Characterization of LoRa Devices
Application Note

Products:
- R&S®FPL1000
- R&S®SMBV100A
- R&S®SGS100A
- R&S®RTO2000
- R&S®RTZVC04

Before devices can be used in a LoRaWAN™ network, they must among other things meet country-specific wireless communications regulations. This application note shows developers and manufacturers of devices with LoRa wireless technology how transmitter measurements are conducted in line with FCC Part 15.247. It also describes how important receiver characteristics can be verified by metrological means. In this context, battery life in particular plays a key role in IoT applications. A further chapter describes how current consumption of LoRa wireless modules can be measured reliably.

Note:
The latest version of this document is available on our homepage:
http://www.rohde-schwarz.com/appnote/1MA295
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LoRa and LoRaWAN are registered trademarks of the Semtech Corporation.
1 What is LoRa?

The term "LoRa" (Long Range) refers to a physical layer (PHY) with a modulation type developed and patented by Cycleo (part of Semtech since 2012). Here, transmission takes place in the license-free ISM bands. Owing to the low power consumption, LoRa is ideal for data transmission in the Internet of Things (IoT). One possible field of application is sensor technology where low bit rates are usually sufficient, the sensor batteries last for months or years, but data often needs to be transmitted over great distances. Examples can be found in industry, logistics, environmental technology, agriculture, smart cities, consumption recording as well as in the smart home.

1.1 LoRa Technology

LoRa is a wireless transmission technology with a very low power consumption and is used to transmit small amounts of data wirelessly over distances of up to 15 km. For data transmission, LoRa uses chirp spread spectrum (CSS) modulation, which was originally developed in the 1940s for radar applications. The term "chirp" stands for Compressed High Intensity Radar Pulse. The linguistic meaning of the term is quite apt when one considers how data is transmitted using this method. Owing to the relative low power consumption for data transmission and its robustness against fading, the Doppler effect and in-band spurious emissions, this modulation technology has in recent decades also been used in many wireless data transmission applications. The CSS PHY has been taken up by the IEEE and defined for low-rate wireless personal area networks (LPWPANs) in the standard 802.15.4a.

The long range is possible thanks to a correlation mechanism which is based on band spreading methods. This mechanism allows even extremely small signals which disappear in the noise, to be modulated in the receiver by means of despreading. LoRa receivers are still able to decode signals which are up to 19.5 dB below the noise. Unlike the direct sequence spread spectrum (DSSS), which is used e.g. for UMTS or WLAN, CSS uses chirp pulses instead of pseudo-random code sequences for frequency spreading.

An FM or GFSK-modulated chirp pulse has a sinewave signal characteristic with constant envelope; over time, this characteristic rises or falls continuously in frequency (Figure 1-1). Here, the frequency bandwidth of the pulse is equivalent to the spectral bandwidth of the signal. With CSS, this signal characteristic is used as a transmit pulse.

This paper focuses to a lesser degree on the GFSK mode used in Europe.
What is LoRa?

Figure 1-1: FM-modulated chirp pulse with linearly rising frequency

Each pulse represents a symbol. Data transmission takes place as a chronological sequence of rising and falling chirp pulses (Figure 1-2).

Figure 1-2: LoRa signal with rising and falling chirp pulses

The following key correlations apply to a LoRa signal:

Equation 1-1:

Symbol rate: \( R_s = \frac{1}{T_s} = \frac{BW}{2SF} \) symbols/sec with bandwidth BW [125 kHz to 500 kHz] and spreading factor SF [7 to 12]

Equation 1-2:

Chirp rate: \( R_C = R_s \times 2^{SF} \) chips/sec
What is LoRa?

The ratio between bandwidth and bit rate can be adjusted using the spreading factor (SF). In this case, the SF is a measure of frequency change over time (Figure 1-3), whereby the smallest change rate exists with SF = 12. Here, the values for the SF can have integer values between 7 and 12.

![Change of frequency over time as a function of spreading factor SF](image)

**Figure 1-3: Change of frequency over time as a function of spreading factor SF**

With SF = 7, a range of 2 km is possible. As the value for the spreading value rises, so does the signal/noise ratio and, as a result, the possible transmission distance increases to more than 15 km (SF = 12). In this case, the symbol and bit rate drops according to **Equation 1-1:** and **Equation 1-3.**

Owing to the orthogonality of the spread sequences, various LoRa devices with different spread sequences and bit rates can share one frequency. The possible bandwidths are 125 kHz, 250 kHz and 500 kHz. This results in bit rates from 290 bit/s to 50 kbit/s.

By adding redundancy, the LoRa modulation offers variably adjustable error correction (FEC, forward error correction). The degree of error correction is set using the code rate (CR). For the bit rate, this results in the following relationship:

**Equation 1-3:**

Bit rate: \( R_b = SF \times \frac{BW}{2SF} = \frac{4}{4+CR} \) bits/sec; code rate, CR [1 to 4]

Optionally, with LoRa the robustness of the wireless connection can be increased by means of frequency hopping.

### 1.2 LoRaWAN

LoRaWAN defines the media access protocol (MAC) and the system architecture for a wide area network (WAN). LoRaWAN is specially designed for the energy efficiency required by IoT devices and for a high transmission range. Furthermore, the protocol
makes communication with server-based Internet applications easier. With its architecture, the LoRaWAN MAC is therefore a decisive factor influencing the battery life of the LoRa devices, the network capacity, the service quality as well as the level of security and the number of applications that the network can offer.

