SECTION 6
CONCLUSIONS

6.1 INTRODUCTION

This report contains a study of the potential impact from emissions of UWB devices to the performance of critical Federal telecommunication systems (except for the GPS). NTIA, in coordination with the Federal agencies, has the responsibility of assessing the potential impact of UWB devices on Federal telecommunication systems, as well as identifying solutions which will ensure compatibility.

The following is a summary of conclusions based on findings contained in this report.

6.2 GENERAL CONCLUSIONS

1. Since UWB devices may be unlicenced, and because of their potential ubiquitous operations, EIRP limits rather than required distance separations may have to be established to ensure compatibility between UWB devices and some Federal telecommunications systems.

2. The spectrum analyzer detector function is key in establishing permitted EIRP levels for UWB devices. Although NTIA recognizes that no single average detector function adequately describes the interference effects of UWB signals, NTIA measurements and analyses indicates that the RMS detector function better quantifies the potential interference affects of UWB signals than the current average-logarithmic detector function used for Part 15 compliance.[66]

3. Further measurements and analysis are required to determine the effects of UWB signal duty cycle on the performance of the SARSAT and FSS Earth stations which have digital signal processing. This information would assist in establishing the UWB signal peak power limit in a 50 MHz bandwidth relative to the average (RMS) power in a 1 MHz bandwidth needed to protect digital modulated systems. Analysis has shown that limiting the peak power in a 50 MHz bandwidth to 30 dB would result in limiting the PRF of non-dithered UWB signals to greater than 3.5 MHz, and the PRF of dithered UWB signals to greater than 12.5 MHz.

4. For receiving systems with high gain antennas, the antenna vertical gain pattern, antenna height, antenna tilt angle and UWB device antenna height can significantly affect the level of UWB device emissions coupled into the receiver.

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[66] *See* ITS Report, supra note 14, at Section § 8.4 (Items 5, 6, 7).

6.3 ASSESSMENT OF COMPATIBILITY FOR A SINGLE UWB DEVICE

The summary results described below were based on calculations using smooth Earth radio propagation (i.e., with no man-made or natural obstructions), typical antenna heights for the receiving systems, and a UWB height above ground of 2 meters. Results will change with significant departures from these key parameters. See Tables 4-56 and 4-57 in Section 4 for a detailed summary of these findings. The results are summarized in four broad bands of frequencies as discussed below.

Below 960 MHz. The SARSAT system was the only system analyzed which operates below 960 MHz. Since this is an satellite uplink analysis, compatibility with a single UWB device is not relevant. See Section 6.4 for conclusions related to potential aggregate interference to the SARSAT.

960–1610 MHz. Six types of receiving systems operating in the 960–1610 MHz frequency band were investigated by NTIA. A seventh system, GPS, is also being investigated and results will be reported separately. Analysis shows that for three of these systems, DME ground interrogators, ARSRs, and SARSAT LUTs, a significant reduction (in the order of 20 dB) in UWB device emission levels below the current levels permitted by Part 15 would be required to meet the receiver protection criteria. Further studies are needed to quantify the performance degradation to these systems to assess the feasibility of adjusting the EIRP limits contained in this report.

1610–3100 MHz. Three types of receiving systems operating in the 1610–3100 MHz frequency band, all radar systems, were investigated by NTIA. Analysis showed that, of these, maritime radars would be the most sensitive to UWB emissions and may require limiting UWB EIRP to below the current Part 15 limit to meet the receiver interference protection criteria for ship targets and shorelines close to the maritime radar. However, further studies of the relative levels of noise, interference, and clutter signals may reveal that relaxation of current receiver protection criteria for close-in targets is possible.

3100–5650 MHz. Of the five types of systems NTIA investigated that operate between 3100 and 5650 MHz, analysis shows that two system types, FSS Earth stations and MLS, would be the most sensitive to UWB emissions.

A. For FSS systems, the worst case situation would occur for receivers located at ground level with a low antenna elevation angle of 5 degrees. For FSS systems located on top of buildings and/or with higher elevation angles, much lower levels of interference would result. However, at this time uncertainty exists as to the effects of UWB signal duty cycle on the performance of the FSS Earth stations which have digital signal processing. This information would assist in establishing the UWB signal peak power limit; NTIA study is continuing on this important consideration.

B. MLS were found to be most sensitive to non-dithered UWB emissions. If UWB systems were required to be dithered in this frequency range, thus avoiding narrow line spectra, then UWB effects are greatly reduced. Nevertheless, operation at the current levels allowed under Part 15 may exceed the receiver interference protection criteria, depending upon the degree of safety margin required. Further analysis/measurements are needed.

The discussion for the three frequency band segments above was based on UWB emitters located close to the ground, specifically at a height of 2 meters. For most systems studied by NTIA, UWB emitters located outdoors at much higher heights - 30 meters was evaluated in this study - the potential interference effects increased and would require significant reduction in UWB EIRP levels to meet the receiver protection criteria. This results from the fact that the UWB emitters would be closer to, or even directly in, the high main beam antenna gain of the receivers. Thus, UWB emitters located on top of buildings or mounted on poles/towers would significantly exceed receiver protection criteria for a wide variety of authorized radiocommunications systems.

6.4 AGGREGATE ANALYSIS

The examination of the potential for aggregate interference effects from UWB devices resulted in a number of key findings. The following are conclusions related to potential performance degradation to Federal radiocommunication systems caused by an aggregate of UWB devices.

1 Both theory and measurements support the view that the average (RMS) power emitted by UWB devices, both total average power as well as average power contained within a narrow bandwidth, is linearly additive in a receiver.

2. Using a uniform distribution of UWB devices, either statistical or deterministic, is a reasonable and practical method to examine the potential aggregate interference effects of UWB devices.

3. Five different aggregate modeling approaches, one deterministic and four statistical, were examined and found to yield nearly identical results within 2 dB for a variety of hypothetical situations.

4. The UWBRings model, developed by NTIA for this study, was found to effectively calculate aggregate interference in a receiver under a variety of conditions and assumptions, and has the ability to easily consider measured 3-dimensional receiver antenna patterns and various radio propagation models.

5. Results of these studies show, *inter alia*, that the received aggregate interference (RMS) from a uniform distribution of identical UWB emitters varies directly with UWB EIRP, UWB emitter density, and UWB transmitter activity factor.

6. All other factors being fixed, there will exist some UWB emitter density where aggregate interference will exceed that from a single UWB emitter. Other published studies which claim that aggregate UWB interference can never exceed that from a single UWB emitter typically used an unrealistic very close-in reference distance for the single UWB emitter, thus leading to misleading conclusions.

7. Results of the NTIA studies show that under ideal radio propagation conditions, with no man-made or natural obstructions, aggregate interference levels from UWB devices can exceed that from a single emitter at densities as low as a few emitters per square kilometer to greater than 1,000 active emitters per square kilometer. TABLE 5-7 summarizes these results.

8. Additional factors that can play a significant role in aggregate interference studies include obstructions due to foliage, natural terrain irregularities, urban/suburban environments, and building penetration losses, as well as UWB antenna directivity. TABLE 5-11 illustrates a possible methodology for applying these factors.

9. Potential UWB interference into a SARSAT uplink was only investigated based on aggregate interference, since a single UWB emitter will not affect the satellite. Results show that if UWB devices operating in the region of 400 MHz were limited to ground penetration radar (GPR) type of devices operating at the current emission levels permitted by Part 15, aggregate interference would be below the receiver protection criteria, for anticipated densities of GPRs.

6.5 INTERFERENCE MEASUREMENTS

Measurements were made on two Telecommunication system, an ARSR-4 and an ASR-8, for the purpose of assessing the adequacy of the EMC analysis procedure and the analytical model discussed in Section 3. The following are conclusions resulting from the measurements.

1. The measurements indicated that the potential for interference to ARSRs and ASRs from UWB devices can occur in an annular ring around each radar. The distance to the angular ring and the diameter of the angular ring depends on the antenna height, antenna gain elevation pattern and the antenna vertical tilt angle. The antenna gain elevation pattern is key in performing an EMC analysis.

2. A comparison of measured maximum permitted EIRP limits with the analytical model indicates that for the ARSR-4 and ASR-8 systems, the analytical model and

the measurements are within a few dB. The EIRP limits determined by measurements were generally lower. This difference may be due to several factors:

A. The analytical model does not take consideration exact terrain variations, and

B. The radar antenna elevation pattern used in the analytical model may not accurately represent the antenna gain in the direction of the UWB device.

APPENDIX A

CHARACTERISTICS OF SELECTED GOVERNMENT EQUIPMENT

A.1 INTRODUCTION

The systems analyzed for this report were the NEXRAD, ARSR-4, ASR-9, RF Altimeters, ATCRBS, DME, MLS, SARSAT LUT and satellite receiver, TDWR, 4 GHz Earth station Receiver, and a shipboard marine radar.

A description of these systems, tables of receiver characteristics, and receiver protection criteria for single entry and aggregate UWB interference are provided in this Appendix. The tables also provide the nominal approach distance for each system which, due to system operational constraints and/or security measures, represents the closest distance to the system receiver that a UWB device would be expected to operate. However, the maximum UWB interference power in the victim receiver may not occur at that distance due to the geometry of the interference scenario.

A.2 NEXT GENERATION WEATHER RADAR (NEXRAD)

System Description

The NEXRAD weather radar provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information with higher spatial and temporal resolutions than previous weather radar systems. NEXRAD radars are operated throughout the United States by the National Weather Service and the DoD at the locations shown in Figure A-1.

The major difference between meteorological radars and other radars operated in the radiodetermination service is in the nature of their targets. Meteorological targets are distributed in space and occupy a large fraction of the spatial resolution cells observed by the radar. Moreover quantitative measurements of the received signals characteristics must be made in order to estimate such parameters as precipitation rate, precipitation type, air motion, turbulence, and wind shear. While many radar applications call for discrimination of relatively few targets from a clutter background, meteorological radars focus on making accurate estimates on the nature of the *weather clutter* itself.[67] In typical clear air operations the NEXRAD antenna rotates 360 degrees in the horizontal plane at 0.5 rpm and uses six successive elevation angles of 0.5, 4.5, 8.5, 12.5, 16.5, and 20.5 degrees. The radar operator can vary NEXRAD antenna's scan mode to monitor specific meteorological events. Detailed NEXRAD system characteristics are shown below in TABLE A-1.

