

Characterization of LoRa Devices

Application Note

Products:

- R&S®FPL1000
- R&S®SMBV100B
- R&S®SGS100A
- R&S®RTO2000
- R&S® RTZVC04
- R&S®CMW100
- R&S®CMW100CRT
- R&S®WinIQSIM2

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.

For Production, use of the R&S®CMW100A Communications Manufacturing Test Set and R&S®CMW100CTR control PC are shown for the LoRa TX Test.

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>

This document is complemented by software. The software may be updated even if the version of the document remains unchanged

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In this application note, the following abbreviations are used for Rohde & Schwarz instruments:

- The R&S®SMBV100B vector signal generator is referred to as the SMBV100B.
- The R&S®SGS100A SGMA RF source is referred to as the SGS100A.
- The R&S®FPL1000 spectrum analyzer is referred to as the FPL1000.
- The R&S®RTO2000 digital oscilloscope is referred to as the RTO.
- The R&S®RT-ZVC04 multi channel power probe is referred to as the ZVC.
- The R&S® CMW100 communications manufacturing test set is referred to as the CMW100
- The R&S® CMW100CRT control PC for R&S®CMW100 is referred to as the CMW100CRT
- The R&S® Forum application for remote control of Rohde & Schwarz instruments is referred to as the Forum
- R&S®WinIQSIM2 simulation software is referred to as the WinIQSIM2

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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.

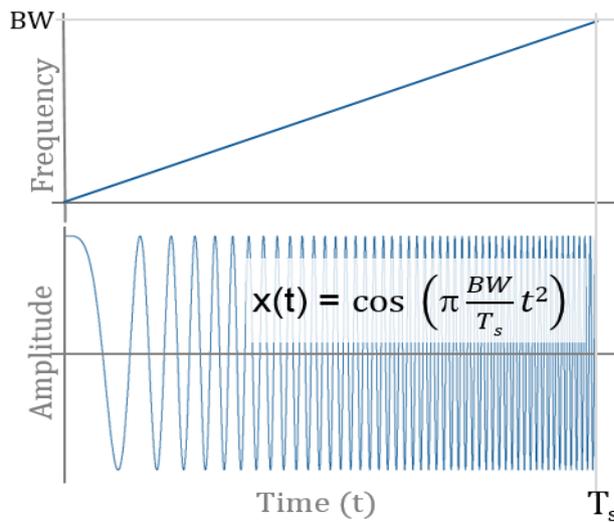


Figure 1-1: FM-modulated chirp pulse with linearly rising frequency

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

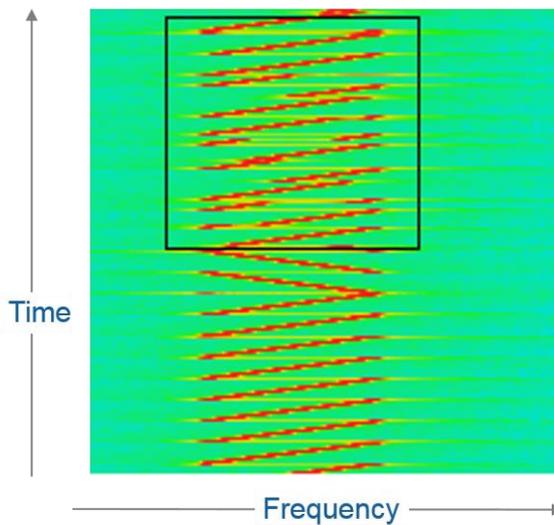


Figure 1-2: LoRa signal with rising and falling chirp pulses

The following key correlations apply to a LoRa signal:

Equation 1-1:

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

Equation 1-2:

Chirp rate: $R_c = R_s * 2^{SF}$ chips/sec

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.

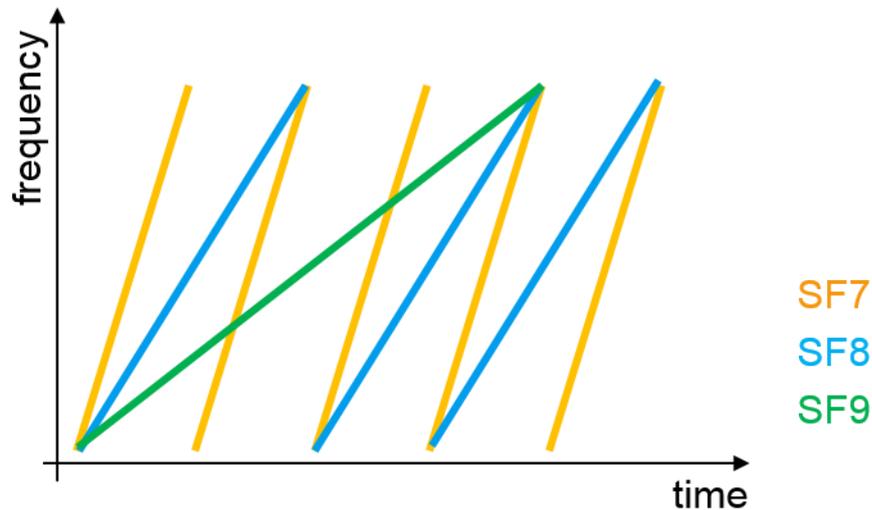


Figure 1-3: Change of frequency over time as a function of spreading factor SF

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:

$$\text{Bit rate: } R_B = SF * \frac{BW}{2^{SF}} * \frac{4}{4+CR} \text{ bits/sec; code rate, CR [1 to 4]}$$

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.

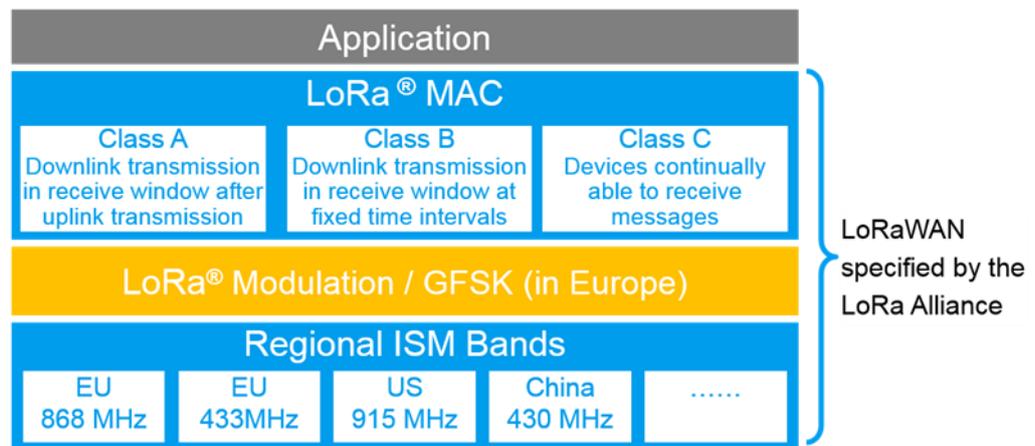


Figure 1-4: LoRaWAN stack

1.2.1 LoRaWAN Network Architecture

Using LoRa wireless technology, it is possible to create wireless networks which can cover a 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).

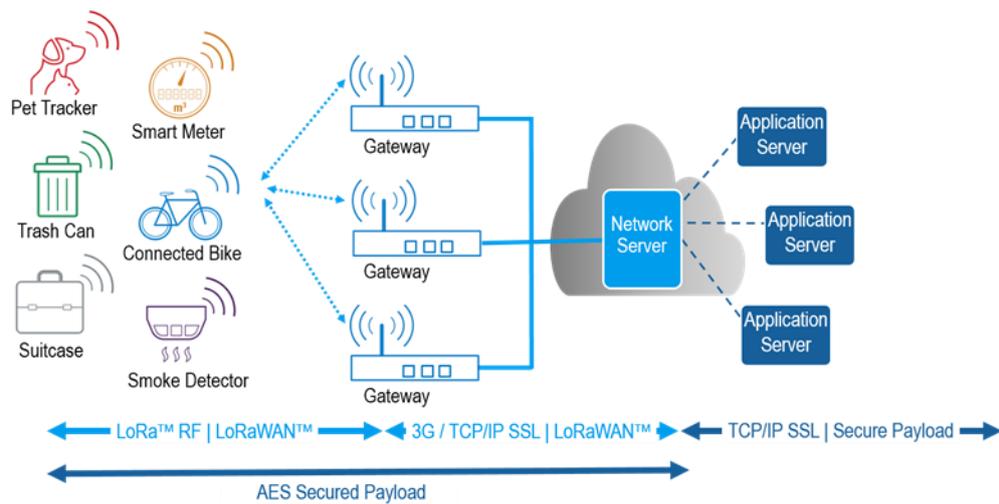


Figure 1-5: LoRaWAN network architecture

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.

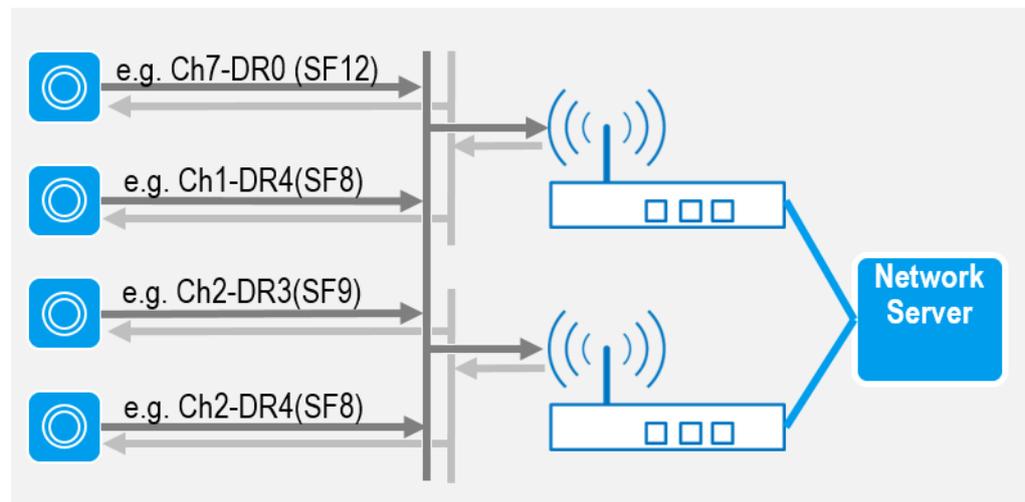


Figure 1-6: Simultaneous reception of data packets from all gateways

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).

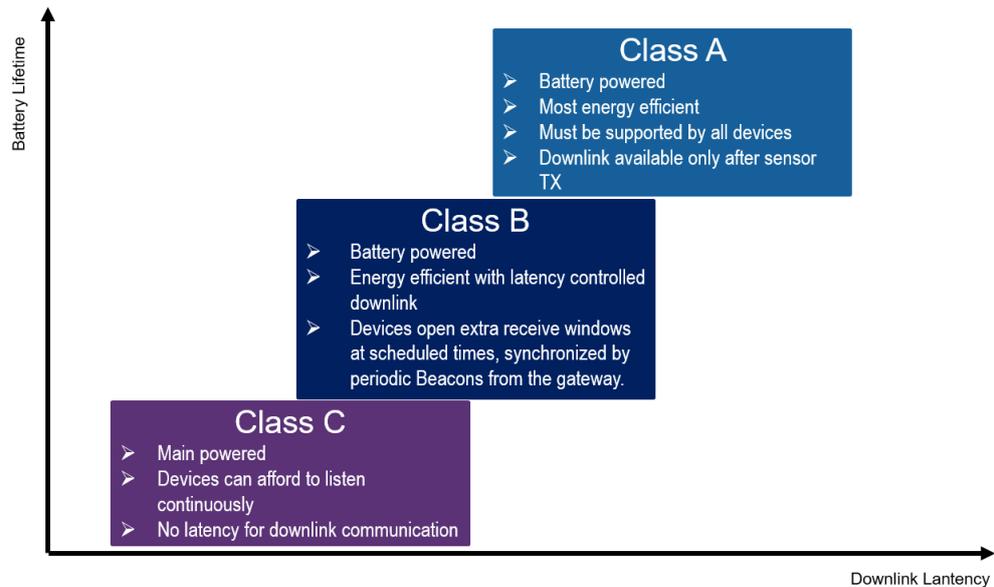


Figure 1-7: LoRaWAN device classes

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.

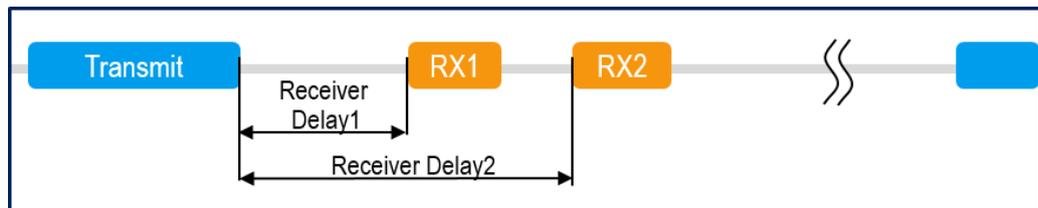


Figure 1-8: Operating principle of device class A

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.

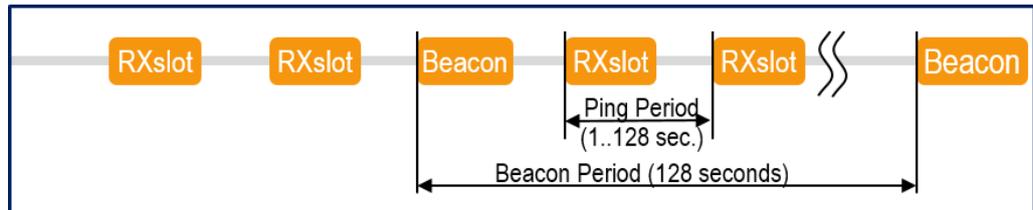


Figure 1-9: Operating principle of device class B

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.

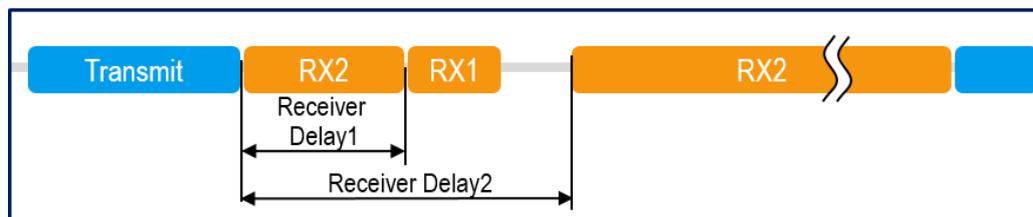


Figure 1-10: Operating principle of device class C

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.

	Europe (ETSI)	North America (FCC)
Frequency band	863 MHz to 869 MHz	902 MHz to 928 MHz
Channels	10	64 +8 +8 ¹⁾
Channel bandwidth Up	125 kHz / 250 kHz	125 kHz / 500 kHz
Channel bandwidth Dn	125 kHz	500 kHz
TX power Up	+14 dBm (+20 dBm allowed)	+20 dBm (+30 dBm allowed)
TX power Dn	+14 dBm	+27 dBm
SF Up	7 to 12	7 to 10
Date rate	250 bps to 50 kbps	980 bps to 21.9 kbps
Link budget Up	155 dB	154 dB
Link budget Dn	155 dB	157 dB

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).

