

Characterization of Sigfox Devices from Lab to Production Line

Application Note

Products:

- R&S®FPL1000
- R&S®VSE
- R&S®SMBV100A
- R&S®Forum
- R&S®RTO2000
- R&S®RT-ZVC04
- R&S®CMW100
- R&S®CMW100CTR
- R&S®CMW-Z10

The application note guides developers and manufactures of Sigfox Devices to perform the required and recommended measurements with test solutions from Rohde & Schwarz. The note will help bring ultra-narrowband IoT devices and applications using Sigfox technology to the market as fast as possible and help ensure the desired quality and performance.

For R&D, Pre-certification and QA, all currently defined Uplink- and Downlink- measurements are shown using the compact R&S®FPL1000 Spectrum Analyzer and R&S®SMBV100A Vector Signal Generator.

For Production, use of the R&S®CMW100A Communications Manufacturing Test Set and R&S®CMW100CTR are shown for the most essential Uplink and Downlink RF tests on Sigfox Devices.

Python scripts for R&S®Forum giving example SCPI commands demonstrate how measurements shown in manual use can easily be automated.

Note:

Please find the most up-to-date document on our homepage
<http://www.rohde-schwarz.com/appnote/1MA294>

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

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1 Introduction

The technology Sigfox is developed, deployed and operated by the French company Sigfox, S.A. It is one of the most prominent low power wide area network (LP-WAN) technologies on the market. Sigfox is especially used and designed for all kinds of sensor networks requiring just tiny amounts of uplink data capacity thus enabling extremely low power consumption (long operation on batteries), and low device cost. Sigfox addresses a wide range of Internet of Things (IoT) applications from tracking of goods to measuring environmental conditions and securing things.

The application note guides developers and manufactures of Sigfox devices to perform the required and recommended measurements with test solutions from Rohde & Schwarz. This paper should help bring IoT hardware and consequently, applications using Sigfox technology faster to the market and with the desired quality and performance.

1.1 Sigfox Technology

Sigfox employs a radio access scheme that enables communication using one of the Industrial, Scientific and Medical (ISM) radio bands. In Europe, spectrum at 868 MHz is used for deployment, whereas 902 MHz is the band used in the USA.

Radio Configuration		Uplink Frequency	Bandwidth	max ERP	Downlink Frequency
		RC1	ETSI: Europe, Oman, South Africa, Iran, Mauritius	868.130 MHz	192 (± 96) kHz
RC2	FCC: North America, Brazil	902.200 MHz	192 (± 96) kHz	+22 dBm	905.200 MHz
RC3a	ARIB: Japan	923.200 MHz	36 (± 18) kHz	+ 14 dBm	922.200 MHz
RC4	FCC: Australia, New Zealand, Singapore, Taiwan, Argentina, Colombia, Hong Kong	920.800 MHz	192 (± 96) kHz	+22 dBm	922.300 MHz
RC5	South Korea	923.25 MHz	92 (± 46)kHz	+12 dBm	922.25 MHz

Table 1-1: Sigfox regional parameter set in the ISM band

Sigfox uses ultra-narrow band (UNB) technology. In RC1 configuration (applicable in Europe under ETSI regulation (Table 1-1), sub-carrier bandwidth of only 100 Hz are deployed over the entire 192 kHz wide spectrum and use D-BPSK modulation, whereas in North America and some other regions (FCC), sub-carrier bandwidth of 600 Hz is used.

Using ultra-narrow band RF technology together with frequency hopping makes Sigfox very resilient against interferers. It allows wide coverage despite the required use of

rather limited uplink output power levels of the sensor of just 12, 14 or 22 dBm ERP, a pre-condition for years of trouble-free operation from the same power source (i.e. small battery cell). Table 1-2 shows the different product classes based on radiated output

Radio Configuration	Uplink power classes			
	Class 0u	Class 1u	Class 2u	Class 3u
RC1	16dBm>EIRP≥12dBm	12dBm>EIRP≥7dBm	7dBm>EIRP≥2dBm	2dBm>EIRP
RC2	24dBm>EIRP≥20dBm	20dBm>EIRP≥15dBm	15dBm>EIRP≥10dBm	10dBm>EIRP
RC3a	16dBm>EIRP≥12dBm	12dBm>EIRP≥7dBm	7dBm>EIRP≥2dBm	2dBm>EIRP
RC4	24dBm>EIRP≥20dBm	20dBm>EIRP≥15dBm	15dBm>EIRP≥10dBm	10dBm>EIRP
RC5	14dBm>EIRP≥10dBm	10dBm>EIRP≥5dBm	5dBm>EIRP≥0dBm	0dBm>EIRP

power level.

Table 1-2: Sigfox Power Classes

Fig. 1-1 shows the flat network architecture with Sigfox access stations listening always on full channel bandwidth for incoming frames and forwarding all received frames to the back-end server.

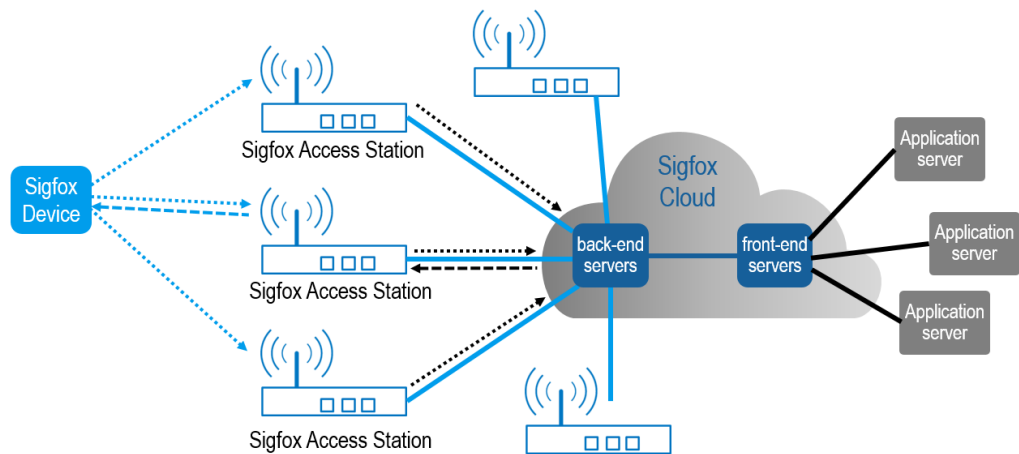


Fig. 1-1: Sigfox network architecture

All communication is initiated by the connected Sigfox device. Using a single message, the Sigfox device can transmit up to 12 Byte of user data. In order to improve the reliability of the communication, each message is transmitted three times (frame #1, #2, #3) on three different frequencies. The time between two uplink frames can be between 0 and 2 seconds in RC1. With a transmission rate of 100 bps with a 100 Hz bandwidth a single frame of 12 Byte user data takes around 2 seconds transmission time. Regulation in Europe (ETSI) allows 1% occupation of the band, which results in the limitation of up to 6 messages per hour or 140 messages per day.

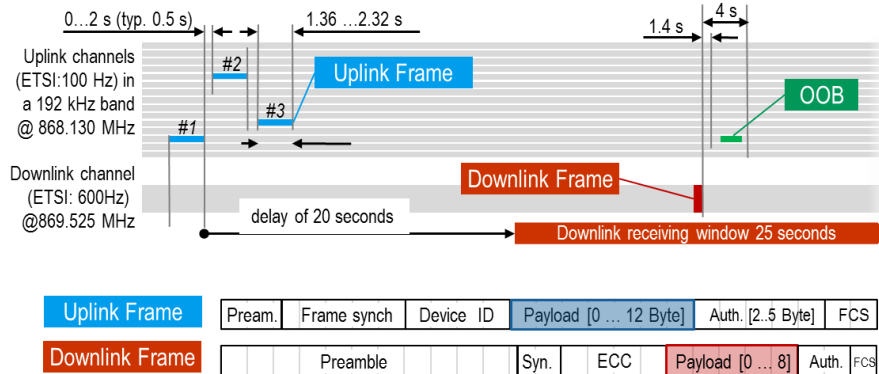


Fig. 1-2: Sigfox bi-directional communication principle

In general, a Sigfox device is not attached to any specific Sigfox access station. Messages are received by any access station that is able to receive the signal - typically 3 or more access stations should be able to receive the frames transmitted by a device. This allows spatial diversity that provides additional robustness in communication on top of the time and frequency diversity.

In order to support bi-directional communication e.g. to get an acknowledgement for sent messages, 20 seconds after the transmission of its first sent frame, the device opens a receiving window of maximum 25 seconds. For the downlink, the backend server selects one of the Sigfox access stations that have received the uplink frames based on the reported RSSI. A single frame carrying up to 8 Byte of user data is sent to the Sigfox device using a dedicated downlink channel with GFSK modulation and 600 bps data rate. The device can acknowledge this downlink frame with a so-called out-of-band frame (OOB). OOB frame can also be used as periodically sent status messages containing information about device temperature, battery voltage and Relative Received Signal Strength (RSSI).

1.2 Sigfox Certification

SIGFOX requires qualification tests in order to ensure compliance towards clearly defined minimum requirements. Each Sigfox device has to go through the Sigfox Ready™ *qualification* before connecting to the Sigfox network. This ensures that the device meets all RF- and Protocol- related specific requirements. Precondition to enter Sigfox ready qualification is the use of a Sigfox Verified™ chipset or module. If not, the new device may be qualified following both, Sigfox Verified™ and Ready™ requirements.

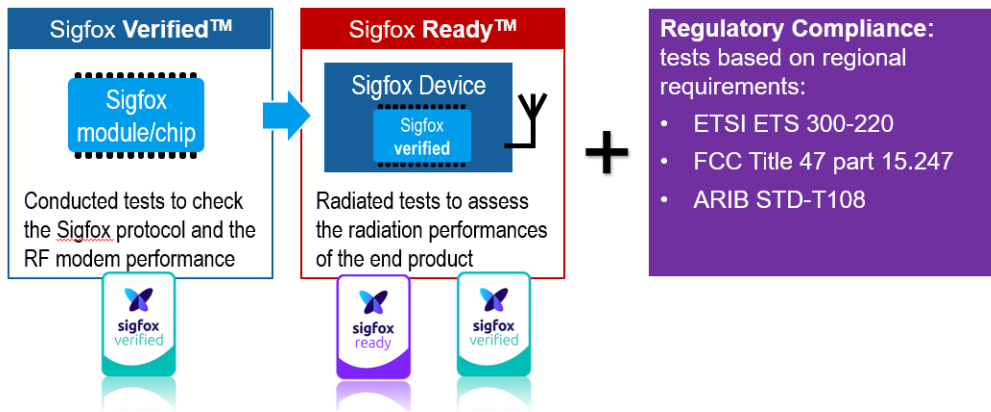


Fig. 1-3: Sigfox certification process

Sigfox will issue Sigfox Ready™ certification. Tests are typically performed by specialized test houses. Sigfox certification does not include regulatory compliance tests as required for devices operating in ISM bands like ETSI ETS 300-220, FCC Title 47 part 15.247, ARIB STD-T108, and other applicable national or regional standards.

Tests required for Sigfox Verified™ and Sigfox Ready™ qualification are available for the different regional Radio Configurations on the Sigfox [developer page](#).

Sigfox Verified™ tests include multiple conducted RF related tests like carrier frequency accuracy/stability, TX Modulation quality, TX phase shift error, TX spectrum occupancy, RX sensitivity, conducted TX power.

