WIRELESS & SENSING PRODUCTS

LoRa® 2.4GHz 3 Channels Single SF Reference Design

Performance Report

Abstract

This document presents all the tests which have been run on the 2.4 GHz 3 Channels Single SF Reference Design (PCB e549v04a) in order to check its compliance to worldwide regulations as well as all the measurements allowing to evaluate its performances.

History

Rev.	Ref.	Change	Author	Date
1.0	-	Doc creation	P. Calvet	Apr. 2020

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1 Introduction

1.1 Presentation

The project concerns the development of a new 2.4 GHz platform (gateway and end-device). The project has been initiated in order to provide a LoRa-based network around the world without facing roaming issues.

A version of the three channels single SF gateway reference design using three receivers and one transmitter is described in the figure 1.1.

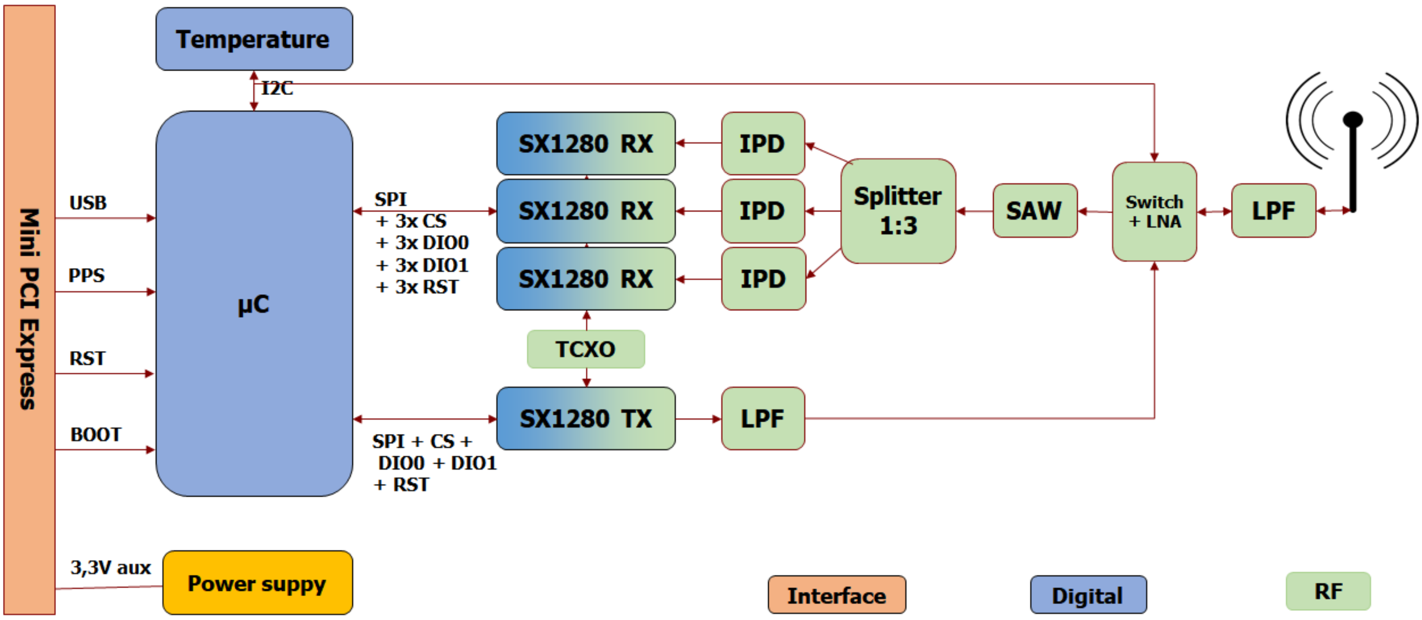


Figure 1.1: Architecture of the 2.4 GHz three channels single SF gateway reference design using 3 receivers and 1 transmitter

A proposal of 2.4 GHz regional parameters has been defined based on regulatory requirements of Europe, US, China, Korea & Japan bandwidth = 812kHz or more with an output power = 10 dBm EIRP.

1.2 Scope

This document gathers all the tests which have been run on the 2.4 GHz gateway reference design in order to check its compliance to worldwide regulations as well as all the measurements allowing to evaluate its performances .

This report concerns the validation of the last gateway PCB (e549v04a) which solve issues discovered during the EMC test campaign. The list of changes introduced in the PCB e549v04a are listed in the section 3.1

1.3 References

The following documents have been used to write the validation plan and are cited in the present document:

1. **ETSI EN 300 440 v2.2.1** European Regulation for Short Range Devices (SRD) used in the 1 GHz to 40 GHz frequency range
2. **CFR 47, Part 15 "Radio Frequency Device", Sections 15.205, 15.209, 15.247** US regulations for intentional radiators operating within the bands 2400-2483.5 MHz.
3. **558074 D01 DTS Meas Guidance v03r05** guidance for performing compliance measurements on Digital Transmission Systems (DTS) operating under Section 15.247.
4. **Communication protocol with GTW 2G4** Definition of all the protocol communication with gateway mcu
5. **SX1280 datasheet - v3.0** Long range, low power 2.4 GHz Wireless RF Transceiver used by the gateway reference design.

1.4 Document convention

Excepted if it is explicitly mentioned, all measurements are performed at ambient temperature i.e +25°C.

→ **Any text inside a framed box means a conclusion of the current section.**

1.5 Modal verbs terminology

In the present document, the modal verbs are used as follow:

- **SHALL** is used to express mandatory requirements that have to be followed. The negative form is **SHALL NOT**.
- **SHOULD** is used to express recommendations. The negative form is **SHOULD NOT**.
- **MAY** is used to express permissible actions. As the negative form **MAY NOT** is ambiguous in English, **NEED NOT** is used instead.

2 Validation testbench

The general test bench used along this document to measure and validate the 2.4 GHz gateway reference design performances and its compliance to the regulation limits is shown in the figure 2.1.

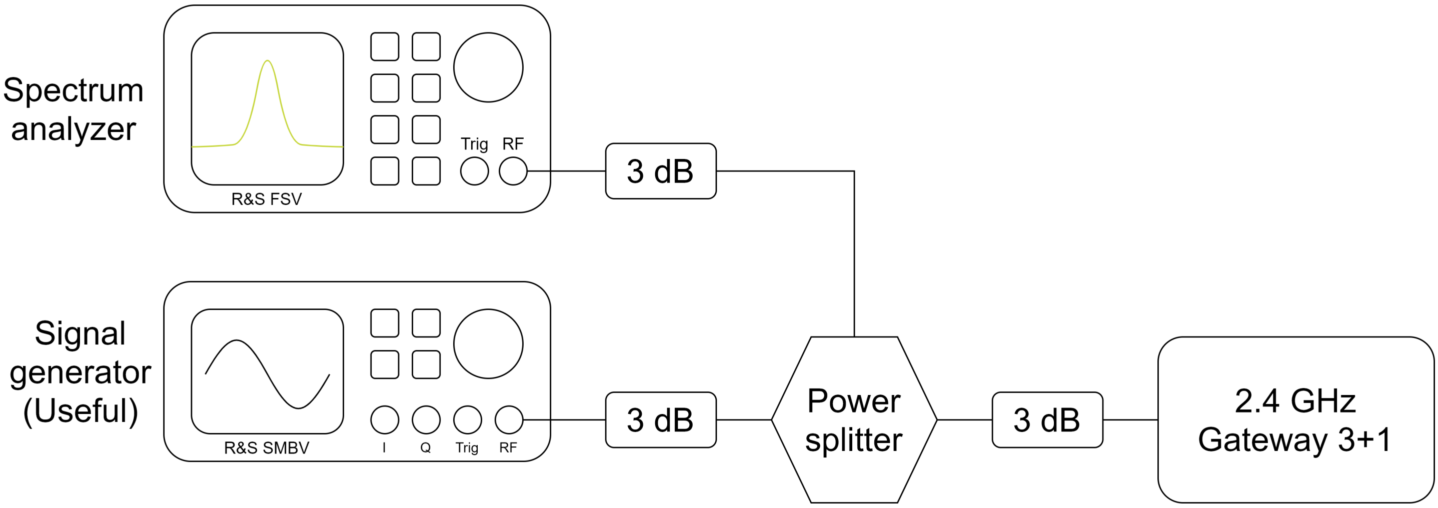


Figure 2.1: Validation test bench used to validate the 2.4 GHz gateway reference design

It uses a power splitter 5:1 with a 20 dB isolation between each port. Additional 3dB attenuators allow to mitigate impedance mismatch to provide accurate results. Unused ports are loaded.

The signal generator allows to generate the packets for the receiver validation.

The power splitter, the interface board with the raspberry Pi and the DUT are all enclosed together in RF shield box to protect against WiFi and other interferers in the vicinity of the testbench.

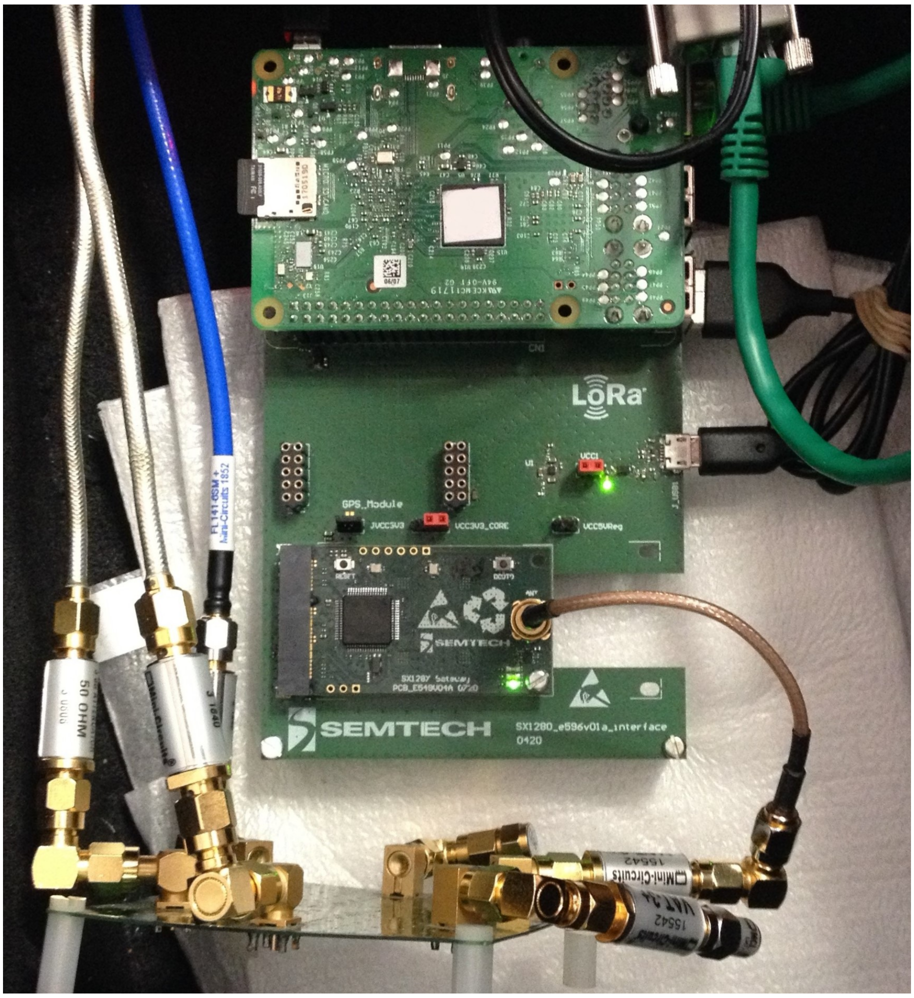


Figure 2.2: The power splitter, the RPI and the DUT are all enclosed in RF shield box to protect against real world

