Station Keeping Equipment
SSGS	Spacecraft Support Ground System
SXI	Solar X-ray Imager
SWPC	Space Weather Prediction Center
TCTS	Tactical Combat Training System
TDD	Time Division Duplex
TLM	Telemetry

TVA	Tennessee Valley Authority
UAV	Unmanned Aerial Vehicles
US&P	United States and Possessions
USMC	United States Marine Corps
USACE	United States Army Corps of Engineers
USAF	U.S. Air Force
USDA	U. S. Department of Agriculture
USGS	U.S. Geological Survey
WCDAS	Wallops Command and Data Acquisition Station
WiMAX	Worldwide Interoperability for Microwave Access
Win-T	War fighter Information Network
WMO	World Meteorological Organization
WRC	World Radiocommunication Conference

1. Introduction

Background

The National Telecommunications and Information Administration (NTIA) is the executive branch agency principally responsible for developing and articulating domestic and (in coordination with the Secretary of State) international telecommunications policy.[1] Accordingly, NTIA conducts studies and makes recommendations regarding telecommunications policies and presents Executive Branch views on telecommunications matters to the Congress, the Federal Communications Commission (FCC), and the public. NTIA is also responsible for managing the Federal Government use of the radio frequency spectrum.

The FCC is an independent agency that was established by the Communications Act of 1934 and is responsible for managing spectrum use by non-Federal entities, including private entities, and state and local governments. Among other things, Section 1 of the Communications Act requires that spectrum management decisions promote new technologies and services, efficient use of the spectrum, national defense, interference protection among licensed stations, public safety, and international harmonization of spectrum use.[2] The FCC makes decisions in a transparent and open process in accordance with laws such as the Administrative Procedures Act and Paperwork Reduction Act. To this end, the FCC seeks comment on proposed rule changes and direct input from potential users of the spectrum prior to adopting any rule changes.

In support of its responsibilities, the NTIA has undertaken numerous spectrum-related studies to assess spectrum utilization, the feasibility of reallocating Federal Government spectrum or relocating Federal Government systems, the feasibility of sharing spectrum between Federal and non-Federal users, to identify existing or potential compatibility problems between systems, to provide recommendations for resolving any compatibility conflicts, to recommend changes to promote efficient and effective use of the radio spectrum, and to improve spectrum management procedures. For example, in 1992, NTIA identified the 1710-1755 megahertz (MHz) band for possible reallocation and in collaboration with the affected Federal agencies completed reallocation viability studies in advance of its reallocation in 2004 to accommodate the Advanced Wireless Service (AWS).

Over the past decade, there has been tremendous worldwide growth in wireless communication systems (e.g., cellular radiotelephone service, personal communications service (PCS), third generation, or other advanced wireless services) and unlicensed access methods

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[1] The Secretary of State is responsible for formulation, coordination, and oversight of foreign policy related to international communications and information policy. *See* 22 U.S.C. § 2707(b).

[2] *See* 47 U.S.C. §§ 151, 301, 302, and 303.

such as Wireless Fidelity.[3] Wireless capabilities have also become more critical for public safety, government operations, national defense and security, aviation and other Federal and local government missions, with growing spectrum requirements. Thus, spectrum requirements must be addressed considering a balanced national approach that includes a long-term strategic perspective.

Third- and fourth-generation advanced wireless systems provide terrestrial and satellite-based broadband and multi-media capabilities, and represent a path for expanding the broadband capabilities and coverage areas. Identifying spectrum that could be made available for fixed and/or mobile wireless broadband is vital as the United States plans its spectrum use and as industry plans to meet the marketplace requirements of the future. The early identification of spectrum is critical to the timely introduction of new broadband services due to the time required to complete the reallocation process, which could include developing service rules or sharing methods, conducting auctions, relocating incumbent users to comparable spectrum as necessary, and the redesign of incumbent systems to accommodate new operations.

America's future competitiveness and global technology leadership depends, in part, upon the availability of spectrum to meet this demand. In order to ensure that this global leadership continues and that the Administration's goal of universal broadband is met, additional spectrum is needed for fixed and mobile wireless broadband systems. Broadband access, including the fastest growing segment – wireless broadband – is critical to enhance America's economic competitiveness, spur job creation, improve access to information, and improve the quality of American life. In addition, advanced wireless capabilities have become essential in supporting Federal agency missions crucial to the nation and in enabling non-Federal public safety operations that safeguard lives and property. As changing government missions increase demands for mobility and agility, and both the private sector and Federal uses continue to expand and to emphasize increased data rates, and mobile or unmetered fixed access, spectrum's role as a critical component intensifies. As a result, spectrum requirements for fixed and mobile wireless communications, including advanced wireless services and wireless broadband, are expected to grow at a rapid rate.

President Obama issued a Presidential Memorandum on June 28, 2010, directing the Department of Commerce, working with the FCC, to identify and make available 500 megahertz of spectrum over the next ten years for expanded wireless broadband use.[4] This spectrum will support both fixed and mobile wireless broadband applications and will be made available from spectrum now used for other Federal and non-Federal services. Some of the spectrum will be

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[3] Connecting America: The National Broadband Plan, Federal Communications Commission, March 16, 2010, at 87, *available at* http://www.broadband.gov/plan/#read-the-plan.

[4] Memorandum for the Heads of Executive Departments and Agencies, Unleashing the Wireless Broadband Revolution, (Presidential Memorandum), released June 28, 2010, 75 Fed. Reg. 38387 (July 1, 2010), available at http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution.

available for licensing by the FCC for exclusive use by wireless providers and some will be made available for shared access between Federal and non-Federal licensed users, between licensed and unlicensed users and among only unlicensed users. The FCC is working closely with NTIA to identify additional spectrum that could be considered for wireless broadband deployment.[5] To support the President's goals for broadband access outlined in the Presidential Memorandum, NTIA has undertaken two initiatives.

First, NTIA has developed a Ten-Year Plan and Timetable, with input from the members of the Policy and Plans Steering Group, to identify and make available 500 megahertz of Federal and non-Federal spectrum for fixed and mobile wireless broadband.[6] The plan identifies steps to determine candidate bands, to assess or evaluate their feasibility, and to identify what resulting actions are necessary to make available spectrum for broadband wireless services. The plan also describes the processes and timetable for executive branch actions in support of the Administration's goal. The plan will be executed over a ten-year period and culminate in the repurposing of Federal, non-Federal or shared spectrum for: (1) exclusive non-Federal use for FCC-licensed wireless broadband systems; (2) shared Federal/non-Federal use (licensed wireless broadband systems); (3) Federal and/or non-Federal use sharing with unlicensed broadband devices; and (4) exclusive use by unlicensed broadband devices. Implementation of the plan will require consideration of various factors such as technical and operational considerations of Federal systems and non-Federal broadband wireless systems as well as the costs to evaluate and implement sharing methods or relocate Federal systems, including identification of comparable spectrum bands if an incumbent system is to be relocated.[7] The Presidential Memorandum also states that "the plan and timetable must take into account the need to ensure no loss of critical existing and planned Federal, State, local, and tribal government capabilities, the international implications, and the need for enforcement mechanisms and authorities."

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[5] Within the Interdepartment Radio Advisory Committee, NTIA worked with the FCC to finalize the service rules for the Wireless Communications Service. *See*, WT Docket No. 07-293, FCC 10-82, Report and Order and Second Report and Order (Amendment of Part 27 of the Commission's Rules to Govern the Operation of Wireless Communications Services in the 2.3 GHz Band Establishment of Rules and Policies for the Digital Audio Radio Satellite Service in the 2310-2360 MHz Frequency Band), RM-8610, (released May 20, 2010).

[6] The Policy and Plans Steering Group, an advisory group of senior, political-level Federal officials advising the NTIA Administrator on spectrum policy and strategic plans, serves as a forum for issue resolution and harmonization as determined by the NTIA Administrator. The PPSG has advised the Assistant Secretary regarding the Fast Track bands as well as the Ten-Year Plan and Timetable. *See* Presidential Memorandum, Section 1(c).

[7] *National Defense Authorization Act for Fiscal Year 2000*, Public Law 106-65, 113 Stat. 512, 768 (1999) (provides for NTIA, in consultation with the FCC, to identify and make available to the Department of Defense for its primary use alternative band(s) of frequencies as a replacement for the band to be surrendered; and for the Secretary of Commerce, jointly with the Secretary of Defense, and the Chairman of the Joint Chiefs of Staff to certify to the Committee on Armed Services and the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Armed Services and the Committee on Commerce of the House of Representatives, that such alternative band(s) provide comparable technical characteristics to restore essential military capability that will be lost as a result of the surrendered band of frequencies.)

Second, NTIA and the Federal agencies performed this Fast Track Evaluation, requested separately by the Office of Management and Budget, the National Economic Council, and the Office of Science and Technology Policy, to evaluate four bands by October 1, 2010, to determine if any spectrum in these bands could be made available on a geographical sharing basis for wireless broadband use within five years. Thus, the Fast Track Evaluation has two bounds. The spectrum needs to be available within five years and a concrete decision needs to be made by October. If a determination could not be made by October 1, 2010 on a specific band, it would remain under consideration for the Ten-Year Plan.

For this Fast Track Evaluation and this report, NTIA identified the following candidate frequency bands: 1675-1710 MHz, 3500-3650 MHz, 4200-4220 MHz, 4380-4400 MHz, and 1755-1780 MHz.[8] NTIA selected the first four of these candidate bands based on factors such as the number of assignments within the band (noting that the number of assignments does not necessarily correlate one-to-one to the number of systems that operate per assignment), type of operations, function, and location that might make possible the reallocation of the spectrum to accommodate wireless broadband systems without relocating Federal operations. NTIA included the 1755-1780 MHz band as recommended by the National Broadband Plan due to strong industry interest and for its potential as a pair for the 2155-2180 MHz band.[9] This Fast Track Evaluation provides the analysis results for these candidate frequency bands and recommends the necessary actions that would be required to accommodate broadband wireless services on a shared basis.

Summary of Results

As supported by the results of this Fast Track Evaluation, NTIA recommends that the 1695-1710 MHz and 3550-3650 MHz bands can be made available for wireless broadband, with some geographic limitations on wireless broadband implementation (see Figures D-56, E-1, E-5, (3550-3650 MHz), and H-1, H-5, H-6, and H-7 (1695-1710 MHz)). Making these bands available for wireless broadband will require planning, and in some cases, changes to Federal operations and equipment redesign, as well as necessary FCC rulemaking. Therefore, making the spectrum available will require funding to be allocated for actual costs of additional technical studies, non-recurring mitigation costs, and new operational and recurring costs incurred as a result of spectrum reallocation.

Considering the information available, NTIA recommends with respect to the 4200-4220 MHz and 4380-4400 MHz bands, that the Federal Government begin working within domestic and international processes to consider the reallocation of this spectrum for wireless broadband. Due to the need to draw information from the commercial aviation industry and affected Federal

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[8] New sharing methods were not considered as part of the Fast Track Evaluation because validation testing could not be completed by the October 1, 2010 deadline.

[9] *See supra*, n. , at 87.

agencies as well as to achieve changes in international regulations, the government must begin now to set in motion those activities that will ultimately determine the feasibility of wireless broadband implementation in these bands.

NTIA could not reach, in the timeframe allowed for the Fast Track Evaluation, a conclusion as to whether the 1755-1780 MHz band could be made available for wireless broadband within five years. This band would require the relocation of significant Federal operations before it could be reallocated for wireless broadband use. This band is of commercial interest because it is harmonized internationally for mobile operations, wireless equipment already exists, and the band provides signal characteristics advantageous to mobile operations. However, Federal/military equipment for critical missions also exists and operates in this band, through North Atlantic Treaty Organization agreements as well as through other bilateral and multilateral agreements that harmonize military use of the band. Therefore, this band will be a priority for analysis, pursuant to the Ten-Year Plan and Timetable.

Having considered options to reallocate the entire 1675-1710 MHz band or to reallocate a portion, NTIA has concluded that the range 1695-1710 MHz offers opportunity for wireless broadband while minimizing overall disruption of operations upon which the domestic and international public safety and weather prediction communities depend. Emergency managers and the public currently rely on information which is broadcast from the National Oceanographic and Atmospheric Administration (NOAA) satellites in the 1690-1695 MHz band. This information includes severe weather warnings and forecasts via the Emergency Manager's Weather Information Network (EMWIN) and re-broadcast data from ground-based sensors, such as flood gauges. NOAA's satellite command and control communications also reside in the 1690-1695 MHz band. It is difficult to provide alternative communications to users without Internet access or who are in areas where a weather event has degraded or destroyed power or communications infrastructure. Without the data provided by these satellite transmissions, emergency managers and other users would have to receive broadcasts through another transmission means, such as commercial satellite broadcasts with an equivalent amount of reliability and availability present in current direct broadcast transmissions.

NOAA indicated EMWIN reaches thousands of Federal, state, local, and tribal government users responsible for issuing severe weather warnings and managing first-responder resources, and these users expect to receive NOAA services in near-real time with an availability of 99.99 percent. For example, EMWIN can activate a local tornado warning siren without human intervention within seconds of the satellite detecting a possible tornado. In the recent Christchurch, New Zealand, earthquake, a NOAA satellite received tsunami warning information from specialized ocean buoys and retransmitted this critical data to the Pacific Tsunami Warning Center less than two minutes after detection. EMWIN has proven its ability to operate during various natural disasters such as in the Gulf Coast region after hurricane landfall and in the area known as "Tornado Alley." If any portion of the spectrum below 1695 MHz is reallocated, an alternative transmission means would have to be implemented to prevent a loss of data to emergency personnel while maintaining the same availability and reliability requirements. Because of the anticipated user impacts, costs, and schedule needs, NTIA concluded not to recommend the spectrum below 1695 MHz for sharing as part of the fast track process. In the 1695-1710 MHz band, the FCC and NTIA will need to add a non-Federal allocation to the National Table of Frequency Allocations for the mobile service. The FCC will need to implement service rules based on license exclusion zones around Federal earth station sites as shown in Figures H-1 through H-7. The radii of these exclusions zones vary, depending on the specific site, between 72 and 121 kilometers. These distances are based on the specific wireless broadband characteristics used in this analysis (see Appendix B of this report) and, if the FCC proposes in the future to implement systems with different characteristics, NTIA will need to revise the analysis. For example, the distances were calculated based on the assumption that the band would be used for broadband handset transmission to the base station. If the FCC proposes to implement a Time Division Duplex (TDD) arrangement, the distances identified here would no longer apply.[10]

In order to make way for the reallocation based on the agreed sharing conditions, a number of steps must take place. First, NOAA must take immediate steps to redesign the future Geostationary Operational Environmental Satellite-R Series (GOES-R) satellite to move its planned EMWIN downlink. NOAA will also need to begin redesign of radiosonde technology to use the spectrum more efficiently to make room for satellite downlinks that are currently above 1695 MHz. In addition, NOAA will need to begin its planning process to provide a mechanism or mechanisms for distribution of some forms of data that will be received at the protected sites but may need to be available to the user community. Much of this data is currently broadcast or rebroadcast directly to the Federal and non-Federal user communities and the data would need to be accessed via other satellites, landline, or other methods to replace the direct satellite access.[11] Federal agencies that directly access the satellite data will need to begin planning their transition to other access means. These planning requirements and conversion of operations to alternative means will require resources to implement. Furthermore, NTIA and the FCC will need to prepare a proposal for the World Radiocommunication Conference (WRC) in 2012 to place on the next conference agenda (probably 2016) an agenda item to add a mobile service allocation to the 1695-1710 MHz band in the International Telecommunication Union Region 2.

Having considered options to reallocate the entire 3500-3650 MHz or to reallocate a portion, NTIA concluded that the range 3550-3650 MHz band offers the opportunity to implement wireless broadband over large portions of the United States. Staying above 3550 MHz greatly reduces the potential for interference from high power radars operating below 3500 MHz. The FCC and NTIA will need to add a non-Federal allocation to the National Table of Frequency Allocations for the fixed and mobile services and associated consequential changes in the 3550-3650 MHz band. As shown in Figures D-45 through D-55, the FCC would need to

[10] Under a TDD arrangement base stations and handsets could operate in the band using a time sharing scheme.

[11] Given that the satellite will continue to transmit their signals, receive-only earth station operators would need to convert to another access mechanism only if and when wireless broadband systems built-out in their area. Since high density metropolitan areas will be the first priority for wireless services, the operators of meteorological-satellite earth stations may find that they can continue to directly access the satellite data unimpeded for some time.

implement service rules based on license exclusion zones along the U.S. coastline to protect base stations from high power U.S. Navy radar systems. Furthermore, exclusion zones will be required around a limited number of fixed land sites and some training and test sites to protect other military operations, including aeronautical operations shown in Figures E-1 through E-5. These exclusions zones will vary, depending on the specific radar operation and site locations. The exclusion zone distances are based on the specific wireless broadband characteristics used in this analysis (see Appendix B of this report) and, if the FCC proposes in the future to implement systems with different characteristics, NTIA will need to revise the analysis.[12] This approach does not require the alteration of military operations. All costs to the Department of Defense (DOD) would stem from analyses that it must conduct in preparation for FCC implementation of any reallocation. At the same time, such a reallocation based on exclusion zones will limit future flexibility of DOD to implement new systems or to operate at new locations. Future operations will need to be limited to shipborne, land-based, and airborne systems with characteristics similar to those considered in this analysis and the same land sites and characteristics considered in this analysis.

In the case of the 4200-4220 and 4380-4400 MHz bands, concurrent with an initial assessment to determine whether there will not be impact on civil aviation and military use in the bands, the FCC and NTIA will need to prepare a proposal for the WRC 2012 to place on the next conference agenda (probably 2016) an agenda item to add fixed and mobile service allocations in these bands. During that process, the Federal Aviation Administration (FAA) as well as other Federal agencies will need to conduct a survey of the technical characteristics of civil and Federal radio altimeters used on their aircraft. The results of such a survey will determine whether technical rule changes and allocation changes can prevent radio altimeter operations from coming into these bands (assuming they do not already use them), or whether the operations already exist in these bands and changes may be feasible to the equipment in the field, without adversely impacting altimeter equipment accuracy, reliability or flight safety. Any actions to limit radio altimeter access to the band will need to be taken in coordination with the International Civil Aviation Organization (ICAO) and the International Telecommunication Union-Radiocommunication Sector (ITU-R). Any FCC and NTIA action to complete a domestic allocation change would be based on the outcome of international actions.

Military test and training communities have spectrum requirements to produce a realistic electromagnetic environment and provide useful and valid results. Therefore, analysis of spectrum use to make spectrum available for wireless broadband must ensure protection of these capabilities.

[12] For example, there were certain assumptions on the base station antenna gain that was used in developing the exclusion zones. If there are changes to the technical parameters or deployment data for the wireless broadband systems, NTIA in collaboration with the affected Federal agencies will need to first determine if it is feasible to implement the proposed changes and determine whether any changes to the sharing conditions, including, possibly reducing separation distances, are appropriate.

Altogether, these recommendations offer the potential for 115 megahertz of additional spectrum available for wireless broadband. While further steps, including FCC rulemakings, will need to be taken to make this a reality, this spectrum represents a significant down payment to meeting the President's direction to identify 500 megahertz available for wireless broadband use. The analyses that highlight these opportunities were based on a number of assumptions and do not represent worst case circumstances. Therefore, interference may occur from operations outside the parameters used in the analyses and wireless broadband users may need to accommodate instances of interference or use additional interference suppression techniques to safeguard the desired service quality.

2. Process of Band Identification for Fast Track Evaluation and the Selection of Potential Options

Introduction

This section describes the approach that NTIA took to select the candidate frequency bands for consideration under the Fast Track Evaluation and the reasoning behind searching for sharing opportunities as the potential options as opposed to relocation. NTIA limited its selection of bands to the 225 MHz to 4400 MHz frequency range because bands below 225 MHz do not offer sufficient contiguous usable bandwidth for wireless broadband and bands above 4400 MHz do not appear to offer immediate opportunities for mobile wireless broadband use. Having limited to the range of 225 MHz to 4400 MHz, NTIA reviewed Federal spectrum use records to determine bands that might satisfy the requirements of the Fast Track Evaluation to reach decisions by October 1, 2010, and to make spectrum available for wireless broadband within five years.

Because of the bounds established for the Fast Track Evaluation, candidate bands had to be considered where relocating systems and the associated development and implementation of relocation plans would not be required. Furthermore, proven forms of geographic or other sharing approaches would have to exist, since the October 1 deadline did not leave time to test and prove new sharing methods. The process requiring relocation of Federal systems or reallocation of spectrum for sharing based on new technologies is more complex and requires much longer time to conduct a thorough analysis, including testing/proving new sharing technologies, assessing operational impact, addressing feasibility to protect mission-critical systems from harmful interference, identification of comparable spectrum for systems that may need to be relocated, as well as implementation of any resulting relocations of systems out of their current operating spectrum.[13] If the outcome of the Fast Track Evaluation determines that sharing via geographically limited licensing is feasible, such sharing would make spectrum available for broadband wireless services within a five-year time frame.

NTIA selected the bands (1) 1675-1710 MHz, (2) 3500-3650 MHz, and (3) 4200-4220 MHz, 4380-4400 MHz for this Fast Track Evaluation based on its assessment of factors such as the number of frequency assignments within the band and the type of operations, functions, and locations of the systems operating in the band.[14] Based on those factors, the bands appeared to lend themselves to rapid decision-making and the possibility that wireless broadband systems could be accommodated without relocating Federal operations. NTIA also selected the 1755-

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[13] National Telecommunications and Information Administration, *An Assessment of the Viability of Accommodating Advanced Mobile Wireless (3G) Systems in the 1710-1770 MHz and 2110-2170 MHz Bands (*July 22, 2002), *available at* http://www.ntia.doc.gov/ntiahome/threeg/va7222002/3Gva072202web.htm.

[14] The number of frequency assignments does not necessarily correlate to the number of systems that operate per assignment.

1780 MHz band for evaluation because of the particular interest of the wireless industry and the recommendation in the National Broadband Plan to pair it with the 2155-2180 MHz band, referred to as Advanced Wireless Service-3 (AWS-3) by the FCC.

1675-1710 MHz

NTIA examined the possibility of making all or a portion of this spectrum available without moving meteorological-satellites or radiosondes from this band, since neither the removal of the satellites or radiosondes could be accomplished within the five year timeframe established to make spectrum available for wireless broadband. Recognizing that this band has an international allocation for meteorological-satellite downlinks for weather data and other countries support satellite downlinks in the band including to U.S. stations, any decision to relocate satellite transmissions would involve creating a WRC future agenda item for the 2016 conference with implementation some time later if the international community supports allocation changes. This would also involve identifying other bands for the satellite transmissions. Regardless of any such decision the existing meteorological-satellites utilizing this band would continue to operate for many years.

Though the satellites would continue to operate in the band, NTIA envisions the potential for wireless broadband operating outside of exclusion zones around the main authorized receive earth stations operated by NOAA and other Federal agencies at such distances as are determined to protect those operations from interference. The FCC could establish these exclusion zones in the wireless broadband licensing process. NTIA recognizes that other non-Federal users directly access meteorological-satellite data. These uses are not licensed or registered. Neither the FCC nor NTIA has records of most of these stations. Therefore, the FCC sought information regarding these users by issuing a public notice to determine the extent of use in the 1675-1710 MHz frequency band.[15]

NTIA also recognized that radiosondes operate in the 1675-1683 MHz portion of the band. They typically operate twice daily from 87 National Weather Service (NWS) launch-sites within the United States and its possessions (US&P), and from some U.S. military, commercial and private sector facilities. The flight time of a radiosonde transmitter is on the average of 2.5 hours. The amount of spectrum radiosondes utilize is driven primarily by a lack of frequency stability (transmitted signal drifts in frequency) and frequency re-use as opposed to transmission bandwidth requirements.

In summary, NTIA examined the possibility that Federal Government operations would not be moved from this spectrum to make spectrum available for wireless broadband. Instead, major receive sites would be protected via geographic exclusion zones regulated through licensed wireless service areas. Use of exclusion zones would not be practical for protection of

[15] *Office of Engineering and Technology Requests Information on Use of the 1675-1710 MHz*, ET Doc. No.10-123, Public Notice, DA 10-1035, released June 4, 2010.

radiosonde sites as the balloons travel over hundreds of miles and their signals require protection down to the horizon. Transportable or other unregistered sites could not be protected. Direct access via earth stations to satellite weather data would be lost only in areas where wireless broadband systems are implemented. For areas where the broadband system build-out occurs, other access methods to distribute the meteorological data would need to be created. Any alternative distribution method must recognize current reliability and availability requirements.

1755-1780 MHz

NTIA selected 1755-1780 MHz, which is part of the 1755-1850 MHz band, for evaluation, as recommended by the National Broadband Plan for its potential to be paired with the 2155-2180 MHz band.[16] This band is particularly attractive to industry since it is adjacent to the 1710-1755 MHz band that was reallocated for AWS mobile stations. Mobile handsets and base station receivers for this band already exist since 1755-1780 MHz is used in many parts of the world for cellular systems and has been identified by the ITU for use by International Mobile Telecommunications.[17]

The Federal use of 1755-1850 MHz has intensified since analyses were performed in 2001 as operations from the 1710-1755 MHz band have been consolidated in this band.[18] The DOD has continued to procure, launch, and operate, satellites using this spectrum that are likely to continue to operate through the year 2030. While the DOD has been given the authority to deploy satellite control links in the 2025-2110 MHz band, the use of that band for electronic news gathering operations on a primary basis, and the lack of required equivalent spectrum protection for Federal use as is in 1755-1850 MHz, has made it unattractive except as a backup to the 1755-1850 MHz band. The DOD has not implemented any ground stations capable of transmitting in the 2025-2110 MHz band. Some of the fixed systems use has moved out of the band with the relocation of associated systems that were relocated from 1710-1755 MHz. Surveillance equipment use has increased as all the systems below 1755 MHz were moved above 1755 MHz. Use for control of small Unmanned Aerial Vehicles (UAVs)/Remotely Piloted Aircraft (RPA) and precision guided munitions (PGMs) has also increased.

For reasons stated in the previous paragraph, the relocation of satellite control networks from this spectrum cannot be accomplished in the 5 year period. Exclusion zones around the satellite control sites may offer a possible solution for sharing the 1755-1850 MHz band on a

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[16] *See supra*, n. , at 87.

[17] International Telecommunication Union, Radio Regulations, Geneva, Volume I, Article 1, Section 5.384A and 5.388 (2008).

[18] NTIA Special Publication 01-46, *The Potential of Accommodating Third Generation Mobile Systems in the 1710-1850 MHz Band: Federal Operations, Relocation Costs, and Operational Impacts*, March 2001, *available at* http://www.ntia.doc.gov/ntiahome/threeg/33001/3g33001.pdf. The report concluded that sharing was not feasible between 3G wireless and the majority of systems that operate in the 1710-1850 MHz band.

geographic basis pending results of further study to determine feasibility, including viable enforcement mechanisms.

Airborne operations require other considerations, which may be more complex. DOD's unique use for aeronautical combat training, small RPAs, and precision guided munitions does not have clear near-term technology or spectrum avenues to transition to other bands. Locating new frequency bands for aeronautical systems is difficult due to the spectrum impact from high altitude transmissions and the requirement for high speed mobility applications. As shown in previous studies, exclusion zones around these operations would eliminate large portions of the United States.[19]

The Air Force and Navy are also currently developing and fielding the P5 Combat Training System (CTS)/Tactical Combat Training System (TCTS), hereinafter P5CTS in the 1755-1850 MHz band. Additionally, those PGMs impacted by the reallocation of the 1710-1755 MHz band are migrating into the 1755-1850 MHz band. Other bands may be available for telemetry (TLM) and command of short-range UAVs; however, further study will be required to identify viable bands.

Point-to-point microwave communication systems operating in the fixed service no longer need to be in this band. With adequate and timely up-front funding, all fixed point-to-point communication systems can be moved to higher bands as technology and spectrum currently exists. However, there are transportable microwave systems in the fixed service that also operate in this band that will need to be addressed. Such systems are required to be repositioned on test and training ranges on a rapid basis. This band is a primary resource supporting such requirements where mobility, range, and bandwidth are needed in supporting this type of connectivity. Further study will be required to identify viable bands.

Nationwide law enforcement surveillance operations are not compatible with wireless broadband systems because of the law enforcement system requirement to operate on a nationwide basis. Therefore, to accommodate broadband wireless systems, surveillance operations would need to be relocated or further possibly limited in spectrum without impacting their mission. Other spectrum options and equipment redevelopment will need to be investigated.

The DOD Mobile Subscriber Equipment (MSE) and the follow-on High Capacity Line-of-Sight (HCLOS) system (a component of Warfighter Information Network (WIN-T)), and Digital Wideband Transmission System (DWTS) will need continued access to the 1755-1850 MHz band as this band and 1350-1390 MHz are the only bands available within the system tuning range. Additionally, there will be continued need to use 1710-1850 MHz at the United

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[19] *See supra*, n. .

States Marine Corps (USMC) training areas at the Cherry Point, North Carolina and Yuma, Arizona.

In summary, decisions by October 1, 2010 regarding the potential availability of the 1755-1780 MHz band for wireless broadband deployment must focus on approaches that are based on wireless broadband operations geographically separated and/or systems modification to mitigate interference from the operations of satellite control, aeronautical combat training and precision guided weapons or by limiting operations in terms of frequency use. Decisions with respect to use of wireless systems in the context of surveillance operations will need to focus on relocation of surveillance systems that operate on a nationwide basis as geographic sharing is not possible. At this point, however, no technical transition path to another comparable frequency band has been identified or proven. NTIA did not have sufficient time to complete the analysis of the 1755-1780 MHz band by the October 1, 2010 deadline established for the Fast Track Evaluation to determine whether this spectrum could be made available for wireless broadband use within five years.

3500-3650 MHz

NTIA selected the 3500-3650 MHz band because Worldwide Interoperability for Microwave Access (WiMAX) equipment has been developed for the band. This band is allocated for the fixed service in portions of the world. NTIA conducted a review of its frequency assignment and spectrum certification databases and determined that existing Federal operations left much of the country sparsely occupied by spectrum activity. NTIA understood this band to be used primarily for high power shipborne radars. Radars have been designed to operate in the 3500-3650 MHz band due to specific propagation and atmospheric conditions unique to this frequency range.[20] The radars in this band represent significant investment on the part of DOD and many are incorporated into ship and aircraft design. The band is also used for communications with missile systems for data updates to the missile while in flight to its target. Redesign for other frequency ranges to make this spectrum available for wireless broadband may require new technology, and significant redesign of their associated platforms.

Radars are increasingly operating over larger bandwidths to improve resolution of images and targets because targets are getting more complex and harder to detect. Therefore, NTIA could only examine the potential for geographic sharing approaches for decision by October 1. Consideration of relocating these radars to other bands would require technology feasibility studies and comparable spectrum band identification would be required. Even if a comparable band could be found and the technology could be altered to achieve the same technical results, and comparable mission capabilities performance, relocation would still not be possible in five years. Therefore, NTIA focused its examination of this band on geographic sharing.

[20] In this region of the spectrum multipath propagation problems decrease which is critical for the detection of targets at low elevation angles.

NTIA also understood that ground-based and airborne high-power radars in the lower adjacent band must be considered as they may pose an interference threat to deployment of wireless broadband systems in the 3500-3650 MHz band.

In summary, NTIA examined geographically-limited licensing to protect a limited number of land sites. It also examined geographic separation distances required to protect shipboard systems, airborne systems, and coastal land sites. Potential interference from in-band and adjacent band radars might significantly limit how much of this spectrum is fully useable.

4200-4220 MHz and 4380-4400 MHz

NTIA examined the existing frequency assignment and spectrum certification databases as well as spectrum measurements in the 4200-4400 MHz band. The limited data available to NTIA indicated that the transmitter emissions for the radio altimeters used on commercial aircraft appear to be concentrated in a range of ± 25 MHz to ± 70 MHz around the center frequency of 4300 MHz.

The entire 4200-4400 MHz band is allocated internationally for the radio altimeters. The International Radio Regulations (RR), a treaty document ratified by Congress, allocates the band 4200-4400 MHz to the aeronautical radionavigation service. The RRs further reserve the use of this band exclusively for radio altimeters installed on aircraft and for associated transponders on the ground. Also, a 1990 ITU-R report concluded "the whole of the band 4200-4400 MHz currently allocated is required up to at least the year 2015."[21] The report also stated that new or alternative techniques might provide the same accuracy in a smaller bandwidth, and it may be possible (around 2015) to reduce the allocated bandwidth.[22]

NTIA envisioned that the upper and lower 20 megahertz of the 4200-4400 MHz band could be made available for wireless broadband systems. In the time available, the FAA could not confirm that all radio altimeters operated by U.S. (commercial and military) or foreign carriers did not operate below 4220 MHz or above 4380 MHz. Radio altimeters do not require FCC or NTIA authorization or equipment certification.[23] Neither RRs nor ICAO regulations require the radio altimeter signal to be in the center or the band, nor do they require the use of any bandwidth less than the entire 200 megahertz. They also do not prohibit the use of swept frequency techniques which could increase transmit bandwidth requirements. Furthermore, the

[21] International Telecommunication Union-Radiocommunication Sector Report M.1186, *Use of the Frequency Band 4200 to 4400 MHz by Radio Altimeters* (1990).

[22] *Id*.

[23] National Telecommunications and Information Administration, U.S. Department of Commerce, *Manual of Regulations and Procedures for Federal Radio Frequency Management*, (May 2010 Revision of the January 2008 Edition) (hereinafter NTIA Manual), at Chapter 7.

FAA could not confirm in the time available, that the altimeter transmitters and receivers do not cover the entire band.[24]

[24] NTIA frequency assignment data does include information on receivers.

3. Federal Systems Description and Characteristics

Introduction

This section provides a description of the Federal systems operating in the candidate frequency bands for the Fast Track Evaluation: 1675-1710 MHz, 1755-1850 MHz, 3500-3650 MHz, 4200-4220 MHz, and 4380-4400 MHz bands.

1675-1710 MHz Band

The 1675-1710 MHz frequency range is allocated to Meteorological-Satellite (space-to-Earth) (MetSat) and meteorological aids (MetAids) (radiosondes) services for shared use by Federal and non-Federal entities. The band is divided into the 1675-1700 MHz and 1700-1710 MHz bands in the National Table of Frequency Allocations.

Meteorological-Satellite Operations

NOAA operates both geostationary and polar-orbiting satellite transmitting systems in the 1675-1710 MHz band. NOAA, DOD, the National Aeronautics and Space Administration (NASA), the Department of Interior (DOI) and other Federal and non-Federal entities operate earth stations used to receive environmental research and weather data transmitted from the Geostationary Operational Environmental Satellite (GOES) and non-geostationary, Polar-Orbiting Environmental Satellites (POES). The data from these satellites is transmitted to four primary receiving earth stations operated by NOAA in the United States (Fairbanks, Alaska, Wallops Island, Virginia, Suitland, Maryland, and Greenbelt, Maryland) for data processing in the 1675-1710 MHz frequency range. The processed data from these primary receiving earth stations is uplinked back to the satellites using another band and then broadcast to Federal and non-Federal receiving earth stations using the 1684-1693 MHz portion of the band. The data are used daily in the protection of life and property and the generation of weather predictions and reports that are broadcast over television and radio stations throughout the country and by U.S. ships in coastal waters. Various Federal and non-Federal entities also receive data from the NOAA meteorological-satellites and process these data for their own emergency manager, weather and environmental related uses. The polar-orbiting satellites do not store the real-time high-resolution imagery and data so that the data related to any particular location is only available at the time that the satellites pass in view of that area.

Within the 1675-1710 MHz frequency range, satellites and earth stations operate in the meteorological-satellite service to distribute environmental related information. The communications facilitate collection of meteorological data associated with NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) geostationary and polar-orbiting weather satellites. NOAA's operational weather satellite systems in this frequency band are composed of two types of satellites: the GOES for rapid real time observations of hurricanes, severe weather, short-range warning and "now-casting" and weather forecast models, and the POES, for high resolution real time hazard observations and weather forecast models.

Both types of satellites are designed to provide complete global weather monitoring capabilities when combined with data from satellites operated by other administrations. Table 3-1 describes NOAA meteorological-satellite operations in the 1675-1710 MHz band. Figure 3-1 illustrates the functions of the major systems in the 1675-1710 MHz band.

Table 3-1. Overview of Links for NOAA Meteorological-Satellite Operations in the 1675-1710 MHz Band[25]

Center Frequency (MHz)	Emission Bandwidth (MHz)	Function	Receive Locations
NOAA GOES N-P Meteorological-Satellite Downlinks			
1676	5.200	Sensor Data Link (SD)	Wallops Island, Virginia Greenbelt, Maryland Omaha, Nebraska Fairbanks, Alaska
1681.478	0.400	Multi-Use Data Link (MDL)	Wallops Island, Virginia Greenbelt, Maryland Boulder, Colorado Omaha, Nebraska
1685.7	4.220	Processed Data Relay (PDR)/GOES Variable (GVAR) (Broadcast)	US&P/Worldwide
1691.0	0.586	Low Rate Information Transmission (LRIT) (Broadcast)	
1692.7	0.027	Emergency Managers Weather Information Network (EMWIN) (Broadcast)	
1694.0	0.016	Command Data Acquisition (CDA)Telemetry	Fairbanks, Alaska Wallops Island, Virginia Greenbelt, Maryland DRGS Sites
1694.5 1694.8	0.400 0.400	Data Collection Platform Report (DCPR)	
NOAA GOES-R Meteorological-Satellite Downlinks			
1690	12.000	GOES-Re-Broadcast Data (GRB)	Western Hemisphere Suitland, Maryland
1697.4	0.096 0.586	EMWIN/High Rate Information Transmission (HRIT)	US&P/Worldwide
1696.3	0.008 0.064	Command and Data Acquisition Telemetry Data	Wallops Island, Virginia Fairmont, West Virginia
1683.3-1683.6	0.400	Data Collection Platform Report (DCP REPORT)	Worldwide (Not including US&P)
NOAA POES Meteorological-Satellites 15-19 Downlinks			
1698	5.340	High Resolution Picture Transmission (HRPT)	US&P/Worldwide Fairbanks, Alaska Wallops Island, Virginia Suitland, Maryland Miami, Florida Monterey, California Honolulu, Hawaii
1702.5			
1707			

[25] For description/characteristics of each function, see Appendix A.

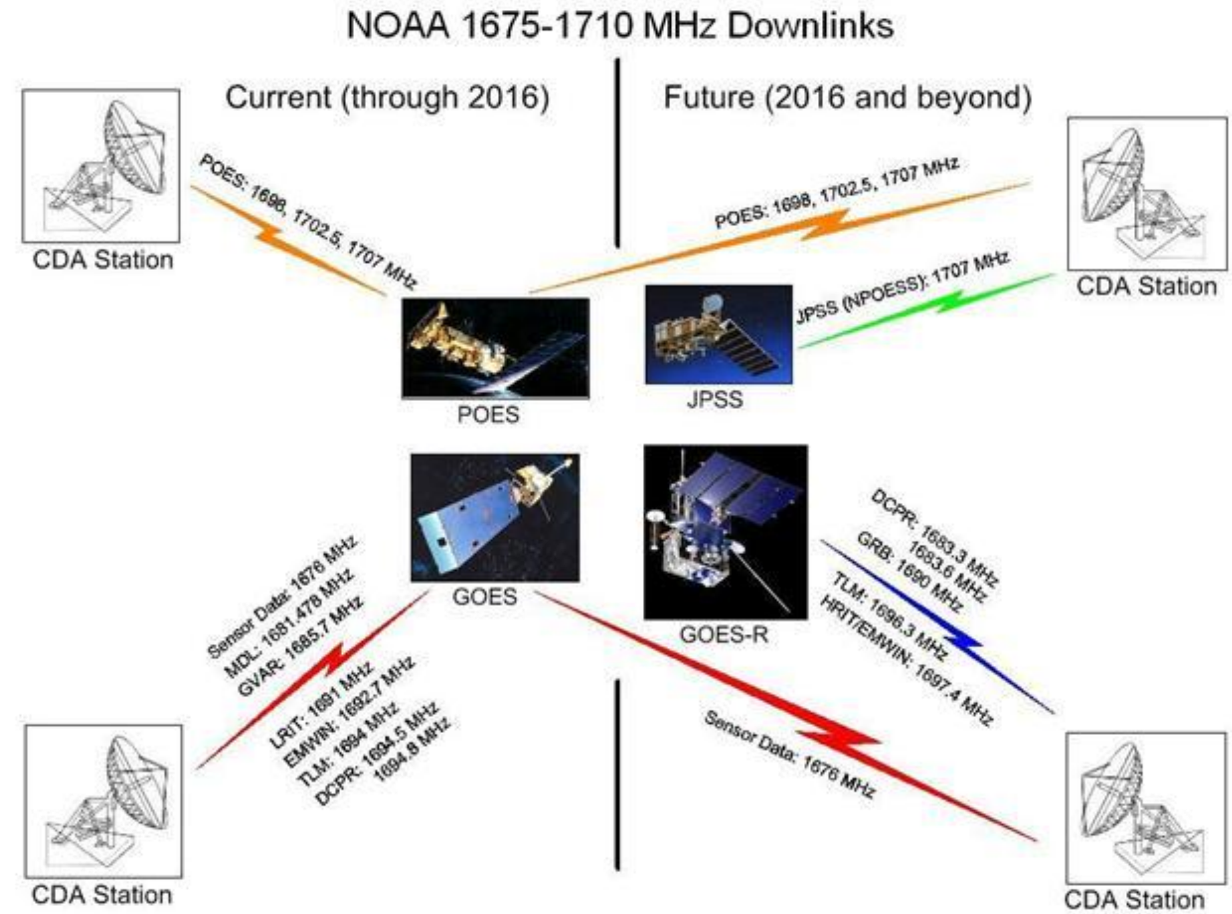


Figure 3-1. Meteorological-Satellite Federal Systems in the 1675-1710 MHz Band

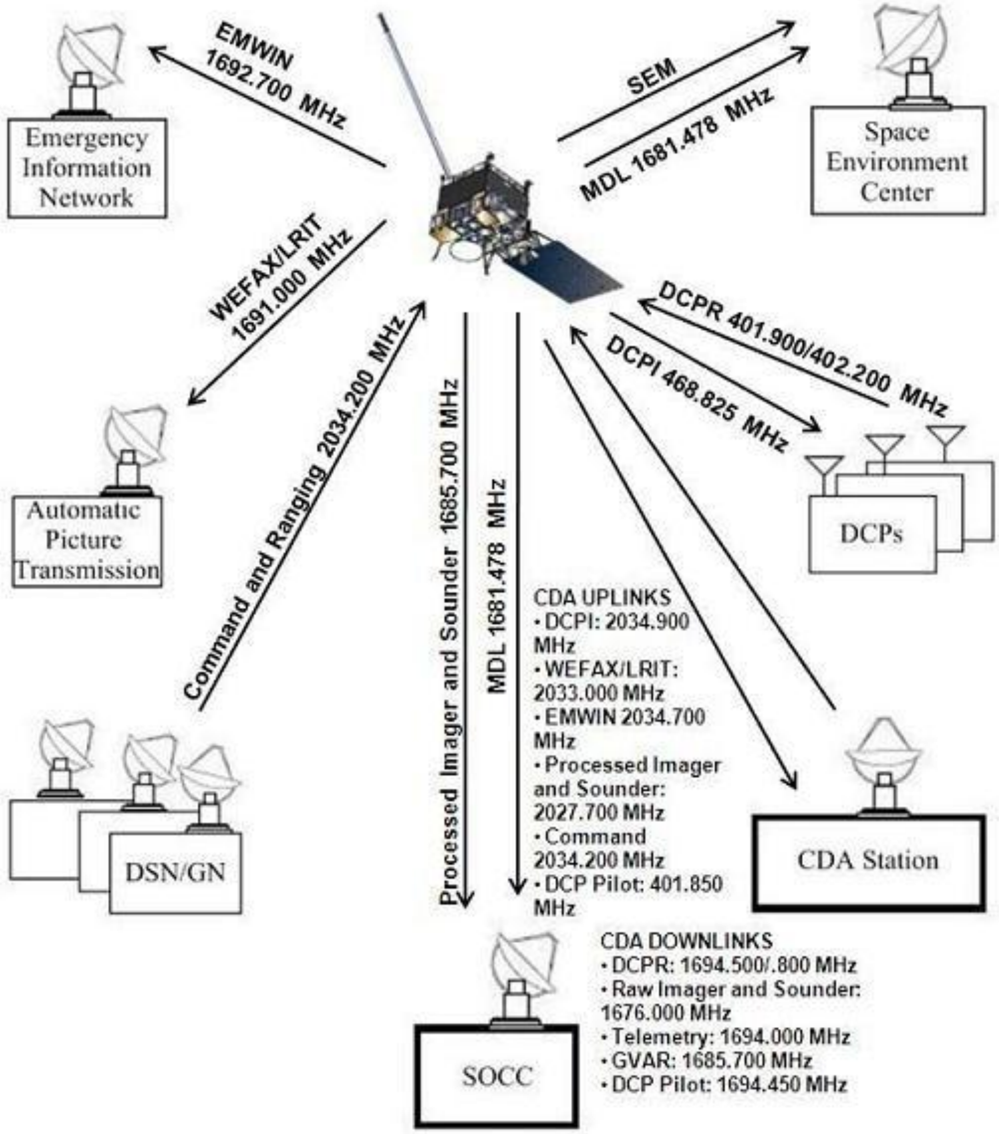
NOAA GOES Meteorological-Satellites

The goals of the GOES system program are to maintain continuous, reliable operational, environmental, and storm warning systems to protect life and property, monitor the Earth's surface and space environmental conditions, introduce improved atmospheric and oceanic observations and data dissemination capabilities and to develop and provide new and improved applications and products for a wide range of Federal agencies, state and local governments, and the public. To address these goals, NOAA's NWS and NESDIS established mission requirements that are the basis for the design of the GOES system and its capabilities. The GOES system thus functions to accomplish an environmental mission serving the needs of operational meteorological, space environmental, and research users.

The NOAA GOES-11/12/13/14/15 are current generation weather satellites designed to provide enhanced coverage of the entire western hemisphere. The spacecraft design enables the primary sensors to focus at Earth and collect important weather related data such as cloud cover, surface temperature, and water vapor distribution. The satellites can track atmospheric phenomena, ensuring real-time coverage of short-lived dynamic events, such as severe local storms, tropical hurricanes and cyclones, volcanic ash, and wildfires, four types of meteorological events that directly affect public safety, property. A data collection system on GOES receives in another band environmental data collected by a network of widely dispersed data collection platforms (DCPs) such as river and rain gauges, seismometers, tide gauges, buoys, ships, and automatic weather stations and relays that data to earth stations at 1694.5 and 1694.8 MHz. DCPs transmit sensor data in both the 402-403 MHz and 2025-2110 MHz bands. The GOES-13/14/15 satellites also provide emergency communications using the EMWIN.

The main mission of the GOES satellites is carried out by the primary payload instruments, referred to as the Imager and the Sounder. The Imager is a multichannel instrument that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere and produces visible and infrared images of Earth's surface, oceans, cloud cover, and severe storm developments, providing the familiar weather pictures seen on television newscasts every day. The Sounder provides data for vertical atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution. Sounder data are also used in computer models to produce short- to long-range weather forecasts. The Imager and Sounder feature flexible scans for small-scale area viewing in regions of the visible and infrared spectrum allowing meteorologists to improve short-term weather forecasts. GOES provides nearly continuous imaging and sounding data, which allow forecasters to better measure changes in atmospheric temperature and moisture distributions, increasing the accuracy of weather forecasts. GOES information is used for a host of applications related to weather, ocean, climate, cryosphere, land, and hazards. The Solar X-ray Imager (SXI) on GOES monitors the sun's X-rays for the early detection of coronal mass ejections and solar flares. This early warning is important because these solar flares affect not only the safety of humans in high-altitude missions, such as the International Space Station, but also military and commercial satellite communications, and commercial aviation flights. The GOES-13/14/15 satellites also carry space environment monitoring instruments which monitor X-rays, extreme ultraviolet and particle emissions including solar protons, alpha particles, and electrons. These space environment monitoring instruments also include a magnetometer which samples the Earth's magnetosphere.

The environmental remote sensing function is executed by the Imager and the Sounder equipment on the GOES. Space environment sensing is performed by the Space Environment Monitor (SEM) covering an extensive range of solar energies. The data collected is processed and distributed in the 1673.4-1678.6 MHz band to users in real-time to meet observation time and timeliness requirements, including revisit cycles (rapid scan operations). Remotely sensed data are obtained over a wide range of areas of the western hemisphere. Area coverage also includes the ability needed to relay signals and data from ground transmitters and platforms to central stations and end users. To accomplish the GOES system mission, space and ground segments are interconnected as shown in Figure 3-2.



Legend

CDA	Command Data Acquisition	GN	Ground Network
DCP	Data Collection Platform	GVAR	GOES Variable Data
DCPI	Data Collection Platform Interrogate	MDL	Multiuse Data Link
DCPR	Data Collection Platform Report	SEM	Space Environment Monitor
DSN	Deep Space Network	SOCC	Satellite Operations Control Center
EMWIN	Emergency Managers Weather Information Network	WEFAX/LRIT	Weather Facsimile/Low Rate Information Transmission

Figure 3-2. GOES System Space and Ground Segments

NOAA GOES-R Meteorological-Satellites

The GOES-R program is a key element of NOAA operations that is currently under development. As such, the GOES-R series of satellites will be comprised of improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, providing real-time continuous coverage of the western hemisphere. The GOES-R satellites are intended to improve support for the detection and observations of meteorological phenomena that directly affect the safety of the public and protection of property. As an integral part of its mission, the GOES-R satellite downlink signals will provide the emergency management community with access to a set of NWS warnings, watches, forecasts, and other products at no cost to the public.

NOAA GOES-13, -14, -15 Meteorological-Satellites

The GOES-13-15 constellation is the current generation weather satellites designed to provide the NOAA with enhanced coverage of the entire western hemisphere. The spacecraft design enables the primary sensors to focus on the Earth and collect important weather related data such as cloud cover, surface temperature, and water vapor distribution. The GOES-13 and 14 track atmospheric phenomena, ensuring real-time coverage of short-lived dynamic events, such as severe local storms and tropical hurricanes and cyclones, two types of meteorological events that directly affect public safety. A data collection system on GOES receives and relays environmental data collected by widely dispersed surface platforms such as river and rain gauges, seismometers, tide gauges, buoys, ships, and automatic weather stations. Platforms transmit sensor data to the satellite using the 402-403 MHz or the 2025-2110 MHz band at pre-assigned times and frequencies, upon interrogation by the satellite, or in an emergency alarm mode whenever a sensor receives information exceeding a preset level.

Department of Interior Meteorological-Satellite Operations

The DOI has five GOES Data Collection System (DCS), Direct Readout Ground Stations (DRGS) and the Tennessee Valley Authority (TVA) has one DRGS. These earth stations receive environmental data directly from the GOES satellites using the 1694.3-1695.0 MHz band. For DOI, the five data processing sites are located at: U. S. Geological Survey (USGS), Earth Resources Observations and Science (EROS), Emergency Data Distribution Networks (EDDN-1 and EDDN-2) facility in Sioux Falls, South Dakota; USGS Caribbean Water Science Center in Guaynabo, Puerto Rico; National Interagency Fire Center (NIFC), Boise, Idaho, operated and maintained by Bureau of Land Management (BLM), and the United States Bureau of Reclamation (BOR), Pacific Northwest Regional Office, Boise, Idaho. The TVA data processing site is located at their River Forecast Center in Knoxville, Tennessee. Any alternative distribution method must recognize current reliability and availability requirements.

Bureau of Land Management, National Interagency Fire Center

The DOI BLM NIFC and the entire wildland fire community are served by the Remote Automated Weather Station (RAWS) Network data received from GOES satellites using the 1694.3-1695.0 MHz band. The RAWS DCPs and their sensor suites are subject to National Fire Danger Rating Systems Standards, which specify mandatory levels of accuracy, resolution, scheduled maintenance, and physical installation. These standards were developed to support fire weather and fire danger analysis, and are not followed by other weather data platforms routinely used by NOAA. The RAWS Network provides meteorological data for use in the calculation and forecast for daily fire danger and these stations report environmental conditions throughout the year. The RAWS Network data supports long-term, regionally-based fire management services, as well as short-term, incident response information about ongoing wildfires. All RAWS Network data is processed by a module within the Wildland Fire Management Information System which was developed for wildfire management purposes to ensure the collection of accurate and reliable environmental data for Interagency Fire programs. The data that is processed at NIFC is distributed to wildfire base camps and fire crews via other radio and telecommunication resources. The RAWS Network consists of DOI BLM; National Parks Service; Bureau of Indian Affairs; Fish and Wildlife Service; U.S. Forest Service; U.S. Army; U.S. Air Force and U.S. Marines as well as equivalent organizations and offices at the state and local government level. There are currently over 2300 stations located throughout the continental United States, Alaska, Hawaii, Guam, Puerto Rico, and the Virgin Islands that participate in the interagency RAWS Network. Any alternative distribution method must recognize current reliability and availability requirements.

U.S. Geological Survey Emergency Data Distribution Network

The USGS EDDN-1 and EDDN-2 are located in Sioux Falls, South Dakota. The EDDN Networks receive the GOES DCS data feeds from the GOES-East and the GOES-West satellites using the 1694.3-1695.0 MHz frequency band. This data is provided for the operational mission of the DOI USGS Water Resources Division which is Federally-mandated to maintain the National Water Information System Program to support the collection, processing, review, storage, and dissemination of hydrologic data. The data that is recorded via the GOES is essential to the implementation and successful completion of a broad range of interpretive studies addressing groundwater, surface-water, water-quality, and water-use issues such as: stream gauge information for flood warning; water record (stream gage height, discharge volume, water quality values); seismic observations and tsunami information. This program is critical to USGS partners in local, State, Tribal, and Federal agencies; non-Federal entities such as power companies and nature conservancy's, as well as the international community, including Canada and numerous Central and South American countries. End users of these data include hydrologists, seismologists, geologists, and biologists for analysis, research, predictions and warnings; and, the American public for various outdoor recreation activities. The network of stream gages extends from Barrow, Alaska to Hilo, Hawaii to Miami, Florida to Bar Harbor, ME and thousands of stations in between. USGS also operates the Caribbean Water Science Center in Guaynabo, Puerto Rico. Moreover, DOI, USGS EROS has signed a Memorandum of Agreement with NOAA to operate as a receive-only back-up site to the NOAA Wallops Island, Virginia earth station.

Bureau of Reclamation, Pacific Northwest Regional Hydromet/Agrimet Center

The DOI BOR, Pacific Northwest Regional Hydromet, and Agrimet Center collect environmental data at a central receiver site in Boise, Idaho. This data is processed and distributed using the 1694.3-1695.0 MHz band for their Hydromet and Agrimet networks. Any alternative distribution method must recognize current reliability and availability requirements. The Hydromet and Agrimet networks primary operational mission is to support the Pacific

Northwest Region for gathering hydrologic and weather data for managing floods, making irrigation water deliveries, determining Federal water rights priorities, meeting Federal endangered species requirements, and regional crop water use modeling to determine crop water use, numerous agricultural research, frost monitoring, and integrated pest and fertility management. DOI, BOR also shares this collected data with other BOR system users to operate dams such as Grand Coulee, and Glen Canyon, and as far south as Hoover, for hydropower and flood control and to provide timely water supply status for river and reservoir operations for water management.

U.S. Geological Survey Earth Resources Observation and Science Center

DOI USGS EROS Center manages the Land Remote Sensing Program and receives Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA POES in the 1696-1710 MHz band. USGS has received NOAA's AVHRR data since 1987 for environmental studies and operational programs supporting hazards assessments. The spatial and spectral characteristics of AVHRR data enabled the development of vegetation condition information appropriate for national assessments of fire danger supporting NIFC and drought monitoring with the National Drought Mitigation Center and agricultural assessments. Both of these activities directly address the DOI strategic goal of resource protection. USGS also works in partnership with the U.S. Agency for International Development to utilize AVHRR data collected over foreign nations, often via direct reception capabilities of those nations, to support food security and famine early relief programs in countries at risk. In addition, the products and services derived from exploitation of the AVHRR reception capability are used to support the U.S. climate change research programs.

The activity of Land Remote Sensing Program products derived from AVHRR provides historical and current perspectives on the trends and impacts of climate change. This information is invaluable to the land management mission of the DOI and is supported through the science of the USGS. The operational nature of this science data stream stems from the requirement to provide timely information to the land remote-sensing community. As such, the AVHRR data are core to the development of phenological characterization and monitoring and measurement of vegetation productivity.

Partners and collaborators in other Federal agencies, academia, and the private sector are dependent on the reliability, timeliness, and capability of the USGS, EROS AVHRR land remote-sensing program products and services to conduct scientific and operational programs. The timeliness of these products and services is critical to USGS EROS mission and is based on the capability to directly receive AVHRR data transmissions using the 1675-1710 MHz band. Loss of this capability or delays in adaption of an alternative frequency band would severely impact DOI and scientific managers and users of this very valuable data. Damage, due to loss of the data, would occur to the land remote-sensing program community and the mission of the DOI USGS to support disaster and hazard mitigation, emergency response, and major scientific activities. Any alternative distribution method must recognize current reliability and availability requirements.

Tennessee Valley Authority River Forecast Center

The TVA River Forecast Center receive earth station, located in Knoxville, Tennessee, gathers environmental data directly from the satellites in the 1694.3-1695.0 MHz band that is used to forecast the operation and management of their controlled dams on the Tennessee River for hydropower and nuclear plants, flood control and water supply. Any alternative distribution method must recognize current reliability and availability requirements.

Department of Defense Meteorological-Satellite Operations

The DOD receives data from the NOAA GOES and POES satellites to provide specialized worldwide meteorological, space environmental and oceanographic analysis, and prediction services in support of military forces and joint operations. Military environmental services directly support all phases of military operations from strategic planning to tactical combat operations. While the Army and USMC each have weather operations capabilities, the Navy and Air Force are the primary sources of military weather products and services. The DOD exploits national and international geostationary and polar-orbiting satellite data and information in support of worldwide military operations through a variety of fixed, mobile, and shipborne meteorological-satellite receivers.

The DOD accesses the NOAA GOES and POES data at various meteorological and oceanographic centers used in execution of global and regional numerical weather and ocean prediction models that extend from space to the bottom of the ocean. In addition, meteorological satellite data is exploited at the operational and tactical levels decision-quality support to all forms of military aviation, fleet and maritime operations, including meteorological-satellite operations on 22 U.S. Navy aircraft carriers and large deck amphibious assault ships, space and missile operations, and ground maneuver operations to ensure wartime readiness and in execution of combat operations.

GOES satellite links are also critical to the United States Army Corps of Engineers (USACE) to provide vital public services to millions of the United States residents for operational capability that safeguards human lives, and trillions of dollars in land and private property assets. While generally associated with dams, canals and floor protection in the United States, USACE is involved in a wide range of public works vital public engineering services in peace and war to strengthen our nation’s security, energize the economy, and reduce risks from disaster. Additionally, many agencies (including NOAA) rely on the data gathered from the 7400 (approx.) USACE uplink DCPs. USACE critical missions include, but are not limited to: planning, designing, building, and operating locks and dams; design and construction of flood protection systems through various federal mandates; environmental regulation and ecosystems restoration. Any alternative distribution method must recognize current reliability and availability requirements.

National Aeronautics and Space Administration Meteorological-Satellite Operations

The NASA Goddard Space Flight Center

The NASA Goddard Space Flight Center (GSFC) operates two GOES receiving stations on the GSFC property. The first station is located at a different location than the NOAA back-up station that is also at GSFC. This station receives GOES Variable (GVAR) signals transmitted from GOES satellites. The second GSFC GOES receive-only station is located at the base of GSFC building number 25, and is also used to receive only the GVAR signal. This Earth station is used for instructional training of high-school and university students and allows them to develop their own software algorithms to display the GVAR data. This training has also been expanded to place similar inexpensive GOES antennas and receivers at many universities to familiarize students with the concept of remote sensing. The GVAR stations at Goddard are distinct from the operational back-up facility which supports NOAA satellite operations. For operations, the Goddard back-up facility falls within the exclusion zone for the NOAA Satellite Operations Facility in Suitland, Maryland.

The NASA Marshall Space Flight Center

The NASA Marshall Space Flight Center (MSFC) earth station receives GOES GVAR signals. The two GVAR receiving antennas are situated on the roof of the National Space Science and Technology Center. These systems provide real-time access to GOES data for algorithm refinement, product development, and decision support for the Short-term Prediction Research and Transition project at MSFC. In addition, satellite data from these antennas are provided to The Weather Channel for use in tropical cyclone imagery analysis. Any alternative distribution method must recognize current reliability and availability requirements.