The Sigfox Ready™ specification focusses on radiated tests for Sigfox devices and include EIRP measurements, 2D or 3D radiation pattern measurement in a continuous wave mode, i.e. w/o Sigfox modulation.

1.3 Test Recommendations

In order to characterize chips, modules and devices before starting the certification process, Rohde & Schwarz recommends running a number of RF tests related to the Sigfox qualification test documents. These tests should help to ensure the desired quality, performance and compliance to applicable regulatory as well as the Sigfox requirements. In this document, we will focus on RF and longevity tests; transmitter (power, spectrum, frequency drift), receiver (receiver sensitivity) and power consumption tests.

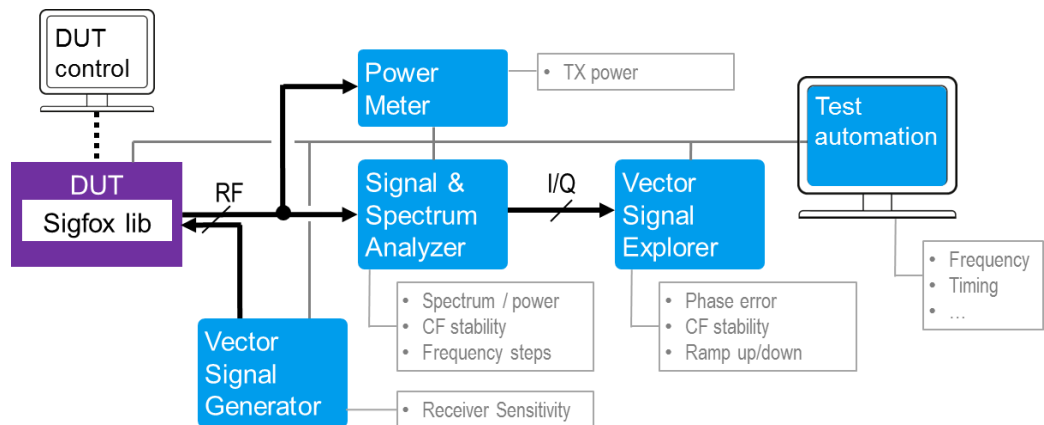


Fig. 1-4: Principle test setup for Sigfox RF testing

Abbreviations

The following abbreviations are used in this application note for Rohde & Schwarz products:

- The R&S®SMBV100A vector signal generator is referred to as SMBV
- The R&S®FSV signal and spectrum analyzer is referred to as FSV
- The R&S®FPL1000 spectrum analyzer is referred to as FPL
- The R&S®VSE vector signal explorer software is referred to as VSE
- The R&S®CMW100 communication manufacturing test set is referred to as CMW100
- The R&S®CMW100CTR control unit for CMW100 is referred to as CONTROL-PC
- The R&S®Forum Application for instrument remote control is referred to as FORUM
- The R&S®RTO2000 digital oscilloscope is referred to as RTO
- The R&S®RT-ZVC04 multi-channel power probe is referred to as ZVC

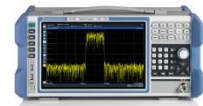
Sigfox Verified™ and Sigfox Ready™ are registered Trademark of Sigfox S.A.

R&S® is a registered Trademark of Rohde & Schwarz GmbH & Co KG

2 Product Introduction

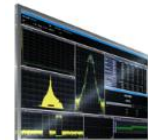
R&S®FPL1000

A versatile **spectrum analyzers** with solid RF performance, lightweight and small footprint. It combines the functionality of a benchtop instrument with the portability of a handheld instrument.



R&S®VSE

The **vector signal explorer** software brings the experience and power of Rohde & Schwarz signal analysis to the desktop, offering a wide range of analysis tools for troubleshooting and optimizing designs



R&S®SMBV

The **vector signal generator** offers excellent RF performance along with very high output level and short setting times. At the same time, it can be equipped with an internal baseband generator



R&S®CMW100

The R&S®CMW100 **communications manufacturing test set** is a new trendsetting product for calibrating and verifying IoT devices. It is capable of performing parallel testing on up to 8 devices.



R&S®CMW-Z10

The **RF shield box** offers excellent shielding effectiveness and superior coupling characteristics for frequencies up to 6 GHz.



R&S®Forum

A **free scripting tool** for remote control of Rohde & Schwarz instruments which allows users to run and edit example script sequences and to write their own script files, as well as on-the-fly remote control of instruments.



R&S®RT-ZVC

Power consumption is a major concern in the Internet of Things (IoT) world as well as all kind of customer electronics devices. The **multi-channel power probe** offers up to four voltage and four current channels with 18-Bit resolution for high-dynamic current and voltage measurements.



R&S®RTO2000

The **digital oscilloscopes** combine excellent signal fidelity, up to 16-bit vertical resolution and high acquisition rate in a compact device format in the 600 MHz to 6 GHz class. They offer a fully integrated multi-domain test solution with frequency, protocol and logic analysis functions. The brilliant touchscreen makes the oscilloscopes very comfortable to use.



3 RF Measurements

3.1 RF Test Requirements

The Sigfox network is usually working on uplink communication. The downlink is an optional feature. The device sends a message to the base stations, which then issues a message into the cloud, which is then forwarded to the user. However, using a spectrum analyzer, a basic functional test of devices can be performed without using the Sigfox network. In the R&D and production line testing phase, the measurements described in this section are highly recommended.

3.2 Measurement Setup Recommended for R&D Lab

The spectrum analyzer FPL is best suited for this purpose. The FPL can be used with its standard bandwidth of 10 MHz. For over the air tests a shielded box is recommended in addition to the FPL. By using the shielded box, spurious electromagnetic radiation from the environment can be prevented. The Sigfox base station and the cloud network are replaced by FPL with an antenna to receive and demodulate the Sigfox signal. The end-user-device is equipped with a small transmit antenna, which can be provisional. With more than 10 dBm, the end-user-device provides sufficient power to perform tests on FPL even for badly matched antennas.

Fig. 2-1 shows the test setup for conducted testing.



Fig. 3-1: Sigfox uplink testing (spectrum)

3.3 Measurement on Sigfox User Equipment

By triggering Sigfox devices periodically, a spectrum measurement can be performed manually on FPL. The result is shown in Fig. 3-2. For each transmit trigger, three frames are sent from the device. For spectrum measurements, it is also possible to use the test-mode of the DUT, which allows, for example, to periodically send test frames on a dedicated channel; the related Sigfox library provides this kind of test modes.

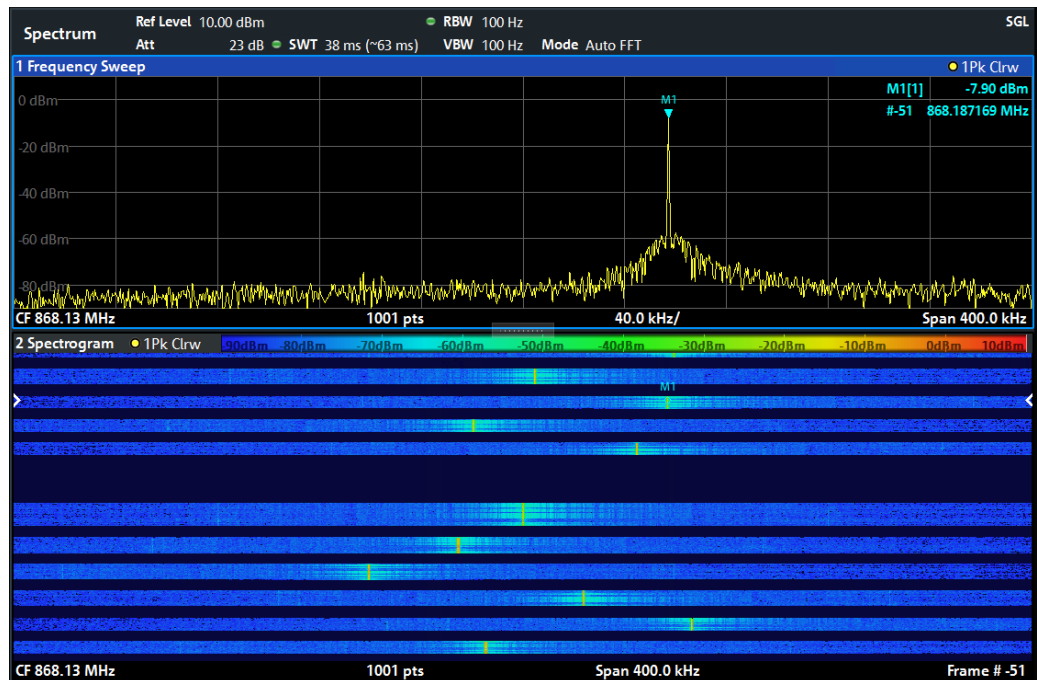


Fig. 3-2: FPL spectrum and spectrogram view

The spectrogram in the lower part of Fig. 3-2 provides information of frequency, time and power spectrum. The relative frequencies are related to the frequency span currently set for the sweep, currently 868.13 MHz at the center frequency and 400 KHz as span. Using the horizontal position and the marker reading, the transmit frequency for each package can be determined. The vertical position of each block provides information about the time relations of transmitted Sigfox frames.

In the spectrogram, the hopping frames and radiated power of each transmitted package can be easily identified by the color variations. The color bar in the center of Fig. 3-2 provides the reference values. The left and right border of the packet blocks are blue. The colors provide the information, that the transmitted power is less than -70 dBm according to the reference bar at the top. The yellow area, for example, represents transmitted power in the range from about -20 dBm and -10 dBm. The center area of the packet blocks in Fig. 3-2 is also yellow; accordingly, the transmitted power in this frequency area is something in between -15 dBm and -10 dBm.

The Sigfox modem is triggered for each test. For manual measurements, freely available terminal emulators like TeraTerm or PUTTY can be used. Each time the send command is issued from the terminal emulator the modem transmits one message frame comprising of three packages. However, it is more convenient to perform the trigger in an automatic way as outlined in the upcoming chapters.

3.3.1 Carrier Frequency

The Sigfox device must respect the operational central frequency of Sigfox network as defined in Table 1-1 .

The test setup as depicted in Fig. 3-1 should be used and the DUT is set to transmit unmodulated continuous wave at 868.13 MHz for example (ETSI)

For the spectrum analyzer FPL the following setting should apply:

- | Center Frequency: 868.13 MHz (868130000 Hz)
- | Span: 10 kHz
- | Trace ⇒ Trace Mode ⇒ Max Hold
- | Marker (M1) ⇒ MKR ⇒ Peak

Fig. 3-3 shows the spectrum plot of CW signal transmitted from the DUT at 868.13 MHz. The marker M1 shows the measured frequency of 868.130360 MHz. The received power level is -4.68 dBm since this is an over-the-air (OTA) measurement and not a conducted measurement. The DUT used in this AN does not come with an SMA connector equipped antenna port. Therefore, the difference between transmit and received power level is a combination of the free space loss and antenna coupling loss.