The interaction between the LoRa MAC, the LoRa waveform and regional factors in the so-called LoRaWAN stack (Figure 1-4) is developed and managed by the standardization body "LoRa Alliance" (www.lora-alliance.org). In this body, semiconductor companies, software companies, manufacturers of sensors and wireless modules, mobile network operators, IT companies and testing institutions are all working toward a harmonized LoRaWAN standard.

1.2.1 LoRaWAN Network Architecture

Using LoRa wireless technology, it is possible to create wireless networks which can cover an area of many square kilometers with one single radio cell. Hundreds of IoT devices can be connected in each radio cell. A LoRaWAN network has a star-shaped structure. The IoT LoRa devices communicate wirelessly with gateways which send their data to a network server. Servers on which the IoT applications run are connected to the network server. To ensure security, communication in the LoRaWAN is encrypted with 128 bit AES, both as far as the network server and as far as the application server (Figure 1-5).
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In the LoRaWAN network, a LoRa device does not connect to a specific gateway. Instead, all gateways scan all channels simultaneously and are able to receive all incoming data packets irrespective of the data rate (spreading factor). Each gateway forwards its receive packets to the cloud-based network server (Figure 1-6). This server contains the actual network intelligence. Here the network is managed, redundant data packets are filtered out, security checks are performed, the data rate is determined, and so on.

As the data is always received by all gateways, no handover procedure is required for a mobile LoRa device. The transmission of data to a LoRa device takes place only via a single gateway selected by the network server.
1.2.2 LoRaWAN Device Classes

To meet the different needs of a wide variety of applications, the LoRa devices are divided into three different classes (A,B,C) in LoRaWAN. At least class A must be supported by all LoRa devices. The main difference between the individual classes is the power consumption and the latency until a LoRa device can be accessed by the gateway in the downlink. The lower the power consumption is the longer the latency will be (Figure 1-7).

![Figure 1-7: LoRaWAN device classes](image)

LoRa devices (class A):

Class A LoRa devices allow bidirectional communication. Each uplink data transmission is followed by two short downlink transmission windows (Figure 1-8). During these transmission windows, packets can be transmitted from the gateway to the device e.g. following a prompt to confirm reception of the packet or other data. Downlink communication from a server must always wait until the subsequently planned uplink. In return, Class A devices have the lowest power consumption.

![Figure 1-8: Operating principle of device class A](image)
LoRa devices (class B):

Class B LoRa devices behave in the same way as class A devices, but can open additional transmission windows at defined times. To allow the LoRa device to open a transmission window at the planned time, every 128 seconds it receives a time-synchronized beacon from the gateway (Figure 1-9). Apart from the network ID, the beacon additionally contains a timestamp, GPS coordinates of the gateway and region-specific information.

LoRa devices (class C):

Class C LoRa devices are usually not battery powered and have transmission windows which are almost always open (Figure 1-10) and are only closed during transmission.

1.2.3 LoRaWAN Regional Parameters

Owing to regional frequency assignment plans and regulatory requirements of standardization bodies (ETSI, FCC, ARIB, etc.), there are slight differences between the LoRaWAN specifications. The regional parameters are listed in the document "LoRaWAN Regional Parameters", which can be requested on LoRAWan Alliance’s website (www.lora-alliance.org). At the time of printing, version 1.0.2 contains specifications for North America, Europe, China, Australia, India and South Korea. By way of example, Table 1-1 shows the parameters defined in North America and Europe by ETSI and FCC.
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<table>
<thead>
<tr>
<th></th>
<th>Europe (ETSI)</th>
<th>North America (FCC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>863 MHz to 869 MHz</td>
<td>902 MHz to 928 MHz</td>
</tr>
<tr>
<td>Channels</td>
<td>10</td>
<td>64 +8 +8 1)</td>
</tr>
<tr>
<td>Channel bandwidth Up</td>
<td>125 kHz / 250 kHz</td>
<td>125 kHz / 500 kHz</td>
</tr>
<tr>
<td>Channel bandwidth Dn</td>
<td>125 kHz</td>
<td>500 kHz</td>
</tr>
<tr>
<td>TX power Up</td>
<td>+14 dBm (+20 dBm allowed)</td>
<td>+20 dBm (+30 dBm allowed)</td>
</tr>
<tr>
<td>TX power Dn</td>
<td>+14 dBm</td>
<td>+27 dBm</td>
</tr>
<tr>
<td>SF Up</td>
<td>7 to 12</td>
<td>7 to 12</td>
</tr>
<tr>
<td>Date rate</td>
<td>250 bps to 50 kbps</td>
<td>980 bps to 21.9 kbps</td>
</tr>
<tr>
<td>Link budget Up</td>
<td>155 dB</td>
<td>154 dB</td>
</tr>
<tr>
<td>Link budget Dn</td>
<td>155 dB</td>
<td>157 dB</td>
</tr>
</tbody>
</table>

Table 1-1: Regional LoRaWAN parameters

1) LoRaWAN defines 64, 125 kHz wide uplink channels from 902.3 MHz to 914.9 MHz in steps of 200 kHz. In addition, there are eight 500 kHz wide uplink channels with an interval of 1.6 MHz in the range 903 MHz to 914.9 MHz. The eight downlink channels are 500 kHz wide and are in the range 923.3 MHz to 927.5 MHz (Figure 1-11).

Figure 1-11: LoRaWAN channel assignment in North America

**Hybrid mode**

In North America, the signal bandwidth of digitally modulated signals in the ISM band must be at least 500 kHz according to FCC Part 15.247. This requirement does not apply to systems with frequency hopping. In order to better utilize the signal band with smaller bandwidths (< 500 kHz), LoRa uses the so-called hybrid mode. This mode allows digital modulation and frequency hopping (FHSS) to be used simultaneously with the same carrier signal. In hybrid mode, the maximum output power is limited to +21 dBm; this means that only eight channels out of 64 uplink channels are used under hybrid mode.