Protection Criteria

The desensitization effect on meteorological radars from other services that generate CW or noise-like interference is related to the intensity of the interference. In any azimuth sectors in which such interference arrives, its power spectral density (PSD) can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 1 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.26, or an I/N ratio of about -6 dB.

Therefore, the protection criteria for NEXRAD radars from UWB devices is an I/N ratio of -6 dB for aggregate interference and for a single interferer. This criteria is contained in ITU-R. Recommendation 1464, "*Characteristics of and Protection Criteria for Radionavigation and Meteorological Radars Operating in the Frequency Band 2700-2900 MHz.*"

The NEXRAD receiver noise power was calculated to be -114 dBm. The permissible aggregate and single entry interference power, using the I/N protection criteria of -6 dB, is calculated to be -120 dBm.

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[67] Robert J. Serafin, *Meteorological Radars*, Radar Handbook, at 23.2 (Merrill I. Skolnik ed., 2d ed. 1990).

TABLE A-1
NEXRAD System Characteristics

Equipment Parameter	Value
Tuning Range	2.7–3.0 GHz
Channelization	NA
Pulse Width and Rate	1.64–4.73 μs with a PRF of 320–1300 pps
3 dB RF Bandwidth	15 MHz
3 dB IF Bandwidth	550 kHz
Noise Figure	2.5 dB
Receiver Noise Power	-114.1 dBm
System Loss (typical value)	2 dB
Antenna Type	Parabolic with center feed, pencil beam pattern
Polarization	Circular
Scan Rate	Vertical 20 Deg/5 min, horizontal 0.5 to 3.4 rpm
Antenna Elevation Angle	-1.0 to 90 degrees, typical installation 0.5 degrees
Main Beam Gain	45 dBi
3 dB Beamwidth	0.9 Degrees horizontal and vertical
Analysis parameter	**Value**
Antenna Height	28 m (average)
Nominal Approach Distance	170 meters
Receiver Protection Criteria	I/N=-6 dB for single entry and aggregate

NEXRAD Antenna Pattern

The NEXRAD vertical antenna pattern is shown below in Figure A-2. The pattern is based on measured data and is symmetrical about the vertical axis.

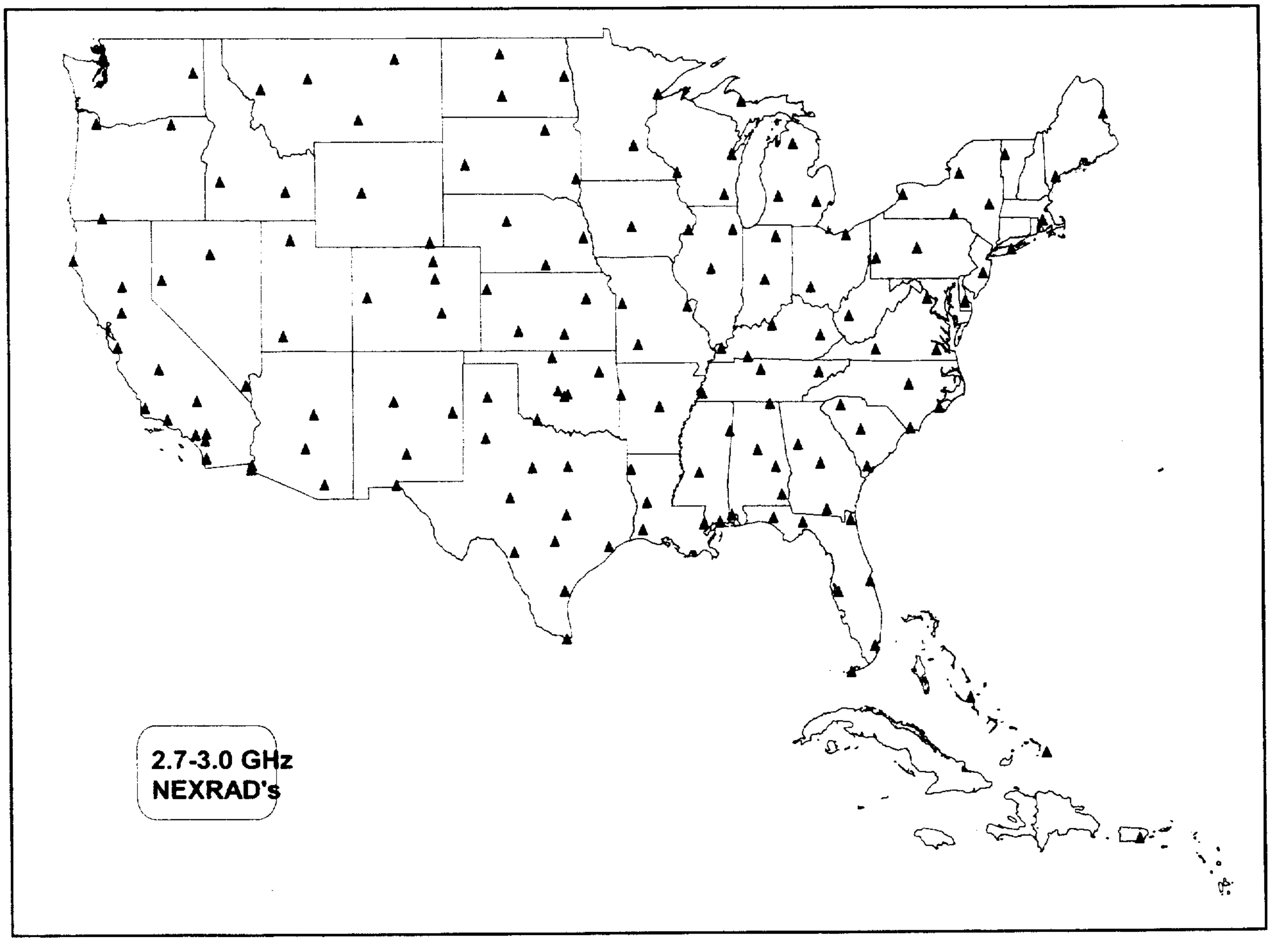

Figure A-1. NEXRAD Radar Locations.

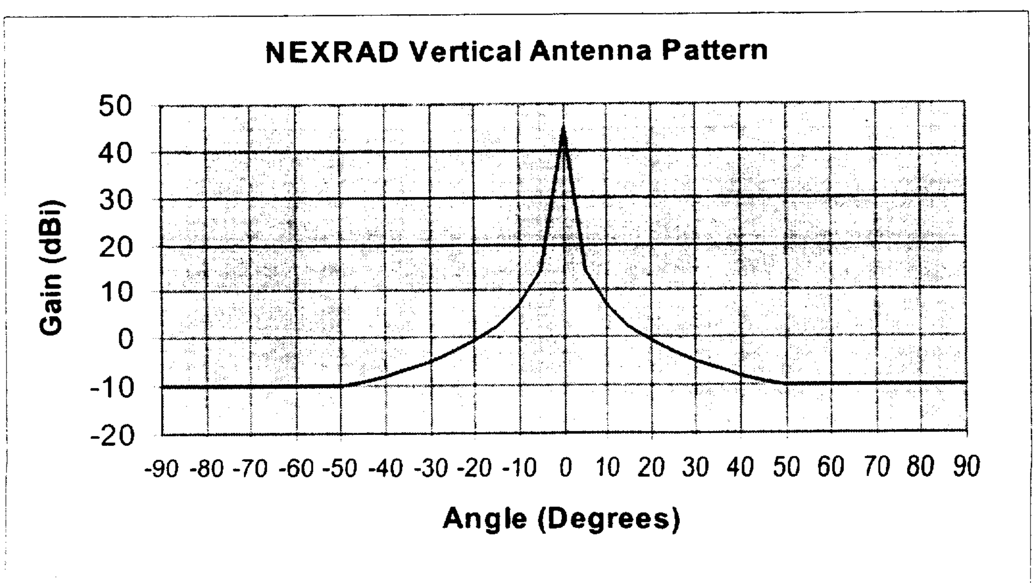

Figure A-2. NEXRAD Vertical Antenna Pattern.

The NEXRAD radars are sited to provide overlapping coverage in most of the United States, especially in areas of severe weather events (tornados, thunderstorms, etc.) like the mid-west and northeast. In addition to the National Weather Service, the FAA and DoD also rely on NEXRAD for weather observations with each agency having its own requirements for range and spatial resolution.

A.3 AIR ROUTE SURVEILLANCE RADAR (ARSR-4)

System Description

The ARSR-4 radar is used by the FAA and DoD to monitor aircraft during enroute flight. It is a pulsed radar with a parabolic reflector and a phased array feedhorn. The range of the radar is 5 to 250 nautical miles up to 100,000 feet. The FAA range requirement is 200 nautical miles and a probability of detection (Pd) of 0.8 or greater for clear air with a target cross section of 2.2 m^2. The DoD range requirement is beyond 200 nautical miles. The range and Pd requirements for ARSR-4 coverage over water, wooded hills and mountains, and during weather events is described in FAA directive FAA-E-2763B. In general, the range requirement for these events and/or terrain conditions is less than the clear air requirements. However, the Pd remains at a minimum of 0.8 for all conditions.

Detailed ARSR-4 system characteristics are shown below in TABLE A-2. The information for these parameters was obtained from the FAA ARSR-4 program office. The locations of the ARSR-4 radars are shown in Figure A-3. Note that the FAA, in addition to the ARSR-4, uses other ARSR radars for enroute aircraft surveillance which would also be located across the country.