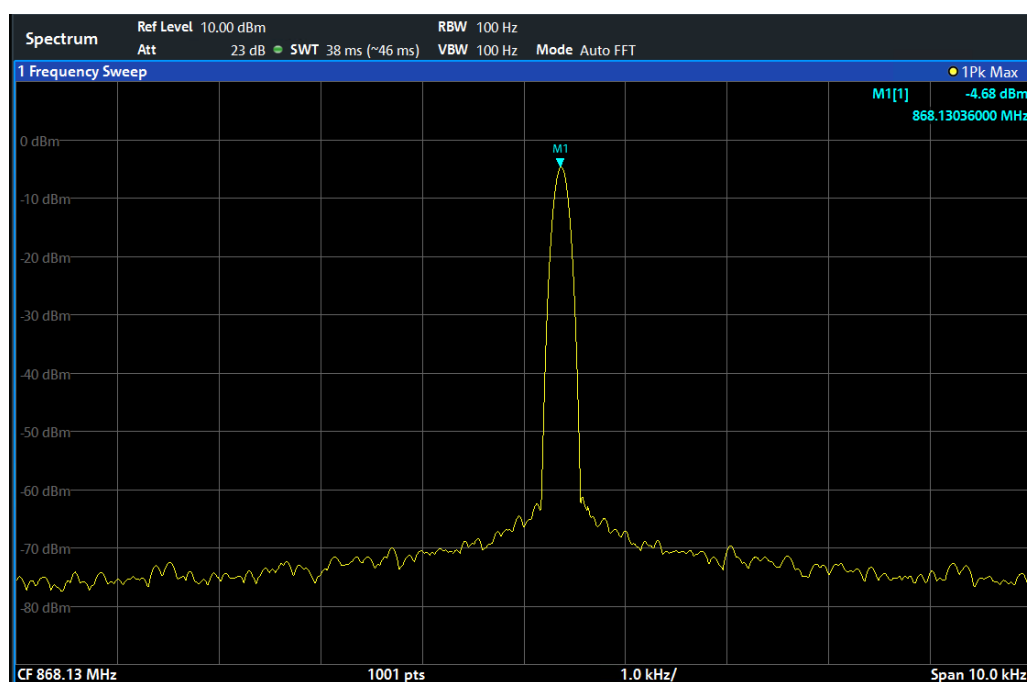


Fig. 3-3: Spectrum plot of Carrier Frequency test

3.3.2 Output Power

In compliance with regulatory requirements and to ensure optimal coverage Sigfox has defined output power classes as listed in Table 3-1. Tx power can be measured with the FPL or with a power meter.

U class	ETSI	FCC
0U	12 dBm ≤ power < 16 dBm*	20 dBm ≤ power < 24 dBm**
1U	7 dBm < power < 12 dBm	15 dBm < power < 20 dBm
2U	0 dBm < power ≤ 7 dBm	5 dBm < power ≤ 15 dBm
3U	power < 0 dBm	power < 5 dBm

* Limit for ETSI is 14 dBm max for output radiated power, anyway, device or module can output more than 14 dBm in conducted mode due to some antenna loss in the complete end product

** Limit for FCC is 22 dBm max for output radiated power, anyway, device or module can output more than 22 dBm in conducted mode due to some antenna loss in the complete end product

Table 3-1: Sigfox power classes for ETSI and FCC

In order to perform a conducted output power measurement, connect the input port of the FPL to the SMA antenna port of the DUT. As shown in Fig. 3-3, the marker would read out the value of the detected maximum radiated output power. In Fig. 3-3, the OTA output power measured in -4.68 dBm.

Total loss = free space loss + coupling loss = 18.67 dB

Therefore radiated output power level is -4.68 dBm + Total loss = 13.99 dBm

3.3.3 Output Spectrum

The Sigfox specification requires the devices to transmit within a predefined spectrum mask as shown in Fig. 3-4 for RC1/3 (100 bps) networks.

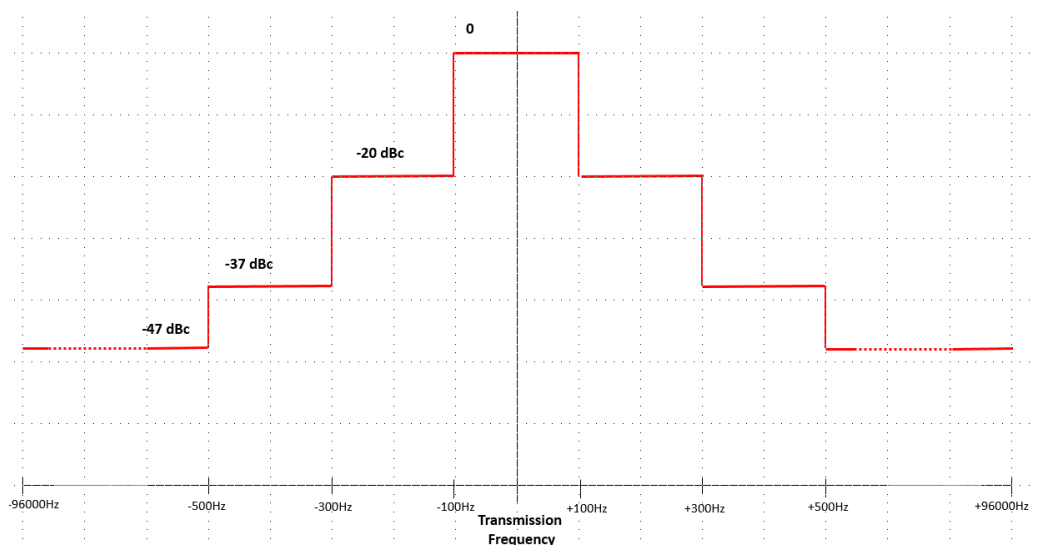


Fig. 3-4: Spectrum occupation limits based on Sigfox specification

Based on Sigfox test specification the measurements should be performed on a set of nine pseudo random frames (see Sigfox library) using the parameters listed below:

ETSI (100 bps): RBW = 50 Hz, VBW = 50 Hz, sweep time = 6 s

Using the same test setup as in chapter 3.3.1, for the spectrum analyzer FSV the following setting should apply for ETSI measurements:

- | Center Frequency: 868.15 MHz (or 868150000 Hz)
- | RBW: 50 Hz
- | VBW: 50 Hz
- | Sweep time: 6s
- | Span: 12.5 kHz
- | Trace ⇒ Trace Mode ⇒ Max Hold
- | Marker (M1) ⇒ MKR ⇒ Peak
- | Marker (D2 & D3) ⇒ MKR ⇒ Delta Marker ⇒ D2_Freq=+100 Hz ⇒ D3_Freq=-100 Hz
- | Marker (D4 & D5) ⇒ MKR ⇒ Delta Marker ⇒ D4_Freq=+300Hz ⇒ D5_Freq=-300Hz
- | Marker (D6) ⇒ MKR ⇒ Delta Marker ⇒ D6_Freq=+500Hz ⇒ D6_Freq=-500Hz

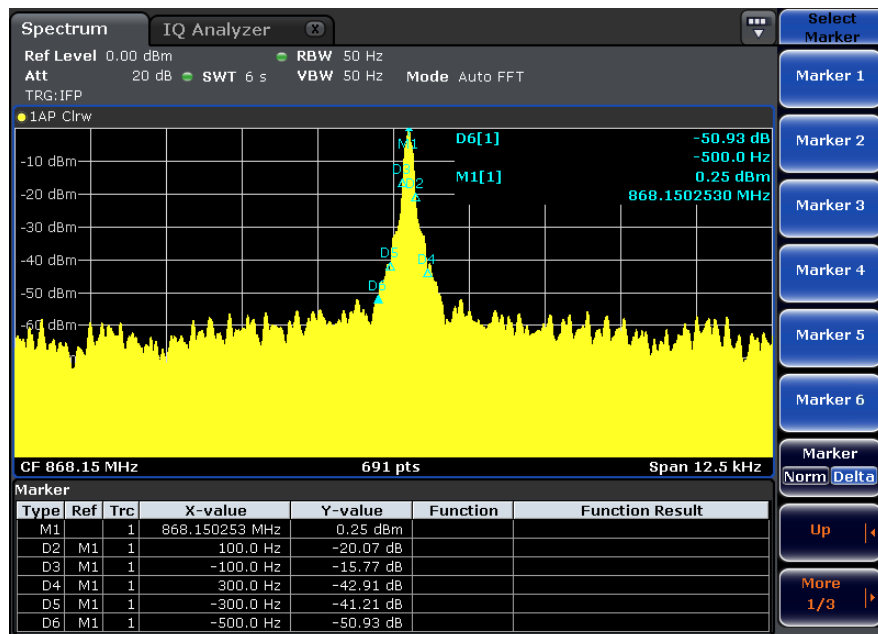


Fig. 3-5: Plot of the spectrum measurement using markers for the limit check

Fig. 3-5 shows the spectrum plot with delta markers defined according to Sigfox requirements. A more elegant way would be to use limit lines to check whether the spectrum passes the test or not. This is possible with the limit lines feature of the FPL as shown on Fig. 3-8. In this example, the red limit lines have been created using a Forum program. It is provided along with the application note and is listed in the appendix. Even though the limits as indicated by the red limit lines are predefined by Sigfox, the Forum software provides easy means to change the values. The appropriate excerpt of the software is shown in Fig. 3-6

```

39 # Limits for Spectrum - ETSI
40 shif = 1.0E-5 # Shifts all Y-Values of the Limit Line by ... dB
41
42 xlw = [ -960E2, -500E0, -300E0, -100, 100E0, 300E0, 500E0 ] # LowerValue in Hz
43 xup = [ -500E0, -300E0, -100E0, +100, 300E0, 500E0, 960E2 ] # UpperValue in Hz
44 lim = [ -47, -37, -20, 0, -20, -37, -47 ] # LimitValue in dB
45

```

Fig. 3-6: Definition of the limit line segments in lists

Lines 38 to 40 of the Script “1MA294_SigFox_Spectrum_Analysis_V1.3c.py” define lists including the limit line information as used for the limit lines. Lines 38 and 39 define the frequency segments, line 40 the power values related to the carrier, i.e. the y-values of the limit lines. The number of segments can be changed by adding or deleting parameters in the lists. Line 36 defines a slight level shift, to get ok-results for proper signals. This value can be changed if there is heavy noise on the signal. Fig. 3-6 shows how the limit lines as defined in Fig. 3-7 are programmed to FPL.

```

220 # Calculate Definition Points for Limit Line...
221
222 for i in range(0, len(lim)):
223     # Horizontal Definition Points:
224     x += str(float(cfrq) + xlw[i]) + ',' + str(float(cfrq) + xup[i]) + ','
225     # Vertical Definition Points:
226     y += str(float(clvl) + lim[i]) + ',' + str(float(clvl) + lim[i]) + ','
227
228 ## Configuring Limit Line for Sigfox Spectrum
229 ## @ref: R&S® FSVA/FSV Signal and Spectrum Analyzer - Operating Manual
230 ## Literature Number: 1176.7510.02 - 09, November 2016, PDF, p. 637ff.
231
232 FSV.write("CALC:LIM1:NAME 'SIGFOX_SpectrumLimits'")
233 FSV.write("CALC:LIM1:CONT:MODE ABS")
234 FSV.write("CALC:LIM1:CONT:SPAC LIN")
235 FSV.write("CALC:LIM1:CONT " + x[:-1])
236 FSV.write("CALC:LIM1:UPP:MODE ABS")
237 FSV.write("CALC:LIM1:UPP " + y[:-1])
238 FSV.write("CALC:LIM1:UPP:SHIF 1.0e-5dB")
239 FSV.write("CALC:LIM1:UPP:STAT ON")
240 FSV.write("CALC:LIM1:STAT ON")
241 FSV.ask("*OPC?")

```

Fig. 3-7: Programming the limit lines to FPL



Fig. 3-8: Sigfox spectrum requirements programmed as FPL limit lines

3.3.4 Phase Measurements

The spectrum occupation phase error of the DBPSK modulated signal should be maximum $\pm 10\%$, which corresponds to ± 18 deg.

