SEMTECH

WIRELESS & SENSING PRODUCTS

Corecell reference design for LBT Spectral Scan gateway

USB / US915 Performances report

Abstract

The Corecell reference design is a gateway plateform designed to allow gateways infrastructure deployments in both indoor and outdoor scenarios and which implement the baseband processor SX1302 and the radio transceiver SX1250. This document presents the compliance measurements results to the tests required by FCC regulation as well as the performance and robustness measurements required for a LoRa gateway.

History

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

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1 Introduction

1.1 Presentation

The Corecell gateway is a reference design based on the SX1302 baseband processor and the radio transceiver SX1250. It has been designed to allow gateways infrastructure deployments in both indoor and outdoor scenarios.

It addresses market needs for cost optimised, low power, low touch development and accelerates gateway design by providing a new reference design.

1.2 Scope

This document presents the measurement performed on the PCB E539v03a for the **US region**. This third version of the Corecell gateway improves the power supply sequence during the boot-up phase. It also enables both the USB link with the host and the LBT functionality.

1.3 References

The following documents are cited in the present one:

1. **Part 15 of Title 47 of the Code of Federal Regulations** Official FCC rules that shall be fulfil by any RF device designed for the US market.
2. **558074 D01 DTS Meas Guidance v03r05** guidance for performing compliance measurements on Digital Transmission Systems (DTS) operating under Section 15.247.
3. **LoRaWAN v1.1 specification** describes the LoRaWAN™ network protocol.
4. **LoRaWAN 1.1 Regional Parameters** The companion document to the LoRaWAN 1.1 protocol specification [3].

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 Frequency plan

The LoRaWan 1.1 Regional Parameters [4] defines the frequency plan in the 902-928 MHz band. It is shown in figure 2.1.

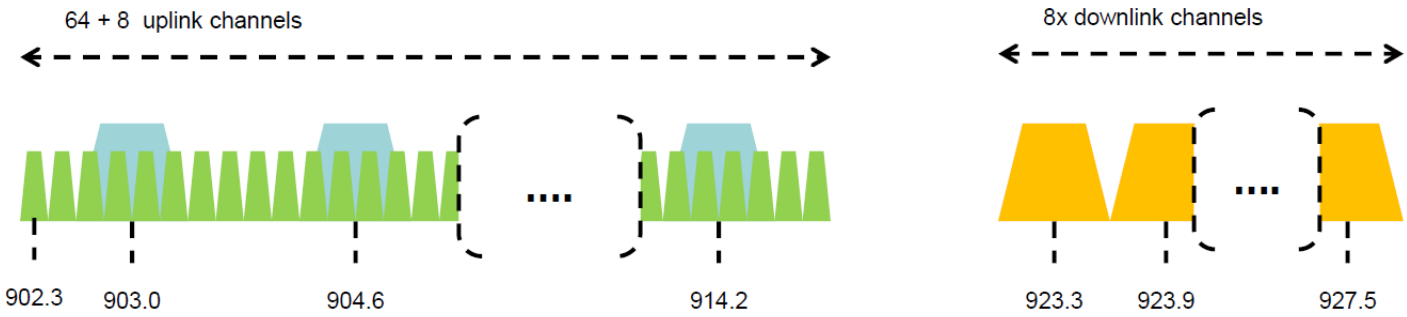


Figure 2.1: Frequency plan applicable in the US band.

2.1 Upstream

64 narrow band channels

Frequencies 902.3 to 914.9 MHz

Channels separation 200 kHz

Bandwidth 125 kHz

Spreading factor SF7 to SF10 (DR0 to DR3)

8 wide band channels

Frequencies 903.0 to 914.2 MHz

Channels separation 1.6 MHz

Bandwidth 500 kHz

Spreading factor SF8 (DR4)

2.2 Downstream

8 wide band channels

Frequencies 923.3 to 927.5 MHz

Channels separation 600 kHz

Bandwidth 500 kHz

Spreading factor SF7 to SF10 (DR10..DR13)

3 Test bench

3.1 General description

The general test bench used along this document to validate the Corecell gateway reference design is shown in figure 3.1. This testbench checks its compliance to the regulation limits as well as evaluates its performances.

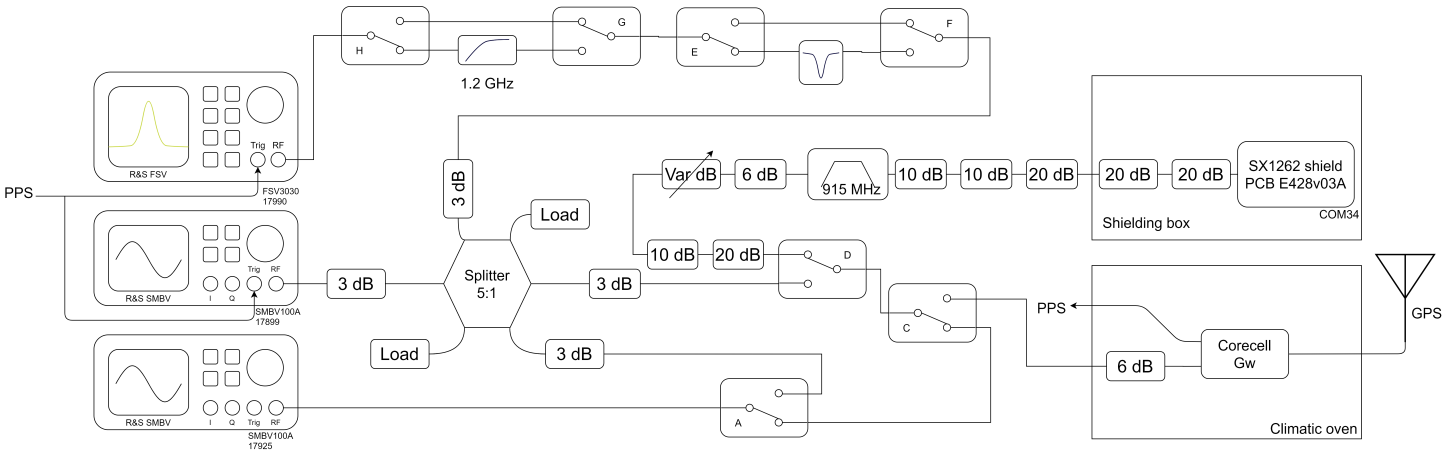


Figure 3.1: Overall test bench setup used to validate the Corecell gateway

This setup allows to perform all the Tx measurements including the downlink PER measurement of chapter 12, the Rx measurements, the blocking profile and the LBT validation without updating the setup. The notch and the HPF are only enabled for spurious emission measurements to decrease the carrier level.

The Corecell gateway interface board (PCB e525v03a) has a GPS module providing the PPS signal to both the signal analyzer and the signal generator and allowing to synchronize the measurements.

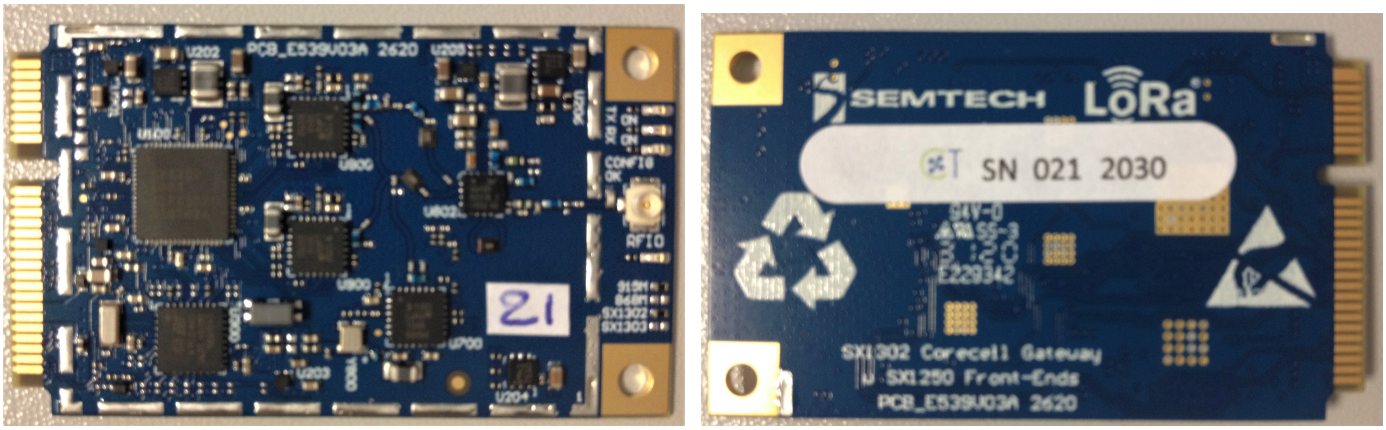
The signal generator TID 17899 is used for all RX measurements. The instrument TID 17925 is used for the blocking profile measurement as well as the Downlink PER measurement (chapter 12).

The JTAG interface of a Nucleo board is used to download the firmware in the on-board MCU.

4 Devices under test

4.1 Presentation

The device used for the measurements of this report is the Corecell gateway V3 (PCB e539v03a) populated for US region; The serial number is SN 021 2030. Along the document, it is referred as **Board US21**. The board SN 002 2042 is also used in this document and is referenced as **Board US0022042**.



(a) Top

(b) Bottom

Figure 4.1: The Corecell gateway V3 (PCB e539v03a) US21 validated along this document

The board is connected on the mini-pcie connector on the interface board (PCB e525v03a) allowing the connection with the host (RPI3) through a USB cable, providing the 3.3V power supply voltage to the Corecell and the PPS signal from the GPS module.

The Corecell gateway mounted on the interface board is placed in the climatic oven to check the performances over temperature.

- The ferrite bead **FB207** is not populated: The power supply voltage **VCCIO33** is provided by the VCC3V3_IN input voltage and not from the on-board 3.3V regulator output.
- The ferrite bead **FB206** is removed; the component is placed on **FB204**: The power supply voltage **VCC_FEM** is provided by the VCC3V3_IN input voltage and not from the on-board 3.3V regulator output.

4.2 Software versions

The following softwares are used in the next measurements:

- **HAL**: v2.0.0
- **Packet forwarder**: v2.0.0
- **Firmware**: v2.0.6

5 Results summary

5.1 Board

Items	Results
Current consumption	Complies with the expected current consumption

5.2 Transmitter

Items	Results
Output power	Provides up to +27 dBm.
Modulation bandwidth	Complies with the minimum -6 dB bandwidth of 500 kHz
Maximum power spectral density level	Complies with the max. PSD level of +8 dBm / 3kHz
Out-of-band / Spurious emissions	Complies with the chapter 15.247 (d) of the FCC regulation
Beacon emission time accuracy	Complies with the LoRaWan class B requirement of 1500 ± 1µs
Downlink PER	The quality of modulation is as expected

5.3 Receiver

Items	Results
Sensitivity level and PER	The sensitivity level and the PER for higher signal input levels comply with the expected performances
RSSI	The RSSI channel and signal provide an accurate estimation of the signal input level over a wide dynamic range
SNR	The LoRa modem provides an accurate SNR value over a wide dynamic range
Blocking and Immunity to interferer	Provides at least 50 dB of interferers rejection
Frequency error tolerance	Tolerant to the end-device Xtal frequency error
Frequency drift tolerance	Robust to the end-device oscillator frequency drift

Part I

Board

6 Current consumption

6.1 Description

The current consumption is monitored in three modes:

1. IDLE mode: The Corecell gateway is plugged in the interface board on its mini-pcie connector and supplied. The MCU firmware is running but the packet forwarder is not launched yet.
2. Tx mode: Using the HAL tool `test_loragw_hal_tx`, the Corecell transmits packets with an extremely long preamble at the highest output power (+27 dBm).
3. Rx mode: The packet forwarder is running. The SX1302 and the two transceivers SX1250 are initialized. The SX1261 used for the LBT and the spectral scan feature is also initialized. Packets are generated externally and received by the gateway.

6.2 Setup

The current is measured using an ammeter connected on the jumper **VCC3V_core**. The `sx1250_setup` function is modified as follow:

```
/* Set Radio in Standby for calibrations */
buff[0] = (uint8_t)STDBY_RC;
err |= sx1250_reg_w(SET_STANDBY, buff, 1, rf_chain);
wait_ms(10);

/* Get status to check Standby mode has been properly set */
buff[0] = 0x00;
err |= sx1250_reg_r(GET_STATUS, buff, 1, rf_chain);
if ((uint8_t)(TAKE_N_BITS_FROM(buff[0], 4, 3)) != 0x02) {
  printf("ERROR: Failed to set SX1250_%u in STANDBY_RC mode\n", rf_chain);
  return LGW_REG_ERROR;
}

/* Enable the DCDC */
if (0) {
  printf("Enable DCDC\n");
  buff[0] = 0x01;
}
else {
  printf("Disable DCDC\n");
  buff[0] = 0x00;
}
err |= sx1250_reg_w(SET_REGULATORMODE, buff, 1, rf_chain);
wait_ms(10);

/* Run all calibrations (TCXO) */
buff[0] = 0x7F;
err |= sx1250_reg_w(CALIBRATE, buff, 1, rf_chain);
wait_ms(10);
```

6.3 Results

Modes	Input voltage (V)	Current consumption (mA)
Idle	3.29	18.1
Rx LDO	3.25	54
Rx DCDC	3.27	46
Tx	3.08	380

Table 6.1: Current consumption, Board US21, Room temperature

6.4 Conclusion

→ **The Corecell V3 complies with the expected current consumption.**

Part II

Transmitter

7 Output power

7.1 Description

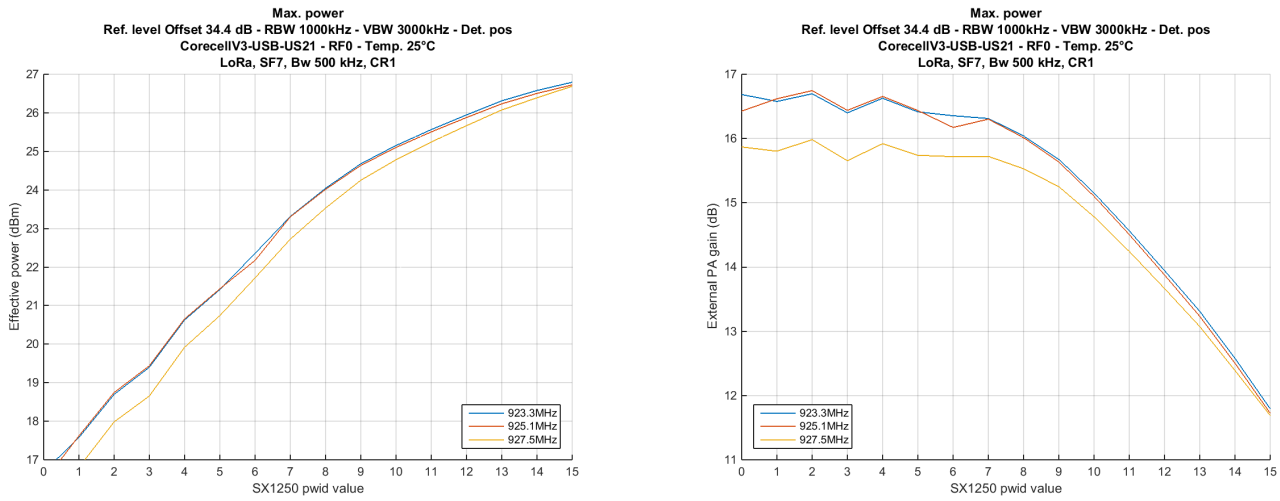
This section evaluates the output power trimming capability.

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.

7.2 Setup

The setup used for this measurement is described in section 3.1. The output power is measured on the SMA connector present on the interface board, including the UFL-UFL cable between the Corecell and the interface boards.

7.3 Frequency influence



(a) Absolute (dBm)

(b) Relative (dB)

Figure 7.1: Output power response vs channel, Board US21, SF7, Bw 500 kHz, 25°C

7.4 Conclusion

→ **The Corecell reference design provides up to +27 dBm. The accuracy of the output power trimming is lower than 0.5dB.**

8 Modulation bandwidth

8.1 Description

The chapter 15.247(a)(2) of the FCC regulation mentions the gateway 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.

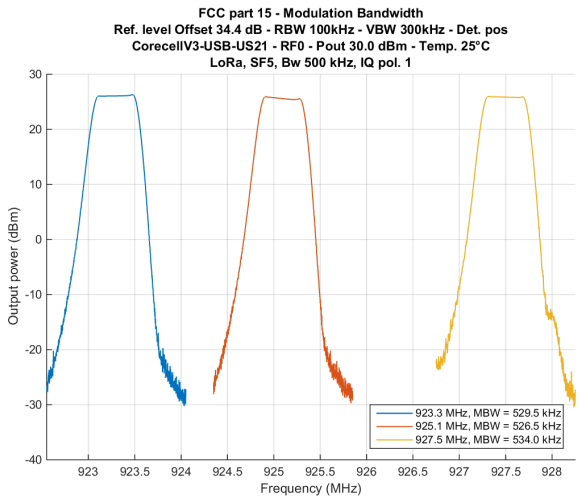
8.2 Setup

The setup used for this measurement is described in the section 3.1.

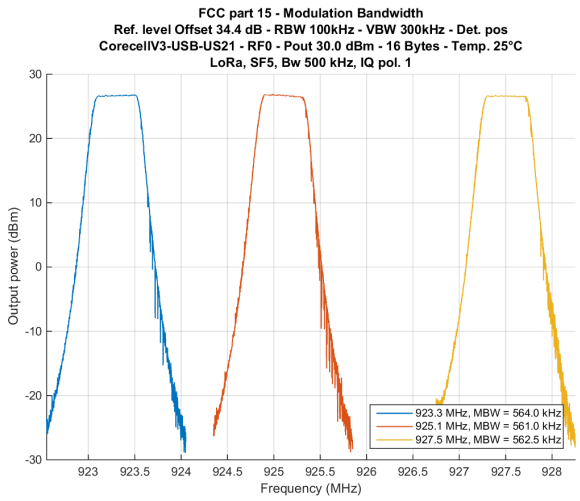
8.3 Frequency influence

→ **The measurements of this section are performed while transmitting one packet with an extremely long unmodulated preamble and over thousands of short packets.**

8.3.1 SF5



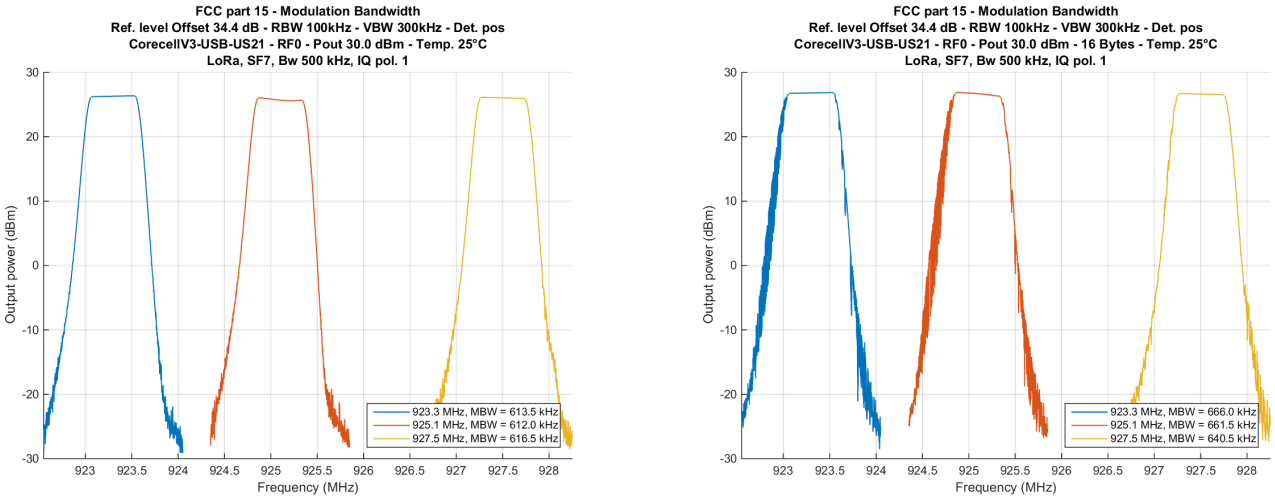
(a) Long preamble



(b) Short packets

Figure 8.1: Modulation bandwidth vs channel, Board US21, SF5, Bw 500 kHz, 25°C

8.3.2 SF7

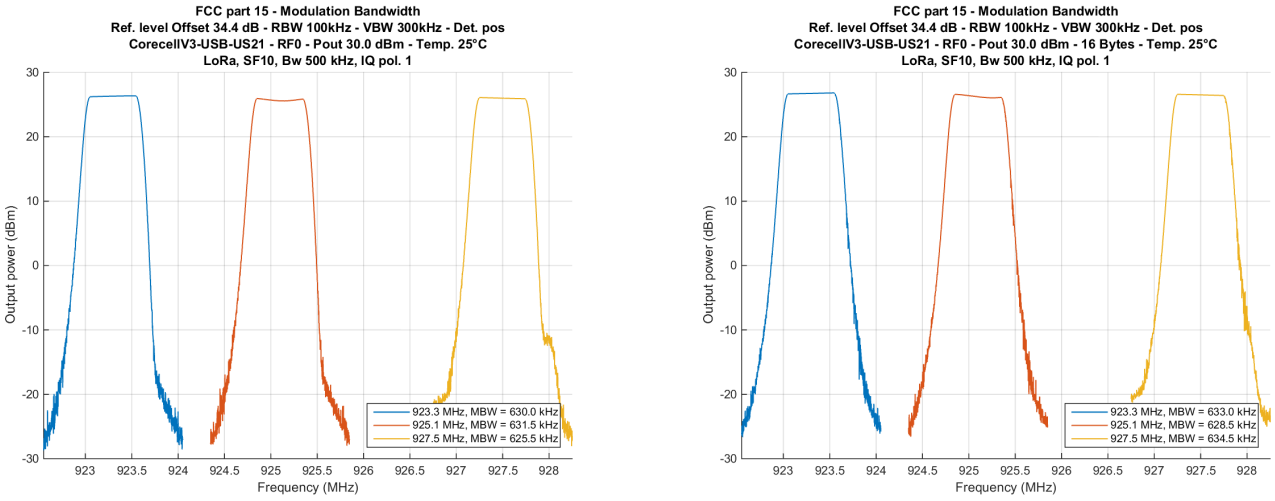


(a) Long preamble

(b) Short packets

Figure 8.2: Modulation bandwidth vs channel, Board US21, SF7, Bw 500 kHz, 25°C

8.3.3 SF10



(a) Long preamble

(b) Short packets

Figure 8.3: Modulation bandwidth vs channel, Board US21, SF10, Bw 500 kHz, 25°C

8.4 Spreading factor influence

8.4.1 923.3 MHz

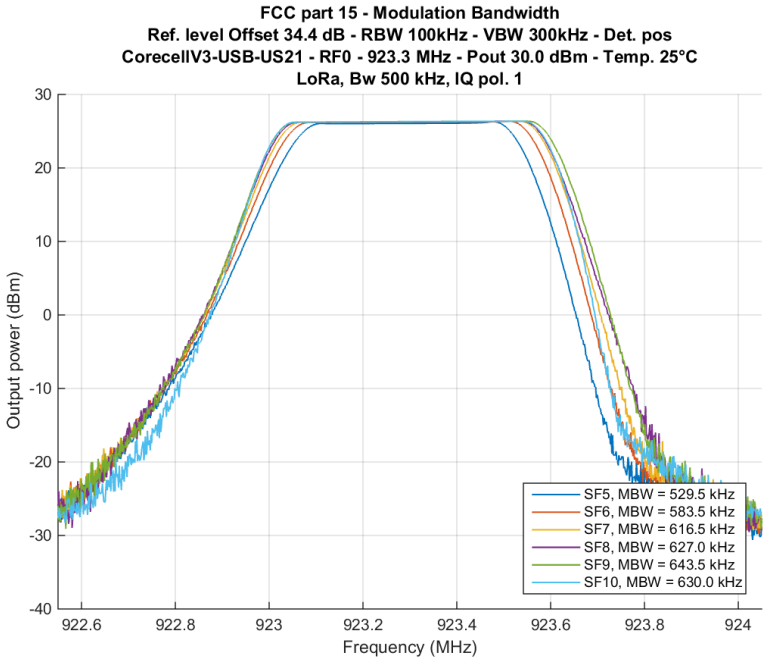


Figure 8.4: Modulation bandwidth vs Spreading factor, Board US21, 923.5 MHz, Bw 500 kHz, 25°C

8.4.2 925.1 MHz

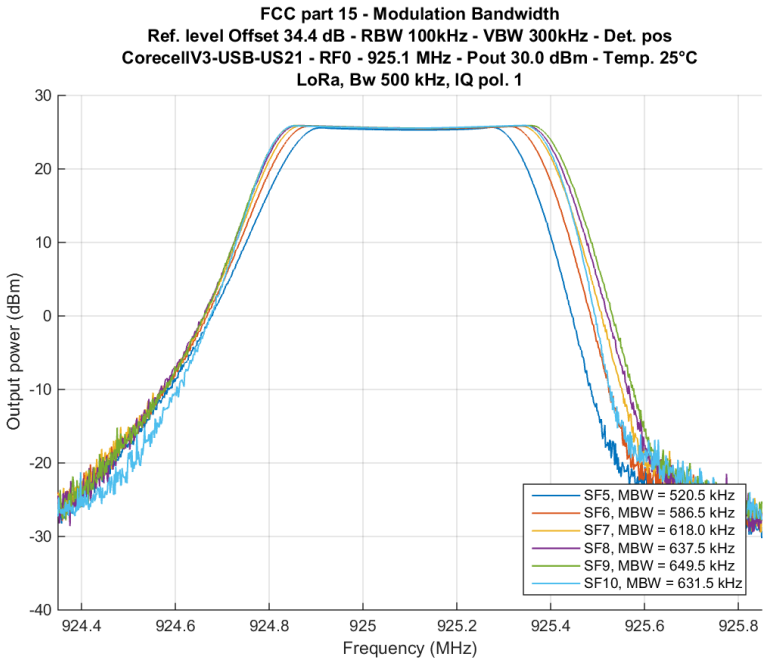


Figure 8.5: Modulation bandwidth vs Spreading factor, Board US21, 925.1 MHz, Bw 500 kHz, 25°C

8.4.3 927.5 MHz

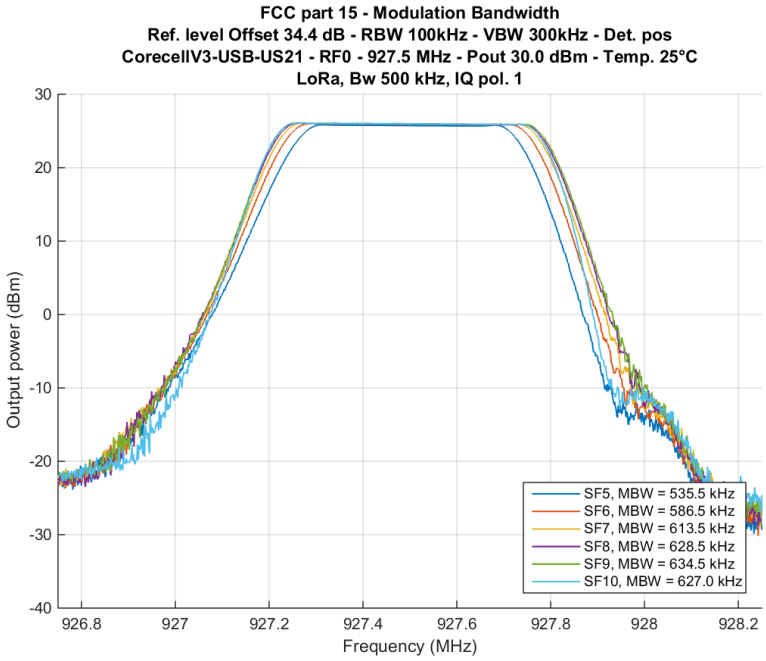


Figure 8.6: Modulation bandwidth vs Spreading factor, Board US21, 927.5 MHz, Bw 500 kHz, 25°C

8.5 Temperature influence

8.5.1 SF5

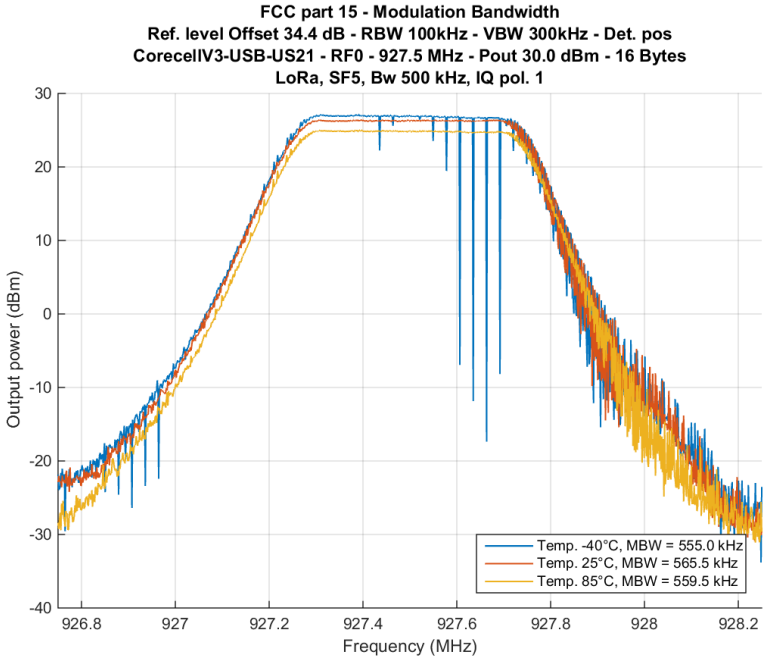


Figure 8.7: Modulation bandwidth vs temperature, Board US21, 927.5 MHz, SF5, Bw 500 kHz

8.5.2 SF7

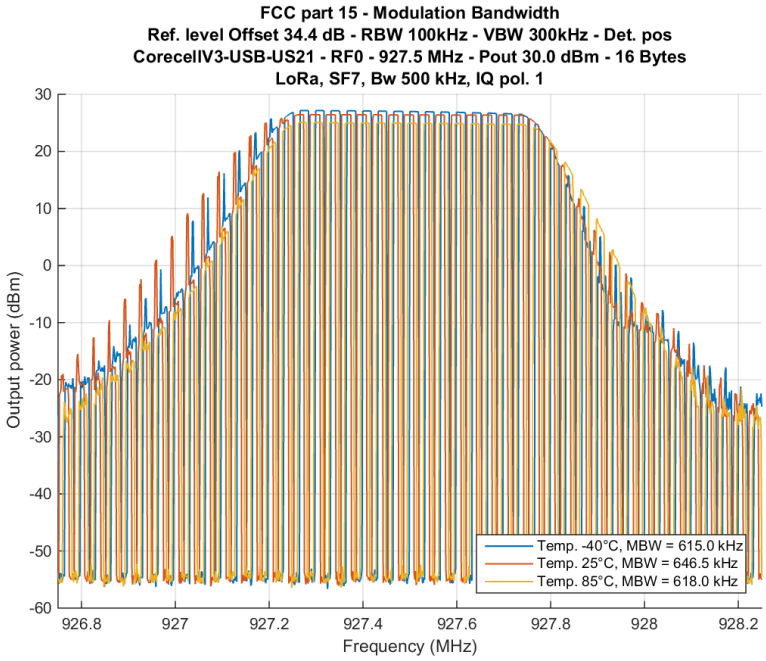


Figure 8.8: Modulation bandwidth vs temperature, Board US21, 927.5 MHz, SF7, Bw 500 kHz

8.5.3 SF10

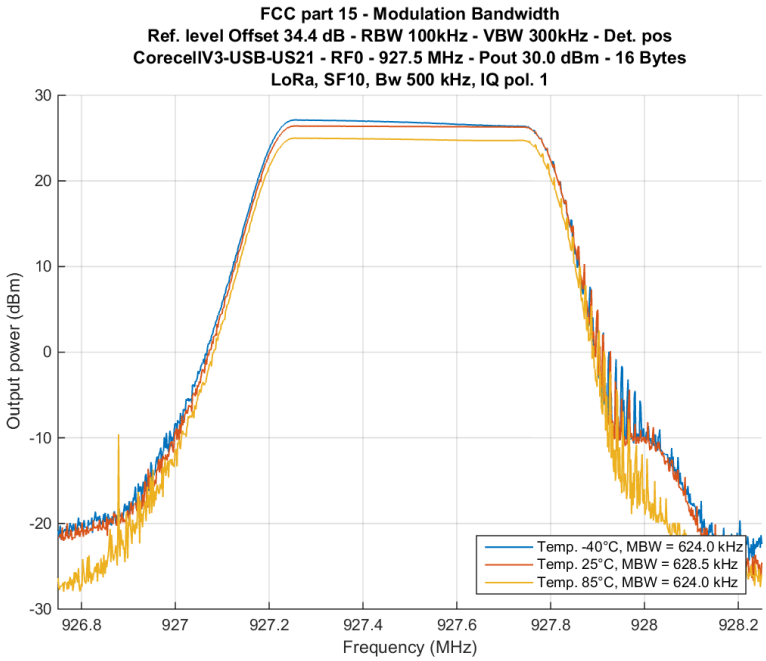


Figure 8.9: Modulation bandwidth vs temperature, Board US21, 927.5 MHz, SF10, Bw 500 kHz

8.6 Conclusion

The lowest margin with the 500 kHz bandwidth limit occurs when transmitting with the higher datarate SF5/Bw500 kHz.

→ **The occupied bandwidth always complies with the minimum -6 dB bandwidth of 500 kHz whatever the channel or the spreading factor.**

9 Maximum power spectral density level

9.1 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 [2].

9.2 Setup

The setup used for this measurement is shown in the figure 3.1.

9.3 Procedure

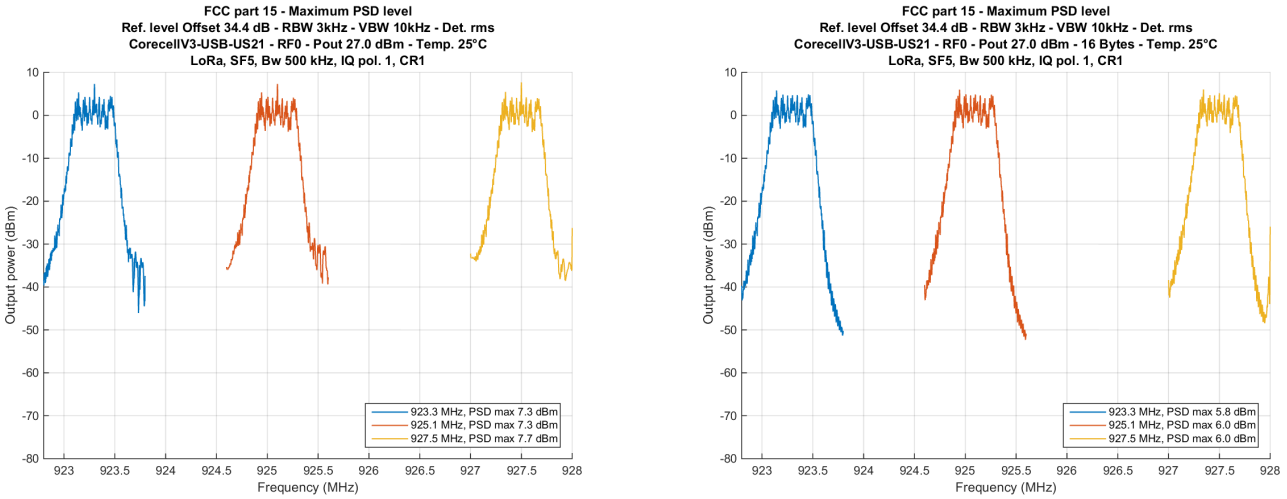
Preliminary measurements have shown the compliance to this item of the regulation shall be performed using modulated packets instead of long unmodulated preamble. Indeed, spikes appear on the spectrum due to the modulated chirps and shall be taken care in the measurement.

The average **AVGPSD-1** method described in reference document [2] is used to demonstrate the compliance to the maximum PSD.

9.4 Frequency influence

The figures 9.1 to 9.3 show the power spectral density level results on three channels and for spreading factors SF5, 7 and 10.

9.4.1 SF5

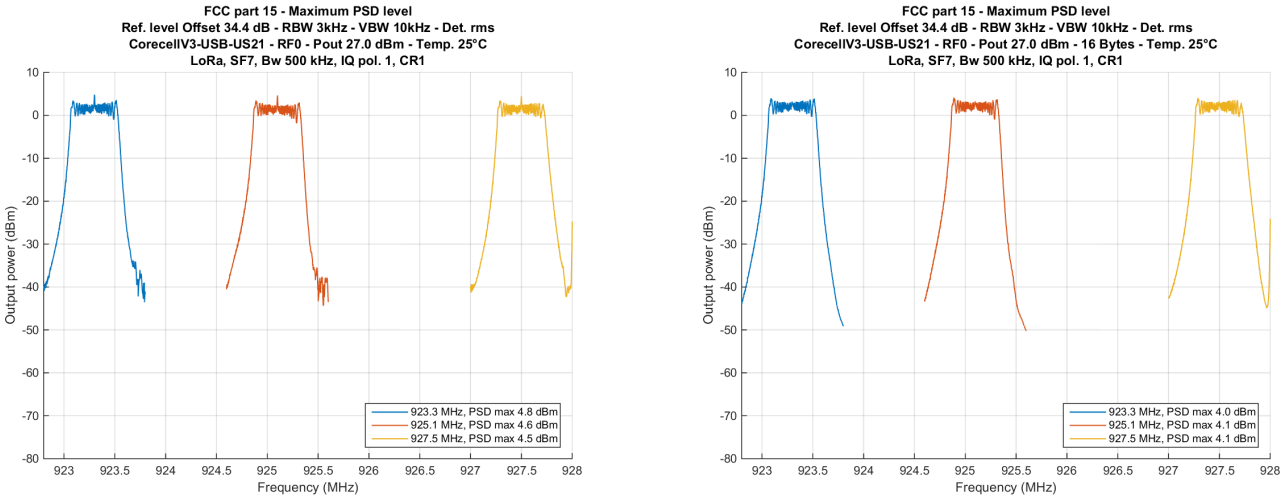


(a) Long preamble

(b) Short packets

Figure 9.1: Maximum PSD level (FCC) vs frequency, Board US21, SF5, Bw 500 kHz, 25°C

9.4.2 SF7

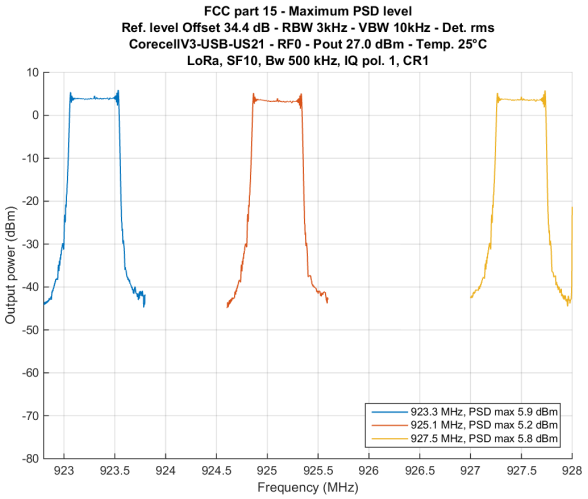


(a) Long preamble

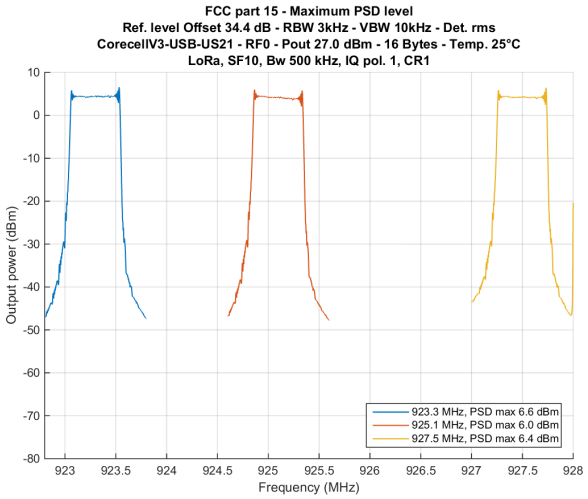
(b) Short packets

Figure 9.2: Maximum PSD level (FCC) vs frequency, Board US21, SF7, Bw 500 kHz, 25°C

9.4.3 SF10



(a) Long preamble

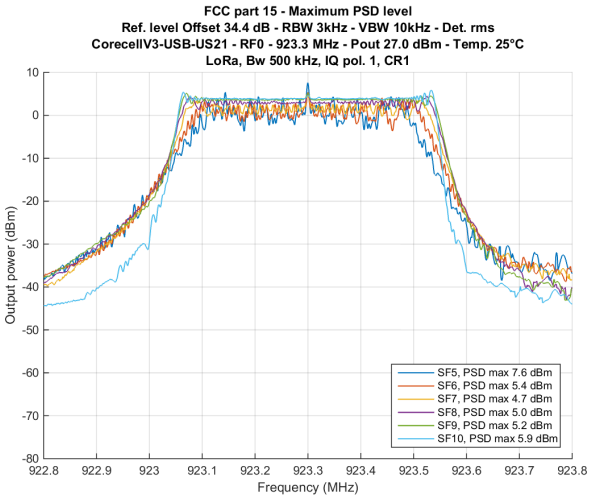


(b) Short packets

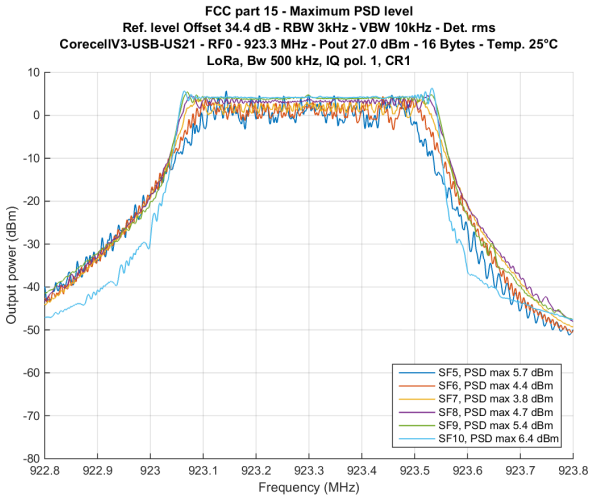
Figure 9.3: Maximum PSD level (FCC) vs frequency, Board US21, SF10, Bw 500 kHz, 25°C

9.5 Spreading factor influence

9.5.1 923.3 MHz



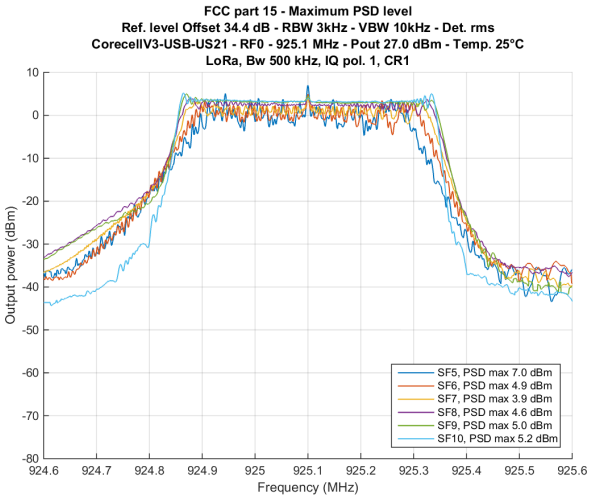
(a) Long preamble



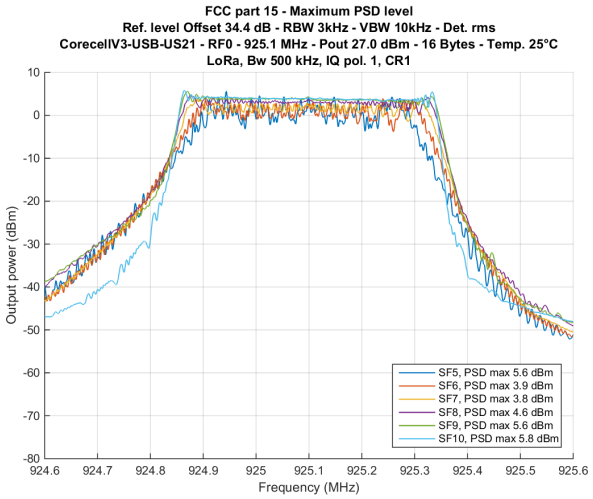
(b) Short packets

Figure 9.4: Maximum PSD level (FCC) vs SF, Board US21, 923.3 MHz, Bw 500 kHz, 25°C

9.5.2 925.1 MHz



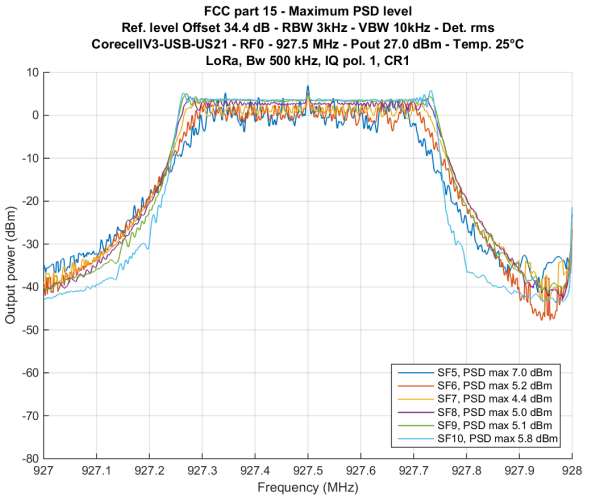
(a) Long preamble



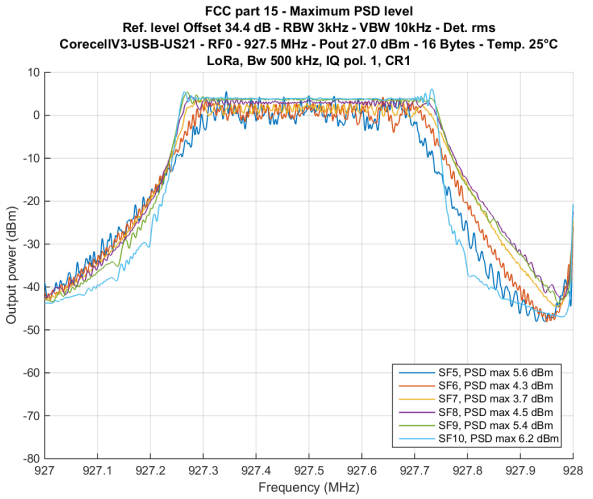
(b) Short packets

Figure 9.5: Maximum PSD level (FCC) vs SF, Board US21, 925.1 MHz, Bw 500 kHz, 25°C

9.5.3 927.5 MHz



(a) Long preamble



(b) Short packets

Figure 9.6: Maximum PSD level (FCC) vs SF, Board US21, 927.5 MHz, Bw 500 kHz, 25°C

9.6 Conclusion

→ **The Corecell gateway always complies with the maximum PSD level of +8 dBm / 3kHz band whatever the channel or the spreading factor.**

10 Out-of-band / Spurious emissions

10.1 Description

The measurement mentioned in this chapter refers to the paragraph 15.247(d) of the FCC regulation (see document [1]) and describes the power level allowed outside the normal emission frequency band (902 to 928 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 and the spurious emissions is shown in the figure 3.1. 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.

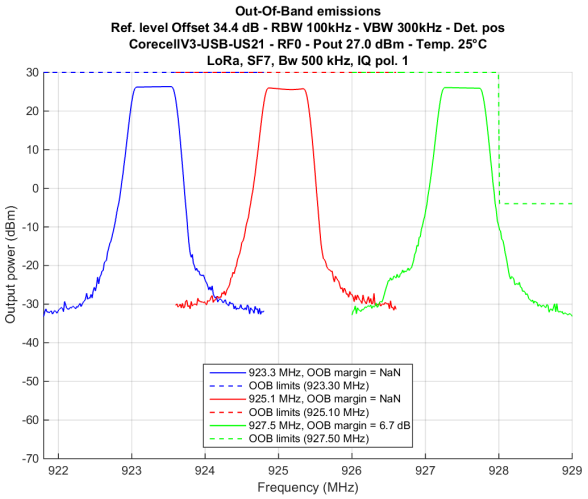
For spurious measurements below 1 GHz, a notch filter is manually tuned for each frequency and allows to reject the fundamental power in order to reduce the instrument reference level and then increase the measurement dynamic. The high pass filter is bypassed.

The ripple of notch filter response is lower than 1 dB from 280 MHz to 1 GHz. As a consequence, it is considered perfect in this frequency range. A more accurate measurement of the notch filter response will only be performed if a spurious is detected close to the regulations limit.

