WIRELESS & SENSING PRODUCTS

# Best Practices for FCC Pre-Compliance testing of LoRaWAN™ Modules



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# 1. Introduction

The purpose of this document is to assist the engineer in understanding the requirements to achieve certification to FCC Part 15.247 as it applies to end-devices wishing to utilize the LoRa Alliance™ US Regional PHY.

This document discusses the permitted modes of operation allowed by Part 15.247 and the methods of measurement, device configuration and pseudocode framework to assist with determining compliance with the relevant rule parts.

Finally, the document discusses the FCC registration and filing process required to complete device certification.

Please note the technical guidance provided by this document is based upon Semtech's interpretation at the time of the publication of this application note of the following documents:

- Code of Federal Regulations, Title 47, Part 15 [1]
- FCC Office of Engineering and Technology's guidance for compliance measurements, KDB publication 558074 [2]
- ANSI 63.10-2013, the American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices [3]. Note that the test methodology described in this document is copyright of the American National Standards Institute and the Institute of Electrical Engineers, Inc. A copy of the standard can be purchased from the link provided. It is also recommended Tables A.1 and A.2 of the Standard, cross-reference Part 15 rule parts to the relevant ANSI C63.10-2013 sub-clauses, be reviewed.

# 2. Overview of FCC Part 15.247 Rules

The following sub-sections provide an overview of Part 15.247 [1] rules as they apply to operation in the license-exempt 902 – 928 MHz band and the three permitted modes of operation:

- Systems employing digital modulation techniques
- Systems employing Frequency Hopping Spread-Spectrum
- Systems employing hybrid mode operation

## 2.1 Systems Employing Digital Modulation

The FCC regulations for systems using digital modulation (often referred to as "DTS") are summarized below and as tabulated in Table 1:

- The 6 dB bandwidth of the transmitted signal shall be at least 500 kHz (ref: 15.247(a)(2))
- The maximum peak conducted output power is 1 W (+30 dBm). Part 15.247 allows for compliance with the 1 W limit to be based on the maximum conducted output power, 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 maximum output power *(ref: 15.247(b)(3))*
- The conducted output power limit is based on the use of antennas with directional gains that do not exceed 6 dBi. If antennas with a directional gain greater than 6 dBi are used, the conducted output power shall be reduced below the stated values by the amount in dB that the directional gain of the antenna exceeds 6 dBi *(ref: 15.247(b)(4))*
- The conducted power spectral density shall not exceed 8 dBm in any 3 kHz band during continuous transmission, measured in accordance with the same method as used to determine the conducted output power *(ref: 15.247(e))*
- While the FCC does not place any restriction on any spurious emissions that occur within the 902 – 928 MHz band (such as adjacent or alternate channel power limits), any spurious emissions measured in any 100 kHz bandwidth outside of this band must be at least 20 dB below the level measured in a 100 kHz bandwidth within this band. If the conducted output power was measured using averaging techniques, this limit is tightened to 30 dB *(ref: 15.247(d))*

- There are restrictions placed on radiated field strength emission limits that fall within what are referred to as Restricted Bands in Part 15.205 and tabulated below in Table 4 shall not exceed the radiated emission limits of Part 15.209, as listed in Table 5. Only spurious emissions are permitted within the restricted frequency bands.

**Table 1: Summary of FCC Regulations for Systems Employing Digital Modulation**

| Rule Part | Parameter | Limit |
|---|---|---|
| 15.247(a)(2) | 6 dB BW | ≥ 500 kHz |
| 15.247(b)(3) | Emission Output Power | +30 dBm |
| 15.247(e) | Power Spectral Density | +8 dBm / 3 kHz |
| 15.247(d) | Non-Restricted Band Emissions | -30 dB |
| | Restricted Band Emissions | Frequency Specific (Refer 15.205, 15.209) |

## 2.2 Systems Employing Frequency Hopping

The FCC regulations for systems using Frequency Hopping Spread Spectrum (FHSS), where they differ from the rules that apply to systems using digital modulation techniques, are summarized and tabulated as follows:

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 *(Ref: 15.247(a)(1))*

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 400 ms within a 20 second period (= 0.4 * 50 channels). 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 400 ms within a 10 second period (= 0.4 * 25 channels). In addition the maximum allowable 20 dB bandwidth of any hopping channel is 500 kHz *(Ref: 15.247(a)(1)(i))*

- The maximum peak conducted output power shall not exceed 1 W (+30 dBm) for systems employing at least 50 hopping channels and 250 mW (+24 dBm) for systems employing less than 50 hopping channels, but at least 25 hopping channels. As opposed to systems employing digital modulation, averaging measurement methods are not permitted
*(Ref: 15.247(b)(2))*
- While the FCC does not place any restriction on any spurious emissions that occur within the 902 – 928 MHz band (such as adjacent or alternate channel power limits), any spurious emissions measured in any 100 kHz bandwidth outside of this band must be at least 20 dB below the level measured in a 100 kHz bandwidth within this band. *(ref: 15.247(d))*
- There are restrictions placed on radiated field strength emission limits that fall within what are referred to as Restricted Bands in Part 15.205 and tabulated below in Table 4 shall not exceed the radiated emission limits of Part 15.209, as listed in Table 5. Only spurious emissions are permitted within the restricted frequency bands
- Frequency hopping systems are not required to employ all available hopping channels during each transmission or use the entire available frequency band. However, the system consisting of both the transmitter and the receiver must be designed to comply with all of the applicable regulations should the transmitter be presented with a continuous data stream.
- Frequency hopping systems must distribute their transmissions over the minimum number of hopping channels specified *(Ref: 15.247(g))*
- Frequency hopping systems must demonstrate that the hopping sequence is pseudo-random and that the system receiver bandwidths match the bandwidth of the hopping transmitter and that frequency hopping occurs in synchronization with the transmitted signal *(Ref: 15.247(a)(1))*.
**Note: Per the LoRaWAN™ Regional Parameters, downlink communications between the Network Gateway and End Device uses the 500 kHz mode and therefor as a receiver the End Device is considered as a digital system and is not required to hop in unison with the transmitter.**
- Frequency hopping systems may incorporate intelligence that permits the system to recognize other users within the spectrum band so that it individually and independently chooses and

adapts its hopping sequence to avoid hopping on occupied channels is permitted. However, 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 *(Ref: 15.247(h))*

**Table 2: Summary of FCC Regulations for Systems Employing Frequency Hopping**

| Rule Part | Parameter | Limit |
|---|---|---|
| 15.247(a)(1) | 20 dB BW | ≤ 500 kHz |
| | Channel Frequency Separation | ≥ 20 dB BW |
| | Pseudo-random Channel Usage | - |
| 15.247(b)(2) | Peak Output Power | +30 dBm (≥ 50 hopping channels) |
| | | +24 dBm (25 ≤ hopping channels < 50) |
| 15.247(d) | Non-Restricted Band Emissions | -20 dB |
| | Restricted Band Emissions | Frequency Specific (Refer 15.205, 15.209) |
| 15.247(g) | Channel Distribution | Over the Frequency Range Specified |

## 2.3 Systems Employing Hybrid Mode

Hybrid mode operation permits a system to employ a combination of both frequency hopping and digital modulation techniques as summarized and tabulated below *(ref: 15.247(f))*:

- The frequency hopping operation, with the direct sequence or digital modulation operation turned off, shall have an average time of occupancy on any frequency not to exceed 400 ms within a time period 0.4 * number of channels
- The digital modulation operation, with the frequency hopping operation turned off, shall comply with the power density requirements of 15.247(d)

FCC KDB publication 558074 [2] provides an overview of hybrid mode implementation scenarios.

**Table 3: Summary of FCC Regulations for Systems Employing Hybrid Mode**

| Rule Part | Parameter | Limit |
|---|---|---|
| 15.247(a)(1) | Channel Frequency Separation | ≥ 20 dB BW |
| | Pseudo-random Channel Usage | - |
| 15.247(b)(2) | Emission Output Power | +30 dBm |
| 15.247(d) | Non-Restricted Band Emissions | -30 dB |
| | Restricted Band Emissions | Frequency Specific (Refer 15.205, 15.209) |
| 15.247(e) | Power Spectral Density | +8 dBm / 3 kHz |
| 15.247(g) | Channel Distribution | Over the Frequency Range Specified |

**Table 4: Part 15.205 Restricted Frequency Bands**

| Frequency [MHz] | | | |
|---|---|---|---|
| 0.090–0.110 | 16.42–16.423 | 399.9–410 | 4.5–5.15 (5) [1] |
| 0.495–0.505 | 16.69475–16.69525 | 608–614 | 5.35–5.46 (6) [1] |
| 2.1735–2.1905 | 16.80425–16.80475 | 960–1240 | 7.25–7.75 (8) [1] |
| 4.125–4.128 | 25.5–25.67 | 1300–1427 | 8.025–8.5 (9) [1] |
| 4.17725–4.17775 | 37.5–38.25 | 1435–1626.5 | 9.0–9.2 (10) [1] |
| 4.20725–4.20775 | 73–74.6 | 1645.5–1646.5 | 9.3–9.5 |
| 6.215–6.218 | 74.8–75.2 | 1660–1710 | 10.6–12.7 |
| 6.26775–6.26825 | 108–121.94 | 1718.8–1722.2 | 13.25–13.4 |
| 6.31175–6.31225 | 123–138 | 2200–2300 | 14.47–14.5 |
| 8.291–8.294 | 149.9–150.05 | 2310–2390 | 15.35–16.2 |
| 8.362–8.366 | 156.52475–156.52525 | 2483.5–2500 | 17.7–21.4 |
| 8.37625–8.38675 | 156.7–156.9 | 2690–2900 (3) [1] | 22.01–23.12 |
| 8.41425–8.41475 | 162.0125–167.17 | 3260–3267 | 23.6–24.0 |
| 2.29–12.293 | 167.72–173.2 | 3332–3339 | 31.2–31.8 |
| 12.51975–12.52025 | 240–285 | 3345.8–3358 | 36.43–36.5 |
| 12.57675–12.57725 | 322–335.4 | 3600–4400 (4) [1] | Above 38.6 |
| 13.36-13.41 | | | |