3 Device under test

3.1 Changes introduced in the PCB e549v04a

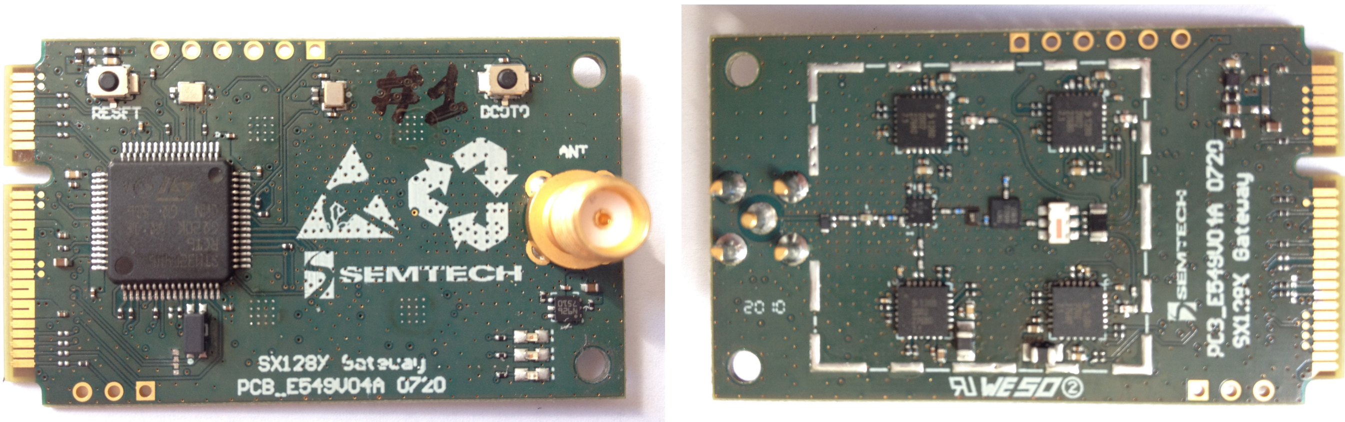
Following internal measurements and the EMC tests campaign performed on the second PCB version (PCB e549v02a), the modifications listed below have been introduced in this PCB version.

- Useless signals have been disconnected from the mini-pcie connector (I2C, SPI, UART)
- A common mode line filter (LUSB) has been added on both USB data signals.
- An additional LPF (C613, L614, C615) has been populated on the RF common path to suppress the harmonics generated by the power amplifier of the transmitter.
- The missing track between SX1280 pins DCC_FB (12) and VDD_IN (2) has been routed again.
- Board is now supplied with 3.3V_Aux voltage only. The on-board linear regulator is not used anymore.

→ **All the measurements have been performed with the original BOM; no modification has been done on the board.**

3.2 Hardware

The board D001 used in the measurements along this report is shown in figure 3.1. This board is plugged-in an interface board (PCB) to connect the gateway to the host (Raspberry Pi).



(a) Top view (b) Bottom view

Figure 3.1: 2.4 GHz 3 Channels Single SF Gateway Reference Design (PCB e549v04a) used in this report - Board D001

3.3 Software

The following software / firmware are used in the measurements of this report:

- **Firmware**: `rlz_fwm_gtw_2g4_01.00.01.bin`
- **HAL / Packet forwarder**: 1.0.0

4 Results summary

4.1 Board level

Tests descriptions	Criteria	Results	Comments
Power consumption	The current consumption at 25°C shall be aligned with the expected value.	PASS	

Table 4.1: Board level results summary

4.2 Transmitter

Tests descriptions	Criteria	Results	Comments
Output power	Output power higher than 10 dBm, 1dB step	PASS	
Modulation bandwidth	Shall be higher than 500 kHz	PASS	
Maximum PSD level	The maximum PSD level shall be lower than +8dBm/3kHz	PASS	
Spurious emission (ETSI)	Lower than -30 dBm	PASS	
Out-of-band (FCC) Conducted spurious emissions (FCC)	The power at the band-edge shall be attenuated by 20 dB The emissions which fall in the restricted bands shall be lower than -41 dBm	PASS PASS	

Table 4.2: Transmitter results summary

4.3 Receiver

Tests descriptions	Criteria	Results	Comments
Sensitivity and PER	Comply with the theoretical computation	PASS	
RSSI	Linear (Error < 2 dB)	PASS	
SNR	Linear (Error < 2 dB)	PASS	

Table 4.3: Receiver results summary

Part I

Board level

5 Power consumption

5.1 Description

The current consumption is monitored in three modes:

1. IDLE mode: The gateway is plugged in the mini-pcie connector and supplied. The firmware is running but the packet forwarder is not launched yet. The RF front-end is ON and the radio 4 used in transmit mode is ready. Finally the three radios 1,2 and 3 used in receive mode are not initialized.
2. Tx mode: Using the HAL tool, the radio 4 generates one of several packets.
3. Rx mode: The packet forwarder is running. The three radios used in receive mode are initialized. Packets are generated externally and received by the gateway.

5.2 Setup

The current consumption is monitored for the three modes described previously.This measurement is performed at room temperature (25°C) using an ammeter connected on the jumper **JVCC3V3** of the interface board (PCB e596v01a).

5.3 Room temperature

Modes	3.3 AUX			
	Min.	Max.	Unit	Remark
Idle	55.8	58.3	mA	
RX	79	83	mA	
Tx	79	84	mA	Max. output power set

Table 5.1: Current consumption, Board D001, Room temperature

→ **Nevertheless, the current consumption at ambient room complies with the requirements.**

Part II

Transmitter

6 Output power

6.1 Description

The ETSI **Equivalent Isotropic Radiated Power (E.I.R.P.)** and the ARIB **Antenna power** tests require that the output power to be lower than +10 dBm. In order to maximize the link budget, the power shall be trimmed as close as possible to the limit.

This section evaluates the output power trimming capability.

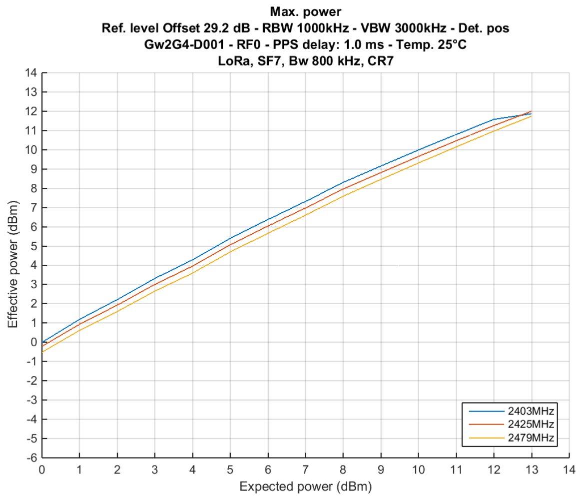
Note: The FCC §15.247 section (b)(3) requires the maximum output power to be lower than 1W (30 dBm). No specific measurement is performed as this item always complies with the regulation.

6.2 Setup

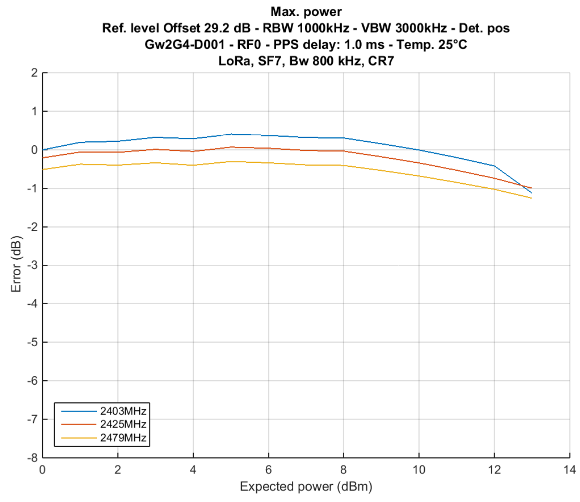
The setup used for this measurement is described in section 2.

6.3 Frequency influence

6.3.1 Board D001



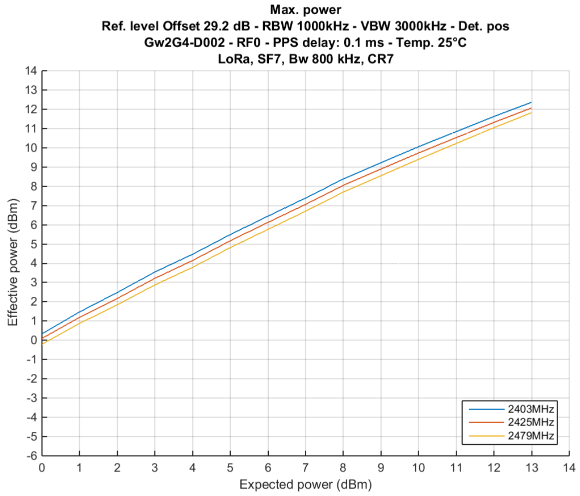
(a) Absolute (dBm)



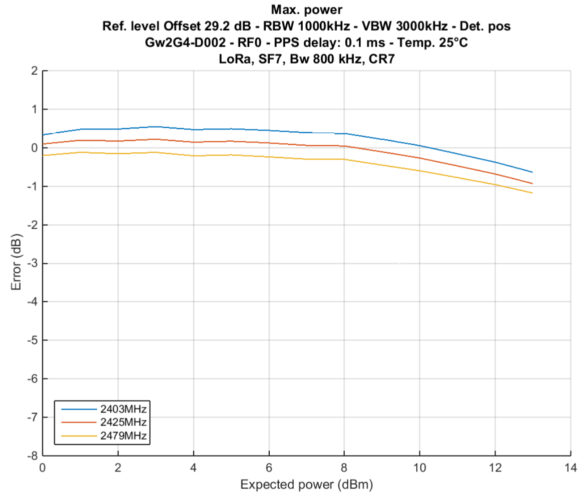
(b) Relative (dB)

Figure 6.1: Output power response, Board D001, 25°C

6.3.2 Board D002



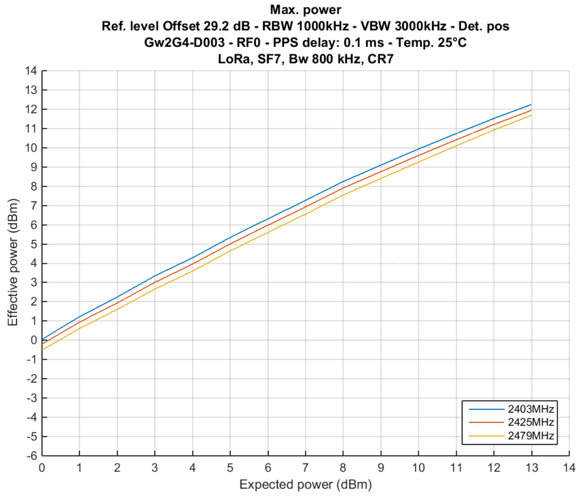
(a) Absolute (dBm)



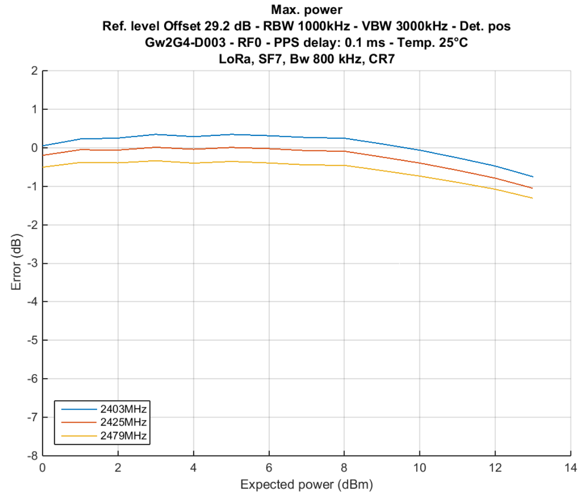
(b) Relative (dB)

Figure 6.2: Output power response, Board D002, 25°C

6.3.3 Board D003



(a) Absolute (dBm)



(b) Relative (dB)

Figure 6.3: Output power response, Board D003, 25°C

6.4 Conclusion

→ The gateway reference design is able to provide an output power which may be trimmed from 0 to 12 dBm with a 1 dB step accuracy.