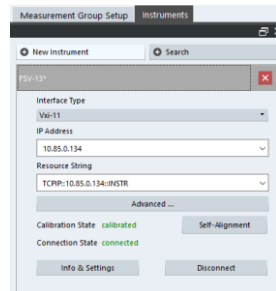
The vector signal explorer software option VSE-K70 (VSA) can perform signal demodulation and phase error measurements as shown on Fig. 3-9.

		Current	Peak	Unit
EVM	RMS	14.25	260.17	%
	Peak	98.25	2559.21	%
MER	RMS	16.93	-8.31	dB
	Peak	0.15	-28.16	dB
Phase Error	RMS	6.19	124.59	deg
	Peak	-46.28	-179.90	deg
Magnitude Error	RMS	13.37	248.15	%
	Peak	-97.45	2559.21	%
Carrier Frequency Error		-23.64	-23.64	Hz
Symbol Rate Error		---	---	ppm
Rho		0.979 972	0.009 709	
I/Q Offset		-31.82	-10.35	dB
I/Q Imbalance		---	---	dB
Gain Imbalance		---	---	dB
Quadrature Error		---	---	deg
Amplitude Droop		0.007 777	0.007 777	dB/sym
Power		0.04	0.04	dBm

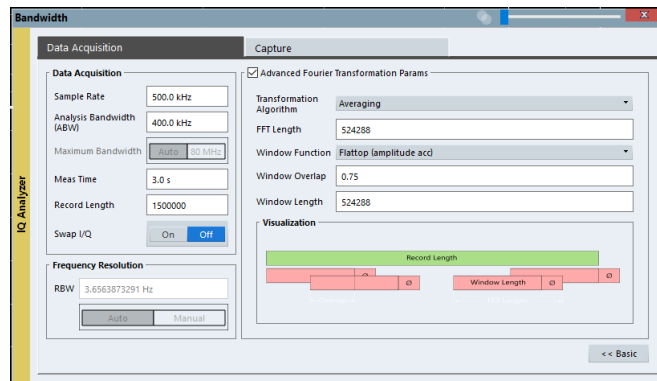
Fig. 3-9: VSE-K70 Result window

For this purpose, the VSE software running on a standard PC is connected to the FPL and is enabled to capture I/Q data for the demodulation and analysis.

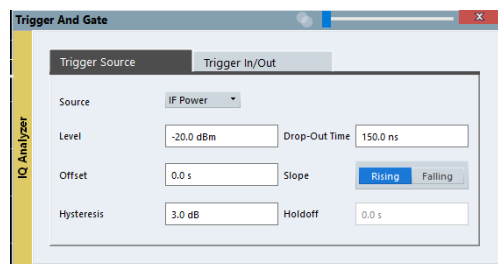
- Connect the FPL in VSE as shown below



- Configure the Data Acquisition setting of the VSE as shown below (measurement time = 25 sec)

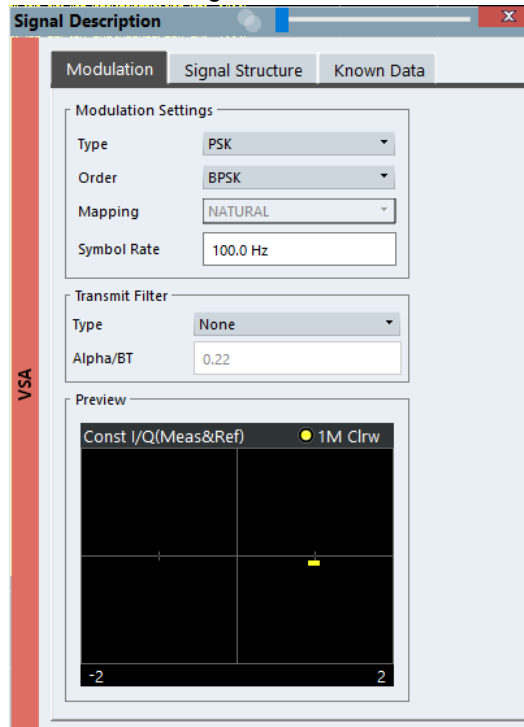


- ▶ Configure the trigger setting as shown below



- ▶ Perform Data Capture in the IQ Analyzer of the VSE

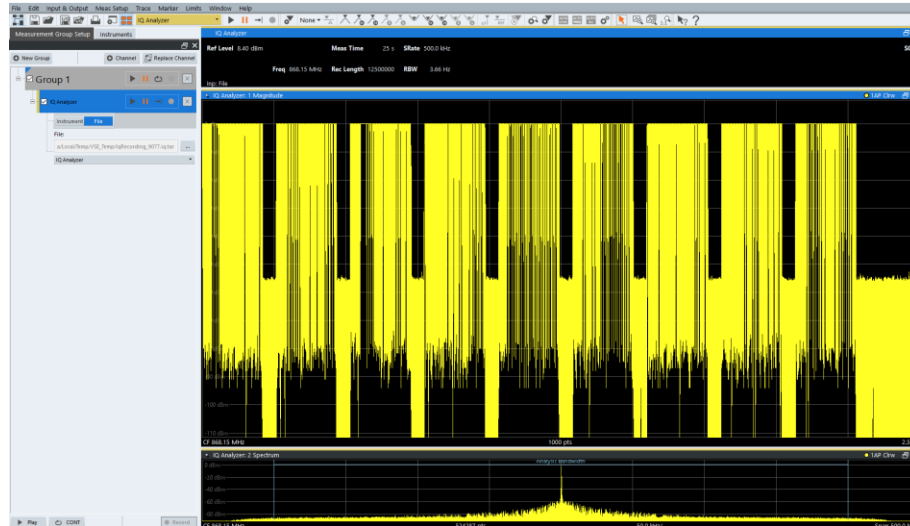
Moreover, the signal characteristics need to be specified as shown below



Alternatively, use the attached Forum code for automatic configuration.

3.3.5 Ramp Up/Ramp Down

- ▶ Perform Data Capture in the IQ Analyzer of the VSE as described before



- ▶ Next Zoom IN to the required start and stop of frame

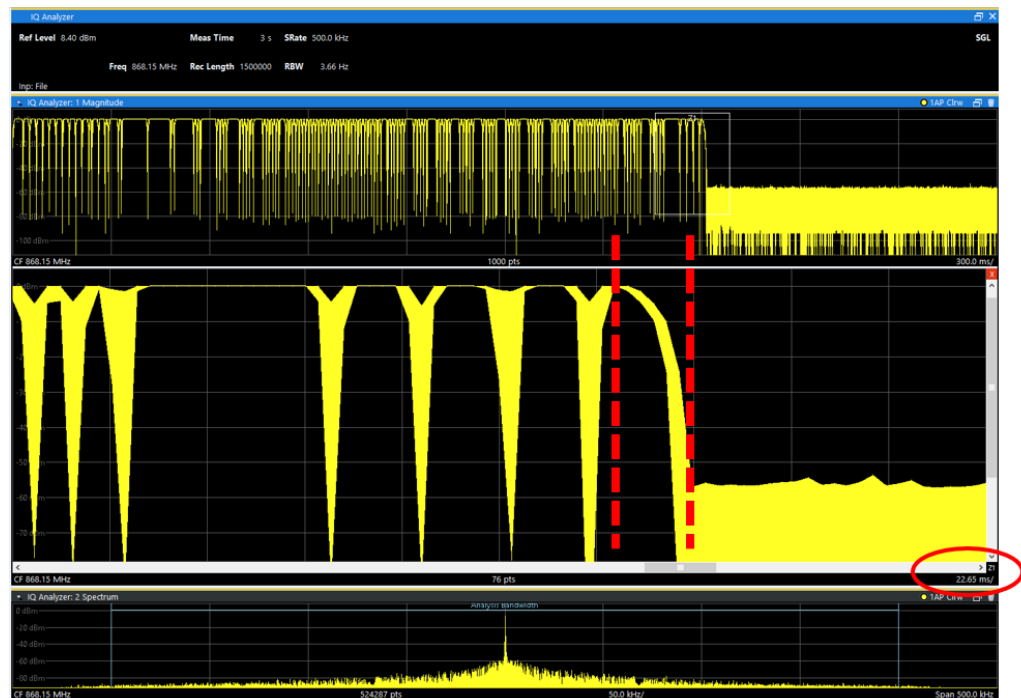


Fig. 3-10: Ramp-down after transmitting last CRC symbol bit

The requirement for frame transmission for Sigfox includes a 1 to 2 symbols duration ramp up and ramp down i.e. 10ms-20ms for ETSI and 1.6 ms-3.2 ms for FCC. Fig. 3-10 shows the ramp-down section at the end of an ETSI Sigfox uplink frame. The IQ analyzer is zoomed in and configured to 22.65 ms per division, to display a portion of the entire frame. The ramped down part falls within the limit of 20 ms.

3.3.6 Receiver Sensitivity with SMBV

Based on the Sigfox specification the receiver sensitivity for the 2GFSK signal should be ≤ -126 dBm. For this purpose, a signal generator (SMBV) is used to generate test frames.

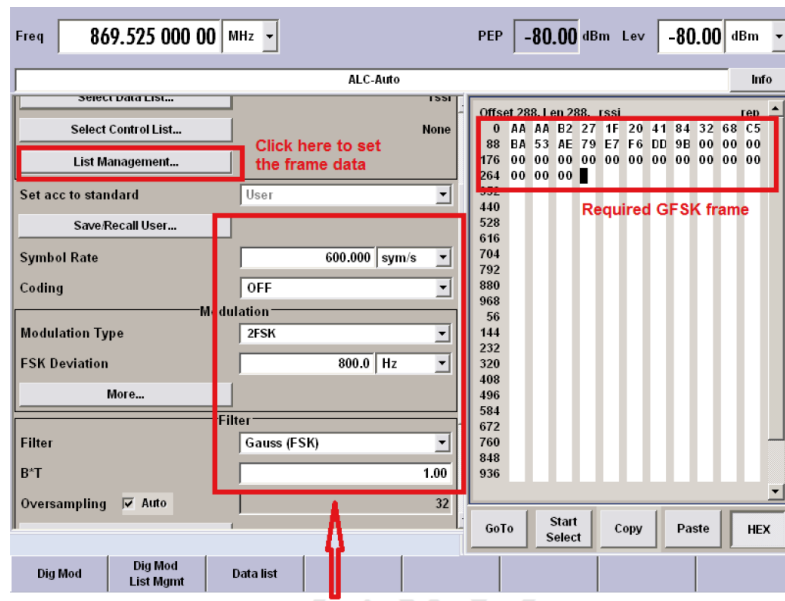


Fig. 3-11: SMBV configuration for generating Sigfox downlink base station signal

The signals are generated using the internal real-time baseband generation capabilities of the SMBV (SMBV-B10 option). Besides setting the correct modulation, symbol rate and filter, the SMBV also allows the use of customizable data lists. Via the "list management", the required GFSK frame content can be defined in line with the Sigfox specification. This data is then modulated onto the RF carrier as the set level and frequency.