[1] Harmonic (n) of a fundamental emission between 902 – 928 MHz may fall within a restricted band of operation

The radiated emission limits is a field strength measurement, expressed in units of µV/m. This field strength can be converted to dBm by applying the formula below:

$$P_{TX} = 20 * log_{10}(Field\ Strenght\ (\mu V) * d(m)) - 104.77\ (\text{dBm})$$

**Table 5: Part 15.209 Radiated Emission Limits for Frequencies above 30 MHz**

| Frequency [MHz] | Field Strength [µV / m] | Measurement Distance [m] | Conducted Power [dBm] |
|---|---|---|---|
| 30-88 | 100 | 3 | -55.2 |
| 88-216 | 150 | 3 | -51.7 |
| 216-960 | 200 | 3 | -49.2 |
| Above 960 | 500 | 3 | -41.2 |

# 3. LoRa Alliance™ US Regional PHY

Both the LoRaWAN™ Regional Parameters and Protocol Specification can be obtained from the LoRa Alliance™ website [4].

For the purposes of this document we consider only the US 902 – 928 MHz license-exempt ISM band uplink channel plan:

- 64 channels numbered 0 to 63 utilizing LoRa 125 kHz BW varying from DR0 to DR3 (SF10 to SF7), using coding rate 4/5, starting at 902.3 MHz and incrementing linearly by 200 kHz to 914.9 MHz
- 8 channels numbered 64 to 71 utilizing LoRa 500 kHz BW at DR4 (SF8) starting at 903.0 MHz and incrementing linearly by 1.6 MHz to 914.2 MHz

# 4. Pseudocode Example Framework

The following sections provide a pseudocode framework to configure the EUT in the required mode to perform the FCC pre-certification tests described in this Application Note.

## 4.1 Digital Modulation Pseudocode

```
Void function Digital Modulation Systems
{
        Write SetPacketType ( PACKET_TYPE_LORA )
        Write SetModulationParameter ( SF_8 , BW_500 , CR_4_5 , LowDataRateOpt_OFF )
        Write SetPacketParams ( PreambleLength , PacketLength_Variable , PayloadLength_MAX ,
        CRC_ON , InvertIQ_OFF )
        Write SetTxParams (TxPower , RampTime )
        Write PaConfig (PaDutyCycle , hpMax ; DeviceSelect , PaLut )
        Write SetRfFrequency ()

        for(i=0;i< PayloadLength;i++)
        {
                Buffer [i] = Random(); // generate pseudo random payload
        {
        While ( true )
        {
                Write SendPayload (Buffer ; PayloadLength )
                Wait RadioTxDone;
        }
}
```

## 4.2 Frequency Hopping Pseudo Code

```
Void function Frequency Hopping Systems
{
        Write SetPacketType ( PACKET_TYPE_LORA )
        Write SetModulationParameter (SF_7 , BW_125 , CR_4_5 , LowDataRateOpt_OFF )
        // Write SetModulationParameter (SF_10 , BW_125 , CR_4_5 , LowDataRateOpt_OFF )
        Write SetPacketParams (PreambleLength , PacketLength_Variable , PayloadLength_SF7 ,
        CRC_ON , InvertIQ_OFF )
        // Write SetPacketParams (PreambleLength , PacketLength_Variable , PayloadLength_SF10 ,
        CRC_ON , InvertIQ_OFF )
        Write SetTxParams  (TxPower , RampTime )
        Write PaConfig (PaDutyCycle , hpMax ; DeviceSelect , PaLut )
        // Define the freq_hop[NumChannels] array

        For ( i = 1 ; i < NumChannels ; i ++ )
        {
                Write SetRfFrequency (Freq + (Channel_spacing * freq_hop[i] ) // Static Channel
                Write SendPayload (Buffer ; PayloadLength )
                Wait RadioTxDone;
                WaitInterPacketDelay //µs
        }
}
```

## 4.3 Hybrid Mode Pseudo Code

```
Void function Hybrid Systems
{
        Write SetPacketType ( PACKET_TYPE_LORA )
        Write SetModulationParameter (SF_7 , BW_125 , CR_4_5 , LowDataRateOpt_OFF )
        // Write SetModulationParameter (SF_10 , BW_125 , CR_4_5 , LowDataRateOpt_OFF )
        Write SetPacketParams (PreambleLength , PacketLength_Variable , PayloadLength_SF7 ,
        CRC_ON , InvertIQ_OFF )
        // Write SetPacketParams (PreambleLength , PacketLength_Variable , PayloadLength_SF10 ,
        CRC_ON , InvertIQ_OFF )
        Write SetTxParams  (TxPower , RampTime )
        Write PaConfig (PaDutyCycle , hpMax ; DeviceSelect , PaLut )
        // Define the freq_hop[NumChannels] array //[4, 8, .., 48]

        For ( i = 1 ; i < NumChannels ; i ++ )
        {
                Write SetRfFrequency (Freq + (Channel_spacing * freq_hop[i] ) // Static Channel
                Write SendPayload (Buffer ; PayloadLength )
                Wait RadioTxDone;
                WaitInterPacketDelay //µs
        }
}
```

# 5. Transmission Duty cycle

Preferably, all measurements of maximum conducted (average) output power will be performed with the EUT transmitting continuously with a duty cycle of greater than or equal to 98 %. Duty cycle refers to the fraction of time over which the transmitter is on and is transmitting at its maximum power control level. The duty cycle is considered constant if variations are less than ± 2 %, otherwise the duty cycle is considered non-constant.

When continuous operation cannot be realized, then the use of sweep triggering/signal gating techniques can be utilized to ensure that measurements are made only during transmissions at the maximum power control level.

When continuous transmission cannot be achieved and sweep triggering/signal gating cannot be implemented, alternate procedures are provided that can be used to measure the average power; however, they will require additional measurements of the transmitter duty cycle.

The measurement of duty cycle and transmission duration shall be performed using one of the techniques outlined in Section 6 of FCC KDB Publication 558074 [2].

# 6. Measurement Methods for Systems Employing Digital Modulation

All measurements were undertaken following the compliance measurement guidance of FCC KDB Publication 558074 [2] and the test methodology of ANSI C63.10 – 2013 [3]

The EUT was configured for nominally +22dBm output power with a 500 kHz LoRa bandwidth of spreading factor, SF8 and coding rate 4/5, unless otherwise specified.

All Parameters were measured on the lower (903.0 MHz), middle (909.4 MHz) and upper (914.2 MHz) channel frequencies of the 500 kHz mode LoRaWAN™ US regional PHY specification.

Note that unless otherwise specified, only the results obtained for the middle channel for each test case is illustrated.

## 6.1 6 dB Bandwidth

As described in Section 8.2 of [2], we refer to sub-clause 11.8.1 of ANSI C63.10 [3] to determine the bandwidth of the LoRa modulated signal complies with 6 dB bandwidth requirement of 15.247(a)(2). We implement the referenced methodology since the configurable RBW and frequency span setting of typical laboratory spectrum or signal analyzers exceeds the expected bandwidth of the signal.

As an alternative, the automatic bandwidth measurement capability of a spectrum analyzer may be employed using the X dB bandwidth mode with X set to 6 dB, if the instrument's configuration can be configured as defined above and as described in sub-clause 11.8.2 of [3].

From the results illustrated below, it can be determined that in 500 kHz mode, the LoRa modulation complies with the minimum 6 dB bandwidth requirement of 500 kHz.

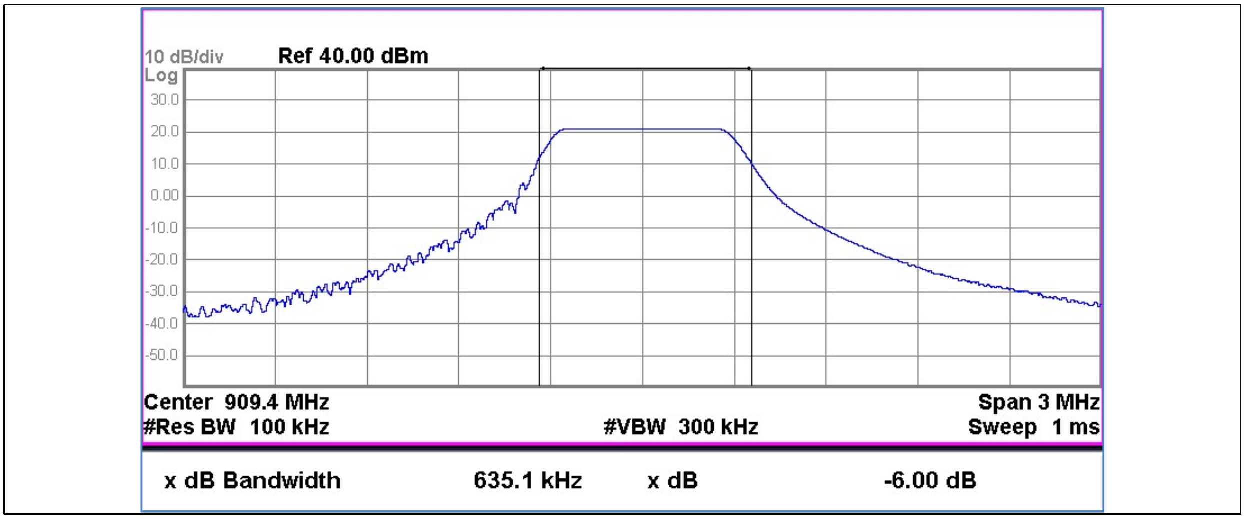



**Figure 1: 6 dB BW Measurement**

## 6.2 Fundamental Emission Output Power

To demonstrate compliance with Part 15.247(b)(3) we implement the maximum conducted (average) output power method, described in Section 8.3.2 of [2], since we will use averaging methods to show compliance with the power spectral density requirements of 15.247(e).