7 Modulation bandwidth

7.1 Description

In order to select the applicable measurement method to check the compliance to the E.I.R.P. (ETSI), the 6 dB transmitter bandwidth shall be determined.

The **Occupied frequency bandwidth** test of the ARIB regulation also requires the spectrum to be measured.

Finally, the chapter 15.247(a)(2) of the FCC regulation mentions the gateway reference design shall be conform to a digital modulation system. In order to justify this classification, this test measures the 6 dB emission bandwidth that shall be higher than 500 kHz.

7.2 Setup

The setup used for this measurement is described in the section 2.

7.3 Spreading factor influence

7.3.1 2403 MHz

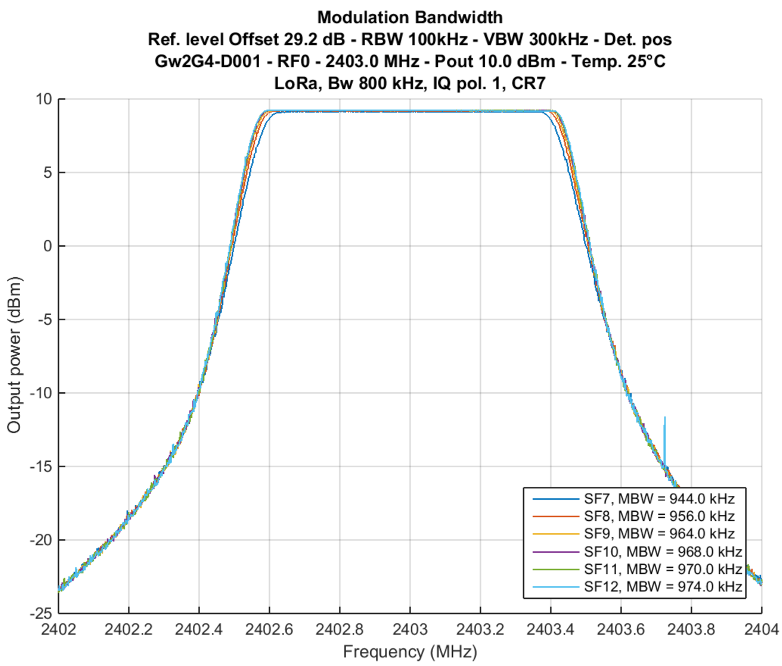


Figure 7.1: Modulation bandwidth vs Spreading factor, Board D001, 2403 MHz, Bw 812.5 kHz, 25°C

7.3.2 2425 MHz

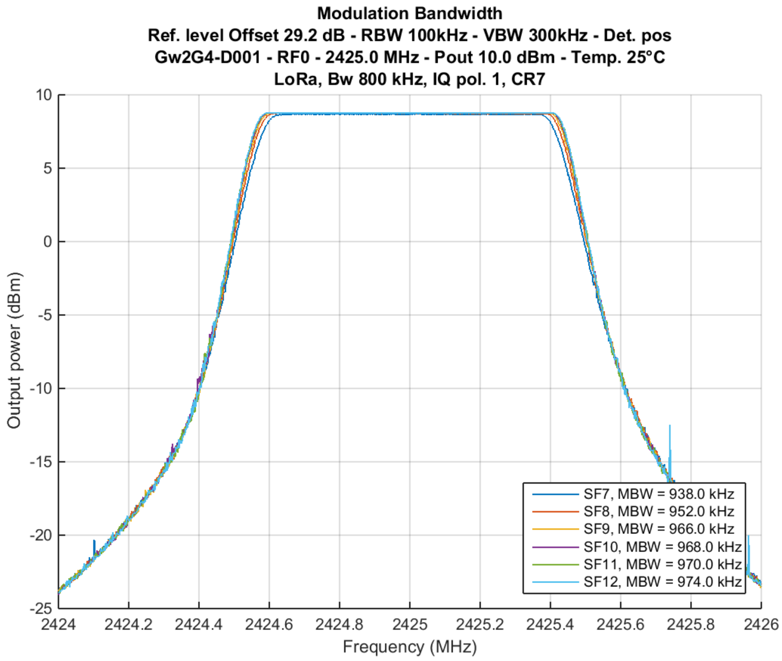


Figure 7.2: Modulation bandwidth vs Spreading factor, Board D001, 2425 MHz, Bw 812.5 kHz, 25°C

7.3.3 2479 MHz

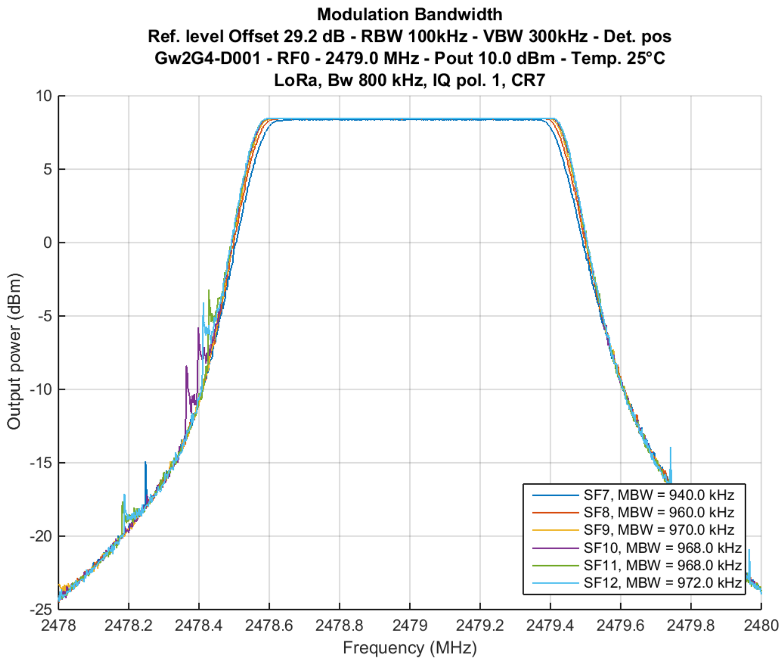


Figure 7.3: Modulation bandwidth vs Spreading factor, Board D001, 2479 MHz, Bw 812.5 kHz, 25°C

7.4 Conclusion

→ **The spreading factor influence on the modulation bandwidth is negligible. The occupied bandwidth always complies with the minimum -6 dB bandwidth of 500 kHz whatever spreading factor.**

8 Maximum power spectral density level

8.1 Description

The chapter 15.247(e) of the FCC regulation mentions the power spectral density shall not be greater than +8 dBm in any 3 kHz band during any time interval of continuous transmission.

This test measures the power spectral density level according to methods mentioned in document [3].

8.2 Setup

The setup used for this measurement is shown in the figure 2.1.

8.3 Procedure

Preliminary measurements have shown the compliance to this item of the regulation shall be performed using modulated packets instead of long unmodulated preamble. Indeed, spikes appear on the spectrum due to the modulated chirps and shall be taken care in the measurement.

Furthermore, the average **AVGPSD-1** method could not be used to demonstrate the compliance to the maximum PSD as the delay between the packets decrease the maximum PSD value. The maximum peak power **PKPSD** method described in reference document [3] is used instead.

8.4 Frequency influence

The figures 8.1, 8.2 and 8.3 show the power spectral density level results on three channels and for spreading factors SF7 to SF12.

8.4.1 SF7

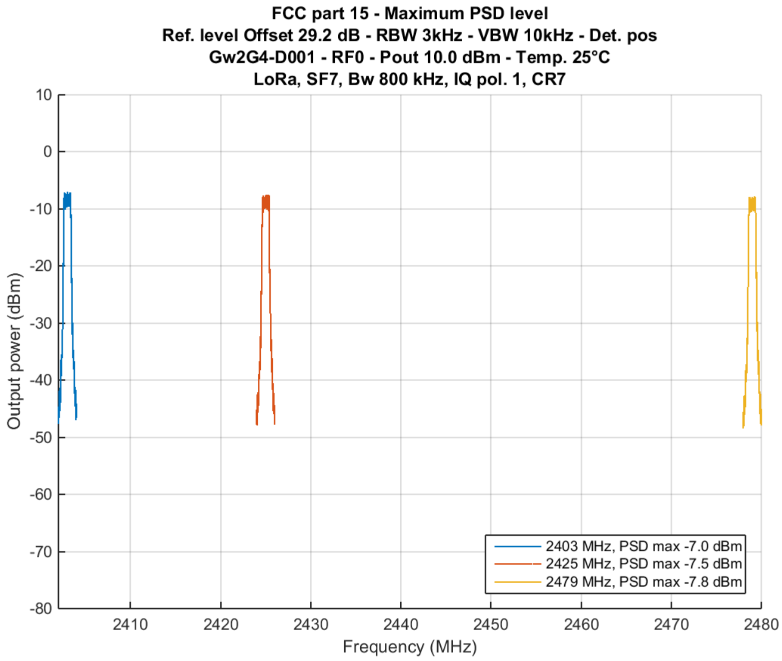


Figure 8.1: Maximum PSD level versus frequency, Board D001, SF7, Bw 812.5 kHz, 25°C

