UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and
Information Administration
Washington, D.C. 20230

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
The Portals
445 Twelfth Street, S.W.
Washington, DC 20554

Re: Revision of Part 15 of the Commission's Rules Regarding Ultrawideband Transmission Systems, ET Docket No. 98-153

Dear Ms. Salas:

Enclosed please an original and two (2) copies of the Letter and accompanying reports from John F. Sopko, Acting Assistant Secretary for Communications and Information, Department of Commerce, to Chairman Michael Powell in the above-referenced proceeding. A copy of the letter and accompanying reports were also hand-delivered to Chairman Powell, each of the Commissioners, and Bruce A. Franca, Acting Chief, Office of Engineering and Technology.

Please direct any questions you may have regarding this letter to the undersigned. Thank you for your cooperation.

Respectfully submitted,

Kathy D. Smith
Chief Counsel

Enclosures

cc: The Honorable Michael Powell
The Honorable Harold Furchtgott-Roth
The Honorable Susan Ness
The Honorable Gloria Tristani
Bruce A. Franca, Acting Chief, Office of Engineering and Technology

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FEDERAL COMMUNICATIONS COMMISSION
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The Honorable Michael Powell
Chairman
Federal Communications Commission
The Portals
445 12th Street, S.W.
Washington, DC 20554

Re: Revisions of Part 15 of the Commissions's Rules Regarding Ultrawideband Transmission Systems, ET Docket No. 98-153

Dear Chairman Powell:

The National Telecommunications and Information Administration (NTIA) has completed its measurement and analysis reports (enclosed) on the effects of Ultrawideband (UWB) signals on Global Positioning System (GPS) receivers that use C/A-code (Coarse/Acquisition code) tracking and Semi-codeless architectures. The two reports document measurements made by the Institute for Telecommunication Sciences, in Boulder, Colorado on the effects of several types of UWB signals on the two GPS receivers measured and an analysis by the Office of Spectrum Management, in Washington, D.C. applying those results to several operation scenarios involving both GPS devices and UWB devices developed at a series of open public meetings.

NTIA is continuing its measurement and analysis of UWB signals on two more GPS receivers. Additional results on a C/A-code tracking receiver employing multiple, narrowly-spaced correlators and a Technical Standard Order (TSO)-C129a compliant aviation, C/A-code tracking receiver, which is used in en-route and non-precision approach applications, will be provided in June 2001.

NTIA will continue to reserve its decision on unlicenced operation of UWB devices until we have reviewed measurements and analysis reports of all commenters.

Sincerely,

John F. Sopko
Acting Assistant Secretary for Communications
and Information

Two Enclosures
- NTIA Report 01-384, Measurements to Determine Potential Interference to GPS Receivers from Ultrawideband Transmission Systems
- NTIA Special Publication 01-45, An Assessment of Compatibility Between Ultrawideband Devices And GPS Receivers

NTIA SPECIAL PUBLICATION 01-45

ASSESSMENT OF COMPATIBILITY BETWEEN ULTRAWIDEBAND (UWB) SYSTEMS AND GLOBAL POSITIONING SYSTEM (GPS) RECEIVERS

SPECIAL PUBLICATION

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

NTIA SPECIAL PUBLICATION- 01-45

ASSESSMENT OF COMPATIBILITY BETWEEN ULTRAWIDEBAND (UWB) SYSTEMS AND GLOBAL POSITIONING SYSTEM (GPS) RECEIVERS

David S. Anderson
Edward F. Drocella
Steven K. Jones
Mark A. Settle

U.S. DEPARTMENT OF COMMERCE
Donald Evans, Secretary

John F. Sopko, Acting Assistant Secretary
for Communications and Information

February 2001

ACKNOWLEDGMENTS

The authors wish to thank the many organizations and persons who contributed to the completion of this report. In particular we wish to thank the Federal agency representatives on the Interdepartment Radio Advisory Committee and the Interagency GPS Executive Board for providing vital comments, information, and review of this report. We also acknowledge the written and verbal comments provided by the US GPS Industry Council, and the Ultrawideband Industry during the public comment process, open public meetings, and one-on-one discussions.

We wish to thank the GPS Joint Program Office, the Department of Aeronautics and Astronautics of Stanford University, and the NTIA's Institute for Telecommunication Sciences for their support and work in the measurement process that is fundamental to this report. We also wish to thank the contributing NTIA employees: Paul Roosa, Robert Sole, and Mike Doolan.

EXECUTIVE SUMMARY

BACKGROUND

The study described in this report was undertaken by the National Telecommunications and Information Administration (NTIA) in response to a Federal Communications Commission (FCC) Notice of Proposed Rule Making (NPRM) concerning the operation of a new class of spectrum-dependent devices, designated as ultrawideband (UWB) devices under the FCC's rules and regulations in Part 15 of Title 47 of the Code of Federal Regulations (CFR). This NPRM raises a number of questions and concerns regarding the electromagnetic compatibility (EMC) of the proposed UWB transmitting devices to those spectrum-dependent systems currently in operation. The NTIA, as the Executive Branch agency principally responsible for developing and articulating domestic and international telecommunications policy affecting Federal Government spectrum users, is particularly interested in the potential for interference to telecommunications infrastructure utilizing Federal Government spectrum for critical and/or safety-of-life functions, many of which operate in spectrum designated as the "restricted frequency bands." These frequency bands have been designated as restricted because the systems operating in them provide critical safety functions. Before NTIA can agree to emissions from UWB devices in restricted frequency bands used by critical Federal Government radiocommunication systems, it must ensure that there is no potential interference introduced from their proposed operations. The Global Positioning System (GPS) is an example of a critical radionavigation system that operates in several of the restricted frequency bands.

In recognition of the need to ensure protection of an existing spectrum asset as important as GPS, NTIA accepted funding from the Interagency GPS Executive Board (IGEB) and the Federal Aviation Administration (FAA) to conduct an assessment of the EMC between proposed UWB devices[1] and GPS receivers.

OBJECTIVE

The primary objective of this study is to define maximum allowable UWB equivalent isotropically radiated power (EIRP)[2] levels that can be tolerated by GPS receivers, when used within various operational applications, without causing degradation to GPS operations. These EIRP levels will then be compared to the emission levels derived from the limits specified for

[1] The UWB emissions considered in this report are limited to those using a burst of a series of impulse-like signals. However, there are several ways of defining UWB signals, one being an emission that has an instantaneous bandwidth of at least 25% of the center frequency of the device. There are also several ways of generating very wide signals, including the use of spread spectrum and frequency hopping techniques.

