Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules	)	ET Docket No. 98-153
Regarding Ultra-Wideband Transmission	)	
Systems	)	
	)	

COMMENTS OF THE NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

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EXECUTIVE SUMMARY

The National Telecommunications and Information Administration (NTIA) supports the Federal Communications Commission (Commission) in its efforts to continue evaluating the rules for ultrawideband (UWB) transmission systems. NTIA believes that the rules adopted by the Commission in the First Report and Order for UWB strike a balance between protecting critical federal systems while permitting UWB technology to evolve. NTIA also agrees with the Commission that significant changes to the rules should not be considered until more experience has been gained with UWB technology.

In the Further Notice of Proposed Rulemaking (FNPRM) in this proceeding, the Commission is proposing additional rules to address issues regarding the operation of low pulse repetition frequency (PRF) UWB transmission systems, including vehicular radars in the 3.1-10.6 GHz frequency range; the operation of frequency hopping vehicular radars in the 22-29 GHz frequency range as UWB devices; the establishment of new peak power limits for wideband Part 15 devices that do not operate as UWB devices; and the definition of a UWB device. NTIA offers the following comments in response to specific issues raised in the FNPRM for UWB transmission systems.

NTIA believes that if the Commission adopts the hand-held UWB device emission limits for expanded outdoor device applications, no restrictions on the PRF are necessary. NTIA agrees with the Commission that this proposal should be limited to UWB systems that employ impulse modulation or high speed chipping rates with a fractional bandwidth equal to or greater than 0.20 or a minimum bandwidth of 500 MHz, as they are currently defined in the Commission's rules. NTIA also believes that if the hand-held emission limits are adopted, there is no technical reason to further limit UWB device applications, as long as the Commission retains the current restrictions forbidding the use of a fixed outdoor infrastructure and the operation of UWB devices in toys.

NTIA supports the Commission's goal of clarifying its guidance set forth at 47 C.F.R. §15.35(b) for properly measuring the emission limits established to ensure compatible operation of Part 15 transmission systems. However, NTIA believes that additional changes to the text are necessary to clarify the existing requirements of the Commission's rules to standardize the compliance measurements and to ensure predictability and certainty for applicants seeking to certify Part 15 devices.

Analyses performed by NTIA indicates that the distance separation required for compatible operation between federal systems and narrowband Part 15 devices meeting the proposed peak power definition (e.g., measured in a 1 MHz bandwidth) are greater than those for narrowband Part 15 devices meeting the current definition, which is based on the total peak power of the signal. The analysis did take into account a few variations of receiver signal processing, which is difficult to quantify and is strongly dependent on the characteristics (pulse width, PRF, duty cycle) of the pulsed interfering signal. In general, there are numerous signal processing features of receivers that can be expected to help suppress low duty cycle pulsed interference, especially from a few isolated sources. A pulsed duty cycle, as determined in the victim receiver bandwidth, that is less than 1% and is asynchronous with the desired signal is not expected to impact receiver performance. Therefore, NTIA believes that defining the peak power in a 1 MHz bandwidth will not adversely affect federal systems, if limits are placed on the allowable duty cycle of the Part 15 device. Since this proposal pertains to the general category of Part 15 devices, adequate measurement procedures would need to be developed to certify compliance with the allowable duty cycles.

NTIA believes that the emission spectrum characteristics of a pulsed frequency hopping (FH) transmitter can vary depending on the following system parameters: pulse width, PRF, frequency hopping bandwidth, frequency hopping pattern, number of frequency hopping channels, hopping channel frequency separation, and the time length of the hopping sequence. NTIA performed measurements to gain further insight into the proper techniques to be used for measuring the emissions of devices employing pulsed FH modulation and to examine the impact that various combinations of the pulsed FH system parameters will have on the compliance measurements. Based on the results of these measurements, NTIA has developed a measurement procedure to be used to demonstrate compliance for 24 GHz vehicular radars employing pulsed FH signals. NTIA has also identified a recommended list of system parameters that should be included for device certification.

An NTIA analysis shows that the interference power level of the pulsed FH signals are comparable to the non-dithered and dithered impulse signals permitted under the Commission's UWB Rules. For the pulsed FH signal characteristics considered, one pulsed FH radar should be no worse, from an interference perspective, than one impulse radar. This analysis is applicable only to assessing the interference impact to an Earth Exploration-Satellite Service sensor because the effective interference signal at a space-borne sensor is an aggregate from a large number of vehicular radars. In addition, this aggregate signal is of concern over an extensive frequency range because the sensors have wide bandwidths of approximately 400 MHz. Thus, the frequency hopping of an individual vehicular radar as a part of an aggregate signal received at a satellite orbit has a different impact than frequency hopping devices would have in other frequency bands where they might operate in close proximity to relatively narrowband ground-based receivers. For ground-based receivers, a single frequency hopping transmitter would be dominant. Thus, setting the effective interference power level in only a relatively narrow frequency range is of primary concern. Therefore, the results of the NTIA analysis cannot be extended to assess the potential interference of a pulsed FH signal on ground-based receivers. Based on the results of the comparative interference analysis, NTIA believes that the operation of pulsed FH vehicular radar systems that comply with the technical standards specified in Section 15.515 of the Commission's Rules is possible. In addition to the technical standards in Section 15.515, the rules must ensure that each hopping channel is used once and only once during the hopping sequence. The same hopping sequence is to be repeated each time.

NTIA believes that technical and economic factors may result in the transition of vehicular radar operations to the 77-81 GHz frequency range. These factors include technology and manufacturing advances in the 77 GHz frequency range and cost reduction from economies of scale achieved through common frequency allocations. NTIA and the Commission should continue to monitor the deployment of vehicular radars in the 24 GHz band, the technology advancements in the 77-81 GHz band, and the development of vehicular radars outside the United States. NTIA will also work with the Commission to ensure that an adequate frequency allocation in the 77-81 GHz band is available for the operation of vehicular radar systems.

NTIA does not support the Commission's proposal to eliminate the minimum bandwidth requirement from the definition of a UWB transmitter nor does there appear to be any public filings in the Docket for this proceeding providing technical support for the change. Such a change could be disruptive to current industry product development and ongoing standards development activities such as those in the Institute of Electrical and Electronics Engineers 802.15 Task Group 3a. NTIA believes that the Commission has established a stable regulatory framework to facilitate the development of a broad range of UWB device technologies, and should allow industry to begin developing products.

Finally, in the Memorandum Opinion and Order, the Commission stated that the wording in 47 C.F.R. §15.521(c) was unclear and made modifications to provide clarification without seeking public comment. The intent of §15.521(c) is to permit emissions from digital circuitry contained within the UWB device to be at a higher level than those specified in SubPart F, as long at it can be clearly demonstrated that those emissions are due solely to the digital circuitry and are not to be radiated from the transmitter antenna. NTIA agrees with the Commission that the language of §15.521(c) required clarification. However, NTIA suggests that further text modifications are necessary in order to achieve the intent of this section of the Commission's rules. NTIA's suggested revisions will ensure predictability and certainty for applicants seeking to certify UWB devices.

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COMMENTS OF THE NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

The National Telecommunications and Information Administration (NTIA), an Executive Branch agency within the Department of Commerce, is the President's principal adviser on domestic and international telecommunications policy, including policies relating to the nation's economic and technological advancement in telecommunications. Accordingly, NTIA makes recommendations regarding telecommunications policies and presents Executive Branch views on telecommunications matters to the Congress, the Federal Communications Commission (Commission), and the public. NTIA, through the Office of Spectrum Management, is also responsible for managing the Federal Government's use of the radio frequency spectrum. NTIA respectfully submits the following comments in response to the Commission's Memorandum Opinion and Order and Further Notice of Proposed Rulemaking in the above-captioned proceeding.[1]

I. BACKGROUND

In the MO&O, the Commission amended Part 15 of its rules regarding the unlicensed operation of ultrawideband (UWB) transmission systems. These amendments responded to fourteen petitions for reconsideration that were filed in response to the First Report and Order

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[1] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, Memorandum Opinion and Order and Further Notice of Proposed Rulemaking, ET Docket No. 98-153, (released March 12, 2003) ("MO&O/FNPRM").

(R&O) in this proceeding.[2] Based on these petitions, the Commission, in the MO&O amended the rules to facilitate the operation of through-wall imaging systems used by law enforcement, emergency rescue and fire fighter personnel in emergency situations; eliminated the requirement that the -10 dB bandwidth for ground penetrating radar (GPR) systems and wall imaging systems be located below 960 MHz or above 3.1 GHz; clarified the limitations on which parties may operate GPR systems and for what purposes; eliminated the requirement for non-hand-held GPR systems to employ a "dead man" switch; clarified the coordination requirements for imaging systems; and clarified the rules regarding emissions produced by digital circuitry used by UWB transmitters.[3]

The Commission as part of the FNPRM in this proceeding now proposes additional rules to address issues raised by petitioners regarding the operation of low pulse repetition frequency (PRF) UWB transmission systems, including vehicular radars in the 3.1-10.6 GHz frequency range; the operation of frequency hopping vehicular radars in the 22-29 GHz frequency range as UWB devices; the establishment on new peak power limits for wideband Part 15 devices that do not operate as UWB devices; and the definition of a UWB device.[4]

NTIA supports the Commission in its efforts to continue evaluating the rules for UWB transmission systems. NTIA believes that the rules adopted by the Commission in the First R&O strike a balance between protecting critical federal systems and allowing UWB technology to evolve. NTIA also agrees with the Commission that significant changes to the rules should not be considered until more experience has been gained with UWB technology. NTIA offers the following comments in response to specific issues raised in the FNPRM for UWB transmission systems.

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[2] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, First Report and Order, ET Docket No. 98-153, 17 FCC Rcd 7435 (2002). *Erratum* in ET Docket 98-153, 17 FCC Rcd 10505 (2002).

[3] MO&O/FNPRM at ¶ 2.

[4] *Id.* at ¶ 153.

II. RESTRICTIONS ON PULSE REPETITION FREQUENCY OR DEVICE APPLICATION ARE NOT NECESSARY IF THE COMMISSION ADOPTS THE EMISSION LIMITS FOR HAND-HELD UWB DEVICES FOR EXPANDED OUTDOOR USE.

The Commission proposes to amend the UWB rules to permit any product under the UWB standards currently designated for hand-held devices as long as the PRF does not exceed 200 kHz and pulsed or impulse modulation is employed.[5] The Commission requests comment on whether a different PRF limit should be employed, if any other changes to the standard, including changes to the emission limits, are necessary to incorporate this addition to the type of UWB devices permitted to operate outdoors, or if the addition to the operation of outdoor UWB devices should be expanded only to include low PRF vehicular radar systems.[6]

The Commission's proposal to establish a PRF limit for UWB device operation is based on the measurements of interference to Global Positioning System (GPS) receivers. The measurements performed by NTIA and the Department of Transportation showed that GPS receivers could tolerate higher signal levels from impulsive signals operating with a PRF of 100 kHz, than from impulsive signals with higher PRFs.[7] In the NTIA measurement program, the 100 kHz PRF UWB signal caused a pulse-like interference effect in the GPS receiver. The pulse-like interference category is primarily a result of the bandlimiting filter in the GPS receiver. The bandwidth of the impulse UWB signal is typically several orders of magnitude wider than the bandlimiting filters in the GPS receiver. Thus, the pulse shape and bandwidth of the bandlimited pulse corresponds to the impulse response of the GPS receiver filter. Pulses are independent (resolved) when the filter bandwidth is greater than the pulse repetition rate. Pulses

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[5] MO&O/FNPRM at ¶ 155.

[6] *Id*.

[7] NTIA Special Publication 01-45, *Assessment of Compatibility Between Ultrawideband (UWB) Systems and Global Positioning System (GPS) Receivers*, National Telecommunications and Information Administration (February 2001) ("NTIA Special Publication 01-45").

that were independent and resolved without dithering can overlap when dithering is introduced.[8] To remain resolved, the pulse repetition period must be greater than the sum of the duration of the filter impulse response and the maximum dither time. The bandlimited pulse will saturate one or more elements in the receiver during the pulse period, if it is resolved and it is of sufficient amplitude. This will result in "holes" in the received GPS signal. If these "holes" are relatively short and of a relatively low duty cycle, they will not seriously degrade GPS receiver performance.[9] An increase in the amplitude of the pulse will not significantly increase the width of the "holes" and thus the interference effect is somewhat independent of UWB signal strength. These interference effects are consistent with the documented GPS interference limits for pulsed interference.[10] NTIA did not develop relationships between PRF and maximum allowable interference power levels for the other federal systems analyzed in its assessment of UWB technology. Therefore, it is not possible to use the NTIA measurements to determine the potential impact on federal systems for establishing a PRF limit of 200 kHz.

The Commission's proposal would require that the UWB device meet the average and peak equivalent isotropically radiated power (EIRP) limits established for hand-held devices that are permitted to operate outdoors.[11] Based on the analyses performed by NTIA, the emission limits for hand-held UWB devices are adequate to protect federal systems from interference independent of the PRF or device application.[12] Therefore, NTIA believes that if the

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[8] Dithering refers to the random or pseudo-random spacing of the pulses. Dithering of the pulses in the time domain spreads spectral line content of a UWB signal in the frequency domain making the signal appear more noise-like.

[9] The duty cycle of a pulsed electronic device is the ratio of the average pulse duration to the average pulse spacing. This is numerically equivalent to the ratio of the average power to peak pulse power, and also to the product of the average pulse duration and the pulse repetition rate. Duty cycle is usually expressed in percent.

[10] Document RTCA/ DO-229B, *Minimum Operational Performance Standards for GPS/Wide Area Augmentation System Airborne Equipment* (January 1996) at 38.

[11] The average power is based on root-mean-square voltage. The limits for outdoor hand-held devices appear at 47 C.F.R. § 15.519.

[12] NTIA Special Publication 01-45; NTIA Special Publication 01-43 *Assessment of Compatibility Between Ultrawideband Devices and Selected Federal Systems*, National Telecommunications and Information Administration (January 2001) ("NTIA Special Publication 01-43").

Commission adopts the hand-held UWB device emission limits for expanded outdoor device applications, no restrictions on the PRF are necessary. NTIA agrees with the Commission that this proposal should be limited to UWB devices that employ impulse modulation or high-speed chipping rates as currently permitted under the Commission's rules.[13] If the Commission adopts the UWB hand-held emission limits there is no technical reason to limit further the UWB device applications, as long as the Commission retains the current restrictions on fixed outdoor infrastructures and use in toys.[14]

III. MODIFICATIONS TO THE COMMISSION'S PROPOSAL TO AMEND SECTION 15.35(b) ARE NECESSARY TO STANDARDIZE THE COMPLIANCE MEASUREMENT PROCEDURES FOR PART 15 DEVICES.

The Commission proposes to amend 47 C.F.R. § 15.35(b) to clarify the text for the existing requirements and to provide an alternative standard for wideband Part 15 transmission systems.[15] The Commission's proposal addresses the measurement bandwidths and detector functions used in the compliance measurements of Part 15 transmission systems.

NTIA supports the Commission's goal of clarifying the language in §15.35(b). This section provides guidance for properly measuring the emission limits established to ensure compatible operation of Part 15 transmission systems. However, NTIA believes that additional changes to the proposed text are necessary and specifically recommends the following modifications to the Commission's proposal:

> (b) Unless otherwise specified on any frequency or frequencies above 1000 MHz, the radiated emission limits are based on the use of ~~the~~ measurement instrumentation employing a~~n~~ ~~average~~ root-mean-square detector function to measure average power. Unless otherwise specified, the average power measurements above 1000 MHz shall be performed using a ~~minimum~~ RBW of 1 MHz. When the average radiated ~~emission~~

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[13] The transmitter would have a fractional bandwidth equal to or greater than 0.20 or would have a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth.

[14] 47 C.F.R. §§ 15.519(a)(2) and 15.521(a).

[15] MO&O/FNPRM at ¶ 164.

> power measurements are specified in this part, including emission measurements below 1000 MHz, there also is a limit on the peak radio frequency emissions. UWB devices operating under Subpart F of this part shall comply with the peak limits specified in that subpart. For all other Part 15 devices subject to limits based on average radiated emissions, the peak level shall comply with one of the following two levels, at the option of the responsible party:
>
> > (1) Unless a different peak limit is specified in the rules, *e.g.*, §15.255 of this chapter, the total peak power shall not exceed by more than 20 dB the average limit permitted at the frequency being investigated. Note that a pulse desensitization correction factor is ~~may be~~ required to measure the total peak emission level if the bandwidth of the signal is greater than the RBW.
> > (2) The peak power shall not exceed an EIRP of -34 ~~20 Log (RBW/50)~~ dBm where ~~RBW is~~ the peak power is measured in a 1 MHz resolution bandwidth. ~~in MHz employed by the measurement instrument. The RBW may not be lower than 1 MHz or greater than 50 MHz. Further, the RBW used in the measurement instrument shall not be greater than one-tenth of the -10 dB bandwidth of the device under test.~~[16]

NTIA believes that these proposed changes are necessary to clarify the existing requirements of the Commission's rules, to standardize the compliance measurements, and to ensure predictability and certainty for applicants seeking to certify Part 15 devices.

IV. THE PROPOSAL TO DEFINE THE PEAK POWER IN A 1 MHZ BANDWIDTH WILL NOT IMPACT COMPATIBILITY WITH WIDEBAND FEDERAL SYSTEMS IF LIMITS ARE PLACED ON THE PART 15 DEVICE DUTY CYCLE.

The Commission requests comment on whether their rules should be amended to permit devices operating above 1000 MHz under the Part 15 general emission standards 47 C.F.R. §15.209 to comply with a peak emission limit of 5000 : V/m at 3 meters based on a measurement using a peak detector, a 1 MHz resolution bandwidth and a video bandwidth of no less than 1 MHz.[17]

Several commenters have stated that from an interference perspective, the full bandwidth peak power is somewhat irrelevant, as it is only the power received within the victim receiver's

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[16] *Id.* (NTIA edits appear in redline/strikeout text).

[17] *Id.* at ¶ 165.

bandwidth that causes interference.[18] The Commission currently requires that a pulse desensitization correction factor (PDCF) be used to determine the total peak power of the signal based on the peak power measured using a spectrum analyzer.[19] NTIA believes that the Commission's proposal to specify the peak power measurement in a 1 MHz resolution bandwidth, instead of specifying the total peak power, will have a greater impact on receivers with bandwidths that are much wider than 1 MHz. For receivers with wider bandwidths, the spectrum analyzer measurement in a 1 MHz resolution bandwidth would underestimate the actual peak power of the signal, possibly increasing the potential for interference. There are also signals that may appear noise-like and follow a 10 Log bandwidth relationship when measured in a 1 MHz receiver bandwidth (e.g., dithered impulse signals). However, when measured using a wider receiver bandwidth, where pulses can be resolved, the signal will appear pulse-like and follow a 20 Log bandwidth relationship.

The impact of the Commission's proposal to specify the peak power in a 1 MHz bandwidth will also depend on the type of signal (*e.g.*, pulsed, noise, continuous wave). For example, noise-like signals will have values of peak-to-average ratio that only range from 10 dB[20] to 14 dB.[21] Pulsed signals on the other hand, can have peak-to-average ratios that vary over a much wider range depending on the duty cycle (e.g., combination of pulse width and PRF).

Measurements and analyses performed by NTIA have shown that the undesired signal level of a pulsed signal at which bit errors start to occur (e.g., interference threshold) in a

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[18] Petition for Reconsideration (Reply Comments), Multispectral Solutions, Inc., ET Docket No. 98-153 (July 29, 2002) at 2; Reply Comments, Preco Electronics Inc., ET Docket No. 98-153 (January 3, 2003) at 2; Written Ex Parte Presentation, Synergent Technologies, ET Docket No. 98-153 (January 12, 2003) at 1.

[19] *Spectrum Analysis of Pulsed RF*, Hewlett Packard Spectrum Analyzer Series, Application Note 150-2 (November 1971).

[20] M. Engelson, *Modern Spectrum Analyzer Measurements* (1991) at 73.

[21] Report No. FAA-RD-72-80 I, *Radio Frequency Emission Characteristics and Measurement Procedures of Incidental Radiation Devices and Industrial, Scientific and Medical Equipment* (September 1972) at 2-38.

digitally modulated signal is based on the peak power of the undesired signal.[22] For example, assuming no bit error correction and a low duty cycle (e.g., 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 an undesired pulsed signal exceeding the interference threshold. Moreover, the relationship of a digital receivers performance degradation is not directly related to the average BER, bursts of errors can have a catastrophic effect on performance degradation. 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 no simple undesired signal-duty cycle relationship. Factors such as 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 can be bounded by placing limits on both the peak and average power levels of the interfering signals.