When using averaging methods to determine the conducted output power, the total power is calculated over the occupied bandwidth (OBW) of the fundamental emission. An OBW measurement procedure is presented in sub-clause 6.9.3 of ANSI C63-10 [3] and is based upon the 99% power bandwidth (i.e. OBW is the frequency bandwidth that below its lower and above its upper frequency limits, the mean powers are each equal to 0.5% of the total mean power of the given emission).

The OBW is measured using the built-in OBW measurement function of the laboratory vector signal analyzer.

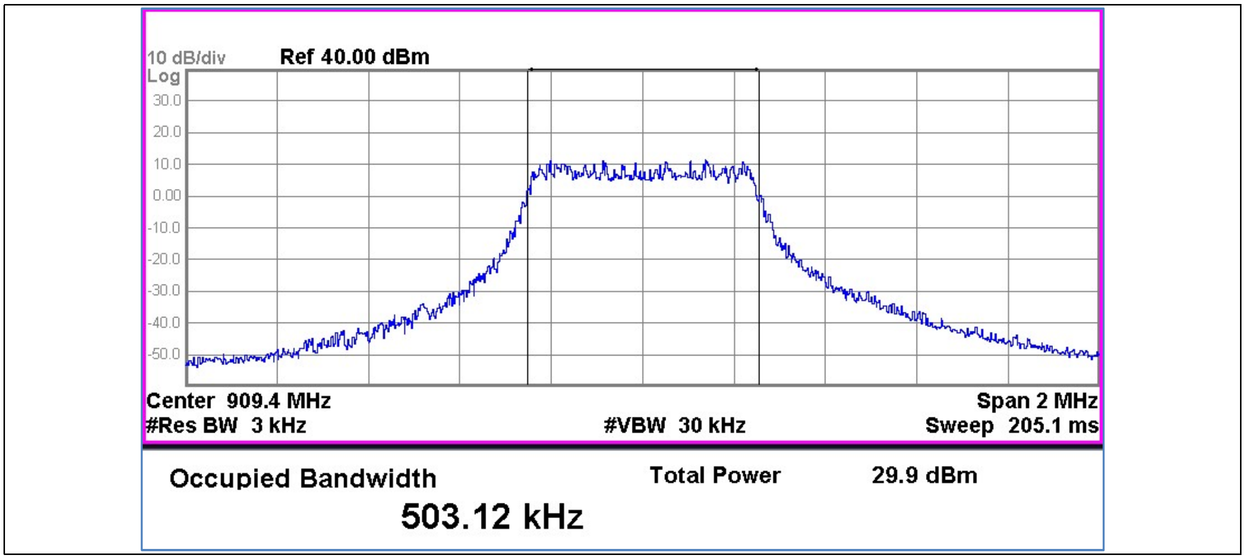



**Figure 2: OBW Measurement**

To measure maximum conducted (average) output power we follow the AVGSA-1 procedure described in sub-clause 11.9.2.2 of [3].

From the results, below, it can be determined that the maximum conducted power integrated over the OBW of the emission does not exceed the published limits.

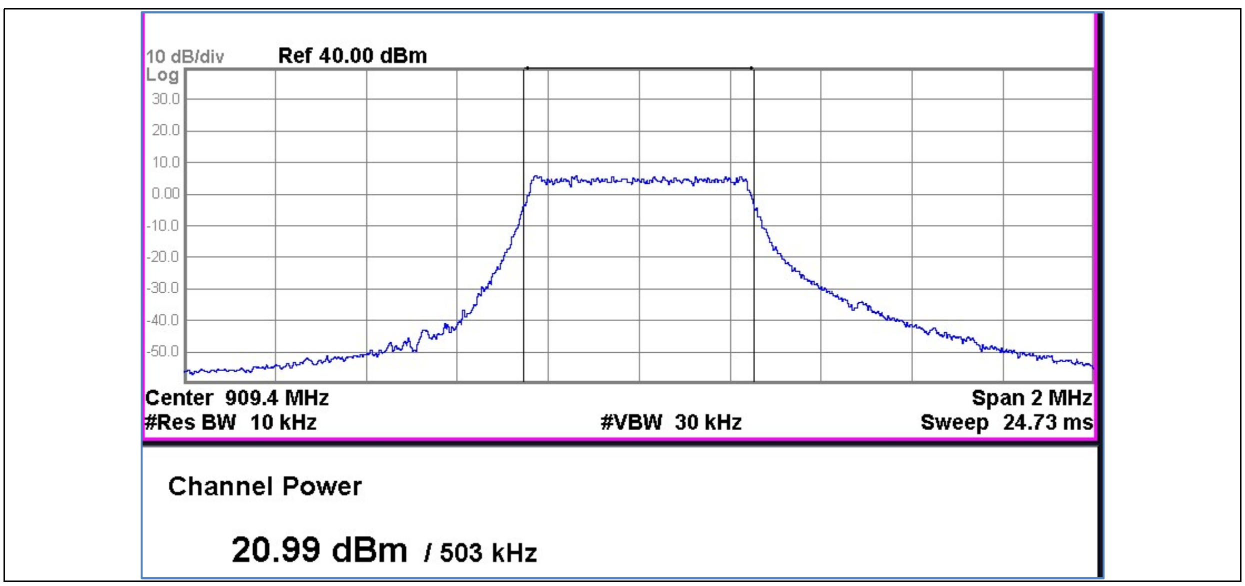



**Figure 3: Fundamental Emission Output Power Measurement**

## 6.3 Power Spectral Density of the Fundamental Emission

To demonstrate compliance with the PSD limit defined in 15.247(e), since measurements are performed using a spectrum analyzer as described in Section 8.4 of [2], the AVGPSD-1 method presented in sub-clause 11.10.3 of [3] is followed. Note the power averaging techniques used are identical to those used to determine the fundamental emission power.

From the results, below, it can be determined that in 500 kHz mode, the LoRa modulation complies with the power spectral density limits specified.

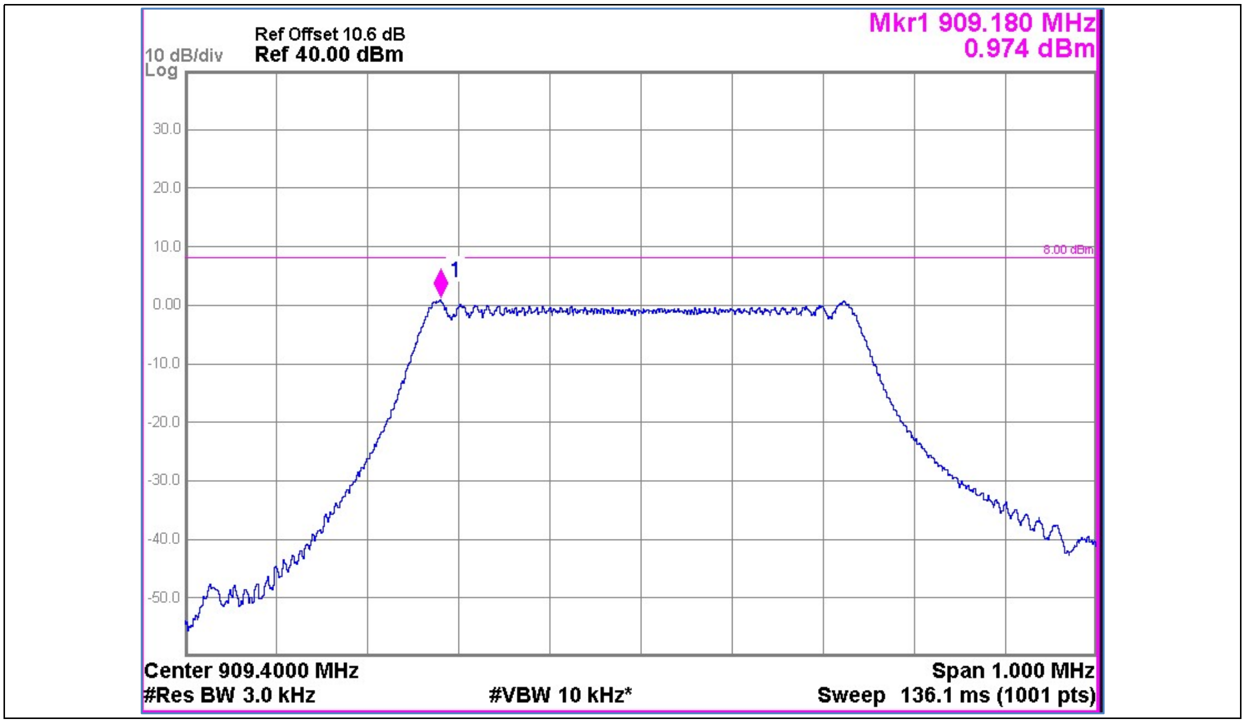



**Figure 4: Power Spectral Density Measurement**

# 6.4 Band-Edge Emissions

As noted by 15.247(d), since the power averaging method is used to determine the conducted emission output power, the limit for emissions falling outside of the 902-928 MHz band is 30 dB below the maximum emission within the band.