Department of Commerce, Meteorological-Satellite Earth Stations

Wallops Island, Virginia, Command and Data Acquisition Station

The Wallops Command and Data Acquisition Station (WCDAS) is responsible for ensuring scheduled data flow from NOAA satellites to designated user subsystems. It manages, operates, and maintains the station. The WCDAS executes spacecraft commands and schedules. It acquires, maintains, and distributes a continuous flow of meteorological-satellite data. The WCDAS develops and maintains records of performance, analyzes system failures, and establishes failure trends and implements corrective action. The WCDAS prepares and issues reports on system anomalies, maintains station configuration control, and ensures operator and maintenance crew proficiency. The WCDAS plans, designs, and implements system modifications testing and evaluating new systems and techniques. The WCDAS assists in developing emergency procedures to safeguard spacecraft health and safety; and executes emergency plans independently in the event of a communications outage with the NESDIS Satellite Operations Control Center.

Fairbanks, Alaska, Command and Data Acquisition Station

The Fairbanks, Alaska Command and Data Acquisition Station (FCDAS) contains antennas, electronic equipment, and support facilities that were designed to provide radio communications with satellites observing the Earth. Due to its location at high latitude, the FCDAS is well-positioned such that line-of-sight conditions exist with polar-orbiting satellites as they converge on the northern polar region. Sensors aboard environmental satellites collect massive amounts of data on atmospheric, oceanic, geophysical, and terrestrial conditions throughout the world. The data are stored on-board the satellite for a portion of an orbit, and then transmitted down to the FCDAS when the satellites pass over the station. FCDAS also serves as a backup for GOES satellite control and production.

Greenbelt, Maryland, (Goddard Space Flight Center) Wallops Back-Up Station

The Wallops Back-Up site is located at GSFC in Greenbelt, Maryland. This site provides a single string of continuous GOES satellite systems backup in the event of an anomaly at the WCDAS. A backup team from the WCDAS station is prepared to travel to the backup site in any emergency. The backup site crew can coordinate all satellite operations, prepare spacecraft schedules, generate spacecraft commands, process satellite data, and disseminate products.

Suitland, Maryland, NOAA Satellite Operations Facility

The NOAA Satellite Operations Facility (NSOF) provides environmental data used to develop weather and climate products, as well as other information products used daily by industry and citizens across the Nation. This facility plays an important role in processing satellite data to support meteorology, oceanography, solid Earth geophysics, and solar-terrestrial sciences. Data and products from NSOF are used for life and property warning and forecasts by the NWS and other Federal and non-Federal worldwide entities.

Boulder, Colorado, Space Weather Prediction Center

The Space Weather Prediction Center (SWPC) continually monitors and forecasts Earth's space environment; provides accurate, reliable, and useful solar-terrestrial information; conducts and leads research and development programs to understand the environment and to improve services; advises policy makers and planners; plays a leadership role in the space weather community; and fosters a space weather services industry. SWPC is the Nation's official source of space weather alerts and warnings.

SWPC is one of nine National Centers for Environmental Prediction and provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances. The SWPC is jointly operated by NOAA and the Air Force and is the national and world warning center for disturbances that can affect people and equipment working in the space environment.

GOES Meteorological Transmission Downlink Signals

Emergency Managers Weather Information Network

The EMWIN is designed to provide vital data to the emergency management community. NOAA's NWS provides a broadcast of live weather and civil emergency information to computers across the United States, the Caribbean, South America, and over most of the Pacific and Atlantic Oceans. EMWIN has been made available by the NWS in cooperation with NESDIS since 1995. Since then, the emergency management community has had immediate access to information pertaining to threats from powerful weather events and the threat of serious civil disasters. Emergency information using the center frequency of 1692.7 MHz is broadcast via the GOES East and West satellites extending the coverage to the eastern edge of Australia. This allows the EMWIN signal to cover roughly two thirds of the Earth's surface and it is used both nationally and internationally. In addition, the use of both satellites allows signal redundancy for most of the continental United States.[26]

The EMWIN system's primary use is warning the public and to send warning products and other processed data (graphics and imagery) that are needed by emergency managers. Its flexibility and low cost allows it to be used by even small emergency management units anywhere in the United States. The warning and weather information is transmitted in digital form and is customized to meet the needs of emergency managers. The data can be received, demodulated, and displayed on a computer by emergency managers, homeland defense, and the general public. The system is typically used to trigger sirens, pager networks, cell phones and other means of communications used by emergency managers. Many users of these systems are mobile in nature (i.e., Red Cross response trucks) and are able to easily make use of the EMWIN signal. The receiver dishes do not require stowing during high winds, allowing the system to be used during severe weather events, including hurricanes. In addition to very fast priority driven weather warning products, EMWIN also provides rapid dissemination of forecasts, graphics, and imagery to aid in increasing lead times for emergency managers. EMWIN not only provides this data but does so in a manner that can continue to work during and following disaster conditions when non-satellite forms of communication are unavailable. Furthermore, the inherent redundancy of the GOES satellite constellation means that EMWIN can continue to operate after the failure of one of the satellites. These attributes allow decision-making to be more accurate and responsive for warning and possibly evacuating communities, saving lives and property.

The NWS gathers live weather and emergency information from NWS forecast offices via the Telecommunications Gateway, which is a message switching center linked via redundant

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[26] The 1675-1710 MHz band frequencies make it a well-suited delivery system for mobile use due to the characteristics that it provides such as minimal rain-fade, small dish size, and availability of affordable receiver components. The EMWIN delivers weather warnings in all weather conditions. An inverter and automobile battery are all that are necessary to power the EMWIN system for hours so as to receive the GOES satellite data stream. However, NOAA did not compare other transmission frequencies.

fiber optic channels to other major network nodes that provide the EMWIN system and other sources across the globe with weather watches, warnings, and forecasts. The EMWIN system then broadcasts selected and prioritized data. Satellite downlink enables users to access the EMWIN data stream of real-time weather information anywhere within the "footprint" of the GOES satellites. Today, the service is transmitted from the GOES satellites using 1692.7 MHz. As a result of the auction of 1695-1710 MHz, NOAA will relocate the GOES-R era EMWIN downlink transmission planned for 1697.4 MHz to a frequency below 1695 MHz.

Low Rate Information Transmission

The Low Rate Information Transmission (LRIT) is a global signal supported by European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Japan Meteorological Agency, and NOAA. The U.S. LRIT service provides visible and infrared sectors as well as full disk imagery to support users from 70ºN-70ºS from 15º W to 170º E. The service also includes selected meteorological and oceanographic charts, in-situ observations, and emergency warning information. The NOAA LRIT system provides digital data, via a broadcast service, through its geostationary satellites. NOAA operates an LRIT broadcast on its GOES-East and GOES-West satellites. On the GOES-R series of satellites, the broadcast is expected to merge with the EMWIN service.

The LRIT broadcast's primary use is to support forecasting and warning in the Caribbean, Central & South America and, in the Pacific Basin, to the principle population centers and outer islands of the Small Island Developing States (SIDS) member countries. Included in the LRIT service are the GOES DCS observations and the NWS's EMWIN broadcasts. In addition to the Pacific Tsunami Warning Center, SIDS member countries are able to receive the same tsunami warnings from the DCS and EMWIN systems via the LRIT. In Central & South America, including the Caribbean region, LRIT is the primary source of satellite data necessary for heavy precipitation monitoring, flood warnings, and general forecasting.

GOES-Rebroadcast

The GOES-Rebroadcast (GRB) will begin on GOES-R, replacing the current GVAR (GOES Variable) system and provide users with a variety of enhanced data and products at a much higher data rate (approximately 31 Mbps as compared to the current data rate of 2.11 Mbps), including a stream of GOES-R processed instrument data, other NWS products and related information to the weather research and Earth sciences community.

High Rate Information Transmission

The High Rate Information Transmission (HRIT) is simply an enhanced replacement of the current LRIT on the current GOES satellites and will be initiated on GOES-R. The data rate will be 400 kbps instead of the current 256 kbps.

Multi-use Data Link

The Multi-use Data Link (MDL) data is received at the Spacecraft Operations Control Center as an independent data link. These data is processed by the Spacecraft Support Ground System and used for diagnosing dynamic interactions among the instruments and the spacecraft. The MDL is also received by the SWPC in Boulder, Colorado, for ingest of SXI and SEM data.

Sensor Data

The Sensor Data downlink in the 1673.4-1678.6 MHz band contains the raw Imager and Sounder data collected by sensors onboard the spacecraft. Without these data, there would be no images to track hurricanes or monitor the rapid development of severe storms that may develop into destructive tornados. This data stream is the basis of many of the satellite products produced continuously and available for public use and by private companies.

Data Collection Platform Report

The Data Collection Platform Report (DCPR) transponder is a bent-pipe, i.e., receiving signals from the DCPs in 401.7-402.4 MHz, then translating these data to a new frequency band, amplifying, and transmitting in the space-to-Earth direction using the 1694.5 and 1694.8 MHz frequencies, but with no other processing.

Command and Data Acquisition Telemetry

The GOES telemetry and command subsystem provides the functional interface between the spacecraft and ground command and control. It is composed of both radio frequency and digital (baseband) segments. Telemetry parameters describing the status, configuration, and health of the spacecraft payload and subsystems are downlinked to the Command and Data Acquisition (CDA) station and sent to the Satellite Operations Control Center. Commands are received onboard the spacecraft for controlling mission operations and managing expendable resources.

GOES Data Collection System Service

The GOES DCS is a system for collecting and transmitting environmental data from remote platforms via government-owned and -operated geostationary satellites. Users are composed of many Federal, State, and local agencies required to monitor environmental and Earth resources for a variety of purposes. These purposes include; meteorological analysis and forecasting, river forecast, tsunami warnings, flood warnings, reservoir management, dam monitoring, water quality monitoring, fire potential, navigation, irrigation control, seismic monitoring, and other highly variable phenomena where observations must be collected frequently and in real-time. The GOES DCS provides near real-time access to data, and is used by state, local, and emergency managers in the United States and in nearby nations to provide early warning of natural and man-made disasters that threaten life and property. Monitoring sites to warn of floods, fires, tsunamis, hurricanes, tornadoes, and dam breaches are only a few of the applications of the system. The GOES DCS is considered critical infrastructure for NOAA

(NWS and National Ocean Service), USGS, DOD, the NIFC, the Bureau of Land Management, the National Forest Service, and international hydro-meteorological agencies in Canada, Mexico, Central America, South America, the Pacific, the Caribbean, all around the western hemisphere.

The GOES DCS system represents user requirements defined by the deployment of more than 30,000 DCPs from Africa westward to eastern Australia. The primary users of the GOES DCS are:[27]

- Department of Interior – Bureau of Land Management
- Department of Interior – U.S. Geological Survey
- Department of Interior – Bureau of Reclamation
- Department of Interior – National Park Service
- Department of Interior – Bureau of Indian Affairs
- Department of Interior – U.S. Fish and Wildlife Service
- International Boundary and Water Commission
- Department of Commerce – National Weather Service
- Department of Commerce – National Ocean Service
- Department of Defense – U.S. Army Corps of Engineers
- Department of Defense – U.S. Air Force
- Department of Defense – U.S. Navy
- U.S. Environmental Protection Agency
- Tennessee Valley Authority
- U.S. Department of Agriculture – Agricultural Research Service
- U.S. Department of Agriculture – Forest Service

The GOES DCS is vital to the operation of several Federal agencies to reduce loss of life and minimize property damage. The USGS uses the GOES DCS to transmit stream gauge information for flood warning and obtain seismic observations to warn the aviation industry of volcanic eruptions. These observations are critical for air traffic safety. In addition, USGS obtains data on earthquake location (size and strength). The Pacific Tsunami Warning Center uses this data to provide tsunami information to countries and islands of the Pacific basin and the Caribbean.

NOAA operates a ground system at the WCDAS in Virginia, and is in the process of completing the installation of a backup site in Suitland, Maryland. Data from these sites are distributed to users in various ways, including rebroadcast to a satellite and distribution through the Internet. Many users who access DCS data for emergency warnings and emergency management also receive data directly from the NOAA satellites, due to the critical nature of their responsibilities.

[27] Over 500 organizations, government agencies, and representatives of government agencies operate the GOES DCS.

High Resolution Picture Transmission

The HRPT data from the NOAA polar-orbiting satellites provides regional data for the assessment of agricultural and forestry vegetation, the determination of sea and land surface temperatures, identification of snow and clouds and aerosol detection. The HRPT data stream also includes non-imagery data from other instruments on board the spacecraft. Due to the higher resolution of the HRPT imagery (1.1 km in the visible band), and the additional spectral channels of information, direct readout users often prefer this data stream, particularly where quantitative analysis is involved. The HRPT data is critical for volcanic ash detection. The National Hurricane Center uses this service and part of the regional operations when a tropical storm is approaching landfall. The NOAA oceanographic centers rely on the HRPT for critical data about the ocean surface to support marine research. The HRPT data provides sea surface temperatures vital to the fishing industry and seafarers. The HRPT data is vital for monitoring ice flows or ice sheets. Mariners require this data to navigate ice sheet on the Great Lakes and other navigable water ways. This real-time data are critical to forecasts and warnings, whether on land or at sea. HRPT data also contains satellite telemetry data and is used to track the satellite when it is within sight of the Climate Data Assimilation System (CDAS) sites at Wallops Island, Virginia and Fairbanks, Alaska. Once the CDAS acquires the satellite, the mission science data stored on-board the satellites are downlinked in the 1675-1710 MHz band. The data downloaded includes low resolution imagery data known as Global Area Coverage (GAC) and high resolution imagery data known as Local Area Coverage (LAC). The satellite is in view of the earth station for approximately 12 to 15 minutes. The GAC and LAC imagery data is recorded at the CDAS and then re-distributed to NOAA's NSOF post contact. HRPT data is also sent real-time during the satellite contact to NSOF since it contains the telemetry data and is required for monitoring and commanding the satellite. The high resolution HRPT data is available to direct readout users in real time via their own receive terminals. NOAA acquires HRPT data from the 5 protected sites.

Processed Data Relay GOES Variable

The GOES-Processed Data Relay (PDR) data transmission format, referred to as GVAR, is primarily used to transmit Imager and Sounder meteorological data. It also includes telemetry, calibration data, text messages, spacecraft navigation data, and auxiliary products.

Joint Polar Satellite System

NOAA will be responsible for management and procurement of the satellites and instruments associated with collecting data during the afternoon orbit, which is most critical to analysis of weather and climate. NOAA will contract with NASA to accomplish some of these tasks. The EUMETSAT (satellites) will be responsible for the mid-morning orbit while NOAA will continue to operate in the afternoon orbit. The DOD will be responsible for the morning orbit that is critical to national defense. NOAA will continue its successful partnership with the Air Force by managing the ground systems development and operations of the Air Force satellites. The restructured Joint Polar Satellite System (JPSS) will continue to address NOAA's requirements to provide global environmental data used in numerical weather prediction models for forecasts, as well as provide space weather observations, search and rescue detection capabilities, and direct read-out and data collection products and services to Federal and non-Federal users. Data and imagery obtained from the JPSS will increase timeliness, accuracy, and cost-effectiveness of public warnings and forecasts of climate and weather events, thus reducing the potential loss of human life and property and advancing the national economy.

Meteorological Aids (Radiosondes) Operations

In the 1675-1683 MHz portion of the 1675-1710 MHz band, NOAA, DOD, the Department of Energy (DOE), and NASA operate radiosonde systems in the MetAids service. A radiosonde is an expendable electronic sensing and data transmission probe that is carried aloft by a balloon to collect atmospheric data (temperature, pressure, and humidity). A radiosonde may also be carried by a rocket as a rocketsonde, or dropped by parachute (usually from an aircraft) as a dropsonde. The data from the radiosonde is used in forecasting models to predict weather events such as tornados, and tropical cyclones. The radiosonde systems perform measurements of the atmospheric pressure, temperature, and relative humidity. The wind speed and direction is determined using radio frequency direction finding measuring the azimuth and elevation angle of the radiosonde with respect to the receiving antenna or for newer systems, using an on-board Global Positioning System receiver to transmit speed, course and position data. Radiosonde observations are conducted by the NOAA/NWS at 87 receive sites within the U.S. and its possessions and are an integral part of the Global Observing System.[28] The radiosonde transmitters are launched at least twice per day, each transmitting for approximately 2.5 hours per flight.[29] Additional launches are made at individual sites based on local weather conditions. Additional launches account for an approximate 10 percent increase in the typical number of operational launches. Areas that are prone to hurricanes and severe weather events operate with additional launches as necessary.[30]

Federal Meteorological Earth Stations

The Federal agencies operate 34 significant sites that receive the real-time meteorological data directly from the NOAA satellites in the 1675-1710 MHz band. Along with these significant sites, there are other Federal agencies using NOAA satellite data including DOD, Department of Homeland Security (DHS), DOI, NASA, Department of Transportation /FAA, U.S. Department of Agriculture (USDA), and DOE. Four of these receive earth station sites are used for the command and control of the POES and GOES satellites (Fairbanks, Alaska, Wallops

[28] The Global Observing System (GOS) is a coordinated system of methods and facilities for making meteorological and other environmental observations on a global scale in support of all World Meteorological Organization (WMO) programs; the system is comprised of operationally reliable surface-based and space-based subsystems. The GOS comprises observing facilities on land, at sea, in the air and in outer space. These facilities are owned and operated by the Member countries of WMO each of which undertakes to meet certain responsibilities in the agreed global scheme so that all countries can benefit from the consolidated efforts.

[29] Radiosonde launches take place twice per day, at approximately 00:00 and 12:00 Coordinated Universal Time.

[30] In addition to the radiosonde receive sites in the United States there are 41 launch sites in Canada, 13 in Mexico and one in Puerto Rico.

Island, Virginia, Suitland, Maryland, and Greenbelt, Maryland). The GOES-R system will have its primary location and function at Wallops Island, Virginia with backup capabilities at a new facility in Fairmont, West Virginia. For GOES satellites, the raw-data is pre-processed with calibrated and navigated information from these primary receiving earth stations and is transmitted back to the satellites for re-broadcast to Federal and non-Federal receiving earth stations in real-time (seconds) using the center frequencies 1685.7, 1691,0, and 1692.7 MHz. The POES satellites broadcast local high resolution meteorological, HRPT, data real-time to any receiving station within view as the satellite passes overhead. The POES satellites do not store high resolution data, so data that is not captured as the satellite passes out-of-view at any particular receive station is lost. The HRPT data is used in the generation of near real-time weather forecasts and hazard warnings that are then broadcast over television and radio stations throughout the country. Table 3-2 provides the 34 critical sites that Federal agencies operate in the upper 20 megahertz (1690-1710 MHz) and Table 3-3 shows 18 critical sites operating in the upper 15 megahertz portion (1695-1710 MHz) of the 1675-1710 MHz band.

Table 3-2. Significant Locations for Federal Meteorological-Satellite Earth Stations (1690-1710 MHz Band Segment)

Agency	Center Frequency (MHz)	Earth Station Location	Latitude	Longitude	Function (Receiver)
DOC	1694/1698, 1702.5, 1707/1694.5, 1694.8	Wallops Island, Virginia	375645N	0752745W	Primary CDA[1]/HRPT[2]/DRGS[3]
DOC	1694/1698, 1702.5, 1707	Fairbanks, Alaska	644814N	1475234W	Primary CDA/HRPT
DOC	1681.478/1691/1692.7/1685.7/ 1694.5, 1694.8	Suitland, Maryland	384900N	0765100W	MDL[4]/LRIT[5]/EMWIN[6] GVAR[7]/DRGS
DOC	1698, 1702.5, 1707/1685.7	Miami, Florida	254700N	0801900W	HRPT/ GVAR
DOC	1681.478/1685.7	Boulder, Colorado	400054N	1051614W	MDL/GVAR
DOC	1696.3	Fairmont, West Virginia	392606N	0800833W	Future GOES-R Backup-Site (CDA)
DOI	1694.5, 1694.8	Sioux Falls, South Dakota	434406N	0963732W	DRGS
DOI	1694.5, 1694.8	Sioux Falls, South Dakota	434418N	0963737W	DRGS
DOI	1698, 1702.5, 1707	Sioux Falls, South Dakota	434409N	0963733W	HRPT
DOI	1694.5, 1694.8	Boise, Idaho	463653N	1161508W	DRGS
DOI	1694.5, 1694.8	Boise, Idaho	433438N	1161240W	DRGS
TVA	1694.5, 1694.8	Knoxville, Tennessee	355758N	0835513W	DRGS
DOC	1698, 1707	Bay St. Louis, Mississippi	302204N	0892717W	DRGS
DOI	1694.5, 1694.8	Guaynabo, Puerto Rico	182544N	0660685W	DRGS
NASA/DOC	1694/1685.7	Goddard Space Flight Center, Greenbelt, Maryland	390500N	0764600W	GOES Backup CDA/NASA (GVAR)
NASA	1685.7	Marshall Space Flight Center, Huntsville, Alabama	343842N	0864029W	NASA (GVAR)
DOD	1694.5, 1694.8	Cincinnati, Ohio	390608N	0843036W	DRGS
DOD	1694.5, 1694.8	Rock Island, Illinois	413104N	0903346W	DRGS
DOD	1694.5, 1694.8	St. Louis, Missouri	383526N	0901225W	DRGS
DOD	1694.5, 1694.8	Vicksburg, Mississippi	322123N	0905129W	DRGS
DOD	1694.5, 1694.8	Sacramento, California	383459N	1212939W	DRGS

Table 3-2. Significant Locations for Federal Meteorological-Satellite Earth Stations (1690-1710 MHz Band Segment) (continued)

Agency	Center Frequency (MHz)	Earth Station Location	Latitude	Longitude	Function (Receiver)
DOD	1694.5, 1694.8	Omaha, Nebraska	411532N	0955520W	DCPR/DRGS
DOD	1685.7/1694.5, 1694.8	Offutt Air Force Base, Nebraska	411532N	0955400W	GVAR/DRGS
DOD	1698, 1702.5, 1707	Anderson Air Force Base, Guam	133452N	1445528E	HRPT/International Polar
DOD	1698, 1702.5, 1707/1685.7	Elmendorf Air Force Base, Alaska	610859N	1492812W	HRPT/International Polar/GVAR
DOD//DOC	1698, 1702.5, 1707/1685.7	Hickam, Air Force Base/Kaena Point, /Pearl Harbor, Hawaii	211907N	1575521W	HRPT/GVAR/International Polar/ International geostationary data
DOD	1698, 1702.5, 1707/1685.7	Norfolk, Virginia	365359N	0761759W	HRPT/International Polar/GVAR
DOD/DOC	1698, 1702.5, 1707/1685.7	Monterey, California	363600N	1215400W	HRPT/International Polar/GVAR
DOD	1698, 1702.5, 1707/1685.7	Stennis Space Center, Mississippi	302359N	0893559W	HRPT/International Polar/GVAR
DOD	1698, 1702.5, 1707/1691	Twenty-Nine Palms, California*	341746N	1160944W	HRPT/LRIT
DOD	1698, 1702.5, 1707/1691	Camp Pendleton, California*	331804N	1172119W	HRPT/LRIT
DOD	1698, 1702.5, 1707/1691	Yuma, Arizona*	323924N	1143622W	HRPT/LRIT
DOD	1698, 1702.5, 1707/1691	Bogue-Field, North Carolina*	344126N	0770147W	HRPT/LRIT
DOD	1698,1702.5,1707/1691	Beaufort, South Carolina*	322850N	0804309W	HRPT/LRIT

Table Footnotes:

[1] Command and Data Acquisition

[2] High Resolution Picture Transmission

[3] Direct Readout Ground Stations

[4] Multi-Use Data Link

[5] Low Rate Information Transmission

[6] Emergency Managers Weather Information Network

[7] GOES Variable

[*] Transportable

Table 3-3. Significant Locations for Federal Meteorological-Satellite Earth Stations (1695-1710 MHz Band Segment)

Agency	Center Frequency (MHz)	Earth Station Location	Latitude	Longitude	Function (Receiver)
DOC	1698, 1702.5, 1707	Wallops Island, Virginia	375645N	0752745W	HRPT
DOC	1698, 1702.5, 1707	Fairbanks, Alaska	644814N	1475234W	HRPT
DOC	1698, 1702.5, 1707	Suitland, Maryland	384900N	0765100W	HRPT
DOC	1698, 1702.5, 1707	Miami, Florida	254700N	0801900W	HRPT
DOC/DOD	1698, 1702.5, 1707	Kaena Point/Hickam Air Force Base, Pearl Harbor, Hawaii	211907N	1575521W	HRPT
DOI	1698, 1702.5, 1707	Sioux Falls, South Dakota	433409N	0963733W	HRPT
DOD	1694.5, 1694.8	Cincinnati, Ohio	390608N	0843036W	DCPR[1]/DRGS
DOD	1694.5, 1694.8	Rock Island, Illinois	413104N	0903346W	DCPR/DRGS
DOD	1694.5, 1694.8	St. Louis, Missouri	383526N	0901225W	DCPR/DRGS
DOD	1694.5, 1694.8	Vicksburg, Mississippi	322123N	0905129W	DCPR/DRGS
DOD	1694.5, 1694.8	Omaha, Nebraska	411532N	0955520W	DCPR/DRGS
DOD	1694.5, 1694.8	Sacramento, California	383459N	1212939W	DCPR/DRGS
DOD	1698, 1702.5, 1707	Elmendorf Air Force Base, Alaska	610859N	1492812W	HRPT/International Polar
DOD	1698, 1702.5,1707	Anderson Air Force Base, Guam	133452N	1445528E	HRPT/International Polar
DOD	1698, 1702.5, 1707	Monterey, California	363600N	1215400W	HRPT/International Polar
DOD	1698, 1702.5, 1707	Stennis Space Center, Mississippi	302359N	0893559W	HRPT/International Polar
DOD	1698, 1702.5, 1707	Twenty-Nine Palms, California*	341746N	1160944W	HRPT
DOD	1698, 1702.5, 1707	Yuma, Arizona*	323924N	1143622W	HRPT

Table Footnotes:

[1] Data Collection Platform Report

* Transportable

Non-Federal Use of the 1675-1710 MHz Band

The 1675-1710 MHz band is allocated on a co-primary basis for Federal and non-Federal use for the meteorological aids service and the meteorological-satellite service (space-to-Earth) and is used for downlinks from weather satellites and radiosondes (weather balloons) administered by NOAA. NOAA provides these services for weather forecasting, storm tracking, flood and drought prediction, and similar activities.

The GOES downlink signals GVAR, LRIT and the EMWIN links are transmitted to Federal and non-Federal users. In the continental United States, EMWIN uses the GOES-East and GOES-West satellites to broadcast the EMWIN data stream. Within the satellite footprint, the EMWIN data stream can be received directly from the satellite for no cost, using a small receiving dish, an inexpensive receiver, down converter and a personal computer for data management and display by the general public. The NOAA indicates there are many non-Federal users who rely on this information from EMWIN provided by the NWS for impending weather conditions and civilian emergency situations (i.e., tornado warnings).

The POES downlink signals, HRPT, and the Advanced Research and Global Observation Satellite (ARGOS) Advanced Data Collection System (ADCS) are transmitted to Federal and non-Federal users as well.[31] In the United States, HRPT data are received at six NOAA Federal Sites (Fairbanks AK, Wallops Island, Virginia, Suitland MD, Miami FL, Monterey CA, and Kaena Point, Hawaii) where the data are used for fire and smoke analysis, sea surface temperature, oil spill analysis, volcanic ash monitoring and more. ARGOS ADCS data are received at the NOAA sites as well as 50 other sites worldwide. ARGOS is a unique worldwide location and data collection system dedicated to studying and protecting the environment. ARGOS provides worldwide tracking and monitoring from any mobile or fixed station fitted with an ARGOS transmitter. This includes the tracking of buoys and floats, birds, fish, marine and land animals, humanitarian programs (health and food distribution), water level and snow cover, adventurers and yacht racers, passenger and cargo ships and more. The data are used in near-real time from the ARGOS system.

There are many non-Federal users who rely on the HRPT data for use in everything from weather forecasts and warning processes to crops and vegetation analysis, snow cover flooding, and ocean analysis.

Comment Summary, ET Docket No. 10-123

Overview

The Commission recognized that NTIA has preliminarily identified the 1675-1710 MHz band for possible mobile broadband use. Accordingly, in a Public Notice issued June 4, 2010 (DA 10-1035), the Commission requested information on current non-Federal use of that band and the viability of the band for mobile broadband use.

Although the 1675-1710 MHz band is allocated to the meteorological aids (radiosondes) and meteorological-satellite (space-to-Earth) services and used by non-Federal entities, the Commission's database shows no active licensees in the spectrum, since users do not need to

[31] The ARGOS program is administered under a joint agreement between NOAA and the French space agency, Centre National d'Etudes Spatiales.

register or receive Commission authorization for their receive sites. Non-Federal entities such as universities, private sector weather forecasters and others employ receive-only stations for reception of meteorological-satellite service downlink transmissions. More than 225 comments were filed in response to the Public Notice including individuals, companies, domestic emergency management organizations, and international and foreign national meteorological organizations including Small Island Nations and smaller countries that rely solely on the LRIT and EMWIN data.[32]

Utility of the 1675-1710 MHz Band for Mobile Broadband

The Public Notice sought comment on the utility of the 1675-1710 MHz band for mobile broadband services, including any pairing, band plan, or other licensing approach that maximizes this utility. Various large and small wireless service providers responded to the Public Notice.[33] Generally, the wireless service providers urged the Commission not foreclose the possible reallocation of the 1755-1780 MHz band to pair with the 2155-2180 MHz band citing benefits to its reallocation including the fact that it is internationally allocated for mobile broadband services, allowing for economies of scale and scope in the development of both infrastructure and mobile devices. They do indicate, however, that the 1675-1710 MHz band could serve a viable alternative if the preferred 1755-1780 MHz band is ultimately unavailable.

While the 1675-1710 MHz band could be used to provide broadband services, the commenters cite several drawbacks (particularly in comparison to the 1710-1755 MHz band). They generally cite difficulties in deploying a paired band plan (particularly with the AWS-3 band at 2155-2180 MHz) that is not harmonized with international spectrum use. Indeed, several commenters focus on the prospect that carriers and manufacturers would have to begin development of U.S.-specific designs tailored to use the band that will not enjoy the benefits of international harmonization. They foresee resulting delays in the development of such equipment, increased deployment costs, and regulatory uncertainty impacting the provision of services. Specifically, they contend that existing base station infrastructure will require modification to utilize 1675-1710 MHz band-capable handsets – thereby increasing costs for companies that have already deployed antennas in the adjacent band and limiting the ability to foster rapid roll-out of services in the band.[34] However, some TDD proponents with experience in 3rd Generation Partnership Project long-term evolution (LTE) find the 1675-1710 MHz band a valuable frequency resource. They note that LTE is able to operate in unpaired spectrum using a range of radio frequency channel bandwidths up to 20 megahertz, making the 1675-1710 MHz band useable by TDD technologies. They recommend making the 1675-1710 MHz band available as an unpaired spectrum block, with technical rules that allow the licensee to use

[32] *See supra*, n. .

[33] Comments filed in response to Office of Engineering and Technology Requests Information on Use of the 1675-1710 MHz, ET Docket No. 10-123, Public Notice, DA 10-1035 (rel. June 4, 2010), available at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-10-1035A1.pdf.

[34] *Id*.

spectrum either in “paired” or “unpaired” configurations. They argue that this designation would give each licensee the flexibility to build its system based on consumer demand and the licensee’s business plan. Opponents of this recommendation argue that adopting it would cause harmful interference to the Frequency Division Duplex (FDD) operations in the adjacent AWS-1 band at 1710-1755 MHz.[35]

Current Use of the 1675-1710 MHz Band

A large number of domestic and international non-Federal users of the 1675-1710 MHz band oppose reallocation of the band because of concern about interference to their use of the band, which, they believe, is critical from both an economic and public safety perspective. These users include universities, State transportation agencies, water agencies, EMWIN station operators, GOES ground station operators, weather information companies, and professional and amateur weather broadcasters.

For example, the World Meteorological Organization (WMO) states that the data accessed from the services operating in the 1675-1710 MHz band play a critical role in saving lives. The WMO maintains that this data are obtained daily and used to determine road conditions, provide warning services for damaging or disruptive weather events, and ensuring that the engineering of reservoirs, levees, bridges, and other infrastructure systems are accurate and capable of protecting the public.[36]

Parties opposed to reallocating the 1675-1710 MHz band to mobile broadband also contend that they cannot confirm that, if the information currently available from the meteorological-satellite service were received at only a few receive sites and distributed via terrestrial services, this would be a functionally equivalent substitute for the direct reception of satellite and radiosonde services. Opponents conclude that the lack of reliability and of “real-time” capabilities of terrestrial distribution could significantly compromise public safety.

International Use of the 1675-1710 MHz Band

NOAA supports several international programs that use the 1675-1710 MHz band. These programs allow users in the western hemisphere to acquire data from foreign spacecraft to support their operations. NOAA, as the founding member of the Coordination Group for Meteorological Satellites, works with other non-Federal environmental satellite operators EUMETSAT, Japan Meteorological Agency, China Meteorological Administration, Russia’s Federal Service for Hydrometeorology and Environmental Monitoring, India Meteorological Department, Korean Meteorological Administration and the WMO to coordinate the frequencies and equator crossing times for all meteorological spacecraft. The most critical of these sites is

[35] *Id*.

[36] Comments of World Meteorological Organization (WMO), in response to FCC Public Notice ET-Docket No. 10-123, *Information on use of 1675-1710 MHz band* (filed June 28, 2010), Annex 1, at 1.

the geostationary antenna in Hawaii collecting Japanese MetSat data. The Japanese satellite provides critical up-stream weather information that greatly improves forecast models for the United States and local forecast for the NWS Pacific Region.

1755-1780 MHz Band

Nationally, the 1755-1780 MHz portion of the 1755-1850 MHz band is allocated on an exclusive basis to the Federal Government for fixed and mobile services. The majority of operations within the 1755-1780 MHz band also operate across the entire 1755-1850 MHz band. Footnote G42 to the National Table of Frequency Allocations provides for the co-equal accommodation of Federal space command, control, and range and range-rate systems for earth station transmission in the 1761-1842 MHz portion of the band.[37] The 1755-1780 MHz band supports many Federal functions: (1) conventional fixed microwave communications systems; (2) military tactical radio relay systems; (3) air combat training systems (ACTS); (4) PGM; (5) high-resolution video data links, and other law enforcement video surveillance applications; (6) telemetry, tracking, and commanding for Federal Government space systems to include Global Positioning System (GPS) Navigational Upload; (7) data links for short-range UAVs/RPAs; and (8) land mobile robotic video functions (e.g., explosive ordnance and hazardous material investigations and disposals). The radio systems supporting these functions are deployed across the United States. The major user of the 1755-1780 MHz band is the DOD and previous studies have provided descriptions of systems that operate in this band.[38] Figure 3-3 presents a pictorial representation of the functions of major Federal systems supported in the 1755-1780 MHz band. Each of the major categories of functions is discussed below.

[37] There are five discrete SGLS frequencies in the 1755-1780 MHz band.

[38] *See supra*, n. .

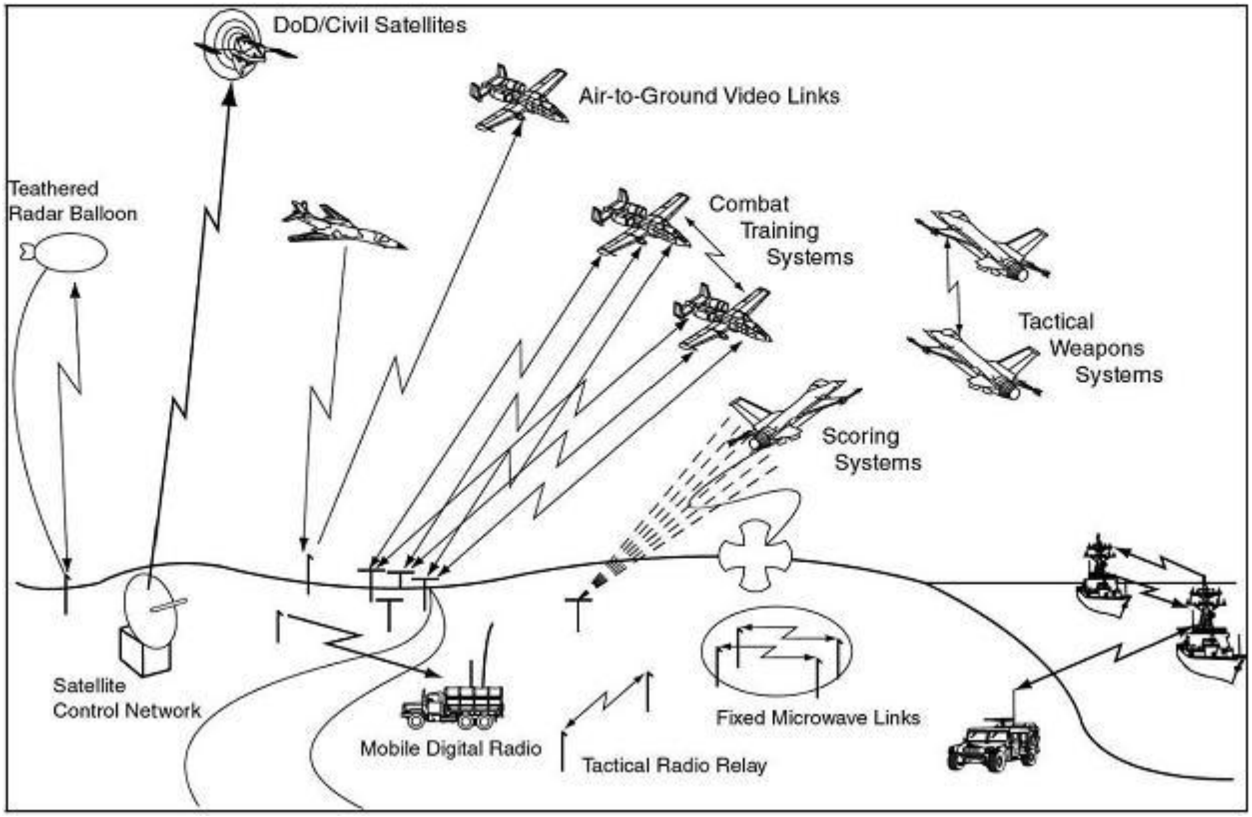

Figure 3-3. Pictorial Representation of Major Systems in the 1755-1780 MHz Frequency Band

Fixed Microwave

The distribution of point-to-point data and video links are the major Federal functions in the 1755-1780 MHz band and both are in the fixed service (i.e., fixed microwave and transportable, respectively). Fixed microwave networks in the band support backbone communications systems for many of the Federal agencies. Fixed microwave links are operated by Federal agencies for voice, data, and/or video communications where wireless service is unavailable, excessively expensive, or unable to meet required reliability. Applications include law enforcement; emergency preparedness; support for the national air space system; military command and control networks; and control links for various power, land, water, and electric-power management systems. Other fixed links include data relay, timing distribution signals, video relay and video surveillance operations and forensic investigations.

Transportable

Transportable encompass, but are not limited to those used by the DOD for radio relay for nodal communications connections and law enforcement community for covert video surveillance operations. In most cases, frequency assignments for the covert video surveillance operations are authorized for US&P use, while assignments for radio relays are mostly confined to DOD training areas and establishments.

Tactical Radio Relay

The Army, Navy, and Marine Corps operate tactical communications systems in this frequency band that provide critical mid/high capacity, digital information to the battlefield. The Army operates the MSE/HCLOS system. MSE/HCLOS is now a component of the WIN-T, in this band. The MSE/HCLOS system is deployed from the corps-level headquarters to the maneuver battalions. These systems provide a digital microwave backbone to link mid-level and lower-level battlefield commanders. The system operates like a high-capacity cellular telephone system with highly transportable base stations. For all DOD systems, the microwave radio equipment and antennas are transportable and robust for field conditions. Maintaining the operator's capability to quickly establish a tactical microwave link requires frequent field training.

The Navy and Marine Corps operate the DWTS in this band. The Navy/Marine Corps DWTS provides a backbone digital communications capability supporting amphibious operations and ground combat operations. The system supports command, control and data transfer from the Marine Expeditionary Force level down to the regimental level. The Marine Corps element of this radio system provides digital backbone services (voice, video, and data) for shore-shore and/or ship-shore communications links. This radio system is the only transmission media available to the Marine Corps with sufficient bandwidth to carry large quantities of critical data such as maps, overlays, intelligence pictures, and other data to the battlefield commanders. The Navy has a ship-to-shore link of DWTS primarily used for amphibious operations where most of the critical information flow is from the ship to the landing forces. Like MSE/HCLOS, DWTS is a tactical system designed to enable microwave links to be quickly established in support of combat operations and maneuver warfare.

While the Navy/Marine Corps DWTS AN/MRC-142 and AN/SRC-57 tunes from 1350-1850 MHz, the MSE/HCLOS tunes from 1350-2690 MHz, much of the tuning range of these systems is not available in the United States during peacetime due to the U.S. Table of Frequency Allocations. These TRR systems require a minimum of 95 megahertz of contiguous spectrum for operations and training.

Video Surveillance Operations

The Federal agencies maintain and conduct authorized electronic video surveillance operations on multiple frequency assignments in the 1755-1780 MHz band to satisfy their law enforcement requirements. Six Federal agencies (DHS, Justice, Housing and Urban Development, Treasury, Agriculture, and Veterans Administration) have US&P frequency assignments for video surveillance applications, mostly for law enforcement operations. In most cases, these requirements necessitate that surveillance equipment be highly–mobile or transportable (although some operate from fixed sites), and therefore be lightweight and easily assembled; must be concealable, as they are used for law-enforcement activities; must be secured from both physical and electronic detection, as to ensure officer/agent safety. Lastly, transmission from the equipment must be protected from interception or corruption of data to be valuable to the law enforcement community. One important requirement; however, does not deal with the equipment but how the frequency assignment is authorized. In this case, the assignment has to be authorized for use within the US&P to enable the flexibility of the surveillance operations.[39]

Air Combat Training and Airborne

The 1755-1850 MHz band is also heavily used to support telemetry and control operations. More often than not these operations include airborne platforms and specifically include ACTS, UAV, RPA, balloon-to-ground systems, missile testing, and PGMs. ACTS systems include such legacy systems as the Tactical Aircrew Combat Training System/Air Combat Maneuvering Instrumentation and newer systems such as P5 CTS/TCTS in varying degrees of development and deployment. The large geographic deployment of these systems and the use on high performance aircraft result in large electromagnetic footprints for these systems. UAV platforms have gained wide acceptance and deployment both within DOD and law enforcement agencies such as DHS as well as other Federal agencies with similar requirements (e.g., oil spill or fire monitoring). Because of its growing importance, far reaching intelligence surveillance reconnaissance (ISR) capability, and the advent of technological advancement, the UAV/RPA has become the DOD's ISR system for the foreseeable future; especially, since the DOD has improved its capabilities. The resulting necessary training and operations requirements often result in large EM footprints from the systems in this band. The NASA carries out its lighter-than-air program mission in the 1755-1780 MHz band using balloons, chase aircraft, and ground units. The 1755-1780 MHz frequency range is a part of the spectrum that the Navy had chosen for air-to-ground telemetry in support of various missiles/weapons tests and evaluations with areas of operation that include California, Florida and Maryland. PGMs recently moved to this band from 1710-1755 MHz. PGMs increase aircrew survivability by allowing the launch of weapons outside of enemy anti-air system threat envelope, decrease enemy collateral damage due to exacting weapons delivery, and require regular testing and training in the United States.

As an example, Figure 3-4 depicts the contours of nominal radio line-of-sight distances surrounding the many operational training areas where PGM-equipped aircraft operate. Because of the large geographic areas involved, establishing protection areas for those operations may prove difficult.[40]

[39] Note that the number of individual pieces of equipment associated with any assignment could be in the thousands.

[40] *See supra*, n. , at Figure 11.

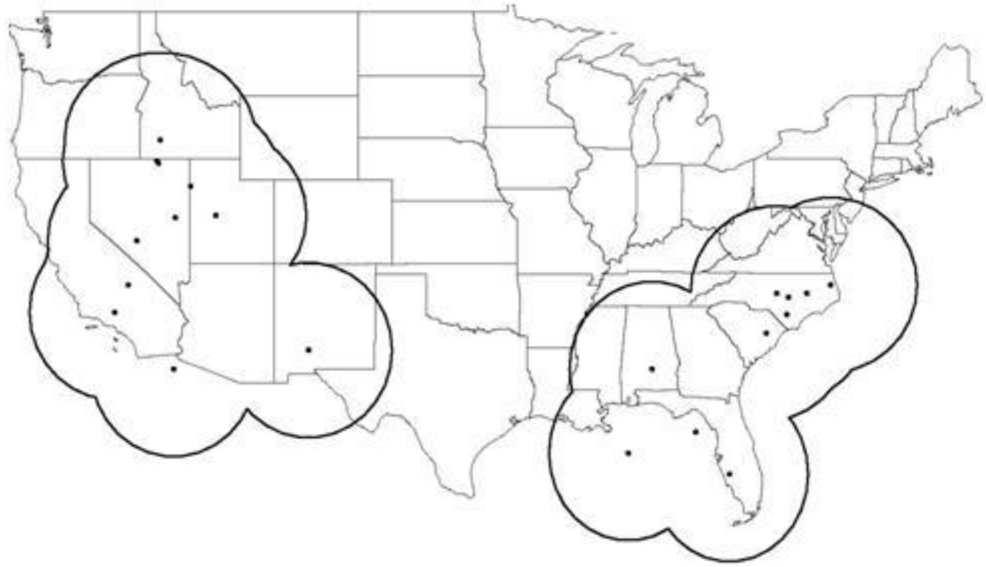

Figure 3-4. Line-of-Sight Distances from PGMs Operational Areas

<u>Satellite Operations</u>

DOD uses the 1755-1780 MHz band for communication links with newly launched National Security Space satellites. This band is also used for command and control of mission payloads, mission data retrieval, and on-orbit maneuvering of its many satellites in all orbits from low earth to geostationary. The Air Force Space Ground Link Subsystem provides continuous, worldwide command and control of national security satellites. The information provided by these satellites to our national level decision-makers, Combatant Commanders, Military Services, and national level decision-makers is crucial to successful execution of our national strategies. Additionally, other Federal agencies, such as the FAA, NASA, the Federal Emergency Management Agency, state and local governments, the private sector and the public benefit from the capabilities of the satellites controlled by this network.

<u>Robotic Video Surveillance Operations</u>

The Air Force operates an analog video surveillance system in the band for explosive ordinance disposal (EOD). This system is used for training exercises and in real world situations. This system is used with suitable robotic devices for the disposal operation in order to reduce “risk to life” of Air Force personnel during explosive ordnance demolition or disposal. The EOD operation entails a video link from a remote controlled robot to the command site to enable the operator to provide command and control for the robot and, at the same time, monitor the ordnance or bomb disposal operation.

3500-3650 MHz Band

The 3500-3650 MHz frequency range is divided into the 3500-3600 and 3600-3650 MHz bands in the U.S. National Table of Frequency Allocations. These two frequency bands include allocations to Federal radiolocation and radionavigation services. Therefore, since the bands represent similar use throughout 3500-3560 MHz band, the 3500-3600 and 3600-3650 MHz bands have been addressed as a single frequency band, 3500-3650 MHz.

Federal Use

This band is critical to DOD radar operations for national defense. The DOD operates high-powered defense radar systems on fixed, mobile, shipborne, and airborne platforms in this band. These radar systems are used in conjunction with weapons control systems and for the detection and tracking of air and surface targets.

The DOD also operates radar systems used for fleet air defense, missile and gunfire control, bomb scoring, battlefield weapon locations, air traffic control (ATC), and range safety.

Radiolocation Service Systems

Stations operating in the radiolocation service in 3500-3650 MHz include DOD radars used for detecting hostile aircraft and systems used for determining position coordinates rather than for navigation. Radiolocation systems in this band include ground, airborne, and shipborne systems.

The radiolocation systems in this band are high-powered surveillance radars, which detect airborne objects. These radars measure target altitude, range, and bearing. Some of the airborne targets are small and some targets must be detected at ranges as great as 300 nautical miles. Therefore, these radars must have great sensitivity and must provide a high degree of suppression for all forms of clutter return, including that from sea, land, and precipitation.

The Air Force uses this band throughout the US&P to assist pilots in formation flying and to support drop-zone training. The Navy uses the band for sustaining operations and training to support shipboard systems. The Navy also uses the 3100-3650 MHz band for a fleet air defense system, and 3400-3650 MHz for missile and gunfire control systems. The Navy uses anti-air search and fire control radars, which have weapons guidance and control functions.

Radionavigation Service Systems

The Navy uses this band for a number of radionavigation purposes, including air operations, ATC, and approach control.[41] Navy operates marshalling air traffic control radar

[41] *See supra*, n. , at Chapter 6. The radionavigation service is defined as "radio determination used for the purposes of navigation, including obstruction warning."

systems on all aircraft carriers and amphibious assault ships for vectoring aircraft into final approach. This ATC system also serves as a backup short-range, air-search radar system. The Navy shipborne radars operate on 21 frequencies or channels throughout this band.

AN/SPN-43C:

The AN/SPN-43C ATC radar is the primary emitter in this band for aircraft carriers and large amphibious assault ships (CV and LH class ships). The AN/SPN-43C transmitter output is 1 megawatt peak envelope power, coupled with an antenna with between 33 and 34 dBi gain, making the effective radiated peak radar beam power approximately 2 gigawatts. The pulse repetition rate is 1000 Hz and the pulse width is 1 microsecond.

The AN/SPN-43 is the Navy's marshalling ATC radar system used on all aircraft carriers and large amphibious assault ships for simultaneous control and identification of aircraft in the terminal area (vectoring aircraft into final approach). The AN/SPN-43C is a two-dimensional, air traffic control, air-surveillance radar system that provides for simultaneous control and identification of aircraft within own ship area of responsibility. The AN/SPN-43C has two sets of transmitters (modulators), receivers, and their associated power supplies; the second set provides an immediate on-line backup capability in case of either a transmitter or receiver equipment failure. The AN/SPN-43C is used in conjunction with other shipboard systems for the marshalling and tactical deployment of aircraft. The AN/SPN-43C is also used in conjunction with the carrier-controlled-approach radar for aircraft landing operations. In addition to the above, the AN/SPN-43C serves as a backup short-range, air-search radar system.

The AN/SPN-43 provides azimuth and range information from 50 miles to a minimum range of 250 yards at altitudes from radar horizon to 30,000 feet. Special indicators in the Carrier Air Traffic Control Center enable operators to direct aircraft along a predetermined azimuth to a point approximately one-quarter mile from touchdown. At this point, the aircraft is "handed-off" to the final approach controller who uses the complementary AN/SPN-42. The AN/SPN-43C is a coherent receive radar system with a pulsed magnetron transmitter.

The AN/SPN-43 radar antenna is mounted at a high point on the ship platform to provide the greatest signal detection range.

The AN/SPN-43C ATC radar routinely operates in and around Naval ports and in close proximity to US&P coastlines to support all aspects of Naval aviation. In addition, three systems are operated on land in the USA; 1) In Service Engineering Agent, Naval Air Warfare Center Aircraft Division St. Inigoes, Maryland; 2) In Service Engineering Agent Pascagoula, Mississippi; and 3) Naval Air Technical Training Command in Pensacola, Florida. Per US footnote 348, the FCC shall coordinate all non-Federal operations in the 3650-3700 MHz band within 80 km of these sites with NTIA on a case-by-case basis due to the reallocation of 3650-3700 MHz under the Omnibus Reconciliation Act of 1993.

U.S. Air Force Airborne Station Keeping Equipment

U.S. Air Force Station Keeping Equipment (SKE), are used to enhance flight safety as well as facilitate the management of cargo multi-ship formations. SKE formations can range in size from a single two-ship element to multi-element formations. The operator selects the desired formation position prior to takeoff and the SKE system uses pulsed radio frequency signals to maintain that position. SKE is installed on cargo aircraft.

The Zone Marker and the Miniaturized Zone Marker are operated in conjunction with SKE equipment. The Zone Marker is a ground-based transceiver used to provide a ground reference point to enhance aircraft navigation.

AN/SPY-1 (A, B, D, and D(V))

The AN/SPY-1B/D/D(V) is a multifunction, passive phased-array radar capable of search, automatic detection, transition to track air and surface targets, and missile engagement support for all AEGIS guided missile cruisers (CG 47 Class) and destroyers (DDG 51 Class). The AN/SPY-1 is also used to detect, track, and engage ballistic missiles on select AEGIS cruisers and destroyers. The CG 47 and DDG 51 Class ships have four antenna array faces. When operating in ballistic missile defense mode, the AN/SPY-1 requires use of all 10 channels simultaneously in high power (i.e., the entire contiguous 3100-3500 MHz band is utilized).

Future Navy Maritime Radars

There are also two advanced radars being developed for all future aircraft carriers, cruisers, and destroyers that utilize this portion of the spectrum.

The DOD Ground-Based Radar

DOD has two mobile ground based radar systems. One (GB-1) radar is specifically designed to locate the firing positions of both rocket and mortar launchers. The system has been tested and has been accepted by the DOD. GB-1 radar systems will replace the aging medium-range radars now in the DOD's inventory. GB-1 radar includes a number of improvements, including 360 degree coverage capability instead of the current radar's 90 degree capability. The Army operates GB-1 radar at many locations within the U.S. However, the sites requiring protection exclusion zones provided in Table 3-4 was limited to the locations where the radar requires use of its full tuning range. The radar does not require use of the upper portion of its tuning range at the many other locations. Ground Based Radar Three (GB-3) is a multi-function system that provides surveillance, air traffic control and fire quality data. These radar systems will also replace aging systems now in DOD's inventory.

Locations for Ground-Based Radar – 1 and 3 are provided in Table 3-4.

Table 3-4. Ground-Based Radar – 1 and 3 Installation Locations

GB-1 Installation Name
Fort Stewart, Georgia
Fort Carson, Colorado
Fort Hood, Texas
Fort Riley, Kansas
Fort Polk, Louisiana
Fort Knox, Kentucky
Fort Drum, New York
Fort Bragg, North Carolina
Fort Wainwright, Alaska
Fort Lewis, Washington
White Sands Missile Range
Yuma Proving Ground
Fort Irwin, California
GB-3 Installation Name
MCB Camp Pendleton, California
MCAS Miramar, California
MAGTFTC 29 Palms, California
MCMWTC Bridgeport, California
MCAS Yuma, Arizona
MCB Camp Lejeune, North Carolina
MCB Quantico, Virginia
MCAS Cherry Point, North Carolina
Bogue Field, North Carolina
MCAS Beaufort, South Carolina
Virginia Beach, Virginia
Fort Worth, Texas
Cheyenne, Wyoming
Ft Sill, Oklahoma
Aurora, Colorado
Pensacola, Florida
Ft Bliss, Texas

Non-Federal Use

The band 3500-3650 MHz is allocated to the radiolocation service on a secondary basis for non-Federal use. The 3600-3650 MHz band is allocated to the fixed-satellite (space-to-Earth) service on a primary basis for non-Federal use. In the band 3600-3650 MHz (space-to-Earth), the use of the non-Federal fixed-satellite service is limited to international inter-continental systems and is subject to case-by-case electromagnetic compatibility analysis. The FCC's policy for these bands is codified at 47 CFR 2.108. The FCC's Private Land Mobile Rule Part 90 applies in the 3500-3650 MHz band.

4200-4220 MHz and 4380-4400 MHz Band

Aeronautical Radionavigation Service

The 4200-4400 MHz band is internationally reserved for radio altimeters. These devices are installed on government and civil aircraft. The altimeters operate continually during flight, wherever the aircraft may travel. A radio altimeter is used to determine the altitude (height above terrain) of the aircraft for visual display to the pilot and for use by the Automatic Flight Control System during automatically controlled approaches and landings. The radio altimeter transmits radio frequency signals toward the ground and times how long it takes them to be reflected back to the aircraft receiver. Because speed, distance, and time are all related to each other, the altimeter can determine the aircraft's distance from the terrain or water surface. Radio altimeters are an integral and essential for flight navigation. Because of the precision and accuracy of radio altimeters at altitudes of 1000 feet or less, they are used as a height controlling sensor in many aircraft automatic approach and landing systems. In many aircraft the radio altimeter is directly connected to the Ground Proximity Warning System which is designed to warn the pilot if the aircraft is flying too low or descending too quickly.

Radio altimeters operating in the 4200-4400 MHz band are utilized in aircraft throughout the Federal Government. The Federal agencies use radio altimeters on tactical and non-tactical fixed wing aircraft and helicopters. Low-level aircraft flights are necessary to support USDA fire fighting and search and rescue operations.[42] The use of radio altimeters for low-level flights may take place anywhere in the United States. The U.S. Coast Guard relies on radio altimeters for sea and land search and rescue operations (e.g., New Orleans during Hurricane Katrina). The FAA uses radio altimeters during the performance of flight inspections of radio navigational aids including flight inspection of satellite-based augmentation systems. NASA has used radio altimeters for Space Shuttle landings and in over 100 aircraft; NASA may use them for landing of future space systems. Radio altimeters are also used on UAVs, tactical weapons (missiles), and drone targets.

Radio altimeters have to be installed on commercial aircraft that are certified for Category II and III approaches and landings.[43] Radio altimeters are necessary for an altitude of 2500 feet to landing for precision approaches, because they are more accurate than barometric altimeters. Below 200 feet, a pilot without a radio altimeter relies on Visual Flight Rules. Above 2500 feet, pilots use the barometric altimeter, but they can use the radio altimeter to validate the barometric altimeter. Every aircraft needs to use the same reference to maintain

[42] Water and fire retardant dumps typically occur at elevations of 150 to 300 feet above the ground.

[43] For automatic landing systems there different landing categories that are defined in terms of minimum visibility and decision height.

vertical separation, so barometric altimeters are used by nearly all aircraft except for Category II and III landings.[44]

DOI Aviation Management Directorate (AMD), Boise, Idaho writes the specifications for aviation contracts that cover well over 1000 aircraft of various sizes. The contract aircraft supports DOI Bureaus' wildfire fighting activities to include support of NIFC wildfire activities. DOI AMD also manages contracts that support such diverse activities as the US Navy and the National Science Foundation. The fixed and rotor wing aviation contracts managed by DOI AMD are equipped by the vendor with radar altimeters. The majority of DOI aviation owned fleet is relatively small, single-engine piston aircraft and are equipped with radio altimeters. Besides DOI Bureaus' wildfire activities, DOI's fleet owned aircraft are used to survey migratory waterfowl, enforce U.S. Fish and Wildlife Service conservation measures, or monitor activity and search and rescue to include joint law enforcement operations at National Parks and other DOI and Tribal lands. DOI's public use missions are often flown at low (100-150 feet above ground level) altitude for prolonged periods of time and over relatively uninhabited areas both within the United States, Canada, and Mexico.

The USDA owns and operates over 200 fixed- and rotary-wing aircraft. In addition, the Forest Service (FS) typically leases 600-800 aircraft every fire season. Over half of the USDA-owned aircraft are ex-military, several of which are still equipped with their military radio altimeter equipment.

Radio or radar altimeters are operational during all phases of flight, and are also used as a sensor in ground proximity warning systems. Low-level flights of USDA's FS aircraft are common for firefighting operations and for search and rescue operations. Helicopters use radio altimeters for long line operations. Lead plane Aerial Supervision Module aircraft use radio altimeters to gauge their height and the height of the airtanker above the drop areas. For firefighting operations, water and fire retardant drops to be effective typically occur at only 150 to 300 feet of elevation above terrain.[45] Contracted airtankers are required by the Forest Service to carry radar altimeter equipment.[46] On smokejumper aircraft, radio altimeters are used for low level flying to determine proper height above ground for personnel and cargo drops in high relief terrain (comparing barometric altimeter to radio altimeter). The smokejumpers go out at 1500

[44] A pressure altimeter (also called barometric altimeter), which does not transmit radio frequency signals, is used on Federal Government, commercial aircraft and on most general aviation aircraft.

[45] Forest Service Handbook National Headquarters (WO) Washington, DC, FSH 5709.16 - *Flight Operations Handbook*, Chapter 30 - *Aircraft Operations*, §35.26 - *Congested Area Retardant Operations*, and §35.27 - *Safe and Effective Drop Height - Fixed Wing Airtankers*, at 22-23, Effective Date March 29, 2006.

[46] Forest Service, *2010 National Exclusive Use Airtanker Service Contract*, January 1, 2010 - December 31, 2010, Section J - List of Attachments, Exhibit 1 - Basic Aircraft Equipment and Fire Equipment, at 36, *available at* http://www.fs.fed.us/fire/contracting/airtankers/airtanker_contract.pdf.

feet absolute and the cargo at 500 feet. These low-level flights may take place anywhere in the US&P. Reliable radio altimeter operation for terrain avoidance and flight safety is imperative. Figure 3-5 shows a USDA Airtanker Fire Retardant Drop Mission at low altitude above terrain.