Receiver Protection Criteria

The desensitization effect on radiolocation radars from other services that generate CW or noise-like interference is related to its intensity. In any azimuth sectors in which such interference arrives, its PSD can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 0.5 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.12, or an I/N ratio of about -10 dB. This represents the aggregate effect of multiple or single entry interferers, when present. An I/N ratio of -10 dB for radiolocation radars will be proposed by the United States in a revision to ITU-R M.1463 in ITU-R Study Group 8B for radars operating in the 1200-1400 MHz frequency band.

Therefore, the protection criteria for the ARSR-4 radars to interference from UWB devices is an I/N ratio of -10 dB for aggregate and single entry interference power. Using the I/N ratio of -10 dB, the maximum permissible interference level for the ARSR-4 is -123 dBm. For the ARSR-4 analysis, an average (RMS) UWB power level was used because the receiver's adaptive threshold algorithm establishes a constant false alarm rate (CFAR) level by taking the average signal level over several range bins. Therefore, the average (RMS) level of the UWB signal will have a bearing in determining a change in the CFAR level.

ARSR-4 Antenna Pattern

The ARSR-4 uses a system of nine narrow receive beams stacked in elevation. The nine receive beams are divided into two groups called the receive high stack and the receive low stack. To provide overlap between the two stacks, beam five is used as the highest receive beam in the low stack and the lowest beam in the high stack The result is that there are five beams in each stack. A tenth beam, the lookdown beam, is available for sites with high installations (such as ridges and mountaintops) where the lookdown capability is used. The elevation angle of the lookdown beam is 7 degrees below the horizontal. Figure A-4 shows the vertical antenna pattern of the ARSR-4 antenna. The pattern was obtained from measured data.

TABLE A-2
ARSR-4 System Characteristics

Parameter	Value
Tuning Range	1215-1400 MHz
Channelization	44 frequency pairs
Pulse Width and Rate	88.8 and 58.8 μs, 291.5 or 312.5 pps
3 dB RF Bandwidth	58 MHz
3 dB IF Bandwidth	690 kHz
Noise Figure	3.6 dB
Receiver Noise Power	-113 dBm
System Loss	0 dB
Antenna Type	Parabolic reflector with phased array feedhorn
Polarization	Vertical, horizontal, RHCP, LHCP
Horizontal Scan Rate	5 rpm
Main Beam Gain	41.8 dBi
Beam One 3 dB Beamwidth	Vertical 2.0, horizontal 1.4 degrees
Analysis Parameters	**Value**
Antenna height	22 m (average)
Nominal Approach Distance[1]	15 m
Receiver Protection Criteria	I/N=-10 dB for single entry and aggregate

[1] Typical distance for public access to radar site

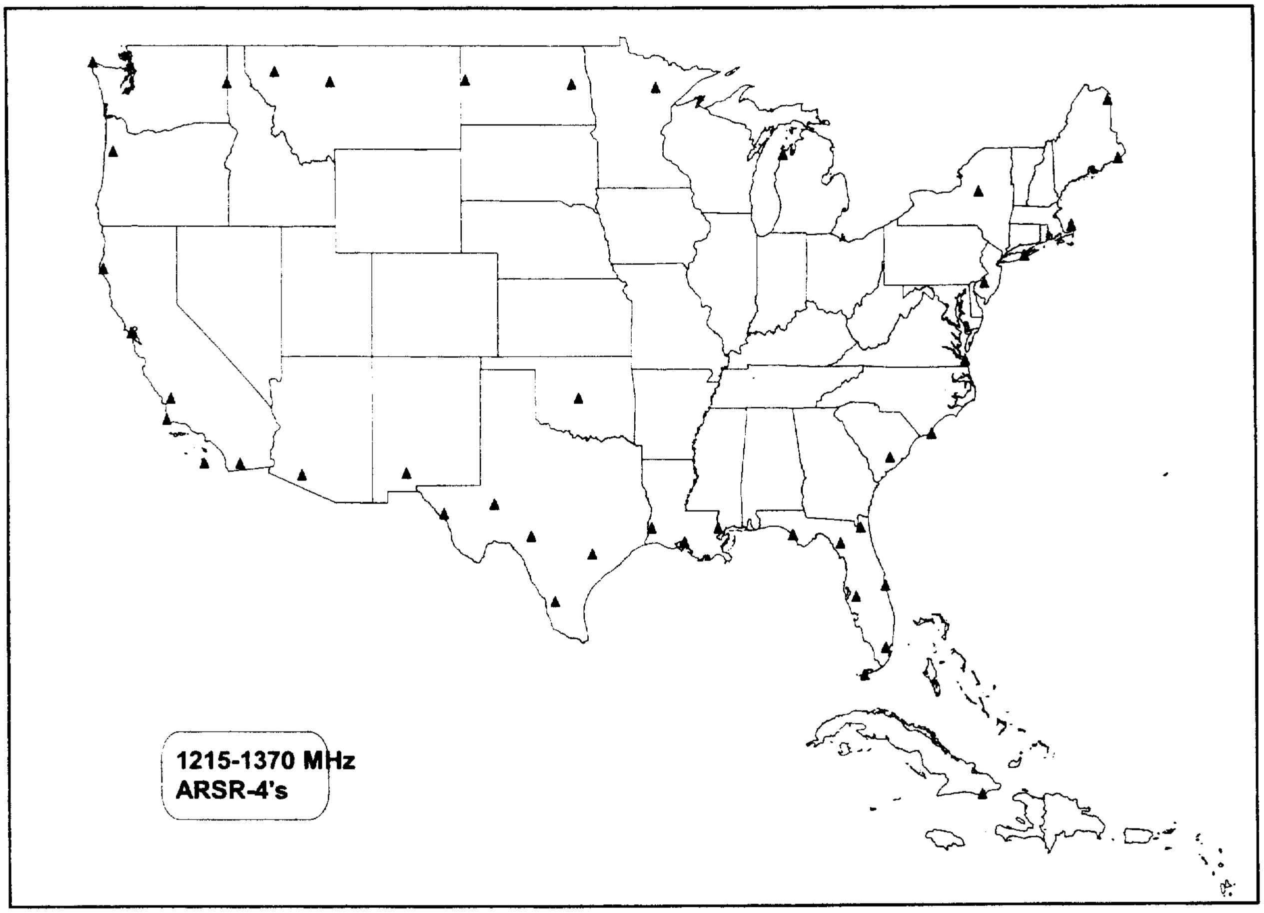

Figure A-3. ARSR-4 Radar Locations.

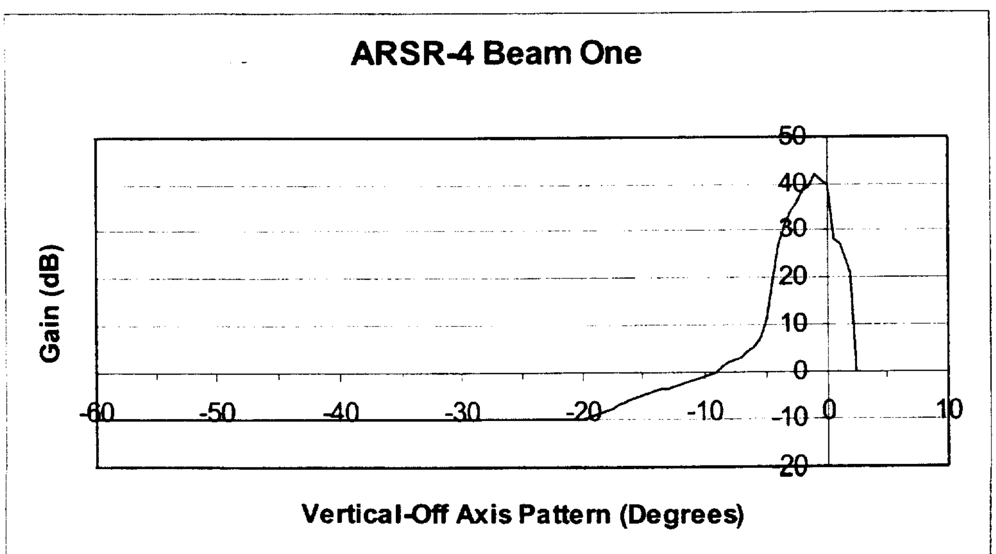

Figure A-4. ARSR-4 Beam One Vertical Antenna Pattern.

A.4 AIRPORT SURVEILLANCE RADAR (ASR-9)

System Description

The ASR-9 radar is used by the FAA and DoD to monitor aircraft in the airspace in and around airports. The FAA has a requirement of a range of 110 km for this radar. Detailed ASR-9 system characteristics are shown below in TABLE A-3. The information for these parameters was obtained from ASR-9 program offices of the FAA. The locations of the ASR-9 radars are shown in Figure A-5. Note that the FAA, in addition to the ASR-9, uses other ASR radars for aircraft surveillance in and around airports. They would also be located across the country.

TABLE A-3
ASR-9 System Characteristics

Parameter	Value
Tuning Range	2700-2900 MHz
Channelization	200 channels, fixed crystal
Pulse Width and Rate	1.08 μs with a PRF of 928 and 1193 up to 1027 and 1321pps
3 dB RF Bandwidth	10 MHz
3 dB IF Bandwidth	653 kHz
Noise Figure	4 dB
Receiver Noise Power	-112 dBm
System Loss (typical value)	2 dB
Antenna Type	Parabolic reflector
Polarization	Right hand circular or linear
Horizontal Scan Rate	12.5 rpm
Main Beam Gain	33.5 dBi
3 dB Beamwidth	1.3 degrees horizontal, 4.8 degrees vertical
Analysis Parameters	**Value**
Antenna Height	17 m (average)
Nominal Approach Distance[1]	15 m
Receiver Protection Criteria	I/N=-10 dB for single entry and aggregate

[1] Typical distance for public access to radar site.