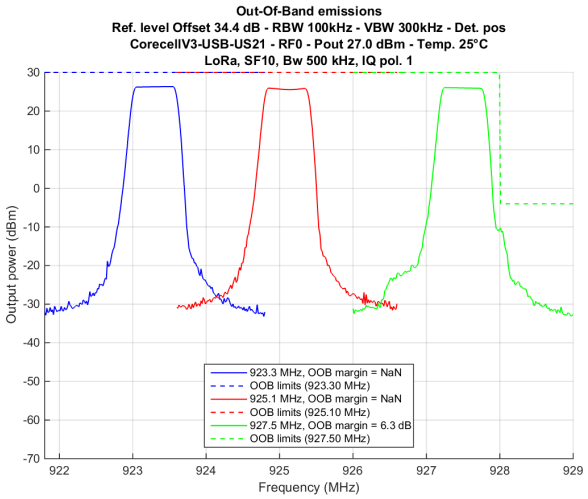
For spurious measurements above 1 GHz, the notch filter is bypassed and the high pass filter with a cut-off frequency at 1.2 GHz is used. Above the cut-off frequency, the attenuation is about 1 dB. So, loss is considered perfect and not compensated while the spurious are far to the regulation limit.

→ **The measurement is performed over thousand of short packets.**

10.3 Frequency influence



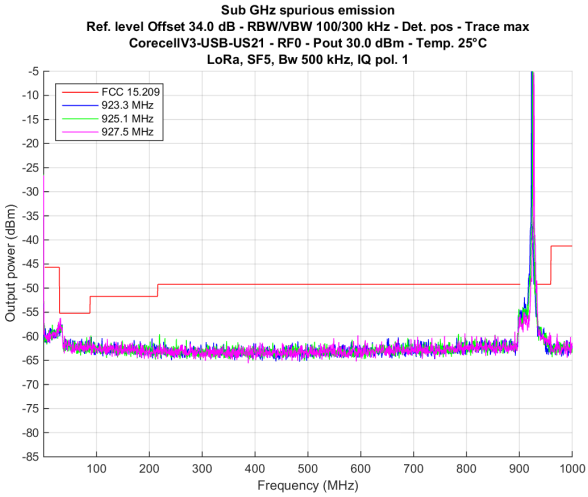
(a) SF7



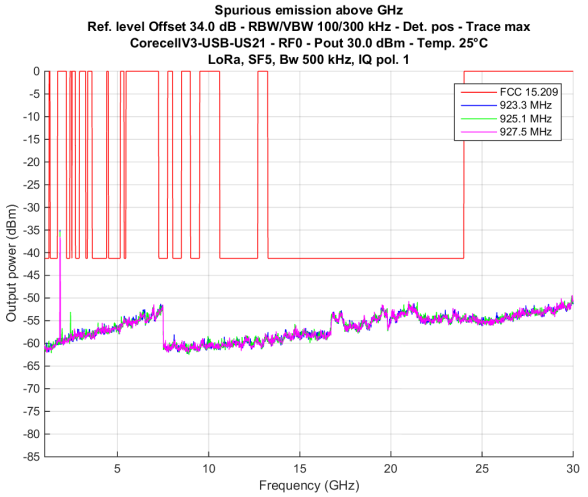
(b) SF10

Figure 10.1: Out-of-band (FCC), Board US21, SF7 and 10, Bw 500 kHz, 25°C

SF5



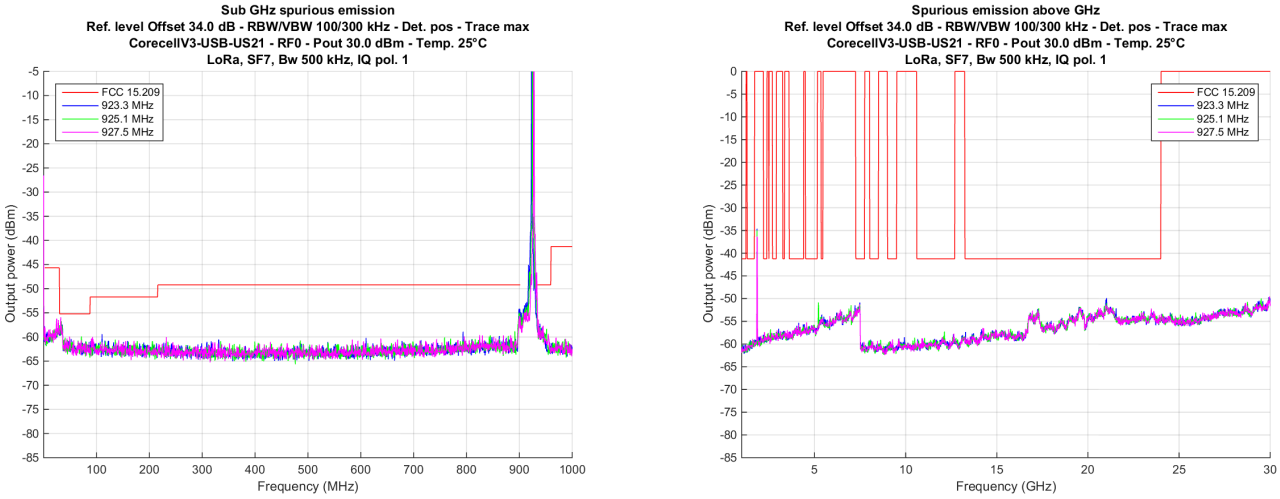
(a) Sub GHz



(b) Above GHz

Figure 10.2: Spurious measurement (FCC), Board US21, LoRa, SF5, Bw 500 kHz, 25°C

SF7

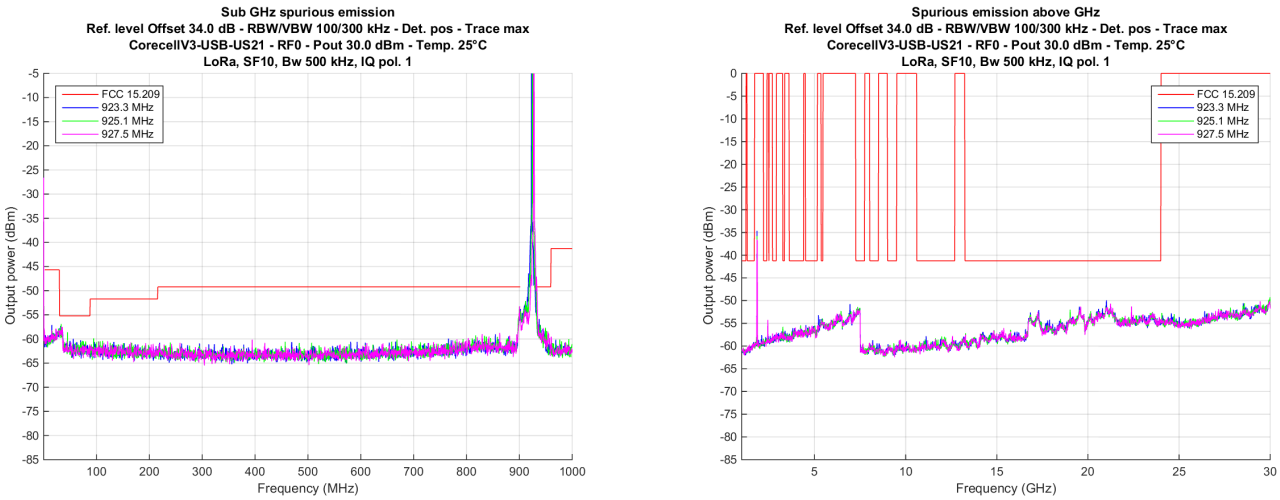


(a) Sub GHz

(b) Above GHz

Figure 10.3: Spurious measurement (FCC), Board US21, LoRa, SF7, Bw 500 kHz, 25°C

SF10



(a) Sub GHz

(b) Above GHz

Figure 10.4: Spurious measurement (FCC), Board US21, LoRa, SF10, Bw 500 kHz, 25°C

10.4 FSK 50 kbits

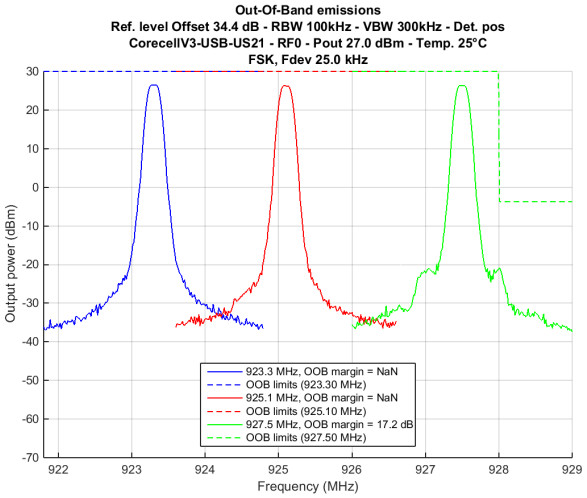
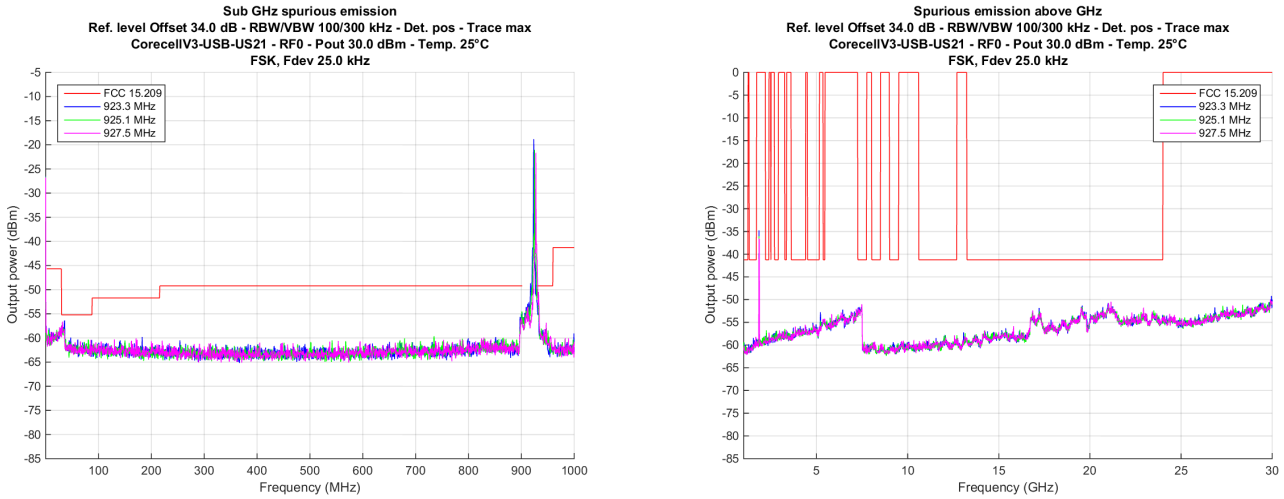


Figure 10.5: Out-of-band (FCC), Board US21, FSK 50 kbits, Fdev 25 kHz, 25°C



(a) Sub GHz

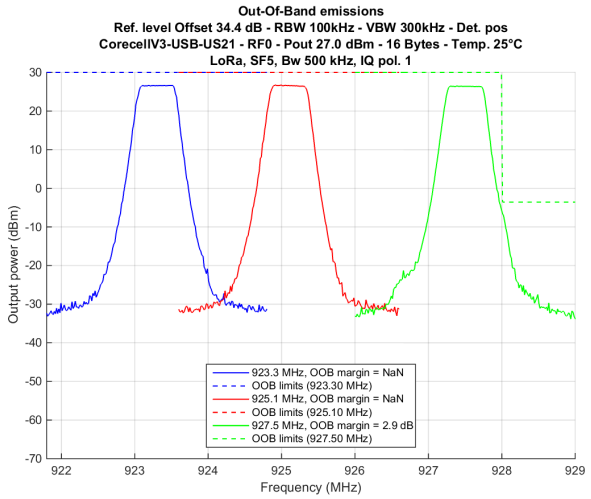
(b) Above GHz

Figure 10.6: Spurious measurement (FCC), Board US21, FSK 50 kbits, Fdev 25 kHz, 25°C

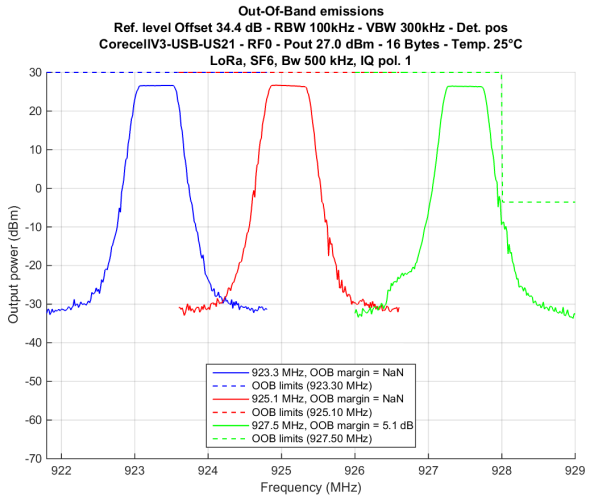
10.5 Measurements over packets

→ **The measurement is performed while transmitting several packets with a 8 symbols preamble.**

10.5.1 SF5 and SF6



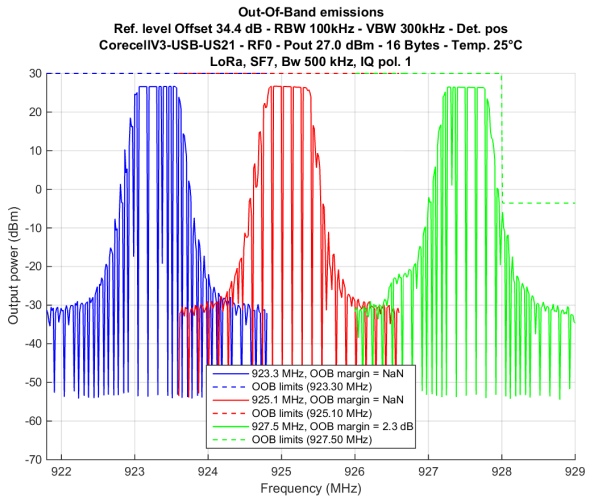
(a) SF5



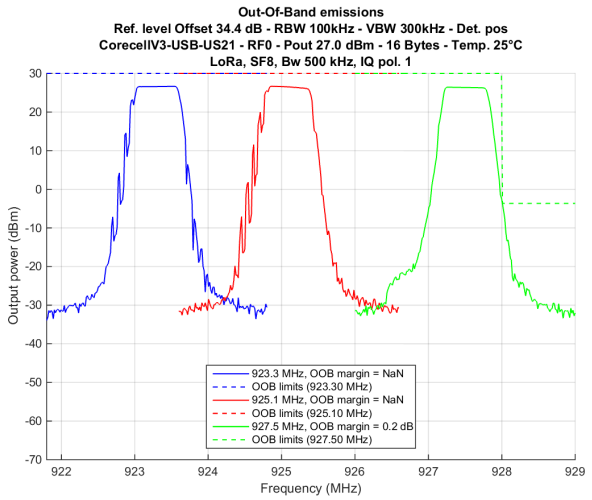
(b) SF6

Figure 10.7: Out-of-band (FCC), Board US21, SF5/6, Bw 500 kHz, 25°C

10.5.2 SF7 and SF8



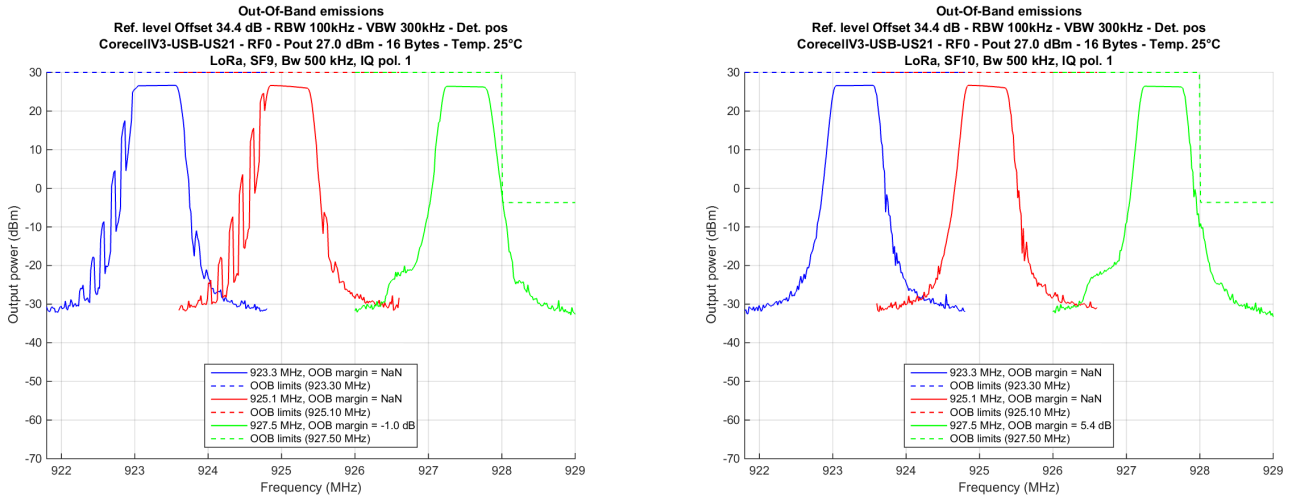
(a) SF7



(b) SF8

Figure 10.8: Out-of-band (FCC), Board US21, SF7/8, Bw 500 kHz, 25°C

10.5.3 SF9 and SF10



(a) SF9

(b) SF10

Figure 10.9: Out-of-band (FCC), Board US21, SF9/10, Bw 500 kHz, 25°C

10.6 Conclusion

→ The Corecell gateway complies with the chapter 15.247 (d) of the FCC regulation. The out-of-band and spurious emissions limits are respected whatever the channel, the spreading factor or the modulation.

11 Beacon emission time accuracy

11.1 Description

In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times. Class B is achieved by having the gateway sending a beacon on a regular basis to synchronize all the end-devices in the network so that the end-device can open a short extra reception window (called ping slot) at a predictable time during a periodic time slot.

From chapter 15.4 of the document [3], the beacon is sent every 128 seconds plus **TBeaconDelay**, whereby TBeaconDelay is 1.5 ms $\pm 1\mu s$ delay. The beacon emission is synchronized to the PPS signal coming from the GPS module.

$\rightarrow$ **This test evaluates the system performances and the compliance to the LoRaWan specification regarding the Class B requirements. The beacon emission time accuracy shall be better than $1.5ms \pm 1\mu s$ after the PPS signal rising edge.**

11.2 Setup

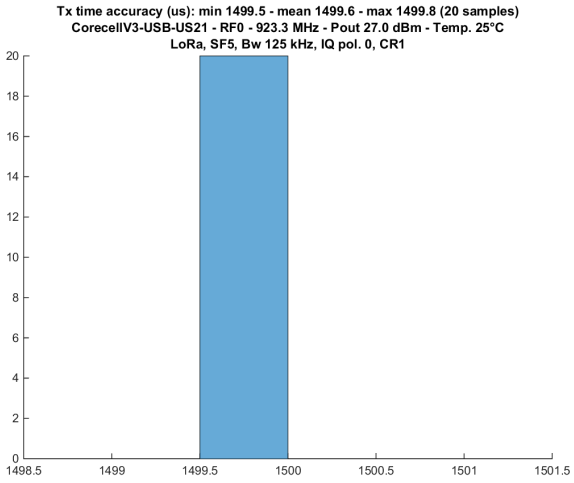
The setup shown in figure 3.1 allows to evaluate the beacon emission time accuracy. The packet emission is synchronized with the rising edge of PPS signal.

The PPS signal is also used to trigger the capture of IQ data by the spectrum analyzer at a sampling frequency of 8 MHz. This sampling frequency reduces the error on the emission time to 125 ns. The data are download to the computer and correlated with a reference LoRa preamble in order to measure accurately the start of the LoRa packets.

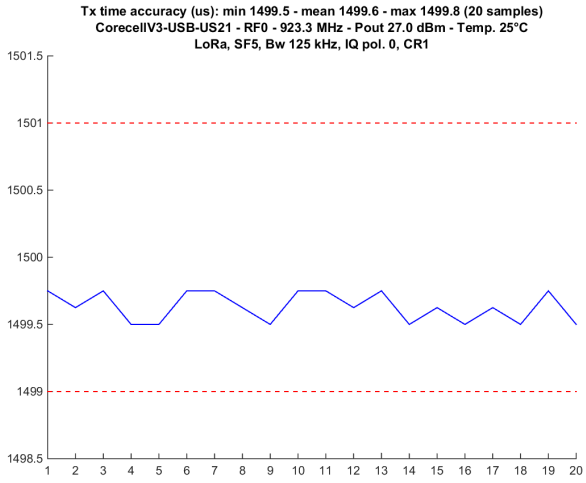
The beacon emission is initiated using the tool `./test_loragw_hal_tx` with the parameter `-t0` (PPS triggered).