8.4.2 SF9

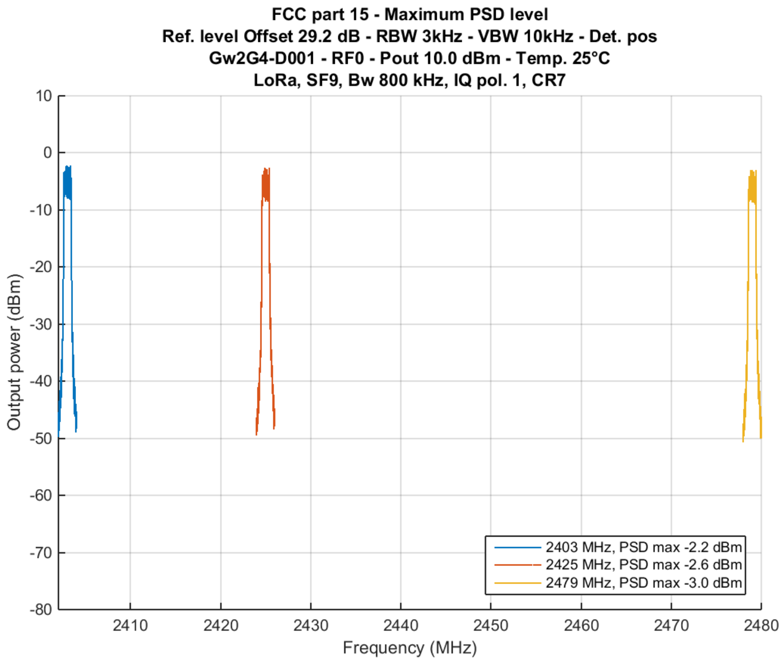


Figure 8.2: Maximum PSD level versus frequency, Board D001, SF9, Bw 812.5 kHz, 25°C

8.4.3 SF12

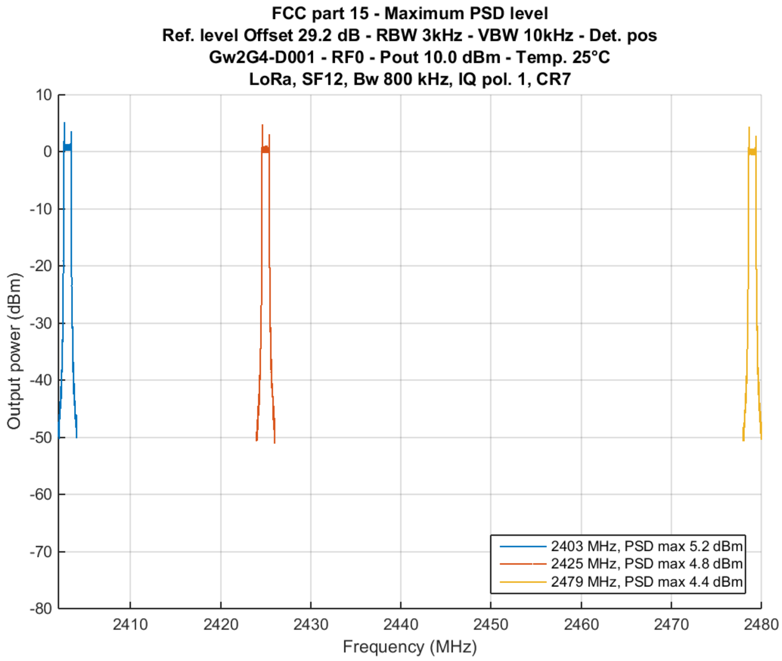


Figure 8.3: Maximum PSD level versus frequency, Board D001, SF12, Bw 812.5 kHz, 25°C

8.5 Spreading factor influence

8.5.1 2403 MHz

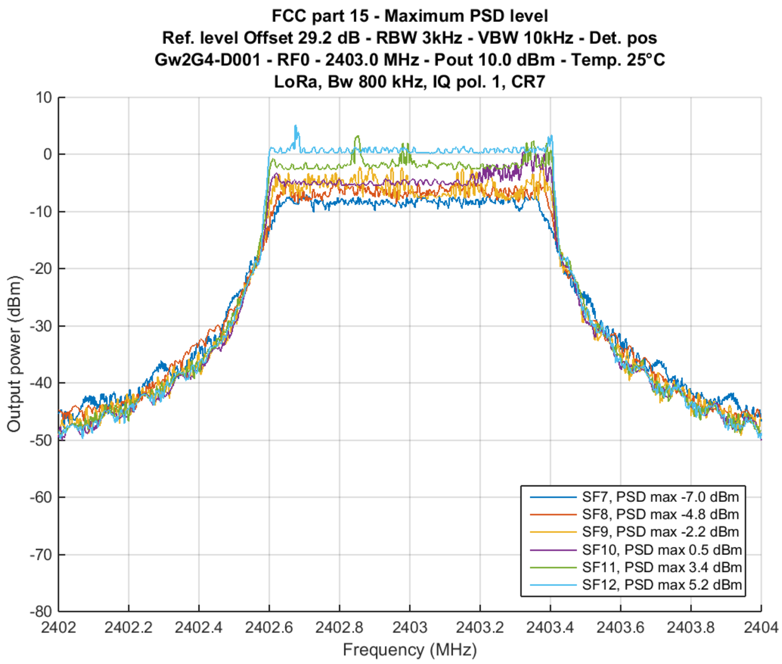


Figure 8.4: Maximum PSD level versus Spreading factor, Board D001, 2403 MHz, Bw 812.5 kHz, 25°C

8.5.2 2425 MHz

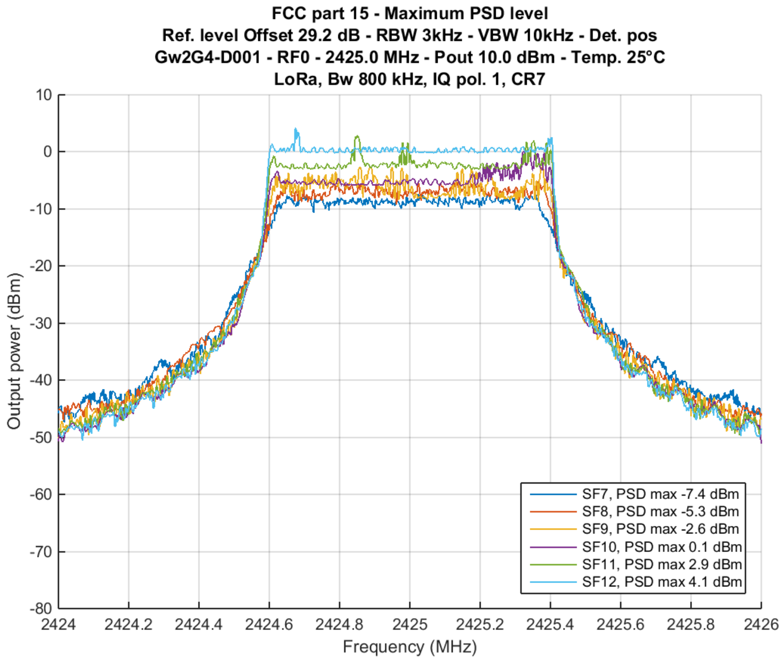


Figure 8.5: Maximum PSD level versus Spreading factor, Board D001, 2425 MHz, Bw 812.5 kHz, 25°C

8.5.3 2479 MHz

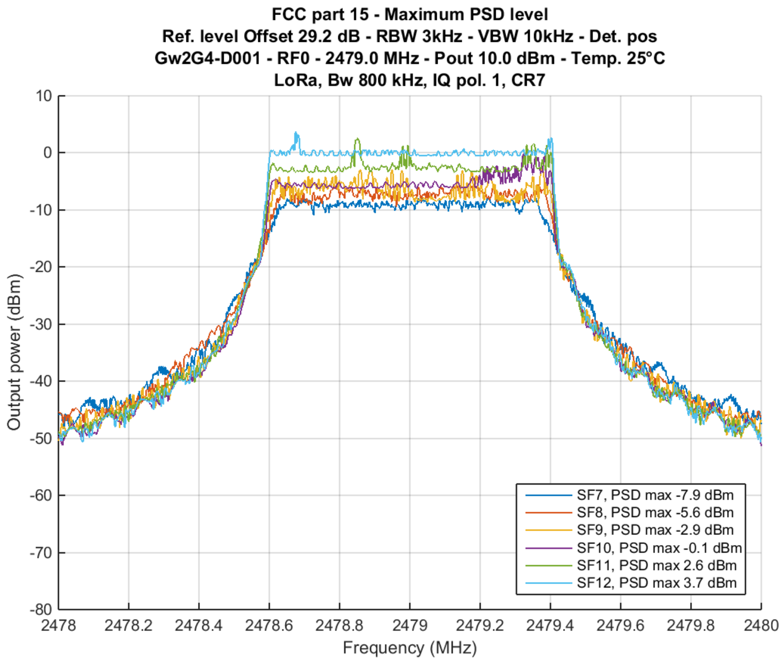


Figure 8.6: Maximum PSD level versus Spreading factor, Board D001, 2479 MHz, Bw 812.5 kHz, 25°C

8.6 Conclusion

→ **The maximum PSD value depends of the spreading factor. Nevertheless, the 2.4 GHz gateway reference design complies with the +8 dBm/3 kHz max PSD limit whatever the frequency or the spreading factor.**

9 Spurious emission (ETSI)

9.1 Description

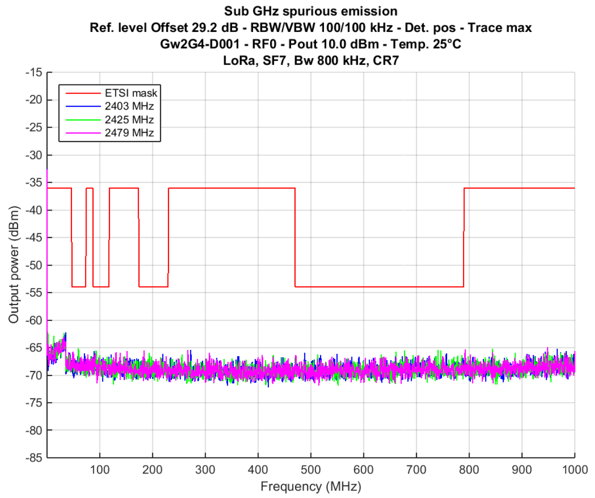
Unwanted emissions in the spurious domain (spurious emissions) are those at frequencies beyond the limit of 250 % of the occupied bandwidth above and below the centre frequency of the emission. The occupied bandwidth is measured in the section 7.

9.2 Setup

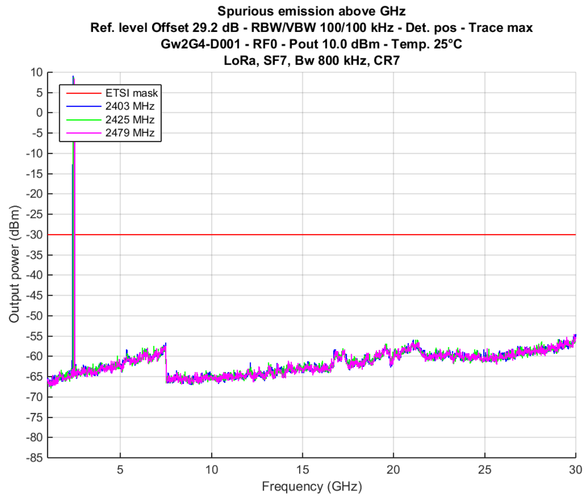
The setup used for this measurement is shown in the figure 2.1.

