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Analysis of 2016 Proposed Changes to Existing Out of Band Emissions (OOBE) Rules:

Adjacent Channel Interference from Unlicensed National Information Infrastructure (UNII) Transmissions into the 5.9 GHz Wireless Access for Vehicular Environment (WAVE) Band

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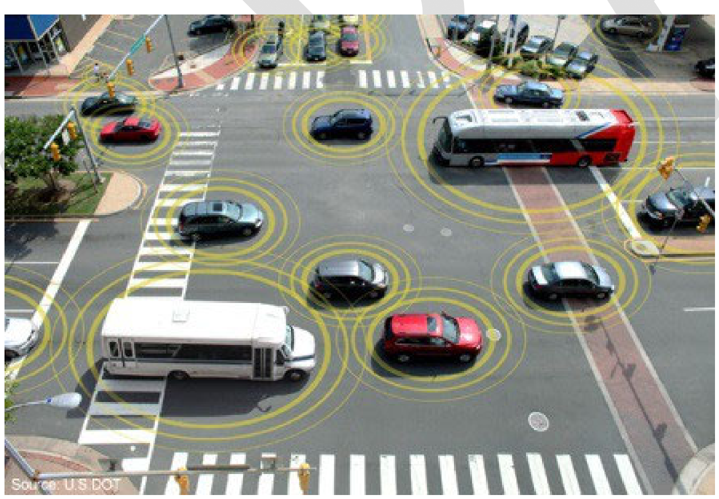

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16. Abstract The Federal Communications Commission (FCC) released a Memorandum of Opinion and Order on March 1, 2016 that has the effect of increasing the out-of-band emission (OOBE) limits for Unlicensed National Information Infrastructure (U-NII) devices operating in the 5725-5850 MHz band. The impact of these new OOBE levels, if used in devices other than point-to-point links can have a significant negative impact on users in adjacent spectrum—the spectrum allocated for transportation safety from 5850-5925 MHz. This USDOT analysis paper examines the changes to the OOBE levels on the Dedicated Short Range Communication Service (DSRCS) that supports safety applications in the transportation sector. The analysis concludes that the new limits potentially increase interference to DSRC, but the specific level cannot be established without a deployment scenario and further analysis.		
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Summary

The Federal Communications Commission (FCC) released a Memorandum of Opinion and Order on March 1, 2016 that has the effect of increasing the out-of-band emission (OOBE) limits for Unlicensed National Information Infrastructure (U-NII) (FCC Rules Part 15.407) devices operating in the 5725-5850 MHz band, bringing them more in line with digitally modulated devices (Part 15.247). The impact of these new OOBE levels, if used in devices with other than point-to-point links, can have a negative impact on users in adjacent spectrum (5850-5925 MHz)—the spectrum allocated for transportation safety.

This USDOT analysis paper examines the changes to the OOBE levels on the Dedicated Short Range Communication Service (DSRCS) that supports safety applications in the transportation sector. The analysis concludes that the new limits potentially increase interference to DSRC, but the specific level cannot be established without studying specific deployment scenarios and conducting further analysis.

1. Background Issue

In a Notice of Proposed Rulemaking (NPRM) released in 2013 by the FCC, the Commission proposed to amend Part 15 of their rules governing operation of Unlicensed National Information Infrastructure (U-NII) devices in the 5 GHz band.[1] The FCC has released several Reports and Orders (R&Os) and Memorandum Opinions and Orders (MO&Os) since 2013 that impact that portion of the 5 GHz band directly below that of the Dedicated Short-Range Communications Service (DSRCS). Most notable from the standpoint of DSRCS are new rules allowing U-NII devices to operate up to 5850 MHz and increasing the permissible Out of Band Emissions (OOBE) levels of U-NII devices.[2,3]

This USDOT analysis paper examines the OOBE changes and the potential impact on DSRCS. Simply stated, the increase in OOBE identified in the MO&O for Part 15.407 (issued March 1, 2016) represents an improvement over the OOBE limits allowed for digitally modulated devices in Part 15.247. However, the new OOBE limits described in Part 15.407 are above the previous levels allowed for U-NII devices and the level of potential interference is very scenario-dependent, and has the potential to significantly disrupt DSRCS access.

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[1] FCC Notice of Proposed Rulemaking 13-22, ET Docket No. 13-49, adopted February 20, 2013, available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-13-22A1_Rcd.pdf, last accessed July 18, 2016.
[2] FCC Report and Order 14-30, ET Docket No. 13-49, adopted March 31, 2014, available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-30A1.pdf, last accessed July 18, 2016.
[3] FCC Memorandum Opinion and Order 16-24, ET Docket No. 13-49, adopted March 1, 2016, available at https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-24A1.docx, last accessed July 18, 2016.

2. DSRC and U-NII Communications Systems

This section describes the basic technologies discussed in this paper: Dedicated Short-Range Communications Systems (DSRCS), operating in the 5.9 GHz band; and Unlicensed National Information Infrastructure (UNII) devices, operating in the 5.0 GHz band.[4]

2.1. Radio Transmission Primer

Fundamental to this discussion is a basic understanding of the physics of a radio signal. A transmitter broadcasting on a specific channel is designed to emit radio frequency (RF) energy at a certain frequency (expressed in Hertz (Hz) or multiples thereof); this assigned frequency is generally known as the "center frequency." Each channel is then assigned a "bandwidth" (also expressed in Hz), which may also correspond to the spacing between channels. For example, DSRC channel 172 has a center frequency of 5860 MHz, and a bandwidth of 10 MHz, and covers a range from 5855 MHz to 5865 MHz. The next channel (channel 174) has a center frequency of 5870, spanning the 10 MHz bandwidth from 5865 MHz to 5875 MHz. **Error! Reference source not found.**Figure 2-1 shows the band plan and channel assignments for DSRC and U-NII-3 devices.

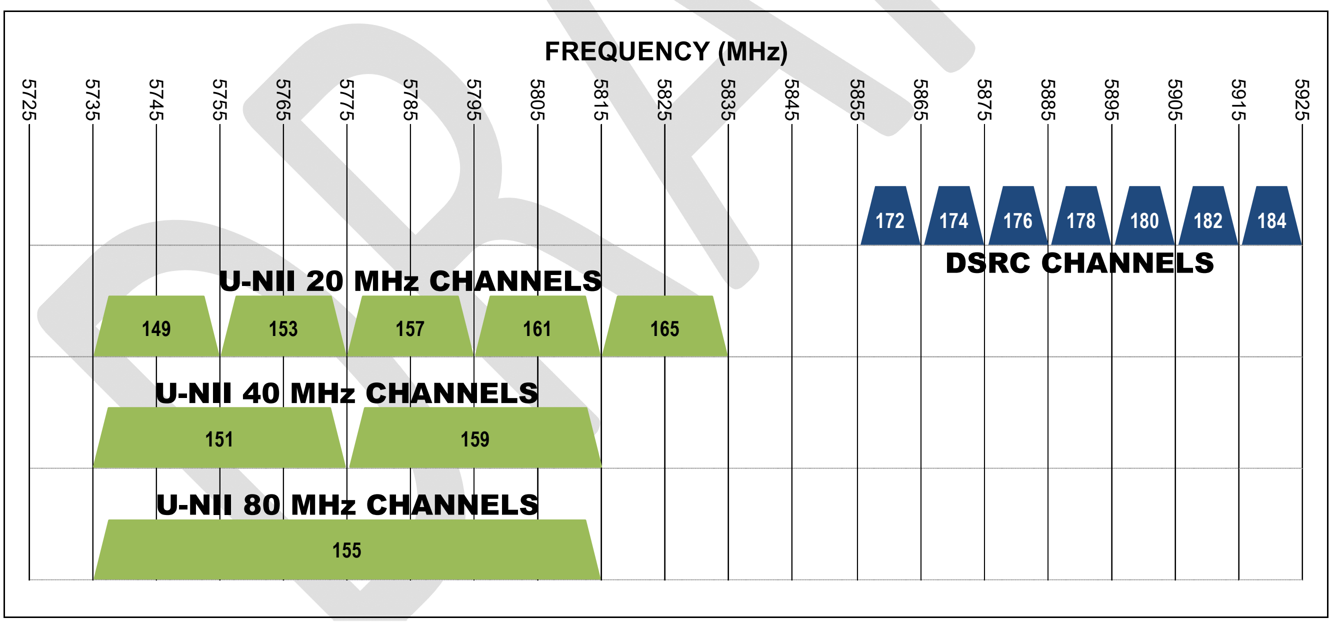

Figure 2-1: DSRC and U-NII-3 Band Plan

[4] For consistency, this report references frequencies that fall within the broad 5 GHz frequency band in equivalent MHz. For example, DSRC channel 172 would be described as 5860 MHz rather than 5.860 GHz.

Due to the physics of radio frequency energy generation, it is virtually impossible for any device—whether a DSRC On-Board Unit (OBU) or a U-NII Wi-Fi device, digitally modified or not—to emit RF energy only at the center frequency of the assigned channel. Some of the radio energy will transmit at slightly higher and slightly lower frequencies, but still falling within the assigned channel's bandwidth. In the case of both DSRC and the UNII transmissions, they use multiple subcarriers within the 10 MHz bandwidth which enables the transmission of more data than a single carrier. In some cases, there can be "spurious emissions" of RF energy into frequencies assigned to other channels. These spurious emissions are known as an Out-Of-Band Emissions (OOBE).

To limit those spurious emissions, each band plan includes a "transmission mask" or "spectral mask" that sets restrictions on the permissible levels of RF energy that can be emitted outside of the center frequency. The spectrum mask is developed by technical committees (such as the Institute of Electrical and Electronics Engineers (IEEE)) comprised of experts in the physics of RF energy transmission and the inherent capabilities of RF transmitters and receivers. Spurious emissions are reduced or attenuated through the use of band-pass filters and other technologies that only limit the transmission of frequencies to a certain range and reducing any RF energy outside the channel as much as possible. Spectrum masks vary widely, depending upon the inherent characteristics of the frequency bands involved. Figure 2-2 plots a radio signal (in yellow) overlaid against the channel's spectral mask (in green).

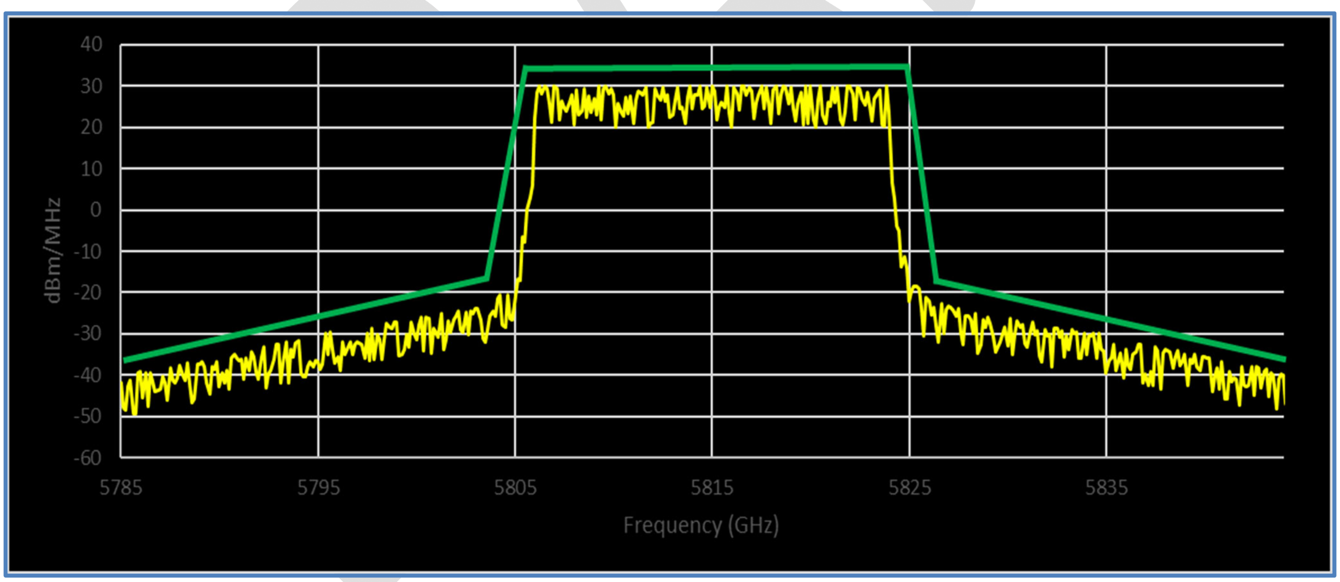

Figure 2-2. Typical Spectral Mask and RF Signal Measurement Plot

2.2. Dedicated Short-Range Communications Systems

DSRC is a Wi-Fi derivative technology designed for use as part of Intelligent Transportation Systems (ITS). While standard Wi-Fi works well in stationary or slow-moving environments, DSRC is uniquely configured to enable continuous, high-speed, trusted and authenticatable data exchange among moving vehicles and between vehicles and roadway infrastructure or mobile devices, to support safety-critical and other transportation-related applications in a highly dynamic operating environment. Current configuration standards are capable of supporting communications between vehicles traveling at relative velocities up to and exceeding 140 mph.

DSRC has been standardized through the Institute of Electrical and Electronics Engineers (IEEE) Standards Association process, and encompasses two families of standards: IEEE 802.11 addresses the physical (PHY) and media access (MAC) layers and IEEE 1609 addresses the upper layers and security.[5] Work on technical standards was originally begun by ASTM in 1999, and subsequently transferred to IEEE. Most recently, the IEEE 802.11p Task Group completed work begun in 2004 to develop and test DSRC technology and to ensure it was sufficiently robust to meet the needs of the high-speed surface transportation environment. The DSRC service must meet specialized requirements for secure, low latency, wireless mobile data communication in both a broadcast and point-to-point operation, using a band of the spectrum with few other users. Amendment "p" was incorporated into the overall IEEE 802.11 standard with revision IEEE 802.11-2012.

As of 2017, no other wireless technology has demonstrated the proven capability to provide all the critical attributes of DSRCS needed to support Connected Vehicle safety applications. DSRCS is important to the Nation as it can be configured to enable real-time crash- avoidance alerts and warnings, with the potential to address 83 percent of light-vehicle crashes involving unimpaired drivers, offering a significant opportunity to achieve a transformation in transportation safety.[6]

2.3. Unlicensed National Information Infrastructure Devices

U-NII devices are commercially available wireless access points and client devices that allow devices to communicate with one another using a local area network or through the Internet. In 1985, the FCC first authorized the operation of unlicensed spread spectrum systems, including in the 2.4 GHz

[5] The design of telecommunications systems follow the Open Systems Interconnection (OSI) conceptual model that characterizes and standardizes the communication functions regardless of underlying internal structure and technology. The goal of the OSI approach is to achieve interoperability of diverse communication systems through standard protocols. The OSI model partitions a communication system into abstraction layers, where standardization at the "lower levels" is essential to device interoperability.

[6] For additional background on DSRC, see "Status of the Dedicated Short-Range Communications Technology and Applications, Report to Congress," July 2015, available at www.its.dot.gov/research_archives/connected_vehicle/ pdf/dsrcreportcongress_final_23nov2015.pdf, accessed July 14, 2016.

(2400 MHz) and 5 GHz (5000 MHz) bands.[7] Work to create an international standard began in earnest in September 1990 under IEEE 802.11, with the first approved and adopted standard published in June 1997.[8] This original standard used the 2.4 GHz band. As Wi-Fi technology began to achieve greater market penetration over the ensuing decade, improvements were made to increase the data rate in the 2.4 GHz band (amendments "b" and "g") and to cover operation in the 5 GHz band (amendment "a") in 1999.[9]

This latter expansion is referred to as Unlicensed National Information Infrastructure/Shared Unlicensed Personal Radio Network (U-NII/SUPERNet) Operations and has significantly changed computing and communications. The higher data rates and reduced level of interference from Industrial, Scientific, and Medical (ISM) allocations were a boon to deployment. Use in wireless networking began to take off after rules were adopted by the FCC for 915 MHz, 2.4 GHz, and 5 GHz devices permitting Orthogonal Frequency Division Multiplexing (OFDM) in 2002.[10] Further improvements and modifications to the IEEE 802.11 standard occurred over the ensuing years, with amendment "n" being approved in 2007 and amendment "ac" approved in 2013. Amendment "ac" offered the first version of Gigabit Wi-Fi.[11]

U-NII/SUPERNet was intended to allow computers and other digital devices (including televisions, video cameras, and other high bandwidth devices) to communicate in unlicensed bands over relatively low power links in relatively stationary environments. In recent years, changes to the 802.11 standard have allowed higher data rates, larger bandwidths and, with antenna gain, higher power point-to-point operation. As shown in Figure 2-3, the frequency bands for U-NII and DSRC devices in the upper portion of the 5 GHz spectrum are adjacent to one another, while there are numerous unlicensed devices that operate in the same DSRC frequency band. This proximity of the DSRC and U-NII frequency bands—and the potential for OOBE interference between U-NII and DSRC services—is the central issue discussed in this report.

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[7] "Report of the Unlicensed Devices and Experimental Licenses Working Group." Federal Communications Commission, Spectrum Policy Task Force. November 15, 2002, p. 8. Available at https://transition.fcc.gov/sptf/files/e&uwgfinalreport.pdf, accessed January 3, 2018.

[8] "IEEE Celebrates Global Impact of Wireless Communications at 25th Anniversary of Ubiquitous IEEE 802.11 Standard," IEEE Press release. Available at https://mentor.ieee.org/802.11/dcn/15/11-15-0844-01-0000-draft-25th-anniversary-press-release.docx. Last accessed December 27, 2017.

[9] "Wireless LAN 802.11 Wi-Fi," Engineering and Technology History Wiki, available at http://ethw.org/Wireless_LAN_802.11_Wi-Fi, last accessed December 27, 2017.

[10] "Unlicensed Spectrum and The U.S. Economy, Quantifying the Market Size and Diversity of Unlicensed Devices," Consumer Electronics Association, no date, Figure 1, Page 2. Available at https://www.cta.tech/cta/media/policyimages/policypdfs/unlicensedspectrumwhitepaper.pdf, accessed December 27, 2017.

[11] SearchNetworking.com website, "802.11ac standard: How did we get here?" Available at http://searchnetworking.techtarget.com/feature/80211ac-standard-How-did-we-get-here, last accessed June 8, 2016.

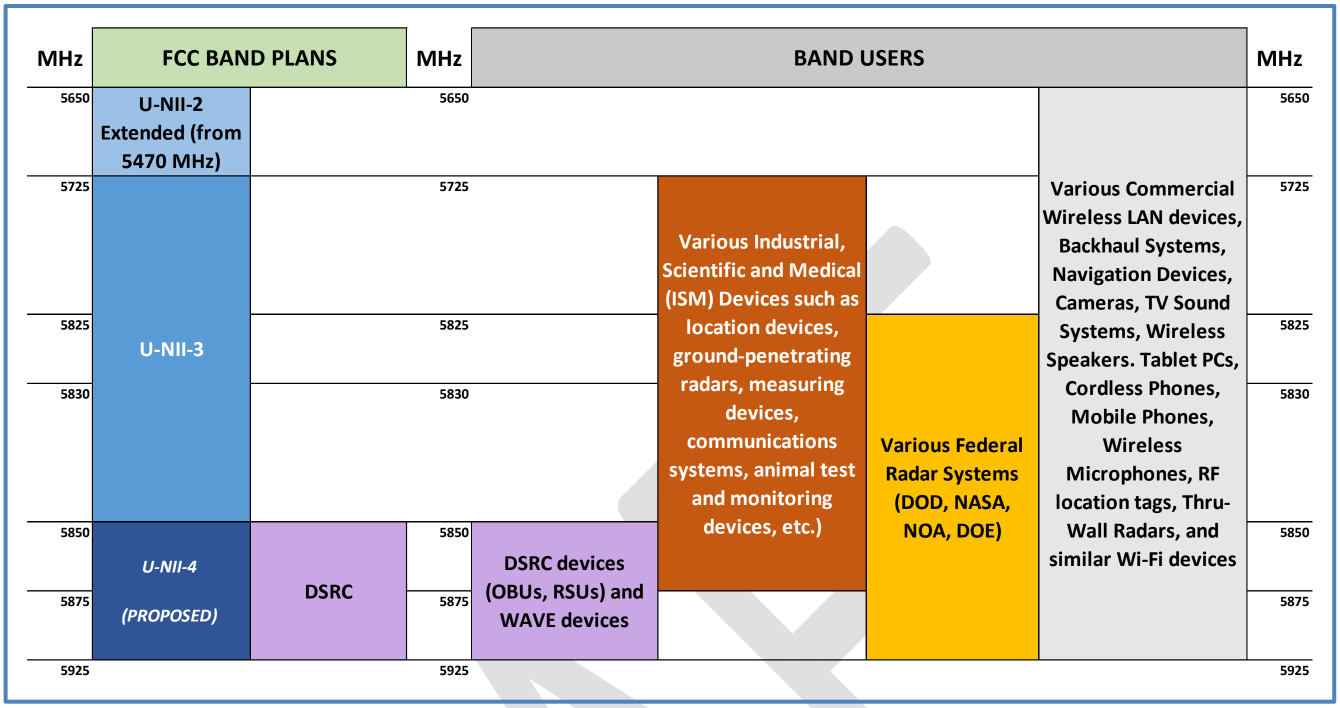

Figure 2-3: Band Plans and Devices Operating in or Adjacent to DSRC Spectrum

3. Rules and Regulations

This section describes the pertinent Federal rules and regulations promulgated by USDOT, the FCC, and other agencies that govern DSRC services and U-NII devices.