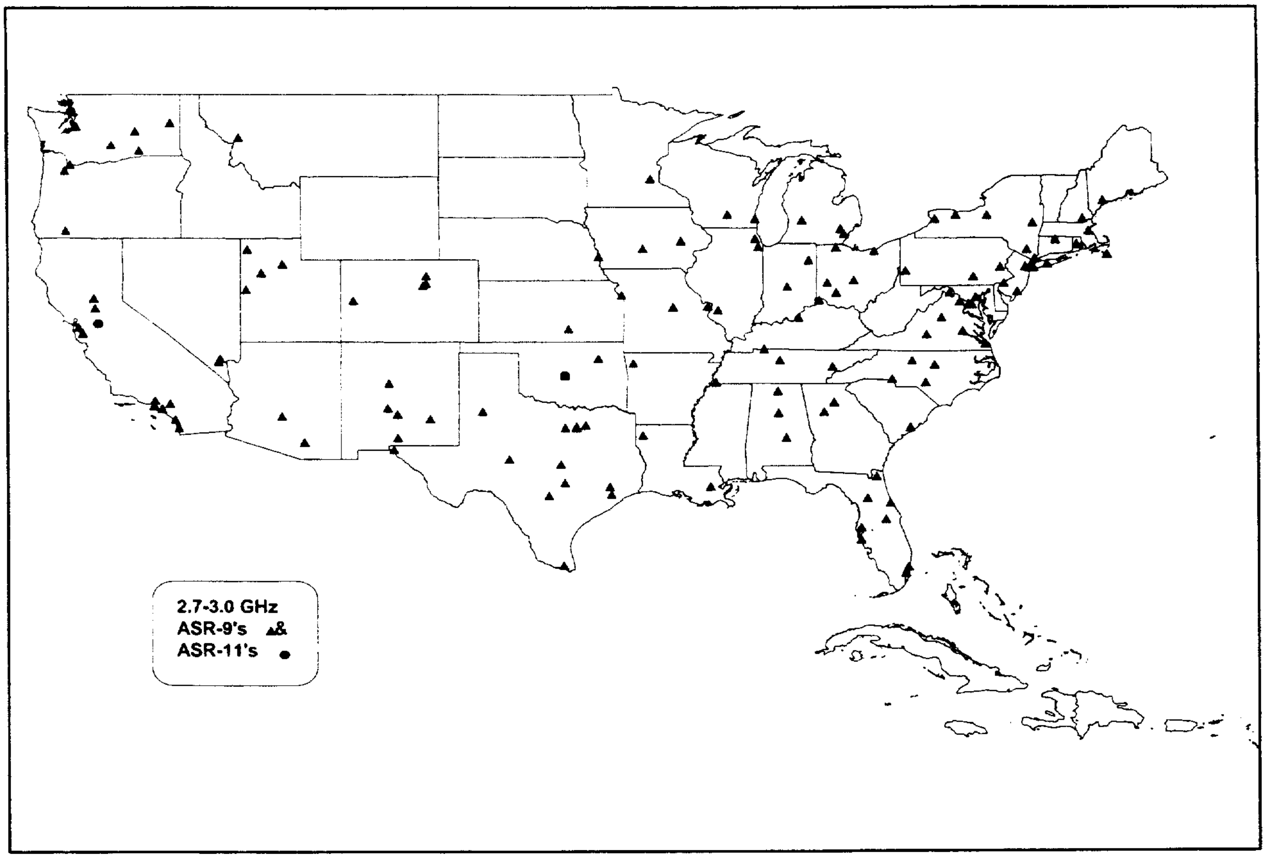

Figure A-5. ASR-9 Locations.

Receiver Protection Criteria

The desensitization effect on radionavigation radars from other services that generate CW or noise-like interference is related to its intensity. In any azimuth sectors in which such interference arrives, its PSD can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation.. If the noise power of the radar receiver is denoted by N_0 and the noise-like interference is represented by I_0, the resultant effective noise power is $I_0 + N_0$. An increase of 0.5 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.12, or an I/N ratio of about -10 dB. This represents the aggregate effect of multiple or single entry interferers, when present. The I/N ratio of -10 dB is contained in a proposed revision to ITU-R M.1464 under consideration by ITU-R Study Group 8.

Therefore, the protection criteria for an ASR-9 radar from UWB devices is an I/N ratio of -10 dB for aggregate interference power and for a single interferer. Using the I/N ratio of -10 dB, the maximum permissible aggregate and single entry interference power is -122 dBm for the ASR-9. For the ASR-9 analysis, an average (RMS) UWB power level was used because the receiver's adaptive threshold algorithm establishes a CFAR level by taking the average signal level over several range bins. Therefore, the average

(RMS) level of the UWB signal will have a bearing in determining a change in the CFAR level.

ASR-9 Antenna Pattern

The vertical antenna pattern for the ASR-9 is shown in Figure A-6. The pattern was obtained from measured data. Negative angles on the X-axis in Figure A-6 are towards the ground.

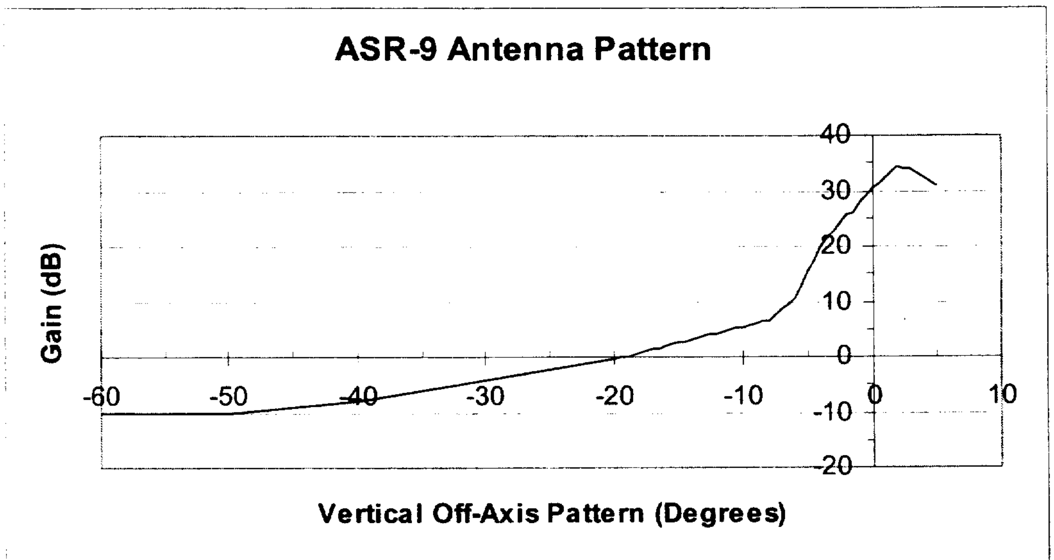

Figure A-6. ASR-9 Vertical Antenna Pattern.

A.5 ALTIMETERS

System Description

Radar altimeters determine and display aircraft height AGL to pilots. They are used in commercial and private aviation as well as in military aircraft. Altimeters that operate in the 4200-4400 MHz frequency band are either pulsed or frequency modulated continuous wave (FMCW) systems. In the FMCW systems the linearly modulated emitted signal is reflected by the terrain and detected by the altimeter receiver. If part of the signal currently being transmitted is mixed with the reflected signal, the result is a difference or beat frequency. The beat frequency is directly proportional to the altimeter altitude and is processed to determine and display altitude. It is also possible to maintain a fixed beat frequency, using a tracking loop, by varying the FM deviation according to the altitude. In this case, variations in deviation are processed to determine the altitude. In pulsed altimeter systems, the time between the pulsed emission and the terrain reflected return is directly proportional to the altimeter altitude.

The system characteristics of typical FMCW and pulsed radar altimeters are shown below in TABLE A-4. The characteristics of the FMCW radar shown in TABLE A-4 are representative of the type used by commercial aviation while the characteristics of the pulsed radar is representative of the type used by the DoD.

Interference Criteria

The UWB and altimeter EMC analysis was performed using a S/(I+N) method by calculating the power of the desired signal (S) from 100 feet to the maximum operating ceiling of the altimeter. The UWB interference in the altimeter receivers was assumed to be noise like and add to its own internal noise. The required S/(I+N) for the pulsed altimeter was 6 dB and for the FMCW it was 12 dB. Since the altimeter's antennas face downward towards the Earth, main beam gain was used in the analysis when calculating the single entry UWB interference to it. The altimeter vertical antenna patterns are shown below in Figure A-7.

TABLE A-4
Altimeter System Characteristics

Parameter	Value	
	Pulsed Type System	**FMCW Type System**
Transmitter Power	5 Watts	0.5 Watts
3 dB Baseband Bandwidth	NA	90 kHz
3 dB IF Bandwidth	30 MHz	NA
Noise Figure	4 dB	4 dB
Receiver Noise Power	-95 dBm	-120
Sensitivity	-83 dBm	-88 dBm
Antenna Gain	10.5 dBi	11 dBi
Antenna 3 dB Beamwidth	45 degrees	60 degrees
Analysis Parameters	**Value**	
Receiver Protection Criteria	S/(N+I)= 6 dB	S/(N+I)= 12 dB
Altitude Measurement Range	100 to 5,000 feet AGL	100 to 2500 feet AGL

NA: Not applicable

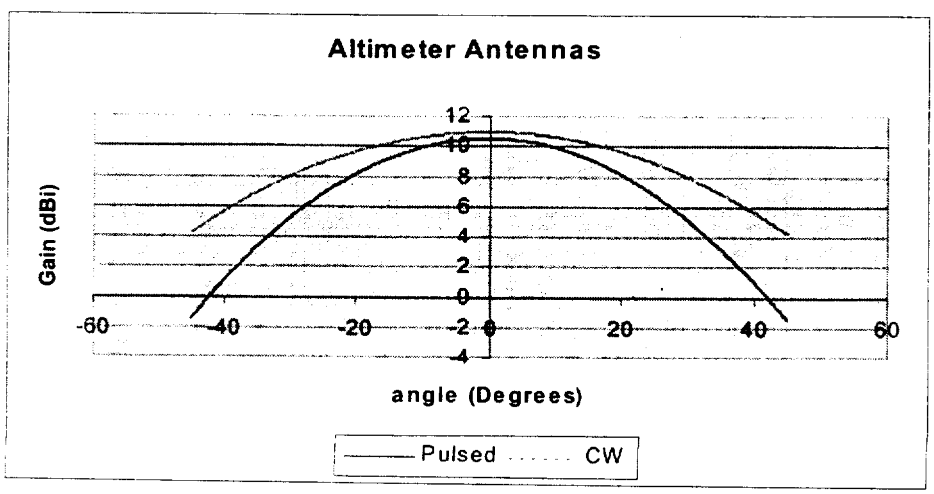

Figure A-7. Altimeter Vertical Antenna Patterns.