Figure 3-5. USDA Airtanker Fire Retardant Drop Mission

The DOD uses radar altimeters in military aircraft and platforms for a variety of missions to include approach and landing, terrain following, etc. The DOD also employs radar altimeters on a very large variety of systems to include aircraft, UASs, and missiles as examples. Because of the diversity in DOD's mission requirements the entire band is used by many of the DOD platforms.

The DOD's Combined Altitude Radar Altimeter is an all-solid-state Frequency Modulation/Continuous Wave radar altimeter system that can operate from 0 to 50,000 feet. It offers inherent low probability of intercept and anti-jam capability as well as conventional analogue and digital outputs for aircraft avionic systems. Military flight training is currently conducted over the routes shown in Figure 3-6. Units need to be able to train in close proximity to their base. Fuel cost and time prohibit the limiting of low level flying to a single region of the United States. Most military applications use 4300 MHz as the center frequency; however, certain altimeters that use a center frequency other than 4300 MHz which shifts the occupied bandwidth and can cause it to overlap (co-channel) with the NTIA proposed guard bands.

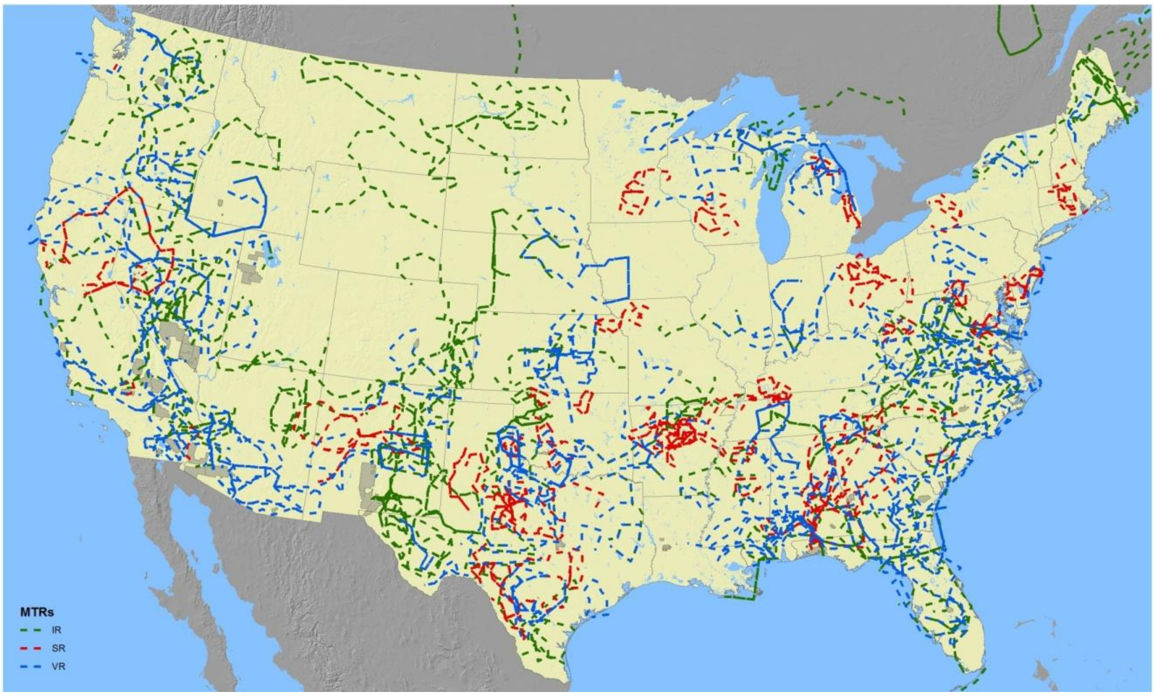

Figure 3-6. Military Flight Training Routes

Standard Frequency and Time-Satellite (Space-to-Earth) Service

The Federal Government does not operate any systems in the standard frequency and time-satellite (space-to-Earth) service.

Earth Exploration-Satellite (Passive) Service

The Federal Government is not using the 4200-4400 MHz band for passive sensing operations at this time.

Space Research (Passive) Service

The Federal Government is not using the 4200-4400 MHz band for space research (passive) operations at this time.

4. Electromagnetic Compatibility Analysis with Federal Systems

Introduction

During the Fast Track Evaluation, NTIA considered the 1675-1710 MHz band for sharing with the wireless broadband services. However, due to large number of fixed/transportable/mobile non-Federal meteorological-satellite earth station receivers that are unlicensed, and rely on meteorological data from weather satellites for public safety and other weather related activities, NTIA limited its compatibility analysis to the 1695-1710 MHz band.[47] Given the time constraints for this Report, and the proximity to the 1710-1755 MHz band that is used for mobile/portable transmitters, the compatibility analysis for the 1695-1710 MHz band will only consider mobile/portable station transmitters and base stations receivers operating in FDD mode (i.e., mobiles only operating in the 1695-1710 MHz band). The compatibility analysis for the 3500-3650 MHz band will consider both base and mobile/portable transmitters and receivers operating in TDD mode to assess compatibility with Federal systems.

A two-way electromagnetic compatibility analysis will be performed between wireless broadband and Federal systems operating in and adjacent to the 1695-1710 MHz and 3500-3650 MHz bands. The analyses will support the determination of the minimum separation distances and/or other technical or operational characteristics necessary to preclude potential interference between Federal and wireless broadband systems.

Generally, spectrum can be made available to wireless broadband through segmentation or sharing. Spectrum sharing entails users authorized in the same spectrum but operating either non-co-channel (temporal sharing) or non-co-coverage (geographical sharing). Temporal sharing of spectrum would require non-co-channel, co-coverage operations through careful coordination among the users, to permit the use of spectrum by one authorized user when that spectrum is unused for portions of time by another authorized user. Geographic sharing would require co-channel, non-co-coverage operations whereby systems authorized to use the same spectrum would avoid overlapping their service areas. Spectrum sharing could also entail operations on a co-channel and co-coverage basis. One method would require the use of relatively low-power devices under specific technical and operational conditions to avoid causing harmful interference to other authorized users. Another example would be Federal and non-Federal users accessing the same infrastructure and devices; interoperability among the Federal and non-Federal users on common frequencies would also be a possibility.

Spectrum segmentation would entail re-allocating spectrum to one or multiple services and developing service rules to create a flexible operating environment for wireless broadband.

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[47] Many of the public safety uses are for mobile or transportable meteorological-satellite earth station receivers (e.g., EMWIN), where it is not possible to establish the sharing exclusion zones under consideration in the Fast Track Evaluation.

Spectrum would be made available to wireless broadband on a non-co-channel, non-co-coverage (exclusive) basis and in this scenario incumbent users would be relocated to alternative spectrum or technologies. Because of the bounds of the initial study, candidate bands for wireless broadband were considered where relocation of incumbent systems would not be required.

Federal System Characteristics

The 1675-1710 MHz band is allocated on a co-primary basis for Federal and non-Federal use for the meteorological aids service and the meteorological-satellite service (space-to-Earth). Specifically, this band is used for downlinks from certain NOAA weather satellites and radiosondes (weather balloons) that are administered by NWS.[48] NOAA provides these services for weather forecasting, tracking of hurricanes and other storms, prediction of flooding and drought conditions, and warning against other hazards to life and property. Appendix A presents the technical characteristics for the Federal systems operating in the 1695-1710 MHz band.

The band 3500-3650 MHz is used by military radar systems with installations on land, on ships and on aircraft. In general, the predominant use by mobile radars is on ships and aircraft while the fixed, land-based systems are operated at a number of coastal sites, training areas and test ranges. Functions performed include search for near-surface and high altitude airborne objects, sea surveillance, tracking of airborne objects, and for multi-purpose test range instrumentation. The analysis used representative characteristics for land-based, shipborne, and airborne radar systems operating in the band 3500-3650 MHz.[49] The analysis will also address the impact of high power military radars operating in the adjacent band on wireless broadband systems in the 3500-3650 MHz band.

Wireless Broadband System Characteristics

In order to perform the necessary compatibility analysis with Federal systems, NTIA sought FCC staff input to establish the technical parameters with which to characterize the wireless broadband systems. These systems, many of which are in the planning or development stage, do not have well-defined or universally accepted values associated with every system parameter. Consequently FCC staff relied heavily upon information published in various wireless network standards and recommendations. In some cases, assumptions were based on consultations with industry experts to identify the equipment characteristics for the wireless systems (some of which are not yet developed and deployed). These technical characteristics will provide the basis for developing the wireless broadband system service rules where NTIA finds that spectrum can be made available via sharing. If there are changes to the technical parameters or deployment data for the wireless broadband systems, as compared to those used for the analysis documented in this report, significant actions will be required. NTIA in

[48] Although not in the immediate adjacent band, NWS requested that the radiosonde transmitters and receivers be considered in the compatibility analysis.

[49] Representative system characteristics were used due to the sensitive nature of operations in this frequency band.

collaboration with the affected Federal agencies will need to first determine if implementation of the proposed changes and determine whether any changes would potentially create an impact to Federal systems and determine whether any changes to the sharing conditions and service rules are required to protect Federal systems. Appendix B summarizes the information provided by FCC staff, such as the transmitter, receiver, and antenna characteristics for the WiMAX TDD and LTE FDD systems to be used in compatibility studies with Federal systems.

Wireless System Deployment Characteristics

A method for portraying the wireless broadband system deployment is to distribute the base and mobile/portable stations over three regions defining the area of the analysis: urban, suburban, and rural. The urban region reflects corporate and public access use. The suburban region reflects corporate, public access, and home use. The rural region reflects only home use. The three regions are assumed to exist within concentric circles as shown in Figure 4-1.

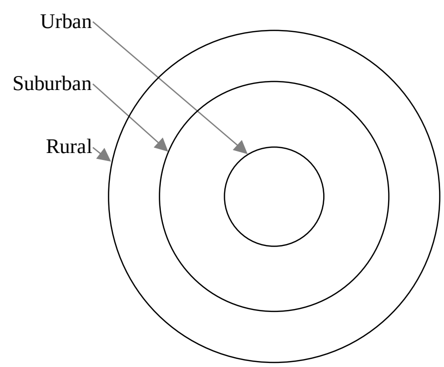

Figure 4-1. Wireless Broadband System Deployment Regions

Each of the individual regions would be expected to contain various types of structures, with maximum structure heights varying from one region to the next. This arrangement of the deployment regions represents the structure of a typical city, with a dense urban core containing structures with greater maximum heights, a less dense suburban region with structures of lesser height, and a more sparsely populated rural region consisting mostly of residential structures. Table 4-1 provides a listing of the parameters that define the deployment regions.[50] The antenna heights of the base and mobile/portable stations within the three regions are determined randomly within a pre-determined range of values using a uniform probability distribution.

[50] Using the Washington, D.C. metropolitan area as an example, the urban area is defined as a 177 square kilometer area, which equates to a radius on approximately 7.5 kilometers.

Table 4-1. Parameters Describing the Base Station Deployment Regions

Parameter	Description	Value
Urban Radius	Distance from the center of the city to the outer edge of the urban region	10 kilometers
Suburban Radius	Distance from the center of the city to the outer edge of the suburban region	30 kilometers
Rural Radius	Distance from the center of the city to the outer edge of the rural region	50 kilometers

Based on the current use of the 1710-1755 MHz band for mobile/portable stations, the compatibility studies in the 1695-1710 MHz frequency band will consider only mobile/portable station transmitters and base stations receivers (i.e., no TDD mode of operation). The compatibility analysis for the 3500-3650 MHz band will consider both base and mobile/portable transmitters and receivers operating in TDD mode. Table 4-2 presents, based on the information provided by the FCC, the deployment characteristics of wireless broadband systems to be considered in the compatibility studies for the 1695-1710 MHz and 3500-3650 MHz bands.

Table 4-2. Wireless Broadband System Deployment Information

1695-1710 MHz Band		
Deployment Region	**Base Station Radius (km)**	**Base Station Separation (km)**
Urban	0.8	1.5
Suburban	2.41	4.6
Rural	4.02	7.6
3500-3650 MHz Band		
Analysis Area	**Base Station Radius (km)**	**Base Station Separation (km)**
Urban	0.64	1.2
Suburban	1.77	3.4
Rural	3.22	6.1

In terms of sector capacity, which is the average number of mobile/portable stations operating on a frequency, the analysis will use an average value of 140.[51] A base station typically has three sectors each 120 degrees wide each with a different frequency. For each base station, the analysis will assume a total of 420 active mobile/portable stations on the three base station frequencies.[52] A frequency re-use factor of 1:3:3 (one site, three sectors, and three frequencies) will be used for the base stations in this analysis.

[51] The range of users per frequency can vary between 120 and 200. The analysis will use 140 as an average. For pico base stations, the analysis will use an average of 60 mobile/portable users per sector.

[52] Based on information from the industry experts mobile/portable handsets will not transmit before they detect a control signal from a base station. Driven primarily by global roaming requirements, the handsets will listen for control channels. Once they find a control channel, they will communicate to determine whether the user has any rights on the system and will act according to instructions.

Types of Compatibility Analysis

The types of analysis to be performed in assessing compatibility between wireless base and mobile/portable stations and Federal systems operating in the 1695-1710 MHz and 3500-3650 MHz bands are summarized in Tables 4-3 and 4-4.

Table 4-3. Types of Analysis Performed for the 1695-1710 MHz Band

Meteorological Satellite		
Transmitter	**Receiver**	**Type of Analysis**
Satellite	Base Station	Co-Frequency Single Entry
Mobile/Portable Stations	Fixed and Transportable Earth Stations	Co-Frequency Aggregate
Meteorological Aids (Radiosonde)		
Airborne Radiosonde	Base Station	Co-Frequency Single Entry
Mobile/Portable Stations	Fixed Ground-Based Radiosonde	Co-Frequency Aggregate

Table 4-4. Types of Analysis Performed for the 3500-3650 MHz Band

Transmitter	Receiver	Type of Analysis
Ground-Based Radar		
Radar	Base Station	Adjacent Band Single Entry
Radar	Mobile/Portable Station	Adjacent Band Single Entry
Base and Mobile/Portable Stations	Radar	Adjacent Band Aggregate
Airborne Radar		
Radar	Base Station	Adjacent Band Single Entry
Radar	Mobile/Portable Station	Adjacent Band Single Entry
Base and Mobile/Portable Stations	Radar	Adjacent Band Aggregate
Shipborne Radar		
Radar	Base Station	Co-Frequency Single Entry
Radar	Mobile/Portable Station	Co-Frequency Single Entry
Base and Mobile/Portable Stations	Radar	Co-Frequency Aggregate

Interference Thresholds

This section describes the criteria used to develop the interference thresholds for the compatibility analysis between Federal and wireless broadband systems. The interference thresholds used to assess compatibility are referred to as long-term thresholds because their derivation assumes that the interfering signal levels are present most of the time.

The interference thresholds (I_T) used in assessing compatibility between Federal and wireless broadband systems will be determined using Equation 4-1:

$$I_T = {}^{I}/_{N} + N \tag{4-1}$$

where:

I/N: Maximum permissible interference-to-noise ratio at the receiver intermediate frequency (IF) output (detector input) necessary to maintain acceptable performance criteria (dB)

N: Receiver inherent noise level at the receiver IF output referred to the receiver input (dBm)

For a known receiver IF bandwidth and receiver noise figure (NF) or system noise temperature, the receiver inherent noise level is given by:

$$N = -114\ [dBm] + 10\log(B_{IF}[MHz]) + NF \tag{4-2}$$

$$N = kT_sB_{IF} = -198.6\ [dBm/K/Hz] + 10\log(T_s\ [K]) + 10\log(B_{IF}\ [Hz]) \tag{4-3}$$

where:

B_{IF}: Receiver IF bandwidth (see equations for units)

NF: Receiver noise figure (dB)

k: Boltzmann's constant, $1.38\text{x}10^{-23}$ (Watts/K/Hz)

T_s: System noise temperature (Kelvin)

Radar Receivers

Radars receivers are affected in fundamentally different ways by unwanted signals of different forms, and an especially sharp difference prevails between the effects of continuous noise-like energy and those of pulses. Continuous-wave interference of a noise-like type inflicts a desensitizing effect on radar receivers, and that effect is predictably related to its intensity. Within any azimuth sectors in which such interference arrives, its power spectral density can, to a reasonable approximation, simply be added to the power spectral density of the radar-system thermal noise. If the radar-system noise power in the absence of interference is denoted by N and that of noise-like interference by I, the resultant effective noise power becomes simply I + N.

Radar protection criteria, based on the penalties incurred to maintain the target-return signal-to-noise ratio in the presence of the interference, require that the target-return power be raised in proportion to the increase of noise power from N to I + N. Thus, meeting protection criteria in the presence of interference requires acceptance of shorter maximum ranges on given targets, sacrificing observation of small targets, or modifying the radar to give it a higher transmitter power or power-aperture product. In modern radars, receiving-system noise is usually already near an irreducible minimum and nearly-optimum signal processing is becoming commonplace.

These penalties vary depending on the function of the radar and the nature of its targets. For most radar systems, an increase in the effective noise level of about 1 dB would inflict the maximum tolerable degradation on performance. In the case of a discrete target having a given average or median radar cross section (RCS), that increase would reduce the detection range by about 6 percent regardless of any RCS fluctuation characteristics that target might have. This effect results from the fact that the achievable free-space range is proportional to the fourth root of the resultant signal-to-noise power ratio (SNR), from the most familiar form of the radar range equation. A 1 dB increase of effective noise power is a factor of 1.26 in power, so it would, if uncompensated, require the free-space range from a given discrete target to be reduced by a factor of $1/((1.26)^{1/4})$, or 1/1.06 (e.g., a range capability reduction of about 6 percent). In the range equation, the SNR is also directly proportional to transmitter power, to power-aperture product (for a surveillance radar), and to target radar cross section. Alternatively, therefore, the 1 dB increase of effective noise power could be compensated by forgoing detection of targets except those having an average RCS 1.26 times as large as the minimum-size target that could be detected in the interference-free regime or by increasing the radar transmitter power or its power-aperture product by 26 percent. Any of these alternatives is at the limit of acceptability in most radar missions, and the system modifications would be costly, impractical, or impossible, especially in mobile radars. For discrete targets, those performance penalties hold for any given probability of detection and false-alarm rate and any target fluctuation characteristics.

The desensitizing effect on a radar system from other services of a noise-like modulation such as those from the wireless broadband systems is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can, to within a reasonable approximation, simply be added to the power density of the radar receiver thermal noise. In this compatibility analysis, the interference threshold for the radar is based on an I/N criterion of -6 dB.[53] An I/N of -6 dB corresponds to a 1 dB increase in the receiver noise. The interference level is based on the aggregate interference from wireless base and mobile/portable transmitters. Table 4-5 provides the interference thresholds for the ground-based and shipborne radar systems.

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[53] International Telecommunication Union-Radiocommunication Sector, Recommendation ITU-R M.1461-1, *Procedures for Determining the Potential for Interference Between Radars Operating in the Radio determination Service and Systems in Other Services* (2000-2003), at Annex 1.

Table 4-5. Interference Thresholds for Radar Systems

Radar Type	Receiver Noise Level (dBm)	I/N Criteria (dB)	Interference Threshold (dBm)
Ground-Based Radar – 1	-103	-6	-109
Ground-Based Radar -3	-96	-6	-102
Shipborne Radar – 1	-108	-6	-114
Shipborne Radar -2	-95	-6	-101
Shipborne Radar - 3	-94	-6	-100

Ground-Based Radar – 2 is used in conjunction with Airborne Radar – 1 and Airborne Radar – 2 as part of an aircraft positioning system. Unlike typical target tracking and search radars these systems receive high desired signals and as such are not noise-limited. Table 4-6 provides the interference thresholds for these radar systems.

Table 4-6. Interference Thresholds for Radar Systems

Radar Type	Receiver Noise Level (dBm)	I/N Criteria (dB)	Interference Threshold (dBm)
Ground-Based Radar – 2	-100	15	-85
Airborne Radar – 1	-92.5	30	-62.5
Airborne Radar – 2	-100	40	-60

Airborne Radar – 1 and 2 and their associated ground component system Ground-Based Radar – 2 are interference limited systems (as opposed to noise limited systems) so the interference thresholds were calculated differently. Considering the specified receiver sensitivity criteria, other technical parameters, and the Airborne Radar – 1 and Airborne Radar – 2 received signal level from another like device operating 10 nautical miles apart (i.e., its maximum designed range), the I/N Threshold was calculated to be 40 dB for Airborne Radar – 1 and 30 dB for Airborne Radar – 2 system. In a similar manner, the I/N Threshold for the associated ground components was calculated to be 15 dB, when used in conjunction with the Airborne Radar – 1 and Airborne Radar – 2 systems.

Radiosonde Station Receivers

The radiosonde receive stations are typically most vulnerable to interference at the maximum slant range of operation and thus the interference criteria must be established to protect this case. A long-term interference threshold of -122.6 dBm for radiosonde receive stations has been established in ITU-R Recommendation RS.1263-1.[54] This is approximately equal to an I/N of -6 dB.

<u>Meteorological-Satellite Earth Station Receivers</u>

The analysis will use an I/N of -10 dB, corresponding to a 0.4 dB increase in the receiver noise to establish the interference threshold for meteorological-satellite earth station receivers.[55]

<u>Wireless Broadband Receivers</u>

The analysis will use an I/N criterion of -6 dB, corresponding to a 1 dB increase in the receiver noise to establish the interference threshold for wireless base and mobile/portable station receivers. The interference threshold for wireless broadband receivers is based on average power.

Table 4-7 provides the interference thresholds for the wireless broadband receivers operating in TDD mode.

Table 4-7. Interference Thresholds for TDD Wireless Broadband Receivers

Receiver Bandwidth (MHz)	Receiver Noise Level (dBm)	I/N Criteria (dB)	Interference Threshold (dBm)
Base Station			
4.75	-104.2	-6	-110.2
9.5	-101.2	-6	-107.2
19	-98.2	-6	-104.2
Mobile/Portable Station			
4.75	-102.2	-6	-108.2
9.5	-99.2	-6	-105.2
19	-96.2	-6	-102.2

The interference thresholds for the wireless broadband receivers operating in FDD mode are provided in Table 4-8.

[54] International Telecommunication Union-Radiocommunication Sector, Recommendation ITU-R RS.1263-1, *Interference Criteria for Meteorological Aid Operated in the 400.15-406 MHz and 1668.4-1700 MHz Bands* (Jan. 2010).

[55] The DOD used a similar approach, which was based on ITU-R Recommendation SA.1026. For a receiver noise temperature of 370 K and a receiver bandwidth of 2.6 MHz, the resultant I/N criteria was -8.4 dB.

Table 4-8. Interference Thresholds for FDD Wireless Receivers

Receiver Bandwidth (MHz)	Receiver Noise Level (dBm)	I/N Criteria (dB)	Interference Threshold (dBm)
Base Station			
4.5	-102.5	-6	-108.5
9	-99.5	-6	-105.5
18	-96.5	-6	-102.5
Mobile/Portable Station			
4.5	-98.5	-6	-104.5
9	-95.5	-6	-101.5
18	-92.5	-6	-98.5

In many cases, wireless communication systems are interference limited. In those cases the signal-to-noise will remain greater than the minimum required value for acceptable performance so that the interference level can be allowed to exceed the receiver noise. The increase in receiver noise (Δ) is related to I/N using the following equation:

$$\Delta = 10 \log \left[10^{(I/N)/10} + 1 \right] \quad (4\text{-}4)$$

Figure 4-2 shows a plot of increased receiver noise as a function of I/N.

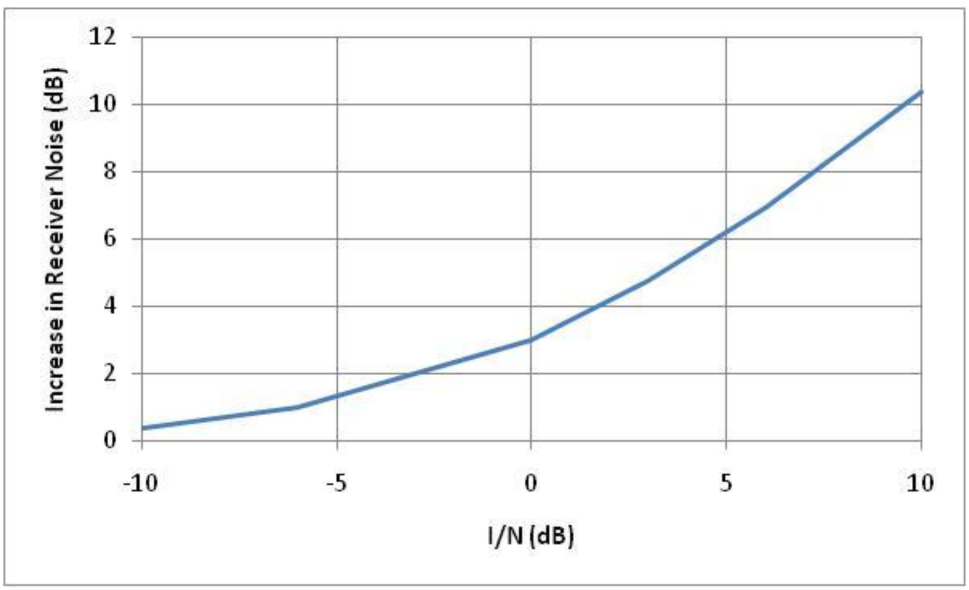

Figure 4-2. Increase in Receiver Noise as a Function of Interference-to-Noise Ratio

The compatibility analysis will also consider, for wireless broadband receivers, I/N values of 0 dB, 3 dB, 6 dB, and 10 dB.

In cases where the pulsed duty cycle is high, the analysis will base the interference to the wireless broadband receiver on the peak power. The equipment manufacturers have not specified peak power criteria for the wireless broadband receivers. An I/N value of 10 dB will be used in this analysis.

Transmitter Power

Federal Systems

Radar Transmitters

Based on the peak transmitter power levels and the maximum duty cycle specified in Table F-1, the analysis will use the average power levels for the ground-based, airborne, and shipborne radar systems. The average power is computed as follows:

$$P_{Avg} = P_{Peak} + 10\log(DC/100) \tag{4-5}$$

where:

P_{Avg}: Average radar transmitter power (dBm)
P_{Peak}: Peak radar transmitter power (dBm)
DC: Radar transmitter duty cycle (Percent)

Appendix F provides an explanation of the effects of pulsed interfering signals on digital receivers. For radars with a high transmit duty cycle, the analysis will use the peak transmit power.

As discussed in Appendix F, the transmit duty cycle for cases where the digital receiver is off-tuned from the radar is less than the on-tune duty cycle. In this analysis the on-tune duty cycle of the radar transmitter will be used to compute the average power, providing a conservative estimate of the radar transmitter power level.[56]

Satellite Transmitters

Appendix A provides the transmitter power levels for the meteorological satellite downlink transmissions for the GOES and POES.

Radiosonde Transmitters

Appendix A provides the power level for the radiosonde transmitter.

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[56] The DOD believes that the peak transmit power should be used in the compatibility analysis independent of the duty cycle.

Wireless Broadband Systems

In this analysis, the transmitter power levels for the base stations will be the levels provided in Appendix B for each of the specified bandwidths.

The mobile/portable transmitters typically employ power control in order to prevent too much unwanted interference. Reduced power means reduced interference problems and increased battery capacity. Because of battery and size limitations, mobile/portable stations typically transmit at power levels below the maximum level permitted under the service rules. For a given deployment of mobile/portable station, this analysis will use a randomly-selected transmitter power level for each station based on a uniform probability distribution with a minimum value of 13 dBm and a maximum value of 23 dBm.

Channel Bandwidth

The analysis will consider multiple channel bandwidths for the wireless base and mobile/portable systems as specified in Tables B-2 and B-4 of Appendix B. Each channel bandwidth will be analyzed separately (e.g., all base and mobile/portable stations in a deployment will have the same channel bandwidth).

Propagation Models

The following discusses the propagation models used in performing the compatibility analysis.

Satellite and Airborne Systems

For all compatibility analysis associated with satellite downlinks and airborne systems the free space model shown in Equation 4-6 was used to compute the propagation loss:

$$L_{FS} = 20\log F + 20\log D + 32.45 \qquad (4\text{-}6)$$

where:

L_{FS}: Free space propagation loss (dB)

F: Frequency (MHz)

D: Separation distance (km)

For airborne systems, when the aircraft is beyond the radio line-of-sight, a diffraction loss of $0.62/\lambda^{0.333}$ dB/km will be added to the free space propagation loss.[57] The wavelength (λ) is in meters. The radio line-of-sight distance was computed using the following equation:

$$D_{LOS} = 4.1\left(\sqrt{h_1} + \sqrt{h_2}\right) \tag{4-7}$$

where:

D_{LOS}:	Radio line-of-sight distance (km)
h_1:	Altitude of the aircraft (m)
h_2:	Height of the base/mobile station (m)

Terrestrial Systems

For the single-entry compatibility analysis associated with the meteorological-satellite receive stations, radiosonde receive stations, ground-based radar systems, and the aggregate compatibility analysis the Irregular Terrain Model (ITM) in the Area Prediction Mode was used.[58]

The ITM estimates radio propagation losses for frequencies between 20 MHz and 20 GHz as a function of distance and the variability of the signal in time and space. ITM is an improved version of the Longley-Rice Model, which gives an algorithm developed for computer applications. The ITM is based on electromagnetic theory and signal loss variability expressions derived from extensive sets of measurements. In the ITM Area Prediction Mode, the "area" is described by the terrain roughness factor Δh, which is defined as the interdecile value computed from the range of all terrain elevations for the area. Suggested values of Δh are available for different types of terrain. Using the Δh value and the antenna heights for the system, the algorithm predicts the signal attenuation as a function of distance. The loss predicted by ITM in the Area Prediction Mode consists of the median attenuation of a radio signal as a function of distance for paths over irregular terrain as well as the variability of the signal in time and space. The computed values attempt to give a statistical description of received radio fields, which can be used for system design or interference analysis. The statistics used are the time variability, the location variability, the situation variability, and the hourly median value.

The time variability is either short-term or long-term. The short-term variability is due to fading. The long-term variability is the observed random long-term variations of the hourly median value, which are due to changes in atmospheric conditions, seasonal conditions such as

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[57] *Propagation of Waves*, P. David and J. Vogel (1969), at 135.

[58] National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode* (April 1982), *available at* http://www.its.bldrdoc.gov/pub/ntia-rpt/82-100/index.php.

snow, moisture content of the soil, foliage and vegetation, and local conditions. The time variability is the fraction of the time during which hourly median values of field strength or available received power are larger than that given and the propagation losses are smaller.

The location variability is the change in path loss due to small changes in the transmitting or receiving antenna location due to random location of trees, buildings or other obstacles. The value predicted after considering time variability is for an average location, i.e., the average of many different locations in the immediate vicinity of the receiver location. The location variability describes the full range of possible signal levels over this small area.

The situation variability is a probability measure imposed on the collection of all possible or conceivable propagation paths and all possible or conceivable moments of time. Since the model is based on many sets of propagation measurements, the predicted propagation value obtained from the model can be biased with the situation variability term. Therefore, the situation variability allows the ITM user to have a certain assurance that the predicted loss has some predefined relation with measured losses.

In case of the single message mode, all three kinds of variability are combined. Therefore, when the confidence level is specified, it defines the situation variability.

Table 4-9 provides the parameters used for ITM in the Area Prediction Mode.

Table 4-9. ITM Area Prediction Mode Parameters

Parameter	Value
Surface Refractivity	301 N-units
Conductivity of Ground	0.005 S/M
Dielectric Constant of Ground	15
Delta h	10 meters and 30 meters
Polarization	Vertical
Mode of Variability	Single Message Mode
Percent Confidence (Time/Situation/Location Variability)	50 percent for mobile/portable stations 20 percent for base stations
Frequency	Variable within the 1695-1710 MHz and 3550-3650 MHz bands
Transmitter Antenna Height	Single Entry Base Station – 60 meters Mobile/Portable – 1.5 meters Radar – Variable Meteorological and Radiosonde – Variable Aggregate Base Station – 5 to 15 (Urban/Suburban) and 15 to 60 meters (Rural) Mobile/Portable – 1.5 to 10 meters Radar – Variable Meteorological and Radiosonde – Variable
Receiver Antenna Height	Single Entry Base Station – 60 meters Mobile/Portable – 1.5 meters Radar – Variable Meteorological and Radiosonde – Variable Aggregate Base Station – 5 to 15 (Urban/Suburban) and 15 to 60 meters (Rural) Mobile/Portable – 1.5 to 10 meters Radar – Variable Meteorological and Radiosonde – Variable
Site Criteria Transmitter	Very Careful – Base Stations Random – Radar Random – Mobile/Portable Stations
Site Criteria Receiver	Very Careful – Base Stations Random – Radar Very Careful – Meteorological and Radiosonde Random – Mobile/Portable Stations
Radio Climate	Continental Temperate

Other Federal agencies used the statistical model defined in ITU-R Recommendation P.452 to predict propagation losses for terrestrial systems.[59] This model takes into account five basic types of propagation mechanisms: line-of-sight (including signal enhancements due to multipath and focusing effects), diffraction (embracing smooth-earth, irregular terrain and sub-

[59] Recommendation ITU-R P.452-14, *Prediction Procedure for the Evaluation of Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.1 GHz* (Oct. 2009).

path cases), tropospheric scatter, anomalous propagation (ducting and layer reflection/refraction), and height-gain variation in clutter (where relevant). Spherical-earth propagation was assumed for all interference paths, except for interference paths into the meteorological-satellite receive stations, where the locations were known and propagation losses due to terrain were included.

For the single-entry analysis of shipborne radar systems, ITM in the Point-to-Point Prediction Mode was used in the compatibility analysis. In the point-to-point mode of ITM, the area is divided into cells and the program extracts the terrain profile from the “point” location to the center of each cell. Using the terrain features and the given antenna heights, the algorithm estimates the signal attenuation from the point to the cell location. The Point-to-Point mode calculations are based on the terrain profile between the transmitter and receiver, and system, environmental and statistical conditions. The terrain profile is extracted from a database using the latitude and longitude of the transmitting and receiving antennas. The United States Geological Survey–3 second topographic data which provides 90 meter resolution is used in the terrain dependent propagation loss calculations.

In the shipborne radar compatibility analysis, the DOD used the Advanced Refractive Effects Prediction System which utilizes the Advanced Propagation Model (APM). APM is a hybrid ray-optic and parabolic equation model that uses the complementary strengths of both methods to construct an accurate composite model. APM is applicable from 2 MHz to 95 GHz. It considers propagation paths over sea, land, or mixed (littoral). APM allows for an unlimited number of terrain points at any resolution, as well as an unlimited number of range-varying refractivity profiles.

Antenna Models

The compatibility analysis will only consider far-field antenna patterns for wireless broadband and Federal systems, even though there may be cases where systems can be located within the antenna near-field. This approach is used because of the complexity of modeling the antenna in the near-field. The following subsections summarize the antenna models for Federal and wireless broadband systems.

Wireless Broadband Systems

The antenna model for the wireless base stations is based on a modification of Recommendation ITU-R F.1336-2.[60] The modifications are made to the equations used to compute the azimuth portion of the antenna pattern.

[60] Recommendation ITU-R F.1336-2, *Reference Radiation Patterns of Omni directional, Sectoral and Other Antennas in Point-to-Multipoint Systems for Use in Sharing Studies in the Frequency Range from 1 GHz to About 70 GHz (*2007).

$$G(\varphi, \theta) = G_{ref}(x) \tag{4-8}$$

$$\alpha = arctan\left(\frac{\tan\theta}{\sin\varphi}\right) \tag{4-9}$$

$$\Psi_\alpha = \frac{1}{\sqrt{\left[\frac{\cos\alpha}{\varphi_3}\right]^2 + \left[\frac{\sin\alpha}{\theta_3}\right]^2}} \tag{4-10}$$

$$\theta_3 = \frac{(31{,}000 \times 10^{-0.1 \cdot G_0})}{\varphi_3} \tag{4-11}$$

$$= \varphi_3 \cdot \theta_3 \cdot \sqrt{\frac{\sin^2\theta + (\sin\varphi \cdot \cos\theta)^2}{(\varphi_3 \cdot \sin\theta)^2 + (\theta_3 \cdot \sin\varphi \cdot \cos\theta)^2}} \quad \text{degrees}$$

$$\Psi = \cos^{-1}(\cos\varphi \cdot \cos\theta) \quad \text{degrees} \tag{4-12}$$

$$x = {}^{\Psi}/_{\Psi_\alpha} \tag{4-13}$$

$$G_{ref}(x) = G_0 - 12x^2 \qquad \text{for } 0 \le \mathrm{x} < x_\mathrm{k} \tag{4-14}$$

$$G_{ref}(x) = G_0 - 16 + 70\log(x^{-1.5} + k) \qquad \text{for } x_k \le x < 4 \tag{4-15}$$

$$G_{ref}(x) = G_0 - \lambda_k - 33.889 - 15\log(x) \qquad \text{for } x \ge 4 \tag{4-16}$$

with

$$\lambda_k = 12 - 10\log(1 + 8k)$$

and

$$x_k = \sqrt{1.25 - 0.36k}$$

where:

$G(\theta)$:	Gain relative to an isotropic antenna (dBi)
G_0 :	Maximum gain in or near the horizontal plane (dBi)
θ:	Absolute value of the elevation angle relative to the angle of maximum gain (degrees)
θ_3:	3 dB beamwidth in the vertical plane (degrees)
k:	Parameter which accounts for increased side-lobe levels above what would be expected for an antenna with improved side-lobe performance
φ:	Azimuth angle relative to the angle of maximum gain (degrees)[61]
φ_3:	3 dB beamwidth of the sectoral antenna in the azimuth plane (degrees)

Recommendation F.1336-2 uses a parameter *k* that accounts for increased sidelobe levels above what would be expected for an antenna with improved sidelobe performance. A value of 0.2 for *k* will be used in this analysis.

Plots of the elevation and azimuth antenna patterns for the base stations are provided in Figure 4-3 and Figure 4-4.

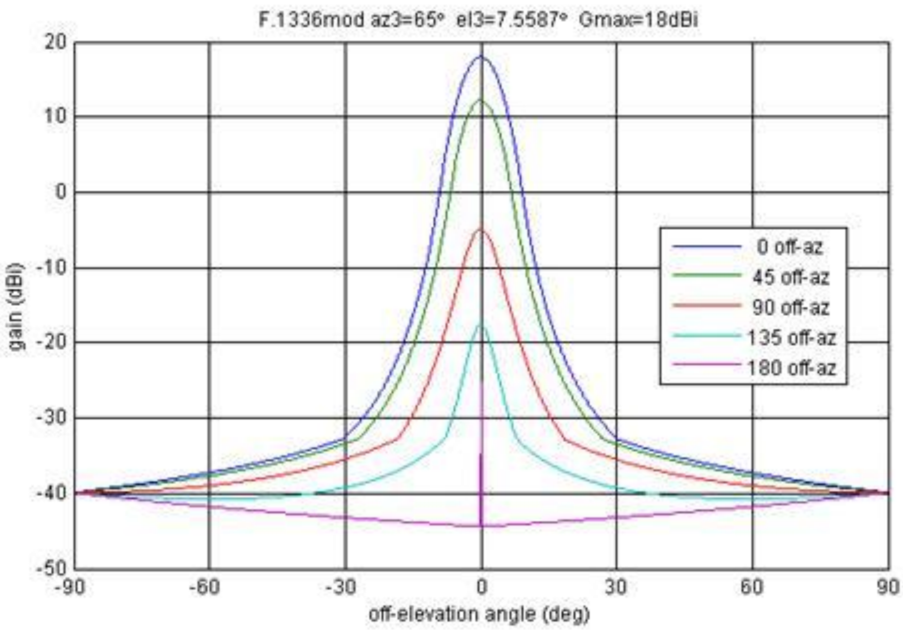

Figure 4-3. Elevation Antenna Pattern

[61] Azimuth angles range from -180 degrees to +180 degrees.

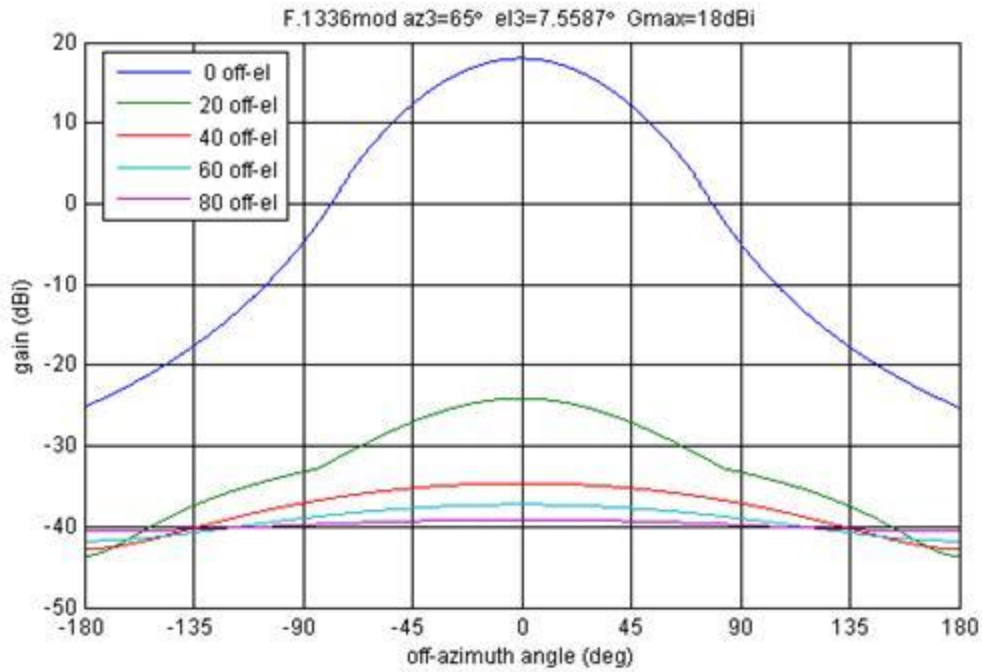

Figure 4-4. Azimuth Antenna Pattern

<u>Meteorological-Satellite Receive Earth Stations</u>

The antenna model for the meteorological-satellite receive Earth stations is based on Recommendation ITU-R F.1245-1.[62]

In cases where the ratio between the antenna diameter and the wavelength is greater than 100 ($D/\lambda > 100$), the following equations will be used:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0° < \varphi < \varphi_m \tag{4-17}$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < \max(\varphi_m, \varphi_r) \tag{4-18}$$

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

$$G(\varphi) = 29 - 25\log\varphi \qquad \text{for } \max(\varphi_\mathrm{m}, \varphi_\mathrm{r}) \le \varphi < 48° \tag{4-19}$$

$$G(\varphi) = -13 \qquad \text{for } 48° \le \varphi \le 180° \tag{4-20}$$

where:

G_{max}:	Maximum antenna gain (dBi)
$G(\varphi)$:	Gain relative to an isotropic antenna (dBi)
φ:	Off-axis angle (degrees)
D:	Antenna diameter (m)
λ:	Wavelength (m)
G_1:	Gain of the first side lobe = 2 + 15 log (D/λ)

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \text{ degrees} \tag{4-21}$$

$$\varphi_r = 12.02(D/\lambda)^{-0.6} \text{ degrees} \tag{4-22}$$

In cases where the ratio between the antenna diameter and the wavelength is less than or equal to 100 ($D/\lambda \le 100$), the following equation will be used:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for } 0° < \varphi < \varphi_m \tag{4-23}$$

$$G(\varphi) = 39 - 5\log(D/\lambda) - 25\log\varphi \qquad \text{for } \varphi_\mathrm{m} \le \varphi < 48° \tag{4-24}$$

$$G(\varphi) = -3 - 5\log(D/\lambda) \qquad \text{for } 48° \le \varphi \le 180° \tag{4-25}$$

D/λ is estimated using the following expression:

$$20\log\frac{D}{\lambda} \approx G_{max} - 7.7$$

where:

G_{max}:	Maximum antenna gain (dBi)

The antenna pattern for a 43 dBi mainbeam antenna gain is shown in Figure 4-5.

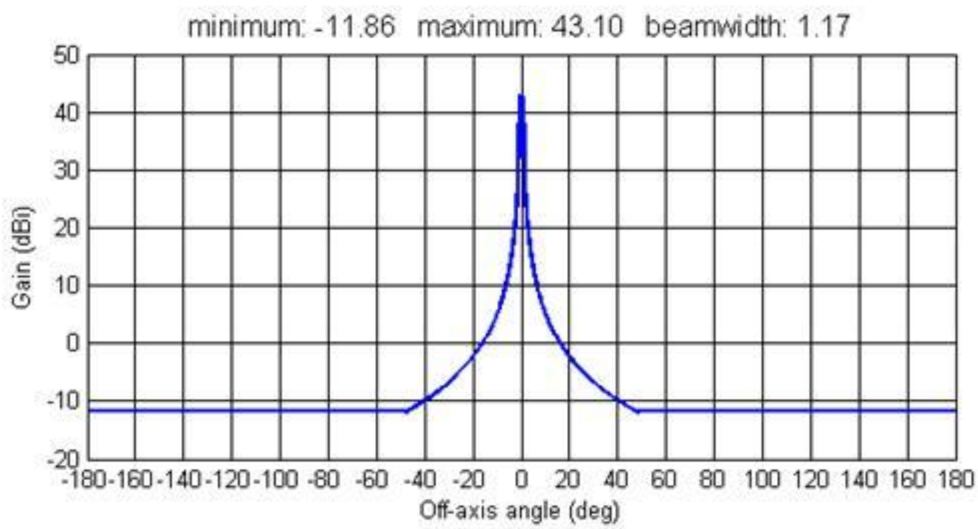

Figure 4-5. Azimuth and Elevation Antenna Pattern

Radar Systems

The gain antenna model described in Recommendation ITU-R M.1851 will be used to determine the antenna gain in the azimuth and elevation orientations for the ground-based and shipborne radar systems.[63] Recommendation ITU-R M.1851 provides a generalized mathematical model for radar systems antenna pattern models that can be used in analyses involving single and multiple interfering sources. Knowledge of the antenna 3 dB beamwidth and first peak side-lobe level, allows selection of equations for both the azimuth and elevation patterns. The model employs a theoretical directivity pattern up to the break point for either the peak or average antenna pattern. The peak pattern mask applies to a single-entry interference analysis and the average pattern mask applies to an aggregate interference analysis. In this analysis a cosine pattern will be used for the radar systems antenna. The equations for the theoretical antenna directivity parameters of the model are provided in Table 4-10. The equations for the peak and average mask patterns used in the model are provided in Table 4-11.

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[63] Recommendation ITU-R M.1851, *Mathematical Models for Radio determination Radar Systems Antenna Patterns for use in Interference Analyses (*June 2009).

Table 4-10. Antenna Directivity Parameters

Relative shape of field distribution $f(x)$ where $-1 \le x \le 1$	**Directivity pattern $F(\mu)$**	**θ_3 half power beam-width (degrees)**	**μ as a function of θ_3**	**First side-lobe level below main lobe peak (dB)**	**Proposed mask floor level (dB)**
Cosine(π*x/2)	$\frac{\pi}{2}\left[\frac{\cos(\mu)}{\left(\frac{\pi}{2}\right)^2-\mu^2}\right]$	$68.8\left(\frac{\lambda}{l}\right)$	$\frac{\pi\cdot 68.8\cdot\sin(\theta)}{\theta_3}$	−23	−50

Table 4-11. Peak and Average Mask Pattern Equations

Pattern type	**Mask equation beyond pattern break point where mask departs from theoretical pattern (dB)**	**Peak pattern break point where mask departs from theoretical pattern (dB)**	**Average pattern break point where mask departs from theoretical pattern (dB)**	**Constant added to the peak pattern to convert it to average mask (dB)**
Cosine	$-17.51\cdot\ln\left(2.33\cdot\frac{\lvert\theta\rvert}{\theta_3}\right)$	−14.4	−20.6	−4.32
The function ln() is the natural log function.				

The following equation will be used to model the off-axis antenna gain pattern for the airborne radar systems:

$$G(\theta) = G_{Max} - 12\left(\frac{\theta}{BW}\right)^2 \qquad (4\text{-}26)$$

where:

- $G(\theta)$: Antenna gain at the off-axis angle of θ in degrees (dBi)
- G_{Max}: Mainbeam antenna gain (dBi)
- BW: Antenna beamwidth (degrees)

Radiosonde Systems

The patterns for the radiosonde receive antenna (azimuth and elevation) and transmit antenna used in the compatibility analyses are shown in Figures 4-6 and 4-7.

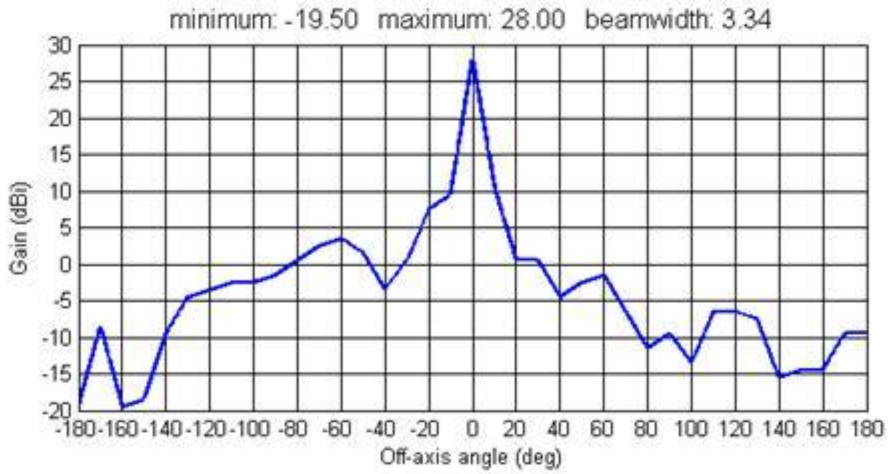

Figure 4-6. Radiosonde Receive Antenna Pattern

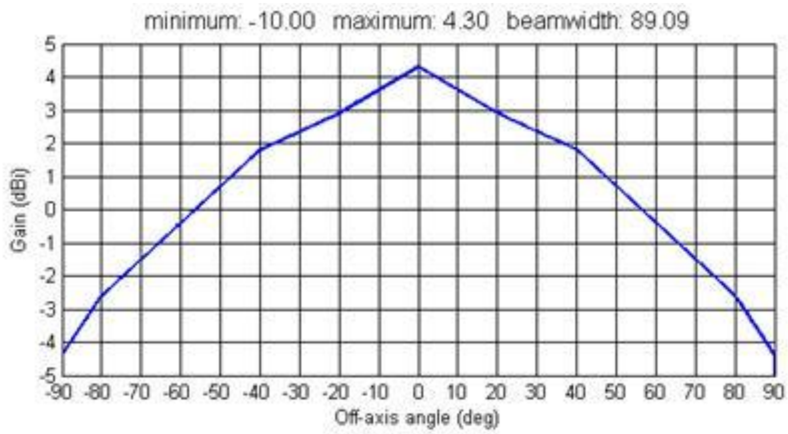

Figure 4-7. Radiosonde Transmit Antenna Pattern

Frequency Dependent Rejection

Frequency Dependent Rejection (FDR) accounts for the fact that not all of the undesired transmitter energy at the receiver input will be available at the detector. FDR is a calculation of the amount of undesired transmitter energy that is rejected by a victim receiver. This FDR attenuation is composed of two parts: on-tune rejection (OTR) and off-frequency rejection (OFR). The OTR is the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of an emission spectrum exceeding the receiver bandwidth, in dB. The OFR is the additional rejection, caused by specified detuning of the receiver with respect to the transmitter, in dB. The FDR values used in this analysis were computed using an automated program.[64]

In the case of an undesired transmitter operating co-frequency to a victim receiver, the FDR is represented by the OTR using the following simplified form shown in Equation 4-27 when the transmit power is based on average power.

$$OTR = \max\left[0, 10\log\left(\frac{B_{tx}}{B_{rx}}\right)\right] \tag{4-27}$$

where:

B_{tx} : Emission bandwidth of the transmitter

B_{rx} : IF bandwidth of the receiver

When the system is pulsed and the transmit power is based on peak power, the FDR is represented by OTR for the case where the transmitter is co-frequency to a victim receiver is determined using the form shown in Equation 4-28.

$$OTR = \max\left[0, 20\log\left(\frac{B_{tx}}{B_{rx}}\right)\right] \tag{4-28}$$

The transmitter emission spectrum and receiver selectivity curves used in the FDR model are defined in terms of a relative attenuation level specified in decibel as a function of frequency offset from center frequency in megahertz.

After the last point in the emission spectrum curve the slope of the last two points is used to extend the curve down to a point defined by 90 + 10 Log (B_{tx}) dB. Beyond this point, the emission spectrum roll-off is 40 dB/decade.

For the receiver selectivity curve the slope of the last two points is used to extend the curve down to a point defined by 80 dB. Beyond this point, the receiver selectivity roll-off is 40 dB/decade.

Additional Losses

In the single-entry compatibility analysis an additional factor is included for insertion loss, cable loss, etc. For the wireless base station transmitters and receivers a nominal value of 2

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[64] The FDR program used in this analysis is part of the NTIA Microcomputer Spectrum Analysis Models (MSAM) software package. MSAM can be downloaded from http://ntiacsd.ntia.doc.gov/msam.

dB will be included in the analysis. The analysis will also include a nominal value of 2 dB for Federal transmitters and receivers.

For the aggregate compatibility analysis, other losses that are taken into account include the loss due to buildings or non-specific terrain. In this analysis, a uniform random number is chosen to represent a varying loss case for building blockage, terrain features, and multi-path, depending on the wireless broadband system deployment regions (urban, suburban, and rural). The range of the non-specific terrain losses used in this analysis is given in Table 4-12.

Table 4-12. Non-Specific Terrain Losses

Wireless System Deployment Region	Range of Non-Specific Terrain Losses
Base Station	
Urban	5 to 10 dB
Suburban	0 to 5 dB
Rural	0 dB
Mobile/Portable Station	
Urban	10 to 20 dB
Suburban	5 to 15 dB
Rural	0 to 5 dB

Transmitter Duty Cycle

The duty cycle is the fraction of time that a system is in an “active” state. The duty cycle used for the Federal and wireless broadband transmitters considered in the compatibility analysis are described in the following subsections.

Wireless Broadband Systems

For the single-entry analysis, a duty cycle of 100 percent will be used for all wireless base and mobile/portable stations.

For the aggregate analysis of wireless FDD systems a duty cycle of 100 percent will be used for mobile/portable stations.

For the aggregate analysis of wireless TDD systems at a given instant in time 62.5 percent of the base stations will be transmitting and 37.5 percent of the mobile/portable stations will be transmitting.

Radar Systems

For radar systems the duty cycle is the product of the pulse duration and pulse repetition frequency of a pulse carrier, equal to the time per second that pulse power is applied. The duty cycle is used to compute the average power of the radar transmitter.

Meteorological Satellite Systems

For the single-entry analysis the meteorological satellite will be transmitting 100 percent of the time.

Radiosonde Systems

For the single-entry analysis the radiosonde will be transmitting 100 percent of the time.

Base and Mobile Station Deployment

1695-1710 MHz Band

Based on the deployment information provided in Table 4-2, there would be 169,680 mobile stations in the 1695-1710 MHz band. Since a base station has three sectors each with a different frequency the total number of mobile stations transmitting on a given frequency considered in this analysis is 56,560.

3500-3650 MHz Band

Based on the deployment information provided in Table 4-2, there would be 675 base and 283,500 mobile stations in the 3500-3650 MHz band. The base and mobile stations have a duty cycle of 62.5 percent and 37.5 percent respectively. The total number of base stations transmitting at a given instant in time is 422, and the total number of mobile stations is 106,313.

Analysis Methodology

As described in Tables 4-3 and 4-4 in assessing compatibility between Federal and wireless broadband systems different types of analysis will be performed depending on the frequency band under consideration. In this analysis compatible operation is defined when the received interference power level from the Federal or wireless broadband system transmitter is below the established receiver interference threshold. The following subsections describe the different analysis methodologies.

Terrestrial Single-Entry Analysis

In assessing the potential interference from a ground-based, shipborne, and airborne radar system transmitter to a wireless base and mobile/portable station receiver a single-entry analysis will be performed. The analysis will determine the minimum required propagation loss between the radar transmitter and the wireless receiver to preclude potential interference. The minimum required propagation loss is computed using Equation 4-29.

$$L_{Required} = P_T + G_T + G_R - L_T - L_T - I_T - FDR \tag{4-29}$$

where:

$L_{Required}$:	Minimum required propagation loss necessary to preclude potential interference (dB)
I_T:	Receiver interference threshold (dBm)
P_T:	Power of the transmitter (dBm)
G_T:	Antenna gain of the transmitter in the direction (azimuth and elevation) of the receiver (dBi)
G_R:	Antenna gain of the receiver in the direction (azimuth and elevation) of the transmitter (dBi)
L_T:	Transmitter insertion loss (dB)
L_R:	Receiver insertion loss (dB)
L_P:	Propagation loss (dB)
FDR:	Frequency dependent rejection (dB)

The minimum required propagation loss computed using Equation 4-29 is then used to determine the minimum separation distance between the radar transmitters and the wireless broadband systems. The minimum separation distance establishes the radius of the exclusion zones around the Federal systems.

The terms in Equation 4-29 can be re-arranged to compute the received interference power level (I).

$$I = P_T + G_T + G_R - L_T - L_R - L_P - FDR \tag{4-30}$$

The available margin can then be computed as follows:

$$M_{Available} = I_T - I \tag{4-31}$$

When the values of available margin are negative potential interference can occur. For positive values of available margin interference will not occur.

<u>Terrestrial Aggregate Analysis</u>

The interference power levels at the Federal system receiver are calculated using Equation 4-32 for each wireless base and mobile/portable station transmitter being considered in the analysis.

$$I = P_T + G_T + G_R - L_T - L_R - L_P - L_L - FDR \tag{4-32}$$

where:

I:	Received interference power at the output of the antenna (dBm)
P_T:	Power of the base or mobile/portable station transmitter (dBm)
G_T:	Antenna gain of the base or mobile/portable station transmitter in the direction of the receiver (dBi)
G_R:	Antenna gain of the receiver in the direction of the base or mobile/portable station transmitter (dBi)
L_T:	Transmitter insertion loss (dB)
L_R:	Receiver insertion loss (dB)
L_P:	Propagation loss (dB)
L_L:	Building and non-specific terrain losses (dB)
FDR:	Frequency dependent rejection (dB)

Using Equation 4-32, the values of interference power level are calculated for each wireless base and mobile/portable station being considered in the analysis. These individual interference power levels are then used in the calculation of the aggregate interference to the Federal system receivers using Equation 4-33.[65]

$$I_{AGG} = 10 \log \left[\sum_{j=1}^{N} I_j \right] + 30 \tag{4-33}$$

where:

I_{AGG}:	Aggregate interference to the Federal system receiver from the wireless base and mobile/portable transmitters (dBm)
N:	Number of wireless base and mobile/portable transmitters
I:	Interference power level at the input of the Federal system receiver from an individual wireless base and mobile/portable transmitter (Watts)

The difference between the received aggregate interference power level computed using Equation 4-33 and the receiver interference thresholds represents the available margin. When the available margin is positive, compatible operation is possible. The distance at which the available margin is zero represents the minimum distance separation that is necessary for compatible operation. This distance is used to establish the radius of the exclusion zones around the Federal systems.

[65] The interference power calculated in Equation 4-32 must be converted from dBm to Watts before calculating the aggregate interference seen by the Federal system receiver using Equation 4-33.

Satellite and Airborne Single Entry Analysis

In this analysis, compatible operation is defined when the received interference power level from the Federal meteorological-satellite transmitters, radiosonde transmitters or airborne radar transmitters is below the interference threshold of the wireless base station receiver. The difference between the received interference power level computed using Equation 4-32 and the interference threshold of the base station receivers represents the available margin. When the available margin is positive, compatible operation is possible.

Compatibility Analysis of Federal Transmitters and Wireless Broadband Receivers

1695-1710 MHz Band Compatibility Analysis

This analysis examines electromagnetic compatibility between the Federal meteorological GOES transmitters, POES transmitters, and radiosonde transmitters and wireless base station receivers based on the LTE standard operating in the 1695-1710 MHz band.

GOES-N to LTE Base Station Analysis

The GOES-N transmitter and antenna characteristics are provided in Appendix A. Examination of the LTE base station receiver characteristics in Appendix B shows the minimum bandwidth to be the 5 MHz channel with a 3 dB receiver IF bandwidth of 4.75 MHz. Comparing the receiver bandwidth with the emission bandwidth shows that all GOES-N transmitter configurations have emissions that would pass through the base station filter with no on-tune rejection. Thus, the base station with the narrowest bandwidth configuration would result in the limiting interference situation as this condition would have the lowest receiver system noise level. The GOES-N Processed Data Relay signal has the highest transmitter power level (44.5 dBm). The GOES-N emission bandwidth combined with the 5 MHz channel base station receiver configuration is examined as the limiting case.

