Application Note

TI mmWave Radar Device Regulatory Compliance Guide

ABSTRACT

This application note covers the requirements for compliance to regulatory standards for mmWave radar devices. Radio Equipment Directive (RED), a standard for equipment sold in Europe and Federal Communications Commission (FCC), the standard for the United States is reviewed in detail. The tools provided by TI for these tests, common issues, and resolutions to these issues are also covered.

The radar portfolio consists of 60GHz and 77GHz devices, however this document broadly focuses on the 60GHz devices. The information applies to both the antenna on PCB and Antenna on Package (AOP) variants of the 60GHz devices.

Note

All test reports and supporting documents can be found in the certification package on the TIREX page.

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Trademarks

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1 Introduction

Note

This document is intended solely as an introductory guide to certifying equipment containing TI's mmWave Radar devices. This document is not an exhaustive reference and must not be considered a replacement for the standards put forward by any regulatory body. Consult your test house, regulatory body, or legal experts for your certification needs and requirements.

Products that emit intentional and non-intentional radiation are sold around the world; these products must adhere to regulatory compliance standards that apply to the regions in which they operate:

- FCC – US
- CE/RED – Europe
- TELEC / MIC – Japan
- ISED – Canada
- KCC / MSIP – Korea
- SRRC / CCC – China

All test reports and supporting documents can be found in the certification package on the TIREX page.

	60 GHz	77 GHz
USA FCC	**57-71 GHz –** Short-Range Field Disturbance Sensors (radars) for non-ADAS functions. License free under specified conditions **61-61.5 GHz** –ISM band, reduced output power restrictions	**75-85 GHz –** Level Probing Radar (Downward-facing narrow beam) **76-81 GHz –** Vehicular Radar, Airplane-installed wingtip radar **76-77 GHz –** FOD at airports, Fixed infrastructure
European Common Market CE / RED	**57-64 GHz** – Open, restrictions on output power, Level Probing Radar, Tank Level Probing Radar **61-61.5 GHz -** Open, reduced restrictions on output power See RED section for more details	**75-85 GHz** – Level Probing Radar, Tank Level Probing Radar **76-77 GHz** – Vehicular Radar, Fixed Traffic Monitoring, Railroad crossings, manned rotorcraft **77-81 GHz** – Vehicular Radar
China SRRC / CCC	* **59-64 GHz –** Open for Radiolocation **61-61.5 GHz** – Open according-ISM rules	**76-77 GHz –** Vehicular Radar
Korea KCC / MSIP	**57-66 GHz** – Open for low output power Rule Code: K176C **61-61.5 GHz -** No regulations so far, possibly open according-ISM rules	**75-85 GHz** – Armature Satellite, Space Research, Radio astronomy, Astronomy Research, Geostationary Orbit Satellite **76-77 GHz** – ADAS Automotive Radar (Rule Code: K37G)
Japan MIC / TELEC	**60-61 GHz** – Low Power Equipment Millimeter-Wave Radar **57-66 GHz** – Millimeter Wave Image Transmission and Millimeter-Wave data Transmission	**76-77 GHz** – Open **77-81 GHz** – Open, possibly for vehicular radar

* Certification within this band is on hold at the time of writing

Figure 1-1. Regions, Applications, and Operating Frequencies

The roles of these regulatory bodies are to verify various devices can co-operate, equipment under test (EUT) can handle interference from other devices without irrecoverable loss of function, in-band and out-of-band power is within specified limits, spurious emissions is at acceptable levels, RF exposure are at safe levels, and so forth.

This document briefly covers some of the tests done and tools provided by TI to setup and run the test on the TI mmWave short range radar. RED and FCC compliance tests are discussed in some detail; however, similar tools and information apply to other regulatory tests.

2 Typical Certification Procedure

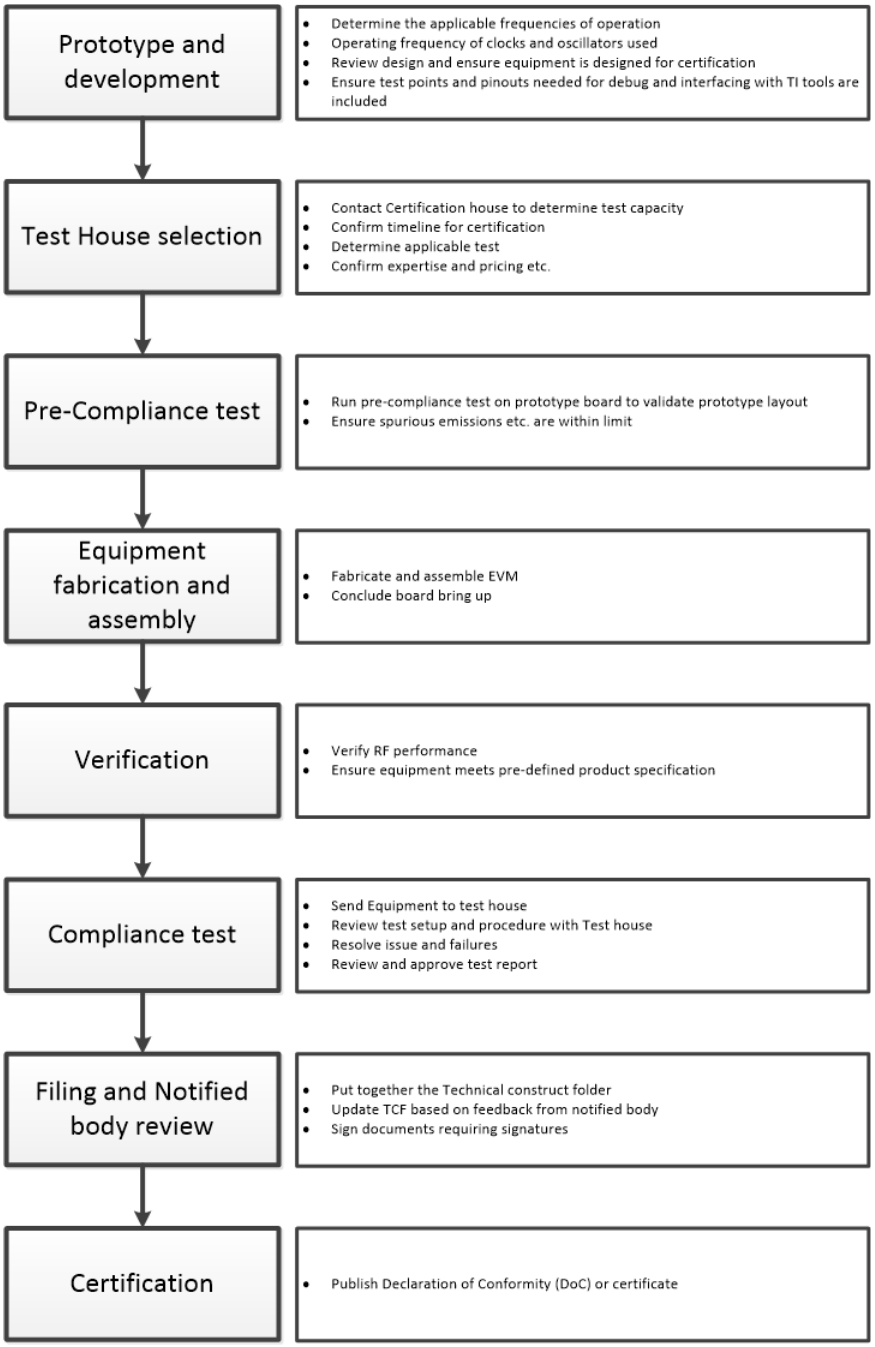


Figure 2-1. Typical Process of Building and Certifying an Equipment

As shown in Figure 2-1, beginning with the prototype and development phase, equipment must be designed with certification in mind to catch and avoid preventable issues later in the product life cycle. This is especially true when operating in multiple regulatory markets.

When selecting a test house, it is important to consider not only cost, but also the technical proficiency of the staff, the knowledgability of the Telecommunications Board (TCB), and the quality of the overall services provided. It can also be helpful to work with reputable test houses and TCBs in your region, as they will be the easiest to develop a relationship with for asking questions, debugging issues, and planning future projects. It is important to select a test house that you are confident in and able to work with successfully, as once testing begins, you will typically not be able to change to a different test house. This is to prevent "shopping" for a certification.

Sometimes it can be very helpful during a design process to send test samples to your test house for a pre-compliance test, also called a "pre-scan". A pre-scan is a type of initial test performed by a test house that focuses on finding gross emissions from an EUT. It is the first step done as part regular compliance testing and uses peak hold detectors and wide bandwidths to search for any emissions. If emissions are detected and the have more than the minimum margin from the limit, a final scan would not be required. However, just because a spur is observed, doesn't mean that the spur amplitude is as high as it is reported during the pre-scan. Often times it can be lower. Like previously mentioned, a pre-scan can be used to find potentially violating spurs. They are a cost-effective option to help improve board design before final release.

With the pre-scan results in mind, further device verification, validation and production can begin. The samples of the end equipment are then made available for compliance testing.

During the compliance testing, it is important to maintain contact with your test house staff on a regular basis. This can help make sure that you are able to quickly find and resolve problems as they occur, whether those problems are end-equipment knowledge gaps on the part of the TCB or potential compliance failures.

After the completion of the testing phase, the TCB often requires additional documentation to be filed and verified before issuance of the certification. Start communications with the TCB early so as to provide enough time to develop any new documents ahead of time so as to reduce cycle time and thus time to market. Often, this documentation requires signatures from a person with authorization to make statements on behalf of your firm. It is important to align internally to determine who should sign such documents. You must also align with your test house staff on which marking standards your device must follow.

After a positive review, the TCB will assist in filing relevant documents at regulatory agencies. In the case of products being sold in the European common market, this will involve a filing with a Notified Body (NB), for the FCC it is a filing with them from the Telecommunications Certification Board.

After acceptance by the FCC developer can homologate the product with the FCC logos and place the FCC ID on the product. After acceptance by the NB, the developer can add the completed standards to their Declaration of Conformity (DoC) and affix the CE logo to their product. The DoC must be made available to the public.

A DoC for products homologated with the CE marking, typically contains the following at a minimum:

- Product Name, type, serial or batch number and purpose
- The name and contact information of the manufacturer
- A compliance statement that identifies the harmonized legislation and standards used
- Details of the Notified Body
- A signature

3 Regulatory Compliance Overview

3.1 European Union Regulations: Radio Equipment Directive (RED)

The DIRECTIVE 2014/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014 on the harmonization of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC. Article 3 essential requirements can be found here.

In accordance with the essential requirement for Radio and electrical equipment sold in the EU, the following harmonized standards can apply to 60GHz and 80GHz radar equipment:

- EN 62311. Safety, RF exposure - *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz to 300 GHz)*. This Standard covers the essential requirements of article 3.1(a) of Directive 2014/53/EU
- EN 62368-1. *Audio/video, information and communication technology equipment - Part 1: Safety requirements*, Electrical safety; This also covers the essential requirements of article 3.1(a) of Directive 2014/53/EU
- EN 301 489-3. *Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 1: Common technical requirements*. This harmonized standard covers the essential requirements of article 3.1(b) of Directive 2014/53/EU and the essential requirements of article 6 of Directive 2014/30/EU.
- EN 305 550. *Short Range Devices (SRD) Radio equipment to be used in the 40 GHz to 246 GHz frequency range; Harmonized Standard for access to radio spectrum*. This covers the essential requirements of article 3.2 of Directive 2014/53/EU.
- EN 302 729. *Short Range Devices (SRD) Level Probing Radar (LPR) equipment operating in the frequency ranges ... 57 GHz to 64 GHz, 75 GHz to 85 GHz*. Harmonized standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU.
- EN 302 264. *Short Range Devices (SRD) Transport and Traffic Telematics (TTT) equipment operating in the 77 GHz to 81 GHz band*. Harmonized Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU.
- EN 301 091. *Short Range Devices (SRD) Transport and Traffic Telematics (TTT); radar equipment operating in the 76 GHz to 77 GHz range*. Harmonized Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU.

Typically, end equipment designers must place the CE mark on the outside of the completed end equipment. This is typically 5mm in height, but if adequate space is not available, the size can be reduced so long as the mark remains clearly visible to the naked eye. If there is utterly no space available, then the CE marking on the housing can be omitted. Justification will need to be made with the NB. Additionally, the CE logo and WEEE logo must be placed on the packaging and in the user guide for the finished equipment.