Configuring SMBV:

- | Select Baseband > Config > Custom Digital Modulation > On
 - o Configure as shown in Fig. 3-11
- | Custom Digital Modulation > Data Source > Data List / Pattern
- | Power level of SMBV settings
 - o Conducted measurement = -126 dBm
 - o Radiated measurement = -80 dBm + antenna coupling loss + free space loss = -126 dBm (as shown in Fig. 3-12)

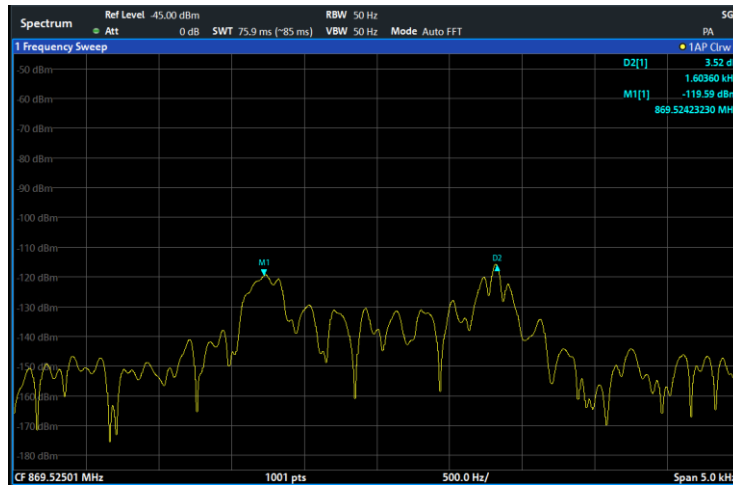
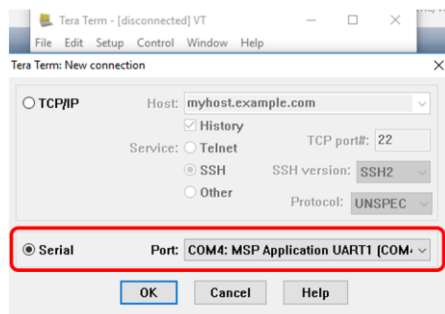


Fig. 3-12: Spectrum plot of the 2GFSK downlink signal generated using SMBV

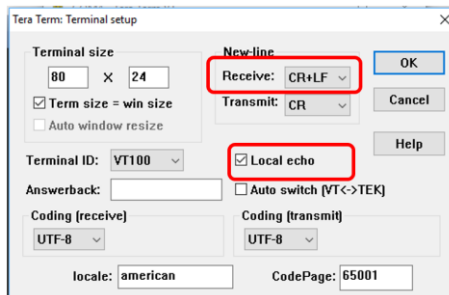
Configuring the DUT using terminal program TERATERM

TERATERM maybe downloaded from <https://tssh2.osdn.jp/index.html.en>

- ▶ Download, install and open the Teraterm program
- ▶ Select serial communication port (in this AN, COM port 4 is selected)



- ▶ Select Setup > Terminal > Configure as shown in figure below



3.4 Measurement Setup for Production Line Testing

The CMW100 is the instrument of choice for production line testing. The measurement routine for production line qualification is not as broad as in the R&D qualification phase. 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. For over the air tests a shielded box is recommended in addition to the CMW100. By using the shielded box, spurious electromagnetic radiation from the environment can be prevented. All eight ports can receive signals from the Sigfox DUT.



Fig. 3-14: Test setup for production testing of Sigfox devices using the CMW100

Fig. 3-14 shows the test setup for OTA testing. For production line testing, it is highly recommended to automate the testing routine. However, in this section, the manual way of configuring the CMW100 to perform a few example measurements will be explained. This will help in understanding the capabilities of the CMW100 and show how easy it is to configure the instrument.

3.4.1 Carrier Frequency and Output Power

To measure the carrier frequency and output power using the CMW100, perform the measurement setup as shown in Fig. 3-14. Next, the CMW100 needs to be configured to act as a spectrum analyzer.

- Switch on the General Purpose RF measurement mode on the CMW100 as shown in Fig. 3-15

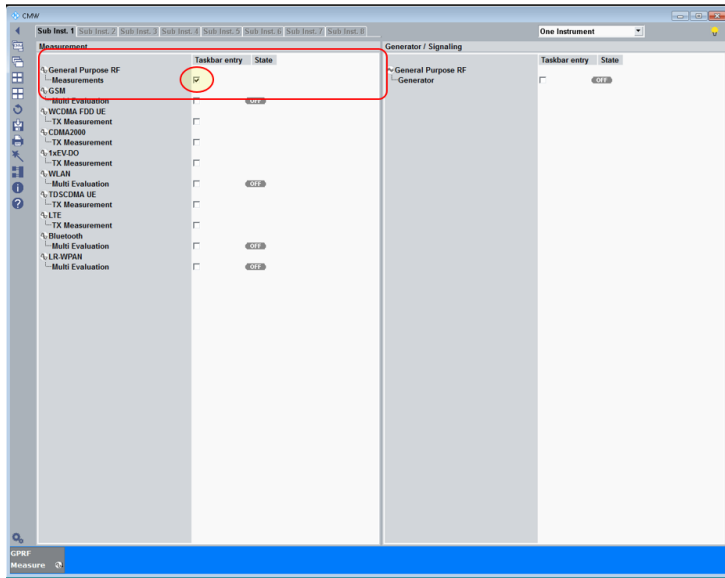


Fig. 3-15: Configuring the general purpose RF measurement mode

► Next select the FFT Spectrum Measurement

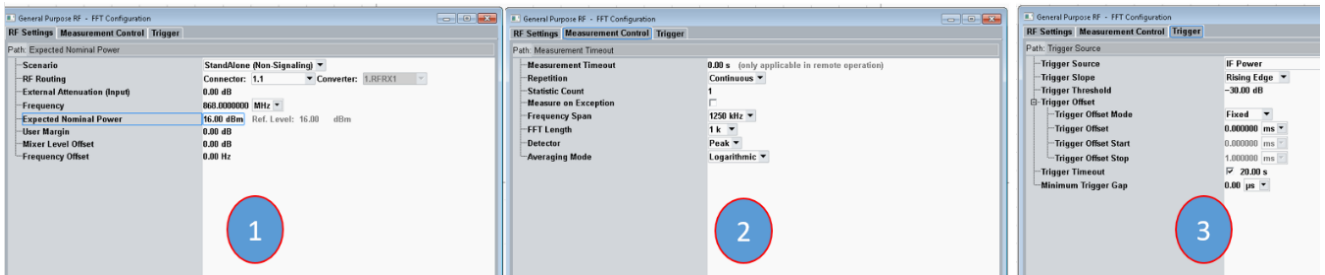


Fig. 3-16: FFT spectrum measurement configuration

For the FFT Spectrum measurement, the following setting should be configured as shown Fig. 3-16 in step 1, 2 and 3:

- | Frequency: 868.00 MHz
- | Span: 1250 kHz
- | FFT Length: 1K (as required)
- | Expected nominal Power: in conducted measurement depends on the device class
- | Detector : Peak

► Run the FFT measurement and from the DUT send frames in CW mode

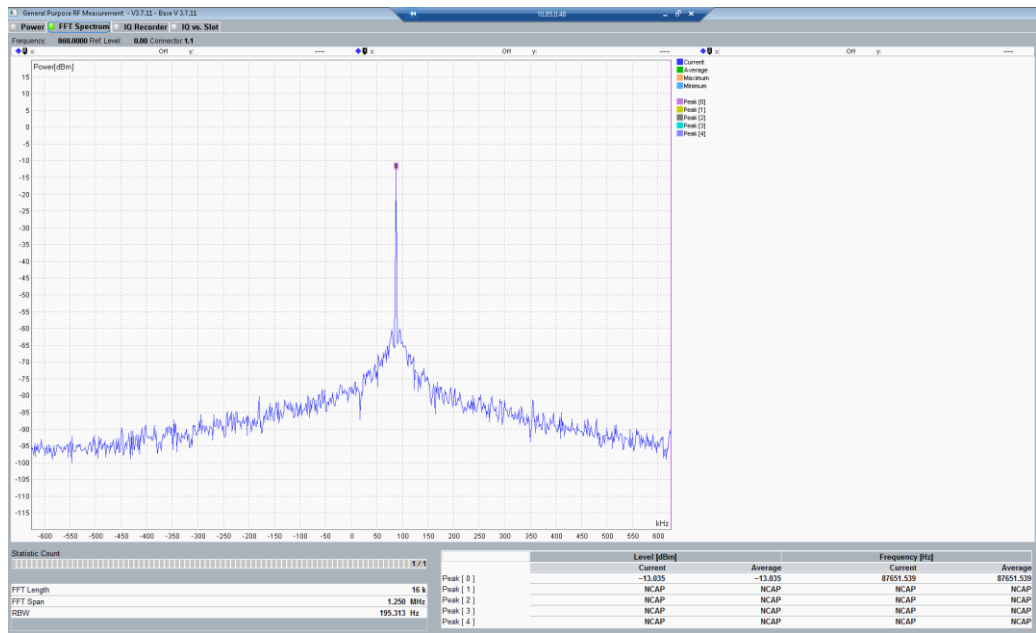


Fig. 3-17: Carrier frequency and output power measurement on the CMW100

Fig. 3-17 shows the carrier frequency and the output power measurement using an OTA setup. Using the peak detector, the signal from the DUT is 868.87651 MHz and the output power level is -13.035 dBm.

3.4.2 Receiver Sensitivity using CMW100

The CMW100 needs to be configured to act as a Signal Generator, in order to transmit the Sigfox recommended data list “AA AA B2 27 1F 20 41 84 32 68 C5 BA 53 AE 79 E7 F6 DD 9B”.

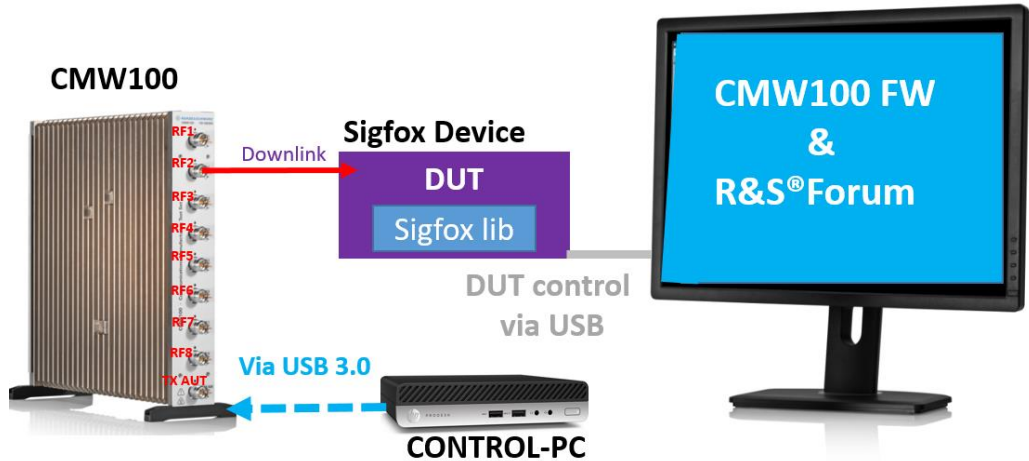


Fig. 3-18: Measurement setup for performing receiver sensitivity test using CMW100

Perform the measurement setup as shown in Fig. 3-18. Next, the CMW-KV687 Sigfox license file needs to be installed on the CONTROL-PC using a USB flash stick or natively on the PC.

The waveform file “KV687_600bps_2GFSK_SIGFOX_Waveform” needs to be installed on the CONTROL-PC and afterwards would be located in the waveform library folder of the CONTROL-PC.

The CMW100 will convert the baseband signal to a RF downlink signal.