[2] The computation of EIRP is in terms of the average power of the UWB signal for all cases considered in this report. This average power is based on root-mean-square (RMS) voltage.

intentional radiators in C.F.R., Title 47, Part 15.209 to assess the applicability of the Part 15 limits to UWB devices.[3]

GPS SYSTEM DESCRIPTION

The GPS is a space-based radionavigation satellite system providing precise position, velocity, and time information on a continuous, worldwide basis. The GPS space segment consists of a 24-satellite constellation with the satellites distributed in six orbital planes at an approximate altitude of 20,000 km. With the current configuration of the GPS constellation, there are typically from 6 to11 satellites simultaneously visible from any point on the surface of the Earth. However, within a metropolitan area, the number of visible satellites is often reduced due to blockage from buildings or other man-made structures. GPS satellites currently transmit a spread spectrum signal using a multiple access capability known as code division multiple access (CDMA) on two microwave frequencies: Link 1 (L1) on 1575.42 MHz, and Link 2 (L2) on 1227.60 MHz. A civil coarse/acquisition (C/A) code and a quadrature-phase precision (P) code are multiplexed on the GPS L1 frequency while only the P-code is modulated on the L2 carrier. The C/A signal supports the standard positioning service and the P signal supports the precise positioning service.

A modernization effort is currently ongoing that will add two new civil signals to the GPS system. A C/A-like signal has been proposed for addition on L2, and a new signal structure has been defined for broadcast in a recently allocated Radionavigation-Satellite Service frequency band (1164-1188 MHz) and will be designated Link 5 (L5).

GPS APPLICATIONS

GPS will become the cornerstone for air navigation for all phases of flight (en-route, precision and non-precision approach) and is the preferred navigation system for maritime operations. In order to meet the exacting standards required from a safety-of-life system, the U.S. Government has either developed, or is developing augmentations to the basic GPS system for aviation, maritime, and land use. The Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS) are under development to enhance aviation uses of GPS. Differential GPS (DGPS) has been fielded to augment GPS to meet maritime harbor and harbor approach requirements, and for use in intercoastal and inland waterways. GPS is also fast becoming an integral component of position determination applications such as Enhanced-911 (E-911) and personal location and medical tracking devices. The telecommunications, banking, and power distribution industries represent another sector that uses GPS for network synchronization timing. Moreover, GPS has proven to be a powerful enabling technology that has driven the creation of many new industries. GPS also provides the U.S. military and its allies with positioning, navigation, and timing capabilities that are critical to peacetime and wartime national and global security operations.

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[3] The existing Part 15 measurement procedure uses an average logarithm detector process and is not equivalent to measurements using an RMS detector process.

APPROACH

A two-part approach consisting of both a measurement and an analysis component was adopted for this assessment. NTIA's Institute for Telecommunication Sciences (ITS) measured the interference susceptibility of various GPS receiver architectures to a set of UWB waveforms. Utilizing the measured GPS receiver interference susceptibility levels, analyses were performed by the NTIA Office of Spectrum Management (OSM) for various operational scenarios to determine the maximum allowable UWB EIRP level that can be tolerated by GPS receivers before performance degradation is realized.

Measurement Component

A measurement plan was developed to guide the measurement component of this study. In this plan, the performance criteria to be used to assess a performance degradation to the GPS receivers under measurement were established, a list of candidate GPS receivers to be measured was defined, and the UWB signal structures to be considered were identified. A set of procedures to be used in performing the measurements was also developed. The plan was published in the Federal Register and public comment was solicited. Comments were received from seven parties. Each set of comments was considered and detailed responses provided. When deemed appropriate, the information contained in the received comments was incorporated into the plan.

GPS Receivers Selected for Testing. Since GPS receivers are used in many applications, NTIA decided that rather than attempt to measure across the space of GPS applications, this study would instead attempt to measure across the space of GPS receiver architectures. One receiver from each of three basic GPS receiver architectures was identified for inclusion in the measurements. The receiver architectures represented are: C/A-code tracking receivers (which make up a significant share of the civil GPS receivers in use today), semi-codeless receivers (used in low-dynamic applications requiring high precision), and C/A-code tracking receivers employing multiple, narrowly-spaced correlators to enhance accuracy and mitigate the effects of multipath. These three GPS receiver architectures encompass most, if not all, of the existing GPS applications.[4] In order to address particular concerns related to the aviation use of GPS, a Technical Standard Order (TSO)-C129a compliant aviation receiver (currently used in en-route and non-precision approach applications) was also included as a part of this measurement effort.[5]

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[4] This effort did not consider the potential impact of UWB operations to military GPS receivers.

[5] Due to unanticipated delays in the execution of the measurement component of this study, the measured data for the narrowly-spaced GPS correlator receiver architecture and the TSO-C129a-compliant receiver were not included in this report. This data will be provided as an addendum to this report as it becomes available.

UWB Signals Examined. NTIA identified 32 UWB signal permutations for examination with respect to their interference potential to GPS receivers. These signal permutations were judged to be representative of those expected to be used in UWB applications. For each of four pulse repetition frequencies (PRFs);100 kHz, 1 MHz, 5 MHz, and 20 MHz, eight distinct UWB waveforms were generated by combining four modulation types (constant PRF, On-Off Keying (OOK), 2% relative dither, and 50% absolute dither) and two states of gating (100% and 20%). The PRF defines the number of pulses transmitted per unit time (one second). The PRF governs both the magnitude and spacing of the spectral lines, and the percentage of time that pulses are present. Gating refers to the process of distributing pulses in bursts by employing a programmed set of periods where the UWB transmitter is turned on or off for a period of pulses. For the measurements performed in this study, the gated UWB signal utilized a scheme where a burst of pulses lasting 4 milliseconds (ms) was followed by a 16 ms period when no pulses were transmitted. This is referred to as 20% gating, because the UWB pulses are transmitted 20% of the time. The signal permutations depicted within this report as 100% gating, define a signal where pulses are transmitted 100% of the time. OOK refers to the process of selectively turning off or eliminating individual pulses to represent data bits. Dithering refers to the random or pseudo-random spacing of the pulses. Two forms of dithered UWB signals were considered in this effort. These are an absolute referenced dither, where the pulse period is varied in relation to the absolute clock, and a relative referenced dither, where the pulse spacing is varied relative to the previous pulse. The data collected from these measurements are applicable only to the UWB signal permutations that were considered in this assessment. No attempt should be made to extrapolate this data beyond these particular UWB parameters.

Performance Criteria Used. After researching available technical standards and other open literature, a set of criteria that was not application specific was adopted for assessing the performance of the GPS receivers in this measurement effort. The two performance criteria examined were "break-lock" and "reacquisition." Break-lock refers to the loss of signal lock between the GPS receiver and a GPS satellite. This condition occurs when an interfering signal reduces the carrier-to-noise density (C/N_0) ratio (i.e., an increase in the undesired signal level, N_0, relative to the desired signal level, C) to such an extent that the GPS receiver can no longer adequately determine the pseudorange (the initial/uncorrected measure of distance from a single GPS satellite to a receiver) for the given satellite signal.

The reacquisition threshold is defined as the UWB power level that results in an abrupt increase in reacquisition time. To determine the impact on reacquisition time, the signal from the GPS satellite of interest was interrupted and a 50-meter step in pseudorange was introduced over a 10-second period. This was done to simulate a GPS-equipped vehicle passing behind a building or other obstacle in the satellite-to-receiver path, causing a temporary loss-of-lock between the GPS receiver and the satellite of interest. As the vehicle clears the obstacle and again becomes visible, the GPS receiver must be able to reacquire the lost satellite signal in the presence of UWB energy in a time consistent with that associated with no UWB energy present.