11.3 Bandwidth 125 kHz

11.3.1 SF5



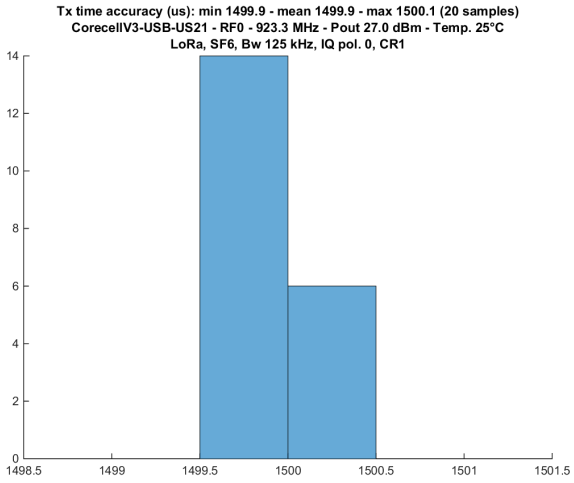
(a) Histogram



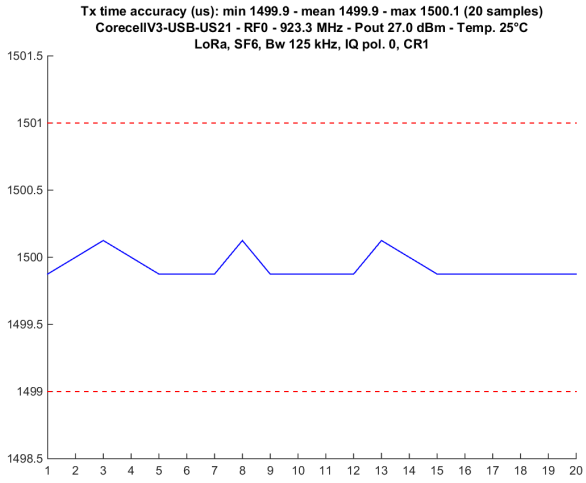
(b) Samples

Figure 11.1: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 125 kHz, SF5

11.3.2 SF6



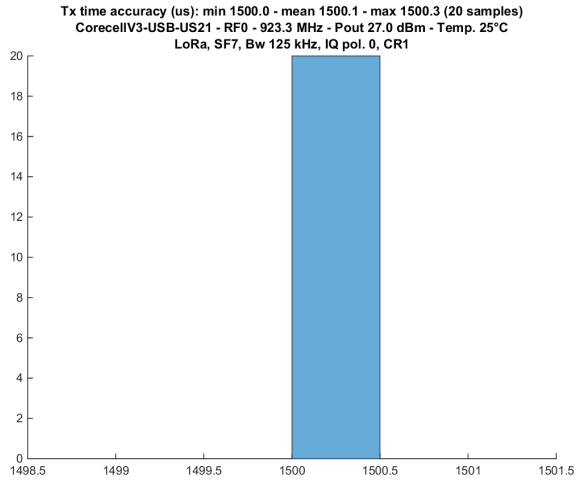
(a) Histogram



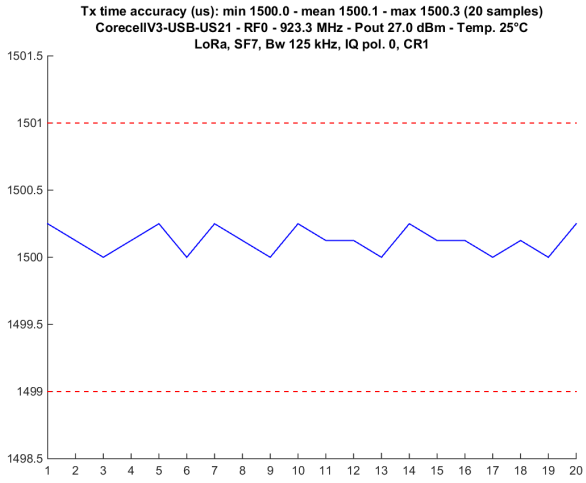
(b) Samples

Figure 11.2: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 125 kHz, SF6

11.3.3 SF7



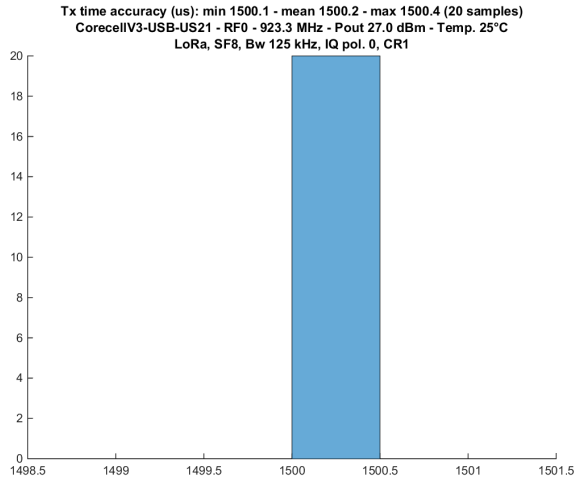
(a) Histogram



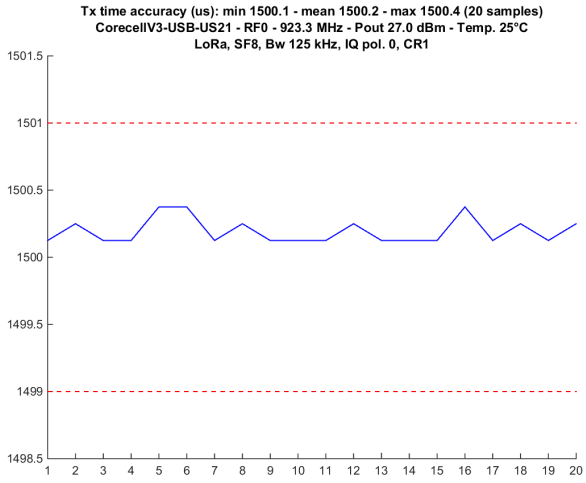
(b) Samples

Figure 11.3: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 125 kHz, SF7

11.3.4 SF8



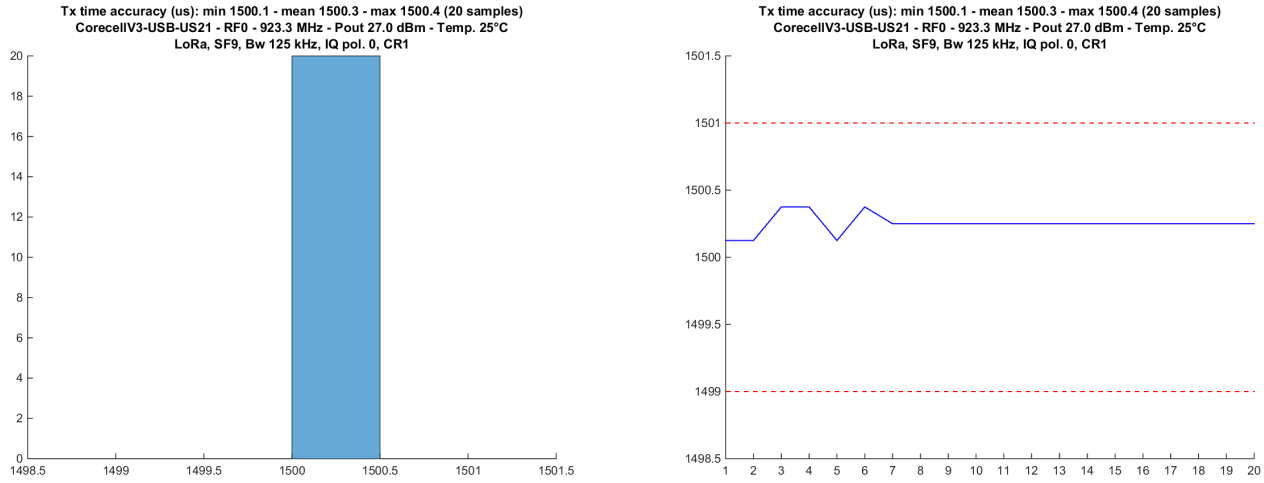
(a) Histogram



(b) Samples

Figure 11.4: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 125 kHz, SF8

11.3.5 SF9

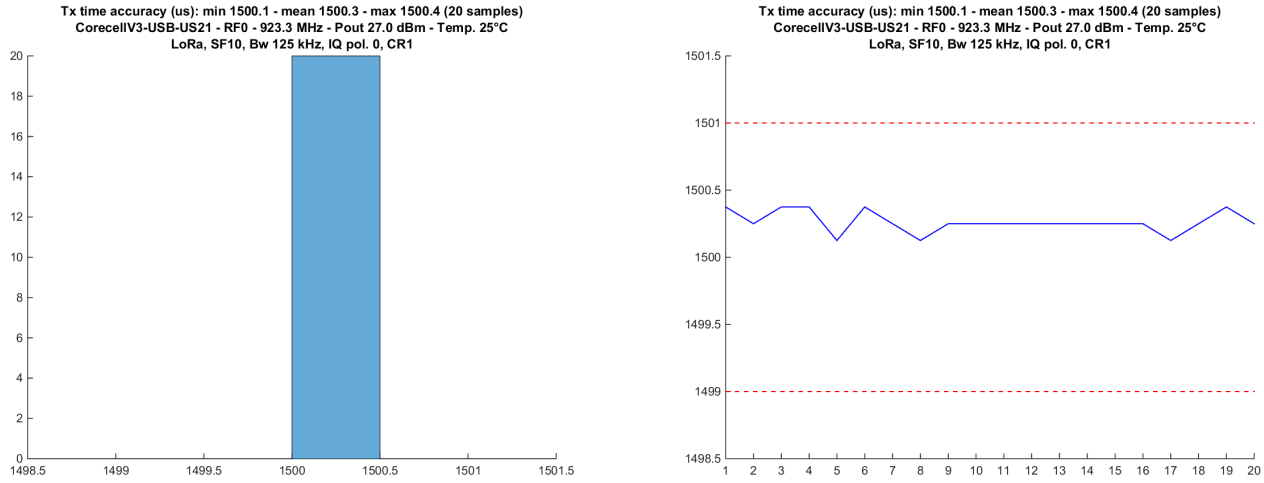


(a) Histogram

(b) Samples

Figure 11.5: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 125 kHz, SF9

11.3.6 SF10



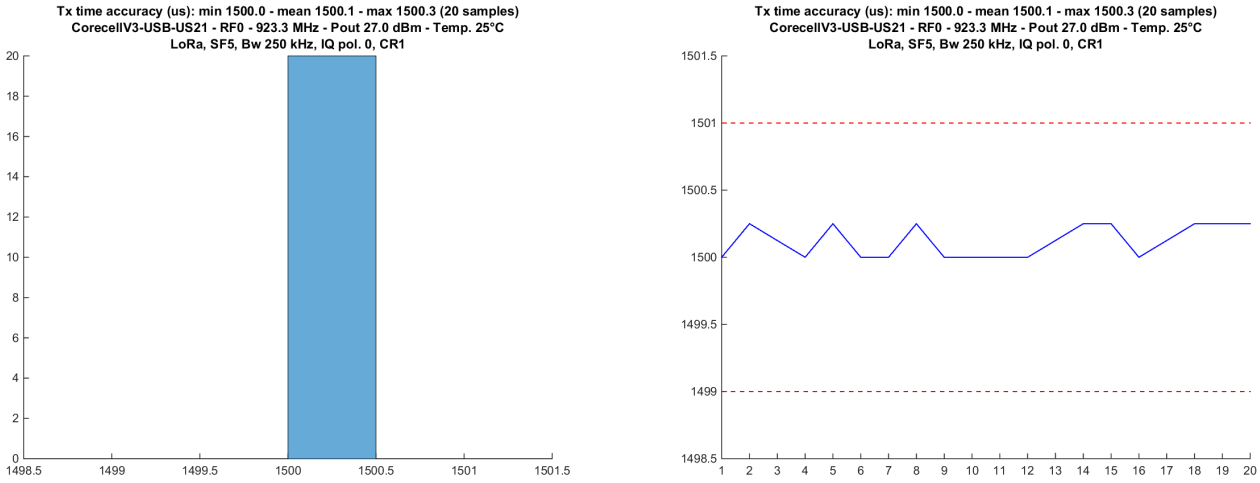
(a) Histogram

(b) Samples

Figure 11.6: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 125 kHz, SF10

11.4 Bandwidth 250 kHz

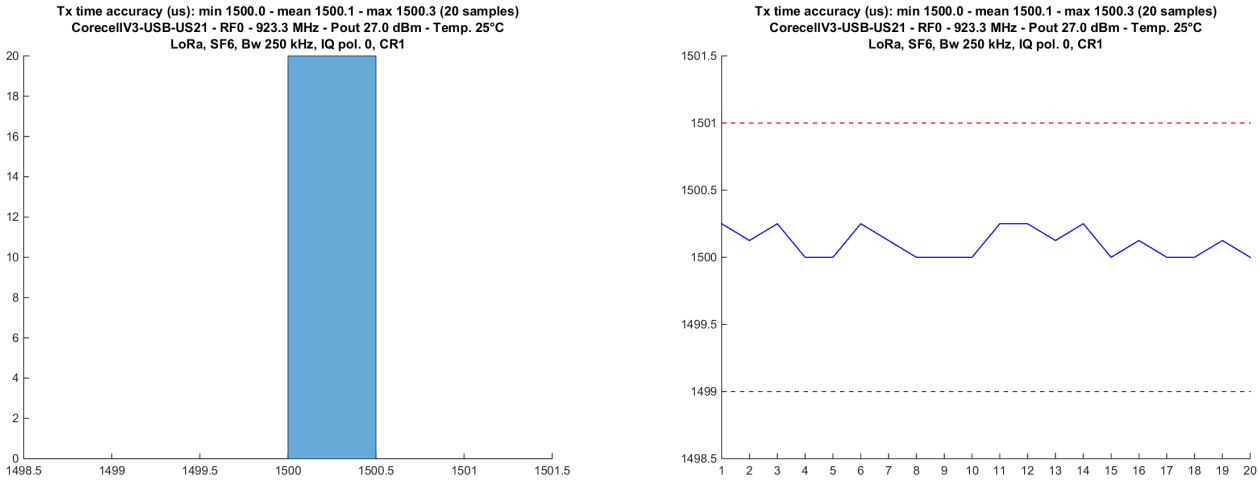
11.4.1 SF5



(a) Histogram (b) Samples

Figure 11.7: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 250 kHz, SF5

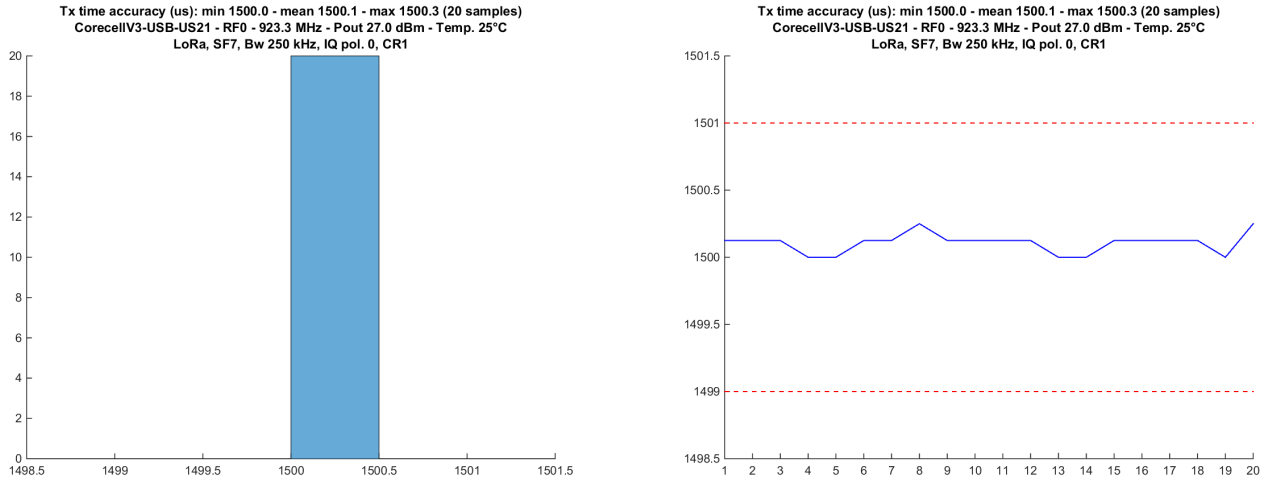
11.4.2 SF6



(a) Histogram (b) Samples

Figure 11.8: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 250 kHz, SF6

11.4.3 SF7

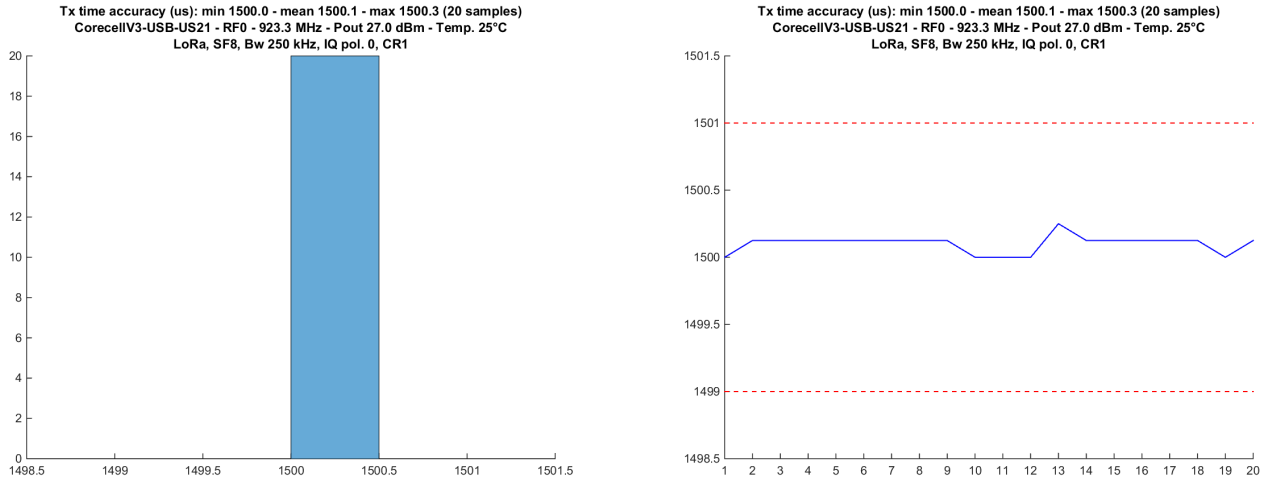


(a) Histogram

(b) Samples

Figure 11.9: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 250 kHz, SF7

11.4.4 SF8

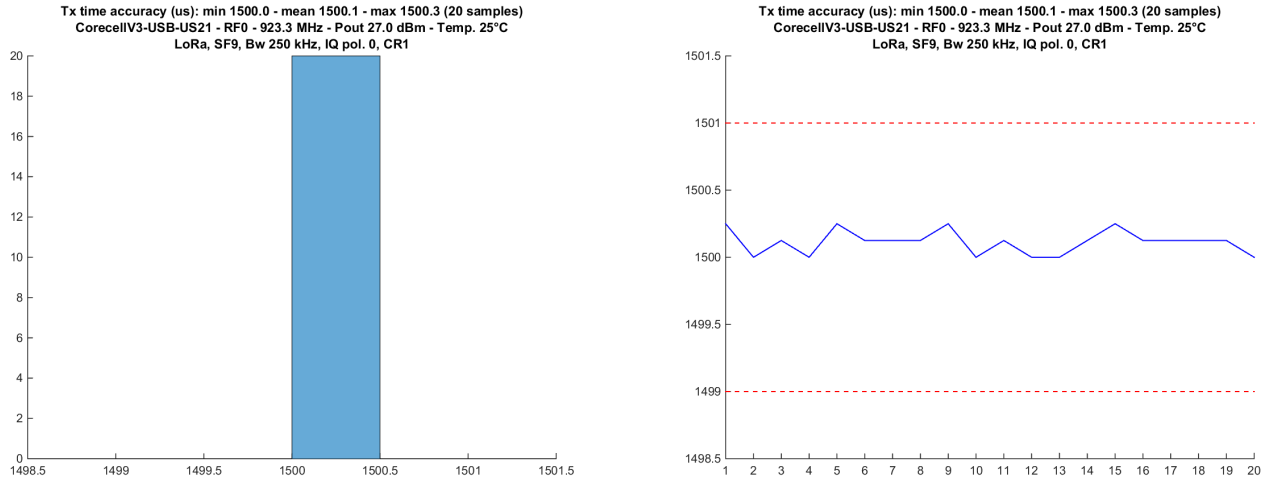


(a) Histogram

(b) Samples

Figure 11.10: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 250 kHz, SF8

11.4.5 SF9

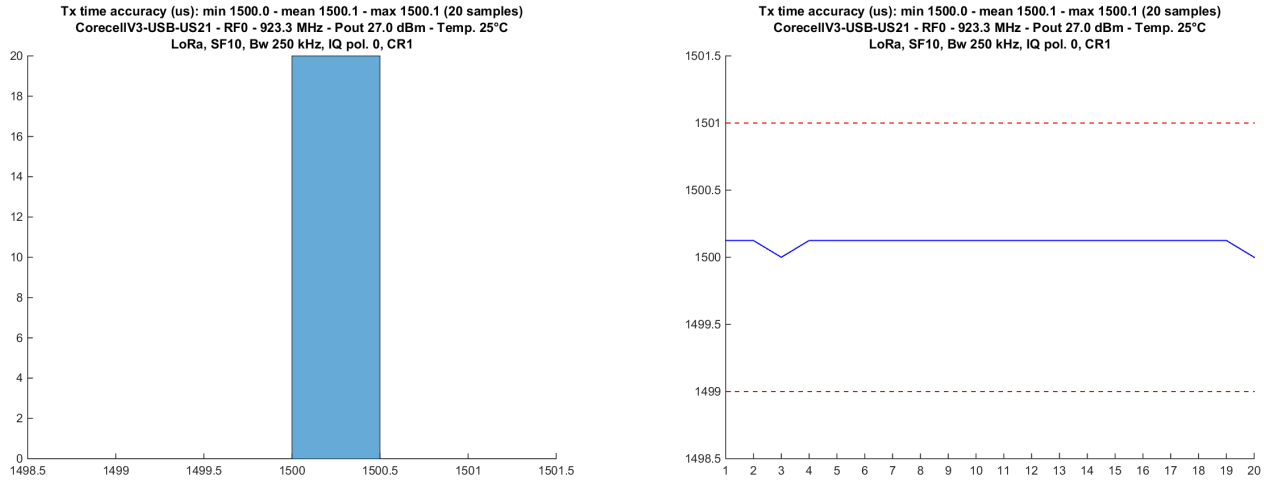


(a) Histogram

(b) Samples

Figure 11.11: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 250 kHz, SF9

11.4.6 SF10



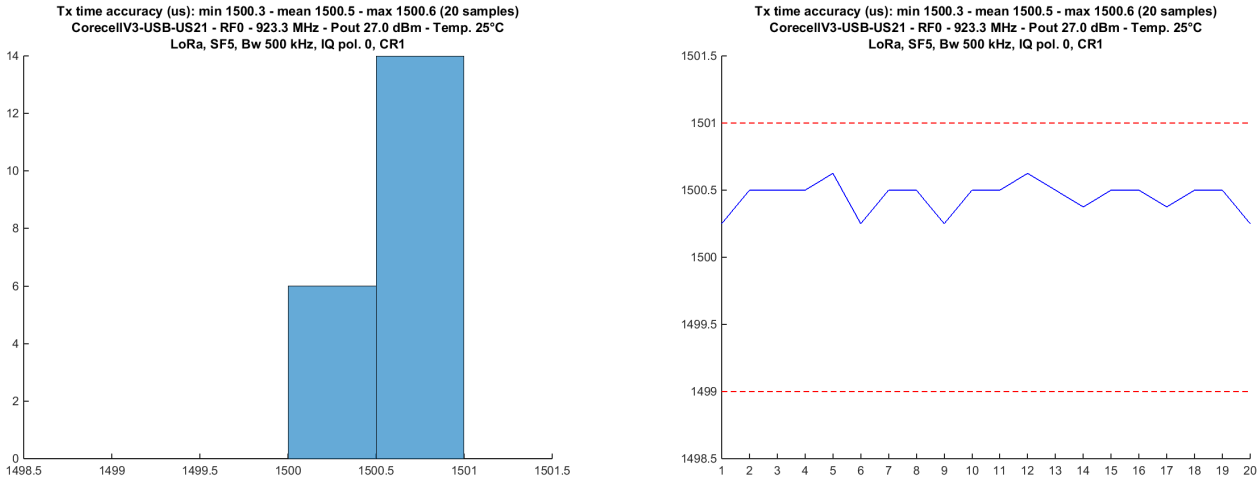
(a) Histogram

(b) Samples

Figure 11.12: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 250 kHz, SF10

11.5 Bandwidth 500 kHz

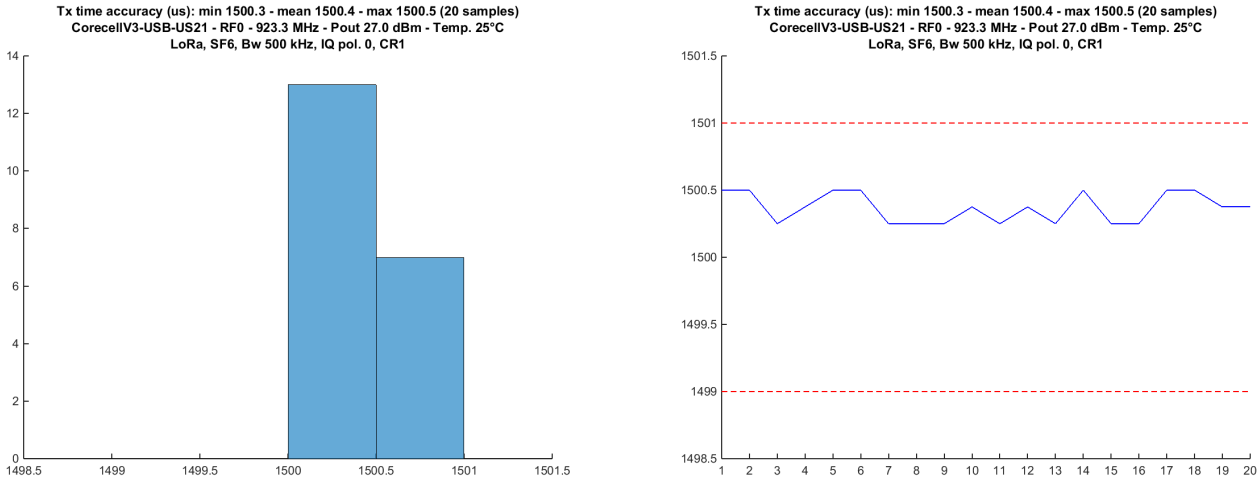
11.5.1 SF5



(a) Histogram (b) Samples

Figure 11.13: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 500 kHz, SF5

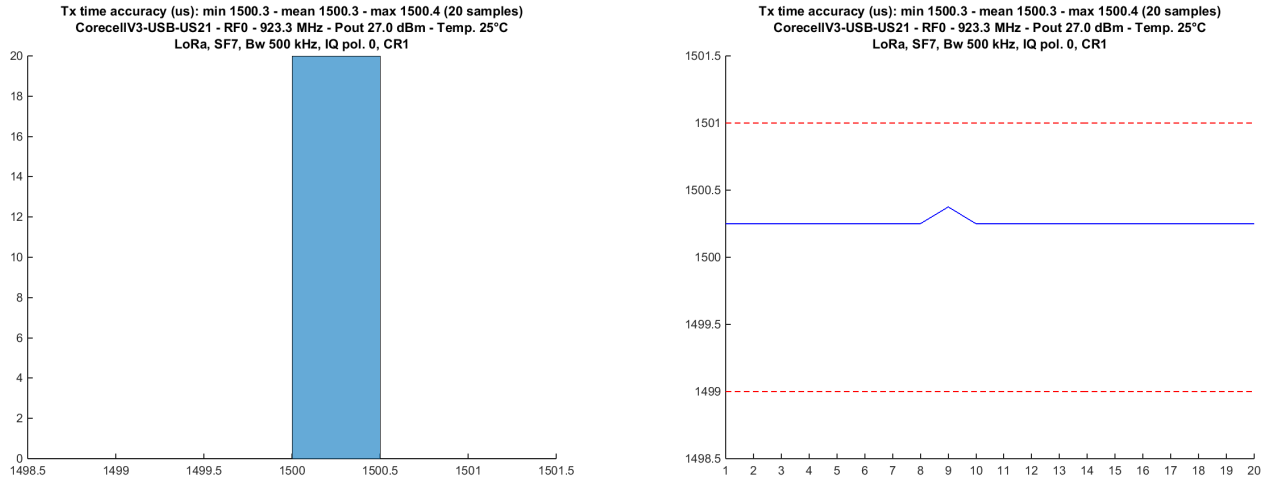
11.5.2 SF6



(a) Histogram (b) Samples

Figure 11.14: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 500 kHz, SF6

11.5.3 SF7

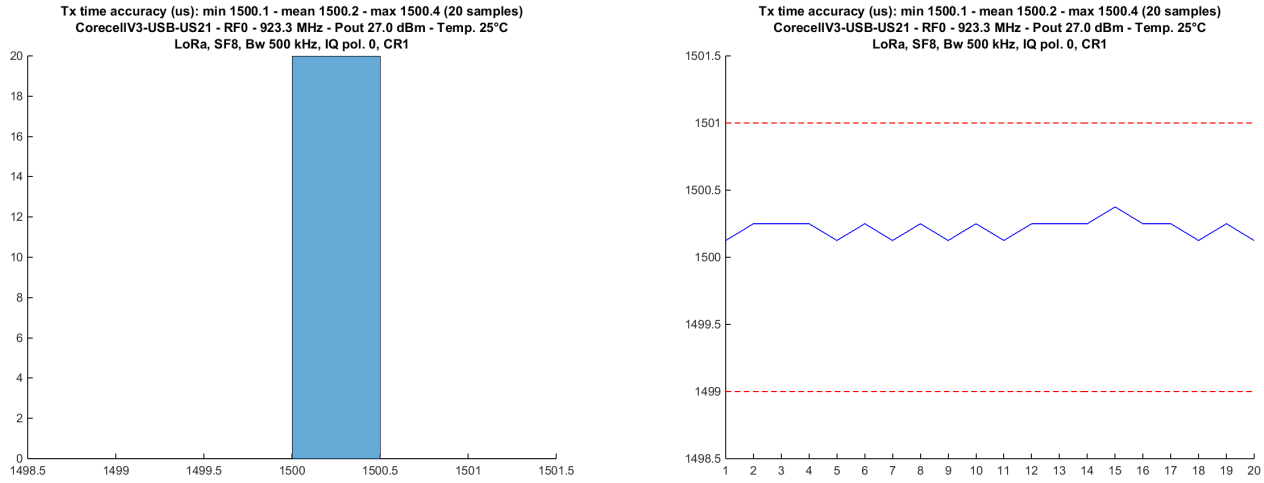


(a) Histogram

(b) Samples

Figure 11.15: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 500 kHz, SF7

11.5.4 SF8

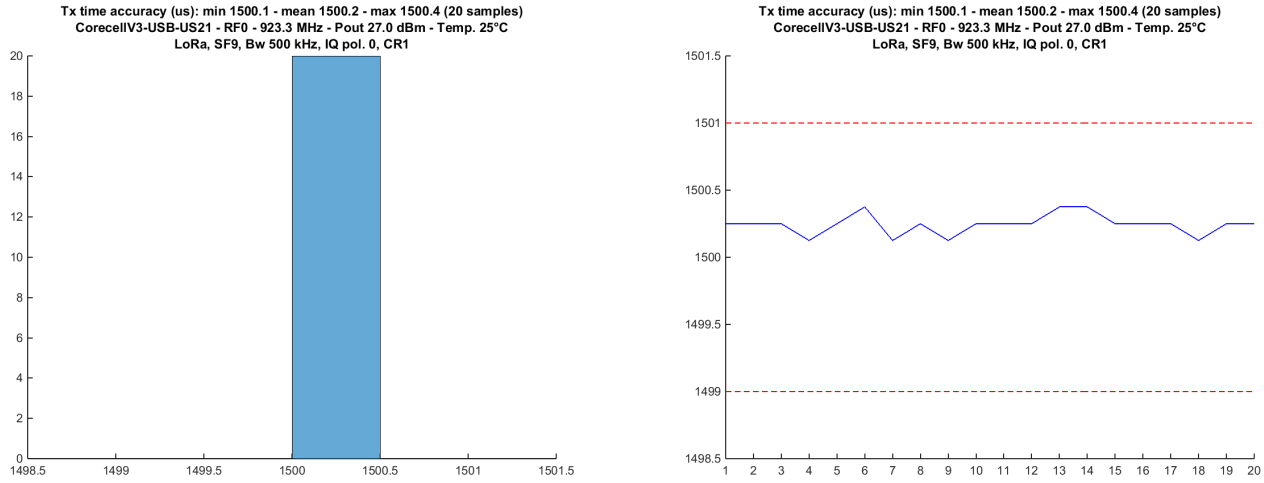


(a) Histogram

(b) Samples

Figure 11.16: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 500 kHz, SF8

11.5.5 SF9

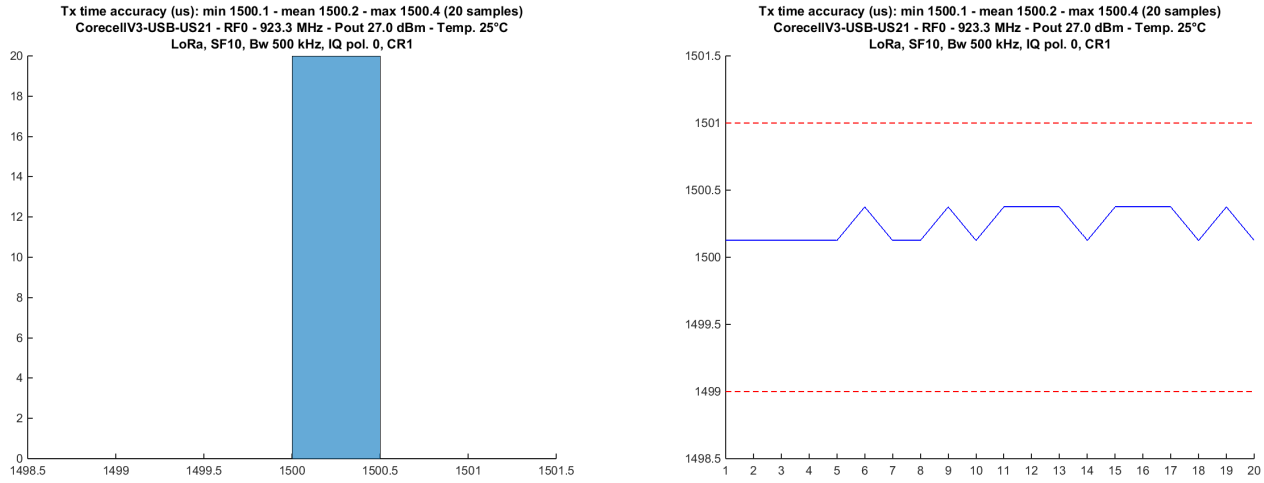


(a) Histogram

(b) Samples

Figure 11.17: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 500 kHz, SF9

11.5.6 SF10

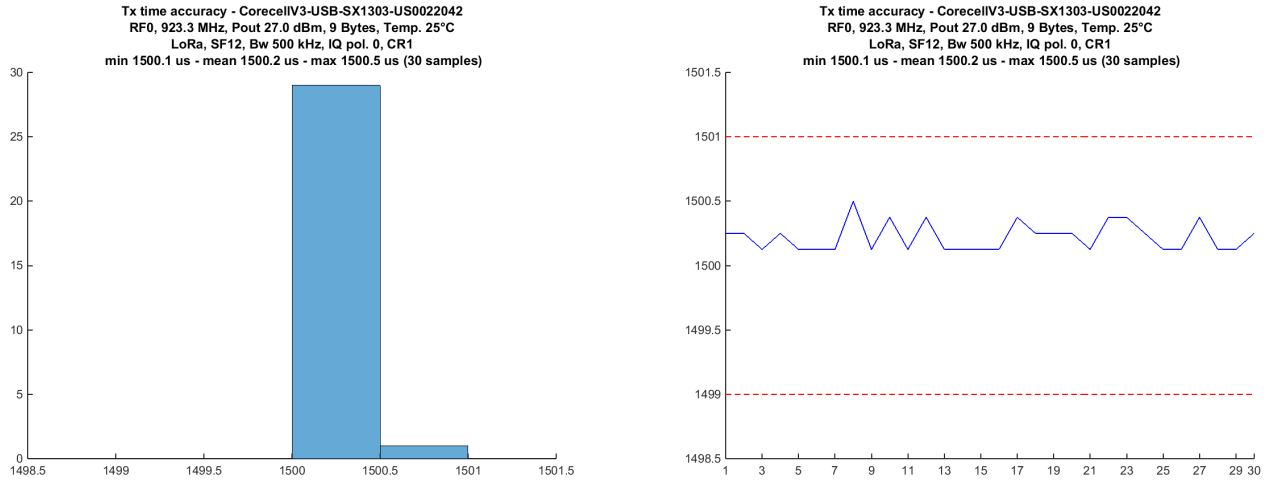


(a) Histogram

(b) Samples

Figure 11.18: Beacon emission time accuracy, Board US21, 923.3 MHz, 27 dBm, Bw 500 kHz, SF10

11.5.7 SF12



(a) Histogram

(b) Samples

Figure 11.19: Beacon emission time accuracy, Board US0022042, 923.3 MHz, 27 dBm, Bw 500 kHz, SF12

11.6 Conclusion

→ **The beacon emission time always complies with the LoRaWan class B requirement of 1500 ± 1µs.**

12 Downlink PER

12.1 Description

This measurement allows to verify that downlinks packets emitted by the gateway are correctly received by a node at its sensitivity level. It evaluates the quality of signal generated by the modulator and the transceiver.

12.2 Setup

The setup used for the downlink PER measurement is shown in figure 3.1.

By using a programmable attenuator, the budget link is progressively attenuated until it reaches the sensitivity level of the node (SX1262 shield).

The attenuation is divided in two parts, one part being inside a Faraday box with the SX1261 inside, the second part outside the box. This reduce the radiated signal across that could reach at the SX1261 input at a higher level than the sensitivity one.

The signal generator output level is adjusted to obtain the same RSSI value when the end device receives packets from the gateway or the signal generator.

12.3 Spreading factor influence, Bandwidth 125 kHz

12.3.1 923.3 MHz

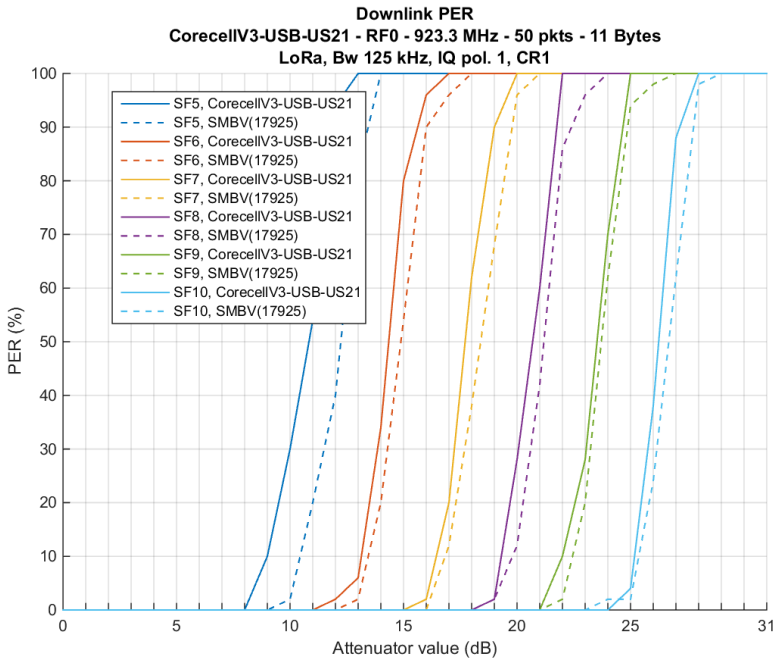


Figure 12.1: Downlink PER vs Spreading factor, Board US21, 923.3 MHz, Bw 125 kHz, Pout 27 dBm

12.3.2 925.1 MHz

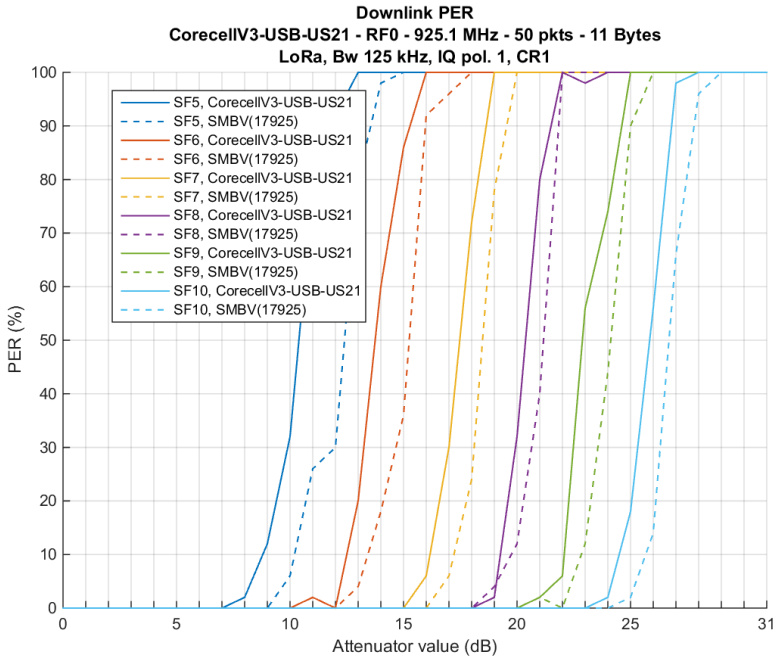


Figure 12.2: Downlink PER vs Spreading factor, Board US21, 925.1 MHz, Bw 125 kHz, Pout 27 dBm

12.3.3 927.5 MHz

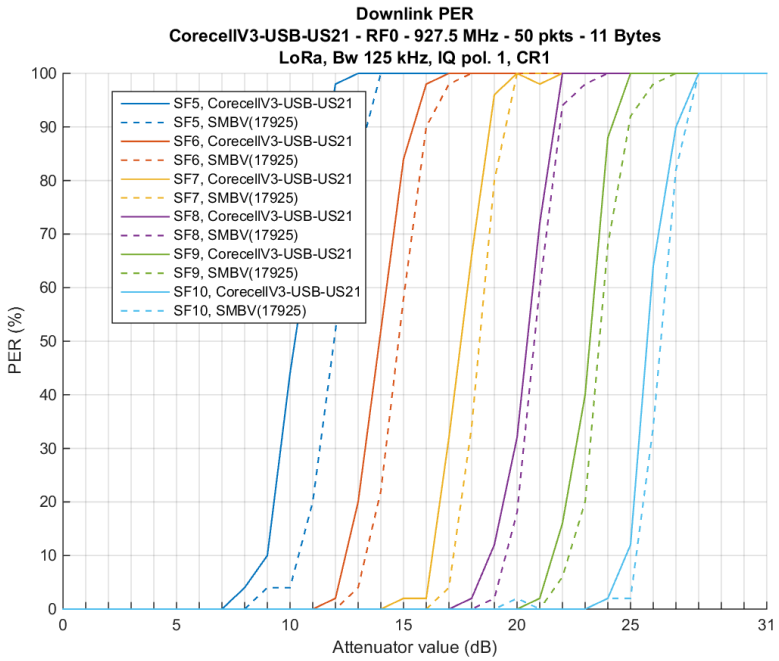


Figure 12.3: Downlink PER vs Spreading factor, Board US21, 927.5 MHz, Bw 125 kHz, Pout 27 dBm

12.4 Spreading factor influence, Bandwidth 500 kHz

12.4.1 923.3 MHz

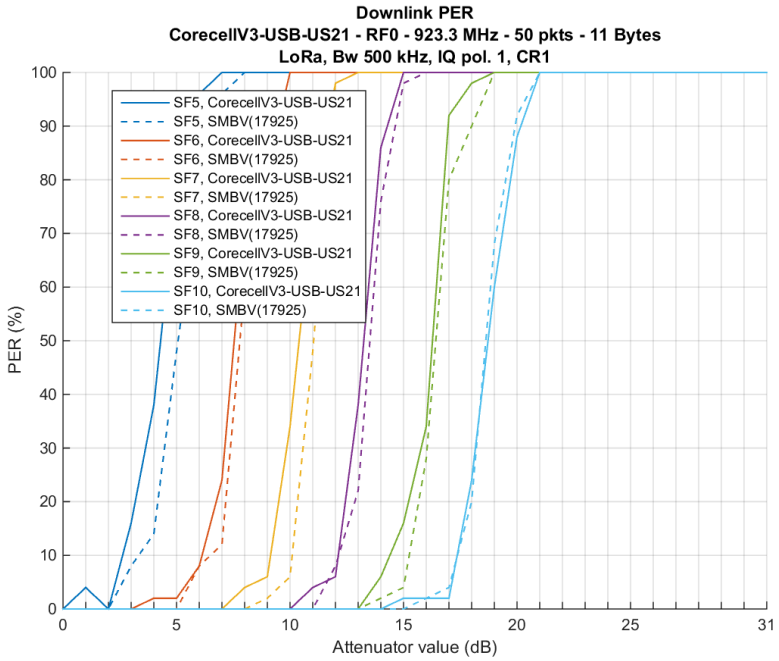


Figure 12.4: Downlink PER vs SF, Board US21, 923.3 MHz, Bandwidth 500 kHz, Pout 27 dBm

12.4.2 925.1 MHz

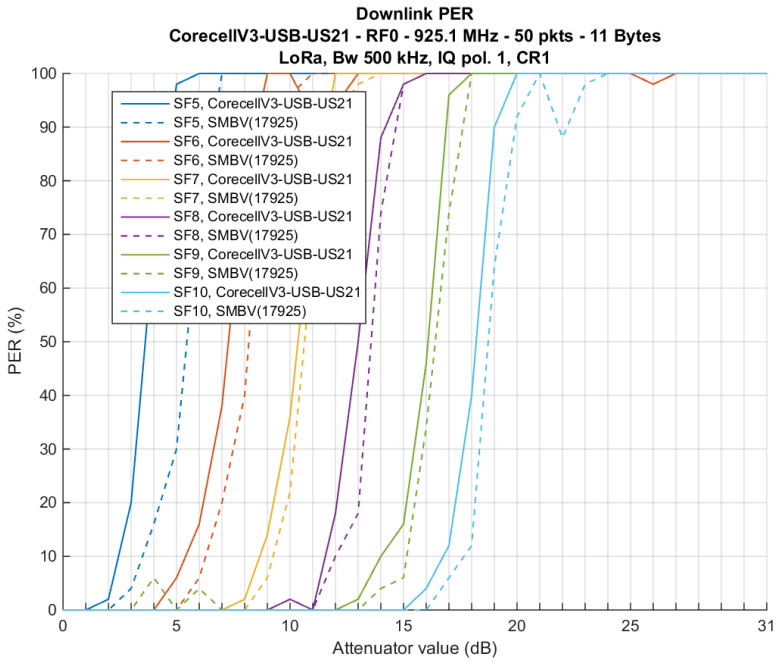


Figure 12.5: Downlink PER vs SF, Board US21, 925.1 MHz, Bandwidth 500 kHz, Pout 27 dBm

12.4.3 927.5 MHz

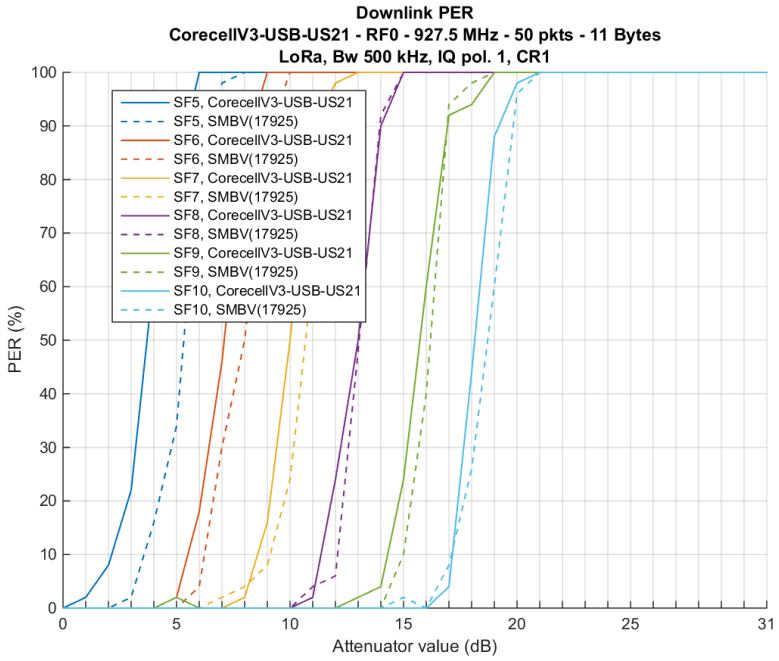


Figure 12.6: Downlink PER vs SF, Board US21, 927.5 MHz, Bandwidth 500 kHz, Pout 27 dBm

12.5 Conclusion

→ The end-device sensitivity level obtained using the Corecell gateway is close to the one obtained using a signal generator. The difference of sensitivity level for SF5 packets is acceptable regarding the corresponding datarate.

Part III

Receiver

13 Sensitivity level and PER

13.1 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 10%. It also verifies the PER remains null for input power above the sensitivity level i.e. no saturation occurs.

13.2 Setup

The sensitivity measurement setup is shown in figure 3.1. 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 by the USB bus and send them to the computer through UDP protocol.

13.3 Theoretical Noise Floor computation

The Friis formula (eq. 13.1) for calculating cascaded noise figure is used to combine the stage contributions:

$$Fin = F1 + \frac{F2-1}{G1} + \frac{F3-1}{G1 \times G2} + ... \tag{13.1}$$

To compute the theoretical noise level value, the following assumption are used:

- The thermal noise in a 125 kHz bandwidth: -174 dBm + 10.log10(125e3) = -123 dBm
- The insertion loss of the filter between the FEM and the connector are neglected.
- The first stage is a SAW filter (RF360 B4344).
  - Its insertion loss (about 1.7 dB between 902 to 915 MHz) contribute to the NF: $F1 = 10^{1.7/10} = 1.48$
  - Furthermore, its insertion loss corresponds directly to its negative gain: $G1 = 10^{-1.7/10} = 0.68$
- The LNA presents in the FEM (Skywork SKY66423-11) has a NF of 1.5 dB and a gain of 18 dB ie. F2 = 1.41 and G2 = 63.1
- The second SAW filter (RF360 B4344) after the LNA and before both SX1250 has 1.7 dB insertion loss i.e. F3 = 1.48 and G3 = 0.68
- The RF path splitting between two SX1250 is considered to be an ideal power splitter
  - Its insertion loss (3dB) contributes to the NF: $F4 = 10^{3/10} = 2$
  - its negative gain: $G4 = 10^{-3/10} = 0.5$
- Finally, the noise figure of the SX1250 is evaluated to 8 dB i.e. F5 = 6.31

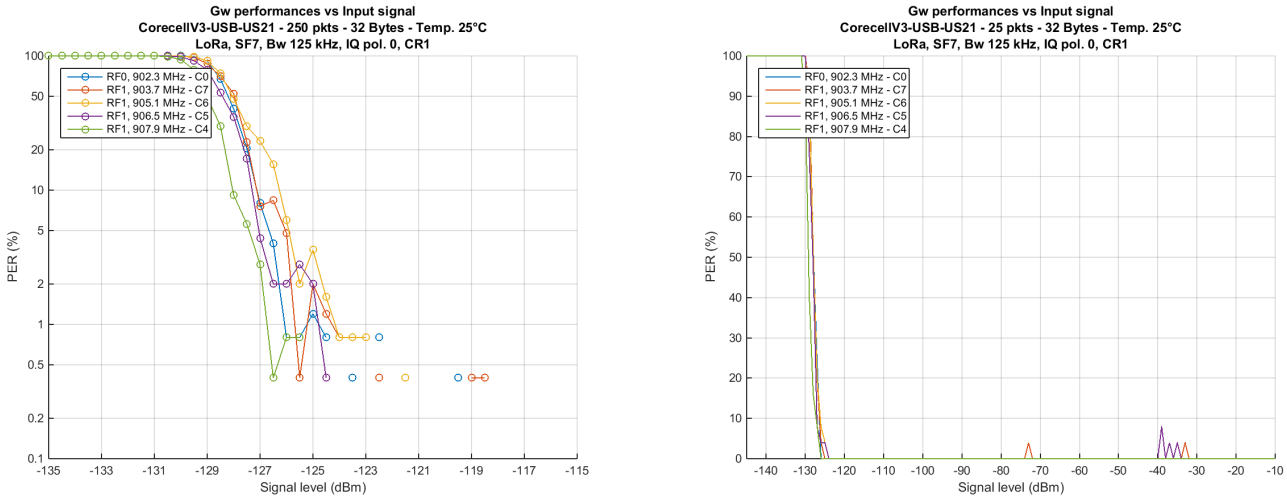
The equivalent input noise figure is:
Fin = 1.48 + (1.41-1)/0.68 + (1.48-1)/(0.68*63.1) + (2-1)/(0.68*63.1*0.68) + (6.31-1)/(0.68*63.1*0.68*0.5) = 2.5 or 4 dB

→ **The theoretical noise floor value is -123 dBm + 4 dB ie -119 dBm.**

Assuming a minimum SNR of -8 dB for SF7 (10% PER), the expected sensitivity level shall be -127 dBm.

13.4 Frequency influence

13.4.1 MultiSF modem (lower band)

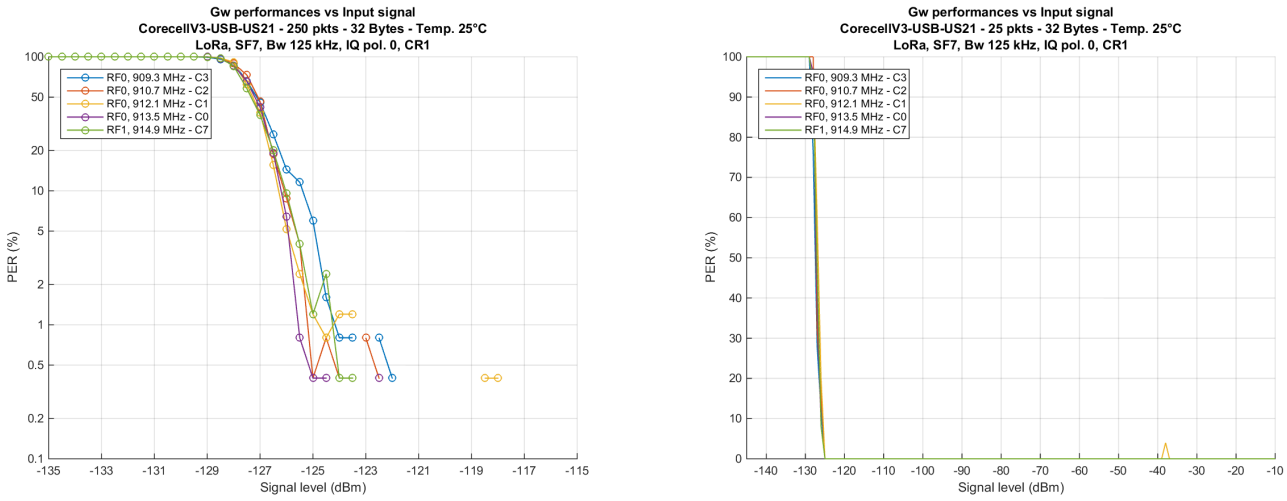


(a) Sensitivity level

(b) High level

Figure 13.1: Sensitivity level and PER vs channels (Lower band), Board US21, SF7, Bw 125 kHz, 32 bytes, 25°C

13.4.2 MultiSF modem (Higher band)

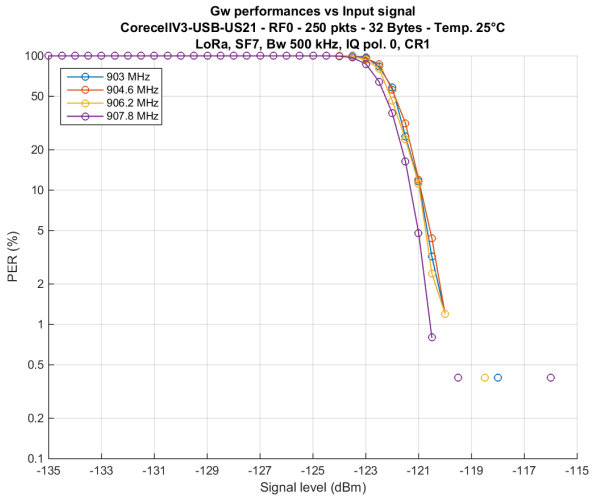


(a) Sensitivity level

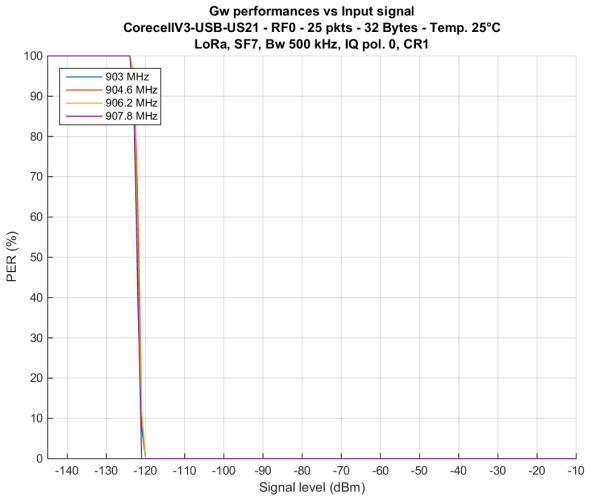
(b) High level

Figure 13.2: Sensitivity level and PER vs channels (Higher band), Board US21, SF7, Bw 125 kHz, 32 bytes, 25°C

13.4.3 SingleSF modem (Lower band)



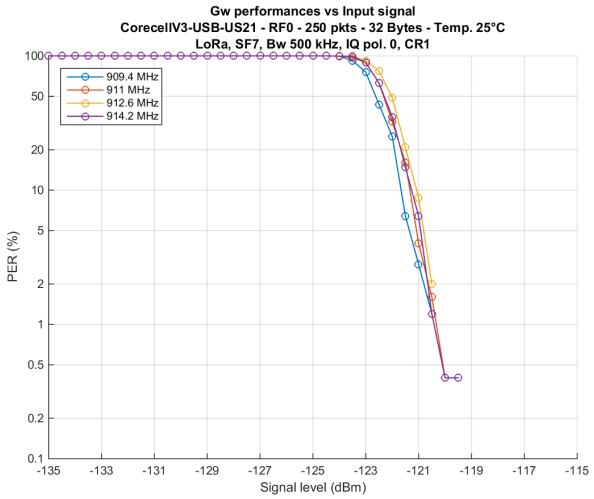
(a) Sensitivity level



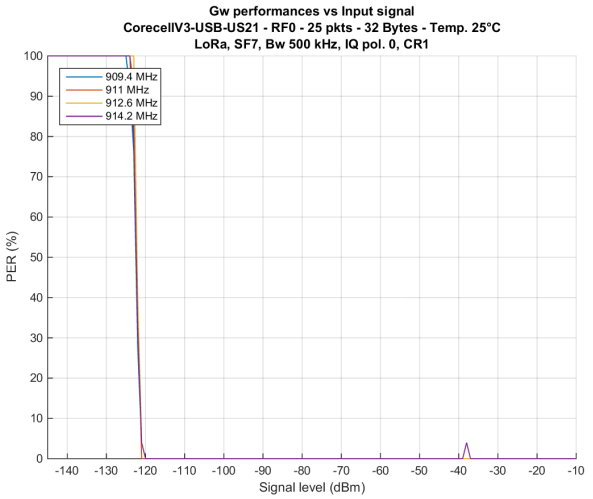
(b) High level

Figure 13.3: Sensitivity level and PER vs channels (Lower band), Board US21, SingleSF modem, SF7, Bw 500 kHz, 32 bytes, 25°C

13.4.4 SingleSF modem (Higher band)



(a) Sensitivity level

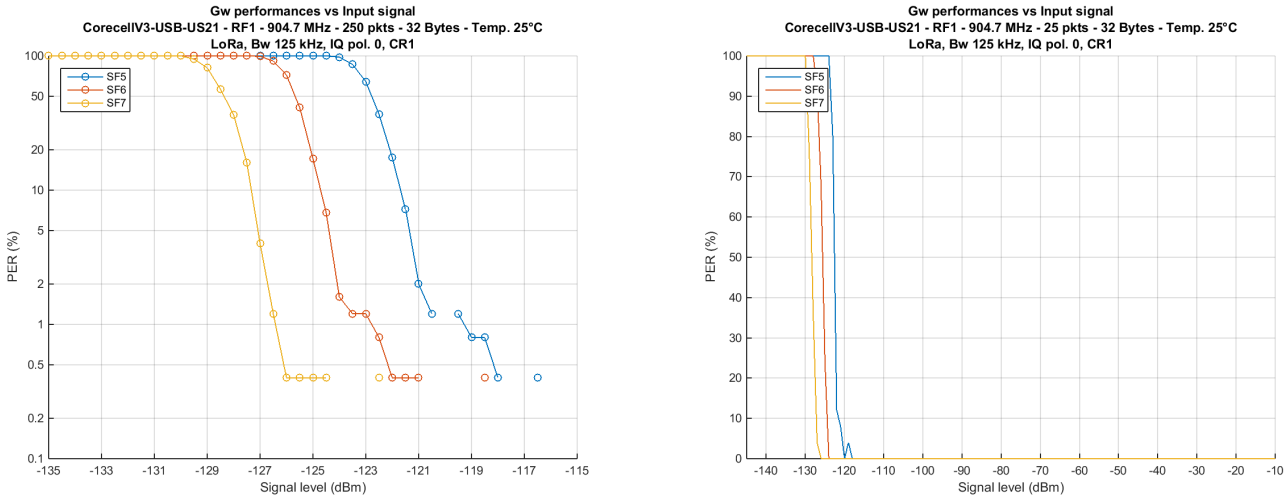


(b) High level

Figure 13.4: Sensitivity level and PER vs channels (Higher band), Board US21, SingleSF modem, SF7, Bw 500 kHz, 32 bytes, 25°C

13.5 Spreading Factor influence

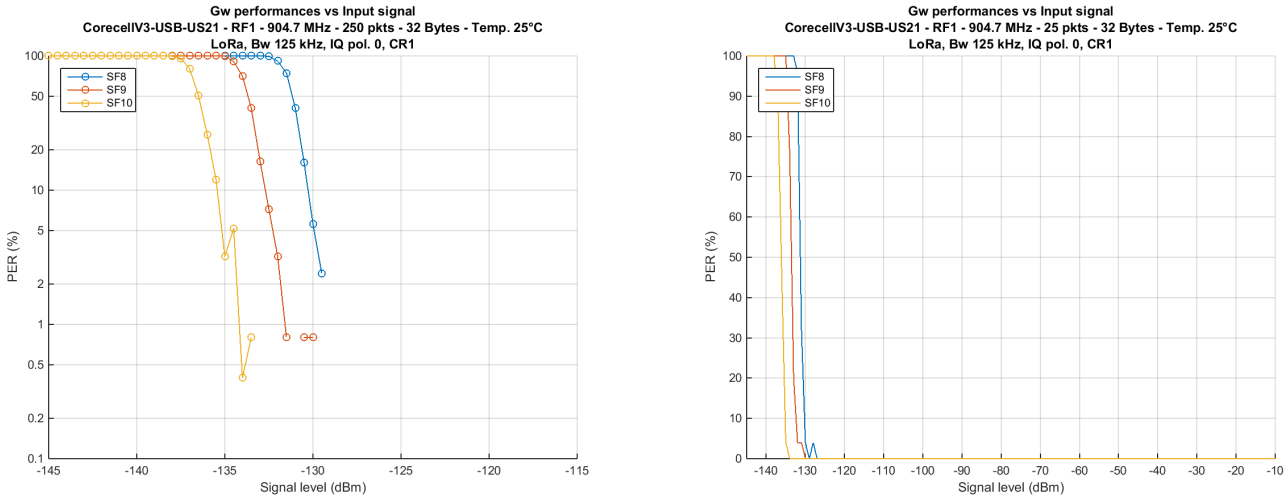
13.5.1 MultiSF modem (904.7 MHz)



(a) Sensitivity level

(b) High level

Figure 13.5: Sensitivity level and PER vs SF (5 to 7), Board US21, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C



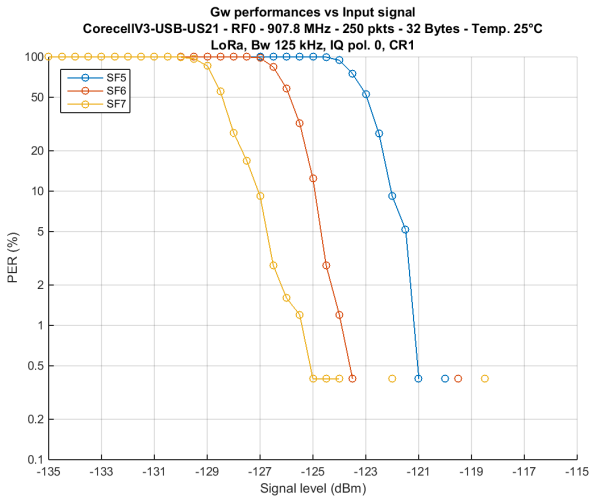
(a) Sensitivity level

(b) High level

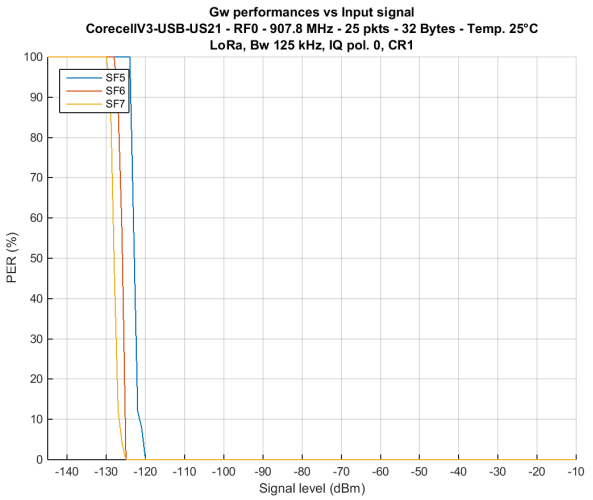
Figure 13.6: Sensitivity level and PER vs SF (8 to 10), Board US21, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C

13.5.2 SingleSF modem (907.8 MHz)

Bandwidth 125 kHz

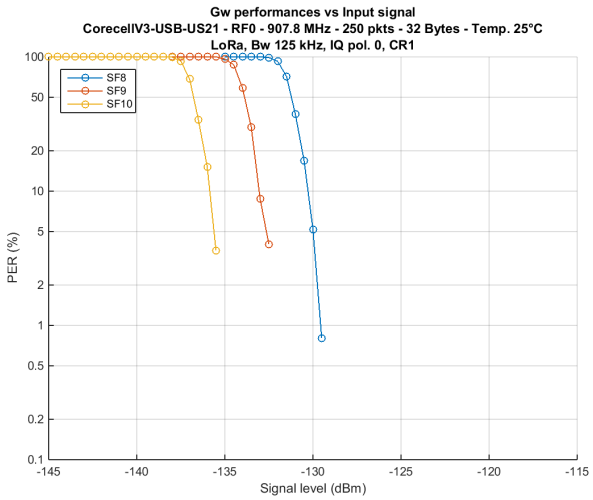


(a) Sensitivity level

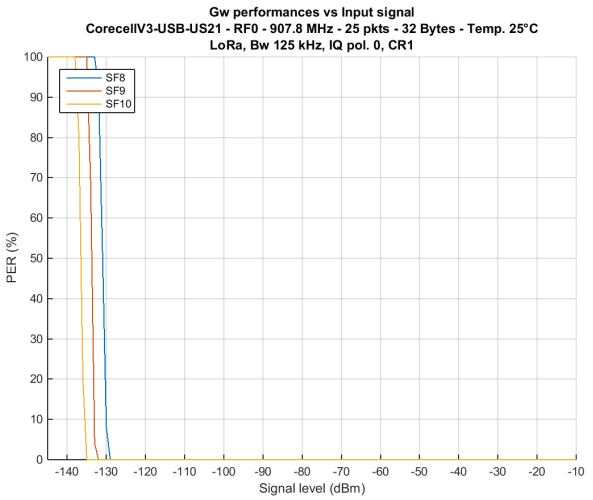


(b) High level

Figure 13.7: Sensitivity level and PER vs SF (5 to 7), Board US21, SingleSF modem, 904.6 MHz, Bw 125 kHz, 32 bytes, 25°C



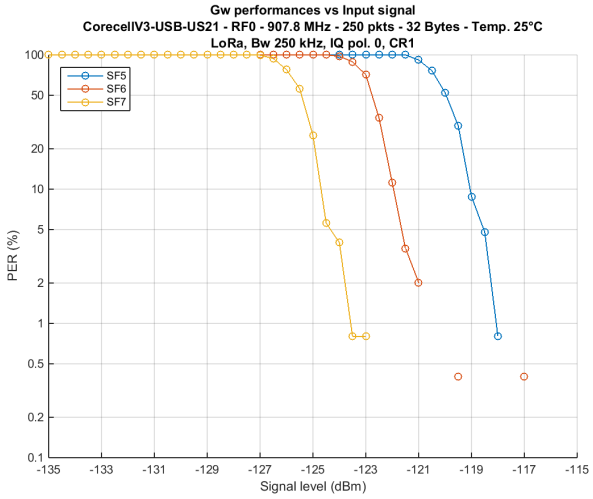
(a) Sensitivity level



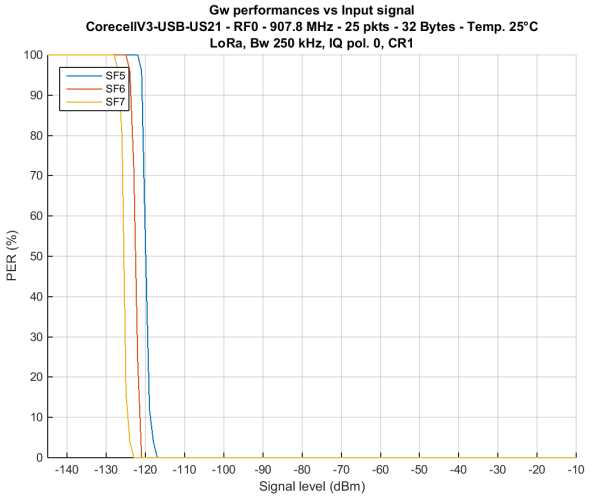
(b) High level

Figure 13.8: Sensitivity level and PER vs SF (8 to 10), Board US21, SingleSF modem, 904.6 MHz, Bw 125 kHz, 32 bytes, 25°C

Bandwidth 250 kHz

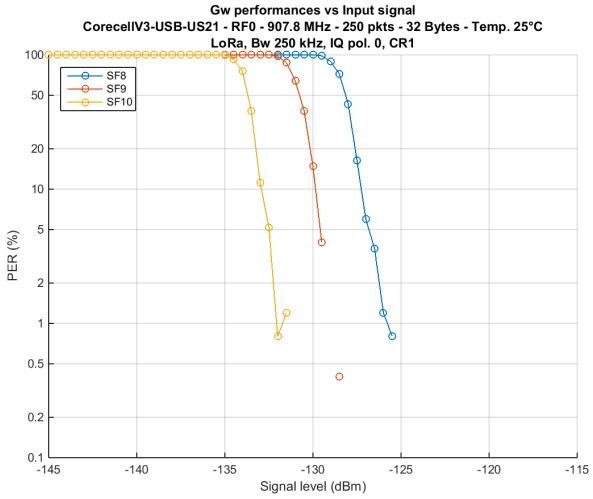


(a) Sensitivity level

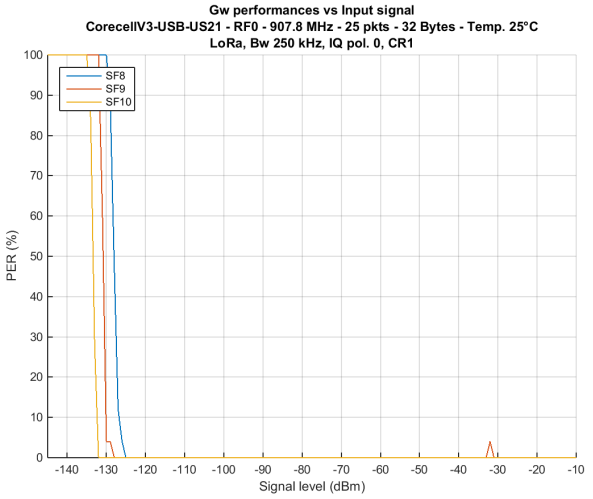


(b) High level

Figure 13.9: Sensitivity level and PER vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C



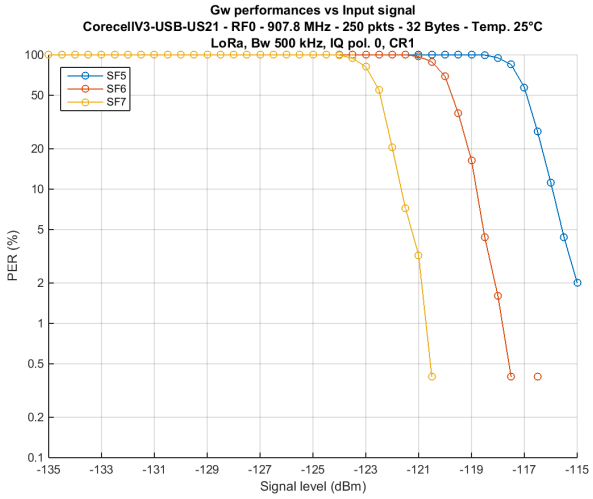
(a) Sensitivity level



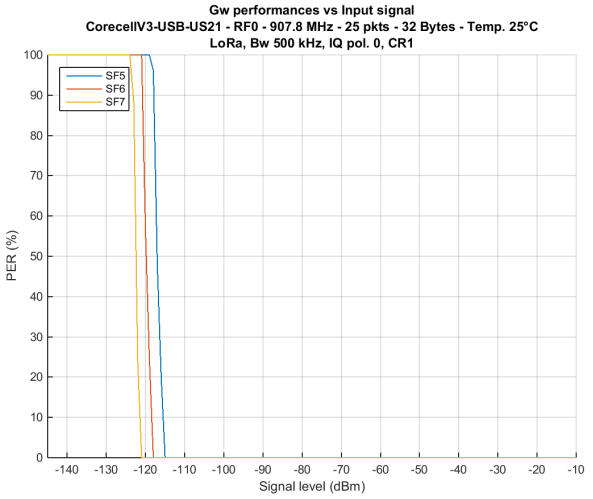
(b) High level

Figure 13.10: Sensitivity level and PER vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C

Bandwidth 500 kHz

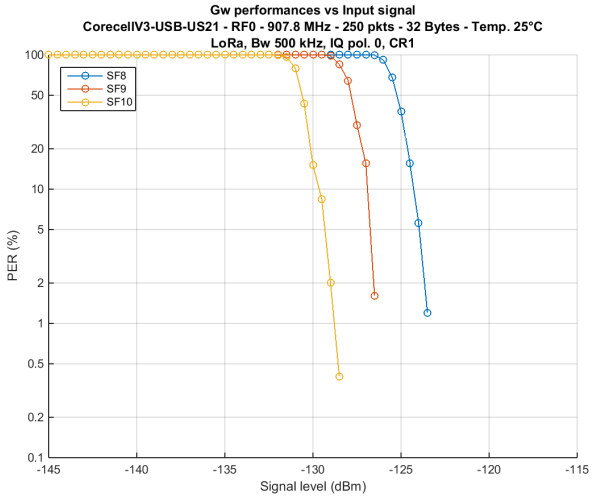


(a) Sensitivity level

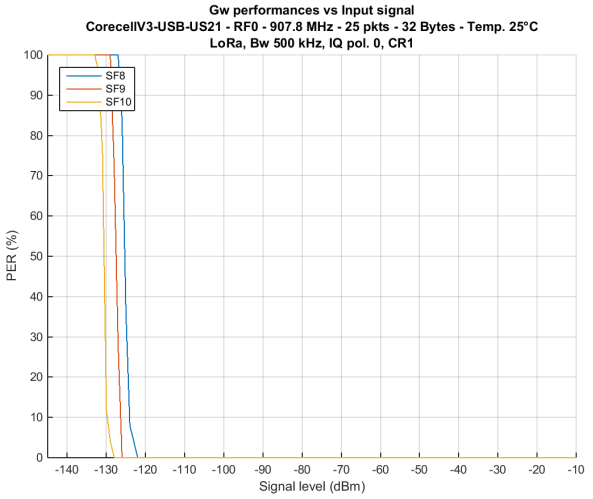


(b) High level

Figure 13.11: Sensitivity level and PER vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C