3.1.1 Short Range Radar (EN 305 550)

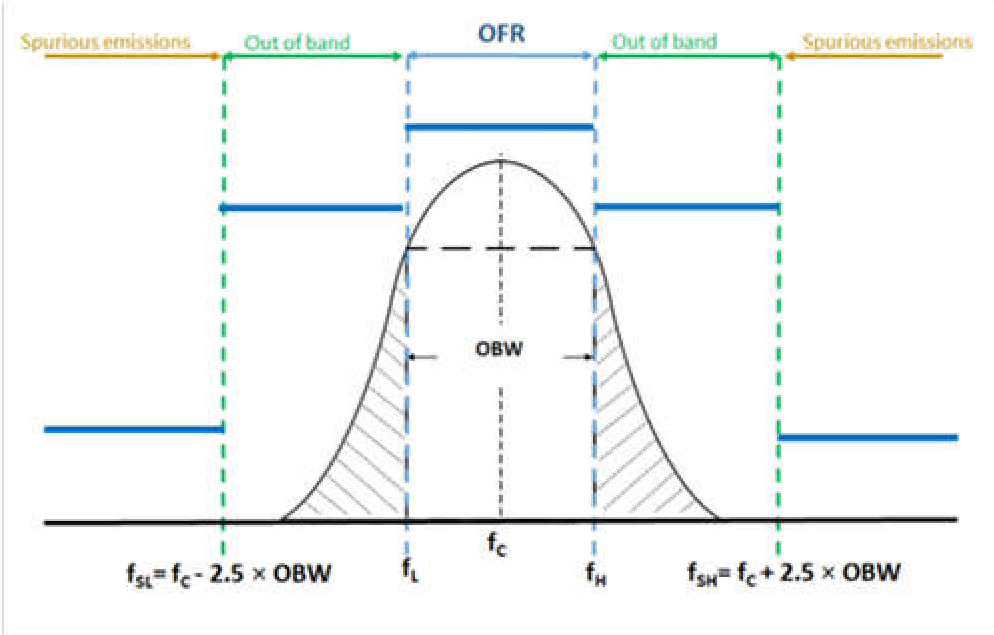


Figure 3-1. OFR, Out of Band and Spurious Emission Frequency Limit

The following limits and tests apply:

- Duty Cycle: The duty cycle is factored into mean power measurement when using a power meter; see section on duty cycle (Section 4.1).
- Permitted range of operating frequencies: See section 4.3.1 of EN 305 550V2.1.0 (section 7.3 EN 305 550-1V1.2.1). This is the authorized frequency range devices are permitted to operate.
- Operating frequency range (OFR): See section 4.3.2 of EN 305 550V2.1.0 . This is the intentional operating frequency range of the device. The IWR6843 mmWave device falls in the 57GHz to 64GHz band and can also be operated in the 61.0GHz to 61.5GHz bandwidth. The occupied bandwidth (OBW) is measured as the bandwidth occupying 99% of the total power in the operating frequency range.

Table 3-1. Operating Frequency Range

Bandwidth (GHz)	FL (GHz)	FH (GHz)
57 - 64	> 57	< 64
61.0 – 61.5	> 61	< 61.5
122 - 123	> 122	< 123
244 - 246	> 244	< 246

- Mean Power: See section 4.3.3 of EN 305 550V2.1.0 (section 7.2 EN 305 550-1V1.2.1) . Mean power is a measure of radiated power or mean equivalent isotropic radiated power (EIRP), and refers to the highest transmitted power level during the transmission cycle. The limit for 57GHz to 64GHz is 100mW EIRP (20dBm EIRP), and the same limit applies to 61.0GHz to 61.5GHz. When taking measurement using a signal analyzer the channel power function is used:

$$20\text{dBm EIRP} = 115.23\text{dBuV/m at 3m} \tag{1}$$

- Mean Power spectral density: See section 4.3.4 of EN 305 550V2.1.0 (section 7.1 EN 305 550-1V1.2.1). This is defined as the emitted power spectral density over the transmission bandwidth in the direction of maximum antenna gain. Limit for 57GHz to 64GHz is 13dBm/MHz EIRP. No limit is defined for 61.0GHz to 61.5GHz.
- Out of band (OOB) emissions: See section 4.3.5 of EN 305 550V2.1.0 (section 7.4 EN 305 550-1V1.2.1). The OOB bandwidth is calculated as in Equation 2.

$$\mathrm{Fsl} = \mathrm{fc} - 25 \times \mathrm{OBW} \tag{2}$$

$$\mathrm{Fsh} = \mathrm{fc} + 25 \times \mathrm{OBW} \tag{3}$$

Table 3-2 shows the limits and bandwidth for out of band and spurious emissions for the mmWave device operating at both the full 4GHz bandwidth and 500MHz bandwidth.

The occupied bandwidth (OBW) is the width of the intentional signal mean power containing 99% of the total mean power. Power below and above this limit (the out of band emission) must be equal to 0.5% of the mean power. This equates to -23dBc bandwidth of the signal.

Table 3-2. Out of Band and Spurious Emissions Bandwidth

OBW/OFR	Permitted operating frequency range	fsl	fl	fc	fh	fsh	OOB limit
4GHz	57GHz to 64GHz	52	60	62	64	72	-20dBm/MHz
500MHz (similar limits to 4GHz applies if operating outside of the 61 to 6.15 range)	61.0GHz to 61.5GHz	60	61	61.25	61.5	62.5	-10dBm/MHz

- Radiated spurious emissions: See section 4.3.6 of EN 305 550V2.1.0 (section 7.5 EN 305 550-1V1.2.1). The spurious emission frequency range includes frequency beyond the OOB limit. The spurious emission is measured up to the 2nd harmonic of the fundamental frequency; the IWR6843 operates from 60-64GHz, with second harmonic at 128GHz.
- Receiver spurious: See section 4.4.2 of EN 305 550V2.1.0 (section 8 EN 305 550-1V1.2.1). Per clause 4.4.2.1 the receiver spurious is only applicable when the equipment can work in receive-only mode. The test does not apply to mmWave devices, as it operates in simultaneous transmit/receive mode.
- Receiver interference signal handling: See section 4.4.3 of EN 305 550V2.1.0. This measures the capability of the device to coexist with other radio applications transmitting within the in-band, OOB, and remote band frequency limit. The interference source must transmit at 10dBm equivalent EIRP for in band frequency and 20dBm equivalent EIRP for OOB and remote band frequency.

$$\text{In band frequency} = \text{center frequency (fc)} \tag{4}$$

$$\text{OOB} = \text{Fc} \pm \text{OBW} \tag{5}$$

$$\text{Remote band} = \text{Fc} \pm 10 \times \text{OBW} \tag{6}$$

3.1.2 Short Range Level Probing Radar (EN 302 729)

Level Probing Radars are radars that are used with process control in many industries to enable contactless measurement of typically fluids, but also other particles or objects filling a designated storage space. This enables customers to static levels, but also fill/transfer rates and detect spills or leaks. LPRs must consist of a combined transmitter and receiver. They must have a dedicated antenna and a narrow field-of-view to reduce scattering. These systems may be FMCW, pulsed radar, or similar techniques.

3.1.2.1 Permitted Frequency Ranges and Operating Bandwidth

ETSI permits four distinct frequency ranges. Of these, the higher two allow the greatest level of target resolution, this is because they have the highest frequencies and the highest bandwidths. For this reason, many customers have begun migrating to these two bands. One thing to notice though, is that while the ETSI has created specific LPR regulations around the 57-64GHz band, the FCC has not, thus for applications seeking market access in both FCC and ETSI regulated markets, the 75-85GHz band may be the most advantageous. The ETSI-permitted LPR frequency bands and their associated bandwidths are detailed in Table 3-3.

To determine the operating range of an LPR, ETSI defines F_L and F_H higher and lower frequencies at which the power has dropped 20dB from the maximum. F_L and F_H must reside completely within the permitted bandwidths of operation.

Table 3-3. Frequencies of Operation

Band Start Frequency (GHz)	Band Stop Frequency (GHz)	Available Bandwidth (GHz)
6	8.5	2.5
24.05	26.5	2.45
57	64	7
75	85	10

- Mean Power Spectral Density: The MPSD sets a limit for how much power can be radiated across the band used. The limits are set for both the main lobe and the half sphere.

Table 3-4. Maximum Mean Power Spectral Density

Operating Frequency Band (GHz)	Maximum Mean EIRP Spectral Density (dBm/MHz) Within Main Beam	Maximum Mean EIRP Spectral Density on the Half-Sphere
6-8.5	-33	-55
24.05-26.5	-14	-41.3
57-64	-2	-41.3
75-85	-3	-41.3

- Maximum Peak Power: The ETSI also sets limits on the peak EIRP with a 50MHz band of the bandwidth of operation.

Table 3-5. Maximum Peak Power

Operating Frequency Bandwidth (GHz)	Maximum EIRP (dBm)	Equivalent Max EIRP Field Strength Levels at 3m (dBµV/M)
6-8.5	7	102.26
24.05-26.5	26	121.26
57-64	35	130.26
75-85	64	129.26

- There are other limits for radiated power in the 6-8.5GHz and 24.05-26.5GHz bands. These are not be discussed in this document. You can find them in EN 302 729 section 4.3.83.

- For radars in the 57-64GHz and 75-85GHz bands, the following limits apply outside of the permitted bands of operation within the main beam: the maximum mean power spectral density must be 20dB lower than the permitted in-band maximum mean power spectral density.

3.1.2.2 Antenna Requirements

Unlike the EN 305 550 standard, the LPR standard includes strict requirements for antenna field-of-view. This is offset however, by very generous permitted gain within the main lobe. This is important to verify good SNR in tall tanks, and when radiating through thick portals or insertions.

To operate an LPR, the antenna must only be pointed downwards, not at any particular tilt or angle.

Table 3-6 describes the permitted antenna beamwidth and side lobe suppression (when the side lobe is at a lower angle than 60 degrees). Figure 3-2 demonstrates how this is measured. ETSI uses the standard definition of antenna beamwidth, which is to say the half-power beam width (HPBW), which is the point at which the gain is reduced 3dB from the peak of the gain.

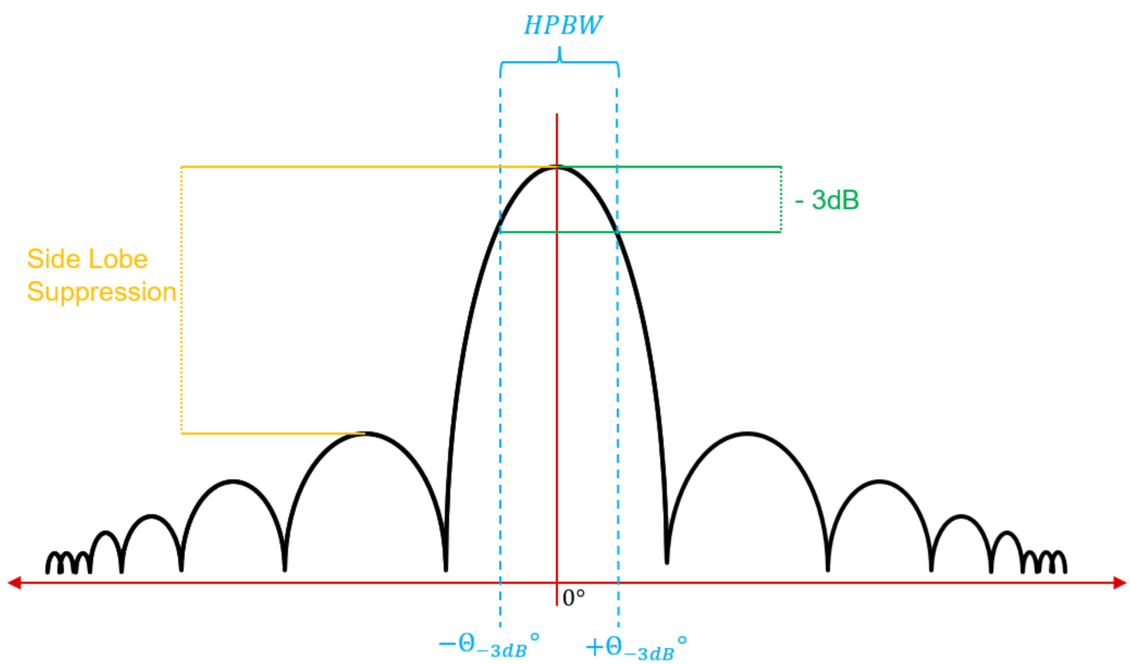


Figure 3-2. Antenna Radiation Pattern Definitions

Table 3-6. Maximum Antenna Beamwidth

Permitted Band of Operations (GHz)	Maximum Antenna Beamwidth in Degrees	Antenna Sidelobe Suppression (dB)
6-8.5	12	-22
24.05-26.5	12	-27
57-64	8	-39
75-85	8	-38

3.1.3 RF Exposure Limit - EN 62311

This limit is set to prevent adverse effect on body tissue or body surface due to RF exposure.

Table 3-7. Frequency Range

Frequency Range	Equivalent plane wave power density (W/m2)
2GHz to 300GHz	10

$$\text{Power density} = \frac{\text{MeanPower(WEIRP)}}{4\pi R^2} \quad (7)$$

where

- R = Minimum separation distance

3.1.4 Electrical Safety - EN 62368

This standard covers safety of various equipment including audio and video, information and communication technology, and business and office machines rated for voltages below 600V. The safety standard and safeguards are to prevent and reduce the chances of pain, injury, fire, and property damage caused by fire outbreaks as a result of equipment use. More on this can be found here.

3.1.5 Electromagnetic Compatibility (EMC) - EN 301 489

The following criteria applies for the test per the standard for EMC emissions and immunity.

Table 3-8. EMC Emissions and Immunity Performance Criteria

Criterion	During Test	After Test
A	Operate as intended. No loss of function. No unintentional responses	Operate as intended. No loss of function. No degradation of performance. No loss of stored data or user programmable functions.
B	Can show loss of function. No unintentional responses	Operate as intended. Lost functions shall be self-recoverable. No degradation of performance. No loss of stored data or user programmable functions.

The following clauses under EN 301 489-1 are applicable to the TI IWR6843 and MMWAVEICBOOST Evaluation Board combo. Since the equipment requires DC power and is not a telecommunication equipment, some of the tests do not apply. Users must determine which test is applicable to their end equipment.

