SEMTECH

WIRELESS & SENSING PRODUCTS

Corecell reference design for LBT Spectral Scan gateway

USB / AS923 Performances report

Abstract

The Corecell gateway reference design is a plateform which implement the baseband processor SX1302 and the radio transceiver SX1250. This document presents the compliance measurements results to the tests required by ARIB 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 **Japan 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

1. **ARIB STD-T108 Version 1.0**: Japan regulation for the 920 MHz band
2. **LoRaWAN v1.1 specification** describes the LoRaWAN™ network protocol.
3. **LoRaWAN v1.1 Regional Parameters** The companion document to the LoRaWAN v1.1 protocol specification [2].

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 Regulation

2.1 Presentation

The **ARIB STD-T108 Version 1.0 920 MHz band - Telemeter, Telecontrol and Data Transmission Radio Equipment** (document [1]) summarizes all the technical requirements to comply with the Japan regulation.

It defines two different types of application: Convenience radio stations and Low-power radio stations. The LoRa gateway only operates in convenience radio station in order to reach the maximum allowed output power of 250 mW.

2.2 Spectrum

The frequency band uses by the LoRaWan network in Japan is contained in the range [920.5 923.5] MHz. The frequency allocation / channelization is fully defined by the Japan regulation.

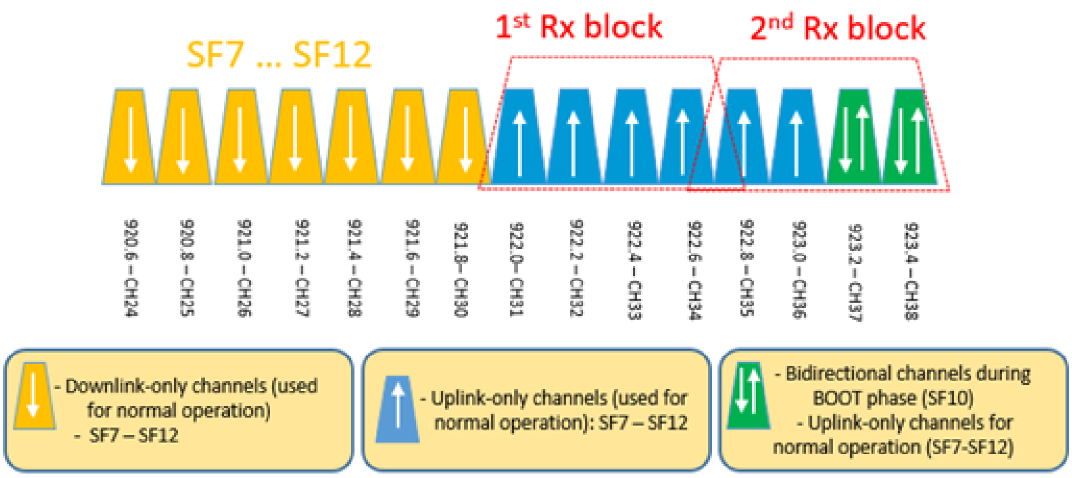


Figure 2.1: Example of frequency allocation used in Japan

One example of frequency plan is shown in figure 2.1. Uplink and downlink channels are one of possibles cases for the network.

The document [3] mentions two bidirectional channels shall be present on all Asian countries and are used during the BOOT phase. All others Uplink channels are located closed to these one. Finally, the downlink channels are located on the lower part of the band.

Even if it is allowed by the regulation, no full duplex is planned for this country. Furthermore, only 125 kHz channels are used for Asian countries.

2.3 Frequency tolerance

The reference frequency tolerance shall be ± 20 ppm making mandatory the use of a TCXO.