A.6 AIR TRAFFIC CONTROL RADIO BEACON SYSTEM (ATCRBS)

System Description

The ATCRBS is used by the FAA and DoD to monitor and identify suitability equipped aircraft in both civil and military aviation applications. The system uses two frequencies, 1030 and 1090 MHz. The aircraft transmits a coded pulse train reply at 1090 MHz in response to interrogations at 1030 MHz from the ground-based station that identifies the aircraft and its altitude. ATCRBS has different modes of operation, defined as modes A, B, C, D, and S. The FAA uses ATCRBS in conjunction with the ASR and ARSR radars to monitor and track aircraft during enroute and approach phases of flight. ATCRBS is also used to monitor aircraft on the ground as they traverse taxiways around the airport. The nominal maximum range for the system is 370 km when used in conjunction with an ARSR radar and about 110 km when used in conjunction with an ASR radar.

The system characteristics and receiver protection criteria of the ATCRBS ground interrogator are shown in TABLE A-5 and the system characteristics and receiver protection criteria of an aircraft ATCRBS transponder are shown below in TABLE A-6. Figures A-3 and A-6 can be used to identify the location of ATCRBS ground stations.

Interference Criteria

The interference criterion of the aircraft transponder is dependent on the ability of its receiver to demodulate and decode requests for the aircraft's identification code and altitude that were transmitted from the ground-based interrogator. The minimum triggering level (MTL) in TABLE A-5 is defined as the minimum input power level referred to the sensor RF port that results in a 90 percent reply ratio if the interrogation signal has all nominal pulse spacings and widths and if the replies are the correct replies assigned to the interrogation format. The criterion is that the transponder receiver be able to demodulate and decode 90 percent of the interrogations that are transmitted in its direction with a signal-to-interference (S/I) ratio of 12 dB.[68]

The interference criterion of the interrogator is dependent on the ability of its receiver to demodulate and decode replies that contain the aircraft's identification code and altitude that were transmitted from the aircraft's transponder. The MTL in TABLE A-6 is defined as the minimum input power level referred to the sensor RF port that results in a 90 percent reply detection probability. The criterion is that the interrogator receiver be able to demodulate and decode 90 percent of the aircrafts replies with an S/I ratio of 12 dB.[69]

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68 Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/MODE S) Airborne Equipment, Radio Technical Commission for Aeronautics, RTCA DO-181A, at 2.2.8.1 (Jan. 1992).

69 Federal Aviation Administration, U.S. Dept. of Transportation, Specification for Mode Select Beacon System (Mode s) Sensor, Amendment 2, FAA-E-2716 (March 1983).

TABLE A-5
ATCRBS Interrogator Characteristics

Parameter	Value
Transmit Frequency	1030 MHz
Transmit Power	59 dBm
Receive Frequency	1090 MHz
Pulse Width and Rate	0.7 -0.9 μs with a PRF of 200 -375 pps
3 dB RF Bandwidth	14.7 MHz
3 dB IF Bandwidth	9 MHz
Noise Figure	2.5 dB
Receiver Noise Power	-102 dBm
Minimum Triggering Level	-79 dBm for 90% reply detection probability
System Loss	2 dB
Antenna Type	Parabolic reflector enroute
Polarization	Vertical
Horizontal Scan Rate	Same as ARSR or ASR radar
Antenna Elevation Angle	Same as ARSR or ASR radar
Main Beam Gain	29 dBi for enroute
3 dB Beamwidth	1.5 degrees horizontal, 4.7 degrees vertical for enroute
Analysis Parameters	**Value**
Antenna Height	Same as ARSR or ASR radar
Nominal Approach Distance	15 m
Receiver Protection Criteria	S/I= 12 dB for single entry and aggregate

In determining the maximum allowable UWB interference power in the ATCRBS interrogator receiver (based on the signal-to-interference (S/I) protection criteria), the ATCRBS transponder desired signal power, S, at the interrogator receiver was set to the minimum triggering level in TABLE A-5.

ATCRBS Interrogator Antenna Pattern

The vertical pattern of the ATCRBS antenna used in conjunction with the ARSR-4 is shown in Figure A-8. The pattern was obtained from measured data. Negative angles on the X-axis in Figure A-8 are towards the ground.

TABLE A-6
ATCRBS Transponder Characteristics

Parameter	Value
Transmit Frequency	1090 MHz
Transmit Power	51 dBm
Receive Frequency	1030 MHz
Pulse Width and Rate	0.7–0.9 μs with a PRF of 200–375 pps
3 dB RF Bandwidth	14.7 MHz
3 dB IF Bandwidth	5.5 MHz
Noise Figure	8 dB
Receiver Noise Power	-98 dBm
Minimum Triggering Level	-77 dBm for 90% reply detection probability
System Loss	2 dB
Antenna Type	omnidirectional flush mount, or blade
Polarization	vertical
Main Beam Gain	4 dBi
Analysis Parameters	**Value**
Antenna Height	10 meters
Operational Height	Airport surface to 40,000+ feet
Receiver Protection Criteria	S/I= 12 dB for single entry and aggregate

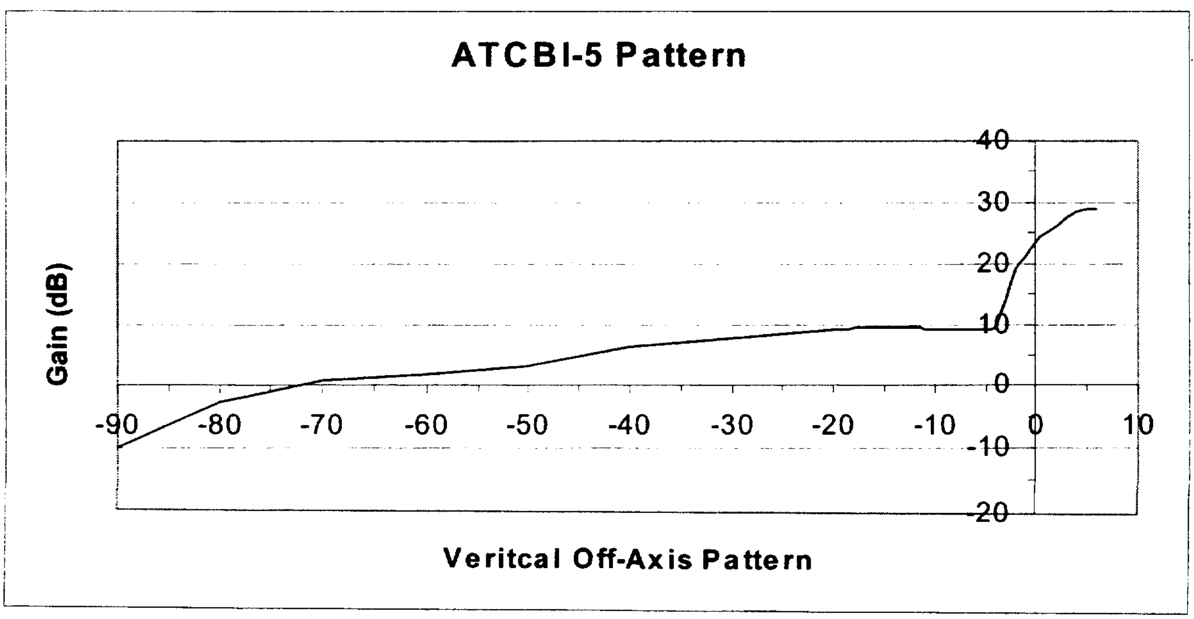

Figure A-8. ATCRBS Interrogator Vertical Antenna Pattern Used in Conjunction with ARSR-4.

ATCRBS Transponder Antenna Pattern

The vertical antenna pattern of the ATCRBS transponder is shown below in Figure A-9. It was based on a measured pattern that was obtained from an avionics antenna manufacturer. The angle 90 degrees is directly under the aircraft.

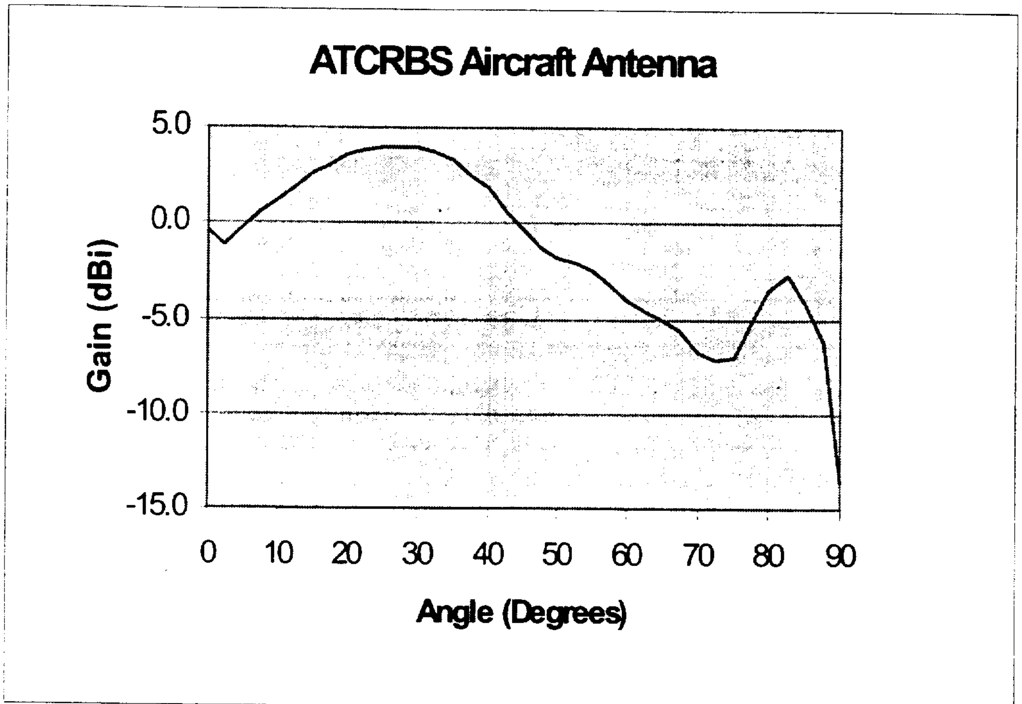

Figure A-9. ATCRBS Transponder Vertical Antenna Pattern.