3.1. DSRCS Rules and Regulations

Basic operating principles. Covered under Part 90, Subpart M (Intelligent Transportation Systems Radio Service), §90.371 through §90.383.[12]

> This part of the FCC rules covers DSRC Roadside Units (RSU) including coordination with Federal radiolocation series, authorization to operate a DSRC RSU, RSU license areas, frequencies available, power levels, channel plan, and standards. These rules have evolved over time. The last modification was made in 2006.

DSRCS On-Board Units. Covered under Part 95, Subpart L, §95.1501 through §95.1511.[13]

> This subpart of the FCC rules sets out the regulations for DSRC On-Board Units (OBU) including authorized locations, eligibility, whether stations are required to transmit an identifier (they are not), the standard the device must be built to, and frequencies available for use.

3.2. Part 15 Rules and Regulations

A broad range of unlicensed devices are allowed access to the U-NII spectrum up to 5850 MHz.[14] Other unlicensed devices are allowed access up to 5875 MHz including Industrial, Scientific, and Medical devices that use radio frequency (RF) energy for purposes other than telecommunications. This paper addresses devices impacted by the change in FCC 16-24, Memorandum Opinion and Order, “Revision of Part 15 of the Commission’s Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band.”[15] Part 15, Section 407 of the FCC Rules includes only those devices operating up to 5850 MHz. Specifically, the FCC modified its rules “to provide a

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[12] FCC Regulations, 47 CFR 90, Subpart M, Governing the Licensing and Use of Frequencies in the 5850-5925 MHz Band for Dedicated Short-Range Communications Service (DSRCS), available at www.ecfr.gov/cgi-bin/text-idx?SID=1ca58f726535c10370ac1d7b745470ff&mc=true&node=sg47.5.90_1365.sg1&rgn=div7, last accessed July 25, 2016.

[13] FCC Regulations, 47 CFR 95, Subpart L, Dedicated Short-Range Communications Service On-Board Units (DSRCS-OBUs) https://www.gpo.gov/fdsys/pkg/CFR-2009-title47-vol5/pdf/CFR-2009-title47-vol5-part95.pdf, last accessed December 27, 2017.

[14] U-NII devices are unlicensed intentional radiators that operate in the frequency bands 5.15-5.35 GHz and 5.47-5.825 GHz, and which use wideband digital modulation techniques to provide a wide array of high data rate mobile and fixed communications for individuals, businesses, and institutions. See 47 CFR §15.403(s).

[15] FCC MO&O, Revision of Part 15 of the Commission’s Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Released March 2, 2016. Available at: https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-24A1_Rcd.pdf (last accessed 10/24/2017)

relaxation of the out-of-band emission (OOBE) limits for operation of U-NII-3 (5.725-5.850 GHz) band devices."[16]

The First R&O extended the band edge from 5825 MHz to 5850 MHz.[17] In March 2016, the FCC published another R&O with the goal of consolidating the provisions applicable to digitally-modulated devices from Section 15.247 with the U-NII rules in Section 15.407 so that "all of the digitally modulated devices operating in the U-NII-3 band will operate under a consistent set of rules." [18]

To understand the implications of this change, the following sections describe what was formerly in 15.247; what was in 15.407 prior to 2016; and, what is now in the new 15.407. It examines the transmitted power, power density, and OOBE, and compares each iteration to provide a perspective on what the changes offer.[19] Since these sections have changed over time, the appendices contain the original text of the rules, at least as far back as when the rule was fully printed in the Federal Register, until the most recent rule was printed. Additionally, any changes to the rule in the intervening years is specified, again, as it appeared in the Federal Register. Since the focus of this paper is the OOBE, many references will be made to the individual sections where data/guidance on the parameters can be found. This document uses a shorthand reference to identify the three principle sections. Table 3-1 provides a cross reference for the reader.

Table 3-1. Terminology Used to Simplify Reference to FCC Rules

Shorthand Reference	FCC Rule (47 CFR Part 15)	Effective date
"247" or "15.247"	Subpart C, §1515.247	Effective, May 1, 2014
"407-Old" or "15.407-Old"	Subpart E, §15.407	Prior to April 6, 2016
"407-New" or "15.407-New"	Subpart E, §15.407	After April 6, 2016

It should also be noted that some of the devices operating under these rules also comply with IEEE-802.11-2016. Within the IEEE 802.11ac modification of this standard, channel bandwidths of 20, 40, 80, and 160 MHz are described. Table 3-2 shows the current IEEE channel plan that incorporates channels leading up to 5850 MHz (i.e., those channels adjacent to the DSRCS band), with channel center frequencies and bandwidths indicated; these channels are also illustrated in Figure 2-1. The

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[16] There are several sub-bands within the U-NII frequency allocation (e.g., U-NII-1, U-NII-2A, U-NII-2B, etc.). This paper is primarily concerned with the upper portion of that band, 5725-5850 MHz which is known as the U-NII-3 band.

[17] "Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (UNII) Devices in the 5 GHz Band, First Report and Order." ET Docket 13-49, 29 FCC Rcd 4127 (2014) (First R&O). See also, 47 C.F.R. Part 15 Subpart E—Unlicensed National Information Infrastructure Devices. See also, 47 C.F.R. § 15.247.

[18] FCC MO&O, Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Released March 2, 2016, paragraph 2. Available at: https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-24A1_Rcd.pdf, accessed January 3, 2018.

[19] "Power density" is the amount of RF power in a given unit. When referencing RF power density, it is typically represented as dBm (the number of decibels (dB) referenced to one milliwatt of power) per MHz of frequency.

FCC rules do not require these channel bandwidths nor specify channel spacing. (It should be noted that not all digitally modulated devices are required to follow the IEEE 802.11 channel plan. One example is the potential sharing of the U-NII bands with cellular off-loading systems.) These bandwidths and channel center frequency, along with the standards spectral mask will be used to determine the potential for interference.

Table 3-2: U-NII-3 Channels Nearest the DSRC Band Edge

Channel	Center Frequency	Bandwidth
165	5825	20
159	5795	40
155	5775	80

FCC Part 15.247 and 15.407 have undergone many changes since first introduced. In 2014, the FCC modified 15.37(h) to make digitally modulated devices manufactured after June 2, 2015 to be compliant with the emission rules in 15.407.[20] The latest change, as noted previously, was intended to align the transmitter characteristics of digitally modulated devices originally operating under 15.247 and U-NII-3 devices in 15.407 and was published in April 2016. To understand this change, the following sections describe the old 407 rules and the current 247 and 407 rules.

3.2.1. Discussion of Part 247 (updated May 2014)

Within 15.247, there were several sections that applied. Pertinent portions are excerpted below for convenience; the asterisks (*****) represent passages that are not directly relevant to the discussion presented in this paper. However, the entirety of Part 15.247 (including deleted sections) can be found in appendix A.

CURRENT RULE (15.247, May 1, 2014)	KEY POINTS PERTINENT TO DISCUSSION
§ 15.247 Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz. (a) Operation under the provisions of this Section is limited to frequency hopping and digitally modulated intentional radiators that comply with the following provisions: *****	

[20] Federal Register, 79 FR 24569, pages 24569-24580, https://www.federalregister.gov/documents/2014/05/01/2014-09279/unlicensed-national-information-infrastructure-u-nii-devices-in-the-5-ghz-band

CURRENT RULE (15.247, May 1, 2014)	KEY POINTS PERTINENT TO DISCUSSION
(2) Systems using digital modulation techniques may operate in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz	**15.247(a)(2) sets the minimum 6 dB bandwidth at 500 kHz.**
*****	
(b) The maximum peak conducted output power of the intentional radiator shall not exceed the following:	
*****	
(3) For systems using digital modulation in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands: 1 Watt. As an alternative to a peak power measurement, compliance with the one Watt limit can be based on a measurement of the maximum conducted output power. Maximum Conducted Output Power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), the *maximum conducted output power* is the highest total transmit power occurring in any mode.	**15.247(b)(3) sets the max power at 1 Watt, based on a conducted measurement.**
(4) The conducted output power limit specified in paragraph (b) of this section is based on the use of antennas with directional gains that do not exceed 6 dBi [decibels-isotropic]. Except as shown in paragraph (c) of this section, if transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1), (b)(2), and (b)(3) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.	**15.247(b)(4) describes power limits based on a directional gain antenna. Any gain more than 6 dBi must have a corresponding reduction in transmitter power so that effective isotropic radiated power (EIRP) does not exceed 36 dBm.**
*****	
(c) Operation with directional antenna gains greater than 6 dBi.	
(1) Fixed point-to-point operation	

CURRENT RULE (15.247, May 1, 2014)	KEY POINTS PERTINENT TO DISCUSSION
*****	
(ii) Systems operating in the 5725-5850 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted output power.	**15.247(c)(1)(ii) specifies that for point-to-point systems the transmit power does not have to be reduced in accordance with 15.247(b)(4) when the directional gain is greater than 6dBi, but does not specify any upper limit to the gain.**
*****	
(d) In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, as permitted under paragraph (b)(3) of this section, the attenuation required under this paragraph shall be 30 dB instead of 20 dB. Attenuation below the general limits specified in § 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) (see § 15.205(c)).	**15.247(d) defines the out-of-band emissions; this will be discussed in more detail.**
(e) For digitally modulated systems, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission. This power spectral density shall be determined in accordance with the provisions of paragraph (b) of this section. The same method of determining the conducted output power shall be used to determine the power spectral density.	**15.247(e) states that the power spectral density shall not be greater than 8 dBm in any 3 kHz band, essentially restating the power in the smallest bandwidth (from 15.247(a)(2)).**

[END OF CITATION]

3.2.2. Discussion of "407-Old" (through December 2014)

There have been many updates to Part 407 since the last full version was published on July 31, 1998. Power, bandwidth, and OOBE measurements are addressed in some revisions, but not all. This section takes 15.407 from December 23, 2014 and identifies the critical text needed to compare the "old" 407 to the newer version. Note that all the changes and a final version can be found in Appendix A.

CURRENT RULE (15.407, December 23, 2014)	KEY POINTS PERTINENT TO DISCUSSION
15.407(a) Power limits *****	
(3) For the band 5.725–5.85 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 [Watt]. In addition, the maximum power spectral density shall not exceed 30 dBm in any 500-kHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. However, fixed point-to-point U–NII devices operating in this band may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted power. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U–NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations. *****	**15.407(a)(3) sets the max power at 1 Watt/30 dBm, based on a conducted measurement and the maximum power spectral density at 30 dBm/500 kHz.** **15.407(a)(3) sets the minimum 6 dB bandwidth at 500 kHz. This is restated in paragraph 15.407(e).** **15.407(a)(3) describes power limits based on antenna gain, limiting any combination of power and gain to no more than 36 dBm EIRP.** **15.407(a)(3) does not impose an upper limit on antenna gain for point-to-point U-NII devices.**

CURRENT RULE (15.407, December 23, 2014)	KEY POINTS PERTINENT TO DISCUSSION
(5) The maximum power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements in the 5.725–5.85 GHz band are made over a reference bandwidth of 500 kHz or the 26 dB emission bandwidth of the device, whichever is less. Measurements in the 5.15–5.25 GHz, 5.25–5.35 GHz, and the 5.47–5.725 GHz bands are made over a bandwidth of 1 MHz or the 26 dB emission bandwidth of the device, whichever is less. A narrower resolution bandwidth can be used, provided that the measured power is integrated over the full reference bandwidth.	**15.407(a)(5) specifies that measurements in the 5725–5850 MHz band are made over a reference bandwidth of 500 kHz or the 26 dB emission bandwidth of the device, whichever is less.**
*****	
(b) Undesirable emission limits. Except as shown in paragraph (b)(7) of this section, the maximum emissions outside of the frequency bands of operation shall be attenuated in accordance with the following limits:	**15.407(b) defines the out-of-band emissions; this will be discussed in more detail.**
*****	
(4) For transmitters operating in the 5.725–5.85 GHz band: All emissions within the frequency range from the band edge to 10 MHz above or below the band edge shall not exceed an e.i.r.p. of -17 dBm/MHz; for frequencies 10 MHz or greater above or below the band edge, emissions shall not exceed an e.i.r.p. of -27 dBm/MHz.[21]	**15.407(b)(4) defines out-of-band emissions in the U-NII-3 band.**
*****	
(e) Within the 5.725–5.85 GHz band, the minimum 6 dB bandwidth of U–NII devices shall be at least 500 kHz.	**15.407(e) reinforces that the minimum bandwidth is 6 dB at 500 kHz.**

[END OF CITATION]

[21] The FCC Rules use various abbreviations for effective isotropic radiated power, including “EIRP” and “e.i.r.p.” This report generally uses the abbreviation EIRP.

Apropos to this discussion, the FCC Rules define Emission Bandwidth in Section 15.403(i) as follows:

CURRENT RULE (15.403)	Key Points Pertinent to Discussion
§ 15.403 Definitions. ***** **(i) Emission bandwidth.** For purposes of this subpart the emission bandwidth shall be determined by measuring the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, that are 26 dB down relative to the maximum level of the modulated carrier. Determination of the emissions bandwidth is based on the use of measurement instrumentation employing a peak detector function with an instrument resolution bandwidth approximately equal to 1.0 percent of the emission bandwidth of the device under measurement.	**15.403(i) specifies how to measure channel bandwidth using the 26 dB down points on either edge of the channel.**

[END OF CITATION]

3.2.3. Discussion of "407-New" (updated April 2016)

Much of what was described in the previous section (407-Old) still applies. The only difference for our purposes is the OOBE have been changed.

[START OF CITATION]

15.407(b)(4)(i) All emissions shall be limited to a level of -27 dBm/MHz at 75 MHz or more above or below the band edge increasing linearly to 10 dBm/MHz at 25 MHz above or below the band edge, and from 25 MHz above or below the band edge increasing linearly to a level of 15.6 dBm/MHz at 5 MHz above or below the band edge, and from 5 MHz above or below the band edge increasing linearly to a level of 27 dBm/MHz at the band edge.

15.407(b)(4)(ii) Devices certified before March 2, 2017 with antenna gain greater than 10 dBi may demonstrate compliance with the emission limits in § 15.247(d), but manufacturing, marketing and importing of devices certified under this alternative must cease by March 2, 2018. Devices certified before March 2, 2018 with antenna gain of 10 dBi or less may demonstrate compliance with the emission limits in § 15.247(d), but manufacturing, marketing and importing of devices certified under this alternative must cease before March 2, 2020.

[END OF CITATION]

4. Creating the Transmitter Envelope

Since the goal of modifying 15.407 was to bring digitally-modulated devices described in 15.247 and U-NII-3 devices from 15.407 into alignment, a side-by-side comparison is offered here. The end goal is to be able to compare all three envelopes on a dBm/MHz scale. The envelopes describe here are required but not sufficient to describe a specific channel. They do not address all aspects of an individual channel, but provide a broad perspective within which a channel must fit.

4.1. In Band Emission Comparison

Energy in band for all three rules are the same, 1 Watt/30dBm. Each is also allowed a 6 dB antenna and a corresponding 36 dBm EIRP for non-point-to-point systems. For point-to-point systems, no maximum antenna gain is indicated.

4.2. Out-Of-Band Emission (OOBE) Comparison

Part 15.247 specifies that in any 100 kHz bandwidth outside the frequency band in which the digitally-modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power.

It is important to note that the OOBE levels are relative to the in-band emission levels. Essentially, the higher the in-band emission, the higher the OOBE. For each dBm in additional power transmitted in-band, the OOBE can increase by a dBm as well.

Part 15.247 also states that the minimum channel 6 dB bandwidth is 500 kHz. If the 1 watt is spread evenly across this 500 kHz, then in a 100 kHz bandwidth, there would be 0.2 watts. 0.2 watts is approximately 23 dBm. Thus, the OOBE levels should be 3 dBm/100 kHz. Converting dBm/100kHz to dBm/MHz requires the formula:

$$dBm + 10 * log_{10}\left(\frac{1\ MHz}{.1\ MHz}\right) \qquad (Eq. 1)$$

The result is 13 dBm/MHz.

Ignoring antenna gain for the moment produces the power density envelope shown in Figure 4-1.

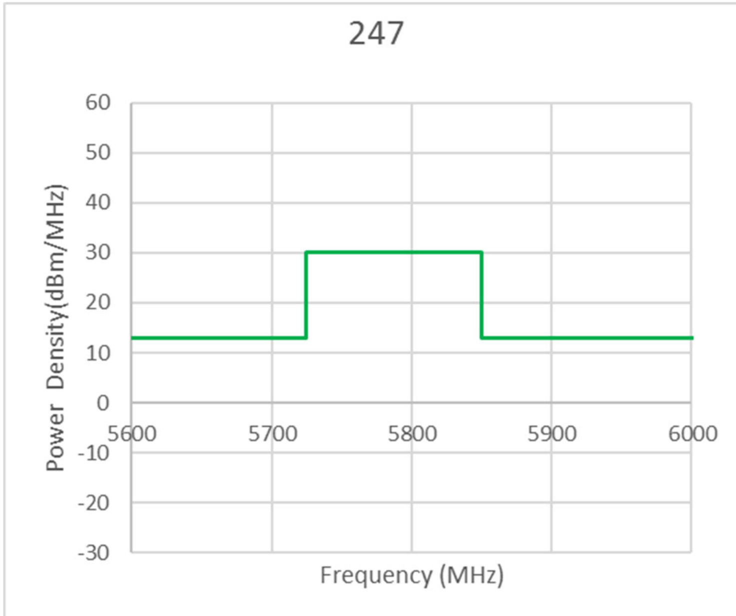

Figure 4-1: Part 15.247 Power Spectral Density Envelope

407-Old specifies that emissions within the frequency range from the band edge to 10 MHz above or below the band edge shall not exceed an EIRP of -17 dBm/MHz; for frequencies 10 MHz or greater above or below the band edge, emissions shall not exceed an EIRP of -27 dBm/MHz.

It is important to note that in 407, the OOBE levels are absolute (which is different than those specified in 247). The in-band energy does not dictate the OOBE. The exception here is that the channel is defined by the 26 dB point of the emission bandwidth. This is interpreted to mean that the energy at the edge of the emission bandwidth—which should not extend above the band edge—must be 26 dB below the main emission.

407(e) also states that the minimum channel 6 dB bandwidth is 500 kHz.[22] Again, ignoring antenna gain, the envelope is found in Figure 4-2. The 26-dB emission bandwidth does not have an impact on the envelope. It may when an individual channel is considered, but that will be discussed shortly.

[22] These are power density envelopes. It has been suggested that the maximum in-band power should be 33 dBm/MHz since the power per 500 kHz is 30 dBm. That could be considered true if the maximum power were not limited to 1 Watt or 30 dBm.

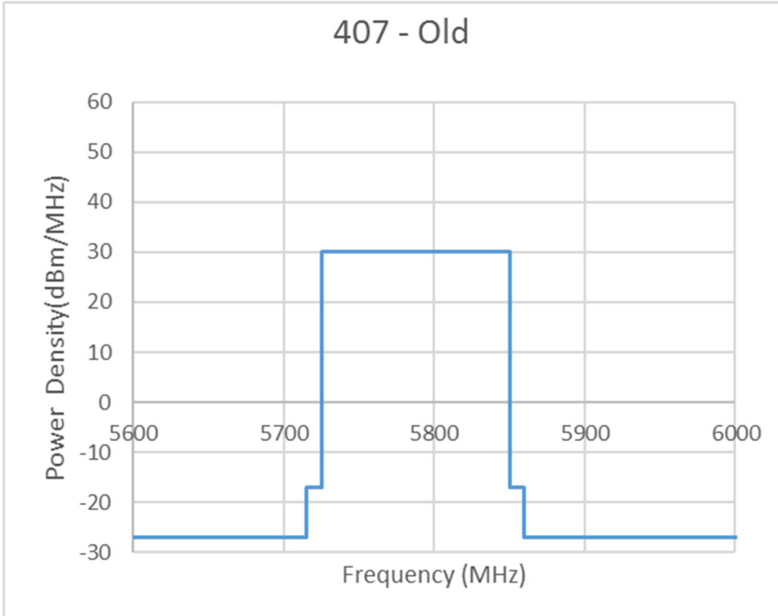

Figure 4-2. Part 15.407-Old Power Spectral Density Envelope

407-New specifies that emissions shall be limited to a level of −27 dBm/MHz at 75 MHz or more above or below the band edge increasing linearly to 10 dBm/MHz at 25 MHz above or below the band edge, and from 25 MHz above or below the band edge increasing linearly to a level of 15.6 dBm/MHz at 5 MHz above or below the band edge, and from 5 MHz above or below the band edge increasing linearly to a level of 27 dBm/MHz at the band edge.

As with 407-Old, the OOBE levels are absolute. The in-band energy does not necessarily dictate the OOBE. The exception here is that the channel is defined by the 26-dB point of the emission bandwidth. For this paper, this is interpreted to mean that the energy at the edge of the emission bandwidth, which should not extend above the band edge, must be 26 dB below the main emission.

407(e) also states that the minimum channel 6 dB bandwidth is 500 kHz. Again, ignoring antenna gain, the envelope is found in Figure 4-3. The 26-dB emission bandwidth does not have an impact on the envelope but will on an individual channel.