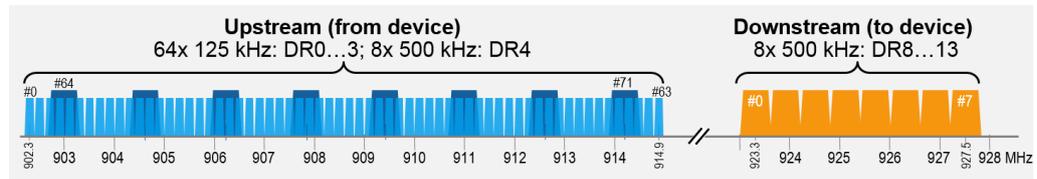


Figure 1-11: LoRaWAN channel assignment in North America

Hybrid mode

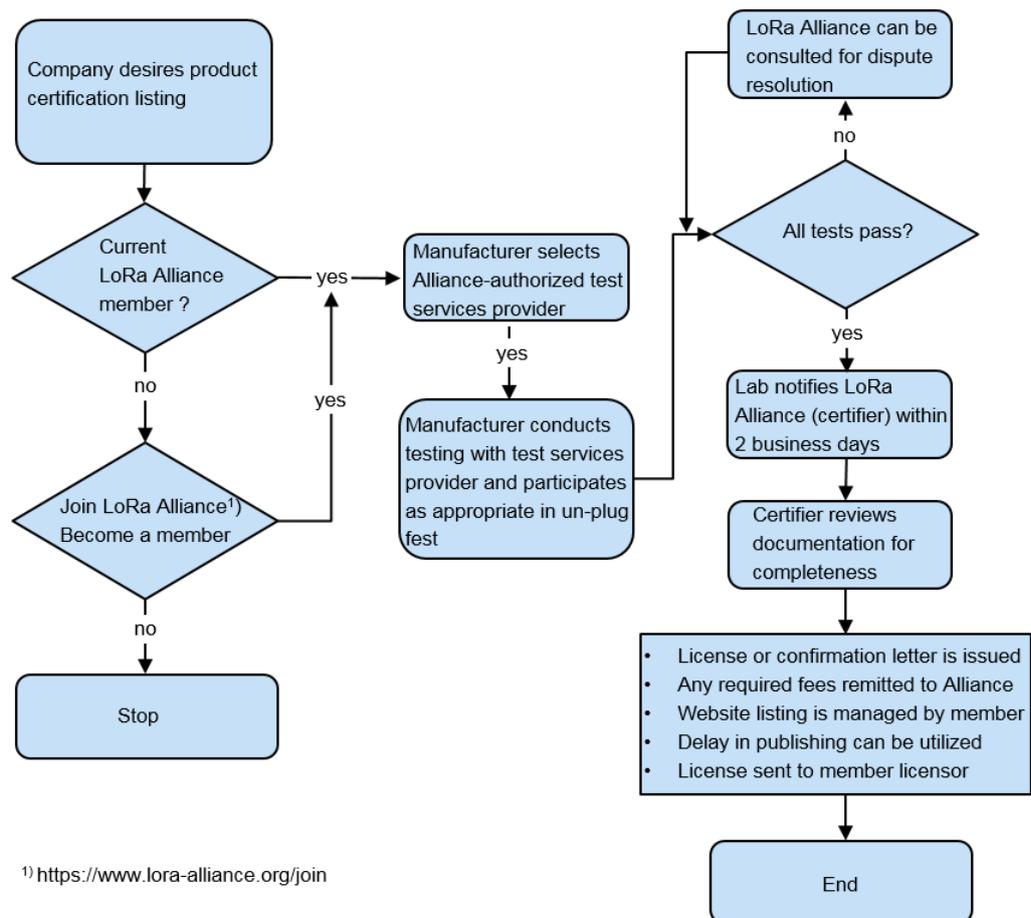
In North America, the signal bandwidth of digitally modulated signals in the ISM band must be at least 500 kHz according to FCC Part 15.247. This requirement does not apply to systems with frequency hopping. In order to better utilize the signal band with smaller bandwidths (< 500 kHz), LoRa uses the 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

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.



¹) <https://www.lora-alliance.org/join>

Figure 1-12: LoRaWAN certification process

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.

Digital modulation mode (TX-Test)		
FCC Anforderung	Parameter	Limit
15.247(a)(2)	6 dB bandwidth	≥ 500 kHz
15.247(b)(3)	Emission output power	+ 30 dBm
15.247(e)	Power spectral density	+ 8 dBm / 3 kHz
15.247(d)	Emissions in non-restricted bands	-30 dBc
Frequency hopping spread spectrum mode (TX-Test)		
FCC Anforderung	Parameter	Limit
15.247(a)(1)	20 dB bandwidth	≤ 500 kHz
15.247(d)	Emissions in non-restricted bands	- 30 dBc
Hybride mode (TX-Test)		
FCC Anforderung	Parameter	Limit
15.247(e)	power spectral density	+ 8 dBm / 3 kHz

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.

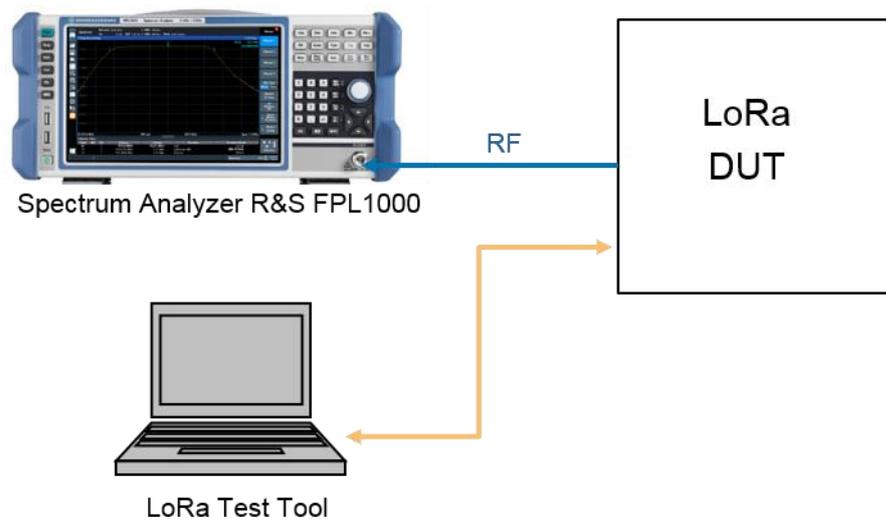


Figure 2-1: Test setup for LoRa transmitter test

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



Figure 2-2: Measurement of 6 dB bandwidth with SF = 7

Settings on DUT:

10. As described under 2.1.1, $f_{rx} = 915$ MHz, SF = 12

Settings on FPL1000:

11. To restart the measurement, press the *Run Cont* key twice. Wait until the trace has stabilized. Note down the value for the 6 dB bandwidth *ndB down BW*.
12. The following condition must be fulfilled: *ndB down BW* \geq 500 kHz (Figure 2-3).



Figure 2-3: Measurement of 6 dB bandwidth with SF = 12

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:

- 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):

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

- 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).
- Press the *Sweep* key and set Sweep Time to 2 ms.
- 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

Settings on DUT:

11. As described under 2.1.1, $f_{\text{TX}} = 915$ 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).



Figure 2-5: Measurement of OBW with SF = 12

Settings on DUT:

14. As described under 2.1.1, $f_{TX} = 915$ 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 OBW_{SF12} (Figure 2-6) and close the window.

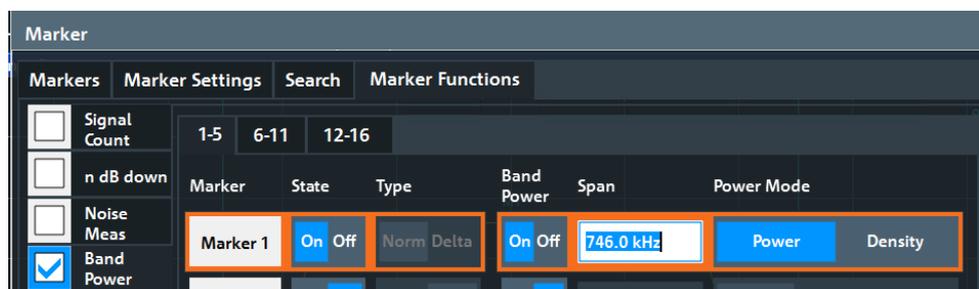


Figure 2-6: Entering channel bandwidth for emission output power measurement

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](#).

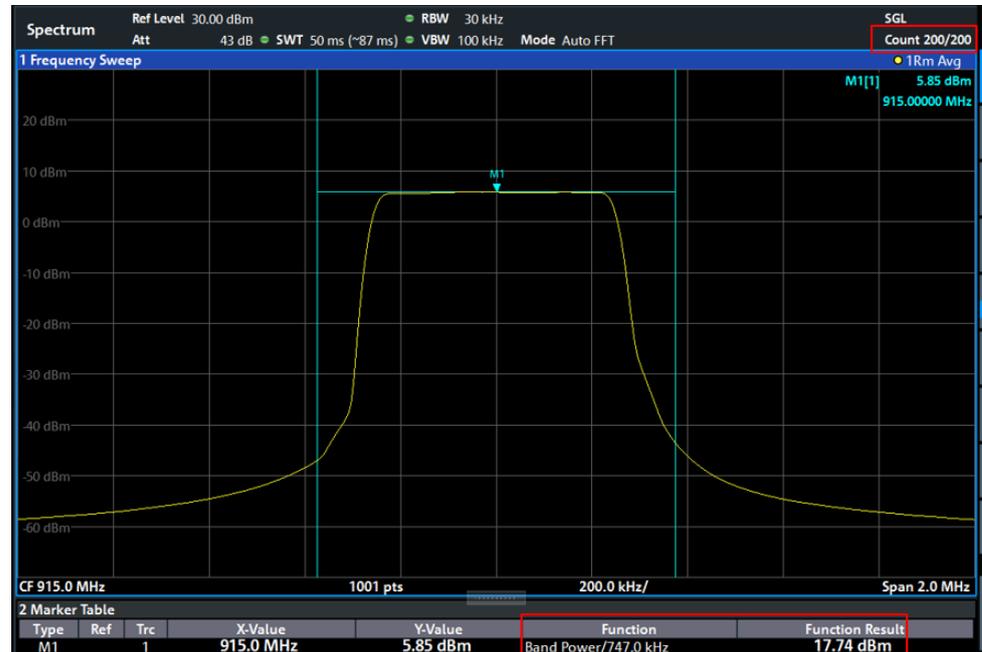


Figure 2-7: Emission output power measurement with SF = 12

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

Settings on DUT:

21. As described under [2.1.1](#), $f_{TX} = 915$ 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](#).

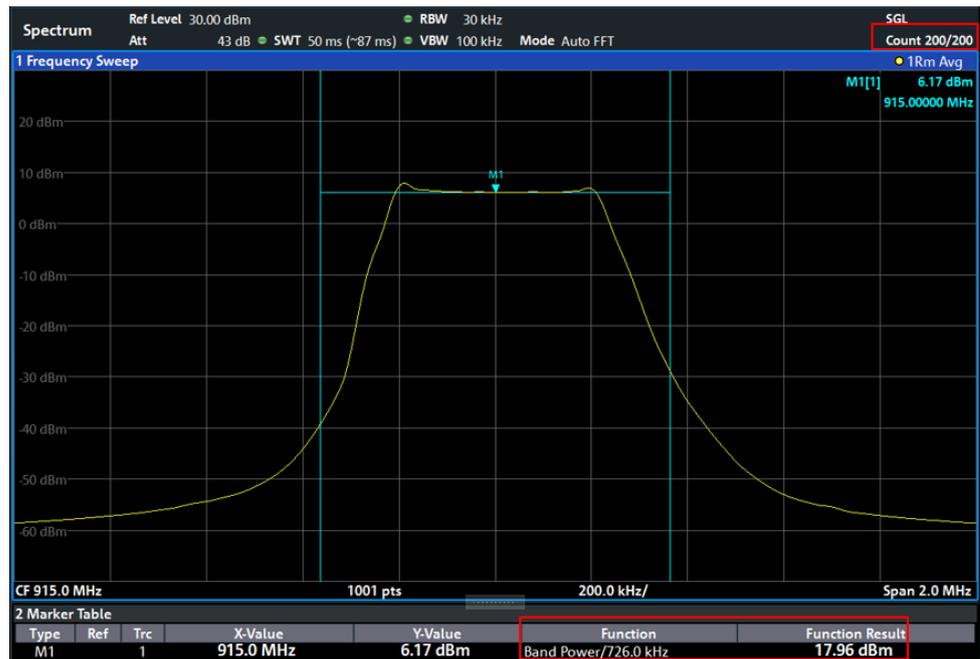


Figure 2-8: Emission output power measurement with SF = 7

24. The following conditions must be fulfilled: Band power \leq 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:

- As described under 2.1.1, $f_{TX} = 915$ MHz, SF = 7

Settings on FPL1000:

- Press the *Preset* key.
- Press the *Freq* key and enter the transmit frequency set on the DUT.
- Press the *Span* key and set the span to at least $1.5 \times \text{OBW}_{\text{SF7}}$ from 2.1.3 (Figure 2-4).
- Press the *BW* key and set the resolution bandwidth (RBW) to 3 kHz and the video bandwidth to $3 \times \text{RBW} \approx 10$ kHz.
- 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.
- Press the *Sweep* key and set *Sweep Time* to 10 ms.
- Press the *Ampt* key and set the reference level using the *Auto Level* menu key.

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](#).

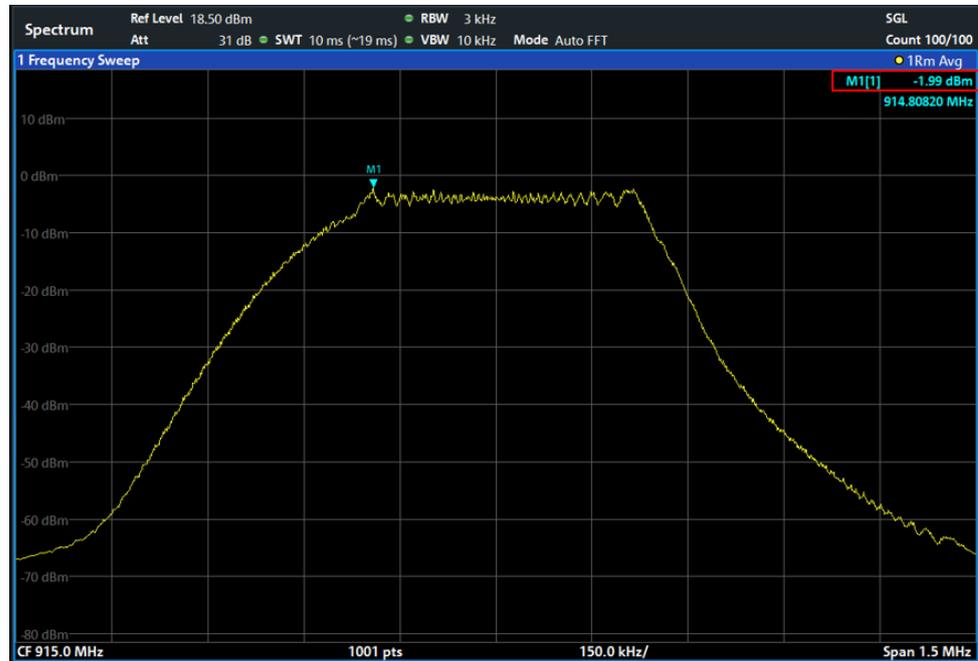


Figure 2-9: Power spectral density measurement with RBW = 3 kHz, SF = 7

11. The following conditions must be fulfilled: Power marker M1 \leq 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 $1.5 \times OBW_{SF12}$ 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](#).