Measurements Performed. ITS performed closed system (conducted) measurements to assess the potential impact to each of the GPS receivers from both a single UWB transmitter (one-on-one) interaction from a multiple UWB transmitter (aggregate) interaction. To examine the applicability of the conducted measurements, the effects of the GPS antenna on the radiated signals within the frequency band of interest were measured. Measurements were performed wherein the UWB signal was radiated and received within an anechoic chamber to prevent outside interference sources from affecting the results. Amplitude probability distribution (APD) measurements were also performed for each of the UWB signal permutations considered in this effort, to aid in classifying the UWB signals. The complete measurement data set is presented in a separate report published by ITS.

Analysis Component

The data collected from the measurements were used in a subsequent analysis effort performed by the NTIA OSM to calculate the maximum allowable EIRP that can be emitted from a UWB transmitter without exceeding the measured interference susceptibility level. A source-path-receiver analysis was performed to calculate these maximum allowable EIRP levels for both a single UWB transmitter-to-GPS receiver interaction and for the case of an aggregate of UWB transmitters-to-GPS receiver interaction. In performing these analyses, related parameters were determined from operational scenarios, which define the conditions under which proposed UWB devices may be in proximity to GPS receivers in operational applications. These operational scenarios were developed in open, public meetings with participation from UWB and GPS manufacturers and users. The specific proposals for operational scenarios to be considered in the NTIA study included GPS receivers used in the following applications: terrestrial[6] (e.g., public safety applications such as cellular phone embedded E-911 and emergency response vehicle navigation, geographic information systems, precision machine control, and general operations), maritime navigation (in constricted waterways, harbors, docking, and lock operations); railway operations (positive train control), surveying, and aviation (en-route navigation and non-precision approach). These scenarios do not represent all possible applications of GPS, however, they do represent a reasonable bound on the parameters necessary to perform the broadly based analyses. For example, the separation distances represented in these scenarios range from a minimum of 2 meters for the embedded E-911 scenario, to a maximum of approximately 300 meters (1000 feet) for the en-route aviation scenario.

RESULTS

This report documents the results of the measurement and analysis program conducted by NTIA. Policy recommendations and/or guidance with respect to proposed UWB operations are not included within the scope of this effort. The following paragraphs discuss the findings of this program.

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[6] Within the context of this report, terrestrial refers to land-based operations.

Measurement Results

The results from the measurement component of this study indicate that both the C/A-code tracking GPS receiver and the semi-codeless GPS receiver demonstrate a tolerance to all of the UWB signal permutations examined with a PRF of 100 kHz. For the scenarios considered in this assessment, aggregate effects were deemed not to be a concern with respect to those UWB waveforms with a PRF of 100 kHz. When the PRF was increased to 1 MHz, the C/A-code receiver began to show continuous wave (CW)-like interference susceptibility to the unmodulated UWB signal permutations at low power levels. When the PRF was increased to 5 MHz and then to 20 MHz, CW-like interference effects to the C/A-code receiver were observed to be more prevalent.

The measurements also show that dithering of the UWB pulses in the time domain, using the techniques considered in this assessment, can be effective in spreading the spectral lines in the frequency domain, making the effective signal appear more noise-like. The GPS C/A-code receiver showed approximately 10 dB less sensitivity to these noise-like UWB signals as compared to those UWB signals deemed as CW-like. For PRFs of 1 MHz, 5 MHz, and 20 MHz, some of the UWB waveforms caused an effect similar to low duty cycle pulsed interference, to which the GPS C/A-code receiver is relatively tolerant. However, the multiple-entry (aggregate) measurements indicate that this advantage is lost when a multiple of as few as three of these UWB signals with equivalent power levels at the GPS receiver input are considered in aggregation. The aggregate measurements also verify that when multiple noise-like UWB signals are considered with equivalent power levels at the GPS receiver input, the effective aggregate signal level in the receiver intermediate frequency (IF) bandwidth is determined by adding the average power of each of the UWB signals.

The measured performance thresholds for the C/A-code GPS receiver were compared with the interference protection criteria documented within the RTCA and the ITU-R. The results of this comparison indicate agreement between the performance thresholds measured as a part of this study and the protection criteria documented in the national and international standards.

The semi-codeless receiver measured in this assessment showed a susceptibility similar to what would be expected from noise-like interference for all of the UWB signal permutations employing PRFs of 1, 5, and 20 MHz. The semi-codeless GPS receiver was also observed to be more susceptible than the C/A-code receiver to noise-like interference.

A comparison between the radiated and conducted path measurements of the APD and the analyses of the magnitude distortion and the variations in the group delay indicate that the GPS antenna gain in the direction of the interference source is the only parameter that needs to be considered in the source-path-receiver analyses. The GPS antenna does not offer any additional mitigating effects to the portion of the UWB signal within the GPS operating band.

The measurements performed in this study assumed GPS operation in the tracking mode of operation (i.e., the GPS receiver was allowed to acquire the satellites necessary to obtain a navigation solution before UWB interference was introduced). The initial (cold-start) acquisition mode of GPS receiver operation is known to be more sensitive to interference than the tracking mode. However, measurements of GPS receiver susceptibility to interference when operating in the cold-start acquisition mode are difficult to perform. Within RTCA and International Telecommunication Union-Radiocommunication Sector (ITU-R) working groups, the initial acquisition mode of operation is accounted for by reducing the tracking mode interference protection levels by 6 dB. This factor was not considered in the analyses performed as a part of this study.

Analysis Results

In the analysis component of this study, NTIA determined the maximum allowable EIRP level for the different UWB signal permutations, using the operational scenarios proposed in the public meetings. The results of the analysis are summarized in Tables 1 through 4. Each table corresponds to a UWB PRF examined in the analysis. The tables provide a description of the: operational scenario; UWB signal characteristics; GPS receiver architecture; interfering signal classification; interference threshold; and the computed values of maximum allowable EIRP. The values of maximum allowable EIRP shown in the Tables 1 through 4 are for a single UWB device interaction, and they represent the highest EIRP at which UWB devices can operate without exceeding the measured performance threshold of the GPS receiver architecture under consideration for the conditions specified by the operational scenarios.

Tables 1 through 4 also include a comparison of the computed maximum allowable EIRP level with the current Part 15 level of -71.3 dBW/MHz. When the interference effects are classified as pulse-like or noise-like, the maximum allowable EIRP level can be directly compared to the current Part 15 level. When the interference effect is classified as CW-like, the maximum allowable EIRP level can be directly compared to the Part 15 level, only if it is assumed that there is a single spectral line in the measurement bandwidth. For those entries where the difference between the current Part 15 level and the computed maximum allowable EIRP level is shown as negative, no additional attenuation below the current Part 15 level is necessary. For those entries where the difference is shown as positive, the value specifies the additional attenuation below the current Part 15 level that is necessary to satisfy the measured performance threshold of the GPS receiver architecture under consideration.