**1.2.4 LoRaWAN Certification**

The LoRaWAN certification (Figure 1-12) includes the verification of the LoRa device’s functionality. For this purpose, a test is conducted to determine whether the protocol stack and the application comply with the LoRaWAN specification. The certification ensures that application-specific LoRa devices function without error in LoRaWAN networks. The certification does not include checking of the physical layer (PHY). To prove that country-specific wireless communications regulations are met, parameters
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such as TX power, RX power, RX sensitivity and so on must be tested separately. The measurements required to do this are described in chapter 2.

To finally receive a Lora Alliance Certified logo for a device, a positive test report for the national compliance test must be submitted to the Alliance certification body. Furthermore, the device manufacturer must be a member of the LoRa Alliance. Tests for the LoRa Alliance Certified product program may be performed by authorized LoRa Alliance test houses only.

Figure 1-12: LoRaWAN certification process

1) https://www.lora-alliance.org/join
2 RF Measurements

The LoRa RF measurements for transmitters (TX) (in line with FCC Part 15.247) and receivers (RX) using instruments from Rohde & Schwarz are described below. Table 2-1 gives an overview of the required FCC transmitter measurements with the associated limits.

<table>
<thead>
<tr>
<th>Digital modulation mode (TX-Test)</th>
<th>FCC Anforderung</th>
<th>Parameter</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.247(a)(2)</td>
<td>6 dB bandwidth</td>
<td>≥ 500 kHz</td>
<td></td>
</tr>
<tr>
<td>15.247(b)(3)</td>
<td>Emission output power</td>
<td>+ 30 dBm</td>
<td></td>
</tr>
<tr>
<td>15.247(e)</td>
<td>Power spectral density</td>
<td>+ 8 dBm / 3 kHz</td>
<td></td>
</tr>
<tr>
<td>15.247(d)</td>
<td>Emissions in non-restricted bands</td>
<td>-30 dBc</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency hopping spread spectrum mode (TX-Test)</th>
<th>FCC Anforderung</th>
<th>Parameter</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.247(a)(1)</td>
<td>20 dB bandwidth</td>
<td>≤ 500 kHz</td>
<td></td>
</tr>
<tr>
<td>15.247(d)</td>
<td>Emissions in non-restricted bands</td>
<td>-30 dBc</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hybride mode (TX-Test)</th>
<th>FCC Anforderung</th>
<th>Parameter</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.247(e)</td>
<td>power spectral density</td>
<td>+ 8 dBm / 3 kHz</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-1: Receiver measurements according to FCC 15.247

Measurements according to ETSI and ARIB are performed accordingly. For receiver (RX) measurements FCC makes no specifications. Typical transmitter measurements (sensitivity and blocking) as recommended by Semtech are described in more detail in chapter 2.2.

2.1 LoRa TX Test

For the transmitter test, a test signal is generated using a test tool from the transmitter module manufacturer (see 2.1.1). The transmit signal generated in this way is fed and analyzed using the FPL1000 spectrum analyzer. The compact FPL1000 has robust RF properties and allows the measurement results to be displayed at high resolution on the large touchscreen with gesture control. The arrangement of result windows on the screen can be changed by the user; the descriptions given in this document are based on the default display settings.
2.1.1 Settings on DUT:

1. Output power 20 dB
2. LoRa signal bandwidth 500 kHz
3. SF = 7 or SF = 12
4. Set the transmit frequency $f_{TX}$ in the range 902 MHz to 928 MHz.
5. TX continuous mode (100% transmit duty cycle)
6. Frequency hopping off

2.1.2 6 dB Bandwidth

According to FCC 15.247 (a)(2), in the frequency range 902 MHz to 928 MHz the 6 dB signal bandwidth of a digitally modulated signal must be at least 500 kHz.

Settings on DUT:
1. As described under 2.1.1, $f_{TX} = 915$ MHz, SF = 7

Settings on FPL1000:
2. Press the Preset key.
3. Press the Freq key and enter the transmit frequency set on the DUT.
4. Press the Span key and set the span to 1.5 MHz.
5. Press the BW key and set the resolution bandwidth (RBW) to 100 kHz and the video bandwidth to $3 \times \text{RBW} = 300$ kHz.
6. Press the Trace key and select Trace 1. Select the Positive Peak detector and Max Hold.
7. Press the Ampt key and set the reference level such that the maximum value of the signal is below the reference level.

8. Press the Mkr key and select Select Marker Function. In the Markers tab, select \textit{n dB down} and enter 6 dB in the Value entry field. Wait until the trace is stable. Note down the value for the 6 dB bandwidth \textit{ndB down BW}.

9. The following condition must be fulfilled: \( \text{ndB down BW} \geq 500 \text{ kHz} \) (Figure 2-2).

![Figure 2-2: Measurement of 6 dB bandwidth with SF = 7](image)

**Settings on DUT:**

10. As described under 2.1.1, \( f_{\text{rx}} = 915 \text{ MHz} \), SF = 12

**Settings on FPL1000:**

11. To restart the measurement, press the \textit{Run Cont} key twice. Wait until the trace has stabilized. Note down the value for the 6 dB bandwidth \textit{ndB down BW}.