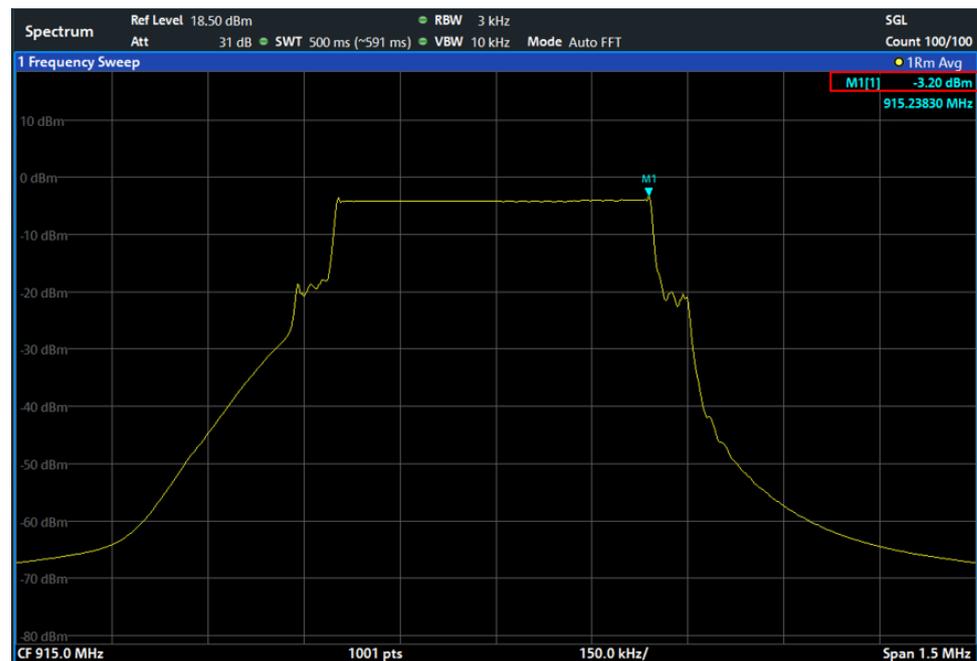


Figure 2-10: Power spectral density measurement with RBW = 3 kHz, SF = 12

18. The following conditions must be fulfilled: Power marker M1 \leq 8 dBm

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:

- As described under 2.1.1, $f_{TX} = 903$ MHz (lowest channel center frequency for a 500 kHz wide LoRa signal (uplink), SF = 7

Settings on FPL1000:

- Press the *Preset* key.
- Press the *Freq* key and enter the transmit frequency set on the DUT.
- Press the *Span* key and set the span to at least 1.5x the 6 dB signal bandwidth from 2.1.2.
- Press the *BW* key and set the resolution bandwidth (RBW) to 100 kHz. Set the video bandwidth to $\geq 3 \times$ RBW.
- 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.
- 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 Ref_{low} (Figure 2-11).

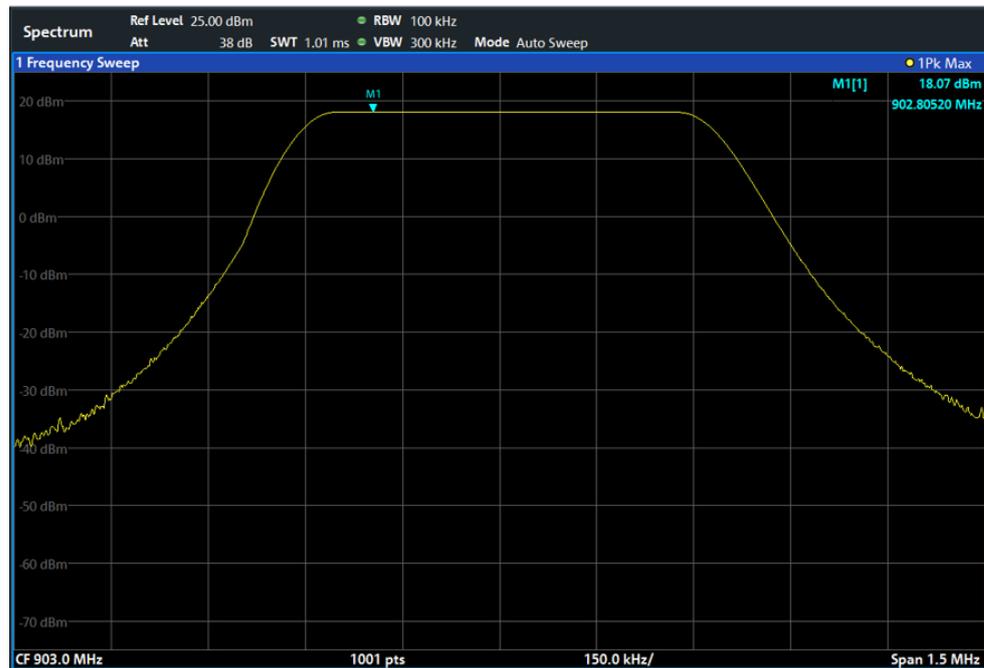


Figure 2-11: Measurement of maximum radiated power as reference value with $f_{TX} = 903$ MHz

Settings on DUT:

9. As described under 2.1.1, $f_{TX} = 914.2$ MHz (highest channel center frequency for a 500 kHz wide LoRa signal (uplink), 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 Ref_{high} (Figure 2-12).

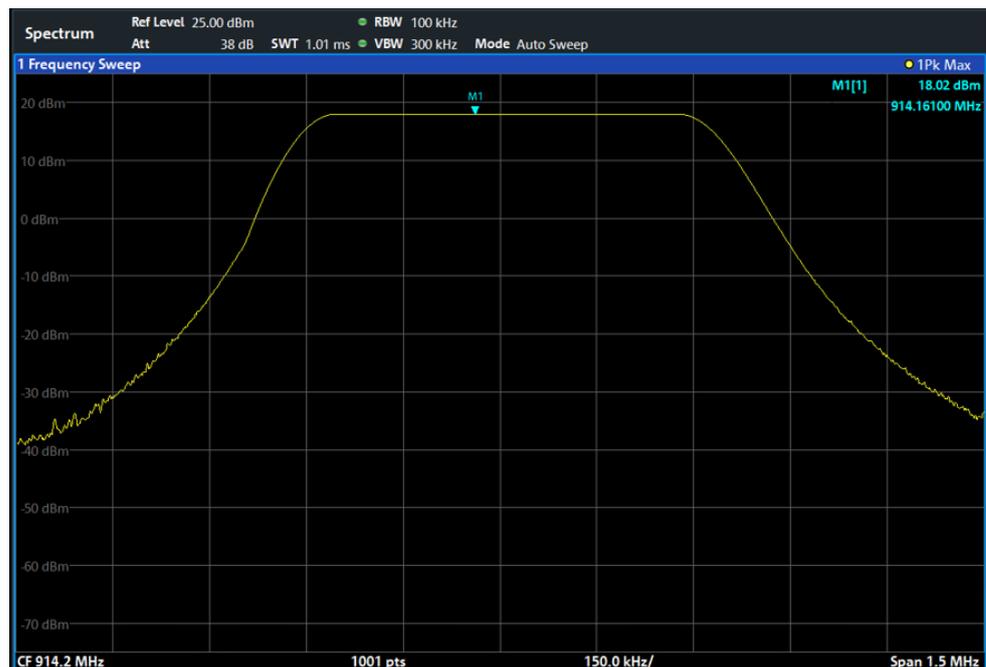


Figure 2-12: Measurement of maximum radiated power as reference value with $f_{TX} = 914.2$ MHz

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)

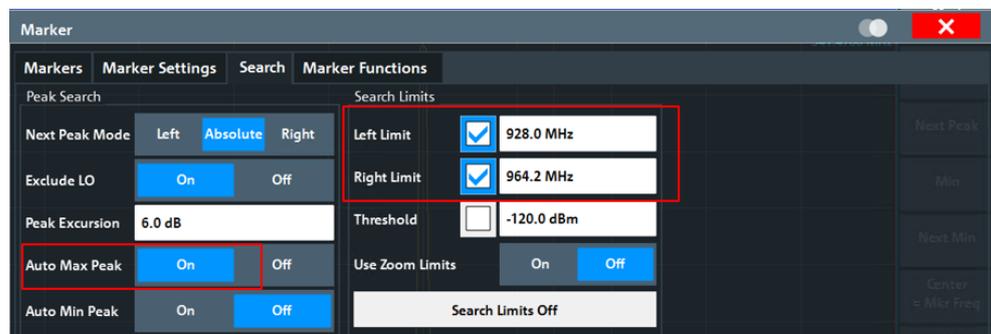


Figure 2-13: Definition of search range for maximum level value above ISM band

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: $\text{Ref}_{\text{high}} - M1 \geq 30$ dB

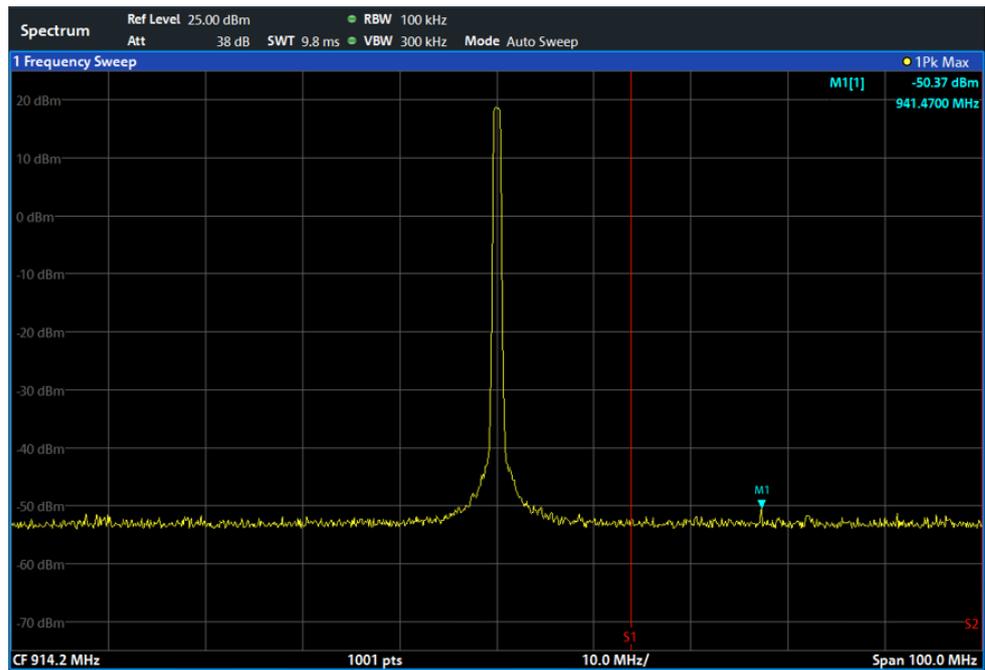


Figure 2-14: Measurement of maximum radiated power at upper edge of ISM band

Settings on DUT:

- As described under 2.1.1, $f_{tx} = 903 \text{ MHz}$, $SF = 7$

Settings on FPL1000:

- Press the *Freq* key and enter the transmit frequency set on the DUT. Retain all other settings.
- Set the frequency SPAN according to the frequency range to be analyzed. In this example, $SPAN = 20 \text{ MHz}$. Wait until the trace is stable.
- Press the *Mkr->* key and select *Search Config*.
- In the *Search* tab, define a range (lower edge of the ISM band) for the marker-to-peak search. Set the *Auto Max Peak* function to *On* (Figure 2-15).

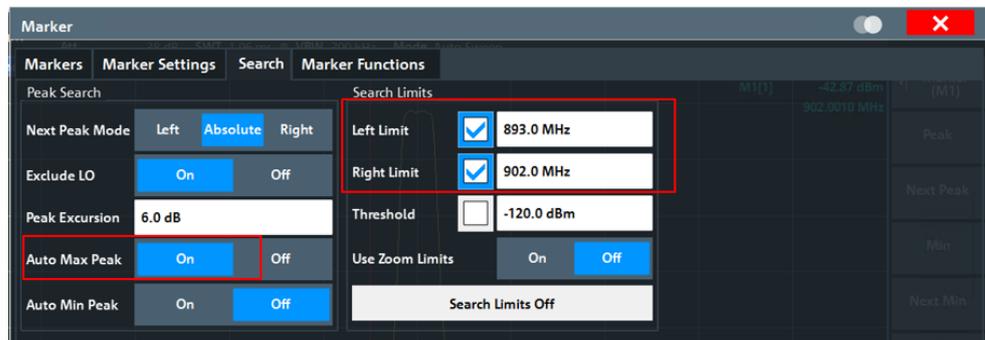


Figure 2-15: Definition of search range for maximum level value below ISM band

21. The marker now indicates the highest level value M1 within the frequency range to be analyzed (Figure 2-16).

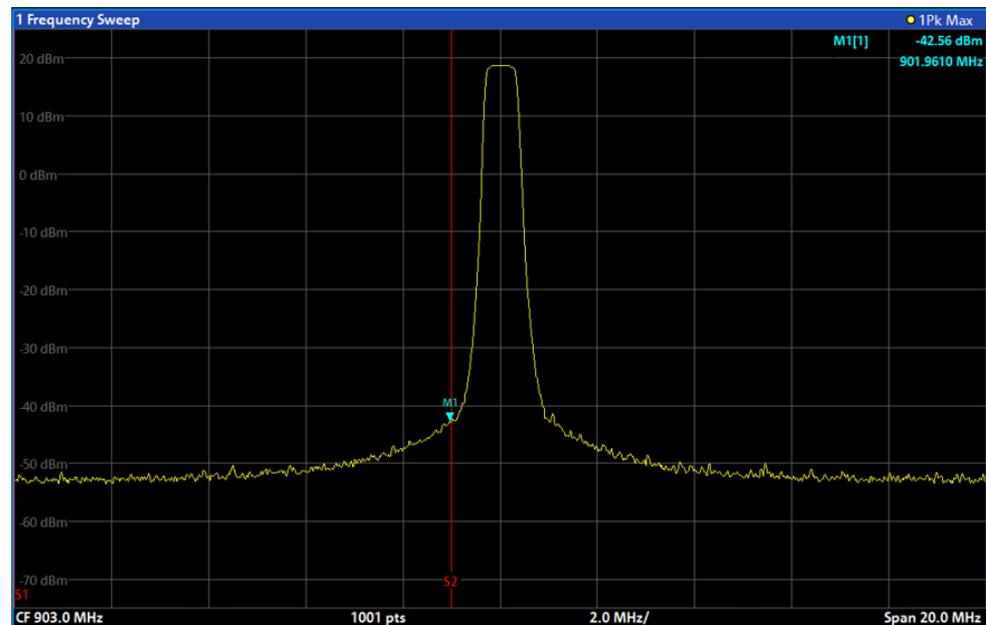


Figure 2-16: Measurement of maximum radiated power at lower edge of ISM band

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

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, $f_{rx} = 915 \text{ MHz}$, 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 x 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 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 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.