9.3 Frequency influence

9.3.1 SF7



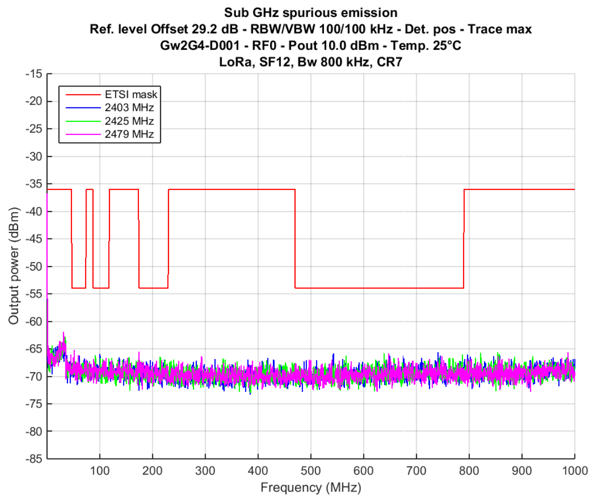
(a) Sub GHz



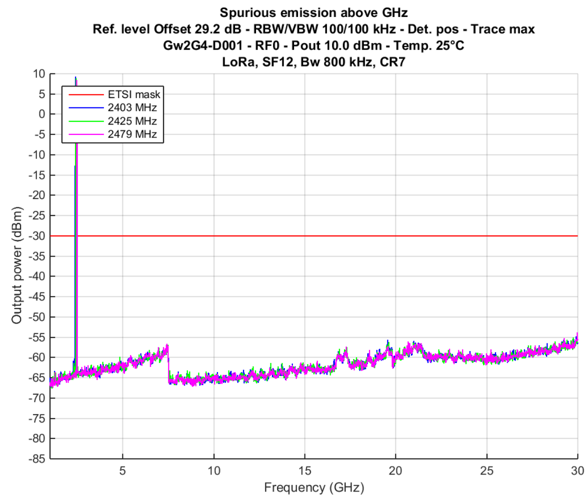
(b) Above GHz

Figure 9.1: Spurious measurement (ETSI), Board D001, LoRa, SF7, Bw 812.5 kHz, 25°C

9.3.2 SF12



(a) Sub GHz



(b) Above GHz

Figure 9.2: Spurious measurement (ETSI), Board D001, LoRa, SF12, Bw 812.5 kHz, 25°C

9.4 Conclusion

→ The 2.4 GHz gateway reference design complies with the ETSI spurious emission limits whatever the frequency or the spreading factor.

10 Out-of-band / Spurious emissions (FCC)

10.1 Description

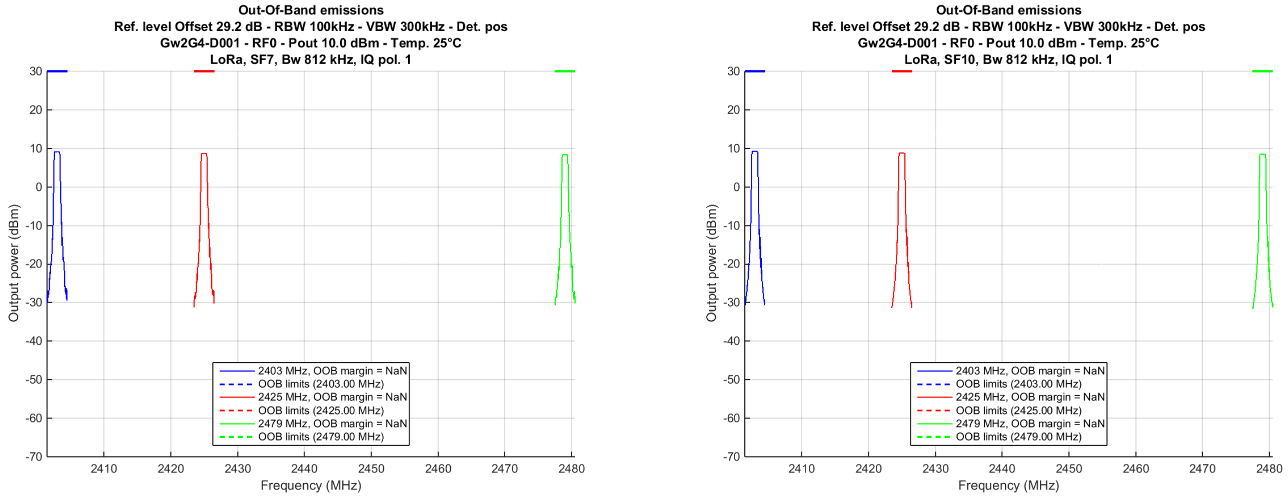
The measurement mentioned in this chapter refers to the paragraph 15.247(d) of the FCC regulation (see document [2]) and describes the power level allowed outside the normal emission frequency band (2400 to 2483.5 MHz).

The emissions which fall in the restricted bands, as defined in §15.205(a), must also comply with the emission limits specified in §15.209(a).

10.2 Setup

The setup used to measure the out of band emissions and the spurious is show in the figure 2.1. Measured in a 100 kHz bandwidth, the power level shall be attenuated by at least 20 dB compared to the highest carrier power level or 30 dB if the measurement uses an RMS averaging over a time interval.

10.3 Frequency influence

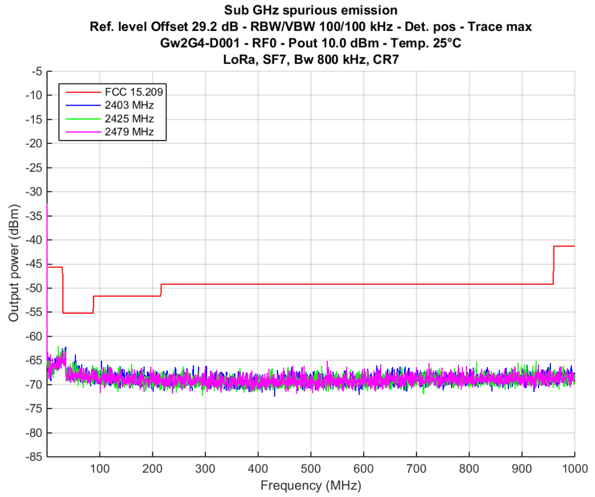


(a) SF7

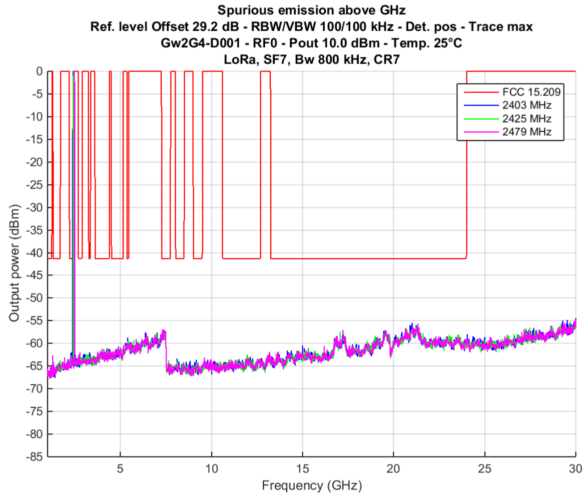
(b) SF10

Figure 10.1: Out-of-band (FCC), Board D001, SF7 and 10, Bw 812.5 kHz, 25°C

SF7



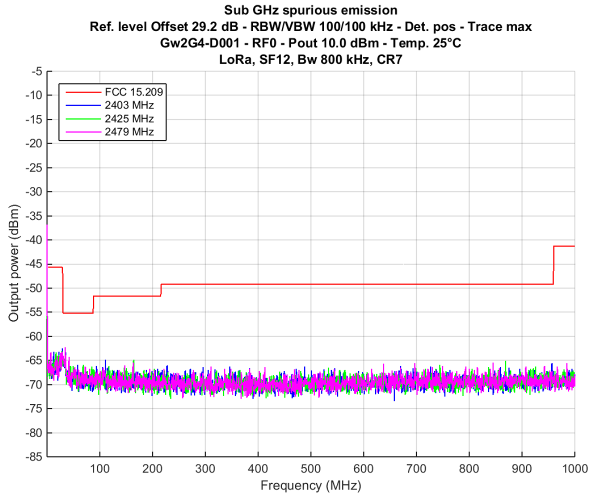
(a) Sub GHz



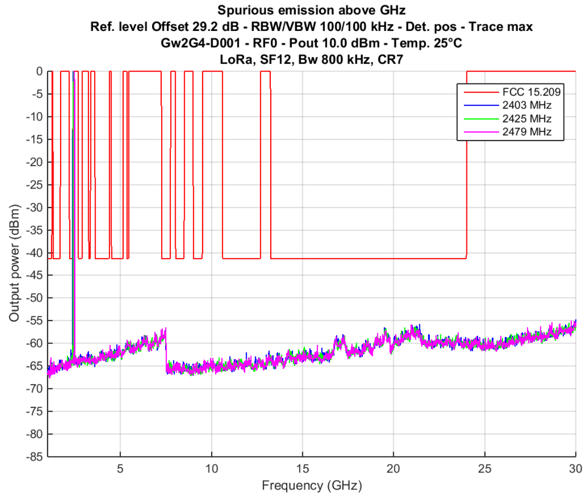
(b) Above GHz

Figure 10.2: Spurious measurement (FCC), Board D001, LoRa, SF7, Bw 812.5 kHz, 25°C

SF12



(a) Sub GHz



(b) Above GHz

Figure 10.3: Spurious measurement (FCC), Board D001, LoRa, SF12, Bw 812.5 kHz, 25°C

10.4 Conclusion

→ The 2.4 GHz gateway reference design complies with the FCC out-of-band and spurious emission limits whatever the frequency or the spreading factor.

Part III

Receiver

11 Sensitivity level and PER

11.1 Description

This measurement determines the sensitivity level i.e. the minimum RF input power needed to demodulate the received packet. It is determined for a PER of 1% according to the SX1280 datasheet (see doc. [5]). It also verifies the PER remains null for input power above the sensitivity level i.e. no saturation occurs.

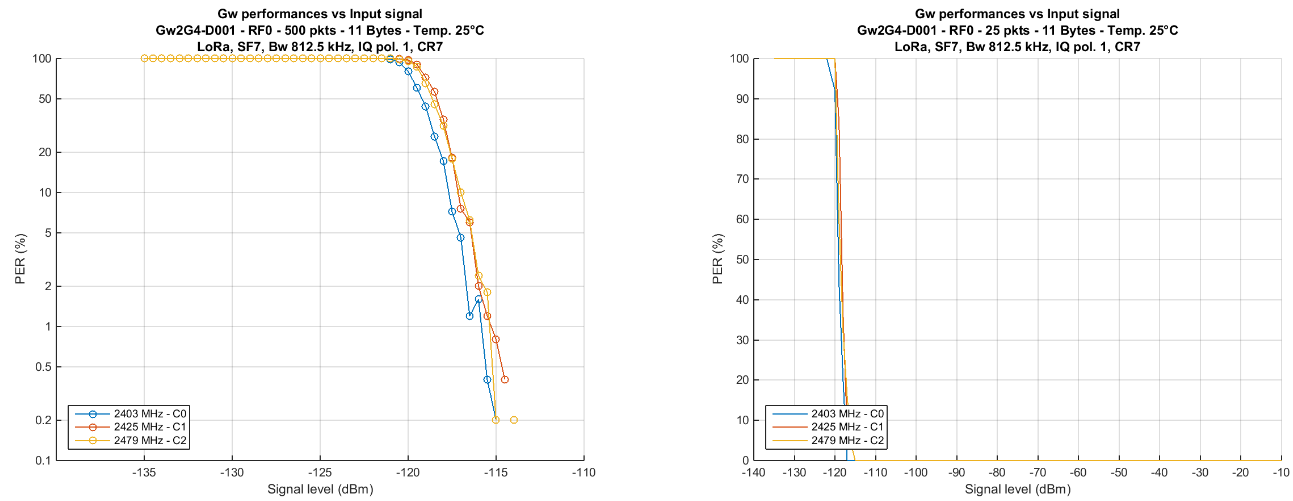
11.2 Setup

The sensitivity measurement setup is shown in figure 2.1. Only one signal generator is used here, the output of the second one is OFF. It generates LoRa packets toward the DUT for several output powers and frequencies. The effect of impedance mismatch is mitigated by the use of attenuators at the power splitter inputs.