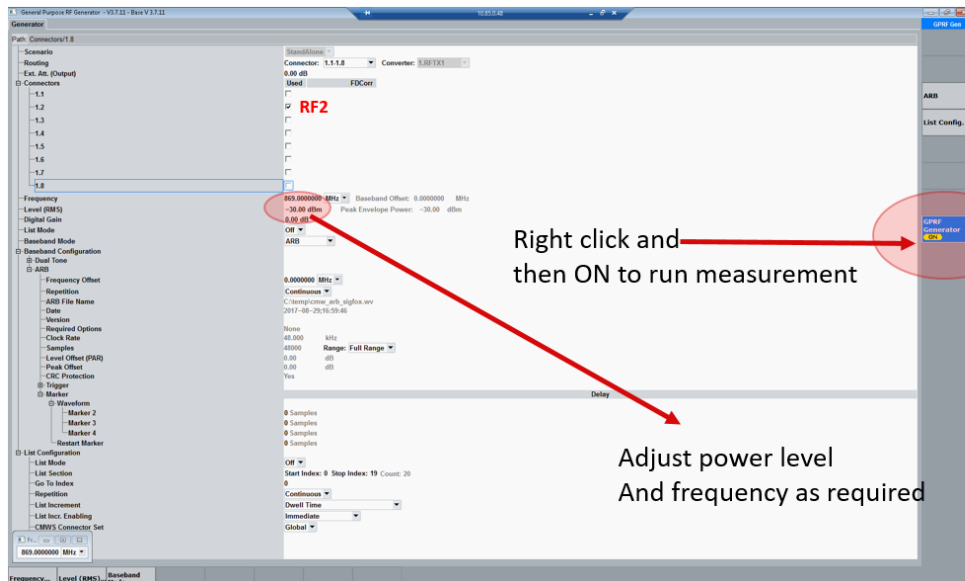
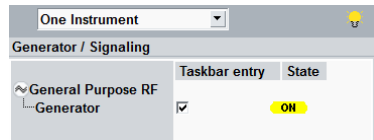


Fig. 3-19: Configuring the CMW100 in order to switch on the signal generator option

Configuration of the general purpose RF generator window of the CMW100 in order to generate a Sigfox downlink signal is shown in [Fig. 3-19](#).

- ▶ Switch on General Purpose RF Generator



- ▶ Configure the window as shown in [Fig. 3-19](#)
 - | Connector 1.2 (For example port RF 2)
 - | Baseband mode: ARB
 - | Adjust output power level and frequency
 - | Select the ARB waveform file from the appropriate waveform library folder
 - | Switch ON Generator

A download link Sigfox base station signal is now transmitted from the CMW100 (Port RF 2 as an example here).

Attention:

The CMW100 Base firmware 3.7.14 or higher is required. The latest firmware version can be downloaded for registered user from R&S [CMW100 Customer Web](#) or contact your local Sales Engineer or Application Engineer.

4 Example of Automation Scripts

The automation scripts introduced in this section were 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 a description, follow: <http://www.rohde-schwarz.com/appnote/1MA196>.

The test sequencer template is attached in the [download space](#) of this application note

Fig. 4-1 shows the Forum screen for the Sigfox application.

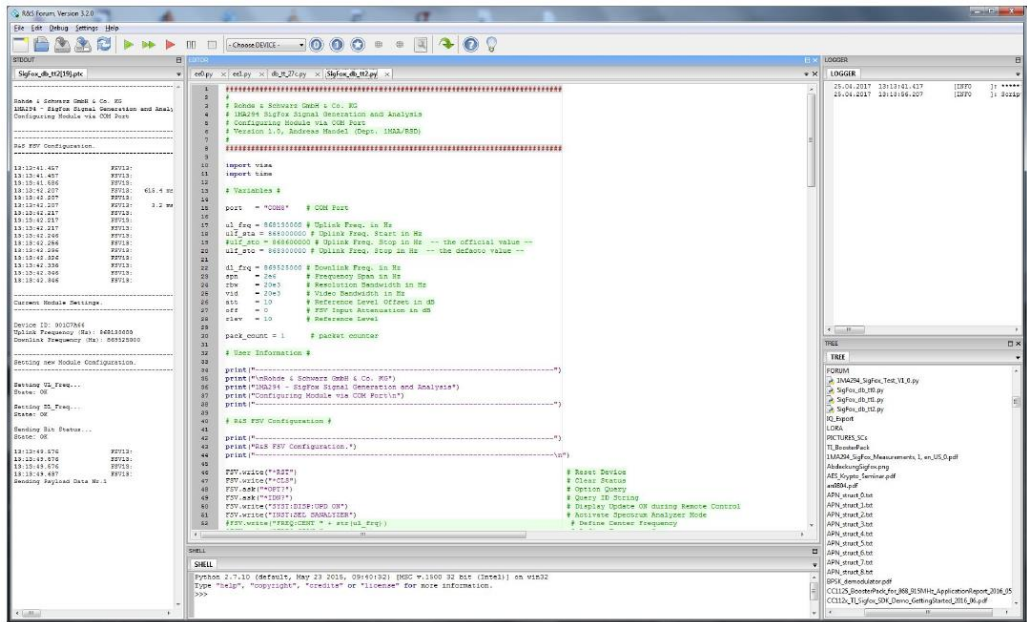


Fig. 4-1: Screenshot of the Forum application for instrument remote control

The T&M instruments and the Sigfox modem can both be directly controlled from this platform. T&M instruments used for this section include FPL, SMBV and CMW100.

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

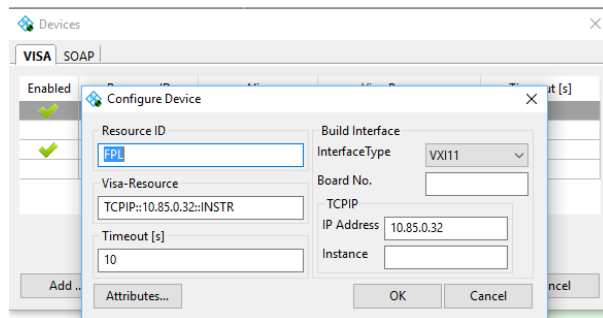


Fig. 4-2: Instrument connection configuration on FORUM

- | In Forum, select Settings > Instruments > Add
- | Configure the T&M instruments as shown in Fig. 4-2

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.

Using the test sequencer, single tests as given in the Forum scripts made available with this application note can be combined to a complete test sequence. Python, the programming language behind Forum, offers various features beyond instrument and modem control. Text output files can be created and written to generate complete test reports.

The appropriate test report provides the results along with tolerances and evaluation. The test sequencer is useful when testing numerous Sigfox devices in a row, e.g. in the production or for incoming goods quality inspection..

4.1 R&D Lab Test Automations

4.1.1 Frequency and Timing

To perform frequency and timing tests in an automatic way, the Forum script “1MA294_Sigfox_Frequency_and_Timing_V1.0.py” is provided along with this document. As explained in detail in Fig. 4-3. On the left the spectrogram as generated by FPL, on the right the explanation. Each colored block on the left is represented by a gray rectangle on the right. Each colored block equates to one packet sent by the Sigfox transmitter. The blocks are moving from the top to the bottom. The picture shows two complete messages, message 1 and message 2 for example. The horizontal position of each block provides information about the transmit frequency of the appropriate package. Using the horizontal position the transmit frequency for each package can be determined, as explained at the right side of Fig. 4-3. For example, frequency label f_1_2 represents the frequency of the second frame of message 1, f_2_3 represents the frequency of the third frame of message 2.

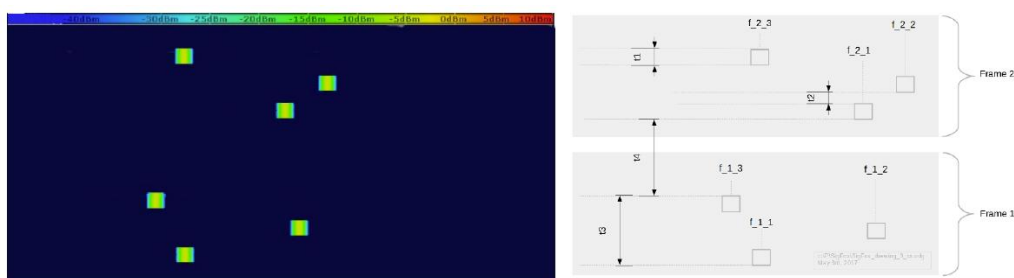


Fig. 4-3: Analyzing frequencies and transmission times for Sigfox modules

The vertical position of each block provides information about the time relations of transmitted Sigfox frames. Time t1 equates to the frame transmit time, t2 is the break time between two adjacent frames. The total time it takes to transmit a whole message is represented by t3, t4 is the break time between two frames. Time t4 normally depends on the user application, in our example we have 5 seconds break time between two messages.

Fig. 4-4 shows an excerpt from beginning of the whole Forum program, which is attached to this application note. A complete listing is given in the appendix. The I/O functions to the Sigfox modem and to the FPL are done via visa calls, which are imported in line 10. Line 15 defines the virtual COM port of the Sigfox modem. The number '8' depends on the computer configuration. With the help of the TeraTerm software, the COMx-port number can be easily detected. Variable definitions in the lines 17 to 29 include some basic settings, which are done at the FPL. The software is performing setup from the reset status of FPL, i.e. no manual settings are expected to perform the test.

```

10 import visa
11 import time
12
13 # Variables #
14
15 port = "COM8" # COM Port
16
17 ul_frq = 868130000 # Uplink Freq. in Hz
18 ulf_sta = 868000000 # Uplink Freq. Start in Hz
19 #ulf_sto = 868600000 # Uplink Freq. Stop in Hz -- the official value --
20 ulf_sto = 868300000 # Uplink Freq. Stop in Hz -- the defacto value --
21
22 dl_frq = 869525000 # Downlink Freq. in Hz
23 spn = 2e6 # Frequency Span in Hz
24 rbw = 20e3 # Resolution Bandwidth in Hz
25 vid = 20e3 # Video Bandwidth in Hz
26 att = 10 # Reference Level Offset in dB
27 off = 0 # FSV Input Attenuation in dB
28 rlev = 10 # Reference Level
29
30 pack_count = 1 # packet counter

```

Fig. 4-4: Basic setup parameters for FPL

The transmit loop software is shown in Fig. 4-5. Some specific settings of FPL are done in lines 143 to 164. Lines 147 to 152 finally include the transmission loop. In line 149, the Sigfox modem is triggered. Line 150 causes a waiting time of 5 seconds between two adjacent frame transmissions. This time appears as time t4 in the spectrogram, refer to Fig. 4-3.

```

136 ## Send Payload (in Bytes)
137 ## @ref: CC112x TI-SIGFOX SDK Demo - Getting Started Guide
138 ## Literature Number: SWRU487, June 2016, PDF, p. 14
139 ## @param: <ul_data>: 0 to 12 Bytes of Uplink Message
140 ## @rspnd: OK<CR>
141 # DISP:TRAC:Y:50 db
142 # SWE:TIME 0.1 s
143 FSV.write("SWE:TIME 0.1 s") # switch sweep time to 100 msec
144 FSV.write("DISP:TRAC:Y:SPAC LOG") #
145 FSV.write("DISP:TRAC:Y 50 db") #
146 FSV.write("CALC:SGR ON") # switch spectrogram display on
147 while(1):
148     print ("Sending Payload Data Nr." + str(pack_count))
149     stat = ti.query("AT$SF=1")
150     time.sleep(5)
151     print "State: " + str(stat.replace("\n", "")) + "\n"
152     pack_count += 1

```

Fig. 4-5: Forum frame transmission loop

The test setup along with the program provides convenient means to put the Sigfox device into operation and to verify its basic functionality. The automatic repetition also allows you to measure energy consumption, correlated with the various operating states of the Sigfox device, as there are idle or active transmission states. The repetition rate can be easily modified by changing the parameter of the Forum sleep-function, refer to line 150 in Fig. 4-5. Therefore, the program allows the verification of

the timing requirements like TX interframe timing and validation of the frequency hopping behavior (hopping range, min, max).