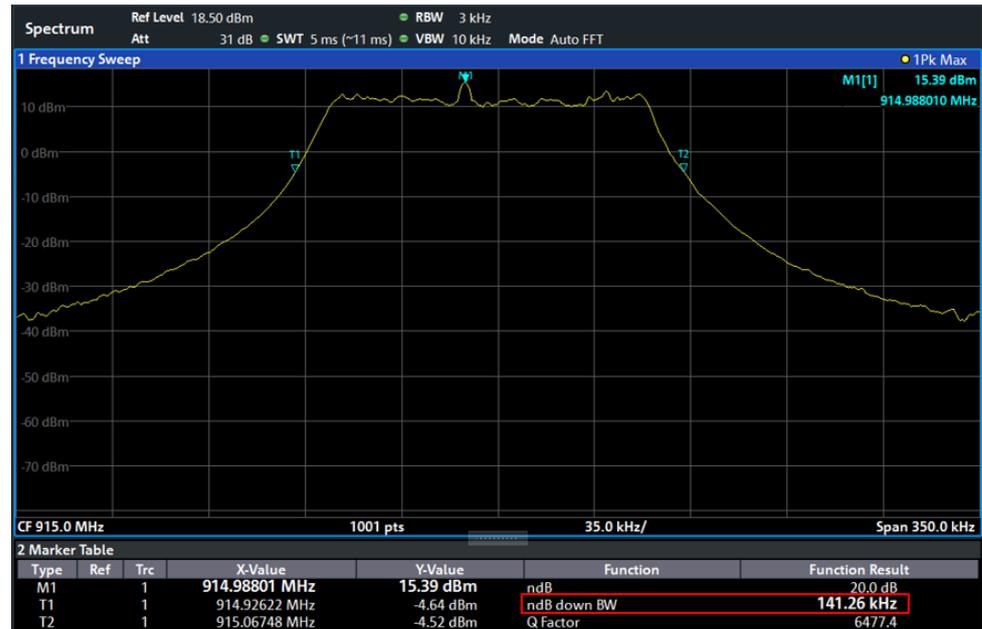


Figure 2-17: Measurement of 20 dB bandwidth, LoRa signal bandwidth 125 kHz, SF = 7

32. The following condition must be fulfilled: $\text{ndB down BW} \leq 500 \text{ kHz}$

Settings on DUT:

33. As described under 2.1.1, $f_{\text{rx}} = 915 \text{ MHz}$, 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.

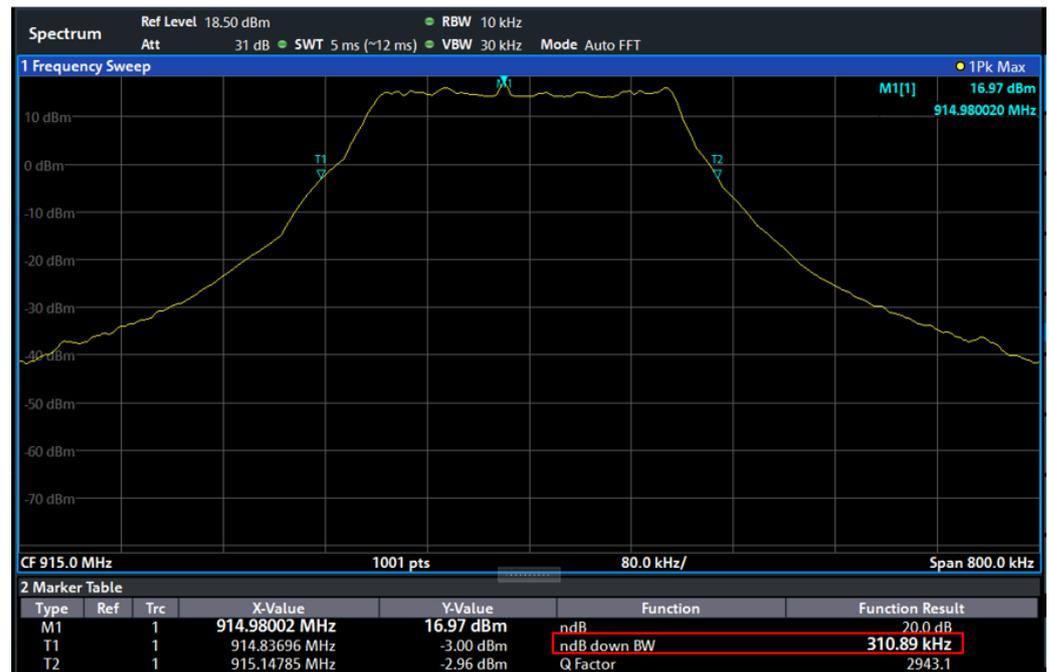


Figure 2-18: Measurement of 20 dB bandwidth, LoRa signal bandwidth 250 kHz, SF = 7

35. The following condition must be fulfilled: $\text{ndB down BW} \leq 500 \text{ kHz}$

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:

- As described under 2.1.1, $f_{\text{rx}} = 915 \text{ MHz}$, 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):

- Press the *Preset* key.
- Press the *Freq* key and enter the transmit frequency set on the DUT.
- Press the *Span* key and set the span to 600 kHz (1.5 to 5 x OBW).
- 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).
- 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 $\text{Occ BW} = \text{OBW}_{\text{SF7},125\text{kHz}}$.

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 $\text{Occ BW} = \text{OBW}_{\text{SF12},125\text{kHz}}$.

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 $1.5 \times \text{OBW}_{\text{SF7},125\text{kHz}}$.
16. Press the *BW* key and set the resolution bandwidth (RBW) to 3 kHz and the video bandwidth to $3 \times \text{RBW} \approx 10 \text{ kHz}$.
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](#).

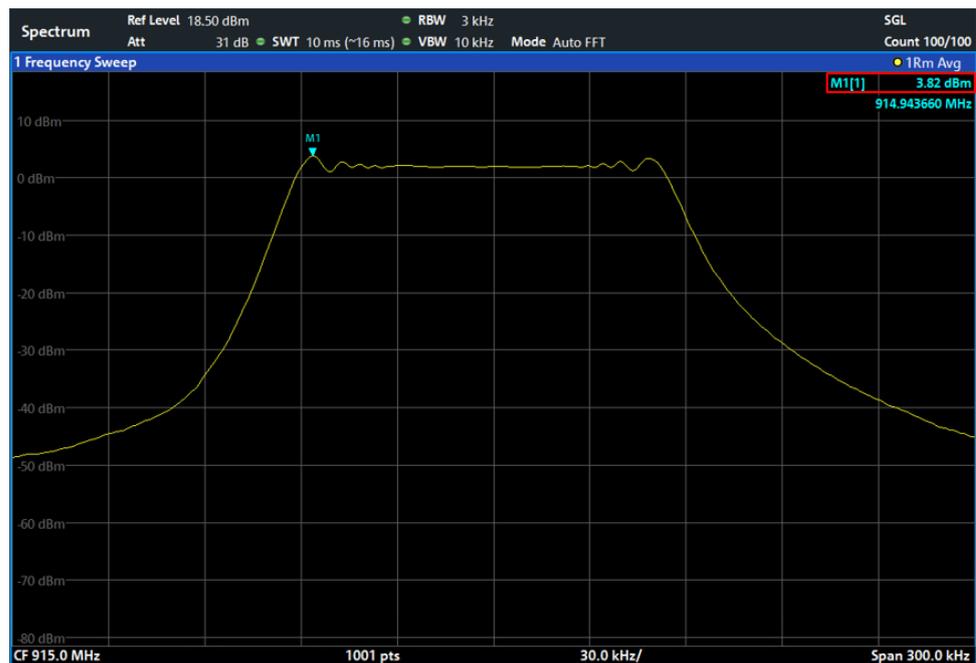


Figure 2-19: Power spectral density measurement, LoRa signal SF = 7, 125 kHz

22. The following conditions must be fulfilled: Power marker M1 \leq 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 $1.5 \times \text{OBW}_{\text{SF}12,125\text{kHz}}$.
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](#).

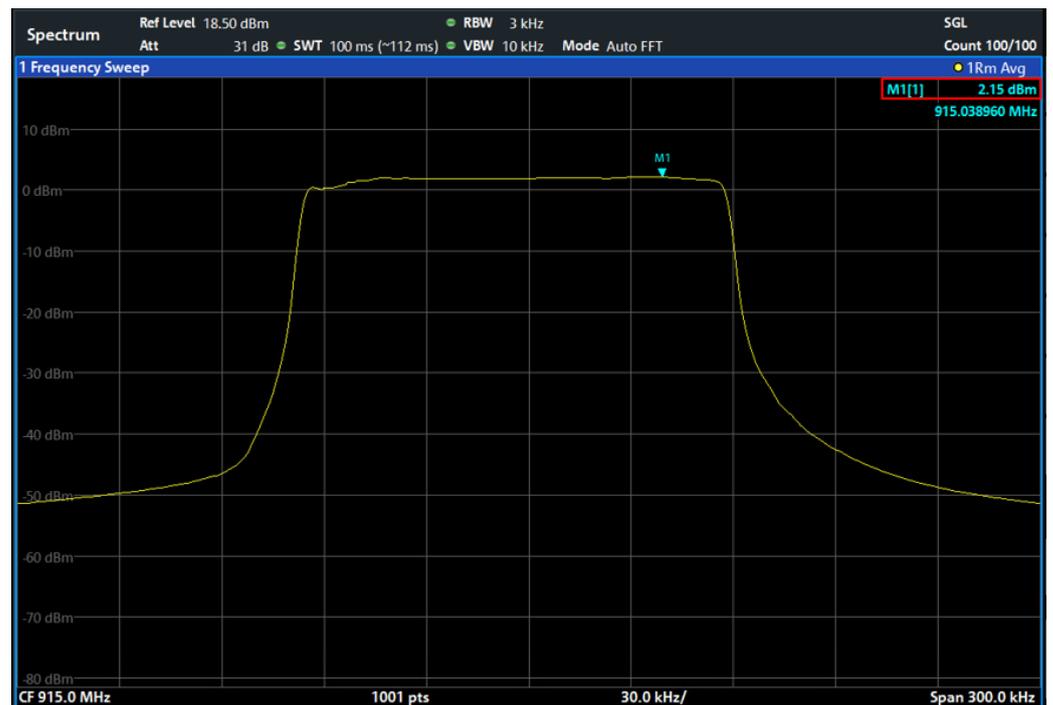


Figure 2-20: Power spectral density measurement, LoRa signal SF = 12, 125 kHz

29. The following conditions must be fulfilled: Power marker M1 \leq 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 $10\log(OBW/RBW)$ 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 $Occ\ BW = OBW_{SF7,250kHz}$.

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 $Occ\ BW = OBW_{SF12,500kHz}$.

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 $1.5 \times OBW_{SF7,250kHz}$.
43. Press the *BW* key and set the resolution bandwidth (RBW) to 3 kHz and the video bandwidth to $3 \times RBW \approx 10\text{ kHz}$.
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](#).

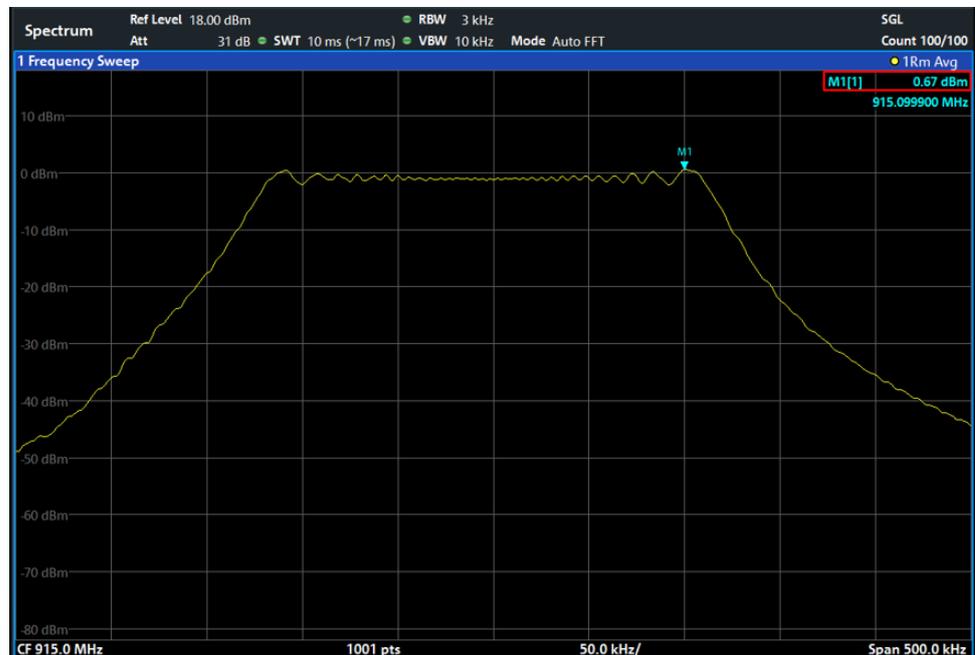


Figure 2-21: Power spectral density measurement, LoRa signal SF = 7, 250 kHz

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 $1.5 \times \text{OBW}_{\text{SF}12,125\text{kHz}}$.
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](#).