The **packet forwarder** software running on the host pulls data from the gateway reference design by the USB bus and send them to the computer through UDP protocol.

11.3 Frequency influence

11.3.1 SF7



(a) Sensitivity level

(b) High level

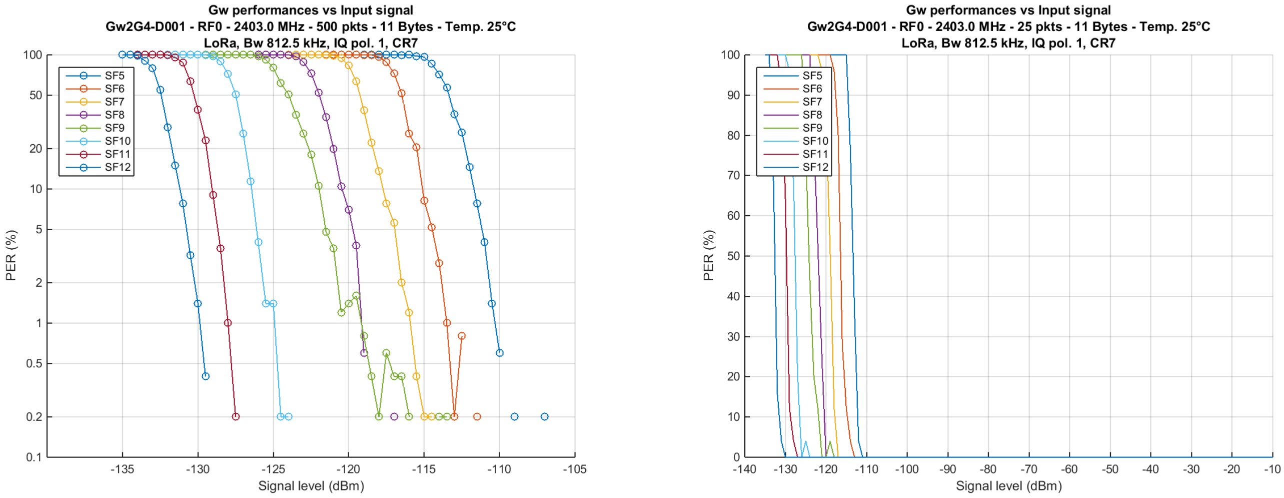
Figure 11.1: Sensitivity level and PER versus channels, Board D001, SF7, Bw 812.5 kHz, 25°C

11.3.2 Conclusion

→ **The sensitivity level for SF7 / 812.5 kHz packets and determined for a PER lower than 1% is -115 dBm**

11.4 Spreading Factor influence

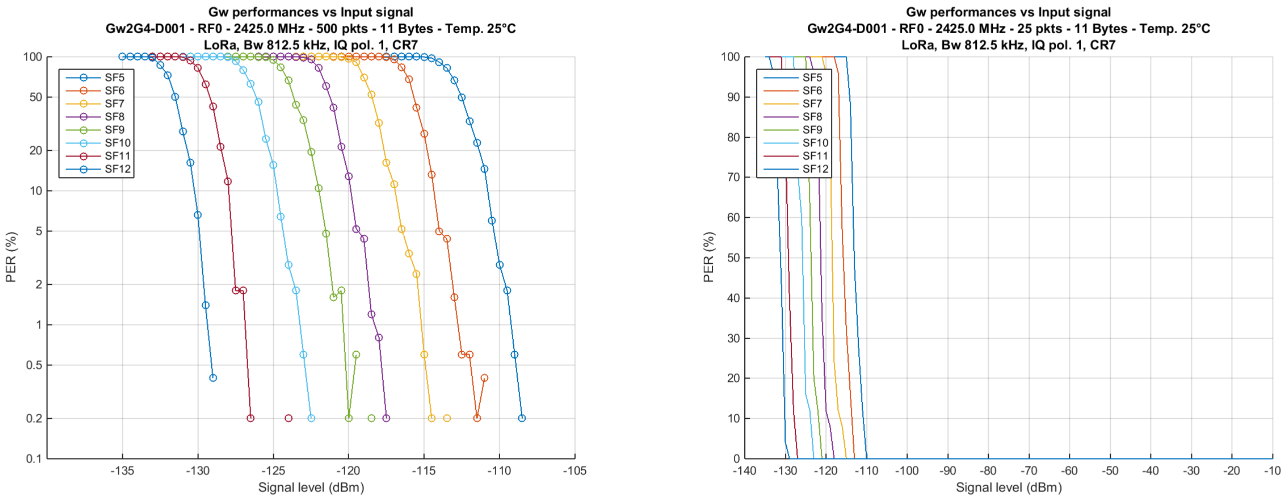
11.4.1 2403 MHz



(a) Sensitivity level (b) High level

Figure 11.2: Sensitivity level and PER versus Spreading factor, Board D001, 2403 MHz, Bw 812.5 kHz, 25°C

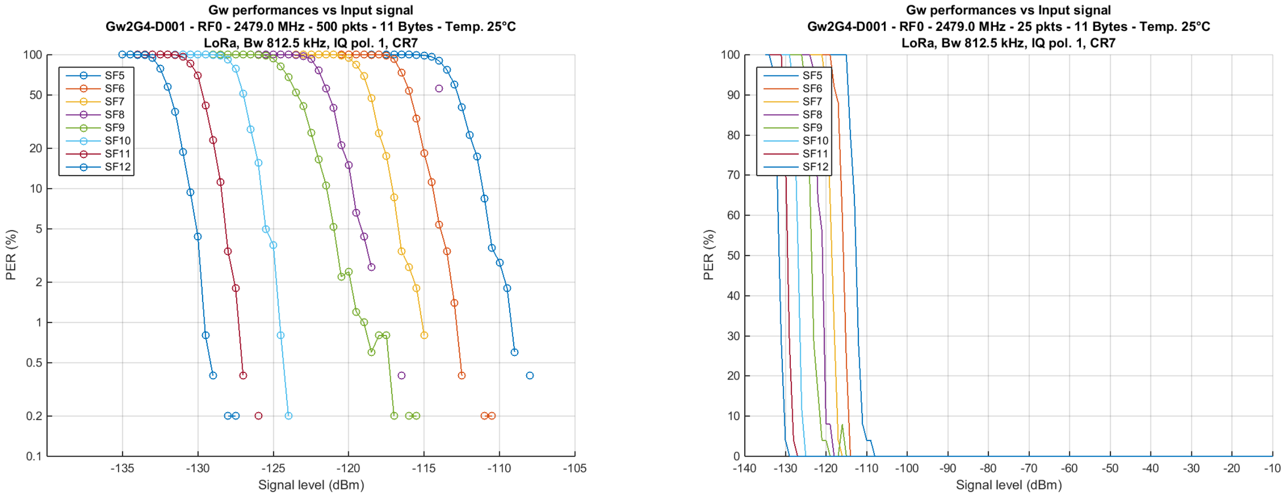
11.4.2 2425 MHz



(a) Sensitivity level (b) High level

Figure 11.3: Sensitivity level and PER versus Spreading factor, Board D001, 2425 MHz, Bw 812.5 kHz, 25°C

11.4.3 2479 MHz



(a) Sensitivity level (b) High level

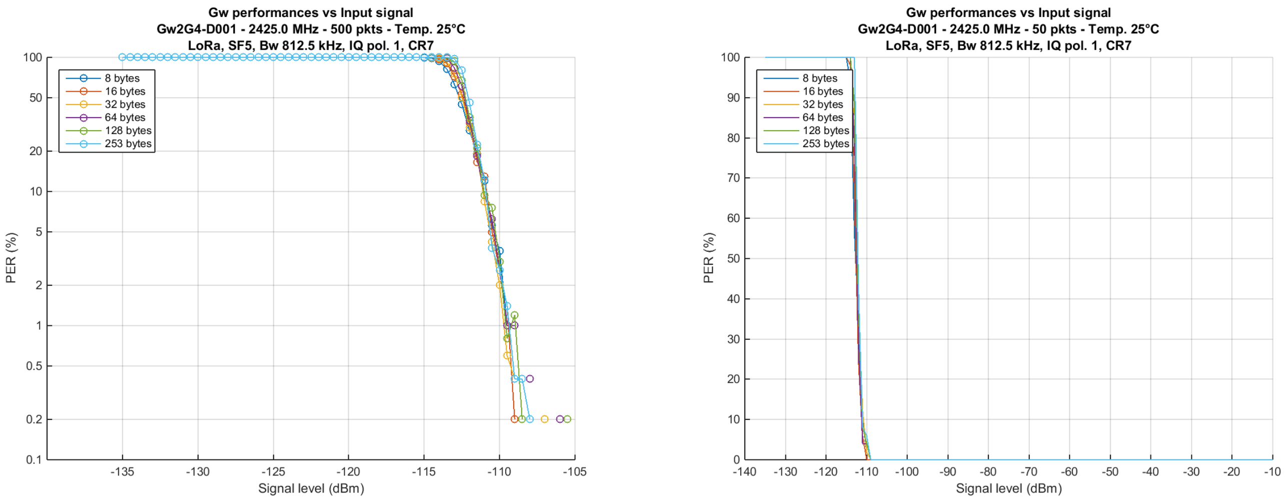
Figure 11.4: Sensitivity level and PER versus Spreading factor, Board D001, 2479 MHz, Bw 812.5 kHz, 25°C

11.4.4 Conclusion

→ The sensitivity level complies with the requirements. The PER remains null whatever the input level and no saturation occurs.