A.7 MICROWAVE LANDING SYSTEM (MLS)

System Description

The ICAO Standard MLS is an aeronautical radionavigation system used for precision approach and landing of aircraft. It is intended for universal application serving both civil and military users to permit all-weather landings as well as curved or segmented approaches to airports. The MLS is allocated in the frequency band 5000-5150 MHz and currently operates on 200 channels in the frequency band 5030-5091 MHz. The MLS ground station supports navigation and guidance for suitably equipped aircraft out to a range of 43 km and an altitude of 20,000 feet. The characteristics of an airborne MLS receiver are shown in TABLE A-7.

TABLE A-7
MLS Receiver Characteristics

Parameter	Value
Service Range	20,000 feet to 100 feet
Tuning Range	5030–5091 MHz
Channelization	0.3 MHz
Pulse Width and Rate	33.3 μs with a PRF of 3500 pps
3 dB RF Bandwidth	100 MHz
3 dB IF Bandwidth	150 kHz
Noise Figure	10 dB
Receiver Noise Power	-112 dBm
Sensitivity	-103 dBm
System Loss	5 dB
Antenna Type	Quarter wave stub
Polarization	Vertical
Main Beam Gain	5 dBi
Analysis Parameter	**Value**
Protection Criteria	I = -134 dBm for single entry and aggregate
Minimum Altitude	30 meters

Interference Criteria

Radio frequency interference can lead to errors in the estimation of time intervals associated with beam passage of the MLS transmitting station's antenna beam. Depending on the frequency components of the error process and the aircraft flight control system guidance loop bandwidth, this could lead to the physical displacement of the aircraft relative to the desired approach path. The International Civil Aviation Organization (ICAO) has specified the maximum permissible interference power into a MLS receiver to be -130 dBm to prevent this from occurring.[70] Another 4 dB is subtracted from the ICAO threshold to partition the UWB interference into the link budget. Therefore, the maximum permissible UWB interference is -134 dBm.

MLS Antenna Pattern

The vertical antenna pattern of the airborne MLS receiver is shown below in Figure A-10. It is based on a measured pattern that was obtained from a an avionics antenna manufacturer. The angle 90 degrees is directly under the aircraft.

70 International Standards and Recommended Practices Annex 10 to the Convention on International Civil Aviation, Volume 1 (Radio Navigation Aids) Fifth Edition, July 1996.

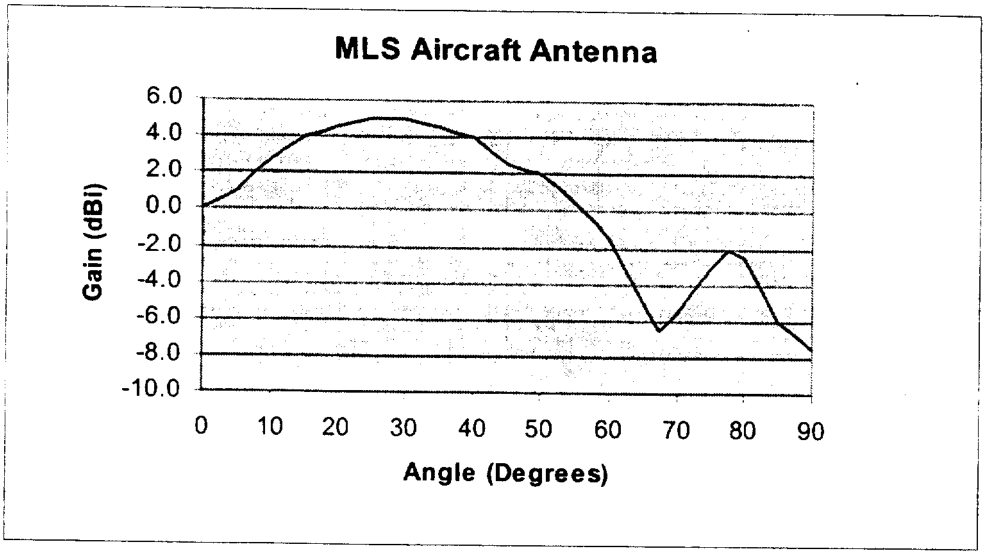

Figure A-10. MLS Antenna Pattern.

A.8 DISTANCE MEASURING EQUIPMENT (DME)

System Description

DME allows aircraft to fly safe, accurate paths during the enroute, terminal, approach, landing, missed approach and departure phases of flight. DME equipment is used across the United States by both civil and military aircraft. DME operates across the 960-1215 MHz frequency band. The DME interrogation and reply frequencies are defined at 1 MHz increments between 962-1213 MHz, leaving 2 MHz guard bands at each end of the band. The system provides user aircraft with range to a ground-based transponder station. In general the ranging systems is air-initiated, with the airborne transmitter interrogating a ground transponder, and calculating range from the time difference between the initiation of the interrogation and receipt of the reply. The maximum range for high altitude service is 240 km with an altitude of 18 km and for low altitude service the distance is 74 km with an altitude of 5.5 km. The maximum range for the standard terminal service is 46 km with an altitude of 3.7 km.[71]

The system characteristics and receiver protection criteria of the transponder are shown in TABLE A-8 and the system characteristics and receiver protection criteria of the interrogator are shown in TABLE A-9.

[71] *See Id.* for a detailed description of the DME service areas.

TABLE A-8
DME Transponder System Characteristics

Parameter	Value
Transmit Power	55 dBm
3 dB RF Bandwidth	22 MHz
3 dB IF Bandwidth	.8 MHz
Noise Figure	9 dB
Receiver Noise Power	-106 dBm
Sensitivity	-94 dBm for 70% reply efficiency
Antenna Type	Dipole array
Polarization	Vertical
Main Beam Gain	5 dBi
3 dB Beamwidth	10 Degrees vertical, 360 degrees horizontal
Analysis Parameters	**Value**
Antenna Height	10 meters
Nominal Approach Distance	15 m
Receiver Protection Criteria	I=-122 dBm for single entry and aggregate

TABLE A-9
DME Interrogator System Characteristics

Parameter	Value
Transmit Power	54 dBm for equipment operating above 18,000 feet 47 dBm for equipment operating below 18,000 feet
3 dB RF Bandwidth	20 MHz
3 dB IF Bandwidth	650 kHz
Noise Figure	8 dB
Receiver Noise Power	-108 dBm
Sensitivity	-83 dBm for 70% reply efficiency
Antenna Type	Quarter wave stub
Polarization	Vertical
Main Beam Gain	4 dBi
3 dB Beamwidth	30 degrees vertical, 360 degrees horizontal
Analysis Parameters	**Value**
Minimum Altitude	30 meters
Receiver Protection Criteria	I = -115 dBm for single entry and aggregate

Interference Criteria

DME interrogators require a 70 percent reply efficiency in the absence of all interfering signals. For DME interrogator equipment intended for dual installations, the receiver shall meet this criteria when a CW signal having a level of -99 dBm is applied on the assigned channel frequency.[72] An additional -10 dB of protection is used to partition the UWB interference into that threshold with an additional 6 dB of protection to account for the aeronautical safety margin. Using this criteria, the maximum permissible UWB interference power in the DME interrogator is -115 dBm.

DME transponders require a 70 percent reply efficiency in the absence of all interfering signals. For DME transponders, the receiver noise floor is -105 dBm. Using a protection criteria of an I/N of -10 dB to partition the UWB interference into the DME link budget and an additional 6 dB for the aeronautical safety margin, the maximum permissible UWB interference power in the transponder receiver is -121 dBm.

A description of the 6 dB aeronautical safety margin and its application is contained in ITU-R Recommendation M.1477.

DME Interrogator Antenna Pattern

The vertical antenna pattern of the airborne DME interrogator is shown below in Figure A-11. It is based on a measured pattern that was obtained from an avionics antenna manufacturer. The angle 90 degrees is directly below the aircraft.

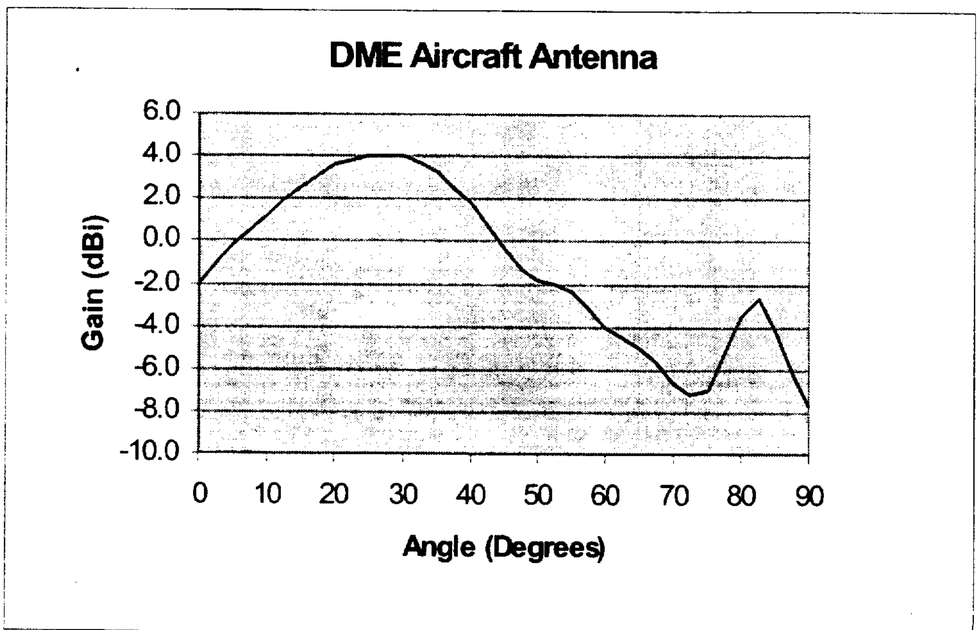

Figure A-11. DME Interrogator Vertical Antenna Pattern.