Table 3-9. Clause 8 of EN 301 489-1 – Methods of Measurement and Limits for EMC Emissions Results

Environmental phenomenon		Verdict
Enclosure of ancillary equipment measured on a standalone basis – Clause 8.2	Ancillary equipment Class B limits given in EN 55032	Pass
Ancillary equipment Radiated disturbance above 1GHz at a measurement distance of 3m		Pass
Ancillary equipment intended to be used in telecommunication centers only Class A limits given in EN 55032		Not applicable
Ancillary equipment intended to be used in telecommunication centers only Radiated disturbance above 1GHz at a measurement distance of 3m		Not applicable
DC power input/output ports – Clause 8.3	Class B limits according to EN 55032	Pass
Equipment intended to be used in telecommunication centers only		Not applicable
AC mains power input/output ports – Clause 8.4	Class B limits given in EN 55032	Not applicable
Equipment intended to be used in telecommunication centers only Class A limits given in EN 55032		Not applicable
Harmonic current emissions (AC mains input port)– Clause 8.5	The appropriate requirements of EN 61000-3-2/A1 for harmonic current emission apply for equipment with an input current up to and including 16A per phase. For equipment with an input current of greater than 16A per phase EN 61000-3-12 applies.	Not applicable
Voltage fluctuations and flicker (AC mains input port) – Clause 8.6	The appropriate requirements of EN 61000-3-3 for voltage fluctuations and flicker apply for equipment with an input current up to and including 16A per phase. For equipment with an input current of greater than 16A per phase EN 61000-3-11 [13] applies.	Not applicable
Telecommunication ports – Clause 8.7	Class B limits given in EN 55032	Not applicable
Equipment intended to be used in telecommunication centers only Class A limits given in EN 55032		Not applicable

Table 3-10. Clause 9 of EN 301 489-1 Test Methods and Levels for Immunity Tests Results

Environmental phenomenon	Test port	Basic standard	Verdict
Radio frequency electromagnetic field (80MHz to 1000MHz and 1000MHz to 6000MHz) – Clause 9.2	Enclosure	EN 61000-4-3	Pass
Electrostatic discharge1 – Clause 9.3	Enclosure	EN 61000-4-2	Pass
Fast transients, Common mode– Clause 9.4	AC mains power port	EN 61000-4-4	Not applicable
Signal ports, telecommunication ports, control ports		Not applicable	

Table 3-10. Clause 9 of EN 301 489-1 Test Methods and Levels for Immunity Tests Results (continued)

Environmental phenomenon	Test port	Basic standard	Verdict
DC power ports		Pass	
Radio frequency, common mode (0.15MHz to 80MHz) – Clause 9.5	AC mains power port	EN 61000-4-6	Not applicable
Signal ports, telecommunication ports, control ports		Not applicable	
DC power ports		Pass	
Transients and surges – Clause 9.6	12V and 24V DC supply voltage input ports of mobile radio and ancillary equipment, which are also intended for mobile use in vehicles.	ISO 7637-2	Not applicable
Voltage dips and interruptions – Clause 9.7	AC mains power port	EN 61000-4-11	Not applicable
Surges line to line and line to ground – Clause 9.8	AC mains power port	EN 61000-4-5	Not applicable
Telecommunication ports		Not applicable	

In addition to EN 301 489-1, there are standards which apply EN 301 489-1 to specific end equipments. They are explanatory and provide more granular detail on how to apply the standards contained within EN 301 489-1. For most 60GHz radars, EN 301 489-3 will be used. It provides clarifications for how EN 301 489-1 should be interpreted. Four key provisions apply here.

The first is that the device must be tested with transmit signals representative of actual use and receive signals for radiated immunity must be 30dB higher than the minimum usable signal. Provisions are made for the case where the defined signal causes saturation of the receiver.

The second, is the recognition of different modes of operation, such as "power off", "standby", and so forth. These modes are typically determined through a reading of the theory of operation. The device should not have an unplanned transmission during its non transmit mode.

The third, is the introduction of clarity of when radiated and conducted emissions at specific ports are applicable. This is covered in Table 4 of EN 301 489-3. From Table 4, radiated emissions are generally applicable to all equipment, DC power input/output port conducted emissions are required for all non-portable use equipment and finally AC mains input/output and wired network conduced emissions only applies to fixed location equipment.

Ultimately EN 301 489-3 shouldn't add any additional testing; rather EN 301 489-3 simply makes clear the requirements of EN 301 489-1 as applied to radars and other specific SRD niches.

3.2 Federal Communications Commission (FCC)

Since its creation by the Communications Act of 1934, the Federal Communications Commission has been charged with managing the use of the wireless spectrum so that it is as available and as usable as possible for all people within the US. FCC rule-making is done by providing updates to Title 47 of the Code of Federal Regulations. These rules are considered binding on all operations within the US and its territories. The FCC Office of Engineering and Technology (OET) issues Knowledge Database (KDB) updates that are used to clarify implementation of the FCC regulations. While the KDB does not amend or replace the regulations, most TCBs will follow them to the letter. While Title 47 is very large, this article focuses only on the sections relevant to 60GHz radar and TLPR.

Upon completion of testing and certification, equipment manufacturers can voluntarily place the FCC logo on their device housing to show compliance with applicable regulations. In all cases, the FCC requires that the approved hardware contain the FCC ID in the form "FCC ID: XXXXXX". The same must be placed on the packaging and in the user guide for the equipment. The FCC does permit electronic labeling of devices.

3.2.1 End Equipment and FCC Clause

Table 3-11 shows key end equipment categories, the allowed frequency band and the applicable FCC clauses based on interpretation of the standard.

Table 3-11 shows understanding at the time of writing and may not be up to date. Recommendation is to confirm the specifics of your use case with FCC.

Table 3-11. End Equipment

End Equipment	Frequency Band	FCC clause
Area scanner for Zone occupancy	60GHz	FCC 15.255 - fixed field disturbance sensors
Automated Doors and Gates	60GHz	FCC 15.255 - fixed field disturbance sensors
Gesture Recognition	60GHz	FCC 15.255 - short-range devices for interactive motion sensing
High accuracy level sensing	60GHz or 77GHz	FCC 15.255 fixed field disturbance sensors FCC 15.256 – level probing radars
Long range people detection	60GHz	FCC 15.255 - fixed field disturbance sensors
People Counting	60GHz	FCC 15.255 - fixed field disturbance sensors
Robotics	77GHz	FCC Part 95 (if robot is used to move people or goods)
Traffic Monitoring	60GHz	FCC 15.255 - fixed field disturbance sensors
Vital signs	60GHz	FCC 15.255 - fixed field disturbance sensors
Automotive In Cabin Sensing	60GHz	FCC 15.255 - fixed field disturbance sensors (if car is stopped)
Automotive Sensing	77GHz	FCC Part 95

3.2.2 60GHz Radar Operation (47 CFR § 15.255)

In August of 2023, the Federal Communications Commission (FCC) updated the regulations for 60GHz radar in the band of (54-71GHz). These new regulations are a part of the FCC's mission to seek harmonization of global EMC/EMI regulations, and create a largely permissive space for 60GHz radar applications in industrial and consumer applications, as well as non-ADAS automotive use cases.

The FCC has structured §15.255, largely by bandwidth. Each available bandwidth has specific frequency, EIRP, locational and potentially duty cycle limitations. We will briefly touch on each of these and provide some examples of potential use cases.

One of the most common bands utilized, is the Industrial, Scientific, and Medical (ISM), band. The ISM band is a 500MHz band which exists from 61GHz to 61.5GHz. Due to its narrow bandwidth, it is permitted a generous 36dBm average and peak EIRP.

One new exciting development is the permission to utilize 60GHz radar for level sensing applications, known as Level Probing Radar (LPR) or Tank Level Probing Radar (TLPR). This is a step in the direction of harmonization with the ETSI. However, unlike the ETSI, the FCC has not created specific 60GHz LPR/TLPR regulations. Designers applying for certification for LPR/TLPR systems under §15.255 must all meet the previously mentioned restrictions. This comes with the benefit of not requiring the use of narrow FOV antennas with low-power side-lobes.

However, this does create challenges for LPR/TLPR system designers wishing to utilize the same hardware for certification under both FCC and ETSI regulations. This is because ETSI does require narrow FOV antennas with low-power side-lobes for 60GHz LPR/TLPR. The difficulty here is the disharmony in regulations concerning peak EIRP for designers seeking greater than 500MHz BW. Essentially, designers may run into a circumstance where they need more gain at higher BWs than is permitted under FCC regulations. Therefore, it may be easier for designers needing interoperability between FCC and ETSI LPR/TLPR regulations to use the 80GHz band. For the FCC this is regulated under 47 CFR 15.256.

Traditionally, Level Probing Radar is regulated by the FCC under 47 CFR 15.256. This regulation opens the 75-85GHz band for downward-facing level probing systems. This band is largely harmonized with the European regulatory agency ETSI's EN 302 729 which offers the most interoperability for LPR/TLPR applications.

3.2.2.1 Fundamental Emission Levels, BWs, and Max Duty Cycle

In the new § 15.255, there are limits not only for the fundamental emission, but also BW limits and limits on the TX active transmit time. Specifically, § 15.255(c)(2) -§ 15.255(c)(3) covers limits for FDS that allow them to avoid a maximum peak conducted power limit. These limits and BWs are tied to specific use cases, and are intended to reduce the odds of conflict between FDS in use.

For the purposes of § 15.255, the transmitter duty cycle limit is actually defined using transmitter off time intervals. In this case, there is a minimum sum of time for which the transmitter must be off in any 33ms window. In this case, any arbitrary, continuous 33ms window can be used and must satisfy the minimum. Further, only intervals where the transmitter is off for at least 2ms will count towards the minimum. Typically, inter-chirp idle times will be too small to count towards the limit. Another way to look at this is to consider the structure of a frame. The frame consists of a set number of chirps in a burst and a set number of bursts in a frame. Typically, the inter chirp idle time and the inter burst period are both much shorter than 2ms. So either the inter-frame period or deep sleep period must be at least 2ms and within any 33ms window, the sum of those 2ms periods must be no less than 16.5ms or 25.5ms.

Limits for BW, EIRP, and BW are covered by § 15.255(c)(2) and are summarized in the table below. LINK below provides a helpful decision tree to assist in determining the appropriate BW and limits to follow.

Frequency Band (GHz)	Average Radiated TX Power	Peak Radiated TX power	Duty Cycle (off time)	Requirements	Regulation
57.0-59.4	No specified limit	20dBm	No specified limit	Indoor; Cannot change mode except after 33ms	§ 15.255(c)(2)(i)
57.0-59.4	No specified limit	30dBm	No specified limit	Outdoor; Cannot change mode except after 33ms	§ 15.255(c)(2)(i)
57.0-61.56	No specified limit	3dBm	No specified limit	Cannot change mode except after 33ms	§ 15.255(c)(2)(ii)
57.0-61.56	No specified limit	20dBm	50%	Cannot change mode except after 33ms	§ 15.255(c)(2)(ii)
57.0-64.0	No specified limit	14dBm	77.3%	Cannot change mode except after 33ms	§ 15.255(c)(2)(iii)(A)
57.0-64.0	No specified limit	20dBm	50%	Outdoors and temporary or fixed application; Cannot change mode except after 33ms	§ 15.255(c)(2)(iii)(B)(1)
57.0-64.0	No specified limit	20dBm	50%	Outdoors & vehicular exterior applications for movement; Cannot change mode except after 33ms	§ 15.255(c)(2)(iii)(B)(2)
61.0-61.5	40dBm	43dBm	No specified limit	None	§ 15.255(c)(2)(iv)

1. For fixed field disturbance sensors operating in the 61.0GHz to 61.5GHz band emissions outside this bandwidth but within the 57GHz to 71GHz must not exceed average power of 10dBm and peak power of 13dBm.

2. Intentional uses cases outside the 61.0GHz to 61.5GHz band must meet the 57GHz to 71GHz band, not the additional limits for out-of-band 61.0GHz to 61.5GHz use cases.

This flow chart can assist in selecting the appropriate regulations governing chirp, burst, and frame configurations.