12. The following condition must be fulfilled: \( \text{ndB down BW} \geq 500 \text{ kHz} \) (Figure 2-3).
2.1.3 Emission Output Power

According to FCC 15.247 (b)(3), the output power of a transmitter in the frequency range 902 MHz to 928 MHz must not exceed 1 W or 30 dBm.

The total output power and the band power respectively are determined by integrating the power over the signal bandwidth. Here, the signal bandwidth corresponds to the occupied bandwidth (OBW). The OBW is the bandwidth in which 99 % of the signal power is contained.

Settings on DUT:
1. As described under 2.1.1, f_TX = 915 MHz, SF = 7

Settings on FPL1000 for measurement of OBW (measurement in line with ANSI C63-10[6] Section 6.9.3):
2. Press the Preset key.
3. Press the Freq key and enter the transmit frequency set on the DUT.
4. Press the Span key and set the span to 2 MHz (1.5 to 5 x OBW).
   Measurement tip: The 6 dB bandwidth from 2.1.2 can be used as a rough indication of the OBW to be expected.
5. Press the BW key and set the resolution bandwidth to 30 kHz (1% to 5% of the OBW) and the video bandwidth to 100 kHz (approx. 3x RBW).
6. Press the Sweep key and set Sweep Time to 2 ms.
7. Press the Trace key and select Trace 1. Select the Positive Peak detector and Max Hold.
8. Press the Ampt key and set Reference Level such that the maximum value of the signal is at least $10\log(\text{OBW}/\text{RBW})$ below the reference level.

9. Press the Meas key and select OBW under Power Measurements. Wait until the trace is stable.

10. Note down the measured value for $\text{Occ BW} = \text{OBW}_{\text{SF7}}$ (Figure 2-4).

![Figure 2-4: Measurement of OBW with SF = 7](image)

**Settings on DUT:**

11. As described under 2.1.1, $f_{TX} = 915$ MHz, SF = 12

**Settings on FPL1000:**

12. Press the Sweep key, set Sweep Time to 15 ms and wait until the trace has stabilized.

13. Note down the measured value for $\text{Occ BW} = \text{OBW}_{\text{SF12}}$ (Figure 2-5).
Settings on DUT:

14. As described under 2.1.1, \( f_{\text{TX}} = 915 \) MHz, \( SF = 12 \)

**Settings on FPL1000 for measurement of emission output power:**

The measurement is performed using the band power measurement function of the FPL1000.

15. Press the *Trace* key and select *Trace 1*. Under Trace 1, select the *Average* mode and, under *Detector Type*, set the *RMS* detector. In the *Average Count* entry field, enter a value of at least 100.

16. Press the *Sweep* key and set *Sweep Time* to 50 ms.

17. Press the *Mkr* key and, for *Marker 1*, enter the value for the transmit frequency set on the DUT.

18. Press the *Select Marker Function* menu key and select the *Band Power* function. In the *Span* field, enter the value noted down for \( \text{OBW}_{\text{SF12}} \) (Figure 2-6) and close the window.
19. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed. The result of the measurement is shown in Figure 2-7.

![Figure 2-7: Emission output power measurement with SF = 12](image1)

20. The following conditions must be fulfilled: Band power ≤ 30 dBm

**Settings on DUT:**

21. As described under 2.1.1, fTX = 915 MHz, SF = 7

**Settings on FPL1000:**

22. Press the Select Marker Function menu key and, in the Span field, enter the value noted down for OBW_{SF7} and then close the window.

23. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed. The result of the measurement is shown in Figure 2-8.
24. The following conditions must be fulfilled: Band power ≤ 30 dBm

2.1.4 Power Spectral Density

According to FCC 15.247(e), the power spectral density of a transmitter in the frequency range 902 MHz to 928 MHz must at no time exceed the value of 8 dBm relative to a bandwidth of 3 kHz during an ongoing data transmission.

Settings on DUT:
1. As described under 2.1.1, \( f_{TX} = 915 \text{ MHz}, \) SF = 7

Settings on FPL1000:
2. Press the Preset key.
3. Press the Freq key and enter the transmit frequency set on the DUT.
4. Press the Span key and set the span to at least \( 1.5 \times OBW_{SF7} \) from 2.1.3 (Figure 2-4).
5. Press the BW key and set the resolution bandwidth (RBW) to 3 kHz and the video bandwidth to \( 3 \times RBW = 10 \text{ kHz} \).
6. Press the Trace key and select Trace 1. Under Trace 1, select the Average mode and, under Detector Type, set the RMS detector. In the Average Count entry field, enter a value of at least 100.
7. Press the Sweep key and set Sweep Time to 10 ms.
8. Press the Ampt key and set the reference level using the Auto Level menu key.

Figure 2-8: Emission output power measurement with SF = 7
9. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed.

10. Press the Mkr-> key and select Peak.

The measurement result is shown in Figure 2-9.

![Power spectral density measurement with RBW = 3 kHz, SF = 7](image)

**Figure 2-9:** Power spectral density measurement with RBW = 3 kHz, SF = 7

11. The following conditions must be fulfilled: Power marker M1 ≤ 8 dBm

**Settings on DUT:**

12. As described under 2.1.1, f_TX = 915 MHz, SF = 12

**Settings on FPL1000:**

13. Press the Span key and set the span to at least 1.5 x OBW_{SF12} from 2.1.3 (Figure 2-5).

14. Press the Sweep key and set Sweep Time to 500 ms.

15. Press the Ampt key and set the reference level using the Auto Level menu key.

16. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed.