For UWB transmission systems, the Commission's rules limit the peak power as measured in a 50 MHz resolution bandwidth. Since all of the federal systems analyzed had receiver bandwidths much less than 50 MHz, NTIA's analysis focused on the average power limits and did not address the impact of peak power. However, based on the proposal to measure the peak power in a 1 MHz resolution bandwidth, the impact to federal systems must be addressed. The federal systems considered by NTIA in its assessment of UWB compatibility and their corresponding receiver intermediate frequency (IF) bandwidths measured at the 3 dB point are provided in Table 1. The Federal Aviation Administration (FAA) provided an additional list of systems shown in Table 2, which NTIA did not consider in its assessment of UWB transmission systems. These systems are different versions of the systems previously analyzed by NTIA, therefore, the analysis results and the UWB average power emission limits

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[22] NTIA Special Publication 01-43 at A-21.

established for compatible operation are the same.

As shown in Tables 1 and 2, the following federal systems have receiver bandwidths wider than 1 MHz, and could be impacted by the Commission's proposal to measure the peak power in a 1 MHz resolution bandwidth: ATCRBS (Interrogator); ATCRBS (Transponder); GPS receivers; maritime radionavigation radars; aircraft altimeters; TCAS; Mode-S; ASR-7; and ASR-8. Appendix A provides an analysis of the impact of the Commission's proposal on these federal systems. As discussed in Appendix A, GPS, pulsed radar altimeters, ATCRBS ground-based Interrogator, ATCRBS Transponder, Mode S, and TCAS airborne receivers will not be impacted by the proposal to define the peak power in a 1 MHz bandwidth. For the remaining federal systems, the analysis in Appendix A indicates that the required separation distances that are necessary for compatible operation will be increased if the peak power is defined in a 1 MHz bandwidth compared to the current definition of Part 15 peak power, which is based on the total peak power of the signal. Table 3 provides a summary of the analysis results for the federal systems considered.

TABLE 1.
Federal Systems Considered in NTIA UWB Compatibility Assessment

System (Operating Frequency Range)	Receiver IF Bandwidth (MHz)	Function
Distance Measuring Equipment (DME) Airborne Interrogator (969-1215 MHz)	0.65	Provides civil and military aircraft pilots with distance from a specific ground beacon (transponder) for navigational purposes.
DME Ground Transponder (1025-1150 MHz)	0.8	Ground transponder component which replies to interrogations from the DME airborne component.
Air Traffic Control Radio Beacon System (ATCRBS) Ground Interrogator (1090 MHz)	9	Used in conjunction with the ASR and ARSR radars to provide air traffic controllers with location, altitude and identity of civil and military aircraft.
ATCRBS Airborne Transponder (1030 MHz)	5.5	ATCRBS airborne transponder component of ATCRBS system which replies to the ground interrogator and provides altitude and aircraft identity information in the reply signal.
Air Route Surveillance Radar-4 (ARSR-4) (1240-1370 MHz)	0.69	Used by the FAA and Department of Defense (DoD) to monitor aircraft during en-route flight to distances of beyond 370 km (200 nm).
Search and Rescue Satellite Land User Terminal (1544-1545 MHz)	0.8	Provides distress alert and location information to appropriate public safety rescue authorities for maritime, aviation, and land users in distress.

Global Positioning System (GPS) (L1: 1559-1610 MHz) (L2: 1215-1240 MHz) (L5: 1164-1188 MHz)	1 - 20[23]	Provides precise position velocity, and time information on a continuous, worldwide basis. Applications include, air and maritime navigation, position location for Enhanced 911 (E911), and network synchronization.
Airport Surveillance Radar (ASR-9) (2700-2900 MHz)	0.653	Monitors location of civil and military aircraft in and around airports to a range of 110 km.
Next Generation Weather Radar (NEXRAD) (2700-2900 MHz)	0.55	Provides quantitative and automated real-time information on storms, precipitation, hurricanes, tornadoes, and a host of other important weather information.
Maritime Radionavigation Radar (2900-3100 MHz)	4 - 20	Maritime radionavigation radars provide a safety service function that assists vessel commanders in safe navigation of waterways. The marine radar provides information on surface craft locations, obstructions, buoy markers, and navigation marks (shore-based racons, radar beacons) to assist in navigation and collision avoidance.
Aircraft Altimeter (Pulsed) (4200-4400 MHz)	30	Radar altimeters determine and display aircraft height to pilots. They are used in commercial and private aviation as well as military aircraft.
Microwave Landing System (MLS) (5030-5091 MHz)	0.15	Used for precision approach and landing of aircraft.
Terminal Doppler Weather Radar (TDWR) (5600-5650 MHz)	0.91	Provides quantitative measurements of gust fronts, wind shear, micro bursts, and other weather hazards for improving the safety of operations at major airports.

TABLE 2.
Federal Systems Not Considered in NTIA UWB Compatibility Assessment

System (Operating Frequency Range)	Receiver IF Bandwidth (MHz)	Function
Traffic advisory and Collision Avoidance System (TCAS) (1030 MHz and 1090 MHz)	9	TCAS provides proximity warnings and resolution advisories to aircraft equipped with Mode S transponders or ATCRBS transponders.
Mode-S Data Link (1030 MHz and 1090 MHz)	8	Mode S is a discrete-address beacon system that selectively interrogates aircraft.
Air Route Surveillance Radar (ARSR-1/2) (1280-1350 MHz)	1	Used by the FAA to monitor aircraft during en-route flight to distances of beyond 370 km (200 nm).
Air Route Surveillance Radar (ARSR-3) (1250-1350 MHz)	0.4	Used by the FAA to monitor aircraft during en-route flight to distances of beyond 370 km (200 nm).
Airport Surveillance Radar (ASR-7) (2700-2900 MHz)	2.4/5.5	Monitors location of civil aircraft in and around airports to a range of 110 km.
Airport Surveillance Radar (ASR-8) (2700-2900 MHz)	1.2/5	Monitors location of civil aircraft in and around airports to a range of 110 km.

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[23] The bandwidth for GPS receivers will vary depending upon the receiver architecture employed. Bandwidths of 1 to 2 MHz are common for coarse acquisition receiver architectures; 12 MHz for narrowly-spaced correlator receiver architectures; and 20 MHz for semi-codeless receiver architectures.

WSR-74 (2700-2900 MHz)	2	Meteorological radar used in the vicinity of an airport.
WSR-88 (2700-2900 MHz)	2.4	Meteorological radar used in the vicinity of an airport.

Table 3.
Summary of Appendix A Analysis Results

System	**Required Distance Separation**	
	Proposed Definition of Part 15 Peak Power	**Current Definition of Part 15 Peak Power**
ASR-7/8	1.6 km	200 m
Maritime Radar	1.9 km	460 m

As discussed in Appendix A, the analysis did not consider an extensive range of receiver signal processing capabilities. As discussed earlier, the effect of pulsed interference on receiver processing is difficult to quantify and is strongly dependent on the characteristics (pulse width, PRF, duty cycle) of the signal. In general, there are numerous signal processing features of radars that can be expected to help suppress low duty cycle pulsed interference, especially from a few isolated sources. A pulsed duty cycle, defined in the radar receiver bandwidth, of less than 1% that is asynchronous with the desired signal will have minimal impact on radar receiver performance.

In addition to the federal systems identified in Tables 1 and 2, the Commission has recently allocated spectrum in the 4940-4990 MHz band ("4.9 GHz Band") to be used to accommodate a variety of broadband applications to support public safety agencies in performing their missions regarding homeland security and protection of life and property.[24] The frequency utilization plan for the 4.9 GHz Band will consist of ten 1 MHz channels and eight 5 MHz channels that can be combined to a maximum of 20 MHz.[25] The Commission permits federal government entities to enter into sharing agreements with public safety licensees

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[24] *In the Matter of The 4.9 GHz Band Transferred from Federal Government Use*, Memorandum Opinion and Order and Third Report and Order, WT Docket No. 00-32 (released May 2, 2003).

[25] *Id*. at ¶ 39.

to use this spectrum.[26] As noted by the Commission, both federal government and non-government public safety entities are potential participants in incident-scene emergency operations, and could benefit from the same broadband communications technologies contemplated for this band.[27] Appendix B provides an assessment of the potential impact of the proposed definition of peak power measured in a 1 MHz resolution bandwidth on these wideband (e.g., 20 MHz) public safety communication systems. As shown in Appendix B, the proposed definition of peak power for wideband Part 15 devices could increase the distance separation required for compatible operation by a factor of 20 compared to the current definition of peak power.

In a separate study, NTIA has examined the effects of pulsed interfering signals on a wideband (e.g., 20 MHz) digital receiver that employed error correction capabilities and bit interleaving, which were not considered in the Appendix B analysis.[28] The measurements examined the susceptibility of the receiver to pulsed interfering signals as a function of pulse characteristics that included pulse width, pulse repetition rate, and peak amplitude. The measurements indicated that the receiver was relatively robust in the presence of low duty cycle interference. When the duty cycle was less than 0.005 (a half percent), interference thresholds exceeded 10 dB above the desired signal level (e.g., signal-to-interference (S/I) = -10 dB). However, interference thresholds converge rapidly to a continuous wave (CW) level of an S/I = 8 dB when the duty cycle exceeds 1%. The results were almost identical for all cases, regardless of absolute pulse repetition rate or pulse width, when the interference exceeds 5%. In that case, the interference threshold is nearly that of a CW signal. In effect, the receiver performance was

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[26] *Id.* at ¶ 25.

[27] *Id.*

[28] NTIA Report 02-393, *Measurements of Pulsed Co-Channel Interference in a 4-GHz Digital Earth Station Receiver*, National Telecommunications and Information Administration (May 2002).

severely affected if 5% or more of the symbols were deleted from the data stream.[29] This report only examined one error correction and bit-interleaving implementation, thus the results could be different for other implementations.[30] The measurement results are consistent with impact of pulsed interference on GPS receivers. In a GPS receiver, pulsed interference will corrupt data bits causing "holes" in the received signal. As long as these "holes" are relatively short (e.g., do not corrupt a large number of data bits) and occur infrequently (e.g., low duty cycle), the pulsed interference will not severely degrade GPS receiver performance.

The analysis performed by NTIA indicates that the distance separations required for compatible operation between federal systems and Part 15 devices meeting the proposed peak power definition are greater than those for Part 15 devices meeting the current peak power definition. However, NTIA believes that if a duty cycle limit of 1% in the victim receiver bandwidth is established, compatible operation of Part 15 devices with federal systems is possible.[31] Since this proposal pertains to the general category of Part 15 devices, adequate measurement procedures would need to be developed to certify compliance with the allowable duty cycles.

V. NTIA HAS DEVELOPED A PROPOSED COMPLIANCE MEASUREMENT PROCEDURE FOR 24 GHZ VEHICULAR RADAR SYSTEMS EMPLOYING PULSED FREQUENCY HOPPING MODULATION.

The Commission is proposing to permit pulsed frequency hopping (FH) systems to operate under the provisions for UWB vehicular radar systems.[32] The Commission requests comment on the measurement procedures to be used for demonstrating compliance with the emission limits, including whether a general measurement procedure can be developed that is

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[29] *Id.* at 19.

[30] In receivers where error correction and bit-interleaving techniques are not implemented, it is expected that the interference impact could be more pronounced.

[31] For an impulsive signal the maximum allowable PRF would be 1% of the receiver bandwidth.

[32] MO&O/FNPRM at ¶ 160.

applicable for a full range of system parameters and whether various system parameters need to be limited to specific ranges of values for the measurements to be meaningful.[33]

The rules adopted in the First R&O permit UWB vehicular radars that operate in the 22-29 GHz frequency range.[34] The 23.6-24 GHz frequency band is a restricted band allocated to passive radio services such as the Radio Astronomy (RA) Service, the Earth Exploration-Satellite Service (EESS), and the Space Research (SR) Service. The rules adopted in the First R&O establish an emission mask to facilitate compatibility with passive sensors used in the EESS.[35] All of the analyses performed to develop the emission limits for UWB vehicular radars were based on impulsive signals.[36] Furthermore, NTIA did not consider pulsed FH systems in developing the compliance measurement procedures adopted for UWB devices in the First R&O.

NTIA believes that the emission spectrum characteristics of a pulsed FH transmitter can vary depending on the following system parameters: pulse width, PRF, frequency hopping bandwidth, frequency hopping pattern, number of frequency hopping channels, hopping channel frequency separation, and the time length of the hopping sequence. Furthermore, unlike impulsive signals, the peak-to-average ratio of a pulsed FH system can vary over a wide range depending on the system parameters. NTIA performed measurements as documented in Appendix C examining the impact that various combinations of the pulsed FH system parameters have on the compliance measurements. The objective of these measurements was to gain further insight into the proper techniques for measuring the emissions of devices employing pulsed FH modulation. Based on the results of these measurements NTIA developed the measurement procedure described in Appendix D, that can be used to demonstrate compliance

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[33] *Id*. at ¶ 161.

[34] *See* 47 C.F.R. §15.515.

[35] *See* 47 C.F.R. §15.515(d) and (c).

[36] Typical pulse widths used by UWB devices currently are on the order of 0.1 to 2 nanoseconds, or less, in width.

with the peak and average power emission limits for 24 GHz vehicular radars that employ pulsed FH modulation. Recommendations regarding the system parameters to be provided by the applicant for device certification are also included in Appendix D.

In the measurement procedures for the average power using a root-mean-square (RMS) detector, an averaging time must be specified. In the FNPRM, the Commission proposed to allow a maximum 10 millisecond (msec) averaging time to accommodate compliance testing for frequency hopping vehicular radar systems.[37] Several commenters are concerned that the proposed 10 msec averaging time for the compliance measurements would produce results that underestimate the amount of interference that pulsed FH signals employed by vehicular radars could cause to EESS sensors.[38] For example, the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Conical Scanning Microwave Imager/Sounder (CMIS) sensor operating in the 23.6 - 24 GHz band has an integration time of 1.2 msec, which is almost an order of magnitude shorter than the 10 msec measurement averaging time proposed by the Commission.[39] The National Academy of Sciences' Committee on Radio Frequencies indicates that future EESS sensors that will operate in this band will have an integration time on the order of 0.1 msec to achieve high-resolution imaging.[40]

NTIA believes in order to have compliance measurements of a pulsed FH signal that are meaningful in assessing potential interference to EESS sensors, a proper balance must be established between: the integration time of the EESS sensor; the frame time period of the pulsed FH signal; and the averaging time for the RMS average power compliance measurement. For example, if the averaging time of the compliance measurement is too long compared to the

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[37] MO&O/FNPRM at ¶ 160.

[38] National Academy of Sciences' Committee on Radio Frequencies Comments, ET Docket 98-153 (July 16, 2003) at 4 ("CORF Comments"); Northrop Gruman Corporation and Ratheheon Company Reply Comments, ET Docket No. 98-153 (August 20, 2003) at 6.

[39] CORF Comments at 6.

[40] *Id*. EESS sensor integration times are defined by the angular resolution and scan geometry.

EESS sensor integration time, this could underestimate the received interference power level seen by the EESS sensor. On the other hand, if the averaging time of the compliance measurement is too short compared to the frame period of the pulsed FH signal, there will not be a sufficient number of pulses available to compute a meaningful RMS level of the average power. In the compliance measurement procedures described in Appendix D, NTIA has proposed an averaging time for the RMS measurement of 1 msec within the 23.6-24 GHz EESS band and 10 msec outside of the EESS band. NTIA believes that the 1 msec averaging time for the compliance measurement withing the 23.6-24 GHz EESS frequency band is necessary to ensure not only the protection of existing EESS sensor operations, but also to allow EESS sensing technology to develop and produce the higher quality of sensing data that is expected from such technology developments.

VI. THE INTERFERENCE IMPACT TO EESS SENSOR RECEIVERS FROM PULSED FREQUENCY HOPPING VEHICULAR RADARS IS COMPARABLE TO THAT OF THE IMPULSE VEHICULAR RADARS PERMITTED BY THE COMMISSION'S UWB RULES.

The Commission is requesting comment on whether the higher instantaneous power delivered by a pulsed frequency hopping system would cause harmful interference to existing systems.[41] Comments are requested on any interference concerns that arise from this new modulation type or its method of measurement.[42] Comments are also requested on the adequacy of the measurement results for the purpose of quantifying the impact to systems that could receive interference from pulsed frequency hopping vehicular radar systems.[43]

In developing the emission limits adopted in the First R&O for UWB vehicular radars, NTIA performed an analysis to assess the potential impact to passive EESS sensors operating in

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[41] MO&O/FNPRM at ¶ 159.

[42] *Id*. at ¶ 161.

[43] *Id*.

the 23.6-24 GHz frequency range.[44] This analysis only addressed the potential impact of impulse UWB signals to EESS sensors. The adopted average power limits for impulsive signals, are to be measured in a 1 msec time interval. At the PRFs proposed for the impulse vehicular radars, the average power is fully defined in a 1 msec time interval. To assess the potential interference impact of allowing pulsed FH vehicular radars to operate under the requirements of the rules adopted in the First R&O, the comparative analysis in Appendix E was performed. The analysis computed the interference level in the EESS receiver from several impulse and pulsed FH signals. Certain parameters that are common (e.g., propagation loss, antenna gains) to all the interference cases considered were not included in the computations. The exclusion of these common parameters does not change the comparative results. The comparative analysis was between representative waveforms of several impulse waveforms with different characteristics and pulsed FH signals with characteristics that were considered representative. The comparative analysis considered eight signal types: two impulse non-dithered signals, an impulse dithered signal, and five variations of pulsed FH signals. The characteristics of the pulsed FH signals are specified in terms of hopping frequency range, pulse width, hopping sequence, number of hop channels, and PRF. The comparative interference power at the output of the EESS receiver filter and whether or not the signal is limited by the peak or average power are summarized in Table 4. The analysis assumes that the measured average power is fully defined in a time interval that does not exceed the integration time of the EESS sensor (e.g., on the order of 1 to 2 msec).

Table 4.
Summary of Comparative Analysis

Signal Type	Average or Peak Power Limited	Comparative Interference Power (dBm/400 MHz)
10 MHz PRF Non-Dithered Impulse	Average Power Limited	-25.3
1 MHz PRF Non-Dithered Impulse	Average Power Limited	-15.3

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[44] Letter from William T. Hatch, Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administrator, to Mr. Edmond J. Thomas, Chief, Office of Engineering and Technology, Federal Communications Commission (February 13, 2002) at Attachment 2 ("Hatch Letter").

Dithered Impulse	Peak Power Limited	-18
Pulsed FH (Partial Overlap of Hop Channels)	Peak Power Limited	-24.9
Pulsed FH (Complete Overlap of Hop Channels)	Peak Power Limited	-24.8
Pulsed FH (No Overlap of Hop Channels)	Peak Power Limited	-24.9
Pulsed FH (No Overlap of Hop Channels)	Average Power Limited	-18.3
Pulsed FH (No Overlap of Hop Channels)	Average Power Limited	-15.3

As shown in Table 4, the comparative interference power level of the pulsed FH signals are comparable to the non-dithered and dithered impulse signals. The values shown in Table 4 must be further adjusted for propagation loss and EESS receive antenna gain to estimate the actual interference power from the one vehicular radar. However, these extra loss values should be the same across all the signals analyzed, and have no effect on a comparative analysis. Thus, for the pulsed FH signal characteristics considered, one pulsed FH radar should be no worse, from an interference perspective, than one impulse vehicular radar.

The analysis in Appendix E is applicable only to assessing the interference impact to an EESS sensor because the effective interference signal at a space-borne sensor is an aggregate from a large number of vehicular radars. In addition, this aggregate signal is of concern over an extensive frequency range because the sensors have wide bandwidths on the order of 400 MHz. Thus, the frequency hopping of an individual radar as a part of an aggregate has a different impact in this case than frequency hopping devices would have in other frequency bands where they might operate in close proximity to relatively narrowband ground-based receivers. For ground-based receivers, a single frequency hoping transmitter would be dominant in setting the effective interference power level and only a relatively narrow frequency range is of primary concern. Therefore, the results of this analysis cannot be extended to assess the potential interference impact of a pulsed FH signal on ground-based receivers.

Based on the results of the comparative interference analysis, NTIA believes that the operation of pulsed FH vehicular radar systems that comply with the technical standards specified in Section 15.515 of the Commission's Rules is possible. In addition to the technical standards in Section 15.515, the rules must ensure that each hopping channel is used once and only once during the hopping sequence. The same hopping sequence is to be repeated each time.

VII. TECHNICAL AND ECONOMIC FACTORS MAY RESULT IN THE TRANSITION OF VEHICULAR RADAR OPERATIONS TO THE 77-81 GHZ FREQUENCY RANGE.