Table 1. Summary of Analysis Results (PRF = 100 kHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold (dBW/MHz)	Maximum Allowable EIRP (dBW/MHz)	Comparison with the Current Part 15 Level (dB)
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-73.2	1.9
Terrestrial		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-57.6	-13.7
Terrestrial		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-62.3	-9
Maritime		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-41.7	-29.6
Maritime		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-48.1	-23.2
Railway		X	X		0.1	100	None	C/A-code	Pulse-Like	-112.6	-56.3	-15
Railway		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-57.8	-13.5
Surveying	X			X	0.1	20	2% Rel.	Semi-Codeless	Noise-Like	-138	-81.1	9.8
Surveying		X		X	0.1	20	2% Rel.	Semi-Codeless	Noise-Like	-138	-81.2	9.9
Aviation-NPA		X		X	0.1	100	None	C/A-code	Pulse-Like	-112.6	-52.9	-18.4
Aviation-ER		X	X		Note 1	Note 1	Note 1	C/A-code	Noise-Like	-134.8	-76.6[2]	5.3
Aviation-ER		X		X	Note 1	Note 1	Note 1	C/A-code	Noise-Like	-134.8	-85.6[2]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)
1. In this operational scenario, it is assumed that there is a large enough number of UWB devices such that independent of the individual UWB signal parameters, the aggregate effect causes noise-like interference.
2. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously .

Table 2. Summary of Analysis Results (PRF = 1 MHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	1	100	None	C/A-code	CW-Like	-143.7	-104.3	33
Terrestrial	X			X	1	100	2% Rel.	C/A-code	Pulse-Like	-131	-91.6	20.3
Terrestrial		X	X		1	100	None	C/A-code	CW-Like	-143.7	-88.7	17.4
Terrestrial		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-85.5	14.2
Terrestrial		X		X	1	100	None	C/A-code	CW-Like	-143.7	-93.4	22.1
Terrestrial		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-90.2	18.9
Maritime		X	X		1	100	None	C/A-code	CW-Like	-143.7	-72.8	1.5
Maritime		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-69.6	-1.7
Maritime		X		X	1	100	None	C/A-code	CW-Like	-143.7	-79.2	7.9
Maritime		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-76	4.7
Railway		X	X		1	100	None	C/A-code	CW-Like	-143.7	-87.4	16.1
Railway		X	X		1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-83.0	11.7
Railway		X		X	1	100	None	C/A-code	CW-Like	-143.7	-88.9	17.6
Railway		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-84.5	13.2
Surveying	X			X	1	100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.1	22.8
Surveying		X		X	1	100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.2	22.9
Aviation-NPA		X		X	1	100	None	C/A-code	CW-Like	-143.7	-84	12.7
Aviation-NPA		X		X	1	20 & 100	Multiple	C/A-code	Noise-Like	-134.5	-80.8	9.5
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)

1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously.

Table 3. Summary of Analysis Results (PRF = 5 MHz)

Operational Scenario Description					UWB Signal Characteristics							
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.	GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
Terrestrial	X			X	5	100	None	C/A-code	CW-Like	-145.5	–106.1	34.8
Terrestrial	X			X	5	20	50% Abs.	C/A-code	Pulse-Like	-105	-65.6	-5.7
Terrestrial	X			X	5	100	50% Abs.	C/A-code	Noise-Like	-137	–97.6	26.3
Terrestrial		X	X		5	100	None	C/A-code	CW-Like	-145.5	-90.5	19.2
Terrestrial		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-88	16.7
Terrestrial		X		X	5	100	None	C/A-code	CW-Like	-145.5	-95.2	23.9
Terrestrial		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-92.7	21.4
Maritime		X	X		5	100	None	C/A-code	CW-Like	-145.5	-74.6	3.3
Maritime		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-72.1	0.8
Maritime		X		X	5	100	None	C/A-code	CW-Like	-145.5	-81	9.7
Maritime		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-78.5	7.2
Railway		X	X		5	100	None	C/A-code	CW-Like	-145.5	-89.2	17.9
Railway		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-137	-85.5	14.2
Railway		X		X	5	100	None	C/A-code	CW-Like	-145.5	-90.7	19.4
Railway		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-87.0	15.7
Surveying	X			X	5	20 & 100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.1	22.8
Surveying		X		X	5	20 & 100	50% Abs.	Semi-Codeless	Noise-Like	-151	-94.2	22.9
Aviation-NPA		X		X	5	100	None	C/A-code	CW-Like	-145.5	-85.8	14.5
Aviation-NPA		X		X	5	100	50% Abs.	C/A-code	Noise-Like	-137	-83.3	12
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)

1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously.

Table 4. Summary of Analysis Results (PRF = 20 MHz)

Operational Scenario Description					UWB Signal Characteristics			GPS Receiver Architecture	Classification of Interfering Signal	Maximum Interference Threshold[1]	Maximum Allowable EIRP[1]	Comparison with the Current Part 15 Level (dB)
GPS Application	UWB Single	UWB Multiple	UWB Indoor	UWB Outdoor	PRF (MHz)	Gating %	Mod.					
Terrestrial	X			X	20	20	OOK	C/A-code	CW-Like	-146.3	-106.9	35.6
Terrestrial	X			X	20	20	50% Abs.	C/A-code	Pulse-Like	-135	-95.6	24.3
Terrestrial	X			X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-98.6	27.3
Terrestrial		X	X		20	20	OOK	C/A-code	CW-Like	-146.3	-91.3	20
Terrestrial		X	X		20	100	50% Abs.	C/A-code	Noise-Like	-138	-89	17.7
Terrestrial		X		X	20	20	OOK	C/A-code	CW-Like	-146.3	-96	24.7
Terrestrial		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-93.7	22.4
Maritime		X	X		20	20	OOK	C/A-code	CW-Like	-145	-75.4	4.1
Maritime		X	X		5	100	50% Abs.	C/A-code	Noise-Like	-138	-73.1	1.8
Maritime		X		X	20	20	OOK	C/A-code	CW-Like	-145	-81.8	10.5
Maritime		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-79.5	8.2
Railway		X	X		20	20	OOK	C/A-code	CW-Like	-145	-90	18.7
Railway		X	X		20	100	50% Abs.	C/A-code	Noise-Like	-138	-86.5	15.2
Railway		X		X	20	20	OOK	C/A-code	CW-Like	-145	-91.5	20.2
Railway		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-88.0	16.7
Surveying	X			X	20	100	50% Abs. & 2% Rel.	Semi-Codeless	Noise-Like	-149.5	-92.6	21.3
Surveying		X		X	20	100	50% Abs. & 2% Rel.	Semi-Codeless	Noise-Like	-149.5	-92.7	21.4
Aviation-NPA		X		X	20	20	OOK	C/A-code	CW-Like	-145	-86.6	15.3
Aviation-NPA		X		X	20	100	50% Abs.	C/A-code	Noise-Like	-138	-84.3	13
Aviation-ER		X	X		Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-76.6[3]	5.3
Aviation-ER		X		X	Note 2	Note 2	Note 2	C/A-code	Noise-Like	-134.8	-85.6[3]	14.3

Notes: En-Route Navigation (ER), Non-Precision Approach (NPA)
1. When the interference effect has been classified as pulse-like or noise-like, the value is expressed in units of dBW/MHz. The value is expressed in units of dBW when the interference effect has been classified as CW-like.
2. In this operational scenario, it is assumed that there is a large enough number of UWB devices, such that independent of the individual UWB signal parameters the aggregate effect causes noise-like interference.
3. This maximum allowable EIRP is based on an assumed density of 200 UWB devices per square kilometer transmitting simultaneously.