[72] Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating Within The Radio Frequency Range of 960-1215 Megahertz, Radio Technical Commission for Aeronautics, RTCA DO-189, at 2.2.11 (Sept. 1985).

A.9 4 GHz EARTH STATION

System Description

The 4 GHz Earth stations are used to receive downlink transmissions from geosynchronous satellites for a variety of applications, including voice, data, and video services for Federal agencies. The system characteristics and receiver protection criteria of the 4 GHz Earth station receiver is shown in TABLE A-10. The system noise temperature is a typical value and includes antenna sky noise and noise due to the Low-Noise amplifier and cabling loss.

TABLE A-10
Earth Station Characteristics

Parameter	Value
Frequency	3750 MHz
3 dB IF Bandwidth	40 MHz
System Noise Temperature	150 K
System Noise Power	-101 dBm
Antenna Type	Parabolic
Vertical Elevation Angle	5 to 20 degrees above horizon
Polarization	Circular
Main Beam Gain	40 dBi
Analysis Parameter	**Value**
Antenna Height	3 m
Receiver Protection Criteria	I/N=-10 dB average and peak power for single entry and aggregate interference[73]

[73] For this study, both peak and average power UWB device signal levels will be used to bound the potential interference level to digital communication systems. Measurements and analysis have shown that the undesired signal level at which bit errors start to occur, interference threshold, in a digital modulated signal are based on the peak power of the undesired signal. For example, assuming no bit error correction and a low duty cycle (0.01 percent) pulsed undesired signal, measured bit errors would start to occur at a certain peak undesired signal level. However, receiver performance degradation is not a simple function of the bit error rate (BER). Error correction and interleaving of bits can make a digital modulated system more robust to the occurrence of the undesired signal exceeding the interference threshold. Also, the relation of digital receiver performance degradation is not directly related to the average BER, bursts of errors can have a catastrophic effect on performance degradation. In summary, once the undesired signal peak power has exceeded the interference threshold, the occurrence of receiver performance degradation is a function of the undesired signal duty cycle. However, there is not a simple undesired signal duty factor relation. Factors such as undesired signal gating, duty cycle during gating period (not overall signal duty cycle), receiver digital modulation type, bit error correction scheme, and interleaving depth need to be considered. This uncertainty in the undesired signal duty cycle which causes receiver performance degradation was bounded by including both the peak and average interference signal levels in the analysis.

Earth Station Antenna Pattern

The antenna pattern that was used in the Earth station analysis is shown below in Figure A-12. It is based on a FCC model.

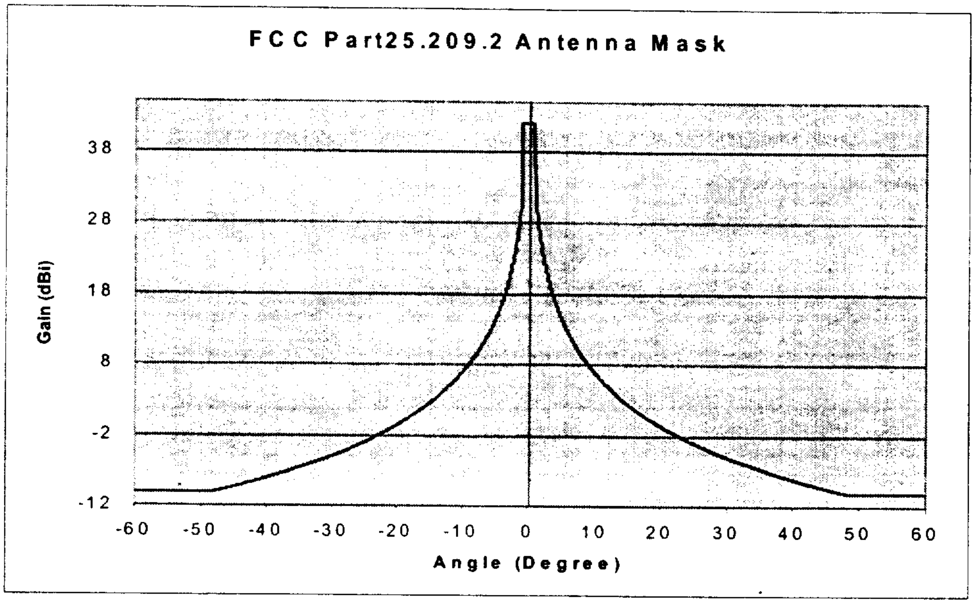

Figure A-12. Earth Station Antenna Pattern.

A.10 SARSAT

System Description

The National Oceanic and Atmospheric Administration (NOAA) operates polar orbiting and geostationary satellites that carry SARSAT payloads that provide distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress. Russia operates very similar instruments known as Cosmicheskaya Systyema Poiska Avariynich Sudov (COSPAS) aboard satellites that are part of a navigation system. Both are being used in an international cooperative search and rescue effort titled COSPAS-SARSAT.

COSPAS-SARSAT consists of a network of satellites, ground stations, mission control centers, and rescue coordination centers. When an emergency beacon is activated, the signal is received by satellite and relayed to the nearest available ground station. The ground station is called a LUT. The LUTs receive information from satellites in the 1544-1545 MHz frequency band. NOAA has 14 LUTs at 7 locations and they are shown below in TABLE A-11. This provides total system redundancy and allows maximization of satellite tracking. The characteristics of the LUTs are shown below in TABLE A-12.

Interference Criteria

The protection criteria for a SARSAT LUT is an I/N ratio of -9 dB. The LUT ground station receiver noise power includes man-made environmental noise, transmission line noise, and internal receiver noise. The total system noise power is the equivalent system noise temperature which is equal to the noise temperature of the antenna plus the noise temperature of the receiver. The antenna noise temperature takes into account both man-made environmental and transmission line noise. The total system noise power of the LUT ground station was found to be -117 dBm. The maximum permissible level of interference is then -126 dBm.

TABLE A-11
SARSAT LUT Locations

LUT Location	Coordinates
Andersen AFB, Guam	13.5784°N 144.9390°E
Vandenberg AFB, CA	34.6624°N 120.5514°W
Sabana Seca USN, PR	18.4317°N 066.1922°W
USCG Station, Wahiawa, HI	21.5260°N 157.9964°W
NASA JSC, Houston, TX	29.5605°N 095.0925°W
Fairbanks, AK	64.9933°N 147.5237°W
Suitland, MD	38.8510°N 076.9310°W

TABLE A-12
SARSAT LUT Characteristics

Parameter	Value
Receiver Locations	See TABLE A-11
Tuning Range	1544-1545 MHz
3 dB IF Bandwidth	800 kHz
System Noise Temp	175.5 K
System Noise Power	-117 dBm
Antenna Type	Parabolic
Antenna Beamwidth	8 degrees
Vertical Elevation Angle	0 degrees
Polarization	Vertical
Analysis Parameter	**Value**
Antenna Height	5 m
Nominal Approach Distance	15.m
Receiver Protection Criteria	I/N=-9 dB for average and peak power for single entry and aggregate[74]

[74] *Id.*

SARSAT LUT Antenna Pattern

The vertical antenna pattern that was used in the SARSAT LUT analysis shown below in Figure A-13. The pattern is symmetrical about the vertical axis.

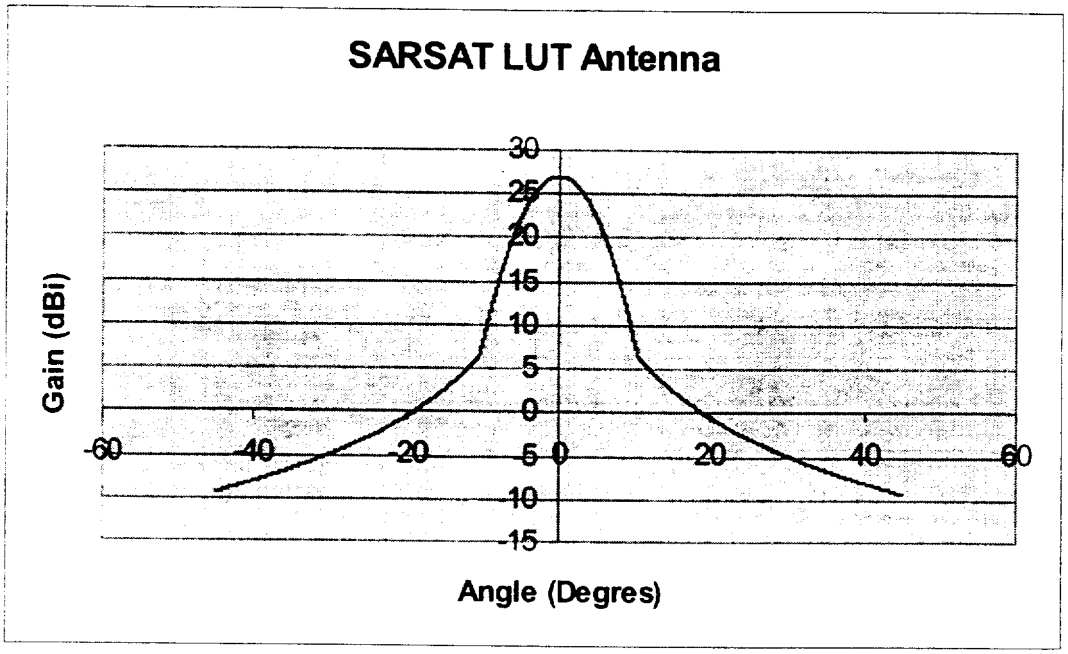

Figure A-13. SARSAT LUT Vertical Antenna Pattern.