In response to the Commission's 76-81 GHz band realignment NPRM,[45] the Short Range Automotive Radar Frequency Allocation Group (SARA)[46] filed comments stating that at the current time, the 77 GHz band is not suitable for vehicular radar systems.[47] SARA indicated that the much greater sensor cost at 77 GHz would render vehicular radars unviable.[48] However, SARA believes that they can reduce the cost of 77 GHz sensors within the next 10 years as new manufacturing processes are developed.[49] Technological advances, along with a more mature product will enable a more cost effective vehicular radar solution in the 77-81 GHz frequency range during the next decade. As pointed out by Delphi Corporation, design, production, and deployment of vehicular radar systems in the 76-77 GHz band has commenced and continues at a steadily increasing pace.[50] Long range vehicular radar systems known as adaptive cruise control (ACC) systems are currently being developed in the 76-77 GHz band. The Long-Range Automotive Radar Frequency Allocation Group expects the number of ACC systems deployed in the United States to increase significantly over the next few years, as improvements in the

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[45] *Amendment of Part 2 of the Commission's Rules to Realign the 76-81 GHz Band and the Frequency Range Above 95 GHz Consistent with International Allocation Changes*, Notice of Proposed Rulemaking, ET Docket No. 01-102, FCC 03-90 (released April 28, 2003).

[46] SARA is an association composed of the world's leading automobile manufacturers and automotive component manufacturers.

[47] Short Range Automotive Radar Frequency Allocation Group Comments, ET Docket No. 03-102 (August 4, 2003) at 6 ("SARA Comments").

[48] *Id.*

[49] *Id.*

[50] Delphi Corporation Comments, ET Docket No. 03-102 (August 4, 2003) at 4.

manufacturing process brings down the cost of the sensors.[51]

SARA also indicates that in order to achieve the economies of scale necessary to make the widespread deployment of vehicular radars possible, automakers need to be able to purchase and install the same units regardless of a vehicle's ultimate destination market.[52] The economies of scale, made possible by the international harmonization of spectrum allocations and service rules, can lower the overall development costs of new and innovative technologies, resulting in potentially lower prices and more widespread deployment of this life saving technology.

In 2002, the United States adopted rules for UWB vehicular radars operating in the 24 GHz frequency range. In developing the emission levels for the vehicular radars, the primary concern in the United States was the potential for interference to EESS passive sensors from vehicular radar systems. In order to protect the EESS passive sensors, the Commission's Rules require the vehicular radar systems to attenuate, by 25 dB below the value of -41.3 dBm/MHz, any emissions within the 23.6-24 GHz band that appear 38 degrees above the horizontal plane. For equipment authorized, manufactured or imported on or after January 1, 2005, this level of attenuation shall be 25 dB for any emissions within the 23.6-24 GHz band that appear 30 degrees or greater above the horizontal plane. For equipment authorized, manufactured or imported on or after January 1, 2010, this level of attenuation shall be 30 dB for any emissions within the 23.6-24 GHz band that appear 30 degrees or greater above the horizontal plane. For equipment authorized, manufactured or imported on or after January 1, 2014, this level of attenuation shall be 35 dB for any emissions within the 23.6-24 GHz band that appear 30 degrees or greater above the horizontal plane. These levels of attenuation can be achieved through the antenna directivity, through a reduction in output power or any other means.[53]

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[51] Long-Range Automotive Radar Frequency Allocation Group Comments, ET Docket No. 03-102 (August 4, 2003) at 7.

[52] SARA Comments at 4.

[53] *See* 47 C.F.R. §15.515(c).

The value of weather, climate, and environmental data, information, and forecasts is growing in importance to the U.S. economy. According to some estimates, up to 40 percent of the approximately $10 trillion U.S. economy is affected by weather and climate events annually.[54] As a consequence of population growth, the costs of U.S. disasters related to weather and climate are rising rapidly. Approximately 90 percent of all Presidentially declared disasters in the United States are weather related.[55] As society becomes more sensitive to weather, the importance and accuracy of weather prediction for the protection of lives and property, and economic growth continues to increase. In order for EESS passive sensors to perform lower sensitivity measurements, needed for global climatic change monitoring and more accurate weather forecasts, greater protection from interference will be necessary. The compatibility analysis performed by NTIA, that formed the basis of the emission limits for impulse UWB vehicular radars,[56] used an interference criteria specified in International Telecommunication Union - Radiocommunication Sector (ITU-R) Recommendation SA.1029.[57] The ITU-R reviews and updates the interference criteria in ITU-R Recommendation SA.1029 on a regular basis to reflect improvements in the sensitivity of the sensors, and to take advantage of other technological advances. After NTIA performed its analysis to develop the emission limits for UWB vehicular radars, the ITU-R modified Recommendation SA.1029, lowering the interference criteria of the EESS passive sensors operating in the 23.6-24 GHz frequency band by 6 dB (i.e., -160 dBW/200 MHz to -166 dBW/200 MHz). SARA indicates that the current level of attenuation in the Commission's Rules required by 2014 will be difficult to achieve while maintaining the required functionality of vehicular radars required for the enhancement of

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[54] National Research Council, Committee on NASA-NOAA Transition for Research to Operations, Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations, The National Academies Press, Washington DC. (2003) at 22. (Internal citations omitted).

[55] *Id.*

[56] Hatch Letter at Attachment 2.

[57] International Telecommunication Union-Radiocommunications Sector, Recommendation SA.1029-2, *Interference Criteria for Satellite Passive Remote Sensing* (2002).

road safety.[58] However, given the current and future protection requirements for EESS passive sensors, any increase in the emission levels in the 23.6-24 GHz band will compromise future weather forecasting capabilities.

European regulators are also currently addressing the best way to accommodate vehicular radar systems. In addition to the potential interference to EESS passive sensors, vehicular radars may interfere with fixed service links authorized to operate in Europe operating in the 24 GHz band. These fixed links will provide back haul communications in support of advanced wireless services. The European Communications Committee of the European Conference of Postal and Telecommunications Administrations has drafted a decision that recognizes that the 24 GHz band provides an immediate and cost effective solution for vehicular radars.[59] This draft decision requires that production of 24 GHz vehicular radars cease by 2014, at which time new vehicular radars would be limited to the 77 GHz frequency range (i.e., 77-81 GHz).[60] Therefore, after 2014 there may no longer be a common frequency allocation for vehicular radars unless the United States establishes an allocation in the 77 GHz frequency range.

NTIA believes that these technical and economic factors may result in the transition of vehicular radar operations to the 77-81 GHz frequency range. These factors include technology and manufacturing advances in the 77 GHz frequency range and cost reduction from economies of scale achieved through common frequency allocations to meet the growing needs of both the automotive industry and the government passive systems. NTIA and the Commission should continue to monitor the deployment of vehicular radars in the 24 GHz band, the technology advancements in the 77-81 GHz band, and the development of vehicular radars outside the United States. NTIA will also work with the Commission to ensure that an adequate frequency

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[58] SARA Comments at 5. *See* 47 C.F.R. §15.515(c). The required level of attenuation of the vehicular radar emission in the 23.6-24 GHz EESS sensing band is required to increase to 35 dB by 2014.

[59] SARA Comments at 3.

[60] *Id.*

allocation in the 77-81 GHz band is available for the operation of vehicular radar systems.

VIII. ELIMINATION OF THE MINIMUM BANDWIDTH REQUIREMENT IN THE DEFINITION OF A UWB TRANSMITTER IS NOT SUPPORTED BY THE PUBLIC COMMENTS, AND WILL POTENTIALLY DISRUPT CURRENT PRODUCT AND STANDARDS DEVELOPMENT EFFORTS, FURTHER DELAYING UWB DEVICE AVAILABILITY.

The Commission is proposing to eliminate the definition of a UWB transmitter in 47 C.F.R. Section 15.503(d).[61] The Commission's proposal would eliminate the minimum bandwidth requirement that is currently in the definition, permitting the operation of any transmission system on an unlicensed basis, regardless of its bandwidth, as long as it complies with the standards for UWB operation set forth in SubPart F of 47 C.F.R. Part 15. NTIA believes that the effect of this change would be to permit intentional emissions in the restricted bands from unlicensed devices authorized by Part 15 regardless of the bandwidth used by the device.[62]

NTIA previously raised concerns with the Commission's proposal to eliminate the definition of a UWB transmitter.[63] NTIA believes the views expressed by commenters regarding manufacturers that would intentionally inject noise into their systems to meet the minimum bandwidth requirement, thus permitting operation under the UWB regulations, are overstated and do not represent a technical basis for eliminating the minimum bandwidth requirement. Furthermore, the intentional addition of unnecessary noise to a signal would violate the Commission's long-standing rules that devices be constructed in accordance with good engineering design and manufacturing practice. This requires that emanations from the device shall be suppressed as much as practicable.[64] It is NTIA's opinion that a device where noise is

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[61] MO&O/FNPRM at ¶ 166.

[62] Part 15 intentional radiators generally are not permitted to operate in certain sensitive or safety related frequency bands that are designated as restricted bands that are listed in 47 C.F.R. §15.205.

[63] Letter from Fredrick R. Wentland, Acting Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administration, to Edmond J. Thomas, Chief, Office of Engineering and Technology, Federal Communications Commission (February 12, 2003) ("Wentland Letter").

[64] 47 C.F.R. §15.15(a).

intentionally injected into the signal should never be certified by the Commission.

A review of the public record indicates that there is very little support for the Commission's proposal. Three automotive commenters indicate that they favor the change, but offer no technical rationale for their support.[65] Moreover, there is a concern that this proposal, may adversely impact standards development activities that are currently ongoing within the Institute of Electrical and Electronics Engineers (IEEE) 802.15 Task Group 3a (802.15.3a).[66] This concern is raised by XtremeSpectrum, Inc (XSI), a UWB device manufacturer, stating that the industry is now going through the difficult process of developing global standards for UWB devices. XSI believes that changing the eligibility rules now will only increase the uncertainty and confusion, further delaying commercial availability of UWB products.[67]

In the First R&O, the Commission established technical standards (peak and average EIRP limits) and operating restrictions for different types of UWB devices based on their potential to cause interference.[68] NTIA believes that these technical standards and operational restrictions are necessary to ensure that UWB devices can co-exist with Federal systems. The analyses performed by NTIA to develop these technical standards and operational restrictions were all based on a wideband (e.g., 500 MHz) impulsive interfering signals. The analyses performed by NTIA did not consider interference from narrowband signals (e.g., noise-like, pulsed) which would be permitted if the Commission eliminated the minimum bandwidth requirement for UWB transmitters. Unlike UWB where the basic type of interfering signal is known (e.g., impulsive), for the Commission's proposal the potential types of signals for the Part

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[65] Comments of Siemens VDO Automotive AG, ET Docket No. 98-153 (July 21, 2003) at 31; Comments of Short Range Automotive Radar Frequency Allocation Group, ET Docket No. 98-153 (July 21, 2003) at 2; Comments of Delphi Automotive Systems Corp., ET Docket No. 98-153 (July 18, 2003) at 8.

[66] UWB is emerging as a solution for the IEEE 802.15.3a standard. The purpose of this standard is to provide a specification for low-complexity, low-cost, low-power consumption, and high data rate wireless connectivity among devices. The standards development effort in IEEE 802.15.3a is focused on the 3.1 - 10.6 GHz frequency range.

[67] XtremeSpectrum Inc., Reply Comments, ET Docket No. 98-153 (August 20, 2003) at 5.

[68] MO&O/FNPRM at ¶ 5.

15 devices are unknown. The Commission needs to provide more details on the types of signals that they would permit under their proposal, in order to perform the necessary compatibility studies with the diverse federal systems operating in this region of the spectrum.

In addition to these considerations, NTIA is concerned that the elimination of the minimum bandwidth requirement from the definition of a UWB transmitter will impact operations in the restricted bands in 47 C.F.R. §15.205 due to the potential interference that could result. Under the current Part 15 rules, only spurious or unintentional emissions at or below a specified field strength are permitted in the restricted frequency bands. The elimination of the minimum bandwidth requirement from the definition of UWB transmitter would effectively allow intentional emissions in these bands by any Part 15 device irrespective of the transmission system or modulation techniques employed. The long-term effects of such a significant change have not been studied. The National Aeronautics and Space Administration is currently undertaking a broad study program to examine the effects of UWB devices on the operations of government systems in several restricted bands. Upon completion the results of this investigation will be made available to the Commission.

NTIA does not support the Commission's proposal to eliminate the minimum bandwidth requirement from the definition of a UWB transmitter. The Commission's proposal does not appear to have a benefit to the public, and will only serve to disrupt the ongoing UWB product and standards development activities, possibly further delaying commercial product availability. Furthermore, the long-term effects of this proposal on government systems are not fully understood. NTIA believes that the Commission has established a stable regulatory framework to facilitate the development of a broad range of commercial UWB device technologies and that it is now time to allow industry to develop products.

IX. MODIFICATIONS TO THE COMMISSION'S AMENDED SECTION 15.521(c) ARE NECESSARY TO ENSURE PREDICTABILITY AND CERTAINTY FOR APPLICANTS SEEKING TO CERTIFY UWB DEVICES.

In the MO&O, the Commission stated that the original wording of Section 15.521(c) of its Rules, 47 C.F.R. §15.521(c), which addresses regulation of limits on emissions produced by digital circuitry used within UWB devices, was unclear.[69] In order to provide clarity, the Commission amended Section 15.521(c) of its Rules in the MO&O without seeking public comment on this change.[70]

The intent of Section15.521(c) of the Commission's Rules is to permit emissions from digital circuitry contained within the UWB device to be at a higher level than those specified in SubPart F, as long at it can be clearly demonstrated that those emissions are due solely to the digital circuitry and are not to be radiated from the transmitter antenna. NTIA agrees with the Commission that the language of Section 15.521(c) required clarification. However, NTIA believes that further text modifications are necessary in order to achieve the intent of this section of the Commission's Rules, and recommends the following further revisions to the amendment of Section 15.521(c):

> Section 15.521 Technical requirements applicable to all UWB devices
>
> (c) Emissions from digital circuitry ~~used to enable~~ associated with the operation of the UWB transmitter shall comply with the limits in Sec. 15.209, rather than the limits specified in this subpart, provided it can be clearly demonstrated that those emissions ~~from the UWB device are due solely to emissions from digital circuitry contained within the transmitter and that the emissions~~ are not ~~intended to be~~ radiated from the transmitter's antenna. ~~Emissions from associated digital devices, as defined in Sec. 15.3(k), *e.g.*, emissions from digital circuitry used to control additional functions or capabilities other than the UWB transmissions, are subject to the limits contained in Subpart B of Part 15 of this part.~~

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[69] *Id*. at ¶ 150.

[70] *Id*. The Commission concluded that since this change to the regulation is interpretive and only clarifies a standard that already has been adopted, prior notice and public comment are unnecessary.

NTIA believes that these additional revisions will ensure predictability and certainty for applicants seeking to certify UWB devices.

X. CONCLUSION

NTIA and the Commission recognize the unique challenges that have been encountered in the development of the rules for UWB device operation. NTIA urges the Commission to consider carefully the issues raised in these comments in an effort to continue the workable arrangement of allowing UWB technology to evolve while protecting critical federal systems.

For the foregoing reasons, NTIA submits these comments.

Respectfully submitted,

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APPENDIX A

ANALYSIS OF POTENTIAL IMPACT OF THE PROPOSAL TO DEFINE THE PEAK POWER IN A 1 MHZ BANDWIDTH ON FEDERAL SYSTEMS

This appendix provides an analysis of the potential impact to Federal systems based on the proposed and current definitions of peak power for wideband Part 15 devices. The analysis will address the following federal receivers: Air Traffic Control Radio Beacon System (ATCRBS) (Interrogator); ATCRBS (Transponder); Global Positioning System (GPS); maritime radionavigation radar; pulsed radar altimeter; Traffic advisory and Collision Avoidance System (TCAS); Mode-S; Air Route Surveillance Radar (ASR)-7; and ASR-8.

CALCULATION OF PART 15 DEVICE PEAK POWER LEVELS

The current and proposed definitions of peak power for wideband Part 15 devices will be considered in this analysis. The current definition of peak power specifies a 20 dB peak-to-average ratio where the peak power is the total peak power. The proposed definition of peak power specifies a 20 dB peak-to-average ratio where the peak power is measured in a 1 MHz resolution bandwidth.

The current and proposed definitions of peak power are expressed in terms of a field strength of 5000 μV/m at a reference distance of 3 meters. The peak equivalent isotropically radiated power (EIRP) is determined from Equation A-1.

$$\text{EIRP (dBm)} = 20 \text{ Log } E_0 + 20 \text{ Log } D_{Ref} - 104.8 \qquad \text{(A-1)}$$

where:

E_0 is the field strength (μV/m);
D_{Ref} is the reference distance (m).

Using Equation A-1, the peak EIRP in a 1 MHz bandwidth is:

$$\text{EIRP} = 20 \text{ Log } (5000) + 20 \text{ Log } (3) - 104.8$$

$$\text{EIRP} = 74 + 9.5 - 104.8 = -21.3 \text{ dBm/MHz}$$

The difference between the current and proposed definitions of peak power is the bandwidth used in the compliance measurement. For the current definition, the peak power is specified as the total peak power of the signal. The compliance measurement would be performed in a resolution bandwidth and a pulse desensitization correction factor is used to relate the measured power in the resolution bandwidth to the peak power of the signal. For the proposed definition the peak power is measured in a 1 MHz resolution bandwidth with no adjustment for the bandwidth of the signal being measured.

CALCULATION OF INTERFERENCE CRITERION FOR PEAK POWER INTERFERING SIGNALS

To properly assess the potential of the peak power of a signal to interfere with a receiver, detailed measurements are required that take into consideration the impact that different combinations of pulse width and pulse repetition frequency (PRF) have on the receiver signal processing. NTIA has performed a limited set of these types of measurements on a 4 GHz earth station receiver, however, this type of detailed information is typically not available.[1] For this analysis, general interference criterion will be developed for three categories of receivers: radars, aeronautical radionavigation, and GPS.

Radar Receivers

The probability of detection of a radar is a function of the signal-to-noise ratio (S/N), which will be used as the basis to develop the interference criterion for peak power interfering signals. For a probability of detection of 90%, an signal-to-noise (S/N) of 15 dB is required.[2] The signal level is based on a peak power and the noise is based on average power. For noise signals the nominal peak-to-average ratio is 10 dB. Expressing the S/N is terms of peak power results in a $(S/N)_p$ of 5 dB. In this analysis a criterion of setting the Part 15 peak power level such that it does not exceed the peak noise level will be used. This results in a interference criterion of $(S/I)_p = 5$ dB. This interference criterion will be used to assess the potential impact of the peak power from Part 15 devices to ASR-7, ASR-8, pulsed radar altimeters, and maritime radionavigation radars.

Aeronautical Radionavigation Receivers

The performance of the aeronautical radionavigation receivers considered in this analysis is based on the receiver's ability to recognize and detect a desired pulse. The interference criterion for the aeronautical radionavigation systems will be based on the impact that the peak power of a Part 15 device will have on the ability of the aeronautical receiver to recognize a desired pulse. There is a limited set of measured data that assesses the impact that peak power signals have on the performance of Distance Measuring Equipment aeronautical radionavigation receivers.[3] The performance of these aeronautical receivers is also based on the ability to recognize a desired pulse, thus this measured data will be used in the development of a general interference criterion for aeronautical radionavigation receivers.

Table A-1 summarizes the measurements for worse case coincidence of timing where an interfering pulse caused a loss in decodes. The power level of the interfering signal where the decode efficiency begins to deviate from the maximum value and the interference power level where there is a 5% reduction in decode efficiency are shown in Table A-1. These measurements were carried out with a desired signal at the measured sensitivity level. The $(S/I)_p$ values for the 5% degradation point are 4 dB, -3 dB, 9 dB, and -3 dB. The measurements represent an extensive range of receiver implementations and designs. Based on the measured data shown in Table A-1, the mean value is 1.75 dB.

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[1] NTIA Report 02-393, *Measurements of Pulsed Co-Channel Interference in a 4-GHz Digital Earth Station Receiver*, National Telecommunications and Information Administration (May 2002).

[2] Merrill I. Skolnik, *Introduction To Radar Systems* (Second Edition) at 28.

[3] Electromagnetic Compatibility Analysis Center, ESD-TR-79-103, *The Effects of JTIDS Signals on TACAN/DME Interrogator Circuitry and the Operational Equivalent Pulse Density* (December 1979).

Table A-1.

Receiver ID	Specified Sensitivity (dBm)	Measured[4] Sensitivity (dBm)	Decode Efficiency Deviation from the Maximum Value (dBm)[5]	Decode Efficiency 5% Below the Maximum Value (dBm)[6]
GA-A	-78	-84	-90	-88
GA-B	-82	-83	-82	-80
CA	-90	-89	-100	-98
CB	-90	-90	-88	-87

Another reference containing measured data showing the impact of peak power interference levels on the detection of desired signals for an aeronautical radionavigation system was reviewed.[7] The aeronautical radionavigation receiver that was tested was a general aviation ATCRBS transponder receiver. The ATCRBS transponder receiver tested had an intermediate frequency (IF) bandwidth of 4 MHz. The ATCRBS signal has a specified pulse width of 0.8 ± 0.1 μsec and the pulses from the interfering signal have a spectral width of 3.5 MHz. Measurements were performed with the pulsed interfering signal operating at 1008 MHz and the ATCRBS transponder receiver operating at 1030 MHz. Specific measurements (involving additional filtering of the interfering pulsed signal) were carried out to determine that the interference effect was caused by the pulsed interfering signal passing through the skirts of the ATCRBS receiver filter rather than the pulsed interfering transmitter noise in the receiver passband.