In addition, this document will concern itself with band-edge emissions from a wanted transmission within 2 MHz of an authorized band-edge and with reference to Section 8.7.1 of [2], the marker-delta procedure described in sub-clause 11.13 of [3] is used

In the example below, we look at the lower band-edge of the 902-928 MHz band and band-edge emissions of the transmission at 903 MHz. As illustrated, emissions in the non-restricted band are greater than 30 dB below the reference emission level and hence the LoRa modulation complies with the requirements of 15.247(d).

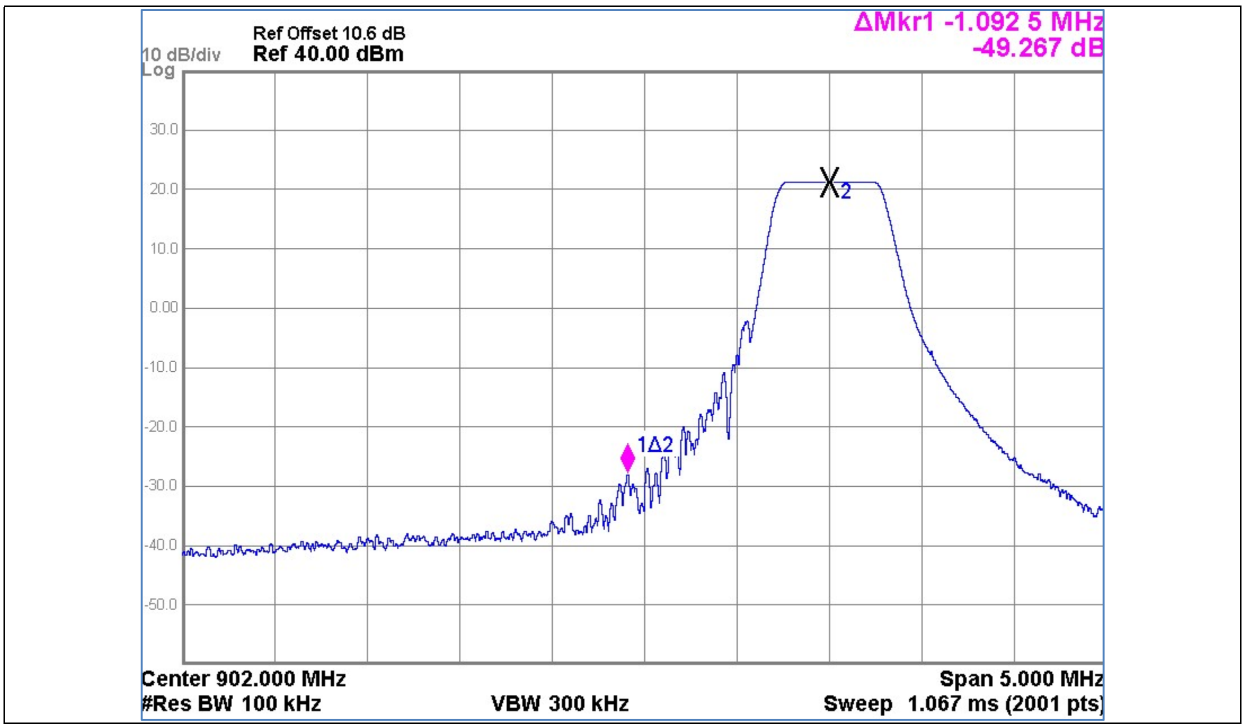



**Figure 5: Band-Edge Emissions – Digital Systems**

# 7. Measurement Methods for Systems Employing Frequency Hopping

All measurements were undertaken following the compliance measurement guidance of FCC KDB Publication 558074 [2] and the test methodology of ANSI C63.10 – 2013.

The EUT is configured for nominally +22 dBm output power and 125 kHz LoRa bandwidth of spreading factors SF7 and SF10, and with coding rate 4/5 unless otherwise specified. For both spreading factors, the maximum permitted payload length is calculated to ensure the average time of occupancy on any frequency shall not be greater than 400 ms within a 20 second period (= 0.4 * 50 channels).

Parameters were measured on the lower (902.3 MHz), middle (908.7 MHz) and upper (914.9 MHz) channel frequencies of the 125 kHz mode LoRaWAN™ US regional PHY specification.

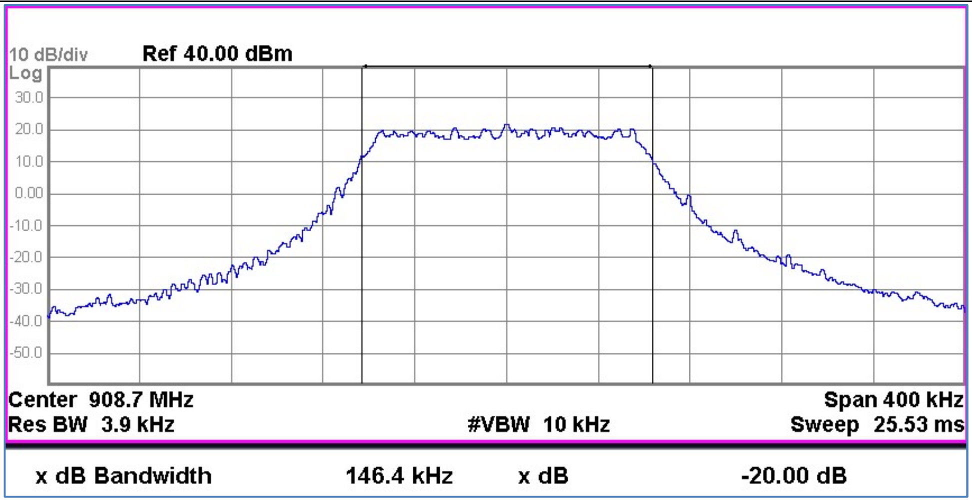
Note that unless otherwise specified, only the results obtained for the middle channel for each test case is illustrated.

## 7.1 20 dB Bandwidth

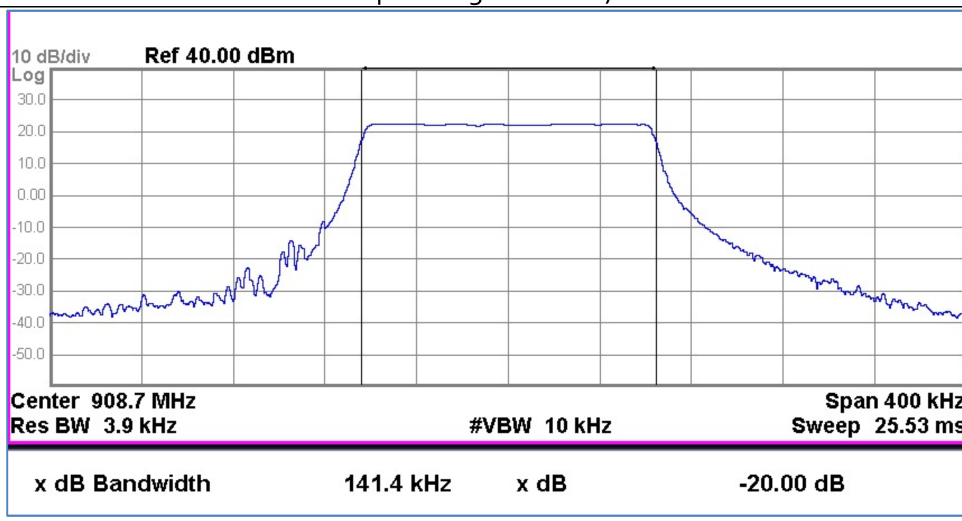
The 20 dB bandwidth of a hopping channel shall not exceed 500 kHz as defined in 15.247(a)(1).

As referenced by Section 9 of [2], and sub-clause 7.8.7 of [3], to determine the occupied bandwidth measurement, the relative measurement procedure presented by sub-clause 6.9.2 of [3] is followed.

As is illustrated below, the 20 dB BW of a 125 kHz BW LoRa modulated signal does not exceed the 20 dB bandwidth limit specified.




Spreading Factor SF7




Spreading Factor SF10

**Figure 6: 20 dB BW Measurement**

# 7.2 Carrier Frequency Separation

15.247(a)(1) stipulates that frequency hopping systems must have a hopping channel separation that is the greater of 25 kHz or the 20 dB BW of the modulated hopping channel signal.

As referenced by Section 9 of [2], we follow the procedure described in sub-clause 7.8.2 of [3].

As illustrated below, we have determined the peak conducted output power level for channel 32 (908.7 MHz) and set the spectrum analyzer's reference level to 20 dB below this level. With the LoRaWAN™ regional PHY specification mandating a 200 kHz channel separation it can be seen that the channel separation between channel 32 and channel 33 (908.9 MHz) exceeds the 20 dB BW of the modulated signal.