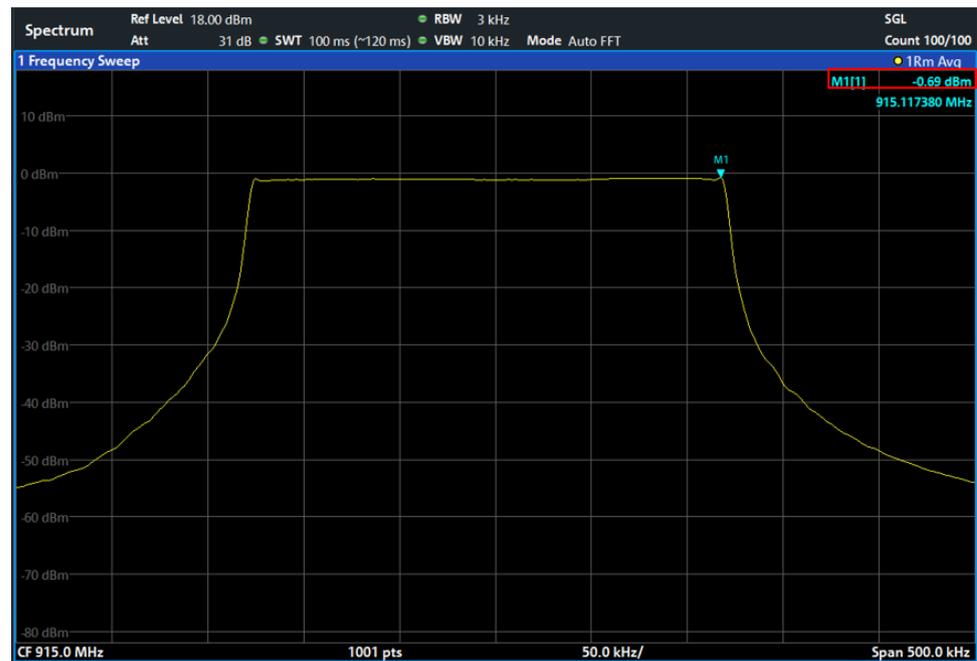


Figure 2-22: Power spectral density measurement, LoRa signal SF = 12, 250 kHz

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

2.2 LoRa RX Test

2.2.1 RX Sensitivity

For the RX sensitivity test, the SMBV100B generates a LoRa test signal. Signal bandwidth, spreading factor, payload length, level, frequency, etc. are variably adjustable. The generated signal is 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 .

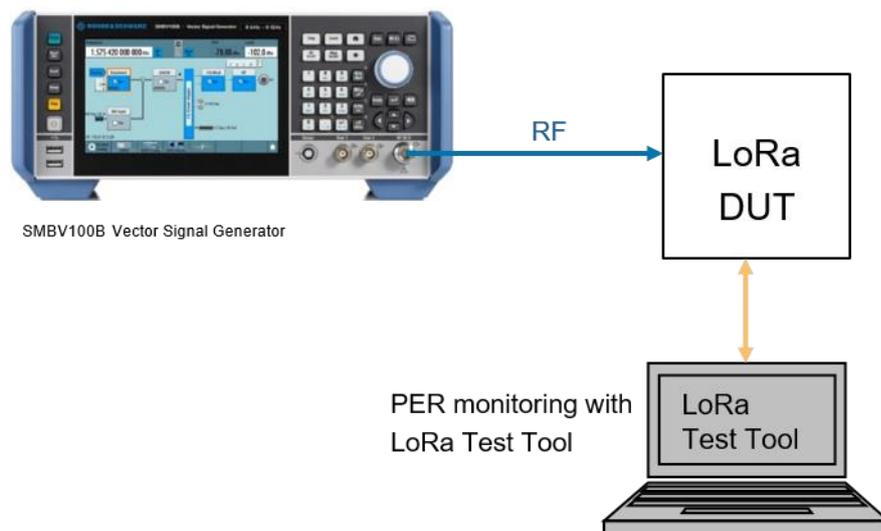
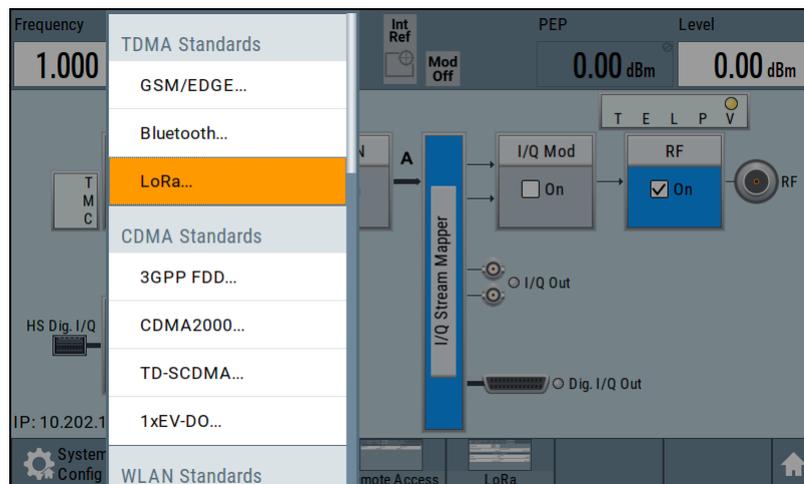


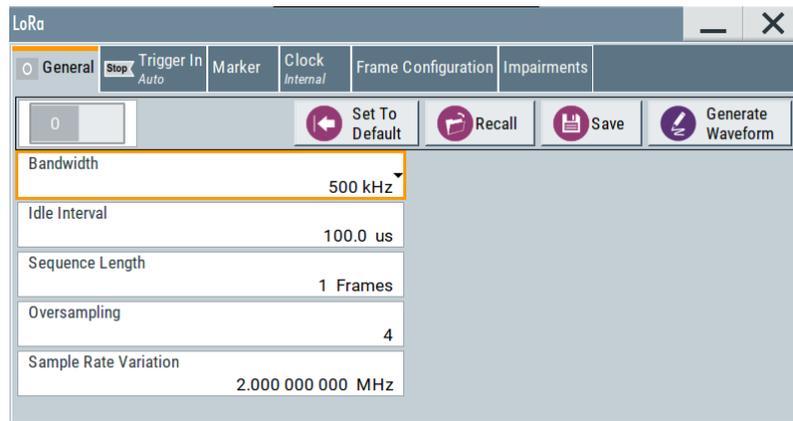
Figure 2-23: Test setup for RX sensitivity measurement

Settings on SMBV100B:

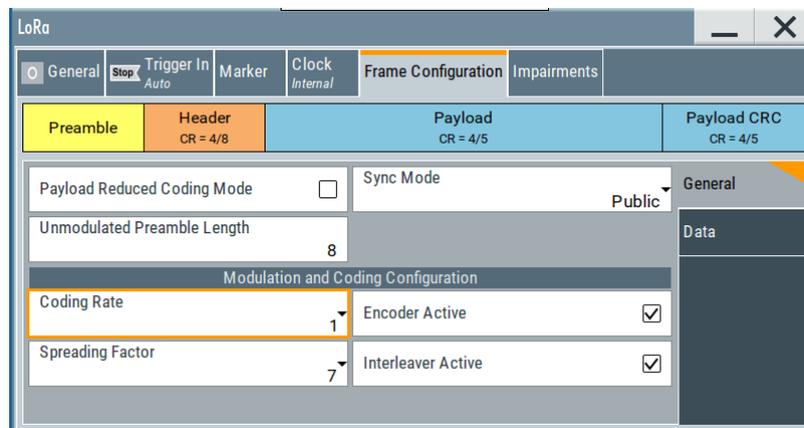
1. Press the PRESET key.
2. Under BASEBAND select the LoRa Standard:



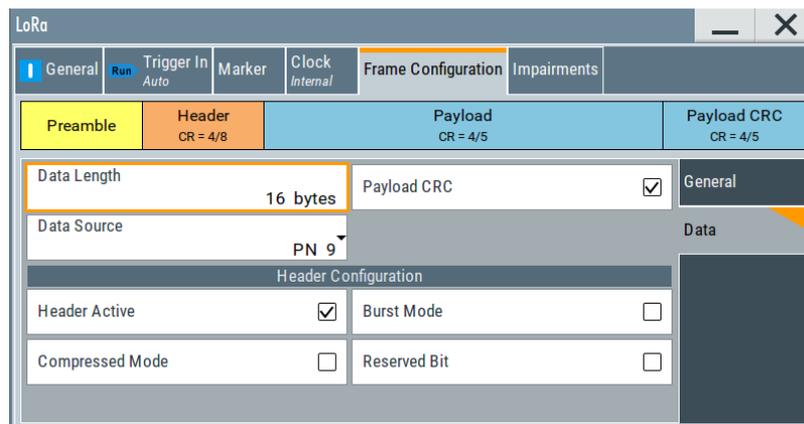
3. Under the Tab *General*, set the desired bandwidth for the LoRa signal, here 500 kHz:



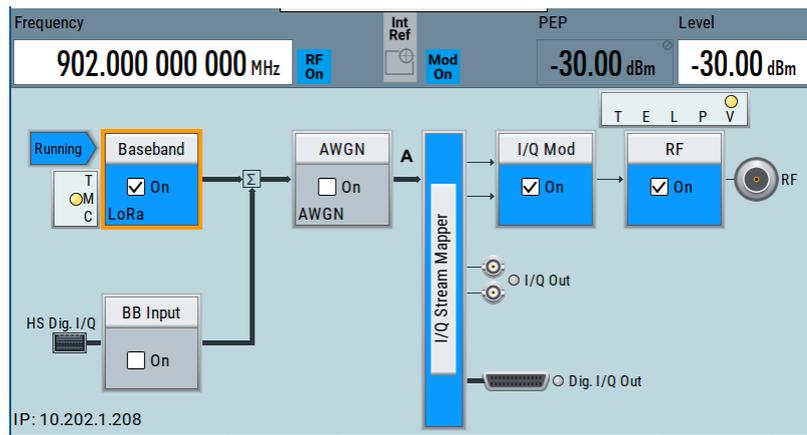
- Under the tab *Frame Configuration General* set the desired values for *Coding Rate* and *Spreading Factor*.



- Under the tab *Frame Configuration Data*, set the *Payload Data Length* and under *Data Source* select suitable *Payload data*:



- Using the *FREQ* and *LEVEL* keys, set the desired frequency and level values. Switch on the test signal using the *RF On/Off* and *Mod On/Off* key:



Settings on DUT:

7. Using the LoRa test tool, configure the receiver for reception of the test signal.
8. 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 2-24 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.

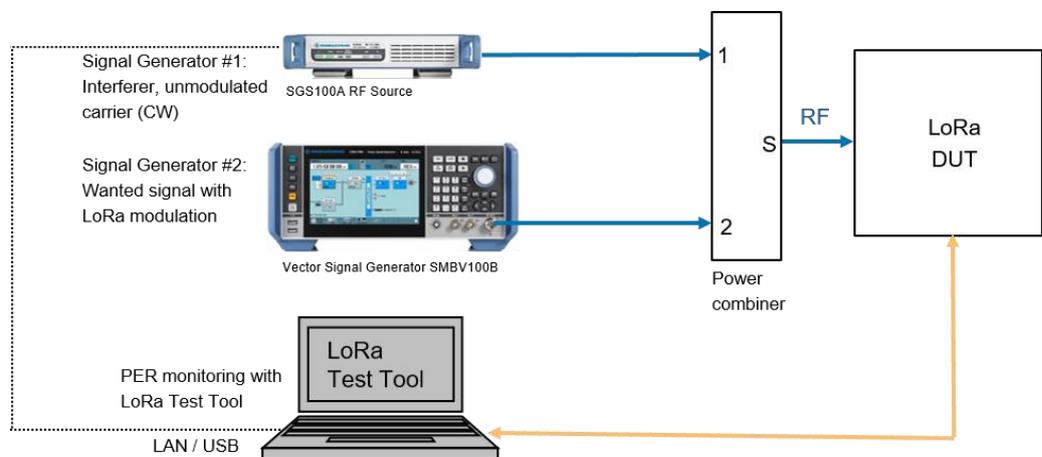


Figure 2-24: Blocking measurement at a LoRa receiver

Adjacent channel blocking:

Settings on SMBV100B and DUT:

1. As described under [2.2.1](#), points 1 to 7.

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 4.
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 8.

Settings on SMBV100B:

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 8.

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 4.
8. Repeat steps 4 to 6.

On-channel blocking:

Settings on SMBV100B and DUT:

9. As described under [2.2.1](#), points 1 to 7.

Settings on SGS100A:

10. Frequency = wanted signal frequency set under [2.2.1](#), point 4
11. Set the level such that it is 20 dB above the receiver sensitivity value determined under [2.2.1](#), point 8.

Settings on SMBV100B:

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 8.

3 Production Line Testing

The CMW100 is the instrument of choice for production line testing. The features that set the CMW100 apart from any other instrument in the market are the reduced test time, measurement accuracy and the capability of performing test on 8 devices in parallel. With the activated CMW100 option R&S®CMW-KW683, all eight ports can transmit LoRa signals for testing the LoRa DUTs. CMW-KW683 comes with one LoRa waveform file with 125 kHz bandwidth as an example. Further LoRa waveforms with different parameters can be created with the free simulation software WinIQSIM2 (see chapter 3.2 [Creating LoRa Waveforms with WinIQSIM2](#)).

R&S® Forum is a free scripting tool for remote control of Rohde & Schwarz instruments. It allows users to create script sequences, as well as interactive remote control of instruments. For automated tests via remote control R&S® Forum can be used ([Figure 3-1](#), [Figure 3-2](#)). R&S® Forum is a free scripting tool for remote control of Rohde & Schwarz instruments. It allows users to create script sequences, as well as interactive remote control of instruments. Script files can range from simple command sequences to complex programs using the popular Python programming language

3.1 LoRa RX Test with CMW100

3.1.1 RX Sensitivity

For the RX sensitivity test, the CMW100 generates a LoRa test signal by using LoRa ARB waveform files with different parameters like signal bandwidth and spreading factor (requires option CMW-KW683). The generated signal is fed to the receiver in the appropriate frequency range ([Figure 3-1](#)). 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.