4.1.2 Signal Demodulation

The forum script “1MA294_SigFox_FSV_VSE-K70_Testing_V1_2c” automates and configures the DUT to transmit three frames with hopping and in parallel configures the VSE to capture the data and analyze the signal in VSE-K70 VSA mode.

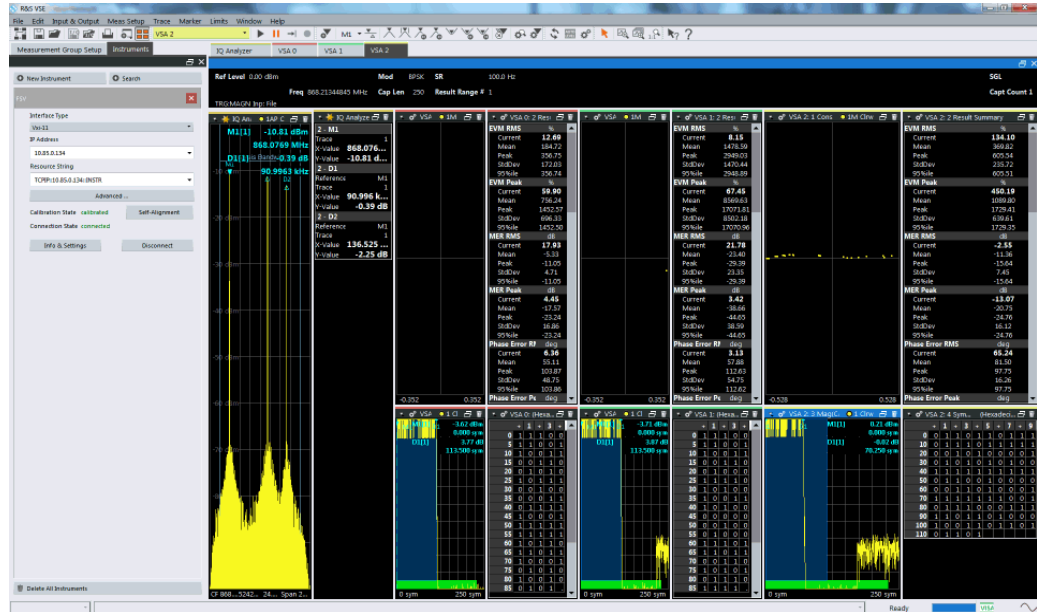


Fig. 4-6: Automatic configuration and measurement using Forum Script

Fig. 4-6 shows the three frames being analyzed automatically for symbol content and the result summary window displays the signal quality relevant information.

4.1.3 Downlink Receiver Tests

Downlink receiver tests can be performed using the signal generator SMBV. Fig. 3-18 shows an excerpt of the appropriate Forum script “1MA294_SigFox_Signal_Generation_V1.0e.py” to configure SMBV.

```

64 # Sigfox Downlink Frame: --- Preamble --- (91 Bits)
65 SMBV.write("BB:DM:DLIS:DATA 1,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0") # Preamble, Bits 1 ... 21
66 SMBV.write("BB:DM:DLIS:DATA:APP 1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0") # Preamble, Bits 22 ... 41
67 SMBV.write("BB:DM:DLIS:DATA:APP 1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0") # Preamble, Bits 42 ... 61
68 SMBV.write("BB:DM:DLIS:DATA:APP 1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0") # Preamble, Bits 62 ... 81
69 SMBV.write("BB:DM:DLIS:DATA:APP 1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0") # Preamble, Bits 82 ... 91
70
71 # Sigfox Downlink Frame: --- Frame Synch --- (13 Bits)
72 SMBV.write("BB:DM:DLIS:DATA:APP 1,1,1,1,0,0,0,0,1,1,1,1,0") # Frame Synch, Bits 1 ... 13
73
74 # Sigfox Downlink Frame: --- ECC --- (32 Bits)
75 SMBV.write("BB:DM:DLIS:DATA:APP 0,0,0,0,1,1,1,1,0,0,0,0,1,1,1,1") # ECC, Bits 1 ... 16
76 SMBV.write("BB:DM:DLIS:DATA:APP 1,1,1,1,0,0,0,0,1,1,1,1,0,0,0,0") # ECC, Bits 17 ... 32
77
78 # Sigfox Downlink Frame: --- Payload --- (0 - 64 Bits)
79 SMBV.write("BB:DM:DLIS:DATA:APP 1,1,0,1,1,0,1,1,0,0,0,0,1,1,1,1") # Payload, Bits 1 ... 16
80
81 # Sigfox Downlink Frame: --- Msg Auth Code --- (16 Bits)
82 SMBV.write("BB:DM:DLIS:DATA:APP 1,1,0,1,1,0,1,1,0,0,0,0,1,1,1,1") # Msg Auth Code, Bits 1 ... 16
83
84 # Sigfox Downlink Frame: --- FCS --- (8 Bits)
85 SMBV.write("BB:DM:DLIS:DATA:APP 1,1,0,1,1,0,1,1") # FCS, Bits 1 ... 8
86
87 # Wait for configuring Generator...
88 SMBV.ask("*OPC?")
89
90 # Define Symbol Rate
91 SMBV.write("BB:DM:SRAT " + str(srate))
92
93 # Disable Coding
94 SMBV.write("BB:DM:COD OFF")
95
96 # Modulation Type: FSK2 | FSK4
97 SMBV.write("BB:DM:FORM FSK2")

```

Fig. 4-7: Forum configuration of SMBV for downlink tests

The data fields are filled with binary random patterns. If real Sigfox data is available, the data fields can be updated accordingly.

4.2 Production Line Test Automations

4.2.1 Carrier Frequency and Output Power

The forum script “1MA294_SigFox_Production_UpLink_Testing_V1.0” automates and configures the DUT in test mode and in parallel configures the **CMW100** to capture the data and perform a peak search in the general-purpose RF measurement mode.

```
43 # R&S CMW Configuration #
44
45 print("-----")
46 print("R&S CMW100: General Purpose RF Measurement.")
47 print("-----")
48
49 CMW.write("**RST")
50 CMW.write("**CLS")
51 CMW.ask("?OPT?")
52 CMW.ask("**IDN?")
53
54 CMW.write("SYST:DISP:UPD ON")
55
56 CMW.write("ROUT:GPRF:MEAS:SCEN:SAL R11, RX11")
57
58 CMW.write("CONF:GPRF:MEAS:RFS:EAIT " + str(str_in))
59 CMW.write("CONF:GPRF:MEAS:RFS:FREQ " + str(ul_frq))
60 CMW.write("CONF:GPRF:MEAS:RFS:ENP " + str(enp))
61
62 CMW.write("TRIG:GPRF:MEAS:FFTS:SOUR \"IF Power\"")
63 CMW.write("TRIG:GPRF:MEAS:FFTS:SLOP REDG")
64 CMW.write("TRIG:GPRF:MEAS:FFTS:THR " + str(thr))
65 CMW.write("TRIG:GPRF:MEAS:FFTS:TOUT " + str(tout))
66
67 CMW.write("CONF:GPRF:MEAS:FFTS:REP CONT")
68 CMW.write("CONF:GPRF:MEAS:FFTS:FSP " + str(fsp) + " MHz")
69 CMW.write("CONF:GPRF:MEAS:FFTS:FFTL " + str(fftl))
70 CMW.write("CONF:GPRF:MEAS:FFTS:DET PEAR")
71 CMW.write("CONF:GPRF:MEAS:FFTS:AMOD LOG")
72
73 #CMW.write("CONF:GPRF:MEAS:FFTS:PSE:NOAM 5")
74 #CMW.write("CONF:GPRF:MEAS:FFTS:PSE_OFF, -100E+01, +100E1, OFF, -300E+01, -100E-01, OFF, +100E+01, +300E+01, OFF, -500E+01, -300E+01, OFF, +300E+01, +500E+01, OFF")
75
76 CMW.write("INIT:GPRF:MEAS:FFTS")
```

Fig. 4-8: Forum configuration of CMW100 for general-purpose measurement mode

Fig. 4-8 shows a part of the FORUM automation script for configuring the CMW100. Lines 49 to 54 initializes the CMW100. Lines 56 to 71 configures the instrument in the general purpose RF measurement mode, sets the trigger power level and selects the FFT peak detection measurement.

4.2.2 Downlink Receiver test with CMW100

The forum script "1MA294_SigFox_Production_DownLink_Testing_V1.0" automates and configures CMW100 in the general-purpose generator mode, selects the ARB file from the destination folder and switches on the RF.

The CMW-KV687 Sigfox license file needs to be installed on the CONTROL-PC using a USB flash stick or natively on the PC.

The waveform file "KV687_600bps_2GFSK_SIGFOX_Waveform" needs to be installed on the CONTROL-PC and afterwards would be located in the waveform library folder of the CONTROL-PC.

```
29 # Arbitrary Waveform File #
30
31 arbfile = "C:\ProgramData\Rohde-Schwarz\CMW\Data\Waveform\KV687_600bps_2GFSK_SIGFOX_Waveform.wv"
32
33 # User Information #
34
35 print("-----")
36 print("\nRohde & Schwarz GmbH & Co. KG")
37 print("1MA294 - Sigfox Signal Generation and Analysis")
38 print("Production Testing with Sigfox Devices\n")
39 print("-----")
40
41 # R&S CMW: General Setup #
42
43 print("-----")
44 print("R&S CMW100: General Setup.")
45 print("-----")
46
47 CMW.write("RST") # Reset Device.
48 CMW.write("CLS") # Clear Status.
49 CMW.ask("OPT?") # Option Query.
50 CMW.ask("IDN?") # Query ID String.
51
52 # R&S CMW: General Purpose Generator #
53
54 print("-----")
55 print("R&S CMW100: General Purpose Generator.")
56 print("-----")
57
58 # Select Connectors and Signal Paths:
59 CMW.write("ROUT:GPRF:GEN:SCEN:SAL R118, TX11")
60
61 # Activate/Deactivates RF Connectors:
62 CMW.write("CONF:GPRF:GEN:CMWS:USAG:TX:ALL R118, OFF, ON, OFF, OFF, OFF, OFF, OFF, OFF")
63
64 CMW.write("SOUR:GPRF:GEN:RFS:EATT " + str(att_out)) # Define External Attenuation.
65 CMW.write("SOUR:GPRF:GEN:RFS:FREQ " + str(dl_frq)) # Define Center Frequency (UL).
66 CMW.write("SOUR:GPRF:GEN:RFS:LEV " + str(lev)) # Define Base RMS Level.
67 CMW.write("SOUR:GPRF:GEN:RFS:DGA " + str(dga)) # Define Digital Gain.
68
69 CMW.write("SOUR:GPRF:GEN:BBM ARB") # Set Baseband Mode to ARB.
70 CMW.write("SOUR:GPRF:GEN:ARB:REP CONT") # Set Reputation to Continuous.
71 CMW.write("SOUR:GPRF:GEN:ARB:FILE '" + str(arbfile) + "'") # Select ARB File.
72 CMW.write("SOUR:GPRF:GEN:STAT ON") # Turn ON the Generator.
```

Fig. 4-9: Forum configuration of CMW100 for general-purpose generator mode

Fig. 4-9 shows a part of the FORUM automation script for configuring the CMW100.