Certain observations were made based on a review of the last column in Tables 1 through 4. This column shows the difference between the current Part 15 level of -71.3 dBW/MHz (considered as an average power limit) and the computed maximum allowable EIRP levels necessary to achieve EMC with the GPS receivers used in the applications represented by the operational scenarios considered in this study.

An examination of Table 1 (PRF = 100 kHz) reflects the measurement observation that a GPS C/A-code receiver is relatively tolerant to low-duty cycle pulsed interference. For the 100 kHz UWB waveforms, the limiting-case operational scenario involving a C/A-code GPS receiver (i.e., aviation en-route navigation assuming outdoor UWB device operations) indicates that a maximum allowable EIRP level of 14.3 dB below the existing Part 15 level is necessary to satisfy the measured performance threshold of the GPS receiver considered within this scenario. This calculation is based on an assumed density of active UWB devices on the order of 200/km^2. However, if UWB operations with a PRF of 100 kHz are limited only to applications such as ground penetrating and through-the-wall imaging, the actual UWB device density will likely be less than what was assumed in the analysis. For example, if the actual UWB device density for these types of applications is assumed to be on the order of 20/km^2, then the calculated maximum allowable EIRP level will increase by 10 dB. Under these conditions, a maximum allowable EIRP of 4.3 dB below the existing Part 15 level for outdoor UWB operations would satisfy the restrictions imposed by the aviation en-route navigation operational scenario. Since this scenario represents the limiting case for operations using GPS C/A-code receivers, this maximum allowable EIRP level would also apply to the use of GPS C/A-code receivers in the remaining operational scenarios considered as a part of this study.

Table 1 also shows the effect of the 100 kHz PRF UWB waveforms on the surveying operational scenario in which the semi-codeless GPS receiver architecture is used. It is noted that surveyors are not the only users of GPS receiver employing semi-codeless techniques; however, the operational scenario is considered to be fairly representative of other uses of this receiver architecture. As observed from the measurement results, the semi-codeless receiver is more susceptible than the C/A-code receiver to interference that is classified as pulse-like or noise-like. As a result, the analysis indicates that for the surveying operational scenario, the UWB signals examined in this study would require a maximum allowable EIRP that is 10 dB below the current Part 15 level to satisfy the measured performance threshold for the semi-codeless receiver architecture. In summary, when considering the 100 kHz PRF UWB waveforms, a maximum allowable EIRP level on the order of 10.0 to 14.3 dB below the current Part 15 level (depending on the assumed UWB device density associated with likely applications for a 100 kHz PRF) is necessary to satisfy the performance criteria for the GPS receiver architectures associated with the operational scenarios considered in this study.

Tables 2 through 4 (UWB waveforms with PRFs of 1, 5, and 20 MHz) show that the maximum allowable EIRP level necessary to satisfy the measured GPS performance criteria must be less than the current Part 15 level for most of the operational scenarios considered. Those interactions that involve operational scenario/UWB signal parameter combinations that require an attenuation of 20 dB or more below the Part 15 level were selected for closer inspection. This examination indicates that in most of these cases, the interactions involve: 1) UWB waveforms that were deemed CW-like in their interference effect to the GPS C/A-code receiver architecture, for which the measurements indicate a greater interference susceptibility; 2) applications using semi-codeless receivers, which were determined from the measurements to be more susceptible to UWB waveforms classified as noise-like or pulse-like interference; or 3) operational scenarios in which the UWB transmitter is considered to be operating at a close distance (within several meters) relative to the GPS receiver. This data suggests that if the spectral line content of the UWB waveforms could be removed from consideration, perhaps through regulation, there still remains a number of interactions involving noise-like UWB waveforms at these PRFs for which the EIRP levels would have to be attenuated to levels up to 27 dB below the current Part 15 level.

As shown in Tables 1 through 4, the results of the analysis indicates that the maximum allowable EIRP necessary to satisfy the measured performance thresholds of the GPS receivers considered in this study is very dependent on the UWB signal structure. This is consistent with the findings of the measurement effort where the performance of the GPS receivers tested was also observed to be dependent on the UWB signal structure. Figures 1 through 4 display computed maximum allowable EIRP levels for those UWB signal permutations that were classified within this study as pulse-like, noise-like, and CW-like with respect to their interference effects on the GPS C/A-code receiver. The values reported in these charts represent the values of the maximum allowable EIRP level determined from an analysis of each UWB signal permutation in potential interactions with the GPS C/A-code receiver that were defined by all of the operational scenarios considered in the study.

For the operational scenarios that considered multiple UWB devices, Figure 1 displays the range of maximum allowable EIRP for the UWB signal structures that were classified within this study as pulse-like. Figure 3 presents the range of maximum allowable EIRP levels for those UWB waveforms that were classified as noise-like when considered in the analysis based on the operational scenarios. Figure 4 presents the range of maximum allowable EIRP levels for those UWB signals that were classified as CW-like in their effects on the GPS C/A-code receiver examined in this study. The labels on the y-axis in Figures 1 through 4 identify the various UWB signal structures in terms of PRF, percent gating, and type of modulation. For example, a UWB signal structure with a PRF of 100 kHz, 100% gating, and no modulation will have a y-axis label of: 100 kHz, 100%, None.

Figure 2 shows those pulse-like interference cases for which a range of EIRP values was not determined in the analysis. These cases involve UWB parameters that cause pulse-like interference in the operational scenarios that consider a single UWB device, but result in noise-like interference in the operational scenarios that consider multiple UWB devices. For the C/A code receiver architecture, there was only one scenario considered in the analysis (Single UWB Device Terrestrial Operational Scenario) that involved a single UWB device. Thus only a single EIRP value is shown in Figure 2.