(a) Sensitivity level



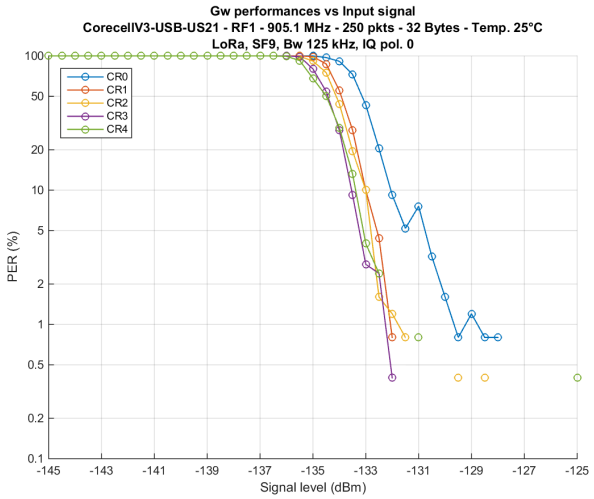
(b) High level

Figure 13.12: Sensitivity level and PER vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C

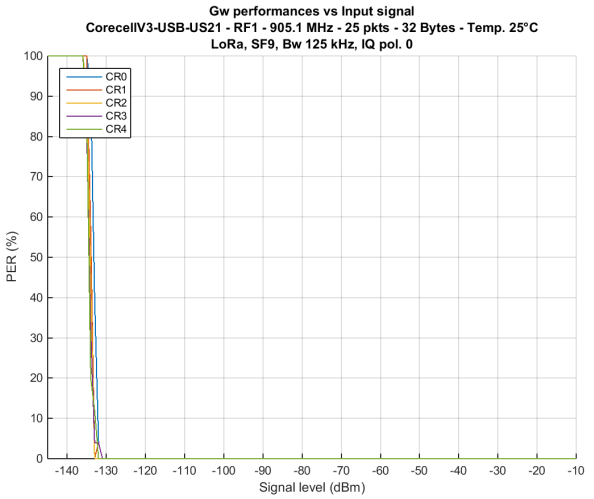
13.6 Coding rate influence

→ **Using the coding rate 0 is not recommended as the reception of packets is degraded.**

13.6.1 MultiSF modem (905.1 MHz)



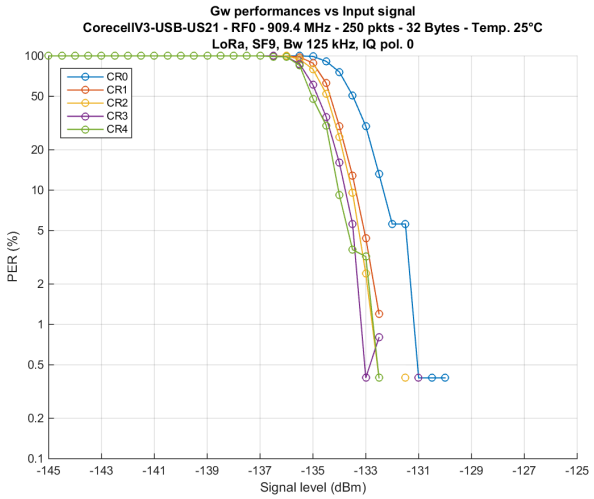
(a) Sensitivity level



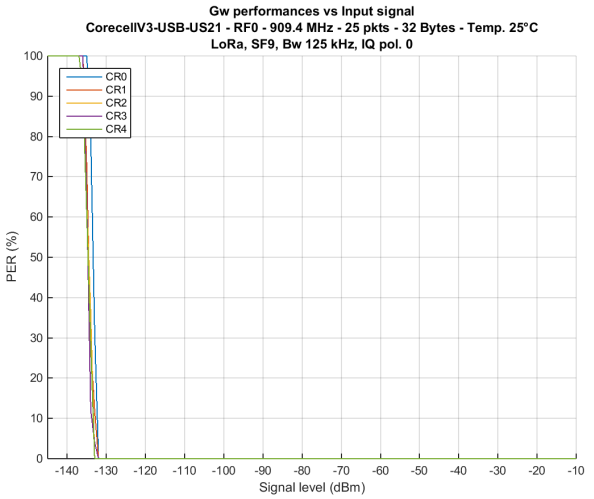
(b) High level

Figure 13.13: Sensitivity level and PER vs Coding rate, Board US21, MultiSF modem, 905.1 MHz, SF9, Bw 125 kHz, 32 bytes, 25°C

13.6.2 SingleSF modem (909.4 MHz)



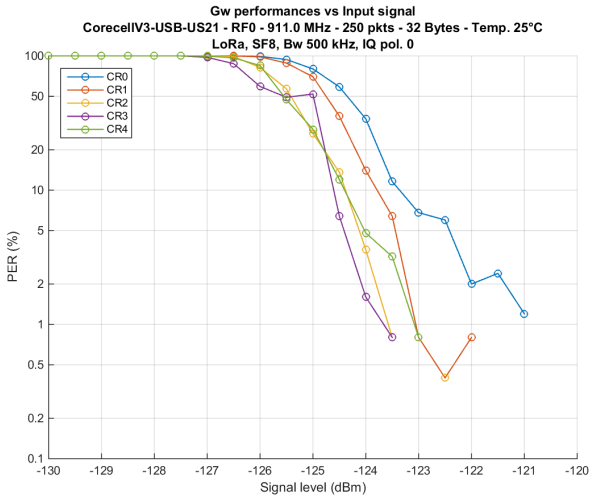
(a) Sensitivity level



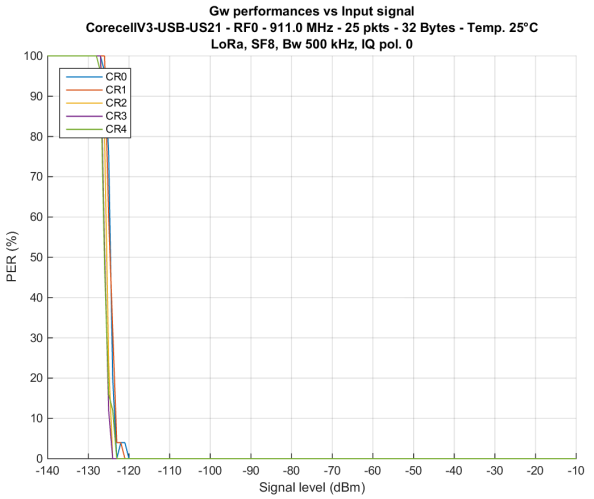
(b) High level

Figure 13.14: Sensitivity level and PER vs Coding rate, Board US21, SingleSF modem, 909.4 MHz, SF9, Bw 125 kHz, 32 bytes, 25°C

13.6.3 SingleSF modem, Implicit header (911.0 MHz)



(a) Sensitivity level



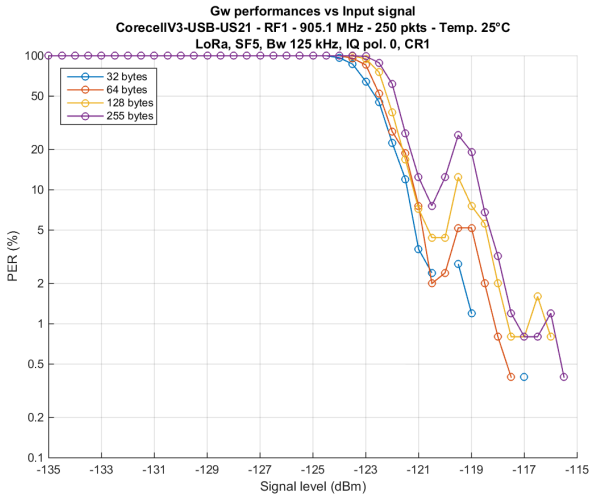
(b) High level

Figure 13.15: Sensitivity level and PER vs Coding rate, Board US21, SingleSF modem, Impl. header, 911.0 MHz, SF8, Bw 500 kHz, 32 bytes, 25°C

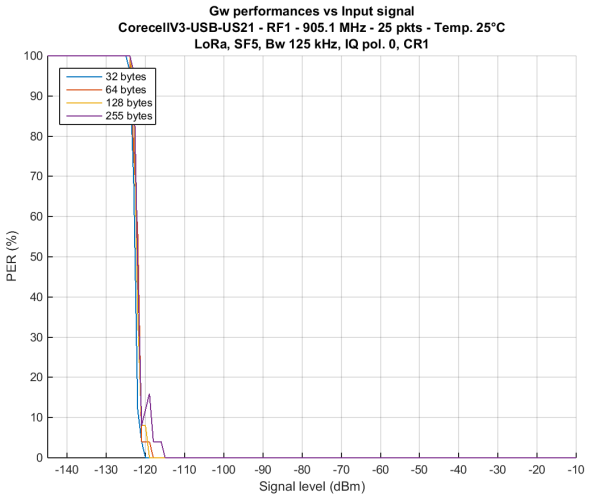
13.7 Payload length influence

13.7.1 MultiSF modem (905.1 MHz)

SF5



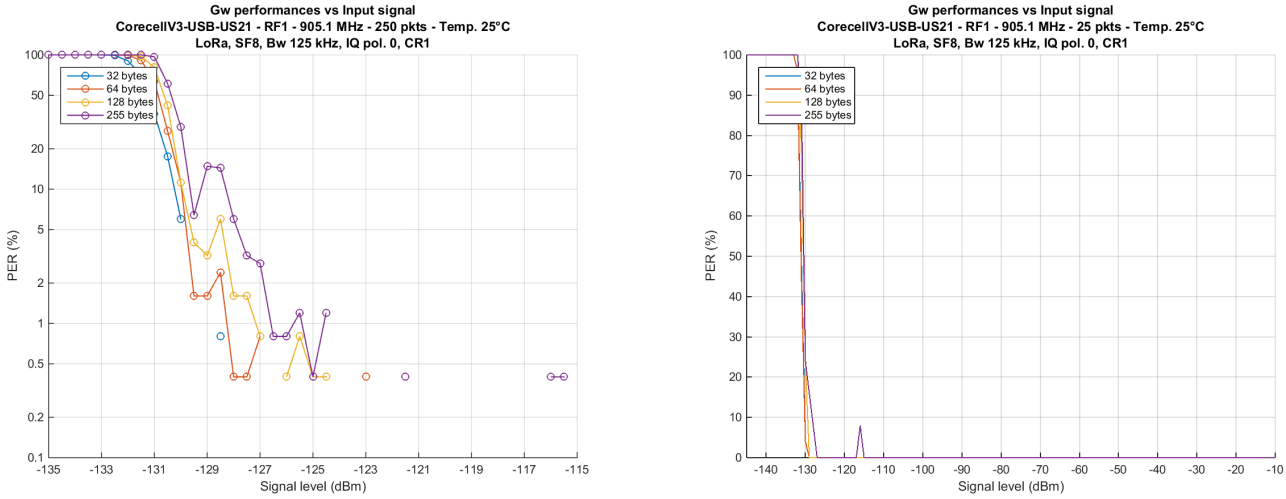
(a) Sensitivity level



(b) High level

Figure 13.16: Sensitivity level and PER vs payload length, Board US21, MultiSF modem, 905.1 MHz, SF5, Bw 125 kHz, CR1, 25°C

SF8



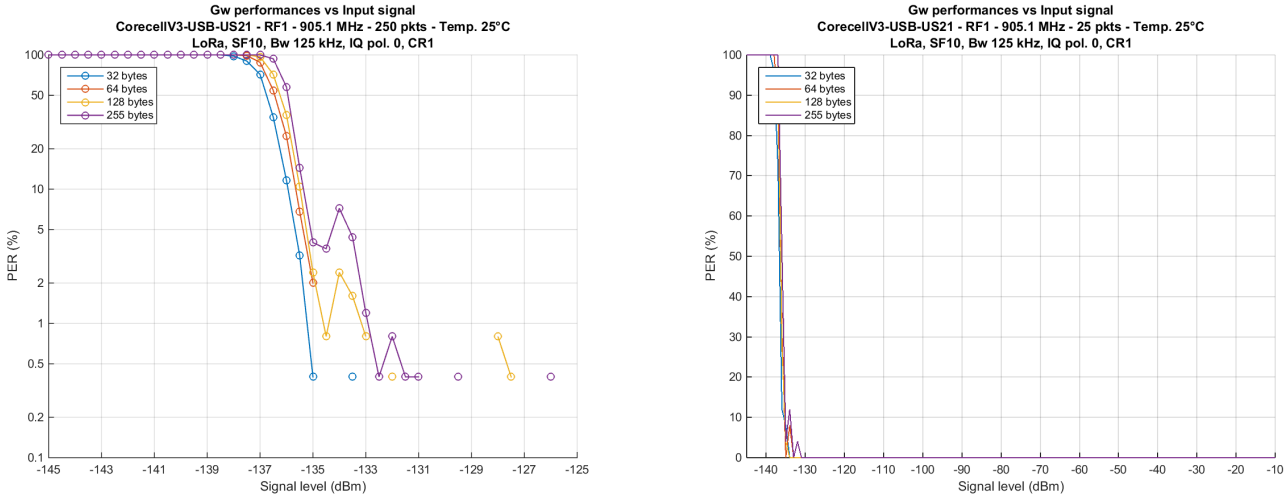
(a) Sensitivity level

(b) High level

Figure 13.17: Sensitivity level and PER vs payload length, Board US21, MultiSF modem, 905.1 MHz, SF8, Bw 125 kHz, CR1, 25°C

SF10

Note: The measurements of this section do not comply with the 400 ms rule of the FCC regulation.

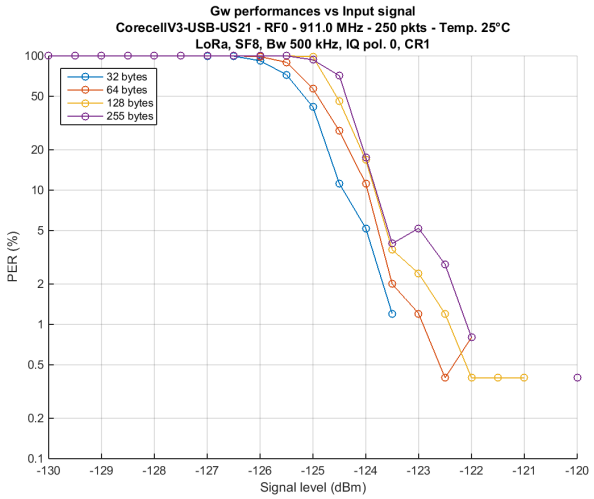


(a) Sensitivity level

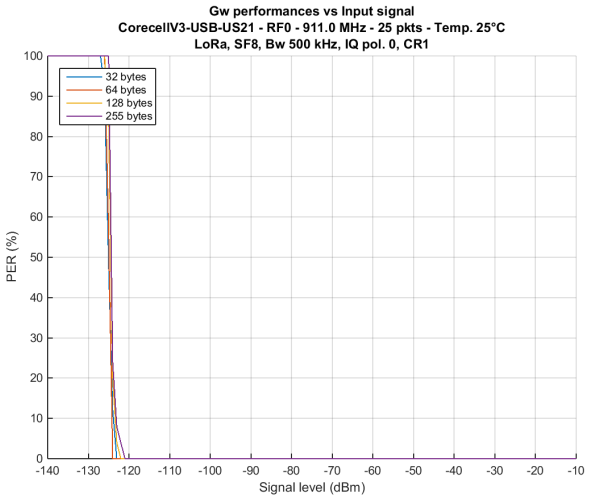
(b) High level

Figure 13.18: Sensitivity level and PER vs payload length, Board US21, MultiSF modem, 905.1 MHz, SF10, Bw 125 kHz, CR1, 25°C

13.7.2 SingleSF modem, Implicit header (911.0 MHz)



(a) Sensitivity level

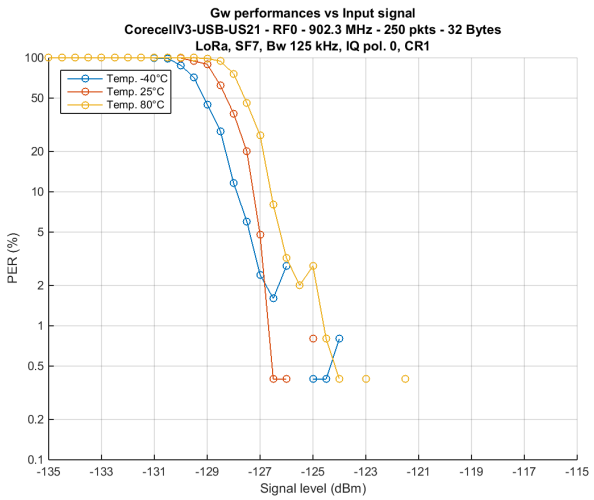


(b) High level

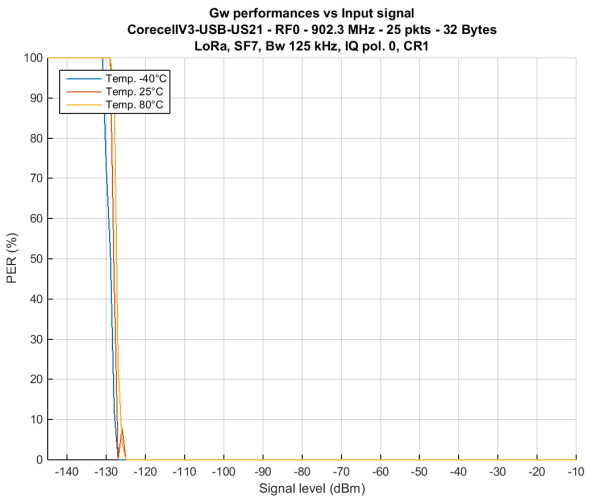
Figure 13.19: Sensitivity level and PER vs payload length, Board US21, SingleSF modem, Impl. header, 911.0 MHz, SF8, Bw 500 kHz, CR1, 25°C

13.8 Temperature influence

13.8.1 MultiSF modem (902.3 MHz)



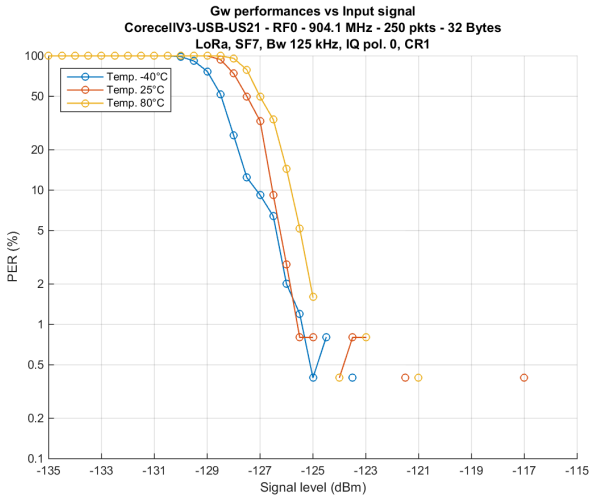
(a) Sensitivity level



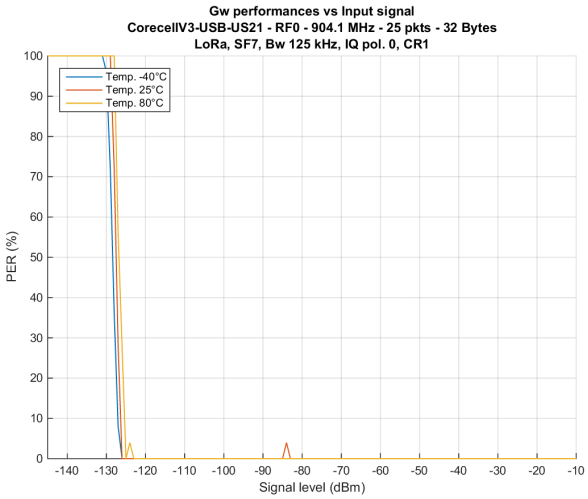
(b) High level

Figure 13.20: Sensitivity level and PER vs temperature, Board US21, 902.3 MHz, SF7, Bw 125 kHz, CR1

13.8.2 MultiSF modem (904.1 MHz)



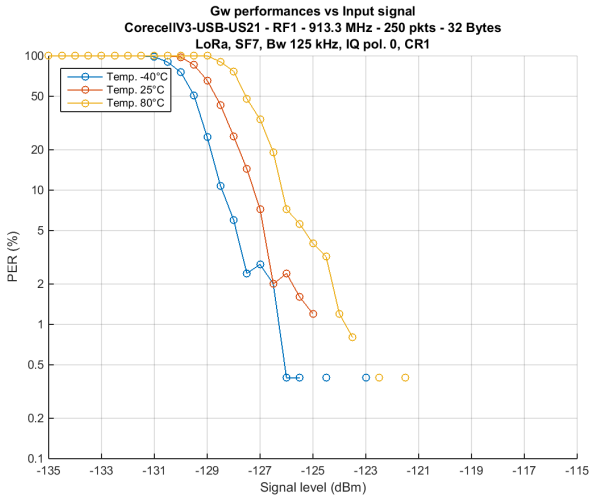
(a) Sensitivity level



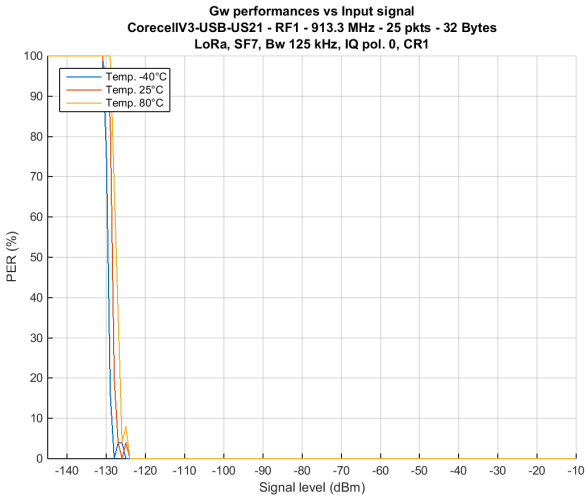
(b) High level

Figure 13.21: Sensitivity level and PER vs temperature, Board US21, 904.1 MHz, SF7, Bw 125 kHz, CR1

13.8.3 MultiSF modem (913.3 MHz)



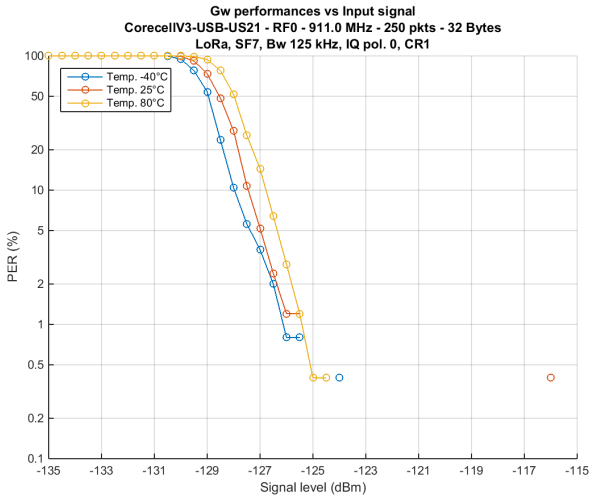
(a) Sensitivity level



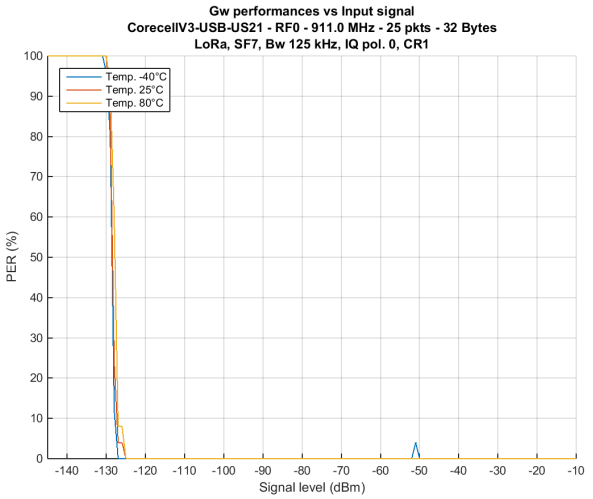
(b) High level

Figure 13.22: Sensitivity level and PER vs temperature, Board US21, 913.3 MHz, SF7, Bw 125 kHz, CR1

13.8.4 SingleSF modem (911.0 MHz)



(a) Sensitivity level

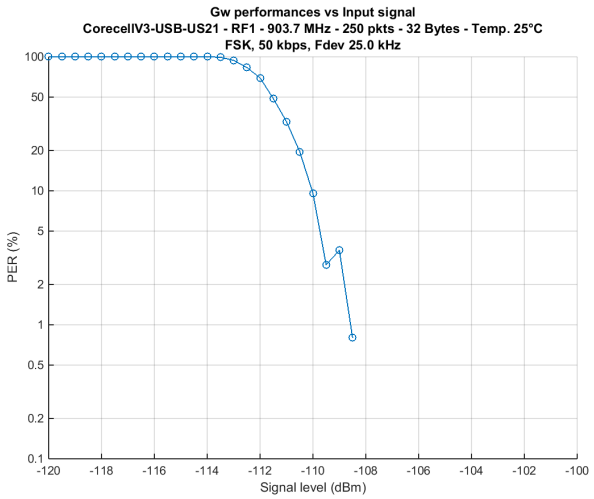


(b) High level

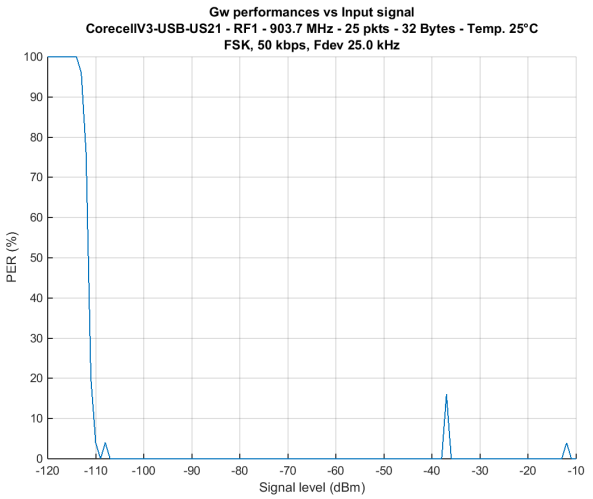
Figure 13.23: Sensitivity level and PER vs temperature, Board US21, 911.0 MHz, SF7, Bw 125 kHz, CR1

13.9 FSK modem

13.9.1 903.7 MHz



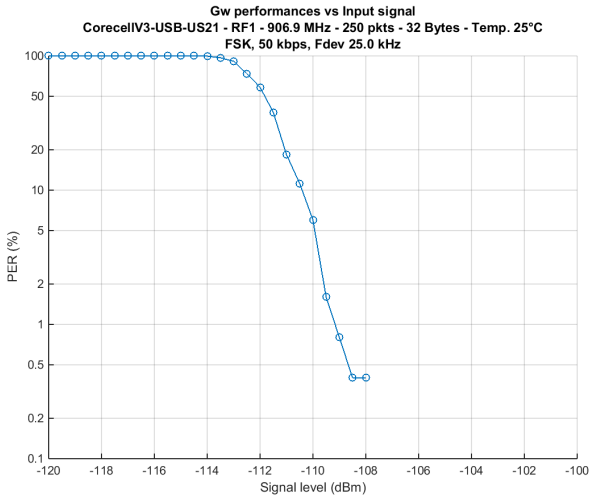
(a) Sensitivity level



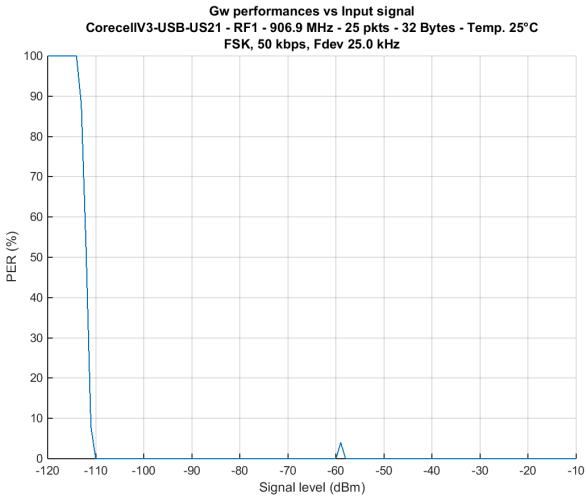
(b) High level

Figure 13.24: Sensitivity level and PER, Board US21, FSK modem, 903.7 MHz, 50 kbits, Fdev 25 kHz, 25°C

13.9.2 906.9 MHz



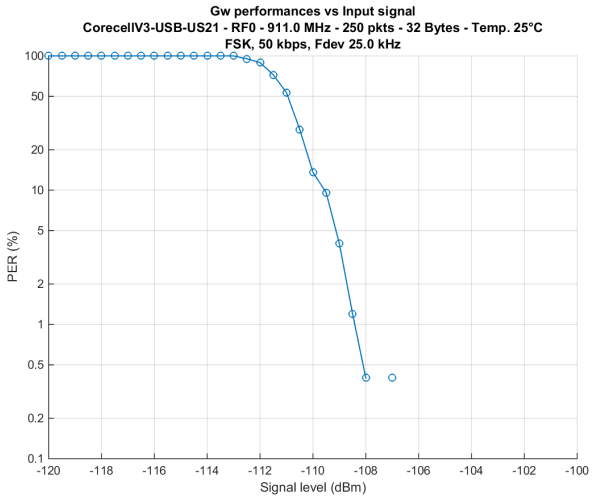
(a) Sensitivity level



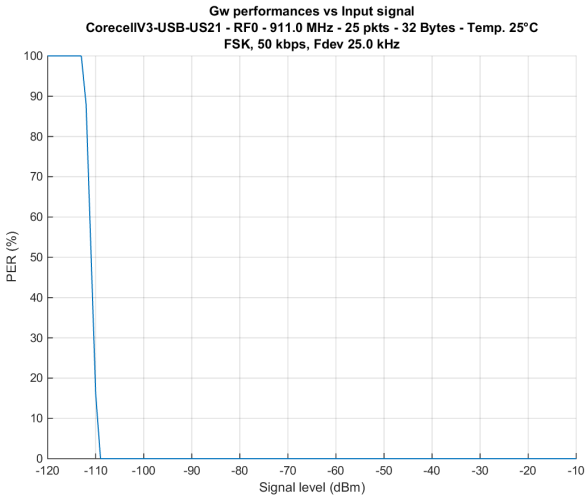
(b) High level

Figure 13.25: Sensitivity level and PER, Board US21, FSK modem, 906.9 MHz, 50 kbits, Fdev 25 kHz, 25°C

13.9.3 911.0 MHz



(a) Sensitivity level



(b) High level

Figure 13.26: Sensitivity level and PER, Board US21, FSK modem, 911.0 MHz, 50 kbits, Fdev 25 kHz, 25°C

13.10 Conclusion

→ **The sensitivity level and the PER for higher signal input levels comply with the expected performances mentioned in section 13.3**

14 RSSI

14.1 Description

The LoRa modems returns two indicators of the received signal level: RSSI Channel and Signal:

- RSSI Channel: This indicator represents the power in the channel bandwidth, taken care the power of signal and the thermal noise. It concerns LoRa and FSK modulations.
- RSSI Signal: This indicator represents the LoRa signal only without taken care the thermal noise power. It only concerns the LoRa modulation; this indicator is not available for the FSK modulation.

14.2 Setup

The RSSI measurement is performed simultaneously of the PER one. The setup is shown in figure 3.1. 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.

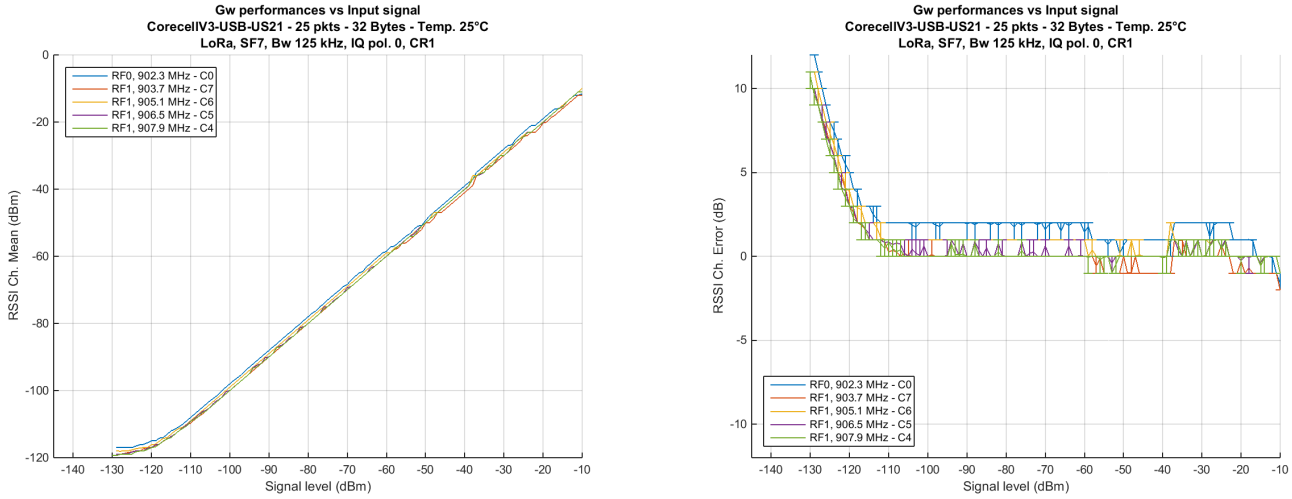
The **packet forwarder** software running on the host pulls data from the gateway by the USB bus and send them to the computer through UDP protocol.

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 or signal) value. They should be close to the mean value.

14.3 Frequency influence

14.3.1 MultiSF modem (Lower band)

RSSI channel

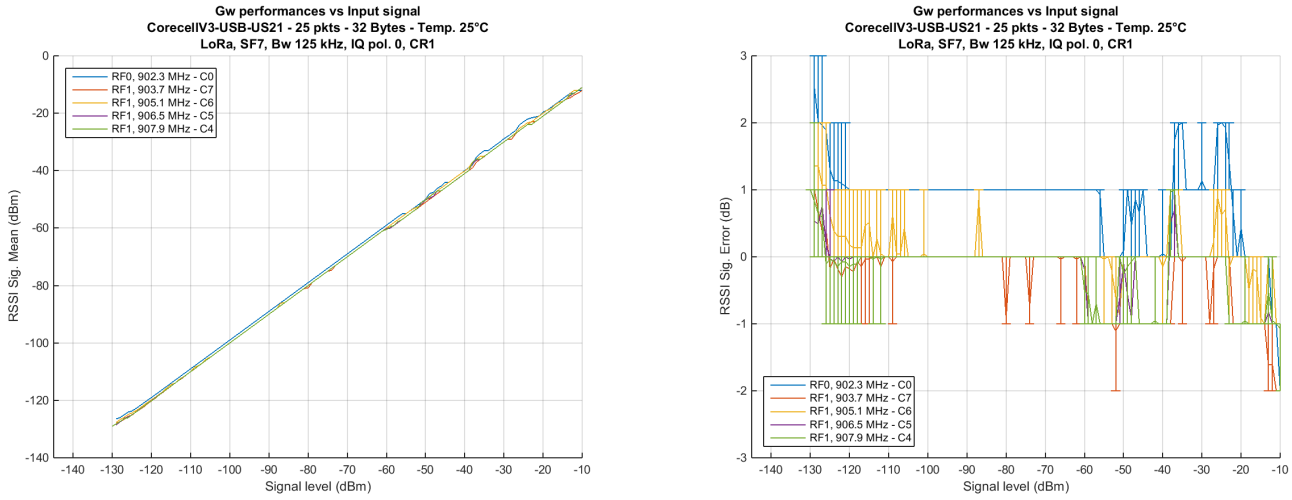


(a) RSSI mean

(b) RSSI error

Figure 14.1: RSSI channel vs channels (Lower band), Board US21, MultiSF modem, SF7, Bw 125 kHz, 32 bytes, 25°C

RSSI signal



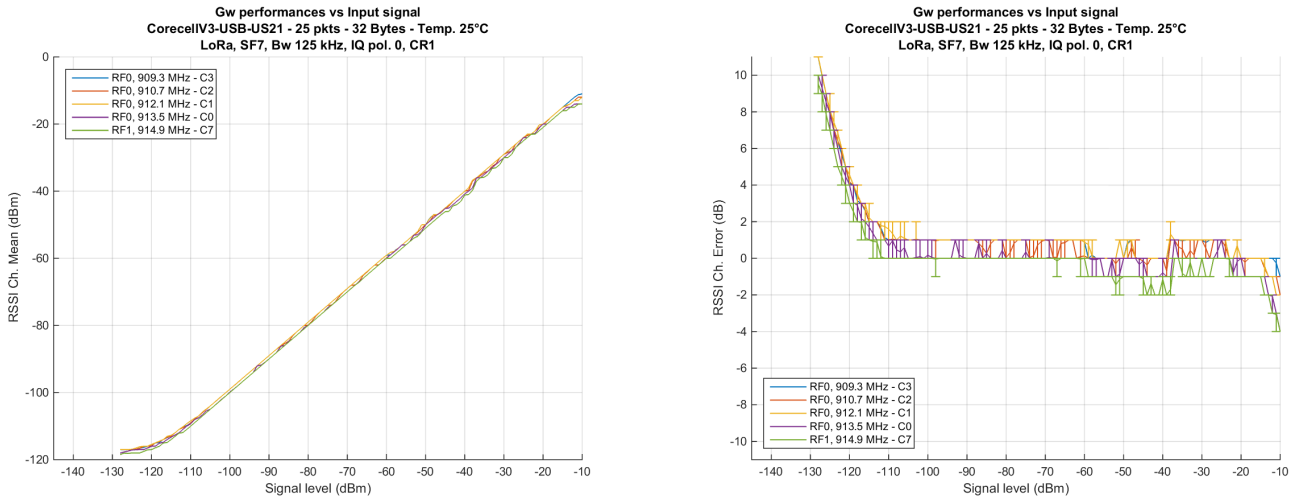
(a) RSSI mean

(b) RSSI error

Figure 14.2: RSSI signal vs channels (Lower band), Board US21, MultiSF modem, SF7, Bw 125 kHz, 32 bytes, 25°C

14.3.2 MultiSF modem (Higher band)

RSSI channel

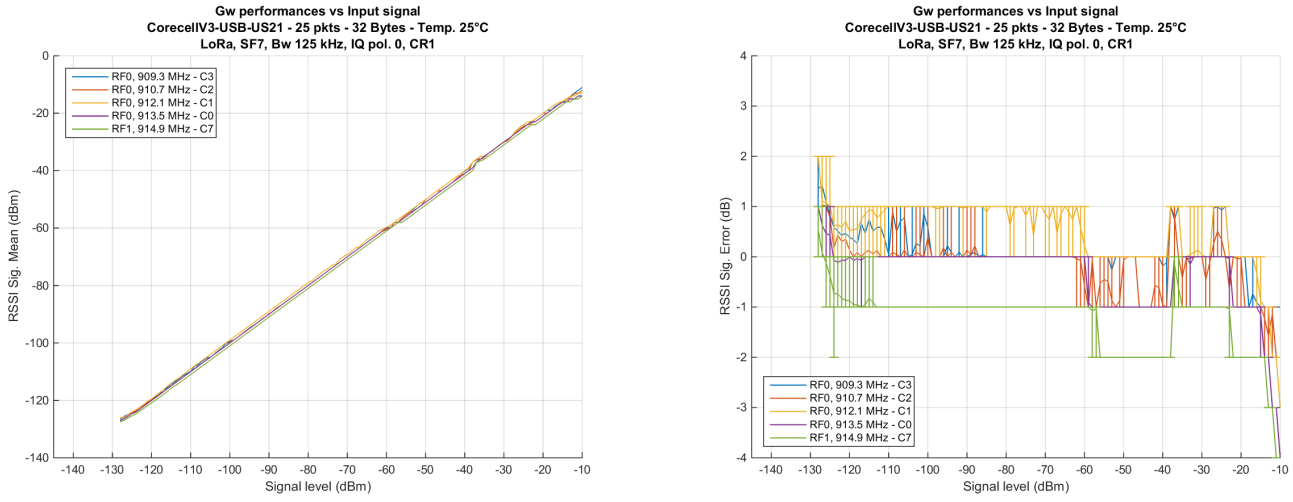


(a) RSSI mean

(b) RSSI error

Figure 14.3: RSSI channel vs channels (Higher band), Board US21, MultiSF modem, SF7, Bw 125 kHz, 32 bytes, 25°C

RSSI signal



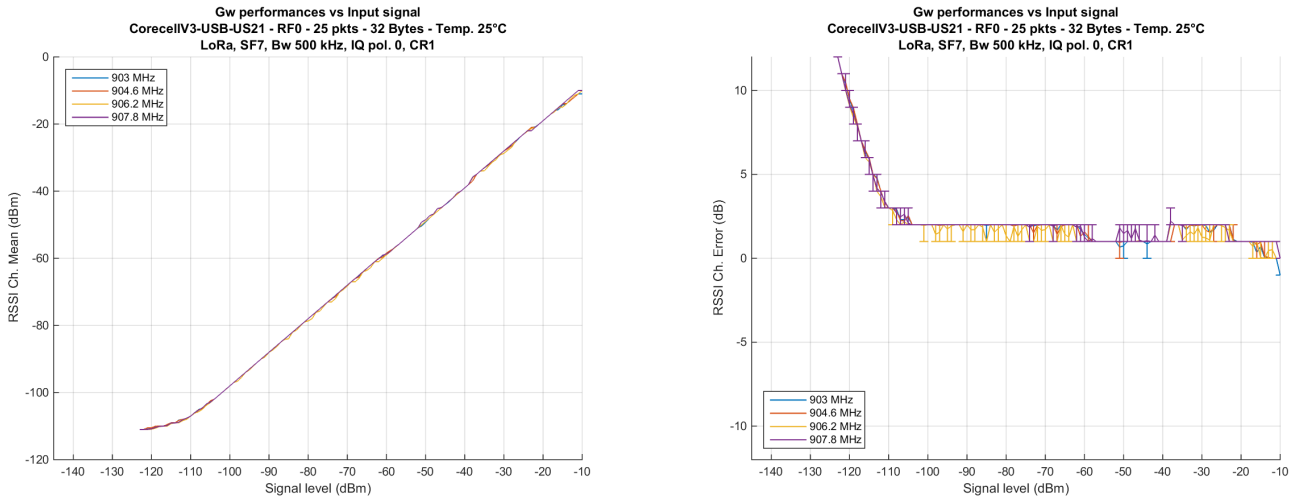
(a) RSSI mean

(b) RSSI error

Figure 14.4: RSSI signal vs channels (Higher band), Board US21, MultiSF modem, SF7, Bw 125 kHz, 32 bytes, 25°C

14.3.3 SingleSF modem (Lower band)

RSSI channel

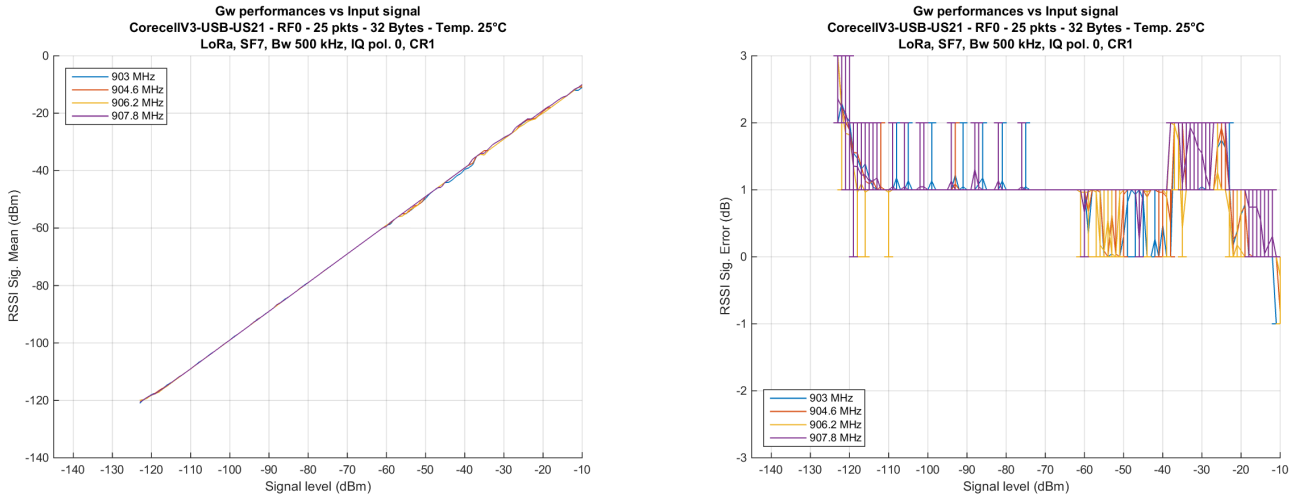


(a) RSSI mean

(b) RSSI error

Figure 14.5: RSSI channel vs channels (Lower band), Board US21, SingleSF modem, SF7, Bw 500 kHz, 32 bytes, 25°C

RSSI signal

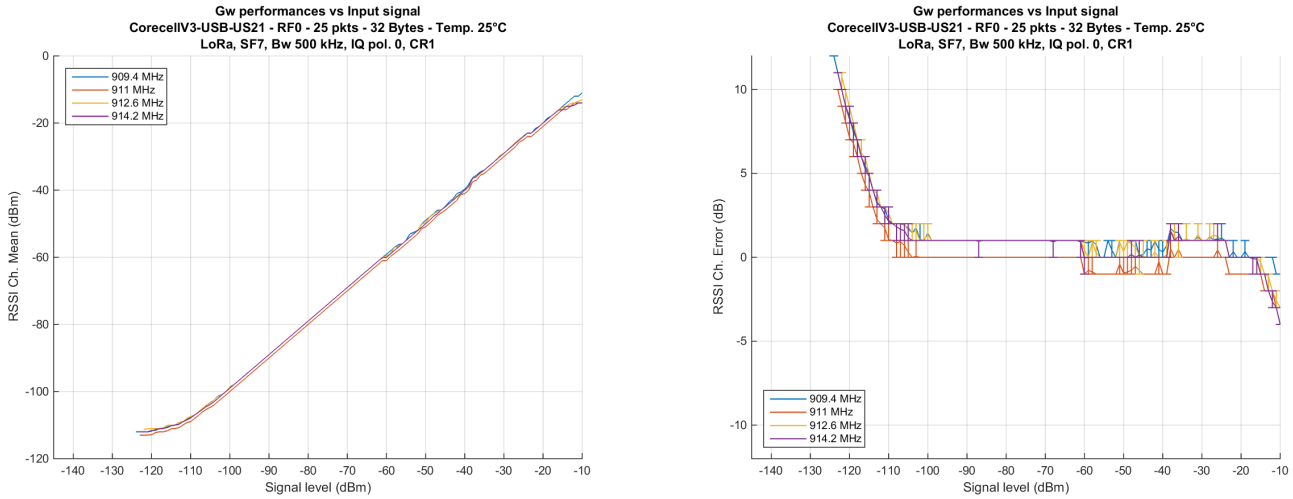


(a) RSSI mean

(b) RSSI error

Figure 14.6: RSSI signal vs channels (Lower band), Board US21, SingleSF modem, SF7, Bw 500 kHz, 32 bytes, 25°C

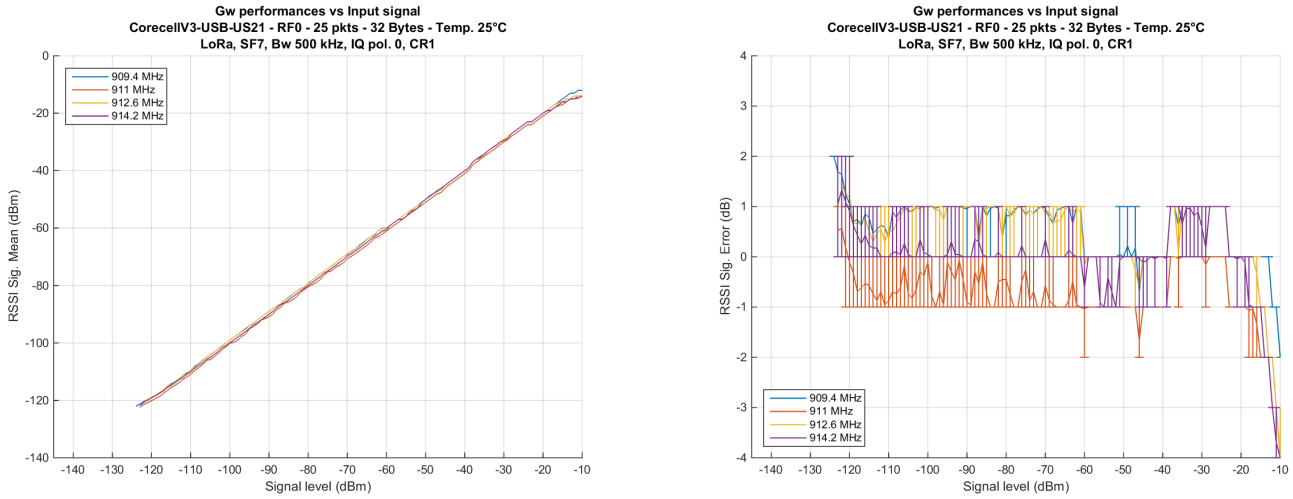
14.3.4 SingleSF modem (Higher band)