The GOES-N transmitter power is 44.5 dBm. The GOES-N transmit main beam antenna gain is 15.6 dBi. The height of the geostationary orbit is 35,800 km above the surface of the Earth. Using Equation 4-6, the minimum free space loss at a frequency of 1700 MHz is:

$$L_{FS} = 32.4 + 20\log 35800 + 20\log 1700 = 188.1 \text{ dB}$$

The antenna gain for the base station was determined from Figure 4-3. The antenna was assumed to be directed at the GOES-N satellite in the azimuth plane. The base station antenna has an antenna down tilt angle of 3 degrees and, for a location in the middle portion of the United States, the antenna elevation angle to the satellite was assumed to be 10 degrees. Thus, the gain for an elevation angle of 12 degrees is -32 dBi.

Using Equation 4-30, the received interference power level in the bandwidth of the base station receiver and referenced to the output of the receiver antenna is:

$$I = 44.5 \text{ dBm} + 15.6 \text{ dBi} - 188.1 \text{ dB} - 32 \text{ dBi} - 2 \text{ dB} - 0 \text{ dB}$$
$$= -162 \text{ dBm}$$

The interference threshold for the base station receiver is -108.5 dBm, corresponding to an I/N of -6 dB.

Comparing the computed received interference power level to the interference threshold the available margin is approximately 54 dB. The other combinations of GOES-N transmitter emissions and wireless base station receiver configurations would result in available margins that exceed 54 dB.

GOES-R to LTE Base Station Analysis

As shown in Appendix A, the GOES-R configurations, HRIT, DCPR#1, DCPR transponder #1 and #2 and Command and Data Acquisition Telemetry (CDA TLM) all have emission bandwidths that are less than 4.75 MHz. The value of 4.75 MHz is the minimum bandwidth of the LTE base station receiver in its narrow channel configuration. For the GOES-R emissions listed above, the transmitter/receiver combinations would have an on-tune rejection of 0 dB for the LTE base station receiver.

The GOES-R transmitter characteristics show the HRIT configuration to have the highest transmitter power (44 dBm) of the HRIT, DCPR#1, DCPR #2, and CDA TLM configurations. The HRIT configuration is the limiting case for computing the received interference power level at the output of the base station receiver. The transmit antenna gain for the HRIT transmission is 16.9 dBi. The propagation loss and base station antenna gain in the direction of the satellite are the same values previously used in the GOES-N analysis. Using Equation 4-30, the received interference signal power level at the input to the base station receiver is:

$$I = 44 \text{ dBm} + 16.9 \text{ dBi} - 188.1 \text{ dB} - 32 \text{ dBi} - 2 \text{ dB} - 0 \text{ dB}$$
$$= -161.2 \text{ dBm}$$

The interference threshold is –108.5 dBm. The difference between the computed received interference power at the receiver and the interference threshold shows that there is an available margin of approximately 53 dB.

Consideration of the GOES-R Rebroadcast (GRB) #1 and #2 configurations results in an increase in transmitter power to 47 dBm and the GOES-R emission bandwidth is increased to 10.8 MHz. Using Equation 4-27, reception of these signals by the base station receiver in the 5 MHz channel configuration would yield an OTR of:

$$OTR = 10 \log\left(\frac{10.8}{4.75}\right) = 3.6 \text{ dB}$$

Using Equation 4-30, the received interference signal power level at the input to the base station receiver is:

$$I = 47 \text{ dBm} + 16.9 \text{ dBi} - 188.1 \text{ dB} - 32 \text{ dBi} - 2 \text{ dB} - 3.6 \text{ dB}$$
$$= -161.8 \text{ dBm}$$

The interference threshold is -108.5 dBm for the 5 MHz base station channel. The resulting available margin is approximately 53 dB.

Using Equation 4-27, for the GRB#1 and GRB#2 emissions with the base station operating with the 10 MHz channel (9.5 MHz 3 dB emission bandwidth), the OTR is:

$$OTR = 10 \log\left(\frac{10.8}{9.5}\right) = 0.6 \text{ dB}$$

Using Equation 4-30, the received interference signal power level at the input to the base station receiver is:

$$I = 47 \text{ dBm} + 16.9 \text{ dBi} - 188.1 \text{ dB} - 32 \text{ dBi} - 2 \text{ dB} - 0.6 \text{ dB}$$
$$= -158.8 \text{ dB}$$

The interference threshold for the 10 MHz base station configuration is -105.5 dBm resulting in an available margin of approximately 53 dB.

POES to LTE Base Station Analysis

The equipment characteristics of the POES transmitter and transmit antenna are provided in Appendix A. The base station characteristics are provided in Appendix B.

The POES transmitter and the base station receiver are assumed to operate co-frequency so the off-frequency rejection used in the analysis will be 0 dB. The minimum (3 dB) bandwidth of the base station receiver is 4.75 MHz. The POES satellite transmitter maximum (3 dB) emission bandwidth is 3.5 MHz. Thus, the satellite emission will pass through the base station receiver with no OTR.

The POES transmitter power is 38 dBm and the antenna gain at the direction of the Earth's horizon is 2.5 dBi.

The satellite transmitter/base station geometry that will be examined initially is that of both terminals looking at a common Earth horizon. For this case, the base station mainbeam directed at the satellite will be considered. The base station antenna has a down-tilt angle of 3 degrees. Using this tilt angle and the base station elevation gain pattern shown in Figure 4-3, the gain at the horizon is 10 dBi.

The path distance from the base station radio horizon to the satellite can be determined by representing the problem as two concentric circles with the smaller circle representing the Earth with a radius of 6371 km and the outer circle with a radius representing of 7211 km (6371+839 km), where 839 km is the average altitude (above the Earth's surface) for the five POES spacecraft. The 7211 km is the height of the satellite above the center of the Earth. A chord of the larger circle is then struck so that it touches a singular point on the inner circle. At this point, the chord is tangent to the inner circle. A line is then drawn from the tangent point to the center of the circles. This line represents the Earth's radius (6371 km). Another line is drawn from one end of the chord to the center of the circles. This represents the radius of the satellite orbit (7211 km). The third side of this triangle is one-half of the chord from the tangent point to the outer circle. This is a right triangle because of the chord being tangent to the inner circle. Thus, the length of the chord (d) from the tangent point to the outer circle can be determined as follows:

$$7211^2 = d^2 + 6371^2$$

$$d = 3377 \text{ km}$$

This is the propagation path length from the base station radio horizon to the POES satellite. One must add the distance to the horizon (from the base station) to 3377 km to get the total path length. For a base station antenna height of 60 m, the distance (d´) to the base station horizon is (4/3 Earth's effective radius):

$$d' = 4.1 \cdot \sqrt{60} = 31.8 \text{ km}$$

The total propagation path length is then 3377 + 31.8 = 3409 km. The free space propagation loss from the satellite to the base station receiver for a frequency of 1700 MHz computed using Equation 4-6 is:

$$L_{FS} = 20 \log 1700 + 20 \log 3409 + 32.45 = 167.7 \text{ dB}$$

The triangle, used to find the path length, can be used to determine the angle between the satellite nadir position and the direction of the Earth horizon is:

$$\cos\theta = \frac{3377}{7211}$$

$$\theta = 62°$$

This is in agreement with the bearing for POES sidelobe antenna gain.

There is an additional loss of 2 dB between the base station antenna and receiver.

The interference threshold for the base station receiver is -108.5 dBm for the 5 MHz channel configuration. This is the most sensitive configuration (worse case). This threshold is for an I/N of -6 dB.

Using Equation 4-30 the received interference signal power level at the input to the base station receiver is:

$$I = 38\text{ dBm} + 2.5\text{ dBi} - 167.7\text{ dB} + 10\text{ dBi} - 2\text{ dB} = -119.2\text{ dBm}$$

The interference threshold is -108.5 dBm for the 5 MHz base station channel. The resulting available margin is approximately 11 dB.

Table 4-13 presents the available margin for different base station receiver I/N values.

Table 4-13. Available Margin for Various Base Station Receiver I/N Values

I/N (dB)	Available Margin (dB)
-6	11
0	17
3	20
6	23
10	27

If the satellite to base station geometry where the base station is at the nadir angle is considered, the propagation path length would be 839 km (compared to 3399.4 km for the common horizon geometry) resulting in a ratio of approximately 1:4. This would result in a 12 dB decrease in path loss. However, the receive antenna gain at the base station zenith angle would be between -40 to -50 dBi and the POES satellite maximum antenna gain, in the nadir direction, is 4.6 dBi. These terms would result in a net decrease in the received interference signal power of approximately 36 dB providing additional margin. Thus, the previous scenario considered is the limiting interference case.

Radiosonde to Base Station Analysis

The radiosonde transmitter characteristics for this analysis are provided in Appendix A. The transmitter power is 23.8 dBm and the antenna gain is 4.3 dBi. The gain of the base station antenna at the horizon with an antenna down tilt angle of 3 degrees is 13 dBi. Non-specific terrain losses are not included in the analysis.

Using Equation 4-30 the received interference power level in the bandwidth of the base station receiver and referenced to the output of the receiver antenna is:

$$I = 23.8 \text{ dBm} + 4.3 \text{ dBi} + 13 \text{ dBi} - 2 \text{ dB} - FDR - L_P$$

The radiosonde transmitter operates in the 1676-1683 MHz band. If base station receivers operate above 1695 MHz, for a 5 MHz Channel the lowest center frequency is 1697.5 MHz. The minimum frequency separation between a radiosonde transmitter and base station receiver is approximately 14 MHz. For a minimum frequency separation of 14 MHz the FDR is 66 dB for a 5 MHz Channel base station configuration and 52 dB for a 10 MHz Channel configuration.

The propagation loss is computed using Equation 4-6 for free space propagation loss for a frequency of 1700 MHz. The calculated received interference power levels between the radiosonde transmitter and a base station receiver are calculated. The available margin for a base station receiver I/N value of -6 dB are provided in Table 4-14 (5 MHz Channel) and Table 4-15 (10 MHz Channel) respectively.

Table 4-14. Available Margin for 5 MHz Channel Base Station Receiver

Distance Between Radiosonde and Base Station (km)[a]	Altitude (km)	L_P (dB)	I (dBm)	I_T (dBm)	Available Margin (dB)
25	0.5	125	-151.9	-108.5	43.4
50	1	131	-157.9	-108.5	49.4
100	5	137	-163.9	-108.5	55.4
150	10	141	-167.9	-108.5	59.4
200	18	143	-169.9	-108.5	61.4
250	20	145	-171.9	-108.5	63.4
320	35	147	-173.9	-108.5	65.4

Table 4-15. Available Margin for 10 MHz Channel Base Station Receiver

Distance Between Radiosonde and Base Station (km)[a]	Altitude (km)	L_P (dB)	I (dBm)	I_T (dBm)	Available Margin (dB)
25	0.5	125	-137.9	-105.5	32.4
50	1	131	-143.9	-105.5	37.4
100	5	137	-149.9	-105.5	44.4
150	10	141	-153.9	-105.5	48.4
200	18	143	-155.9	-105.5	50.4
250	20	145	-157.9	-105.5	52.4
320	35	147	-159.9	-105.5	54.4

Using the methodology above, the available margin when a radiosonde transmitter is directly above a base station is computed. The radiosonde transmitter characteristics for this analysis are provided in Appendix A. The transmitter power is 23.8 dBm and the antenna gain is 4.3 dBi. The gain of the base station antenna in the direction of a radiosonde transmitter that is directly above the base station is approximately 0 dBi. Non-specific terrain losses are not included in the analysis.

Using Equation 4-30, the received interference power level in the bandwidth of the base station receiver and referenced to the output of the receiver antenna is:

$$I = 23.8 \text{ dBm} + 4.3 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - FDR - L_P$$

For a minimum frequency separation of 13 MHz, the FDR is 65 dB for a 5 MHz Channel configuration and 51 dB for a 10 MHz Channel configuration.

The propagation loss is computed using Equation 4-6 for free space propagation loss for a frequency of 1700 MHz. The calculated received interference power levels between the radiosonde transmitter and a base station receiver are calculated. The available margin for a base station receiver I/N value of -6 dB are provided in Table 4-16 (5 MHz Channel) and Table 4-17 (10 MHz Channel), respectively.

Table 4-16. Available Margin for 5 MHz Channel Base Station Receiver

Altitude Above Base Station (km)	L_P (dB)	I (dBm)	I_T (dBm)	Available Margin (dB)
0.5	91	-130.9	-108.5	22.4
1	97	-136.9	-108.5	28.4
5	111	-150.9	-108.5	42.4
10	117	-156.9	-108.5	48.4
18	122	-151.9	-108.5	53.4
20	123	-162.9	-108.5	54.4
35	128	-167.9	-108.5	59.4

Table 4-17. Available Margin for 10 MHz Channel Base Station Receiver

Altitude Above Base Station (km)	L_P (dB)	I (dBm)	I_T (dBm)	Available Margin (dB)
0.5	91	-116.9	-105.5	11.4
1	97	-122.9	-105.5	17.4
5	111	-136.9	-105.5	31.4
10	117	-142.9	-105.5	37.4
18	122	-147.9	-105.5	42.4
20	123	-148.9	-105.5	43.4
35	128	-153.9	-105.5	48.4

A MATLAB computer simulation was also performed that calculates the power received at the input of a base station receiver from a radiosonde transmitter. The results of the radiosonde simulation are provided in Appendix C.

As shown in the analysis and the simulation, radiosonde transmitters operating in the 1676-1683 MHz band will not cause interference to base station receivers operating above 1695 MHz.

3500-3650 MHz Band Compatibility Analysis

Ground-Based Radar – 1 to WiMAX Base Station Analysis

The average power of the Ground-Based Radar – 1 transmitter for a 10 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 75 \text{ dBm} + 10 \log\left(\frac{10}{100}\right) = 65 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 36 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR computed using Equation 4-27 is 0 dB.

The minimum required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using Equation 4-29:

$$L_{Required} = 65 \text{ dBm} + 36 \text{ dBi} + 13 \text{ dBi} - 2 \text{ dB} - 2 \text{ dB} - 0 \text{ dB} - OFR - I_T$$

Using the ITM with the parameters specified in Table 4-9, the minimum separation distance for Ground-Based Radar – 1 for different frequency offsets is computed. The required separation distances are computed for base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB.[66] The analysis results are summarized in Table 4-18 (5 MHz Channel), Table 4-19 (10 MHz Channel), and Table 4-20 (20 MHz Channel).

[66] The DOD analysis for the base station started with receiver at the edge of the rural region. The receiver was stepped away sequentially from the regions in 0.5 kilometer distance increments. At each distance increment, the interference level from the ground-based radar transmitter was calculated. These calculated interference levels were used to create distance versus interference plots where a minimum separation distance was determined based on the interference threshold.

Table 4-18. Ground-Based Radar – 1 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	220.2	380
50	89	131.2	23
100	95	125.2	16
I/N = 0 dB			
0	0	214.2	320
50	89	125.2	16
100	95	119.2	9
I/N = 3 dB			
0	0	211.2	292
50	89	122.2	12
100	95	116.2	6
I/N = 6 dB			
0	0	208.2	266
50	89	119.2	9
100	95	113.2	4.5
I/N = 10 dB			
0	0	204.2	232
50	89	115.2	5.5
100	95	109.2	3

Table 4-19. Ground-Based Radar – 1 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	217.2	349
50	84	133.2	25
100	90	127.2	19
I/N = 0 dB			
0	0	211.2	292
50	84	127.2	19
100	90	121.2	11
I/N = 3 dB			
0	0	208.2	266
50	84	124.2	15
100	90	118.2	8
I/N = 6 dB			
0	0	205.2	240
50	84	121.2	11
100	90	115.2	5.5
I/N = 10 dB			
0	0	201.2	208
50	84	117.2	7
100	90	111.2	3.5

Table 4-20. Ground-Based Radar – 1 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	214.2	320
50	66	148.2	40
100	79	135.2	27
I/N = 0 dB			
0	0	208.2	266
50	66	142.2	34
100	79	129.2	21
I/N = 3 dB			
0	0	205.2	240
50	66	139.2	30
100	79	126.2	17
I/N = 6 dB			
0	0	202.2	216
50	66	136.2	27.5
100	79	123.2	13
I/N = 10 dB			
0	0	198.2	184
50	66	132.2	24
100	79	119.2	9

Ground-Based Radar – 1 to WiMAX Mobile Station Analysis

The average power of the Ground-Based Radar – 1 transmitter for a 10 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 75\text{ dBm} + 10\log\left(\frac{10}{100}\right) = 65\text{ dBm}$$

The radar transmitter antenna gain in the direction of a mobile station is 16 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR computed using Equation 4-27 is 0 dB.

The minimum required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using Equation 4-29:

$$L_{Required} = 65\text{ dBm} + 16\text{ dBi} + 0\text{ dBi} - 2\text{ dB} - 0\text{ dB} - I_T$$

Using the ITM with the parameters specified in Table 4-9, the minimum separation distance for Ground-Based Radar – 1 is computed. The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations for a frequency separation of 0 MHz are summarized in Table 4-21.

Table 4-21. Ground-Based Radar – 1 to WiMAX Mobile Station, 5 MHz Channel, 0 MHz Frequency Separation

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	187.2	184.2	181.2	54	50	46
0	181.2	178.2	175.2	46	43	39
3	178.2	175.2	172.2	43	39	35
6	175.2	172.2	169.2	39	35	32
10	171.2	168.2	165.2	34	31	27

A frequency separation of greater than 40 MHz will reduce the minimum separation distances in Table 4-21 to less than 1 km.

Ground-Based Radar – 2 to WiMAX Base Station Analysis

The peak power of the Ground-Based Radar – 2 transmitter is 53 dBm. The average power of the radar transmitter for a duty cycle is computed using Equation 4-5:

$$P_{AVG} = 53\text{ dBm} + 10\log 0.0001 = 14.6\text{ dBm}$$

The radar transmitter mainbeam antenna gain is 8 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR computed using Equation 4-27 is 0 dB for all base station channel configurations.

The minimum required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using Equation 4-29:

$$L_{Required} = 14.6\text{ dBm} + 8\text{ dBi} + 13\text{ dBi} - 2\text{ dB} - 2\text{ dB} - 0\text{ dB} - OFR - I_T$$

Using the ITM with the parameters specified in Table 4-9, the minimum separation distance for Ground-Based Radar – 2 for different frequency offsets are computed. The required separation distances are computed for base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results are summarized in Table 4-22 (5 MHz Channel), Table 4-23 (10 MHz Channel), and Table 4-24 (20 MHz Channel).

Table 4-22. Ground-Based Radar – 2 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	141.8	33
40	46	95.8	< 1
100	66	75.8	< 1
I/N = 0 dB			
0	0	135.8	27
40	46	89.8	< 1
100	66	69.8	< 1
I/N = 3 dB			
0	0	132.8	24
40	46	86.8	< 1
100	66	66.8	< 1
I/N = 6 dB			
0	0	129.8	22
40	46	83.8	< 1
100	66	63.8	< 1
I/N = 10 dB			
0	0	125.8	17
40	46	79.8	< 1
100	66	59.8	< 1

Table 4-23. Ground-Based Radar – 2 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	138.8	30
40	43	95.8	< 1
100	64	74.8	< 1
I/N = 0 dB			
0	0	132.8	25
40	43	89.8	< 1
100	64	68.8	< 1
I/N = 3 dB			
0	0	129.8	22
40	43	86.8	< 1
100	64	65.8	< 1
I/N = 6 dB			
0	0	126.8	19
40	43	83.8	< 1
100	64	62.8	< 1
I/N = 10 dB			
0	0	122.8	13
40	43	79.8	< 1
100	64	58.8	< 1

Table 4-24. Ground-Based Radar – 2 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	135.8	27
40	41	94.8	< 1
100	62	73.8	< 1
I/N = 0 dB			
0	0	129.8	22
40	41	88.8	< 1
100	62	67.8	< 1
I/N = 3 dB			
0	0	126.8	18
40	41	85.8	< 1
100	62	64.8	< 1
I/N = 6 dB			
0	0	123.8	14
40	41	82.8	< 1
100	62	61.8	< 1
I/N = 10 dB			
0	0	119.8	10
40	41	78.8	< 1
100	62	57.8	< 1

Ground-Based Radar – 2 to WiMAX Mobile Station Analysis

The peak power of the Ground-Based Radar – 2 transmitter is 53 dBm. The average power of the radar transmitter for a duty cycle is computed using Equation 4-5:

$$P_{AVG} = 53 \text{ dBm} + 10 \log(0.0001) = 14.6 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 8 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the mobile station antenna is approximately 0 dBi. The OTR computed using Equation 4-27 is 0 dB.

The minimum required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using Equation 4-29:

$$L_{Required} = 14.6 \text{ dBm} + 8 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - 0 \text{ dB} - I_T$$

Using the ITM with the parameters specified in Table 4-9, the minimum separation distance for Ground-Based Radar – 2 are computed. The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-25.

Table 4-25. Ground-Based Radar – 2 to WiMAX Mobile Station

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	128.8	125.8	122.8	3	2.5	1.5
0	122.8	119.8	116.8	1.5	1	< 1
3	119.8	116.8	113.8	1	< 1	< 1
6	116.8	113.8	110.8	< 1	< 1	< 1
10	112.8	109.8	106.8	< 1	< 1	< 1

A frequency separation of greater than approximately 10 MHz will reduce the minimum separation distances in Table 4-25 to less than 1 km.

Ground-Based Radar – 3 to WiMAX Base Station Analysis

The average power of the Ground-Based Radar – 3 transmitter is computed using Equation 4-5:

$$P_{Avg} = 78\text{ dBm} + 10\log(0.16) = 70\text{dBm}$$

The radar transmitter mainbeam antenna gain is 39.7 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR values are 3.3 dB (5 MHz Channel), 0 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The minimum required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using Equation 4-29:

$$L_{Required} = 70\text{ dBm} + 39.7\text{ dBi} + 13\text{ dBi} - 2\text{ dB} - 2\text{ dB} - 0 - OFR - I_T$$

The minimum separation distance for Ground-Based Radar – 3 for different frequency offsets is computed. The required separation distances are computed for base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results are summarized in the tables below for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel.

Table 4-26. Ground-Based Radar – 3 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	3.3	225.6	439
50	62	166.9	61
100	85	143.9	35
I/N = 0 dB			
0	3.3	219.6	373
50	62	160.9	54
100	85	137.9	29
I/N = 3 dB			
0	3.3	216.6	343
50	62	157.9	50
100	85	134.9	26
I/N = 6 dB			
0	3.3	213.6	314
50	62	154.9	47
100	85	131.9	24
I/N = 10 dB			
0	3.3	209.6	278
50	62	150.9	42
100	85	127.9	20

Table 4-27. Ground-Based Radar – 3 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	225.9	442
50	58	167.9	63
100	81	144.9	36
I/N = 0 dB			
0	0	219.9	377
50	58	161.9	56
100	81	138.9	30
I/N = 3 dB			
0	0	216.9	346
50	58	158.9	52
100	81	135.9	27
I/N = 6 dB			
0	0	213.9	317
50	58	155.9	49
100	81	132.9	25
I/N = 10 dB			
0	0	209.9	280
50	58	151.9	44
100	81	128.9	21

Table 4-28. Ground-Based Radar – 3 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	222.9	409
50	55	167.9	63
100	77	145.9	37
I/N = 0 dB			
0	0	216.9	346
50	55	161.9	56
100	77	139.9	31
I/N = 3 dB			
0	0	213.9	317
50	55	158.9	52
100	77	136.9	28
I/N = 6 dB			
0	0	210.9	289
50	55	155.9	48
100	77	133.9	25
I/N = 10 dB			
0	0	206.9	255
50	55	151.9	44
100	77	129.9	22

Ground-Based Radar – 3 to WiMAX Mobile Station Analysis

The peak power of the Ground-Based Radar – 3 transmitter is 78 dBm. The average power of the radar transmitter for a 16 percent duty cycle is computed using Equation 4-5:

$$P_{AVG} = 78 \text{ dBm} + 10 \log(0.16) = 70 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 39.7 dBi. For a 5 degree off-axis, the radar transmit antenna gain is approximately 16 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the mobile station antenna is approximately 0 dBi. The OTR computed using Equation 4-27 is 3.3 dB (5 MHz Channel) and 0 dB (10 and 20 MHz Channel).

The minimum required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using Equation 4-29:

$$L_{Required} = 70 \text{ dBm} + 16 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - OTR - I_T$$

Using the ITM with the parameters specified in Table 4-9, the minimum separation distance for Ground-Based Radar – 3 are computed. The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations and a frequency offset of 0 MHz are summarized in Table 4-29.

Table 4-29. Ground-Based Radar – 3 to WiMAX Mobile Station (Frequency Offset of 0 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	189	189.2	186.2	56	56	52
0	183	183.2	180.2	48	48	45
3	180	180.2	177.2	45	45	41
6	177	177.2	174.2	41	41	38
10	173	173.2	170.2	36	36	33

The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations and a frequency offset of 50 MHz are summarized below.

Table 4-30. Ground-Based Radar – 3 to WiMAX Mobile Station (Frequency Offset of 50 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	127	131.2	131.2	2.5	3.5	3.5
0	121	125.2	125.2	1.5	2	2
3	118	122.2	122.2	1	1.7	1.7
6	115	119.2	119.2	< 1	1.3	1.3
10	111	115.2	115.2	< 1	< 1	< 1

Airborne Radar – 1 to WiMAX Base Station Analysis

The average power of the Airborne Radar – 1 transmitter for a 0.09 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 60\text{ dBm} + 10\log\left(\frac{0.09}{100}\right) = 29.5\text{ dBm}$$

The radar transmitter antenna gain is 17 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna with an antenna down tilt angle of 2.5 degrees in the direction of the aircraft is approximately 0 dBi. A value of 2 dB is used for the receiver insertion loss.

The aircraft is assumed to be at an altitude of 304.5 meters (1000 feet) and 6097 meters (20,000 feet).

The minimum separation distance between the radar transmitter and the WiMAX base station receiver will be determined using Equation 4-29:

$$L_{Required} = 29.5\text{ dBm} + 17\text{ dBi} + 0\text{ dBi} - 2\text{ dB} - 2\text{ dB} - FDR - I_T$$

Using the freespace propagation model in Equation 4-6 and a frequency of 3500 MHz, the minimum separation distance for different frequency offsets are computed. Base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are also considered in computing the minimum separation distances. The results are summarized in Table 4-31 (5 MHz Channel), Table 4-32 (10 MHz Channel), and Table 4-33 (20 MHz Channel) for the 1000 foot aircraft altitude.

Table 4-31. Airborne Radar – 1 to WiMAX Base Station, 1000 Foot Altitude, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	1	151.7	263
40	56	96.7	< 1
100	86	66.7	< 1
I/N = 0 dB			
0	1	145.7	132
40	56	90.7	< 1
100	86	60.7	< 1
I/N = 3 dB			
0	1	142.7	93
40	56	87.7	< 1
100	86	57.7	< 1
I/N = 6 dB			
0	1	139.7	66
40	56	84.7	< 1
100	86	54.7	< 1
I/N = 10 dB			
0	1	135.7	42
40	56	80.7	< 1
100	86	50.7	< 1

Table 4-32. Airborne Radar – 1 to WiMAX Base Station, 1000 Foot Altitude, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	149.7	209
40	52	97.7	< 1
100	83	66.7	< 1
I/N = 0 dB			
0	0	143.7	105
40	52	91.7	< 1
100	83	66.7	< 1
I/N = 3 dB			
0	0	140.7	74
40	52	88.7	< 1
100	83	57.7	< 1
I/N = 6 dB			
0	0	137.7	53
40	52	85.7	< 1
100	83	54.7	< 1
I/N = 10 dB			
0	0	133.7	33
40	52	81.7	< 1
100	83	50.7	< 1

Table 4-33. Airborne Radar – 1 to WiMAX Base Station, 1000 Foot Altitude, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	146.7	148
40	48	98.7	< 1
100	76	70.7	< 1
I/N = 0 dB			
0	0	140.7	744
40	48	92.7	< 1
100	76	64.7	< 1
I/N = 3 dB			
0	0	137.7	52
40	48	89.7	< 1
100	76	61.7	< 1
I/N = 6 dB			
0	0	134.7	37
40	48	86.7	< 1
100	76	58.7	< 1
I/N = 10 dB			
0	0	130.7	23
40	48	82.7	< 1
100	76	58.7	< 1

For an aircraft altitude of 20,000 feet the radar transmitter antenna gain is 15 dBi. The gain of the base station antenna with an antenna down tilt angle of 2.5 degrees in the direction of the aircraft is approximately 10 dBi. A value of 2 dB is used for the insertion loss of the transmitter and the WiMAX base station receiver.

The minimum separation distance between the radar transmitter and the WiMAX base station receiver will be determined using Equation 4-29:

$$L_{Required} = 29.5 \text{ dBm} + 15 \text{ dBi} + 10 \text{ dBi} - 2 \text{ dB} - 2 \text{ dB} - FDR - I_T$$

Using the freespace propagation model in Equation 4-6 and a frequency of 3500 MHz, the minimum separation distance for different frequency offsets are computed. Base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are also considered in computing the minimum separation distances. The results are summarized in Table 4-34 (5 MHz Channel), Table 4-35 (10 MHz Channel), and Table 4-36 (20 MHz Channel) for the 20,000 foot aircraft altitude.

Table 4-34. Airborne Radar – 1 to WiMAX Base Station, 20,000 Foot Altitude, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	1	159.7	356
40	56	104.7	1.2
100	86	74.7	< 1
I/N = 0 dB			
0	1	153.7	352
40	56	98.7	< 1
100	86	68.7	< 1
I/N = 3 dB			
0	1	150.7	234
40	56	95.7	< 1
100	86	65.7	< 1
I/N = 6 dB			
0	1	147.7	166
40	56	92.7	< 1
100	86	62.7	< 1
I/N = 10 dB			
0	1	143.7	105
40	56	88.7	< 1
100	86	58.7	< 1

Table 4-35. Airborne Radar – 1 to WiMAX Base Station, 20,000 Foot Altitude, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	157.7	355
40	52	105.7	1.3
100	83	74.7	< 1
I/N = 0 dB			
0	0	151.7	350
40	52	99.7	< 1
100	83	68.7	< 1
I/N = 3 dB			
0	0	148.7	186
40	52	96.7	< 1
100	83	65.7	< 1
I/N = 6 dB			
0	0	145.7	132
40	52	93.7	< 1
100	83	62.7	< 1
I/N = 10 dB			
0	0	141.7	83
40	52	89.7	< 1
100	83	58.7	< 1

Table 4-36. Airborne Radar – 1 to WiMAX Base Station, 20,000 Foot Altitude, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	154.7	352
40	48	106.7	1.5
100	76	82.7	< 1
I/N = 0 dB			
0	0	148.7	186
40	48	100.7	< 1
100	76	76.7	< 1
I/N = 3 dB			
0	0	145.7	132
40	48	97.7	< 1
100	76	73.7	< 1
I/N = 6 dB			
0	0	142.7	93
40	48	94.7	< 1
100	76	76.7	< 1
I/N = 10 dB			
0	0	138.7	59
40	48	90.7	< 1
100	76	66.7	< 1

Airborne Radar – 1 to WiMAX Mobile Station Analysis

The average power of the Airborne Radar – 1 transmitter for a 0.09 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 60\text{ dBm} + 10\log\left(\frac{0.09}{100}\right) = 29.5\text{ dBm}$$

The radar transmitter mainbeam antenna gain is 18 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR is 1 dB and OFR is 0 dB.

The minimum separation distance between the radar transmitter and the WiMAX mobile station receiver will be determined using Equation 4-29:

$$L_{Required} = 29.5\text{ dBm} + 18\text{ dBi} + 0\text{ dBi} - 2\text{ dB} - 1\text{ dB} - I_T$$

Using the freespace propagation model in Equation 4-6 and a frequency of 3500 MHz, the minimum separation distance for different frequency offsets are computed. Mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are also considered in computing the minimum separation distances. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-37.

Table 4-37. Airborne Radar – 1 to WiMAX Mobile Station

I/N (dB)	**Required Propagation Loss (dB)**			**Minimum Separation Distance (km)**		
	5 MHz Channel	**10 MHz Channel**	**20 MHz Channel**	**5 MHz Channel**	**10 MHz Channel**	**20 MHz Channel**
-6	152.7	149.7	146.7	295	208.9	147.9
0	146.7	143.7	140.7	147.9	104.7	74.1
3	143.7	140.7	137.7	104.7	74	52.5
6	140.7	137.7	134.7	74	52.4	37.2
10	136.7	133.7	130.7	46.8	33.1	23.4

A frequency separation of greater than 35 MHz will reduce the minimum separation distances in Table 4-37 to less than 1 km.

Airborne Radar – 2 to WiMAX Base Station Analysis

The average power of the Airborne Radar – 2 transmitter for a 0.09 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 53\text{ dBm} + 10\log\left(\frac{0.09}{100}\right) = 23\text{ dBm}$$

The radar transmitter mainbeam antenna gain is 17 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna with an antenna down tilt angle of 2.5 degrees in the direction of an aircraft is 0 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR is 1 dB.

The aircraft is at an altitude of 304.5 meters (1000 feet) and 6097 meters (20,000 feet).

The minimum separation distance between the radar transmitter and the WiMAX base station receiver will be determined using Equation 4-29:

$$L_{Required} = 23\text{ dBm} + 17\text{ dBi} + 0\text{ dBi} - 2\text{ dB} - 2\text{ dB} - FDR - I_T$$

Using the freespace propagation model in Equation 4-6 and a frequency of 3500 MHz, the minimum separation distance for different frequency offsets are computed. Base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are used to compute the minimum separation distances. The results are summarized in Table 4-38 (5 MHz Channel), Table 4-39 (10 MHz Channel), and Table 4-40 (20 MHz Channel) for the 1000 foot altitude.

Table 4-38. Airborne Radar – 2 to WiMAX Base Station, 1000 Foot Altitude, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	1	145.2	124
40	46	100.2	< 1
100	63	84.2	< 1
I/N = 0 dB			
0	1	140.2	62
40	46	93.2	< 1
100	63	76.2	< 1
I/N = 3 dB			
0	1	137.2	44
40	46	90.2	< 1
100	63	73.2	< 1
I/N = 6 dB			
0	1	134.2	31
40	46	87.2	< 1
100	63	70.2	< 1
I/N = 10 dB			
0	1	130.2	20
40	46	83.2	< 1
100	63	66.2	< 1

Table 4-39. Airborne Radar – 2 to WiMAX Base Station, 1000 Foot Altitude, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	142.2	88
40	44	98.2	< 1
100	63	79.2	< 1
I/N = 0 dB			
0	0	136.2	44
40	44	92.2	< 1
100	63	73.2	< 1
I/N = 3 dB			
0	0	133.2	31
40	44	89.2	< 1
100	63	70.2	< 1
I/N = 6 dB			
0	0	130.2	22
40	44	86.2	< 1
100	63	67.2	< 1
I/N = 10 dB			
0	0	126.2	14
40	44	82.2	< 1
100	63	63.2	< 1

Table 4-40. Airborne Radar – 2 to WiMAX Base Station, 1000 Foot Altitude, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	139.2	62
40	41	98.2	< 1
100	61	78.2	< 1
I/N = 0 dB			
0	0	133.2	31
40	41	92.2	< 1
100	61	72.2	< 1
I/N = 3 dB			
0	0	130.2	22
40	41	89.2	< 1
100	61	69.2	< 1
I/N = 6 dB			
0	0	127.2	16
40	41	86.2	< 1
100	61	66.2	< 1
I/N = 10 dB			
0	0	123.2	10
40	41	82.2	< 1
100	61	62.2	< 1

For the 20,000 foot altitude the radar transmitter antenna gain is 15 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna with an antenna down tilt angle of 2.5 degrees in the direction of an aircraft is 0 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR is 1 dB.

The minimum separation distance between the radar transmitter and the WiMAX base station receiver will be determined using Equation 4-29:

$$L_{Required} = 23\text{ dBm} + 15\text{ dBi} + 0\text{ dBi} - 2\text{ dB} - 2\text{ dB} - FDR - I_T$$

Using the freespace propagation model in Equation 4-6 and a frequency of 3500 MHz, the minimum separation distance for different frequency offsets are computed. Base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are used to compute the minimum separation distances. The results are summarized in Table 4-41 (5 MHz Channel), Table 4-42 (10 MHz Channel), and Table 4-43 (20 MHz Channel) for the 20,000 foot altitude.

Table 4-41. Airborne Radar – 2 to WiMAX Base Station, 20,000 Foot Altitude, 5 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	1	143.2	99
40	46	98.2	< 1
100	63	81.2	< 1
I/N = 0 dB			
0	1	137.2	50
40	46	91.2	< 1
100	63	74.2	< 1
I/N = 3 dB			
0	1	134.2	31
40	46	88.2	< 1
100	63	71.2	< 1
I/N = 6 dB			
0	1	131.2	25
40	46	85.2	< 1
100	63	68.2	< 1
I/N = 10 dB			
0	1	127.2	16
40	46	81.2	< 1
100	63	64.2	< 1

Table 4-42. Airborne Radar – 2 to WiMAX Base Station, 1000 Foot Altitude, 10 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	141.2	79
40	44	97.2	< 1
100	63	78.2	< 1
I/N = 0 dB			
0	0	135.2	32
40	44	91.2	< 1
100	63	72.2	< 1
I/N = 3 dB			
0	0	132.2	28
40	44	88.2	< 1
100	63	69.2	< 1
I/N = 6 dB			
0	0	129.2	26
40	44	85.2	< 1
100	63	66.2	< 1
I/N = 10 dB			
0	0	125.2	12
40	44	81.2	< 1
100	63	62.2	< 1

Table 4-43. Airborne Radar – 2 to WiMAX Base Station, 1000 Foot Altitude, 20 MHz Channel

Frequency Offset (MHz)	FDR Attenuation (dB)	Required Propagation Loss (dB)	Minimum Separation Distance (km)
I/N = -6 dB			
0	0	138.2	56
40	41	97.2	< 1
100	61	77.2	< 1
I/N = 0 dB			
0	0	132.2	28
40	41	91.2	< 1
100	61	71.2	< 1
I/N = 3 dB			
0	0	129.2	20
40	41	88.2	< 1
100	61	68.2	< 1
I/N = 6 dB			
0	0	126.2	14
40	41	85.2	< 1
100	61	65.2	< 1
I/N = 10 dB			
0	0	122.2	9
40	41	81.2	< 1
100	61	61.2	< 1

Airborne Radar – 2 to WiMAX Mobile Station Analysis

The average power of the Airborne Radar – 2 transmitter for a 0.09 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 53 \text{ dBm} + 10 \log\left(\frac{0.09}{100}\right) = 23 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 18 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR is 1 dB and the OFR is 0 dB.

The minimum separation distance between the radar transmitter and the WiMAX mobile station receiver will be determined using Equation 4-29:

$$L_{Required} = 23 \text{ dBm} + 18 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - 1 \text{ dB} - 0 \text{ dB} - I_T$$

Using the freespace propagation model in Equation 4-6 and a frequency of 3500 MHz, the minimum separation distance for different frequency offsets are computed. Mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are used to compute the minimum separation distances. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-44.

Table 4-44. Airborne Radar – 2 to WiMAX Mobile Station

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	146.2	143.2	140.2	139.6	98.9	70
0	140.2	137.2	134.2	70	49.5	35.1
3	137.2	134.2	131.2	49.5	35.1	24.8
6	134.2	131.2	128.2	35.1	24.8	17.6
10	130.2	127.2	124.2	22.1	15.7	11.1

A frequency separation of greater than approximately 30 MHz will reduce the minimum separation distances in Table 4-44 to less than 1 km.

Shipborne Radar – 1 to WiMAX Base Station Analysis

The average power of the Shipborne Radar – 1 transmitter for a 0.1 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 90 \text{ dBm} + 10\log\left(\frac{0.1}{100}\right) = 60 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 32 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR computed using Equation 4-27 is 0 dB.

The required propagation loss between the radar transmitter and the WiMAX base station receiver will be determined using Equation 4-29:

$$L_{Required} = 60 \text{ dBm} + 32 \text{ dBi} + 13 \text{ dBi} - 2 \text{ dB} - 2 \text{ dB} - 0 \text{ dB} - FDR - I_T$$

The values of required propagation loss for different frequency offsets and base station receiver interference thresholds are summarized in the tables below.

Table 4-45. Shipborne Radar – 1 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	OFR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	211.2
50	50	161.2
100	59	152.2
I/N = 0 dB		
0	0	205.2
50	50	155.2
100	59	146.2
I/N = 3 dB		
0	0	202.2
50	50	152.2
100	59	143.2
I/N = 6 dB		
0	0	199.2
50	50	149.2
100	59	140.2
I/N = 10 dB		
0	0	195.2
50	50	145.2
100	59	136.2

Table 4-46. Shipborne Radar – 1 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	OFR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	208.2
50	49	159.2
100	57	151.2
I/N = 0 dB		
0	0	202.2
50	49	153.2
100	57	145.2
I/N = 3 dB		
0	0	199.2
50	49	150.2
100	57	142.2
I/N = 6 dB		
0	0	196.2
50	49	147.2
100	57	139.2
I/N = 10 dB		
0	0	192.2
50	49	143.2
100	57	135.2

Table 4-47. Shipborne Radar – 1 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	OFR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	205.2
50	45	160.2
100	54	151.2
I/N = 0 dB		
0	0	199.2
50	45	154.2
100	54	145.2
I/N = 3 dB		
0	0	196.2
50	45	151.2
100	54	142.2
I/N = 6 dB		
0	0	193.2
50	45	148.2
100	54	139.2
I/N = 10 dB		
0	0	189.2
50	45	144.2
100	54	135.2

Shipborne Radar – 1 to WiMAX Mobile Station Analysis

The average power of the Shipborne Radar – 1 transmitter for a 0.1 percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 90\ \text{dBm} + 10\log\left(\frac{0.1}{100}\right) = 60\ \text{dBm}$$

The radar transmitter antenna gain in the direction of the mobile station is 32 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR and OFR are 0 dB.

The required propagation loss between the radar transmitter and the WiMAX base station receiver will be determined using Equation 4-29:

$$L_{Required} = 60\ \text{dBm} + 32\ \text{dBi} + 0\ \text{dBi} - 2\ \text{dB} - 0\ \text{dB} - 0\ \text{dB} - I_T$$

Using the ITM with the parameters specified in Table 4-12, the minimum separation distance for different frequency offsets are computed. Base station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB are used to compute the minimum separation distances. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations and a frequency offset of 0 MHz are summarized in Table 4-48.

Table 4-48. Shipborne Radar – 1 to WiMAX Mobile Station Separation Distances

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance for a Ship 10 km from Coast (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	198.2	195.2	192.2	68	65	61
0	192.2	189.2	186.2	61	58	54
3	189.2	186.2	183.2	58	54	50
6	186.2	183.2	180.2	54	51	47
10	182.2	179.2	179.2	49	46	46

Shipborne Radar – 2 to WiMAX Base Station Analysis

The average power of the Shipborne Radar – 2 transmitter is computed using Equation 4-5:

$$P_{Peak} = 83 \text{ dBm} + 10\log\left(\frac{15}{100}\right) = 75 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 47 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR values are 6.4 dB (5 MHz Channel), 3.5 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using Equation 4-30:

$$L_{Required} = 75 \text{ dBm} + 47 \text{ dBi} + 13 \text{ dBi} - 2 \text{ dB} - 2 \text{ dB} - OTR - OFR - I_T$$

The values of required propagation loss for different frequency offsets and base station receiver interference thresholds are summarized in the tables below.

Table 4-49. Shipborne Radar – 2 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	6.4	234.8
50	56	185.2
100	63	178.2
I/N = 0 dB		
0	6.4	228.8
50	56	179.2
100	63	172.2
I/N = 3 dB		
0	6.4	225.8
50	56	176.2
100	63	169.2
I/N = 6 dB		
0	6.4	222.8
50	56	173.2
100	63	166.2
I/N = 10 dB		
0	6.4	218.8
50	56	169.2
100	63	162.2

Table 4-50. Shipborne Radar – 2 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	3.5	234.7
50	53	185.2
100	60	178.2
I/N = 0 dB		
0	3.5	228.7
50	53	179.2
100	60	172.2
I/N = 3 dB		
0	3.5	225.7
50	53	176.2
100	60	169.2
I/N = 6 dB		
0	3.5	222.7
50	53	173.2
100	60	166.2
I/N = 10 dB		
0	3.5	218.7
50	53	169.2
100	60	162.2

Table 4-51. Shipborne Radar – 2 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	235.2
50	50	185.2
100	57	178.2
I/N = 0 dB		
0	0	229.2
50	50	179.2
100	57	172.2
I/N = 3 dB		
0	0	226.2
50	50	176.2
100	57	169.2
I/N = 6 dB		
0	0	223.2
50	50	173.2
100	57	166.2
I/N = 10 dB		
0	0	219.2
50	50	169.2
100	57	162.2

Shipborne Radar – 2 to WiMAX Mobile Station Analysis

The average power of the Shipborne Radar – 2 transmitter for a percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 83 \text{ dBm} + 10 \log\left(\frac{15}{100}\right) = 75 \text{ dBm}$$

The radar transmit mainbeam antenna gain is 47 dBi. A value of 2 dB is used for the insertion loss of the radar transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR values are 6.4 dB (5 MHz Channel), 3.5 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The minimum required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using:

$$L_{Required} = 75 \text{ dBm} + 47 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - FDR - I_T$$

Using the ITM with the parameters specified in Table 4-9 the minimum separation distance is computed.

The minimum separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-52.

Table 4-52. Shipborne Radar – 2 to WiMAX Mobile Station (Frequency Offset of 50 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	172.2	172.2	172.6	32	32	32
0	166.2	166.2	166.6	25	25	25
3	163.2	163.2	163.6	22	22	22
6	160.2	160.2	160.6	19	19	19
10	156.2	156.2	156.6	15	15	15

Shipborne Radar – 3 to WiMAX Base Station Analysis

The average power of the Shipborne Radar – 3 transmitter is computed using Equation 4-5:

$$P_{Avg} = 98 \text{ dBm} + 10\log(0.016) = 80 \text{ dBm}$$

The radar transmitter mainbeam antenna gain is 41.8 dBi. A value of 3.4 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss. The OTR values are 10 dB (5 MHz Channel), 7 dB (10 MHz Channel), and 4 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using:

$$L_{Required} = 80 \text{ dBm} + 41.8 \text{ dBi} + 13 \text{ dBi} - 3.4 \text{ dB} - 2\text{dB} \\ - OTR — OFR - I_T$$

The values of required propagation loss for different frequency offsets and base station receiver interference thresholds are summarized in the tables below.

Table 4-53. Shipborne Radar – 3 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	10	229.6
50	43	196.6
100	55	184.6
I/N = 0 dB		
0	10	223.6
50	43	190.6
100	55	178.6
I/N = 3 dB		
0	10	220.6
50	43	187.6
100	55	175.6
I/N = 6 dB		
0	10	217.6
50	43	184.6
100	55	172.6
I/N = 10 dB		
0	10	213.6
50	43	180.6
100	55	168.6

Table 4-54. Shipborne Radar – 3 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	7	229.6
50	40	196.6
100	52	184.6
I/N = 0 dB		
0	7	223.6
50	40	190.6
100	52	178.6
I/N = 3 dB		
0	7	220.6
50	40	187.6
100	52	175.6
I/N = 6 dB		
0	7	217.6
50	40	184.6
100	52	172.6
I/N = 10 dB		
0	7	213.6
50	40	180.6
100	52	168.6

Table 4-55. Shipborne Radar – 3 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	4	229.6
50	36	197.6
100	49	184.6
I/N = 0 dB		
0	4	223.6
50	36	191.6
100	49	178.6
I/N = 3 dB		
0	4	220.6
50	36	188.6
100	49	175.6
I/N = 6 dB		
0	4	217.6
50	36	185.6
100	49	172.6
I/N = 10 dB		
0	4	213.6
50	36	181.6
100	49	168.6

Shipborne Radar – 3 to WiMAX Mobile Station Analysis

The average power of the Shipborne Radar – 3 transmitter for a percent duty cycle is computed using Equation 4-5:

$$P_{Avg} = 98 \text{ dBm} + 10 \log(0.016) = 80 \text{ dBm}$$

The radar transmit mainbeam antenna gain is 41.8 dBi. A value of 3.4 dB is used for the insertion loss of the radar transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR values are 10 dB (5 MHz Channel), 7 dB (10 MHz Channel), and 4 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using:

$$L_{Required} = 80 \text{ dBm} + 41.8 \text{ dBi} + 0 \text{ dBi} - 3.4 \text{ dB} - FDR - I_T$$

Using the ITM with the parameters specified in Table 4-9 the minimum separation distance is computed.

The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-56

Table 4-56. Shipborne Radar – 3 to WiMAX Mobile Station (Frequency Offset of 50 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	183.6	184.6	185.6	45	46	47
0	177.6	178.6	179.6	38	39	40
3	174.6	175.6	176.6	34	35	36
6	171.6	172.6	173.6	31	32	33
10	167.6	168.6	169.6	26	28	29

Shipborne Radar – 4 to WiMAX Base Station Analysis

The peak power of the Shipborne Radar – 4 transmitter is 84 dBm. The radar transmitter mainbeam antenna gain is 38.9 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss.

The OTR values are 3.4 dB (5 MHz Channel), 0 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using:

$$L_P = 84\ \text{dBm} + 38.9\ \text{dBi} + 13\ \text{dBi} - 2\ \text{dB} - 2\ \text{dB} - OTR - OFR - I_T$$

For peak power the OTR is based on a 20 Log (BWTX/BWRX)

The values of required propagation loss for different frequency offsets and base station receiver interference thresholds are summarized in the tables below.

Table 4-57. Shipborne Radar – 4 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	3.4	238.7
50	49	193.1
100	62	180.1
I/N = 0 dB		
0	3.4	232.7
50	49	187.1
100	62	184.1
I/N = 3 dB		
0	3.4	229.7
50	49	184.1
100	62	171.1
I/N = 6 dB		
0	3.4	226.7
50	49	181.1
100	62	168.1
I/N = 10 dB		
0	3.4	222.7
50	49	177.1
100	62	164.1

Table 4-58. Shipborne Radar – 4 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	239.1
50	46	193.1
100	59	180.1
I/N = 0 dB		
0	0	233.1
50	46	187.1
100	59	174.1
I/N = 3 dB		
0	0	230.1
50	46	184.1
100	59	171.1
I/N = 6 dB		
0	0	227.1
50	46	181.1
100	59	168.1
I/N = 10 dB		
0	0	223.1
50	46	177.1
100	59	164.1

Table 4-59. Shipborne Radar – 4 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	OFR and OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	236.1
50	43	193.1
100	56	180.1
I/N = 0 dB		
0	0	230.1
50	43	187.1
100	56	174.1
I/N = 3 dB		
0	0	227.1
50	43	184.1
100	56	171.1
I/N = 6 dB		
0	0	224.1
50	43	181.1
100	56	168.1
I/N = 10 dB		
0	0	220.1
50	43	177.1
100	56	164.1

Shipborne Radar – 4 to WiMAX Mobile Station Analysis

The peak power of the Shipborne Radar – 4 transmitter is 84 dBm. The radar transmit mainbeam antenna gain is 38.9 dBi. A value of 2 dB is used for the insertion loss of the radar transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR values are 3.4 dB (5 MHz Channel), 0 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using:

$$L_{Required} = 84 \text{ dBm} + 38.9 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - OTR - OFR - I_T$$

Using the ITM with the parameters specified in Table 4-9 the minimum separation distance is computed.

The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-60.

Table 4-60. Shipborne Radar – 4 to WiMAX Mobile Station (Frequency Offset of 0 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	225.7	226.1	223.1	308	312	280
0	219.7	220.1	217.1	244	249	216
3	216.7	217.1	214.1	212	216	184
6	213.7	214.1	211.1	180	184	153
10	209.7	210.1	207.1	139	143	116

The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-61.

Table 4-61. Shipborne Radar – 4 to WiMAX Mobile Station (Frequency Offset of 50 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	152.1	153.8	153.8	11	13	13
0	146.1	147.8	147.8	7	8	8
3	143.1	144.8	144.8	4	6	6
6	140.1	141.8	141.8	2	3	3
10	136.1	137.4	137.8	1	< 1	< 1

Shipborne Radar – 5 to WiMAX Base Station Analysis

The peak power of the Shipborne Radar – 5 transmitter is 93.3 dBm. The radar transmitter mainbeam antenna gain is 43.3 dBi. A value of 2 dB is used for the insertion loss of the transmitter.

The gain of the base station antenna at the horizon with an antenna down tilt angle of 2.5 degrees is approximately 13 dBi. A value of 2 dB is used for the receiver insertion loss.

The OTR values are 6 dB (5 MHz Channel), 0 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX base station receiver to preclude potential interference will be determined using:

$$L_{Required} = 93.3 \text{ dBm} + 43.3 \text{ dBi} + 13 \text{ dBi} - 2 \text{ dB} - 2 \text{ dB} - OTR - I_T$$

For peak power the OTR is based on a 20 Log (BWTX/BWRX).[67]

The values of required propagation loss for different frequency offsets and base station receiver interference thresholds are summarized in the tables below.

[67] The emission spectra data for this radar was not available. Only the co-frequency case was considered in the analysis.

Table 4-62. Shipborne Radar – 5 to WiMAX Base Station, 5 MHz Channel

Frequency Offset (MHz)	OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	6	249.8
I/N = 0 dB		
0	6	243.8
I/N = 3 dB		
0	6	240.8
I/N = 6 dB		
0	6	237.8
I/N = 10 dB		
0	6	233.8

Table 4-63. Shipborne Radar – 5 to WiMAX Base Station, 10 MHz Channel

Frequency Offset (MHz)	OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	252.8
I/N = 0 dB		
0	0	246.8
I/N = 3 dB		
0	0	243.8
I/N = 6 dB		
0	0	240.8
I/N = 10 dB		
0	0	236.8

Table 4-64. Shipborne Radar – 5 to WiMAX Base Station, 20 MHz Channel

Frequency Offset (MHz)	OTR Attenuation (dB)	Required Propagation Loss (dB)
I/N = -6 dB		
0	0	249.8
I/N = 0 dB		
0	0	243.8
I/N = 3 dB		
0	0	240.8
I/N = 6 dB		
0	0	237.8
I/N = 10 dB		
0	0	233.8

Shipborne Radar – 5 to WiMAX Mobile Station Analysis

The peak power of the Shipborne Radar – 5 transmitter is 93.3 dBm. The radar transmit mainbeam antenna gain in the direction of the mobile station is 45.3 dBi. A value of 2 dB is used for the insertion loss of the radar transmitter.

The gain of the mobile station antenna is 0 dBi. The OTR values are 6 dB (5 MHz Channel), 0 dB (10 MHz Channel), and 0 dB (20 MHz Channel).

The required propagation loss between the radar transmitter and the WiMAX mobile station receiver to preclude potential interference will be determined using:

$$L_{Required} = 93.3 \text{ dBm} + 45.3 \text{ dBi} + 0 \text{ dBi} - 2 \text{ dB} - OTR - I_T$$

Using the ITM with the parameters specified in Table 4-9 the minimum separation distance is computed.

The required separation distances are computed for mobile station receiver interference thresholds based on I/N values of -6 dB, 0 dB, 3 dB, 6 dB, and 10 dB. The analysis results for 5 MHz Channel, 10 MHz Channel, and 20 MHz Channel configurations are summarized in Table 4-65.

Table 4-65. Shipborne Radar – 5 to WiMAX Mobile Station (Frequency Offset of 0 MHz)

I/N (dB)	Required Propagation Loss (dB)			Minimum Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel	5 MHz Channel	10 MHz Channel	20 MHz Channel
-6	238.8	241.8	238.8	458	490	458
0	232.8	235.8	232.8	386	421	386
3	229.8	232.8	229.8	352	386	352
6	226.8	229.8	226.8	320	352	320
10	222.8	225.8	222.8	277	309	277

Shipborne Radar Terrain Dependent Exclusions Distances

Using the values of maximum required propagation loss for each shipborne radar, ITM in the Point-to-Point Mode was used to determine the terrain dependent exclusion zone distances.[68] The values of maximum required propagation loss for each shipborne radar are summarized in Table 4-66.

[68] The DOD analyses for the shipborne radars used the Advanced Refractive Effects Prediction System. The analysis incorporated Digital Terrain and Elevation Data Level 1 terrain data and both recently measured weather data and historical weather data. The shipborne radars were placed 2 kilometers from the coast with the radar antenna main beam allowed to rotate over 360 degrees in 1 degree increments. Each propagation path was then evaluated to find the inland-directed bearing that afforded the longest propagation distance. Once this worst case bearing was found, the required separation distance for each radar could be determined by indexing into the propagation data with the loss value calculated.

Table 4-66. Shipborne Radar to WiMAX Base Station Exclusion Zone Distances

Radar Identifier	Maximum Required Propagation Loss (dB)	Maximum Separation Distance Along Coast (km)		
		East Coast	Gulf Coast	West Coast
Shipborne Radar – 1	211.2	361	339	343
Shipborne Radar – 1	205.2	323	291	307
Shipborne Radar – 1	202.2	300	340	299
Shipborne Radar – 1	199.2	231	286	286
Shipborne Radar – 1	195.2	209	192	286
Shipborne Radar – 2	185.2	154	106	235
Shipborne Radar – 2	179.2	166	100	235
Shipborne Radar – 2	176.2	166	100	235
Shipborne Radar – 2	173.2	166	99	218
Shipborne Radar – 2	169.2	149	98	211
Shipborne Radar – 3	197.6	224	200	286
Shipborne Radar – 3	191.6	173	156	274
Shipborne Radar – 3	188.6	173	133	235
Shipborne Radar – 3	185.6	173	108	235
Shipborne Radar – 3	181.6	166	106	235
Shipborne Radar – 4	239.1	567	570	571
Shipborne Radar – 4	233.1	541	534	554
Shipborne Radar – 4	230.1	498	529	479
Shipborne Radar – 4	227.1	481	468	455
Shipborne Radar – 4	223.1	448	458	404
Shipborne Radar – 5	252.8	567	570	571
Shipborne Radar – 5	246.8	555	557	565
Shipborne Radar – 5	243.8	541	534	554
Shipborne Radar – 5	240.8	494	529	475
Shipborne Radar – 5	236.8	455	557	415

The values of required propagation loss in Table 4-66 were used to create the terrain dependent exclusion zone distances for Shipborne Radar – 1 through Shipborne Radar – 5 shown in Figures 4-8 through 4-12. The detailed exclusion zone distances for the shipborne radars are provided in Appendix D.

Figure 4-8. Terrain Dependent Exclusion Zone Distances for Shipborne Radar – 1

Figure 4-9. Terrain Dependent Exclusion Zone Distances for Shipborne Radar – 2

Figure 4-10. Terrain Dependent Exclusion Zone Distances for Shipborne Radar – 3

Figure 4-11. Terrain Dependent Exclusion Zone Distances for Shipborne Radar – 4

Figure 4-12. Terrain Dependent Exclusion Zone Distances for Shipborne Radar – 5

Radar Transmitter Large Signal Analysis

Since the radar transmitters have such high peak power levels, an analysis examining large signal effects such as burnout and saturation was performed for the radar systems. The burnout and saturation levels for WiMAX receivers were not available. In this analysis, threshold values of 0 dBm (burnout) and -30 dBm (saturation) were used for the large signal analysis of WiMAX base and mobile station receivers. Table 4-67 provides a summary of the distance separations at which burnout and saturation can occur for WiMAX base and mobile receivers.

Table 4-67. WiMAX Burnout and Saturation Separation Distances, Large Signal Radar

Radar Type	Burnout Separation Distance (km)	Saturation Separation Distance (km)
Base Station Receiver		
Ground-Based Radar – 1	15	51
Ground-Based Radar – 2	Below Threshold	2
Ground-Based Radar – 3	25	58
Airborne Radar – 1	Below Threshold	Below Threshold
Airborne Radar – 2	Below Threshold	Below Threshold
Shipborne Radar – 1	45	80
Shipborne Radar – 2	56	80
Shipborne Radar – 3	62	88
Shipborne Radar – 4	50	75
Shipborne Radar – 5	60	85
Mobile Station Receiver		
Ground-Based Radar – 1	2	17
Ground-Based Radar – 2	Below Threshold	Below Threshold
Ground-Based Radar – 3	4	24
Airborne Radar – 1	Below Threshold	Below Threshold
Airborne Radar – 2	Below Threshold	Below Threshold
Shipborne Radar – 1	20	43
Shipborne Radar – 2	20	42
Shipborne Radar – 3	27	48
Shipborne Radar – 4	15	37
Shipborne Radar – 5	25	47

The details of the large signal analysis are provided in Appendix G. As shown in Table 4-67, high power radar signals can cause receiver saturation to occur. If the base and mobile front-end filters are too wide, radar systems operating below 3550 MHz can also cause receiver saturation to occur. Installing radio frequency filters with sufficient rejection to signals below 3550 MHz should mitigate the problem. A radio frequency front-end filter with between 30 to 40 dB of attenuation at 3500 MHz would be necessary to minimize front-end effects.