The measurements were performed with a desired signal at the minimum triggering level which varied, throughout the test period, from -74 dBm to -77 dBm.[8] Measurements of ATCRBS transponder receiver selectivity show a rejection of 60 dB to an interfering signal at 1008 MHz.[9] The performance degradation measurements showed a decrease in detection of desired signals when the pulsed interfering signal power exceeded a level of -23 dBm at the receiver input.[10] This peak power signal level would be attenuated by 60 dB due to the receiver selectivity, resulting in an effective peak interference power level of -83 dBm. Comparing this to the range of ATCRBS transponder desired signal levels (-74 to -77 dBm), results in $(S/I)_p$ levels ranging from 6 to 9 dB, where I is the peak power of the interfering pulse.

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[4] *Id.* at 107.

[5] *Id.* at 71.

[6] *Id.*

[7] Electromagnetic Compatibility Analysis Center, ESD-TR-79-103, *The Effects of High JTIDS Signal Levels on an ATCRBS Transponder* (December 1979).

[8] *Id.* at 16.

[9] *Id.* at 20.

[10] *Id.* at 27.

Although these $(S/I)_p$ values are a little higher than the results presented previously, they do support the rationale that an interfering signal approaching the amplitude of the desired pulse (e.g., S/I slightly positive) and coincident in time, will inhibit the ability of the ATC receiver to correctly detect the desired signal. The impact of peak interfering signals can be somewhat mitigated if the interfering signal duty cycle is low, resulting in a limited number of errors, and can be further mitigated by error correction techniques providing a critical proportion of the desired pulsed are correctly detected.

Based on the results of these limited measurements, an $(S/I)_p$ of 2 dB is used in this analysis to assess the potential impact of peak power signals from Part 15 device to ATCRBS (Interrogator), ATCRBS (Transponder), TCAS, and Mode-S receivers.

GPS Receivers

The performance of GPS receivers has been shown not to be severely degraded by low duty cycle pulsed interfering signals. Most, if not all, GPS receivers are designed not to have an extensive dynamic range capability. This is a cost-effective measure as the received GPS signal level varies only over a small range of useful power levels. If the GPS signal is too low it is not useful. With a limited dynamic range, some element of the receiver will saturate at a relatively low level, acting like a limiter.[11] Some GPS receivers actually implement a limiter to protect it from any excessive interference. The limiting action does not effect signals at normal levels, but it clips (e.g., blocks) higher powered signals. As long as the receiver has been designed to recover quickly from pulse interference, the clipping action caused by low duty cycle interference will usually not cause a GPS receiver to fail. The limiting action of a pulsed interfering signal blocks the GPS signal in the receiver. However, if this limiting action takes place only a small percentage of the time, the pulse signal is mitigated as long as the receiver front-end is protected from damage.[12] For the case of in-band pulsed interference, the RTCA derived criterion is a peak power level of +20 dBm for pulsewidths less than 1 millisecond and pulsed duty cycles less than 10%.[13]

RADAR ANALYSIS

ASR-7 and ASR-8

The ASR-7 and 8 operate in the 2700-2900 MHz band. The ASR-7 and ASR-8 will be characterized with a 4 dB noise figure, a 5 MHz IF receiver bandwidth, and a system loss of 2 dB. The receiver system noise is computed using the following equation:

$$N = -114 + 10 \text{ Log } (BW) + NF \qquad \text{(A-2)}$$

where:

N is the receiver system noise (dBm);
BW is the IF bandwidth of the receiver (MHz);

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[11] A limiter is a device in which some characteristic of the output is automatically prevented from exceeding a predetermined value.

[12] Elliott D. Kaplan (Editor), *Understanding GPS Principles and Applications*, Artech House, Inc. (1996) at 214.

[13] Document Number RTCA/DO-229B, *Minimum Operational Performance Standard for GPS/Wide Area Augmentation System Airborne Equipment* (January 1996).

NF is the noise figure of the receiver (dB).

Using Equation A-2, the receiver system noise is -102.6 dBm.

As discussed earlier, to achieve a probability of detection of 90%, the S/N is 15 dB and the system loss is 2 dB, the minimum peak signal level is computed by:

$$S_p = N + S/N + L_s \qquad \text{(A-3)}$$

$$S_p = -102.6 + 15 + 2 = -85.6 \text{ dBm}$$

For the interference susceptibility criterion of $(S/I)_p$ of 5 dB, the peak interference threshold is:

$$I_p = S_p - (S/I)_p \qquad \text{(A-4)}$$

$$I_p = -85.6 - 5 = -90.6 \text{ dBm}$$

Based on the proposal to define the peak power in a 1 MHz bandwidth, the EIRP is -21.3 dBm/MHz. Representing this in the 5 MHz IF bandwidth of the ASR-7/8 receiver results in:

$$EIRP_{peak} = -21.3 + 20 \text{ Log } (5 \text{ MHz}/1 \text{ MHz}) = -7.3 \text{ dBm}/5 \text{ MHz}$$

Using the current definition the peak EIRP is:

$$EIRP_{peak} = -21.3 \text{ dBm}/5 \text{ MHz.}$$

The maximum allowable EIRP for compatible operation is computed using the following equation:

$$EIRP_{max} = I_{max} - G_R(2) + L_p + L_s \qquad \text{(A-5)}$$

where:

I_{max} is the maximum allowable interference based on the interference susceptibility criterion (dBm);
$G_R(2)$ is the receive elevation pattern antenna gain in the direction of the Part 15 device (dBi);
L_p is the propagation loss computed using the Irregular Terrain Model (dB);[14]
L_s is the system loss (dB).

In Equation A-5 using the peak EIRP (based on the proposed and current definitions) as the maximum allowable EIRP and the elevation antenna pattern for the ASR-9,[15] the required distance separations for compatible operation with the ASR-7 and ASR-8 radars for the proposed and current definitions of peak power for a Part 15 device are: 1.6 km (proposed definition) and 200 m (current definition).[16] As shown in this analysis defining the peak power in terms of a 1

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[14] NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode*, National Telecommunications and Information Administration (April 1982).

[15] NTIA Special Publication 01-43 at A-10.

[16] The lowest separation distance considered in the analysis was 200 m.

MHz bandwidth as proposed will increase the distance separation required for compatible operation by a factor of 8.

The analysis does not include the signal processing in the radar receivers. The effect of pulsed interference is difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. In general, numerous features of radiodetermination radars can be expected to help suppress low-duty cycle pulsed interference, especially from a few isolated sources.[17]

Pulsed Radar Altimeter

The pulsed radar altimeters operate in the 4200-4400 MHz frequency band and have a IF bandwidth of 30 MHz. In this analysis the desired signal will be calculated for both the minimum and maximum altimeter altitudes. The desired signal to peak interference power will then be calculated and compared to the interference criterion of $(S/I)_p$ of 5 dB.

In the UWB compatibility analysis the desired signal level at the minimum altitude of 30 meters was computed to be -30.4 dBm. For the maximum altitude of 1524 meters, the calculated desired signal level was computed to be -64.3 dBm.[18]

Based on the proposal to define the peak power in a 1 MHz bandwidth, the EIRP is -21.3 dBm/MHz. Representing this in the 30 MHz IF bandwidth of the pulsed radar altimeter receiver results in:

$$\text{EIRP}_{\text{peak}} = -21.3 + 20 \text{ Log } (30 \text{ MHz}/1 \text{ MHz}) = 8.2 \text{ dBm}/30 \text{ MHz}$$

The peak interference power level is calculated using the following equation:

$$I_{\text{peak}} = \text{EIRP}_{\text{peak}} + G_R - L_s - L_p \qquad \text{(A-6)}$$

where:

G_R is the pulsed radar altimeter receive antenna gain (dBi);
L_s is the system loss (dB);
L_p is the propagation loss (dB).

The propagation loss is calculated using the following equation:

$$L_p = 20 \text{ Log } F + 20 \text{ Log } D - 27.55 \qquad \text{(A-7)}$$

where:

F is the frequency (MHz);
D is the separation distance (m).

For a center frequency of 4300 MHz and using the minimum and maximum altitudes as

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[17] Recommendation ITU-R M.1464, *Characteristics of an Protection Criteria for Radionavigation and Meteorological Radars Operating in the Frequency Band 2700-2900 MHz* (2000).

[18] NTIA Special Publication 01-43 at 4-18.

the separation distances, the values of propagation loss are:

$$L_p = 20 \text{ Log } 4300 + 20 \text{ Log } 30 - 27.55 = 74.7 \text{ dB} \qquad \text{(Minimum)}$$

$$L_p = 20 \text{ Log } 4300 + 20 \text{ Log } 1524 - 27.55 = 108.9 \text{ dB} \qquad \text{(Maximum)}$$

For a receive antenna gain of 10.5 dBi and a 2 dB system loss, the peak interference power levels using Equation A-6 are:

$$I_{peak} = 8.2 - 74.7 + 10.5 - 2 = -58 \text{ dBm} \qquad \text{(Minimum)}$$

$$I_{peak} = 8.2 - 108.9 + 10.5 - 2 = -92.2 \text{ dBm} \qquad \text{(Maximum)}$$

The desired signal to peak interference power ratio is calculated using the following equation:

$$S/I_{peak} = S - I_{peak} \qquad \text{(A-8)}$$

For the minimum and maximum altitudes the values of S/I_{peak} are:

$$S/I_{peak} = -30.4 - (-58) = 27.6 \text{ dB} \qquad \text{(Minimum)}$$

$$S/I_{peak} = -64.3 - (-92.2) = 27.9 \text{ dB} \qquad \text{(Maximum)}$$

The computed S/I_{peak} values for the minimum and maximum altitudes are approximately 23 dB higher than the $(S/I)_p$ criterion of 5 dB. Therefore, the proposal to define the peak power in a 1 MHz bandwidth should not impact the performance of pulsed radar altimeter receivers.

Maritime Radionavigation Radar

The maritime radars operate in the 2900-3100 MHz band. The maritime radar will be characterized with a 4 dB noise figure, a 4 MHz IF receiver bandwidth,[19] and a system loss of 2 dB. The receiver system noise computed using Equation A-2 is -103.9 dBm.

As discussed earlier, to achieve a probability of detection of 90%, the S/N is 15 dB and the system loss is 2 dB, the minimum peak signal level computed using Equation A-3 is -86.9 dBm.

For the interference susceptibility criterion of $(S/I)_p$ of 5 dB, the peak interference threshold computed using Equation A-4 is -91.9 dBm.

Based on the proposal to define the peak power in a 1 MHz bandwidth, the EIRP is -21.3 dBm/MHz. Representing this in the 4 MHz IF bandwidth of the marine radar receiver results in:

$$EIRP_{peak} = -21.3 + 20 \text{ Log } (4 \text{ MHz}/1 \text{ MHz}) = -9.2 \text{ dBm}/4 \text{ MHz}$$

Using the current definition the peak EIRP is:

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[19] The IF bandwidth of the marine radar can vary over a range of 4 to 20 MHz depending on the mode of operation.

$$\mathrm{EIRP}_{\mathrm{peak}} = -21.3 \text{ dBm/4 MHz.}$$

Using Equation A-5, the peak EIRP as the maximum allowable EIRP and the elevation antenna pattern for the marine radar,[20] the required distance separations for compatible operation with the marine radars for the proposed and current definitions of peak power for a Part 15 device are: 1.9 km (proposed definition) and 460 m (current definition). As shown in this analysis defining the peak power in terms of a 1 MHz bandwidth as proposed will increase the distance separation required for compatible operation by a factor of 4.

The analysis does not include the signal processing in the radar receivers. As discussed for the ASR-7/8, the effect of pulsed interference is difficult to quantify and is strongly dependent on receiver/processor design and mode of operation. In particular, the differential processing gains for valid-target return, which is synchronously pulsed, and interference pulses, which are usually asynchronous, often have important effects on the impact of given levels of pulsed interference. In general, numerous features of radiodetermination radars can be expected to help surpress low-duty cycle pulsed interference, especially from a few isolated sources. The newer generation radar systems use digital signal processing after detection for range, azimuth and Doppler processing. Generally, included in the signal processing are techniques used to enhance the detection of desired targets and to produce target symbols on the display. The signal processing techniques used for the enhancement and identification of desired targets also provides some suppression of low-duty cycle interference, less than 5%, that is asynchronous with the desired signal.[21]

AERONAUTICAL RADIONAVIGATION RECEIVER ANALYSIS

The aeronautical radionavigation systems considered in this analysis operate at either 1030 MHz or 1090 MHz. The ATCRBS Interrogator is a ground-based receiver that will be analyzed differently than the ATCRBS Transponder, Mode S, and TCAS receivers which are airborne.

ATCRBS Interrogator

The minimum signal level for the ATCRBS Interrogator receiver to satisfy its reply detection probability is -79 dBm.

For the interference susceptibility criterion of $(S/I)_p$ of 2 dB, the peak interference threshold computed using Equation A-4 is -81 dBm.

Based on the proposal to define the peak power in a 1 MHz bandwidth, the EIRP is -21.3 dBm/MHz. Representing this in the 9 MHz IF bandwidth of the ATCRBS Interrogator receiver[22] results in:

$$\mathrm{EIRP}_{\mathrm{peak}} = -21.3 + 20 \text{ Log } (9 \text{ MHz}/1 \text{ MHz}) = -2.2 \text{ dBm/9 MHz}$$

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[20] NTIA Special Publication 01-43 at A-28.

[21] Draft Revision of Recommendation ITU-R M.1464, *Characteristics of Radiolocation Radars, and Characteristics and Protection Criteria for Aeronautical Radionavigation and Meteorological Radars in the Radiodeterminiation Service Operating in the Frequency Band 2700-2900 MHz* (March 25, 2003) at 11.

[22] The Mode S receiver has an 8 MHz IF bandwidth which will result in a a peak EIRP that is 1 dB lower than the value used in the analysis results.

Using the current definition the peak EIRP is:

$$EIRP_{peak} = -21.3 \text{ dBm/9 MHz.}$$

In Equation A-5, using EIRP as the maximum allowable EIRP and the elevation antenna pattern for the ATCRBS Interrogator,[23] the required distance separations for compatible operation with the ATCRBS Interrogator receiver for the proposed and current definitions of peak power for a Part 15 device are: 570 m (proposed definition) and 200 m (current definition).[24] As shown in this analysis defining the peak power in terms of a 1 MHz bandwidth as proposed will increase the distance separation required for compatible operation by a factor of approximately 3. The proposal to define the peak power referenced to a 1 MHz resolution bandwidth does not dramatically increase the separation distance necessary for compatible operation and, therefore should not have an impact on ATCRBS Interrogator receiver performance.

ATCRBS Transponder, Mode S, and TCAS

The minimum signal level for the ATCRBS Transponder, Mode S, and TCAS receivers to satisfy their reply detection probabilities are: -77 dBm, -79 dBm, and -74 dBm respectively.

For the interference susceptibility criterion of $(S/I)_p$ of 2 dB, the peak interference thresholds computed using Equation A-4 are -79 dBm for ATCRBS Transponder receivers, -81 dBm for Mode S receivers, and -76 dBm for TCAS receivers.

Based on the proposal to define the peak power in a 1 MHz bandwidth, the EIRP is -21.3 dBm/MHz. Representing this in the 9 MHz IF bandwidth of the TCAS receiver results in:

$$EIRP_{peak} = -21.3 + 20 \text{ Log } (9 \text{ MHz}/1 \text{ MHz}) = -2.2 \text{ dBm/9 MHz}$$

Using the current definition the peak EIRP is:

$$EIRP_{peak} = -21.3 \text{ dBm/9 MHz.}$$

Representing the peak EIRP in the 5.5 MHz IF bandwidth of the ATCRBS Transponder/Mode S receiver results in:

$$EIRP_{peak} = -21.3 + 20 \text{ Log } (5.5 \text{ MHz}/1 \text{ MHz}) = -6.5 \text{ dBm/5.5 MHz.}$$

Using the current definition the peak EIRP is:

$$EIRP_{peak} = -21.3 \text{ dBm/5.5 MHz.}$$

The analysis will consider an ATCRBS Transponder/Mode S and TCAS receiver used for en-route navigation. For en-route navigation, the aircraft will be at a minimum altitude of

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[23] NTIA Special Publication 01-43 at A-15.

[24] The lowest separation distance considered in the analysis was 200 m.

1000 feet (300 meters).[25] Using Equation A-7, the values of propagation loss for the ATCRBS Transponder/Mode S and TCAS receivers are:

$$L_p = 20 \text{ Log } 1030 + 20 \text{ Log } 300 - 27.55 = 82.2 \text{ dB} \qquad \text{(ATCRBS/Mode S)}$$

$$L_p = 20 \text{ Log } 1090 + 20 \text{ Log } 300 - 27.55 = 82.7 \text{ dB} \qquad \text{(TCAS)}$$

The receive antenna gains are: 4 dBi (ATCRBS), 5 dBi (Mode S), and 6 dBi (TCAS). The analysis will include a 2 dB system loss for all systems.

Using Equation A-5, the maximum allowable EIRP to satisfy the interference thresholds for ATCRBS, Mode S, and TCAS receivers are:

$$\text{EIRP}_{\text{max}} = -79 - 4 + 82.2 + 2 = 1.2 \text{ dBm} \qquad \text{(ATCRBS)}$$

$$\text{EIRP}_{\text{max}} = -81 - 5 + 82.2 + 2 = -1.8 \text{ dBm} \qquad \text{(Mode S)}$$

$$\text{EIRP}_{\text{max}} = -76 - 6 + 82.7 + 2 = 2.7 \text{ dBm} \qquad \text{(TCAS)}$$

The computed values of maximum allowable EIRP for compatible operation of the ATCRBS Transponder, Mode S, and TCAS receivers are above the EIRP values permitted by the proposal to define the peak power in a 1 MHz bandwidth. Therefore, the proposal to define the peak power in a 1 MHz bandwidth should not impact the performance of ATCRBS Transponder, Mode S, and TCAS receivers used for en-route navigation.

GPS RECEIVER ANALYSIS

The bandwidth for GPS receivers will vary depending upon the receiver architecture employed. For coarse/acquisition (C/A) code receiver architectures bandwidths of 1 to 2 MHz are typical; for narrowly-spaced correlator receiver architectures bandwidths are on the order of 12 MHz; and for semi-codeless receiver architectures the bandwidths approach 20 MHz. The proposal to define the peak power in a 1 MHz bandwidth will have a potential impact on narrowly-spaced correlator and semi-codeless receiver architectures.

For the narrowly-spaced correlator receiver architectures, the proposed peak power definition expressed in a 12 MHz band is:

$$\text{EIRP}_{\text{peak}} = -21.3 + 20 \text{ Log } (12/1) = -21.3 + 21.6 = 0.3 \text{ dBm/12 MHz}$$

Using the current definition the peak EIRP is:

$$\text{EIRP}_{\text{peak}} = -21.3 \text{ dBm/12 MHz.}$$

Assuming a 0 dBi gain antenna, the peak power using both the current and proposed definitions are well below the +20 dBm threshold for in-band pulsed interference.

For the semi-codeless receiver architecture, the proposed peak power definition

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[25] Document No. RTCA/DO-235, *Assessment of Radio Frequency Interference Relevant to the GNSS* (January 27, 1997) at A-2.

expressed in a 20 MHz band is:

$$\mathrm{EIRP}_{peak} = -21.3 + 20 \mathrm{Log} (20/1) = -21.3 + 26 = 4.7 \mathrm{\ dBm/20\ MHz}$$

Using the current definition the peak EIRP is:

$$\mathrm{EIRP}_{peak} = -21.3 \mathrm{\ dBm/12\ MHz.}$$

Assuming a 0 dBi gain antenna, the peak power using both the current and proposed definitions are well below the 20 dBm threshold for in-band pulsed interference.

The proposal to define the peak power referenced to a 1 MHz resolution bandwidth should not have an impact on GPS receiver performance.

APPENDIX B

ANALYSIS OF THE POTENTIAL IMPACT TO WIDEBAND PUBLIC SAFETY SYSTEMS OPERATING IN THE 4940-4990 MHZ BAND

This appendix provides an analysis of the potential interference impact to wideband public safety systems based on the proposed and current definitions for the peak power of wideband Part 15 devices.