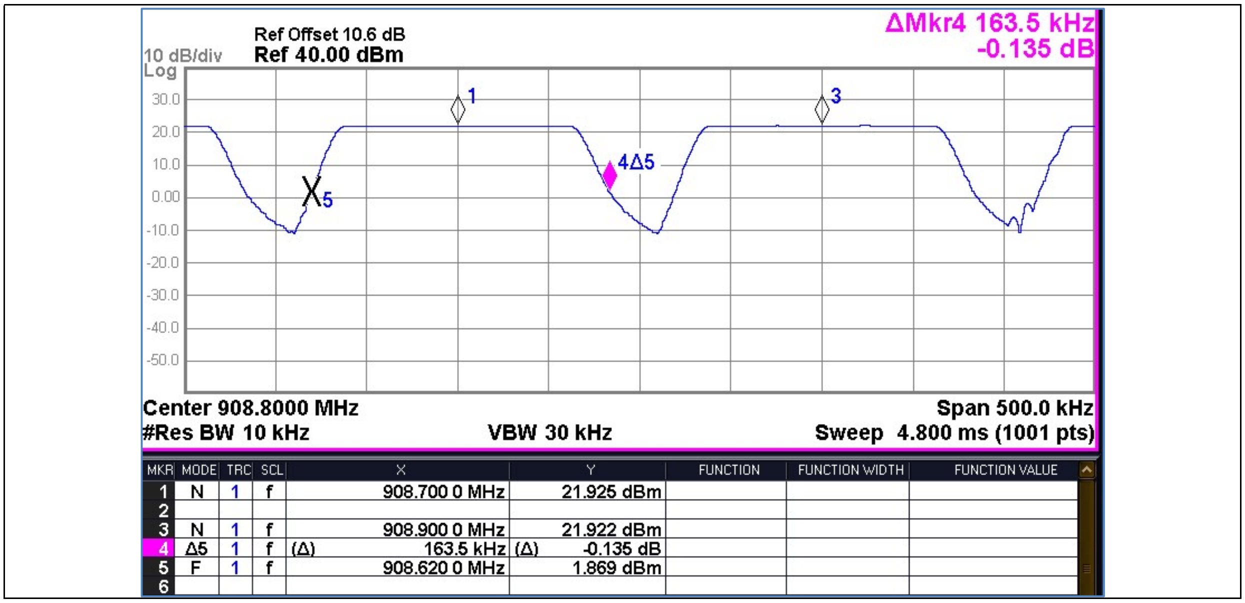


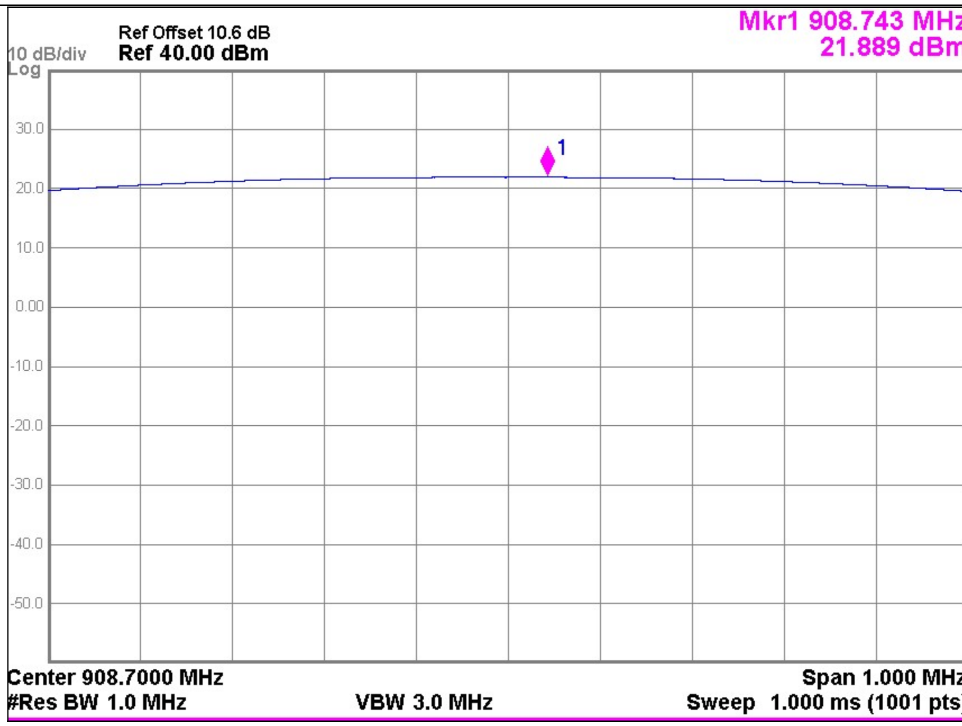

**Figure 7: Measurement of Carrier Frequency Separation**

## 7.3 Maximum Peak Conducted Output Power

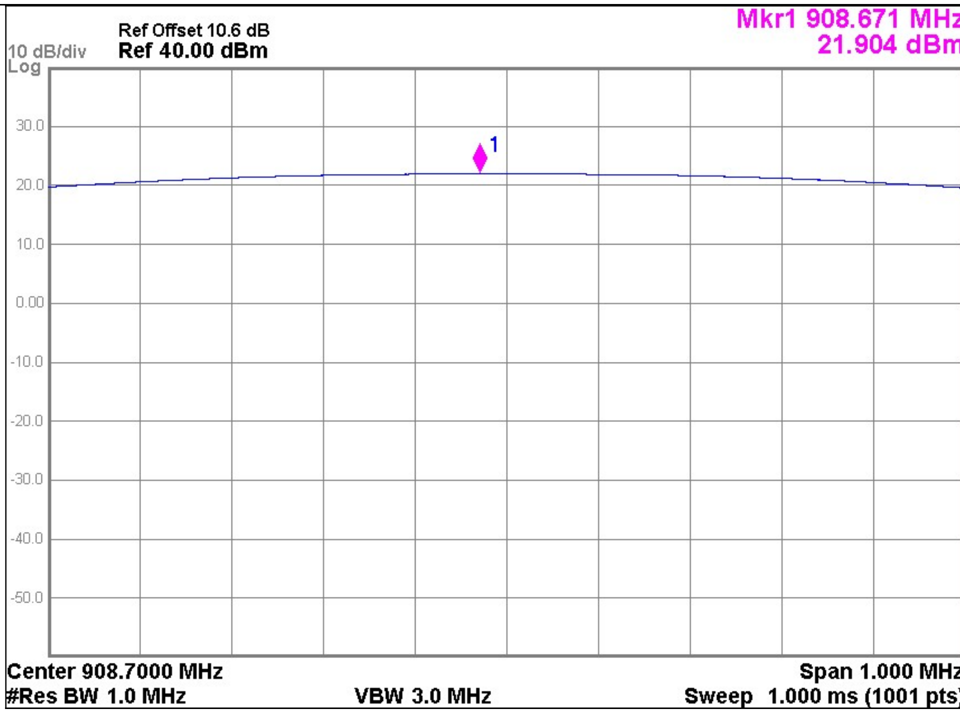
With reference to Part 15.247(a)(1)(i), frequency hopping systems employing 125 kHz BW LoRa modulation must use at least 50 hopping channels. Part 15.247(b)(2) stipulates that the maximum peak conducted output power in this scenario is 1 W (+30 dBm).

As referenced by Section 9 of [2], the procedure described in sub-clause 7.8.5 of [3] is used.

The maximum peak conducted output power of the EUT is nominally +22 dBm and as expected, from the results illustrated below, complies with this rule part.



Spreading Factor SF7




Spreading Factor SF10

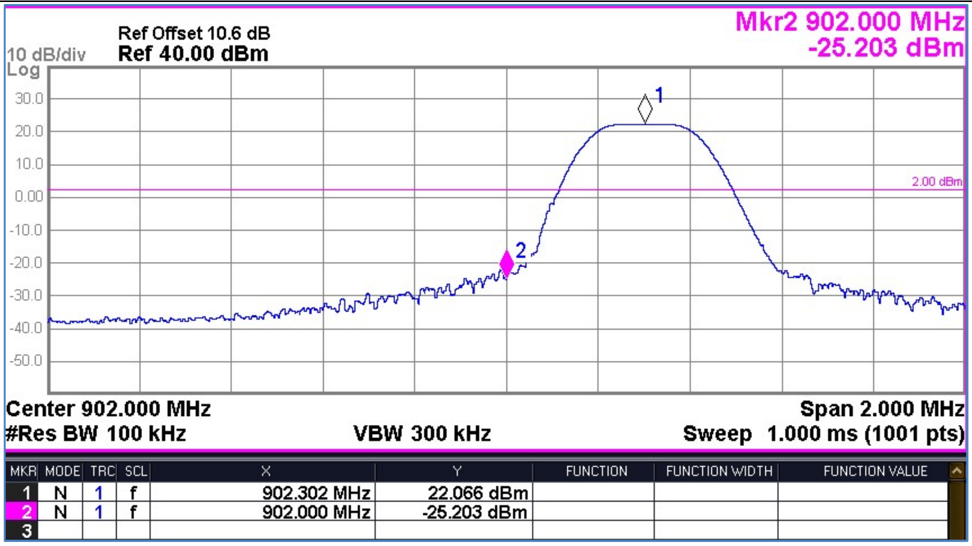
**Figure 8: Peak Conducted Output Power Measurement**

# 7.4 Band Edge Emissions

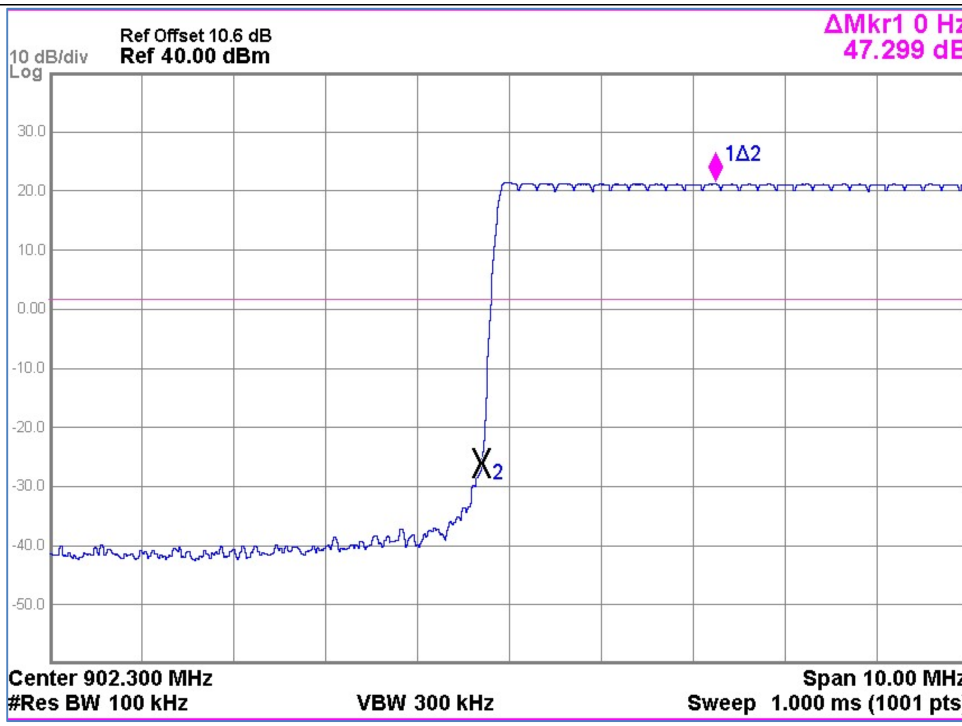
Part 15.247(d) states any spurious emissions measured in any 100 kHz bandwidth outside of this band must be at least 20 dB below the level measured in a 100 kHz bandwidth within this band.