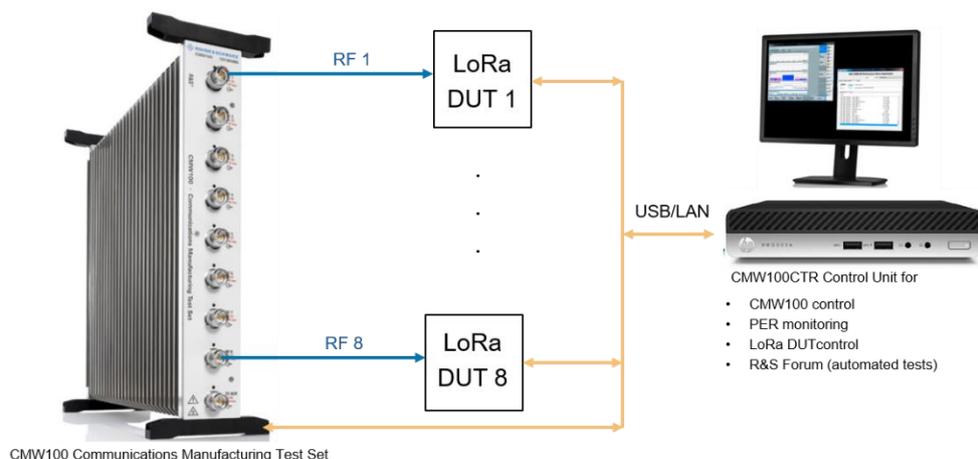
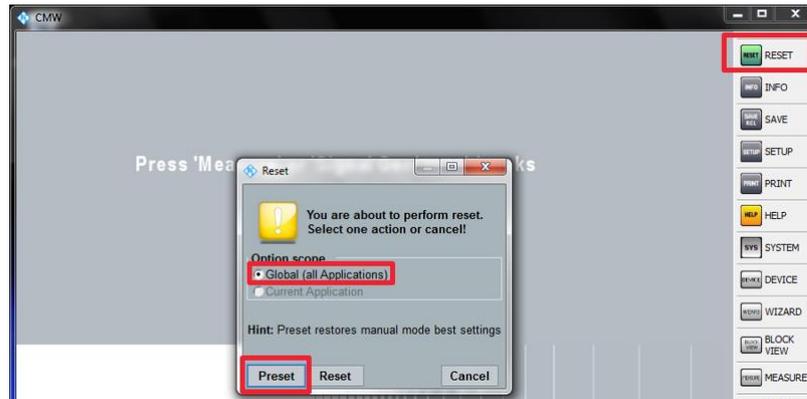


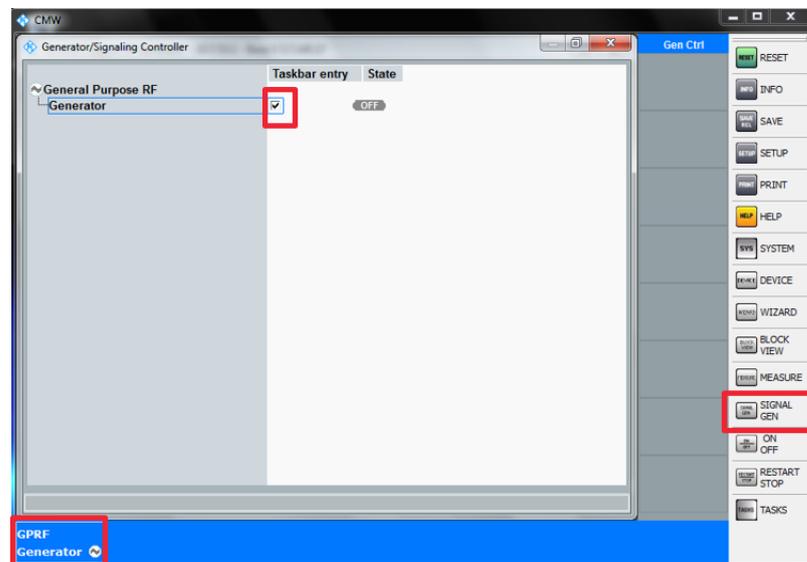
Figure 3-1: Test setup for RX sensitivity measurement with CMW100

Settings on CMW100:

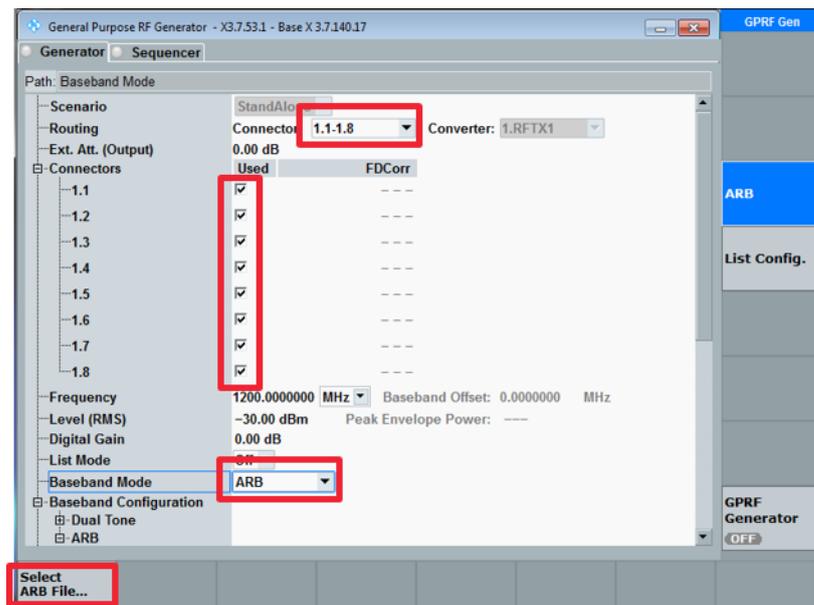
1. Start the CMW100 Firmware on the PC and press the *RESET* key from the right toolbar key. Select *Global (all Applications)* and press *Preset*:



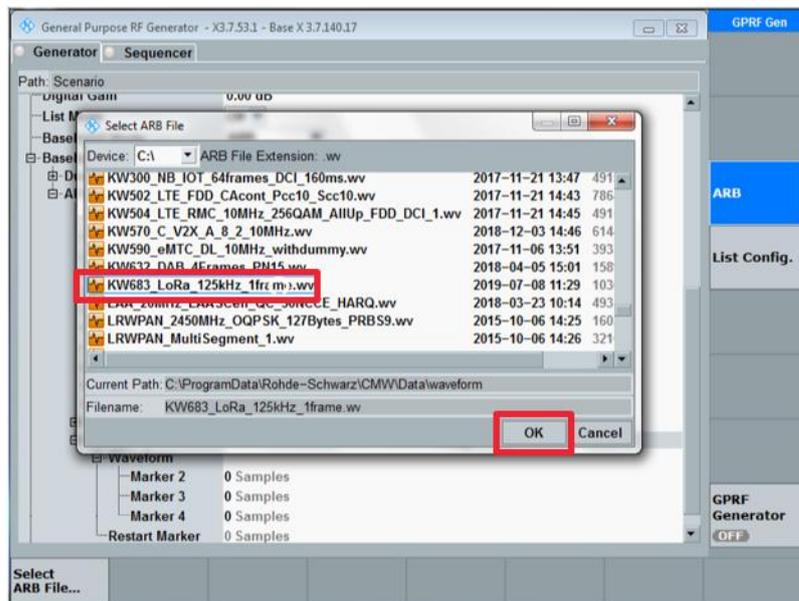
2. In order to activate the signal generator press the *SIGNAL GEN* key from the right toolbar and mark the generator taskbar entry. Press the *GPRF Generator* key from the button toolbar.



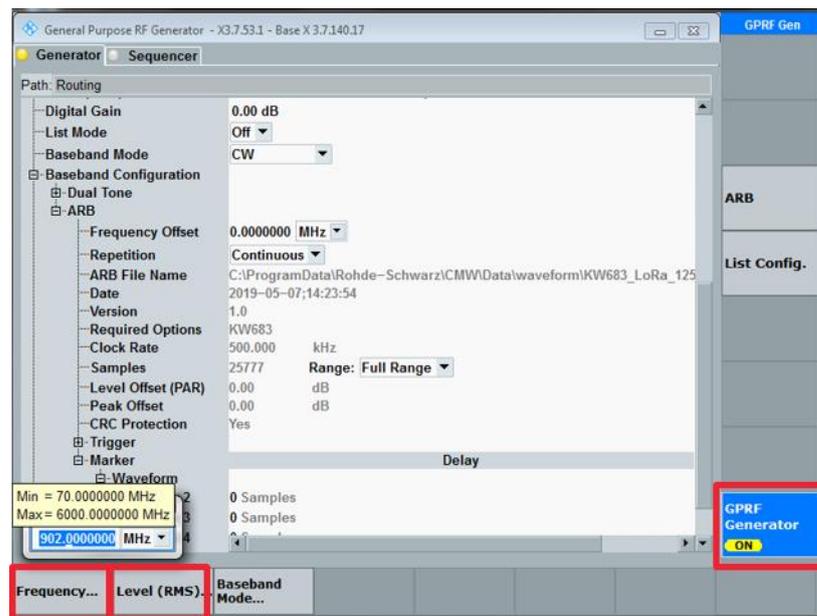
3. Select the RF connectors on which the LORA signal should be output. Set the baseband Mode to *ARB* and press the key *Select ARB file...* from the bottom toolbar:



- Choose the LoRa waveform file to use for the RX sensitivity test:



- Using the *FREQ* and *LEVEL* keys on the bottom toolbar, set the desired frequency and level values. Switch on the test signal using the GPRF Generator button from the right toolbar:



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.

3.1.2 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 3-2](#) 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 (CMW100) supplies the LoRa wanted signal, which is generated as described under [3.1.1](#). The PER value is measured using the LoRa test tool.

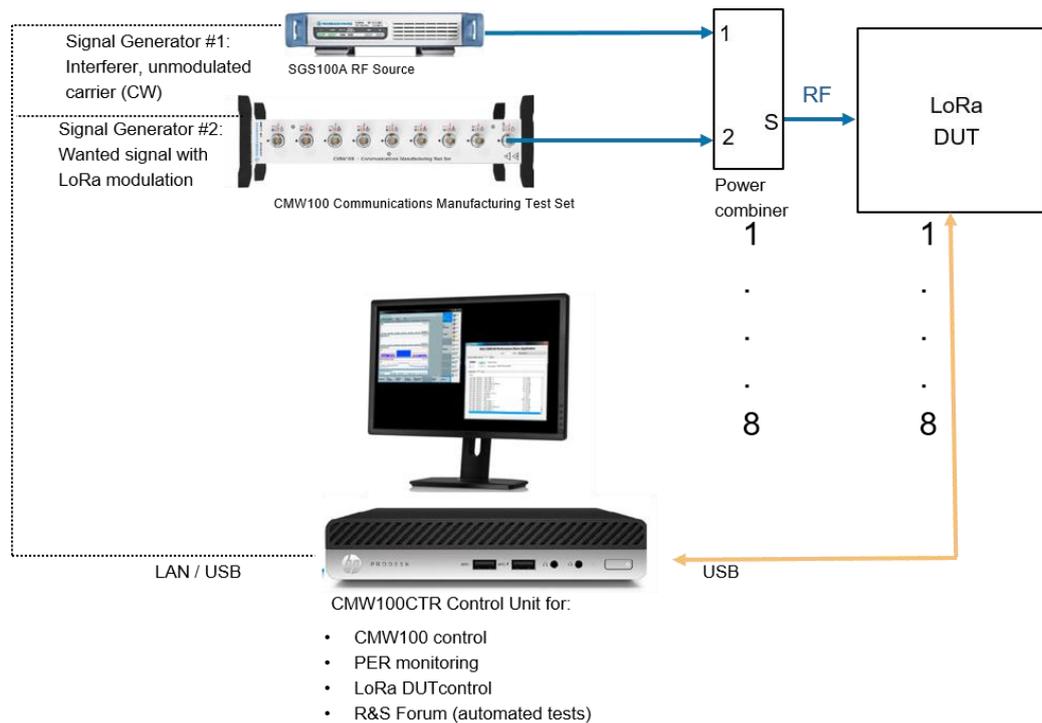


Figure 3-2: Blocking measurement at a LoRa receiver with CMW100

Adjacent channel blocking:

Settings on CMW100 and DUT:

1. As described under 3.1.1, 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 3.1.1, point 5.
4. Set the level such that it is 82 dB (uplink) or 78 dB (downlink) above the receiver sensitivity value determined under 3.1.1, point 7.

Settings on CMW100:

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 3.1.1, 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 CMW and DUT:

- As described under 2.2.1, points 1 to 6.

Settings on SGS100A:

- Frequency = wanted signal frequency set under 2.2.1, point 5.
- Set the level such that it is 20 dB above the receiver sensitivity value determined under 2.2.1, point 7.

Settings on CMW100:

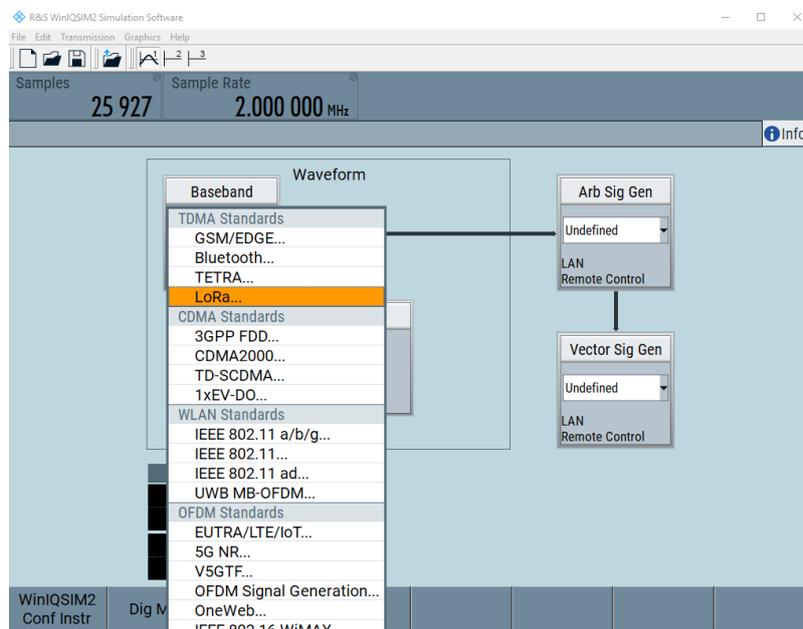
- Increase the wanted signal level until PER < 1% is reached.
- The following condition must be fulfilled: The wanted signal level now set must not be more than 3 dB above the receiver sensitivity value determined in 2.2.1, point 7.

3.2 Creating LoRa Waveforms with WinIQSIM2

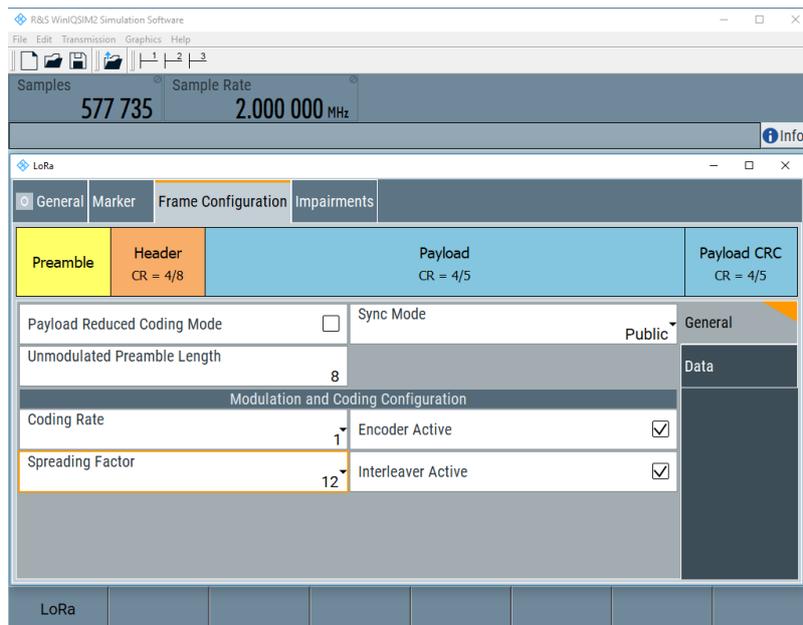
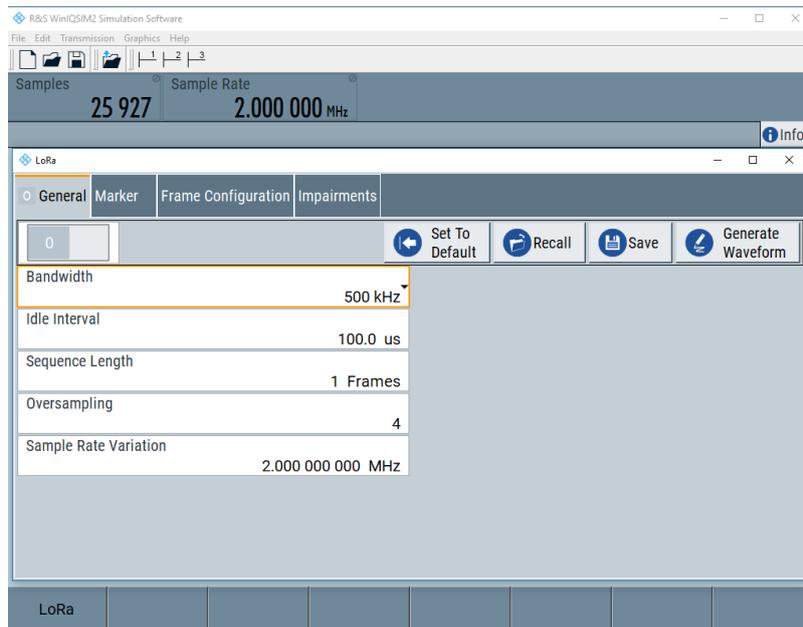
WinIQSIM2 was especially developed to easily generate digitally modulated signals on a PC. The graphical user interface allows intuitive operation by offering a convenient way to create standard-conforming waveforms for many configurable digital standards. WinIQSIM2 is a freeware and can be downloaded from the R&S website.