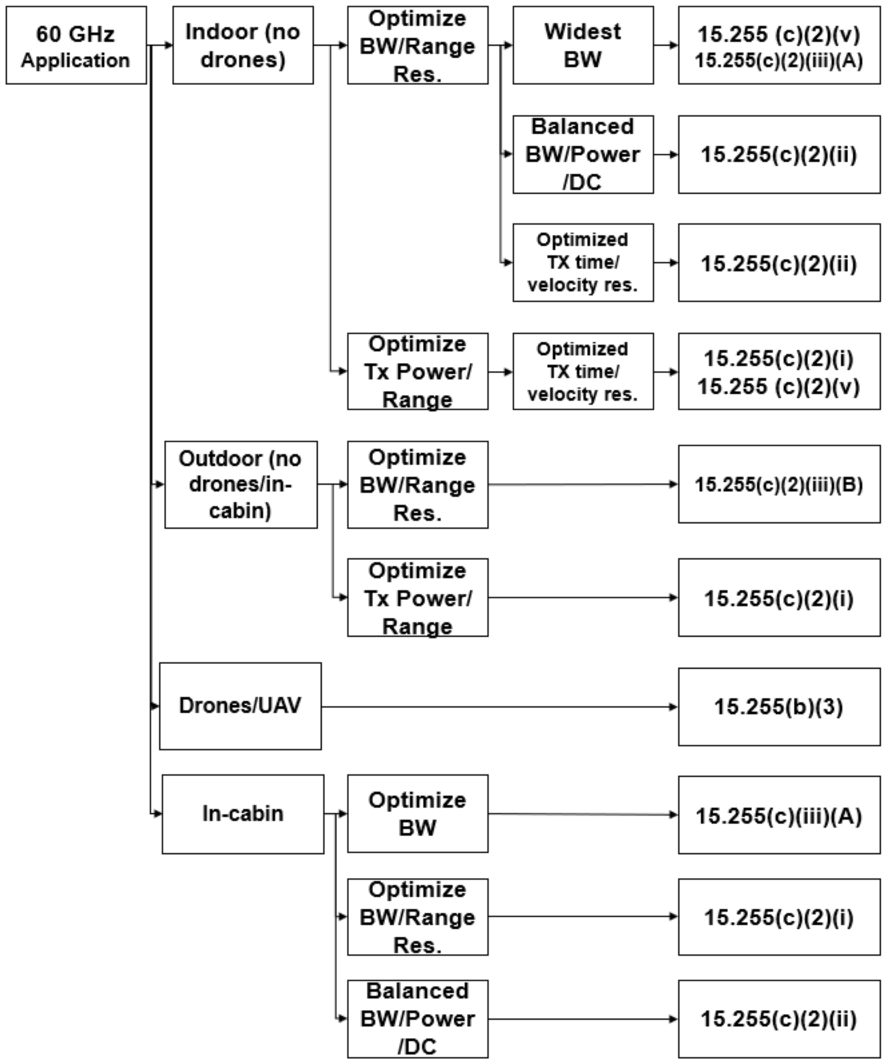


Figure 3-3. FCC § 15.255 Application Specific Chirp Recommendation

3.2.2.2 Spurious Emissions

Spurious emissions are covered under § 15.255(d). Below 40GHz, spurious emissions must meet the limits given in FCC § 15.209. Between 40GHz and 200GHz, spurious emissions outside of 57GHz to 71GHz, must not exceed 90pW/cm^2 at a distance of 3 meters. This is summarized in Table 3-12.

Table 3-12.

Frequency (MHz)	Field Strength (microvolts/meter)	Measurement Distance (meters)
0.009-0.490	2400/F(kHz)	300
0.490-1.705	24000/F(kHz)	30
1.705-30.0	30	30
30-88	100**	3
88-216	150**	3
216-960	200**	3

Table 3-12. (continued)

Frequency (MHz)	Field Strength (microvolts/meter)	Measurement Distance (meters)
960-40000	500	3
40000-57000	20000	3
71000-200000	20000	3

In general, the spurious emission must not exceed the level of the fundamental emission.

3.2.2.3 Frequency Stability

The frequency stability limits are set under § 15.255(f). The fundamental emission must stay within the allowed bands mentioned in § 15.255(c)(2) - §15.255(c)(4) and must do so across -20°C to 50°C as well as an input voltage variation from 85% to 115% rated input voltage.

Some test houses prefer to perform this as a Continuous Wave (CW) measurement. This is because it is simpler than the alternative which is an FMCW measurement. CW measurements can be achieved by connecting the device to mmWAVESTUDIO, but is not necessarily straight forward. The simplest option as a system integrator is simply to have the test house perform the measurement as an FMCW test.

3.2.2.4 FCC Waiver and Other Relevant Information

In the past, the FCC has granted waivers for some applications under specific use cases and conditions, these waivers allow usage outside the previous interpretations of the FCC § 15.255 standards. An example of a request for waiver of part 15 that was approved under short range interactive motion sensing devices can be found here.

With the rollout of the updated § 15. 255 regulations, the need for waivers has almost, if not entirely, disappeared. However, customers interested in applying for waivers need to begin the process in the early stages of the product design as the turnaround time for waiver process is undefined.

3.2.3 Level Probing Radar (47 CFR § 15.256)

While it is possible to use 60GHz radar to create a Tank Level Probing Radar under § 15.255, there are some serious disadvantages compared to § 15.256. The primary advantage of § 15.256 is that it allows for much greater power than § 15.255, which can make it much more useful for taller towers or silos. Fortunately, system designers of TLPR and LPR systems can take advantage of the global harmonization between the ETSI and the FCC in terms of level probing radar regulations, thus reducing development and deployment costs.

3.2.3.1 Usage Limitations

Under § 15.256, a Level Probing Radar (LPR) cannot be marketed to residential consumers. LPRs are typically intended for commercial or industrial use. LPRs also must be installed in a fixed location and must not operate whilst in motion or transit, even if in a confined space. LPRs must also have a dedicated or integrated antenna and have the antenna's main beam be directed vertically downward. Most of these requirements are not a part of § 15.255, however, as shown next, the fundamental emissions power is much higher.

3.2.3.2 Fundamental Emissions, BWs

An LPR must operate with a minimum 50MHz BW, no matter which frequency band the LPR is operating under. For this section, the FCC defines the BW as the width between two points found above and below the center frequency which experience a 10dB drop of power outside. This is distinct from the ETSI regulations which use a 20dB drop.

Table 3-13. LPR Fundamental Emission Limits

Permitted Band of Operation (GHz)	Avg EIRP (dBm in any 1MHz)	Peak EIRP (dBm in any 50MHz)
5.925-7.250	-33	7
24.05-29.00	-14	26
75-85	-3	34

The FCC places a limit on both the average and the peak EIRP of an LPR. This is done in a special manner compared to other operations. The FCC doesn't use spectral density like the ETSI. Rather, for the average EIRP, the FCC requires it be computed by finding the average EIRP by finding and reporting the maximum power level found within any 1MHz BW while using a power averaging detector. You can imagine this as having an averaging detector with a 1MHz window that slides across the BW and reports only the highest power it detected as well as the frequency it was detected.

For the peak power, the FCC uses a peak power detector with a 50MHz BW centered at the location of the of the frequency with the highest average power detected. This 50MHz BW must be entirely located within the authorized BW shown above. In the case where the RBW of the detector is less than 50MHz, as is often the case, the Peak EIRP limit is reduced according to the table below. Keep in mind that the RBW must not be lower than 1MHz or greater than 50MHz. The VBW must not be less than the RBW.

Table 3-14. Peak EIRP Reduction based on Detector RBW

Detector RBW (MHz)	EIRP Limit Reduction
50	N/A
1 ≥ RBW > 50	20 × log(RBW/50)dB

3.2.3.3 Antenna Restrictions

As mentioned previously, the antenna used for an LPR must be either dedicated or integrated into the design and the main beam of the antenna (boresight) must be pointed vertically down. Additionally, the FCC places limits on the antenna side lobes. To measure this and the fundamental emissions shown above, the location of true boresight (rather than theoretical) are determined by finding the angles of highest coupling between the detector and the antenna.

Please see Figure 3-2 for visual depiction of the antenna HPBW and side lobe suppression. Table 3-15 describes the regulatory HPBW and side lobe suppression set forth by the FCC for LPRs. These values are identical to the ETSI regulations with the exception that the FCC has not approved 57GHz to 64GHz radar to be used for LPR.

Table 3-15. HPBW and Sidelobe Suppression

Frequency Band (GHz)	HPBW (degrees)	Sidelobe Suppression (dB)
5.925-7.250	12	-22
24.05-29.00	12	-27
75-85	8	-38

3.2.3.4 Unwanted Emissions

The unintended emissions are simply those listed in § 15.209.

3.2.4 Modular Approval (47 CFR § 15.212)

For some radar users, it can be advantageous to create a radar module that can be certified once, and then integrated into multiple different host systems without the need for each end product to undergo in-band (§ 15.255) testing. This solution is called a "modularly approved" radar. This radar consists of a single PCB which contains the radar chip, crystal oscillator, and power supplies, all of which must be covered under a shield. This modular approval process is covered in 47 CFR §15.212 and detailed in KDB 44637. The major benefits of this are that a company or its customers can save both time and money by reducing the overall test burden.

This is the same process that is used to create Bluetooth® and WiFi® modules, amongst others. This process is flexible to create both modules for use within one company and its products, or for sales to other businesses for inclusion in their final products.

There are key filings that must be made as part of a modularly approved radar, namely in terms of documentation for customers. Customers need to be made aware of exactly how to integrate the module into their host system, as well as what tests are recommended to make sure there are no unexpected emissions. This requirement is more relaxed for internal modules only. It is important to note however, that this process only removes the need for the final integrated system to perform inband testing. This process does not waive any safety or EMC testing requirements.

As with other FCC filings, you need to establish an FCC Registration Code to identify the contact person for your filings, as well as an FCC ID. The FCC ID consists of a prefix of three to five characters, followed by up to 15 characters selected by the manufacturer. The first three to five characters are assigned to by the FCC and is known as the Grantee Code. You need to apply for a Grantee code and paying the associated fees prior to filing for a modular grant. This is the same as for other FCC equipment approvals.

Unfortunately, modular approval for radars is only permitted by the FCC and not other regulatory agencies. However, within other regulatory environments, (like ETSI or JRL), it is be possible to perform inband tests on the module one time and then leverage them with future host integrations to lower the overall testing burden. Consult your test house or legal adviser for the most up to date interpretations of these regulations.

3.2.5 Radiation Exposure Requirement

There are various sections of the FCC standard applicable to radiation exposure and compliance to all is mandated depending on the use cases.

1. 1.1307(b) - Actions that can have a significant environmental effect, for which Environmental Assessments (EAs) must be prepared.
2. 1.1310 - Radiofrequency radiation exposure limits.
3. 2.1091 - Radiofrequency radiation exposure evaluation: mobile devices.
4. 2.1093 - Radiofrequency radiation exposure evaluation: portable devices.

3.3 Japan Radio Law

End equipments sold or important into Japan are subject to the Japan Radio Law (JRL). This law is implemented and enforced by several regulations and notices, namely: The Regulations for Enforcement of Radio Law, the Ordinance Regulating Radio Equipment (ORE), and the Ordinance Concerning Technical Regulations Certification of Specified Radio Equipment. The JRL and all accompanying regulations are further incorporated in the ARIB Standard T-73. The regulations and enforcement of the JRL are conducted by the Ministry of Internal Affairs and Communications (MIC).

Equipment which successfully demonstrates compliance is issued an MIC registration number which must be displayed along with the Giteki symbol. If the device contains a telecommunications modem, then the device can also be given a Technical Regulations Conformity Certification Number that must also be shown with the MIC registration number. The Giteki symbol is typically be 3mm in diameter. The symbol can be reduced in size so long as the symbol and the registration numbers remain clearly visible with the naked eye. In cases where there is not enough space, the Giteki mark can be shown in an electronic label or in the user manual. In any case where the Giteki mark cannot be shown on the device housing, the Giteki must be added to the product packaging.

3.3.1 BW, Designated Frequency, and Tolerances

The Japan Radio Law allows mmWave Radars to operate in the 57GHz to 64GHz band, or the recognized ISM band of 61GHz to 61.5GHz. This is summarized in Table 3-16. Similar to the FCC, the JRL requires that the transmitted signal be duty cycled such that the TX on time is no more than 3.0ms for every 33ms interval. The purpose of this is to make sure that there is ample time for other radar systems to transmit uninterrupted.

Table 3-16.

ISM Band	Full Frequency Band
61GHz to 61.5GHz	57GHz to 64GHz

The JRL requires that frequency tolerance be tested in CW and not functional (FMCW) mode. Plans must be made to enable this kind of testing. However, it can be possible to petition the MIC to create an alternate test plan. Users must discuss this with their test houses. The frequency tolerance is simply that the center frequency of any FMCW chirp must not depart from the designated frequency band, as shown above.

Compared to ETSI or the FCC regulations, JRL permits a relatively low TX EIRP of only 13dBm or less. This is in addition to a limit on input power to the antennas of 10dBm. This is designed to create a limit on the output power of not only the whole system, but also of the transmitter as well. Additionally, the TX EIRP, called "antenna power" is only allowed to deviate upwards by 50% and downwards by 70% from the certified value. However, this does not permit violating the max TI EIRP of 13dBm. This is summarized in Table 3-17.

Table 3-17.

Limit	Power Tolerance
Upper Limit	+50% Antenna Power
Lower Limit	-70% Antenna Power

3.3.2 Out of Band and Spurious Emissions

As with all other regulatory acts, the JRL also maintains standards for spurious and out-of-band emissions. However, unlike ETSI, these bands are determined more by the absolute frequency than the 99% OBW. The applicable limits for spurious and out-of-band emissions are listed in Table 3-18.

Table 3-18.

Frequency	Max Field Strength	Domain
> 55.62GHz	-30dBm/MHz	Spurious
55.62GHz to 57GHz	-26dBm/MHz	Out-of-Band
64GHz to 67.5GHz	-26dBm/MHz	Out-of-Band
< 67.5GHz	-30dBm/MHz	Spurious

In addition to limits on the TX spurious and OOB emissions, JRL places limits on the emissions from sources that do not interfere with other radio equipment. This is measured with a pseudo antenna circuit that is designed such that the circuit maintains the same electric characteristics as the receiving antenna. These secondary emissions are limited to 20nW.