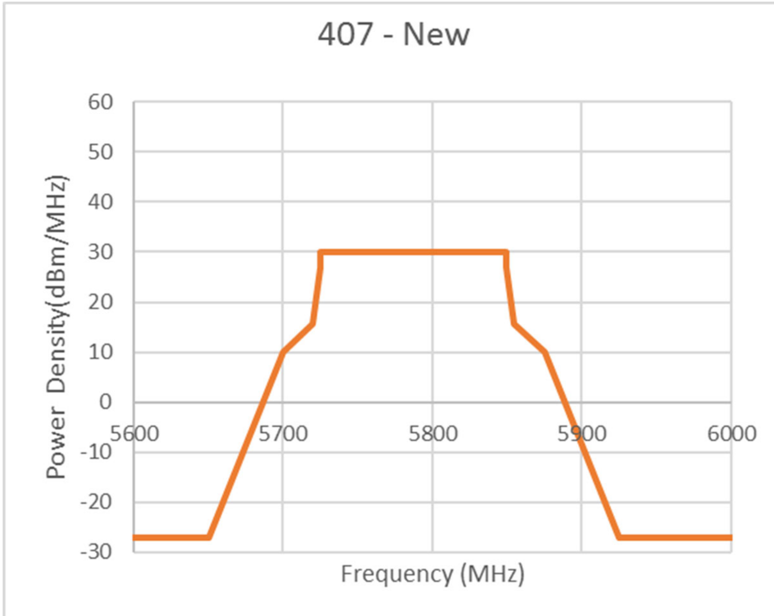

Figure 4-3. Part 15.407-New Power Spectral Density

Error! Reference source not found. overlays these three spectral densities (247, 407 Old, and 407-New) on a single chart; it offers a perspective on the differences but does fully illustrate the impact from a transmitter on adjacent band devices.

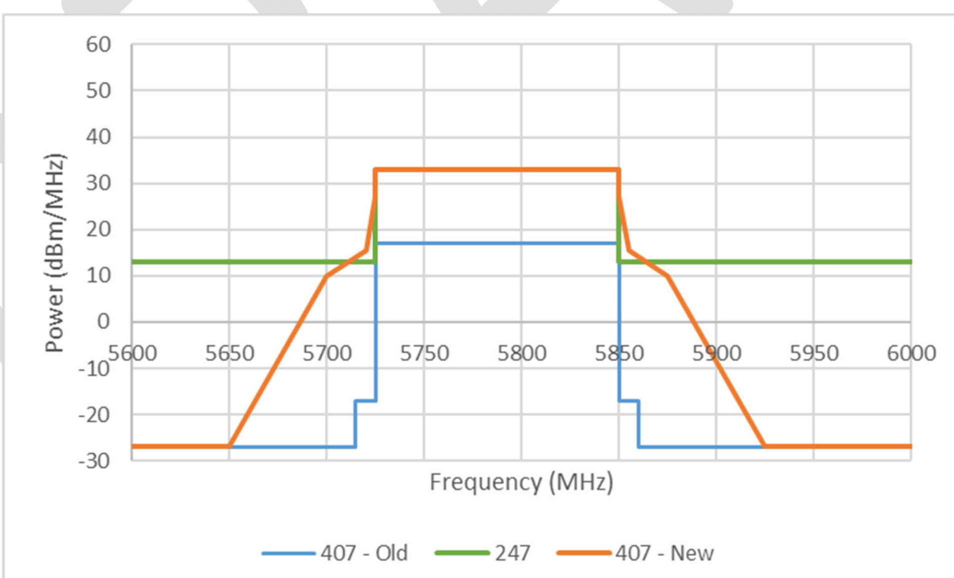

Figure 4-4. Power Spectral Density for Three Versions of FCC Rules

The FCC goal of bringing 15.407 and 15.247 in line with each other appears to have succeeded. The effect, at least when looking at the envelope is significantly more OOBE under 407-New versus 407-Old. But this only examines the envelope. To fully understand the change, specific channel widths need to be considered.

4.3. UNII Channel Mask from IEEE 802.11-2016

Figure 4-5 and Table 4-1 illustrate the transmitter mask for 802.11ac devices; values are in decibels relative to reference level (dBr).

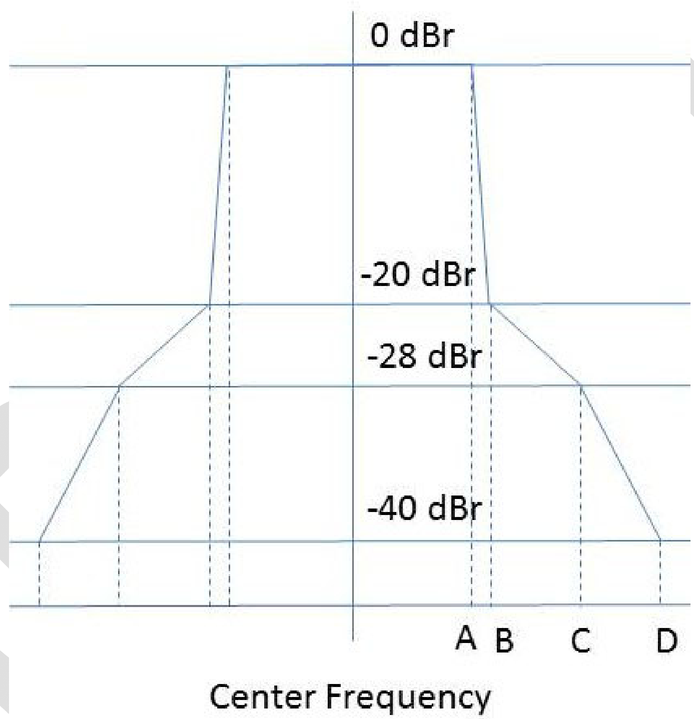

Figure 4-5. Spectral Mask for IEEE 802.11ac Transmitters

Table 4-1. Frequency Offsets for Spectral Mask for IEEE 802.11ac Transmitters (Figure 4-5)

Channel Bandwidth (MHz)	Point A (MHz)	Point B (MHz)	Point C (MHz)	Point D (MHz)
20	9	11	20	30
40	19	21	40	60
80	39	41	80	120
160	79	81	160	240

Combining the individual transmission masks for three U-NII channels (155, 159, and 165) into a single chart (Figure 4-6**Error! Reference source not found.**) offers a better perspective on the possibility of interference to an adjacent channel.

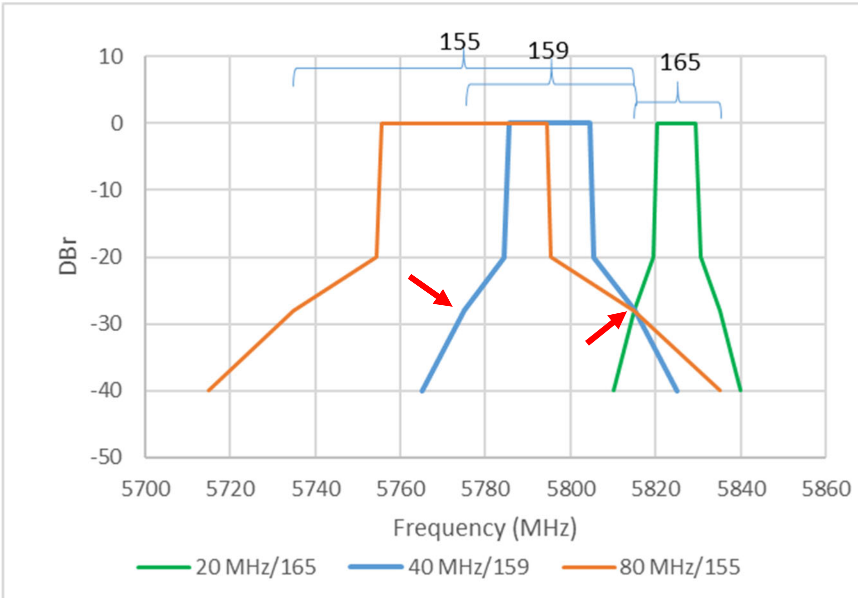

Figure 4-6: Graphical Depiction of Transmitter Masks for U-NII-3 Channels 155, 159, and 165

There are several items of note concerning these masks.

- First, the emission bandwidth (the -26 dB down points, shown with red arrows ➔) of one or more channels falls within the defined channel bandwidth.
- Second, the masks are relative to the maximum power in the channel – set the transmit power to 36 dBm/MHz and all the masks are now relative to that level. When additional antenna gain is added, they are again relative to that highest power.
- Third, the masks are designed such that the wider the channel, the wider the mask. However, the relationship between channel width and data rate is not linear, but dependent upon several additional factors including antenna configuration, channel mask, and signal modulation. The careful design of a system will optimize these complex relationships to maximize data throughput.
- Fourth, the mask is not defined below -40 dBr, but it is a reasonable assumption that the energy will continue to fall and there may still be energy encroaching (as OOBE) into adjacent channels.
- Finally, the devices compliant with the IEEE 802.11-2016 are not likely to have a significant impact on operations in adjacent bands. The devices that are not compliant with IEEE 802.11-2016 may have an impact and may require further investigation.

5. Impacts on Individual Channels

With the understanding of the emission envelopes described in the previous section, and an understanding of DSRC, this section focuses on interference from individual channels into DSRC channel 172. Individual U-NII-3 channels are described and an overlay of DSRC channel 172 is provided. This section focuses on out-of-band emissions associated with non-compliant (non-802.11-2016) devices.

5.1. Individual U-NII/Digitally Modulated Channels

In this section, an individual U-NII/digitally modulated channel (not IEEE 802.11-2016 compliant) is considered. It is important to keep in mind the FCC's goal of providing a common set of characteristics for the operation of both U-NII-3 (under 15.407) and digitally modulated devices (under 15.247) operating in the 5725-5850 MHz band. Thus, there is no further distinction drawn in this paper between U-NII and digitally modulated channels. They are referred to as digitally modulated channels but operating under two parts of the FCC rules.

The parameters used to define a channel put forward here are for illustrative purposes only. There are many combinations and several additional channel scenarios will be examined in the remainder of this document. But, a starting point is required. Thus, the initial set of operating characteristics are:

- Bandwidth: 20 MHz
- Center Frequency: 5840 MHz
- Antenna Gain: 0 dBi
- Maximum Conducted Power: 1 Watt/30 dBm

For this paper, we will make two assumptions. First, the transmission mask is identical above and below the main emission bandwidth. Second, the maximum power is spread evenly across the channel. Using the formula below yields a power spectral density (PSD) of 17 dBm/MHz for a 20 MHz wide channel:

$$30dBm + 10 * log_{10}\left(\frac{1\ MHz}{20\ MHz}\right) = 17\frac{dBm}{MHz} \qquad (Eq. 2)$$

247 requires the OOBE to be 20 dB below the maximum in-channel power in 100 kHz. The amount of energy in 100 kHz would be .005 watts or 7 dBm, if the 1 watt is spread across 20 MHz. 20 dB down from this is -13 dBm. In dBm/MHz, this would be -3 dBm/MHz. This scenario is shown in Figure 5-1.

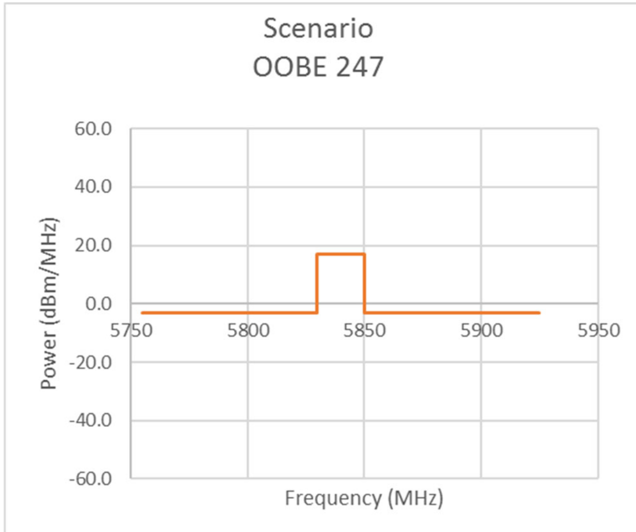

Figure 5-1. Part 15.247 20 MHz Channel Envelope

Examining 407-Old, the OOBE are fixed, making it relatively straight forward, emissions within the frequency range from the band edge to 10 MHz above or below the band edge shall not exceed an EIRP of -17 dBm/MHz; for frequencies 10 MHz or greater above or below the band edge, emissions shall not exceed an EIRP of -27 dBm/MHz. This is illustrated in Figure 5-2.

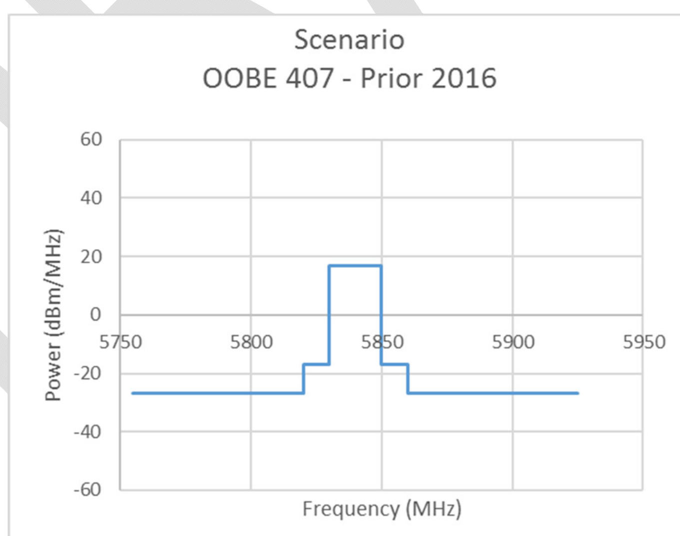

Figure 5-2. Part 15.407-Old 20 MHz Channel Envelope

Examining 407-New, the in-band power has already been noted as 17 dBm/MHz. The OOBE shall be limited to a level of −27 dBm/MHz at 75 MHz or more above or below the band edge increasing linearly to 10 dBm/MHz at 25 MHz above or below the band edge, and from 25 MHz above or below the band edge increasing linearly to a level of 15.6 dBm/MHz at 5 MHz above or below the band edge, and from 5 MHz above or below the band edge increasing linearly to a level of 27 dBm/MHz at the band edge.

There appears to be a contradiction here. If the in-band power is 17 dBm/MHz, but the channel edge is allowed to be 27 dBm/MHz, the OOBE appears to be greater than the in-band signal. Using this, the channel should appear as in Figure 5-3. This interpretation of 15.407-New represents a significant ambiguity or lack of clarity.

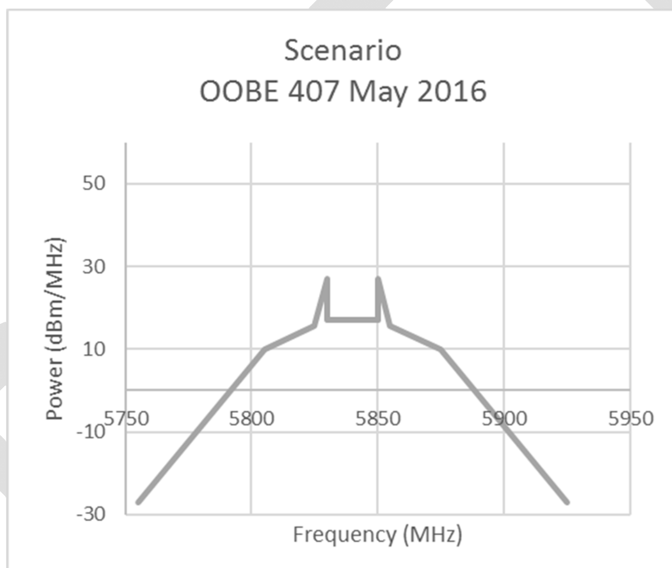

Figure 5-3. Part 15.407-New 20 MHz Channel Envelope

Going back to the definition for emission bandwidth (measured as described in 15.403(i)), it notes that the edges must be 26 dB below the power in the channel. The question is, how to apply this value? In practice, the measurement of the power density is made in 1 percent of the channel bandwidth using a peak detector and then integrated over 1 MHz using the power integrator tool of the spectrum analyzer. The 26 dB down point is referenced to this. The edge of the channel—at least in this case since it is the same as the band edge—must be 26 dBm/MHz down from the in-band emission. Figure 5-4 provides a graphical view of this interpretation.

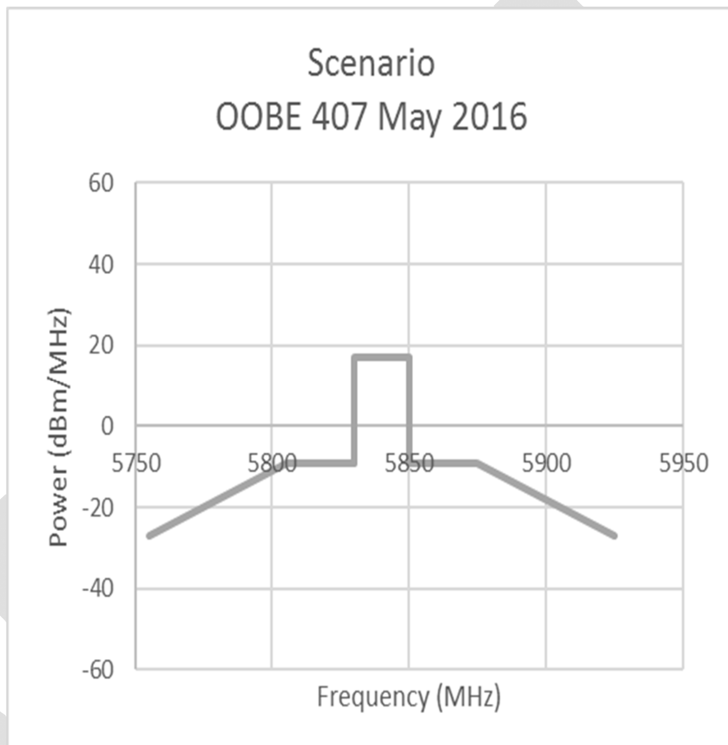

Figure 5-4. Part 15.407-New 20 MHz Channel Envelope and Including 26 dB Points as Specified in 15.402(i).

Using this interpretation, the OOBE that are defined within the three references (247, 407-Old, and 407 New) are overlaid together in Figure 5-5 for comparison.

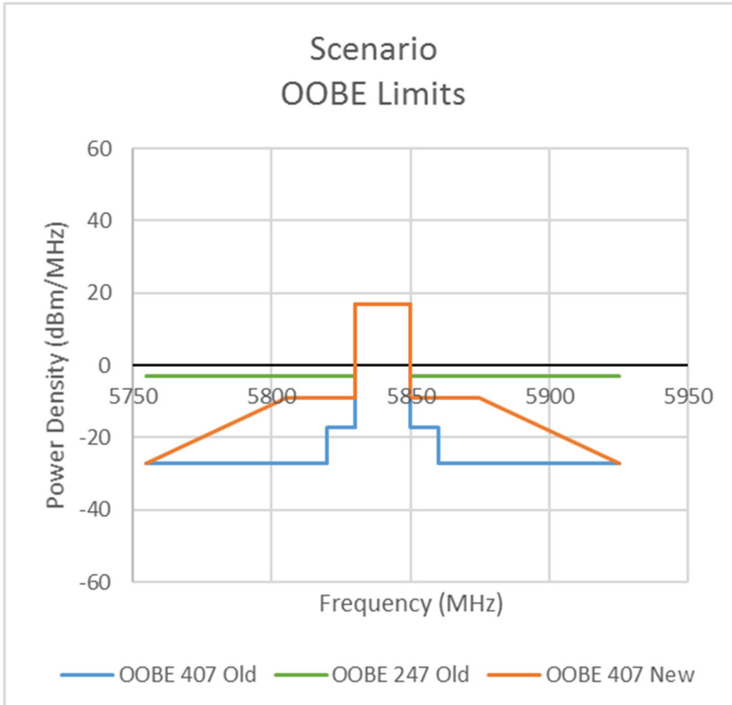

Figure 5-5. 20 MHz Channel Envelope for Three Options

5.2. Other Channel Masks

Again, the previous charts assume an antenna gain of 0 dBi. This may not be a realistic scenario, but it provides a simple basis for understanding the differences in the OOBE of the three options. At this point, it can be observed from the previous figures that the OOBE are lower in 407-New than in 247, but they are higher than in 407-Old.

It is important to note that as the channel/emission width increases, the in-channel PSD will drop to maintain the total conducted power out of 30 dBm. This will in turn impact other points on the OOBE limits. If we consider a simple 6 dB gain antenna, keeping all other parameters as before, then the plots, using the parameters in the previous section, appear as in Figure 5-6.