In order to create new LoRa waveforms for the TX test follow the steps below:

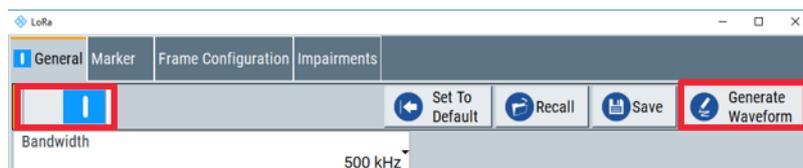
- In WinIQSim2 select *LoRa..* in the *Baseband* menu:



- Configure the LoRa waveform parameters like bandwidth, number of frames, coding rate, spreading factor etc. for your needs:



3. After all parameters are adjusted start the calculation of the LoRa waveform by using the on / off switch. Press *Generate Waveform* and store the new LoRa waveform on the CMW100 control PC in "C:\ProgramData\Rohde-Schwarz\CMW\Data\waveform\"



4. The new waveform is now ready for use together with the CMW100 as described under 3.1.1, points 1 to 6.

3.3 Example for Automation Scripts

The automation script introduced in this section is written in Python programming language for use with the Forum development environment. Forum is a freeware and can be downloaded from the R&S website. For detailed information, please see the Application Note [1MA196 R&S® Application for Remote Control of Rohde & Schwarz Instruments](#). Fig. 3-1 shows the Forum screen for the LoRa application.

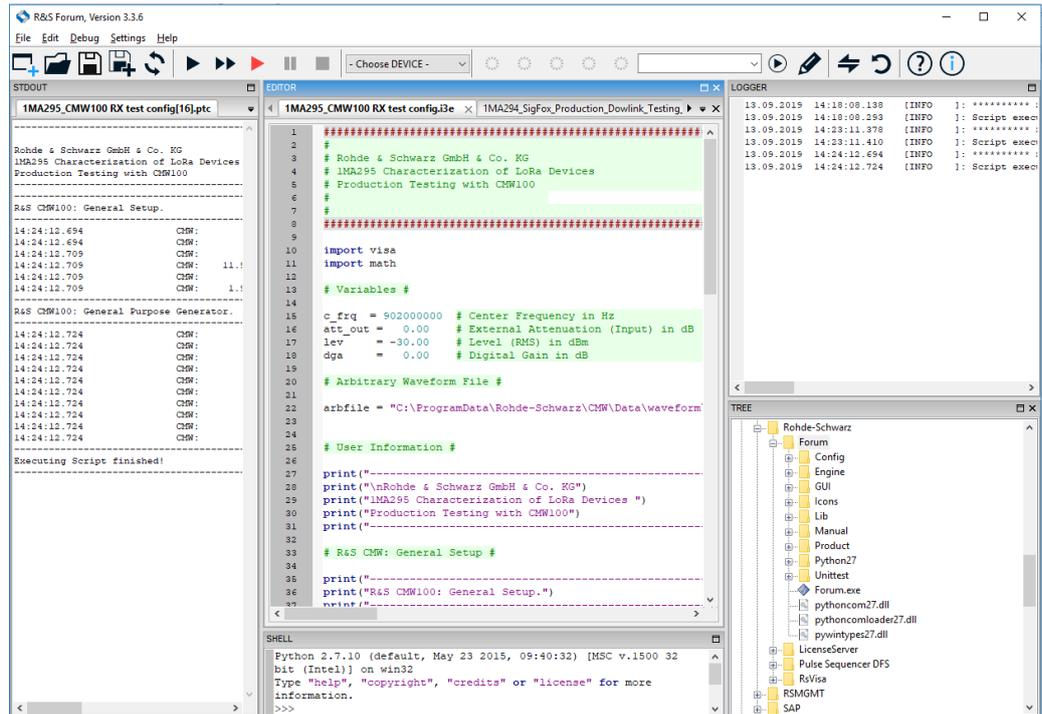


Fig. 3-1: Screenshot of the Forum application for instrument remote control

The T&M instruments and the LoRa device under test can both be directly controlled from this platform.

When FORUM is started for the first time, the T&M instruments need to be connected:

In Forum, select Settings > Instruments > Add
 Configure the T&M instruments as shown in Fig. 3-2

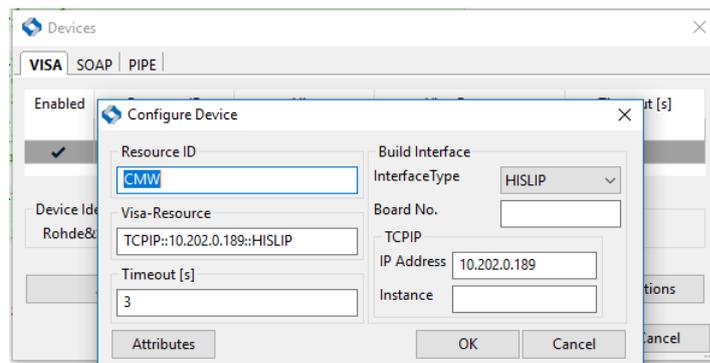


Fig. 3-2: Instrument connection configuration on FORUM

Setup parameters can be easily changed in the program. After the next restart, the changes are accounted. The automatic run can be halted at any time and some additional tests then can be done by operating the instrument manually. DUT control commands can also be directly issued from Forum in an interactive way, so that the automatic run can be optimized step-by-step.

Python, the programming language behind Forum, offers various features beyond instrument and DUT control. Text output files can be created and written to generate complete test reports.

As an example the forum script "1MA295_CMW100 RX test config" automates and configures CMW100 in the general-purpose generator mode, selects the ARB file from the destination folder and switches on the RF.

The option R&S®CMW-KW683 needs to be installed on the CONTROL-PC.

The example waveform file "KW683_LoRa_125kHz_1frame.wv" is located in "C:\ProgramData\Rohde-Schwarz\CMW\Data\waveform\" Fig. 3-3 shows a part of the FORUM automation script for configuring the CMW100.

```

19
20 # Arbitrary Waveform File #
21
22 arbfile = "C:\ProgramData\Rohde-Schwarz\CMW\Data\waveform\KW683_LoRa_125kHz_1frame.wv"
23
24
25 # User Information #
26
27 print("-----")
28 print("\nRohde & Schwarz GmbH & Co. KG")
29 print("1MA295 Characterization of LoRa Devices ")
30 print("Production Testing with CMW100")
31 print("-----")
32
33 # R&S CMW: General Setup #
34
35 print("-----")
36 print("R&S CMW100: General Setup.")
37 print("-----")
38
39 CMW.write("*RST") # Reset Device.
40 CMW.write("*CLS") # Clear Status.
41 CMW.ask("*OPT?") # Option Query.
42 CMW.ask("*IDN?") # Query ID String.
43
44 # R&S CMW: General Purpose Generator #
45
46 print("-----")
47 print("R&S CMW100: General Purpose Generator.")
48 print("-----")
49
50 # Select Connectors and Signal Paths:
51 CMW.write("ROUT:GPRF:GEN:SCEN:SAL R118, TX11")
52
53 # Activate/Deactivates RF Connectors:
54 CMW.write("CONF:GPRF:GEN:CMWS:USAG:TX:ALL R118, ON, ON, ON, OFF, OFF, OFF, OFF, OFF")
55
56 CMW.write("SOUR:GPRF:GEN:RFS:EATT " + str(att_out)) # Define External Attenuation.
57 CMW.write("SOUR:GPRF:GEN:RFS:FREQ " + str(c_freq)) # Define Center Frequency.
58 CMW.write("SOUR:GPRF:GEN:RFS:LEV " + str(lev)) # Define Base RMS Level.
59 CMW.write("SOUR:GPRF:GEN:RFS:DGA " + str(dga)) # Define Digital Gain.
60
61 CMW.write("SOUR:GPRF:GEN:BBM ARB") # Set Baseband Mode to ARB.
62 CMW.write("SOUR:GPRF:GEN:ARB:REP CONT") # Set Reputation to Continuous.
63 CMW.write("SOUR:GPRF:GEN:ARB:FILE " + str(arbfile) + ".wv") # Select ARB File.
64 CMW.write("SOUR:GPRF:GEN:STAT ON") # Turn ON the Generator.
65

```

Fig. 3-3: Forum configuration of CMW100 for general-purpose generator mode

Line 63 loads the ARB file, which is defined in line 22 from the destination waveform library folder. Lines 39 to 42 initializes the CMW100 and lines 51 to 64 configures the instrument in the general purpose RF generator mode, sets the frequency, power level and switches ON the RF signal transmission.

4 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 4-1](#).

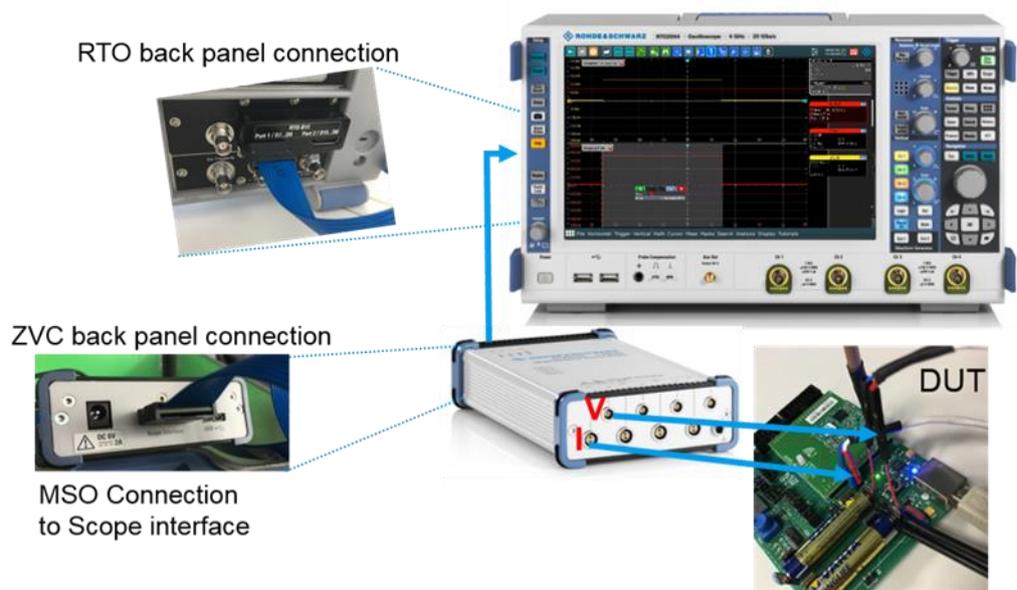


Figure 4-1: Test setup for power consumption measurement on LORA devices

2. Next select *Horizontal* -> *Setup* and Configure as shown in [Figure 4-2](#)

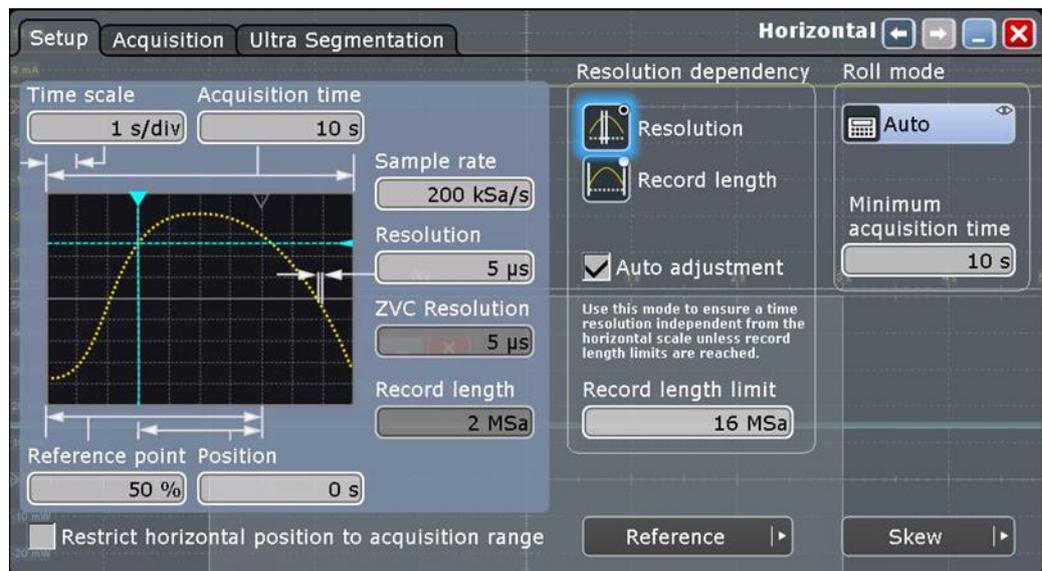


Figure 4-2: Data Acquisition Setup on the RTO

3. Next select *Vertical* -> *ZVC Multi-Channel Probe*
4. Configure as shown in [Figure 4-3](#)

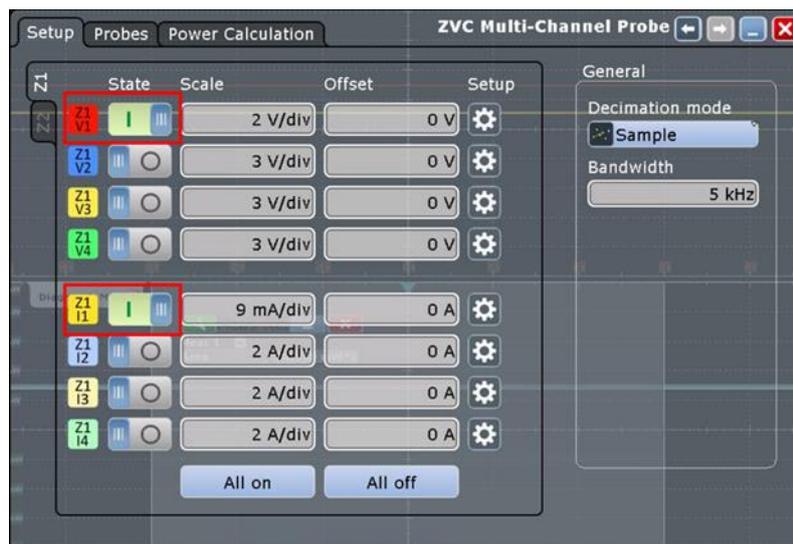


Figure 4-3: ZVC measurement configuration on the RTO

5. Next Select click on setting button  for Z111

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 4-4](#)).