3.3.3 Controller Functions

To prevent interference from other radio equipment in the same enclosure, the radar must, by modulation method or other means, determine whether the detected wave is from the radar in question, or another radio device. With this information, the radar must be able to halt its transmission. This is discussed in the ORE Articles 14-2-1-1 and 14-2-2-1.

3.4 Wireless Planning and Coordination Wing (WPC)

The Wireless Planning and Coordination Wing (WPC) is a part of the Department of Telecommunications within the Ministry of Communications of India. Unlike other nations, WPC combines the functions of spectrum access with spectrum allocation. However, much like other nations, permission from WPC is required for access to the electromagnetic spectrum.

3.4.1 Permitted Frequency of Operations and Approval

The WPC has, at the time of writing, have only permitted the access to the Industrial, Scientific, and Medical (ISM) Band. This band was permitted upon publication of Rule 3 of the "Use of Low Power and Very Low Power Short Range Radio Frequency Devices (Exemption of Licensing) Rules, 2018", (G.S.R. 1047(E)) The Gazette of India, Extraordinary, Part II, Section 3(i), dated 18th October 2018.

Rule 3, Table IX row 15 permits unlicensed operations between the frequency of 61.0GHz and 61.5GHz with a peak power limit of 100mW EIRP (20dBm EIRP). Row 15 further enumerates the ETSI standard EN 305 550 as the controlling standard for this band.

At present, WPC has not authorized access to the 57GHz to 64GHz band beyond the ISM band. They have, however published notification of intent to explore future access to this band in alignment with global standards.

Satisfaction of the RED, marking the product with the CE logo and issuance of a DoC is sufficient to meet the requirements of WPC for showing compliance.

3.4.2 Equipment Type Authorization

Further, under rule 5 of G.S.R. 1047(E), all radio equipment must receive Equipment Type Authorization from the WPC prior to importation to India. Failure to receive the ETA can result in seizure of the radio equipment at the border. Likewise, radio equipment sold in India also requires ETA from WPC. ETAs are applicable for all companies importing the same equipment, regardless of which company applied for the ETA.

As long as the chirp BW of their integrated product is the same as seen in the TI EN 305 550 report for the same device, then the importer can be able to use TI's reports in their ETA application, smoothing import to the Indian market. TI stores these reports publicly in the TI Radar Toolbox (mmWave radar sensors → Hardware kits and boards → <EVM Name> → Emissions Certification → Red Certification Collateral → Report Name).

3.5 Federal Telecommunications Institute (IFT)

IFT is the regulatory agency which governs the use of radio frequency devices in The United Mexican States. IFT have maintained independent regulations for mmWave, which include recognition of the ISM band.

3.5.1 Fundamental Emission Levels and BWs

IFT has permitted the use of the ISM band and other BWs under some restrictions. It can be possible to receive permission from IFT to deviate from these standards by requesting an exemption to follow either FCC or ETSI regulations.

As promulgated, IFT sets the following BW and EIRP restrictions:

Table 3-19. Permitted System EIRP

Frequency Band (GHz)	Max BW (MHz)	Avg EIRP (dBm)	Peak EIRP (dBm)
61-61.5	500	40	43
57-64	500	10	13
57-64	--	-10	10

IFT has not implemented any restrictions on duty cycle in the way that the FCC has. Additionally, IFT has placed limitations on the transmitter power, these limitations are detailed in Table 3-20.

Table 3-20. Max Permitted Transmitter Power

BW	Max Transmitter Power
>100MHz	500mW (27dBm)
< 100MHz	BW (MHz) × 500 (mW) / 100 (MHz)

3.6 National Telecommunications Agency (ANATEL)

The relevant regulatory agency for the Federative Republic of Brazil is ANATEL. ANATEL issues regulations and interpretations of laws issued by the National Congress. mmWave Radar devices are subject to their jurisdiction.

3.6.1 Fundamental Emissions Levels, BWs, and Max Duty Cycle

ANATEL has recently harmonized their regulations with the FCC's 47 CFR 15.255 regulations. This means that a device that is in compliance with FCC regulations is automatically in compliance with Brazilian regulations as well.

3.6.2 Licenses

ANATEL licenses can only be issued to local agents and must be acquired prior to importation or sale of radar devices. These licenses must be renewed every 12 to 24 months depending on the device type. Evaluation modules are exempt from licensing.

3.7 Ministry of Transport and Communications (MTC)

MTC, the regulatory agency of Peru has recently deregulated the 57GHz to 64GHz band. The only requirement is that a system containing a radar must be tested for EIRP, OBW, and periodicity, and make that test data available through scanning an embedded QR code on the final product and that the applicant apply for equipment type approval from the MTC. Once issued, a ETA certificate is valid permanently. Those seeking to import radio devices to Peru must seek the ETA prior to importation.

3.8 National Communications Entity (ENACOM)

ENACOM is the radio devices regulatory agency for the Argentine Republic. Much like the FCC or the ETSI, ENACOM is empowered to implement national laws through regulation. For mmWave radars, ENACOM has allowed operations in the 57GHz to 71GHz band with the limitation that the average power not exceed 40dBm, and the peak power not exceed 43dBm.

Conveniently, ENACOM can permit the use of testing reports generated outside of their country. This can enable the reuse of other testing reports, like those for the FCC or ETSI.

4 Applicable Terms and Equations

4.1 Duty Cycle Factor

The duty cycle factor is calculated as the duty cycle across bursts multiplied by the duty cycle within each burst.

$$\text{Duty Cycle Factor(dB)} = 10\log\left(\frac{1}{X}\right) \quad (8)$$

Where X = Duty Cycle

Table 4-1. Duty Cycle Correction Calculated Using Duty Cycle Within and Between Bursts

BW Mode	On Time	Period	Duty Cycle	On Time	Period	Duty Cycle	Duty Cycle Linear	Duty Cycle	Duty Cycle Correction
	Between Burst			Within Burst			Total		
1300	4.29	16.06	0.267	29.66	33.33	0.890	0.24	23.76	6.24

4.2 Effective Isotropic Radiated Power (EIRP)

EIRP is defined as the sum of the transmitted power and antenna gain, when these two parameters are known the EIRP can be calculated as in Equation 9. EIRP indicates the maximum radiated power at the peak angle of a non-isotropic antenna.

$$\text{EIRP} = P_t - L_c + G_a \quad (9)$$

where

- P_t is the TX power
- L_c is Cable or routing loss
- G_a is the antenna gain

4.3 Friis Equation

For the test setup, a power meter is used to measure received power (Pr), the gain of the receiving antenna (Gr) is known, operating frequency and the distance of the receiving antenna to the EUT is measured. The unknown transmit power of the EUT TX chain is calculated using the Friis equation, as shown in Equation 10.

$$\text{EIRP(Friis)} = P_T \times G_T = \frac{P_R}{G_R} \times \left(\frac{4\pi D}{\lambda}\right)^2 \quad (10)$$

where

- P_R is the measured power
- G_R is the gain of receive measurement antenna
- D is the measurement distance
- λ is the wave length

4.4 Far-Field Boundary

The far field boundary is given as in Equation 11. As the name implies, the far field boundary is the region far from the antenna. The fundamental signal is measured beyond this boundary because the characteristics of the electromagnetic field, such as antenna pattern, do not change in the far field of the EUT.

$$\text{R(far} - \text{field)} = \left(\frac{2 \times L^2}{\lambda}\right) \quad (11)$$

where

- L is the largest antenna dimension in meters
- λ is the wave length in meters

5 Tools and Setup

TI's MMWAVESTUDIO is designed for evaluation and characterization of TI mmWave sensors. MMWAVEVISUALIZER enables real-time point cloud plotting of the data output of the mmWave software development kit (SDK) and mmWave Low Power SDK out-of-the-box demos. Both tools allow for chirp parameter configuration needed for the tests.

5.1 Hardware Setup

For certification, test, and characterization of EUT, TI recommends adding an option to include the 60-pin SAMTEC connector compatible with MMWAVEICBOOST. The MMWAVEICBOOST carrier card enables debug, emulation, and direct interface to mmWave tools such as the MMWAVESTUDIO and mmWave visualizer through USB connectivity. Raw analog-to-digital converter (ADC) data capture can be enabled by pairing the MMWAVEICBOOST with a DCA1000EVM real-time data capture adapter. To configure the MMWAVEICBOOST, refer to the user's guide.

For customers unable to include the 60-pin connector, Figure 5-1 shows the essential peripherals needed to interface with mmWave studio and mmWaveVisualizer for test and certification purposes. This is to verify access to functionality such as continuous wave mode, which can be required by some regulatory standards.

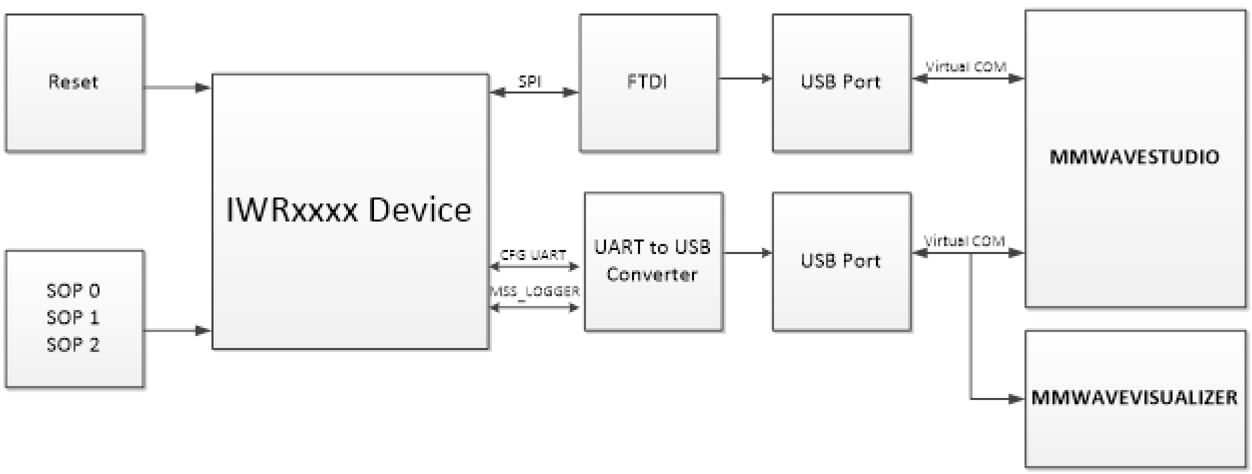


Figure 5-1. Interfacing with TI Tools

5.2 Internal Laboratory Test Setup

Often, it can be desirable to evaluate a design internally to determine the ability of a system to pass certification ahead of time. Performing the same measurements to the same level of detail as a TCB is often times too cumbersome, costly, and time consuming to complete in-house. This is due to the cost and complexity of anechoic chambers, cables, antennas, calibration, validation, and certification.

However, that does not mean that it is impossible to take simpler actions to help debug and prepare a system for pre-scan or certification. This section discusses a few important technologies and setups that can be used to prepare for certification or debug emissions reports.

5.2.1 Near-Field Circuit Probing

If an emission is detected, it can sometimes prove difficult to locate the source of the emission. One technique which can assist is called near-field probing. Also known as "sniffing", near-field probing involves using specifically sized probe antennas to track down the source of a radiated emission. Typically the following equipment would be used:

- Probe antennas
  - The antennas must be tuned or sized to detect a particular range of frequencies, specifically those of interest
- Cables
- Spectrum Analyzer

  - The frequency range of the analyzer must be greater than the signal of interest
- Shield Chamber or Anechoic chamber
  - Chosen to prevent other outside signals from interfering with the measurement

The process is typically as follows:

- The EUT, SA, antennas and supporting equipment are loaded into the chamber. Electronics other than the EUT and SA are left outside the chamber to prevent contamination of the measurement.
- The SA is set to have its trace in Max Hold mode with the peak detector. This causes the SA to hold the highest power spike detected on its screen.
- The probe antenna is then slowly and systematically passed over the whole of the EUT, not making contact with the components or the platter, but rather staying approximately 1 to 2 centimeters above them.
- Upon finding a spike, the screen can be cleared and reset to confirm the location of the emission

Once an emissions source is located, it is then possible to intuit the source origin based on the location of the radiation and it's frequency. This can be done by considering the length of a trace or the size of populated metallic components. As their size approaches one-quarter wavelength of the emission, they begin to act effectively as antennas.

While this technique is helpful for finding emissions, it is important to realize that not all near-field emissions result in a far-field emission. Thus, not all near-field emissions present EMC issues. For this reason, it is often best used as a reactive or debug exercise. While this section has discussed manual techniques for measurement, there are automated test solutions that are available at some cost.

5.2.2 Occupied Bandwidth Testing

Many modern spectrum analyzers contain occupied bandwidth tests as an optional software package or as a standard part of the purchase. This can be useful in determining if the radar meets FCC or ETSI 99%OBW testing or peak EIRP tests. This can be done in two ways:

- Calibrated Measurements
  - This is the gold standard for measurement but can be time consuming and costly to achieve, as the losses of the system must be measured and calculated and then de-embedded from the system.
- Relative Measurements
  - Used when the true value of the EIRP is not needed. This is when the frequency content and its relative power is important

It is important to note that it is not always possible to use every spectrum analyzer to measure the inband tone of the radar. For this reason, it is often necessary to use a down converter or range extension module. This is typically a well-controlled and calibrated down mixer which divides down the in-band signal to a frequency that the spectrum analyzer can interpret. On key concern when using range extension modules is that they can introduce spurs into the spectrum so it is important to properly characterize any range extension module prior to measurement of the EUT.