Compatibility Analysis of Wireless Broadband Transmitters and Federal Receivers

<u>1695-1710 MHz Band Analysis</u>

This analysis examines electromagnetic compatibility between the LTE wireless mobile station transmitters and Federal meteorological-satellite earth stations receiving signals from the GOES and POES satellites and radiosonde station receivers.

Wireless Broadband Systems to Meteorological-Satellite Receive Earth Station Analysis

The LTE wireless mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider both 5 MHz and 10 MHz channel configurations. The interference power level at the meteorological-satellite earth station receiver from each mobile/portable station is calculated using Equation 4-30. The aggregate interference level from the deployment of mobile stations is computed using Equation 4-31. In this analysis, the meteorological-satellite Earth station receiver was assumed to be pointing at the mobile station deployment. Since a base station has three sectors each with a different frequency, only one-third of the mobile/portable stations will be actively transmitting on a given frequency. The analysis considers 5 MHz and 10 MHz channel configurations.[69] A summary of the radii of the exclusion zones that are necessary to preclude potential interference from a deployment of mobile/portable stations to meteorological-satellite receive stations in the 1695-1710 MHz band is provided in Table 4-68.

Table 4-68. Exclusion Zones, Protection of Meteorological-Satellite Receive Stations

Earth Station Location	Latitude	Longitude	Exclusion Zone Radius (km)
Wallops Island, Virginia	375645N	752745W	90
Fairbanks, Alaska	644814N	1475234W	90
Suitland, Maryland	384900N	765100W	121
Miami, Florida	254700N	801900W	110
Kaena Point/Hickam Air Force Base/Pearl Harbor, Hawaii	211907N	1575521W	110
Sioux Falls, South Dakota	433409N	963733W	80
Cincinnati, Ohio	390608N	843036W	97
Rock Island, Illinois	413104N	903346W	78
St. Louis, Missouri	383526N	901225W	76
Vicksburg, Mississippi	322123N	905129W	72
Omaha, Nebraska	411532N	955520W	76
Sacramento, California	383459N	1293929W	72
Elmendorf Air Force Base, Alaska[b]	613600N	150000W	110
Anderson Air Force Base, Guam	133452N	1445528E	110
Monterey, California	363600N	1215400W	110
Stennis Space Center, Mississippi	302359N	893559W	110
Twenty-Nine-Palms, California[a]	341746N	1160944W	110
Yuma, Arizona[a]	323924N	1143622W	110
Note a: Earth station is transportable. Note b: Latitude and Longitude coordinates are for the center point of the exclusion zone, not the MetSat receive location.			

Wireless Broadband System to Radiosonde Receive Station Analysis

The LTE wireless mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider both 5 MHz and 10 MHz channel configurations. The

[69] Since specific locations of the meteorological satellite receivers were known, the DOD interference calculations were performed using the point-to-point propagation model with specific terrain data. A single point source was used to represent the aggregate EIRP of all mobile/portable stations in the urban, suburban, and rural regions. This results in a 10*Log (56,560) increase in EIRP over a single mobile/portable station.

interference power level at the radiosonde station receiver from each mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of mobile/portable stations is computed using Equation 4-33. In this analysis, the radiosonde station receiver was assumed to be pointing at the mobile station deployment. Since a base station has three sectors each with a different frequency, only one-third of the mobile/portable stations will be actively transmitting on a given frequency. Since the elevation of the radiosonde earth station receive antenna varies, the analysis considers several different representative elevation angles. The highest center frequency used by the radiosonde transmitter is 1682 MHz. The analysis calculates the aggregate interference power level at the input to the radiosonde receiver from mobile transmitters operating on center frequencies of 1697.5 MHz (5 MHz Channel) and 1700 MHz (10 MHz Channel). The aggregate interference level is then compared to the interference threshold to determine the available margin. A summary of the available margin for the 5 MHz Channel and 10 MHz Channel configurations minimum provided in Table 4-69.

Table 4-69. Available Margin for Radiosonde Receive Stations from Mobile/Portable LTE Stations

Radiosonde Receive Earth Station Elevation Angle (degrees)	Aggregate Interference Level (dBm)	Radio Receiver Interference Threshold (dBm)	Available Margin (dB)
5 MHz Channel			
3	-132.5	-113	19.5
5	-138.3	-113	25.3
10	-139	-113	26
20	-141.8	-113	28.8
10 MHz Channel			
3	-127.2	-113	14.2
5	-133.1	-113	20.1
10	-133.7	-113	20.7
20	-136.4	-113	23.4

Based on the analysis results shown in Table 4-69, if mobile/portable stations are limited to operation above 1695 MHz there will be no interference to radiosonde receive stations.

3500-3650 MHz Band Analysis

This analysis examines electromagnetic compatibility between the wireless base and mobile/portable station transmitters and Federal ground-base, airborne, and shipborne radar system receivers.

Wireless Broadband Systems to Ground-Based Radar – 1 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. Minimum frequency separations between the radar receivers and the base and mobile/portable station transmitters were considered in the analysis.[70] A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations for on-frequency and off-frequency operation are provided in Table 4-70.

Table 4-70. Minimum Separation Distances Between Ground-Based Radar – 1 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	201	196	183
50	5	17	24
100	< 1	< 1	< 1

Wireless Broadband Systems to Ground-Based Radar – 2 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. Minimum frequency separations between the radar receivers and the base and mobile/portable station transmitters are considered in the analysis. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations for on-frequency and off-frequency operation are provided in Table 4-71.

[70] The DOD analysis for the ground-based radar systems started with radar receiver at the edge of the rural region. The radar receiver was stepped away sequentially from the regions in 0.5 km distance increments. At each distance increment, the interference level from all base and mobile/portable stations was calculated. These calculated interference levels were used to create distance versus interference plots where a minimum separation distance was determined based on the interference threshold.

Table 4-71. Minimum Separation Distances Between Ground-Based Radar – 2 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	40	44	45
40	< 1	< 1	< 1
120	< 1	< 1	< 1

Wireless Broadband Systems to Ground-Based Radar – 3 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. Minimum frequency separations between the radar receivers and the base and mobile/portable station transmitters are considered in the analysis. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations for on-frequency and off-frequency operation are provided in Table 4-72.

Table 4-72. Minimum Separation Distances Between Ground-Based Radar – 3 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	217	243	252
50	14	25	32
100	< 1	< 1	< 1

Wireless Broadband Systems to Airborne Radar – 1 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. Aircraft altitudes of 1000, 5000, 10,000, and 20,000 feet are considered in the analysis. Minimum frequency separations between the radar receivers and the base and mobile/portable station transmitters are considered in the analysis. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations for on-frequency and off-frequency operation are provided in Table 4-73.

Table 4-73. Minimum Separation Distances Between Airborne Radar – 1 and Base/Mobile/Portable WiMAX Stations

Aircraft Altitude (ft)	Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
		5 MHz Channel	10 MHz Channel	20 MHz Channel
1,000	0	39	53	57
1,000	40	< 1	< 1	< 1
1,000	120	< 1	< 1	< 1
5,000	0	54	113	123
5,000	40	< 1	< 1	< 1
5,000	120	< 1	< 1	< 1
10,000	0	< 1	131	167
10,000	40	< 1	< 1	< 1
10,000	120	< 1	< 1	< 1
20,000	0	< 1	< 1	< 1
20,000	40	< 1	< 1	< 1
20,000	120	< 1	< 1	< 1

Wireless Broadband Systems to Airborne Radar – 2 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. Aircraft altitudes of 1000, 5000, 10,000, and 20,000 feet are considered in the analysis. Minimum frequency separations between the radar receivers and the base and mobile/portable station transmitters are considered in the analysis. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations for on-frequency and off-frequency operation are provided in Table 4-74.

Table 4-74. Minimum Separation Distances Between Airborne Radar – 2 and Base/Mobile/Portable WiMAX Stations

Aircraft Altitude (ft)	Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
		5 MHz Channel	10 MHz Channel	20 MHz Channel
1,000	0	98	100	101
1,000	40	< 1	< 1	< 1
1000	120	< 1	< 1	< 1
5,000	0	180	185	187
5,000	40	< 1	< 1	< 1
5000	120	< 1	< 1	< 1
10,000	0	239	248	250
10,000	40	< 1	< 1	< 1
10,000	120	< 1	< 1	< 1
20,000	0	325	336	339
20,000	40	< 1	< 1	< 1
20,000	120	< 1	< 1	< 1

Wireless Broadband Systems to Shipborne Radar – 1 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. In developing the exclusion zone distance it was assumed that the shipborne radar was operating 10 km from the coast line. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations for on-frequency and off-frequency operation are provided in Table 4-75 and Table 4-76 for Shipborne Radar – 1.

Table 4-75. Minimum Separation Distances Between Shipborne Radar – 1 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	304	309	310
50	< 1	31	44
100	< 1	< 1	30

Table 4-76. Minimum Separation Distances Between Shipborne Radar – 1 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	259	287	305
50	8	36	44
100	< 1	5	30

Wireless Broadband Systems to Shipborne Radar – 2 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. In developing the exclusion zone distance it was assumed that the shipborne radar was operating 10 km from the coast line. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations are provided in Table 4-77 for Shipborne Radar – 2.

Table 4-77. Minimum Separation Distances Between Shipborne Radar – 2 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	355	389	409
50	30	40	45
100	5	35	40

Wireless Broadband Systems to Shipborne Radar – 3 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. In developing the exclusion zone distance it was assumed that the shipborne radar was operating 10 km from the coast line. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations are provided in Table 4-78 for Shipborne Radar – 3.

Table 4-78. Minimum Separation Distances Between Shipborne Radar – 3 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	250	270	289
50	47	50	53
100	17	31	37

Wireless Broadband Systems to Shipborne Radar – 4 Analysis

The WiMAX wireless base and mobile/portable station transmitter characteristics are provided in Appendix B. The analysis will consider 5 MHz, 10 MHz, and 20 MHz channel configurations. The interference power level at the radar receiver from each base and mobile/portable station is calculated using Equation 4-32. The aggregate interference level from the deployment of base and mobile/portable stations is computed using Equation 4-33. In this analysis, the radar receiver was assumed to be pointing at the wireless broadband system deployment. For TDD systems 62.5 percent of the base stations in the deployment are transmitting and 37.5 percent of the mobile/portable stations are transmitting. In developing the exclusion zone distance it was assumed that the shipborne radar was operating 10 km from the coast line. A summary of the minimum required separation distances to preclude potential interference from a deployment of base and mobile/portable stations are provided in Table 4-79 for Shipborne Radar – 4.

Table 4-79. Minimum Separation Distances Between Shipborne Radar – 4 and Base/Mobile/Portable WiMAX Stations

Frequency Offset (MHz)	Minimum Required Separation Distance (km)		
	5 MHz Channel	10 MHz Channel	20 MHz Channel
0	301	303	305
50	61	64	67
100	51	53	56

5. Summary of Analysis Results

1695-1710 MHz Band

Radiosonde Transmitter

As shown in the analysis and the simulation, radiosonde transmitters operating in the 1676-1683 MHz band will not cause interference to base station receivers operating above 1695 MHz.

Radiosonde Receive Stations

Based on the analysis results, if mobile/portable station transmitters are limited to operation above 1695 MHz there will be no interference to radiosonde receive stations.

Meteorological-Satellite Transmitters

No interference to base station receivers is predicted from GOES transmitters and POES transmitters operating in and adjacent to the 1695-1710 MHz band.

Meteorological-Satellite Receive Stations

NTIA chose to limit its technical analysis and the development of exclusion zones to the systems that operate in the 1695-1710 MHz portion of the band after considering a few factors. First, a large number of transportable Federal and non-Federal meteorological-satellite earth station receivers operate at a frequency of 1692.7 MHz. Many of these receivers support emergency management. Because they do not require licenses, the users and their locations are unknown. Furthermore, some of these receivers operate on mobile platforms. Therefore, it is not possible to develop exclusion zones around these earth stations. The exclusion zones around the meteorological-satellite receive stations operating in the 1695-1710 MHz band are summarized in Table 5-1.

Table 5-1. Summary of Exclusion Zones Around Meteorological-Satellite Receive Stations

Earth Station Location	Latitude	Longitude	Exclusion Zone Radius (km)
Wallops Island, Virginia	375645N	752745W	90
Fairbanks, Alaska	644814N	1475234W	90
Suitland, Maryland	384900N	765100W	121
Miami, Florida	254700N	801900W	110
Kaena Point/Hickam Air Force Base/Pearl Harbor, Hawaii	211907N	1575521W	110
Sioux Falls, South Dakota	433409N	963733W	80
Cincinnati, Ohio	390608N	843036W	97
Rock Island, Illinois	413104N	903346W	78
St. Louis, Missouri	383526N	901225W	76
Vicksburg, Mississippi	322123N	905129W	72
Omaha, Nebraska	411532N	955520W	76
Sacramento, California	383459N	1212939W	72
Elmendorf Air Force Base, Alaska[b]	613600N	150000W	110
Anderson Air Force Base, Guam	133452N	1445528E	110
Monterey, California	363600N	1215400W	110
Stennis Space Center, Mississippi	302359N	893559W	110
Twenty-Nine-Palms, California[a]	341746N	1160944W	110
Yuma, Arizona[a]	323924N	1143622W	110
Note a: Earth station is transportable. Note b: Latitude and Longitude coordinates are for the center point of the exclusion zone, not the MetSat receive location.			

A plot of the exclusion zones shown in Table 5-1 is provided in Figure 5-1. A detailed plot of the exclusion zones is provided in Appendix H.

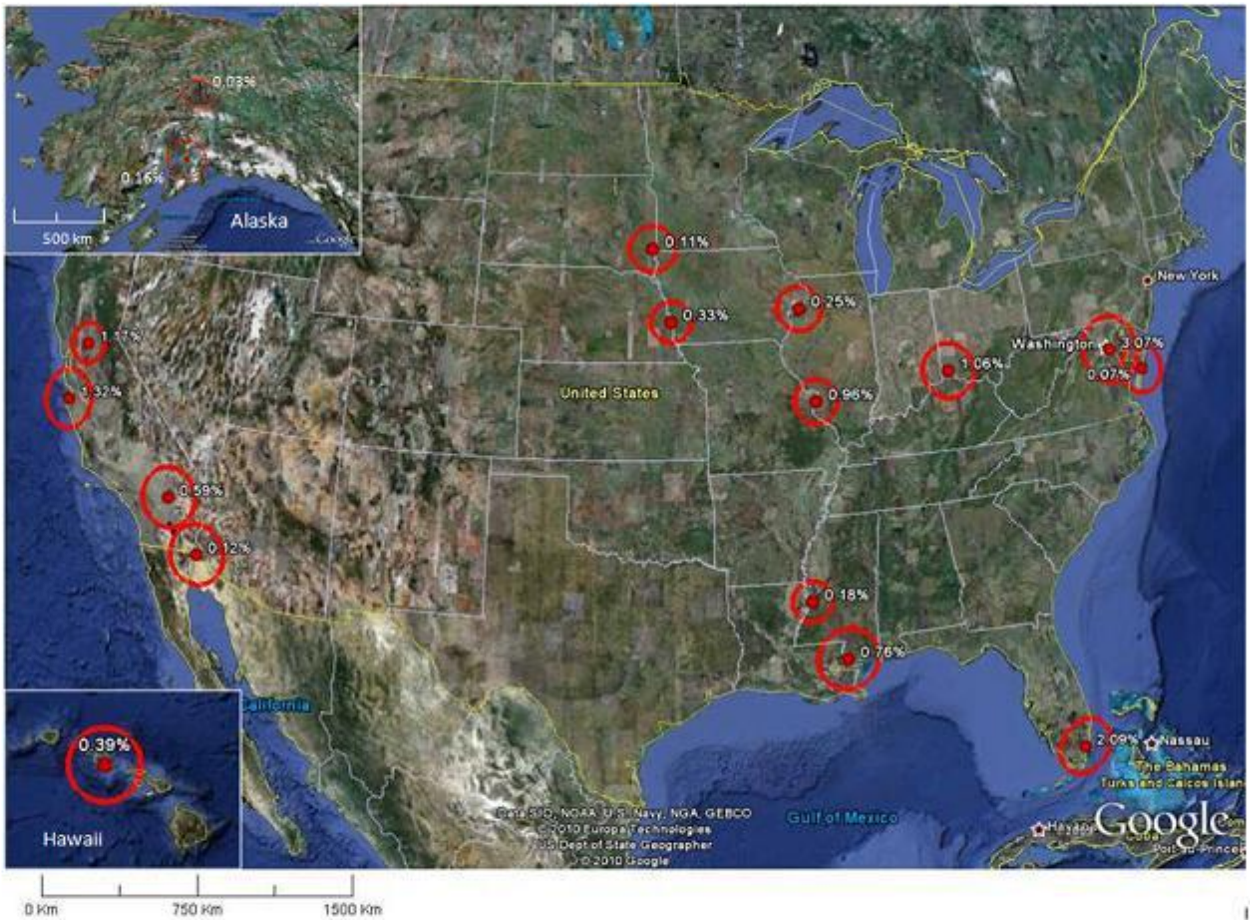

Figure 5-1. Plot of Exclusion Zones, Meteorological-Satellite Receive Stations

3500-3650 MHz Band

Originally, NTIA sought to examine sharing in the entire 3500-3650 MHz band using exclusion zones to protect the radar systems operating in the band. There are ground-based, airborne, and shipborne radar systems. Based on the analysis it was determined that co-frequency operation with the ground-based radars required separation distances on the order of several hundred kilometers. In order to minimize the required separation distances a frequency offset of 50 MHz was needed. As shown in the analysis, co-frequency operation with the airborne radar systems would require large exclusion zones (in excess of 300 km). Furthermore, establishing exclusions is generally not a practical approach to sharing with airborne systems. Therefore, NTIA concluded that a frequency off-set of approximately 40 MHz was needed to eliminate the need for exclusion zones for airborne radar systems. The analysis considered interference interactions between ground-based and shipborne radar systems and base and mobile systems operating in the 3550-3650 MHz portion of the band. Although NTIA examined several different interference thresholds for assessing potential interference to base and mobile stations the analysis results are based on a I/N of -6 dB for average radar transmitter power and +10 dB for radar transmitter peak power.

<u>Ground-Based Radar Systems</u>

The radius of the exclusion zones around the ground-based radar systems are given in Table 5-2.

Table 5-2. Summary of Exclusion Zones, Ground-Based Radar Systems

Radar to Wireless System Interaction	Ground-Based Radar – 1		Ground-Based Radar – 2		Ground-Based Radar – 3	
	Frequency Offset (MHz)	Radius of Exclusion Zone (km)	Frequency Offset (MHz)	Radius of Exclusion Zone (km)	Frequency Offset (MHz)	Radius of Exclusion Zone (km)
Radar to Base (Single Entry)	50	40	40	< 1	50	63
Radar to Mobile (Single Entry)	50	< 1	40	< 1	50	3.5
Base and Mobile to Radar (Aggregate)	50	24	40	< 1	50	32

A plot of the exclusion zones shown in Table 5-2 is provided in Figure 5-2. A detailed plot of the exclusion zones is provided in Appendix D. It should be noted that Ground-Based Radar – 1 and – 3 operate at many locations within the United States. However the number of sites requiring protection exclusion zones was limited to a small portion of the locations, as the radar does not require use of the upper portion of its tuning range at many locations. To accommodate this much-reduced number of exclusion zones, the radio frequency filter of the base stations would need to provide 30 to 40 dB of attenuation at 3500 MHz (approximately 50 MHz below the band of interest, 3550-3650 MHz) to mitigate the potential of high-power interference effects.

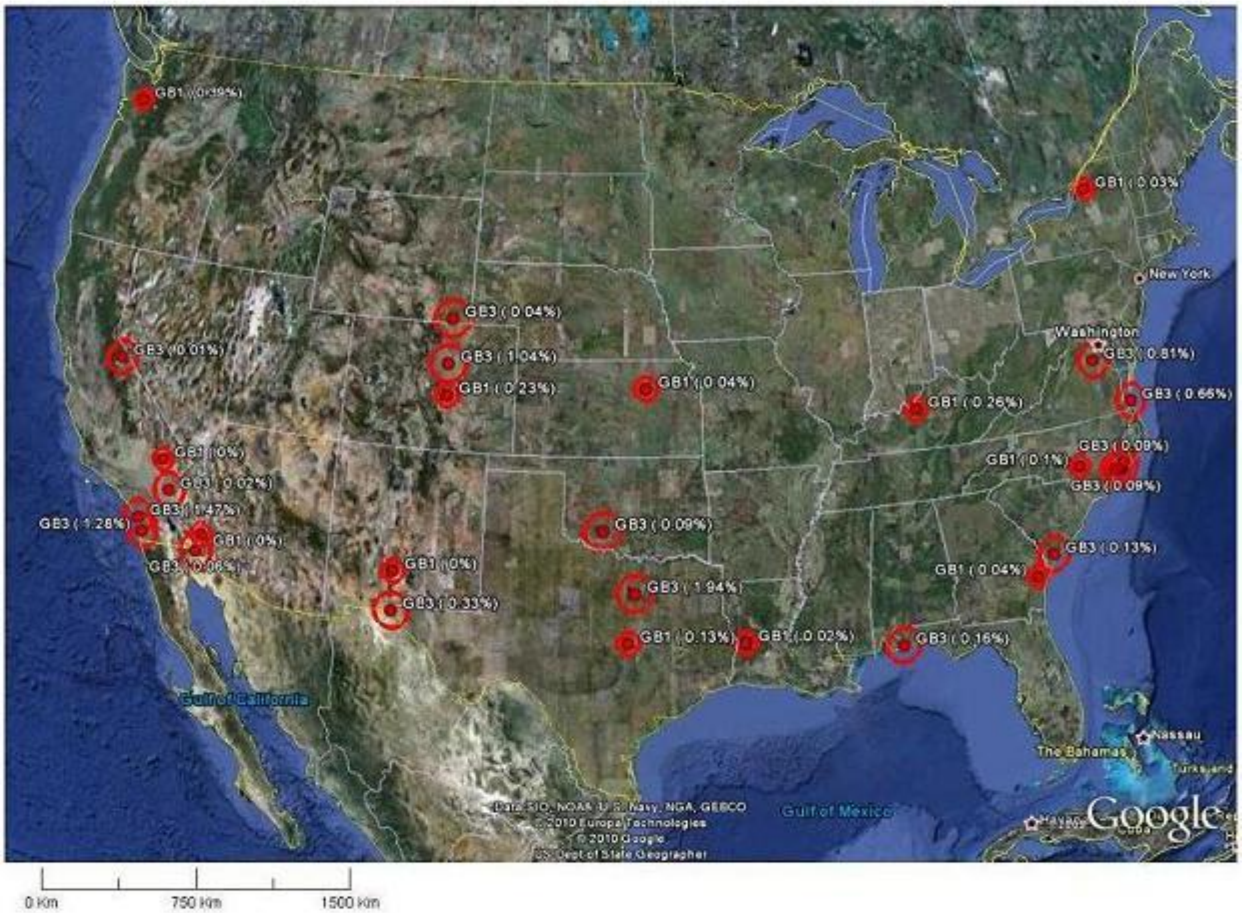

Figure 5-2. Plot of Exclusion Zones, Ground-Based Radar Systems

Airborne Radar Systems

As shown in Table 5-3, with a frequency offset of 40 MHz exclusion zones are not needed for airborne radar systems.

While the results indicate no separation distances are required to preclude interference between military station keeping equipment and commercial broadband licensees, broadband users may need to accommodate instances of interference or use additional interference suppression techniques to safeguard the desired service quality.

Table 5-3. Summary of Exclusion Zones, Airborne Radar Systems

Radar to Wireless System Interaction	Airborne Radar – 1		Airborne Radar – 2	
	Frequency Offset (MHz)	Exclusion Zone Distance (km)	Frequency Offset (MHz)	Exclusion Zone Distance (km)
Radar to Base (Single Entry)	40	< 1	40	< 1
Radar to Mobile (Single Entry)	40	< 1	40	< 1
Base and Mobile to Radar (Aggregate)	40	< 1	40	< 1

Shipborne Radar Systems

For the shipborne radar systems, the exclusion zone is defined by a distance from the coast line considering interference to and from the base and mobile systems. In developing the exclusion zone distance, it was assumed that the shipborne radar was operating 10 km from the coast line. The exclusion zone distances referenced in-land from the coast line are given in Table 5-4.

Table 5-4. Summary of Exclusion Zone Distances, Shipborne Radar Systems

Radar Identifier	Radar to Wireless Broadband System Interaction			
	Radar-to-Base (Single Entry)		Radar-to-Mobile (Single Entry)	Base/Mobile-to-Radar (Aggregate)
	Geographic Area	Exclusion Zone Distance (km)[a]	Exclusion Zone Distance (km)	Exclusion Zone Distance (km)
Shipborne Radar – 1	East Coast	361	68	
	West Coast	343		
	Gulf Coast	339		310
Shipborne Radar – 2	East Coast	154	32	
	West Coast	235		45
	Gulf Coast	106		
Shipborne Radar – 3	East Coast	224		
	West Coast	286	47	53
	Gulf Coast	200		
Shipborne Radar – 4	East Coast	448		305
	West Coast	404		
	Gulf Coast	458	143	
Shipborne Radar – 5	East Coast	455		Not Available
	West Coast	415	309	
	Gulf Coast	557		
Note a: The exclusion zone distance is based on the maximum value. The detailed terrain dependent exclusion zone distances are provided in Appendix E.				

Figure 5-3 provides a composite of the exclusion zone distances for the shipborne radar systems.

Figure 5-3. Composite Depiction of Exclusion Zone Distances, Shipborne Radar Systems

Broadband Wireless System Standards

In the U.S. regulatory environment, sometimes it is not clear whether interference problems resulting from design faults in the receiver are the responsibility of the receiver owner or the transmitter owner to resolve. Without standards, the quality of the receiver and its interference susceptibility is left to the buyer of a piece of radio equipment as an aspect of market-place choices. Nevertheless, typically the onus is on changing transmitter operations regardless of the actual cause of the interference. Domestically, there has been no clear consensus regarding the best means to assure development and use of suitably designed receivers. In some commercial services, such as PCS, system designers have successfully applied receiver standards. In other areas, especially where the consumers have access to products that achieve significantly different levels of performance, the lack of known standards and compliance may make it difficult for them to make an informed choice.

In order to maximize the usefulness of the bands proposed in the Fast Track, wireless broadband access system characteristics will need to be provided as a basis for adopting service rules for the 1695-1710 MHz and 3550-3650 MHz bands. Several technical characteristics to consider would include transmitter power, emission spectrum curves, receiver RF and IF selectivity curves, antenna patterns and pointing angles – defining the sidelobe power level at the horizon, and specifications associated with high power effects (e.g., receiver burnout, saturation, and 1-dB gain compression). If there are changes to the technical parameters or deployment data for the wireless broadband systems, as compared to those used in the analysis documented in this report, NTIA in collaboration with the affected Federal agencies will need to determine whether any changes to the sharing conditions are required to protect Federal systems .

If the base and mobile front-end filters are too wide radar systems operating below 3550 MHz can also cause receiver saturation to occur. Installing radio frequency (RF) filters with sufficient rejection to signals below 3550 MHz should mitigate the problem. The RF filter will need to provide 30 to 40 dB of attenuation at 3500 MHz (approximately 50 MHz below the band of interest, 3550-3650 MHz).

The specifications and standards should also require that design techniques be used which ensure robust wireless broadband receiver performance in a high power pulsed signal environment. Examples of design techniques which contribute to robust receiver performance include receiver filtering, forward error correction (FEC) coding, interleaving, adaptive data rate (based upon interference conditions), and adaptive modulation and coding (also based upon signal conditions), and increased Orthogonal Frequency Division Multiplexing Fast Fourier Transform size. FEC coding including Low Density Parity Check, Turbo Product Code and concatenated Reed-Solomon and convolutional coding can be particularly effective in a pulsed signal environment.

Appendix A. Technical Characteristics for Federal Systems Operating in the 1695-1710 MHz Band

This appendix provides the technical characteristics for the Federal systems operating in the 1695-1710 MHz band. The 1675-1710 MHz band is allocated on a co-primary basis for Federal and non-Federal use for the meteorological aids service and the meteorological-satellite service (space-to-Earth). Specifically, this band is used for downlinks from certain weather satellites and radiosondes (weather balloons) that are administered by the National Oceanic and Atmospheric Administration (NOAA). NOAA provides these services for weather forecasting, tracking of hurricanes and other storms, prediction of flooding and drought conditions, and warning against other hazards to life and property using data collected from the Geostationary Operational Environmental Satellite (GOES) and Polar Operational Environmental Satellite (POES) systems.

Table A-1. WCDAS Polar Receiver Equipment, TIP Link

Parameter	Value
Center Frequency (MHz)	1698, 1707, 1702.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.328
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	-3 dB @ +/- 0.664 MHz -20 dB @ +/- 1.328 MHz -60 dB @ +/- 6.640 MHz
Noise Figure (dB)	2.2
Antenna Gain (Mainbeam) (dBi)	43.1
Antenna Height (meters) above local terrain	17 m
Elevation Angle (degrees)	14

Table A-2. FCDAS Polar Receiver Equipment, Fairbanks, Alaska, AVHRR Link

Parameter	Value
Center Frequency (MHz)	1698, 1707, 1702.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	2.66
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	-3 dB @ +/- 1.33 MHz -20 dB @ +/- 2.66 MHz -60 dB @ +/- 13.3 MHz
Noise Figure (dB)	2.2
Antenna Gain (Mainbeam) (dBi)	43.1
Antenna Height (meters) above local terrain	17 m
Elevation Angle (degrees)	14

Table A-3. FCDAS Polar Receiver Equipment, TIP Link

Parameter	Value
Center Frequency (MHz)	1698, 1707, 1702.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.328
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	-3 dB @ +/- 0.664 MHz -20 dB @ +/- 1.328 MHz -60 dB @ +/- 6.640 MHz
Noise Figure (dB)	2.2
Antenna Gain (Mainbeam) (dBi)	43.1
Antenna Height (meters) above local terrain	17 m
Elevation Angle (degrees)	14

Table A-4. FCDAS Polar Receiver Equipment, HRPT Link

Parameter	Value
Center Frequency (MHz)	1698, 1707, 1702.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.3308
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	-3 dB @ +/- 0.6654 MHz -20 dB @ +/- 1.3308 MHz -60 dB @ +/- 6.654 MHz
Noise Figure (dB)	2.2
Antenna Gain (Mainbeam) (dBi)	43.1
Antenna Height (meters) above local terrain	17 m
Elevation Angle (degrees)	14

Table A-5. NSOF Suitland, Maryland HRPT link

Parameter	Value
Center Frequency (MHz)	1698, 1707, 1702.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.3308
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	-3 dB @ +/- 0.665 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12.0 MHz
Noise Figure (dB)	1.8
Antenna Gain (Mainbeam) (dBi)	29.5
Antenna Height (meters) above local terrain	86.8 m
Elevation Angle (degrees)	5

Table A-6. Miami Command and Data Acquisition Station Polar Receiver Equipment, Miami Florida, High Resolution Picture Transmission Link.

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.058
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.1 MHz -20 dB @ +/- 0.3 MHz -60 dB @ +/- 0.674 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above local terrain	33
Elevation Angle (degrees)	5

Table A-7. Department of Interior, USGS Earth Resources Observations and Science (EROS), Land Remote Sensing Program (LRSP), Sioux Falls, South Dakota

Parameter	Value
Center Frequency (MHz)	1698, 1707, 1702.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.328
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	-3 dB @ +/- 0.664 MHz -20 dB @ +/- 1.328 MHz -60 dB @ +/- 6.640 MHz
Noise Figure (dB)	1.2
Antenna Gain (Mainbeam) (dBi)	31
Antenna Height (meters) above local terrain	14.5 m
Elevation Angle (degrees)	27.7 and 26.7

Table A-8. Radiosonde Receiver Parameters

Parameter	Radiosonde Telemetry Receiver Wide Angle Gathering Sensor (WAGS) Antenna (1)	Radiosonde Telemetry Receiver Narrow Angle Gathering Sensor (NAGS) Antenna
Tuning Range (MHz)	1668.4-1700	1668.4-1700
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	0.150 ± 0.015	0.150 ± 0.015
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	0.150 MHz -3 dB 0.270 MHz -20 dB 0.600 MHz -60 dB	0.150 MHz -3 dB 0.270 MHz -20 dB 0.600 MHz -60 dB
Noise Figure (dB)	6.5	6.5
Antenna Gain (Mainbeam) (dBi)	7	28

Table A-8. Radiosonde Receiver Parameters (continued)

Parameter	Radiosonde Telemetry Receiver Wide Angle Gathering Sensor (WAGS) Antenna (1)	Radiosonde Telemetry Receiver Narrow Angle Gathering Sensor (NAGS) Antenna
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Not Available (1)	-19.5 @ -180° -8.5 @ -170° -19.5 @ -160° -18.5 @ -150° -9.5 @ -140° -4.5 @ -130° -3.5 @ -120° -2.5 @ -110° -2.5 @ -100° -1.5 @ -90° 0.5 @ -80° 2.5 @ -70° 3.5 @ -60° 1.5 @ -50° -3.5 @ -40° 0.5 @ -30° 7.5 @ -20° 9.5 @ -10° 10.5 @ 10° 0.5 @ 20° 0.5 @ 30° -4.5 @ 40° -2.5 @ 50° -1.5 @ 60° -6.5 @ 70° -11.5 @ 80° -9.5 @ 90° -13.5 @ 100° -6.5 @ 110° -6.5 @ 120° -7.5 @ 130° -15.5 @ 140° -14.5 @ 150° -14.5 @ 160° -9.5 @ 170° -9.5 @ 180°
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Not Available	Same as Azimuth Pattern
Antenna Polarization	Left Hand Polarization	Left Hand Polarization
Antenna Height (meters)	5	5
Antenna Horizontal Sector (degrees)	100	15

Table A-8. Radiosonde Receiver Parameters (continued)

Parameter	Radiosonde Telemetry Receiver Wide Angle Gathering Sensor (WAGS) Antenna (1)	Radiosonde Telemetry Receiver Narrow Angle Gathering Sensor (NAGS) Antenna
Antenna Down Tilt Angle (degrees)(2)	Variable	Variable
Cable, Insertion, or Other Losses (dB)	1.5	1.5
(1) The wide mode of the antenna is used to provide a wider dynamic range. When the radiosonde is in close proximity to the ground receiver system, the high gain of the narrow mode would exceed the receiver's input limit, causing distortion and data loss. The wide mode is only active for the first few minutes of operation and does not need to be considered for interference analysis. (2) The antennas elevation can vary between 10 degrees below and 91 degrees above the horizontal plane as a function of the radiosonde flight pattern.		

Table A-9. Radiosonde Transmitter Parameters

Parameter	GPS Radiosonde Transmitter
Emission 3 dB Bandwidth (kHz)	135
Tuning Range (MHz)	Operates on four channels with center frequencies of 1676 MHz, 1678 MHz, 1680 MHz, and 1682 MHz
Power (Peak) (dBm)	23.8
Emission Spectrum Relative Attenuation (dB) as a function of Frequency Offset (MHz))	36 dB @ 0.2 MHz 48 dB @ 0.4 MHZ 52 dB @ 0.6 MHz 56 dB @ 0.8 MHz 58 dB @ 1 MHz
Modulation	Frequency Shift Keying
Duty Cycle (percent)	100
Data Rate (bit/s)	9600
Antenna Gain (Mainbeam) (dBi)	4.3 (Vertical plane, pointed downward)
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees) (1) and (2)	Same as Elevation Pattern
Elevation Off-Axis Antenna Pattern Antenna Gain (dBi) as a function of off-axis angle (degrees) (2)	+2.9 dBi @ 20° +1.8 dBi @ 40° -0.4 dBi @ 60° -2.6 dBi @ 80° -4.4 dBi @ 90°
Antenna Height (meters)	1 to 33000 m
Antenna Polarization	Left Hand Circular
Antenna Horizontal Sector (degrees)	360
Antenna Down Tilt Angle (degrees)	90 Once launched, the antenna is pointing towards the Earth
(1) The radiosonde antenna is oriented in an earthward in the vertical plane. The 0 degree angle is equivalent to -90 degrees for an antenna that is oriented horizontally. Angles above 0 degrees would have further gain reductions as it is in the backplane, which has not been measured, and are considered irrelevant as they would be pointing upward on a system that is airborne, thereby radiating away from ground-based base stations and handsets. (2) The antenna is a patch antenna with a basically, hemispherical pattern. It is assumed that the azimuth and vertical planes are symmetrical, although there are some variations.	

GOES-N Transmitter and Antenna Characteristics

Table A-10. GOES-N Satellite Transmitter Characteristics

LINK DESIGNATION	SD	PDR	LRIT	EMWIN	MDL	DCPR	CDA TLM
Manufacturer's Name	Boeing Satellite Systems	Boeing Satellite Systems	Boeing Satellite Systems	Boeing Satellite Systems	Boeing Satellite Systems	Boeing Satellite Systems	Boeing Satellite Systems
System Nomenclature	Sensor Data transmitter	Processed Data transponder	LRIT/WEFAX transponder	EMWIN transponder	MDL transmitter	DCPR transponder	CDA Telemetry transmitter
Tuning Range	1676.0 MHz	1685.7 MHz	1691.0 MHz	1692.7 MHz	1681.478 MHz	1694.5 MHz, 1694.8 MHz	1694.0 MHz
Method of Tuning	Fixed	Fixed	Fixed	Fixed	Fixed	Switched filter	Fixed
RF Channeling	One	One	One	One	One	Two	One
Frequency Stability	+/- 3.0 ppm over S/C lifetime	+/- 3.0 ppm over S/C lifetime	+/- 3.0 ppm over S/C lifetime	+/- 3.0 ppm over S/C lifetime	+/- 3.0 ppm over S/C lifetime	+/- 3.0 ppm over S/C lifetime	+/- 2.5 ppm over S/C lifetime
Emission Designator	5M2G7DDX	4M22G1DBN	586KG1DCN	27KG1DCN	400KG7DDX	400KG7DBF 400KG7DEF	16KG1DBN
Emission Bandwidth	Measured	Calculated	Calculated	Calculated	Measured	Measured	Measured
-3 dB	2.2 MHz	2.2 MHz	200 kHz	18 kHz	150 kHz	507 kHz	12 kHz
-20 dB	8.0 MHz	6.2 MHz	600 kHz	26 kHz	400 kHz	650 kHz	40 kHz
-60 dB	11.2 MHz	11.0 MHz	4.5 MHz	200 kHz	4.0 MHz	5.6 MHz	2.0 MHz
Filter Employed	Band Pass	Band Pass	Band Pass	Band Pass	Band Pass	Band Pass	Band Pass
Maximum Bit Rate	2.66 Mbps	2.11 Mbps	293 kbps	35.94 kbps	400 kbps	1800 bps per individual user	4 kbps
Power	W4.9 (6.9 dBW)	W28 (14.5 dBW)	W10.4 (10.2 dBW)	W1.3 (1.2 dBW)	W6.7 (8.2 dBW)	W6.3 (8.0 dBW)	W2.8 (4.5 dBW)
Spurious Level	-70 dB	-75 dB	-75 dB	-65 dB	-70 dB	-65 dB	-65 dB
Harmonic Level (2nd)	-60 dB	-67 dB	-63 dB	-69 dB	-60 dB	-61 dB	-65 dB
Harmonic Level (3rd)	-60 dB	-67 dB	-63 dB	-69 dB	-60 dB	-61 dB	-65 dB
Harmonic Level (other)	-80 dB	-80 dB	-80 dB	-80 dB	-80 dB	-80 dB	-80 dB

Table A-11. GOES-N Satellite Transmit Antenna Characteristics

PURPOSE	TRANSMIT ONLY	TRANSMIT AND RECEIVE	CDA Tlm
Manufacturers Name	Boeing Satellite Systems	Boeing Satellite Systems	Boeing Satellite Systems
System Nomenclature	S-band Antenna A	S-band Antenna B	L-band T&C
Type	Planar Cup Dipole 15.2 in diameter	Planar Cup Dipole 15.2 in diameter	Horn and Omni w/ power split
Frequency Range	1670- 1710 MHz	1670-1710 MHz	1670- 1710 MHz
Polarization	Linear (N-S)	Linear (N-S)	Right Hand Circular
Gain, Main Beam	15.6 dBi	15.6 dBi	0 dBi
Gain, Side Lobe	-6 dBi @ 60°	-6 dBi @ 60°	-1.5 dBi @ 122°
3 dB Beamwidth (Horizontal)	32°	32°	56°
3 dB Beamwidth (Vertical)	32°	32°	56°
Remarks	This antenna used for SD, PDR, and EMWIN downlinks	This antenna used for MDL, LRIT, and DCPR downlinks	Operates over >85% of 4 PI steradians
		PLUS the PDR, LRIT, DCPI, and EMWIN uplinks	Works with linear polarized ground antenna

GOES-R Transmitter and Antenna Characteristics

Table A-12. GOES-R Satellite Transmitter Characteristics

LINK DESIGNATION	GRB #1	GRB #2	HRIT/EMWIN	DCPR #1	DCPR #2	CDA Tlm
System Nomenclature	GOES-Rebroadcast Data transponder	GOES-Rebroadcast Data transponder	HRIT/EMWIN transponder	DCPR transponder (Basic)	DCPR transponder (Expansion)	CDA Telemetry transmitter
Tuning Range	1690.0 MHz	1690.0 MHz	1697.4 MHz	1683.3 MHz 1683.6 MHz	1683.9 MHz	1696.3 MHz
Method of Tuning	Fixed	Fixed	Fixed	Switched filter	Fixed	Synthesizer
RF Channeling	One	One	One	Two	One	One
Frequency Stability	+/- 1 ppm over S/C lifetime	+/- 1 ppm over S/C lifetime	+/- 1 ppm over S/C lifetime	+/- 1 ppm over S/C lifetime	+/- 1 ppm over S/C lifetime	+/- 1 ppm over S/C lifetime
Emission Designator	12M0G1DEN	12M0G1DEN	1M20G1DCN	400KG7DBF 400KG7DEF	400KG7DBF 400KG7DEF	73K3G1DCN
Emission Bandwidth	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated
-3 dB	10.800 MHz	10.800 MHz	0.950 MHz	0.400 MHz	0.400 MHz	0.063 MHz
-20 dB	12.000 MHz	12.000 MHz	1.200 MHz	402.000 MHz	0.402 MHz	0.073 MHz
-60 dB	108.000 MHz	108.000 MHz	6.000 MHz	4.000 MHz	4.000 MHz	0.600 MHz
Filter Employed	Band Pass	Band Pass	Band Pass	Band Pass	Band Pass	Band Pass
Maximum Bit Rate	25.9 Mbps	25.9 Mbps	927 kbps	1800 bps per individual user	1800 bps per individual user	36.65 kbps
Power (W and dBW)	50W 17 dBW	50W 17 dBW	25W 14 dBW	6W 8 dBW	6W 8 dBW	3W 5 dBW
Max Power Density	-52 dBW/Hz	-52 dBW/Hz	-46 dBW/Hz	-48 dBW/Hz	-48 dBW/Hz	-42 dBW/Hz
Δ to min Pwr and PD	3 dB	3 dB	3 dB	3 dB	3 dB	3 dB
Spurious Level	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB
Harmonic Level (2nd)	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB
Harmonic Level (3rd)	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB
Harmonic Level (other)	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB	-60 dB

Table A-13. GOES-R Satellite Transmit Antenna Characteristics

PURPOSE	TRANSMIT	TRANSMIT AND RECEIVE	CDA Tlm	CDA Tlm
System Nomenclature	L-band Antenna A	L-band Antenna B	L-band Antenna C	
Type	Horn	Horn	Helix	Hemi
Frequency Range	1680-1700 MHz	1680-1700 MHz	1670-1700 MHz	1670-1700 MHz
Polarization	Dual RCP/LCP	Linear (N-S)	RHCP	RHCP
Gain, Main Beam	16.9 dBi	16.9 dBi	13.5 dBi	2 dBi
Gain, Side Lobe	-3 dBi @40°	-3 dBi @40°	Not Available	Not Available
3 dB Beamwidth (Horizontal)	18°	Not Available	18°	110°
3 dB Beamwidth (Vertical)	18°	Not Available	18°	110°
Pointing Accuracy	±0.02°	Not Available	±0.02°	±0.02°
Remarks	This antenna used for GRB downlinks	This antenna used for DCPR and HRIT /EMWIN downlinks PLUS DCPC CDA Cmd and HRIT /EMWIN uplinks	Used when spacecraft points to earth center	Used when the spacecraft is at a random orientation

POES Transmitter and Antenna Characteristics

Table A-14. POES Satellite Transmitter Characteristics

LINK DESIGNATION	HPRT/CDA	CDA	HRPT/CDA
System Nomenclature	STX-1	STX-2	STX-3
Tuning Range	1698 MHz	1702.5 MHz	1697.4 MHz
Method of Tuning	Fixed	Fixed	Fixed
RF Channeling	One	One	One
Frequency Stability	+/- 20 ppm over S/C lifetime	+/- 20 ppm over S/C lifetime	+/- 20 ppm over S/C lifetime
Emission Designator	5M34G7D	5M34G7D	5M34G7D
Emission Bandwidth	Calculated	Calculated	Calculated
-3 dB	3.5 MHz	3.5 MHz	3.5 MHz
-20 dB	5.34 MHz	5.34 MHz	5.34 MHz
-40 dB	11.445 MHz	11.445 MHz	11.445 MHz
-60 dB	23.8 MHz	23.8 MHz	23.8 MHz
Filter Employed	Band Pass	Band Pass	Band Pass
Maximum Bit Rate	2.6616 Mbps	2.6616 Mbps	2.6616 Mbps
Power (W and dBW)	6.3W 8 dBW	6.3 W 8 dBW	6.3W 8 dBW
Spurious Level	-60 dBc	-60 dB	-60 dB
Harmonic Level (2nd)	-60 dBc	-60 dB	-60 dB
Harmonic Level (3rd)	-60 dBc	-60 dB	-60 dB
Harmonic Level (other)	-60 dBc	-60 dB	-60 dB

Table A-15. POES Satellite Transmit Antenna Characteristics

PURPOSE	TRANSMIT	TRANSMIT	TRANSMIT	TRANSMIT
System Nomenclature	SBA-1, SBA-2, and SBA-3	SBA	SOA-1, SOA-2	SBA-2
Type	Quad Helix	Self Phase Resonant Quadrifilar	Self Phase Resonant Quadrifilar	Self Phase Resonant Quadrifilar
Frequency Range	1698-1707 MHz	1698-1707 MHz	1702.5 MHz	1702.5 MHz
Polarization	Right Hand Circular	Right Hand Circular	Right Hand Circular and Left Hand Circular	Left Hand Circular
Gain, Main Beam	-2.5 dBi	2.1 dBi @63°off nadir	4.6 dBi	2.1 dBi @63°off nadir
Gain, Side Lobe	2.5 dBi @±63 deg. off axis	Not Available	0.4 dBi @±63 deg off axis	Not Available
Scan Characteristics	Fixed	Fixed	Fixed	Fixed
3 dB Beamwidth (Horizontal)	126º	60º	126º	60º
3 dB Beamwidth (Vertical)	126º	Not Available	126º	Not Available

DOD Receiver and Antenna Characteristics

Table A-16. DOD Receiver Equipment, Cincinnati, Ohio, DCPR

Parameter	Value
Center Frequency (MHz)	1694.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.5
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.75 MHz -20 dB @ +/- 2.25 MHz -60 dB @ +/- 5.04 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	39
Antenna Height (meters) above local terrain	200
Elevation Angle (degrees)	43.9

Table A-17. DOD Receiver Equipment, Rock Island, Illinois, DCPR

Parameter	Value
Center Frequency (MHz)	1694.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.5
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.75 MHz -20 dB @ +/- 2.25 MHz -60 dB @ +/- 5.04 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	39.6
Antenna Height (meters) above local terrain	25
Elevation Angle (degrees)	24.4

Table A-18. DOD Receiver Equipment, Saint Louis, Missouri, DCPR

Parameter	Value
Center Frequency (MHz)	1694.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.5
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.75 MHz -20 dB @ +/- 2.25 MHz -60 dB @ +/- 5.04 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	36.7
Antenna Height (meters) above local terrain	20
Elevation Angle (degrees)	42.6

Table A-19 DOD Receiver Equipment, Vicksburg, Mississippi, DCPR

Parameter	Value
Center Frequency (MHz)	1694.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.5
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.75 MHz -20 dB @ +/- 2.25 MHz -60 dB @ +/- 5.04 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	36.7
Antenna Height (meters) above local terrain	20
Elevation Angle (degrees)	48.6

Table A-20. DOD Receiver Equipment, Omaha, Nebraska, DCPR

Parameter	Value
Center Frequency (MHz)	1694.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.5
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.75 MHz -20 dB @ +/- 2.25 MHz -60 dB @ +/- 5.04 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	36.7
Antenna Height (meters) above local terrain	20
Elevation Angle (degrees)	28

Table A-21. DOD Receiver Equipment, Sacramento, California, DCPR

Parameter	Value
Center Frequency (MHz)	1694.5
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.5
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.75 MHz -20 dB @ +/- 2.25 MHz -60 dB @ +/- 5.04 MHz
Noise Temperature (K)	269
Mainbeam Antenna Gain (dBi)	36.7
Antenna Height (meters) above local terrain	20
Elevation Angle (degrees)	43.2

Table A-22. Receiver Equipment, Elmendorf Air force Base, Alaska, HRPT

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.3309
Receiver IF Selectivity (Relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above local terrain	33
Elevation Angle (degrees)	5

Table A-23. Receiver Equipment, Anderson Air force Base, Guam, HRPT

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.33
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above local terrain	33
Elevation Angle (degrees)	5

Table A-24. Receiver Equipment, Monterey, California, HRPT

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.33
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above local terrain	33
Elevation Angle (degrees)	5

Table A-25. Receiver Equipment, Kaena Point/Hickam Air Force Base/Pearl Harbor, Hawaii, High Resolution Picture Transmission Link

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.33
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above terrain	33
Elevation Angle (degrees)	5

Table A-26. Receiver Equipment, Stennis Space Center, Mississippi, HRPT

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.33
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above terrain	33
Elevation Angle (degrees)	5

Table A-27. Receiver Equipment, Twenty-Nine Palms, California, HRPT

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.33
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above terrain	33
Elevation Angle (degrees)	5
Note: This is a transportable receiver	

Table A-28. Receiver Equipment, Yuma, Arizona, HRPT

Parameter	Value
Center Frequency (MHz)	1698, 1702.5, 1707
Receiver 3 dB Intermediate Frequency Bandwidth (MHz)	1.33
Receiver IF Selectivity (relative attenuation (dB) as a function of frequency offset (MHz))	-3 dB @ +/- 0.6655 MHz -20 dB @ +/- 1.34 MHz -60 dB @ +/- 12 MHz
Noise Figure (dB)	1.8
Mainbeam Antenna Gain (dBi)	29
Antenna Height (meters) above terrain	33
Elevation Angle (degrees)	5
Note: This is a transportable receiver	

Appendix B. Technical Characteristics for Wireless Broadband Systems

This appendix provides the transmitter, receiver, and antenna characteristics for the commercial WiMAX, TDD, and LTE FDD systems to be used in compatibility studies with Federal systems.

The equipment characteristics for WiMAX TDD transmitters and receivers are provided in Tables B-1 and B-2.

Table B-1. WiMAX (TDD) Transmitter Characteristics

Parameter	Base Station		Mobile/Portable Station	
Emission 3 dB Bandwidth (MHz)	4.75, 9.5, and 19		4.75, 9.5, and 19	
Power (Peak) (dBm)	40 (5 MHz Channel) 43 (10 MHz Channel) 46 (20 MHz Channel)		13 to 23[1]	
Emission Spectrum (Relative Attenuation (dB) as a Function of Frequency Offset from Center Frequency (MHz))	Attenuation	ΔF	Attenuation	ΔF
	5 MHz Channel			
	0 dB	0 MHz	0 dB	0 MHz
	0 dB	2.25 MHz	0 dB	2.25 MHz
	27 dB	2.375 MHz	27 dB	2.375 MHz
	30 dB	2.5 MHz	30 dB	2.5 MHz
	37 dB	2.725 MHz	37 dB	2.725 MHz
	40 dB	3MHz	40 dB	3 MHz
	48 dB	4.875 MHz	48 dB	4.875 MHz
	50 dB	6MHz	50 dB	6 MHz
	53 dB	7.375 MHz	53 dB	7.375 MHz
	55 dB	>9 MHz	55 dB	> 9 MHz
	10 MHz Channel			
	0 dB	0 MHz	0 dB	0 MHz
	0 dB	4.5 MHz	0 dB	4.5 MHz
	27 dB	4.75 MHz	27 dB	4.75 MHz
	30 dB	5 MHz	30 dB	5 MHz
	37 dB	5.45 MHz	37 dB	5.45 MHz
	40 dB	6 MHz	40 dB	6 MHz
	48 dB	9.75 MHz	48 dB	9.75 MHz
	50 dB	12 MHz	50 dB	12 MHz
	53 dB	14.75 MHz	53 dB	14.75 MHz
	55 dB	> 18 MHz	55 dB	> 18 MHz
	20 MHz Channel			
	0 dB	0 MHz	0 dB	0 MHz
	0 dB	9 MHz	0 dB	9 MHz
	27 dB	9.5 MHz	27 dB	9.5 MHz
	30 dB	10 MHz	30 dB	10 MHz
	37 dB	10.9 MHz	37 dB	10.9 MHz
	40 dB	12 MHz	40 dB	12 MHz
	48 dB	19.5 MHz	48 dB	19.5 MHz
	50 dB	24 MHz	50 dB	24 MHz
	53 dB	29.5 MHz	53 dB	29.5 MHz
	55 dB	> 36 MHz	55 dB	> 36 MHz

Table B-1. WiMAX (TDD) Transmitter Characteristics (continued)

Parameter	Base Station	Mobile/Portable Station
TDD Duty Cycle (Percent)	62.5	37.5
Antenna Gain (Mainbeam) (dBi)	18	0
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Modified ITU-R Recommendation F.1336-2	Omni-directional
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-2	Omni-directional
Antenna Height (meters)[2]	5 to 15 (Urban/Suburban) 15 to 60 (Rural)	1.5 to 10
Antenna Polarization	Linear	Linear
Antenna Azimuth 3 dB Beamwidth (degrees)[3]	65 (Urban/Suburban) 90 (Rural)	360
Antenna Down Tilt Angle (degrees)	2.5	0
Cable, Insertion, or Other Losses (dB)	2	0
Note 1: The lower power limit assumes 10 dB of transmitter power control. Note 2: For single entry analysis, the maximum antenna height of 60 meters for base stations and 1.5 meters for mobile/portable stations will be used. For aggregate analysis antenna heights will be varied between the minimum and maximum values shown in the table. Note 3: A base station typically has three sectors each 120 degrees wide.		

Table B-2. WiMAX (TDD) Receiver Characteristics

Parameter	Base Station		Mobile/Portable Station	
Receiver 3 dB Intermediate Frequency (IF) Bandwidth (MHz)	4.75, 9.5, and 19		4.75, 9.5, and 19	
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	Attenuation	ΔF	Attenuation	ΔF
	5 MHz Channel			
	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 2.25 MHz 2.375 MHz 2.5 MHz 2.725 MHz 3 MHz 4.875 MHz 6 MHz 7.375 MHz > 9 MHz	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 2.25 MHz 2.375 MHz 2.5 MHz 2.725 MHz 3 MHz 4.875 MHz 6 MHz 7.375 MHz > 9 MHz
	10 MHz Channel			
	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 4.5 MHz 4.75 MHz 5 MHz 5.45 MHz 6 MHz 9.75 MHz 12 MHz 14.75 MHz > 18 MHz	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 4.5 MHz 4.75 MHz 5 MHz 5.45 MHz 6 MHz 9.75 MHz 12 MHz 14.75 MHz > 18 MHz
	20 MHz Channel			
	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 9 MHz 9.5 MHz 10 MHz 10.9 MHz 12 MHz 19.5 MHz 24 MHz 29.5 MHz > 36 MHz	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 9 MHz 9.5 MHz 10 MHz 10.9 MHz 12 MHz 19.5 MHz 24 MHz 29.5 MHz > 36 MHz
Noise Figure (dB)	3		5	
Receiver System Noise (dBm)	-104.2 (4.75 MHz) -101.2 (9.5 MHz) -98.2 (19 MHz)		-102.2 (4.75 MHz) -99.2 (9.5 MHz) -96.2 (19 MHz)	
Antenna Gain (Mainbeam) (dBi)	18		0	
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Modified ITU-R Recommendation F.1336-2		Omni-directional	
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-2		Omni-directional	
Antenna Polarization	Linear		Linear	

Table B-2. WiMAX (TDD) Receiver Characteristics (continued)

Parameter	Base Station	Mobile/Portable Station
Antenna Height (meters)[1]	5 to 15 (Urban/Suburban) 15 to 60 (Rural)	1.5 to 10
Antenna Azimuth 3 dB Beamwidth (degrees)[2]	65 (Urban/Suburban) 90 (Rural)	360
Antenna Down Tilt Angle (degrees)	2.5	0
Cable, Insertion, or Other Losses (dB)	2	0
Note 1: For single entry analysis, the maximum antenna height of 60 meters for base stations and 1.5 meters for mobile/portable stations will be used. For aggregate analysis antenna heights will be varied between the minimum and maximum values shown in the table. Note 2: A base station typically has three sectors each 120 degrees wide.		

The equipment characteristics for LTE FDD transmitters and receivers are provided in Tables B-3 and B-4.

Table B-3. LTE (FDD) Transmitter Characteristics

Parameter	**Base Station**		**Mobile/Portable Station**	
Emission 3 dB Bandwidth (MHz)	4.5 and 9		4.5 and 9	
Power (Peak) (dBm)	40 (5 MHz Channel) 43 (10 MHz Channel)		13 to 23[1]	
Emission Spectrum (Relative Attenuation (dB) as a Function of Frequency Offset from Center Frequency (ΔF) (MHz))	Attenuation	ΔF	Attenuation	ΔF
	5 MHz Channel			
	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 2.25 MHz 2.375 MHz 2.5 MHz 2.725 MHz 3 MHz 4.875 MHz 6 MHz 7.375 MHz > 9 MHz	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 2.25 MHz 2.375 MHz 2.5 MHz 2.725 MHz 3 MHz 4.875 MHz 6 MHz 7.375 MHz > 9 MHz
	10 MHz Channel			
	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 4.5 MHz 4.75 MHz 5 MHz 5.45 MHz 6 MHz 9.75 MHz 12 MHz 14.75 MHz > 18 MHz	0 dB 0 dB 27 dB 30 dB 37 dB 40 dB 48 dB 50 dB 53 dB 55 dB	0 MHz 4.5 MHz 4.75 MHz 5 MHz 5.45 MHz 6 MHz 9.75 MHz 12 MHz 14.75 MHz > 18 MHz
Antenna Gain (Mainbeam) (dBi)	18		0	
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Modified ITU-R Recommendation F.1336-2		Omni-directional	
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-2		Omni-directional	
Antenna Height (meters)[2]	5 to 15 (Urban/Suburban) 15 to 60 (Rural)		1.5 to 10	
Antenna Polarization	Linear		Linear	
Antenna Azimuth 3 dB Beamwidth (degrees)[3]	65 (Urban/Suburban) 90 (Rural)		360	
Antenna Down Tilt Angle (degrees)	3		0	
Cable, Insertion, or Other Losses (dB)	2		0	
Note 1: The lower power limit assumes 10 dB of transmitter power control. Note 2: For single entry analysis, the maximum antenna height of 60 meters for base stations and 1.5 meters for mobile/portable stations will be used. For aggregate analysis antenna heights will be varied between the minimum and maximum values shown in the table. Note 3: A base station typically has three sectors each 120 degrees wide.				