Line 29 loads the ARB file from the destination waveform library folder. Lines 47 to 50 initializes the CMW100 and lines 58 to 72 configures the instrument in the general purpose RF generator mode, sets the downlink frequency, power level and switches ON the RF signal transmission.

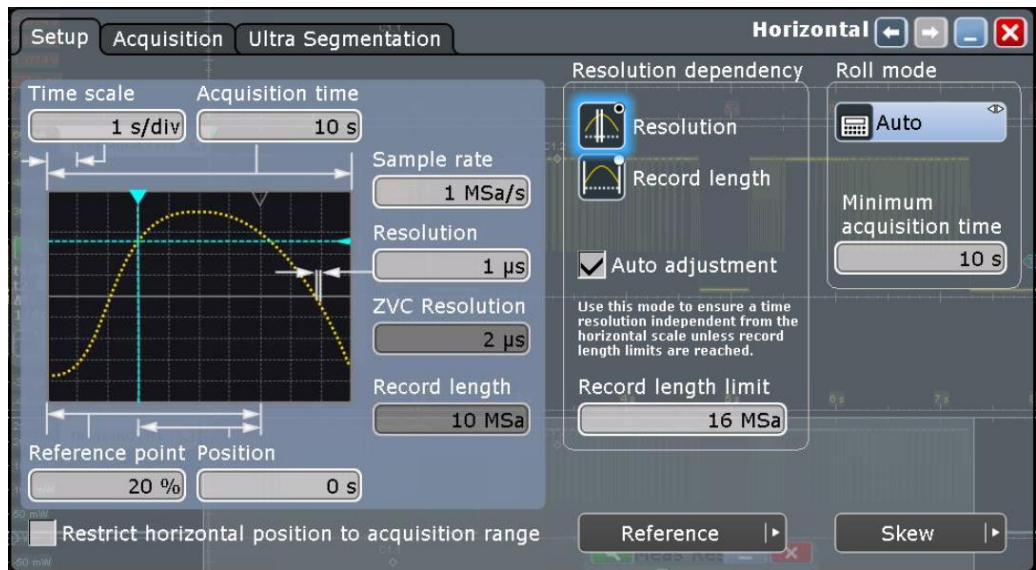


Fig. 5-2: Data Acquisition Setup on the RTO



Fig. 5-3: ZVC measurement configuration on the RTO

- ▶ Next select Vertical > ZVC Multi-Channel Probe
- ▶ Configure as shown in Fig. 5-3

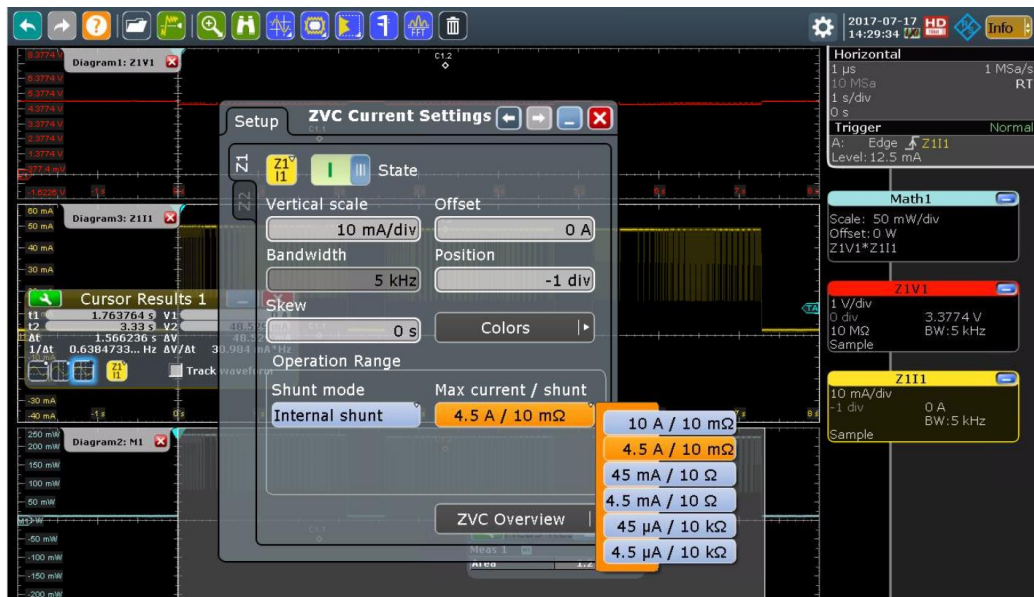



Fig. 5-4: Current Measurement configuration on the RTO

- ▶ Next Select click on setting button  for Z111
- ▶ Configure ZVC Current Settings as shown in Fig. 5-4
 - The maximum current consumption of the DUT appears to be ~49mA, which means that the 4.5A current range has to be chosen, the maximum current is just outside the 45mA range.

For optimum sensitivity, however, it is recommended to work with the external shunt mode. This allows adjusting the full-scale range exactly to the application by selecting an appropriate shunt resistor. Using, for instance, a 4.7Ω resistor in the 450mV external shunt measurement range gives a full-scale range of $450\text{mV} / 4.7\Omega = 95\text{mA}$ which fits to the maximum current expected but allows for a much higher resolution and lower noise than the 4.5A range with an internal shunt of 10mΩ.

For the sake of simplicity, this application note uses the internal shunt with 4.5A current range.

- ▶ Next select Trigger > Setup
- ▶ Configure as shown in Fig. 5-5

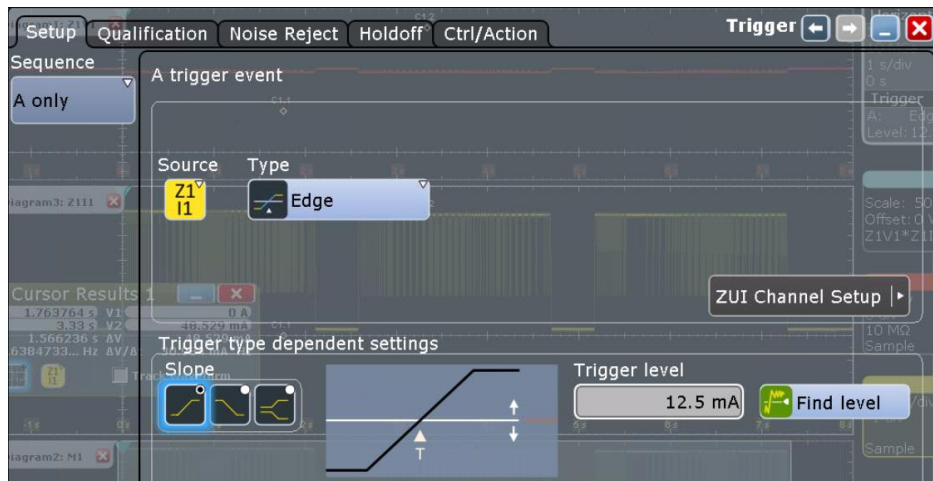


Fig. 5-5: Trigger setup on the RTO



Fig. 5-6: Math function configuration on the RTO

- ▶ Click on Math > Math Setup
- ▶ Configure the two sources and operator as shown in Fig. 5-6



Fig. 5-7: Power consumption measurement results on the RTO

Fig. 5-7 shows three plots in total. The first plot is the supply voltage plot and it is at a fixed level of ~4.85V. The second diagram is the current drain plot over time. In this plot, the current drain during packet transmission can be seen. The non-operational current drain is at 2.574 mA (t1 on the cursor result window) and the maximum drain level is +49mA (t2 on the cursor result window). The third 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 415.53mWs.

In order to configure gated area measurement,

- ▶ Select Meas > Setup > Enable > Source 1st : M1
 - Select Main : Area
- ▶ Select Meas > Gate/Display > Use Gate
 - Set Start and stop time as required.
 - In Fig. 5-7, Start: 0sec & Stop: 2.01s. In Fig. 5-8, Start: 0s & Stop: 7.6s

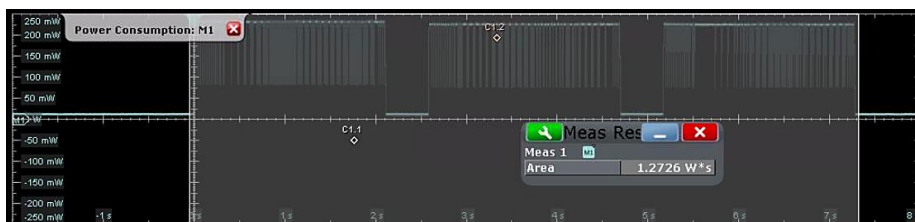


Fig. 5-8: Total Power consumption of the DUT while transmitting three Sigfox frames

Each individual Sigfox packet contains three frames. Fig. 5-8 shows the total energy consumption of 1.2726W during the transmission of three Sigfox frames. The energy drain during non-operational mode is also clearly visible in the plot.

6 Ordering Information

Designation	Type	Order No.
Digital Oscilloscope and Power Probe (for measurements on power consumption)		
R&S®RTO2002	Digital oscilloscope 600MHz, 2 channels, 10 Gsamples/s, 50/100 Msample	1329.7002k02
R&S®RTO-B1E	Digital Extension Port for RT-ZVC Support	1333.0738.02
R&S®RT-ZVC04	Multi channel power probe, 1 MHz, 5 MSa/s, 18 Bit, 2/4 current inputs, 2/4 voltage inputs	1326.0259.04
R&S®RT-ZA35	Extended Cable Set, 1 current and 1 voltage lead, length: 1 m	1333.1905.02
R&S®RT-ZA36	Solder-in Cable set, 4 current and voltage solder-in cables, solder-in pins	1333.1911.02
Signal and Spectrum Analyzer		
R&S®FPL1003	Spectrum Analyzer, 5KHz to 3 GHz	1304.0004.03
R&S®FPL1-B4	OCXO Reference Frequency	1323.1902.02
R&S®VSE	Vector Signal Explorer	1320.7500.02
R&S®FSPC	License Dongle	1310.0002K02
R&S®VSE-K70	Vector Signal Analysis	1320.7522.02
Signal Generator		
R&S®SMBV100A	Vector Signal Generator	1407.6004.02
R&S®SMBV-B103	9 KHz to 3.2 GHz	1407.9603.02
R&S®SMBV-B1	Reference Oscillator OCXO	1407.8407.02
R&S®SMBV-B10	Baseband Generator	1407.8607.04
Communications Manufacturing Test Set		
R&S®CMW100	Communications Manufacturing Test Set	1201.0002K03
R&S®CMW100CTR	Control PC for R&S®CMW100	1210.7935K02
R&S®CMW-KV687	Low Power WPAN (Sigfox), Waveform for ARB	1211.2643.02
R&S®CMW100 communications manufacturing test set can be operated only in combination with a standard computer, which is not included. The required R&S®CMW100 software must be installed on the computer. It can be downloaded free of charge or ordered as accessory R&S®CMW100-Z31.		

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Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

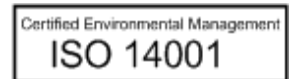
Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 | +86 400 650 58 96
customersupport.china@rohde-schwarz.com

Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership



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