To properly take this measurement the following steps are taken:

1. Set the spectrum analyzer to max hold and peak detector mode
2. Set the resolution bandwidth to 1MHz (this is inline with ANSI standards)
3. Set the sweep time to a large value, say 600 seconds (this is to provide enough time for appreciable chirp power to develop on the detector)
4. Configure the radar and allow it to chirp and fill up the spectrum analyzer

The resulting data can be used to confirm that desired configuration occurs within regulatory limits and that the power is flat, or lacking any apparent power spikes. If using a relative measurement, it is important to keep in mind that the power level will be different than measured.

5.2.3 Radiation Pattern Measurement

When designing custom antennas or evaluating radome and lens system performance, it is highly desirable to measure the radiation pattern and the field-of-view. Radiation pattern measurement can also be useful for regulatory filings, especially for JRL. This section will introduce a simple means of measuring the radiation patterns.

The following is needed for such measurements:

- High Frequency Anechoic Chamber
- Automated 1 or 2 Axis Gimble
- Corner reflector and mount

The anechoic chamber need not be a large room sized chamber, rather more the size of a refrigerator box. Just as well the costs of the automated gimble and chamber don't need to be high. Millibox.org is one vendor that provides cost effective options.

The following procedure is used to find the antenna radiation pattern:

1. Place the corner reflector and EUT at opposite ends of the chamber.
2. Determine a chirp sweep to perform.
   a. Typically 500MHz or 1GHz, where the center frequency is the frequency of interest. This test can be repeated multiple times at different chirp start frequencies to provide a fuller picture of antenna performance across frequency.
3. Configure the radar and set the gimble to sweep the azimuth or elevation at a desired step size.
   a. Finer step sizes result in better detail at the cost of additional test time.
   b. Off axis measurements can also be undertaken if desired also at the cost of additional test time.
4. At every angle step, have the radar chirp and perform a raw ADC capture using the DCA1000 or SPI-ADC capture if your device supports it.

At the end of testing, gather all the ADC files and post process them. The data will be formed as a radar cube. The data can be post-processed using MATLAB, python, or another computational system. Search the radar cube to find the strong peak caused by the reflector. There should be one result for each virtual antenna (enabled-RX × enabled-TX). Plotting the peak power level against the associated angle will result in finding the virtual antenna radiation pattern.

If needed, it is possible to further decompose this into antenna gains if the transmitting and receiving antenna pairs each have the same gain.

To find boresight, simply find the peak gain. The Half-Power Beamwidth in this case is defined as the angular range on either side of boresight at which power falls 6dB from peak. This stands in contrast to the traditional definition of HPBW which is the -3dB point. This is because the plot represents the virtual antenna pair so the HPBW must indicate two antennas instead of one.

There are other techniques for measuring CW radiation patterns, however that topic is more complicated and will be reserved for another application note.

5.3 MMWAVESTUDIO

mmWave Studio provides an easy to use platform to set up and configure chirps needed for certification. Using LUA scripts some level of automation can be achieved. For more on the use of mmWave Studio, refer to the DCA1000EVM Data Capture Card user's guide.

5.3.1 Running LUA Scripts

To run the scripts, click *browse*, navigate to the directory containing the LUA script, select the script, and select *Run*. Sample LUA scripts used for certifying the IWR6843 EVMs are included in the certification package.

The TIREX package needs to be downloaded and installed to access the LUA scripts

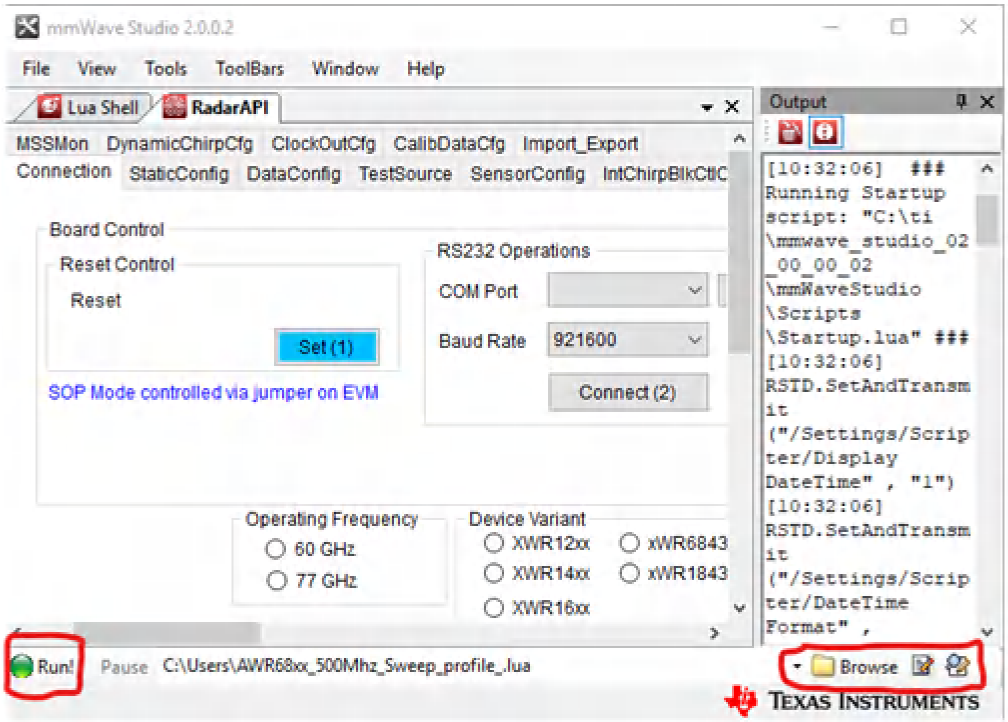


Figure 5-2. Running the LUA Script

5.4 mmWave Visualizer

The effect of EMC and interference can be tested using the mmWave Visualizer. Using a corner reflector at a known distance, normal operation and post-interference behavior of the EUT is confirmed. For more on the SDK out-of-box demo, refer to the TIREX page. The mmWave Visualizer can also be used to configure the mmWave device to transmit various chirps needed for the test.

5.5 IWR6843ISK-ODS Test Case

For the IWR6843 test, mmWave studio was used for chirp generation and test relating to Section 3.1.1, mmWave Visualizer and Out-of-box demo was used for Section 3.1.5.

Three different chirp configurations were tested; the LUA scripts can be found in the certification package.

Table 5-1. Chirp Configurations

Bandwidth	Operating Frequency Range	Review
300MHz	61-61.5GHz	ar1.ProfileConfig(0, 61.1, 2, 3.4, 18, 0, 0, 0, 0, 0, 0, 16.693, 1, 128, 10000, 0, 131072, 30)
		ar1.ChirpConfig(0, 0, 0, 0, 0, 0, 0, 1, 0, 1)
		ar1.FrameConfig(0, 0, 0, 128, 16 , 0, 1)
1300MHz	57-64GHz	ar1.ProfileConfig(0, 60.25, 3.6, 3.5, 29.7,0, 0, 0, 0, 0, 0, 43.995, 1, 256, 10000, 0, 131072, 30)
		ar1.ChirpConfig(0, 0, 0, 0, 0, 0, 0, 1, 0, 1)
		ar1.FrameConfig(0, 0, 0, 128, 16 , 0, 1)
4000MHz	57-64GHz	ar1.ProfileConfig(0, 60.25, 7, 5.0, 69.5, 0, 0, 0, 0, 0, 0, 53.265, 1, 256, 4000, 0, 131072, 30)
		ar1.ChirpConfig(0, 0, 0, 0, 0, 0, 0, 1, 0, 1)
		ar1.FrameConfig(0, 0, 0, 128, 16 , 0, 1)

A breakdown of the configuration parameter is shown in Table 5-1. Details on the Ar1 commands used in the script can be found by entering "help ar1.command"; for example, "help ar1.ProfileConfig" in the Lua shell of mmWave studio. For a complete list of supported ar1 commands, enter "help ar1" in the lua shell.

- Profile configuration API which defines chirp profile parameters - ar1.ProfileConfig(UInt16 profileId, Single startFreqConst, Single idleTimeConst, Single adcStartTimeConst, Single rampEndTime, UInt32 tx0OutPowerBackoffCode, UInt32 tx1OutPowerBackoffCode, UInt32 tx2OutPowerBackoffCode, Single tx0PhaseShifter, Single tx1PhaseShifter, Single tx2PhaseShifter, Single freqSlopeConst, Single txStartTime, UInt16 numAdcSamples, UInt16 digOutSampleRate, UInt32 hpfCornerFreq1, UInt32 hpfCornerFreq2, Char rxGain).
- Chirp configuration API which defines which profile is to be used for each chirp in a frame - ar1.ChirpConfig(UInt16 chirpStartIdx, UInt16 chirpEndIdx, UInt16 profileId, Single startFreqVar, Single freqSlopeVar, Single idleTimeVar, Single adcStartTimeVar, UInt16 tx0Enable, UInt16 tx1Enable, UInt16 tx2Enable).
- Frame Configuration API defines Frame formation which has sequence of chirps to be transmitted subsequently - ar1.FrameConfig(UInt16 chirpStartIdx, UInt16 chirpEndIdx, UInt16 frameCount, UInt16 loopCount, Single periodicity, Single triggerDelay, UInt16 TriggerSelect).

Focusing on the 1300MHz test case:

- As shown in Table 4-1, the On time within a burst is approximately the rampEndTime period, which is the sum of rampEndTime and idleTimeConst. Between burst, the period is the periodicity shown in frame configuration.
- The far field boundary was calculated using Equation 11. With the largest antenna dimension as 13mm, the far field is calculated as shown in Table 5-2. All RF tests were done in the far field region.

Table 5-2. Far Field Boundary

Center Frequency	L (m)	Lambda (m)	Far Field (m)
60.85	0.0130	0.0049	0.0690

- More details on the test results, standards, and measurement are covered in Section 3.1 and can be found in the certification package on TIREX.

6 Common Issues and Resolutions

6.1 Peak Power

Problem statement: peak power is above the regulatory limit.

Solution: Implement TX power back off

ar1.ProfileConfig (0, 60.25, 7, 5.0, 69.5, *TXBO, TXBO, TXBO*, 0, 0, 0, 53.265, 1, 256, 4000, 0, 131072, 30)

Power back off, TXBO = 3, 6, 9, 12 … (see SDK Documentation for supported values)

Deep Dive:

- IWR6843ISK TX Power = 10dBm/TX antenna
- TX gain = 8dBi

For simultaneous 3 TX use case:

$$\text{TX power} = 10\log\left(10^{10} + 10^{10} + 10^{10}\right) \tag{12}$$

$$\text{Total TX Power} = \text{TX power} + \text{TX gain} = 14.8 + 8 = 228\text{dB} \tag{13}$$

When using the mmWave Visualizer and accompanying config file instead of a LUA script the TX power back-off is specified by setting the TX backoff in the ProfileCFG parameter where each of the 8 bit values corresponds to TX1, TX2, and TX3 respectively.

For example, for a 6dB back-off on all TX channels, the TX power control word would be 0x060606i.e. 394758 (use this decimal value). Here is the corresponding profileCfg command:

profileCfg 0 62.00 30 10 69.72 **394758** 0 28.42 1 128 2180 0 0 24

This is defined in the mmwavelink html documentation.

6.2 Occupied Bandwidth

Problem statement: Device is not transmitting within the permitted ISM occupied bandwidth.

Solution: Update signal bandwidth as needed.

Deep Dive:

According to Draft ETSI EN 305 550V2.1.0, occupied bandwidth is defined as the width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to 0.5% of the total mean power of a given emission. This roughly corresponds to the –23dBc bandwidth of the signal.

For larger bandwidth, such as the 4GHz bandwidth, there is a large frequency jump from (64GHz to 60GHz) which results in undershoots, affects the settling time, and can result in failure of the –23dBc bandwidth limit.

For example, the 1300MHz use case in the bandwidth is determine as shown in Table 6-1: it can be changed by either changing the slope or chirp parameter in the chirp config.

Table 6-1. ProfileCFG

Bandwidth	ProfileCFG
1300MHz	ar1.ProfileConfig(0, 60.25, 3.6, 3.5, 29.7,0, 0, 0, 0, 0, 0, 43.995, 1, 256, 10000, 0, 131072, 30)

$$\text{Bandwidth} = \text{Frequency slope (MHz/uS)} \times \text{Ramp end time(uS)} \tag{14}$$

$$= 43.983 / 29.70 \tag{15}$$

$$= 1306.3\text{MHz} \tag{16}$$

6.3 Spurious Emissions

Problem Statement: Spurious emissions measurements show spikes at certain frequencies, resulting in failure.

Solution: Add a metal shield over the device and make sure it is properly connected to ground.

Deep Dive: An embedded system design typically consists of various clocks and clock sources running at different frequencies. Depending on layout, these clocks can introduce noise (emissions) at fundamental frequency or multiples of fundamental frequency. Adding a shield sufficiently connected to ground around the device and clock sources creates a Faraday cage that keeps the electromagnetic field enclosed.

6.3.1 14.4GHz Harmonics

Problem Statement: Spurious EMI showing at multiples of 14.4GHz on the non-AOP evaluation kit.

Solution: Use of metal shield or RF absorber.