(a) RSSI mean

(b) RSSI error

Figure 14.7: RSSI channel vs channels (Higher band), Board US21, SingleSF modem, SF7, Bw 500 kHz, 32 bytes, 25°C



(a) RSSI mean

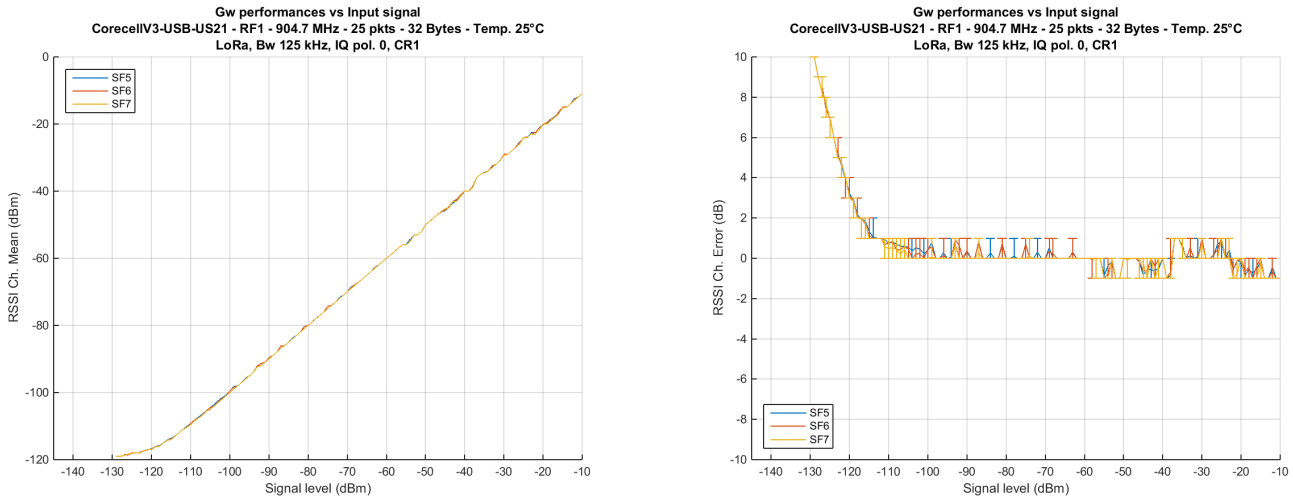
(b) RSSI error

Figure 14.8: RSSI signal vs channels (Higher band), Board US21, SingleSF modem, SF7, Bw 500 kHz, 32 bytes, 25°C

14.4 Spreading factor influence

14.4.1 MultiSF modem (904.7 MHz)

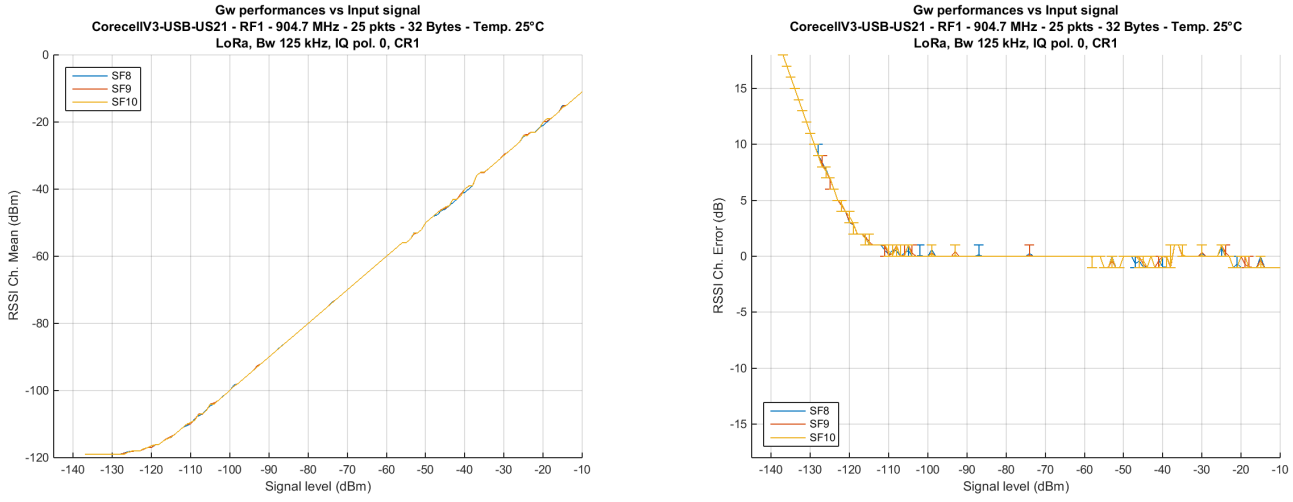
RSSI channel



(a) RSSI mean

(b) RSSI error

Figure 14.9: RSSI channel vs SF (5 to 7), Board US21, MultiSF modem, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C

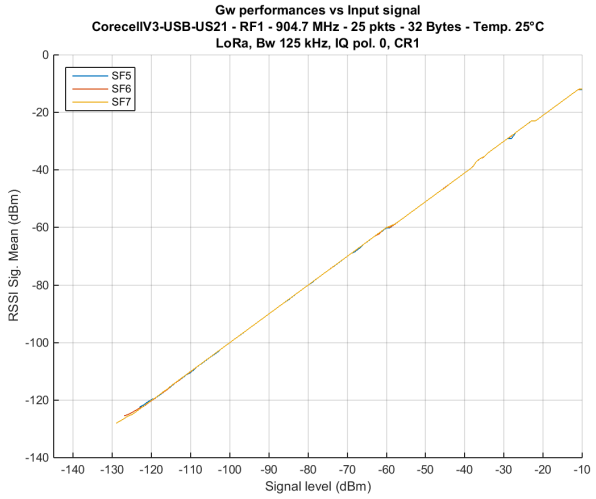


(a) RSSI mean

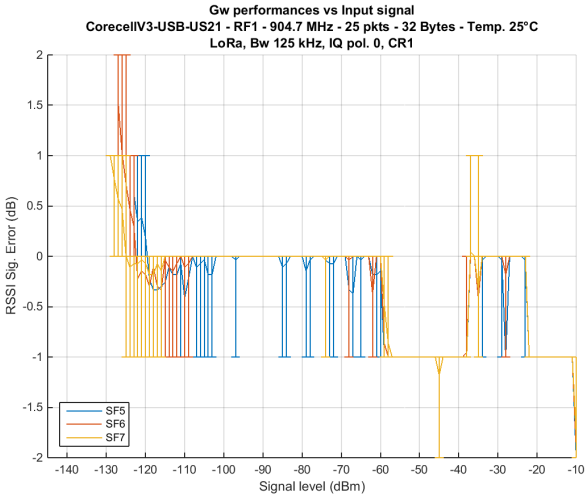
(b) RSSI error

Figure 14.10: RSSI channel vs SF (8 to 10), Board US21, MultiSF modem, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C

RSSI signal

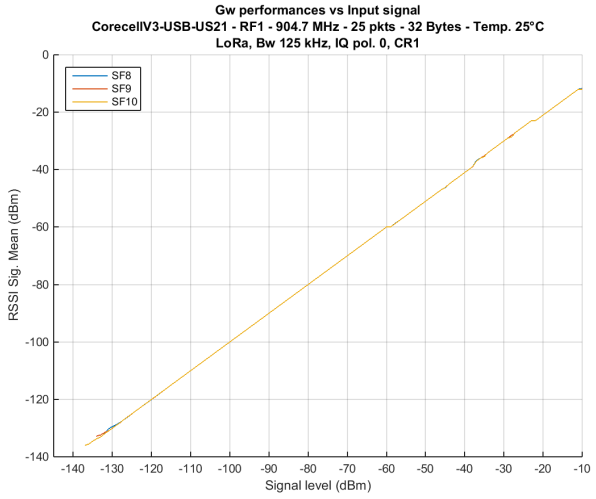


(a) RSSI mean

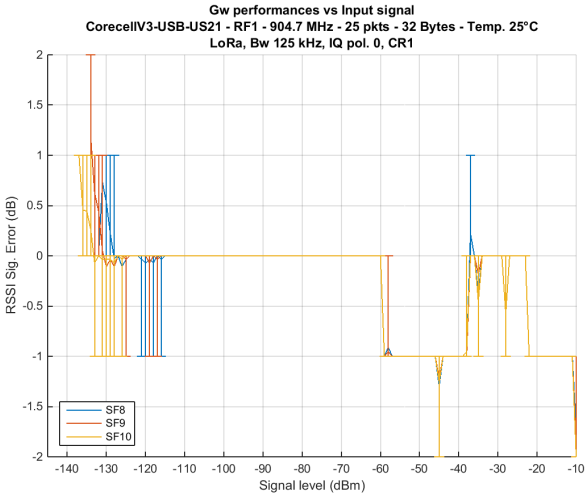


(b) RSSI error

Figure 14.11: RSSI signal vs SF (5 to 7), Board US21, MultiSF modem, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C



(a) RSSI mean

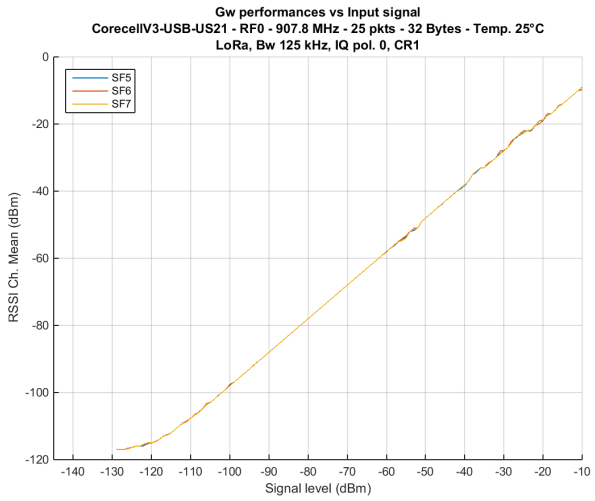


(b) RSSI error

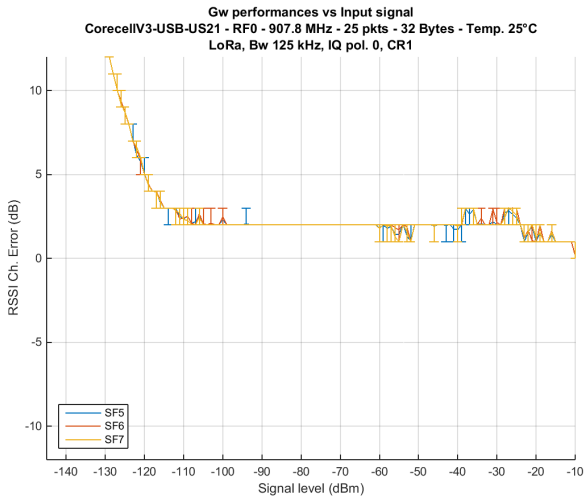
Figure 14.12: RSSI signal vs SF (8 to 10), Board US21, MultiSF modem, 904.5 MHz, Bw 125 kHz, 32 bytes, 25°C

14.4.2 SingleSF modem (907.8 MHz), Bandwidth 125 kHz

RSSI channel

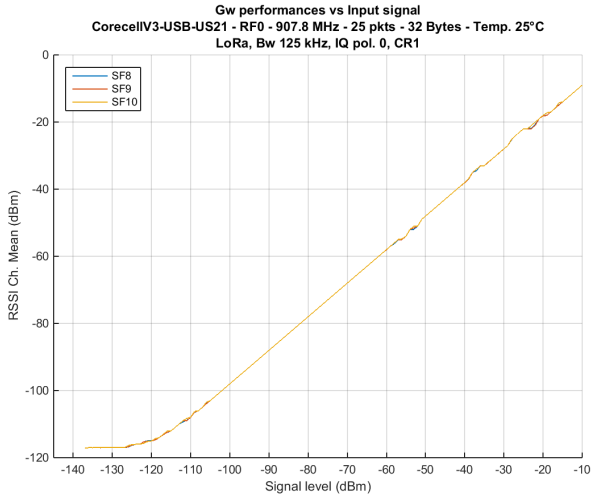


(a) RSSI mean

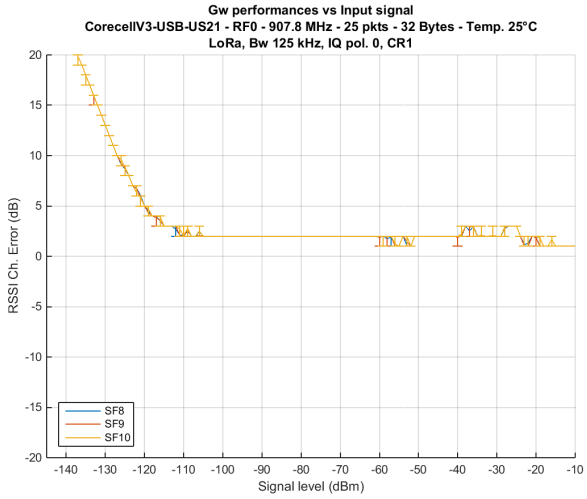


(b) RSSI error

Figure 14.13: RSSI channel vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C



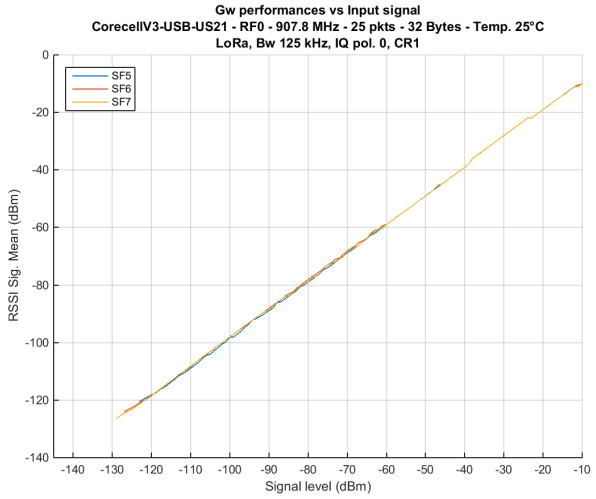
(a) RSSI mean



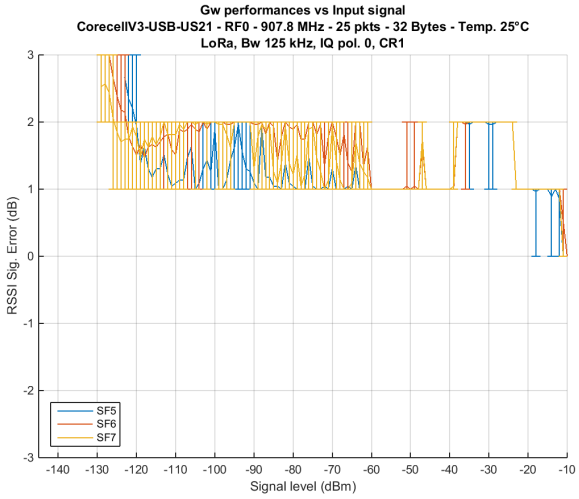
(b) RSSI error

Figure 14.14: RSSI channel vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C

RSSI signal

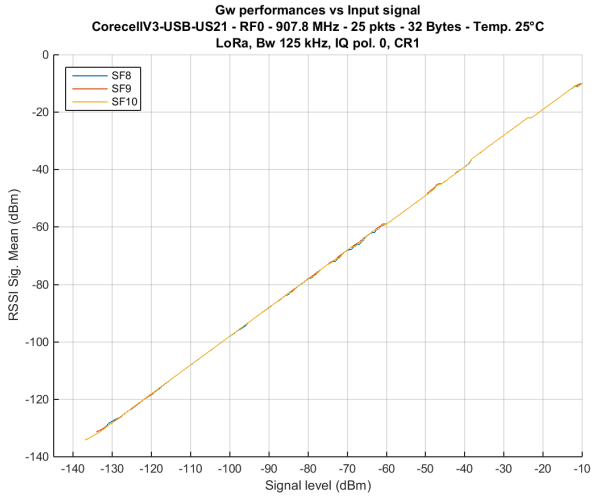


(a) RSSI mean

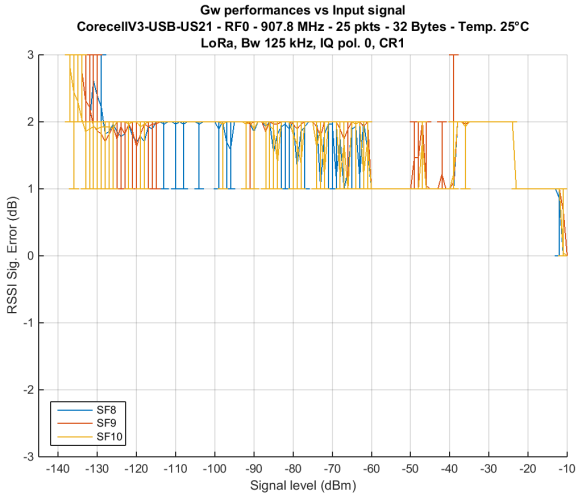


(b) RSSI error

Figure 14.15: RSSI signal vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C



(a) RSSI mean

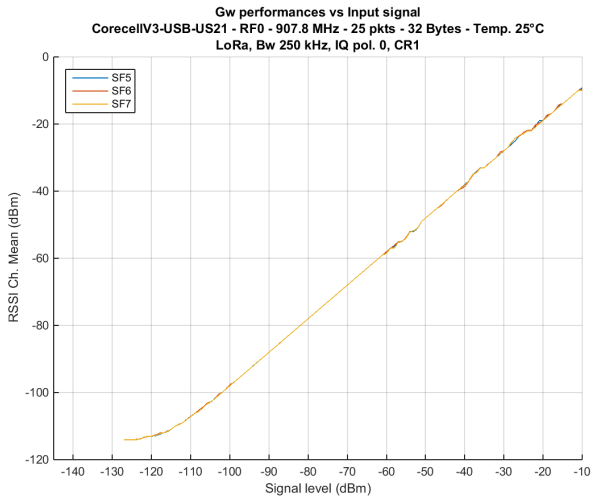


(b) RSSI error

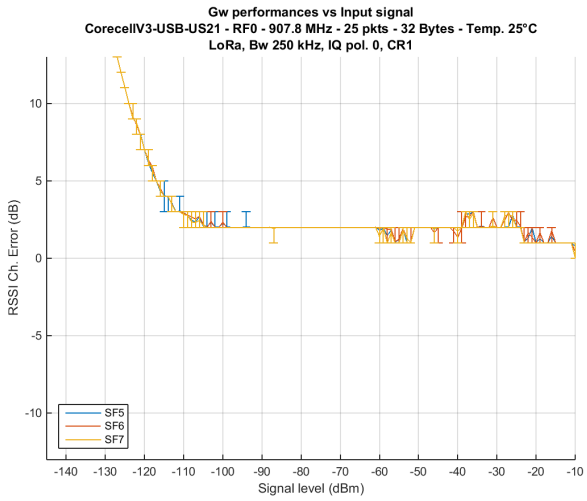
Figure 14.16: RSSI signal vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C

14.4.3 SingleSF modem (907.8 MHz), Bandwidth 250 kHz

RSSI channel

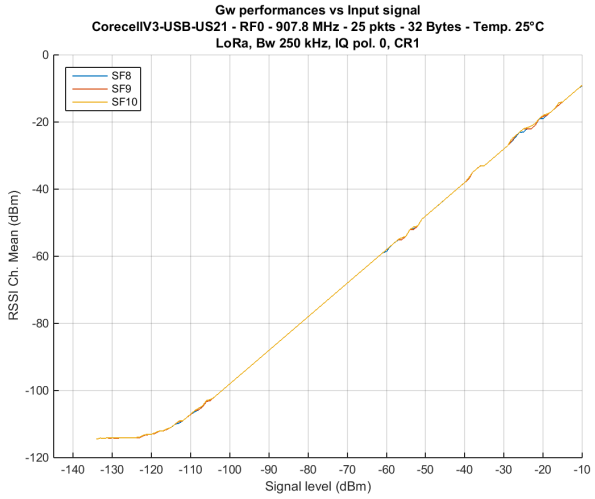


(a) RSSI mean

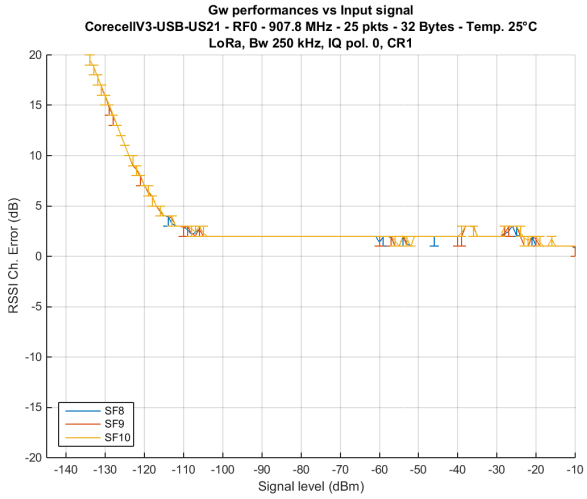


(b) RSSI error

Figure 14.17: RSSI channel vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C



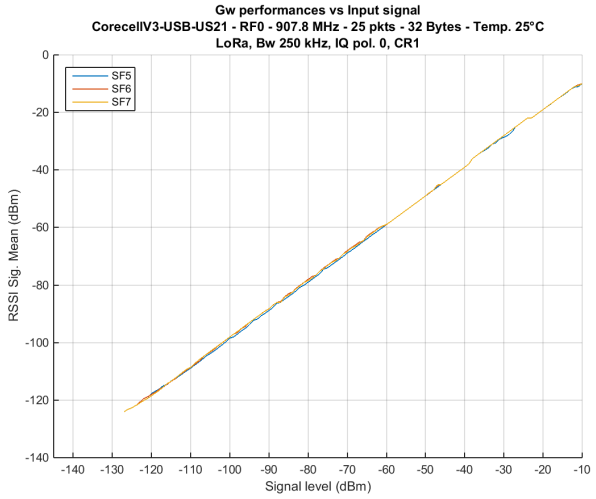
(a) RSSI mean



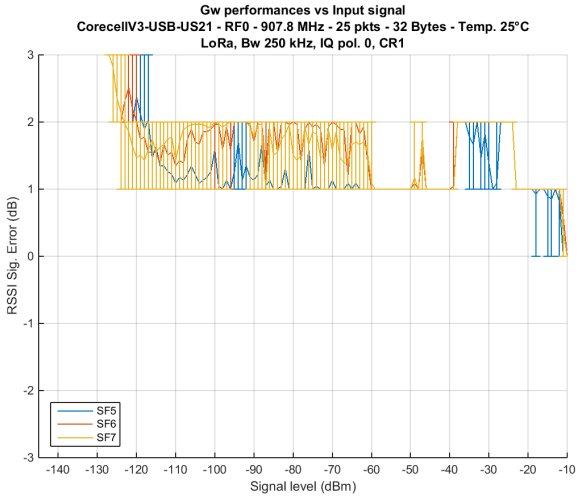
(b) RSSI error

Figure 14.18: RSSI channel vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C

RSSI signal

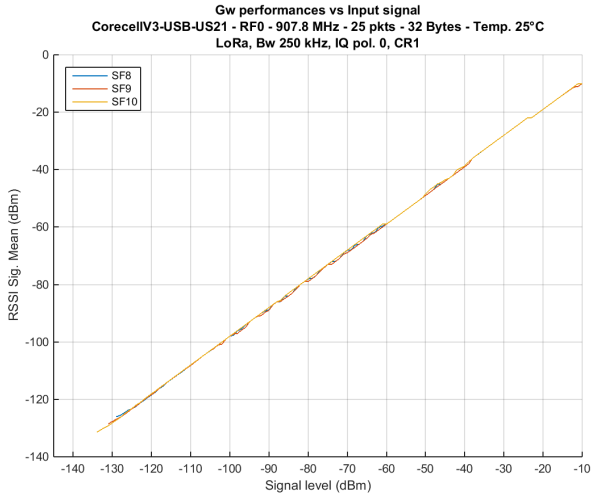


(a) RSSI mean

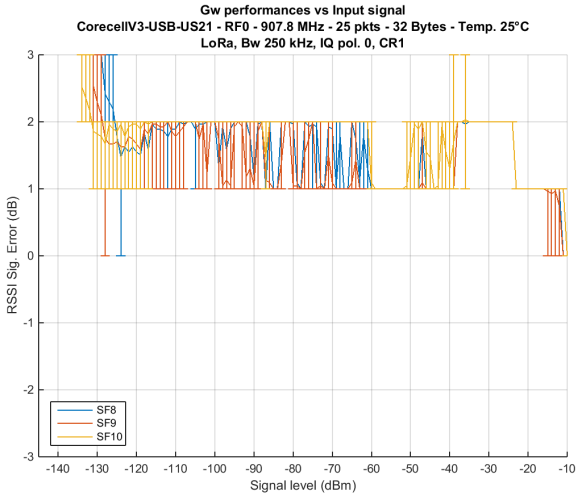


(b) RSSI error

Figure 14.19: RSSI signal vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C



(a) RSSI mean

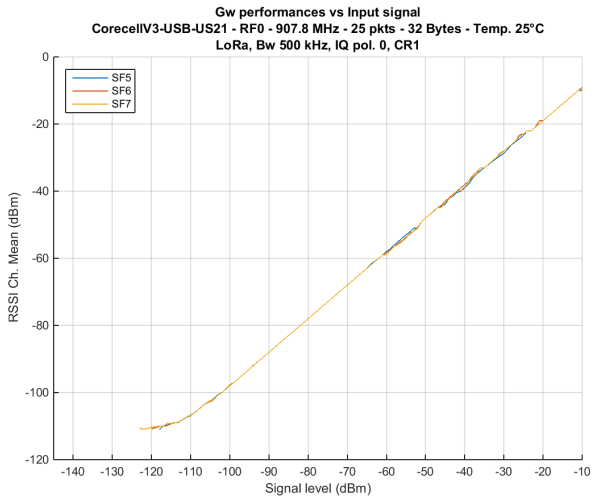


(b) RSSI error

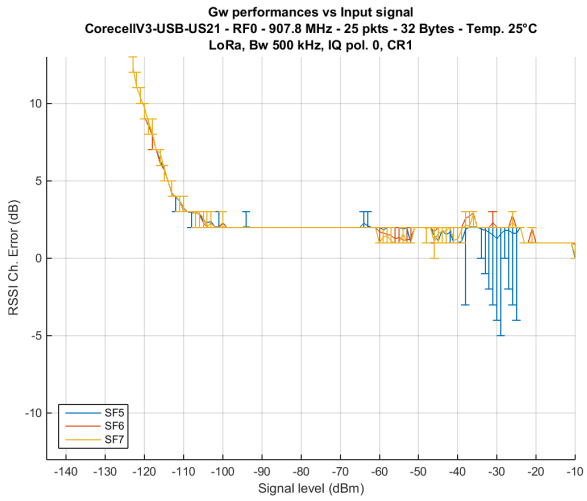
Figure 14.20: RSSI signal vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C

14.4.4 SingleSF modem (907.8 MHz), Bandwidth 500 kHz

RSSI channel

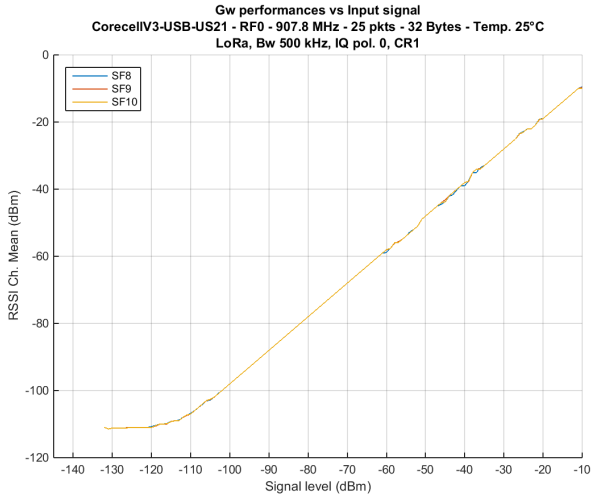


(a) RSSI mean

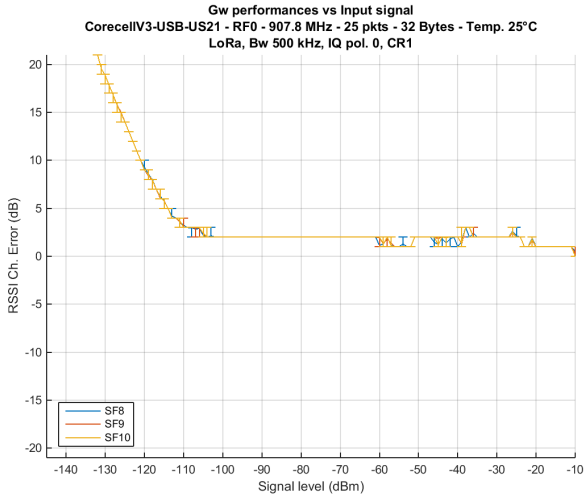


(b) RSSI error

Figure 14.21: RSSI channel vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C



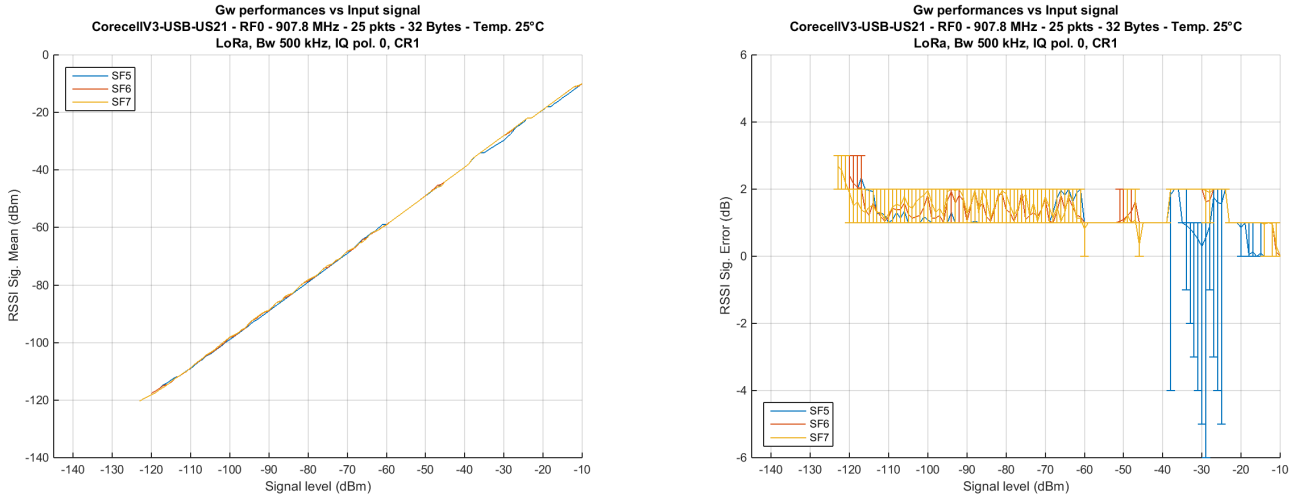
(a) RSSI mean



(b) RSSI error

Figure 14.22: RSSI channel vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C

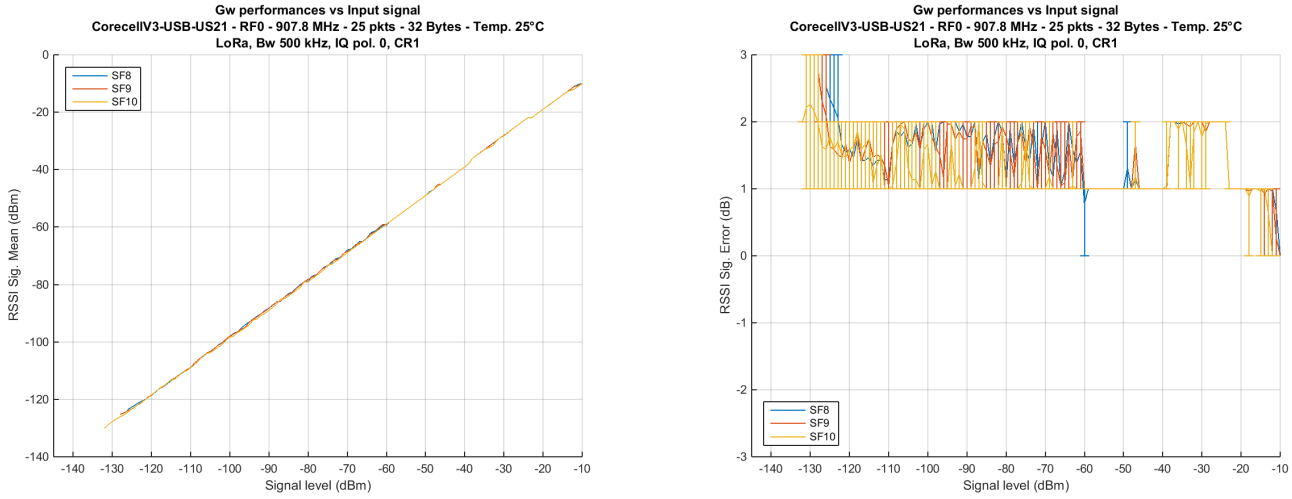
RSSI signal



(a) RSSI mean

(b) RSSI error

Figure 14.23: RSSI signal vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C



(a) RSSI mean

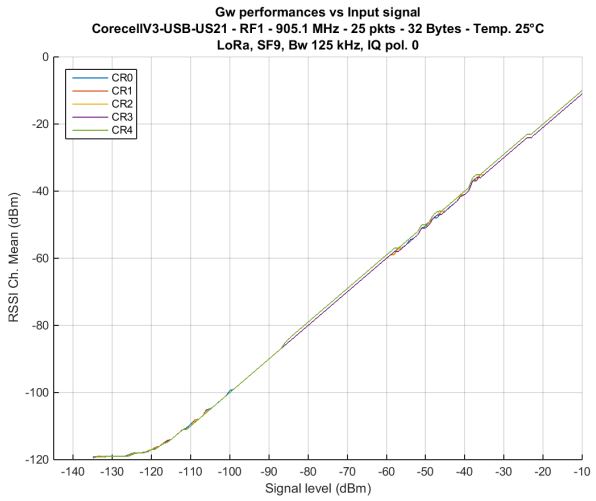
(b) RSSI error

Figure 14.24: RSSI signal vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C

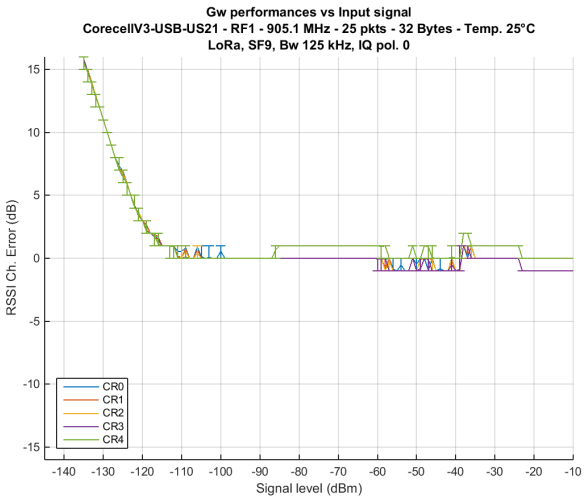
14.5 Coding rate influence

14.5.1 MultiSF modem (905.1 MHz)

RSSI channel



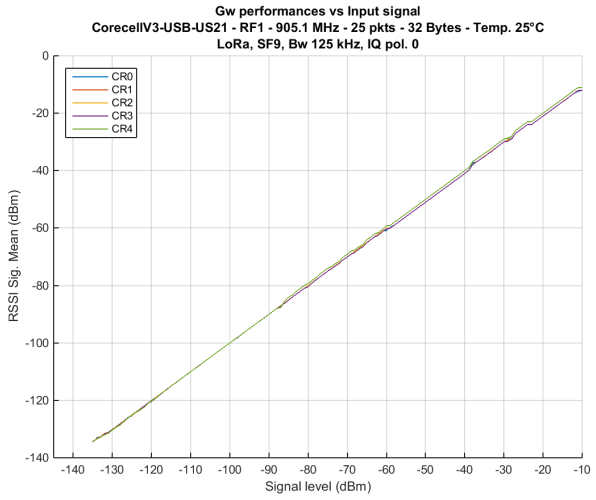
(a) RSSI mean



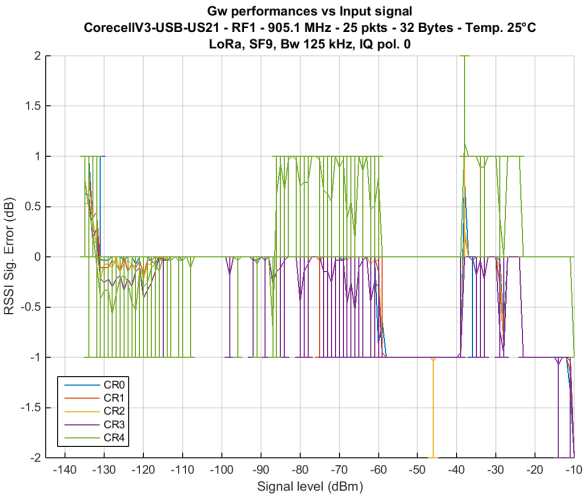
(b) RSSI error

Figure 14.25: RSSI channel vs coding rate, Board US21, MultiSF modem (905.1 MHz), SF9, Bw 125 kHz, 32 bytes, 25°C

RSSI signal



(a) RSSI mean

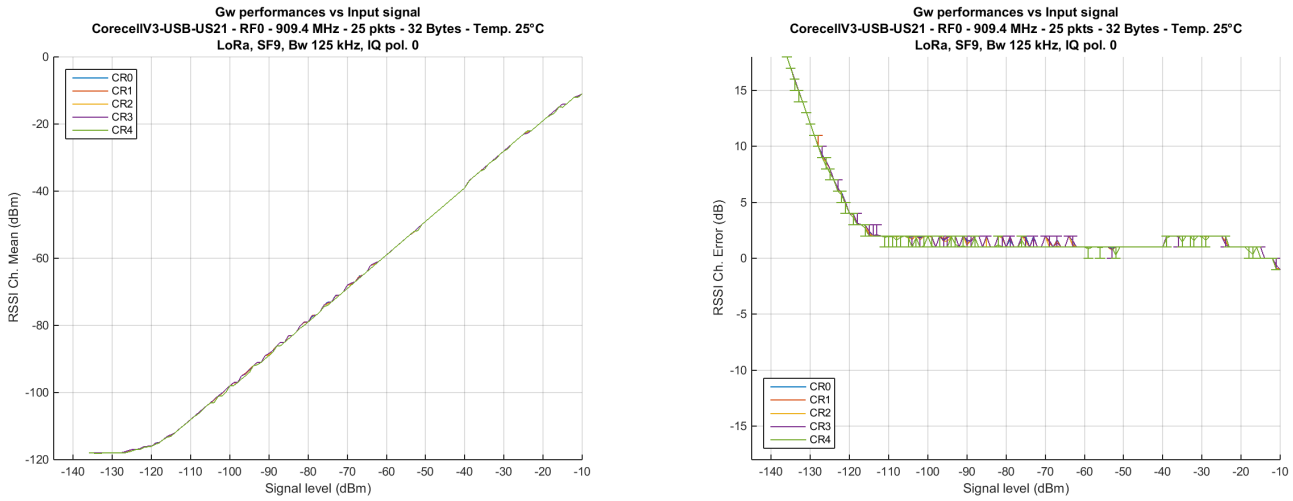


(b) RSSI error

Figure 14.26: RSSI signal vs coding rate, Board US21, MultiSF modem (905.1 MHz), SF9, Bw 125 kHz, 32 bytes, 25°C

14.5.2 SingleSF modem (909.4 MHz)

RSSI channel

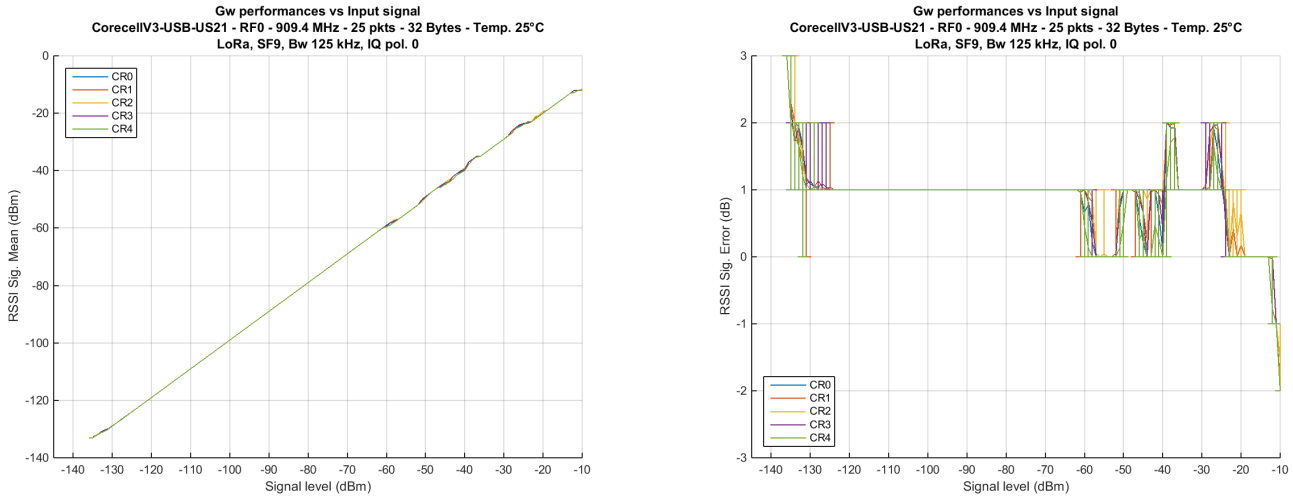


(a) RSSI mean

(b) RSSI error

Figure 14.27: RSSI channel vs coding rate, Board US21, SingleSF modem (909.4 MHz), SF9, Bw 125 kHz, 32 bytes, 25°C

RSSI signal



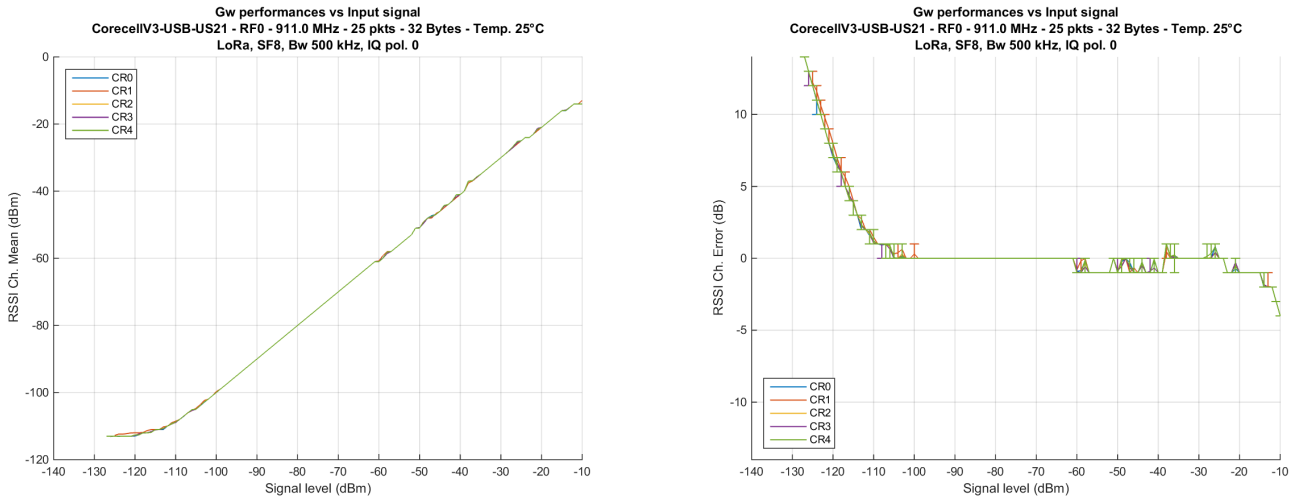
(a) RSSI mean

(b) RSSI error

Figure 14.28: RSSI signal vs coding rate, Board US21, SingleSF modem (909.4 MHz), SF9, Bw 125 kHz, 32 bytes, 25°C

14.5.3 SingleSF modem, Implicit header (911.0 MHz)

RSSI channel

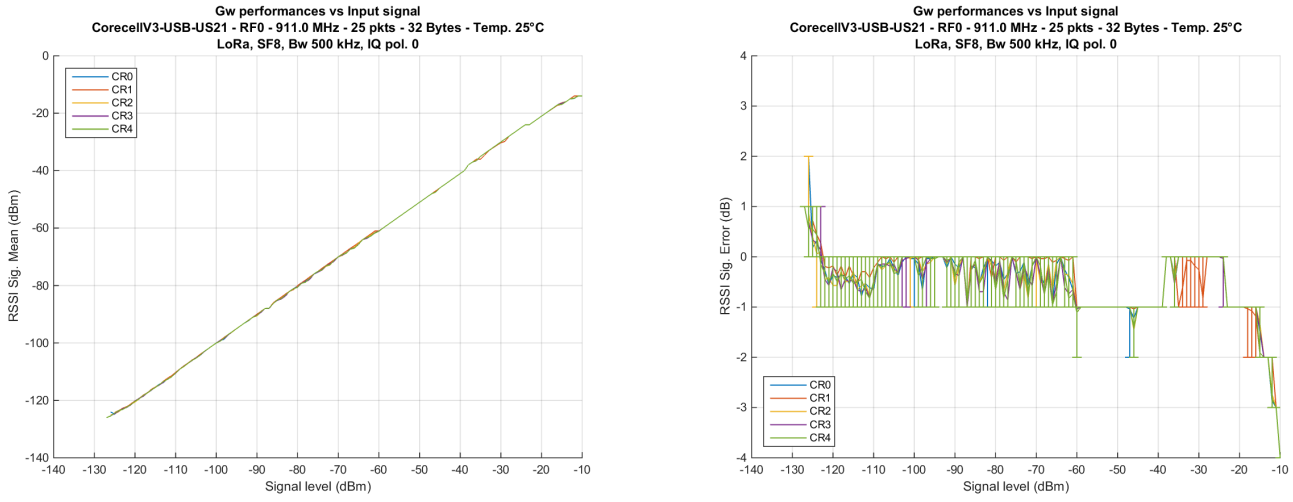


(a) RSSI mean

(b) RSSI error

Figure 14.29: RSSI channel vs coding rate, Board US21, SingleSF modem, Impl. header (911 MHz), SF8, Bw 500 kHz, 32 bytes, 25°C

RSSI signal



(a) RSSI mean

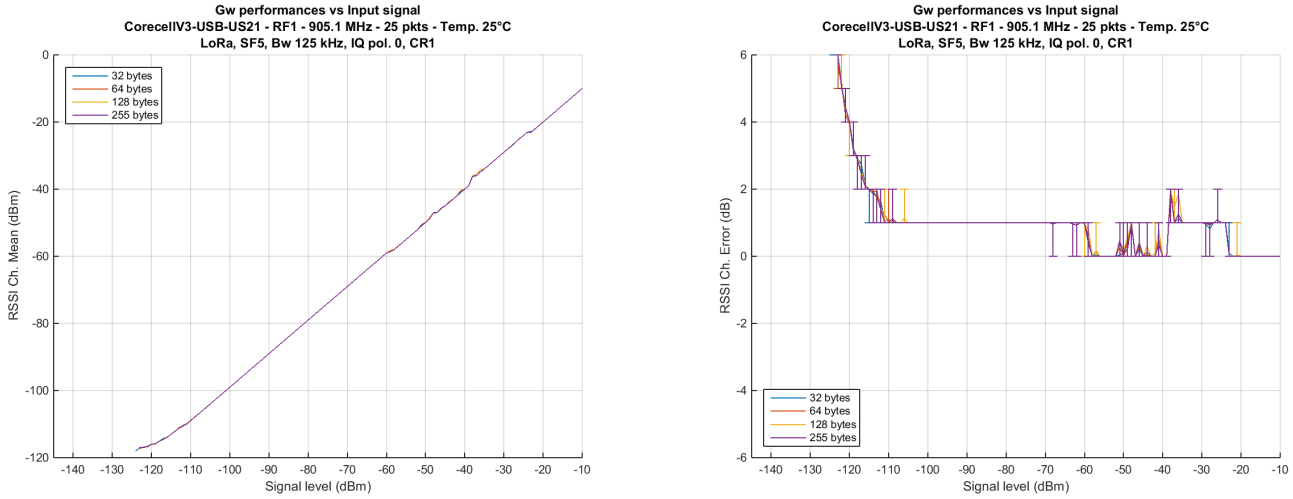
(b) RSSI error

Figure 14.30: RSSI signal vs coding rate, Board US21, SingleSF modem, Impl. header (911 MHz), SF8, Bw 500 kHz, 32 bytes, 25°C