2.4 Permissible value for occupied bandwidth

The permitted occupied bandwidth, defined as 99% of the power within the unit channel bandwidth. It shall be (200 x n) kHz or less where n is a number of unit radio channels constituting the radio channel and is an integer from 1 to 5

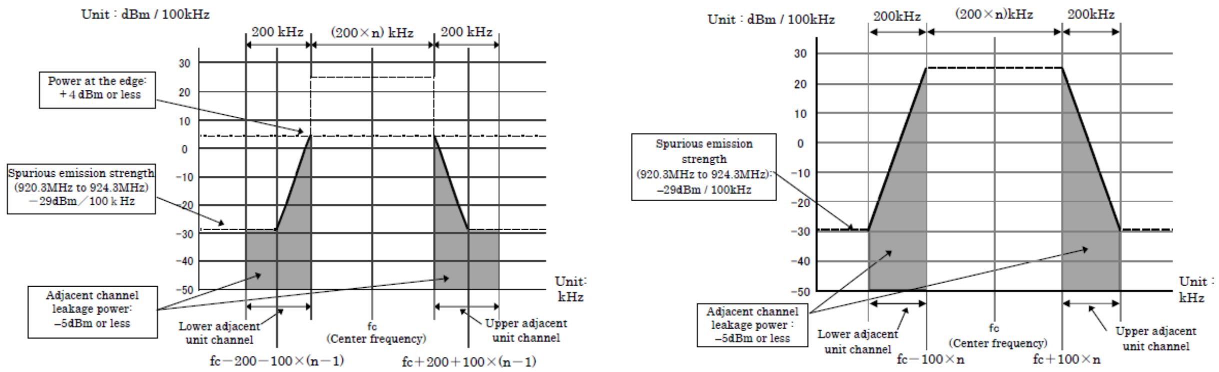
→ **The occupied bandwidth shall be lower than 200 kHz.**

2.5 Adjacent channel leakage power

The Tx spectrum shall comply with the following requirements:

- Only for channels from 920.5 to 922.3 MHz: Spectral power at the edge of a radio channel shall be lower than +4 dBm. This value corresponds to a level 20 dB below the maximum carrier level. This requirement is not applicable for channels from 922.3 to 923.5 MHz.
- The leakage power in the adjacent channel shall be lower than -5 dBm. This value corresponds to a level 29 dB below the maximum carrier level.

The figures 2.2 summarizes these requirements.



(a) Channels from 920.5 to 922.3 MHz

(b) Channels from 922.3 to 923.5 MHz

Figure 2.2: Adjacent channel leakage power requirements

2.6 Output power

The maximum antenna power allowed by the ARIB regulation is 250 mW i.e. 24 dBm for an antenna gain lower than 3 dBi. The latter may be higher than 3 dBi if the antenna power is lower than 24 dBm.

→ **The maximum radiated power allowed for the gateway is +27 dBm.**

The tolerance on antenna power is contained in the range [+20% -80%].

2.7 Unwanted Emission

2.7.1 Transmitter

The spurious emissions generated by the transmitter shall be lower than the values mentioned in table 2.1.

Frequency (MHz)	Max. level (dBm)	RBW (kHz)
$f \leq 710$	-36	100
$710 < f \leq 900$	-55	1000
$900 < f \leq 915$	-55	100
$915 < f \leq 920.3$	-36	100
$920.3 < f \leq 924.3$ *	-29	100
$924.3 < f \leq 930$	-36	100
$930 < f \leq 1000$	-55	100
$1000 < f \leq 1215$	-45	1000
$1215 < f$	-30	1000

* except for $|f - fc| <= (200 + 100 \times n)$ kHz; n=number of bundled element channels

Table 2.1: Spurious emissions limits (level at Tx output)

2.7.2 Receiver

The spurious emissions level generated by the receiver shall be lower than the values mentioned in table 2.2.

Frequency (MHz)	Max. level (dBm)	RBW (kHz)
$f \leq 710$	-54	100
$710 < f \leq 900$	-55	1000
$900 < f \leq 915$	-55	100
$915 < f \leq 930$	-54	100
$930 < f \leq 1000$	-55	100
$1000 < f$	-47	1000

Table 2.2: Spurious emission limits (level at Rx input)

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.