Table B-4. LTE (FDD) Receiver Characteristics

Parameter	Base Station		Mobile/Portable Station	
Receiver 3 dB Intermediate Frequency (IF) Bandwidth (MHz)	4.5 and 9		4.5 and 9	
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	Attenuation	ΔF	Attenuation	ΔF
	5 MHz Channel			
	0 dB	0 MHz	0 dB	0 MHz
	0 dB	2.25 MHz	0 dB	2.25 MHz
	27 dB	2.375 MHz	27 dB	2.375 MHz
	30 dB	2.5 MHz	30 dB	2.5 MHz
	37 dB	2.725 MHz	37 dB	2.725 MHz
	40 dB	3 MHz	40 dB	3 MHz
	48 dB	4.875 MHz	48 dB	4.875 MHz
	50 dB	6 MHz	50 dB	6 MHz
	53 dB	7.375 MHz	53 dB	7.375 MHz
	55 dB	> 9 MHz	55 dB	> 9 MHz
	10 MHz Channel			
	0 dB	0 MHz	0 dB	0 MHz
	0 dB	4.5 MHz	0 dB	4.5 MHz
	27 dB	4.75 MHz	27 dB	4.75 MHz
	30 dB	5 MHz	30 dB	5 MHz
	37 dB	5.45 MHz	37 dB	5.45 MHz
	40 dB	6 MHz	40 dB	6 MHz
	48 dB	9.75 MHz	48 dB	9.75 MHz
	50 dB	12 MHz	50 dB	12 MHz
	53 dB	14.75 MHz	53 dB	14.75 MHz
	55 dB	> 18 MHz	55 dB	> 18 MHz
Noise Figure (dB)	5		9	
Receiver System Noise (dBm)	-102.5 (4.5 MHz) -99.5 (9 MHz)		-98.5 (4.5 MHz) -95.5 (9 MHz)	
Antenna Gain (Mainbeam) (dBi)	18		0	
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Modified ITU-R Recommendation F.1336-2		Omni-directional	
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-2		Omni-directional	
Antenna Polarization	Linear		Linear	
Antenna Height (meters)[1]	5 to 15 (Urban/Suburban) 15 to 60(Rural)		1.5 to 10	
Antenna Azimuth 3 dB Beamwidth (degrees)[2]	65 (Urban/Suburban) 90 (Rural)		360	
Antenna Down Tilt Angle (degrees)	3		0	
Cable, Insertion, or Other Losses (dB)	2		0	
Note 1: For single entry analysis the maximum antenna height of 60 meters for base stations and 1.5 meters for mobile/portable stations will be used. For aggregate analysis antenna heights will be varied between the minimum and maximum values shown in the table. Note 2: A base station typically has three sectors each 120 degrees wide.				

Appendix C. Radiosonde Transmitter to Base Station Receiver Interference Analysis

This appendix provides the results of a MATLAB simulation that computes the received signal power at the input of a base station receiver from a radiosonde transmitter. The figures show the power level at the input to the base station receiver (y-axis) as a function of distance from the radiosonde transmitter (x-axis). The base station receiver is located at 0 km in each figure. The radiosonde transmitter flies directly into mainbeam of the base station antenna. The base station receiver interference threshold considered is based on an interference-to-noise ratio of -6 dB shown as a dashed line. Potential interference can occur if the received signal from the radiosonde transmitter exceeds the base station interference threshold.

Figures C-1 through C-9 provides the simulation results for a 5 MHz base station channel configuration.

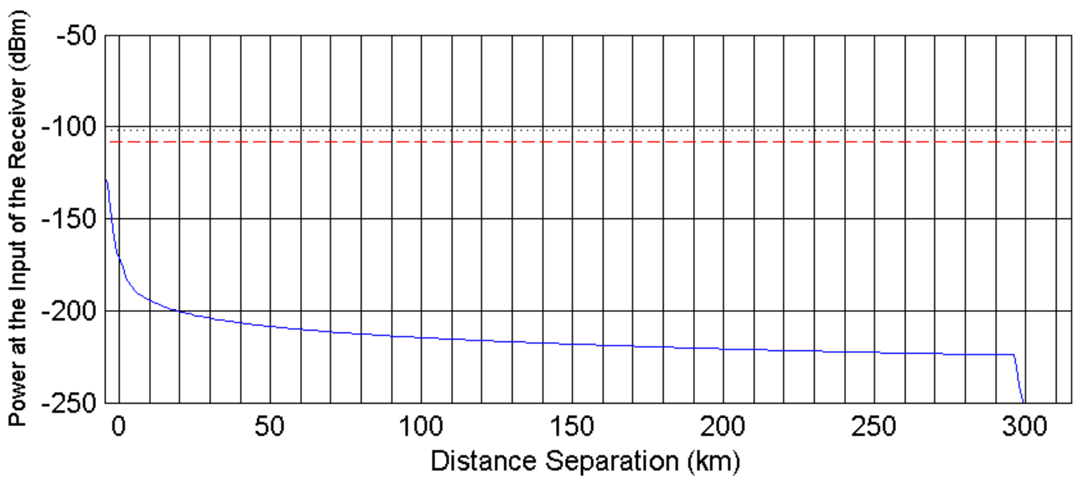

Figure C-1. Radiosonde Starts 5 km from Base Station and Flies Directly into Mainbeam

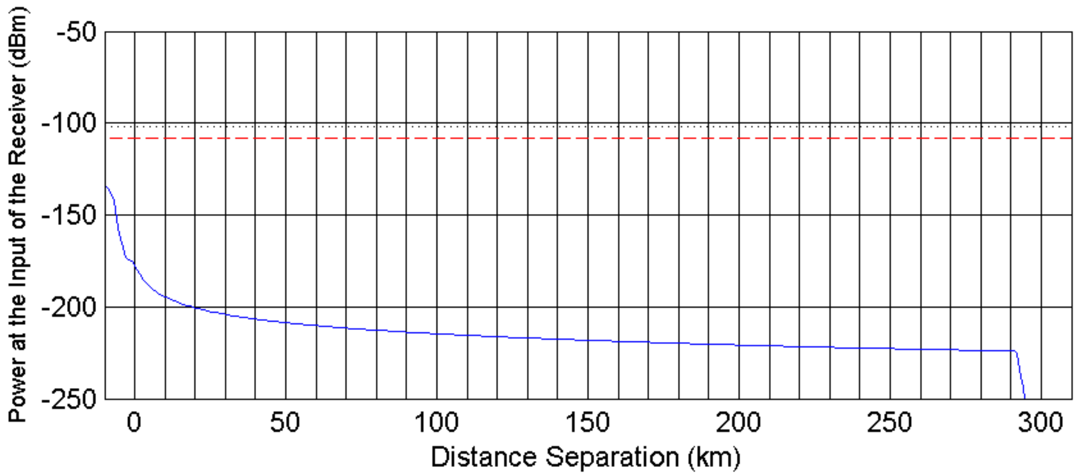

Figure C-2. Radiosonde Starts 10 km from Base Station and Flies Directly into Mainbeam

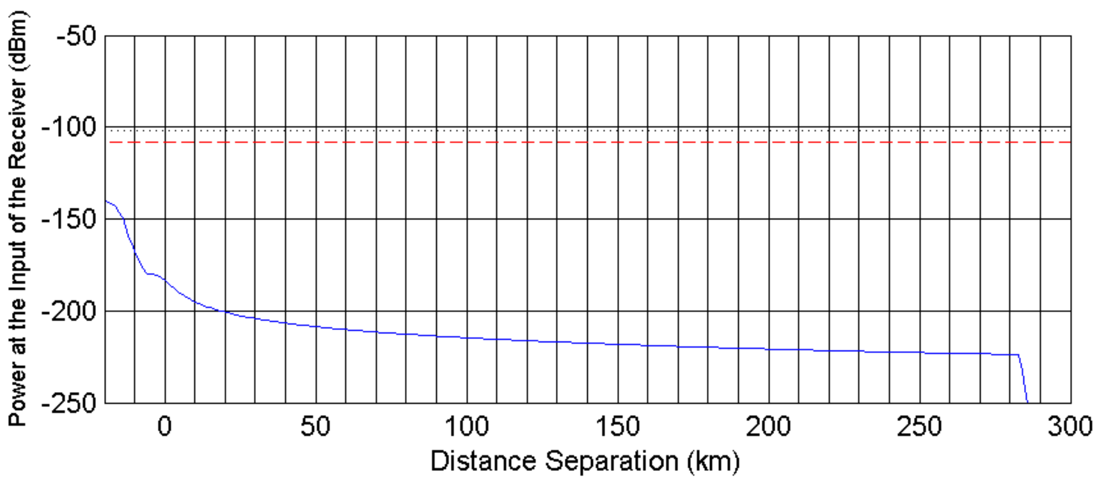

Figure C-3. Radiosonde Starts 20 km from Base Station and Flies Directly into Mainbeam

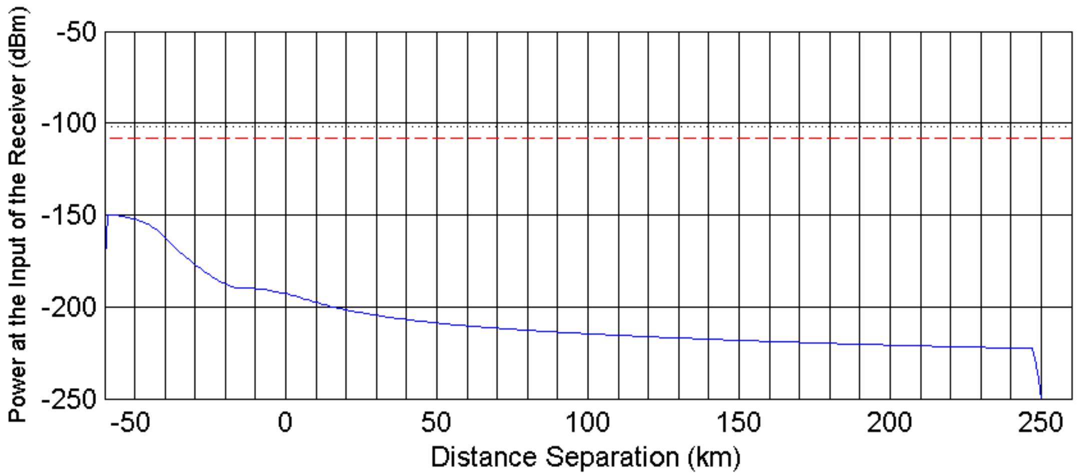

Figure C-4. Radiosonde Starts 60 km from Base Station and Flies Directly into Mainbeam

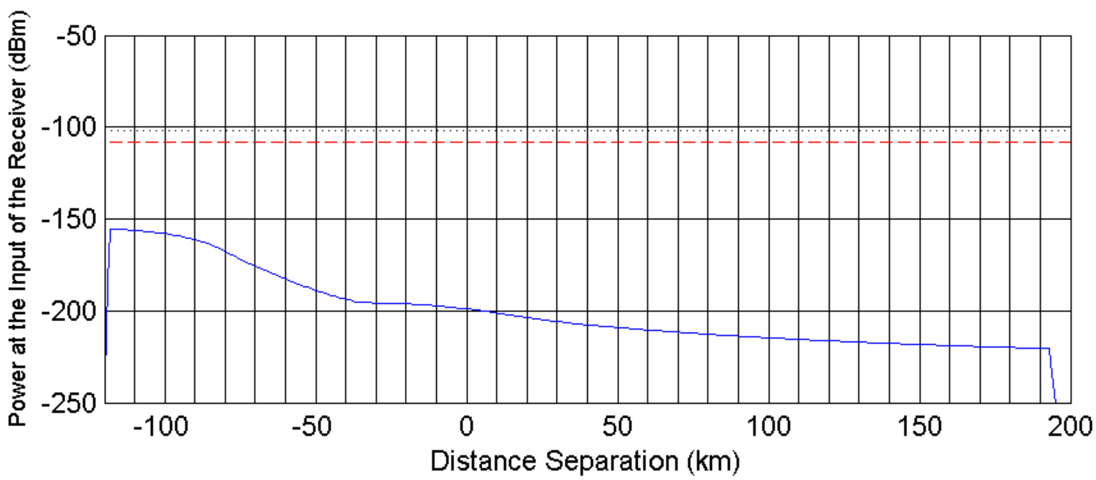

Figure C-5. Radiosonde Starts 120 km from Base Station and Flies Directly into Mainbeam

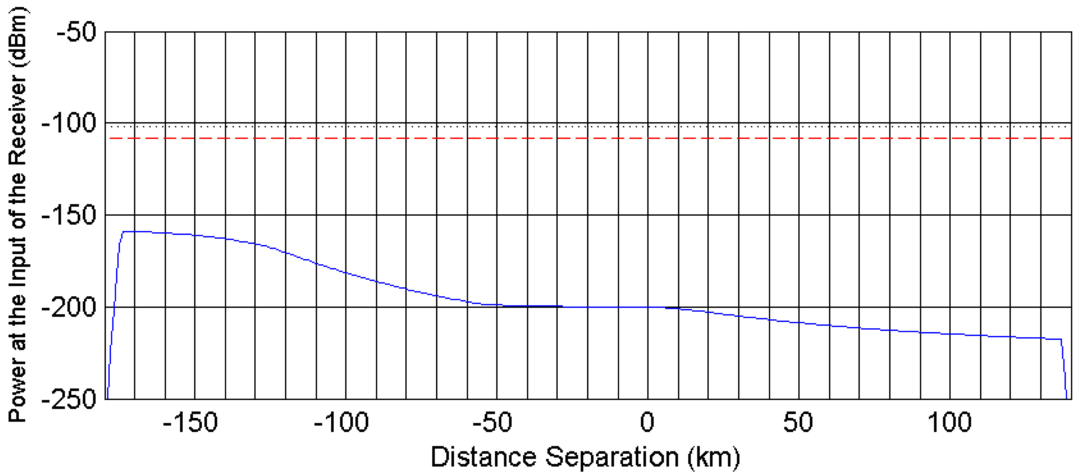

Figure C-6. Radiosonde Starts 180 km from Base Station and Flies Directly into Mainbeam

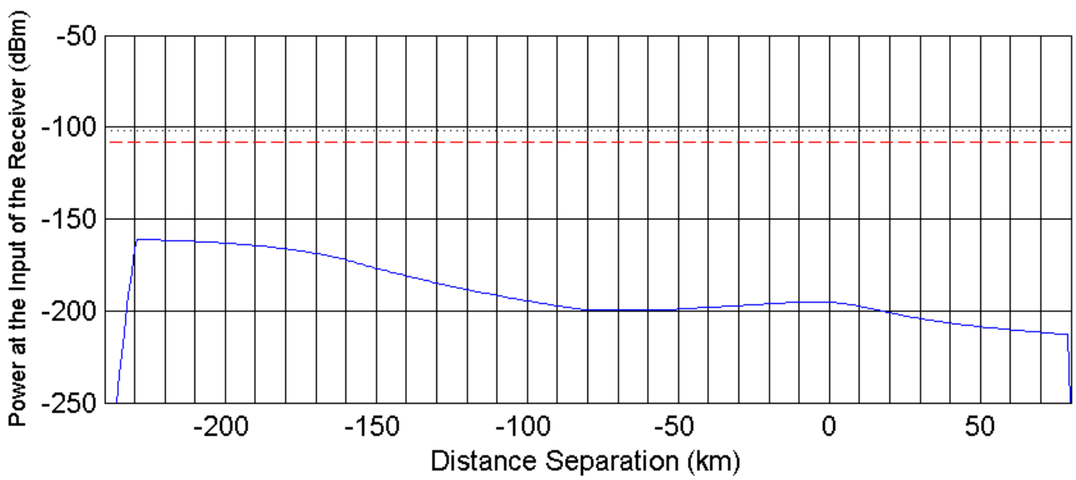

Figure C-7. Radiosonde Starts 240 km from Base Station and Flies Directly into Mainbeam

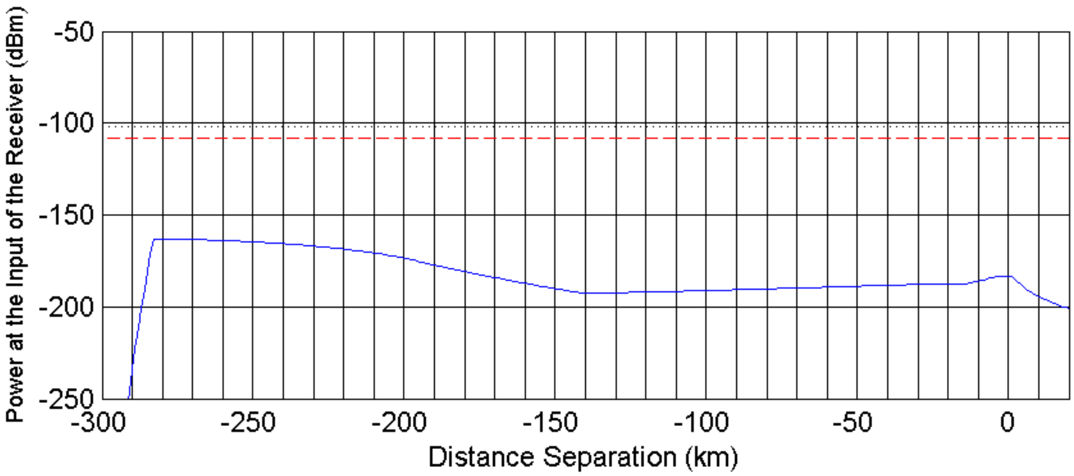

Figure C-8. Radiosonde Starts 300 km from Base Station and Flies Directly into Mainbeam

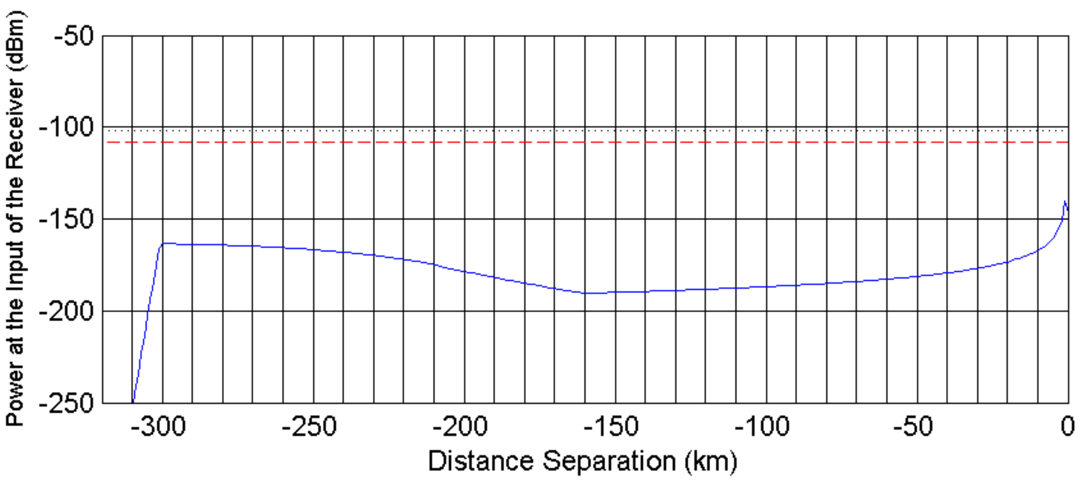

Figure C-9. Radiosonde Starts 320 km from Base Station and Flies Directly into Mainbeam

The results for the 10 MHz base station channel configuration are provided in Figures C-10 through C-18.

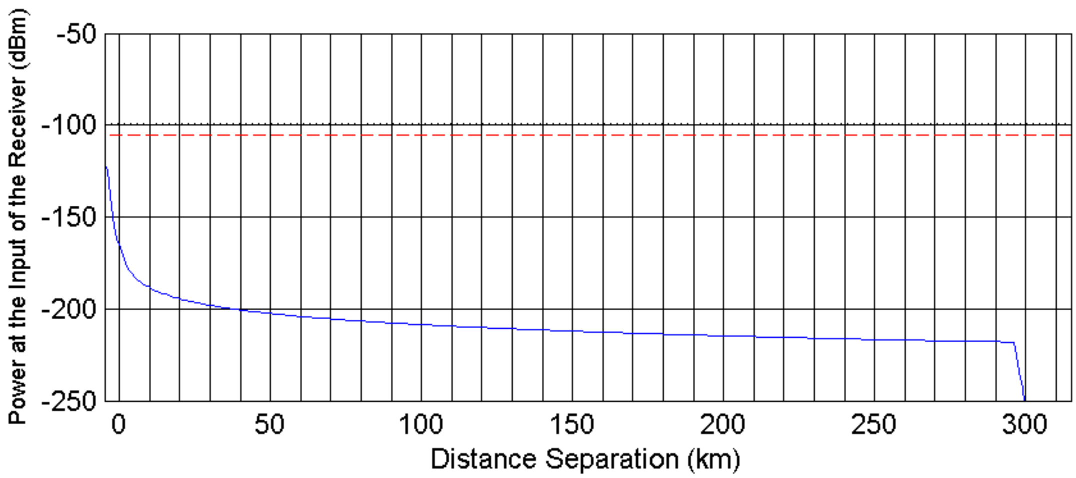

Figure C-10. Radiosonde Starts 5 km from Base Station and Flies Directly into Mainbeam

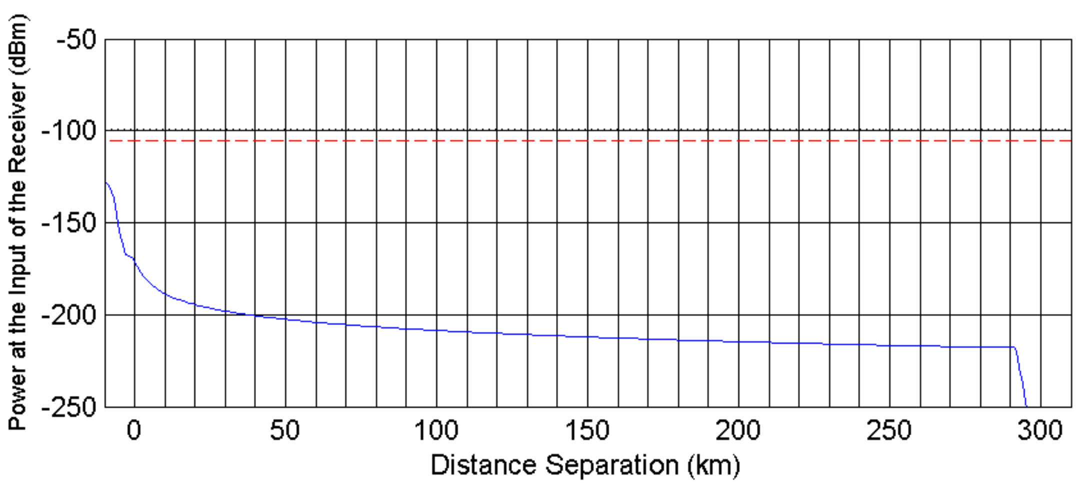

Figure C-11. Radiosonde Starts 10 km from Base Station and Flies Directly into Mainbeam

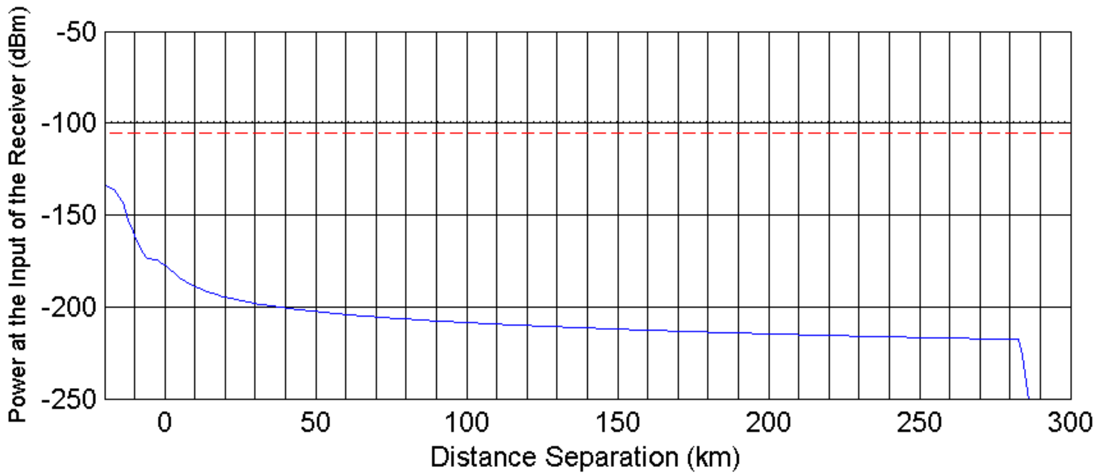

Figure C-12. Radiosonde Starts 20 km from Base Station and Flies Directly into Mainbeam

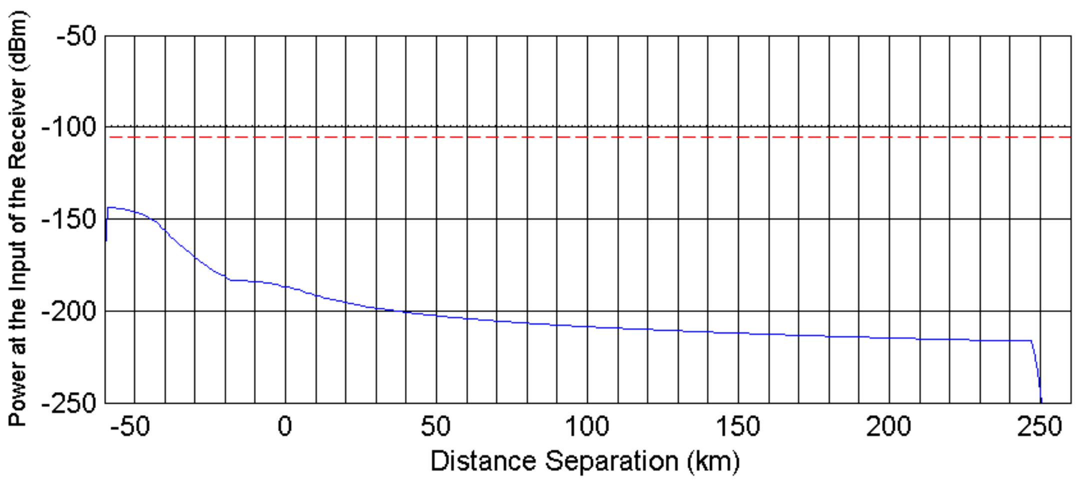

Figure C-13. Radiosonde Starts 60 km from Base Station and Flies Directly into Mainbeam

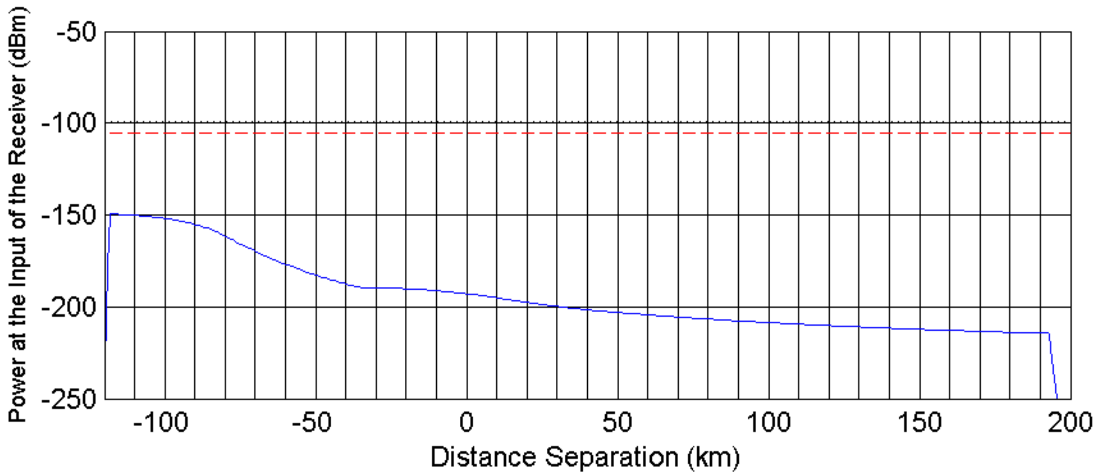

Figure C-14. Radiosonde Starts 120 km from Base Station and Flies Directly into Mainbeam

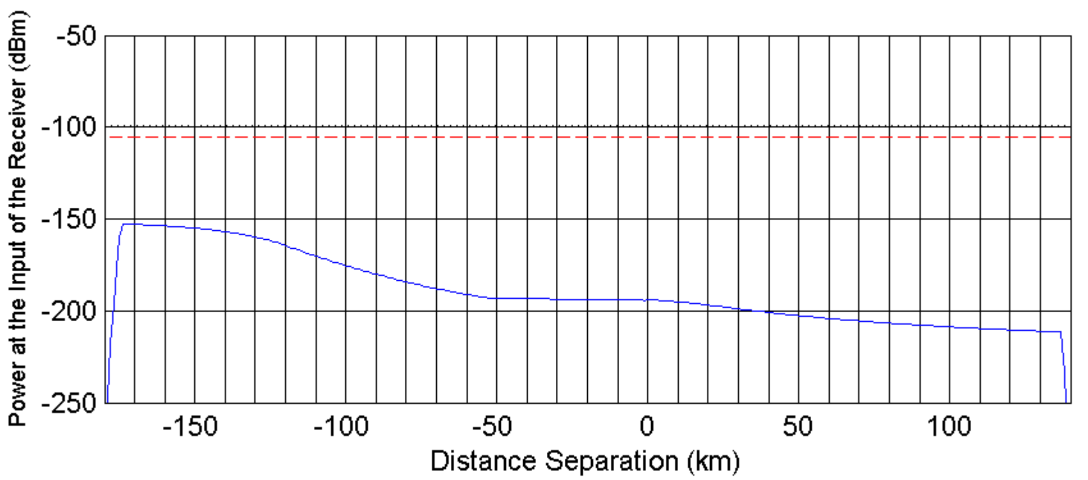

Figure C-15. Radiosonde Starts 180 km from Base Station and Flies Directly into Mainbeam

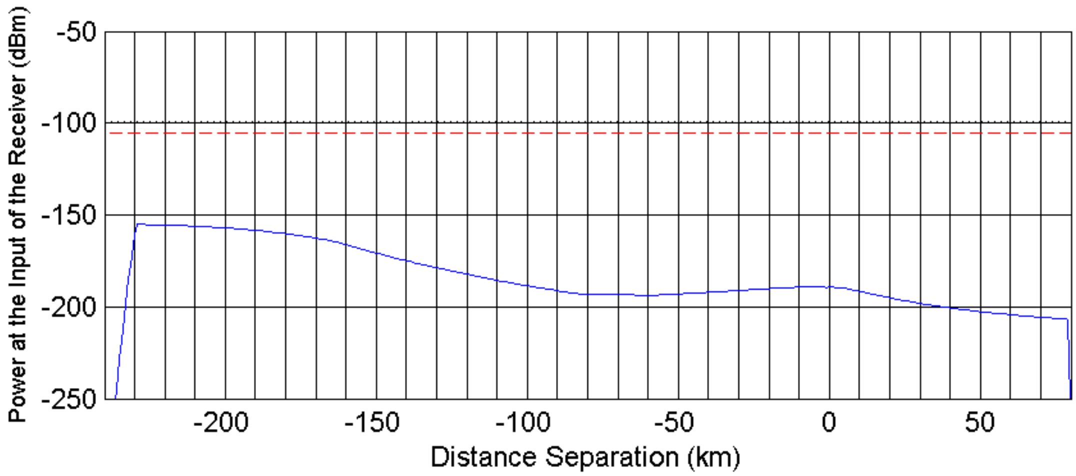

Figure C-16. Radiosonde Starts 240 km from Base Station and Flies Directly into Mainbeam

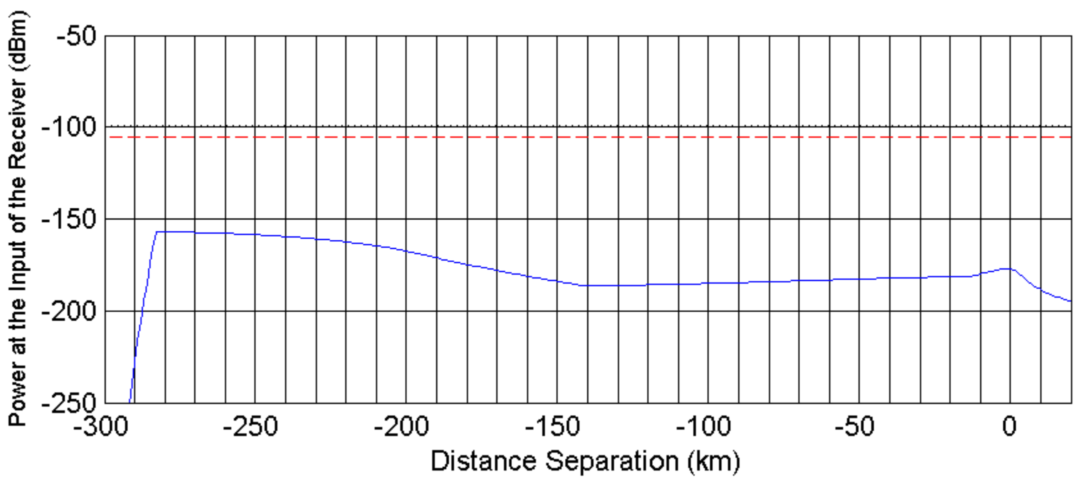

Figure C-17. Radiosonde Starts 300 km from Base Station and Flies Directly into Mainbeam

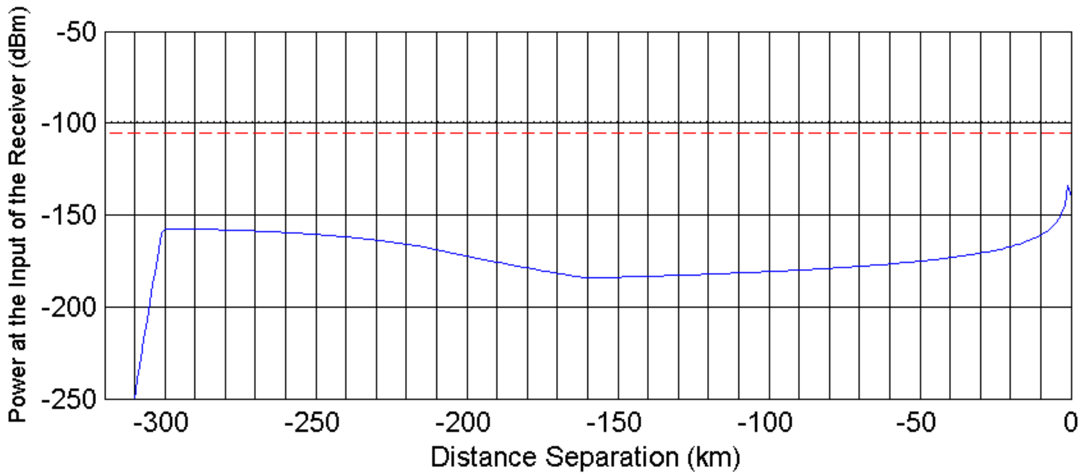

Figure C-18. Radiosonde Starts 320 km from Base Station and Flies Directly into Mainbeam

Appendix D. Shipborne Radar Exclusion Zones

This appendix provides the terrain dependent exclusion zone distances for Shipborne 1-5 radar systems determined through a simulation using the ITM in the point-to-point mode. The ITM and simulation parameters are summarized in Table D-1.

Table D-1. ITM and Simulation Parameters

ITM Parameters
Frequency: 3500 MHz
Ship Antenna Height: 50 m (Shipborne Radar – 1) and 30 m (Shipborne Radar – 2 to Shipborne Radar – 5)
Base Station Antenna Height: 60 m
Reliability and Confidence : 20 %
Surface Refractivity: 301 N-units
Dielectric: 15
Conductivity: 0.005
United States Geological Survey – 3 second topographic data (90 m resolution)
Simulation Parameters
Ship Distance from Coast: 10 km
Step Distance Along the Coast: 10 km
Full Distance Inland: 600 km
Step Distance Inland: 1 km

For the East and Gulf Coasts the simulation moves a ship along the coast in 10 km increments. At each 10 km increment a terrain profile is generated. Using the computed values of required propagation loss the point farthest in-land along the terrain profile corresponding to the required propagation loss is used to determine the exclusion zone distance. Because of the severe terrain features along the West Coast a different approach was used. The simulation still moves the ship along the coast in 10 km increments, but instead of generating a single terrain profile at each increment, individual terrain profiles within a 40 degree sector spaced 1 degree apart are generated. The forty individual terrain profiles generated at each increment along the coast are then used to determine the exclusion zone distances.

Figures D-1 through D-11 show the exclusion zone distances along the U.S. coasts for Shipborne Radar – 1, Figures D-12 through D-22 show the exclusion zones distances for Shipborne Radar – 2, Figures D-23 through D-33 show the exclusion zones distances for Shipborne Radar – 3, Figures D-34 through D-44 depict the exclusion zone distances for Shipborne Radar – 4, Figures D-45 through D-55 illustrate the exclusion zone distances for radar Shipborne Radar – 5, and Figures D-56 through D-66 depict the exclusion zone distances for radar Shipborne Radars – 1-5 in overlay.