14.6 Payload length influence

14.6.1 MultiSF modem (905.1 MHz), SF5

RSSI channel

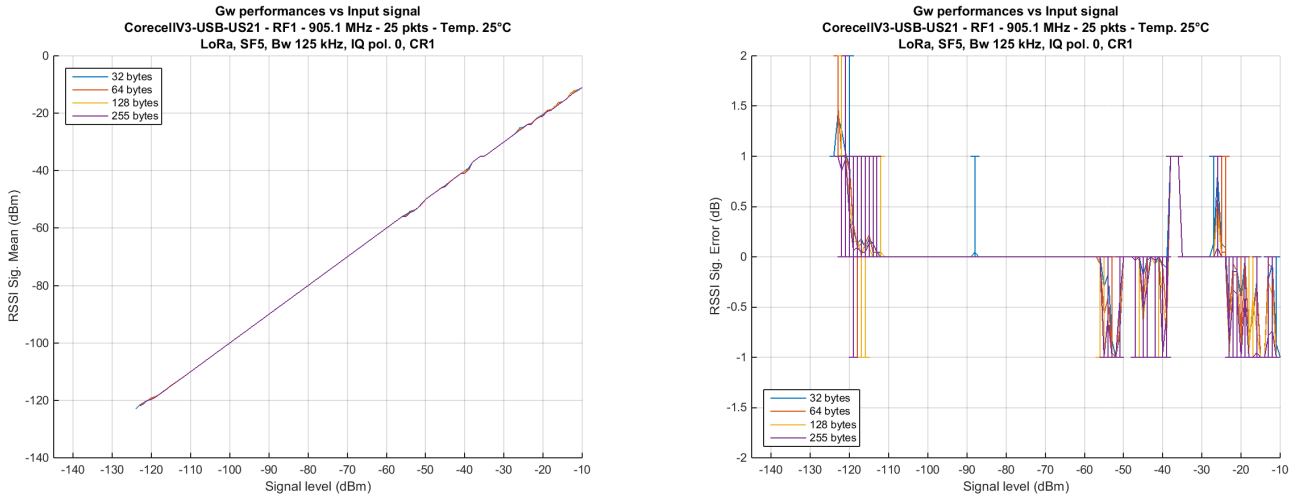


(a) RSSI mean

(b) RSSI error

Figure 14.31: RSSI channel vs payload length, Board US21, 905.1 MHz, SF5, Bw 125 kHz, CR1, 25°C

RSSI signal



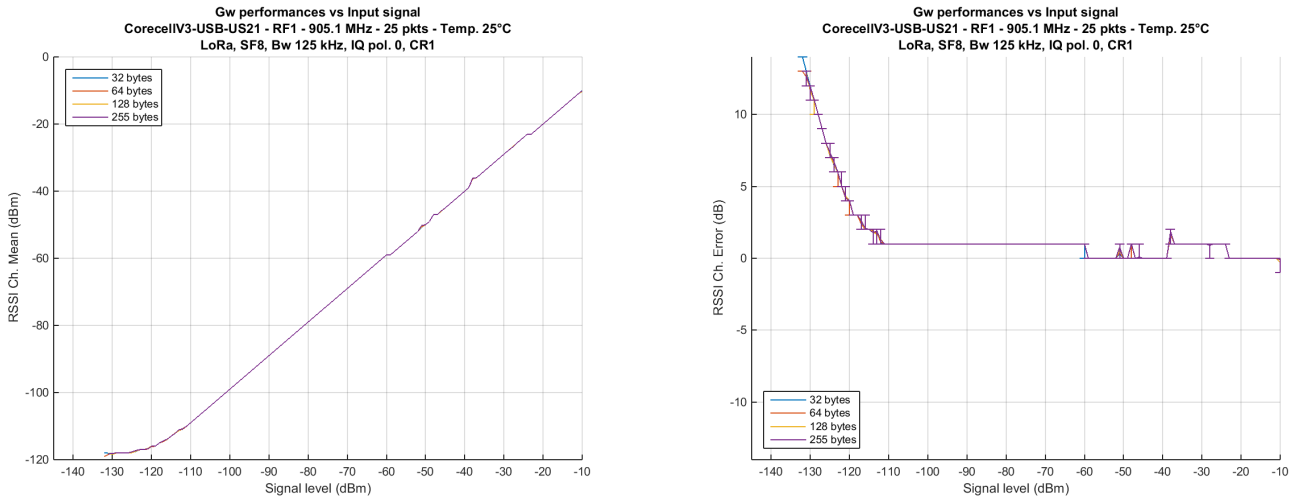
(a) RSSI mean

(b) RSSI error

Figure 14.32: RSSI signal vs payload length, Board US21, 905.1 MHz, SF5, Bw 125 kHz, CR1, 25°C

14.6.2 MultiSF modem (905.1 MHz), SF8

RSSI channel

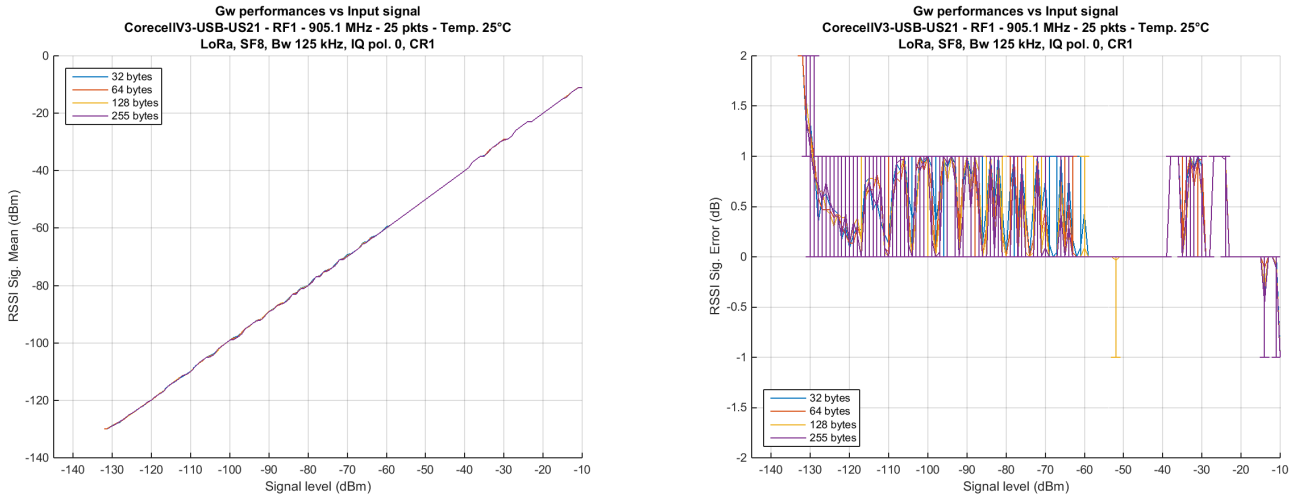


(a) RSSI mean

(b) RSSI error

Figure 14.33: RSSI channel vs payload length, Board US21, 905.1 MHz, SF8, Bw 125 kHz, CR1, 25°C

RSSI signal



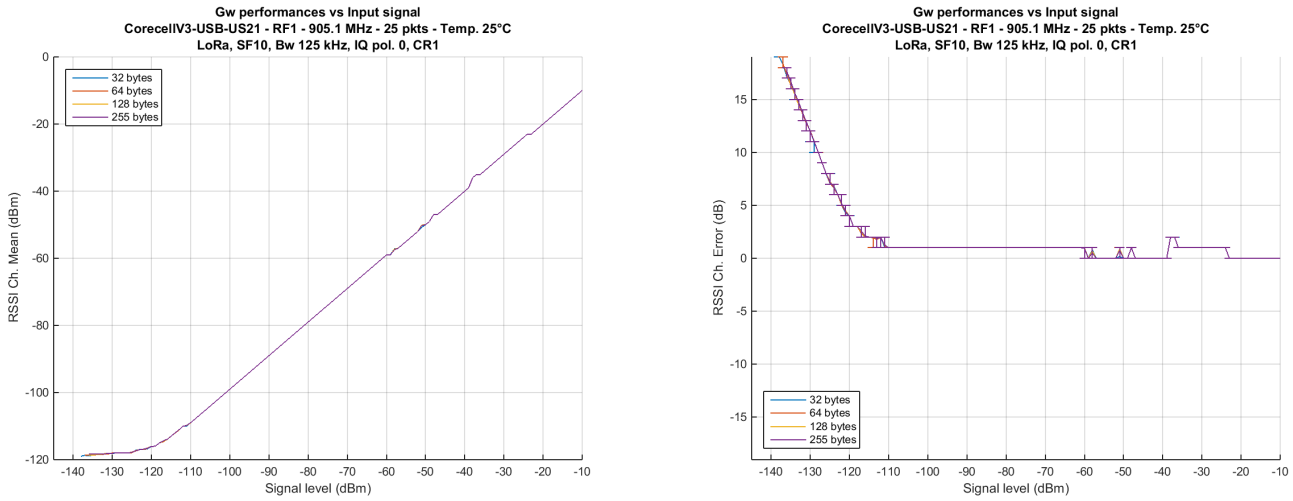
(a) RSSI mean

(b) RSSI error

Figure 14.34: RSSI signal vs payload length, Board US21, 905.1 MHz, SF8, Bw 125 kHz, CR1, 25°C

14.6.3 MultiSF modem (905.1 MHz), SF10

RSSI channel

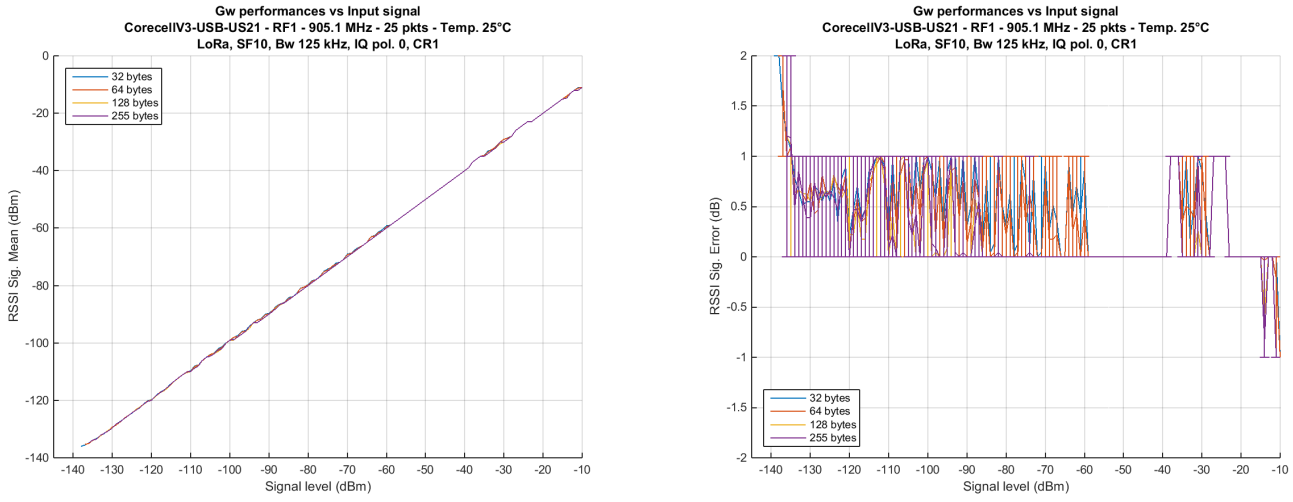


(a) RSSI mean

(b) RSSI error

Figure 14.35: RSSI channel vs payload length, Board US21, 905.1 MHz, SF10, Bw 125 kHz, CR1, 25°C

RSSI signal



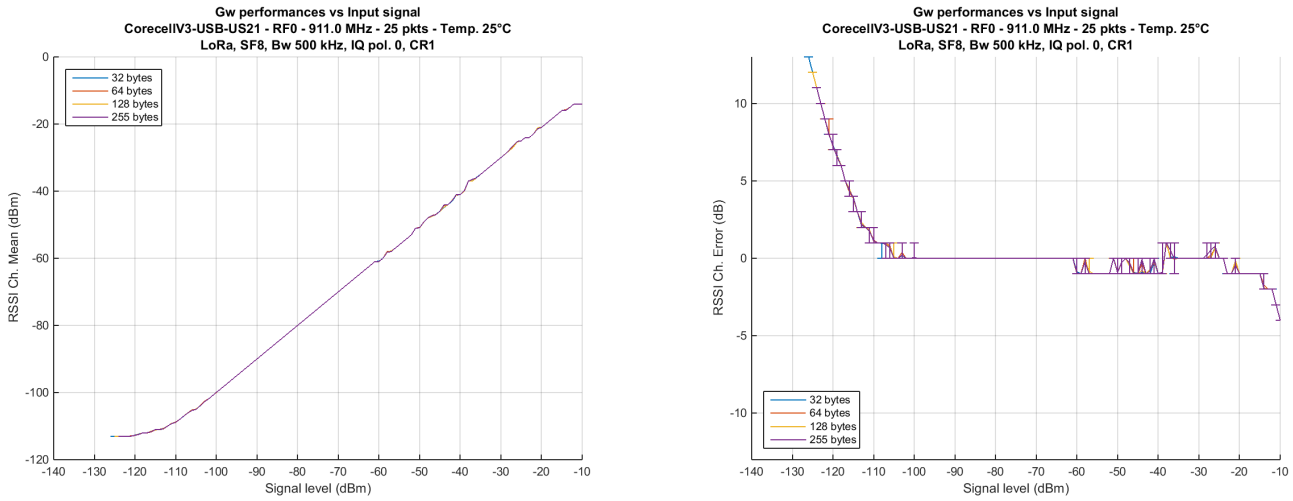
(a) RSSI mean

(b) RSSI error

Figure 14.36: RSSI signal vs payload length, Board US21, 905.1 MHz, SF10, Bw 125 kHz, CR1, 25°C

14.6.4 SingleSF modem, Implicit header (911.0 MHz)

RSSI channel

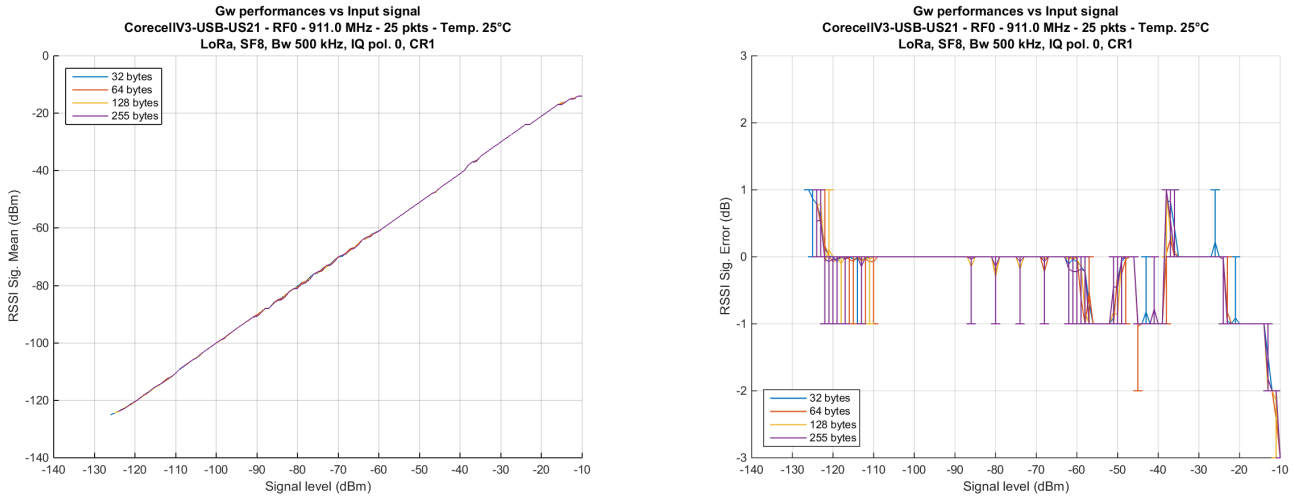


(a) RSSI mean

(b) RSSI error

Figure 14.37: RSSI channel vs coding rate, Board US21, SingleSF modem, Impl. header (911 MHz), SF8, Bw 500 kHz, 32 bytes, 25°C

RSSI signal



(a) RSSI mean

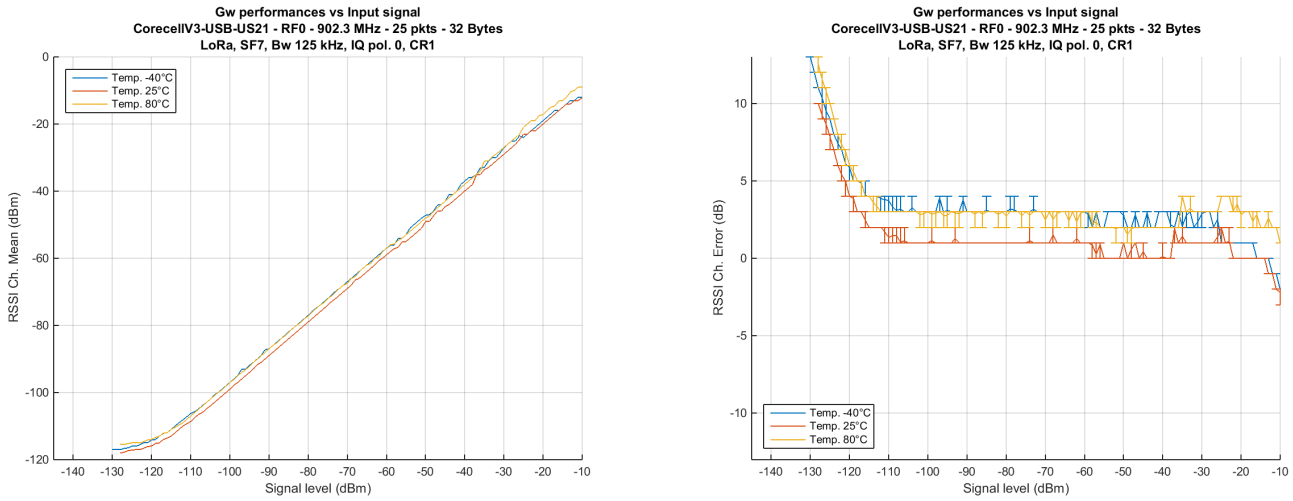
(b) RSSI error

Figure 14.38: RSSI channel vs coding rate, Board US21, SingleSF modem, Impl. header (911 MHz), SF8, Bw 500 kHz, 32 bytes, 25°C

14.7 Temperature influence

14.7.1 MultiSF modem (902.3MHz)

RSSI channel

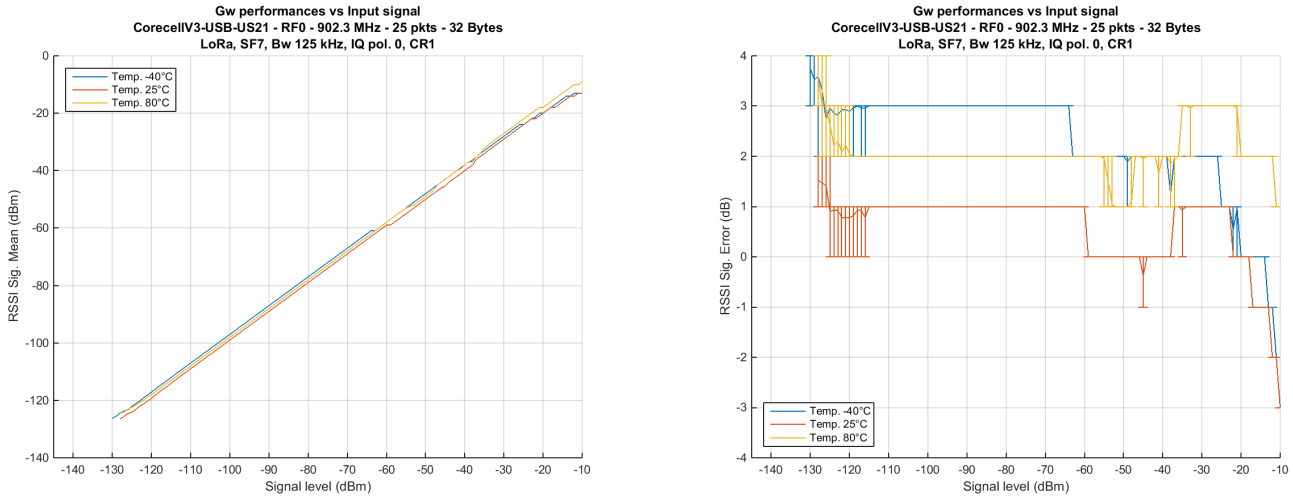


(a) RSSI mean

(b) RSSI error

Figure 14.39: RSSI channel vs temperature, Board US21, MultiSF modem (902.3 MHz), SF7, Bw 125 kHz, CR1

RSSI signal



(a) RSSI mean

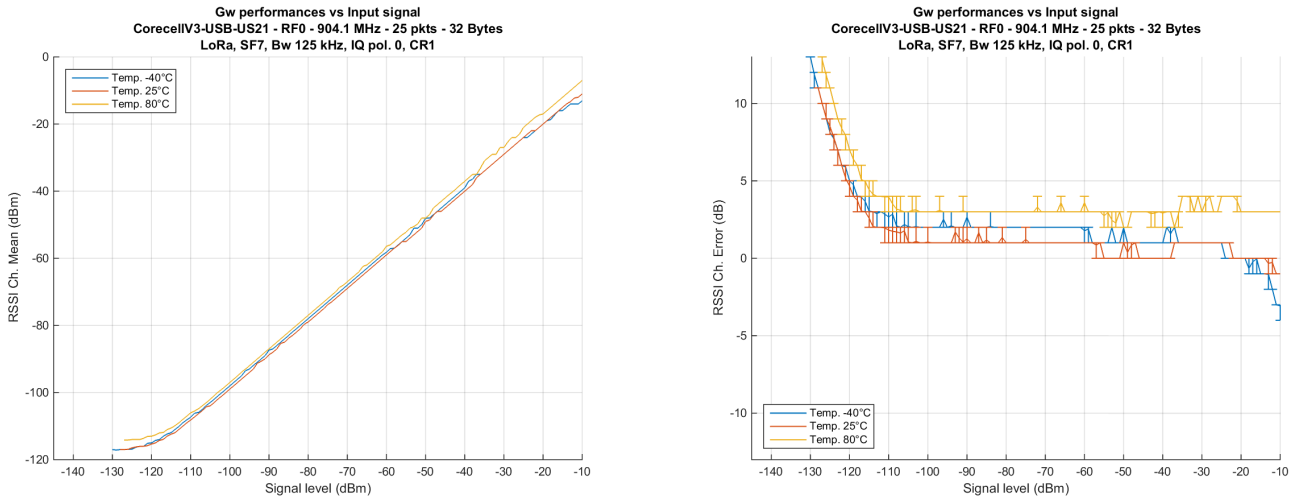
(b) RSSI error

Figure 14.40: RSSI signal vs temperature, Board US21, MultiSF modem (902.3 MHz), SF7, Bw 125 kHz, CR1

The RSSI temperature compensation algorithm efficiency is limited for channels located at the band edge.

14.7.2 MultiSF modem (904.1MHz)

RSSI channel

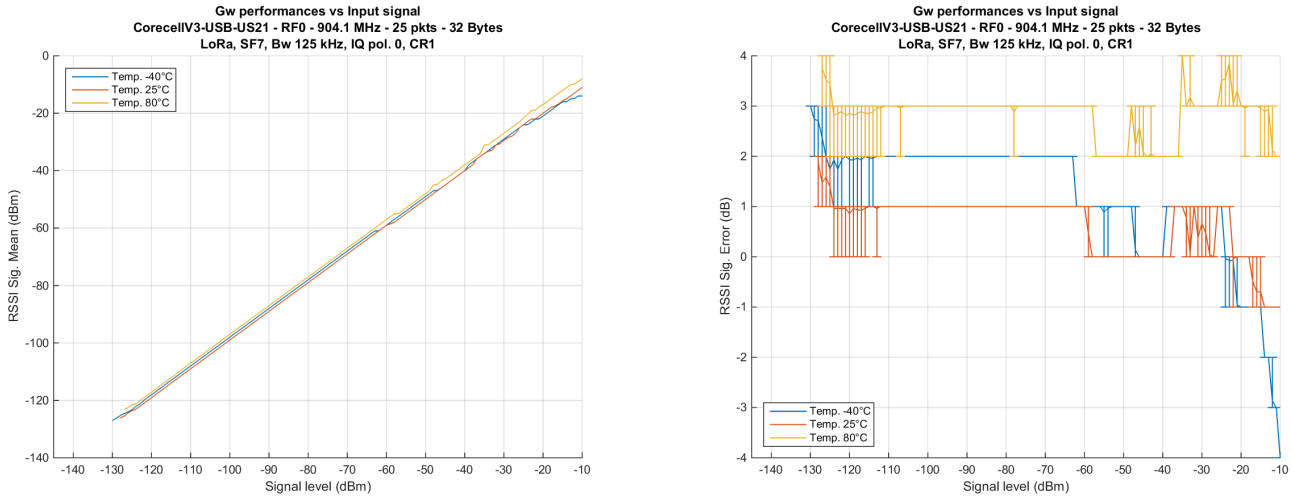


(a) RSSI mean

(b) RSSI error

Figure 14.41: RSSI channel vs temperature, Board US21, MultiSF modem (904.1 MHz), SF7, Bw 125 kHz, CR1

RSSI signal



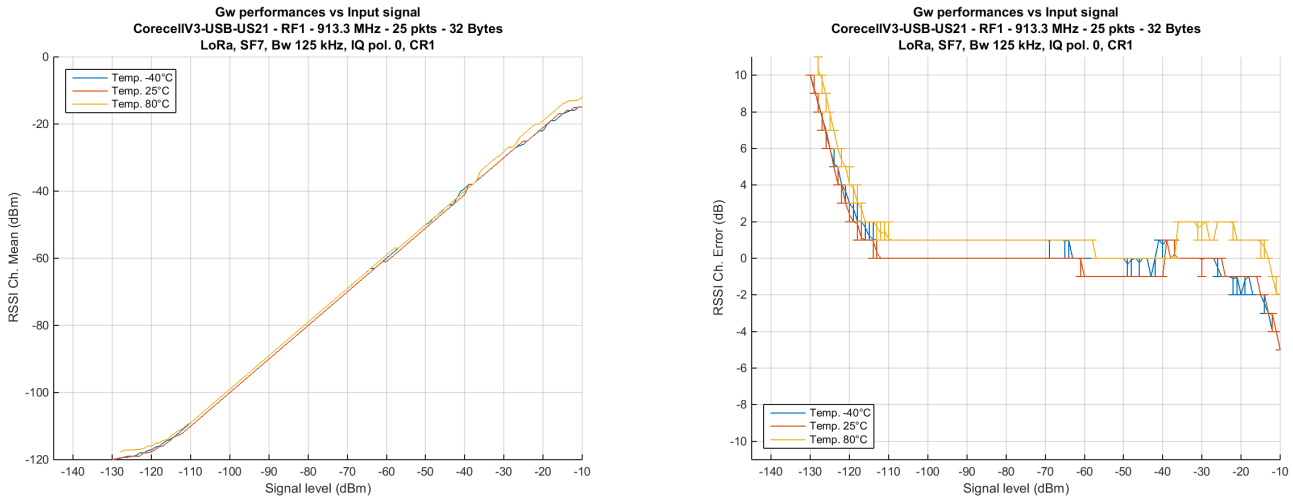
(a) RSSI mean

(b) RSSI error

Figure 14.42: RSSI signal vs temperature, Board US21, MultiSF modem (904.1 MHz), SF7, Bw 125 kHz, CR1

14.7.3 MultiSF modem (913.3MHz)

RSSI channel

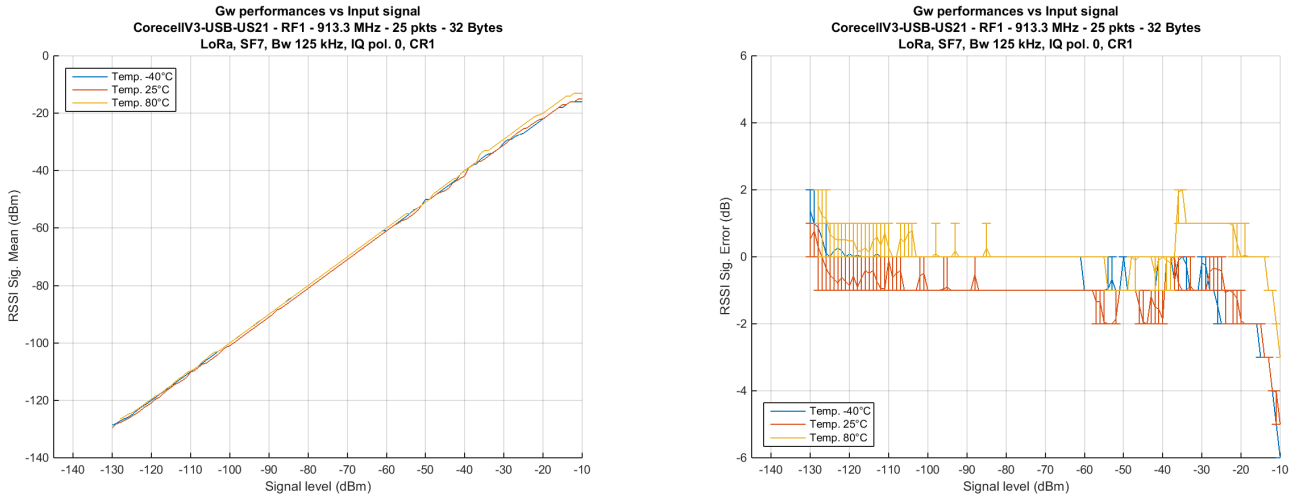


(a) RSSI mean

(b) RSSI error

Figure 14.43: RSSI channel vs temperature, Board US21, 913.3 MHz, SF7, Bw 125 kHz, CR1

RSSI signal



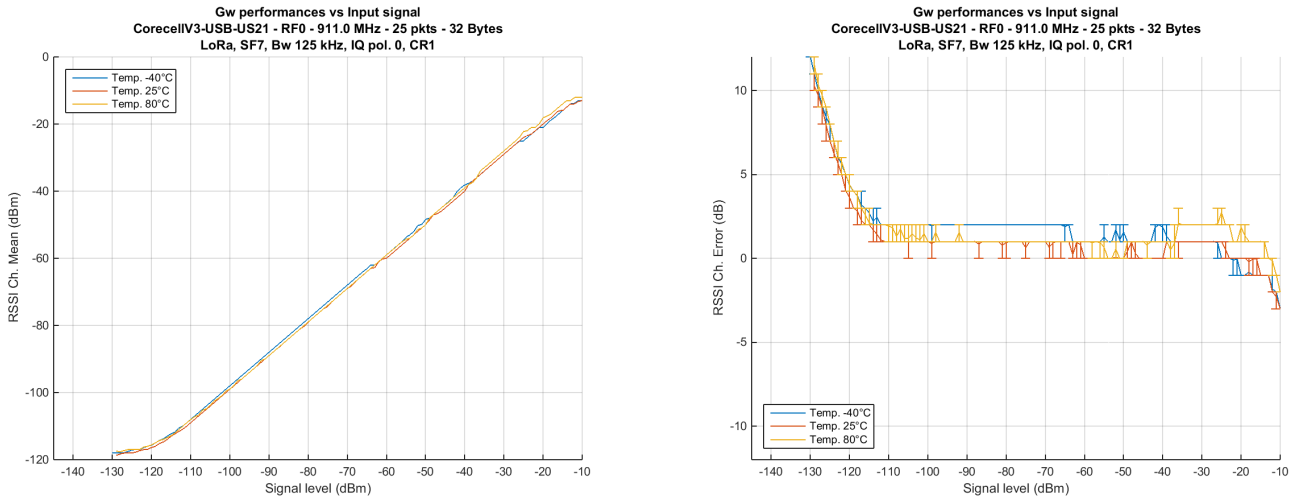
(a) RSSI mean

(b) RSSI error

Figure 14.44: RSSI signal vs temperature, Board US21, 913.3 MHz, SF7, Bw 125 kHz, CR1

14.7.4 SingleSF modem (911.0 MHz)

RSSI channel

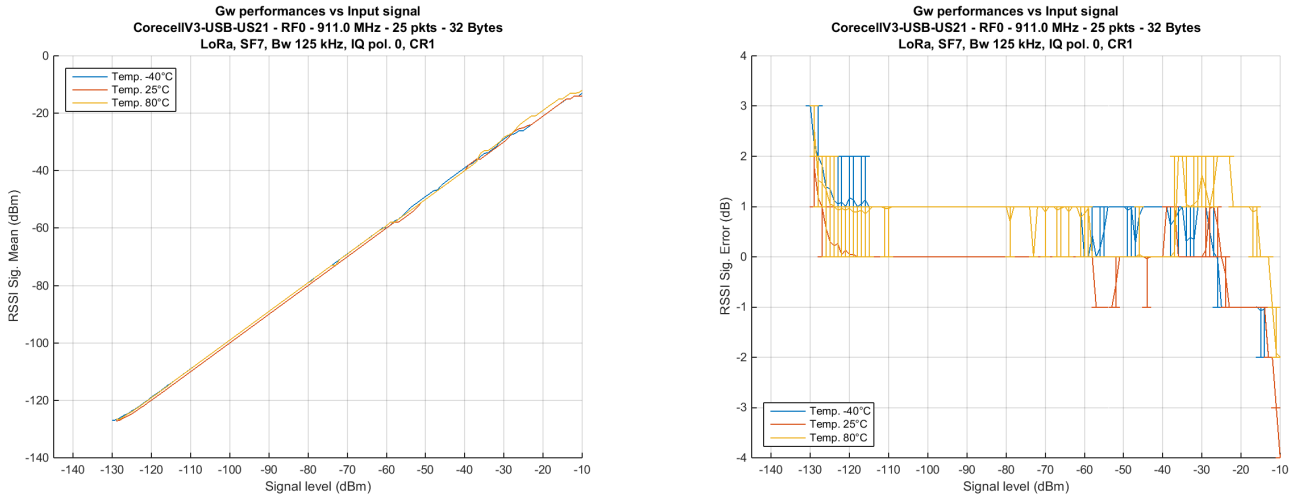


(a) RSSI mean

(b) RSSI error

Figure 14.45: RSSI channel vs temperature, Board US21, SingleSF modem (911.0 MHz), SF7, Bw 125 kHz, CR1

RSSI signal



(a) RSSI mean

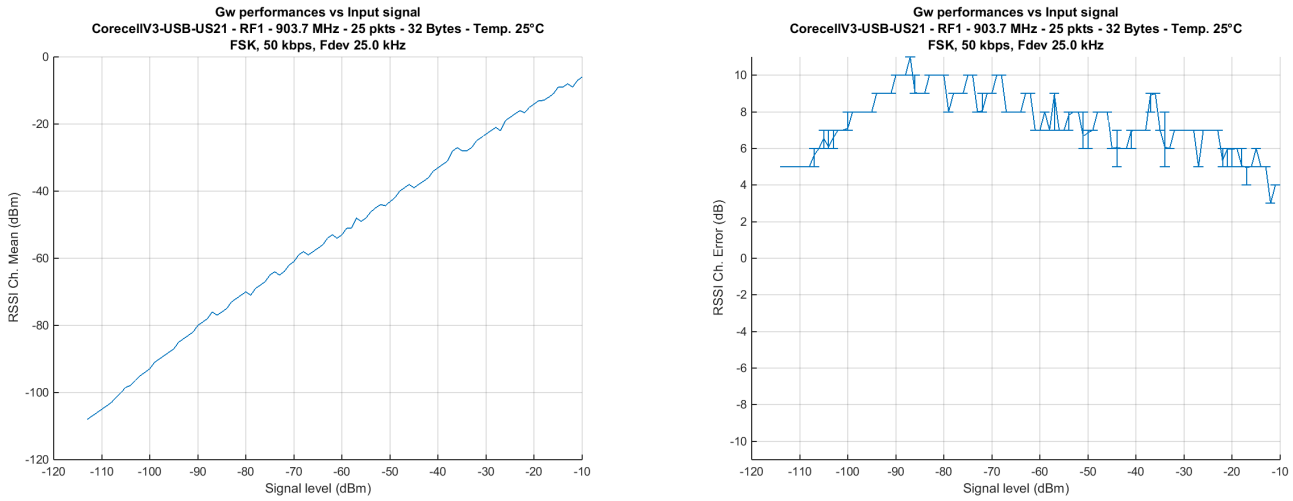
(b) RSSI error

Figure 14.46: RSSI signal vs temperature, Board US21, SingleSF modem (911.0 MHz), SF7, Bw 125 kHz, CR1

14.8 FSK modem

14.8.1 903.7 MHz

RSSI channel



(a) RSSI mean

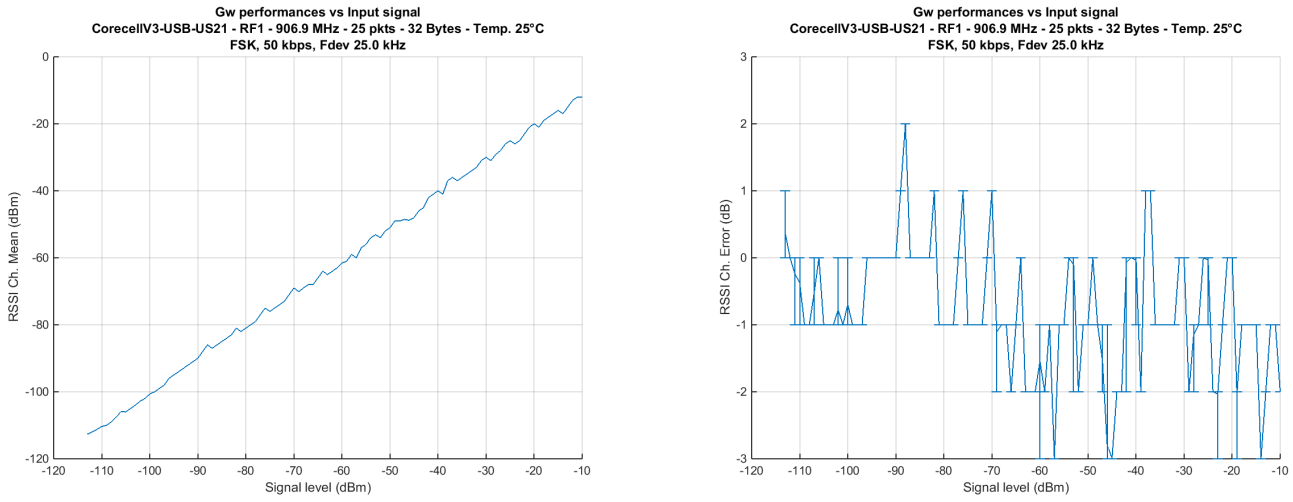
(b) RSSI error

Figure 14.47: RSSI channel, Board US21, FSK modem, 903.7 MHz, 50 kbits, Fdev 25 kHz, 25°C

The RSSI modem includes polynomial coefficients allowing to linearize the RSSI value over the signal input range. This measurement was performed with the coefficients not correctly initialized (default values).

14.8.2 906.9 MHz

RSSI channel



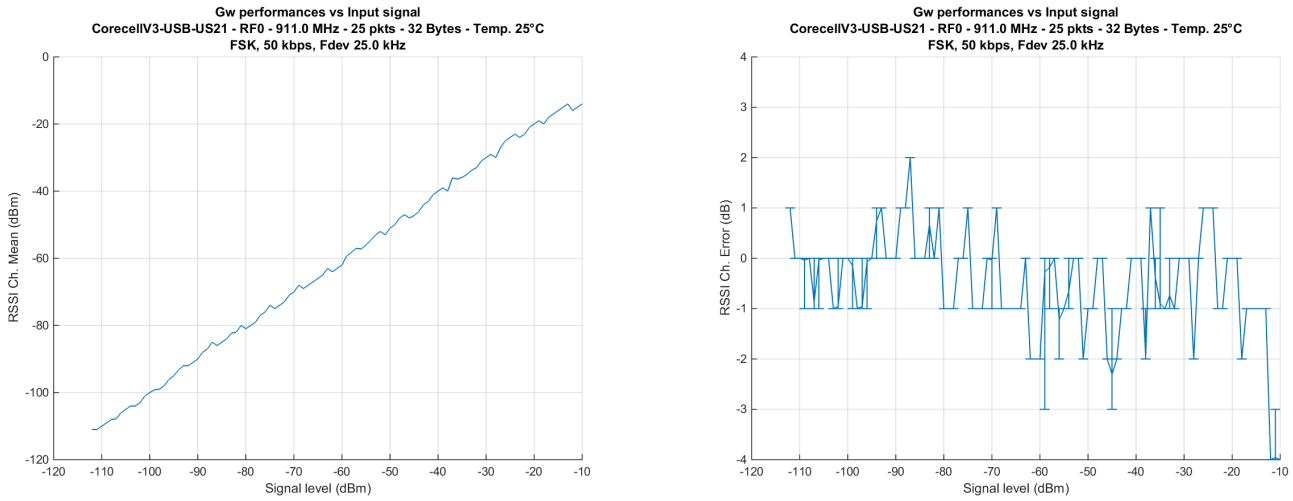
(a) RSSI mean

(b) RSSI error

Figure 14.48: RSSI channel, Board US21, FSK modem, 906.9 MHz, 50 kbits, Fdev 25 kHz, 25°C

14.8.3 911.0 MHz

RSSI channel



(a) RSSI mean

(b) RSSI error

Figure 14.49: RSSI channel, Board US21, FSK modem, 911.0 MHz, 50 kbits, Fdev 25 kHz, 25°C

14.9 Conclusion

→ **The RSSI channel and signal provide an accurate estimation of the signal input level over a wide dynamic.**

15 SNR

15.1 Presentation

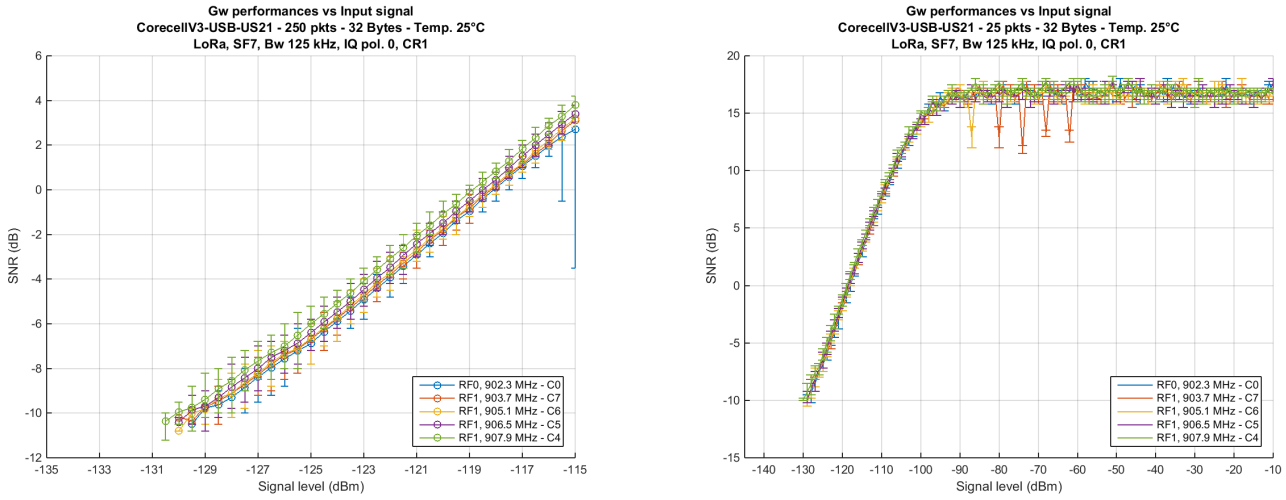
In conjunction with the RSSI value, the LoRa modem determines the Signal-To-Noise Ratio while receiving packets. This test verifies the accuracy of this indicator according the packet parameters (Spreading Factor, payload length, ...)

15.2 Setup

The SNR is measured using the setup presented in figure 3.1 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.

15.3 Frequency influence

15.3.1 MultiSF modem (Lower band)

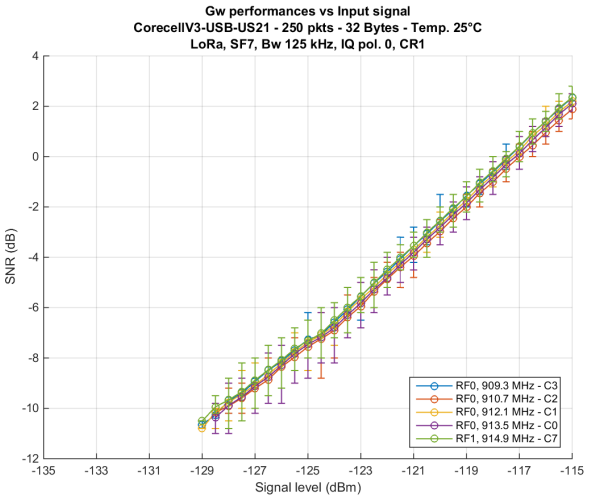


(a) Sensitivity level

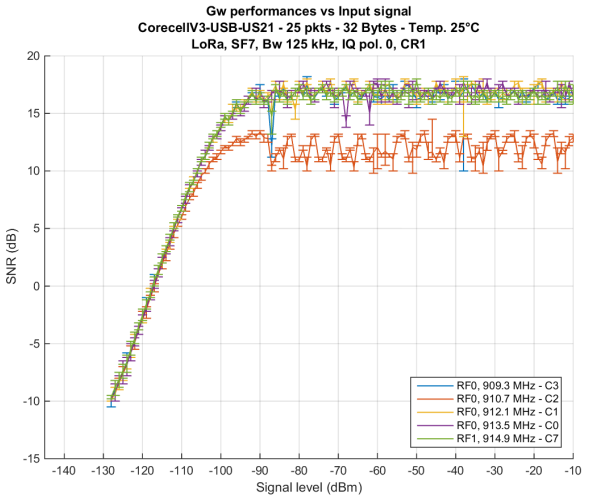
(b) High level

Figure 15.1: SNR vs channels (Lower band), Board US21, SF7, Bw 125 kHz, 32 bytes, 25°C

15.3.2 MultiSF modem (Higher band)



(a) Sensitivity level

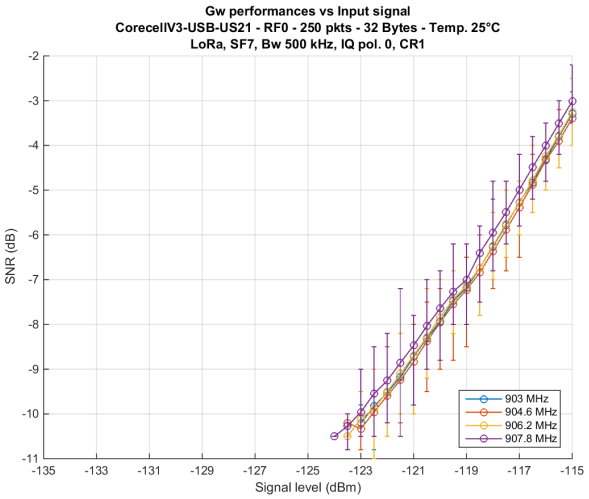


(b) High level

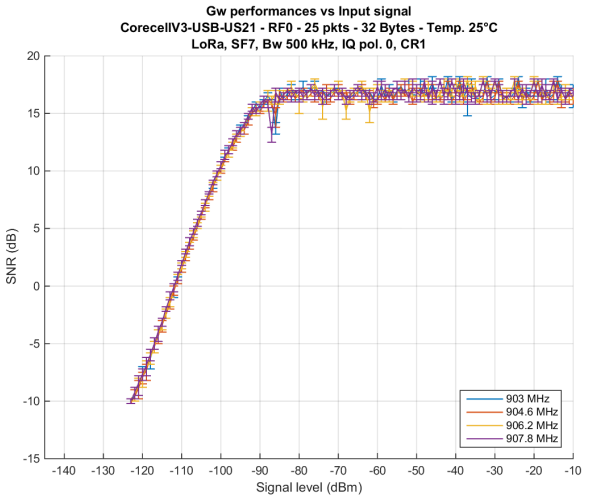
Figure 15.2: SNR vs channels (Higher band), Board US21, SF7, Bw 125 kHz, 32 bytes, 25°C

The SNR value for high signal level is lower at 910.7 MHz than for the other channels due to the DC notch present at the Zero-IF channel.