The analysis will assume that a digital receiver has a bandwidth of 20 MHz, which is matched to the widest permitted transmit bandwidth permitted by the Commission's Rules. For the proposed peak field strength of 5000 : V/m at a reference distance of 3 meters the peak equivalent isotropically radiated power (EIRP) is determined from Equation B-1.

$$\text{EIRP (dBm)} = 20 \text{ Log } E_0 + 20 \text{ Log } D_{Ref} - 104.8 \qquad \text{(B-1)}$$

where:

E_0 is the field strength (: V/m);
D_{Ref} is the reference distance (m).

Using Equation B-1, the peak EIRP in a 1 MHz bandwidth is:

$$\text{EIRP} = 20 \text{ Log } (5000) + 20 \text{ Log } (3) - 104.8$$

$$\text{EIRP} = 74 + 9.5 - 104.8 = -21.3 \text{ dBm/MHz}$$

The peak EIRP of -21.3 dBm/MHz expressed in a 20 MHz bandwidth is:

$$-21.3 + 20 \text{ Log } (20/1) = 4.7 \text{ dBm/20 MHz}$$

Using the current peak power definition, where the a 20 dB peak-to-average ratio is specified and the peak is the total peak power in a 20 MHz bandwidth, the peak EIRP would be 26 dB lower (20 Log (20)) than the value computed above or -21.3 dBm/20 MHz.

Thus, the difference in the peak power level between the current and proposed definitions is 26 dB.

The system noise is calculated using the following equation:

$$N = -114 + 10 \text{ Log (IFBW)} + \text{NF} \qquad \text{(B-2)}$$

where:

IFBW is the receiver intermediate frequency bandwidth (MHz);
NF is the noise figure (dB).

Using Equation B-2, for the 20 MHz receiver bandwidth and a 5 dB noise figure the system noise is -96 dBm.

Measurements performed by NTIA on a digital receiver with a bandwidth of 20 MHz and error correction signal processing show the degradation of performance is directly related to the carrier-to-peak interference ratio (C/I).[1] The peak interference level is the level in the digital 20 MHz receiver bandwidth.

In order not to cause additional degradation of performance due to the proposed change in the definitions of peak power, the peak interference in the receiver would have to be reduced by 26 dB. That is the propagation loss would have to increase by 26 dB through increased distance separation to maintain the same performance.

The NTIA measurements were performed with a 15 dB signal-to-noise level which resulted in acceptable performance. With a noise level of -96 dBm calculated using Equation B-2, the resultant desired carrier signal level would be -81 dBm (-96 dBm + 15 dB). With an interfering duty cycle (in the receiver passband) of 0.01, the measurements show a range of susceptibility levels (depending on the interfering signal pulse repetition frequency (PRF)) from a C/I of -22 dB to +2 dB. Using a median susceptibility value C/I = -10 dB (corresponding to a PRF of 100 kHz) the peak interference threshold level in the receiver would be:

$$C/I = C - I \qquad \text{(B-3)}$$

$$I = C - C/I \qquad \text{(B-4)}$$

$$I = -81 - (-10) = -71 \text{ dBm}$$

The required distance separation for compatible operation assuming free space propagation loss is determined from the following equation:

$$20 \text{ Log } D_{Req} = -20 \log F - I + EIRP + G_R + 27.55 \qquad \text{(B-5)}$$

where:

D_{Req} is the required separation distance (m);
F is the frequency (MHz);
I is the peak interference threshold level (dBm);
EIRP is the Part 15 device peak EIRP level (dBm);
G_R is the receive antenna gain (dBi).

Using peak EIRP calculated based on the current Part 15 definition, the mid-band frequency of 4965 MHz and a receive antenna gain of 0 dBi, the required separation distance is:

$$D_{Req} = 1.5 \text{ m}$$

The NTIA measurements also show a range of susceptibility C/I values of 0 to 8 dB for a interfering duty cycle of 0.1. Using the median C/I value of 4 dB (corresponding to a PRF of 100 kHz) Equation B-4 yields an interference threshold of:

$$I = -81 - 4 = -85 \text{ dBm}$$

Using Equation B-5, the required distance separation is:

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[1] NTIA Report 02-393, *Measurements of Pulsed Co-Channel Interference in a 4-GHz Digital Earth Station Receiver*, National Telecommunications and Information Administration (May 2002) ("NTIA Report 02-393") at 13 (Figure 10).

$$D_{Req} = 7.4 \text{ m}$$

The distance separations of 1.5 and 7.4 m are based on the current definition of Part 15 peak limits. Using the same methodology the corresponding required separation distances for Part 15 devices operating at proposed peak power limits would have to be increased to take into account an additional 26 dB of propagation loss. Under free space propagation conditions, this results in an increase of approximately 20 times the distance or 30 and 150 m respectively.

The NTIA measurements examined the susceptibility of a digital receiver to pulsed interference as a function of pulse characteristics that included pulse width, pulse repetition rate, and peak amplitude. The measurements indicated that the digital receiver was relatively robust in the presence of low duty cycle interference. When the duty cycle was less than 0.005 (a half percent), interference thresholds exceeded the desired signal level. But interference thresholds converge rapidly to a continuous wave (CW) level when the duty cycle exceeds 1%. The results were almost identical for all cases, regardless of absolute pulse repetition rate or pulse width, when the interference exceeds 5%. In that case, the interference threshold is nearly that of a CW signal. In effect, the digital receiver performance was severely affected if 5% or more of the symbols were deleted from the data stream.[2] This report only examined one error correction and bit interleaving implementation, thus the results could be different for other implementations.

As shown in this analysis, the proposed definition of peak power for Part 15 devices based on a 1 MHz bandwidth would increase the distance separation required for compatible operation by a factor of approximately 20 compared to the current definition of peak power which is based on the total peak power. Depending upon the operational scenario considered this could be a potential problem.

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[2] *Id*. at 19.

APPENDIX C

MEASUREMENT TECHNIQUES FOR PULSED FREQUENCY HOPPING VEHICULAR RADARS

1. INTRODUCTION

The ultrawideband (UWB) First Report and Order (R&O) provides rules for the operation of UWB vehicular radar systems in the 22-29 GHz frequency range.[1] The Short-Range Automotive Radar Association (SARA), an association composed of the world's leading automobile manufacturers and automotive component manufacturers, is currently promoting the development and deployment of short-range vehicular radars operating in the 24 GHz frequency range.[2] These radars are being promoted as the core component of the next generation of collision mitigation and have the potential to reduce the incidence and severity of automobile accidents.[3] The various component manufacturing members of SARA are designing vehicular radars based on different modulation types. Siemens VDO (Siemens), a member of SARA, is designing a 24 GHz vehicular radar using a pulsed frequency hopping (pulsed FH) system.

The 23.6-24 GHz portion of the 22-29 GHz frequency band is a restricted band allocated to passive radio services such as the Radio Astronomy (RA) Service, the Earth Exploration Satellite Service (EESS), and the Space Research (SR) Service.[4] The rules adopted in the First R&O establish an emission mask and other restrictions on emission at higher elevation angles to facilitate compatibility with passive sensors used in the EESS.[5] All of the measurements and analysis used to develop these emission limits for vehicular radars were based on the analysis of impulsive UWB signals performed by NTIA.[6] NTIA, when assessing the potential interference impact to the EESS sensors or developing the compliance measurement procedures for impulsive UWB transmission systems, did not consider pulsed FH systems since this type of modulation was not considered by the Commission as being covered by the UWB rules.

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[1] *See* First Report and Order in ET Docket No. 98-153, 17 FCC Rcd 7435 (released April 22, 2002) (hereinafter "UWB R&O"). An Erratum to the First Report and Order was adopted on May 30, 2002. *See Erratum* in ET Docket No. 98-153, 17 FCC Rcd 10505 (May 30, 2002). *See also,* 47 C.F.R. §15.515.

[2] SARA in its filed comments, has stated that there are advantages of vehicular radars operating in the 24 GHz frequency range as compared to those operating in the 5.8 GHz and 77 GHz frequency ranges.

[3] *Ex Parte* Filing, Short Range Automotive Radar Frequency Allocation (SARA) Group in ET Docket No. 98-153 (November 27, 2001).

[4] "Restricted bands" of operation are listed in 47 CFR § 15.205. With certain exceptions, the only emissions radiated from unlicensed devices, that are allowed in these bands are spurious emissions. Spurious emissions per 47 CFR 2.1, are emissions "… which may be reduced without affecting the corresponding transmission of information."

[5] *See* C.F.R. §15.515 (c), (d).

[6] Typical pulse widths used by UWB devices currently are on the order of 0.1 to 2 nanoseconds, or less, in width. The emission spectrum appears as a fundamental lobe with adjacent side lobes that can decrease slowly in amplitude. The rise time of the leading edge of the pulse and the pass band of the radiating antenna are major factors in determining the bandwidth of the UWB emission.

In response to the rules adopted in the First R&O, Siemens filed a petition for reconsideration requesting revisions to the existing UWB rules.[7] As part of its petition, Siemens also submitted a proposed measurement technique for measuring the emissions of pulsed FH vehicular radar systems.[8] The Commission addressed the Siemens Petition in its Memorandum Opinion and Order (MO&O) and Further Notice of Proposed Rulemaking (FNPRM) by denying the petition for reconsideration and by seeking advice from the public in the FNPRM.[9]

2. MEASUREMENT PLAN OBJECTIVES

The objectives of these measurements are to gain further insight into the proper techniques for measuring the emissions of devices employing pulsed FH modulation for compliance and use in compatibility studies. The measurements in this plan are to be performed by NTIA's Institute for Telecommunication Sciences (ITS) in conjunction with NTIA's Office of Spectrum Management (OSM).

3. APPROACH

NTIA believes that the emission spectrum characteristics of a pulsed FH transmitter can vary depending on the following system parameters: pulse width (PW), pulse repetition frequency (PRF), frequency hopping bandwidth, frequency hopping pattern, number of frequency hopping channels, hopping channel frequency separation, and time length of the hopping sequence. There are two questions that will be addressed by these measurements. First, what impact does varying the combinations of the pulsed FH system parameters have on the compliance measurements? Second, since the compliance measurements are performed in a narrow resolution bandwidth (e.g., 1 MHz) and the EESS sensor has a relatively wide bandwidth (e.g., 400 MHz), can compliance measurements of the emissions be used in performing compatibility studies?[10]

In order to accomplish the objectives of the measurement plan, the following approach will be taken:

- Develop a prototype of a pulsed FH signal generator. The prototype will be capable of varying the pulsed FH system parameters as required to address the questions in the FNPRM.
- Perform measurements to verify the pulsed FH system parameters. These measurements include but are not limited to the: frequency range of hopping channels, frequency difference in hopping channels, number of hopping channels, hopping frequency characteristics (e.g., hopping pattern, length of sequence,

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[7] *Petition for Reconsideration of Siemens VDO Automotive AG*, ET Docket No. 98-153.

[8] *Id.* at Appendix A.

[9] *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, Memorandum Opinion and Order and Further Notice of Proposed Rulemaking, ET Docket No. 98-153 (released March 12, 2003).

[10] Because of hardware limitations it is necessary to scale the pulse FH system parameters and the measurement settings. This is explained in more detail in Section 4.

repetitiveness of frames), and bandwidth of a single pulse at the highest, lowest and intermediate hopping channels.

- Measure the power level of the pulsed FH signal with peak and root-mean-square (RMS) detectors in a filter bandwidth of 50 kHz. Measurements are to be performed using a swept frequency measurement algorithm.
- Measure the peak and RMS power levels of a pulsed FH signal in a 30 kHz, 50 kHz, 100 kHz, 300 kHz, 1 MHz, 3 MHz, 5 MHz, and 20 MHz bandwidth filter centered on one of the hopping frequency channels.
- Measure the peak and RMS power levels of a dithered impulse UWB signal in a 1 MHz, 2 MHz, 3 MHz, 4 MHz, 5 MHz, 6 MHz, 8 MHz filter bandwidth and a 150 MHz filter bandwidth.

4. MEASUREMENT SETUP

The measurement setup shown in Figure C-1 will be used to generate the pulsed FH and impulse UWB signals and perform the required frequency and time domain measurements.

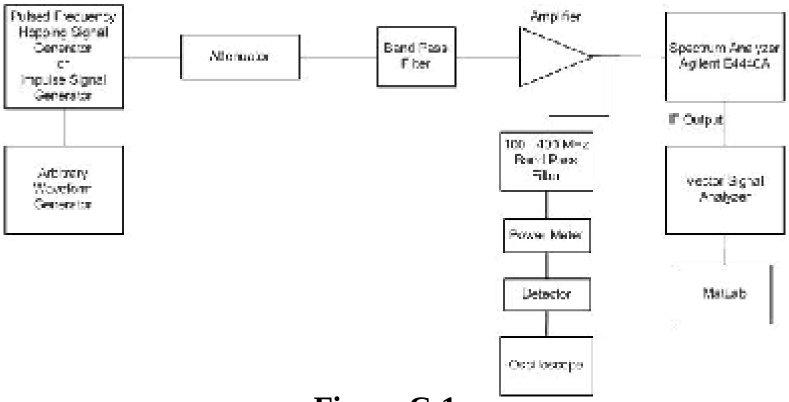

Figure C-1.

Siemens has proposed that the pulsed FH vehicular radars be permitted to operate in the 22-29 GHz frequency range as currently permitted by the Commission's Rules for impulse UWB vehicular radars. The EESS sensors operate in the 23.6-24 GHz band. However, as a result of hardware limitations at these higher frequencies, these tests will use a pulsed FH signal at a center frequency of 26 MHz.[11] Hardware limitations encountered in generating the pulsed FH signal resulted in scaling the system parameters by a factor of 20. In order to perform the measurements the filter bandwidths and measurement times also had to be scaled accordingly. Table C-1 provides a summary of the original and scaled pulsed FH signal parameters and the measurement equipment settings used in performing the measurements.

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[11] This basically sets the carrier frequencies for the pulses and is thus of concern only in setting the frequencies to be measured.

Table C-1.

Parameter	Original Value	Scaled Value
Pulse Width	50 nanosecond	1 microsecond
Pulse Repetition Frequency	1 MHz	50 kHz
Hopping Frequency Range	1 GHz	50 MHz
Number of Hop Channels	200, 100, 25	200, 100, 25
Spectrum Analyzer Resolution Bandwidth	1 MHz	50 kHz
Measurement Times	20, 10, and 2.5 milliseconds per data point	400, 200, and 50 milliseconds per data point
EESS Sensor Bandwidth	400 MHz	20 MHz
Frequency Hopping Pattern	Pseudo Random	Pseudo Random

For the pseudo random hopping pattern the first frequency from the available hop set is randomly selected. This frequency is no longer available for selection. This random frequency selection without replacement process continues until all of the frequencies in the hop set have been selected. The frequency hopping sequence then repeats beginning with the first frequency that was originally selected. This results in returning to each hopping channel on a regular periodic basis. The scaling of the pulsed FH system parameters and the measurement equipment settings should have no impact on the measurement results gathered to address the questions in the FNPRM.

5. MEASUREMENT PROCEDURES

5.1 COMPLIANCE MEASUREMENT PROCEDURES

The measurement procedures described below are to be used to address the questions in the Commission's FNPRM related to the techniques for pulsed FH signal compliance measurements.

A. The Arbitrary Waveform Generator (AWG) will be programmed to generate a pulsed FH signal with the following parameters: **Center Frequency**: 26 MHz; **PW**: 1 microsecond; **PRF**: 50 kHz; **Hopping Frequency Range**: 50 MHz; **Number of Hop Channels**: 200, 100, and 25; and **Frequency Hopping Pattern**: pseudo random.

B. Using a spectrum analyzer in sweep mode, measure the emission spectrum of the pulsed FH signal operating in the hopping mode with a 100 frequency hopset. The emission spectrum should be measured to at least 20 dB below the maximum level. Set up the spectrum analyzer with the following settings: **Video Bandwidth**: greater than or equal to the resolution bandwidth, **Resolution Bandwidth**: 50 kHz for the scaled-down signal, **Detection**: Peak detect, **Start Frequency**: 0 MHz (for the scaled-down signal), **Stop Frequency**: 10 MHz greater than the highest hopping frequency(60 MHz for the scaled-down signal), **Display Points**: (stop freq - start freq) / RBW (1200 points for the scaled-down signal), **Sweep Time**: (1/PRF) * (frequency bins) * 100 * Display points = (480 s for 200 bins, 240 s for 100 bins, 60 s for 25 bins - for the scaled-down signal). The sweep time is set so that peak and average power, as represented by a single data point on the monitor, is determined from enough data samples to include 100 repetitions of the entire hopping sequence. This insures that, at least, 100 pulses are sampled to determine the power parameters and is necessary because, for narrow bandwidths, only a single pulse within the entire hopping sequence will be passed through the passband for each repetition of the hopping sequence.

C. Repeat Step B using average power (RMS) detection.

D. Digitize the pulsed FH signal. The signal must be down converted so that the lowest pulse frequency is centered at a frequency equal to the reciprocal of the pulse width. The data must be acquired at a sampling frequency greater than or equal to 2.5 times the highest hop frequency (after down conversion) and must be acquired for a period of time equal to or greater than (1/PRF) * (FrBins + 6), where FrBins is the number of frequency bins in the frequency hopping scheme. The digitized time domain signal will be analyzed using a digital signal processing routine to determine the following: 1) Verify the minimum and maximum frequencies in the hop set; 2) Verify the frequency difference between the hopping channels in a hop set; 3) Verify the number of hopping channels in a hop set. 4) Verify the hopping frame pattern. Is the hopping pattern random? What is the length of the sequence? Are the frames repetitive? 5) Measure the bandwidth of a single pulse at the lowest frequency, at the highest frequency, and at 2 intermediate frequencies in the hop set. These parameters are determined by breaking up the digitized data into individual pulses. A plot of five consecutive pulses will be used to verify the PRF. A plot of any single pulse will be used to verify the pulse width. Fast Fourier Transforms (ffts) of each individual plot will be used to determine the frequency hopping sequence, as well as, the length of the sequence, spacing between adjacent frequencies, and the spectrum of individual pulses.

E. Repeat Steps B through D for the 200 frequency and 25 frequency hop sets.

5.2 COMPATIBILITY STUDY MEASUREMENT PROCEDURES

The measurement procedures described below are to be used to examine whether the compliance measurements can be used in compatibility studies for assessing interference to EESS sensors.

A. The AWG will be programmed to generate a pulsed FH signal with the following parameters: **Center Frequency**: 30 MHz; **PW**: 1 microsecond; **PRF**: 50 kHz; **Hopping Frequency Range**: 50 MHz; **Number of Hop Channels**: 200, 100, and 25; **Frequency Hopping Pattern**: pseudo random.

B. Using an E4440A spectrum analyzer in sweep mode, zero span, and centered on one of the hopping frequencies located midway across the span of hopping frequencies, measure the peak power of the pulsed FH signal operating in the hopping mode with a 100 frequency hopset. Set up the spectrum analyzer with the following settings: **Video Bandwidth**: greater than or equal to the resolution bandwidth, **Resolution Bandwidth**: 30 kHz, **Detection**: Peak detect; **Center Frequency**: centered on one of the hopping frequencies located midway across the span of hopping frequencies; **Span**: zero span; **Display Points**: as desired, **Sweep Time**: (1/PRF) * (frequency bins) * 100 * Display points = (480 s for 200 bins, 240 s for 100 bins, 60 s for 25 bins - for the scaled-down signal). Using any single point near the center of the display, record the power.

C. Repeat Step B with resolution bandwidths of 50 kHz, 100 kHz, 300 kHz, 1 MHz, 3 MHz, 5 MHz, and 8 MHz and record.

D. Repeat Steps B and C using a mean power (RMS) detector.

E. Using the Vector Signal Analyzer (VSA), digitize the 70 MHz intermediate frequency (IF) output of the E4440A spectrum analyzer set up as follows: **Center Frequency**: centered on one of the hopping frequencies located midway across the span of hopping frequencies; **Span**: zero span; **Sweep**: Single. Resolution bandwidth, video bandwidth, detection mode, display points, and sweep time can be set as desired, as these do not affect the IF output. Use the AWG to generate a pulsed FH signal with a 100 frequency hop set. After a single sweep of the spectrum analyzer is completed, the signal is digitized long enough to obtain 100 complete repetitions of the entire hopping sequence. Using digital signal processing of the baseband signal, filter to equivalent RF bandwidths of 30 kHz, 50 kHz, 100 kHz, 300 kHz, 1MHz, 3 MHz, 5 MHz, 8 MHz, and 20 MHz. Compute the sum of the squares of the filtered in-phase and quadrature signals to obtain the envelope detected signal. Then compute the peak and average power of the resulting envelope detected signal.

F. Repeat Steps B through E for the 200 frequency and 25 frequency hop sets.

5.3 IMPULSE UWB SIGNAL MEASUREMENTS

The measurement procedures described below are to be used to compare the power level of an impulse UWB signal at the output of a filter representing the EESS sensor filter.

A. The AWG will be programmed to control the impulse generator to develop a 50% absolute referenced dithered impulse signal with a PRF of 1 MHz. The characteristics of the impulse signal will be such that it produces a flat spectrum across a bandwidth of 150 MHz centered at 1.3 GHz.