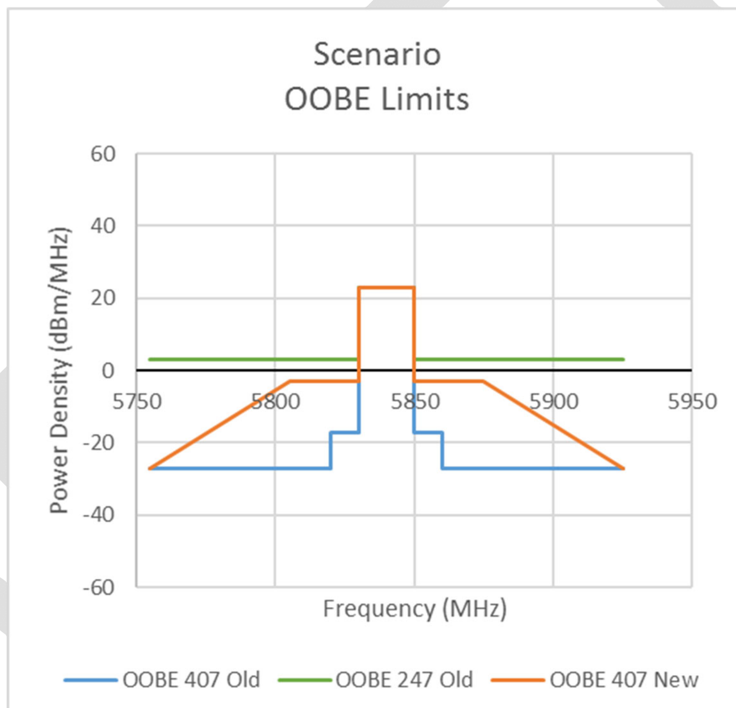

Figure 5-6. 20 MHz Channel Envelope for Three Options and Adding 6 dB Antenna Gain

Examining a point-to-point system with 23 dB gain antenna, again keeping all other parameters as before, would produce the plot in Figure 5-7. (Note that the choice of a 23 dB gain antenna is arbitrary and for illustrative purposes only.)

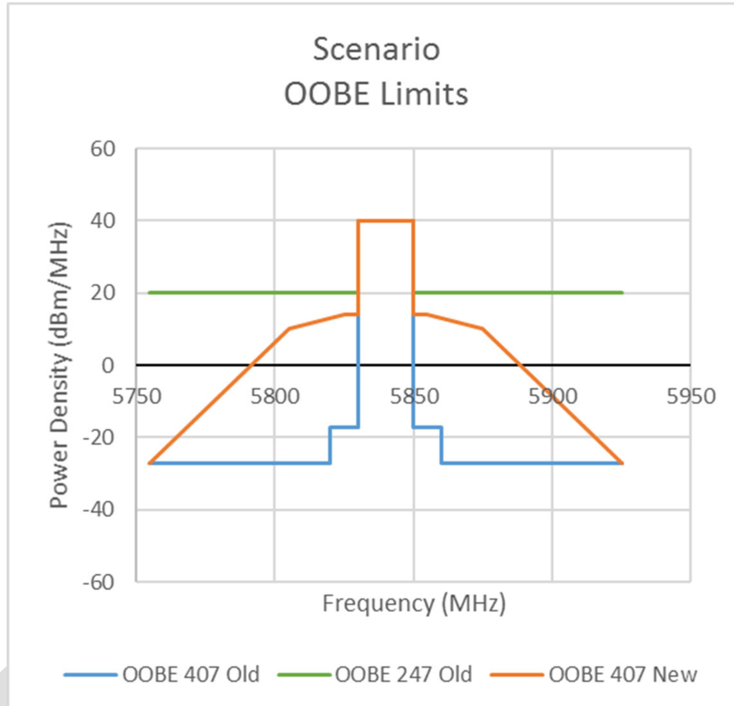

Figure 5-7. 20 MHz Channel Envelope for Three Options and Adding 23 dB Antenna Gain

The rules, as written, suggest that the points described in 15.407(b)(4)(i) for OOBE do not change unless they are above the 26 dB down points. Thus, as the channel increases in width, the OOBE will become a straight line until they become flat. Figure 5-8 illustrates this with the following parameters:

- Channel Bandwidth: 125 MHz
- Top Channel Edge: 5850 MHz
- Antenna Gain: 0 dB
- Power: 1 Watt total across emission bandwidth.

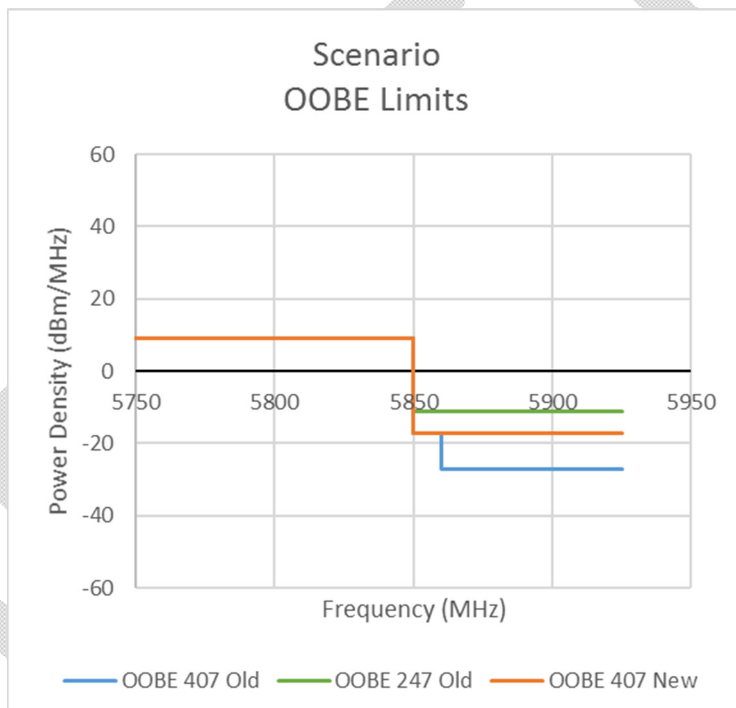

Figure 5-8. Channel Envelope for Three Options, 0 dB Antenna Gain and 125 MHz Emission Bandwidth

Figure 5-9 considers the very narrow band case of a 1 MHz emission bandwidth. Note that a realistic implementation of this particular option may not be possible. The narrowness of the emission bandwidth is limiting and its practicality in a consumer device is questionable. However, it is included as a means of defining the upper and lower bounds (or extremes).

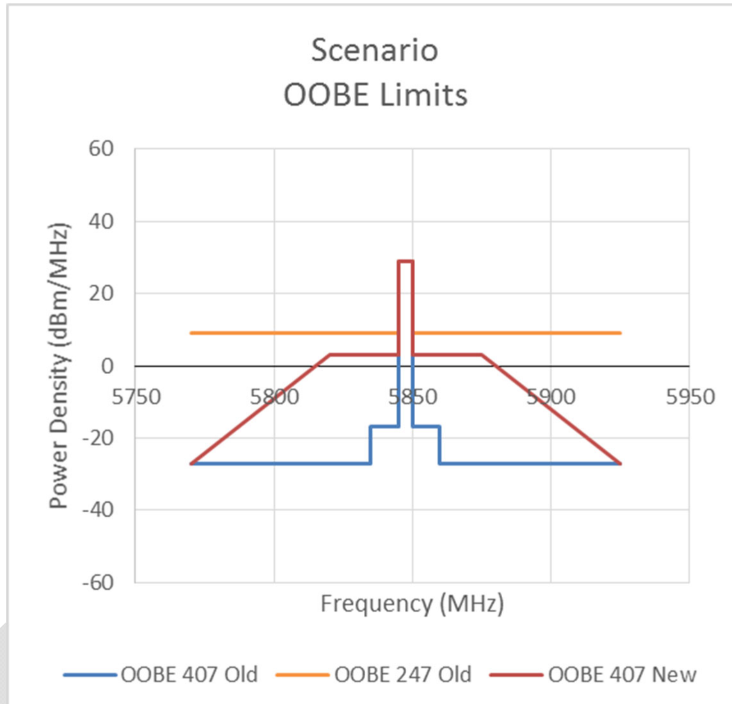

Figure 5-9. Channel Envelope for Three Options, 23 dB Antenna Gain, 1 MHz Emission Bandwidth

5.3. Section Summary

Clearly, there is OOBE into the DSRCS band. 407-New is an improvement over 247, but not as good as 407-Old. It is also clear the OOBE varies with the channel width and antenna gain. The narrower and more directional (higher gain) the antenna, the more OOBE into the DSRCS band. It is important to remember that the link is now a very directional data link. This information and the DSRC receiver parameters will be brought evaluated in Section 7.

6. DSRC Receiver Description

It is important to note that the concern this paper is addressing is the impact to the DSRC System. To understand the impact, knowledge of both DSRC devices and the potential interference sources is necessary to understand how the DSRC device may suffer the interference. This section addresses two key parameters: *receiver sensitivity* and *channel rejection*.

6.1. Receiver Sensitivity

The goal of any radio receiver is to demodulate and provide to the end user the information received from the transmitting source. There are several factors that impact this. First, the receiver's sensitivity which describes the ability of a receiver to "hear" in the RF environment. Additionally, the receiver must be able to distinguish between the desired signal and radio frequency (RF) energy in the environment. This energy may be from unwanted or spurious signals. These unwanted signals are collectively known as "noise." Some RF noise occurs naturally, through atmospheric activity such as lightning or solar flares, or through emissions from high-voltage transmissions lines. Even in the quietest spectrum, this equates to a noise "floor" of about -174 dBm/Hz (the background noise of the universe). Other types of noise are generated by electronic components themselves; anytime electronic components are added to an electrical circuit, noise is also added. Finally, noise can take the form of unwanted radio signals transmitting on adjacent frequencies. By careful component design, the overall noise can be reduced, but it cannot be eliminated.

A second factor in determining receiver sensitivity is channel bandwidth. The DSRCS channel plan works with a 10 MHz channel bandwidth that will have, assuming a perfect receiver, a theoretical noise floor of about -104 dBm for any of the 10 MHz channels.[23] Figure 6-1 shows the measured receiver sensitivity of a commercial DSRC radio across the seven DSRC channels.

[23] Absolute noise floor for a 10 MHz channel is -174 dBm/Hz*10^7 Hz=-174 dBm/Hz+70 dB Hz = -104 dBm

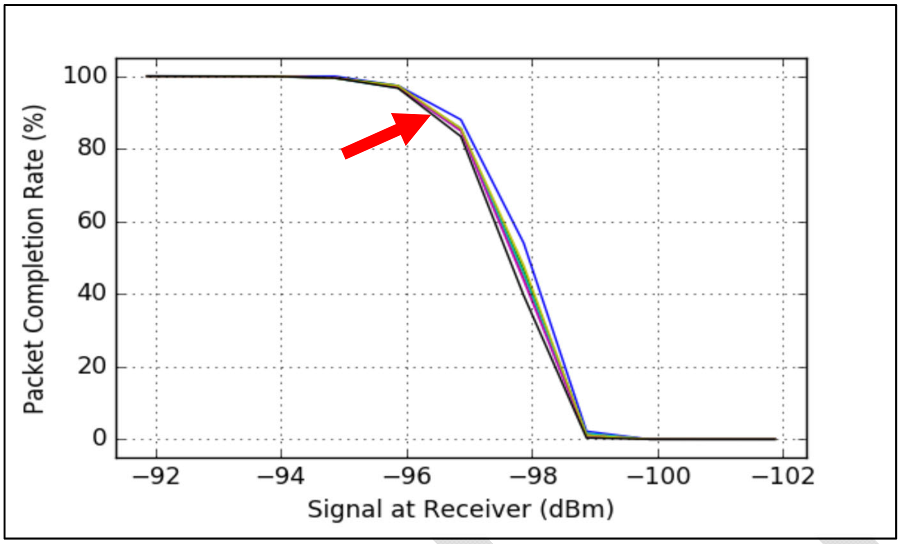

Figure 6-1. Receiver Sensitivity Across Seven DSRC Channels

Typically, a 90 percent Packet Completion Rate (or its corollary, a 10 percent Packet Error Rate (or ratio) (PER)) is used to define when the receiver is operating within its defined performance criteria. In this figure, this occurs at a received signal level at roughly -96 dBm (denoted by the red arrow ➔ in the figure), which is well above the -104 dBm noise floor calculated earlier.

6.2. Adjacent and Non-Adjacent Channel Rejection

Recalling Figure 2-1, DSRC operates in seven 10 MHz adjacent channels. Operation in adjacent channels requires some level of adjacent and non-adjacent channel rejection (ACR and nACR). Radio receivers accept input (RF energy) over a range of frequencies. In the case of DSRC, the “pass band” – the frequency band over which the DSRC radio is interested in receiving – is 5850-5925 MHz. Most receivers are general purpose and are capable of detecting frequencies over a much broader range. Therefore, to limit the impact of extraneous RF energy, a DSRC receiver is fitted with a “band pass filter” that attenuates unwanted frequencies. IEE 802.11-2012 specifies what this rejection should be.

Review of the DSRC receiver data sheets and conversations with manufacturers show that the band pass filters associate with DSRC units are very broad, allowing frequencies from 5700 MHz up to 6000 MHz to enter the receiver. Depending on receiver design, this frequency range can either be shifted to a much lower frequency (down converted) that is easier to work with, or digitized and filtered by a computer. A receiver may employ either or both methods.

In either case, individual DSRC channels are filtered and then demodulated. This filtering is where the ACR is important. Simply described, ACR rejects or suppresses RF energy in adjacent channels so that it does not impact the channel of interest. Non-adjacent channel rejection (nACR) is similar but describes rejection of the immediate non-adjacent channel and those channels further out. These rejection values are documented in IEEE 802.11-2012 and are shown in Table 6-1. The highlighted row shows the modulation scheme used for DSRC channel 172, Vehicle-to-Vehicle communications of the Basic Safety Message (BSM).

Table 6-1. Adjacent and Non-Adjacent Channel Rejection Receiver Performance Thresholds

Modulation	Adjacent Channel Rejection (ACR) (dB)	Non-Adjacent Channel Rejection (nACR) (dB)
BPSK 1/2	28	42
BPSK 3/4	27	41
QPSK 1/2	25	39
QPSK 3/4	23	37
16 QAM 1/2	20	34
16 QAM 3/4	16	30
64 QAM 2/3	12	26
64 QAM 3/4	11	25

6.3. Section Summary

This section described the impact of noise and bandwidth on receiver sensitivity, as well as rejection thresholds for adjacent and non-adjacent channels. As noted, DSRC is based on the IEEE 802.11 standard also used for Wi-Fi implementation, but enhanced to operate in the highly dynamic surface transportation environment. With these enhancements, IEEE 802.11 offers great flexibility and low cost.

7. Impacts to DSRC

7.1. Interference to DSRC from Existing U-NII-3 Channels.

To begin the analysis, consider the transmitter masks/envelopes presented in Figure 4-5 and **Error! Reference source not found.** based on IEEE-802.11-2016 for "ac" type devices. Based on the information currently available and discussed in this paper, Figure 7-1 indicates the theoretical range at which DSRC will potentially see interference from U-NII-3 devices operating with the band plan as defined in IEEE 802.11.

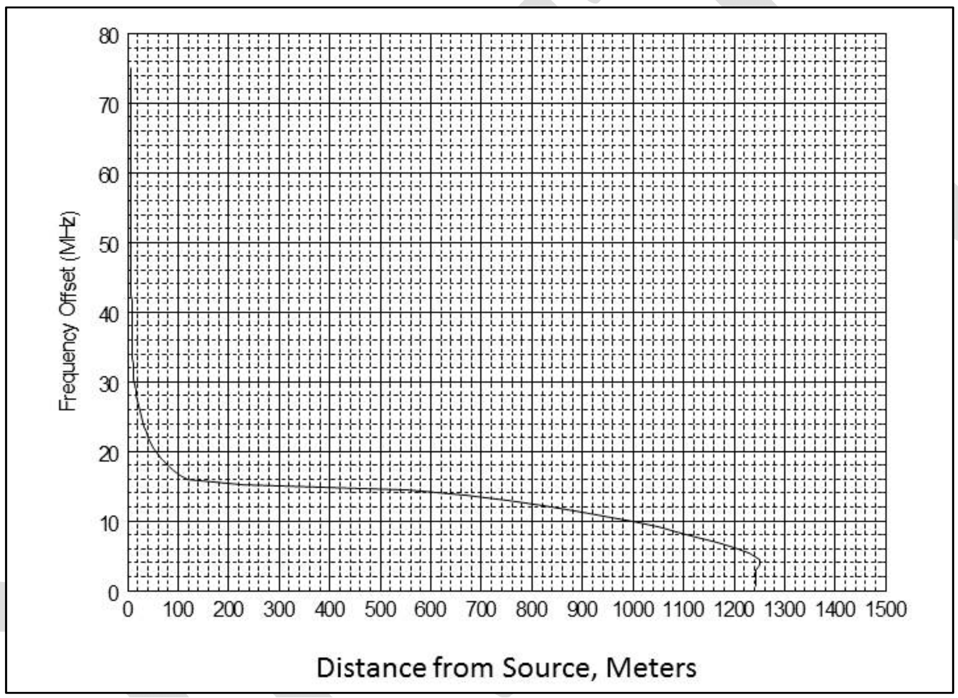

Figure 7-1. Frequency Offset vs Distance (Separation Distance between U-NII-3 Source to DSRC Receiver)

The model used to generate the frequency versus separation distance for this plot is the Undisturbed Field Model using the following variables.[24]

- Height of the Interference Source: h_i = 1.5m[25]
- Height of the transmitting antenna for the DSRCS: h_t=1.5m
- Height of the receiving antenna for the DSRCS: h_r=1.5m
- Level at which U-NII interferes with DSRCS: I=-83 dBm
- DSRC Signal Level: S=-69 dBm
- U-NII emission bandwidth: 20 MHz

It should be noted that the plot is constant, and would not change based on use of the pre- or post-2016 OOBE limits in 247 or 407. The OOBE values are set by the IEEE 802.11 standard for U-NII-3 devices built to that standard.

The model examines several factors that impact the amount of energy that will be seen at the receiver of interest (i.e., a DSRC receiver) including received signal level, adjacent channel rejection, the signal power level of the desired signal (i.e., a DSRC signal from another vehicle or RSU) and the interfering signal (e.g., from a nearby U-NII device), etc. Thus, rather than a simple plot of attenuation (dB) versus range, the data is plotted as center frequency offset from the center frequency of the receiver to the center frequency of the interfering signal. In the case identified in Figure 7-1, the interfering source is a 20 MHz U-NII-3 transmitter (built to the IEEE 802.11ac standard) and the receiver is a 10 MHz DSRC built to IEEE 802.11p. Both of these amendments are now incorporated into IEEE 802.11-2016.

For the 20 MHz U-NII-3 channel centered at 5825 MHz to the 10 MHz DSRC Channel 172 centered at 5860 MHz, the offset is 35 MHz. Using the existing IEEE 802.11ac parameters (not the new OOBE parameters in the FCC MO&O), the potential for interference beyond roughly 10 meters is unlikely. However, if such devices are ever placed in vehicles or at the roadside, there is a higher probability of interference with DSRC devices. Thus, depending on the operational scenario (e.g., DSRC RSU placement, natural and built infrastructure, meteorological conditions, location and density of DSRC OBUs, location and density of U-NII devices, etc.), this may impact DSRCS operations, but is very scenario dependent.

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[24] While the Undisturbed Field Model generated the figure, other models were used as input. For example, a frequency dependent rejection (FDR) model was used to compute the rejection due to off-tuning the interference source with respect to the victim receiver. System parameters, as well as the signal-to-interference ration (S/I) and signal-to-noise ratio (S/N) also play a factor in the total computation.

[25] In this model, 1.5 meters was used as height of the interference source, but actual installations are likely to be higher, increasing the potential for interference.

Reducing the center frequency offset will increase the amount of interference seen by DSRC receivers. This is clearly illustrated by following the curve in Figure 7-1; a frequency offset of 10 MHz could see interference at a separation distance of 1000 meters, while a frequency offset of 30 MHz reduces that distance to less than 20 meters.

7.2. Interference to DSRC Based on New OOBE.

Examining the OOBE limits specified by 407-New, the envelope in Figure 4-3 is a reasonable place to start. Figure 7-2 reproduces that figure and adds lines for the upper band edge of the U-NII-3 devices (at 5850 MHz) and at the upper and lower band edges of DSRC Channel 172 (5855-5865 MHz).