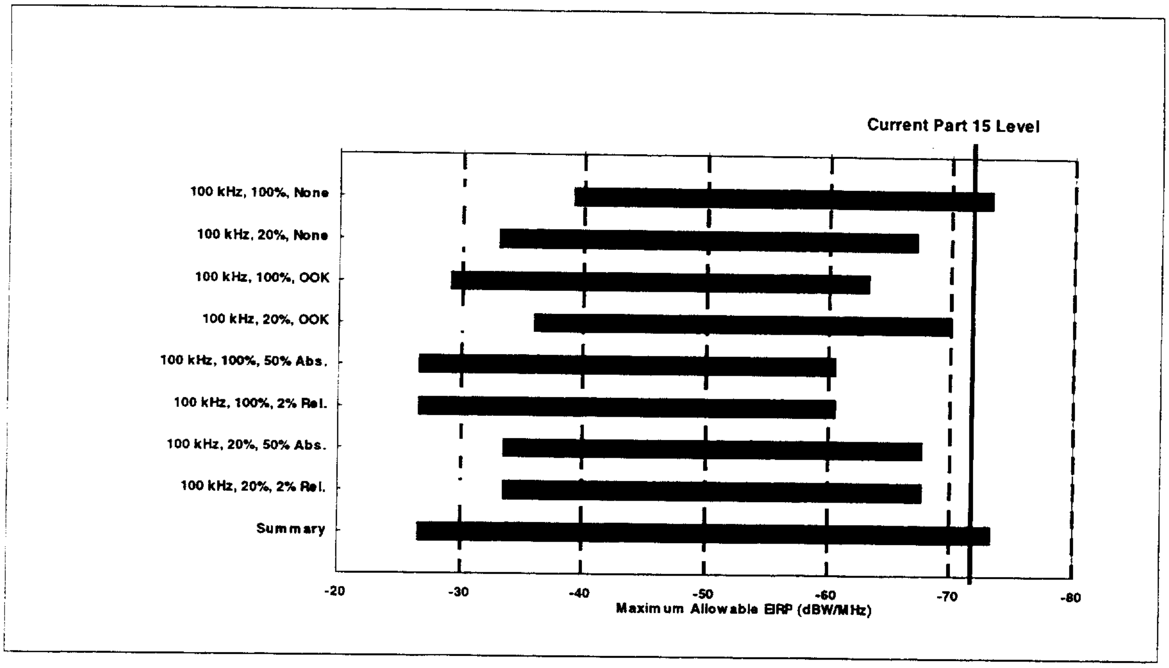

Figure 1. Range of Maximum Allowable EIRP for Pulse-Like UWB Signal Structures for the C/A-Code Receiver Architecture (Multiple UWB Device Operational Scenario)

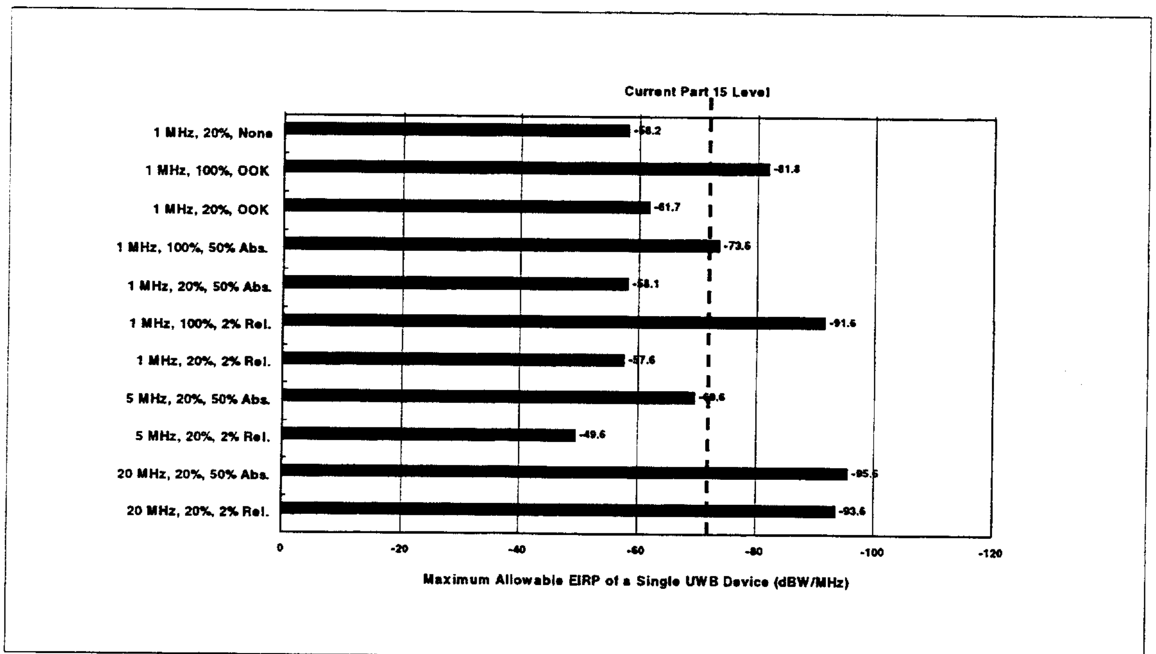

Figure 2. Maximum Allowable EIRP for Pulse-Like UWB Signal Structures for the C/A-Code Receiver Architecture (Single UWB Device Operational Scenario)

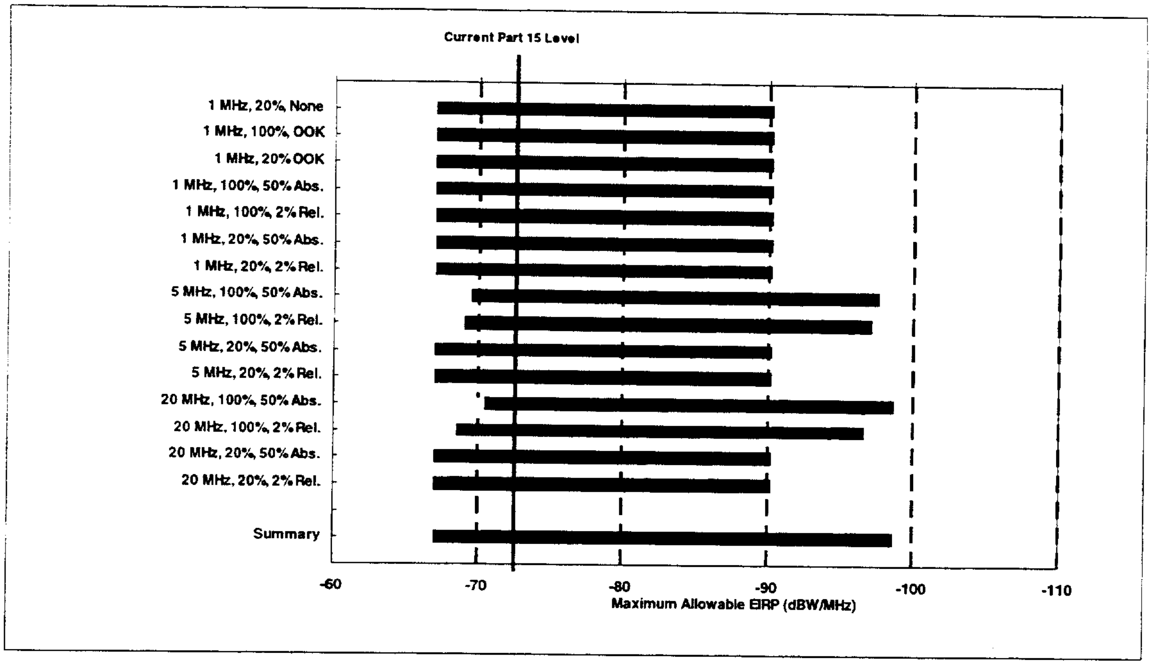

Figure 3. Range of Maximum Allowable EIRP for Noise-Like UWB Signal Structures for the C/A-Code Receiver Architecture (Multiple UWB Device Operational Scenario)