11.5 Payload length influence

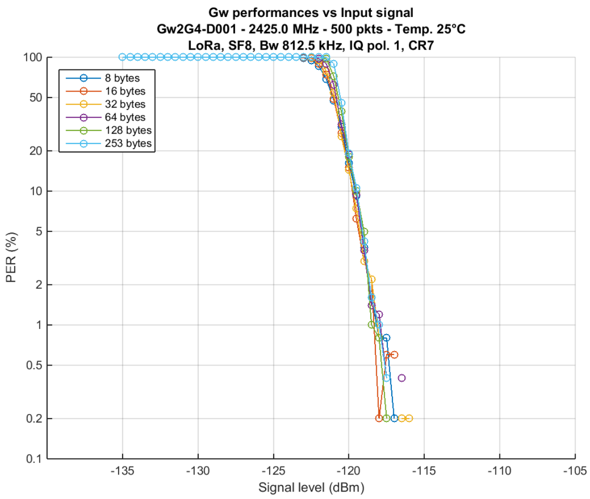
11.5.1 SF5



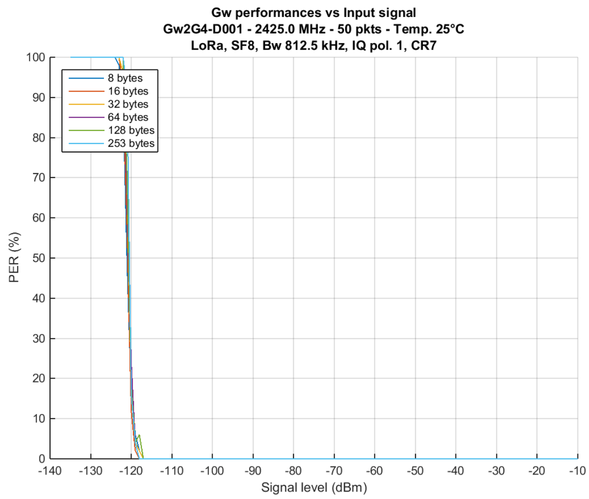
(a) Sensitivity level (b) High level

Figure 11.5: Sensitivity level and PER versus payload length, Board D001, 2425 MHz, SF5, Bw 812.5 kHz, 25°C

11.5.2 SF8



(a) Sensitivity level



(b) High level

Figure 11.6: Sensitivity level and PER versus payload length, Board D001, 2425 MHz, SF8, Bw 812.5 kHz, 25°C

11.5.3 Conclusion

→ **The payload length does not influence the sensitivity level whatever the spreading factor. It does not cause any issue at high input power.**

12 RSSI

12.1 Description

The LoRa modems returns an indicator of the received signal level, the RSSI Channel. This indicator represents the power in the channel bandwidth, taken care the power of signal and the thermal noise.

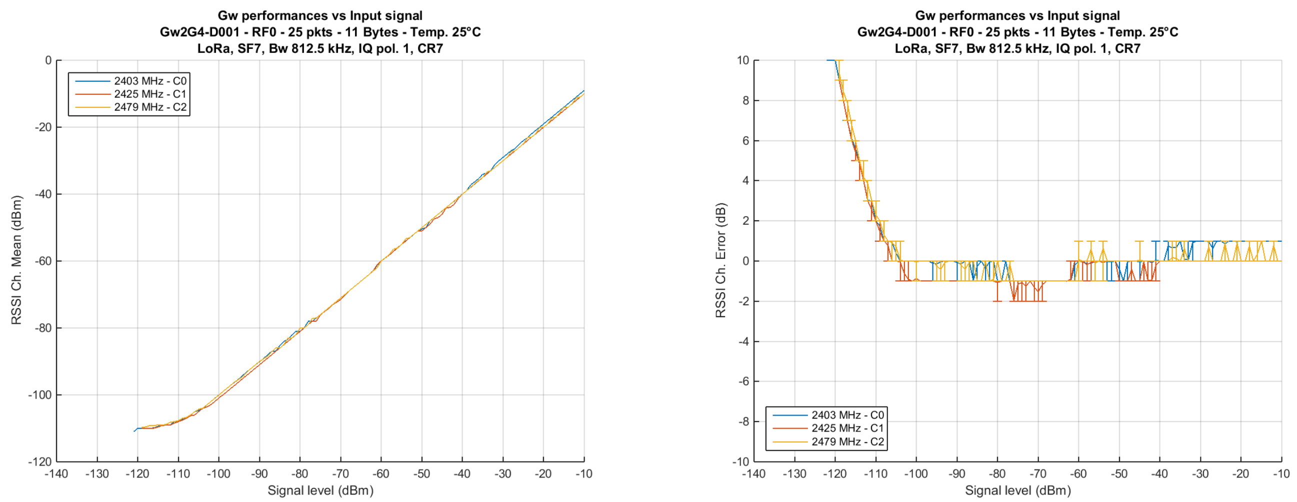
12.2 Setup

The RSSI measurement is performed simultaneously of the PER one. The setup is shown in figure 2.1. Only one signal generator is used here, the output of the second one is OFF. It generates LoRa packets toward the DUT for several output powers and frequencies. The effect of impedance mismatch is mitigated by the use of attenuators at the power splitter inputs.

The **packet forwarder** software running on the host pulls data from the gateway reference design by the USB bus and send them to the computer through UDP protocol.

The results present the mean value computed with the linear values of measured samples then expressed in a logarithm way. For each measurement step, the top and bottom horizontal bars represent the maximum and the minimum RSSI channel value. They should be close to the mean value.

12.3 Frequency influence



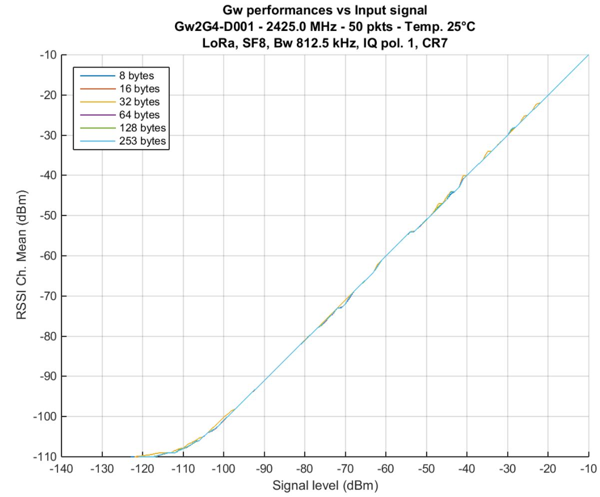
(a) RSSI mean

(b) RSSI error

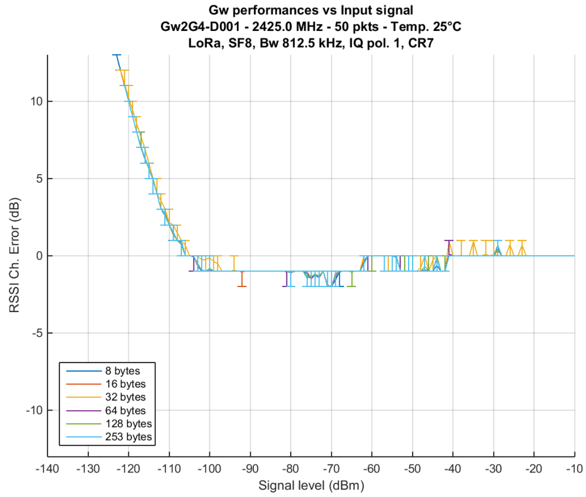
Figure 12.1: RSSI versus channels, Board D001, SF7, Bw 812.5 kHz, 11 bytes, 25°C

12.4 Payload length influence

12.4.1 SF8



(a) RSSI mean



(b) RSSI error

Figure 12.2: RSSI versus payload length, Board D001, 2425 MHz, SF8, Bw 812.5 kHz, 25°C

12.4.2 Conclusion

→ **Above -70 dBm for SF5 and SF6, the RSSI indicator may be inaccurate. This issue is currently under investigation. This issue is not present for higher spreading factors.**

13 SNR

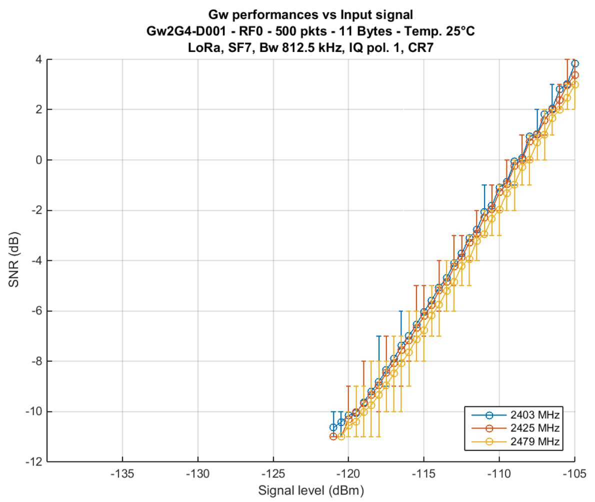
13.1 Presentation

In conjunction with the RSSI value, the LoRa modem determines the Signal-To-Noise Ratio while receiving packets. This test verifies the accuracy of this indicator according the packet parameters (Spreading Factor, payload length, ...)

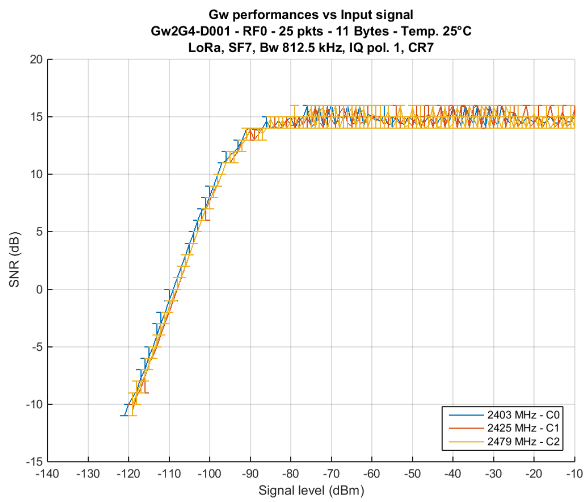
13.2 Setup

The SNR is measured using the setup presented in figure 2.1 and performed simultaneously of the PER and the RSSI measurements. The results present the mean value computed with the linear values of measured samples then expressed in a logarithm way. For each measurement step, the top and bottom horizontal bars represent the maximum and the minimum SNR value. They should be close to the mean value.

13.3 Frequency influence



(a) Sensitivity level

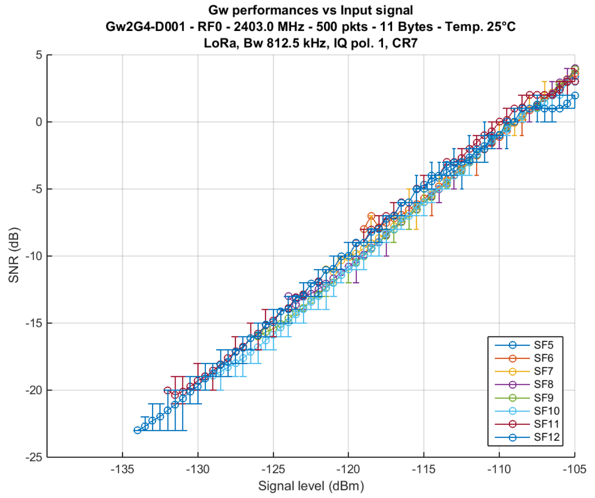


(b) High level

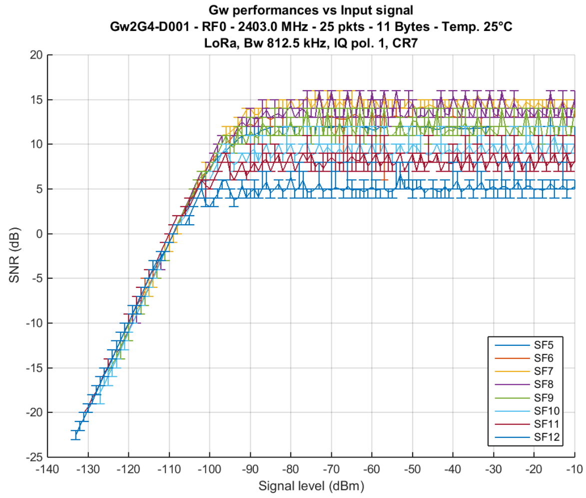
Figure 13.1: SNR versus channels, Board D001, SF7, Bw 812.5 kHz, 25°C