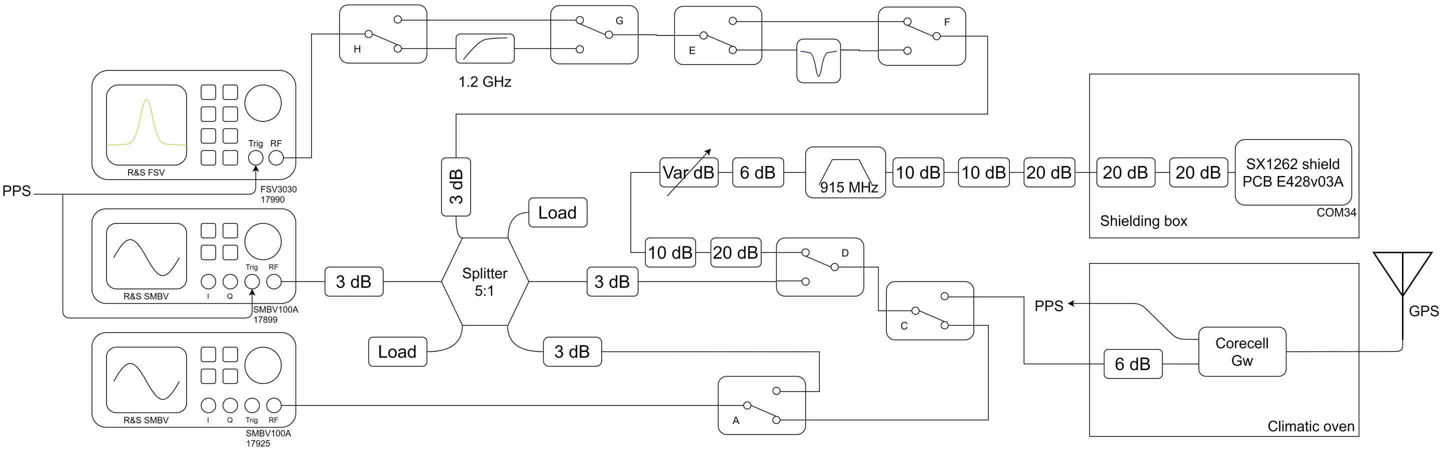


Figure 3.1: Overall test bench setup used to validate the Corecell gateway

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.

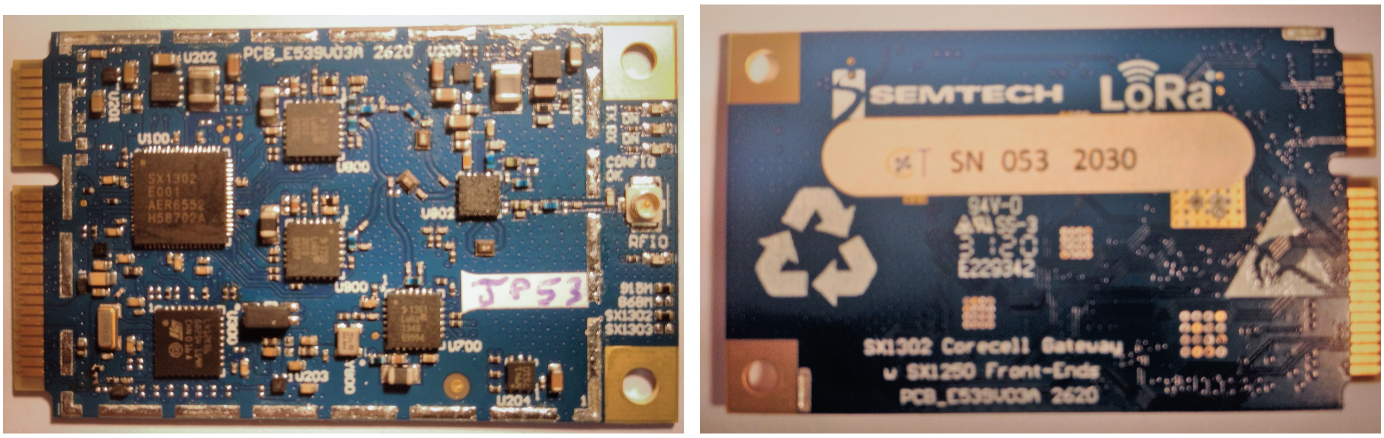
The Corecell gateway interface board (PCB e525v04a) has a GPS module providing the PPS signal to both the signal analyzer and the signal generator and allowing to synchronize the measurements.