Deep Dive:

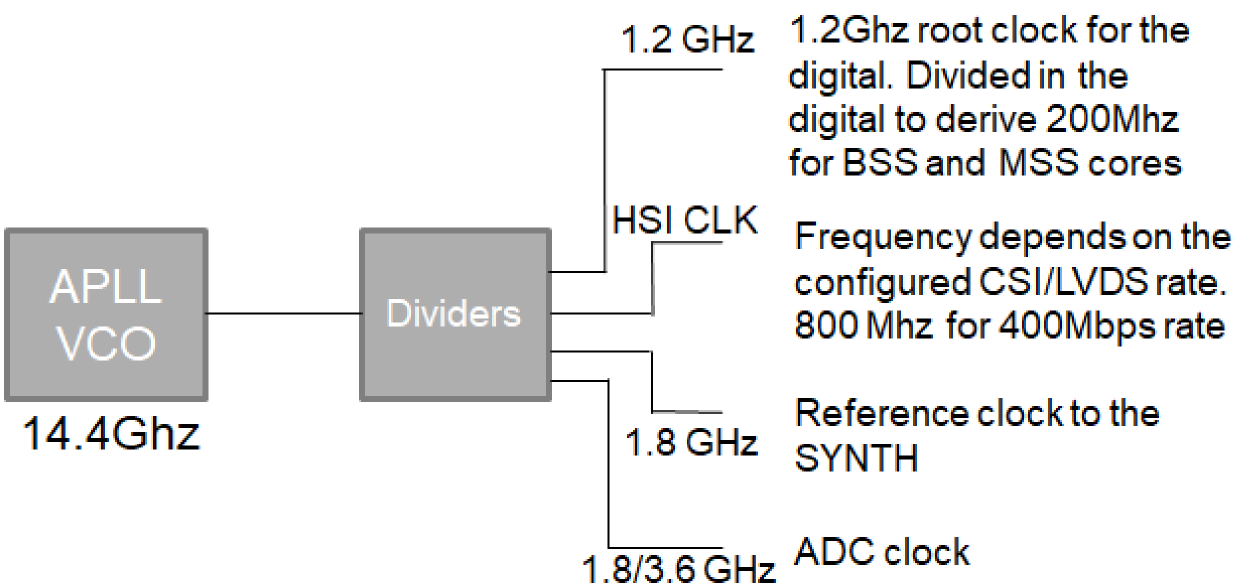


Figure 6-1. APLL VCO Clock

All the clocks in the system are derived from the 14.4GHz APLL. Figure 6-1 shows the root clock tree within the radar device. During test and certification, 14.4GHz peak and harmonics of this frequency can show up as spurious emissions, as shown in Figure 6-2, the 2nd harmonics of 14.4GHz (28.8GHz) causing radiated emission beyond the regulatory limit.

6.3.2 Suggested Resolution

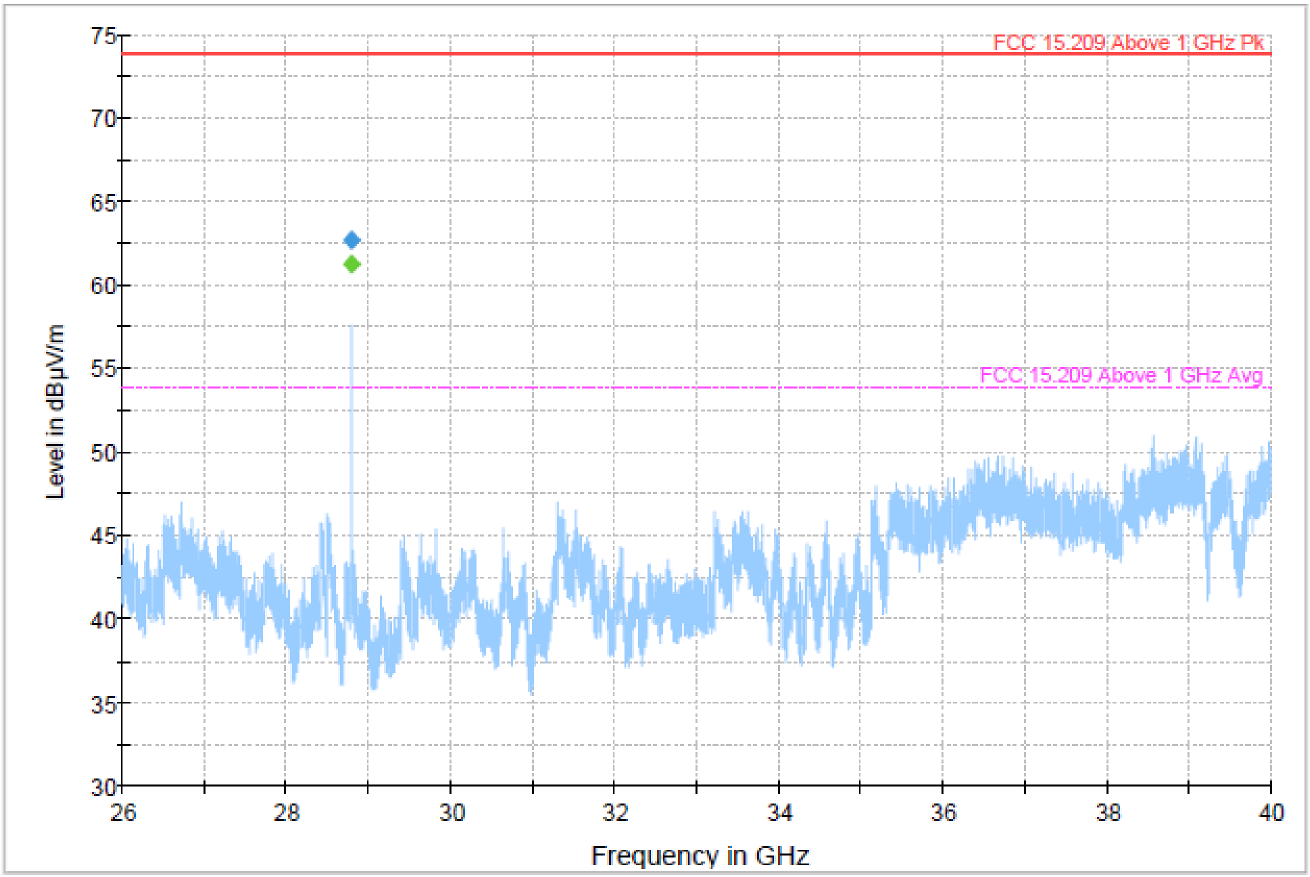
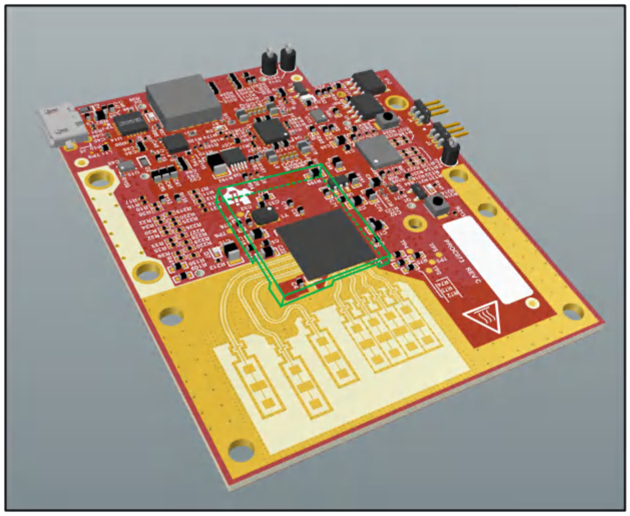


Figure 6-2. 28.8GHz Spurious EMI

6.3.2.1 Hardware Measures

- The shield or absorber must be placed as shown in Figure 6-3 and Figure 6-4.
- Applicable mmWave devices, decoupling caps, crystal, and the surrounding PCB area must be covered by a shield or absorber.
- The shield must be well grounded, covering the components of interest, and absorbers must be properly adhered to PCB and components of interest.
- Make sure the height of the shield from the PCB is greater than or equal to 2mm above the RF traces; otherwise the RF transmission lines can couple with the shield and RF matching can get disturbed. Manufacturing tolerances, wear and tear, shield assembly, and so forth must be considered so that a 2mm+ height from the board is always maintained.
- When using an RF absorber, the antenna must not be covered; the absorber must be placed such that the absorber does not go beyond the edge of the IC on the areas with the TX and RX traces.
- Example of an absorber used to suppress the emission is Cuming Microwave (GDX/PPGA 0.03").



All RF traces must be at least 2mm away from shielding cover.

Figure 6-3. Shield Placement

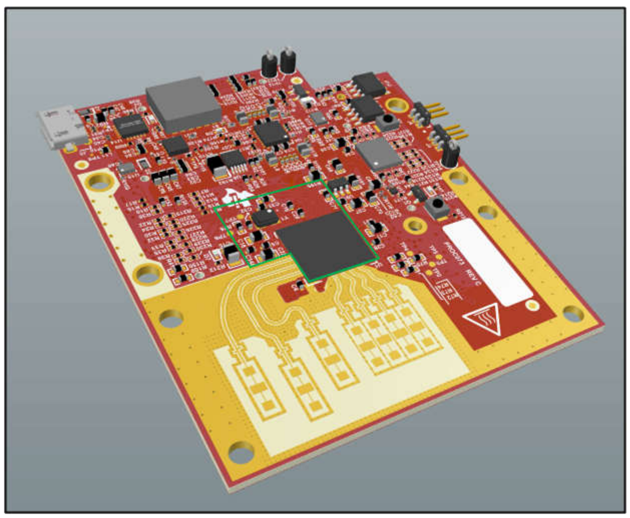


Figure 6-4. RF Absorber Placement

6.3.2.2 Software Measures

6.3.2.2.1 APLL Duty Cycling

One method for reducing 14.4GHz and 28.8GHz spurs is by duty cycling the APLL. This is done by placing the APLL in power down mode. This can be performed by first treating needed system clocks and then disabling the APLL. The RFAFE and APLL power down can be completed with the GPADC either enabled or disabled depending on user needs. The AFE and the APLL is then re-enabled prior to chirping.

APLL duty cycling does not totally eliminate the spur, but can greatly reduce the average emissions caused by the APLL. APLL duty cycling is a preferable first option to more aggressive options like RTRIM changes. This is because changes to RTRIM can cause instability in the synthesizer and must only be performed if absolutely needed. For more information on APLL duty cycling, see the Software Strategies to Achieve Power Optimizations in TI Millimeter Wave Sensors application note.

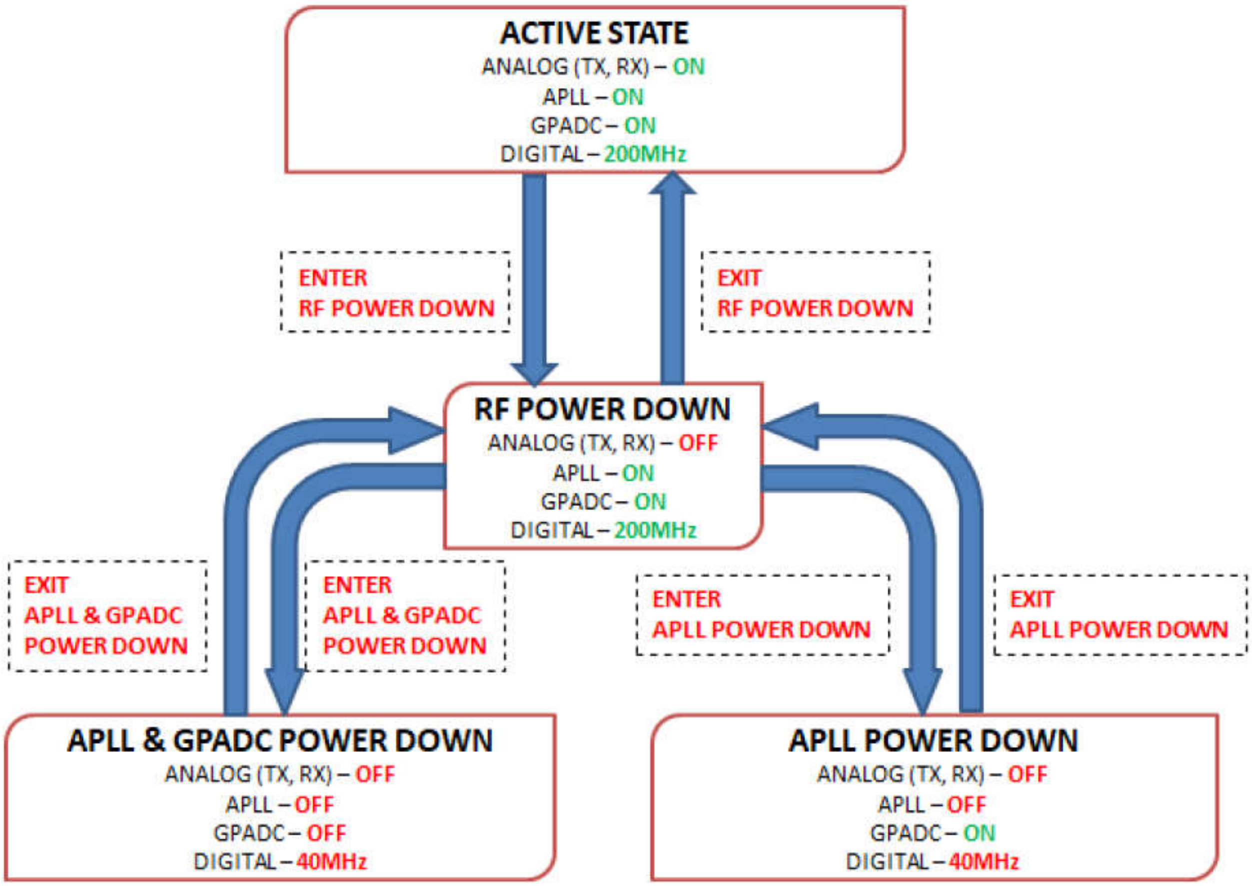


Figure 6-5. Analog Domain Power States

6.3.2.2.2 APLL VCO RTRIM Setting in BSS Firmware

APLL VCO RTRIM setting in BSS firmware:

- Emissions for 14.4GHz and its harmonics can be reduced by changing the setting of the APLL VCO on applicable mmWave devices. Appropriate APLL VCO RTRIM settings can decrease the magnitude of the spurious emissions at 14.4GHz and 28.8GHz
- For detailed instructions on how to modify application software to change the APLL VCO RTRIM setting and allowed values, refer to the following guide within the mmWave Industrial Toolbox:

  <MMWAVE_INDUSTRIAL_TOOLBOX_INSTALL_PATH>/certification/RTRIM Modification Guide

  Example Path: Industrial Toolbox or Navigate to Industrial Toolbox from mmWave Sensors

6.4 Overshoot

Problem Statement: Test results shows an overshoot or undershoot at the start of the chirp.