B. With an instrument setup as shown in Figure C-2, calibrate the HP8474C Detector by injecting increasing levels of a CW signal and measuring the power on the power meter and the voltage on the oscilloscope. Produce a calibration curve relating the voltage measured on the oscilloscope to the power measured on the power meter (the power meter considered as the standard).

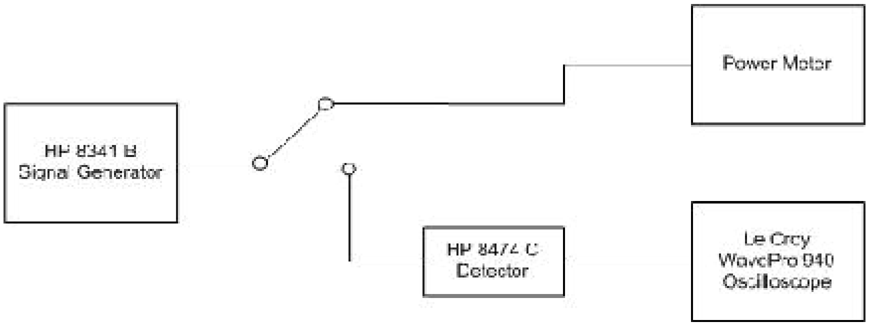

Figure C-2.

C. With an instrument setup as shown in Figure C-3, calibrate the E4440A Spectrum Analyzer by injecting increasing levels of a CW signal and measuring the average power on the power meter and the spectrum analyzer (detection mode set to average power). Produce a calibration curve relating the power measured on the spectrum analyzer and the power meter (the power meter considered as the standard).

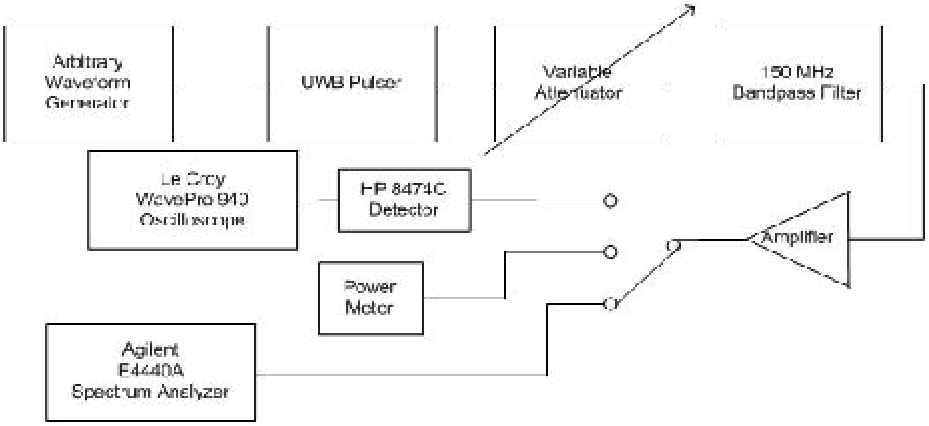

Figure C-3.

D. Set up the spectrum analyzer as follows: **Video Bandwidth**: 8 MHz or greater; **Resolution Bandwidth**: 8 MHz; **Center Frequency**: 1300 MHz; **Span**: zero; **Sweep Time**: 60 ms (100 pulses per data point); **Points Per Display**: 601. With an instrument setup as shown in Figure C-4, inject the 50%-absolute-referenced-dithered impulse signal into the detector and adjust the variable attenuator so that the signal is not compressed by the front end of the spectrum analyzer. This is accomplished by increasing the level of the signal and observing for any non-linearities in the measured peak and average power. Once the proper attenuation level is determined, use the spectrum analyzer to measure peak and average power at the following bandwidths: 1MHz, 2 MHz, 3 MHz, 4 MHz, 5 MHz, 6 MHz, and 8 MHz. Adjust the numbers using the calibration curve described in C so that the powers are referenced to the power meter. Next, switch to the power-meter path and measure the mean power passing through the 150 MHz filter; this will be the mean power measured in a 150 MHz bandwidth. Finally, switch to the oscilloscope path and measure the voltage at the detected pulse peak, and using the calibration curve produced in B, translate the power to that measured by the power meter; this will be the peak power measured in a 150 MHz bandwidth.

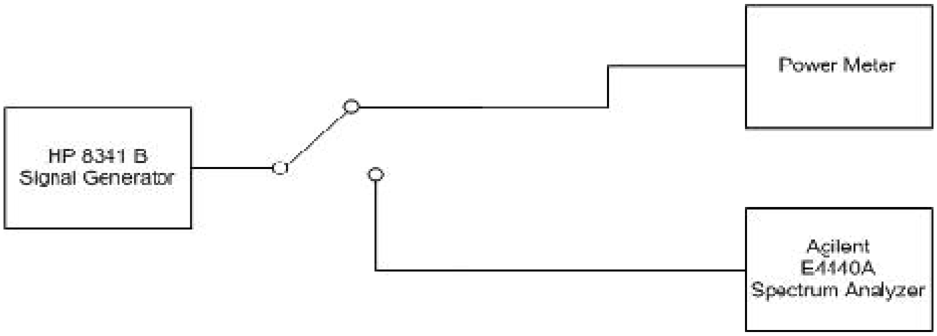

Figure C-4.

E. Using the oscilloscope measure the time waveform at the output of the detected, 150-MHz-bandwidth signal.

APPENDIX D

PROPOSED CERTIFICATION MEASUREMENT PROCEDURES FOR PULSED FREQUENCY HOPPING VEHICULAR RADAR SYSTEMS OPERATING IN THE 22-29 GHZ FREQUENCY RANGE

BACKGROUND

The Federal Communications Commission (Commission) Rules for ultrawideband (UWB) transmission systems provide for the operation of vehicular radar systems. The Short-Range Automotive Radar Association (SARA), an association composed of the world's leading automobile manufacturers and automotive component manufacturers, is working to promote the development and deployment of short-range vehicular radar systems, operating in the 22-29 GHz frequency range. These radar systems are being promoted as a core component of the next generation of collision avoidance and have the potential to reduce the incidence and severity of automobile accidents.[1] The various component manufacturer members of SARA are designing vehicular radar systems based on different modulation techniques.

In the Further Notice of Proposed Rulemaking (FNPRM) in the UWB proceeding, the Commission is proposing to permit the operation of vehicular radar systems that employ pulsed Frequency Hopping (FH) modulation under the rules for vehicular radar systems that employ impulse modulation techniques. As proposed by the Commission, the pulsed FH vehicular radar systems would operate in the same frequency range as the impulse vehicular radar systems, and would have to comply with the same peak and average Equivalent Isotropically Radiated Power (EIRP) limits. The measurement procedures developed for vehicular radar systems did not include provisions for pulsed FH signals.

Appendix C describes a measurement plan used to develop of certification measurement procedures for vehicular radar systems employing pulsed FH signals. Based on the measurements performed in Appendix C, this appendix provides a proposal for the certification measurement procedures to be used for vehicular radar systems that employ pulsed FH signals.

PULSED FH SYSTEM PARAMETERS REQUIRED FOR DEVICE CERTIFICATION

The emission characteristics of a pulsed FH signal are defined by its system parameters. The applicant requesting device certification should be required to provide the following system parameters: pulse width, pulse repetition frequency (PRF), frequency hopping bandwidth, number of frequency hopping channels, hopping channel frequency separation, the time length of the frequency hopping sequence, and the frequency hopping pattern (e.g., pseudo random, linear step). These parameters will define a specific mode of operation for the vehicular radar. If there are multiple operating modes the system parameters for each mode is to be provided by the applicant.

OVERVIEW OF RULES FOR UWB VEHICULAR RADAR SYSTEMS

Section 15.515 of the FCC's Rules, provide for the operation of UWB vehicular radar systems in the 22-29 GHz frequency range using directional antennas on terrestrial transportation vehicles provided the center frequency of the emission and the frequency at which

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[1] These devices are able to detect the location and movement of objects near a vehicle, enabling features such as near collision avoidance, improved airbag activation, and suspension systems that better respond to road conditions.

the highest radiated emission occurs are greater than 24.075 GHz. For UWB vehicular radars, the EIRP limit, measured with a root-mean-square (RMS) detector in the 23.6-24 GHz band is - 41.3 dBm/MHz. The maximum allowable EIRP levels are summarized in Table 1 which shows the emission limits above 960 MHz that are applicable to unlicensed UWB vehicular radar systems. Below 960 MHz the Part 15 general emission limits are applicable.

Table 1. Unlicensed UWB Vehicular Radar Emission Limits

Frequency Band (MHz)	Maximum Allowable EIRP (dBm)
960-1610	-75.3
1610-22000	-61.3
22000-29000	-41.3
29000-31000	-51.3
Above 31000	-61.3

There is also a limit on the peak level of the emissions. The peak EIRP is 0 dBm when measured with a resolution bandwidth (RBW) of 50 MHz and 20 Log (RBW/50) dBm when measured with a resolution bandwidth ranging from 1 MHz to 50 MHz. RBW is the spectrum analyzer resolution bandwidth, in megahertz, that is actually employed in the measurement. The minimum resolution bandwidth employed is 1 MHz; the maximum resolution bandwidth that may be employed is 50 MHz.[2]

The vehicular radar systems are also required to attenuate any emissions within the 23.6-24 GHz band that appear 38 degrees above the horizontal plane by 25 dB below the value of -41.3 dBm/MHz. For equipment authorized, manufactured or imported on or after January 1, 2005, this level of attenuation shall be 25 dB for any emissions within the 23.6-24 GHz band that appear 30 degrees or greater above the horizontal plane. For equipment authorized, manufactured or imported on or after January 1, 2010, this level of attenuation shall be 30 dB for any emissions within the 23.6-24 GHz band that appear 30 degrees or greater above the horizontal plane. For equipment authorized, manufactured or imported on or after January 1, 2014, this level of attenuation shall be 35 dB for any emissions within the 23.6-24 GHz band that appear 30 degrees or greater above the horizontal plane. These levels of attenuation can be achieved through the antenna directivity, through a reduction in output power, or any other means.[3]

OVERVIEW OF CERTIFICATION MEASUREMENT PROCEDURES

The general measurement setup used in the certification measurements is shown in Figure 1.

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[2] 47 C.F.R. § 15.515(d), (f).

[3] 47 C.F.R. § 15.515(c).

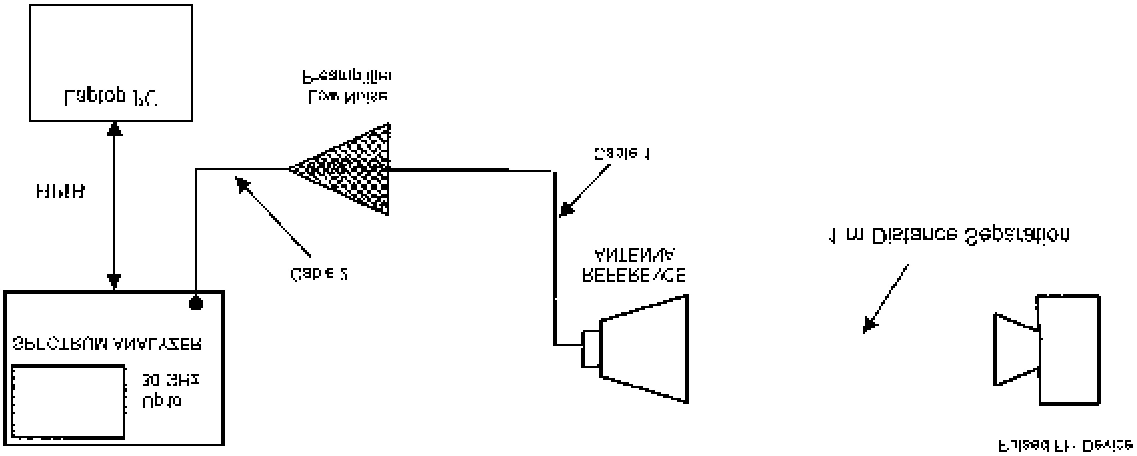

Figure 1. General Measurement Setup

The certification measurements will require two test setups. The first test setup will be used to measure the emission characteristics of the unit under test (UUT) primarily within the 22 to 29 GHz frequency range and the antenna gain characteristics. The second test setup will be used to measure emission characteristics in the 1 to 3 GHz frequency range. Both test setups will use the equipment shown in Figure 1, the only difference will be the applicable frequency range of the preamplifier and the measurement antenna.

The 22 to 29 GHz frequency range test setup will use a 1 meter separation distance with no surface that could provide significant reflections in the vicinity of the test setup. The UUT including the transmit antenna is to be located at a height of approximately 1 to 2 meters. The UUT antenna support must be such that the antenna can rotated (in the horizontal plane) from +90 degrees to -90 degrees, relative to direct alignment with the measurement antenna. The rotation should be such that the antenna can be moved in 5 degree increments. The required commercially available measurement equipment includes:

- Spectrum analyzer with a peak detector, RMS detector, and maximum hold[4] capabilities, and capable of operating up to 30 GHz;

- Measurement antenna with a gain on the order of 15 dBi over the approximate frequency range of 18 to 26 GHz;

- Low noise preamplifier with a gain of at least NF + L + 5 dB,where NF is the noise figure of the spectrum analyzer, and L is the loss of the cable connecting the low noise preamplifier to the spectrum analyzer. The low noise preamplifier should have a noise figure of less than 2 dB over the frequency range of 18 to 26 GHz;

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[4] The maximum hold capability retains the maximum value for each point on the spectrum analyzer display over the selected number of display scans.

- Low loss cable to connect measurement antenna to low noise preamplifier input with a cable loss on the order of 0.2 dB at 24 GHz;

- Suitable cable(s) are required to connect the low noise preamplifier output to the spectrum analyzer. This connection might require a variable attenuator to avoid saturation;

- A personal computer connected to the spectrum analyzer is recommended to control the analyzer and to store the measured data.

The 1 to 3 GHz measurement setup requires the following commercially available measurement equipment:

- Spectrum analyzer with a peak detector, RMS detector, and maximum hold capabilities and capable of operating up to 30 GHz;

- Measurement antenna with a gain on the order of 10 dBi over the approximate frequency range of 1 to 3 GHz (a minimum antenna gain of 8 dBi is required across the 1170 to 1580 MHz frequency range);

- Low noise preamplifier with a gain of at least NF + L + 5 dB, where NF is the noise figure of the spectrum analyzer, and L is the loss of the cable connecting the low noise preamplifier to the spectrum analyzer. The low noise preamplifier should have a noise figure of less than 2 dB over the frequency range of 1 to 3 GHz;

- Low loss cable to connect measurement antenna to low noise preamplifier input with a cable loss on the order of 0.2 dB at 2 GHz;

- Suitable cable(s) are required to connect the low noise preamplifier output to the spectrum analyzer. This connection might require a variable attenuator to avoid saturation;

- A personal computer connected to the spectrum analyzer is recommended to control the analyzer and to store the measured data.

The test setup including and test equipment must be calibrated so that the EIRP of the UUT can be measured. This calibration must be applicable across the frequency range that is defined by the operating frequency range of the measurement equipment combination. If the measurements are not performed in an anechoic chamber, the signal environment must be monitored to determine if there are any extraneous signals.

Measurement of Peak Power Levels, -10 dB Bandwidth, and Center Frequency

These measurements are to be carried out using the first measurement setup. The UUT antenna is to be pointed directly at the measurement antenna and the UUT is to be mounted in an upright position as it would be mounted on a vehicle. With the UUT operating in the frequency hopping mode[5] and the spectrum analyzer set to the peak detector mode with a resolution bandwidth of 3 MHz and video bandwidth of at least 3 MHz. The peak EIRP emissions of the UUT should be measured across the range of 22 to 26 GHz. The dwell time for each 3 MHz interval is 2 seconds and the peak value for each interval is to be recorded.

The data is then to be analyzed to determine the maximum of the peak power values and the lowest frequency where a peak value is 20 dB and 10 dB below the maximum peak value. The highest frequency at which the peak value is 10 dB below the maximum peak value will also be determined. If the highest frequency 10 dB down point is not contained within the measured data, the frequency range of the peak measurements must be extended to the 26 to 29 GHz range.

For certification the maximum peak value is not to exceed -24 dBm in the 3 MHz resolution bandwidth, the difference in frequency between the two 10 dB down points, which defines the UWB bandwidth, is to be at least 500 MHz. The mid-point in frequency between the 10 dB down points is to be 24.075 GHz or greater. The 20 dB down point on the lower frequency end must be greater than or equal to 22 GHz and the 10 dB down point at the upper frequency end of the UUT spectrum must be less than or equal to 29 GHz.

Measurement of Average Power Levels

These measurements are to be carried out using the first test setup. The UUT antenna is to be pointed directly at the measurement antenna with the UUT antenna in the upright position. With the UUT operating in the frequency hopping mode and the spectrum analyzer set to the RMS detector with a resolution bandwidth of 1 MHz and video bandwidth of at least 3 MHz, the average EIRP emission levels are to be measured across the range of the UUT 10 dB bandwidth. The average emissions are to be measured over a 1 millisecond time interval for each 1 MHz interval. This average EIRP measurement is to be repeated, with the analyzer in the maximum hold mode, until there is no significant increase in any of the maximum hold values. No significant increase would be less than 3 dB. The maximum RMS emission level for each 1 MHz interval is to be recorded. The spectrum analyzer sweep time, sweep width, and number of frequency bins (number of points on the display) need to be properly coordinated to yield the required data. For example, if there are 1000 frequency bins, set the sweep width to 1 GHz and set the sweep time to 1 second. This will result in a 1 millisecond per bin integration time and a 1 MHz frequency interval per bin. The maximum values of multiple sweeps is to be determined for each frequency bin as the frequency hopping period[6] may last longer than the 1 millisecond integration time. The 10 dB bandwidth of the UUT may have to be segmented to obtain the full data set. For the above example, only 1 GHz is covered for the set of selected parameters. For certification the maximum of all of the average EIRP measurements each in a 1 MHz resolution bandwidth over a 1 millisecond time interval is not to exceed –41.3 dBm. If the maximum value of the average EIRP measurement is less than -41.3 dBm, the reduced EIRP level can be used in assessing the vertical antenna gain limits.

Measurements of Vertical Antenna Gain

These measurements are to be carried out using the first test setup. However, for these

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[5] If the UUT has more than one mode of operation, a complete set of all measurements are required for each mode.

[6] The frequency hopping period is the time it takes to revisit the same frequency in the hop set.

tests the UUT is to be mounted on its side (rotated 90 degrees from the upright position). The UUT is to be operated in the frequency hopping mode. The spectrum analyzer is to be in the peak detector mode with a resolution bandwidth of 3 MHz and a video bandwidth of at least 3 MHz. For these tests the spectrum analyzer will be operated in the zero span mode at frequencies of 24 GHz, 23.875 GHz, 23.750 GHz, and 23.6 GHz. If the lower frequency point defining the 10 dB bandwidth is greater than 23.6 GHz this frequency should be used for the antenna measurements instead of 23.6 GHz.

The peak power measurements are to be made over a 2 second interval for each of the four test frequencies with the antenna of the UUT and the measurement antenna directly aligned (this is referred to as boresight). The UUT is then to be realigned 5 degrees from boresight and the peak measurements at each of the four frequencies are to be repeated. This procedure is repeated in 5 degree increments until the UUT is 90 degrees from boresight. The UUT is then to be returned to boresight and a data set measured. The UUT antenna is then to be rotated in 5 degree increments in the opposite direction until the UUT antenna is 90 degrees from boresight. The values of antenna gain reduction are then determined from the difference between the boresight power level and the power level measured at each off-axis (5 degree increments) angle.

The EIRP levels in the 23.6-24 GHz band have to be reduced by 25 dB relative to the -41.3 dBm/MHz limit for elevation angles 38 degrees or more from boresight. This applies to all equipment manufactured or imported prior to January 1, 2005. For equipment manufactured or imported after January 1, 2005 the reduction of the EIRP in the 23.6-24 GHz band must be 25 dB for angles 30 degrees or more from boresight. The attenuation of the EIRP in the 23.6-24 GHz band is to be increased to 30 dB by January 1, 2010, further increased to 35 dB by January 1, 2014.

For certification, the sum of the reduction if any in the EIRP (from the -41.3 dBm limit) expressed in dB and the antenna gain reduction in dB must be at least the above values. That is 25 dB for angles 38 degrees above the horizontal and then 25, 30, and 35 dB for angles 30 degrees above the horizontal as required in the time-phased schedule for the emission limits in the 23.6-24 GHz band.

Measurement of Out-Of-Band Average Power Levels

These measurements are to be carried out using the first test setup. Again the UUT antenna is to be aligned with the measurement antenna. With the UUT operating in the frequency hopping mode and the spectrum analyzer set to the RMS detector with a resolution bandwidth of 1 MHz and a video bandwidth of at least 3 MHz, average EIRP emission levels are to be measured.