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).

4 Device under test

4.1 Presentation

The device used for the measurements of this report is the Corecell gateway V3 (PCB e539v03a) populated for the AS923 region; Two boards are used along the validation; the serial numbers are **SN 053 2030** and **SN 055 2030**. Along the document, they are referred as **Board JP53** and **Board JP55**.



(a) Top (b) Bottom

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

The board is connected on the mini-pcie connector on the interface board (PCB e525v04a) 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. Remarks concerning the BOM:

- The ferrite bead **FB202** is populated; not the **FB207**: The power supply voltage **VCCIO33** is provided by the VCC3V3_IN input voltage, not from the on-board 3.3V LDO regulator.
- The ferrite bead **FB206** is populated, not the FB204 or FB211: The power supply voltage **VCC_FEM** is provided by the on-board 3.3V DCDC regulator.
- The SAW filter **U805** is replaced by the reference **B2619** from RF360.

4.2 Software versions

The following software 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	Always lower than 200 kHz
Adjacent channel leakage power	Comply with the adjacent channel leakage power requirement if the output power is reduced to 21 dBm
Unwanted emission - Tx	Comply with the ARIB regulation limit if output level lower than 18 dBm
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
Unwanted emission - Rx	Complies with the Unwanted emission in Rx mode limits
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 Carrier sense / LBT feature	Robust to the end-device oscillator frequency drift Comply with the ARIB standard requirements