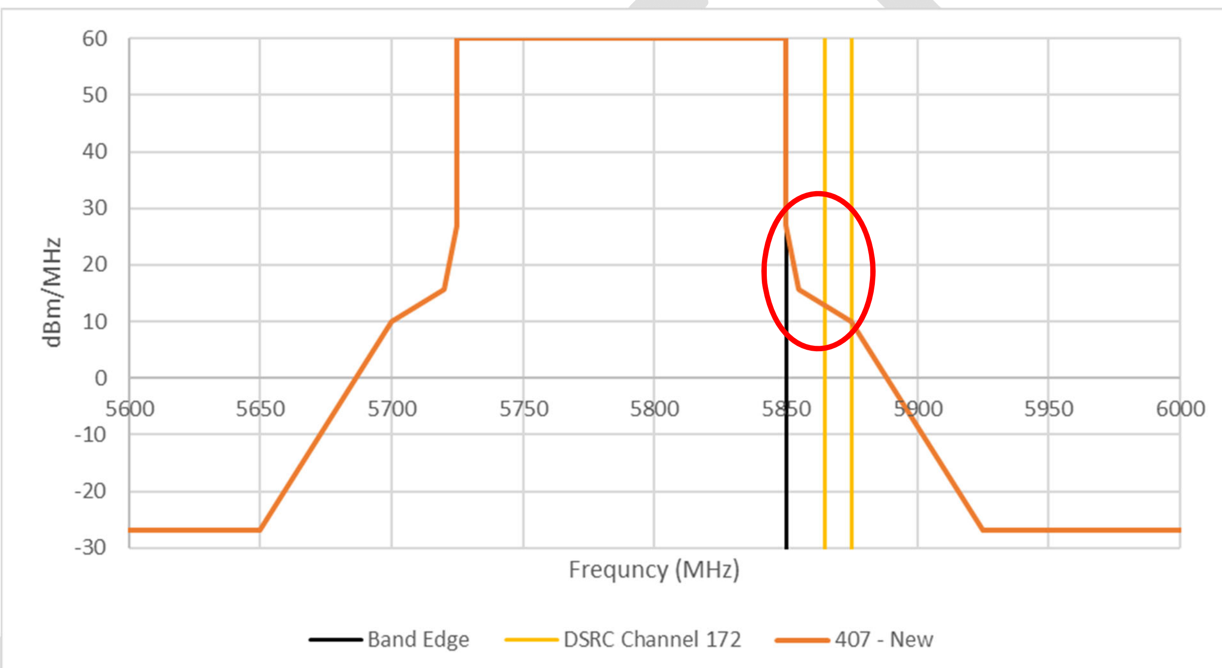


Figure 7-2. Emission Envelope for U-NII-3 devices

Examining the level of interference if a device were allowed to operate to the parameter of the envelope, there appears to be a significant potential for interference; note the overlap of the "407-New" U-NII-3 band with DSRC Channel 172, indicated with the red oval **0** in the figure above. While this may not occur in all cases, it does provide the opportunity to identify a worst-case scenario.

The new OOBE limits can also be described as "on-channel" for several of the DSRC channels. The ideal methodology used to examine interference is to utilize a vector signal generator to generate additive white Gaussian noise (AWGN) and introduce it to the channel under study. However, to generate an AWGN signal for a 20 MHz transmission with the new OOBE limits exceeded the capability of the vector signal generator available to the research team. An alternative methodology was used, namely to generate an on-channel signal that overlapped DSRC channel 172; the results are shown in Figure 7 3 which highlights the level at which the DSRC signal must be above the interfering AWGN signal to be demodulated and understood. .

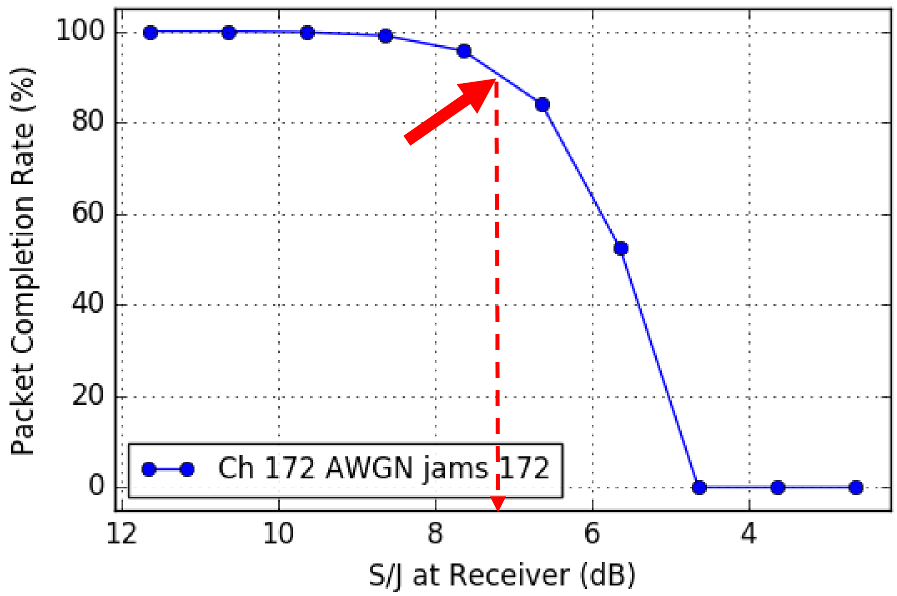


Figure 7-3. Signal to Jamming for On-Channel Interference

In order to meet the 90 percent Packet Completion Rate (equal to a 10 percent PER) standard for signal reliability and processing (described in section 6.1 and shown above by the red arrow ➔), the DSRC signal must be 7 to 8 dB above the “jamming” signal in order to be demodulated and processed by the DSRC receiver. The question that remains is, *how much power could Channel 172 see from this new OOBE limit*?

Referring back to Figure 7-2 and using a linear interpretation for the potential energy in channel 172, the power decreases linearly from 15.6 to 12.8 dBm/MHz. This yields an average of 14.2 dBm/MHz in channel 172. To compare this value to the measured data, the units must be converted to power/channel, in this case a 10 MHz channel, yielding 24.2 dBm/10MHz channel as shown in Equation 3.

$$14.2 + 10 * log_{10}\left(\frac{10\ MHz}{1\ MHz}\right) = 24.2\frac{dBm}{10MHz} \qquad (Eq.3)$$

As noted previously, the output power for channel 172 is 20 dBm/10 MHz channel. As also noted previously, to receive and demodulate the DSRC signal, the DSRC signal must be 7 to 8 dB above any interfering signal. The potential on-channel interference to channel 172 posed by the new OOBE limits is cumulative:

Channel 172 signal:	20 dBm/10MHz
S/J margin:	-7 dB
OOBE from U-NII devices at Band Edge	-24.2 dBm/10MHz

Signal Margin	-11.2 dBm/10MHz

The resulting signal margin (-11.2 dB), is negative meaning **DSRC will not function at this level of interference**. This “interference margin” measurement is the metric used to determine the impact of the various combinations of regulations (247, 407-Old, 407-New) and channel bandwidth. It is important to note that this ignores any off channel energy that would be received by the DSRC receiver. This assumes the DSRC receiver is next to the digitally modulated transmitter and raises the question of how far away a DSRC receiver can “hear” a DSRC transmitter. This will be addressed shortly.

This is not to say DSRC will not work. Recall that this analysis is looking at the envelope, not a specific device. While it is possible to see this level of energy from a point-to-point U-NII device, it is focused into a directional beam so surface transportation users will likely pass through quickly.

Take the example of a 1 MHz channel at the band edge with significant antenna gain (Figure 5-9). This is a very specific example of a point-to-point system using 407-New. In general, these point-to-point systems may generate this level of interference but the number of such systems is unknown but hypothesized to be relatively limited, at least in urban settings. In rural areas, they may be more common but are less likely to interfere with surface transportation. A more thorough study should be undertaken to quantify the potential risk.

As the U-NII transmitter channel bandwidth widens, the energy into the adjacent DSRC channel decreases.

Table 7-1 catalogues the total power integrated across DSRC channel 172 for several digitally modulated channel sizes (bandwidths) under the three regulatory frameworks (247, 407-New, and 407-Old) for point-to-point, digitally modulated systems. It is apparent that U-NII-3 systems operating adjacent to the upper edge of the U-NII-3 band will cause some level of interference to DSRC Channel 172 under both 247 and 407-New (indicated by the negative values in the red boxes).

Table 7-1. Bandwidth vs. Energy in DSRC Channel 172 for Digitally Modulated, Point-to-Point U-NII Systems Operating at the Upper Edge of the U-NII-3 Band

Regulatory Framework Applied		U-NII Channel Bandwidth (MHz)							
		1	2	5	10	20	40	80	125
Part 15.407-New	Maximum dBm/MHz	15.6	15.6	15.6	15.6	14.0	11.0	8.0	6.0
	Minimum dBm/MHz	12.8	12.8	12.8	12.8	12.0	10.5	8.0	6.0
	Integrated dBm/10 MHz	24.2	24.2	24.2	24.2	23.0	20.8	18.0	16.0
	Interference Margin (dB)	-11.2	-11.2	-11.2	-11.2	-10.0	-7.8	-5.0	-3.0
Part 15.247	Maximum dBm/MHz	33.0	30.0	26.0	23.0	20.0	17.0	14.0	12.0
	Minimum dBm/MHz	33.0	30.0	26.0	23.0	20.0	17.0	14.0	12.0
	Integrated dBm/10 MHz	43.0	40.0	36.0	33.0	30.0	27.0	24.0	22.0
	Interference Margin (dB)	-30.0	-27.0	-23.0	-20.0	-17.0	-14.0	-11.0	-9.0
Part 15.407-Old	Maximum dBm/MHz	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0
	Minimum dBm/MHz	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0
	Integrated dBm/10 MHz	-17.0	-17.0	-17.0	-17.0	-17.0	-17.0	-17.0	-17.0
	Interference Margin (dB)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0

Figure 7-4 consolidates this data into a single chart for easy comparison.

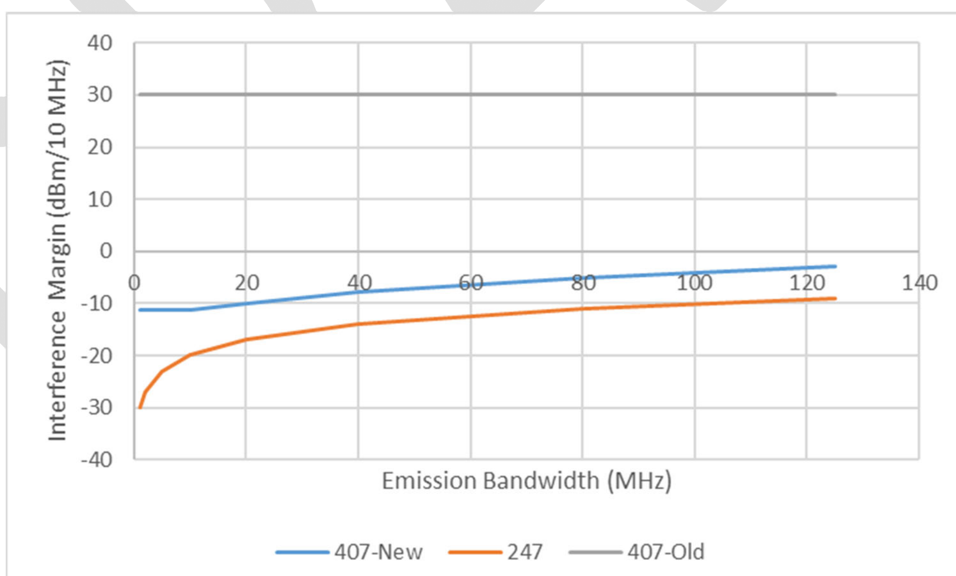


Figure 7-4. Consolidated Data on Point-to-Point Devices (Table 7-1)

A similar analysis (highlighting the 20MHz channel as an example) for non-point-to-point system yields

Table 7-2.

Table 7-2. Bandwidth vs. Energy in DSRC Channel 172 for Digitally Modulated, Non-Point-to-Point U-NII Systems Operating at the Upper Edge of the U-NII-3 Band

Regulatory Framework Applied		U-NII Channel Bandwidth (MHz)							
		1	2	5	10	20	40	80	125
Part 15.407-New	Maximum dBm/MHz	10.0	7.0	3.0	0.0	-3.0	-6.0	-9.0	-11.0
	Minimum dBm/MHz	10.0	7.0	3.0	0.0	-3.0	-6.0	-9.0	-11.0
	Integrated dBm/10 MHz	20.0	17.0	13.0	10.0	7.0	4.0	1.0	-1.0
	Interference Margin (dB)	**-7.0**	**-4.0**	**0.0**	**3.0**	**6.0**	**9.0**	**12.0**	**14.0**
Part 15.247	Maximum dBm/MHz	16.0	13.0	9.0	6.0	3.0	0.0	-3.0	-5.0
	Minimum dBm/MHz	16.0	13.0	9.0	6.0	3.0	0.0	-3.0	-5.0
	Integrated dBm/10 MHz	26.0	23.0	19.0	16.0	13.0	10.0	7.0	5.0
	Interference Margin (dB)	**-13.0**	**-10.0**	**-6.0**	**-3.0**	**0.0**	**3.0**	**6.0**	**8.0**
Part 15.407-Old	Maximum dBm/MHz	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0
	Minimum dBm/MHz	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0
	Integrated dBm/10 MHz	-17.0	-17.0	-17.0	-17.0	-17.0	-17.0	-17.0	-17.0
	Interference Margin (dB)	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**

Table 7-2 indicates there is still potential for interference in certain combinations of regulatory frameworks and channel bandwidth (indicated by negative values in red). Figure 7-5 presents the data from

Table 7-2 in a graphic format.

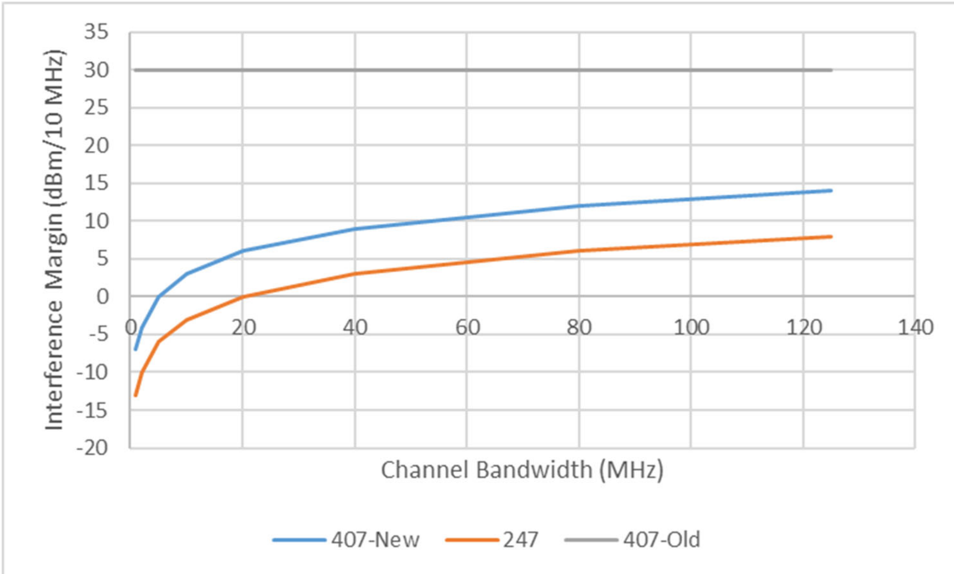


Figure 7-5. Consolidated Data from Non-Point-to-Point Devices (Table 7-2)

Reiterating the parameters for Figure 7-5, the digitally modulated/U-NII-3 device parameters are:

- Power: 1 watt/30 dBm evenly spread across the emission bandwidth
- Antenna Gain: 6dBi
- System: Non-point-to-point systems

Comparing the three curves from an energy into DSRC Channel 172 perspective, 407-New is an improvement over 247, but the values generated by 407-Old are significantly better. It is important to note that this comparison only looks at energy in DSRC Channel 172 and does not consider energy that may enter the receiver from portions of the band adjacent to the channel but still within the receivers pass band.

Going back to the question of how to interpret this information we know that if a DSRC receiver is co-located with a digitally modulated point-to-point device operating under 15.247, its receiver will be completely saturated and unable to receive any DSRC transmissions.

We have made the assumption the point-to-point systems require further study. We can look at the information we have and determine the impact of a non-point-to-point system.

7.3. Interference Range for Non-Point-to-Point systems

Narrowing the analysis, Table 7-3 lists the parameters for the digitally modulated device.

Table 7-3. Digitally Modulated Device Parameters

Transmitter Power	1 Watt/30 dBm
Bandwidth	20 MHz
Antenna Gain	6 dBi
Center Frequency	5840 MHz

Using 407-New as the starting point, the energy on channel with DSRC channel 172 is 7 dBm/10MHz (see the highlighted column in

Table 7-2) from a digitally modulated device with the operating parameters in Table 7-3 if the two devices are co-located. As described previously, a DSRC transmitter generates 20dBm/10 MHz. As also noted previously, the S/J ratio for DSRC receivers is 7 dB. Thus, the "margin" between all the background noise and the signal to jamming ratio needed to demodulate the desired signal given the DSRC transmit power is calculated in Table 7-4, using dB:

Table 7-4. DSRC Energy at DSRC Receiver

Parameter	Value	Units
DSRC TX Power	20	dBm/10 MHz
Digitally Modulated/ U-NII device TX Power	-7	dBm/10 MHz
S/J	-7	dB
Total Margin	**6**	**dBm/10 MHz**

This represents a worst-case scenario, where the DSRC transmitter, DSRC receiver, and digitally modulated U-NII device are all co-located. This is an unlikely scenario. However, as the DSRC transmitter is moved away from the DSRC receiver, the margin gradually decreases; at what separation distance between the DSRC receiver and the DSRC transmitter does the margin reach zero - the break point? For this, a model of free space path loss (FSPL) must be considered. The following equation is applied, where (d) is the distance between receiver and transmitter and (f) is the transmission frequency, and (c) is the speed of light.

$$FSPL = 20Log_{10}(d) + 20Log_{10}(f) + 20Log_{10}\left(\frac{4\pi}{c}\right) \qquad (Eq\ 4)$$

The last portion of the equation can be set as a constant; assuming distance values are in meters and frequency is in MHz, this becomes -27.55. Colocation assumes some minimal separation distance. Thus, the power at the DSRC receiver from the digitally modulated U-NII device (DMD) is:

$$DSRC_{RX\ to\ DMD} = 7\frac{dBm}{10MHz} - (20Log_{10}(d_1) + 20Log_{10}(f_1) - 27.55) \qquad (Eq\ 5)$$

The values for d_1 and f_1 are the distance from the DMD to the DSRC receiver in meters and the frequency in MHz. Note that the $Log_{10}(0)$ is undefined so d_1 for this example will be set to 1 meter. The frequency is set to 5860, the center frequency of DSRC channel 172. Using these parameters, the power at the DSRC receiver is calculated to be approximately -40dBm/10MHz.

Next, the power from the DSRC transmitter must be considered. Going back to equation 4 for DSRC to DSRC yields:

$$DSRC_{Rx\ to\ Tx} = 20 - (20Log_{10}(d_2) + 20Log_{10}(f) - 27.55) \qquad (Eq\ 6)$$

Where d_2 is the distance between the DSRC receiver and DSRC transmitter in meters and f is 5860 MHz. Where does $DSRC_{\text{Rx to Tx}}$ equal $DSRC_{\text{Rx to DMD}}$? Setting the two equations equal and solving for d_2 yields:

$$d_2 = 10^{\frac{20-7+20Log_{10}(d_1)}{20}} \qquad (Eq\ 7)$$

If d_1 is 1 meter, then d_2 is 4.47 meters. As the DMD moves away from the DSRC receiver, this range will increase as shown in Figure 7-7.

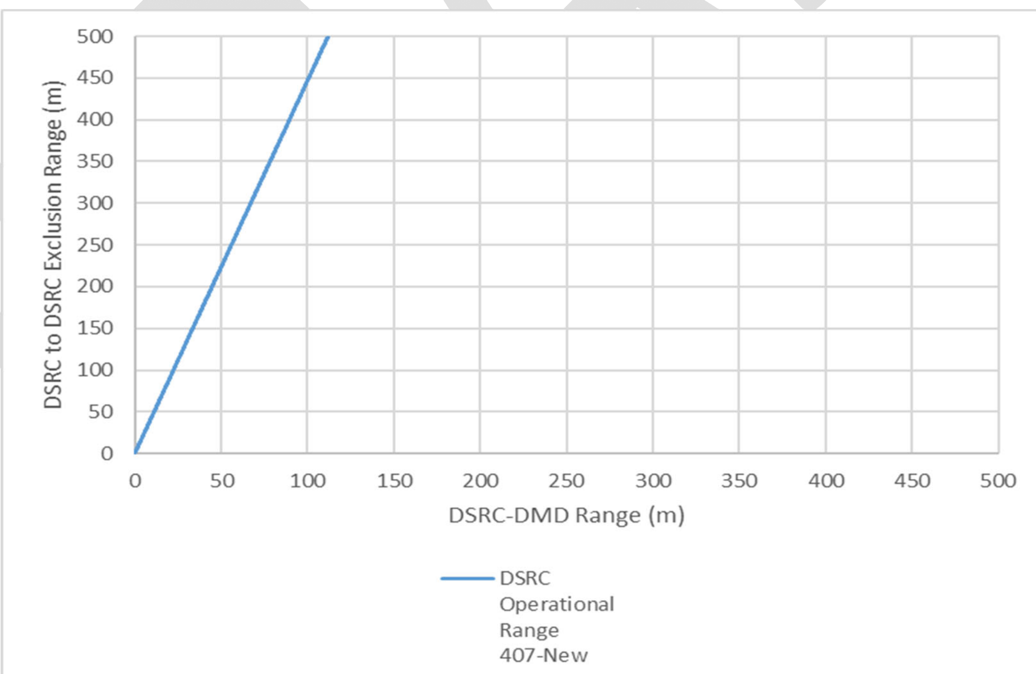


Figure 7-6. DSRC Operational Range under Part 15.407-New

To interpret this figure, the vertical, y-axis shows the range from DSRC receiver to DSRC transmitter while the horizontal x-axis shows the range from the DSRC receiver to the DMD transmitter. For a given DMD transmitter to DSRC receiver range, anything above the line indicates reception of DSRC transmissions is impacted due to the DMD signal creating too much noise to demodulate the DSRC signal.