17. Press the Mkr-> key and select Peak.

The measurement result is shown in Figure 2-10.
2.1.5 Emissions in Non-Restricted Frequency Bands

According to FCC 15.247(d), the radiated power outside the ISM band (902 GHz to 928 GHz) must be at least 30 dB below the maximum RF emission within the ISM band. Below is an example demonstrating the analysis of the RF emissions of a LoRa signal with SF7 at the lower and upper band limit.

Settings on DUT:
1. As described under 2.1.1, frx =903 MHz (lowest channel center frequency for a 500 kHz wide LoRa signal (uplink), SF = 7

Settings on FPL1000:
2. Press the Preset key.
3. Press the Freq key and enter the transmit frequency set on the DUT.
4. Press the Span key and set the span to at least 1.5x the 6 dB signal bandwidth from 2.1.2.
5. Press the BW key and set the resolution bandwidth (RBW) to 100 kHz. Set the video bandwidth to ≥ 3 x RBW.
6. Press the Trace key and select Trace 1. Under Trace 1, select the Max Hold mode and, under Detector Type, set the Positive Peak detector.
7. Press the Ampt key and adjust the reference level accordingly to the maximum signal level. Wait until the trace is stable.
8. Press the Mkr key, select Peak and note down the marker value as the reference value \( \text{Ref}_{\text{low}} \) (Figure 2-11).

![Figure 2-11: Measurement of maximum radiated power as reference value with \( f_{TX} = 903 \, \text{MHz} \)](image)

**Settings on DUT:**

9. As described under 2.1.1, \( f_{TX} = 914.2 \, \text{MHz} \) (highest channel center frequency for a 500 kHz wide LoRa signal (uplink), \( \text{SF} = 7 \))

**Settings on FPL1000:**

10. Press the Freq key and enter the transmit frequency set on the DUT. Retain all other settings. Wait until the trace is stable. Using the peak marker, note down the value as the reference value \( \text{Ref}_{\text{high}} \) (Figure 2-12).
11. Set the frequency SPAN according to the frequency range to be analyzed. In this example, SPAN = 5 MHz. Wait until the trace is stable.

12. Press the Mkr-> key and select Search Config.

13. In the Search tab, define a range (upper edge of the ISM band) for the marker-to-peak search. Set the Auto Max Peak function to On (Figure 2-13)

14. The marker now indicates the highest level value M1 within the frequency range to be analyzed (Figure 2-14).

15. The following condition must be fulfilled: $\text{Ref}_{\text{high}} - M1 \geq 30 \text{ dB}$
Settings on DUT:

16. As described under 2.1.1, \( f_{\text{TX}} = 903 \text{ MHz} \), \( SF = 7 \)

Settings on FPL1000:

17. Press the \textit{Freq} key and enter the transmit frequency set on the DUT. Retain all other settings.

18. Set the frequency SPAN according to the frequency range to be analyzed. In this example, SPAN = 20 MHz. Wait until the trace is stable.

19. Press the \textit{Mkr} key and select \textit{Search Config}.

20. In the \textit{Search} tab, define a range (lower edge of the ISM band) for the marker-to-peak search. Set the \textit{Auto Max Peak} function to \textit{On} (Figure 2-15).

Figure 2-14: Measurement of maximum radiated power at upper edge of ISM band

Figure 2-15: Definition of search range for maximum level value below ISM band
21. The marker now indicates the highest level value M1 within the frequency range to be analyzed (Figure 2-16).

![Figure 2-16: Measurement of maximum radiated power at lower edge of ISM band](image)

22. The following condition must be fulfilled: $\text{Ref_{low}} - M1 \geq 30 \text{ dB}$

2.1.6 20 dB Bandwidth (FHSS)

According to FCC 15.247(a)(1), in the frequency range 902 MHz to 928 MHz the 20 dB bandwidth of a frequency hopping spread spectrum (FHSS) transmit signal must not exceed the value of 500 kHz. For a LoRa signal in FHSS mode, this means that the 20 dB bandwidth of 500 kHz must not be exceeded for the signal bandwidths 125 kHz and 250 kHz. The following measurements are performed in line with FCC Public Notice DA 00-705 Measurement Guidelines for FHSS Systems.

**Settings on DUT:**

23. As described under 2.1.1, $f_{TX} = 915 \text{ MHz}$, but LoRa signal bandwidth 125 kHz, $SF = 7$

**Settings on FPL1000:**

24. Press the *Preset* key.

25. Press the *Freq* key and enter the transmit frequency set on the DUT.

26. Press the *Span* key and set the span to at least 2 to 3 times the 20 dB bandwidth to be expected.

27. Press the *BW* key and set the resolution bandwidth (RBW) to approx. 1% of the 20 dB bandwidth to be expected. Set the video bandwidth to $3 \times \text{RBW}$.

28. Press the *Trace* key and select *Trace 1*. Under *Trace 1*, select the *Max Hold* mode and, under *Detector Type*, set the *Positive Peak* detector.

29. Press the *Sweep* key and set *Sweep Time* to 5 ms.
30. Press the *Ampt* key and set the reference level using the *Auto Level* menu key.

31. Press the *Mkr* key and select *Select Marker Function*. In the *Markers* tab, select \( n \text{ dB down} \) and enter 20 dB in the *Value* entry field. Wait until the trace is stable. If necessary, use the measured value for the 20 dB bandwidth (\( n \text{ dB down BW} \)) to adjust the span and resolution bandwidth in line with the conditions named above. Wait until the trace has stabilized. Figure 2-17 shows the result of the measurement.