As referenced by Section 9 of [2], and proscribed by sub-clause 7.8.6 of [3], the procedure presented by sub-clause 6.10 of [3] is followed. Again, this document will concern itself with band-edge emissions from a wanted transmission within 2 MHz of an authorized band-edge.

From the results illustrated in Figure 9, below, the EUT complies with the band-edge emission requirements when measured as both a static channel and with frequency hopping enabled.




Static Channel Case




Hopping Enabled Case

**Figure 9: Band-Edge Emissions – Frequency Hopping Systems**

# 7.5 Number of Hopping Channels

As noted in Section 6.3 of this document, frequency hopping systems employing 125 kHz BW LoRa modulation must use at least 50 hopping channels.

As referenced by Section 9 of [2], the procedure described in sub-clause 7.8.3 of [3] is used. The EUT shall have its hopping function enabled and the spectrum analyzer sweep left running until all channels have been captured. Note it may be necessary to divide the frequency range of operation across multiple spans on the spectrum analyzer, to allow the individual channels to be clearly seen.

Note that Part 15.247 states that a frequency hopping system is not required to employ all available hopping channels during each transmission or use the entire available frequency band.

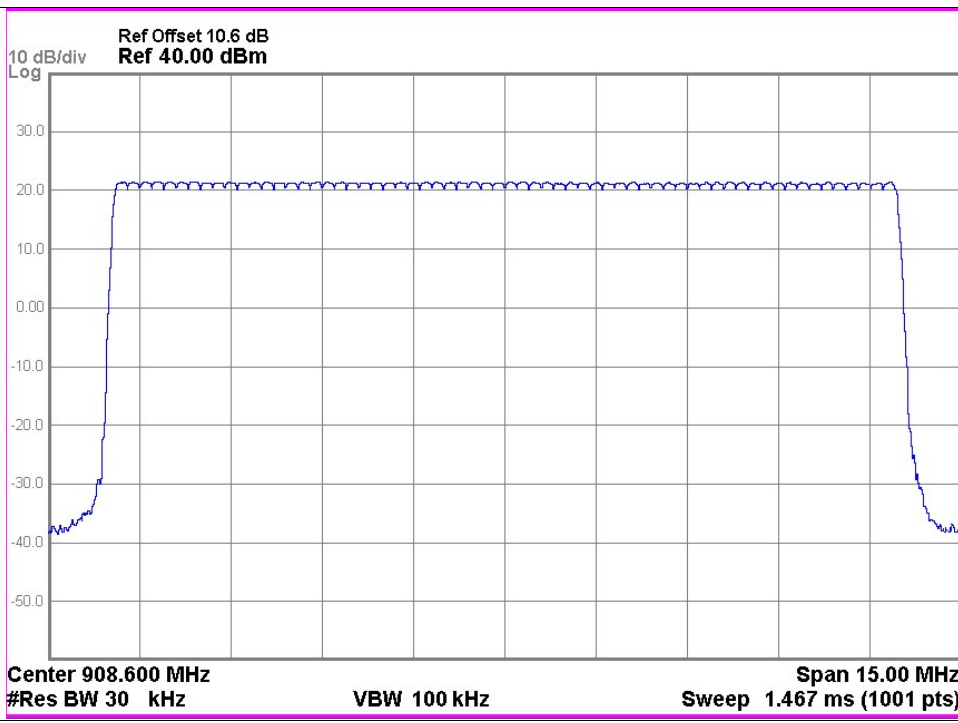


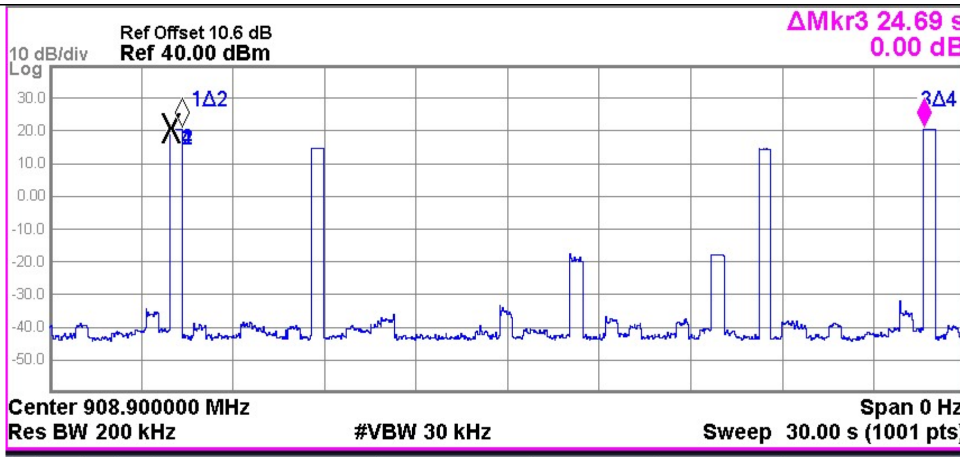

**Figure 10: 64-Channel Usage**

# 7.6 Channel Dwell Time (Time of Occupancy)

As stated in 15.247(a)(1)(i) since 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 400 ms within a 20 second period (= 0.4 * 50 channels)

As referenced by Section 9 of [2], the procedure described in sub-clause 7.8.4 of [3] is used. Note both the channel dwell time per hop sequence and the average time of occupancy over the period specified in the rule part (in this case 20 seconds) shall be determined.

As is illustrated in Figure 11, a channel is occupied for typically 390 ms in a time-period of 24.7 seconds.




| MKR | MODE | TRC | SCL | X | | Y | FUNCTION | FUNCTION WIDTH | FUNCTION VALUE |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Δ2 | 1 | t | (Δ) 390.0 ms | (Δ) | 0.00 dB | | | |
| 2 | F | 1 | t | 3.961 s | | 20.50 dBm | | | |
| 3 | Δ4 | 1 | t | (Δ) 24.69 s | (Δ) | 0.00 dB | | | |
| 4 | F | 1 | t | 3.961 s | | 20.50 dBm | | | |
| 5 | | | | | | | | | |

Figure 11: 64-Channel Average Time of Occupancy

# 7.7 System Level Considerations

As part of the process in FCC filings for FHSS devices, it shall be demonstrated that the equipment complies with all the system level requirements of Part 15.247(a)(1) as documented in Section 9.3 of [3] and as summarized below:

1. Describe how the pseudo-random frequency hopping sequence is generated. An example of hopping sequence channels shall be provided to demonstrate that the sequence meets the requirement specified in the definition of an FHSS system, as found in Part 2.1(c). Per this definition, the hop set shall appear as random in the near term, shall appear as evenly distributed in the long term, and sequential hops shall be randomly distributed in both direction and magnitude of change.
2. Describe how each individual EUT meets the requirement that each of its hopping channels is used equally on average (e.g., that each new transmission event begins on the next channel in the hopping sequence after the final channel used in the previous transmission event).
3. If applicable, describe how the associated receiver(s) complies with the requirement that the input (channel) bandwidth matches the bandwidth of the transmitted signal.
4. If applicable, describe how the associated receiver(s) has the ability to shift frequencies in synchronization with the transmitted signal, if applicable.
5. If applicable, for short burst systems, describe how the EUT complies with the requirement that it is designed to be capable of operating as a true frequency hopping system. Specifically, the device shall comply with the equal frequency use and pseudorandom hopping sequence requirement when transmitting in short bursts, and shall be designed to comply when presented with continuous data (or information) stream.
6. Describe how the EUT complies with the requirement that it does not have the ability to be coordinated with other FHSS systems in an effort to avoid the simultaneous occupancy of individual hopping frequencies by multiple transmitters.

Note that for a LoRaWAN™ compliant system and as highlighted in Section 2.2, in the downstream communication channel is considered as digital modulation since the 6 dB bandwidth of the signal is at least 500 kHz. Thus the requirements of points (3), (4) and (5) are not applicable.