Figure D-1. Shipborne Radar – 1 Exclusion Zone, Lower 48 States

Figure D-2. Shipborne Radar – 1 Exclusion Zone, East Coast

Figure D-3. Shipborne Radar – 1 Exclusion Zone, New England Coast

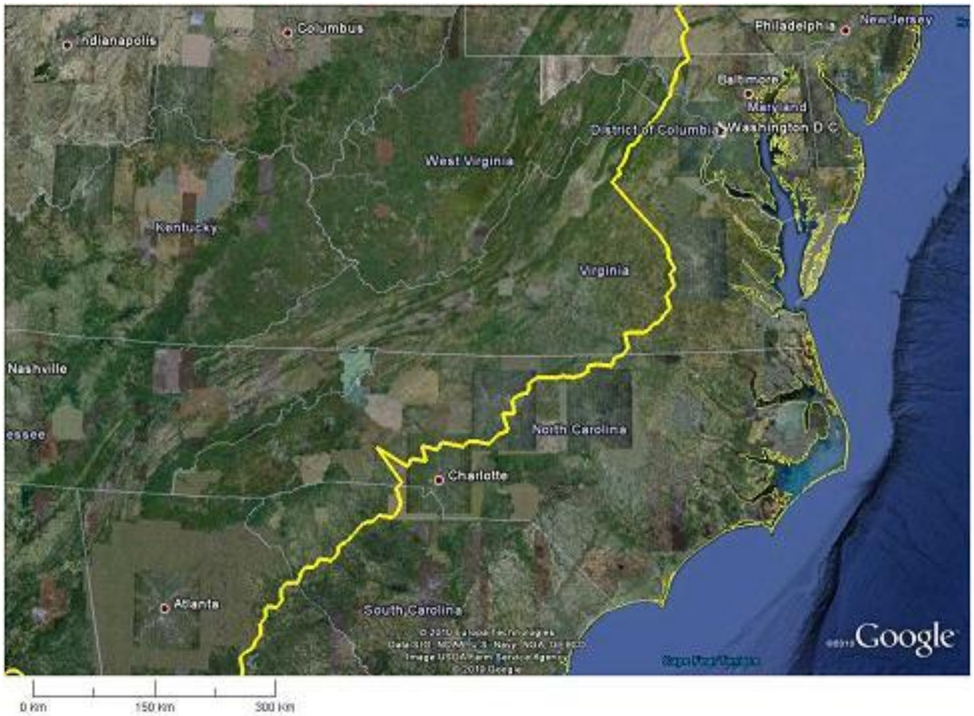

Figure D-4. Shipborne Radar – 1 Exclusion Zone, Mid-Atlantic Coast

Figure D-5. Shipborne Radar – 1 Exclusion Zone, Southeast Coast

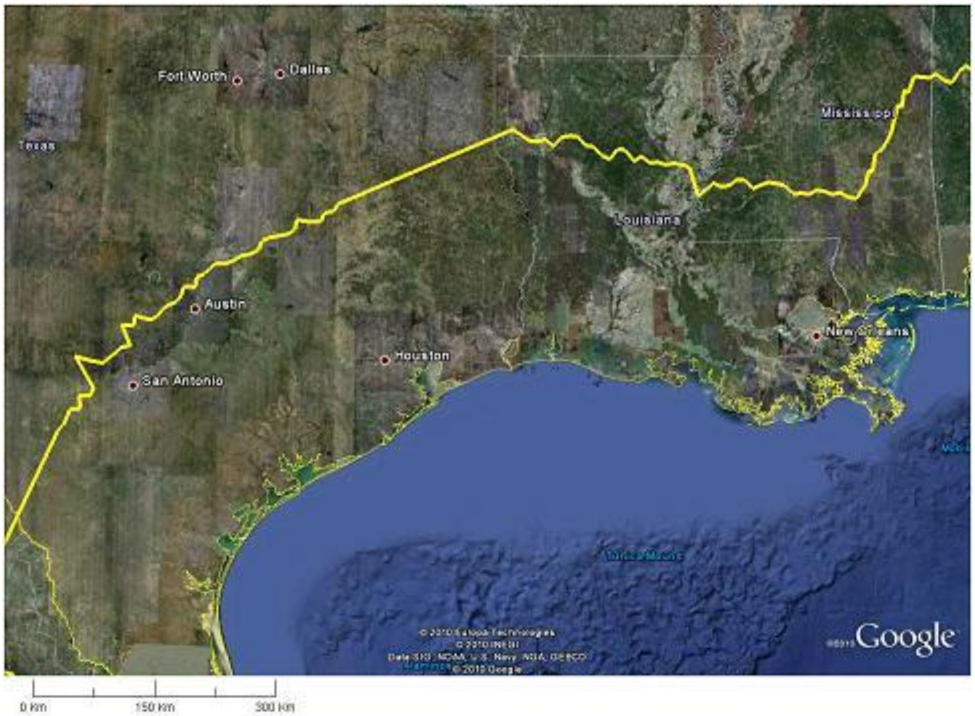

Figure D-6. Shipborne Radar – 1 Exclusion Zone, Gulf Coast

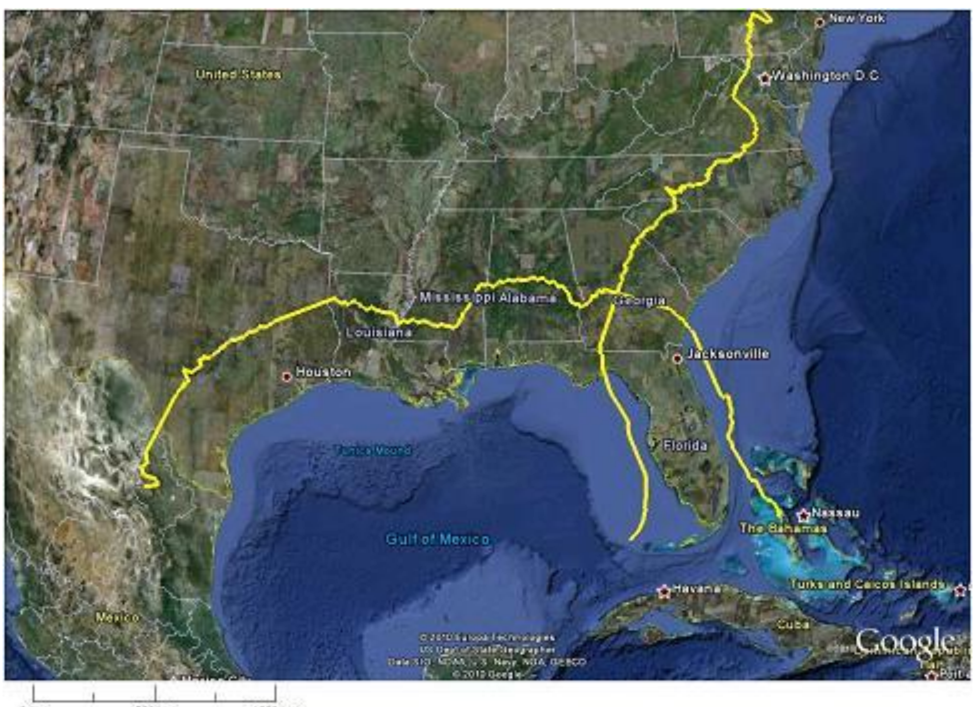

Figure D-7. Shipborne Radar – 1 Exclusion Zone, Southeast and Gulf Coasts

Figure D-8. Shipborne Radar – 1 Exclusion Zone, West Coast

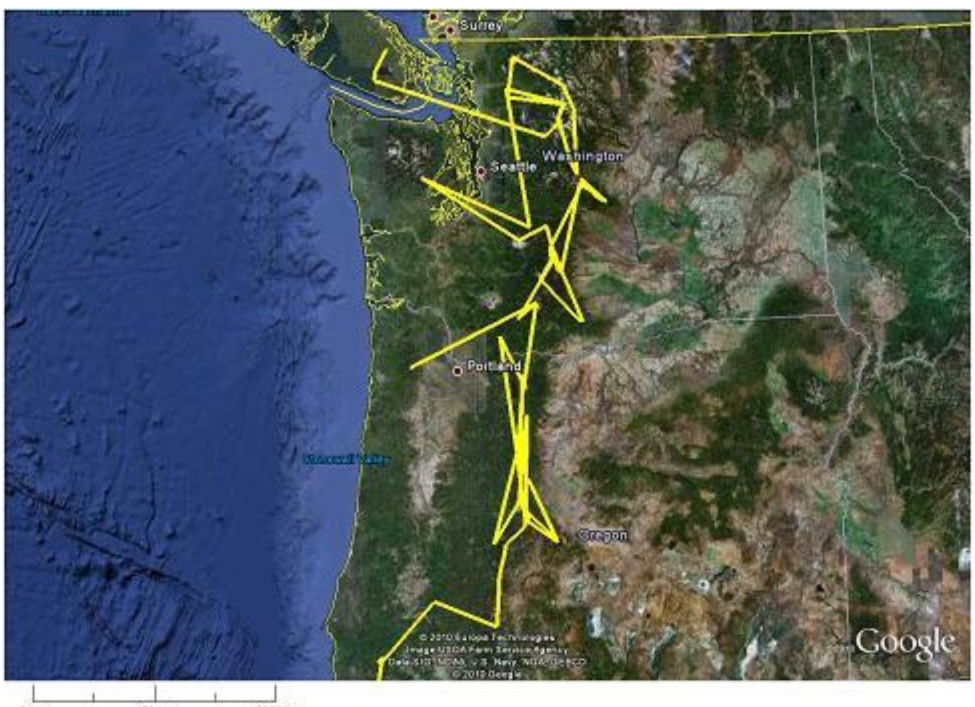

Figure D-9. Shipborne Radar – 1 Exclusion Zone, Northwest Coast

Figure D-10. Shipborne Radar – 1 Exclusion Zone, Northern California Coast

Figure D-11. Shipborne Radar – 1 Exclusion Zone, Southern California Coast

Figure D-12. Shipborne Radar – 2 Exclusion Zone, Lower 48 States

Figure D-13. Shipborne Radar – 2 Exclusion Zone, East Coast

Figure D-14. Shipborne Radar – 2 Exclusion Zone, New England Coast

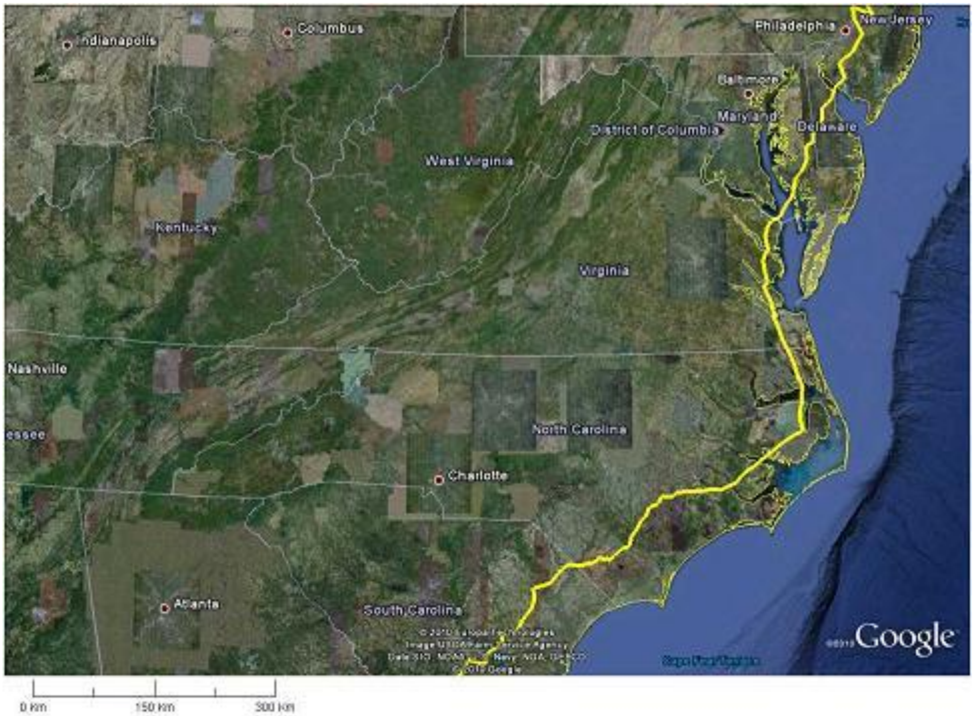

Figure D-15. Shipborne Radar – 2 Exclusion Zone, Mid-Atlantic Coast

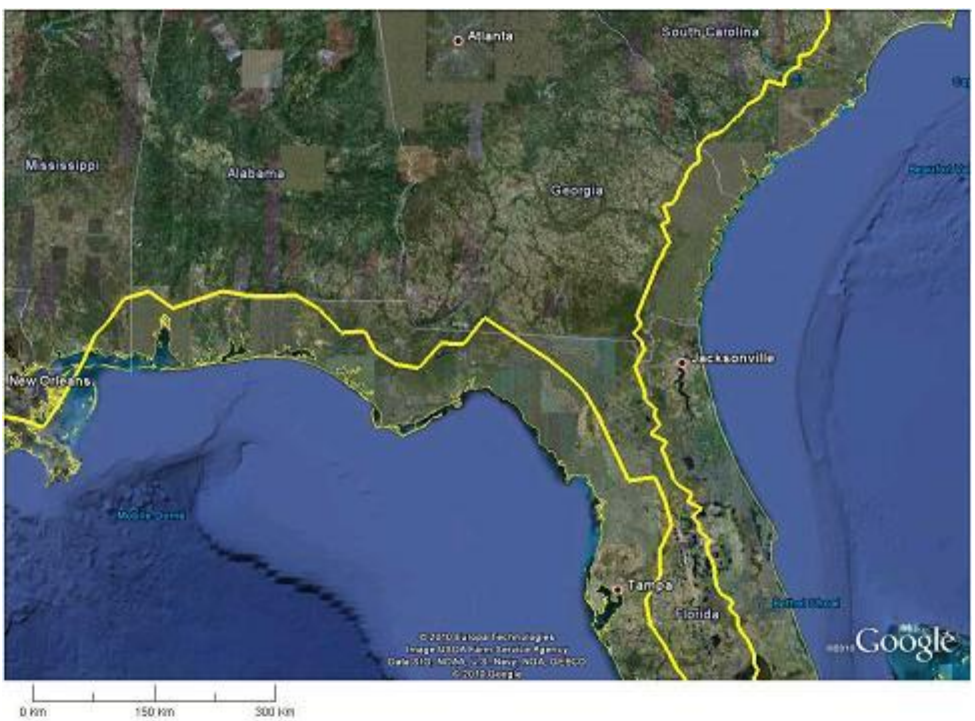

Figure D-16. Shipborne Radar – 2 Exclusion Zone, Southeast Coast

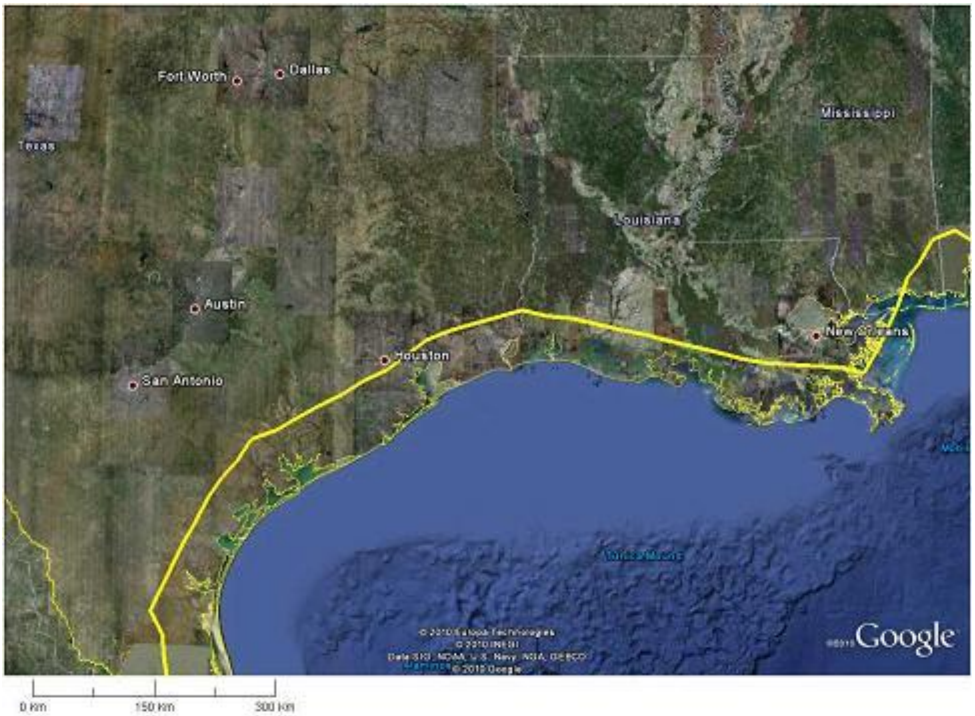

Figure D-17. Shipborne Radar – 2 Exclusion Zone, Gulf Coast

Figure D-18. Shipborne Radar – 2 Exclusion Zone, Southeast and Gulf Coasts

Figure D-19. Shipborne Radar – 2 Exclusion Zone, West Coast

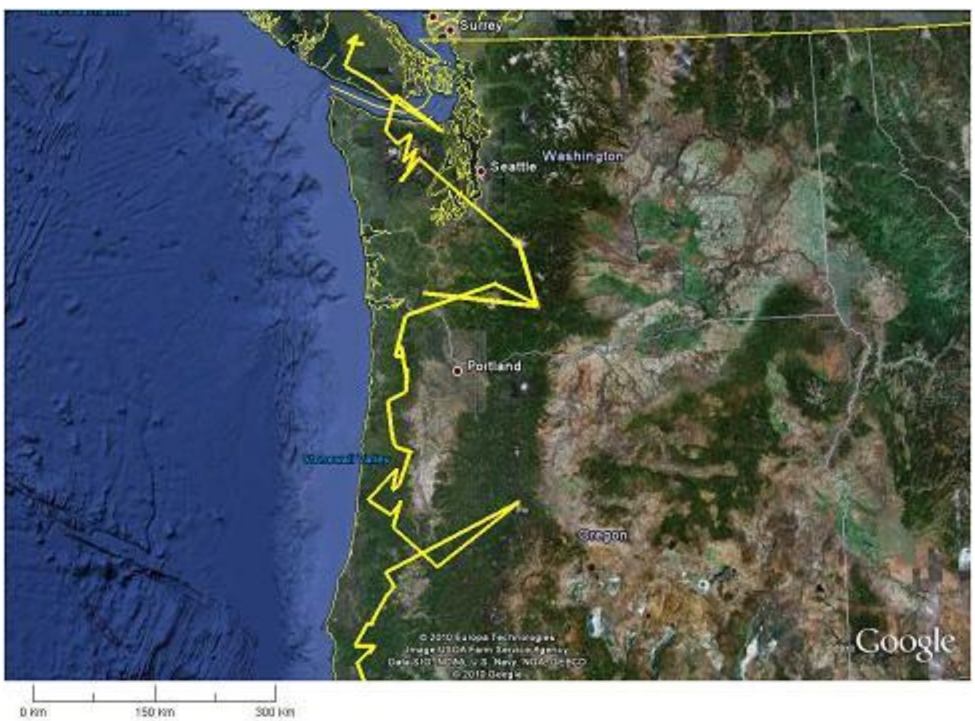

Figure D-20. Shipborne Radar – 2 Exclusion Zone, Northwest Coast

Figure D-21. Shipborne Radar – 2 Exclusion Zone, Northern California Coast

Figure D-22. Shipborne Radar – 2 Exclusion Zone, Southern California Coast

Figure D-23. Shipborne Radar – 3 Exclusion Zone, Lower 48 States

Figure D-24. Shipborne Radar – 3 Exclusion Zone, East Coast

Figure D-25. Shipborne Radar – 3 Exclusion Zone, New England Coast

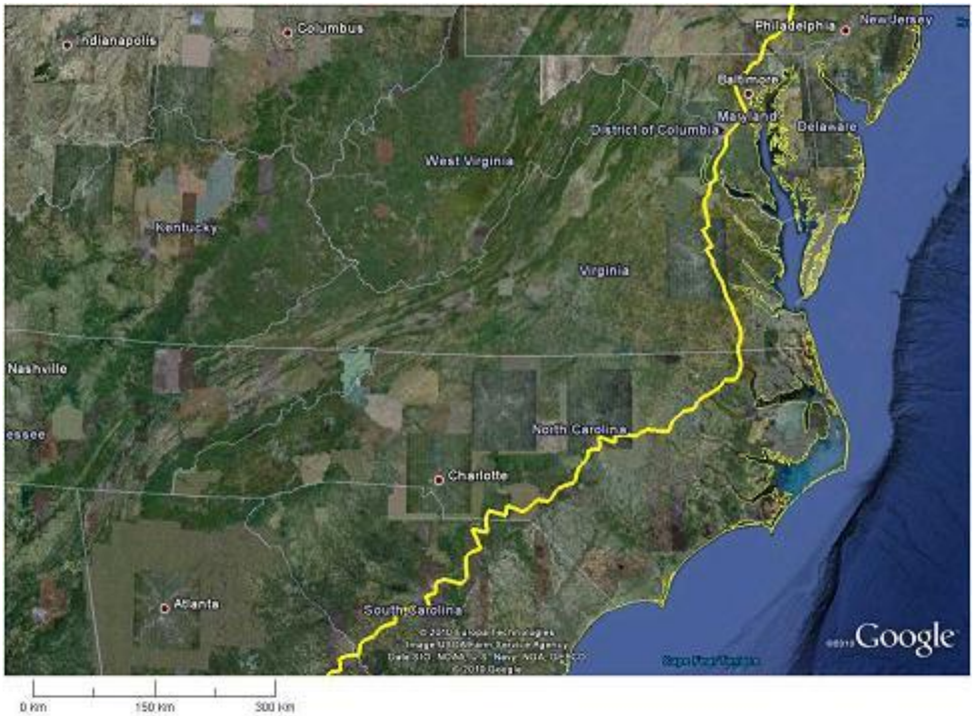

Figure D-26. Shipborne Radar – 3 Exclusion Zone, Mid-Atlantic Coast

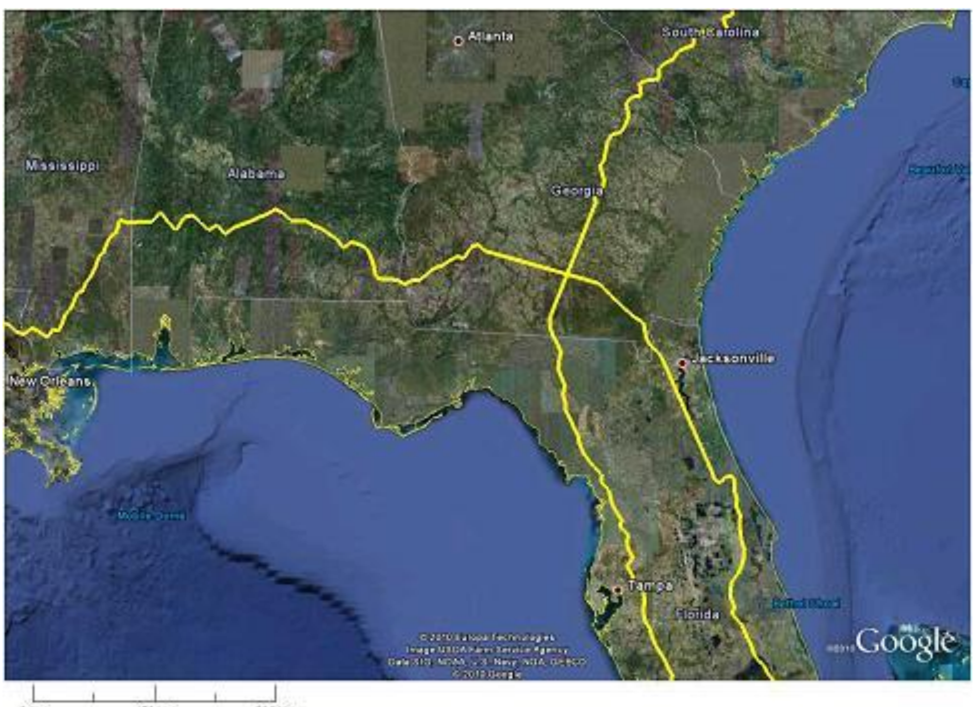

Figure D-27. Shipborne Radar – 3 Exclusion Zone, Southeast Coast

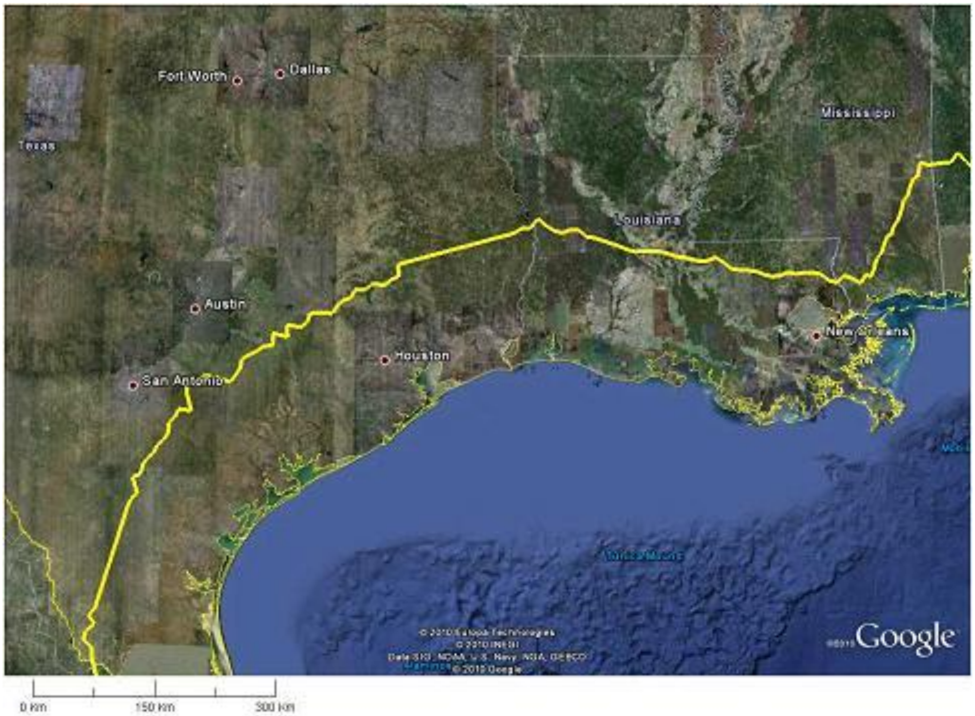

Figure D-28. Shipborne Radar – 3 Exclusion Zone, Gulf Coast

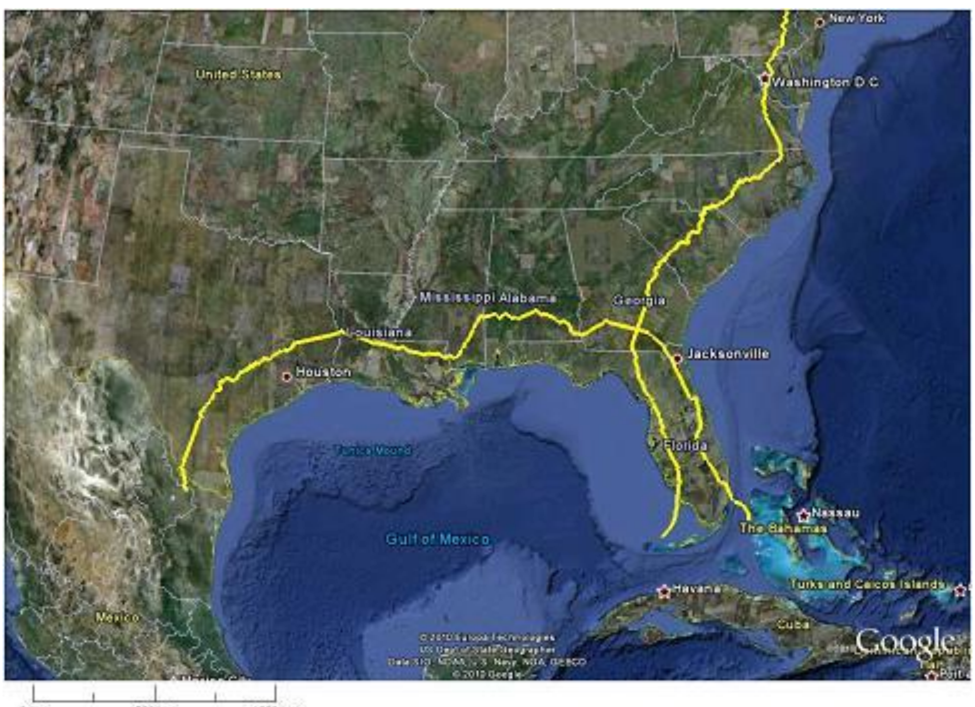

Figure D-29. Shipborne Radar – 3 Exclusion Zone, Southeast and Gulf Coasts

Figure D-30. Shipborne Radar – 3 Exclusion Zone, West Coast

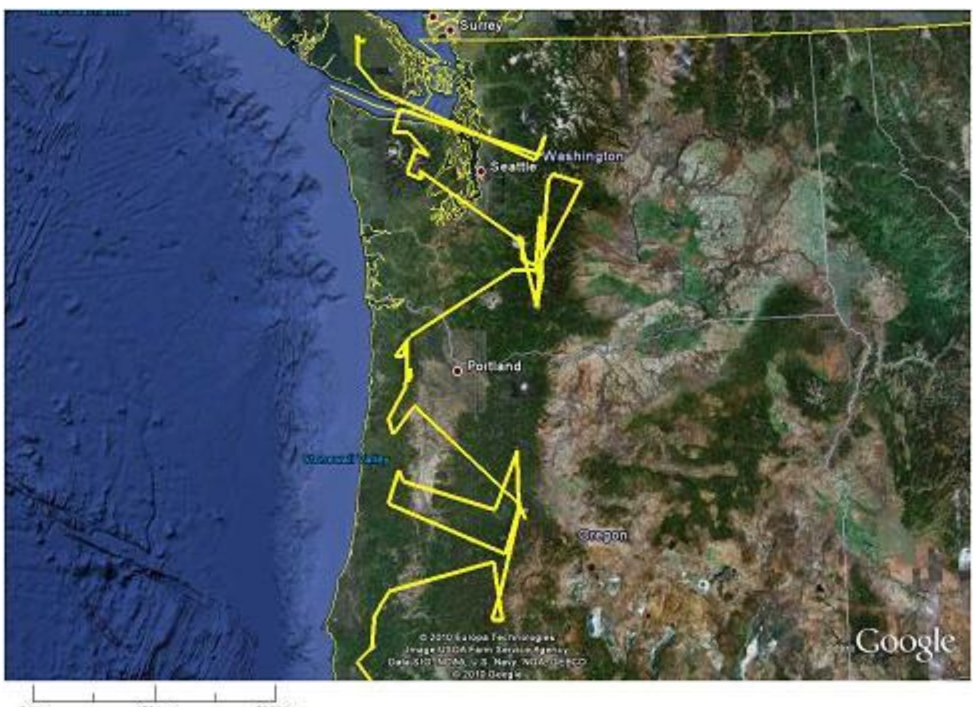

Figure D-31. Shipborne Radar – 3 Exclusion Zone, Northwest Coast

Figure D-32. Shipborne Radar – 3 Exclusion Zone, Northern California Coast

Figure D-33. Shipborne Radar – 3 Exclusion Zone, Southern California Coast

Figure D-34. Shipborne Radar – 4 Exclusion Zone, Lower 48 States

Figure D-35. Shipborne Radar – 4 Exclusion Zone, East Coast

Figure D-36. Shipborne Radar – 4 Exclusion Zone, New England Coast

Figure D-37. Shipborne Radar – 4 Exclusion Zone, Mid-Atlantic Coast

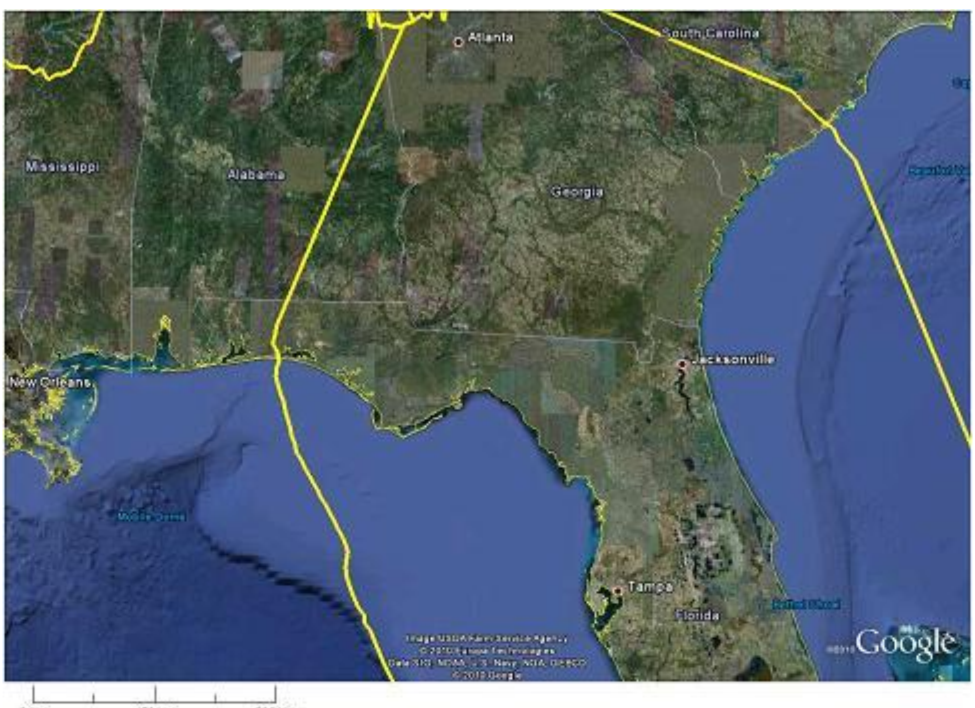

Figure D-38. Shipborne Radar – 4 Exclusion Zone, Southeast Coast

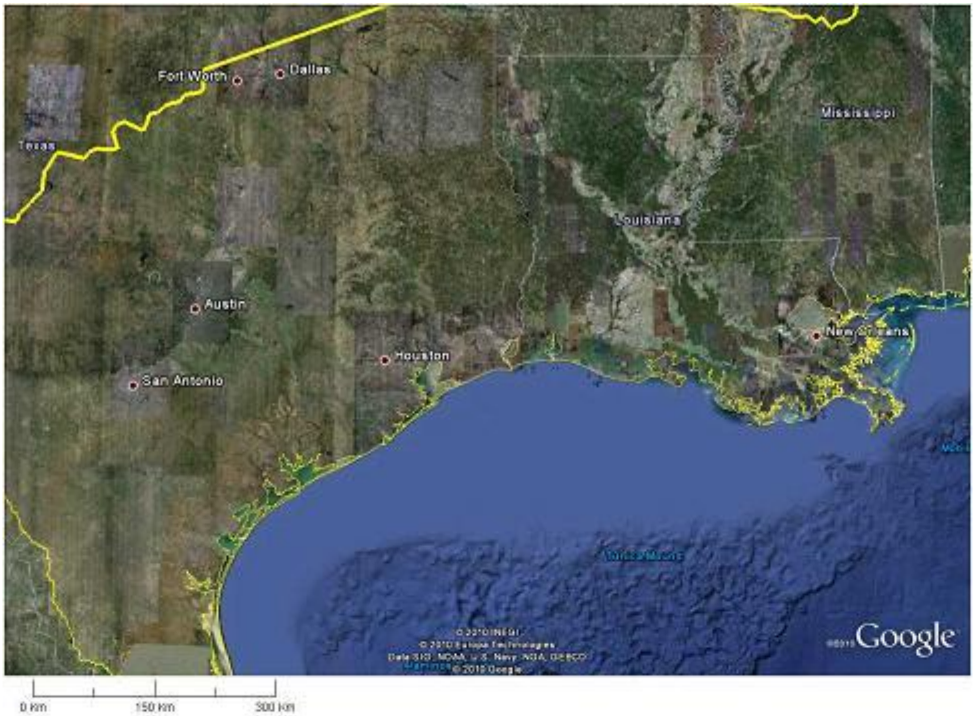

Figure D-39. Shipborne Radar – 4 Exclusion Zone, Gulf Coast

Figure D-40. Shipborne Radar – 4 Exclusion Zone, Southeast and Gulf Coasts

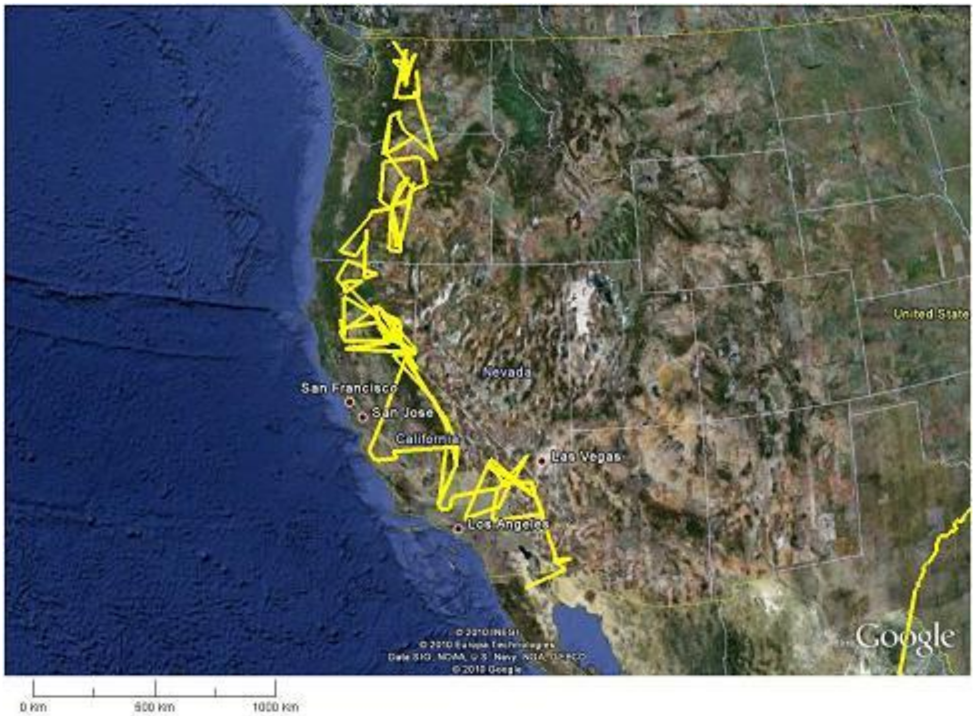

Figure D-41. Shipborne Radar – 4 Exclusion Zone, West Coast

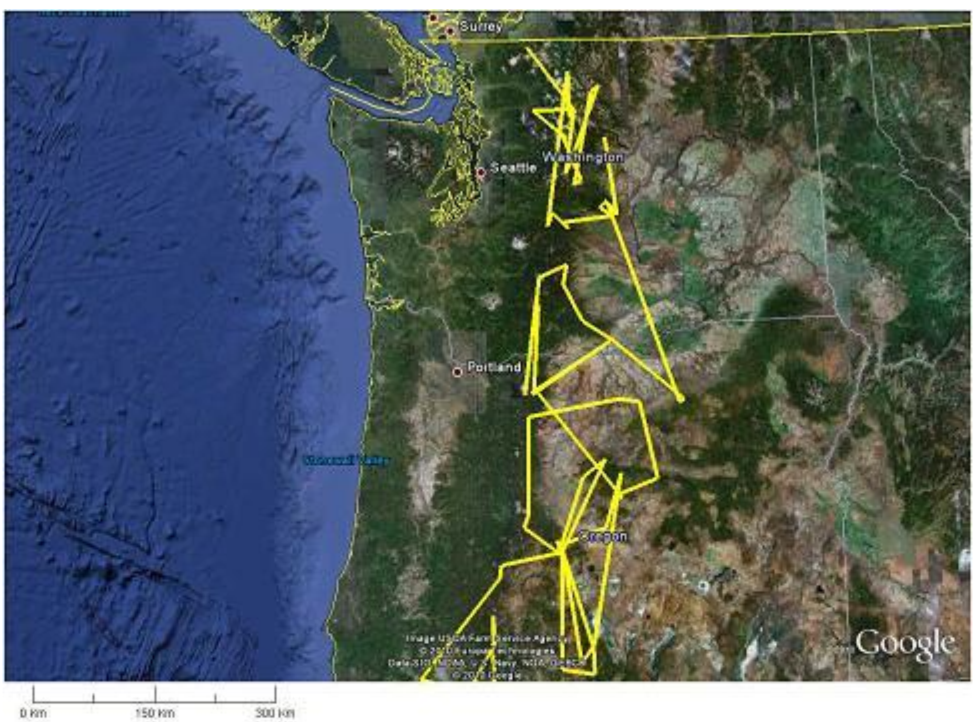

Figure D-42. Shipborne Radar – 4 Exclusion Zone, Northwest Coast

Figure D-43. Shipborne Radar – 4 Exclusion Zone, Northern California Coast

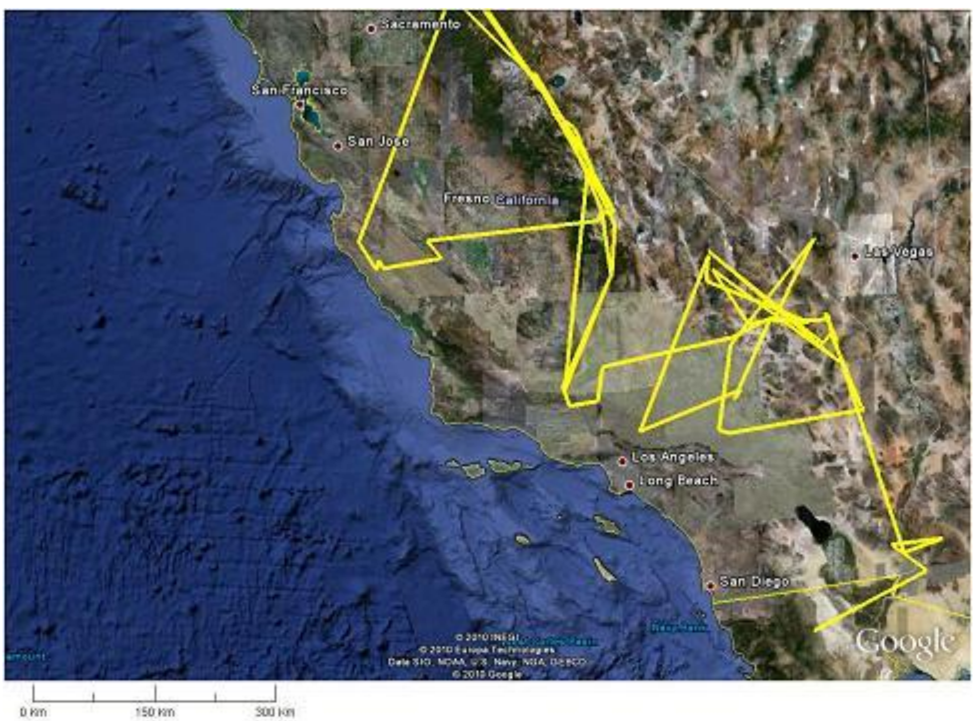

Figure D-44. Shipborne Radar – 4 Exclusion Zone, Southern California Coast

Figure D-45. Shipborne Radar – 5 Exclusion Zone, Lower 48 States

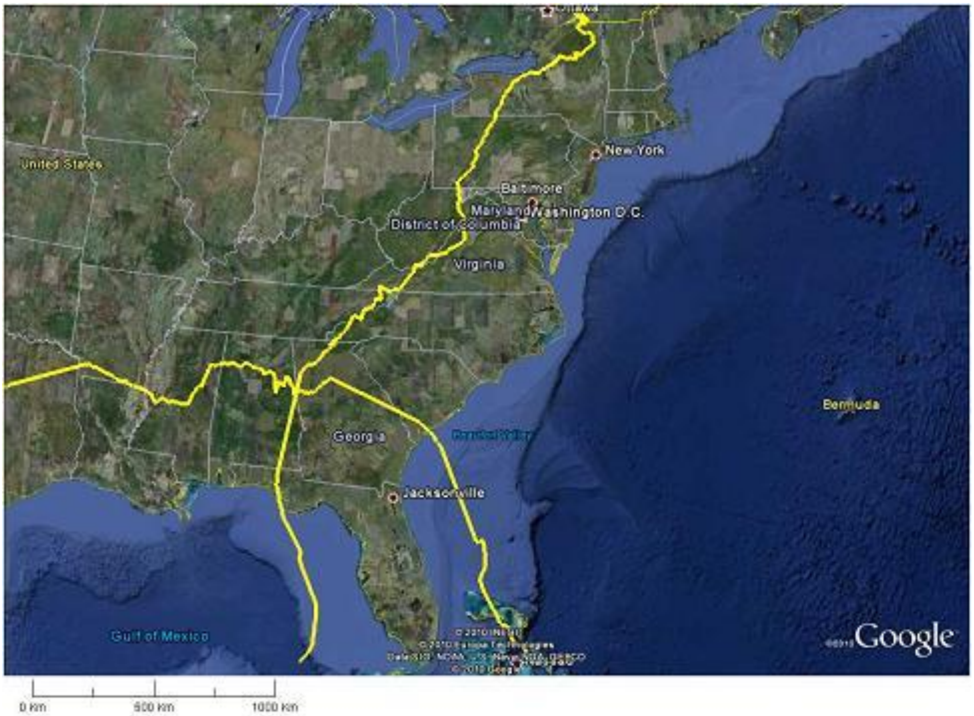

Figure D-46. Shipborne Radar – 5 Exclusion Zone, East Coast

Figure D-47. Shipborne Radar – 5 Exclusion Zone, New England Coast

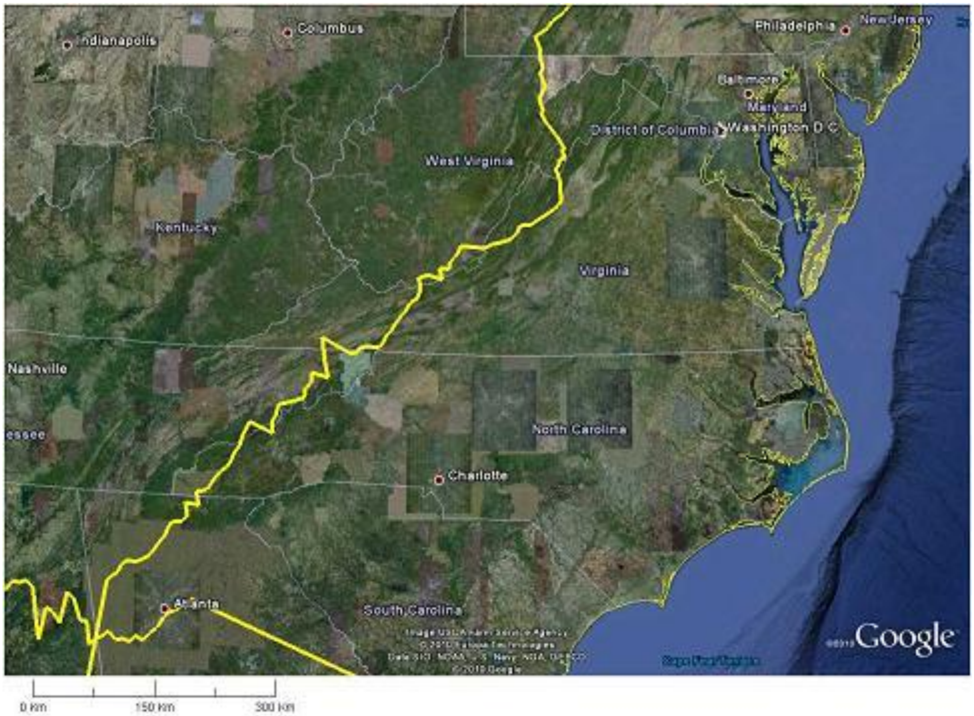

Figure D-48. Shipborne Radar – 5 Exclusion Zone, Mid-Atlantic Coast

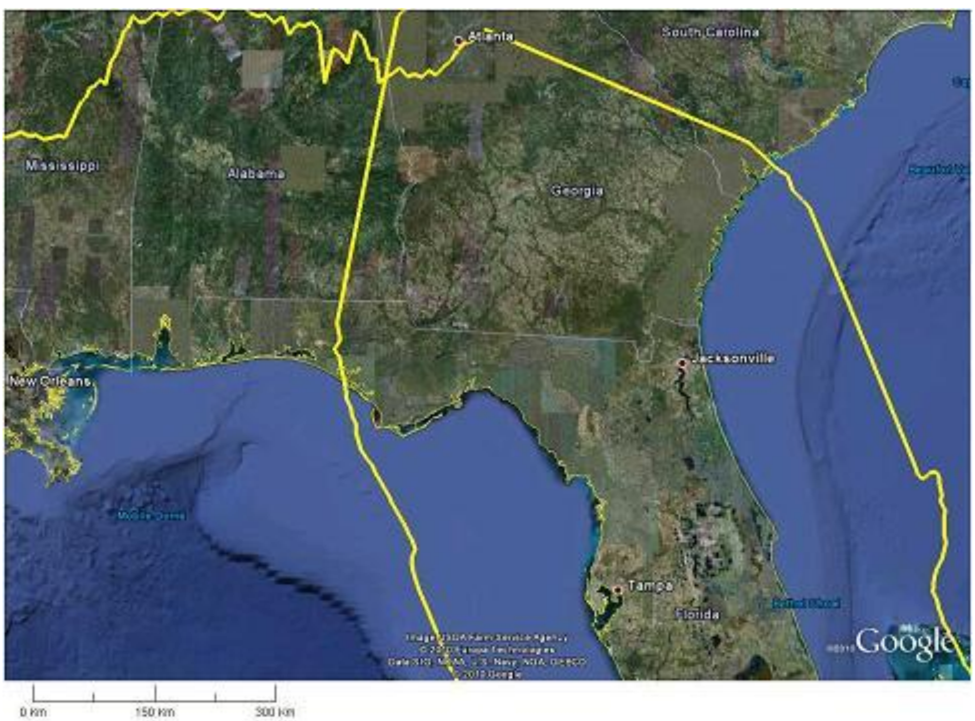

Figure D-49. Shipborne Radar – 5 Exclusion Zone, Southeast Coast

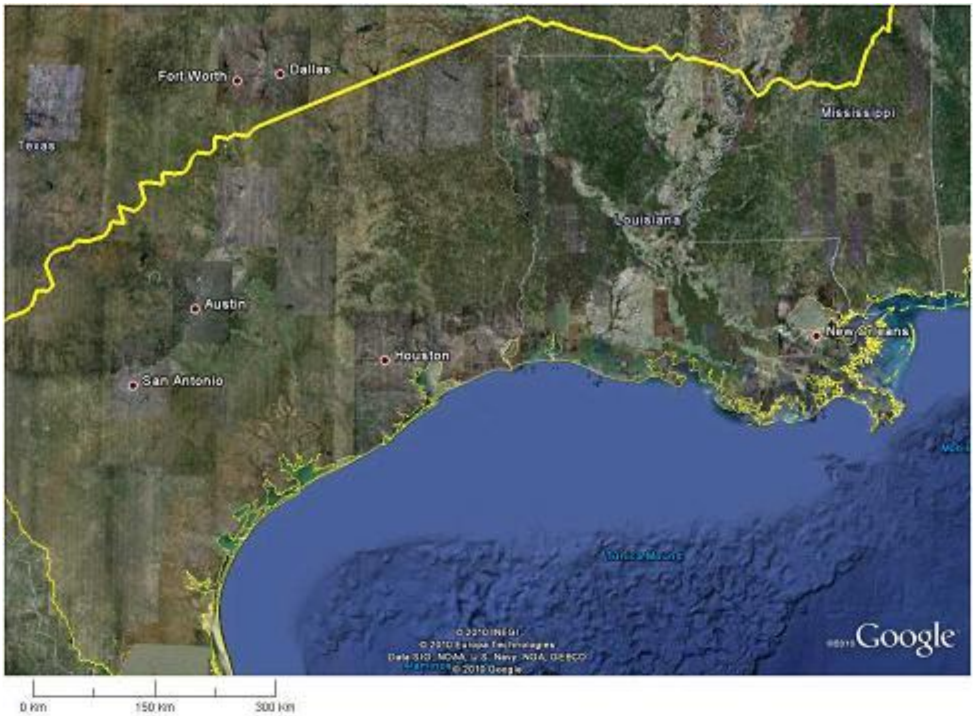

Figure D-50. Shipborne Radar – 5 Exclusion Zone, Gulf Coast

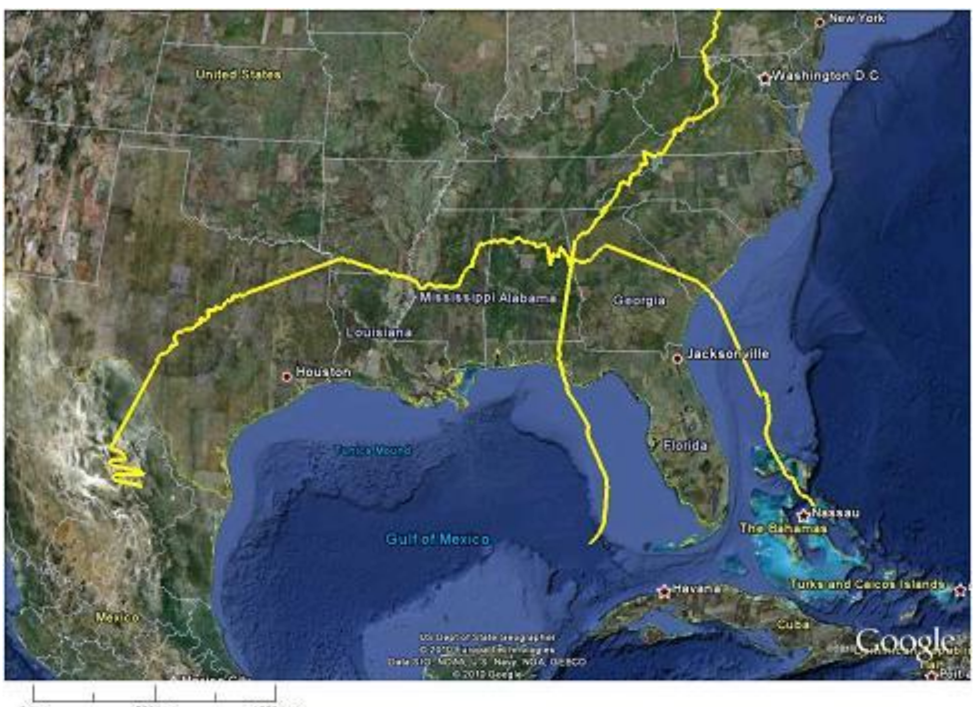

Figure D-51. Shipborne Radar – 5 Exclusion Zone, Southeast and Gulf Coasts

Figure D-52. Shipborne Radar – 5 Exclusion Zone, West Coast

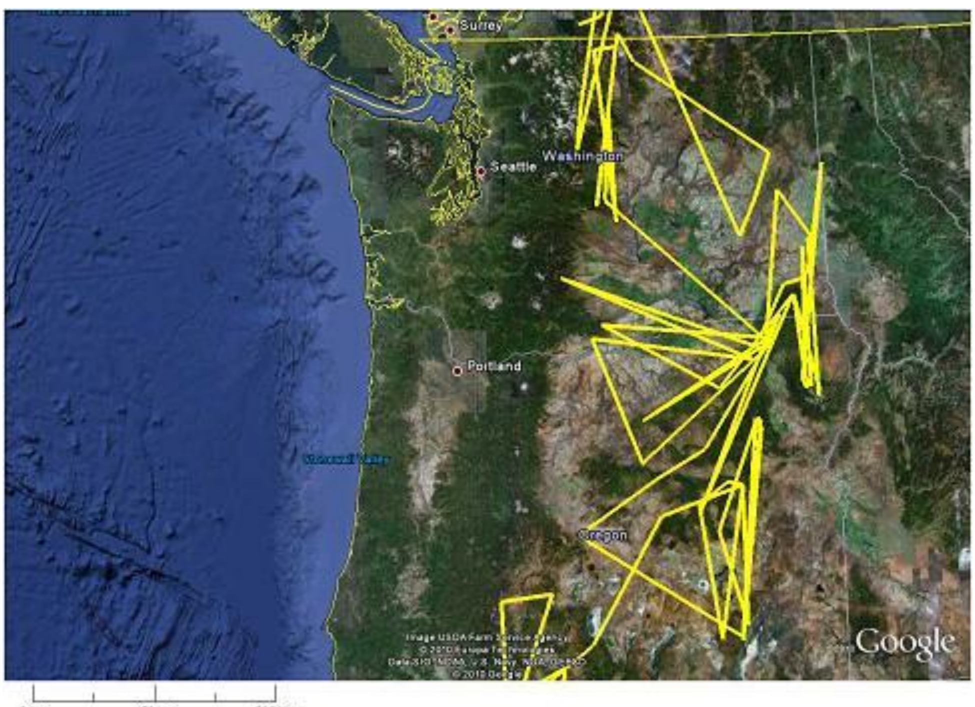

Figure D-53. Shipborne Radar – 5 Exclusion Zone, Northwest Coast

Figure D-54. Shipborne Radar – 5 Exclusion Zone, Northern California Coast

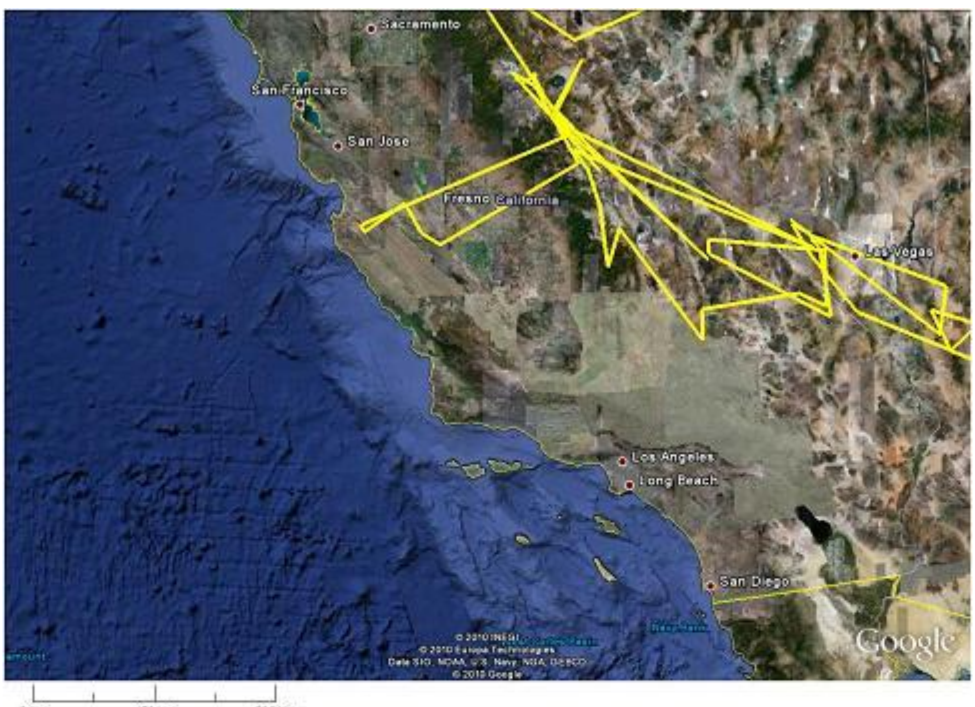

Figure D-55. Shipborne Radar – 5 Exclusion Zone, Southern California Coast

Figure D-56. Shipborne Radar – 1-5 Exclusion Zone Overlay, Lower 48 States

Figure D-57. Shipborne Radar – 1-5 Exclusion Zone Overlay, East Coast

Figure D-58. Shipborne Radar – 1-5 Exclusion Zone Overlay, New England Coast

Figure D-59. Shipborne Radar – 1-5 Exclusion Zone Overlay, Mid-Atlantic Coast

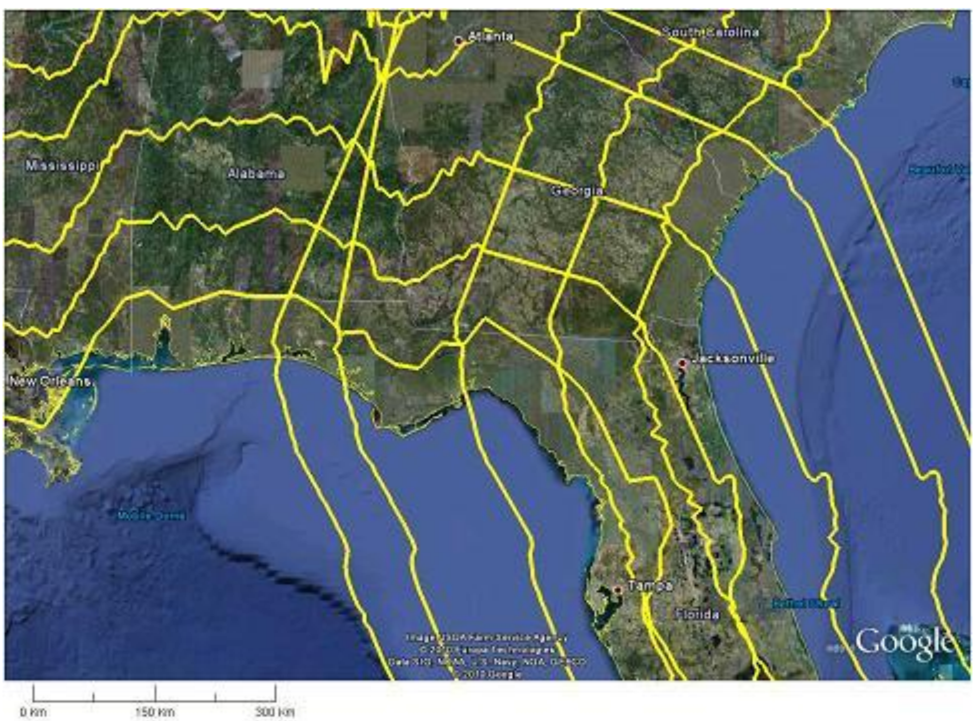

Figure D-60. Shipborne Radar – 1-5 Exclusion Zone Overlay, Southeast Coast

Figure D-61. Shipborne Radar – 1-5 Exclusion Zone Overlay, Gulf Coast

Figure D-62. Shipborne Radar – 1-5 Exclusion Zone Overlay, Southeast and Gulf Coasts

Figure D-63. Shipborne Radar – 1-5 Exclusion Zone Overlay, West Coast

Figure D-64. Shipborne Radar – 1-5 Exclusion Zone Overlay, Northwest Coast

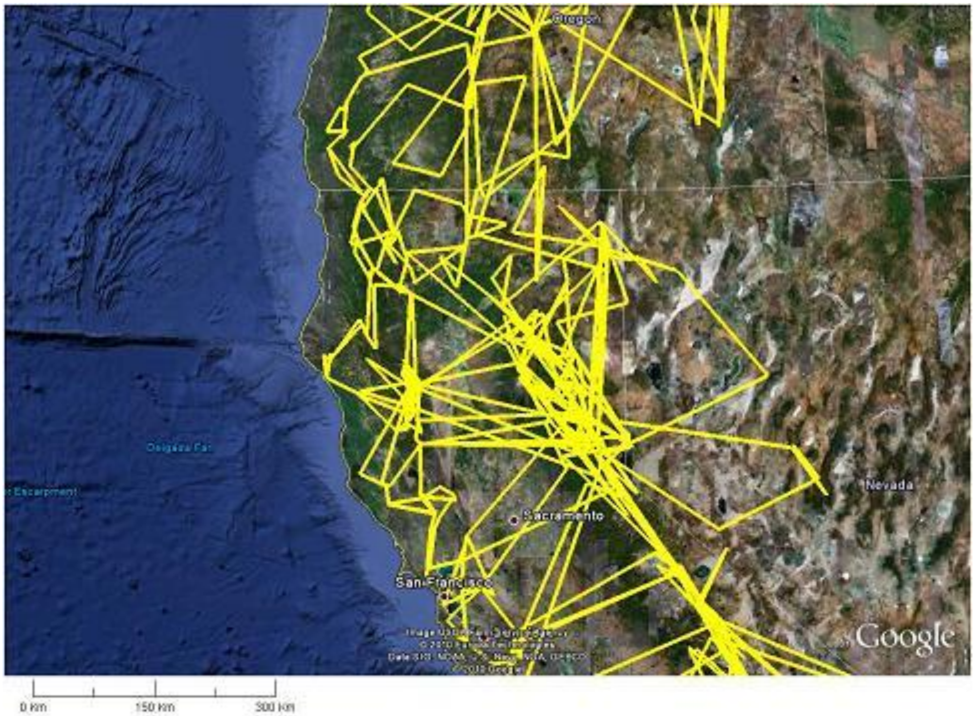

Figure D-65. Shipborne Radar – 1-5 Exclusion Zone Overlay, Northern California Coast

Figure D-66. Shipborne Radar – 1-5 Exclusion Zone Overlay, Southern California Coast

Appendix E. Ground-Based Radar Exclusion Zones

This appendix provides a graphical representation of the 3550-3650 MHz ground-based radar exclusion zones.

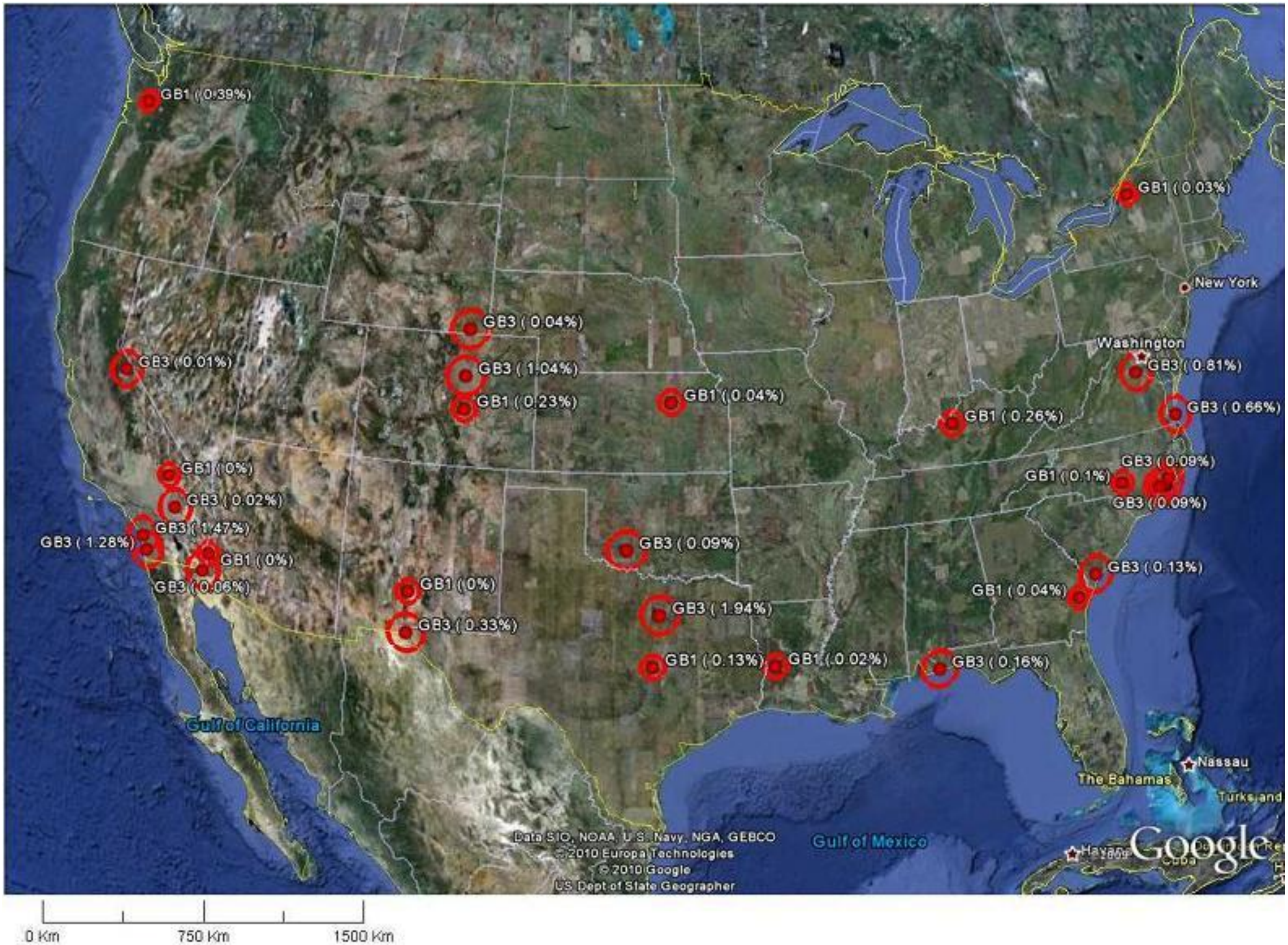

Figure E-1. Ground-Based Radar Exclusion Zones, Lower 48 States

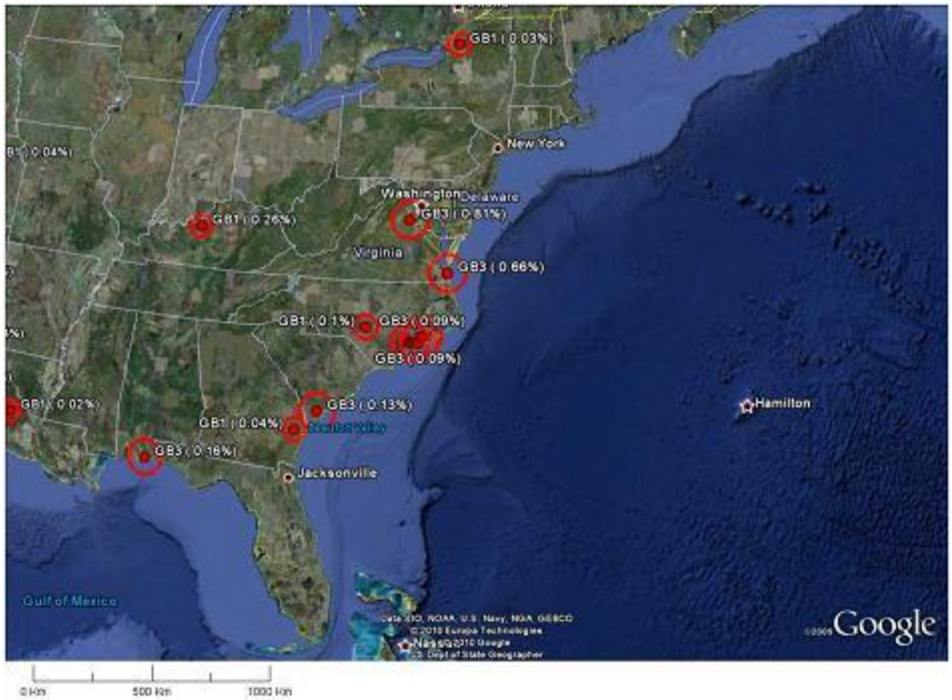

Figure E-2. Ground-Based Radar Exclusion Zones, Eastern United States

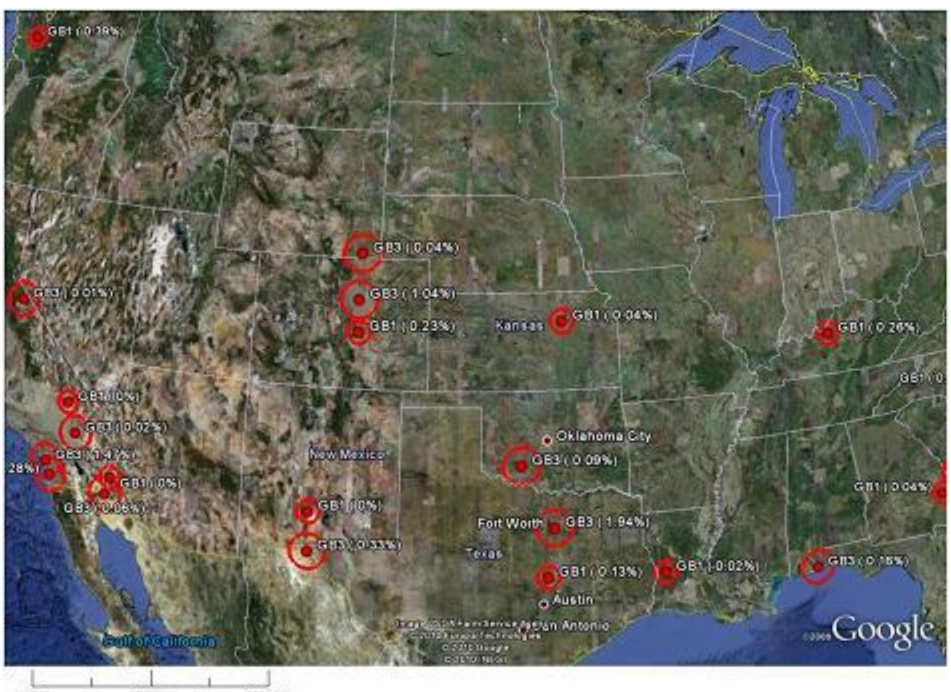

Figure E-3. Ground-Based Radar Exclusion Zones, Central United States

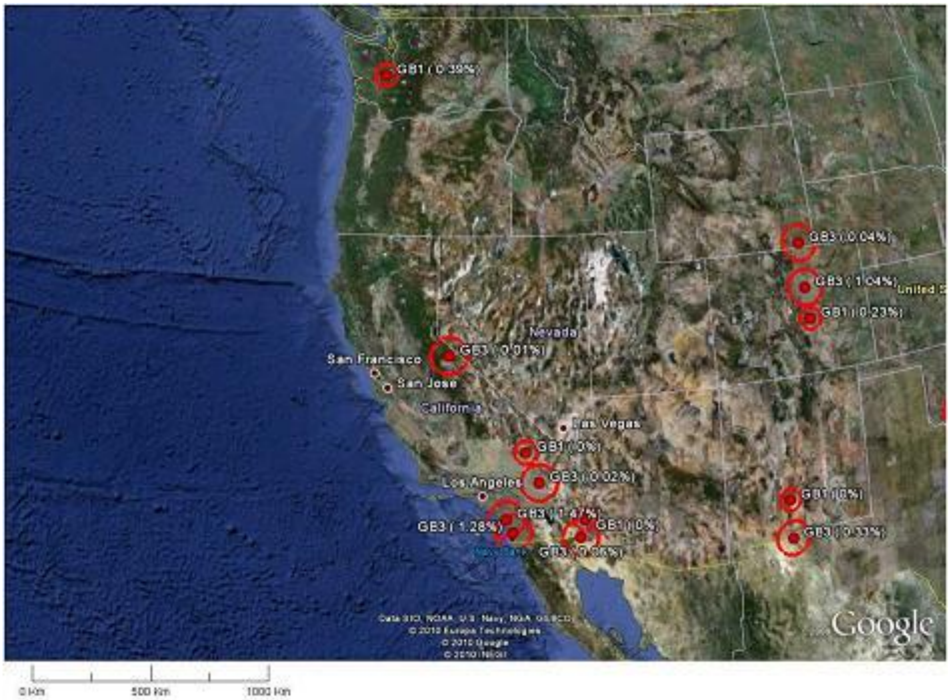

Figure E-4. Ground-Based Radar Exclusion Zones, Western United States

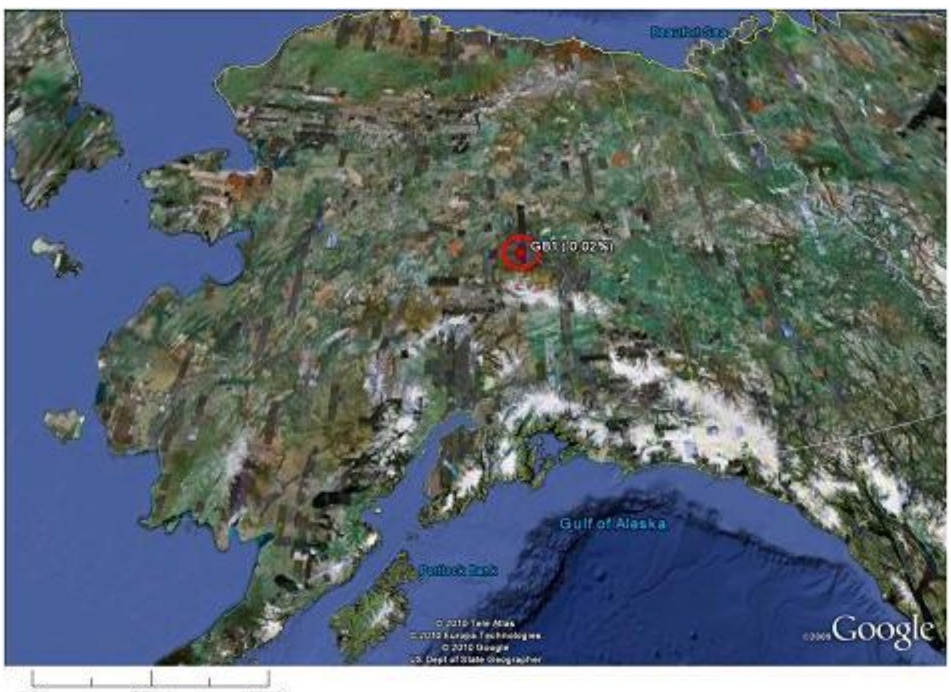

Figure E-5. Ground-Based Radar Exclusion Zones, Alaska

Appendix F. Effects of Pulsed Signals on Digital Receivers

This appendix provides an explanation to support the use of average power in assessing potential interference between low duty cycle radar transmitters and digital receivers.

The peak and average transmitter power levels for a radar system are related using the following equation:

$$P_{Avg} = P_{Peak} + 10\log\left(\frac{DC}{100}\right) \tag{F-1}$$

where:

P_{Avg}: the average radar transmitter power (dBm)
P_{Peak}: the peak radar transmitter power (dBm)
DC: the radar transmitter duty cycle (percent)

To address compatibility issues related to radar and wireless base and mobile systems a frequency offset of 40 to 50 MHz is necessary. Table F-1 summarizes the radars considered in the compatibility analysis, the radar transmit duty cycle, and whether the radar system will operate on-tune or off-tune with the wireless receivers.

Table F-1. Radars Considered in Compatibility Analysis

Radar Type	Transmit Duty Cycle (Percent)	On-Tune/Off-Tune
Ground-Based Radar – 1	10	Off-Tune
Ground-Based Radar – 2	0.01	Off-Tune
Ground-Based Radar – 3	16	Off-Tune
Airborne Radar – 1	0.09	Off-Tune
Airborne Radar – 2	0.09	Off-Tune
Shipborne Radar – 1	0.1	On-Tune
Shipborne Radar – 2	15	Off-Tune
Shipborne Radar – 3	1.6	Off-Tune
Shipborne Radar – 4	20	On-Tune
Shipborne Radar – 5	20	On-Tune

The off-tune pulsed radar signal that would appear after the front-end filtering of a digital receiver will not look like the on-tune pulsed radar signal. In the case of the off-tune pulse signal, the receiver filter produces an impulse response at the trailing and leading edges of the pulse.[71] The receiver impulse response is the inverse of the receiver bandwidth. The impulse responses are separated by the inter-pulse period of the transmitted pulse signal.[72] The amplitude of these off-tune pulses are less than the on-tune transmitted pulse. This effect was seen in a

[71] This effect is a result of convolving spectrum emission lines that do not include center-frequency emissions.

[72] The inter-pulse period is the ratio of the pulsewidth and duty cycle. Inter-Pulse Period = Pulsewidth/Duty Cycle.

joint DOD and Department of Transportation analysis examining the effect of adjacent band radar systems on Global Positioning System receivers.[73]

Information contained in the receiver degradation handbook indicates that pulsed interfering signals have minimal impact on digital receivers that employ block coding techniques.[74] That is when the pulsed signal duty cycle is low, a code block is not compromised (e.g., does not impact enough coded symbols), thereby thermal noise in combination with average interference power level and not pulsed interference drives the overall performance of the digital receiver. This effect can be seen in measurements examining adjacent band interference to digital Universal Mobile Telecommunication System and WiMAX receivers.[75] The duty cycles of the radar signals considered in these measurements ranged from 0.07 to 7 percent. The measurements showed that the degradation to the digital receivers was dominated by the average power as opposed to the intermittent peak power.[76] Other measurements indicate that digital receivers are relatively robust in the presence of low duty cycle pulsed interference.[77] The robustness to low duty cycle pulsed signals is due to the error correction and bit interleaving techniques that are used in all digital receivers.[78] For radars with a low duty cycle, it is appropriate to use the average transmit power in the compatibility analysis. A duty cycle on the order of 1 to 2 percent is considered to be a low duty cycle signal in this analysis.

As shown in Table F-1, the duty cycle for Ground-Based Radar – 2 , and Airborne Radar – 1 and 2 are well below 1 percent, and thus it is appropriate to use the average transmit power in the compatibility analysis. There are three radar systems shown in Table F-1 (Ground-Based Radar – 1 and 2, and Shipborne Radar – 2) operate off-tune from the digital receivers but have a high on-tune duty cycle. The off-tune duty cycle for these radar systems will be computed below.

Ground-Based Radar – 1 operates off-tune to the wireless broadband receivers and has an on-tune duty cycle of 10 percent. It is necessary to compute the duty cycle that an off-tune receiver would see. For a 5 MHz channel configuration the bandwidth of the receiver is 4.75 MHz. As discussed earlier, the off-tune pulsed signal will be made up of pairs of impulses at the trailing and leading edges of the radar pulse each with a width of $1/4.75 \times 10^{-6} = 2.1 \times 10^{-7}$

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[73] Department of Transportation and Department of Defense, Global Positioning System Third Civil Signal Implementation Steering Group, *Final Report of Working Group 1, Technical Feasibility of Coexistence* (July 9, 1999).

[74] Joint Spectrum Center, JSC-CR-10-004 *Communications Receiver Performance Degradation Handbook* (October 2010).

[75] ERA Technology Ltd., *Interference from Radars into Adjacent Band UMTS and WiMAX Syste*ms (Sept. 2007).

[76] *Id.* at 3.

[77] NTIA Report 02-393, *Measurements of Pulsed Co-Channel Interference in a 4 GHz Digital Earth Station Receiver* (May 2002).

[78] The industry developed standards for both WiMAX and Long-Term Evolution systems require error detection and correction techniques be employed.

seconds. The pairs of impulses will be separated by the inter-pulse period of the radar signal which is 400×10^{-6} seconds (40×10^{-6}/0.1 seconds), resulting in a pulse pair count of $1/400 \times 10^{-6}$ = 2500 pulse pairs per second. The off-tune duty cycle would then be $2 \times (2.1 \times 10^{-7}) \times (2500)$ = 0.00105 = 0.105 percent. The off-tune duty cycles for the 10 MHz channel and the 20 MHz channel configurations are 0.05 percent and 0.026 percent, respectively.[79] Since the pulsed duty cycle as seen by the off-tune digital receiver is well below 1 percent, it is appropriate to use the average transmit power in the compatibility analysis.

Ground-Based Radar – 3 operates off-tune to the wireless broadband receivers and has an on-tune duty cycle of 16 percent. It is necessary to compute the duty cycle that an off-tune receiver would see. For a 5 MHz channel configuration the bandwidth of the receiver is 4.75 MHz. As discussed earlier, the off-tune pulsed signal will be made up of pairs of impulses at the trailing and leading edges of the radar pulse each with a width of $1/4.75 \times 10^{-6} = 2.1 \times 10^{-7}$ seconds. The pairs of impulses will be separated by the inter-pulse period of the radar signal which is 5×10^{-5} seconds (8×10^{-6}/0.16 seconds), resulting in a pulse pair count of $1/5 \times 10^{-5}$ = 20000 pulse pairs per second. The off-tune duty cycle would then be $2 \times (2.1 \times 10^{-7}) \times (20000)$ = 0.008 = 0.84 percent. The off-tune duty cycles for the 10 MHz channel and the 20 MHz channel configurations are 0.42 percent and 0.21 percent, respectively. Since the pulsed duty cycle as seen by the off-tune digital receiver is well below 1 percent, it is appropriate to use the average transmit power in the compatibility analysis.