Figure 7-7 plots the DSRC operational ranges based upon the three different rules frameworks (247, 407-Old, and 407-New).

Figure 7-7. Potential Interference Range Between DSRC and Digitally-Modulated Device (DMD)

Looking at the DSRC-DMD separation distance of 50 meters, the 407-New limits indicate 223 meters (indicated by the red arrow ➔) while the 247 limits indicate 110 meters (indicated by the blue arrow ➔). Note that the 407-Old limits are off the chart. Given this scenario, the 407-New limits are an improvement over the 247 limits, but, the 407-Old limits are much better.

8. Conclusions

U-NII-3 devices that conform to the parameters defined in the existing 802.11-2016 standard, including amendment “ac,” show low potential for interference with DSRC devices and pose minimal risk to DSRC operations. Point-to-point digitally modulated systems that do not conform to the 802.11-2016 standards, but which comply with the new 15.407 rules show a moderate level of interference but a more comprehensive analysis should be completed to fully assess the impact of these devices using a realistic deployment scenario. Non-Point-to-Point systems have a lower risk of interference to DSRC systems, but there is some level of risk. Table 8-1 attempts to graphically show the potential risks.

Table 8-1. Summary Chart of Potential for Interference

Type of System	U-NII-3 Devices	Other Digitally Modulated Devices
Point-to-Point	**Low potential for interference with DSRC Service**	**Moderate potential for interference with DSRC Service**
Non-Point-to-Point	**Low potential for interference with DSRC Service**	**Moderate potential for interference with DSRC Service**

Appendix A – Part 15.247 Evolution from 1989 through 2017

The FCC, on April 25, 1989, entirely revised Part 15. What is contained in this appendix is the initial Part15.247 from 1989 and all modifications to through October, 2017. At the end of this appendix is a fully updated version of 15.247.

15.247 as of April 25, 1989

§ 15.247 Operation within the bands 902- 928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz.

(a) Operation under the provisions of this section is limited to frequency hopping and direct sequence spread spectrum intentional radiators that comply with the following provisions:

(1) For frequency hopping systems, at least 75 hopping frequencies, separated by at least 25 kHz, shall be used. The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 30 second period. The maximum bandwidth of the hopping channel is 25 kHz.

(2) For direct sequence systems, the minimum 6 dB bandwidth shall be at least 500 kHz.

(b) The maximum peak output power of the intentional radiator shall not exceed one watt.

(c) Radio frequency output power outside these frequency bands over any 100 kHz bandwidth shall be at least 20 dB below that in any 100 kHz bandwidth within the band that contains the highest level of the desired power.

> *Note: Spread spectrum systems are sharing these bands on a noninterference basis with systems supporting critical Government requirements that have been allocated the usage of these bands, secondary only to ISM equipment operated under the provisions of Part 18 of this chapter. Many of these Government systems are airborne radiolocation systems that emit a high EIRP which can cause interference to other users. Also, investigations of the effect of spread spectrum interference to U. S. Government operations in the 902-928 MHz band may require a future decrease in the power limits allowed for spread spectrum operation.*

15.247 as modified, July 13, 1990

§ 15.247 Operation within the bands 902- 928s MHz, 2400-2483.5 MHz, and 5725-5850 MHz.

(a) * * *

(1) Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter. The system receivers shall have input bandwidths that match the hopping channel bandwidths of their corresponding transmitters and shall shift frequencies in synchronization with the transmitted signals.

(i) Frequency hopping systems operating in the 902-928 MHz band shall use at least 50 hopping frequencies. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz. The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period.

(ii) Frequency hopping systems operating in the 2400-2483.5 MHz and 5725-5850 MHz bands shall use at least 75 hopping frequencies. The maximum 20 dB bandwidth of the hopping channel is 1 MHz. The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 30 second period.

* * * * *

(b) The maximum peak output power of the transmitter shall not exceed 1 Watt. If transmitting antennas of directional gain greater than 6 dBi are used, the power shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(c) If any 100 kHz bandwidth outside these frequency bands, the radio frequency power that is produced by the modulation products of the spreading sequence, the information sequence and the carrier frequency shall be either at least 20 dB below that in any 100 kHz bandwidth within the band that contains the highest level of the desired power or shall not exceed the general levels specified in 5 15.209(a), whichever results in the lesser attenuation. All other emissions outside these bands shall not exceed the general radiated emission limits specified in § 15.209(a).

(d) For direct sequence systems, the transmitted power density averaged over any 1 second interval shall not be greater than 8 dBm in any 3 kHz bandwidth within these bands.

(e) The processing gain of a direct sequence system shall be at least 10 dB. The processing gain shall be determined from the ratio in dB of the signal to noise ratio with the system spreading code turned off to the signal to noise ratio with the system spreading code tinned on, as measured at the demodulated output of the receiver.

(f) Hybrid systems that employ a combination of both direct sequence and frequency hopping modulation techniques shall achieve a processing gain of at least 17 dB from the combined techniques. The frequency hopping operation of the hybrid system, with the direct sequence operation turned off, shall have an average time of occupancy on any frequency not to exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies employed multiplied by 0.4.

The direct sequence operation of the hybrid system, with the frequency hopping operation turned off, shall comply with the power density requirements of paragraph (d) of this section.

* * * * *

15.247 as modified May 13, 1997

§ 15.247 Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz.

(a)* * *

(1) * * *

(i) For frequency hopping systems operating in the 902–928 MHz band: if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than0.4 seconds within a 20 second period; if the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.

* * * * *

(b) The maximum peak output power of the intentional radiator shall not exceed the following:

(1) For frequency hopping systems operating in the 2400–2483.5 MHz or 5725–5850 MHz band and for all direct sequence systems: 1 watt.

(2) For frequency hopping systems operating in the 902–928 MHz band: 1 Watt for systems employing at least 50hopping channels; and, 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels, as permitted under paragraph (a)(1)(i) of this section.

(3) Except as shown in paragraphs (b)(3) (i), (ii) and (iii) of this section, if transmitting antennas of directional gain greater than 6 dBi are used the peak output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1) or (b)(2) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(i) Systems operating in the 2400–2483.5 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi provided the maximum peak output power of the intentional radiator is reduced by 1 dB for every 3 dB that the directional gain of the antenna exceeds 6 dBi.

(ii) Systems operating in the 5725–5850 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter peak output

Power.

(iii) Fixed, point-to-point operation, as used in paragraphs (b)(3)(i) and (b)(3)(ii) of this section, excludes the use of point-to-multipoint systems, omnidirectional applications, and multiple co-located intentional radiators transmitting the same information. The operator of the spread spectrum intentional radiator or, if the equipment is professionally installed, the installer is responsible for ensuring that the system is used exclusively for fixed, point-to-point operations. The instruction manual furnished with the intentional radiator shall contain language in the installation instructions informing the operator and the installer of this responsibility.

(4) Systems operating under the provisions of this section shall be operated in a manner that ensures that the public is not exposed to radio frequency energy levels in excess of the Commission's guidelines. See § 1.1307(b)(1) of this chapter.

(c) In any 100 kHz bandwidth outside the frequency band in which the spread spectrum intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement. Attenuation below the general limits specified in § 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) (see § 15.205(c)).

(d) For direct sequence systems, the peak power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

(e) The processing gain of a direct sequence system shall be at least 10 dB. The processing gain represents the improvement to the received signal-to-noise ratio, after filtering to the information bandwidth, from the spreading/de-spreading function. The processing gain may be determined using one of the following methods:

(1) As measured at the demodulated output of the receiver: the ratio in dB of the signal-to-noise ratio with the system spreading code turned off to the signal-to-noise ratio with the system spreading code turned on.

(2) As measured using the CW jamming margin method: a signal generator is stepped in 50 kHz increments across the passband of the system, recording at each point the generator level required to produce the recommended Bit Error Rate (BER). This level is the jammer level. The output power of the intentional radiator is measured at the same point. The jammer to signal ratio (J/S) is then calculated, discarding the worst 20% of the J/S data points. The lowest

remaining J/S ratio is used to calculate the processing gain, as follows: Gp = (S/N) o + Mj + Lsys, where Gp = processing gain of the system, (S/N) o = signal to noise ratio required for the chosen BER, Mj = J/S ratio, and Lsys = system losses. Note that total losses in a system, including intentional radiator and receiver, should be assumed to be no more than 2 dB.

* * * * *

(g) Frequency hopping spread spectrum systems are not required to employ all available hopping channels during each transmission. However, the system, consisting of both the transmitter and the receiver, must be designed to comply with all of the regulations in this section should the transmitter be presented with a continuous data (or information) stream. In addition, a system employing short transmission bursts must comply with the definition of a frequency hopping system and must distribute its transmissions over the minimum number of hopping channels specified in this section.

(h) The incorporation of intelligence within a frequency hopping spread spectrum system that permits the system to recognize other users within the spectrum band so that it individually and independently chooses and adapts its hopsets to avoid hopping on occupied channels is permitted. The coordination of frequency hopping systems in any other manner for the express purpose of avoiding the simultaneous occupancy of individual hopping frequencies by multiple transmitters is not permitted.

* * * * *

Note: *The following appendix will not appear in the Code of Federal Regulations.*

Appendix—Measurement Procedure for Spread Spectrum Transmitters
Federal Communications Commission
Equipment Authorization Division,
7435 Oakland Mills Road, Columbia, MD 21046
Telephone: (301) 725–1585,
Facsimile: (301) 344–2050
Guidance on Measurements for Direct Sequence Spread Spectrum Systems

Part 15 of the FCC Rules provides for operation of direct sequence spread spectrum transmitters. Examples of devices that operate under these rules include radio local area networks, cordless telephones, wireless cash registers, and wireless inventory tracking systems.

The Commission frequently receives requests for guidance as to how to perform measurements to demonstrate compliance with the technical standards for such systems. No formal measurement procedure has been established for determining compliance with the technical standards. Such tests are to be performed following the general guidance in Section 15.31 of the FCC Rules and using good engineering practice. The following provides information on the measurement techniques the Commission has accepted in the past for equipment authorization purposes. Alternative techniques may be acceptable upon consultation and approval by the Commission staff. The information is organized according to the pertinent FCC rule sections.

Section 15.31(m): This rule specifies the number of operating frequencies to be examined for tunable equipment.

Section 15.207: Power line conducted emissions. If the unit is AC powered, an AC power line conducted test is also required per this rule.

Section 15.247(a)(2): Bandwidth. Make the measurement with the spectrum analyzer's resolution bandwidth (RBW) = 100 kHz. In order to make an accurate measurement, set the span >> RBW.

Section 15.247(b): Power output. This is an RF conducted test. Use a direct connection between the antenna port of the transmitter and the spectrum analyzer, through suitable attenuation. Set the RBW > 6 dB bandwidth of the emission or use a peak power meter.

Section 15.247(c): Spurious emissions. The following tests are required:

(1) RF antenna conducted test: Set RBW = 1 0 kHz, Video bandwidth (VBW) > RBW, scan up through 10th harmonic. All harmonics/spurs must be at least 20 dB down from the highest emission level within the authorized band as measured with a 100 kHz RBW.

(2) Radiated emission test: Applies to harmonics/spurs that fall in the restricted bands listed in Section 15.205. The maximum permitted average field strength is listed in Section 15.209. A pre-amp (and possibly a high-pass filter) is necessary for this measurement. For measurements above 1 GHz, set RBW = 1 MHz, VBW = 10 Hz, Sweep: Auto. If the emission is pulsed, modify the unit for continuous operation, use the settings shown above, then correct the reading by subtracting the peak-average correction factor, derived from the appropriate duty cycle calculation. See Section 15.35(b) and (c).

Section 15.247(d): Power spectral density. Locate and zoom in on emission peak(s) within the passband. Set RBW = 3 kHz, VBW > RBW, Sweep = (SPAN/3 kHz) e.g., for a span of 1.5 MHz, the sweep should be 1.5 ´ 106 ¸ 3 ´ 103= 500 seconds. The peak level measured must be no greater than +8 dBm. If external attenuation is used, don't forget to add this value to the reading. Use the following guidelines for modifying the power spectral density measurement procedure when necessary.

· For devices with spectrum line spacing greater than 3 kHz no change is required.

· For devices with spectrum line spacing equal to or less than 3 kHz, the resolution bandwidth must be reduced below 3 kHz until the individual lines in the spectrum are resolved. The measurement data must then be normalized to 3 kHz by summing the power of all the individual spectral lines within a 3 kHz band (in linear power units) to determine compliance.

· If the spectrum line spacing cannot be resolved on the available spectrum analyzer, the noise density function on most modern conventional spectrum analyzers will directly measure the noise power density normalized to a 1 Hz noise power bandwidth. Add 34.8 dB for correction to 3 kHz.

· Should all the above fail or any controversy develop regarding accuracy of measurement, the Laboratory will use the HP 89440A Vector Signal Analyzer for final measurement unless a clear showing can be made for a further alternate.

Section 15.247(e): Processing Gain. The Processing Gain may be measured using the CW jamming margin method. Figure 1 shows the test configuration. The test consists of stepping a signal generator in 50 kHz increments across the passband of the system. At each point, the generator level required to produce the recommended Bit Error Rate (BER) is recorded. This level is the jammer level. The output power of the transmitting unit is measured at the same point. The Jammer to Signal (J/S) ratio is then calculated. Discard the worst 20% of the J/ S data points. The lowest remaining J/S ratio is used when calculating the Processing Gain.

In a practical system, there are always implementation losses which degrade the performance below that of an optimal theoretical system of the same type. Losses occur due to non-optimal filtering, lack of equalization, LO phase noise, ‘‘corner cutting in digital processing’’, etc. Total losses in a system, including transmitter and receiver, should be assumed to be no more than 2 dB.

The signal to noise ratio for an *ideal* non-coherent receiver is calculated from:

(1)

$$P_e = \frac{1}{2} e^{\left(-\frac{1}{2}\left(\frac{S}{N}\right)_0\right)}$$

where:

Pe = probability of error (BER)

(S/N)o = the required signal to noise ratio at the receiver output for a given received signal quality

This is an example. You should use the equation (or curve) dictated by your demodulation scheme.

Ref.: Viterbi, A. J. Principles of Coherent Communications, (New York: McGraw-Hill 1966), Pg. 207.

Using equation (1) shown above, calculate the signal to noise ratio required for your chosen BER. This value and the measured J/S ratio are used in the following equation to calculate the Processing Gain (Gp) of the system.

$$G_p = \left(\frac{S}{N}\right)_0 + M_j + L_{sys}$$

where:

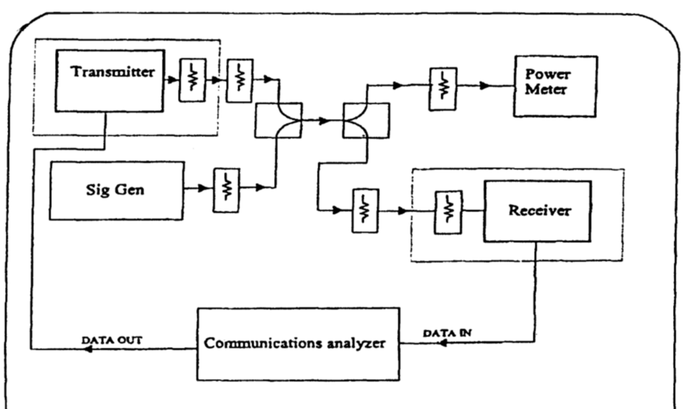
(S/N)o = Signal to noise ratio

M_j = J/S ratio

L_{sys} = System losses.

Ref.: Dixon, R., Spread Spectrum Systems

(New York: Wiley, 1984), Chapter 1.



Jamming Test Setup
Figure 1

Alternative Test Procedures. If antenna conducted tests cannot be performed on this device, radiated tests to show compliance with the various conducted requirements of Section 15.247 are acceptable. As stated previously, a pre-amp must be used in making the following measurements.

(1) Calculate the transmitter's peak power using the following equation:

$$E = \frac{\sqrt{30PG}}{d}$$

Where:

E is the measured maximum field strength in V/m utilizing the widest available RBW.

G is the numeric gain of the transmitting antenna over an isotropic radiator.

d is the distance in meters from which the field strength was measured.

P is the power in watts for which you are solving:

$$P = \frac{(Ed)^2}{30G}$$

(2) Measure the power spectral density as follows:

A. Tune the analyzer to the highest point of the maximized fundamental emission. Reset the analyzer to a RBW = 3 kHz, VBW > RBW, span = 300 kHz, sweep = 100 sec.

B. From the peak level obtained in (A), the field strength, E, by applying the appropriate antenna factor, cable loss, preamp gain, etc. Using the equation listed in (1), calculate a power level for comparison to the +8 dBm limit.

As modified, September 25, 2000

§ 15.247 Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz.

(a) * * *

(1) * * *

(iii) Frequency hopping systems in the 2400—2483.5 MHz band may utilize hopping channels whose 20 dB bandwidth is greater than 1 MHz provided the systems use at least 15 non-overlapping channels. The total span of hopping channels shall be at least 75 MHz. The average time of occupancy on any one channel shall not be greater than 0.4 seconds within the time period required to hop through all channels.

(b) * * *

(1) For frequency hopping systems in the 2400–2483.5 MHz band employing at least 75 hopping channels, all frequency hopping systems in the 5725– 5850 MHz band, and all direct sequence systems: 1 watt. For all other frequency hopping systems in the 2400–2483.5 MHz band: 0.125 watts.

As modified, June 25, 2002

§ 15.247 Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz.

(a) Operation under the provisions of this section is limited to frequency hopping and digitally modulated intentional radiators that comply with the following provisions:

(1) * * *

(ii) Frequency hopping systems operating in the 5725–5850 MHz band shall use at least 75 hopping frequencies. The maximum 20 dB bandwidth of the hopping channel is 1 MHz. The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 30 second period. (iii) Frequency hopping systems in the 2400–2483.5 MHz band shall use at least 15 non-overlapping channels. The average time of occupancy on any channel shall not be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Frequency hopping systems which use fewer than 75 hopping frequencies may employ intelligent hopping techniques to avoid interference to other transmissions. Frequency hopping systems may avoid or suppress transmissions on a particular hopping frequency provided that a minimum of 15 non-overlapping channels are used. (2) Systems using digital modulation techniques may operate in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz.

(b) * * *

(1) For frequency hopping systems in the 2400–2483.5 MHz band employing at least 75 hopping channels, and all frequency hopping systems in the 5725–5850 MHz band: 1 Watt. For all other frequency hopping systems in the 2400–2483.5 band: 0.125 Watt.

* * * * *

(3) For systems using digital modulation in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands: 1 Watt.

* * * * *

(c) In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement. Attenuation below the general limits specified in § 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) (see § 15.205(c)).

(d) For digitally modulated systems, the peak power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

* * * * *

(f) For the purposes of this section, hybrid systems are those that employ a combination of both frequency hopping and digital modulation techniques. The frequency hopping operation of the hybrid system, with the direct sequence or digital modulation operation turned off, shall have an average time of occupancy on any frequency not to exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies employed multiplied by 0.4. The digital modulation operation of the hybrid system, with the frequency hopping operation turned off, shall comply with the power density requirements of paragraph (d) of this section.

As modified, September 7, 2004

§ 15.247 Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz.

(a) Operation under the provisions of this Section is limited to frequency hopping and digitally modulated intentional radiators that comply with the following provisions:

(1) Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the 2400–2483.5 MHz band may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the 20 dB bandwidth of the hopping channel, whichever is greater, provided the systems operate with an output power no greater than 125 mW. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter. The system receivers shall have input bandwidths that match the hopping channel bandwidths of their corresponding transmitters and shall shift frequencies in synchronization with the transmitted signals.

(i) For frequency hopping systems operating in the 902–928 MHz band: if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period; if the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.

(ii) Frequency hopping systems operating in the 5725–5850 MHz band shall use at least 75 hopping frequencies. The maximum 20 dB bandwidth of the hopping channel is 1 MHz. The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 30 second period. (iii) Frequency hopping systems in the 2400–2483.5 MHz band shall use at least 15 channels. The average time of occupancy on any channel shall not be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Frequency hopping systems may avoid or suppress transmissions on a particular hopping frequency provided that a minimum of 15 channels are used.

(2) Systems using digital modulation techniques may operate in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz.

(b) The maximum peak conducted output power of the intentional radiator shall not exceed the following:

(1) For frequency hopping systems operating in the 2400–2483.5 MHz band employing at least 75 non-overlapping hopping channels, and all frequency hopping systems in the 5725–5850 MHz band: 1 watt. For all other frequency hopping systems in the 2400–2483.5 MHz band: 0.125 watts.

* * * * *

(3) For systems using digital modulation in the 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz bands: 1 Watt. As an alternative to a peak power measurement, compliance with the one Watt limit can be based on a measurement of the maximum conducted output power. Maximum Conducted Output Power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), the *maximum conducted output power* is the highest total transmit power occurring in any mode.

(4) The conducted output power limit specified in paragraph (b) of this section is based on the use of antennas with directional gains that do not exceed 6 dBi. Except as shown in paragraph (c) of this section, if transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1), (b)(2), and (b)(3) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(c) Operation with directional antenna gains greater than 6 dBi.

(1) Fixed point-to-point operation:

(i) Systems operating in the 2400–2483.5 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi provided the maximum conducted output power of the intentional radiator is reduced by 1 dB for every 3 dB that the directional gain of the antenna exceeds 6 dBi.