# 8. Measurement Methods for Systems Employing Hybrid Mode

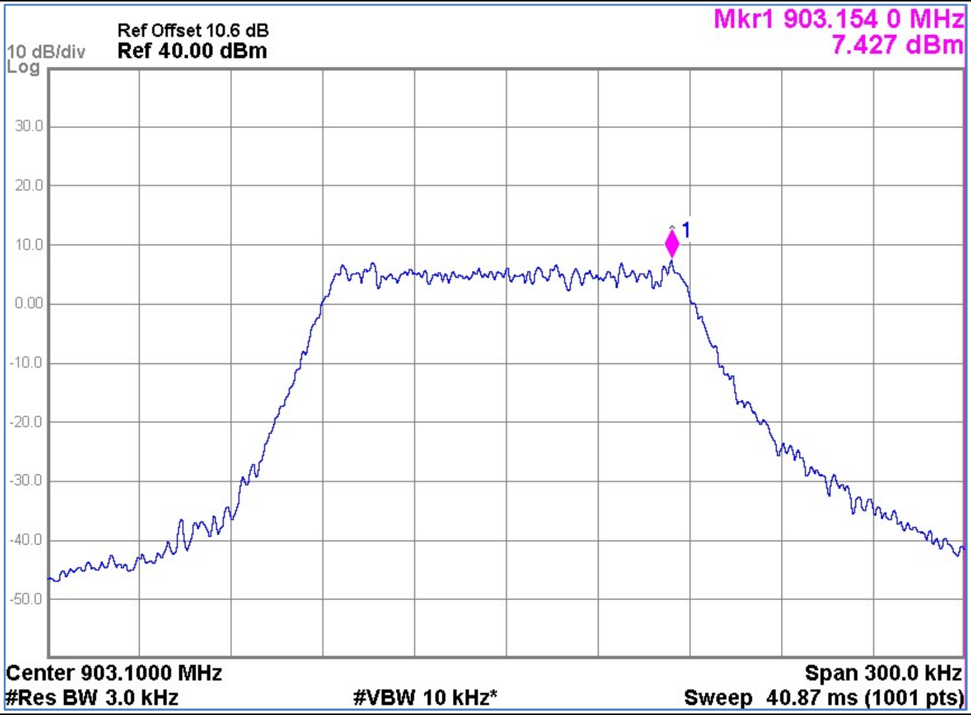
As has been previously documented, hybrid mode operation permits a system to employ a combination of both frequency hopping and digital modulation techniques. Further details concerning the requirements for hybrid mode or hybrid spread-spectrum devices can be found in Section 10 of [2].

For the purposes of this document a scenario is considered where a hybrid system utilizes the lower 8 LoRaWAN™ 125 kHz channels from 902.3 MHz to 903.7 MHz.

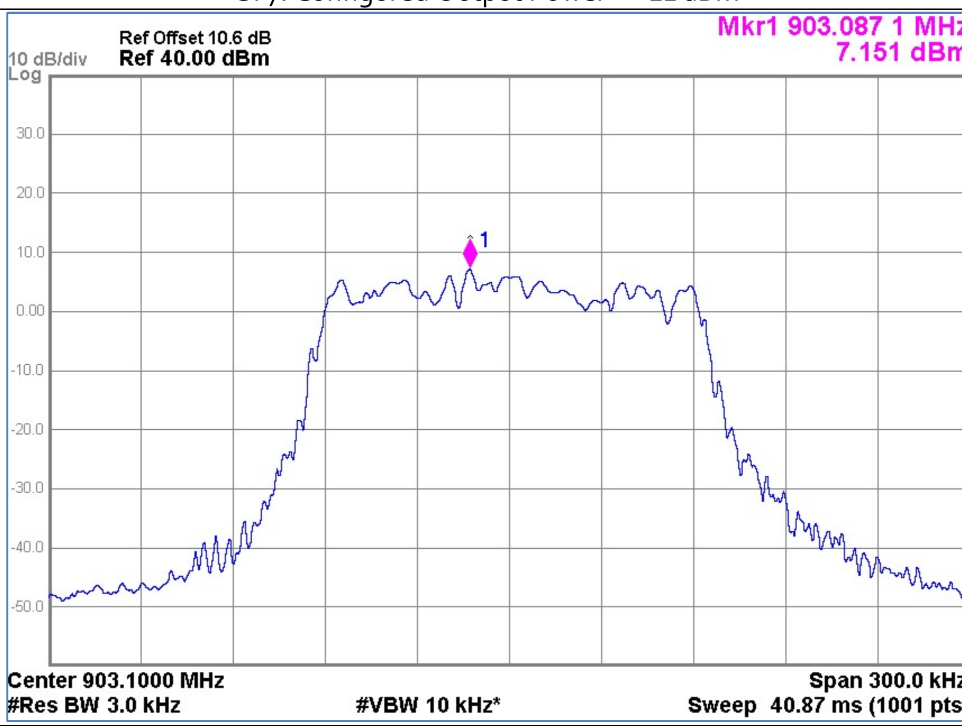
## 8.1 Power Spectral Density of the Fundamental Emission

The power spectral density of the 125 kHz LoRa mode is measured, using the AVGPSD-1 method presented in sub-clause 11.10.3 of [3].

The EUT was configured for a 125 kHz LoRa bandwidth with spreading factors, SF7 and SF10 with coding rate 4/5. Power spectral density was measured on the lower (902.3 MHz), middle (908.7 MHz) and upper (914.9 MHz) channel frequencies of the 125 kHz mode US regional PHY specification and the output power configured for each spreading factor in-turn until the power spectral density requirements are achieved.




SF7: Configured Output Power = +21 dBm

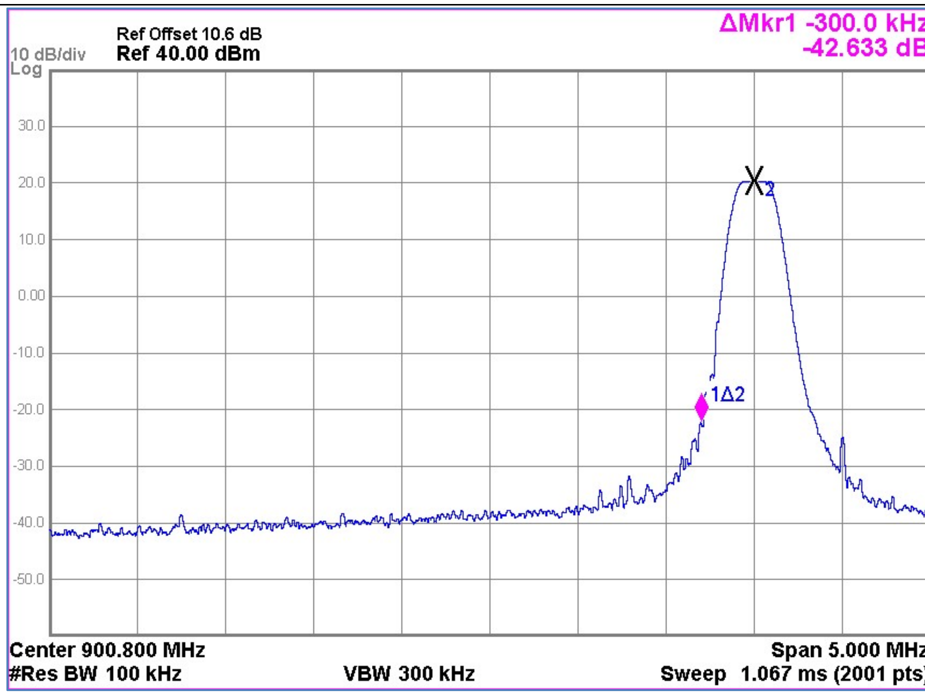



SF10: Configured Output Power = + 20 dBm

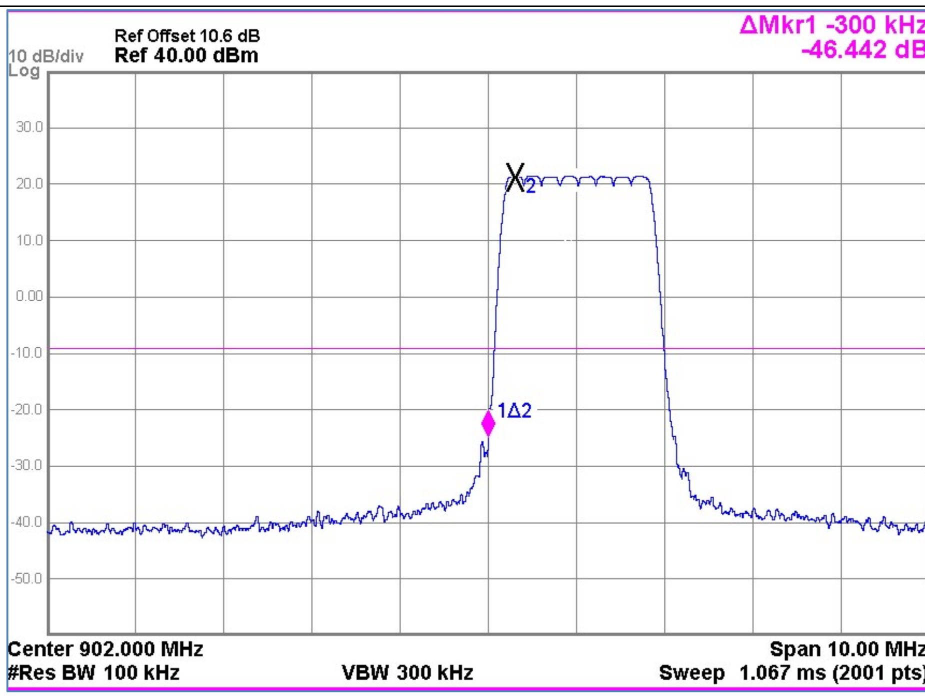
**Figure 12: Power Spectral Density Measurement**

# 8.2 Band-Edge Emissions

The methodology described in Section 6.4 is used to determine compliance with the band-edge emissions, as illustrated below in Figure 13.




Static Channel Case




Hopping Enabled Case

**Figure 13: Band-Edge Emissions – Hybrid Systems**

# 8.3 Number of Hopping Channels and Dwell Time

The methodology outlined in Sections 7.5 and 7.6 are used to determine the number of channels hopped across and the average time of channel occupancy.