Shipborne Radar – 2 operates off-tune to the wireless broadband receivers and has an on-tune duty cycle of 15 percent. It is necessary to compute the duty cycle that an off-tune receiver would see. For a 5 MHz channel configuration the bandwidth of the receiver is 4.75 MHz. As discussed earlier, the off-tune pulsed signal will be made up of pairs of impulses at the trailing and leading edges of the radar pulse each with a width of $1/4.75 \times 10^{-6} = 2.1 \times 10^{-7}$ seconds. The impulses will be separated by the inter-pulse period of the radar signal which is 500×10^{-6} seconds (78×10^{-6}/0.15 seconds), resulting in a pulse pair count of $1/500 \times 10^{-6}$ = 2000 pulse pairs per second. The off-tune duty cycle would then be $2 \times (2.1 \times 10^{-7}) \times (2000)$ = 0.00084 = 0.084 percent. The off-tune duty cycles for the 10 MHz channel and the 20 MHz channel configurations are 0.042 percent and 0.021 percent, respectively. Since the pulsed duty cycle as seen by the off-tune digital receiver is well below 1 percent, it is appropriate to use the average transmit power in the compatibility analysis.

Shipborne Radar – 4 and Shipborne Radar – 5 shown in Table F-1 can operate on-tune with the wireless base and mobile receivers and have a duty cycle of 20 percent. The radar peak transmit power should be used in the compatibility analysis.

[79] The bandwidth for the 10 MHz channel configuration is 9.5 MHz and the bandwidth for the 20 MHz channel configuration is 19 MHz.

Appendix G. Large Signal Analysis of Base and Mobile Receivers Operating in the 3550-3650 MHz Band

This appendix provides the results of the analysis assessing large signal interference from high power radar transmitters to base station and mobile station receivers operating in the 3550-3650 MHz band.

The power at the input to the base and mobile station receiver is computed by:

$$I = P_T + G_T + G_R - L_T - L_R - L_P \tag{G-1}$$

where:

I:	Received interference power at the output of the antenna (dBm)
P_T:	Peak power of the radar transmitter (dBm)
G_T:	Antenna gain of the radar transmitter in the direction of the base/mobile receiver (dBi)
G_R:	Antenna gain of the base/mobile receiver in the direction of the radar transmitter (dBi)
L_T:	Transmitter insertion loss (dB)
L_R:	Receiver insertion loss (dB)
L_P:	Propagation loss (dB)

For the ground-based and shipborne radar systems, the ITM in the Area Mode is used to compute the propagation loss. For airborne radar systems, the free space propagation model is used to compute the propagation loss.

The burnout and saturation levels for base and mobile receivers are not available. In this analysis, threshold values of 0 dBm for burnout and -30 dBm for saturation are used for the large signal analysis of base and mobile receivers.

Figure G-1 shows the power received at the input of the base station receiver from Ground-Based Radar – 1 as a function of separation distance.

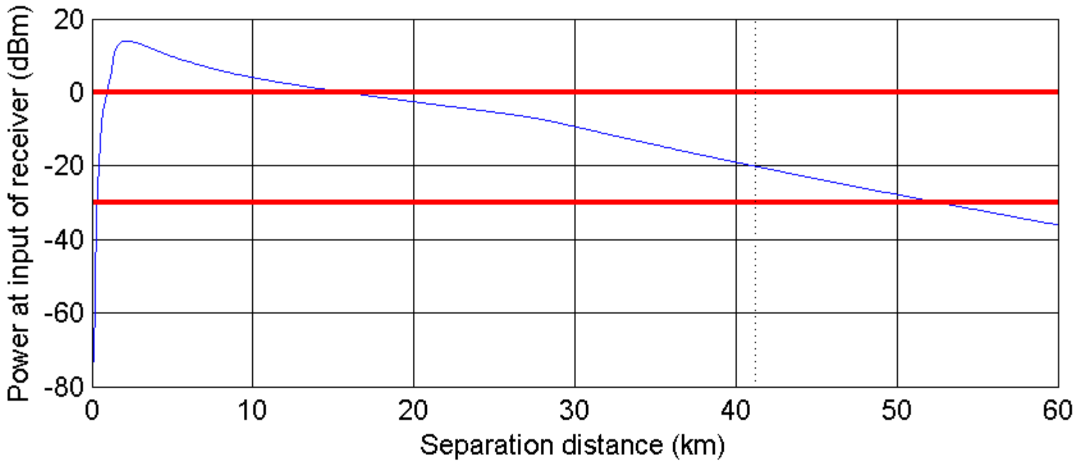

Figure G-1. Base Station Received Power from Ground-Based Radar – 1

Figure G-2 shows the power received at the input of the mobile station receiver from Ground-Based Radar – 1 as a function of separation distance.

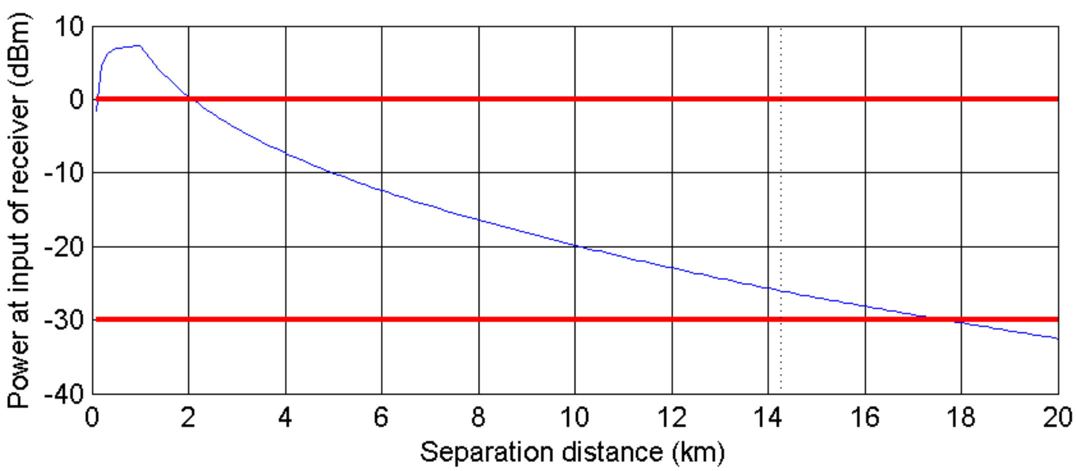

Figure G-2. Mobile Station Received Power from Ground-Based Radar – 1

Figure G-3 shows the power received at the input of the base station receiver from Ground-Based Radar – 2 as a function of separation distance.

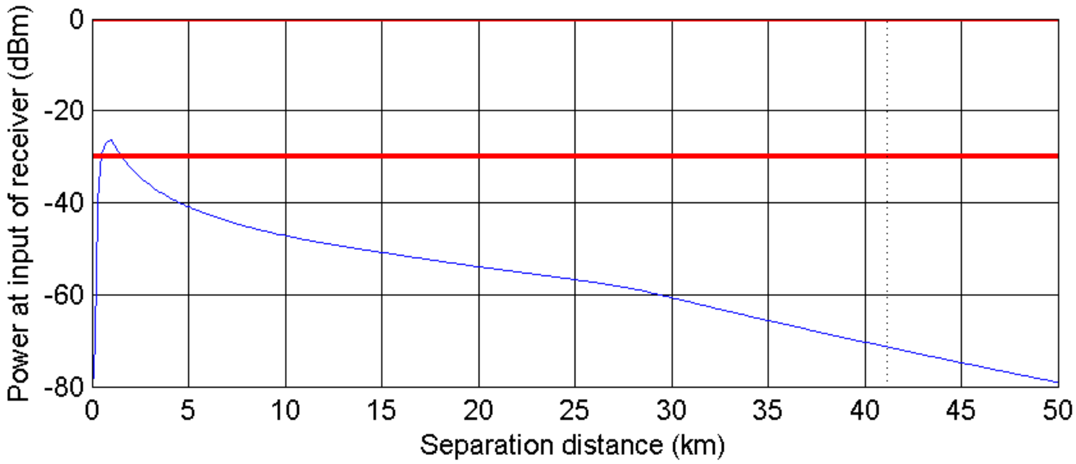

Figure G-3. Base Station Received Power from Ground-Based Radar – 2

Figure G-4 shows the power received at the input of the mobile station receiver from Ground-Based Radar – 2 as a function of separation distance.

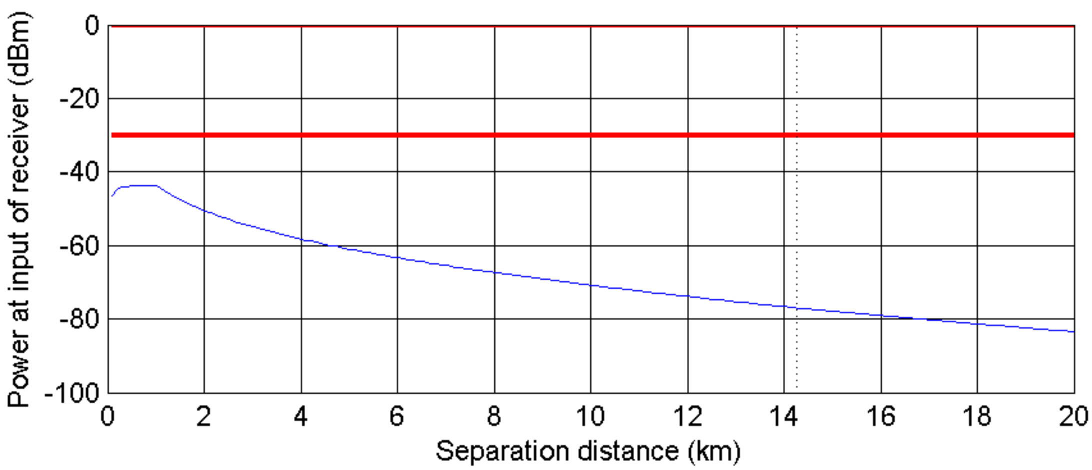

Figure G-4. Mobile Station Received Power from Ground-Based Radar – 2

Figure G-5 shows the power received at the input of the base station receiver from Ground-Based Radar – 3 as a function of separation distance.

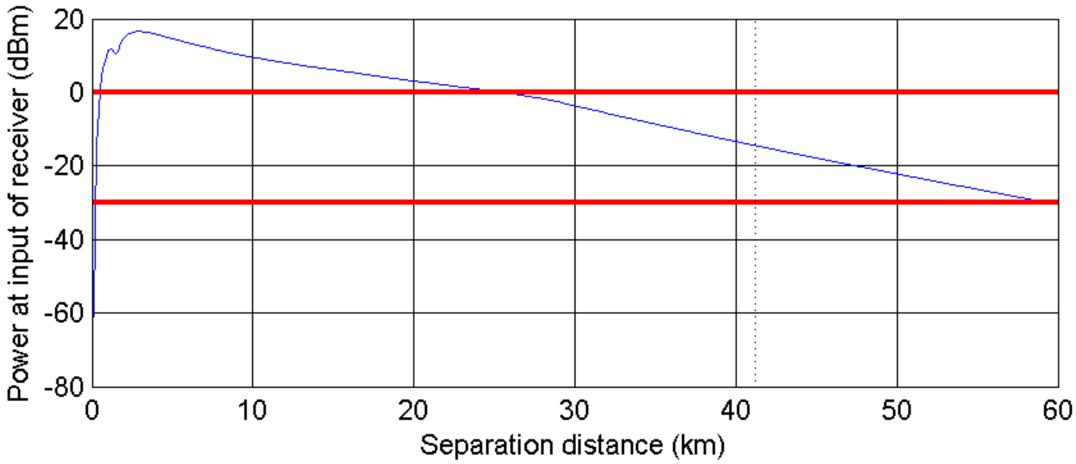

Figure G-5. Base Station Received Power from Ground-Based Radar – 3

Figure G-6 shows the power received at the input of the mobile station receiver from Ground-Based Radar – 3 as a function of separation distance.

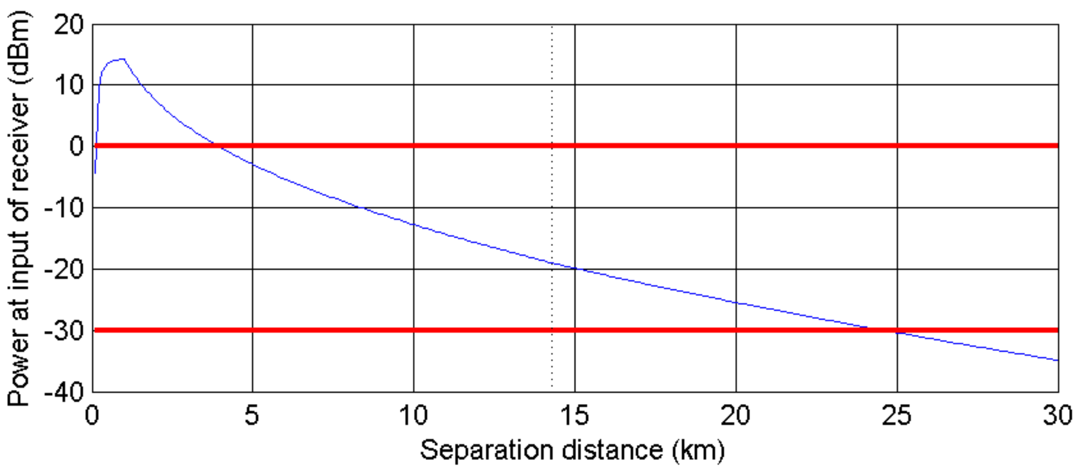

Figure G-6. Mobile Station Received Power from Ground-Based Radar – 3

Figure G-7 shows the power received at the input of the base station receiver from Airborne Radar – 1 at an altitude of 1000 feet as a function of separation distance.

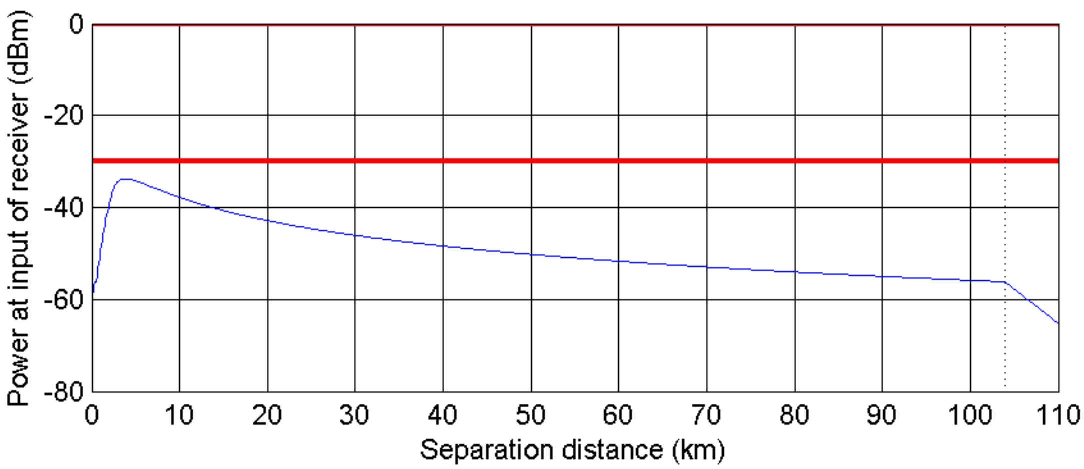

Figure G-7. Base Station Received Power from Airborne Radar – 1 at 1000 Foot Altitude

Figure G-8 shows the power received at the input of the mobile station receiver from Airborne Radar – 1 at an altitude of 1000 feet as a function of separation distance.

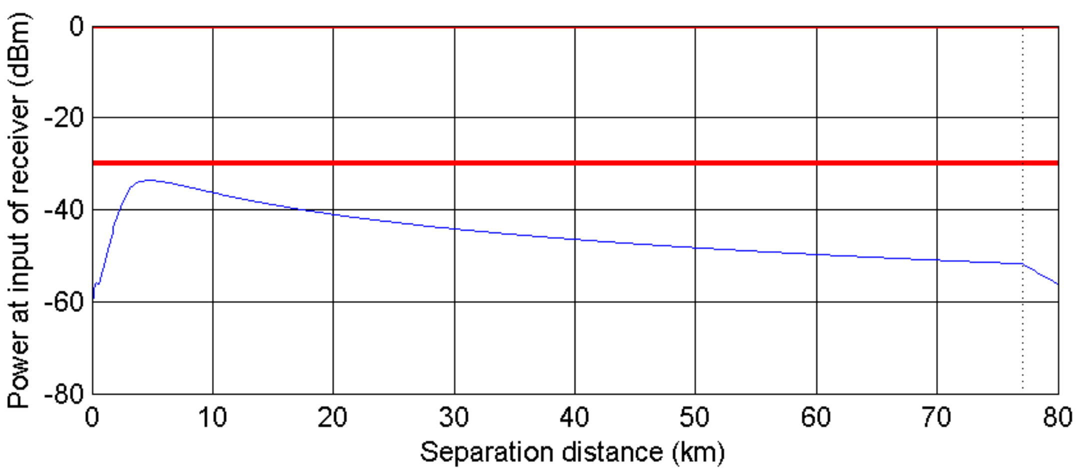

Figure G-8. Mobile Station Received Power from Airborne Radar – 1 at 1000 Foot Altitude

Figure G-9 shows the power received at the input of the base station receiver from Airborne Radar – 1 at an altitude of 20,000 feet as a function of separation distance.

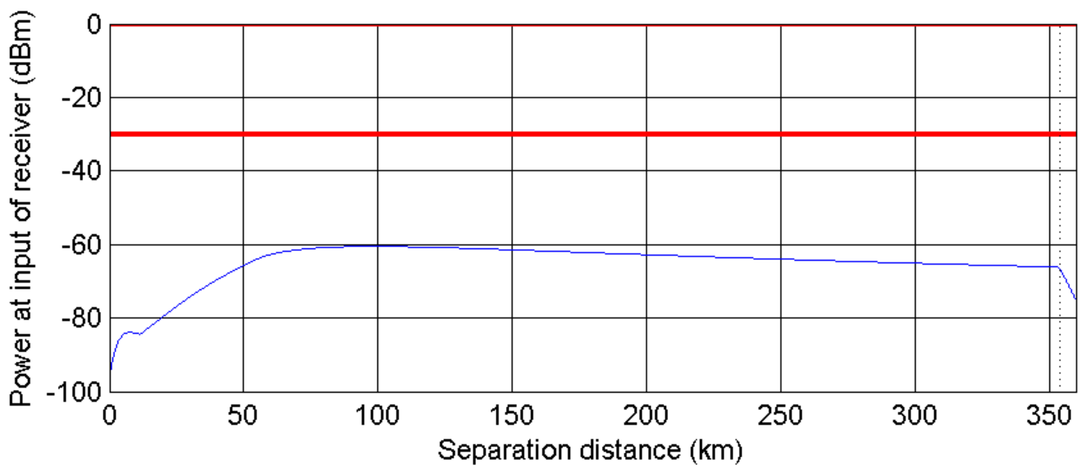

Figure G-9. Base Station Received Power from Airborne Radar – 1 at 20,000 Foot Altitude

Figure G-10 shows the power received at the input of the mobile station receiver from Airborne Radar – 1 at an altitude of 20,000 feet as a function of separation distance.

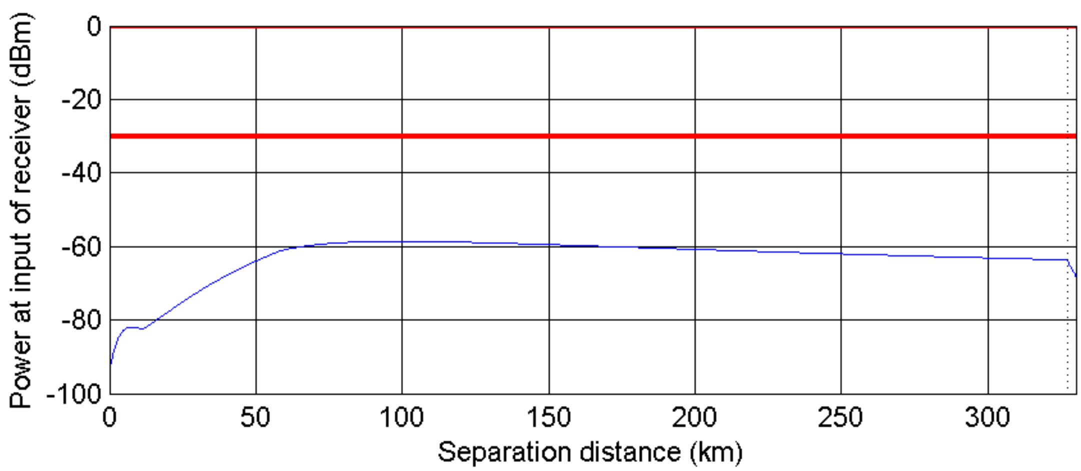

Figure G-10. Mobile Station Received Power from Airborne Radar – 1 at 20,000 Foot Altitude

Figure G-11 shows the power received at the input of the base station receiver from Airborne Radar – 2 at an altitude of 1000 feet as a function of separation distance.

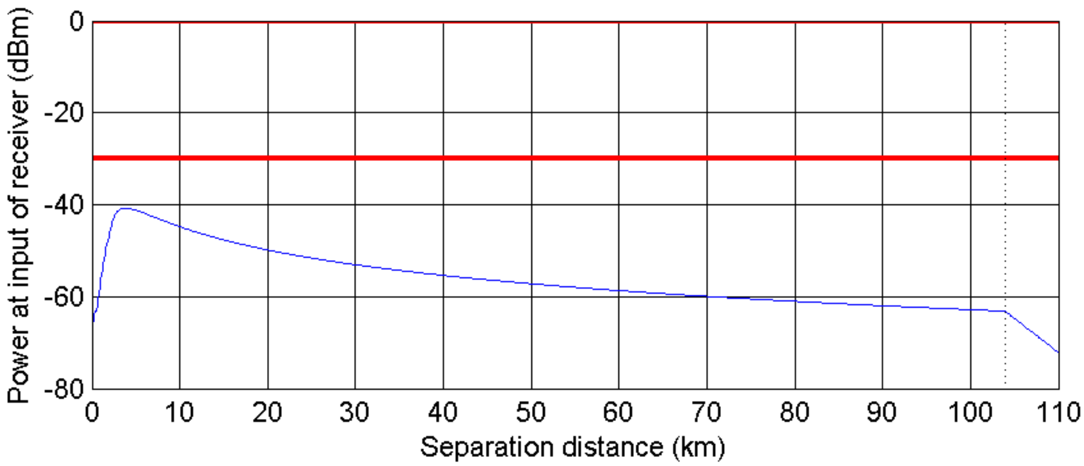

Figure G-11. Base Station Received Power from Airborne Radar – 2 at 1000 Foot Altitude

Figure G-12 shows the power received at the input of the mobile station receiver from Airborne Radar – 2 at an altitude of 1000 feet as a function of separation distance.

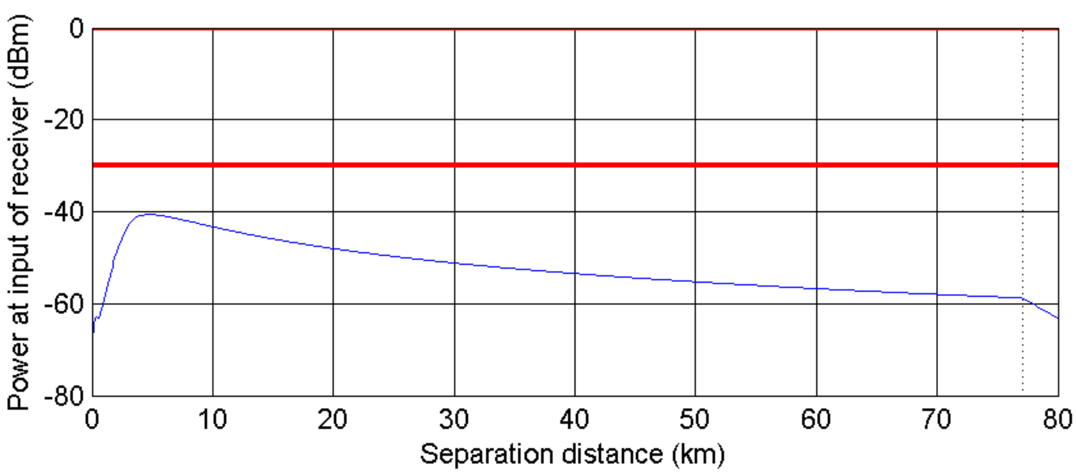

Figure G-12. Mobile Station Received Power from Airborne Radar – 2 at 1000 Foot Altitude

Figure G-13 shows the power received at the input of the base station receiver from Airborne Radar – 2 at an altitude of 20,000 feet as a function of separation distance.

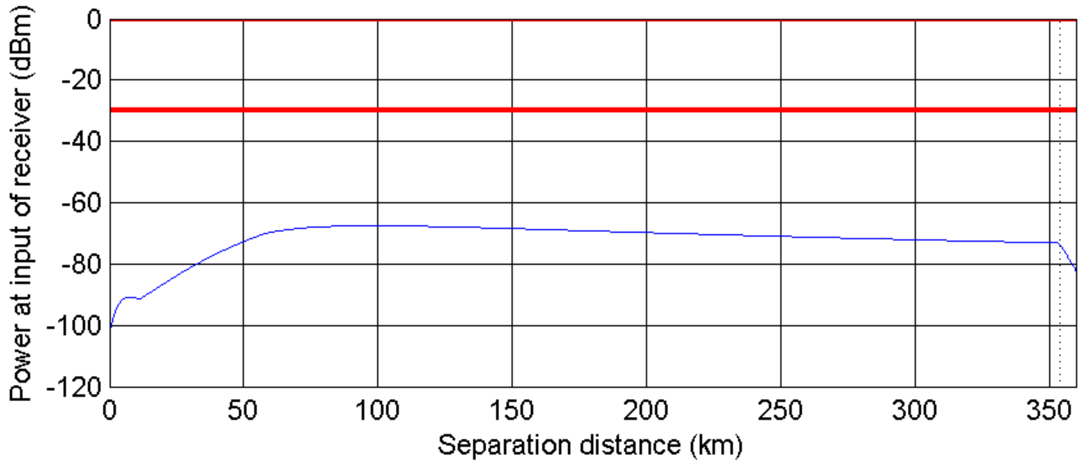

Figure G-13. Base Station Received Power from Airborne Radar – 2 at 20,000 Foot Altitude

Figure G-14 shows the power received at the input of the mobile station receiver from Airborne Radar – 2 at an altitude of 20,000 feet as a function of separation distance.

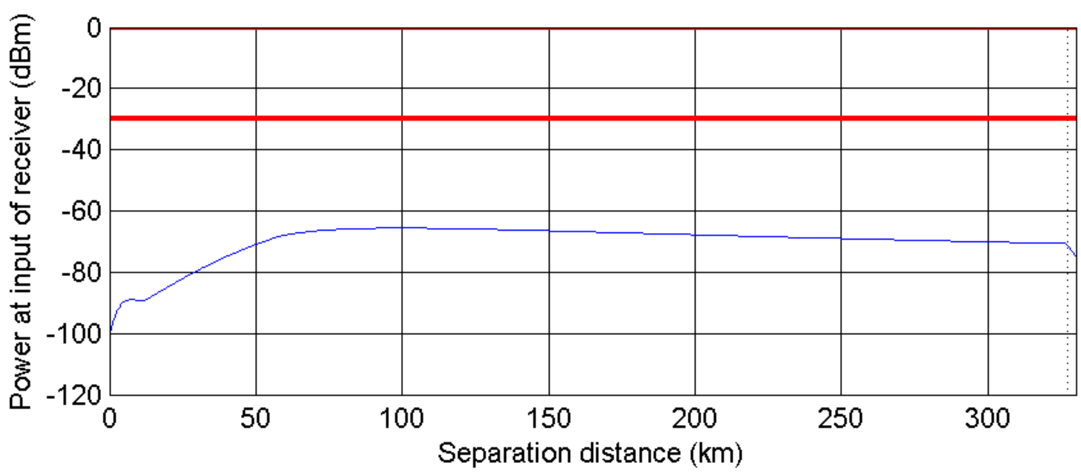

Figure G-14. Mobile Station Received Power from Airborne Radar – 2 at 20,000 Foot Altitude

Figure G-15 shows the power received at the input of the base station receiver from Shipborne Radar – 1 as a function of separation distance.

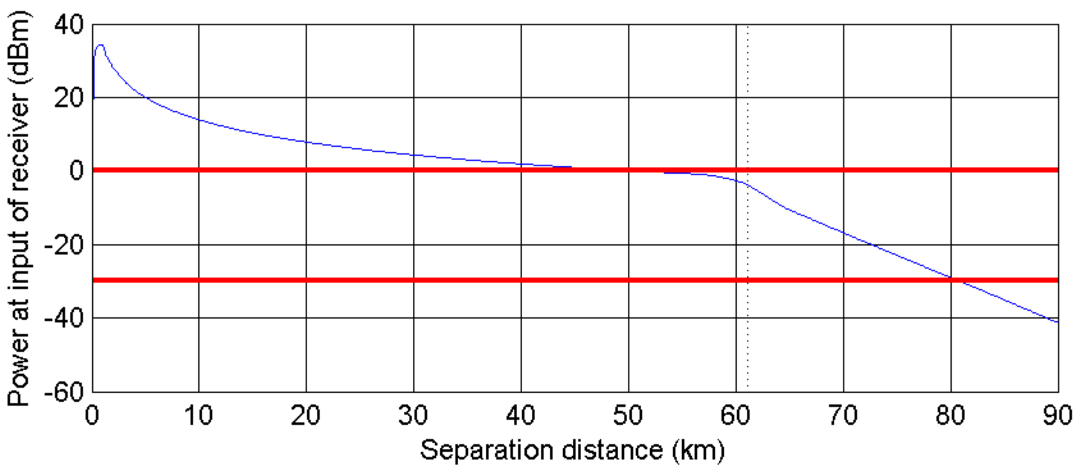

Figure G-15. Base Station Received Power from Shipborne Radar – 1

Figure G-16 shows the power received at the input of the mobile station receiver from Shipborne Radar – 1 as a function of separation distance.

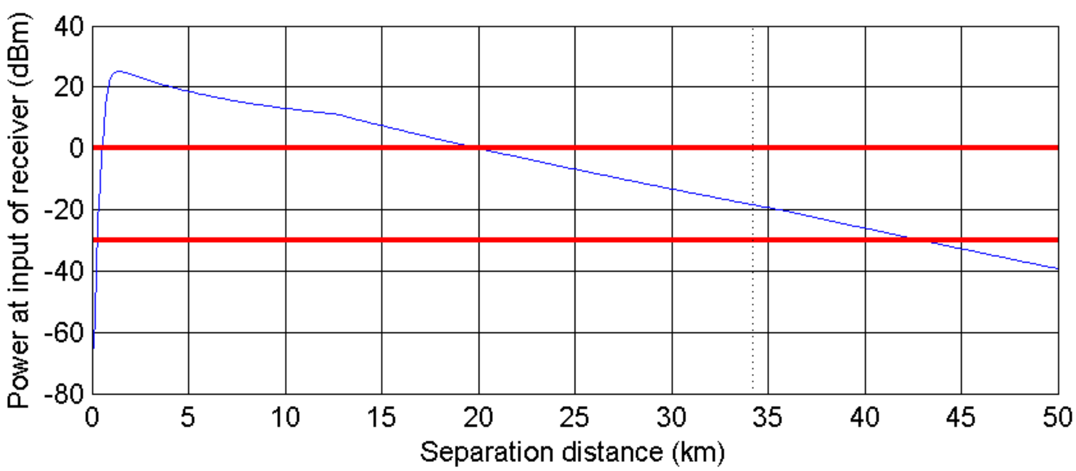

Figure G-16. Mobile Station Received Power from Shipborne Radar – 1

Figure G-17 shows the power received at the input of the base station receiver from Shipborne Radar – 2 as a function of separation distance.

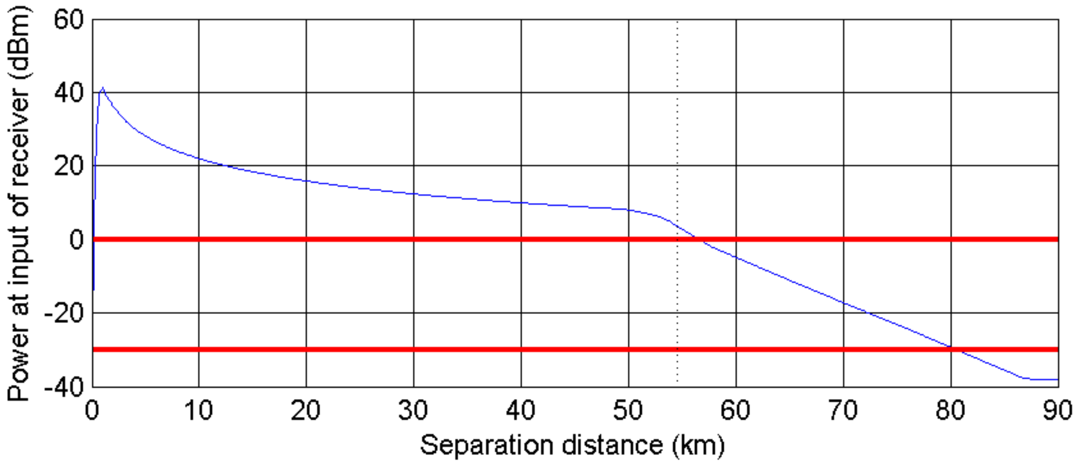

Figure G-17. Base Station Received Power from Shipborne Radar – 2

Figure G-18 shows the power received at the input of the mobile station receiver from Shipborne Radar – 2 as a function of separation distance.

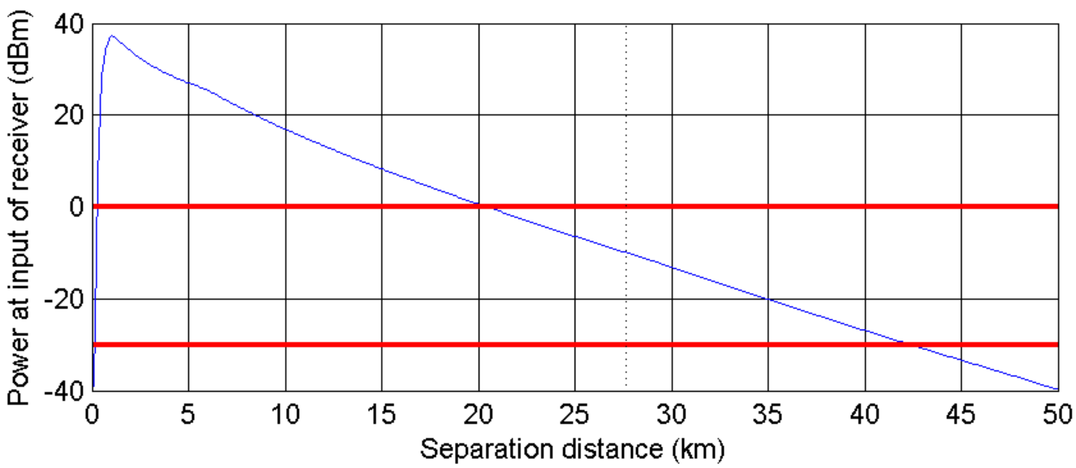

Figure G-18. Mobile Station Received Power from Shipborne Radar – 2

Figure G-19 shows the power received at the input of the base station receiver from Shipborne Radar – 3 as a function of separation distance.

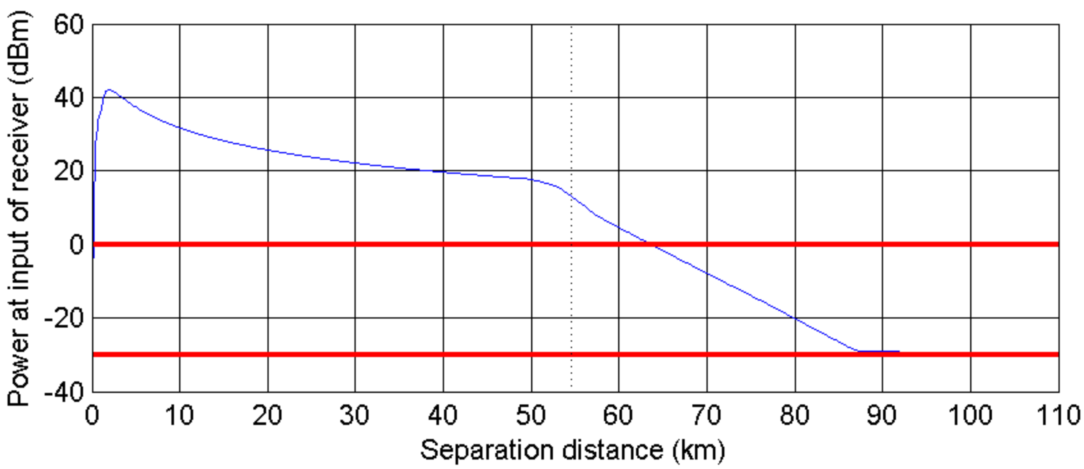

Figure G-19. Base Station Received Power from Shipborne Radar – 3

Figure G-20 shows the power received at the input of the mobile station receiver from Shipborne Radar – 3 as a function of separation distance.

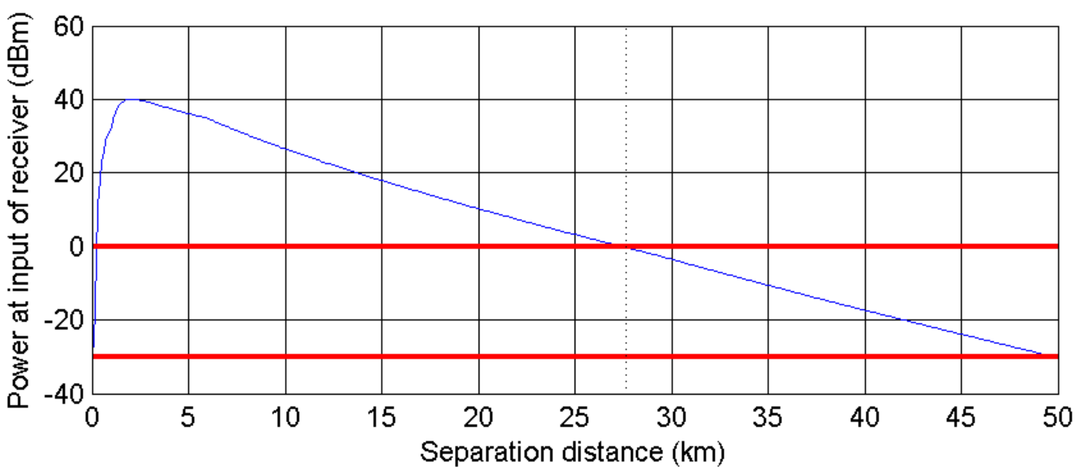

Figure G-20. Mobile Station Received Power from Shipborne Radar – 3

Figure G-21 shows the power received at the input of the base station receiver from Shipborne Radar – 4 as a function of separation distance.

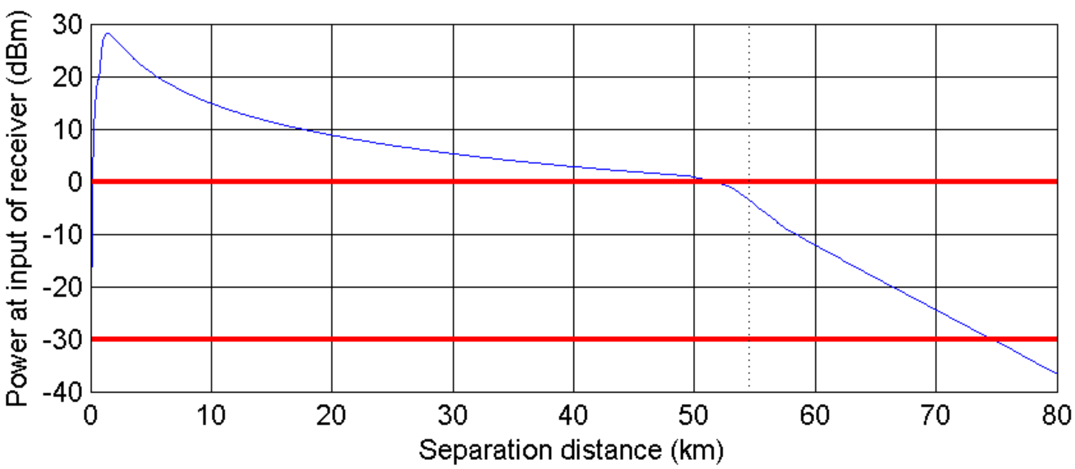

Figure G-21. Base Station Received Power from Shipborne Radar – 4

Figure G-22 shows the power received at the input of the mobile station receiver from Shipborne Radar – 4 as a function of separation distance.

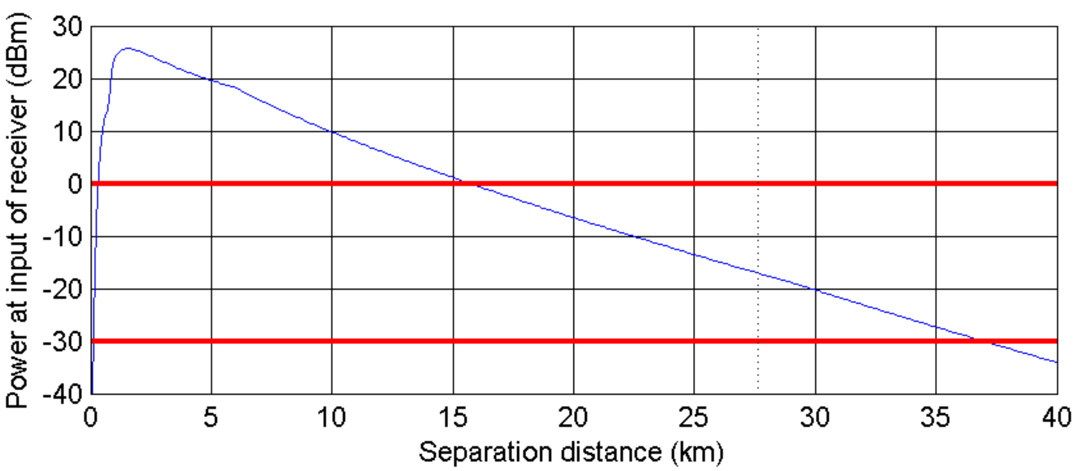

Figure G-22. Mobile Station Received Power from Shipborne Radar – 4

Figure G-23 shows the power received at the input of the base station receiver from Shipborne Radar – 5 as a function of separation distance.

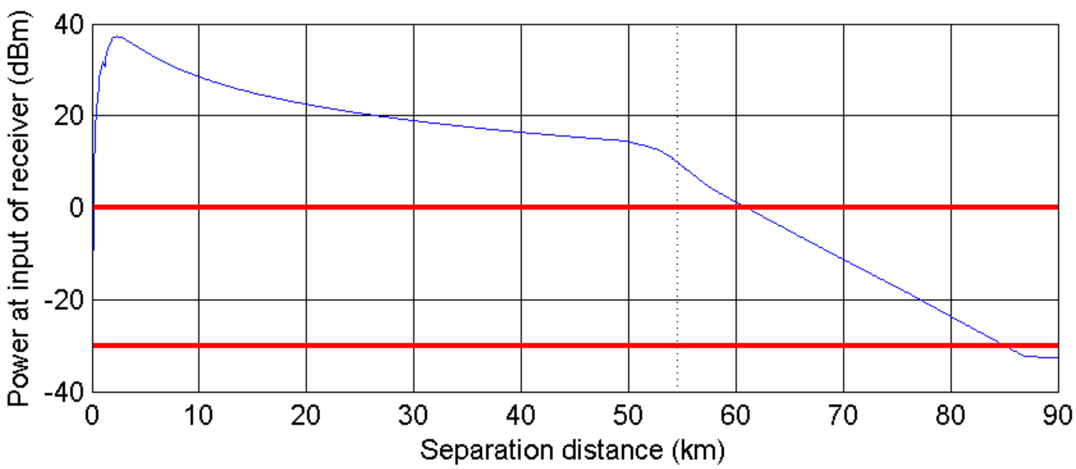

Figure G-23. Base Station Received Power from Shipborne Radar – 5

Figure G-24 shows the power received at the input of the mobile station receiver from Shipborne Radar – 5 as a function of separation distance.

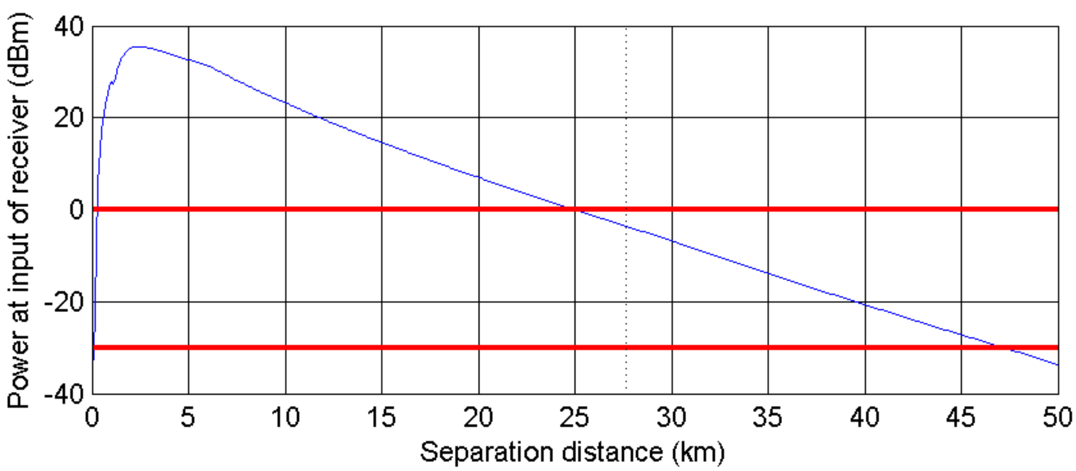

Figure G-24. Mobile Station Received Power from Shipborne Radar – 5

Appendix H. Meteorological-Satellite Receive Stations Exclusion Zones

This appendix provides a graphical representation of the exclusion zones around meteorological-satellite receive stations operating in the 1695-1710 MHz band. A percentage of the population impacted by the exclusion zones is shown on the plots.[80]

[80] The percentages are based on 2000 U.S. Census data.

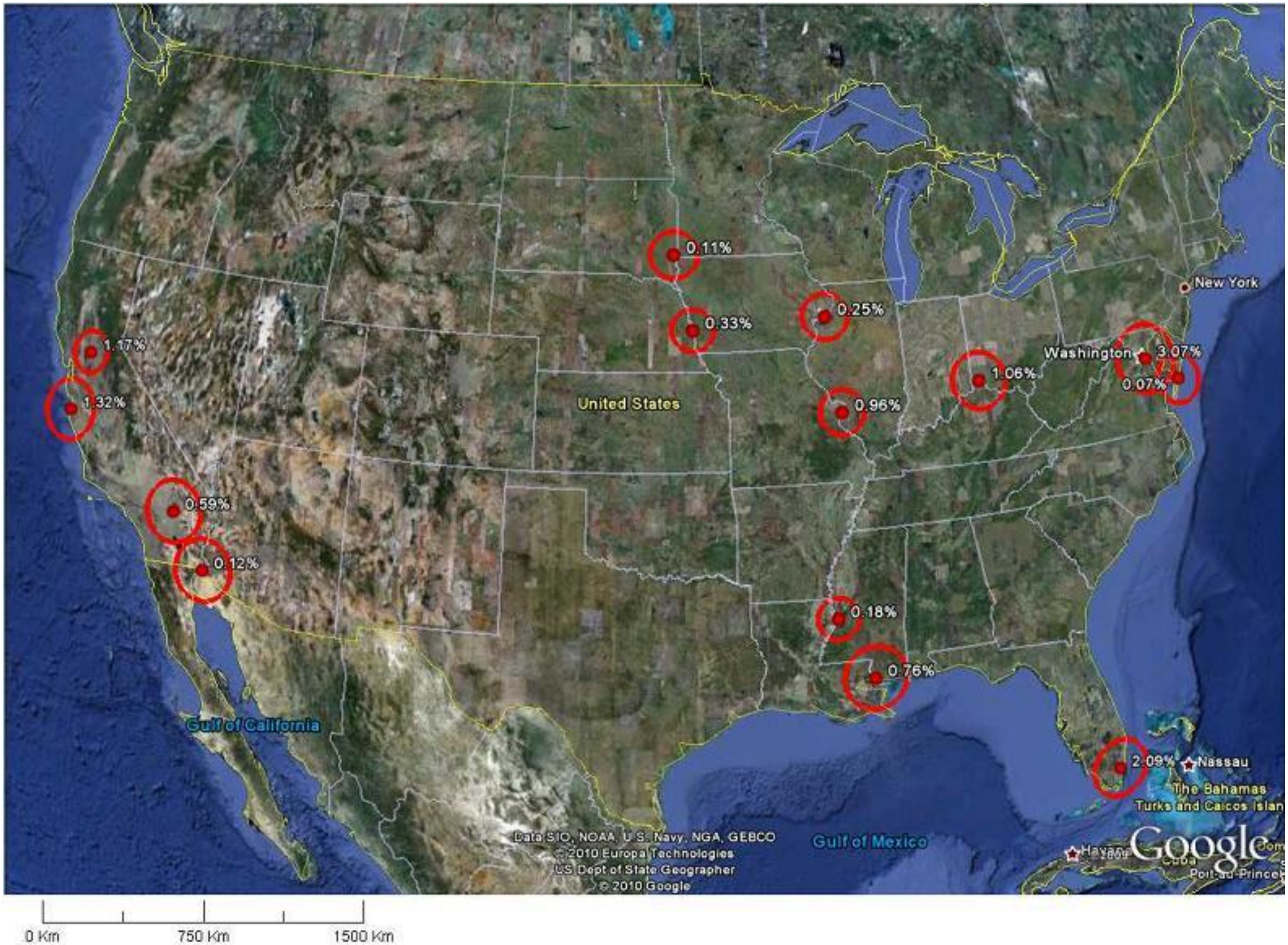

Figure H-1. Meteorological-Satellite Receive Station Exclusion Zones, Lower 48 States

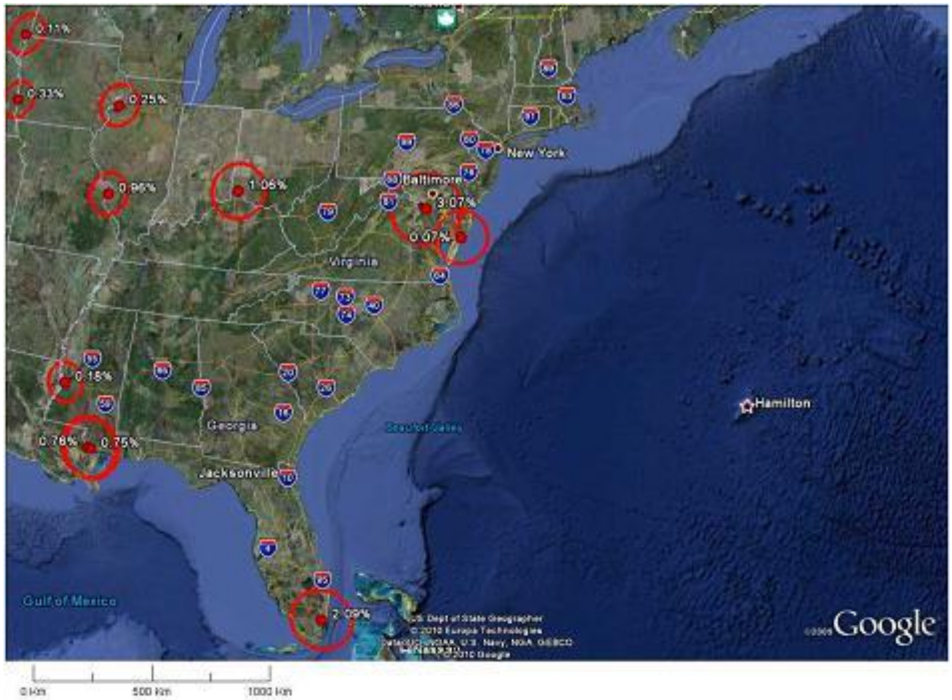

Figure H-2. Meteorological-Satellite Receive Station Exclusion Zones, Eastern United States

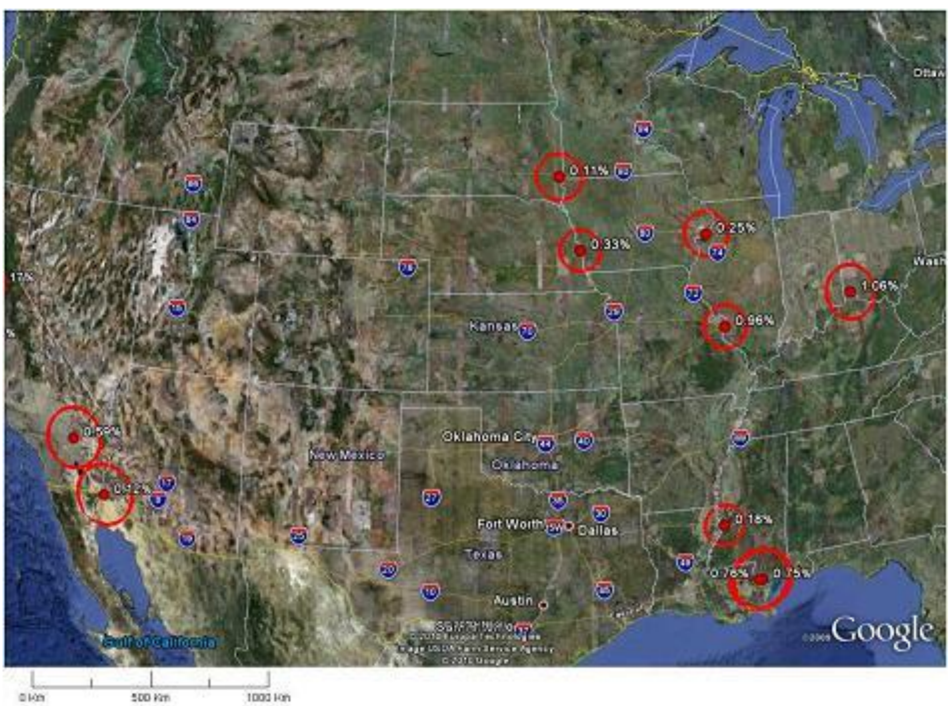

Figure H-3. Meteorological-Satellite Receive Station Exclusion Zones, Central United States

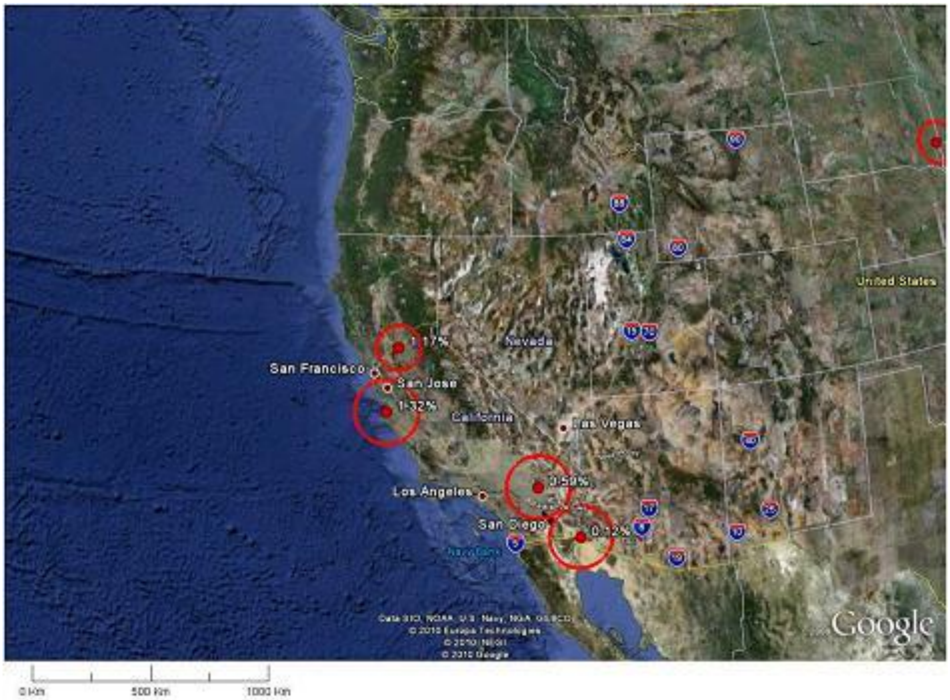

Figure H-4. Meteorological-Satellite Receive Station Exclusion Zones, Western United States

Figure H-5. Meteorological-Satellite Receive Station Exclusion Zones, Alaska

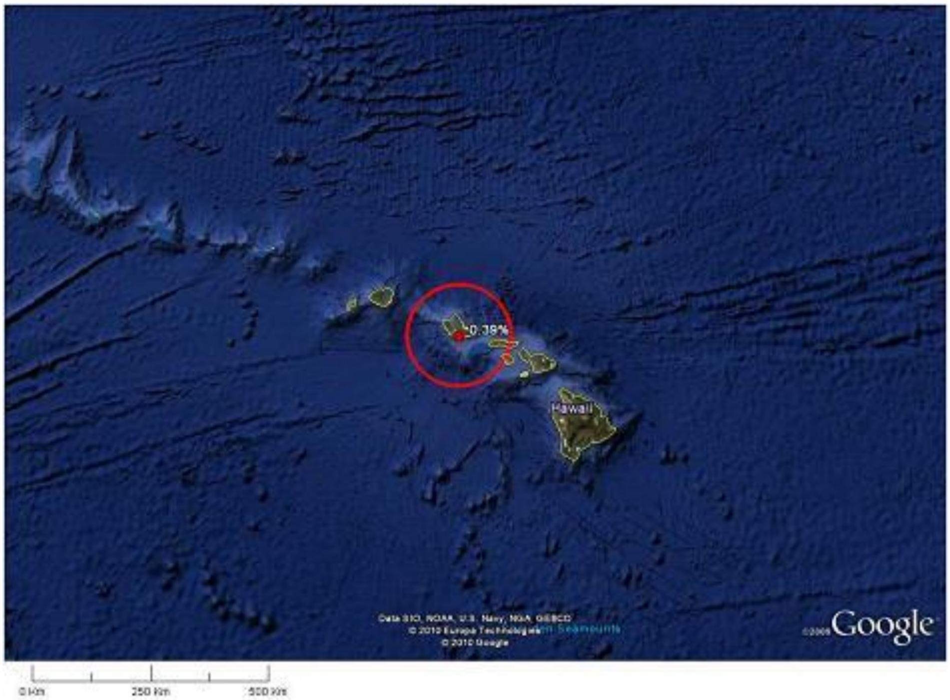

Figure H-6. Meteorological-Satellite Receive Station Exclusion Zones, Hawaii

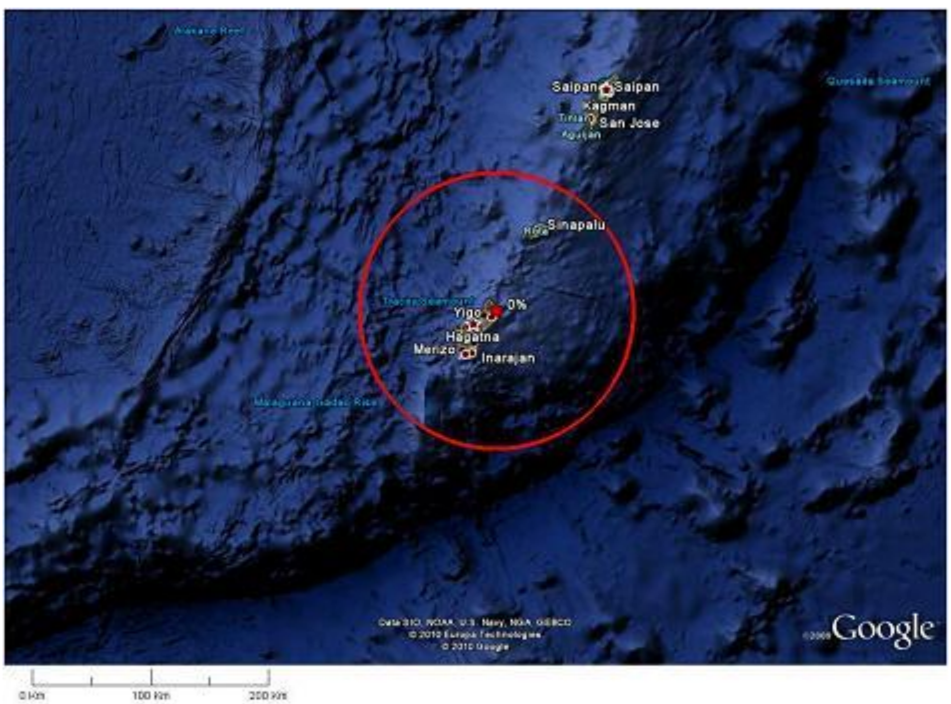

Figure H-7. Meteorological-Satellite Receive Station Exclusion Zones, Guam

Appendix I. Table of Tables

Appendix J. Table of Figures