For these measurements, the spectrum analyzer should be operated in the zero span mode. The average power is to be measured over a 10 millisecond interval with the UUT on and a 10 millisecond interval with the UUT turned off, at 1 GHz intervals from the low end of the test setup applicable frequency range to the frequency of the lower –10 dB bandwidth point. The average power is to also be measured with the UUT on and then turned off at both the –20 dB and –10 dB lower frequency points. These -20 dB and -10 dB frequencies were determined earlier. The average power is to be measured from the highest -10 dB bandwidth point to the highest test setup applicable frequency in 1 GHz steps. The average power is to be measured over a 10 millisecond interval with the UUT turned on and then turned off.

For certification, the maximum allowable EIRP levels are as stated in Table 1 which shows the emission limits above 960 MHz, expressed in terms of the maximum allowable EIRP levels, that are applicable to unlicensed UWB vehicular radar systems. Below 960 MHz the Part 15 general emission limits are applicable.

Measurement of Average Power in the 1164-1700 MHz Frequency Range

These measurements are to be carried out using the second test setup. The UUT antenna is to be pointed directly at the measurement antenna. The UUT is to be operated in the frequency hopping mode. The spectrum analyzer is to be operated in the zero span mode using the RMS detector function with a resolution bandwidth of 1 MHz and a video bandwidth of at least 3 MHz. At each fixed frequency the average power is to be measured over a 10 millisecond interval with the UUT turned on and then with the UUT turned off.

Average power measurements are to be made at the following frequencies: 1171.5 MHz, 1176.5 MHz, 1181.5 MHz, 1227.6 MHz, 1575.4 MHz, 1615 MHz, 1700 MHz. Measurements are then to be made in 100 MHz steps to the highest frequency of the test setup applicable frequency range.

For certification, the EIRP measured at each frequency with the UUT turned on cannot exceed the levels in Table 1.

CALIBRATION AND ENVIRONMENTAL SIGNAL MONITORING

The test setup (required to include path loss) and test equipment must be calibrated so that the EIRP of the UUT can be measured. This calibration must be applicable across the frequency range that is defined by the operating frequency range of the measurement equipment combination. As part of the test setup and calibration with the UUT turned on, measurements should be performed to determine if the low noise preamplifier is being saturated. If saturation occurs, attenuation can be properly employed to eliminate the problem.

The applicable frequency range, for each measurement setup will be determined from the operating frequency range of the measurement antenna and the low-noise preamplifier in combination. Thus, if the antenna is rated from 18 to 28 GHz and the low-noise preamplifier from 20 to 30 GHz, the applicable frequency range of the measurement setup is 20 to 28 GHz. The applicable frequency range is used to establish certain measurement limits.

If the measurements are not performed in an anechoic chamber, the signal environment must be monitored to determine if there are any extraneous signals. In cases where such signals are present, in the frequency ranges of concern, steps should taken to turn off the signals or to shield them from the test setup. If the presence of such signals is significant the test site should not be used. If the presence of such signals is relatively minimal the data for those effected frequencies should be ignored.

APPENDIX E

COMPARATIVE ANALYSIS ASSESSING THE POTENTIAL IMPACT TO EESS SENSOR RECEIVERS FROM IMPULSE AND PULSED FREQUENCY HOPPING SIGNALS USED BY VEHICULAR RADAR SYSTEMS

INTRODUCTION

The NTIA performed an analysis to assess the potential impact of vehicular radars employing impulse signals to the passive sensors operated in the Earth Exploration-Satellite Service (EESS) by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) in the 23.6-24 GHz frequency band.[1] In order to assess the potential interference impact of allowing vehicular radars using pulsed frequency-hopping (FH) signals to operate under the requirements of the rules adopted in the ultrawideband (UWB) First Report and Order (R&O), a comparative analysis was carried out. That is the interference level in the EESS sensor receiver from several impulse and pulsed FH radar signals was computed. These results were comparative in that certain parameters that are common (e.g., propagation loss) to all the interference cases considered were not included in the computations. The exclusion of these common parameters does not change the comparative results. The comparative analysis examined impulse signals and pulsed FH signals with different characteristics. The analysis will also examine what impact the specific pulsed FH characteristics such as pulse width, pulse repetition frequency, hop-channel spacing will have on compatibility with EESS sensor receivers.

UWB RULES FOR VEHICULAR RADARS

Section 15.515 of the FCC's Rules, provide for the operation of UWB vehicular radar systems in the 22-29 GHz frequency range using directional antennas on terrestrial transportation vehicles provided the center frequency of the emission and the frequency at which the highest radiated emission occurs are greater than 24.075 GHz. It is envisioned that these devices will be able to detect the location and movement of objects near a vehicle, enabling features such as near collision avoidance, improved airbag activation, and suspension systems that better respond to road conditions. The emissions must be attenuated by greater than 25 dB for elevations 35 degrees or more above the horizontal plane. The attenuation is to be increased to 30 dB by 2010 and further increased to 35 dB by 2014. These levels of attenuation can be achieved through the antenna directivity, through a reduction in output power or any other means.

For UWB vehicular radars, the EIRP limit, measured with a root-mean-square (RMS) detector in the 23.6-24 GHz band is -41.3 dBm/MHz. There is also a limit on the peak level of the emissions. The peak EIRP is 0 dBm when measured with a resolution bandwidth (RBW) of 50 MHz and 20 Log (RBW/50) dBm when measured with a resolution bandwidth ranging from 1 MHz to 50 MHz. RBW is the spectrum analyzer resolution bandwidth, in megahertz, that is actually employed in the measurement. The minimum resolution bandwidth to be employed is 1 MHz; the maximum resolution bandwidth that may be employed is 50 MHz. In all cases, the certification measurement approach and associated emission limits contained in the UWB R&O were considered in establishing the permitted radar emission limits.

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[1] Letter from William T. Hatch, Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administrator, to Mr. Edmond J. Thomas, Chief, Office of Engineering and Technology, Federal Communications Commission (February 13, 2002) at Attachment 2.

PEAK AND AVERAGE POWER LIMITED SIGNALS

In the comparative analysis a determination is made as to whether a signal considered in the analysis is peak or average power limited. As described above, the Commission's Rules, establish limits on the peak and average power levels as follows:

Peak power of the waveform referenced to 50 MHz (P_{50}) # 0 dBm

Average power measured in a 1 MHz bandwidth $(A_m) < -41.3$ dBm

To determine whether a signal is peak or average power limited the following conditions will apply:

$$A_m = P_{50} - C$$

If $C > 41.3$ the signal is peak power limited

If $C < 41.3$ the signal is average power limited

For an example of a peak limited signal, if A_m is -41.3 dBm then P_{50} would be 1.7 dBm, if C is 43. This would violate the 0 dBm peak limit, thus the peak power must be reduced. Therefore, this signal would be peak power limited. That is $P_{50} = 0$ dBm and $A_m = -43$ dBm/MHz. For an average power limited signal, if A_m is -41.3 dBm and $C = 40$, then P_{50} would be -1.3 dBm. This signal would be average power limited becasue the peak power can be increased by 1.3 dB before the 0 dBm limit is exceeded, but it is limited by the average power limit of -41.3 dBm. The main point is that for the UWB signals there is a fixed 41.3 dB difference between the peak power in a 50 MHz bandwidth and the average power in a 1 MHz bandwidth that must be maintained.

COMPARATIVE ANALYSIS OF INTERFERENCE TO EESS SENSOR RECEIVERS

The comparative analysis considered impulse non-dithered, impulse dithered, and pulsed FH signals. For non-dithered signals there are spectral lines at the pulse repetition frequency (PRF).[2] Dithering of the pulses in the time domain spreads the spectral line content of a signal in the frequency domain making the signal appear more noise-like. The characteristics of the pulsed FH signals are specified in terms of hopping frequency range, pulse width (PW), hopping sequence, number of hop channels, and PRF.

For the pulsed FH signals, the overlapping of hop channels is from the perspective of measuring the average power with a 1 MHz RBW. If the hopping channels are closely spaced, with respect to the bandwidth of an individual radar pulse, then significant power from adjacent hop channels can fall into the spectrum analyzer (SA) RBW thus apparently increasing the average power of the hop channel being measured. If the hop channels are more widely spaced this overlap effect is not significant. However, if the overlap causes an increase in the measured average power this must be taken into account. The effect of overlapping pulses will not cause a similar increase in the peak power.

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[2] The PRF defines the number of pulses transmitted per unit time (one second). The PRF also effects the spectral line magnitude, spacing, and the percentage of time that the pulses are present.

10 MHz PRF Non-Dithered Impulse Signal

The first signal investigated was for an impulse radar with pulses having a one nanosecond PW and a constant (non-dithered) PRF of 10 MHz. A 10 MHz PRF represents an inter-pulse period of 0.1 microsecond, which is the round-trip-time for a radar to target separation of 15 meters.[3] This waveform has a duty cycle (DC) of:

$$DC = -10 \log (PRF \times PW) = 20 \text{ dB},$$

and thus the relationship between the peak power (P_w) and the average power (A_w) for this waveform is:

$$A_w = P_w - DC = P_w - 20 \text{ dB}$$

According to the UWB R&O, this signal is to be measured using a SA with a RBW of 1 MHz. With a constant PRF of 10 MHz, this signal consists of spectral lines each spaced 10 MHz apart. When measured with a 1 MHz RBW, the SA can see at most only one spectrum line and this occurs only when the SA is tuned to a line. For the case of one line in the resolution bandwidth, the measured peak (P_m) and average (A_m) power levels will be the same (e.g., $P_m = A_m$).

To determine the peak and average power from the 1 MHz bandwidth measured values, P_m is corrected by 20 log (waveform bandwidth) /(measurement bandwidth) and A_m is corrected by 10 log of the same bandwidth ratio. For the waveform discussed here, the waveform bandwidth is 1/PW or 1 GHz. However, these corrections do not completely hold for the present case because the power measured is not really the power in a 1 MHz bandwidth. It is the power in a 10 MHz bandwidth (the spacing between the lines). If one were to step this 1 MHz measurement bandwidth in 1 MHz steps across this impulse signal, one would find that in nine out of ten steps the signal would not be measured. Furthermore, if one were to measure this signal in a 10 MHz bandwidth (recognizing that most SAs do not have a 10 MHz resolution bandwidth capability), you would obtain the same values of P_m and A_m as that measured with a 1 MHz bandwidth centered on the spectral line. Thus to obtain the value of P_w from the measured value of P_m (measured in a 1 MHz bandwidth), the correction is 20 log (1 GHz/10 MHz) so that:

$$P_w = P_m + 40 \text{ dB}$$

To obtain the value of A_w from the measured value of A_m (measured in a 1 MHz bandwidth), the correction is 10 log (1 GHz/10 MHz) so that:

$$A_w = A_m + 20 \text{ dB}$$

For the signal being considered $P_m = A_m$ and so the corrected measurements for P_w and A_w show a peak-to-average ratio of 20 dB which agrees with the basic waveform.

The Commission's Rules limit the peak power, as adjusted for a reference bandwidth of 50 MHz (P_{50}), to 0 dBm. The average power, in a 1 MHz bandwidth, is limited to – 41.3 dBm. That is the ratio of peak power (in 50 MHz) to the average power (in 1 MHz) is limited to 41.3 dB. Thus some systems (usually lower PRF systems) can be peak power limited and other signals (usually higher PRF systems) can be average power limited.

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[3] The range is computed from ½x(Round Trip Time)x(Speed of Light).

The measured peak power (in 1 MHz) is corrected by 20 log 50 to determine $P_{50} = P_m$ + 34 dB. For this signal $P_{50} = A_m$ + 34 dB (for this waveform $P_m = A_m$) and the limiting condition is the average power of - 41.3 dBm. If this average power is corrected to determine the average power of the basic waveform, one obtains:

$$A_w = -41.3 \text{ dBm} + 10 \log (1 \text{ GHz}/10 \text{ MHz}) = -21.3 \text{ dBm}$$

In this analysis, the EESS sensor receiver is modeled as a band pass filter (very wide bandwidth) followed by an integrator. The integration time is long compared to the filter response time and to the inter-pulse period of the vehicular radar waveform. The EESS sensor minimum integration time is on the order of 2 millisecond. Thus, the average power of the interference at the output of the band pass filter will determine the impact on the EESS sensor receiver.

For the signal under consideration (- 21.3 dBm average power in 1 GHz), the average power output of the EESS sensor receiver filter with a 400 MHz bandwidth is:

$$-21.3 \text{ dBm} + 10 \log (400 \text{ MHz}/1\text{GHz}) = -25.3 \text{ dBm}$$

This value must be further adjusted for propagation loss, antenna gains, etc. to estimate the actual interference power from the one radar. However, these extra loss values should be the same across all the signal cases being analyzed and thus have no effect on a comparative analysis. Since the actual total interference impact of automotive radars to the EESS sensor receiver is due to an aggregate effect and because the parameter of concern is average power, one can add the average power attributed to each radar to determine the actual ensemble interference. It should be remembered that these radars should not be operated so as to be coherent.

1 MHz PRF Non-Dithered Impulse Signal

Similarly, an impulse radar with a one nanosecond PW and a constant PRF of 1 MHz has a duty cycle:

$$DC = -10 \log (PRF \times PW) = 30 \text{ dB}$$

The relationship between P_w and A_w for this waveform is:

$$A_w = P_w - 30 \text{ dB}$$

For this waveform, a 1 MHz resolution bandwidth would contain one spectral line and again $P_m = A_m$. However, there will be one line in every 1 MHz step across the radar emission spectrum so that the measured spectral density is the power in 1 MHz. The peak power of the waveform as determined by correcting P_m is:

$$P_w = P_m + 20 \log (1 \text{ GHz}/1 \text{ MHz}) = P_m + 60 \text{ dB}$$

and the determination of the average power of the waveform is:

$$A_w = A_m + 10 \log (1 \text{ GHz} /1 \text{ MHz}) = A_m + 30 \text{ dB}$$

Since $A_m = P_m$, the peak-to-average ratio of the waveform is 30 dB as stated previously.

The peak power referenced to 50 MHz as determined according to the Commission's Rules is:

$$P_{50} = P_m + 20 \log (50 \text{ MHz}/1 \text{ MHz}) = P_m + 34 \text{ dB}$$

which is limited to 0 dBm and A_m is limited to - 41.3 dBm/MHz. Similar to the 10 MHz non-dithered signal, this signal is average power limited. Thus, the limiting constraint is A_m = - 41.3 dBm and A_w will be limited to:

$$A_w = - 41.3 \text{ dBm} + 10 \log (1 \text{ GHz}/1 \text{ MHz}) = -11.3 \text{ dBm}$$

Considering this at the output of a 400 MHz EESS receiver filter will result in an average power of:

$$-11.3 \text{ dBm} + 10 \log (400 \text{ MHz}/1 \text{ GHz}) = -15.3 \text{ dBm}$$

This is 10 dB higher than the 10 MHz PRF non-dithered impulse signal.

Dithered Impulse Signal

If the impulse radar is dithered so that the radar signal looks noise-like, the comparative EESS sensor receiver interference power can also be estimated. However, with the wide EESS sensor receiver bandwidth (nearly comparable to the impulse spectrum bandwidth), it could be difficult to make the signal truly noise-like. The signal could look noise-like to a SA with a 1 MHz resolution bandwidth and here the SA would show an approximate 10 dB peak-to-average ratio. Thus, using the Commission's procedure, the peak power level referenced to 50 MHz relative to the average power in one MHz would be:

$$P_{50} = A_m + 10 \text{ dB} + 20 \log 50 = A_m + 44\text{dB}$$

above the average power level (measured in 1 MHz) and the signal would be peak limited Because, as previously explained the UWB Rules effectively limit this ratio to 41.3 dB. The average power would have to be reduced by 2.7 dB to a level of - 44 dBm (in one MHz) and then the computed peak (relative to 50 MHz) would be 0 dBm. This average power would result in an average power in the EESS sensor receiver of:

$$-44 \text{ dBm} + 10 \log (400 \text{ MHz}/1 \text{ MHz}) = -18 \text{ dBm}$$

which is between the values computed for the 1 MHz and 10 MHz non-dithered impulse signals.

Pulsed FH Signal (Partial Overlap of Hop Channels)

For this analysis, the following pulsed FH system characteristics are considered:

> Hopping frequency range - 1 GHz with hopping through out the 23.6 to 24 GHz band;
>
> Number of hop channels - 100, resulting in a 10 MHz spacing between hop channels;
>
> PW - 50 nanoseconds, resulting in a pulse bandwidth of 20 MHz;

Hopping sequence - sampling without replacement to define the order for one cycle. This cycle is then repeated resulting in the return to each hopping channel on a regular periodic basis;

PRF - 1 MHz.

Because of the partial overlapping of hop channels, measuring the average power in a 1 MHz measurement bandwidth the average power would be twice the average power of a single channel without overlap. An additional one-half the average power of the single channel being contributed by the next adjacent lower hopping channel and a similar one-half from the next higher adjacent channel. Beyond the two adjacent hop channels there should be no significant contribution to an increase in average power due to overlap because of spectral fall-off of a pulse.[4]

With a PRF of 1 MHz and 100 hopping channels, one would expect to see spectral lines with a 10 kHz spacing, when viewed by a SA. This is due to the hopping sequence repeating every 100 microseconds ($1/1\text{x}10^6$ x 100). This is similar to the repeating of the Global Positioning System coarse/acquisition code sequence (every 1 millisecond) that results in a line spectra with a 1 kHz spacing. Thus, when measured with a 1 MHz resolution bandwidth, there should be no concern for considering the occurrence of a single spectral line, since there will be 100 lines within a 1 MHz bandwidth.

The duty cycle of the hopping waveform is:

$$\text{DC} = -\,10 \log (\text{PRF x PW}) = 13 \text{ dB}$$

For an individual hopping channel, the duty cycle, because of the hopping sequence assumed, would be:

$$\text{DC}_h = -\,10 \log (\text{PW x PRF/No. of channels}) = 33 \text{ dB}$$

If the peak power of a pulse is set to P_w, then the average power on a single hop channel would be:

$$A_{wh} = P_w - 33 \text{ dB}$$

with both P_w and A_{wh} referenced to a 20 MHz bandwidth (e.g., pulse bandwidth). This computation of A_{wh} ignores power from adjacent hop set pulses. When measured in a 1 MHz bandwidth, the peak power (P_m) would be:

$$P_m = P_w - 20 \log (20 \text{ MHz}/1 \text{ MHz}) = P_w - 26 \text{ dB}$$

The pulses that overlap in the frequency domain are resolved in the time domain, when measured in a 1 MHz bandwidth. That is, the peak power will not increase because of the frequency overlap.

The average power (including signal overlap in the frequency domain) would be:

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[4] The pulse is represented by a sinx/x funtion with the first sidelobe down 13 dB, the second sidelobe down 17.8 dB, and the third sidelobe down 20.3 dB.

$$A_m = P_w - 33 \text{ dB} - 10 \log (20 \text{ MHz}/1 \text{ MHz}) + 3 \text{ dB} = P_w - 43 \text{ dB}$$

The 3 dB factor takes into account the overlapping pulses in the measurement bandwidth. Adjusting P_m for a 50 MHz bandwidth results in:

$$P_{50} = P_w - 26\text{dB} + 20 \log (50 \text{ MHz}/1 \text{ MHz}) = P_w + 8 \text{ dB}$$

Comparing the P_{50} to the measured average power of P_w - 43 dB indicates that the frequency hopping signal will be peak power limited (according to the emission limits) not average power limited. Furthermore, the waveform pulse peak power is limited to -8 dBm to satisfy the constraint that the peak power referenced to 50 MHz (P_w + 8 dB) is limited to 0 dBm.

Thus, the peak power measured in a 1 MHz bandwidth would be:

$$P_m = - 8 \text{ dBm} - 26 \text{ dB} = -34 \text{ dBm}$$

and the corresponding average power would be:

$$A_m = -8 \text{ dBm} - 43 \text{ dB} = -51 \text{ dBm}$$

Because of the minimum integration time of the EESS sensor receiver, this average value must be measured over a period of less than or equal to 2 millisecond. That is a steady state average value must be attained in this time period. The alternative is to measure samples of average power level over a number of time periods less than or equal to 2 millisecond across the 23.6 - 24 GHz band and compare the maximum value to the limit for compliance.