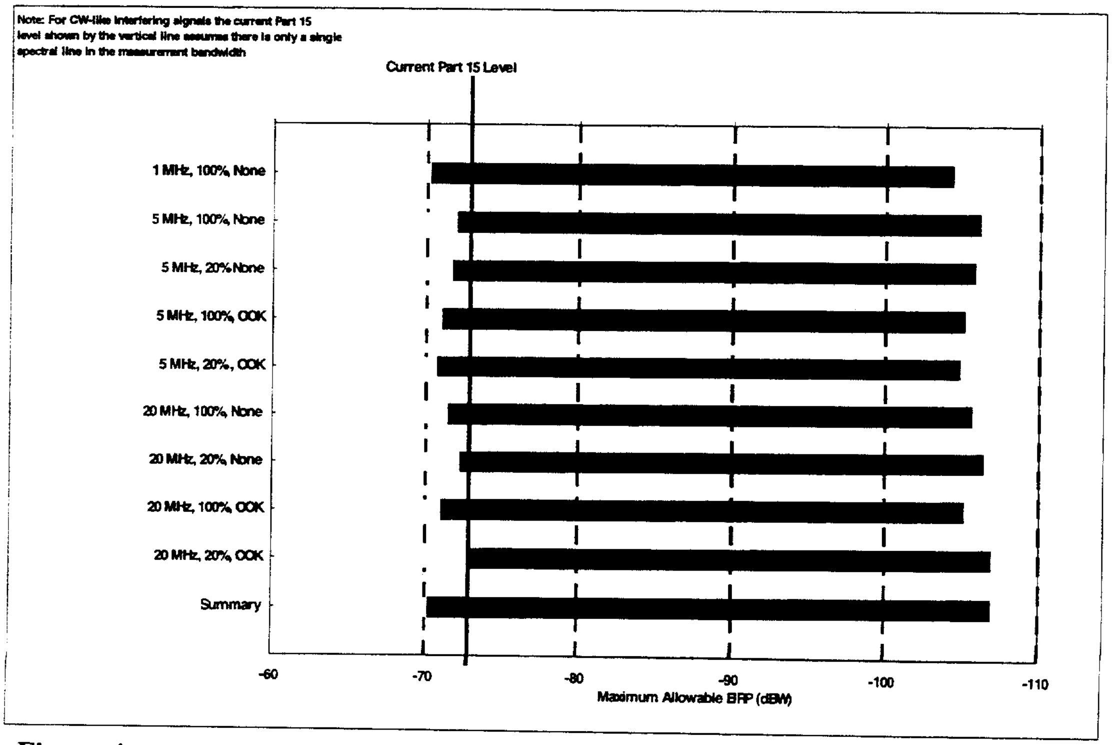

Figure 4. Range of Maximum Allowable EIRP for CW-Like UWB Signal Structures for the C/A-Code Receiver Architecture (Multiple UWB Device Operational Scenario)

An examination of Figures 1 through 4 indicates that the maximum allowable EIRP levels required to satisfy the measured performance threshold of the GPS C/A-code receiver, across all of the operational scenarios, is a function of the PRF of the UWB signal. Figure 1 shows the maximum allowable EIRP levels corresponding to those UWB signal permutations with a PRF of 100 kHz. The EIRP level shown in this figure for the unmodulated, 100% gated UWB waveform was computed based on a measured break-lock threshold. For the remaining UWB signal permutations represented in the figure, neither a break-lock nor a reacquisition threshold could be measured for UWB power levels up to the maximum power available from the UWB signal generator. For these cases, the maximum UWB signal generator power level was used to compute the EIRP level. Thus, the reported EIRP level represents a lower limit for these cases. That is, the actual maximum allowable EIRP level may be higher than the level shown in the figure for these 100 kHz PRF UWB waveforms. From Figure 1, it can be observed that the maximum EIRP levels necessary to satisfy the measured performance threshold for the C/A-code GPS receiver over all of the operational scenarios considered in this study range from -73.2 to -26.5 dBW/MHz.

Figure 3 shows that the maximum allowable EIRP levels necessary to satisfy the measured performance thresholds over all of the operational scenarios considered in this study range from -98.6 to -67.0 dBW/MHz for those UWB signals employing PRFs of 1 MHz, 5 MHz, and 20 MHz, that are classified as noise-like in their interference effects to the GPS C/A-code receiver.

The data presented in Figure 4 shows that the maximum allowable EIRP levels range from -106.9 to -70.2 dBW over all of the operational scenarios considered for those UWB signals that are classified as CW-like in their interference effects on the GPS C/A-code receiver. These EIRP levels are based on the power in a single spectral line and in order to compare to the Part 15 level, it must be assumed that only a single spectral line appears in the measurement bandwidth.

Figures 5 and 6 present summary plots showing the maximum allowable EIRP calculated for the surveying operational scenarios assuming the use of the semi-codeless receiver architecture measured in this study. The analysis results are presented as a function of the various UWB signal structures examined. For the semi-codeless receiver architecture, the interference effects of all of the UWB signals examined are classified as either pulse-like or noise-like. Figure 5 shows that for those UWB signals examined with a PRF of 100 kHz, the calculated maximum allowable EIRP is above the current Part 15 emission level (i.e., no additional attenuation is necessary) with one exception: the 20% gated, 2% relative dithered signal.

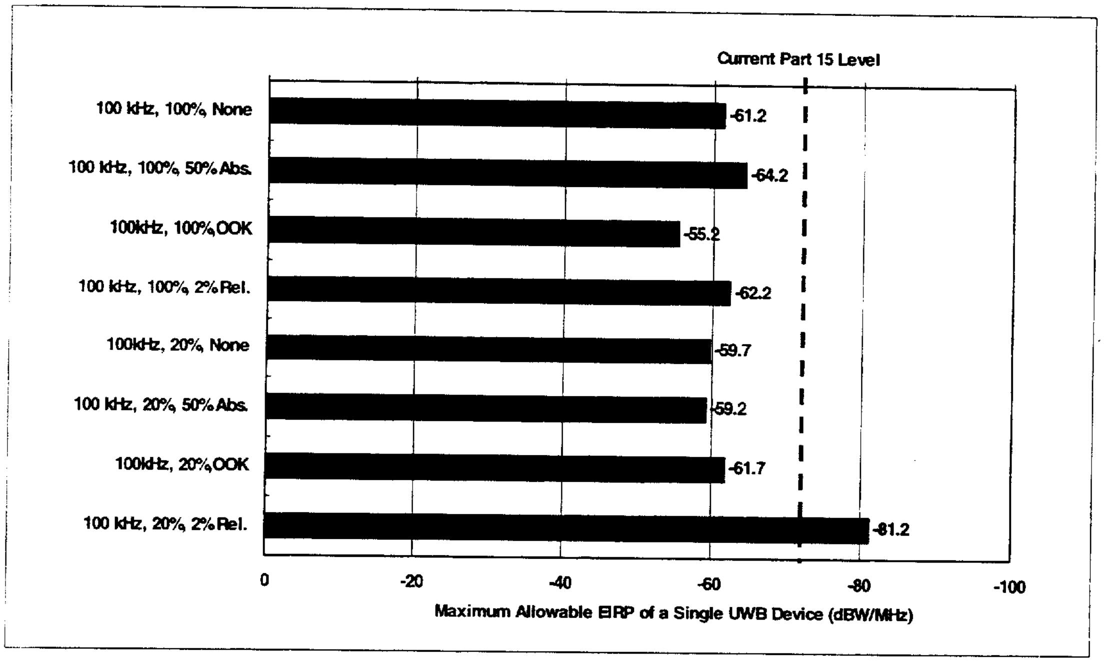

Figure 5. Maximum Allowable EIRP as a Function of UWB Signal Structure for the Semi-Codeless Receiver Architecture (Pulse-Like UWB Signals)