![Figure 2-17: Measurement of 20 dB bandwidth, LoRa signal bandwidth 125 kHz, SF = 7](image)

32. The following condition must be fulfilled: \( n \text{dB down BW} \leq 500 \text{ kHz} \)

**Settings on DUT:**

33. As described under 2.1.1, \( f_\text{TX} = 915 \text{ MHz} \), but LoRa signal bandwidth 250 kHz, \( SF = 7 \)

**Settings on FPL1000:**

34. As described above under points 1 to 10. Figure 2-18 shows the result of the measurement for a LoRa signal with 250 kHz bandwidth.
RF Measurements

Figure 2-18: Measurement of 20 dB bandwidth, LoRa signal bandwidth 250 kHz, SF = 7

35. The following condition must be fulfilled: ndB down BW ≤ 500 kHz

2.1.7 Power Spectral Density (Hybrid Mode)

According to FCC 15.247 (a)(2), in the frequency range 902 MHz to 928 MHz the 6 dB signal bandwidth of a digitally modulated signal must be at least 500 kHz. For smaller LoRa bandwidths 125 kHz and 250 kHz, the data transmission must therefore take place in the so-called hybrid mode. This mode allows a combination of frequency hopping and digital modulation technology. According to FCC 15.247(e), the power spectral density (PSD) of a transmitter must at no time exceed the value of 8 dBm relative to a bandwidth of 3 kHz during an ongoing data transmission.

Settings on DUT:
1. As described under 2.1.1, fTX = 915 MHz, but LoRa signal bandwidth 125 kHz, SF = 7

Settings on FPL1000 for measurement of OBW (measurement in line with ANSI C63-10[6] Section 6.9.3):
2. Press the Preset key.
3. Press the Freq key and enter the transmit frequency set on the DUT.
4. Press the Span key and set the span to 600 kHz (1.5 to 5 x OBW).
5. Press the BW key and set the resolution bandwidth to 10 kHz (1% to 5% of the OBW) and the video bandwidth to 30 kHz (approx. 3x RBW).
6. Press the Sweep key and set Sweep Time to 10 ms.
7. Press the Trace key and select Trace 1. Select the Positive Peak detector and Max Hold.

8. Press the Ampt key and set Reference Level such that the maximum value of the signal is at least $10\log(\text{OBW}/\text{RBW})$ below the reference level.

9. Press the Meas key and select OBW under Power Measurements. Wait until the trace is stable.

10. Note down the measured value for $\text{Occ BW} = \text{OBW}_{\text{SF7},125kHz}$.

**Settings on DUT:**

11. SF = 12; retain all other settings.

**Settings on FPL1000:**

12. Press the Sweep key, set Sweep Time to 100 ms and wait until the trace has stabilized.

13. Note down the measured value for $\text{Occ BW} = \text{OBW}_{\text{SF12},125kHz}$.

**Settings on DUT:**

14. SF = 7; retain all other settings.

**Settings on FPL1000 for measurement of PSD:**

15. Press the Span key and set the span to at least $1.5 \times \text{OBW}_{\text{SF7},125kHz}$.

16. Press the BW key and set the resolution bandwidth (RBW) to 3 kHz and the video bandwidth to $3 \times \text{RBW} = 10 \text{kHz}$.

17. Press the Trace key and select Trace 1. Under Trace 1, select the Average mode and, under Detector Type, set the RMS detector. In the Average Count entry field, enter a value of at least 100.

18. Press the Sweep key and set Sweep Time to 10 ms.

19. Press the Ampt key and set the reference level using the Auto Level menu key.

20. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed.

21. Press the Mkr-> key and select Peak.

The measurement result is shown in Figure 2-19.
22. The following conditions must be fulfilled: Power marker M1 ≤ 8 dBm

**Settings on DUT:**

23. SF = 12; retain all other settings.

**Settings on FPL1000:**

24. Press the Span key and set the span to at least 1.5 x OBW_{SF12,125kHz}.
25. Press the Sweep key and set Sweep Time to 100 ms.
26. Press the Ampt key and set the reference level using the Auto Level menu key.
27. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed.
28. Press the Mkr-> key and select Peak.

The measurement result is shown in Figure 2-20.
29. The following conditions must be fulfilled: Power marker M1 ≤ 8 dBm

**Settings on DUT:**

30. As described under 2.1.1, $f_{TX} = 915$ MHz, but LoRa signal bandwidth 250 kHz, SF = 7

**Settings on FPL1000 for measurement of OBW** (measurement in line with ANSI C63-10[6] Section 6.9.3):

31. Press the Span key and set the span to 750 kHz (1.5 to 5 x OBW).
32. Press the BW key and set the resolution bandwidth to 10 kHz (1% to 5% of the OBW) and the video bandwidth to 30 kHz (approx. 3x RBW).
33. Press the Sweep key and set Sweep Time to 10 ms.
34. Press the Trace key and select Trace 1. Select the Positive Peak detector and Max Hold.
35. Press the Ampt key and set Reference Level such that the maximum value of the signal is at least $10\log(\text{OBW}/\text{RBW})$ below the reference level.
36. Press the Meas key and select OBW under Power Measurements. Wait until the trace is stable.
37. Note down the measured value for $\text{Occ BW} = \text{OBW}_{\text{SF7,250kHz}}$.