Solution: Increase the TX start time

ar1.ProfileConfig (0, 62.10, 2, 3.4, 18, 0, 0, 0, 0, 0, 0, 16.693, **1**, 128, 10000, 0, 131072, 30))

The highlighted parameter above signifies TX start time of 1µS.

Deep Dive:

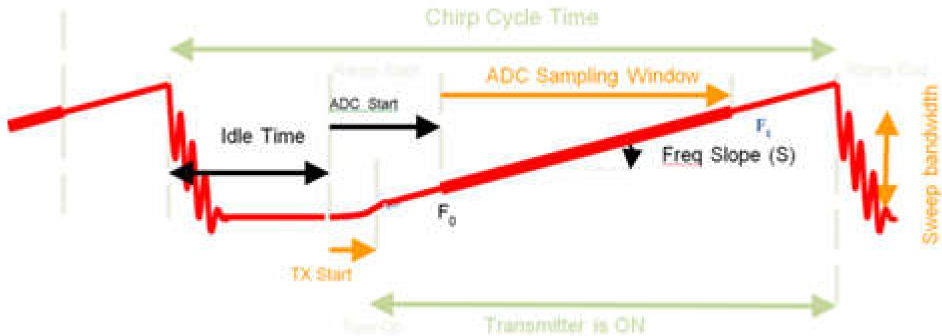


Figure 6-6. Chirp Diagram

TX start time indicates the time elapsed from the start of the frequency ramp to the time the transmitter is turned on. At the beginning of the ramp marked by ramp start in Figure 6-6 , the synthesizer, HPF analog filter, decimation filter, and so forth are switched on, and can require some settling time. If TX is turned on within the transient period, this can result in overshoot or undershoot in the transmitted signal.

6.5 Frequency Stability

6.5.1 Generating CW Signal

Problem Statement: Generating CW signal for frequency stability measurement.

Solution: Using the DCA1000EVM and MMWAVESTUDIO tor transmit a CW signal.

Deep Dive: The continuous wave LUA script (AWR68xx_xxGHz_CW_profile.lua) included in the certification package can be used to generate CW signals. The frequency generated is a single tone at the set frequency using the ar1.ContStrConfig API.

6.5.2 Frequency Stability Over Temperature and Voltage Range

Problem Statement: Frequency is not within the limit over the temperature and voltage range.

Solution: Adjust the capacitors on the clock to verify approximately 0PPM deviation at room temperature.

Deep Dive: FCC part 15.255, Frequency stability: Fundamental emissions must be contained within the frequency bands specified in this section during all conditions of operation. Equipment is presumed to operate over the temperature range −20℃ to +50℃ with an input voltage variation of 85% to 115% of rated input voltage, unless justification is presented to demonstrate otherwise.

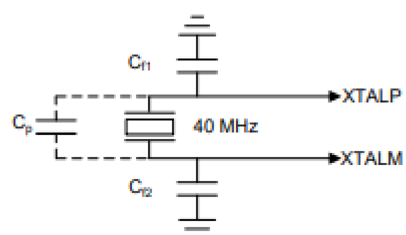


Figure 6-7. 40MHz Crystal Capacitance

$$\text{LoadCapacitor } C_L = C_{f1} \times \frac{C_{f2}}{C_{f1} + C_{f2}} + C_p \quad (17)$$

where

- C_p is the parasitic capacitance
- C_{f1} and C_{f2} are capacitors in parallel

IWR6843 requires a 40MHz crystal or external oscillator to the CLKP pin; this is used for initial boot up and as reference for the internal APLL and other clocks. For the IWR6843ISK EVM, the crystal is implemented as shown in Figure 6-7. The capacitors are chosen to satisfy requirement shown in Table 6-2.

Table 6-2. Capacitor Requirements

Name	Description	Min	Typ	Max	Unit
Fp	Parallel resonance crystal frequency		40		MHz
CL	Crystal load capacitance	5	8	12	pF
Temperature range	Expected temp range of operation	-40		105	°C
Frequency tolerance	Crystal frequency tolerance	-50		50	ppm

To meet the FCC requirements, the capacitors must be tuned such that the oscillator frequency deviation is at 0ppm at room temperature and frequency deviation stays within the frequency band across voltage and temperature .

6.6 EIRP Spiking and Spectrum Analyzer BW

When performing the peak power measurement under EN 305 550 or 47 CFR 15.255, it is possible to see an apparent EIRP spike in the carrier. This can often be seen at the start and stop frequencies of the chirp. The chirp start frequency spike is typically the highest power of the two. In actuality, these EIRP spikes are not real, but rather measurement artifacts. The spikes originate in the test BW of the spectrum analyzer.

It is important to take a moment to discuss the background here: in a perfect world, the BW of spectrum analyzer would be much larger than the bandwidth of the signal of interest and have a sampling rate high enough to sample the full signal on the first pass. However, for many signals (such as multi-GHz FMCW radar chirps) this is not practical or possible. Additionally, it is not uniform for all regulatory applicants. To seek uniformity in testing, ANSI recommended that the BW of the spectrum analyzer be fixed at 1MHz.

This causes significant changes in measurement performance. Imagine if you will, the signal of interest is zipping by the detector so fast, that there is now not enough time for energy to accumulate on the detector. This causes large under measurement of radiated power, known as desensitization. To combat this, ANSI provides calculations that can be performed to compensate for this reduction in detected power. This is often called the desensitization correction factor.

At the beginning and end of a chirp, there can be overshoot and undershoot events as the VCO and synthesizer reset for the next chirp. While the total power emitted does not violate regulations in actuality, the desensitized detector now is able to collect additional energy from the non-FMCW overshoot and undershoot. This results in an apparent spike in the carrier, which the test-house will apply a correction factor to. This will significantly erode margin and in some cases cause regulatory excursion. Since this occurs at the start and stop frequency, it is difficult to prove it is not part of the FMCW signal. Therefore, we recommend increasing the TX start time until the apparent EIRP spike dissipates. This will reduce the BW marginally; however, it will reduce the power of the spike, and it will push the spike down into the spurious region. Greatly improving margin and passing. Typically this can be achieved with 1.5µs to 2µs of TX start time delay.

Figure 6-8 shows an example of this. The scope has been placed in 1MHz RBW, causing desensitization of the detector. The blue trace shows a chirp with EIRP spiking that can cause FCC regulatory failure. The black curve shows the same chirp configuration but with a 1us TX on time. Notice the EIRP spikes remain but are now in the OOB region.

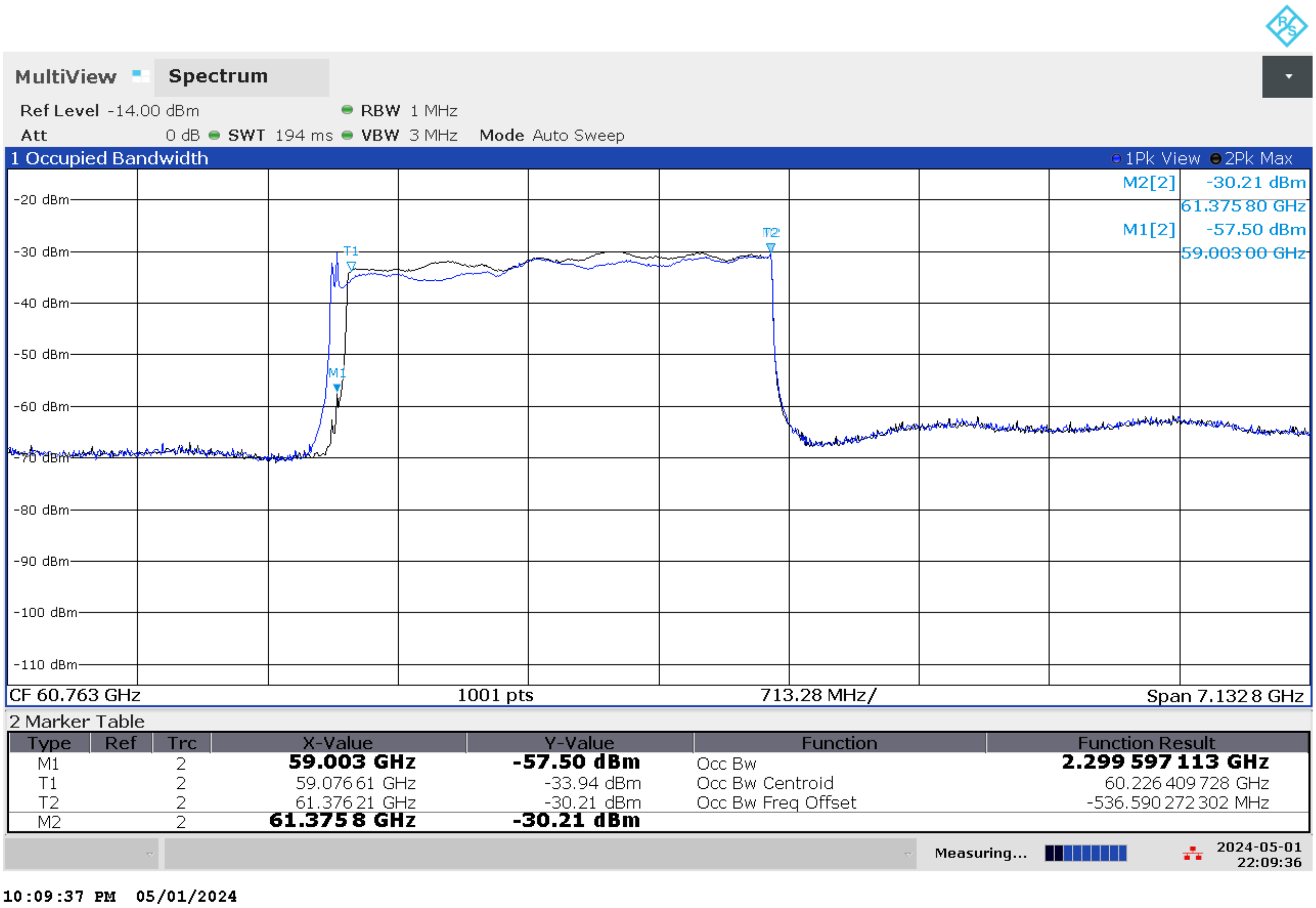


Figure 6-8. Example of EIRP Spike and Resolution

7 References

- Radio Equipment Directive (RED)
- ISM-Band and Short Range Device Regulatory Compliance Overview, Matthew Loy, Raju Karingattil, Louis Williams
- DIRECTIVE 2014/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
- Short Range Devices (SRD); Radio equipment to be used in the 40 GHz to 246 GHz frequency range; Harmonised Standard for access to radio spectrum
- ElectroMagnetic Compatibility (EMC)standard for radio equipment and services; Part 1: Common technical requirements; Harmonised Standard covering the essential requirements of article 3.1(b) of Directive 2014/53/EU and the essential requirements of article 6 of Directive 2014/30/EU
- Short Range Devices; Measurement Techniques for Automotive and Surveillance Radar Equipment
- 1999/519/EC: Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)
- ElectroMagnetic Compatibility (EMC)standard for radio equipment and services; Part 1: Common technical requirements; Harmonised Standard covering the essential requirements of article 3.1(b) of Directive 2014/53/EU and the essential requirements of article 6 of Directive 2014/30/EU
- Texas Instruments, Programming Chirp Parameters in TI Radar Devices, application report.
- FCC Part 15
- FCC Part 95
- ARIB T-73 Standard
- IFT Regulations
- ANATEL Regualtions
- "Use of Low Power and Very Low Power Short Range Radio Frequency Devices (Exemption of Licensing) Rules, 2018", (G.S.R. 1047(E)) The Gazette of India, Extraordinary, Part II, Section 3(i), dated 18th October 2018.

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (December 2021) to Revision D (August 2026)	Page
• Complete document refresh	3

Changes from Revision B (February 2021) to Revision C (December 2021)	Page
• Updated Suggested Resolution section	30