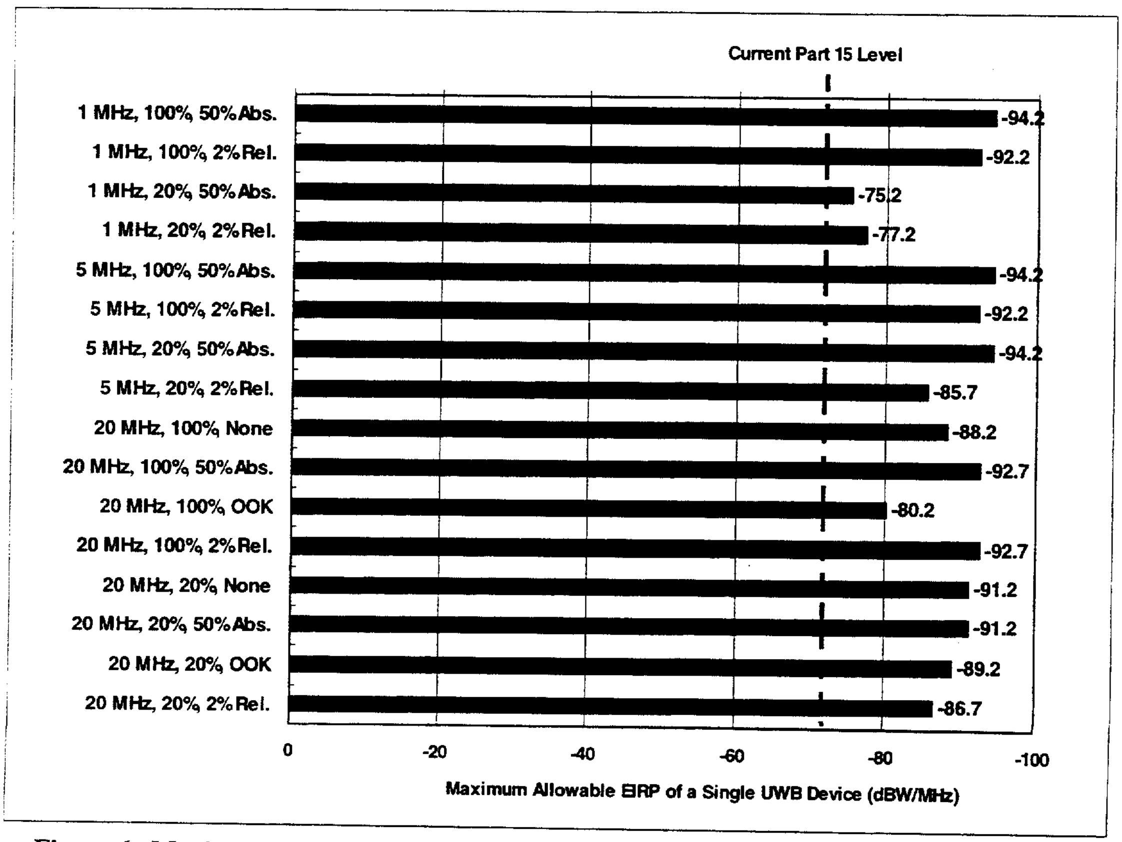

Figure 6. Maximum Allowable EIRP as a Function of UWB Signal Structure for the Semi-Codeless Receiver Architecture (Noise-Like UWB Signals)

Figure 6 shows that for the PRFs of 1 MHz, 5 MHz, and 20 MHz, those UWB signal structures that were classified as noise-like, the maximum allowable EIRP level must be as much as 23 dB below the current Part 15 level to satisfy the measured performance threshold of the semi-codeless GPS receiver in the applicable operational scenarios. The measurements of the semi-codeless receiver indicated a relative immunity to CW-like interference effects. This is because the semi-codeless receiver architecture uses the P-code signal which, because of its longer code length, has essentially no spectral lines.

CONCLUSIONS

The data collected in this assessment demonstrates that when considered in potential interactions with GPS receivers used in applications represented by the operational scenarios considered in this study, some of the UWB signal permutations examined exceeded the measured GPS performance thresholds at EIRP levels well below the current Part 15 emission level. Likewise, other UWB signal permutations (e.g., the 100 kHz PRF UWB signals) only slightly exceeded, and in some cases did not exceed, the measured GPS performance thresholds when considered in potential interactions with GPS receivers defined by the operational scenarios considered as a part of this study.

The following general conclusions were drawn based on the findings of this study:

1) The GPS receiver performance thresholds measured within this study are consistent with the interference protection limits developed within national and international GPS study groups.

2) When multiple noise-like UWB signals with equivalent power levels at the GPS receiver input are considered, the effective aggregate signal level in the receiver IF bandwidth is determined by adding the average power of each of the UWB signals.

3) Within the limitations of this study (i.e., the available number of UWB signal generators), it was found that when multiple CW-like UWB signals are considered, the effective aggregate interference effect to a C/A-code GPS receiver is the same as that of a single CW-like signal. The interference mechanism is a result of the alignment of a UWB spectral line with a GPS C/A-code line.

4) The CW-like interference effect is not applicable to the semi-codeless receiver examined when operating in the dual frequency mode.

5) A GPS antenna does not offer any additional attenuation to that portion of a UWB signal within the GPS frequency band.

6) For those UWB signals examined with a PRF of 100 kHz, maximum permissible EIRP levels between -73.2 and -26.5 dBW/MHz are necessary to ensure EMC with the GPS applications defined by the operational scenarios considered within this study.

7) For those UWB signals examined with a PRF of 1 MHz, the maximum allowable EIRP levels necessary to achieve EMC with the GPS receiver applications considered in this study range from -70.2 to -104.3 dBW for the CW-like (unmodulated) UWB waveforms, and -57.6 to -91.6 dBW/MHz for the noise-like (modulated and/or dithered) UWB waveforms.

8) For those UWB signals examined with a PRF of 5 MHz, the maximum allowable EIRP levels necessary to ensure EMC with the GPS receiver applications considered in this study range from -70.7 to -106.1 dBW for the CW-like (non-dithered) UWB waveforms, and from -49.6 to -97.6 dBW/MHz for the noise-like (dithered) UWB waveforms.

9) For those UWB signals examined with a PRF of 20 MHz, the maximum allowable EIRP levels required to ensure EMC with all of the GPS receiver applications considered in this study range from -71.0 to -106.9 dBW for the CW-like (non-dithered) UWB waveforms, and from -60.0 to -98.6 dBW/MHz for the noise-like (dithered) UWB waveforms.

It must be noted that these results are applicable only to those UWB signal permutations examined within this study and to those applications of GPS that are defined by the operational scenarios presented for consideration herein.

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