13.4 Spreading Factor influence

13.4.1 2403 MHz



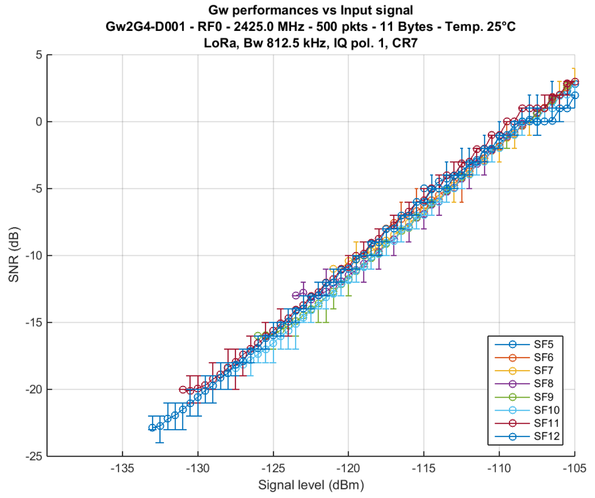
(a) Sensitivity level



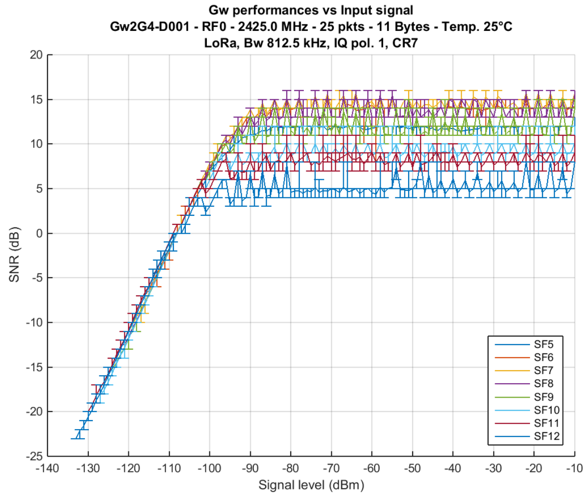
(b) High level

Figure 13.2: SNR versus Spreading factor, Board D001, 2403 MHz, Bw 812.5 kHz, 25°C

13.4.2 2425 MHz



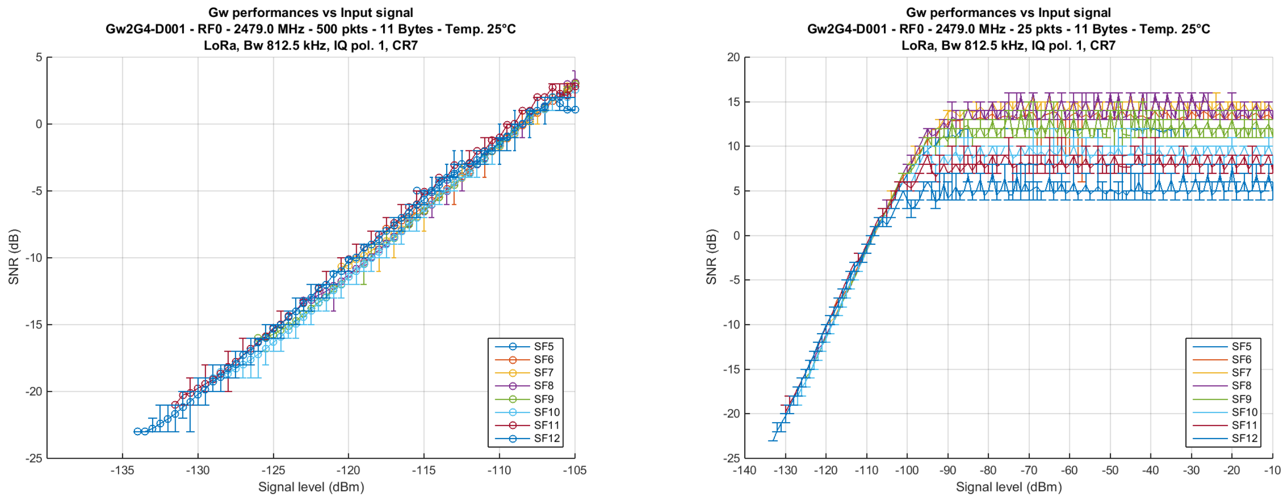
(a) Sensitivity level



(b) High level

Figure 13.3: SNR versus Spreading factor, Board D001, 2425 MHz, Bw 812.5 kHz, 25°C

13.4.3 2479 MHz

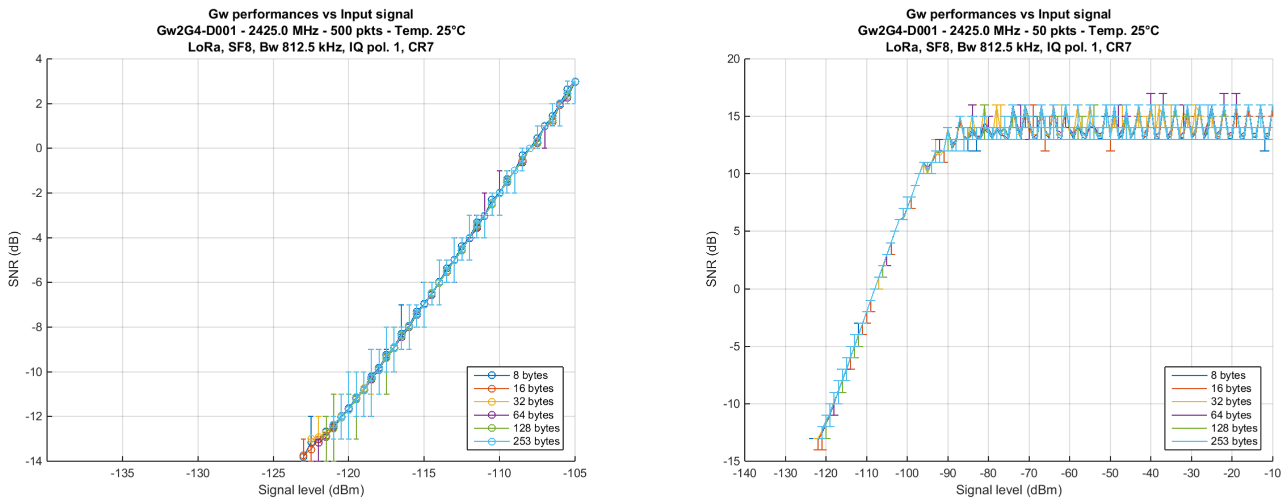


(a) Sensitivity level (b) High level

Figure 13.4: SNR versus Spreading factor, Board D001, 2479 MHz, Bw 812.5 kHz, 25°C

13.5 Payload length influence

13.5.1 SF8



(a) Sensitivity level (b) High level

Figure 13.5: SNR versus payload length, Board D001, 2425 MHz, SF8, Bw 812.5 kHz, 25°C

A Acronyms and Glossary

ADC chipset function, analog digital converter

ARIB Association of Radio Industries and Businesses

ATE automatic test equipment used to test the integrated chipset

AWGN Additive White Gaussian Noise

BOM bill of material for a given printed board circuit

BS base station of a radio system

CCAS Clear Channel assessment. This process is intended to be used for allocating or reserving the correct channel for the RF transmission

CDMA code division multiple access. In order to have several communication on the same medium, we can separate them by code projection means

CW carrier wave, used in radio frequency transmission

CPW coplanar waveguide for a transmission line

CPWG coplanar grounded waveguide for a transmission line

CPU central processing unit

DAC Digital Analog Converter

dBc unit description, decibel relative to the carrier maximum power

dBd dB towards dipole antenna (2.14 dBi)

dBi dB isotropic, used to define antenna gain

dBm unit description, decibel relative to milliwatt

DRC Design Rules Check

DPI Design Public Interface, define the interface of a design in terms of mechanics, materials, constraint.

DUT Device Under Test during measurement

EIRP Emitted Isotropic Radiated Power

EMC electromagnetic compliance

ERC Electrical Rules Check

ETSI European Telecommunications Standard Institute

FCC Federal Communications Commission

FEC Forward Error Correction, algorithm used by combining received data and redundancy codes to recover from false data

FER Frame Error Rate

FHSS Frequency Hopping Spread Spectrum used in radio frequency transmission

FM Frequency Modulation used in radio frequency transmission

FTS Fine TimeStamps identifying when a packet is received

HAL Hardware Abstraction Layer

IEC International Electrotechnical Commission

IF radio frequency term as intermediate frequency, used to describe the frequency used in up or down conversion system

IFA inverted F antenna : an antenna that looks like and inverted F letter

IL Insertion Loss

ISA industry standard architecture

ISM industrial, scientific and medical frequency band as described in the ERC70-3

JIT Just In Time TX scheduling

LBT Listen Before Talk. Process that oblige a device to listen a RF channel before using it, in order to ensure that this channel is not occupied

LIC Least Interferer Channel. A type of LBT process

LOS Line Of Sight. This term describe how the wave are propagated between a transmitter and a receiver, in a direct manner

LPF Low Pass Filter. Electronic function where high frequencies are attenuated whereas low frequencies stay unchanged

MIPS million instruction per second

MMIC Monolithic Microwave Integrated Circuit used to describe the integrated circuit in microwave technologies

MOSI Master Output Slave Input, Synchronous Serial Link

MISO Master Input Slave Output, Synchronous Serial Link

MS mobile station

N/A not applicable or not available

NLOS Non Line Of Sight. This term describe how the wave are propagated between a transmitter and a receiver, in a non direct manner. only reflection are taken into account

NRI National Radio Interface

OCW Occupied Channel Bandwidth

OOB out of band, describe the spurious that do not belong to the wanted emission spectrum, and outside the authorized band in usage

OSR Over Sampling Ratio, uses to determine a sampling frequency

p.d.f. probability density function

PA Power Amplifier

PIFA plate inverted F antenna describe an antenna that looks like a plate that has a F letter shape seen from the side

PPS Pulse Per Second. Electrical signal uses for precise timekeeping and time measurement

PSD Power Spectral Density

PSU Power Supply Unit

RBW resolution bandwidth, spectrum analyzer setting

RF Radio Frequency

RFU Reserved for Future Use

RPI Raspberry Pi, development board

RSSI receiving signal strength indicator used in radio frequency system

RAM random access memory

Rx Receiver

SF Spreading Factor, a LoRa modulation parameter

SNR Ratio of signal power to the noise power

SPDT single path dual through, describe the type of switch only a single is connected at a given time

SPI serial peripheral interface used to connect different chip with a reduced number of signals

SRD Short Range Devices

SWR Standing Wave Ratio, a measurement to express the impedance matching efficiency

UFL U.FL miniature microwave connector

VBW video bandwidth, spectrum analyzer setting

VLT Victim Link transmitter

VNA Vector Network Analyzer

XO crystal oscillator

Important Notice

Contact Information

Semtech Corporation
Wireless & Sensing Products
200 Flynn Road, Camarillo, CA 93012
Phone: (805) 498-2111, Fax: (805) 498-3804