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 $450\text{mV} / 2.2\ \Omega = 205\ \text{mA}$. For the sake of simplicity, this application note uses the internal shunt with 4.5 A current range.

- The maximum current consumption of the DUT appears to be $\sim 150\ \text{mA}$, which means that the 4.5A current range has to be chosen. Configure ZVC Current Settings as shown in [Figure 4-4](#)

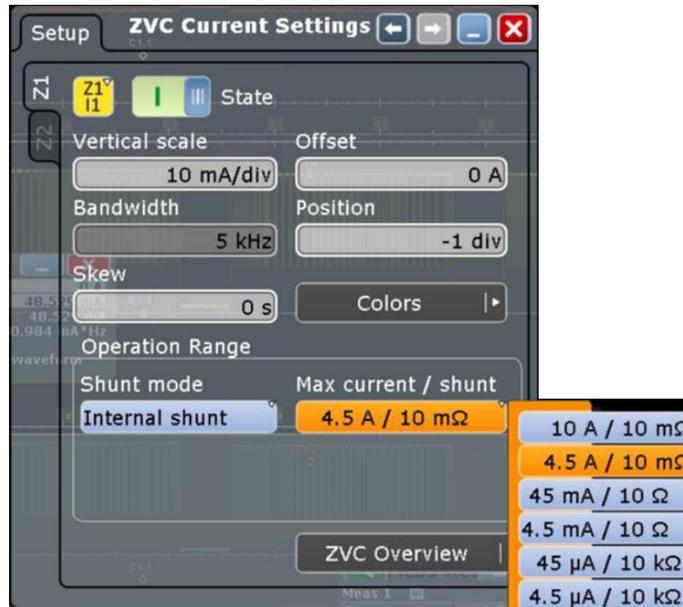


Figure 4-4: Current Measurement configuration on the RTO

- Click on *Math* -> *Math Setup*
- Configure the two sources and operator as shown in [Figure 4-5](#).

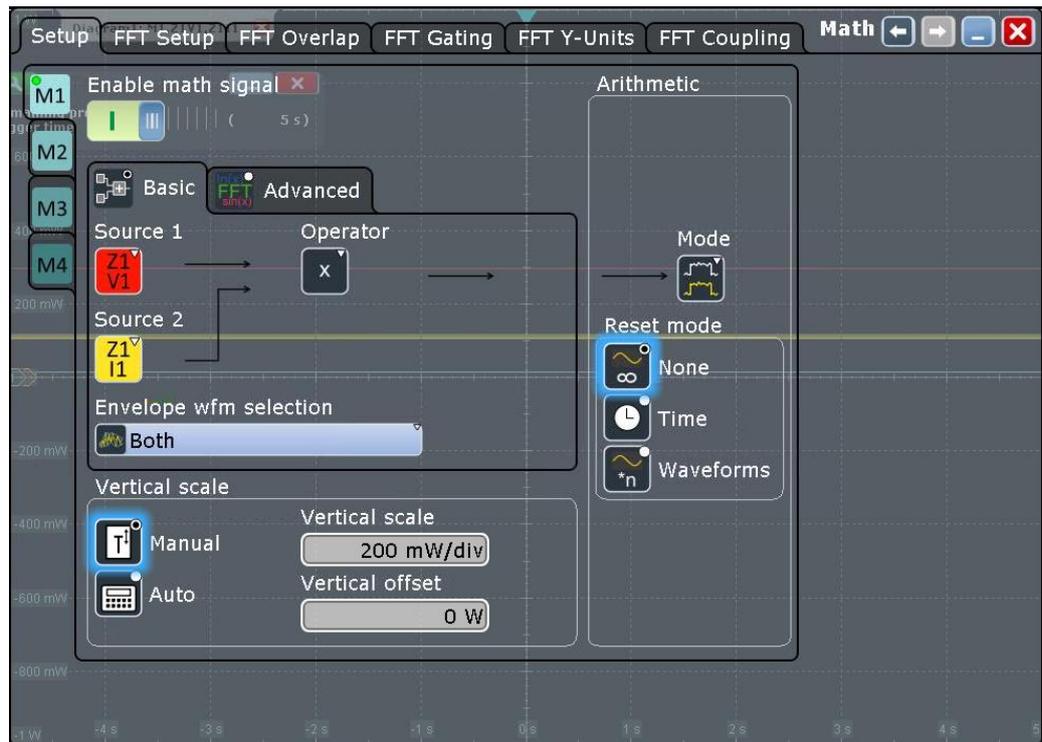


Figure 4-5: Math function configuration for power measurement on the RTO

9. Next select Measurements -> Setup

10. Configure the *Measurement Area* as shown in Figure 4-6

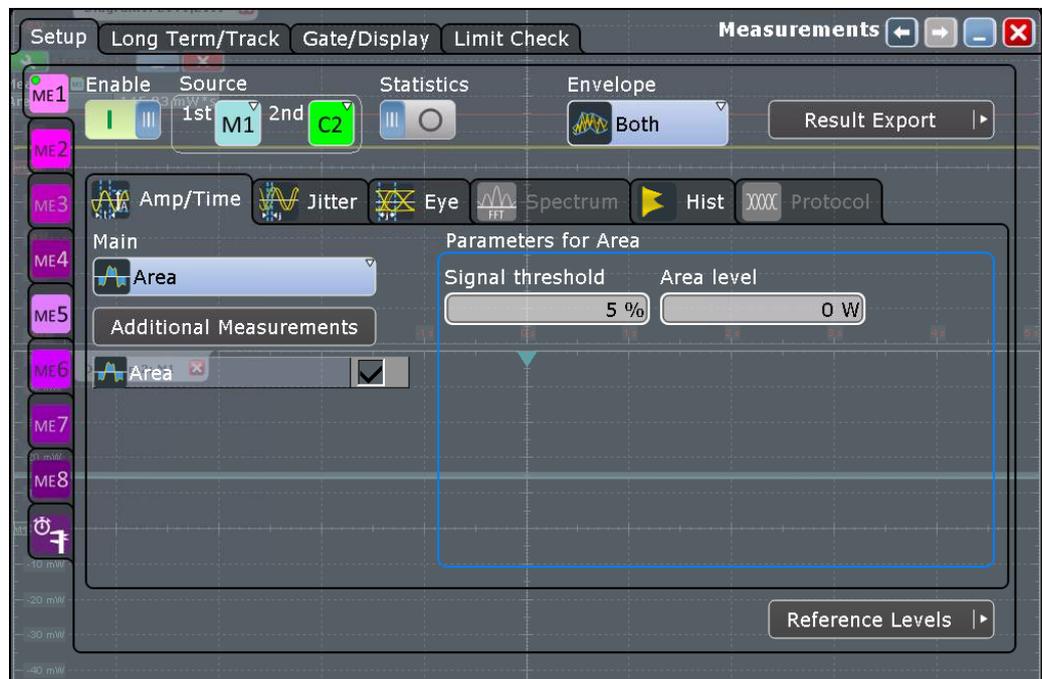


Figure 4-6: Measurement Area settings

Figure 4-7 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.

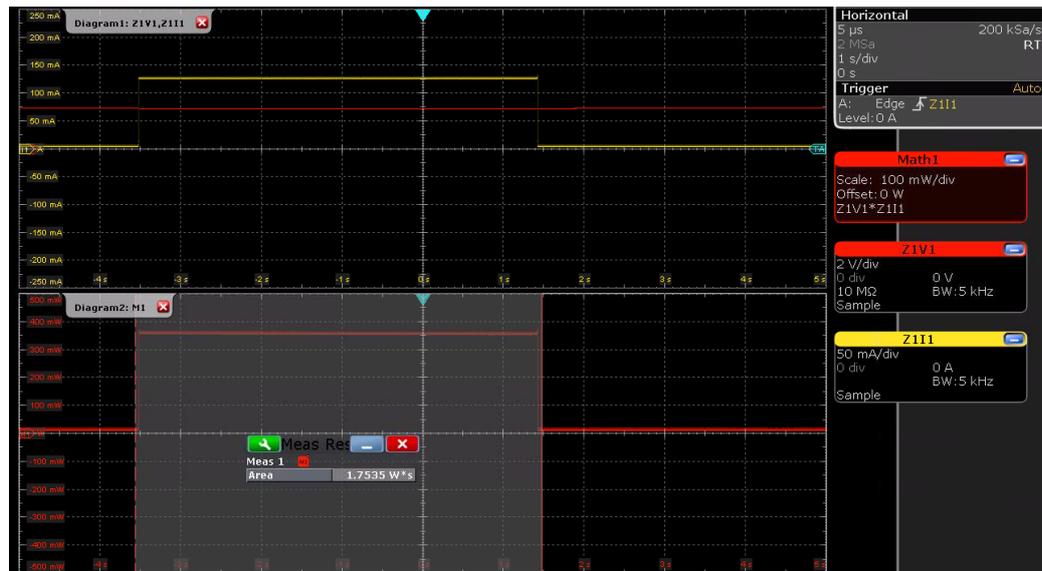


Figure 4-7: Power consumption measurement results on the RTO

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 4-8, Start: -3 s & Stop: + 3s.

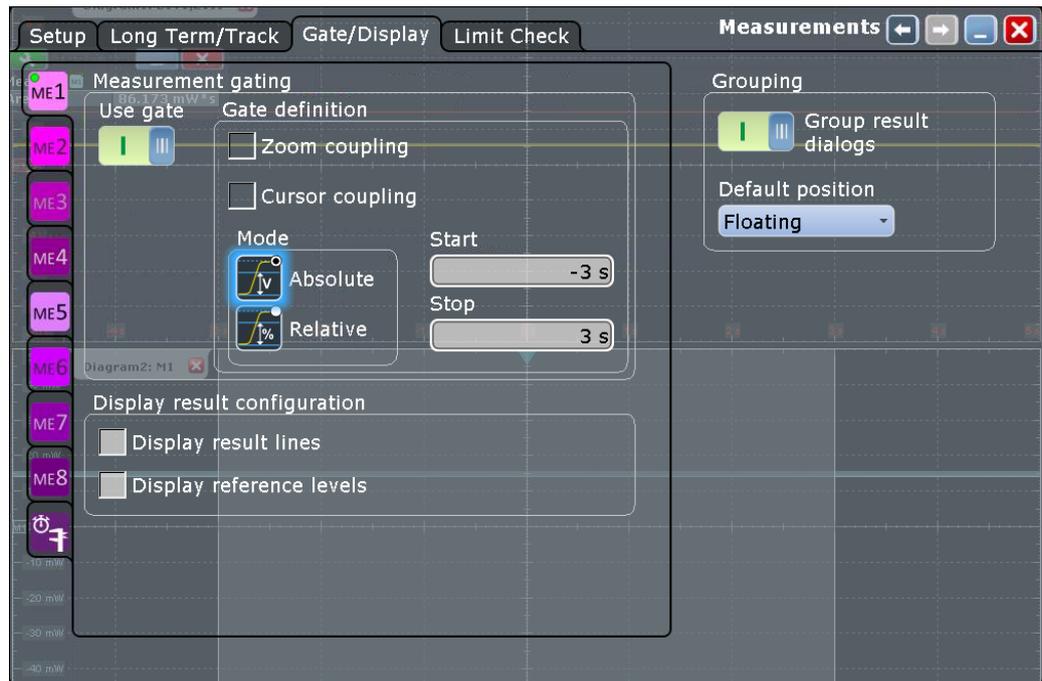


Figure 4-8: Settings for the gated area measurement

5 References

- [1] **Federal Communications Commission. 2017.** *Part 15.247 of the Electronic Code of Federal Regulations.* 2017.
- [2] **IEEE. 2013.** *American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices.* 2013. ANSI C63.10-2013.
- [3] **LoRa Alliance. 2017.** *LoRaWAN 1.1 Regional Parameters.* 2017.
- [4] **—.** **2017.** *LoRaWan 1.1 Specification.* 2017.
- [5] **SEMTECH. 2015.** *AN1200.22 LoRa Modulation Basics.* 2015.
- [6] **—.** **2015.** *AN1200.26 LoRa and FCC Part 15.247 Measurement Guidance.* 2015.
- [7] **Technical Marketing Workgroup 1.0. 2015.** *LoRaWan What is it?* 2015.

6 Ordering Information

Spectrum analyzer		
Designation	Type	Order No.
Spectrum Analyzer 5 kHz to 3 GHz ¹⁾	R&S®FPL1003	1304.0004.03

Signal generators		
Designation	Type	Order No.
Vector Signal Generator including baseband generator with ARB (64 Msamples, 120MHz RF bandwidth) ¹⁾	R&S®SMBV100B	1423.1003.02
8 kHz to 3 GHz	R&S®SMBVB-B103	1423.6270.02
Baseband Realtime Extension	R&S®SMBVB-K520	1423.7676.02
LoRa	R&S®SMBVB-K131	1423.8720.02
SGMA RF Source ¹⁾	R&S®SGS100A	1416.0505.02
1 MHz to 6 GHz, CW (no modulation)	R&S®SGS-B106	1416.2308.02
Electronic Step Attenuator	R&S®SGS-B26	1416.1353.02

Digital oscilloscope		
Designation	Type	Order No.
Digital oscilloscope 600MHz, 2 channels, 10 Gsamples/s, 50/100 Msample ¹⁾	R&S®RTO2002	1329.7002k02
Digital Extension Port for RT-ZVC Support	R&S®RTO-B1E	1333.0738.02
Multi channel power probe, 1 MHz, 5 MSa/s, 18 Bit, 2/4 current inputs, 2/4 voltage inputs	R&S®RT-ZVC04	1326.0259.04
Extended Cable Set, 1 current and 1 voltage lead, length: 1 m	R&S®RT-ZA35	1333.1905.02
Solder-in Cable set, 4 current and voltage solder-in cables, solder-in pins	R&S®RT-ZA36	1333.1911.02

1) Further equipment options can be found at www.rohde-schwarz.com or contact your local Rohde & Schwarz representative.

Communications Manufacturing Test Set		
Designation	Type	Order No.
Communications Manufacturing Test Set	R&S®CMW100	1201.0002K03
Control Unit for R&S®CMW100	R&S®CMW100CTR	1210.7935K03
Spectrum analyzer	R&S®CMW-KM010	1203.5953.02
Low Rate WAN (LoRa), enable WinIQSIM2 waveforms for ARB generator	R&S®CMW-KW683	1211.4081.02

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