A.11 TERMINAL DOPPLER WEATHER RADAR (TDWR)

System Description

TDWR provide quantitative measurements of gust fronts, wind shear, micro bursts, and other weather hazards for improving the safety of operations at major airports in the United States. The radar operates in the 5600-5650 MHz frequency band. An advantage of operating the radar at this frequency is using a small antenna, an important consideration near airports. The system characteristics and receiver protection criteria of the TDWR receiver is shown in TABLE A-13. The vertical antenna pattern of the TDWR is shown in Figure A-14.

The TDWR antenna uses two basic scanning modes. The first is Monitor Mode which is used when no significant weather returns have been detected within 25 nautical miles of the airport. The second is the Hazardous Weather Detection Mode which is used when hazardous weather is has been detected or is expected. The TDWR antenna is designed to operate from a minimum vertical elevation angle of -1° up to a maximum of

60°. In typical operations, the vertical elevation angle is 0.2° for Hazardous Weather Detection Mode and 0.4° for Monitor Mode.

Interference Criteria

The interference protection criteria for the TDWR receiver is an I/N ratio of -6 dB for single entry and aggregate interference. This criteria is contained in an ITU-R draft new recommendation under consideration by ITU-R Study Group 8 titled, "*Characteristics of and Protection Criteria for Radiolocation, Aeronautical Radionavigation, and Meteorological Radars Operating in the Frequency bands Between 5250-5850 MHz.*" Using this criteria, the maximum permissible UWB interference noise power is -118.5 dBm.

TABLE A-13
TDWR Characteristics

Parameter	Value
Frequency	5600-5650 MHz
3 dB IF Bandwidth	.910 MHz
Noise Figure	2.3 dB
Receiver Noise Power	-112.5 dBm
Antenna Type	25 foot parabolic reflector
Beamwidth	.55 degrees horizontal and vertical
Vertical Elevation Angle	0.2 degrees for hazardous mode, 0.4 degrees for monitor mode
Polarization	Circular
Main Beam Gain	50 dBi
Analysis Parameter	**Value**
Antenna Height	27 m (average)
Receiver Protection Criteria	I/N=-6 dB for single entry and aggregate

TDWR Antenna Pattern

The vertical antenna pattern that was used in the TDWR analysis shown below in Figure A-14. The pattern is symmetrical about the vertical axis.

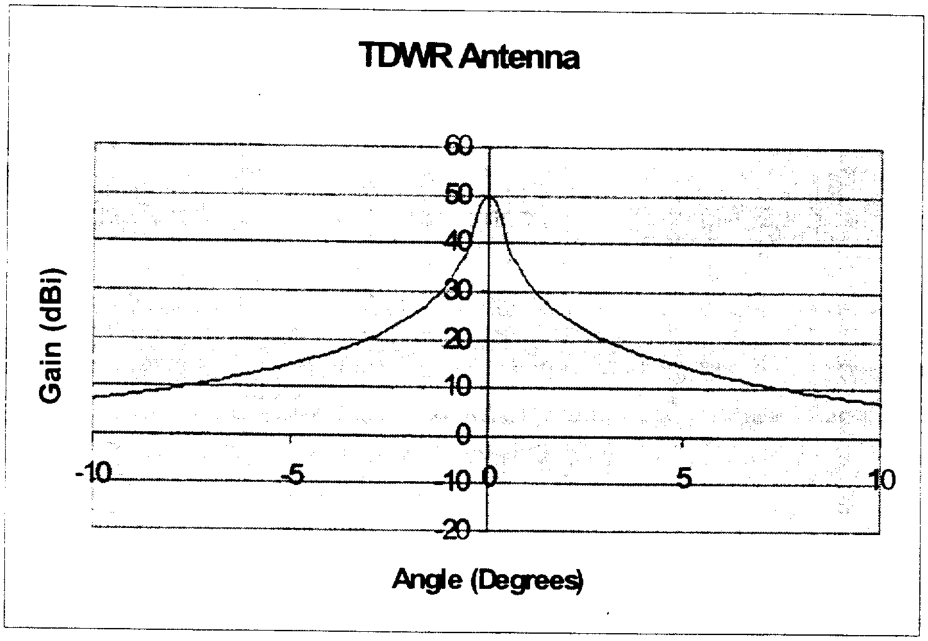

Figure A-14. TDWR Vertical Antenna Pattern.

A.12 S-BAND (10cm) MARINE RADAR

System Description

The S-Band (10cm) marine radar provides ships with surface search, navigation capacities, and tracking services, particularly in foul weather. This radar is used by all categories of commercial and Government vessels, including thousands of foreign and U.S.-flagged cargo, oil tanker and passenger ships operating in U.S. waters, and is a vital sensor for safe navigation of waterways. Vessel traffic services also useS-Band marine radars, and shore-based racons (radar beacons) also operate with marine radars in this band to aid navigation. The marine radar provides indications and data on surface craft, obstructions, buoy markers, and navigation marks to assist in navigation and collision avoidance. S-Band marine radars provide significantly superior target detection in severe weather and can, for example, detect a ship or obstruction at approximately 10 times the range of an X-band (3cm) marine radar during snowfall.

Typical marine radar components include the following; antenna, signal waveguide, transmitter/receiver, and operator display/console. The antenna is a horizontal slotted waveguide array mounted on a pedestal for rotational support. The antenna is typically 12 feet long. The signal waveguide interfaces the antenna with the transmitter/receiver and can be a single shielded cable. Detailed S-Band (10cm) marine radar system characteristics are shown below in TABLE A-14.

TABLE A-14
Marine Radar Characteristics

Parameter	Value
Frequency	2900-3100 MHz
Pule Width and Rate	.08-1.2 us, 500-2200 pps
RF Bandwidth	60 MHz
3 dB IF Bandwidth	4 to 20 MHz
Noise Figure	4 dB
Receiver Noise Power	-104 dBm
Antenna Type	Slotted waveguide array
Beamwidth	2 degrees horizontal, 25 degrees vertical
Vertical Elevation Angle	0 degrees
Horizontal Scan Rate	30 revolutions per minute
Polarization	Horizontal, vertical
Main Beam Gain	27 dBi
Analysis Parameter	**Value**
Antenna Height	20 meters over water line
Nominal Approach Distance	4 meters
Receiver Protection Criteria	I/N=-10 dB for single entry and aggregate

Receiver Protection Criteria

The desensitization effect on radionavigation radars from other services that generate CW or noise-like interference is related to its intensity. In any azimuth sectors in which such interference arrives, its PSD can simply be added to the PSD of the radar receiver thermal noise, within a reasonable approximation. If the noise power of the radar receiver is denoted by N_O and the noise-like interference is represented by I_O, the resultant effective noise power is $I_O + N_O$. An increase of 0.5 dB in the effective noise power would constitute a desensitization of the radar's receiver. Such an increase corresponds to an (I+N)/N ratio of 1.12, or an I/N ratio of about -10 dB. This represents the aggregate effect of multiple or single entry interferers, when present. The I/N ratio of -10 dB is contained in a proposed revision to ITU-R M.1313-1 under consideration by ITU-R Study Group 8 titled ,"*Technical Characteristics of Maritime Radionavigation Radars*".

Therefore, the protection criteria for marine radars from UWB devices is an I/N ratio of -10 dB for aggregate interference power and for a single interferer. Using the I/N ratio of -10 dB, the maximum permissible aggregate and single entry interference power is -114 dBm for the marine radar receiver.

Antenna Pattern

The vertical antenna pattern of the Marine radar receiver is shown below in Figure A-14. It is based on a measured pattern that was obtained from a marine radar manufacturer. Angles from 0 to +90 degrees are towards the sky.

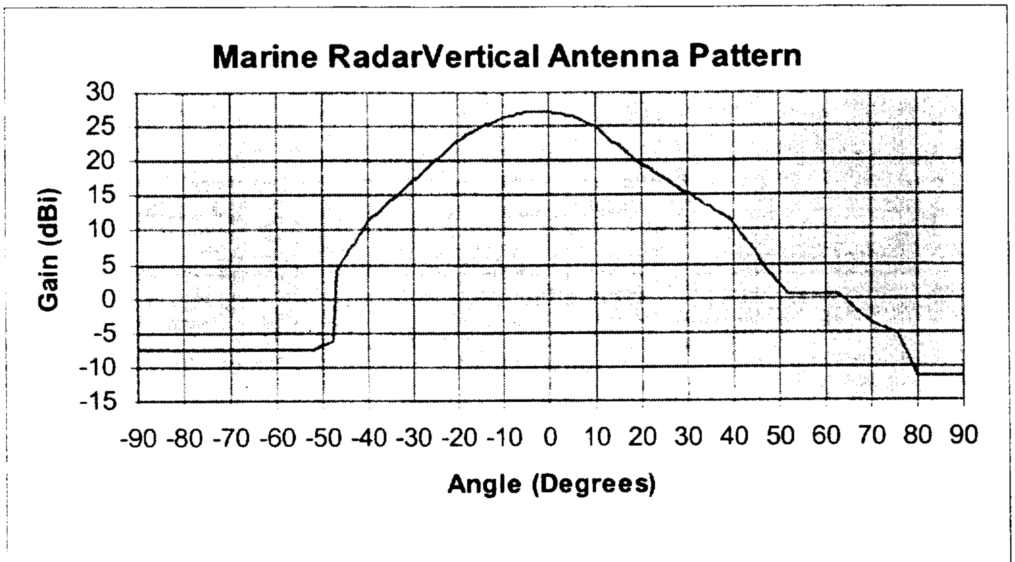

Figure A-14. Marine Radar Vertical Antenna Pattern.