(ii) Systems operating in the 5725–5850 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted output power.

(iii) Fixed, point-to-point operation, as used in paragraphs (c)(1)(i) and (c)(1)(ii) of this section, excludes the use of point-to-multipoint systems, omnidirectional applications, and multiple co-located intentional radiators transmitting the same information. The operator of the spread spectrum or digitally modulated intentional radiator or, if the equipment is professionally installed, the installer is responsible for ensuring that the system is used exclusively for fixed, point-to-point operations. The instruction manual furnished with the intentional radiator shall contain language in the installation instructions informing the operator and the installer of this responsibility.

(2) In addition to the provisions in paragraphs (b)(1), (b)(3), (b)(4) and (c)(1)(i) of this section, transmitters operating in the 2400–2483.5 MHz band that emit multiple directional beams, simultaneously or sequentially, for the purpose of directing signals to individual receivers or to groups of receivers provided the emissions comply with the following:

(i) Different information must be transmitted to each receiver.

(ii) If the transmitter employs an antenna system that emits multiple directional beams but does not do emit multiple directional beams simultaneously, the total output power conducted to the array or arrays that comprise the device, i.e., the sum of the power supplied to all antennas, antenna elements, staves, etc. and summed across all carriers or frequency channels, shall not exceed the limit specified in paragraph (b)(1) or (b)(3) of this section, as applicable. However, the total conducted output power shall be reduced by 1 dB below the specified limits for each 3 dB that the directional gain of the antenna/antenna array exceeds 6 dBi. The directional antenna gain shall be computed as follows:

(A) The directional gain shall be calculated as the sum of 10 log (number of array elements or staves) plus the directional gain of the element or stave having the highest gain.

(B) A lower value for the directional gain than that calculated in paragraph (c)(2)(ii)(A) of this section will be accepted if sufficient evidence is presented, e.g., due to shading of the array or coherence loss in the beamforming.

(iii) If a transmitter employs an antenna that operates simultaneously on multiple directional beams using the same or different frequency channels, the power supplied to each emission beam is subject to the power limit specified in paragraph (c)(2)(ii) of this section. If transmitted beams overlap, the power shall be reduced to ensure that their aggregate power does not exceed the limit specified in paragraph (c)(2)(ii) of this section. In addition, the aggregate power transmitted simultaneously on all beams shall not exceed the limit specified in paragraph (c)(2)(ii) of this section by more than 8 dB.

(iv) Transmitters that emit a single directional beam shall operate under the provisions of paragraph (c)(1) of this section.

(d) In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, as permitted under paragraph (b)(3) of this section, the attenuation required under this paragraph shall be 30 dB instead of 20 dB. Attenuation below the general limits specified in § 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) (see § 15.205(c)).

(e) For digitally modulated systems, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission. This power spectral density shall be determined in accordance with the provisions of paragraph (b) of this section. The same method of determining the conducted output power shall be used to determine the power spectral density.

(i) Systems operating under the provisions of this section shall be operated in a manner that ensures that the public is not exposed to radio frequency energy levels in excess of the Commission's guidelines. *See* § 1.1307(b)(1) of this chapter.

As modified, February 7, 2007

§ 15.247 [Amended]

2. Section 15.247 is amended by removing paragraph (b)(5) and by revising paragraph (e) and by adding paragraph (i) to read as follows:

* * * * *

(e) For digitally modulated systems, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission. This power spectral density shall be determined in accordance with the provisions of paragraph (b) of this section. The same method of determining the conducted output power shall be used to determine the power spectral density.

* * * * *

(i) Systems operating under the provisions of this section shall be operated in a manner that ensures that the public is not exposed to radio frequency energy levels in excess of the Commission's guidelines. *See* § 1.1307(b)(1) of this chapter.

* * * * *

As modified, May 1, 2014

§ 15.247 Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz.

* * * * *

(f) For the purposes of this section, hybrid systems are those that employ a combination of both frequency hopping and digital modulation techniques. The frequency hopping operation of the hybrid system, with the direct sequence or digital modulation operation turned off, shall have an average time of occupancy on any frequency not to exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies employed multiplied by 0.4. The power spectral density conducted from the intentional radiator to the antenna due to the digital modulation operation of the hybrid system, with the frequency hopping operation turned off, shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

Note to paragraph (f): The transition provisions found in § 15.37(h) will apply to hybrid devices beginning June 2, 2015.

Current Rule:

§ 15.247 Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz.

(a) Operation under the provisions of this Section is limited to frequency hopping and digitally modulated intentional radiators that comply with the following provisions:

(1) Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. Alternatively, frequency hopping systems operating in the 2400-2483.5 MHz band may have hopping channel carrier frequencies that are separated by 25 kHz or two-thirds of the 20 dB bandwidth of the hopping channel, whichever is greater, provided the systems operate with an output power no greater than 125 mW. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter. The system receivers shall have input bandwidths that match the hopping channel bandwidths of their corresponding transmitters and shall shift frequencies in synchronization with the transmitted signals.

(i) For frequency hopping systems operating in the 902-928 MHz band: if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period; if the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.

(ii) Frequency hopping systems operating in the 5725-5850 MHz band shall use at least 75 hopping frequencies. The maximum 20 dB bandwidth of the hopping channel is 1 MHz. The average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 30 second period.

(iii) Frequency hopping systems in the 2400-2483.5 MHz band shall use at least 15 channels. The average time of occupancy on any channel shall not be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Frequency hopping systems may avoid or suppress transmissions on a particular hopping frequency provided that a minimum of 15 channels are used.

(2) Systems using digital modulation techniques may operate in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz.

(b) The maximum peak conducted output power of the intentional radiator shall not exceed the following:

(1) For frequency hopping systems operating in the 2400-2483.5 MHz band employing at least 75 non-overlapping hopping channels, and all frequency hopping systems in the 5725-5850 MHz band: 1 watt. For all other frequency hopping systems in the 2400-2483.5 MHz band: 0.125 watts.

(2) For frequency hopping systems operating in the 902-928 MHz band: 1 watt for systems employing at least 50 hopping channels; and, 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels, as permitted under paragraph (a)(1)(i) of this section.

(3) For systems using digital modulation in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands: 1 Watt. As an alternative to a peak power measurement, compliance with the one Watt limit can be based on a measurement of the maximum conducted output power. Maximum Conducted Output Power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), the *maximum conducted output power* is the highest total transmit power occurring in any mode.

(4) The conducted output power limit specified in paragraph (b) of this section is based on the use of antennas with directional gains that do not exceed 6 dBi. Except as shown in paragraph (c) of this section, if transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1), (b)(2), and (b)(3) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(c) Operation with directional antenna gains greater than 6 dBi.

(1) Fixed point-to-point operation:

(i) Systems operating in the 2400-2483.5 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi provided the maximum conducted output power of the intentional radiator is reduced by 1 dB for every 3 dB that the directional gain of the antenna exceeds 6 dBi.

(ii) Systems operating in the 5725-5850 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted output power.

(iii) Fixed, point-to-point operation, as used in paragraphs (c)(1)(i) and (c)(1)(ii) of this section, excludes the use of point-to-multipoint systems, omnidirectional applications, and multiple co-located intentional radiators transmitting the same information. The operator of the spread spectrum or digitally modulated intentional radiator or, if the equipment is professionally installed, the installer is responsible for ensuring that the system is used exclusively for fixed, point-to-point operations. The instruction manual furnished with the intentional radiator shall contain language in the installation instructions informing the operator and the installer of this responsibility.

(2) In addition to the provisions in paragraphs (b)(1), (b)(3), (b)(4) and (c)(1)(i) of this section, transmitters operating in the 2400-2483.5 MHz band that emit multiple directional beams, simultaneously or sequentially, for the purpose of directing signals to individual receivers or to groups of receivers provided the emissions comply with the following:

(i) Different information must be transmitted to each receiver.

(ii) If the transmitter employs an antenna system that emits multiple directional beams but does not do emit multiple directional beams simultaneously, the total output power conducted to the array or arrays that comprise the device, *i.e.*, the sum of the power supplied to all antennas, antenna elements, staves, etc. and summed across all carriers or frequency channels, shall not exceed the limit specified in paragraph (b)(1) or (b)(3) of this section, as applicable. However, the total conducted output power shall be reduced by 1 dB below the specified limits for each 3 dB that the directional gain of the antenna/antenna array exceeds 6 dBi. The directional antenna gain shall be computed as follows:

(A) The directional gain shall be calculated as the sum of 10 log (number of array elements or staves) plus the directional gain of the element or stave having the highest gain.

(B) A lower value for the directional gain than that calculated in paragraph (c)(2)(ii)(A) of this section will be accepted if sufficient evidence is presented, e.g., due to shading of the array or coherence loss in the beamforming.

(iii) If a transmitter employs an antenna that operates simultaneously on multiple directional beams using the same or different frequency channels, the power supplied to each emission beam is subject to the power limit specified in paragraph (c)(2)(ii) of this section. If transmitted beams overlap, the power shall be reduced to ensure that their aggregate power does not exceed the limit specified in paragraph (c)(2)(ii) of this section. In addition, the aggregate power transmitted simultaneously on all beams shall not exceed the limit specified in paragraph (c)(2)(ii) of this section by more than 8 dB.

(iv) Transmitters that emit a single directional beam shall operate under the provisions of paragraph (c)(1) of this section.

(d) In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, as permitted under paragraph (b)(3) of this section, the attenuation required under this paragraph shall be 30 dB instead of 20 dB. Attenuation below the general limits specified in § 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) (see § 15.205(c)).

(e) For digitally modulated systems, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission. This power spectral density shall be determined in accordance with the provisions of paragraph (b) of this section. The same method of determining the conducted output power shall be used to determine the power spectral density.

(f) For the purposes of this section, hybrid systems are those that employ a combination of both frequency hopping and digital modulation techniques. The frequency hopping operation of the hybrid system, with the direct sequence or digital modulation operation turned-off, shall have an average time of occupancy on any frequency not to exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies employed multiplied by 0.4. The power spectral density conducted from the intentional radiator to the antenna due to the digital modulation operation of the hybrid system, with the frequency hopping operation turned off, shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

> ***Note to paragraph (f):*** *The transition provisions found in § 15.37(h) will apply to hybrid devices beginning June 2, 2015.*

(g) Frequency hopping spread spectrum systems are not required to employ all available hopping channels during each transmission. However, the system, consisting of both the transmitter and the receiver, must be designed to comply with all of the regulations in this section should the transmitter be presented with a continuous data (or information) stream. In addition, a system employing short transmission bursts must comply with the definition of a frequency hopping system and must distribute its transmissions over the minimum number of hopping channels specified in this section.

(h) The incorporation of intelligence within a frequency hopping spread spectrum system that permits the system to recognize other users within the spectrum band so that it individually and independently chooses and adapts its hopsets to avoid hopping on occupied channels is permitted. The coordination of frequency hopping systems in any other manner for the express purpose of avoiding the simultaneous occupancy of individual hopping frequencies by multiple transmitters is not permitted.

> ***Note:*** *Spread spectrum systems are sharing these bands on a noninterference basis with systems supporting critical Government requirements that have been allocated the usage of these bands, secondary only to ISM equipment operated under the provisions of part 18 of this chapter. Many of these Government systems are airborne radiolocation systems that emit a high EIRP which can cause interference to other users. Also, investigations of the effect of spread spectrum interference to U. S. Government operations in the 902-928 MHz band may require a future decrease in the power limits allowed for spread spectrum operation.*

(i) Systems operating under the provisions of this section shall be operated in a manner that ensures that the public is not exposed to radio frequency energy levels in excess of the Commission's guidelines. *See* § 1.1307(b)(1) of this chapter.

Appendix B – Part 15.407 Evolution from 1998 through 2017

As published in the Federal Register, July 31, 1998

§ 15.407 General technical requirements.

(a) *Power limits:*

(1) For the band 5.15–5.25 GHz, the peak transmit power over the frequency band of operation shall not exceed the lesser of 50 mW or 4 dBm + 10logB, where B is the 26-dB emission bandwidth in MHz. In addition, the peak power spectral density shall not exceed 4 dBm in any 1-MHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the peak transmit power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(2) For the band 5.25–5.35 GHz, the peak transmit power over the frequency band of operation shall not exceed the lesser of 250 mW or 11 dBm + 10logB, where B is the 26-dB emission bandwidth in MHz. In addition, the peak power spectral density shall not exceed 11 dBm in any 1-MHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the peak transmit power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(3) For the band 5.725–5.825 GHz, the peak transmit power over the frequency band of operation shall not exceed the lesser of 1 W or 17 dBm + 10logB, where B is the 26-dB emission bandwidth in MHz. In addition, the peak power spectral density shall not exceed 17 dBm in any 1-MHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the peak transmit power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. However, fixed point-to-point U–NII devices operating in this band may employ transmitting antennas with directional gain up to 23 dBi without any corresponding reduction in the transmitter peak output power or peak power spectral density. For fixed, point-to-point U–NII transmitters that employ a directional antenna gain greater than 23 dBi, a 1 dB reduction in peak transmitter power and peak power spectral density for each 1 dB of antenna gain in excess of 23 dBi would be required. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omni directional applications, and multiple collocated transmitters transmitting the same information. The operator of the U–NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

Note to paragraph (a)(3): *The Commission strongly recommends that parties employing U–NII devices to provide critical communications services should determine if there are any nearby Government radar systems that could affect their operation.*

(4) The peak transmit power must be measured over any interval of continuous transmission using instrumentation calibrated in terms of an rms-equivalent voltage. The measurement results shall be properly adjusted for any instrument limitations, such as detector response times, limited resolution bandwidth capability when compared to the emission bandwidth, sensitivity, etc., so as to obtain a true peak measurement conforming to the definitions in this paragraph for the emission in question.

(5) The peak power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements are made over a bandwidth of 1 MHz or the 26 dB emission bandwidth of the device, whichever is less. A resolution bandwidth less than the measurement bandwidth can be used, provided that the measured power is integrated to show total power over the measurement bandwidth. If the resolution bandwidth is approximately equal to the measurement bandwidth, and much less than the emission bandwidth of the equipment under test, the measured results shall be corrected to account for any difference between the resolution bandwidth of the test instrument and its actual noise bandwidth.

(6) The ratio of the peak excursion of the modulation envelope (measured using a peak hold function) to the peak transmit power (measured as specified in this paragraph) shall not exceed 13 dB across any 1 MHz bandwidth or the emission bandwidth whichever is less.

(b) *Undesirable emission limits:* Except as shown in paragraph (b)(6) of this section, the peak emissions outside of the frequency bands of operation shall be attenuated in accordance with the following limits:

(1) For transmitters operating in the 5.15–5.25 GHz band: all emissions outside of the 5.15–5.35 GHz band shall not exceed an EIRP of –27 dBm/MHz.

(2) For transmitters operating in the 5.25–5.35 GHz band: all emissions outside of the 5.15–5.35 GHz band shall not exceed an EIRP of –27 dBm/MHz. Devices operating in the 5.25–5.35 GHz band that generate emissions in the 5.15–5.25 GHz band must meet all applicable technical requirements for operation in the 5.15–5.25 GHz band (including indoor use) or alternatively meet an out-of-band emission EIRP limit of –27 dBm/MHz in the 5.15–5.25 GHz band.

(3) For transmitters operating in the 5.725–5.825 GHz band: all emissions within the frequency range from the band edge to 10 MHz above or below the band edge shall not exceed an EIRP of –17 dBm/MHz; for frequencies 10 MHz or greater above or below the band edge, emissions shall not exceed an EIRP of –27 dBm/MHz.

(4) The emission measurements shall be performed using a minimum resolution bandwidth of 1 MHz. A lower resolution bandwidth may be employed near the band edge, when necessary, provided the measured energy is integrated to show the total power over 1 MHz.

(5) Unwanted emissions below 1 GHz must comply with the general field strength limits set forth in § 15.209. Further, any U–NII devices using an AC power line are required to comply also with the conducted limits set forth in § 15.207.

(6) The provisions of § 15.205 apply to intentional radiators operating under this section.

(7) When measuring the emission limits, the nominal carrier frequency shall be adjusted as close to the upper and lower frequency block edges as the design of the equipment permits.

(c) The device shall automatically discontinue transmission in case of either absence of information to transmit or operational failure. These provisions are not intended to preclude the transmission of control or signaling information or the use of repetitive codes used by certain digital technologies to complete frame or burst intervals. Applicants shall include in their application for equipment authorization a description of how this requirement is met.

(d) Any U–NII device that operates in the 5.15–5.25 GHz band shall use a transmitting antenna that is an integral part of the device.

(e) Within the 5.15–5.25 GHz band, U–NII devices will be restricted to indoor operations to reduce any potential for harmful interference to co-channel MSS operations.

(f) U–NII devices are subject to the radio frequency radiation exposure requirements specified in § 1.1307(b), § 2.1091 and § 2.1093 of this chapter, as appropriate. All equipment shall be considered to operate in a ''general population/uncontrolled'' environment. Applications for equipment authorization of devices operating under this section must contain a statement confirming compliance with these requirements for both fundamental emissions and unwanted emissions. Technical information showing the basis for this statement must be submitted to the Commission upon request.

(g) Manufacturers of U–NII devices are responsible for ensuring frequency stability such that an emission is maintained within the band of operation under all conditions of normal operation as specified in the user's manual.

As modified January 20, 2004

§ 15.407 General technical requirements.

(a) * * *

(2) For the 5.25–5.35 GHz and 5.47– 5.725 GHz bands, the peak transmit power over the frequency bands of operation shall not exceed the lesser of 250 mW or 11 dBm + 10log B, where B is the 26 dB emission bandwidth in megahertz. In addition, the peak power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the peak transmit power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

* * * * *

(b) * * *

(3) For transmitters operating in the 5.47–5.725 GHz band: all emissions outside of the 5.47–5.725 GHz band shall not exceed an EIRP of -27 dBm/MHz.

* * * * *

(h) Transmit Power Control (TPC) and Dynamic Frequency Selection (DFS).

(1) Transmit power control (TPC). UNII devices operating in the 5.25–5.35 GHz band and the 5.47–5.725 GHz band shall employ a TPC mechanism. The UNII device is required to have the capability to operate at least 6 dB below the mean EIRP value of 30 dBm. A TPC mechanism is not required for systems with an e.i.r.p. of less than 500 mW.

(2) Radar Detection Function of Dynamic Frequency Selection (DFS). UNII devices operating in the 5.25–5.35 GHz and 5.47–5.725 GHz bands shall employ a DFS radar detection mechanism to detect the presence of radar systems and to avoid co-channel operation with radar systems. The minimum DFS detection threshold for devices with a maximum e.i.r.p. of 200 mW to 1 W is -64 dBm. For devices that operate with less than 200 mW e.i.r.p. the minimum detection threshold is ¥62 dBm. The detection threshold is the received power averaged over 1 microsecond referenced to a 0 dBi antenna. The DFS process shall be required to provide a uniform spreading of the loading over all the available channels.

(i) Operational Modes. The DFS requirement applies to the following operational modes:

(A) The requirement for channel availability check time applies in the master operational mode.

(B) The requirement for channel move time applies in both the master and slave operational modes.

(ii) Channel Availability Check Time. A U-NII device shall check if there is a radar system already operating on the channel before it can initiate a transmission on a channel and when it has to move to a new channel. The UNII device may start using the channel if no radar signal with a power level greater than the interference threshold values listed in paragraph (h)(2) of this part, is detected within 60 seconds.

(iii) Channel Move Time. After a radar's presence is detected, all transmissions shall cease on the operating channel within 10 seconds. Transmissions during this period shall consist of normal traffic for a maximum of 200 ms after detection of the radar signal. In addition, intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel. (iv) Non-occupancy Period. A channel that has been flagged as containing a radar system, either by a channel availability check or in-service monitoring, is subject to a nonoccupancy period of at least 30 minutes. The non-occupancy period starts at the time when the radar system is detected.

As published, September 7, 2004

§ 15.407 General technical requirements.

(a) * * *

(1) For the band 5.15–5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed the lesser of 50 mW or 4 dBm + 10 log B, where B is the 26–dB emission bandwidth in MHz. In addition, the peak power spectral density shall not exceed 4 dBm in any 1–MHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(2) For the 5.25–5.35 GHz and 5.47– 5.725 GHz bands, the maximum conducted output power over the frequency bands of operation shall not exceed the lesser of 250 mW or 11 dBm + 10 log B, where B is the 26 dB emission bandwidth in megahertz. In addition, the peak power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(3) For the band 5.725–5.825 GHz, the maximum conducted output power over the frequency band of operation shall not exceed the lesser of 1 W or 17 dBm + 10 log B, where B is the 26-dB emission bandwidth in MHz. In addition, the peak power spectral density shall not exceed 17 dBm in any 1–MHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the peak power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. However, fixed point-to-point U–NII devices operating in this band may employ transmitting antennas with directional gain up to 23 dBi without any corresponding reduction in the transmitter peak output power or peak power spectral density. For fixed, point-to-point U–NII transmitters that employ a directional antenna gain greater than 23 dBi, a 1 dB reduction in peak transmitter power and peak power spectral density for each 1 dB of antenna gain in excess of 23 dBi would be required. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U–NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

Note to paragraph (a)(3): *The Commission strongly recommends that parties employing U–NII devices to provide critical communications services should determine if there are any nearby Government radar systems that could affect their operation.*

(4) The maximum conducted output power must be measured over any interval of continuous transmission using instrumentation calibrated in terms of an rms-equivalent voltage. The measurement results shall be properly adjusted for any instrument limitations, such as detector response times, limited resolution bandwidth capability when compared to the emission bandwidth, sensitivity, etc., so as to obtain a true peak measurement conforming to the above definitions for the emission in question.