With the EESS sensor receiver bandwidth of 400 MHz, the peak power out of the filter will be -8 dBm as the receiver would see the complete (resolved) 20 MHz wide pulse. In the 400 MHz bandwidth, the EESS sensor receiver would see 40 hop channels (10 MHz hop channel spacing) plus one-half the power of a pulse on each end of the 400 MHz bandwidth because of spectral overlap. This is equivalent to 41 hop channels for a repetitive hopping sequence based on sampling without replacement to define the sequence for a single cycle. The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 13 dB. However, in the 400 MHz only an effective 41 out of 100 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 41/100. This effective duty cycle is then:

$$DC_e = -10 \log (PRF \times 0.41 \times PW) = 16.9 \text{ dB}$$

and the average power is 16.9 dB below the peak power or - 8 dBm - 16.9 dB = -24.9 dBm

Instead of defining the peak power in a 50 MHz bandwidth, the peak power can be defined in the spectral bandwidth of the pulse. For this example the bandwidth would be 20 MHz. Limiting the peak power to 0 dBm in a 20 MHz bandwidth would increase the peak power in the EESS sensor bandwidth to 0 dBm and the average power in the sensor bandwidth would be -16.9 dBm.

Pulsed FH Signal (Complete Overlap of Hop Channels)

For this analysis, the following pulsed FH system characteristics are considered:

Hopping frequency range - 1 GHz with hopping through out the 23.6 to 24 GHz band;

Number of hop channels - 200, resulting in a 5 MHz spacing between hop channels;

PW - 50 nanoseconds, resulting in a pulse bandwidth of 20 MHz;

Hopping sequence - sampling without replacement to define the order for one cycle. This cycle is then repeated resulting in the return to each hopping channel on a regular periodic basis;

PRF - 1 MHz.

Looking at the average power in a 1 MHz measurement bandwidth the level would approach 6 dB or four times the average power of a single channel without overlap. An additional average power of a single hop channel being contributed by the next adjacent lower hopping channel and similarly by the next adjacent higher hopping channel. The second adjacent channels would each contribute one-half the average power of a single channel. Beyond the first and second adjacent hop channels there should be no significant contribution to an increase in average power due to overlap because of spectral fall-off of a pulse.

The duty cycle of the hopping waveform is:

$$DC = -10 \log (PRF \times PW) = 13 \text{ dB}$$

For an individual hopping channel, the duty cycle, because of the hopping sequence assumed, would be:

$$DC_h = -10 \log (PW \times PRF/\text{No. of channels}) = 36 \text{ dB}$$

If the peak power of a pulse is set to P_w, then the average power on a single hop channel would be:

$$A_{wh} = P_w - 36 \text{ dB}$$

with both P_w and A_{wh} referenced to a 20 MHz bandwidth. This computation of A_{wh} ignores power from adjacent hop set pulses. When measured in a 1 MHz bandwidth, the peak power (P_m) would be

$$P_m = P_w - 20 \log (20 \text{ MHz}/1 \text{ MHz}) = P_w - 26 \text{ dB}$$

The pulses that overlap in the frequency domain are resolved in the time domain, when measured in a 1 MHz bandwidth. That is, the peak power will not increase because of the frequency overlap.

The average power (including signal overlap in the frequency domain) would be

$$A_m = P_w - 36\text{ dB} - 10\log(20\text{ MHz}/1\text{ MHz}) + 6\text{ dB} = P_w - 43\text{ dB}$$

The 6 dB factor in the above equation accounts for the overlapping pulses in the measurement bandwidth. Adjusting P_m for a 50 MHz bandwidth, results in:

$$P_{50} = P_w - 26\text{dB} + 20\log(50\text{ MHz}/1\text{ MHz}) = P_w + 8\text{ dB}$$

Comparing the P_{50} to the measured average power of P_w - 43 dB indicates that the frequency hopping radar will be peak power limited (according to the emission limits) not average power limited. Furthermore, the waveform pulse peak power is limited to -8 dBm to satisfy the constraint that the peak power referenced to 50 MHz (P_w + 8 dB) is limited to 0 dBm.

Thus, the peak power measured in a one MHz bandwidth would be:

$$P_m = -8\text{ dBm} - 26\text{ dB} = -34\text{ dBm}$$

and the corresponding average power would be:

$$A_m = -8\text{ dBm} - 43\text{ dB} = -51\text{ dBm}$$

With the EESS sensor bandwidth of 400 MHz, the peak power out of the filter will be -8 dBm as the receiver would see the complete (resolved) 20 MHz wide pulse. In the 400 MHz bandwidth, the EESS sensor receiver would see 80 hop channels (400/1000 x 200) plus 1.5 times the power of a pulse on each end of the 400 MHz bandwidth because of spectral overlap. This is equivalent to 83 hop channels for a repetitive hopping sequence based on sampling without replacement to define the sequence for a single cycle. The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 13 dB. However, in the 400 MHz bandwidth only an effective 83 out of 200 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 83/200. This effective duty cycle is then:

$$DC_e = -10\log(PRF \times 0.42 \times PW) = 16.8\text{ dB}$$

and the average power is 16.8 dB below the peak power or - 8 dBm -16.8 dB = -24.8 dBm

Instead of defining the peak power in a 50 MHz bandwidth, the peak power can be defined in the spectral bandwidth of the pulse. For this example the bandwidth would be 20 MHz. Limiting the peak power to 0 dBm in a 20 MHz bandwidth would increase the peak power in the EESS sensor bandwidth to 0 dBm and the average power in the sensor bandwidth would be -16.8 dBm.

Pulsed FH Signal (No Overlap of Hop Channels)

For this analysis, the following pulsed FH system characteristics are considered:

Hopping frequency range - 1 GHz with hopping through out the 23.6 to 24 GHz band;

Number of hop channels - 50, resulting in a 20 MHz spacing between hop channels;

PW - 50 nanoseconds, resulting in a pulse bandwidth of 20 MHz;

Hopping sequence - sampling without replacement to define the order for one cycle. This cycle is then repeated resulting in the return to each hopping channel on a regular periodic basis;

PRF - 1 MHz.

The duty cycle of the hopping waveform is:

$$DC = -10 \log (PRF \times PW) = 13 \text{ dB}$$

For an individual hopping channel, the duty cycle, because of the hopping sequence assumed, would be:

$$DC_h = -10 \log (PW \times PRF/\text{No. of channels}) = 30 \text{ dB}$$

If the peak power of a pulse is set to P_w, then the average power on a single hop channel would be:

$$A_{wh} = P_w - 30 \text{ dB}$$

with both P_w and A_{wh} referenced to a 20 MHz bandwidth. When measured in a 1 MHz bandwidth, the peak power (P_m) would be:

$$P_m = P_w - 20 \log (20 \text{ MHz}/1 \text{ MHz}) = P_w - 26 \text{ dB}$$

The average power would be:

$$A_m = P_w - 30 \text{ dB} - 10 \log (20 \text{ MHz}/1 \text{ MHz}) = P_w - 43 \text{ dB}$$

Adjusting P_m for a 50 MHz bandwidth, results in:

$$P_{50} = P_w - 26\text{dB} + 20 \log (50 \text{ MHz}/1 \text{ MHz}) = P_w + 8 \text{ dB}$$

Comparing this to the measured average power of P_w - 43 dB and the frequency hopping signal will be peak power limited (according to the emission limits) not average power limited. Furthermore, the waveform pulse peak power is limited to -8 dBm to satisfy the constraint that the peak power referenced to 50 MHz (P_w + 8 dB) is limited to 0 dBm.

Thus, the peak power measured in a one MHz bandwidth would be:

$$P_m = -8 \text{ dBm} - 26 \text{ dB} = -34 \text{ dBm}$$

and the corresponding average power would be:

$$A_m = -8 \text{ dBm} - 43 \text{ dB} = -51 \text{ dBm}$$

With the EESS sensor receiver bandwidth of 400 MHz, the peak power out of the filter will be - 8 dBm as the receiver would see the complete (resolved) 20 MHz wide pulse. In the 400 MHz bandwidth, the EESS sensor receiver would see 20 hop channels (400/1000 x 50). The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 13 dB. However, in the 400 MHz bandwidth only an effective 20 out of 50 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 20/50. This effective duty cycle is then:

$$DC_e = -10 \log (PRF \times 0.4 \times PW) = 16.9 \text{ dB}$$

and the average power is 16.9 dB below the peak power or - 8 dBm -16.9 dB = -24.9 dBm

Instead of defining the peak power in a 50 MHz bandwidth, the peak power can be defined in the spectral bandwidth of the pulse. For this example the bandwidth would be 20 MHz. Limiting the peak power to 0 dBm in a 20 MHz bandwidth would increase the peak power in the EESS sensor receiver bandwidth to 0 dBm and the average power in the sensor bandwidth would be -16.9 dBm.

Pulsed FH Signal (No Overlap of Hop Channels)

For this analysis, the following pulsed FH system characteristics are considered:

Hopping frequency range - 1 GHz with hopping through out the 23.6 to 24 GHz band;

Number of hop channels - 100, resulting in a 10 MHz spacing between hop channels;

PW - 0.2 microseconds, resulting in a pulse bandwidth of 5 MHz;

Hopping sequence - sampling without replacement to define the order for one cycle. This cycle is then repeated resulting in the return to each hopping channel on a regular periodic basis;

PRF - 1 MHz.

The duty cycle of the hopping waveform is:

$$DC = -10 \log (PRF \times PW) = 7 \text{ dB}$$

For an individual hopping channel, the duty cycle, because of the hopping sequence assumed, would be:

$$DC_h = -10 \log (PW \times PRF/\text{No. of channels}) = 27 \text{ dB}$$

If the peak power of a pulse is set to P_w, then the average power on a single hop channel would be:

$$A_{wh} = P_w - 27 \text{ dB}$$

with both P_w and A_{wh} referenced to a 5 MHz bandwidth. When measured in a 1 MHz bandwidth, the peak power (P_m) would be:

$$P_m = P_w - 20 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 14 \text{ dB}$$

The average power would be:

$$A_m = P_w - 27 \text{ dB} -10 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 34 \text{ dB}$$

This case is average power limited to -41.3 dBm/MHz, if the peak power is determined in the bandwidth of the pulse (e.g., the peak power is limited to 0 dBm in 5 MHz, P_w = 0 dBm).

$$-41.3 = P_w - 34 \text{ dB}$$

$$P_w = -7.3 \text{ dBm}$$

In the 400 MHz bandwidth, the EESS receiver would see 40 hop channels (400/1000 x 100). The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 7 dB. However, in the 400 MHz bandwidth only an effective 40 out of 100 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 40/100. This effective duty cycle is then:

$$DC_e = -10 \log (PRF \times 0.4 \times PW) = 11 \text{ dB}$$

and the average power is 11 dB below the peak power or -7.3 dBm -11 dB = -18.3 dBm

Pulsed FH Signal (No Overlap of Hop Channels)

For this analysis, the following pulsed FH system characteristics are considered:

Hopping frequency range - 1 GHz with hopping through out the 23.6 to 24 GHz band;

Number of hop channels - 200, resulting in a 5 MHz spacing between hop channels;

PW - 0.2 microseconds, resulting in a pulse bandwidth of 5 MHz;

Hopping sequence - sampling without replacement to define the order for one cycle. This cycle is then repeated resulting in the return to each hopping channel on a regular periodic basis;

PRF - 1 MHz.

The duty cycle of the hopping waveform is:

$$DC = -10 \log (PRF \times PW) = 7 \text{ dB}$$

For an individual hopping channel, the duty cycle, because of the hopping sequence assumed, would be:

$$DC_h = -10 \log (PW \times PRF/\text{No. of channels}) = 30 \text{ dB}$$

If the peak power of a pulse is set to P_w, then the average power on a single hop channel would be:

$$A_{wh} = P_w - 30 \text{ dB}$$

with both P_w and A_{wh} referenced to a 5 MHz bandwidth. When measured in a 1 MHz bandwidth, the peak power (P_m) would be:

$$P_m = P_w - 20 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 14 \text{ dB}$$

The average power would be:

$$A_m = P_w - 30 \text{ dB} - 10 \log (5 \text{ MHz}/1 \text{ MHz}) = P_w - 37 \text{ dB}$$

This case is average power limited to -43.1 dBm/MHz, if the peak power is determined in the bandwidth of the pulse (e.g., the peak power is limited to 0 dBm in 5 MHz, P_w = 0 dBm).

$$-41.3 = P_w - 37 \text{ dB}$$

$$P_w = -4.3 \text{ dBm}$$

In the 400 MHz bandwidth, the EESS sensor receiver would see 80 hop channels (400/1000 x 200). The determination of the average power in the 400 MHz bandwidth requires first computing the effective duty cycle. The duty cycle of the complete waveform was previously shown to be - 10 log (PRF x PW) = 7 dB. However, in the 400 MHz bandwidth only an effective 80 out of 200 hopping channels will be seen. Thus, the PRF used in the waveform duty cycle determination must be reduced by the ratio of 80/200. This effective duty cycle is then:

$$DC_e = -10 \log (PRF \times 0.4 \times PW) = 11 \text{ dB}$$

and the average power is 11 dB below the peak power or -4.3 dBm -11 dB = -15.3 dBm

ASSESSMENT OF PEAK POWER TO EESS SENSOR RECEIVERS

The interference impact to EESS sensors is based on the aggregate average power from a number of vehicular radars. The average power from one radar is below the EESS sensor interference threshold. However, the question of whether the peak power from a vehicular radar would exceed the interference threshold of the EESS sensor was also addressed. The peak power from a number of vehicular radars will not increase due to the aggregation effect, rather the peak power from an individual vehicular radar is of concern. For an impulse UWB vehicular radar, the peak power is limited to 0 dBm/50 MHz and will increase by 20 Log (400 MHz/50 MHz) in the 400 MHz sensor bandwidth. For the pulsed FH vehicular radars the peak power is limited to 0 dBm/50 MHz or to 0 dBm if the individual pulsed FH vehicular radar has a bandwidth narrower than 50 MHz. Regardless of the pulsed FH pulse bandwidth, the peak power in the sensor bandwidth cannot exceed 0 dBm + 20 Log (400 MHz/50 MHz) and in most cases is expected to be no greater than 0 dBm. Thus, the analysis using 0 dBm + 20 Log (400

MHz/50 MHz) is applicable to impulse radars and is the limiting condition for pulsed FH vehicular radars. The link budgets shown in Tables E-1 through E-4 examine the impact that the peak power will have on the EESS sensor receivers operating in the 23.6-24 GHz band. As shown in Tables E-1 through E-4 the peak power is below the interference threshold. Based on the results of this analysis if the peak power of the pulsed FH signal is limited to 0 dBm/50 MHz there will not be a problem.

The interference threshold for 23.6-24 GHz EESS sensors used in this analysis are the same as the one used to develop the current UWB vehicular radar rules. This interference threshold is specified in International Telecommunication Union - Radiocommunication Sector (ITU-R) Recommendation SA.1029.[5] The interference criteria in ITU-R SA.1029 are regularly updated to reflect improvements in the sensitivity of the sensors, and to take advantage of other technological advances. Since the original analysis was performed by NTIA, the interference criteria of the EESS sensors operating in the 23.6 - 24 GHz has been lowered by 6 dB (e.g., -160 dBW/200 MHz to -166 dBW/MHz). Increasing the interference protection requirements for EESS sensors reduces the available margin.

Table E-1.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	705	AMSR-E Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15.515(e)
Conversion from Measurement Bandwidth to EESS Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15.515 (c)
Free Space Propagation Loss (dB)	-180.9	Based on Slant Range of 1120 km
Atmospheric Loss (dB)	-1	ITU-R Recommendation P.676
Sensor Mean Antenna Gain (dBi)	45.2	AMSR-E Sensor Specification 46.7-1.5 dB
Receiver Power at the Sensor (dBW/400 MHz)	-173.7	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA.1029-1
Available Margin (dB)	16.7	Difference Between Received Power at the Sensor and the Interference Threshold

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[5] International Telecommunication Union-Radiocommunications Sector, Recommendation SA.1029-2, *Interference Criteria for Satellite Passive Remote Sensing* (2002).

Table E-2.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	833	AMSU-A Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15.515(e)
Conversion from Measurement Bandwidth to EESS Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15.515 (c)
Free Space Propagation Loss (dB)	-178.4	At Nadir
Atmospheric Loss (dB)	-1	ITU-R Recommendation P.676
Sensor Mean Antenna Gain (dBi)	34.5	AMSU-A- Sensor Specification 36-1.5 dB
Receiver Power at the Sensor (dBW/400 MHz)	-181.9	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA.1029-1
Available Margin (dB)	24.9	Difference Between Received Power at the Sensor and the Interference Threshold

Table E-3.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	825	ATMS Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15.515 (e)
Conversion from Measurement Bandwidth to EESS Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15.515 (c)
Free Space Propagation Loss (dB)	-178.3	At Nadir
Atmospheric Loss (dB)	-1	ITU-R Recommendation P.676
Sensor Mean Antenna Gain (dBi)	31	ATMS Sensor Specification 32.5-1.5 dB

Receiver Power at the Sensor (dBW/400 MHz)	-185.3	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA.1029-1
Available Margin (dB)	28.3	Difference Between Received Power at the Sensor and the Interference Threshold

Table E-4.

Parameter	Value	Comment
Center Frequency (MHz)	23800	Center Frequency of 23600-24000 MHz EESS Band
Sensor Orbital Altitude (km)	816	CMIS Sensor Specification
Peak EIRP (dBW/50 MHz)	-30	Peak EIRP Limit Specified in Section 15.515(e)
Conversion from Measurement Bandwidth to Sensor Bandwidth (dB)	18	20 Log (400 MHz/50 MHz)
Peak EIRP (dBW/400 MHz)	-12	Peak EIRP Limit Referenced to EESS Bandwidth
EIRP Reduction (dB)	-25	Reduction of EIRP in Direction of EESS Sensor as Specified in Section 15.515 (c)
Free Space Propagation Loss (dB)	-182.5	Based on Slant Range of 1331.6 km
Atmospheric Loss (dB)	-1	ITU-R Recommendation P.676
Sensor Mean Antenna Gain (dBi)	52	CMIS Sensor Specification 53.5-1.5 dB
Receiver Power at the Sensor (dBW/400 MHz)	-168.5	
Interference Threshold (dBW/400 MHz)	-157	ITU-R Recommendation SA.1029-1
Available Margin (dB)	11.5	Difference Between Received Power at the Sensor and the Interference Threshold

SUMMARY

The comparative interference power at the output of the EESS sensor receiver and whether or not the signal is limited by the peak or average power are summarized in Table E-5.

Table E-5.

Signal Type	Average or Peak Power Limited	Comparative Interference Power (dBm/400 MHz)
10 MHz PRF Non-Dithered Impulse	Average Power Limited	-25.3
1 MHz PRF Non-Dithered Impulse	Average Power Limited	-15.3
Dithered Impulse	Peak Power Limited	-18
Pulsed FH (Partial Overlap of Hop Channels)	Peak Power Limited	-24.9

Pulsed FH (Complete Overlap of Hop Channels)	Peak Power Limited	-24.8
Pulsed FH (No Overlap of Hop Channels)	Peak Power Limited	-24.9
Pulsed FH (No Overlap of Hop Channels)	Average Power Limited	-18.3
Pulsed FH (No Overlap of Hop Channels)	Average Power Limited	-15.3

As shown in Table E-5, the interference power levels of the pulsed FH signals are comparable to the non-dithered impulse and dithered impulse signals. The values shown in the table must be further adjusted for propagation loss, antenna gains, etc. to estimate the actual interference power from the one radar. However, these extra loss values should be the same across all the signal cases being analyzed, and have no effect on a comparative analysis. Thus, for the pulsed FH signal characteristics considered, one pulsed FH radar should be no worse, from an interference standpoint, than one impulse radar.

This analysis is applicable only to assessing the interference impact to an EESS sensor receiver, because the effective interference signal at a space-borne sensor is an aggregate from a large number of vehicular radars. In addition, this aggregate signal is of concern over an extensive frequency range because the sensors are wide bandwidth devices. Thus, the frequency hopping of an individual radar as a part of an aggregate has a different impact in this case than frequency hopping devices would have in other bands where they might operate in close proximity to relatively narrowband ground-based receivers. For ground-based receivers, a single frequency hopping transmitter would be dominant in setting the effective interference power level and only a relatively narrow frequency range is of primary concern. Thus, the results of this analysis cannot be extended to assess the potential interference of a pulsed FH signal on ground-based receivers.

For the pulsed FH, the worst practical case would appear to be a hopping frequency range of 1 GHz, since this covers the entire 23.6-24 GHz EESS band, given the limitation that the center frequency must be located above 24.075 GHz. As shown in the analysis, the number of hop channels is not a factor. The average power in the 400 MHz sensor bandwidth would be -15.3 dBm (-41.3 + 10 Log (400)). For an average power of -41.3 dBm the same average power is in a 400 MHz bandwidth as the limiting impulse case considered in the study previously performed by NTIA.

It should be noted that the peak and average power measurements must be performed at the maximum values across the 23.6-24 GHz frequency band. The compatibility of pulsed FH signals with EESS sensor receivers will not be impacted by the frequency hopping pattern employed (e.g., psuedo random). However, for the compliance measurements and compatibility it is important that the Commission's Rules require the frequency hopping channels to be used on a regular periodic basis. These issues will be addressed in greater detail in the proposed measurement procedures.