**Settings on DUT:**

38. SF = 12; retain all other settings.
Settings on FPL1000:

39. Press the Sweep key, set Sweep Time to 100 ms and wait until the trace has stabilized.

40. Note down the measured value for Occ BW = OBW_{SF12.5kHz}.

Settings on DUT:

41. SF = 7; retain all other settings.

Settings on FPL1000 for measurement of PSD:

42. Press the Span key and set the span to at least 1.5 x OBW_{SF7,250kHz}.

43. Press the BW key and set the resolution bandwidth (RBW) to 3 kHz and the video bandwidth to 3 x RBW = 10 kHz.

44. Press the Trace key and select Trace 1. Under Trace 1, select the Average mode and, under Detector Type, set the RMS detector. In the Average Count entry field, enter a value of at least 100.

45. Press the Sweep key and set Sweep Time to 10 ms.

46. Press the Ampt key and set the reference level using the Auto Level menu key.

47. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed.

48. Press the Mkr-> key and select Peak.

The measurement result is shown in Figure 2-21.

Figure 2-21: Power spectral density measurement, LoRa signal SF = 7, 250 kHz

49. The following conditions must be fulfilled: Power marker M1 \leq 8 \text{ dBm}

Settings on DUT:

50. SF = 12; retain all other settings.
Settings on FPL1000:

51. Press the Span key and set the span to at least 1.5 x OBW_{SF12.125kHz}.
52. Press the Sweep key and set Sweep Time to 100 ms.
53. Press the Ampt key and set the reference level using the Auto Level menu key.
54. Press the Run Single key and wait until the number of averaging operations set under Average Count have been performed.
55. Press the Mkr-> key and select Peak. The measurement result is shown in Figure 2-22.

![Figure 2-22: Power spectral density measurement, LoRa signal SF = 12, 250 kHz](image)

56. The following conditions must be fulfilled: Power marker M1 ≤ 8 dBm

2.2 LoRa RX Test

2.2.1 RX Sensitivity

For the RX sensitivity test, Semtech provides a set of LoRa ARB waveform files for R&S Signal Generators for testing the sensitivity of the receiver. The set of files contains waveforms with various signal bandwidths and spreading factors. A RF carrier signal is modulated using these baseband ARB files, which are loaded in the SMBV100A vector signal generator, and fed to the receiver in the appropriate frequency range (Figure 2-23). While the signal power is being reduced, the LoRa test tool is used to read out and monitor the packet error rate (PER). The receiver sensitivity up to which no bit errors or very few bit errors occur depends on the used spreading factor and ranges from approx −117 dBm to −137 dBm.
The used SMBV100A vector signal generator offers excellent RF properties together with an extremely high output power level and short setting times. The optional built-in baseband generator with ARB allows a wide variety of digital standards to be generated.

Figure 2-23: Test setup for RX sensitivity measurement

Settings on SMBV100A:

1. Copy the waveform files to a USB stick and insert the USB stick into a free USB port of the SMBV100A.
2. Press the PRESET key.
3. Press the MENU key and select ARB… in the list:
4. Under Load Waveform…, load the desired ARB file in the USB directory. Set Status to On (Figure 2-24).
5. Using the FREQ and LEVEL keys, set the desired frequency and level values. Switch on the test signal using the RF Off key (Figure 2-24).
Settings on DUT:

6. Using the LoRa test tool, configure the receiver for reception of the test signal.

7. Reduce the level of the test signal until a defined PER value is exceeded, e.g. 1%. The level set on the signal generator corresponds to the receiver sensitivity.

2.2.2 Blocking Test

The blocking test is used to check the behavior of the receiver when an interference signal is applied.

The test setup in Figure 2-25 consists of two signal generators, the signals from which are fed to the DUT as a sum signal via a power combiner. Generator #1 generates an unmodulated, sinewave interference signal which is transmitted either with a spacing of 200 kHz relative to the wanted signal (adjacent channel blocking) or at the same frequency as the wanted signal (on-channel blocking). The SGS100A signal generator used here is configured via a LAN or USB connection using a PC and the R&S SGMA GUI software. Generator #2 supplies the LoRa wanted signal, which is generated as described under 2.2.1. The PER value is measured using the LoRa test tool.
Adjacent channel blocking:

**Settings on SMBV100A and DUT:**
1. As described under 2.2.1, points 1 to 6.

**Settings on SGS100A:**
2. Perform a preset.
3. Set the frequency with a spacing of +200 kHz relative to the wanted signal frequency used under 2.2.1, point 5.
4. Set the level such that it is 82 dB (uplink) or 78 dB (downlink) above the receiver sensitivity value determined under 2.2.1, point 7.

**Settings on SMBV100A:**
5. Increase the wanted signal level until PER < 1% is reached.
6. The following condition must be fulfilled: The wanted signal level now set must not be more than 3 dB above the receiver sensitivity value determined in 2.2.1, point 7.

**Settings on SGS100A:**
7. Set the frequency with a spacing of –200 kHz relative to the wanted signal frequency used under 2.2.1, point 5.
8. Repeat steps 4 to 6.

On-channel blocking:

**Settings on SMBV100A and DUT:**
9. As described under 2.2.1, points 1 to 6.

**Settings on SGS100A:**
10. Frequency = wanted signal frequency set under 2.2.1, point 5.
11. Set the level such that it is 20 dB above the receiver sensitivity value determined under 2.2.1, point 7.

Settings on SMBV100A:

12. Increase the wanted signal level until PER < 1% is reached.

13. The following condition must be fulfilled: The wanted signal level now set must not be more than 3 dB above the receiver sensitivity value determined in 2.2.1, point 7.
3 Battery Life Measurement

The power consumption of a LoRa device per transmission over time is a significant performance metric. A key requirement for any IoT device is to have a long battery life. In order to calculate the total service time or end of life using the same set of battery(s), the power consumption per packet transmission need to be measured. The devices normally switch to sleep mode for majority of its life span and only switch on to operational mode in order to transmit data to the LoRa gateway. While operating in sleep mode, the device experiences almost no battery drain and thus has a battery life of ~10 to 15 years. To make sure that the mentioned battery life will be achieved, it is also necessary to measure the power consumption in sleep mode.