15.3.3 SingleSF modem (Lower band)



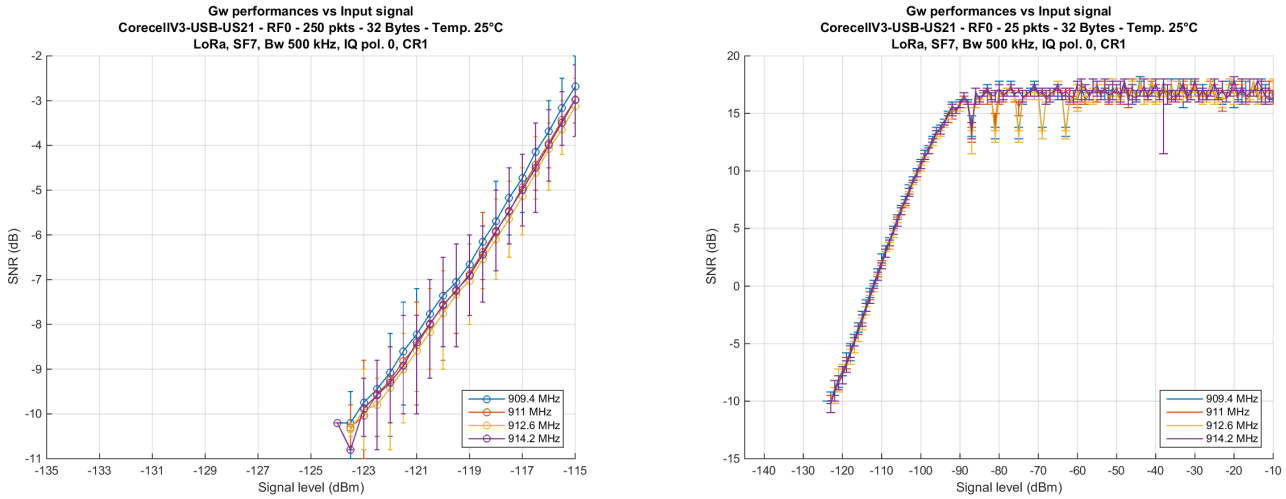
(a) Sensitivity level



(b) High level

Figure 15.3: SNR vs channels (Lower band), SingleSF modem, Board US21, SF7, Bw 500 kHz, 32 bytes, 25°C

15.3.4 SingleSF modem (Higher band)



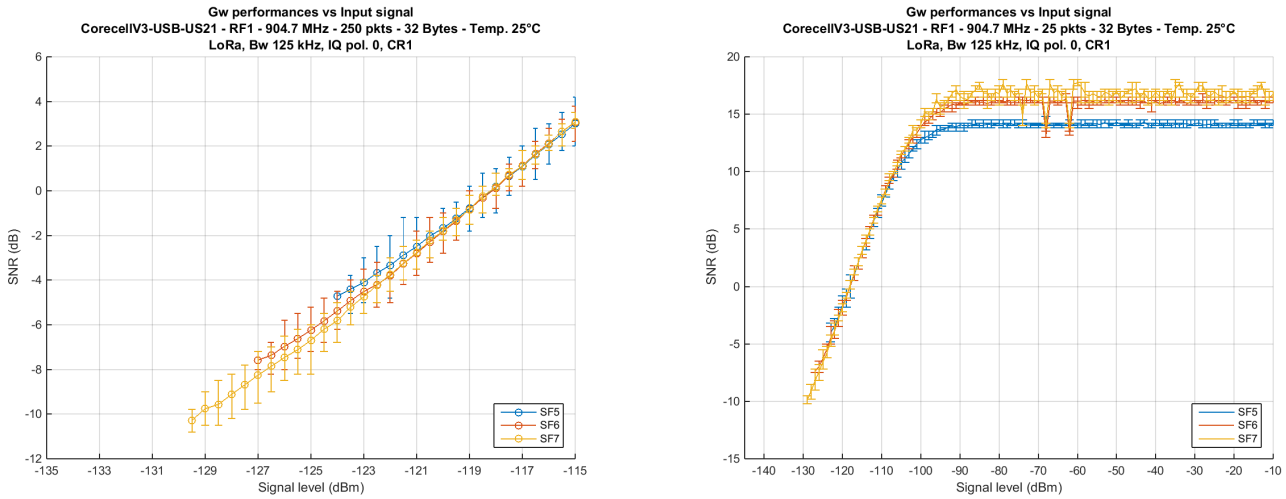
(a) Sensitivity level

(b) High level

Figure 15.4: SNR vs channels (Higher band), SingleSF modem, Board US21, SF7, Bw 500 kHz, 32 bytes, 25°C

15.4 Spreading Factor influence

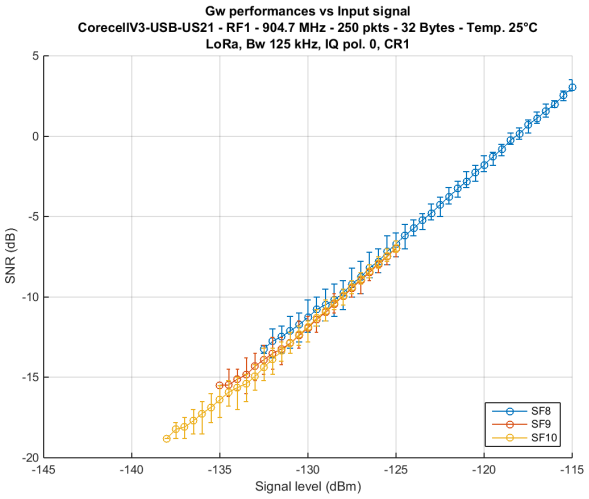
15.4.1 MultiSF modem (904.7 MHz)



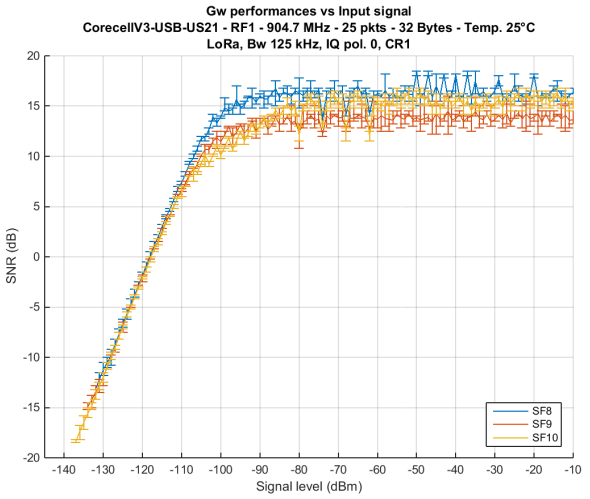
(a) Sensitivity level

(b) High level

Figure 15.5: SNR vs SF (5 to 7), Board US21, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C



(a) Sensitivity level

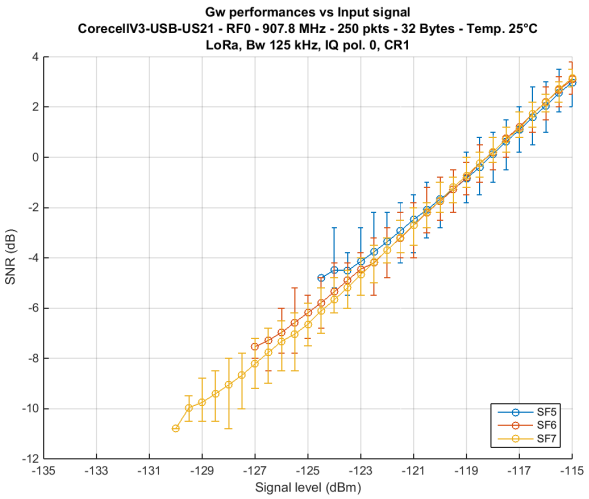


(b) High level

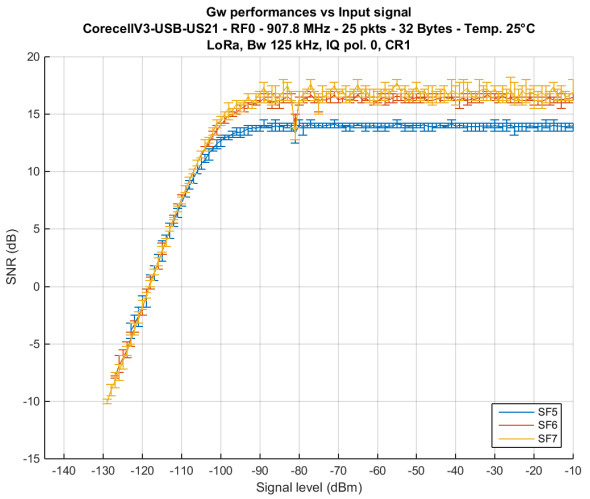
Figure 15.6: SNR vs SF (8 to 10), Board US21, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C

15.4.2 SingleSF modem (904.6 MHz)

Bandwidth 125 kHz

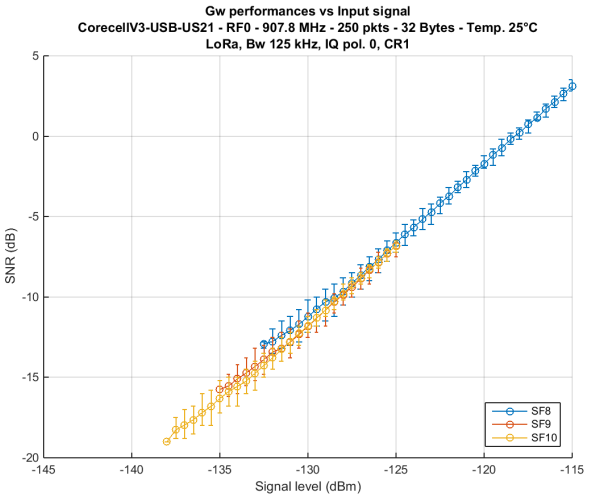


(a) Sensitivity level

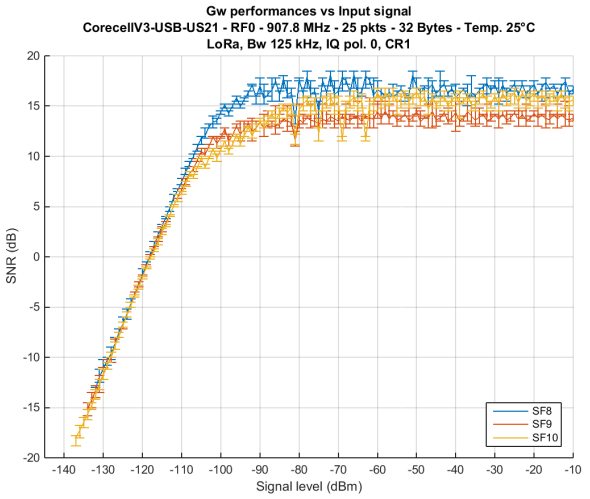


(b) High level

Figure 15.7: SNR vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C



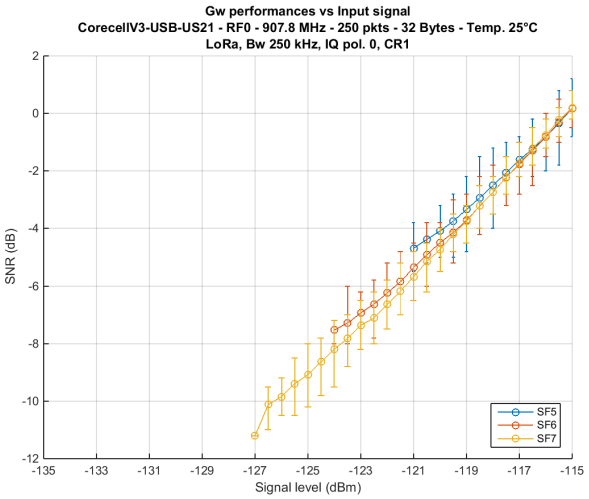
(a) Sensitivity level



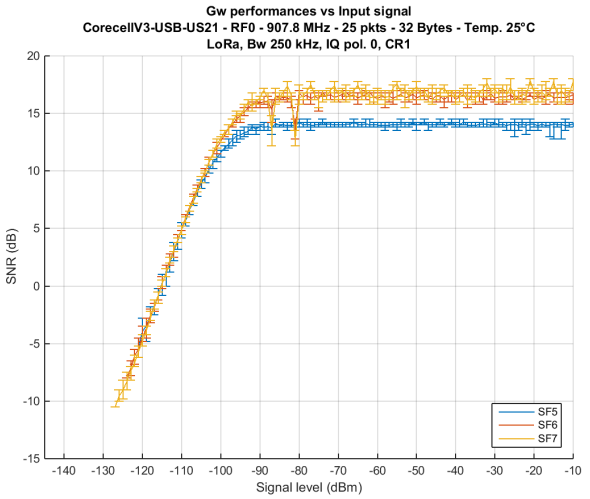
(b) High level

Figure 15.8: SNR vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C

Bandwidth 250 kHz

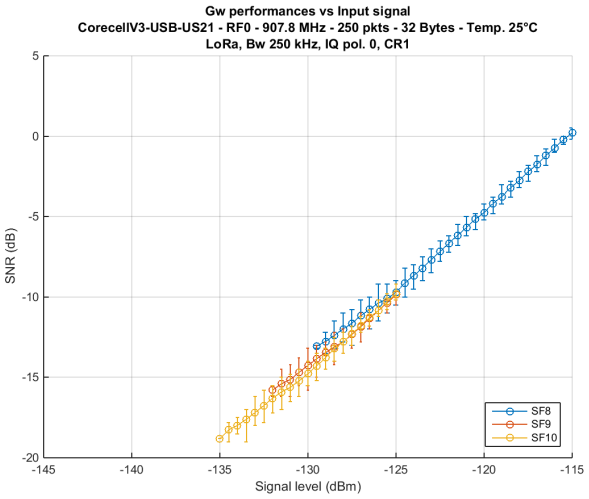


(a) Sensitivity level

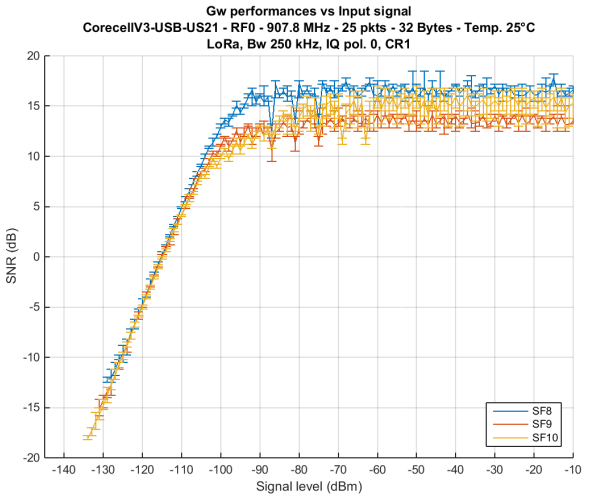


(b) High level

Figure 15.9: SNR vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C



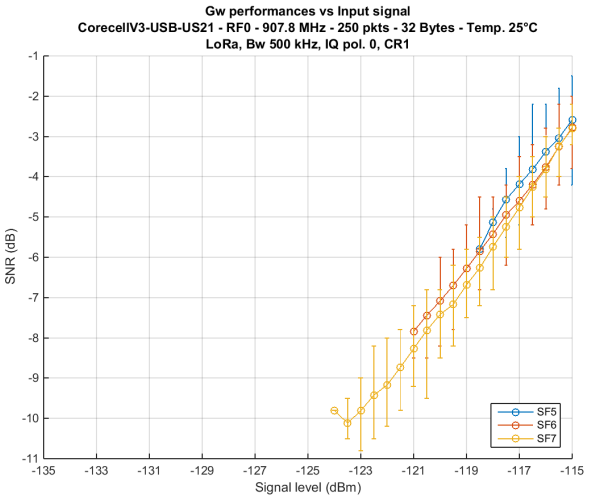
(a) Sensitivity level



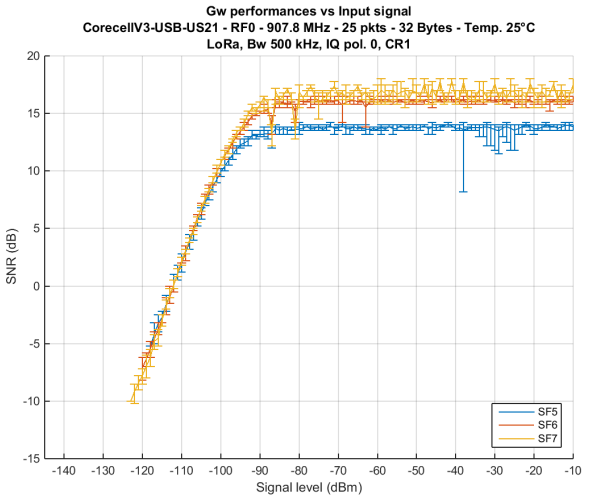
(b) High level

Figure 15.10: SNR vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C

Bandwidth 500 kHz

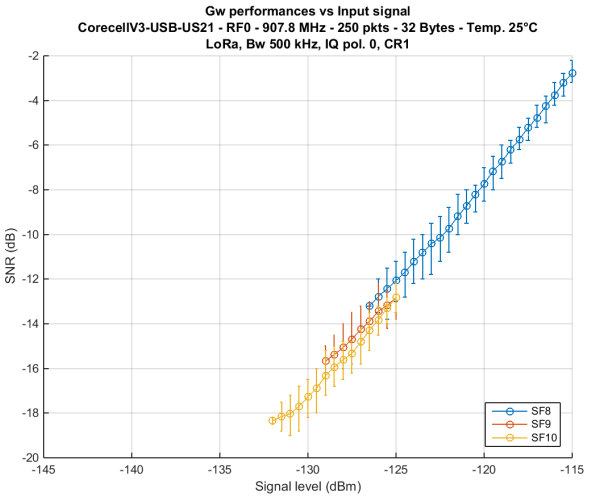


(a) Sensitivity level

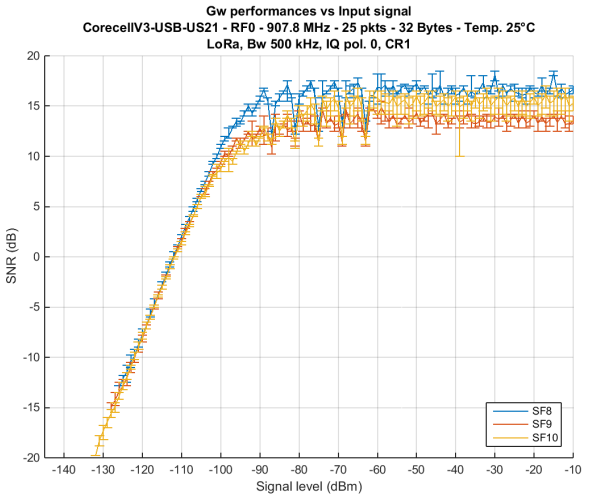


(b) High level

Figure 15.11: SNR vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C



(a) Sensitivity level

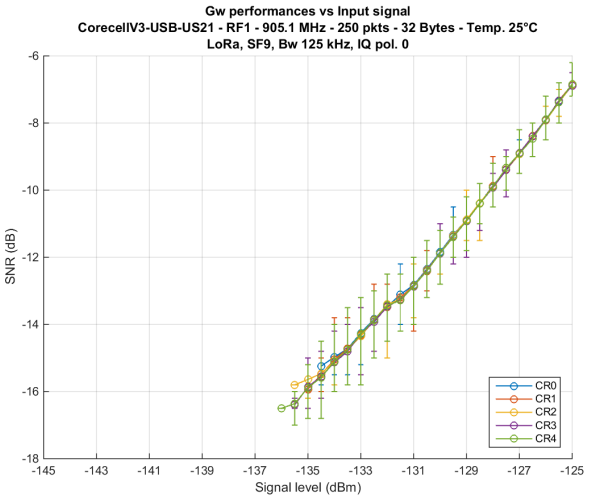


(b) High level

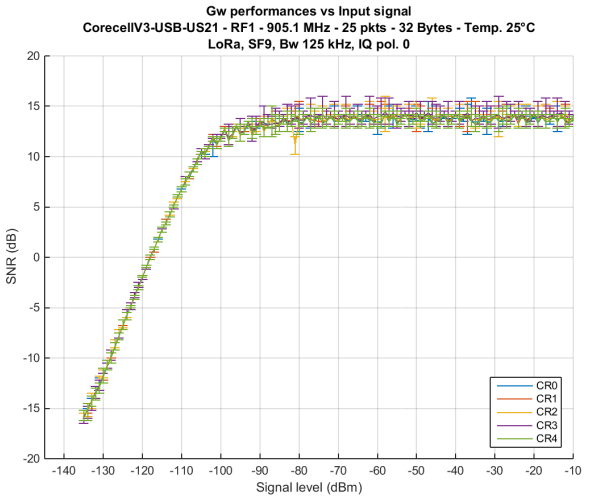
Figure 15.12: SNR vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C

15.5 Coding rate influence

15.5.1 MultiSF modem (905.1 MHz)



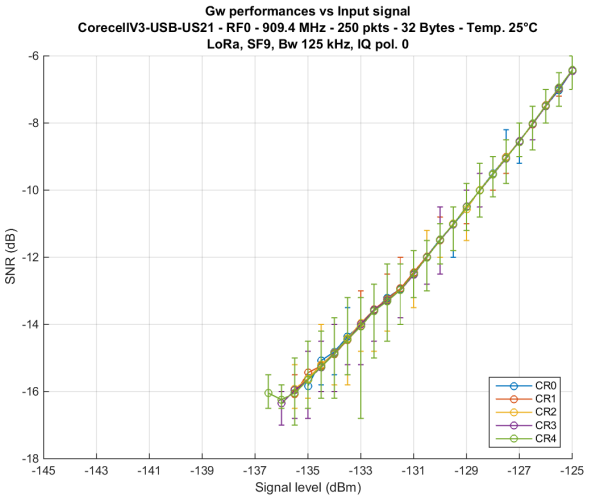
(a) Sensitivity level



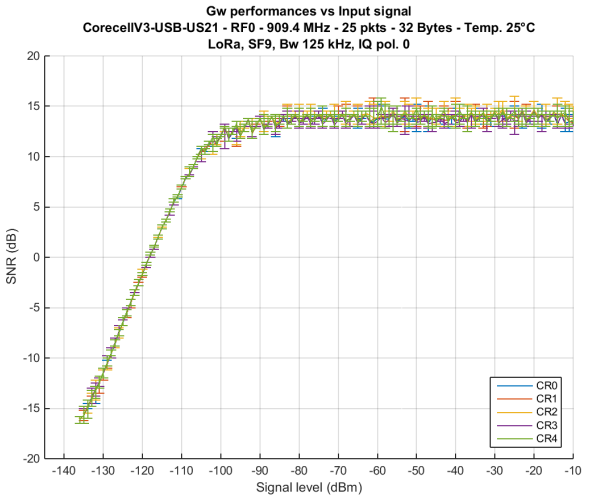
(b) High level

Figure 15.13: SNR vs coding rate, Board US21, 905.1 MHz, SF9, Bw 125 kHz, 32 bytes, 25°C

15.5.2 SingleSF modem (909.4 MHz)



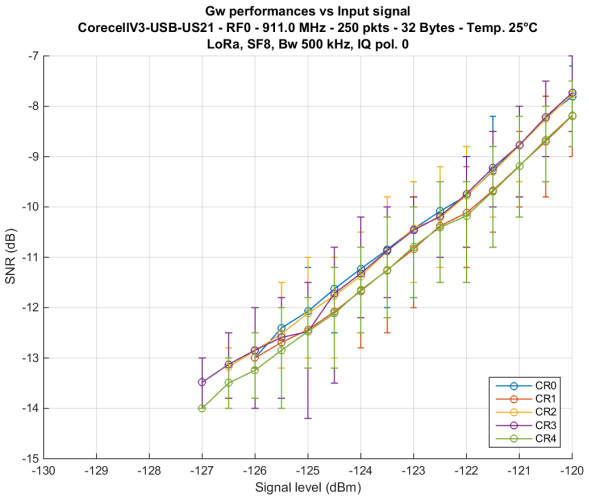
(a) Sensitivity level



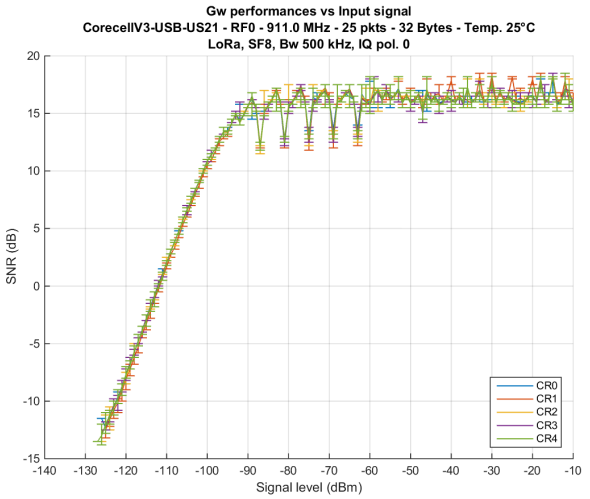
(b) High level

Figure 15.14: SNR vs coding rate, Board US21, SingleSF modem, 909.4 MHz, SF9, Bw 125 kHz, 32 bytes, 25°C

15.5.3 SingleSF modem, Implicit header (911.0 MHz)



(a) Sensitivity level



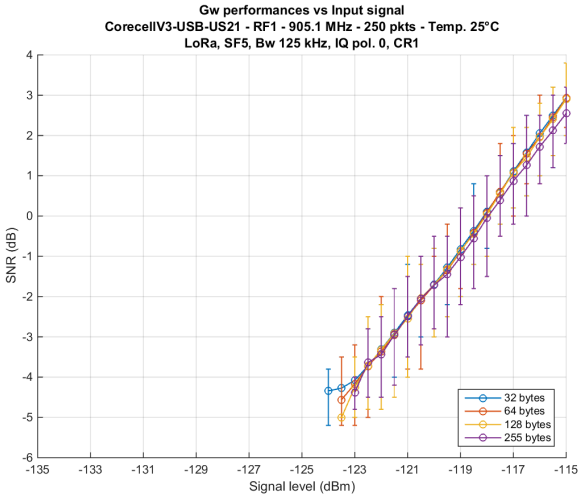
(b) High level

Figure 15.15: SNR vs coding rate, Board US21, SingleSF modem, Impl. header, 911.0 MHz, SF9, Bw 125 kHz, 32 bytes, 25°C

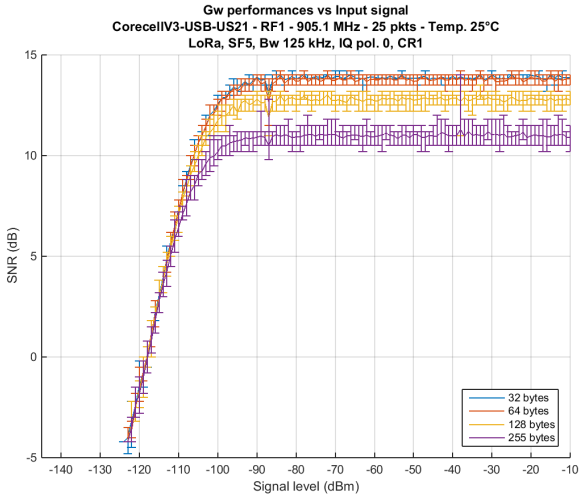
15.6 Payload length influence

15.6.1 MultiSF modem (905.1 MHz)

SF5



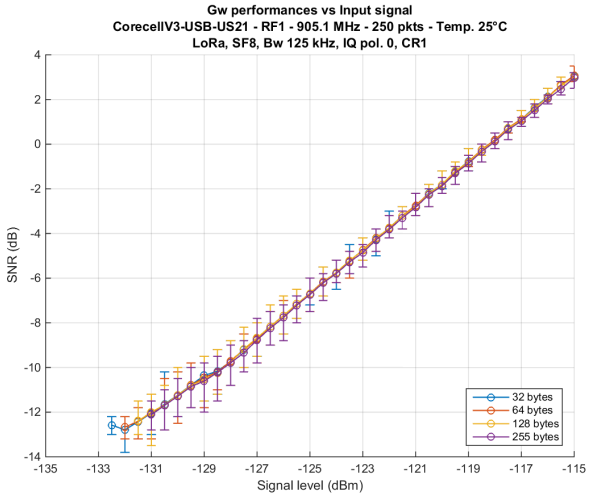
(a) Sensitivity level



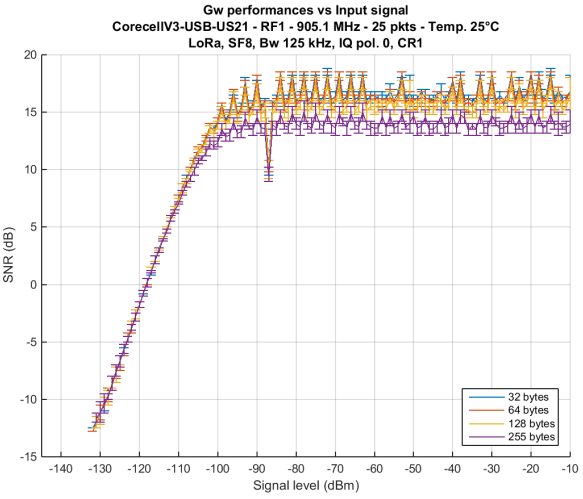
(b) High level

Figure 15.16: SNR vs payload length, Board US21, 905.1 MHz, SF5, Bw 125 kHz, CR1, 25°C

SF8



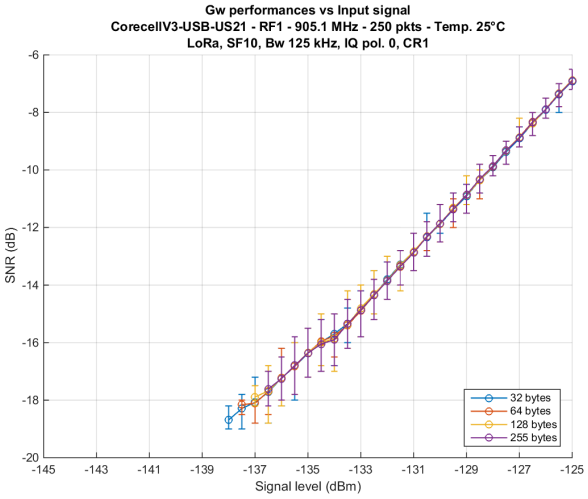
(a) Sensitivity level



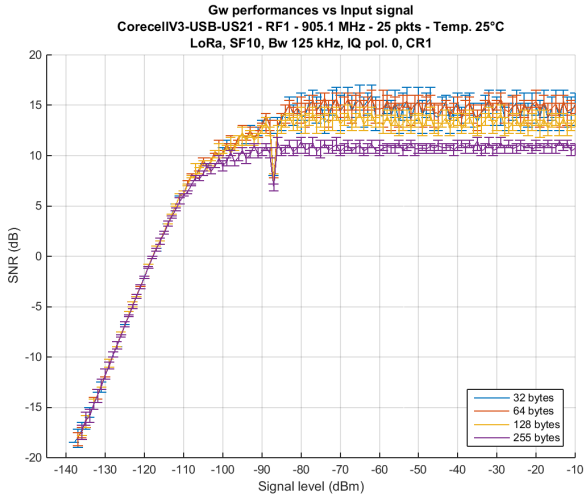
(b) High level

Figure 15.17: SNR vs payload length, Board US21, 905.1 MHz, SF8, Bw 125 kHz, CR1, 25°C

SF10



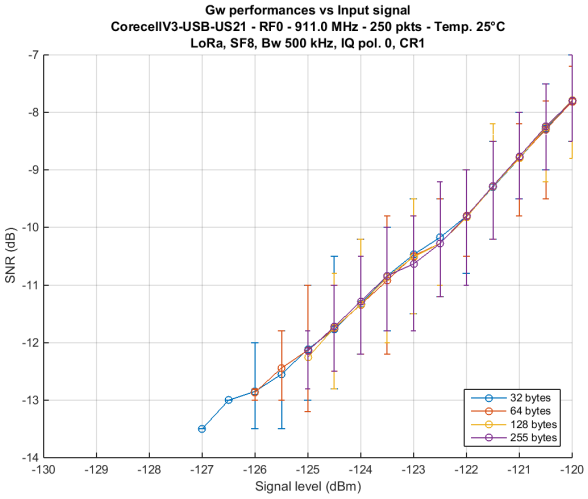
(a) Sensitivity level



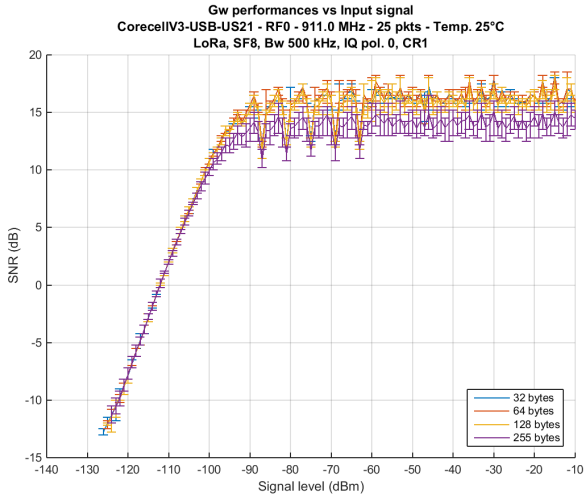
(b) High level

Figure 15.18: SNR vs payload length, Board US21, 905.1 MHz, SF10, Bw 125 kHz, CR1, 25°C

15.6.2 SingleSF modem, Implicit header (911.0 MHz)



(a) Sensitivity level

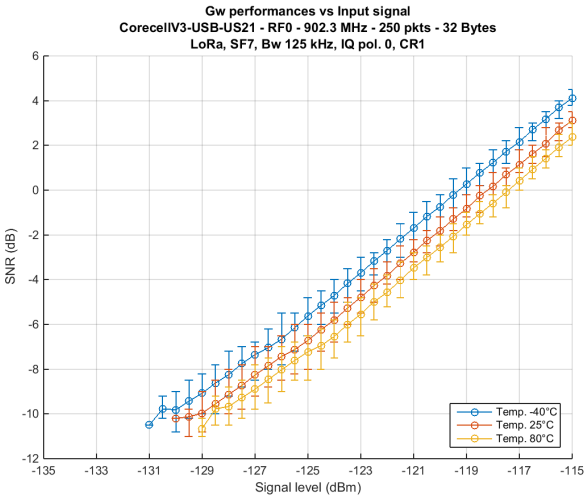


(b) High level

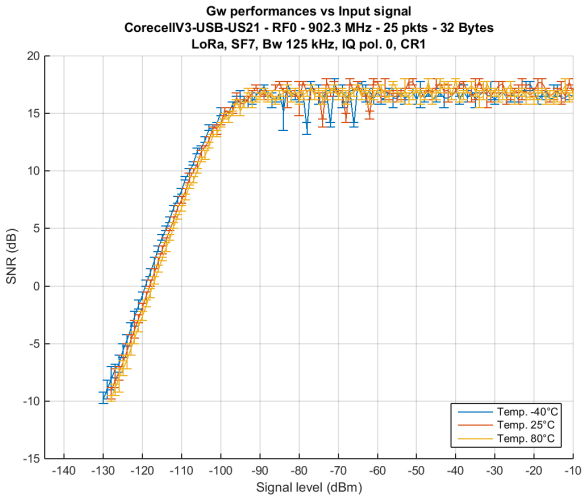
Figure 15.19: SNR vs payload length, Board US21, SingleSF modem, Impl. header, 911.0 MHz, SF8, Bw 500 kHz, CR1, 25°C

15.7 Temperature influence

15.7.1 MultiSF modem (902.3 MHz)



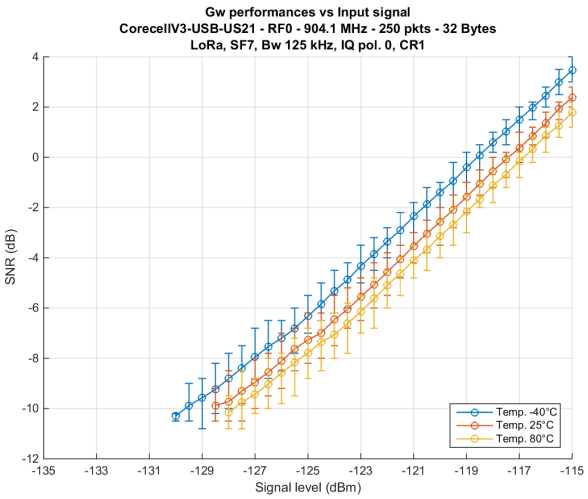
(a) Sensitivity level



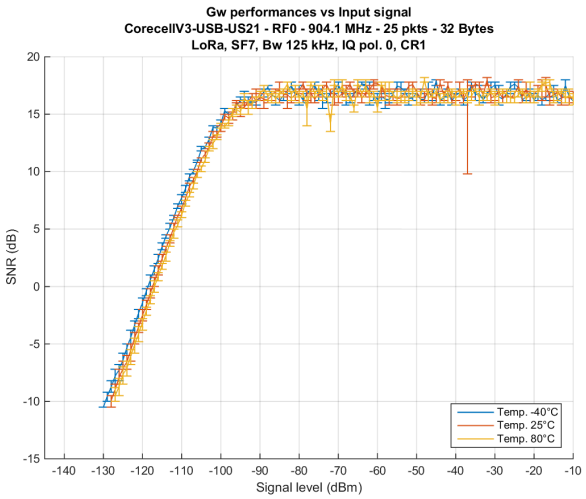
(b) High level

Figure 15.20: SNR vs temperature, Board US21, MultiSF modem, 902.3 MHz, SF7, Bw 125 kHz, CR1

15.7.2 MultiSF modem (904.1 MHz)



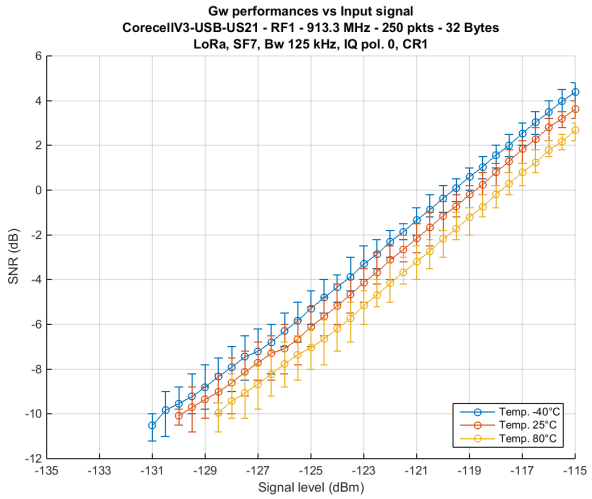
(a) Sensitivity level



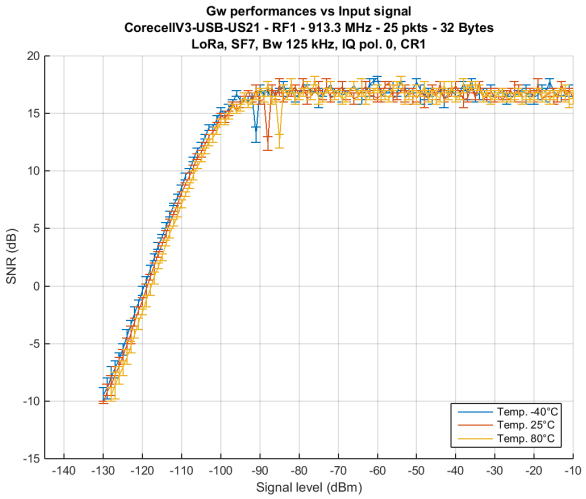
(b) High level

Figure 15.21: SNR vs temperature, Board US21, MultiSF modem, 904.1 MHz, SF7, Bw 125 kHz, CR1

15.7.3 MultiSF modem (913.3 MHz)



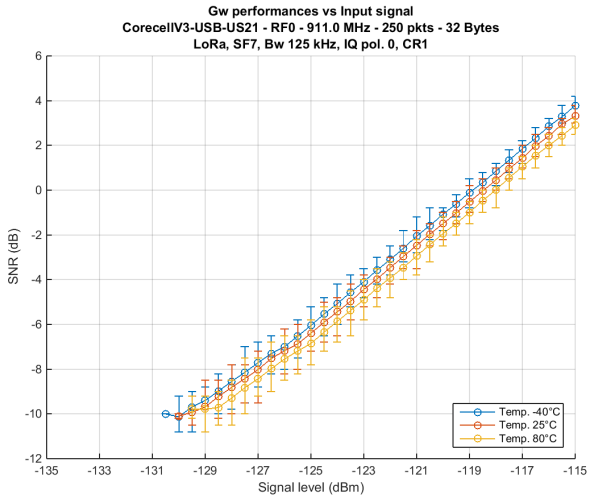
(a) Sensitivity level



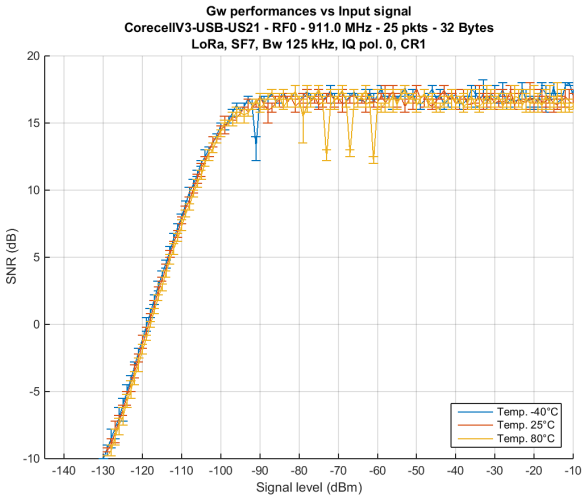
(b) High level

Figure 15.22: SNR vs temperature, Board US21, 913.3 MHz, SF7, Bw 125 kHz, CR1

15.7.4 SingleSF modem (911.0 MHz)



(a) Sensitivity level



(b) High level

Figure 15.23: SNR vs temperature, Board US21, SingleSF modem, 911.0 MHz, SF7, Bw 125 kHz, CR1

15.8 Conclusion

→ **The LoRa modem provides an accurate SNR value whatever the frequency, the spreading factor, the coding rate, the payload length and the temperature.**

16 Blocking and Immunity to interferer

16.1 Description

A blocking profile measurement is performed to evaluate the system robustness to interferer in the vicinity of the gateway.

16.2 Setup

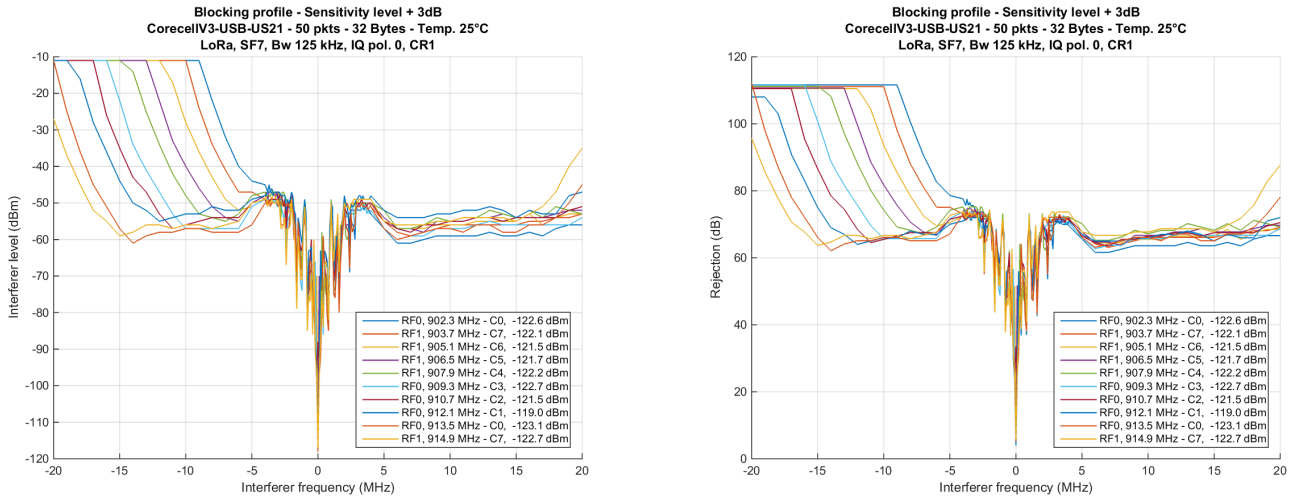
The test bench allowing to assess the coexistence robustness is shown in figure 3.1. Useful signal and interferer are combined in the power splitter/combiner. The attenuators allow to reduce the mutual interference between both signal generators.

The interferer is a continuous carrier wave swept from -20 to +20 MHz in comparison with the carrier frequency, with a variable step in order to find sensitive frequencies.

For each interferer step, the output power of the useful signal is set to the sensitivity level + 3 dB. The PER measurement is done on 50 packets. The interferer level is adjusted automatically to cause a PER of 10%.