(5) The peak power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements are made over a bandwidth of 1 MHz or the 26 dB emission bandwidth of the device, whichever is less. A resolution bandwidth less than the measurement bandwidth can be used, provided that the measured power is integrated to show total power over the measurement bandwidth. If the resolution bandwidth is approximately equal to the measurement bandwidth, and much less than the emission bandwidth of the equipment under test, the measured results shall be corrected to account for any difference between the resolution bandwidth of the test instrument and its actual noise bandwidth.

(6) The ratio of the peak excursion of the modulation envelope (measured using a peak hold function) to the maximum conducted output power (measured as specified above) shall not exceed 13 dB across any 1 MHz bandwidth or the emission bandwidth whichever is less.

As modified, May 1, 2014

§ 15.407 General technical requirements.

(a) * * *

(1) For the band 5.15–5.25 GHz.

(i) For an outdoor access point operating in the band 5.15–5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 17 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. The maximum e.i.r.p. at any elevation angle above 30 degrees as measured from the horizon must not exceed 125 mW (21 dBm).

(ii) For an indoor access point operating in the band 5.15–5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 17 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(iii) For fixed point-to-point access points operating in the band 5.15–5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W. Fixed point-to-point U–NII devices may employ antennas with directional gain up to 23 dBi without any corresponding reduction in the maximum conducted output power or maximum power spectral density. For fixed point-to-point transmitters that employ a directional antenna gain greater than 23 dBi, a 1 dB reduction in maximum conducted output power and maximum power spectral density is required for each 1 dB of antenna gain in excess of 23 dBi. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U–NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

(iv) For mobile and portable client devices in the 5.15–5.25 GHz band, the maximum conducted output power over the frequency band of operation shall not exceed 250 mW provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(2) For the 5.25–5.35 GHz and 5.47– 5.725 GHz bands, the maximum conducted output power over the frequency bands of operation shall not exceed the lesser of 250 mW or 11 dBm 10 log B, where B is the 26 dB emission bandwidth in megahertz. In addition, the maximum power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(3) For the band 5.725–5.85 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W. In addition, the maximum power spectral density shall not exceed 30 dBm in any 500-kHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. However, fixed point-to-point U–NII devices operating in this band may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted power. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U–NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

> ***Note to paragraph (a)(3):*** *The Commission strongly recommends that parties employing U–NII devices to provide critical communications services should determine if there are any nearby Government radar systems that could affect their operation.*

(4) The maximum conducted output power must be measured over any interval of continuous transmission using instrumentation calibrated in terms of an rms-equivalent voltage.

(5) The maximum power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements in the 5.725–5.85 GHz band are made over a reference bandwidth of 500 kHz or the 26 dB emission bandwidth of the device, whichever is less. Measurements in the 5.15–5.25 GHz, 5.25–5.35 GHz, and the 5.47–5.725 GHz bands are made over a bandwidth of 1 MHz or the

26 dB emission bandwidth of the device, whichever is less. A narrower resolution bandwidth can be used, provided that the measured power is integrated over the full reference bandwidth.

(b) *Undesirable emission limits.* Except as shown in paragraph (b)(7) of this section, the maximum emissions outside of the frequency bands of operation shall be attenuated in accordance with the following limits:

(1) For transmitters operating in the 5.15–5.25 GHz band: All emissions outside of the 5.15–5.35 GHz band shall not exceed an e.i.r.p. of -dBm/MHz.

(2) For transmitters operating in the 5.25–5.35 GHz band: All emissions outside of the 5.15–5.35 GHz band shall not exceed an e.i.r.p. of -27 dBm/MHz.

(3) For transmitters operating in the 5.47–5.725 GHz band: All emissions outside of the 5.47–5.725 GHz band shall not exceed an e.i.r.p. of -27 dBm/MHz.

(4) For transmitters operating in the 5.725–5.85 GHz band: All emissions within the frequency range from the band edge to 10 MHz above or below the band edge shall not exceed an e.i.r.p. of -17 dBm/MHz; for frequencies 10 MHz or greater above or below the band edge, emissions shall not exceed an e.i.r.p. of -27 dBm/MHz.

* * * * *

(8) When measuring the emission limits, the nominal carrier frequency shall be adjusted as close to the upper and lower frequency band edges as the design of the equipment permits.

* * * * *

(e) Within the 5.725–5.85 GHz band, the minimum 6 dB bandwidth of U–NII devices shall be at least 500 kHz.

* * * * *

(h) * * *

(2) Radar Detection Function of Dynamic Frequency Selection (DFS). U– NII devices operating with any part of its 26 dB emission bandwidth in the 5.25–5.35 GHz and 5.47–5.725 GHz bands shall employ a DFS radar detection mechanism to detect the presence of radar systems and to avoid co-channel operation with radar systems. Operators shall only use equipment with a DFS mechanism that is turned on when operating in these bands. The device must sense for radar signals at 100 percent of its emission bandwidth. The minimum DFS detection threshold for

devices with a maximum e.i.r.p. of 200 mW to 1 W is -64 dBm. For devices that operate with less than 200 mW e.i.r.p. and a Power Spectral Density of less than 10 dBm in a 1 MHz band, the minimum detection threshold is -62 dBm. The detection threshold is the received power averaged over 1 microsecond referenced to a 0 dBi antenna. For the initial channel setting, the manufacturers shall be permitted to provide for either random channel selection or manual channel selection.

* * * * *

(i) *Device Security.* All U–NII devices must contain security features to protect against modification of software by unauthorized parties.

(1) Manufacturers must implement security features in any digitally modulated devices capable of operating in any of the U–NII bands, so that third parties are not able to reprogram the device to operate outside the parameters for which the device was certified. The software must prevent the user from operating the transmitter with operating frequencies, output power, modulation types or other radio frequency parameters outside those that were approved for the device. Manufacturers may use means including, but not limited to the use of a private network that allows only authenticated users to download software, electronic signatures in software or coding in hardware that is decoded by software to verify that new software can be legally loaded into a device to meet these requirements and must describe the methods in their application for equipment authorization.

(2) Manufacturers must take steps to ensure that DFS functionality cannot be disabled by the operator of the U–NII device.

(j) Operator Filing Requirement: Before deploying an aggregate total of more than one thousand outdoor access points within the 5.15–5.25 GHz band, parties must submit a letter to the Commission acknowledging that, should harmful interference to licensed services in this band occur, they will be required to take corrective action. Corrective actions may include reducing power, turning off devices, changing frequency bands, and/or further reducing power radiated in the vertical direction. This material shall be submitted to Laboratory Division, Office of Engineering and Technology, Federal Communications Commission, 7435 Oakland Mills Road, Columbia, MD 21046. Attn: U–NII Coordination, or via Web site at https://www.fcc.gov/labhelp with the SUBJECT LINE: ‘‘U–NII–1 Filing’’.

As modified, September 24, 2014

§ 15.407 General technical requirements.

(a) * * *

(2) For the 5.25–5.35 GHz and 5.47– 5.725 GHz bands, the maximum conducted output power over the frequency bands of operation shall not exceed the lesser of 250 mW or 11 dBm + 10 log B, where B is the 26 dB emission bandwidth in megahertz.

* * *

* * * * *

(h) * * *

(2) Radar Detection Function of Dynamic Frequency Selection (DFS). U–NII devices operating with any part of its 26 dB emission bandwidth in the 5.25–5.35 GHz and 5.47–5.725 GHz bands shall employ a DFS radar detection mechanism to detect the presence of radar systems and to avoid co-channel operation with radar systems. Operators shall only use equipment with a DFS mechanism that is turned on when operating in these bands. The device must sense for radar signals at 100 percent of its emission bandwidth. The minimum DFS detection threshold for devices with a maximum e.i.r.p. of 200 mW to 1 W is -64 dBm. For devices that operate with less than 200 mW e.i.r.p. and a power spectral density of less than 10 dBm in a 1 MHz band, the minimum detection threshold is -62 dBm. The detection threshold is the received power averaged over 1 microsecond referenced to a 0 dBi antenna. For the initial channel setting, the manufacturers shall be permitted to provide for either random channel selection or manual channel selection.

(i) Operational Modes. The DFS requirement applies to the following operational modes:

(A) The requirement for channel availability check time applies in the master operational mode.

(B) The requirement for channel move time applies in both the master and slave operational modes.

(ii) Channel Availability Check Time. A U–NII device shall check if there is a radar system already operating on the channel before it can initiate a transmission on a channel and when it has to move to a new channel. The U–NII device may start using the channel if no radar signal with a power level greater than the interference threshold values listed in paragraph (h)(2) of this section, is detected within 60 seconds.

(iii) Channel Move Time. After a radar's presence is detected, all transmissions shall cease on the operating channel within 10 seconds. Transmissions during this period shall consist of normal traffic for a maximum of 200 ms after detection of the radar signal. In addition, intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel.

(iv) Non-occupancy Period. A channel that has been flagged as containing a radar system, either by a channel availability check or in-service monitoring, is subject to a nonoccupancy period of at least 30 minutes. The non-occupancy period starts at the time when the radar system is detected.

As modified, December 23, 2014

§ 15.407 General technical requirements.

(a) * * *

(1) * * *

(iii) For fixed point-to-point access points operating in the band 5.15–5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W. In addition, the maximum power spectral density shall not exceed 17 dBm in any 1 megahertz band. Fixed point-to-point U–NII devices may employ antennas with directional gain up to 23 dBi without any corresponding reduction in the maximum conducted output power or maximum power spectral density. For fixed point-to-point transmitters that employ a directional antenna gain greater than 23 dBi, a 1 dB reduction in maximum conducted output power and maximum power spectral density is required for each 1 dB of antenna gain in excess of 23 dBi. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U–NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

As modified, April 6, 2016

§ 15.407 General technical requirements.

(a) * * *

(1) * * *

(iv) For client devices in the 5.15–5.25 GHz band, the maximum conducted output power over the frequency band of operation shall not exceed 250 mW provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

* * * * *

(b) * * *

(4) For transmitters operating in the 5.725–5.85 GHz band:

(i) All emissions shall be limited to a level of -27 dBm/MHz at 75 MHz or more above or below the band edge increasing linearly to 10 dBm/MHz at 25 MHz above or below the band edge, and from 25 MHz above or below the band edge increasing linearly to a level of 15.6 dBm/MHz at 5 MHz above or below the band edge, and from 5 MHz above or below the band edge increasing linearly to a level of 27 dBm/MHz at the band edge.

(ii) Devices certified before March 2, 2017 with antenna gain greater than 10 dBi may demonstrate compliance with the emission limits in § 15.247(d), but manufacturing, marketing and importing of devices certified under this alternative must cease by March 2, 2018. Devices certified before March 2, 2018 with antenna gain of 10 dBi or less may demonstrate compliance with the emission limits in § 15.247(d), but manufacturing, marketing and importing of devices certified under this alternative must cease before March 2, 2020.

§ 15.407 General technical requirements. (Updated May, 2016)

(a) Power limits:

(1) For the band 5.15-5.25 GHz.

(i) For an outdoor access point operating in the band 5.15-5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 17 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. The maximum e.i.r.p. at any elevation angle above 30 degrees as measured from the horizon must not exceed 125 mW (21 dBm).

(ii) For an indoor access point operating in the band 5.15-5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 17 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(iii) For fixed point-to-point access points operating in the band 5.15-5.25 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W. In addition, the maximum power spectral density shall not exceed 17 dBm in any 1 megahertz band. Fixed point-to-point U-NII devices may employ antennas with directional gain up to 23 dBi without any corresponding reduction in the maximum conducted output power or maximum power spectral density. For fixed point-to-point transmitters that employ a directional antenna gain greater than 23 dBi, a 1 dB reduction in maximum conducted output power and maximum power spectral density is required for each 1 dB of antenna gain in excess of 23 dBi. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U-NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

(iv) For client devices in the 5.15-5.25 GHz band, the maximum conducted output power over the frequency band of operation shall not exceed 250 mW provided the maximum antenna gain does not exceed 6 dBi. In addition, the maximum power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(2) For the 5.25-5.35 GHz and 5.47-5.725 GHz bands, the maximum conducted output power over the frequency bands of operation shall not exceed the lesser of 250 mW or 11 dBm 10 log B, where B is the 26 dB emission bandwidth in megahertz. In addition, the maximum power spectral density shall not exceed 11 dBm in any 1 megahertz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(3) For the band 5.725-5.85 GHz, the maximum conducted output power over the frequency band of operation shall not exceed 1 W. In addition, the maximum power spectral density shall not exceed 30 dBm in any 500-kHz band. If transmitting antennas of directional gain greater than 6 dBi are used, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi. However, fixed point-to-point U-NII devices operating in this band may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter conducted power. Fixed, point-to-point operations exclude the use of point-to-multipoint systems, omnidirectional applications, and multiple collocated transmitters transmitting the same information. The operator of the U-NII device, or if the equipment is professionally installed, the installer, is responsible for ensuring that systems employing high gain directional antennas are used exclusively for fixed, point-to-point operations.

> ***Note to paragraph (a)(3)****: The Commission strongly recommends that parties employing U-NII devices to provide critical communications services should determine if there are any nearby Government radar systems that could affect their operation.*

(4) The maximum conducted output power must be measured over any interval of continuous transmission using instrumentation calibrated in terms of an rms-equivalent voltage.

(5) The maximum power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements in the 5.725-5.85 GHz band are made over a reference bandwidth of 500 kHz or the 26 dB emission bandwidth of the device, whichever is less. Measurements in the 5.15-5.25 GHz, 5.25-5.35 GHz, and the 5.47-5.725 GHz bands are made over a bandwidth of 1 MHz or the 26 dB emission bandwidth of the device, whichever is less. A narrower resolution bandwidth can be used, provided that the measured power is integrated over the full reference bandwidth.

(b) *Undesirable emission limits.* Except as shown in paragraph (b)(7) of this section, the maximum emissions outside of the frequency bands of operation shall be attenuated in accordance with the following limits:

(1) For transmitters operating in the 5.15-5.25 GHz band: All emissions outside of the 5.15-5.35 GHz band shall not exceed an e.i.r.p. of −27 dBm/MHz.

(2) For transmitters operating in the 5.25-5.35 GHz band: All emissions outside of the 5.15-5.35 GHz band shall not exceed an e.i.r.p. of −27 dBm/MHz.

(3) For transmitters operating in the 5.47-5.725 GHz band: All emissions outside of the 5.47-5.725 GHz band shall not exceed an e.i.r.p. of −27 dBm/MHz.

(4) For transmitters operating in the 5.725-5.85 GHz band:

(i) All emissions shall be limited to a level of −27 dBm/MHz at 75 MHz or more above or below the band edge increasing linearly to 10 dBm/MHz at 25 MHz above or below the band edge, and from 25 MHz above or below the band edge increasing linearly to a level of 15.6 dBm/MHz at 5 MHz above or below the band edge, and from 5 MHz above or below the band edge increasing linearly to a level of 27 dBm/MHz at the band edge.

(ii) Devices certified before March 2, 2017 with antenna gain greater than 10 dBi may demonstrate compliance with the emission limits in § 15.247(d), but manufacturing, marketing and importing of devices certified under this alternative must cease by March 2, 2018. Devices certified before March 2, 2018 with antenna gain of 10 dBi or less may demonstrate compliance with the emission limits in § 15.247(d), but manufacturing, marketing and importing of devices certified under this alternative must cease before March 2, 2020.

(5) The emission measurements shall be performed using a minimum resolution bandwidth of 1 MHz. A lower resolution bandwidth may be employed near the band edge, when necessary, provided the measured energy is integrated to show the total power over 1 MHz.

(6) Unwanted emissions below 1 GHz must comply with the general field strength limits set forth in § 15.209. Further, any U-NII devices using an AC power line are required to comply also with the conducted limits set forth in § 15.207.

(7) The provisions of § 15.205 apply to intentional radiators operating under this section.

(8) When measuring the emission limits, the nominal carrier frequency shall be adjusted as close to the upper and lower frequency band edges as the design of the equipment permits.

(c) The device shall automatically discontinue transmission in case of either absence of information to transmit or operational failure. These provisions are not intended to preclude the transmission of control or signaling information or the use of repetitive codes used by certain digital technologies to complete frame or burst intervals. Applicants shall include in their application for equipment authorization a description of how this requirement is met.

(d) [Reserved]

(e) Within the 5.725-5.85 GHz band, the minimum 6 dB bandwidth of U-NII devices shall be at least 500 kHz.

(f) U-NII devices are subject to the radio frequency radiation exposure requirements specified in § 1.1307(b), § 2.1091 and § 2.1093 of this chapter, as appropriate. All equipment shall be considered to operate in a “general population/uncontrolled” environment. Applications for equipment authorization of devices operating under this section must contain a statement confirming compliance with these requirements for both fundamental emissions and unwanted emissions. Technical information showing the basis for this statement must be submitted to the Commission upon request.

(g) Manufacturers of U-NII devices are responsible for ensuring frequency stability such that an emission is maintained within the band of operation under all conditions of normal operation as specified in the user’s manual.

(h) Transmit Power Control (TPC) and Dynamic Frequency Selection (DFS).

(1) Transmit power control (TPC). U-NII devices operating in the 5.25-5.35 GHz band and the 5.47-5.725 GHz band shall employ a TPC mechanism. The U-NII device is required to have the capability to operate at least 6 dB below the mean EIRP value of 30 dBm. A TPC mechanism is not required for systems with an e.i.r.p. of less than 500 mW.

(2) Radar Detection Function of Dynamic Frequency Selection (DFS). U-NII devices operating with any part of its 26 dB emission bandwidth in the 5.25-5.35 GHz and 5.47-5.725 GHz bands shall employ a DFS radar detection mechanism to detect the presence of radar systems and to avoid co-channel operation with radar systems. Operators shall only use equipment with a DFS mechanism that is turned on when operating in these bands. The device must sense for radar signals at 100 percent of its emission bandwidth. The minimum DFS detection threshold for devices with a maximum e.i.r.p. of 200 mW to 1 W is −64 dBm. For devices that operate with less than 200 mW e.i.r.p. and a power spectral density of less than 10 dBm in a 1 MHz band, the minimum detection threshold is −62 dBm. The detection threshold is the received power averaged over 1 microsecond referenced to a 0 dBi antenna. For the initial channel setting, the manufacturers shall be permitted to provide for either random channel selection or manual channel selection.

(i) Operational Modes. The DFS requirement applies to the following operational modes:

(A) The requirement for channel availability check time applies in the master operational mode.

(B) The requirement for channel move time applies in both the master and slave operational modes.

(ii) Channel Availability Check Time. A U-NII device shall check if there is a radar system already operating on the channel before it can initiate a transmission on a channel and when it has to move to a new channel. The U-NII device may start using the channel if no radar signal with a power level greater than the interference threshold values listed in paragraph (h)(2) of this section, is detected within 60 seconds.

(iii) Channel Move Time. After a radar's presence is detected, all transmissions shall cease on the operating channel within 10 seconds. Transmissions during this period shall consist of normal traffic for a maximum of 200 ms after detection of the radar signal. In addition, intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel.

(iv) Non-occupancy Period. A channel that has been flagged as containing a radar system, either by a channel availability check or in-service monitoring, is subject to a non-occupancy period of at least 30 minutes. The non-occupancy period starts at the time when the radar system is detected.

(i) Device Security. All U-NII devices must contain security features to protect against modification of software by unauthorized parties.

(1) Manufacturers must implement security features in any digitally modulated devices capable of operating in any of the U-NII bands, so that third parties are not able to reprogram the device to operate outside the parameters for which the device was certified. The software must prevent the user from operating the transmitter with operating frequencies, output power, modulation types or other radio frequency parameters outside those that were approved for the device. Manufacturers may use means including, but not limited to the use of a private network that allows only authenticated users to download software, electronic signatures in software or coding in hardware that is decoded by software to verify that new software can be legally loaded into a device to meet these requirements and must describe the methods in their application for equipment authorization.

(2) Manufacturers must take steps to ensure that DFS functionality cannot be disabled by the operator of the U-NII device.

(j) Operator Filing Requirement: Before deploying an aggregate total of more than one thousand outdoor access points within the 5.15-5.25 GHz band, parties must submit a letter to the Commission acknowledging that, should harmful interference to licensed services in this band occur, they will be required to take corrective action. Corrective actions may include reducing power, turning off devices, changing frequency bands, and/or further reducing power radiated in the vertical direction. This material shall be submitted to Laboratory Division, Office of Engineering and Technology, Federal Communications Commission, 7435 Oakland Mills Road, Columbia, MD 21046. Attn: U-NII Coordination, or via Web site at *https://www.fcc.gov/labhelp* with the SUBJECT LINE: "U-NII-1 Filing".

[63 FR 40836, July 31, 1998, as amended at 69 FR 2687, Jan. 20, 2004; 69 FR 54036, Sept. 7, 2004; 79 FR 24579, May 1, 2014; 79 FR 56988, Sept. 24, 2014; 79 FR 76903, Dec. 23, 2014; 81 FR 19901, Apr. 6, 2016]