The DUT that is used in this section is a LoRa capable prototype.

1. Set up the DUT and the test Instruments as shown in Figure 3-1.

   Figure 3-1: Test setup for power consumption measurement on LORA devices

2. Next select Horizontal -> Setup and Configure as shown in Figure 3-2

   Figure 3-2: Next select Vertical -> ZVC Multi-Channel Probe

3. Configure as shown in Figure 3-3

   Figure 3-3: ZVC measurement configuration on the RTO

5. Next Select click on setting button for Z1I1

   For the current measurement the RTO contains switchable shunts with the values 10 mΩ, 10 Ω and 10 kΩ. Thus, current measuring ranges from 4.5 μA to 10 A full scale are available (Figure 3-4).

   Measurement tip: for maximum flexibility, the probe can also be operated with an external shunt that should ideally be integrated into the test setup from the beginning. This allows adjusting the full-scale range to the expected current consumption by selecting an appropriate shunt resistor. This leads to a measurement with higher resolution and lower noise. In this example, the maximum expected current is ~150 mA. A 2.2 Ω resistor in the 450mV measurement range gives a current full-scale range of 450mV / 2.2 Ω = 205 mA. For the sake of simplicity, this application note uses the internal shunt with 4.5 A current range.

6. The maximum current consumption of the DUT appears to be ~150 mA, which means that the 4.5A current range has to be chosen. Configure ZVC Current Settings as shown in Figure 3-4
7. Click on Math -> Math Setup

8. Configure the two sources and operator as shown in Figure 3-5.

9. Next select Measurements -> Setup

10. Configure the Measurement Area as shown in Figure 3-6
Figure 3-6: Measurement Area settings

Figure 3-7 shows two plots in total. The upper plot shows both the supply voltage plot and the current drain over time. In this plot, the current drain during packet transmission can be seen. The lower plot shows the total power consumption over time. Using the area (integral) measurement function on the math channel with gating enabled allows to measure the energy consumed during one transmit frame which was 1.7535 Ws.

Figure 3-7: Power consumption measurement results on the RTO
In order to configure gated area measurement:

- Select Meas -> Setup -> Enable > Source 1 : M1
  - Select Main : Area
- Select Meas -> Gate/Display -> Use Gate
  - Set Start and stop time as required.

In Figure 3-8, Start: -3 s & Stop: + 3s.

Figure 3-8: Settings for the gated area measurement


4 References


## 5 Ordering Information

### Spectrum analyzer

<table>
<thead>
<tr>
<th>Designation</th>
<th>Type</th>
<th>Order No.</th>
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<tr>
<td>Spectrum Analyzer 5 kHz to 3 GHz&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>R&amp;S®FPL1003</td>
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### Signal generators

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<td>Vector Signal Generator Base Unit&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>R&amp;S®SMBV100A</td>
<td>1407.6004.02</td>
</tr>
<tr>
<td>9 kHz to 3.2 GHz</td>
<td>R&amp;S® SMBV-B103</td>
<td>1407.9603.02</td>
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<tr>
<td>Reference Oscillator OCXO</td>
<td>R&amp;S® SMBV-B1</td>
<td>1407.8407.02</td>
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<tr>
<td>Baseband Generator with ARB (32 Msample), 60 MHz RF bandwidth</td>
<td>R&amp;S® SMBV-B51</td>
<td>1407.9003.04</td>
</tr>
<tr>
<td>SGMA RF Source&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>R&amp;S® SGS100A</td>
<td>1416.0505.02</td>
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<tr>
<td>1 MHz to 6 GHz, CW (no modulation)</td>
<td>R&amp;S® SGS-B106</td>
<td>1416.2308.02</td>
</tr>
<tr>
<td>Electronic Step Attenuator</td>
<td>R&amp;S® SGS-B26</td>
<td>1416.1353.02</td>
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<tr>
<td>Reference Oscillator OCXO</td>
<td>R&amp;S® SGS-B1</td>
<td>1416.2408.02</td>
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### Digital oscilloscope

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</thead>
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<td>Digital oscilloscope 600MHz, 2 channels, 10 Gsamples/s, 50/100 Msample&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>R&amp;S®RTO2002</td>
<td>1329.7002k02</td>
</tr>
<tr>
<td>Digital Extension Port for RT-ZVC Support</td>
<td>R&amp;S®RTO-B1E</td>
<td>1333.0738.02</td>
</tr>
<tr>
<td>Multi channel power probe, 1 MHz, 5 MSA/s, 18 Bit, 2/4 current inputs, 2/4 voltage inputs</td>
<td>R&amp;S®RT-ZVC04</td>
<td>1326.0259.04</td>
</tr>
<tr>
<td>Extended Cable Set, 1 current and 1 voltage lead, length: 1 m</td>
<td>R&amp;S®RT-ZA35</td>
<td>1333.1905.02</td>
</tr>
<tr>
<td>Solder-in Cable set, 4 current and voltage solder-in cables, solder-in pins</td>
<td>R&amp;S®RT-ZA36</td>
<td>1333.1911.02</td>
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</tbody>
</table>

<sup>1)</sup> Further equipment options can be found at [www.rohde-schwarz.com](http://www.rohde-schwarz.com) or contact your local Rohde & Schwarz representative.
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