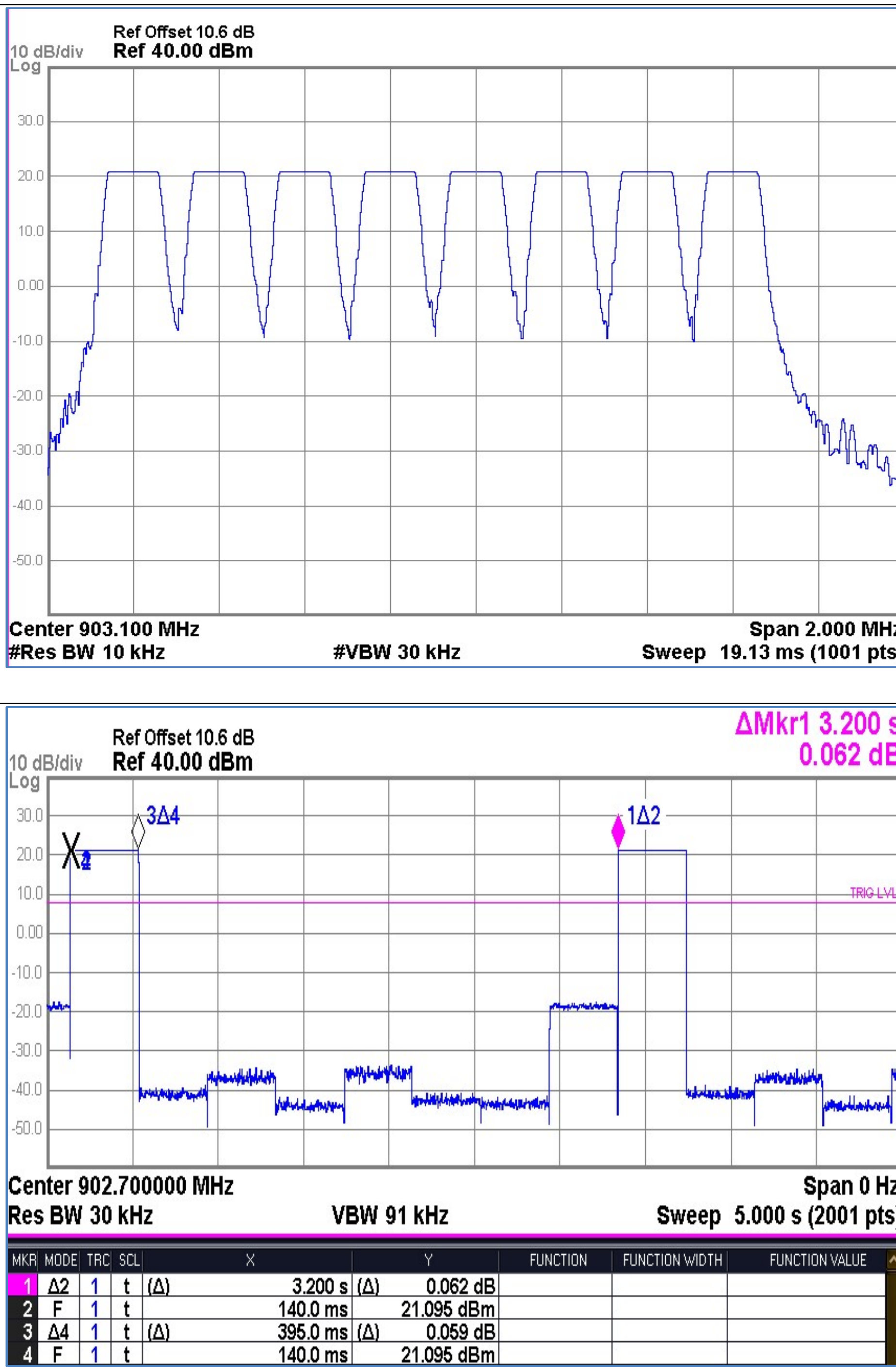



**Figure 14: Hybrid Mode Number of Hopping Channels and Average Time of Occupancy**

# 9. Measurement of Emissions in Non-Restricted and Restricted Frequency Bands

All the parameters previously described in this document are to demonstrate compliance with the requirements of Part 15.247. They are obtained using conducted measurement techniques and can thus be easily performed in the laboratory as part of any pre-scan procedure prior to the formal certification process.

However, emissions in the restricted bands as defined in Part 15.205(c) must comply with radiated emission limits. In addition, while emissions in the non-restricted frequency bands can be measured using conducted methods, these are typically measured at the same time as emissions in the restricted frequency band.

As part of the filing process described in Section 10, the user should specify the lower, middle and upper frequencies applicable to the application for each mode of operation.

# 10. FCC Filing Process

As part of the FCC filing process, both administrative and technical documents will be required to be submitted. These are summarized below.

## 10.1 FCC Registration Number and FCC Grantee Code

To start the process, a new applicant will require both a Grantee Code and, if not previously obtained, a valid FCC Registration Number (FRN). Details regarding the application for both can be found in FCC KDB 204515 [5]. Alternatively, the TCB may offer their services on behalf of the applicant, either directly or via the test laboratory the applicant has engaged.

## 10.2 FCC ID

This is the unique identification code for the device, and which consists of the Grantee Code (assigned by the FCC) and a product identifier (to a maximum of 14 characters (A-Z, 0-9, -) which is assigned by the applicant.

## 10.3 Authorization Letter

This will be supplied directly by the TCB or via the test laboratory and is required if the applicant is using an agent to act on their behalf.

## 10.4 FCC Label Information

Examples of both the FCC ID label artwork and a drawing or photograph of the location on the product are required. Further details, applying to both printed and e-labels, can be found in FCC KDB 784748 [6].

## 10.5 Confidentiality Letter

Information submitted to the FCC will be considered to be in the public domain and posted on the FCC OET Equipment Authorization System website [7], unless a letter requesting confidentiality is submitted. A draft template will typically be supplied directly by the TCB or via the test laboratory.

## 10.6 Technical Documentation

In addition to the requirements listed in Section 7.7, the following technical documentation must be included with the application:

- Complete schematic diagram(s) of the device, not just the radio section(s).
- Block diagram of the device, including all oscillator / clock sources and operational range of the transmitter section
- A document outlining the theory or a technical description of device operation
- Details of all transmitter antenna(s) and gain(s). If an antenna port is terminated with a connector, include details of the antenna(s) used for the certification process and demonstrate that a "non-standard" antenna connector is used to ensure the intended antenna cannot be easily replaced
- The user guide intended to be supplied with product. Note that the user guide for Part 15 devices must include the FCC Interference Statement [6]
- Internal and external photographs of the device
- Additional information as requested by either the test laboratory or TCB as part of the submission process

Typically, the TCB will provide a checklist, which describes the documentation they will require from the applicant for the filing process.

A similar process also applies for Canadian certification to ISED (formally Industry Canada, IC). Since the test and measurement procedures for the relevant standards are similar, TCBs can typically process both applications. The test laboratory or TCB will advise as to the relevant documentary requirements for Canada as well as those of other countries or regions (such as the European Union) for which they are accredited.

# 11. Conclusion

This document demonstrates that a LoRa device when configured as a US region LoRaWAN™ end-node can be shown to be compliant with the requirements of Part 15.247.

The document also details both the device configuration and references the recommended test methodology for each measurement example.

Finally, the document summarizes the steps required to achieve certification and complete the FCC filing process.

# 12. Revision History

| Version | Date | Modifications |
|---|---|---|
| 1.0 | November 2020 | Final: Public Release |

# 13. Glossary

| | |
|---|---|
| **ANSI** | American National Standards Institute |
| **AVGSA** | Average Detector Spectrum Analyzer |
| **BW** | Bandwidth |
| **FCC** | Federal Communications Commission |
| **DTS** | Digital Transmission Systems |
| **EUT** | Equipment Under Test |
| **FCC** | Federal Communications Commission |
| **FHSS** | Frequency Hopping Spread-Spectrum |
| **FRN** | FCC Registration Number |
| **KDB** | FCC Knowledge Database |
| **ISED** | Innovation, Science and Economic Development Canada |
| **ISM** | Industrial, Scientific and Medical (radio spectrum) |
| **LoRa** | Long Range modulation technique |
| **LoRaWAN™** | LoRa low power Wide Area Network protocol |
| **OBW** | Occupied Bandwidth |
| **PA** | Power Amplifier |
| **PHY** | Physical Layer |
| **PSD** | Power Spectral Density |
| **RF** | Radio-Frequency |
| **RBW** | Resolution Bandwidth |
| **RMS** | Root Mean Square |
| **TCB** | Telecommunications Certification Body |
| **TX** | Transmitter |
| **US** | United States |
| **VBW** | Video Bandwidth |

# 14. References


[1] Code of Federal Regulations, Title 47, Part 15
https://www.gpo.gov/fdsys/pkg/CFR-2017-title47-vol1/pdf/CFR-2017-title47-vol1-part15.pdf

[2] FCC KDB publication 558074 "D01 DTS Measurement Guidance v04"; April 2nd 2019
https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?switch=P&id=21124

[3] ANSI C63.10 – 2013 "American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices"
https://standards.ieee.org/findstds/standard/C63.10-2013.html

[4] LoRa Alliance™ Website
https://www.lora-alliance.org/

[5] FCC KDB publication 204515 "D01 Grantee Code v01r3"; March 2nd 2020
https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?id=41677&switch=P

[6] FCC KDB Publication 784748 "Labeling and User Information"
https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?switch=P&id=27980

[7] FCC OET Laboratory Division Equipment Authorization System Website
https://apps.fcc.gov/oetcf/eas/

## Important Notice



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