16.3 Frequency influence

16.3.1 MultiSF modem (Full band)



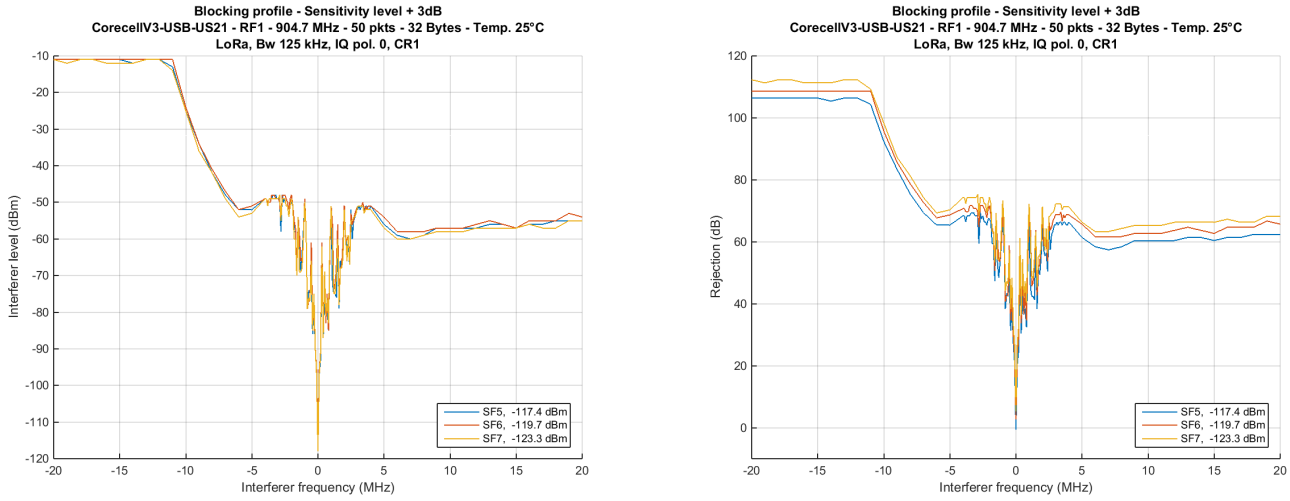
(a) Interferer level (dBm)

(b) Rejection (dB)

Figure 16.1: Blocking profile vs channels (Full band), Board US21, MultiSF modems, SF7, 25°C

16.4 Spreading factor influence

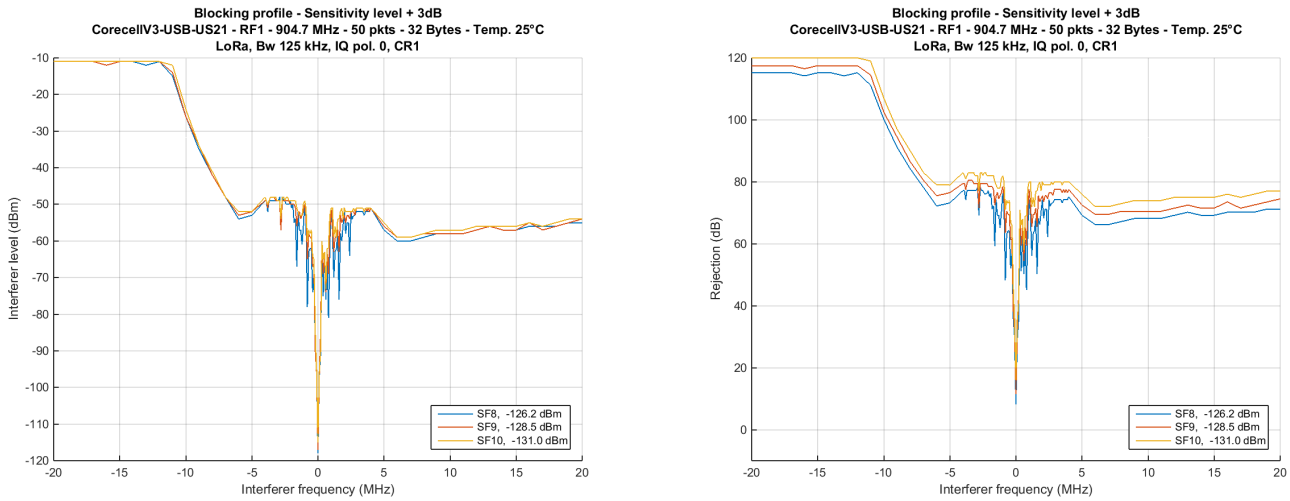
16.4.1 MultiSF modem (904.7 MHz)



(a) Interferer level (dBm)

(b) Rejection (dB)

Figure 16.2: Blocking profile vs SF (5 to 7), Board US21, MultiSF modem, 904.7 MHz, Bw 125 kHz, 25°C

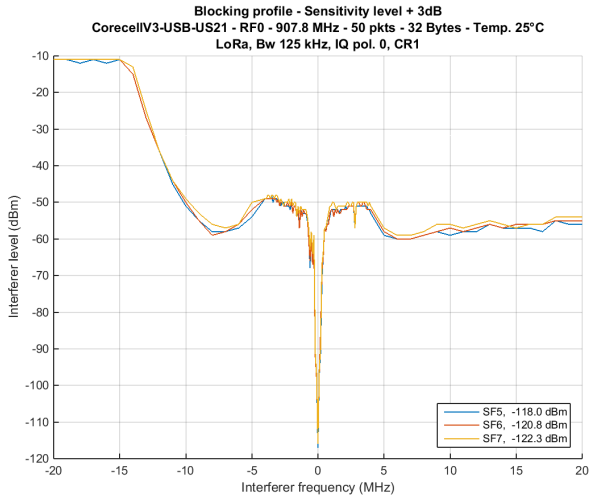


(a) Interferer level (dBm)

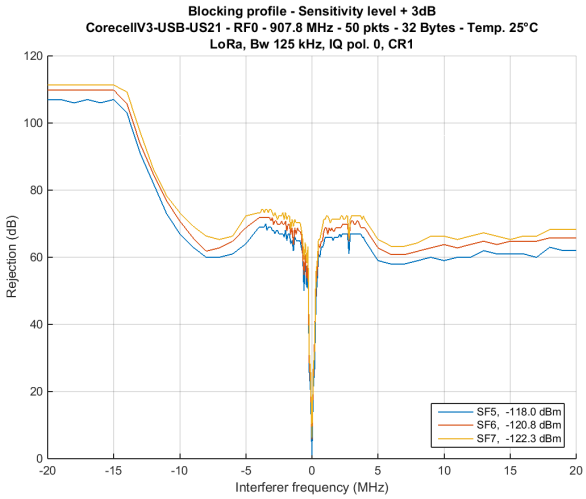
(b) Rejection (dB)

Figure 16.3: Blocking profile vs SF (8 to 10), Board US21, MultiSF modem, 904.7 MHz, Bw 125 kHz, 25°C

16.4.2 SingleSF modem (907.8 MHz) - Bw 125 kHz

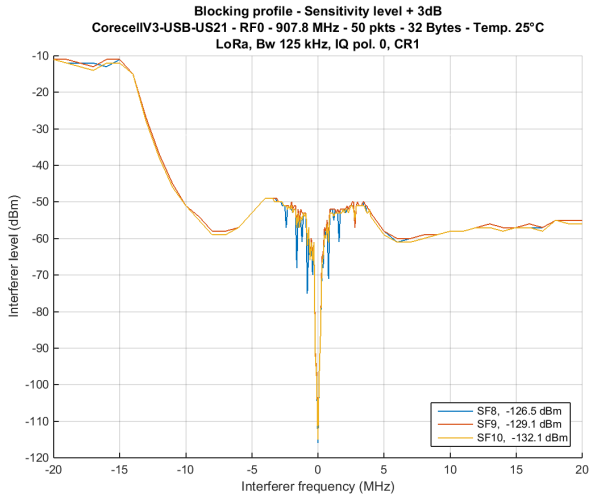


(a) Interferer level (dBm)

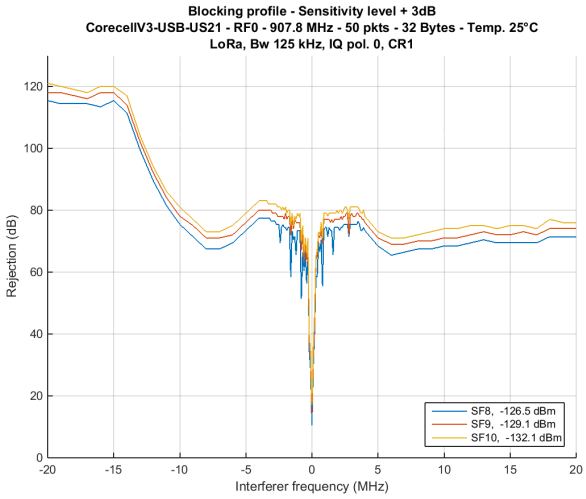


(b) Rejection (dB)

Figure 16.4: Blocking profile vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 25°C



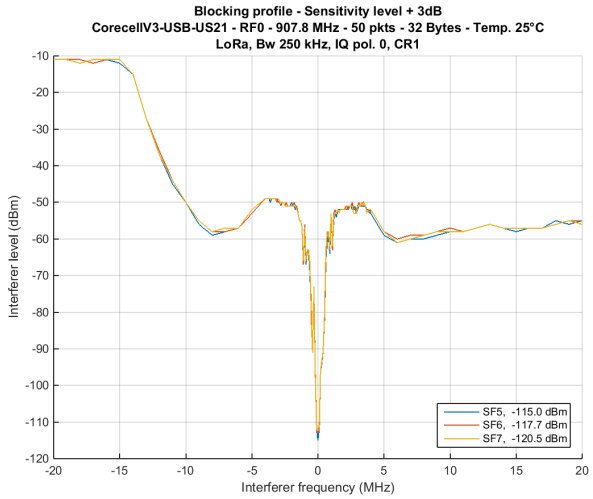
(a) Interferer level (dBm)



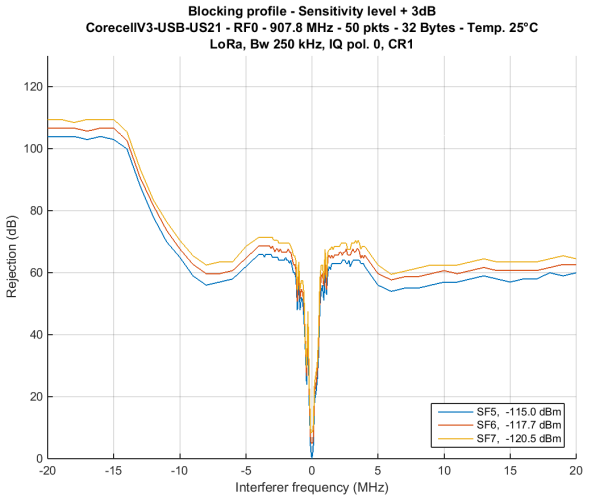
(b) Rejection (dB)

Figure 16.5: Blocking profile vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 25°C

16.4.3 SingleSF modem (907.8 MHz) - Bw 250 kHz

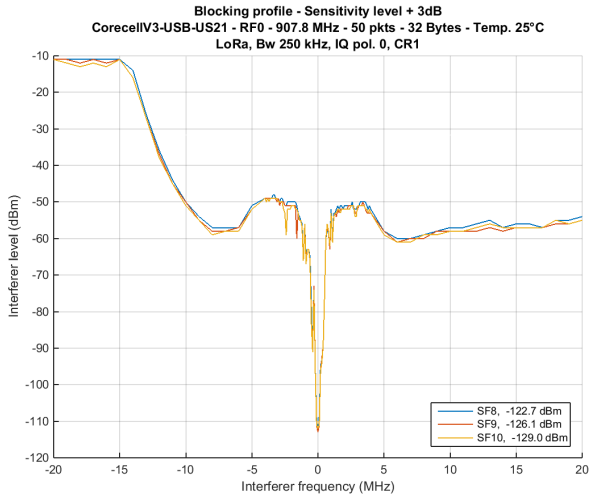


(a) Interferer level (dBm)

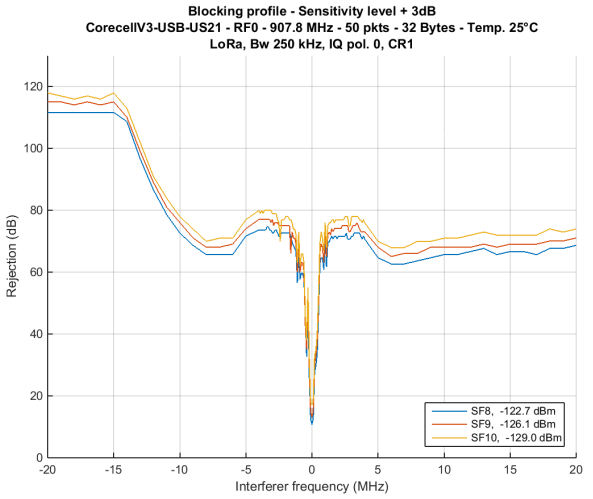


(b) Rejection (dB)

Figure 16.6: Blocking profile vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 25°C



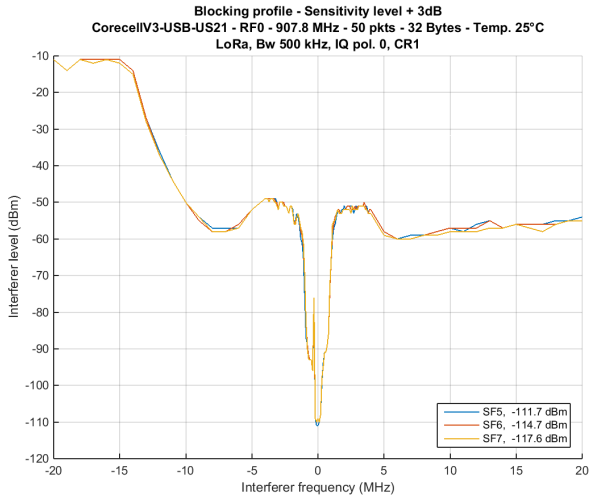
(a) Interferer level (dBm)



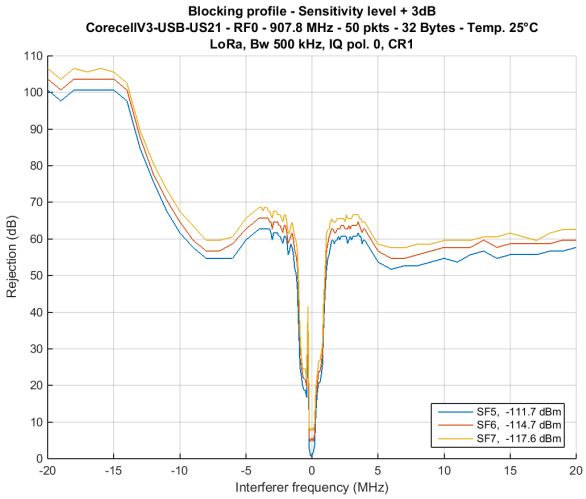
(b) Rejection (dB)

Figure 16.7: Blocking profile vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 25°C

16.4.4 SingleSF modem (907.8 MHz) - Bw 500 kHz

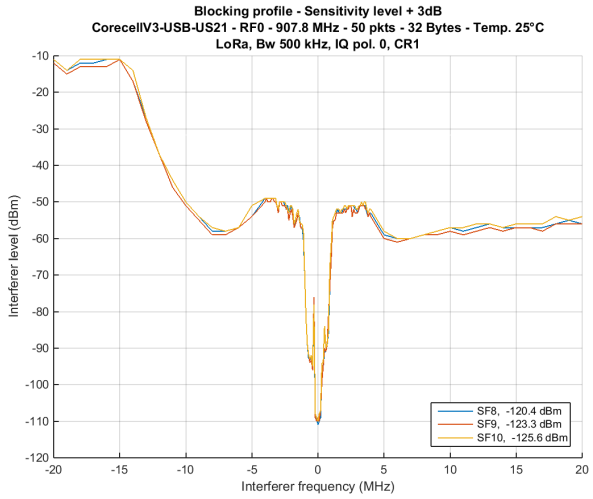


(a) Interferer level (dBm)

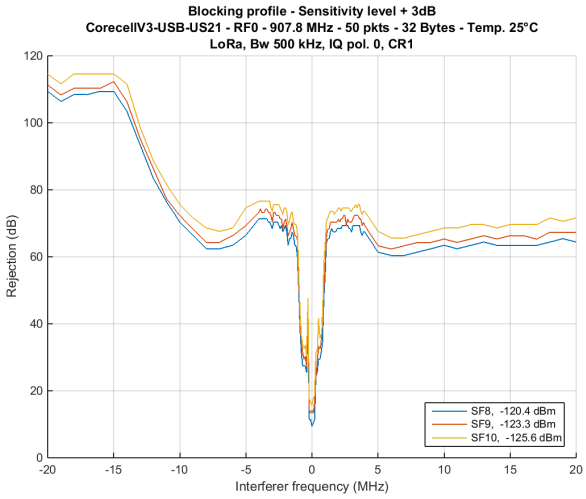


(b) Rejection (dB)

Figure 16.8: Blocking profile vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 25°C



(a) Interferer level (dBm)



(b) Rejection (dB)

Figure 16.9: Blocking profile vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 25°C

The high interferer rejection at -300 kHz offset corresponds to the DC notch inside the SX1302.

16.5 Conclusion

→ **The Corecell gateway provides at least 50 dB of rejection whatever the spreading factor, the bandwidth or the channel.**

17 Frequency error tolerance

17.1 Description

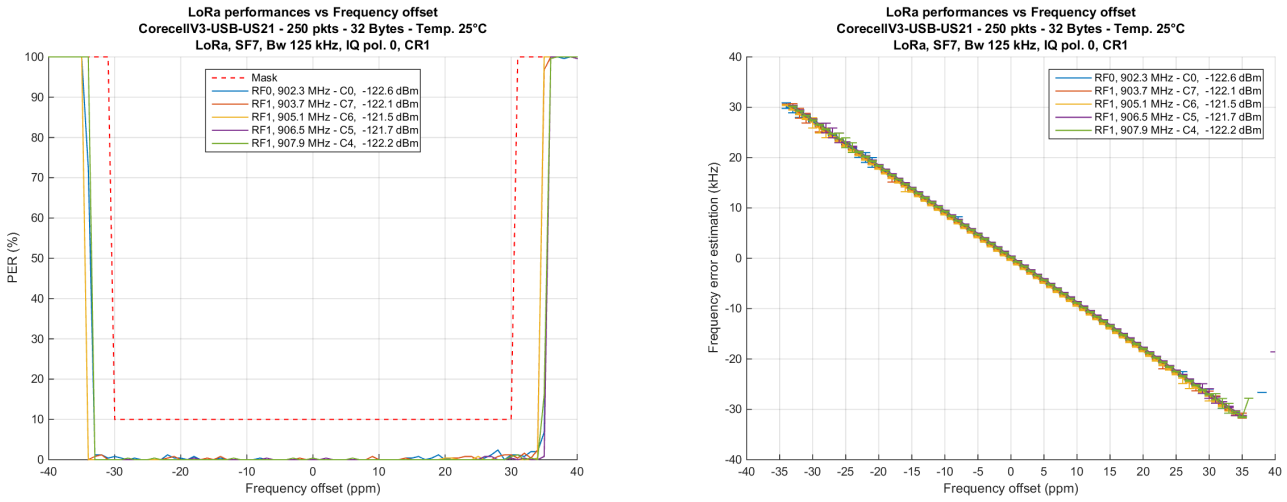
The LoRa modems present in the SX1302 base band processor are tolerant to an error on the transmitter reference clock frequency. This test evaluates the robustness of compensation mechanisms.

17.2 Setup

The setup used for this measurement is shown in the figure 3.1. In order to simulate the remote transmitter crystal imperfection, both the baseband and the RF frequencies shall be updated simultaneously with the evaluated error.

17.3 Frequency influence

17.3.1 MultiSF modem (Lower band), Bandwidth 125 kHz

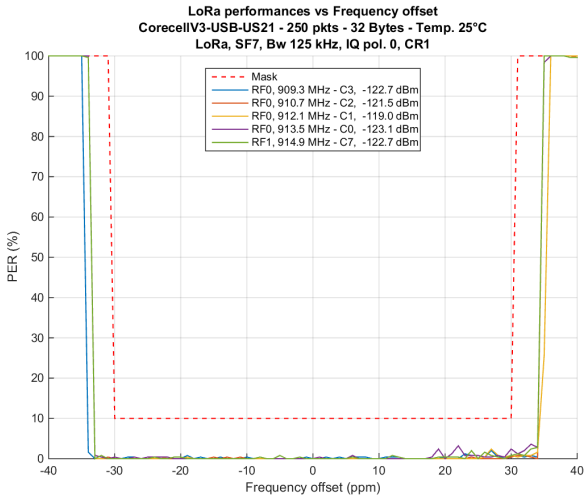


(a) Tolerance

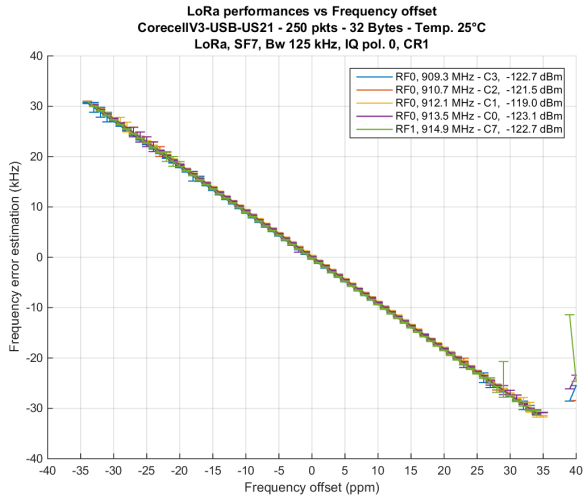
(b) Freq. Estimation

Figure 17.1: Frequency error tolerance vs channels, MultiSF modems (Lower band), Board US21, SF7, Bw 125 kHz, 32 bytes, 25°C

17.3.2 MultiSF modem (Higher band), Bandwidth 125 kHz



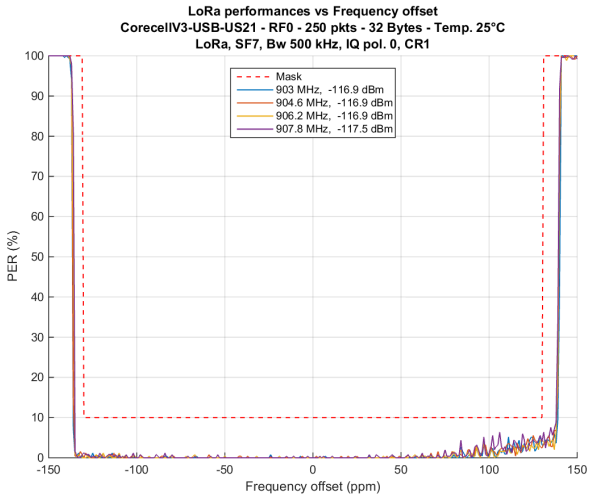
(a) Tolerance



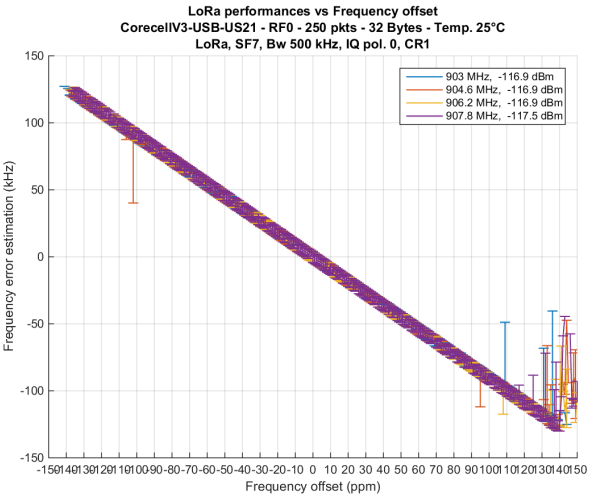
(b) Freq. Estimation

Figure 17.2: Frequency error tolerance vs channels, MultiSF modems (Higher band), Board US21, SF7, Bw 125 kHz, 32 bytes, 25°C

17.3.3 SingleSF modem (Lower band), Bandwidth 500 kHz



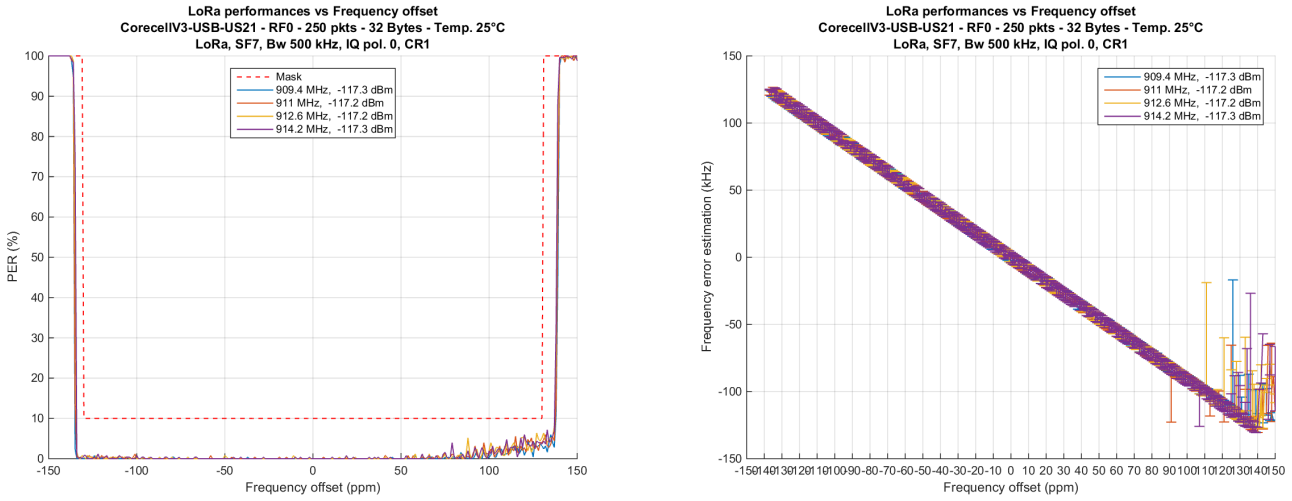
(a) Tolerance



(b) Freq. Estimation

Figure 17.3: Frequency error tolerance vs channels, SingleSF modems (Lower band), Board US21, SF7, Bw 500 kHz, 32 bytes, 25°C

17.3.4 SingleSF modem (Higher band), Bandwidth 500 kHz



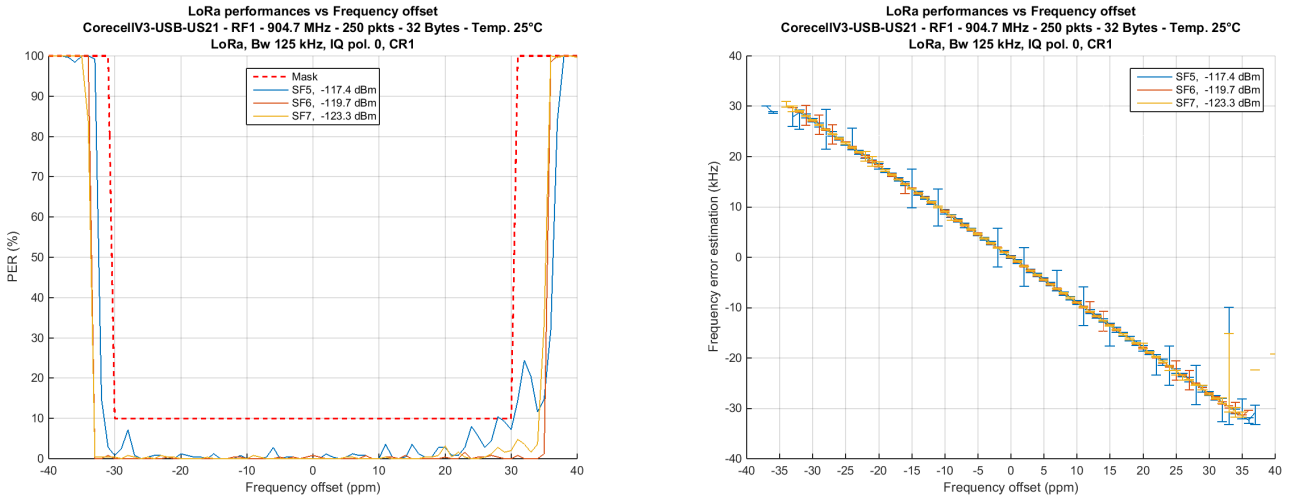
(a) Tolerance

(b) Freq. Estimation

Figure 17.4: Frequency error tolerance vs channels, SingleSF modems (Higher band), Board US21, SF7, Bw 500 kHz, 32 bytes, 25°C

17.4 Spreading factor influence

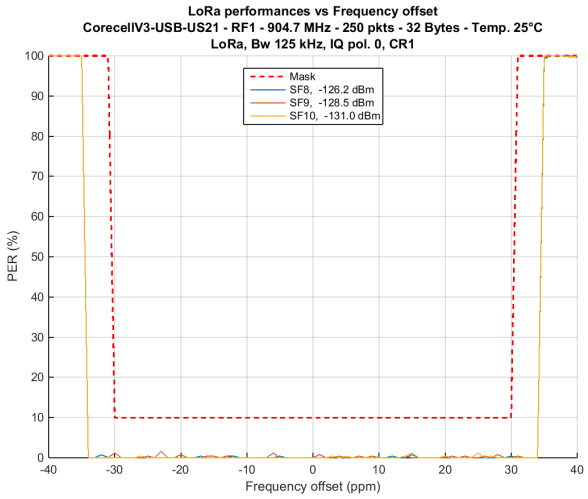
17.4.1 MultiSF modem (904.7 MHz)



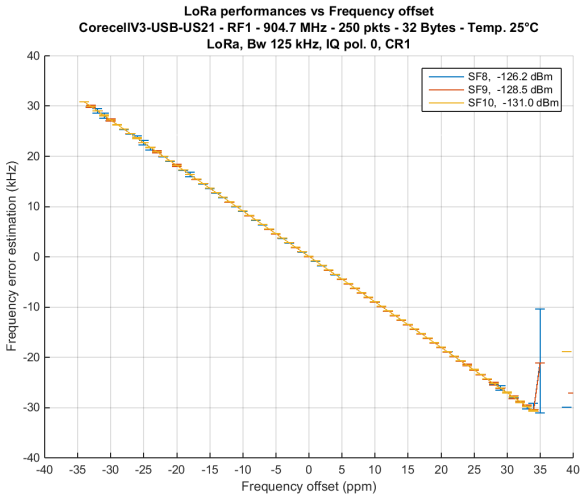
(a) Tolerance

(b) Freq. Estimation

Figure 17.5: Frequency error tolerance vs SF (5 to 7), Board US21, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C



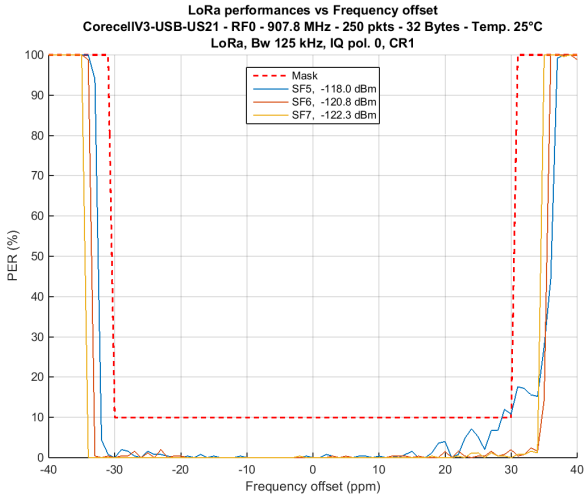
(a) Tolerance



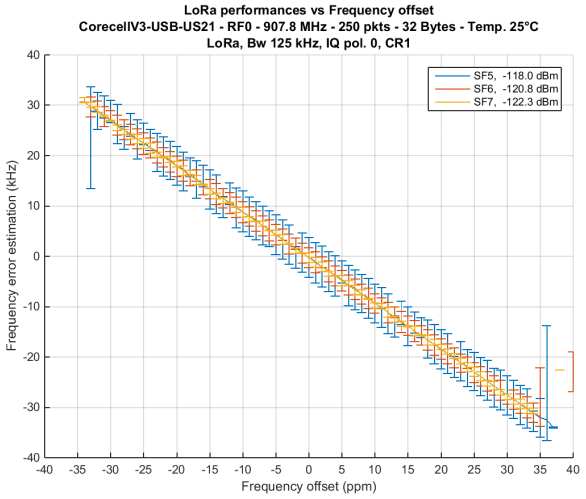
(b) Freq. Estimation

Figure 17.6: Frequency error tolerance vs SF (8 to 10), Board US21, 904.7 MHz, Bw 125 kHz, 32 bytes, 25°C

17.4.2 SingleSF modem (907.8 MHz) - Bw 125 kHz

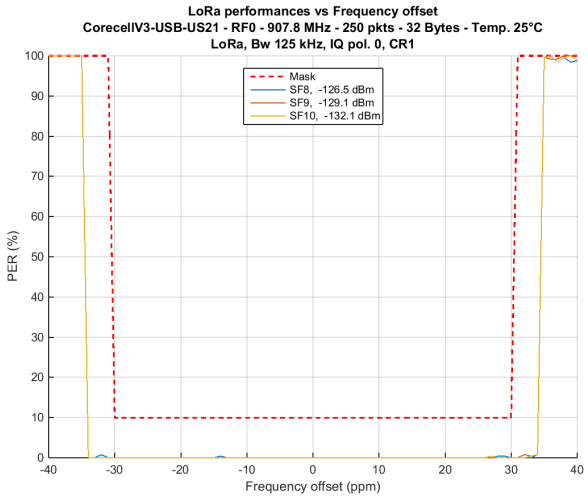


(a) Tolerance

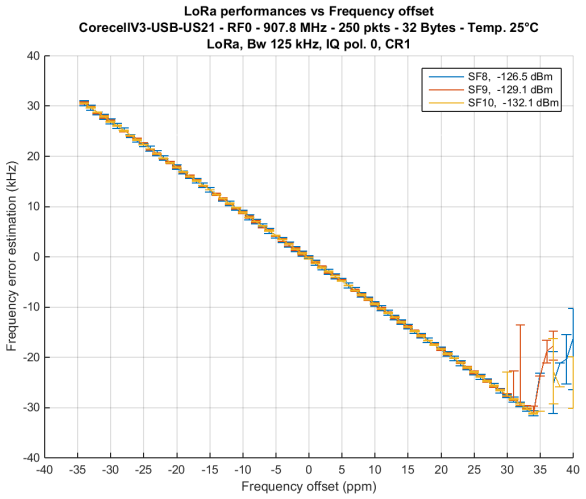


(b) Freq. Estimation

Figure 17.7: Frequency error tolerance vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C



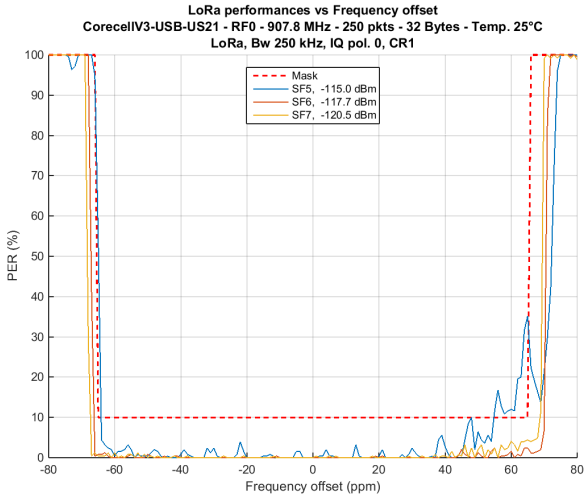
(a) Tolerance



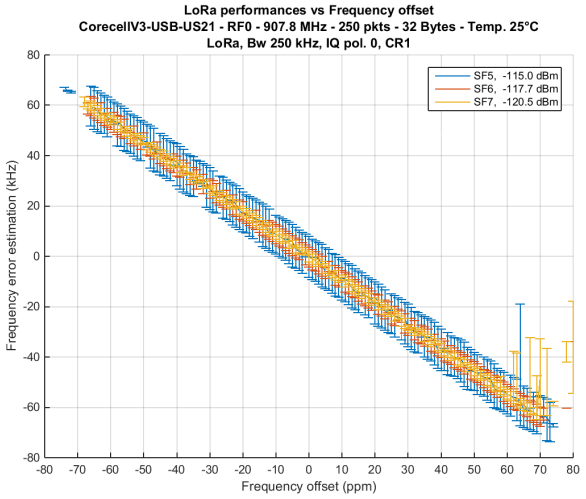
(b) Freq. Estimation

Figure 17.8: Frequency error tolerance vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 125 kHz, 32 bytes, 25°C

17.4.3 SingleSF modem (907.8 MHz) - Bw 250 kHz

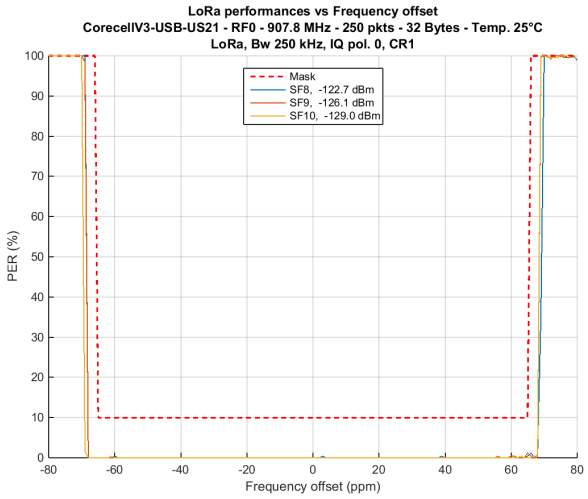


(a) Tolerance

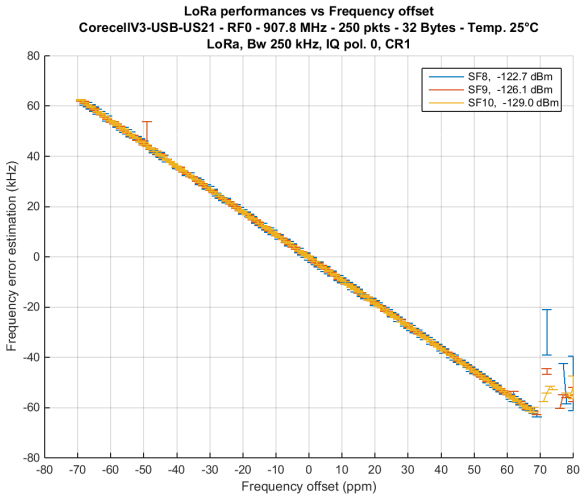


(b) Freq. Estimation

Figure 17.9: Frequency error tolerance vs SF (5 to 7), Board US21, SingleSF modem, 904.6 MHz, Bw 250 kHz, 32 bytes, 25°C



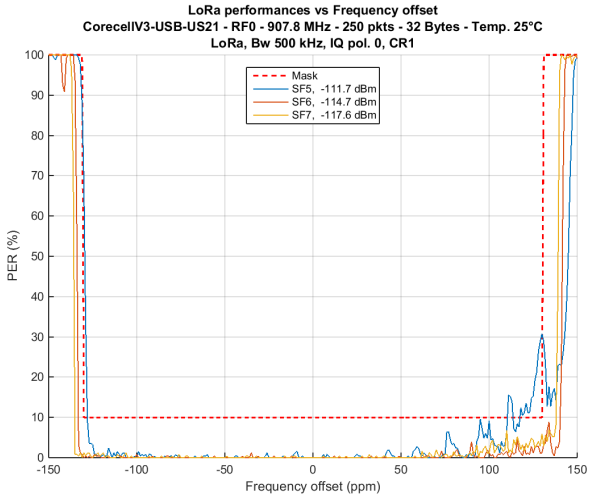
(a) Tolerance



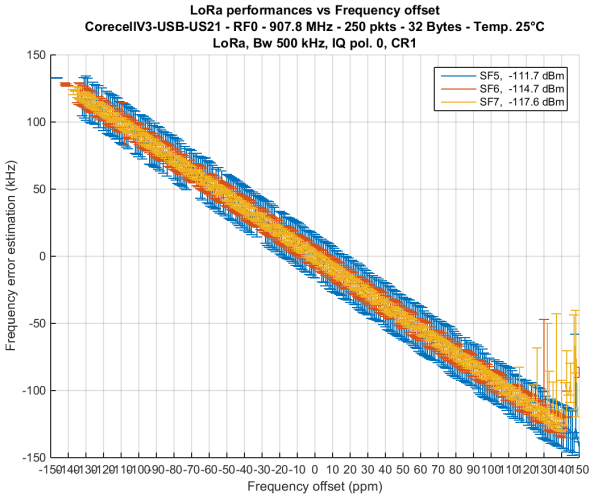
(b) Freq. Estimation

Figure 17.10: Frequency error tolerance vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 250 kHz, 32 bytes, 25°C

17.4.4 SingleSF modem (907.8 MHz) - Bw 500 kHz

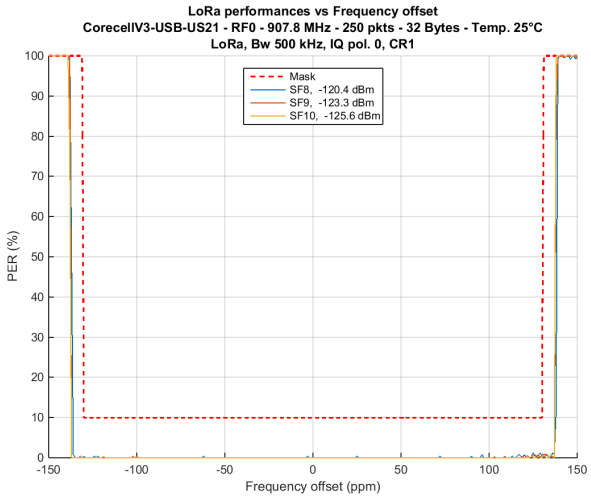


(a) Tolerance

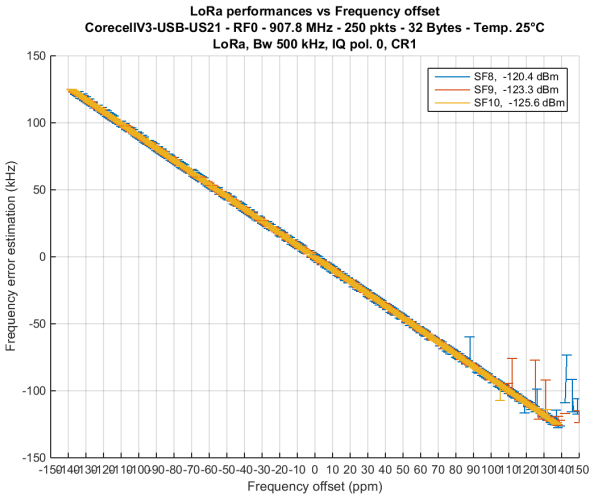


(b) Freq. Estimation

Figure 17.11: Frequency error tolerance vs SF (5 to 7), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C



(a) Tolerance



(b) Freq. Estimation

Figure 17.12: Frequency error tolerance vs SF (8 to 10), Board US21, SingleSF modem, 907.8 MHz, Bw 500 kHz, 32 bytes, 25°C

17.5 FSK modem

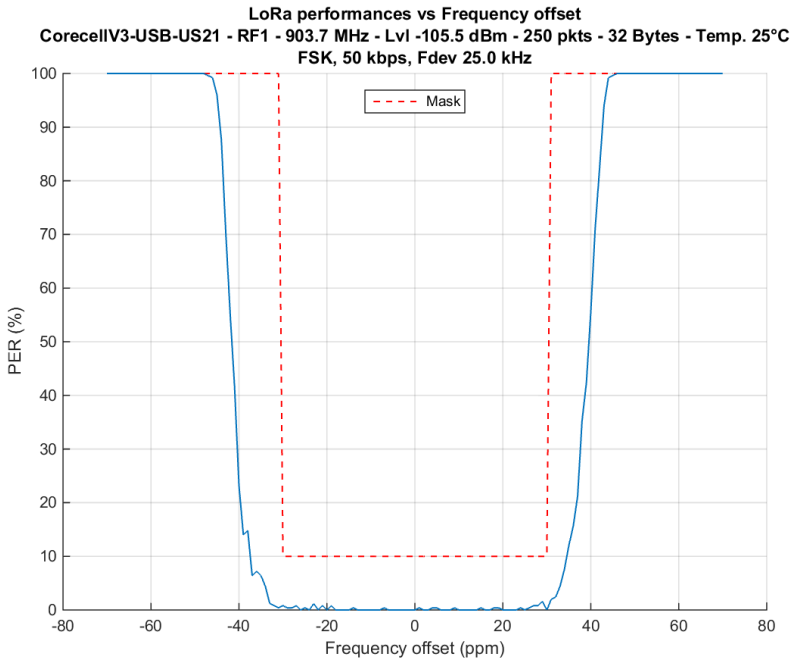


Figure 17.13: Frequency error tolerance, Board US21, FSK modem, 903.7 MHz, 32 bytes, 50 kbits, Fdev 25 kHz, 25°C

17.6 Conclusion

→ **Excepted for the lowest spreading factor, the MultiSF or the SingleSF modem is tolerant to a Xtal frequency error. For SF5, some packets are lost for high positive error.**

18 Frequency drift tolerance

18.1 Description

The SX1302 is able to track the frequency drift of received packets due to the heating of the end-device crystal by its PA. This issue is accentuated with the packet duration.

This section measures the PER in function of the frequency drift and allows to determinate the range for which the SX1302 is able to track.

18.2 Setup

The setup used for this measurement is shown in figure 3.1. Only the direct path and the signal generator are used.

For each measurement step, a packet is generated accelerated/decelerated with the value of the frequency drift. So, the sampling frequency as well as the radio frequency are updated simultaneously. The measurement is performed over a minimum of 100 packets in order to average the results.

18.3 MultiSF modem (904.7 MHz)

The FCC regulation limits the transmission duration to 400 ms. As a consequence, the maximum payload length for US is 24 bytes.

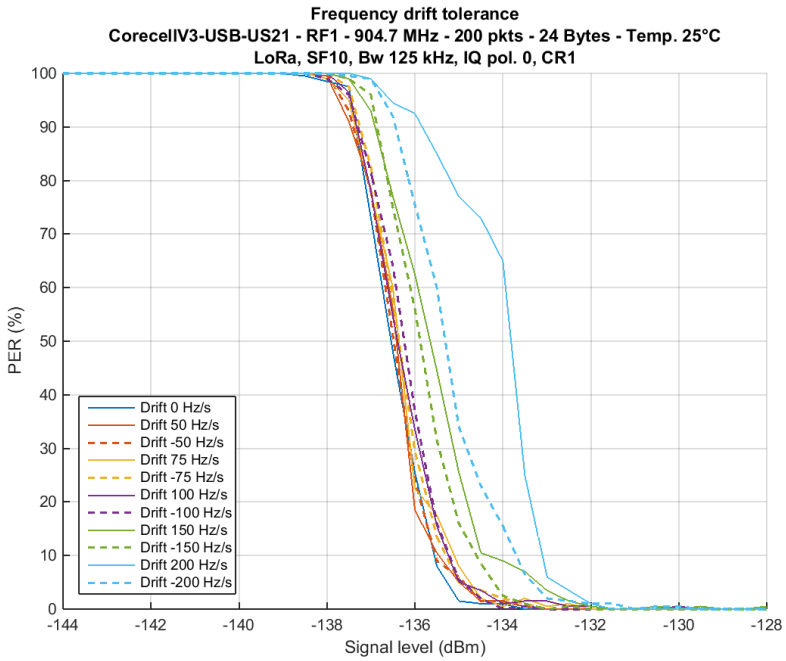


Figure 18.1: Frequency drift tolerance, Board US21, MultiSF modem, 904.7 MHz, SF10, Bw 125 kHz, 24 bytes, 25°C

18.4 SingleSF modem (904.6 MHz), Bandwidth 500 kHz

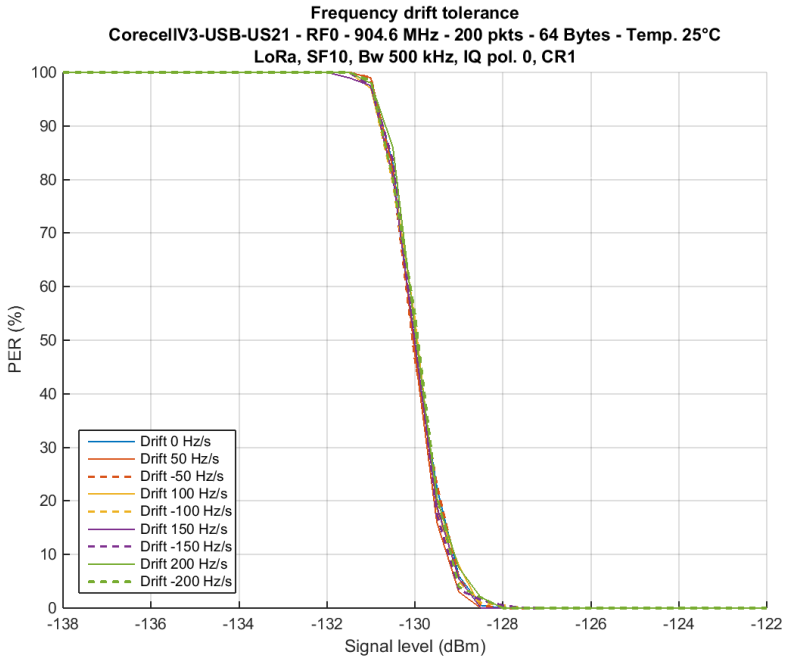


Figure 18.2: Frequency drift tolerance, Board US21, SingleSF modem, 904.6 MHz, SF10, Bw 500 kHz, 64 bytes, 25°C

The SingleSF modem configured with a 500 kHz bandwidth is not influenced by the frequency drift as the symbol time is 4 times shorter, relaxing the constraints on the compensation loops.

Even if the packet duration is increased to about 400 ms with a payload of 177 bytes, the SingleSF modem is not influenced by the frequency drift when the bandwidth is 500 kHz.

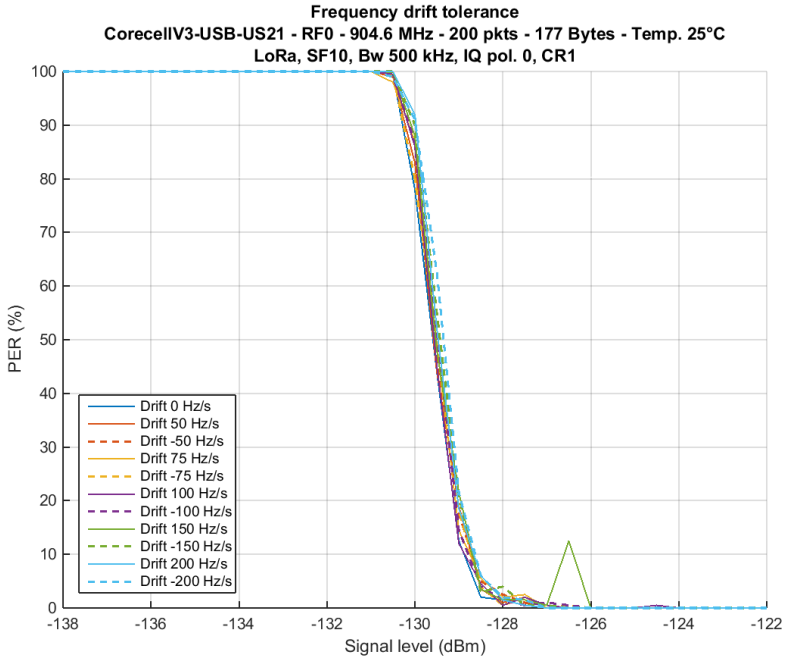


Figure 18.3: Frequency drift tolerance, Board US21, SingleSF modem, 904.6 MHz, SF10, Bw 500 kHz, 177 bytes, 25°C

18.5 Conclusion

The SingleSF modem with a bandwidth of 500 kHz is not influenced by the frequency drift of the oscillator.

The MultiSF modem (125 kHz bandwidth) sensitivity level is degraded by 3dB when the frequency drift reaches $\pm$200 Hz/s.

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

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