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 (+24 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 instead of the jumper **VCC3V_core**. The function **sx1250_setup** presents in the file `loragw_sx1250.c`) is modified as follow to evaluate both SX1250 regulator modes:

```
/* 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

The board current consumption is summarized in the table 6.1

Modes	Input voltage (V)	Current consumption (mA)
Idle	3.27	17.5
Rx LDO	3.25	55
Rx DCDC	3.26	45
Tx	3.1	354

Table 6.1: Current consumption, Board JP55, 25°C

6.4 Conclusion

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

Part I

Transmitter

7 Output power

7.1 Description

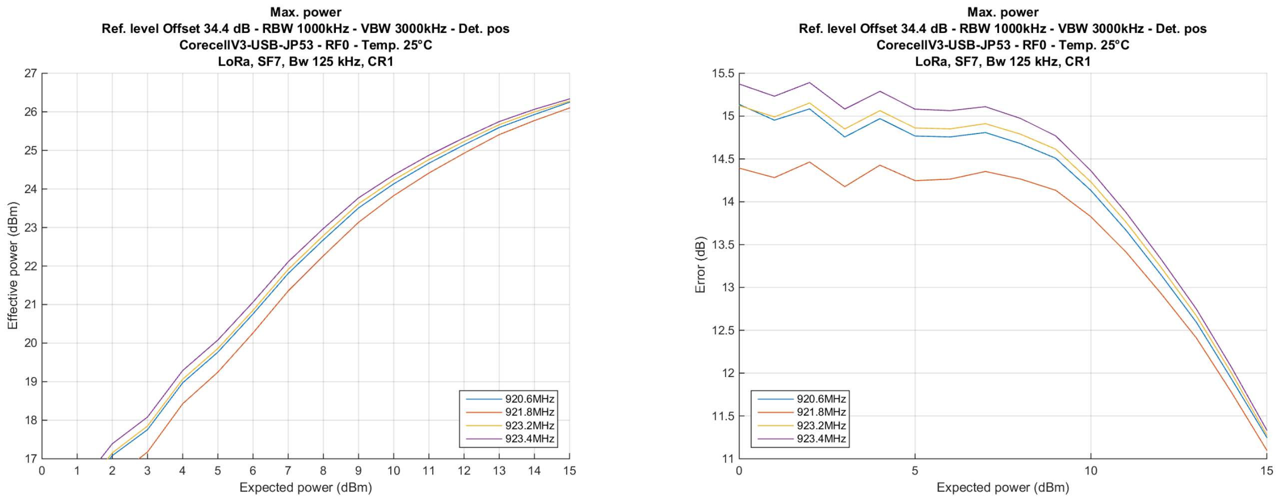
The ARIB **Antenna power** tests require that the output power to be lower than +24 dBm. In order to maximize the link budget, the power shall be trimmed as close as possible to the limit.

This section evaluates the output power trimming capability.

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 board.

7.3 Frequency influence



(a) Absolute (dBm) (b) Relative (dB)

Figure 7.1: Output power response vs channel, Board JP53, SF7, Bw 125 kHz, 25°C

7.4 Conclusion

→ **The Corecell reference design provides an output power up to +27 dBm. The accuracy of the output power trimming is lower than 0.5dB. The SX1250 parameter pwid is set to 9 to trim the output power to 24 dBm.**

8 Modulation bandwidth

8.1 Description

The ARIB regulation test **Permissible value for occupied bandwidth** requires the spectrum to be measured. The limit is one unit channel i.e. 200 kHz.

8.2 Setup

The setup used for this measurement is described in section 3.1. The output signal is measured on the SMA connector present on the interface board.

The measurement is performed using the built-in instrument function which measure the OBW at 99%.

8.3 Frequency influence

8.3.1 SF7

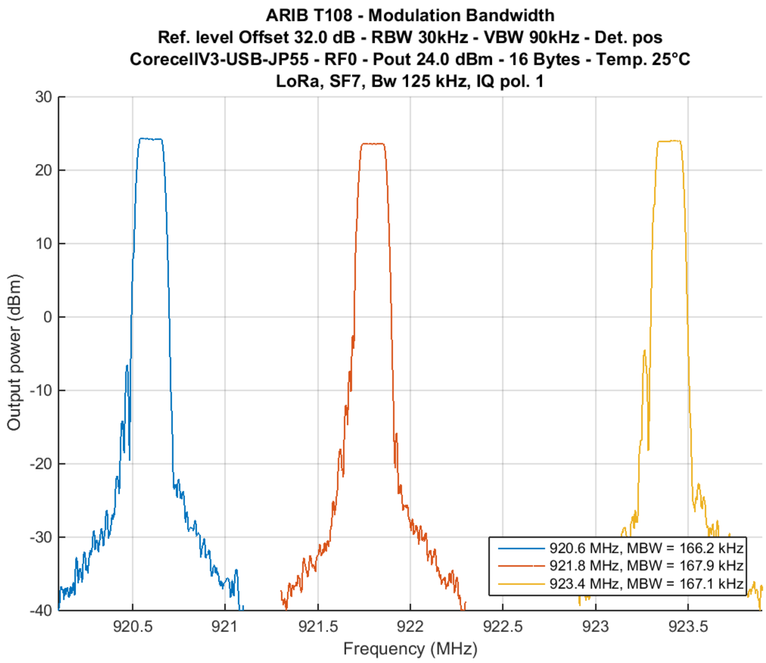
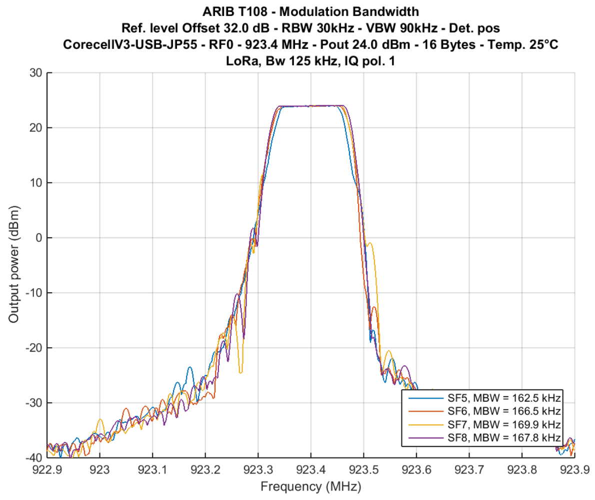
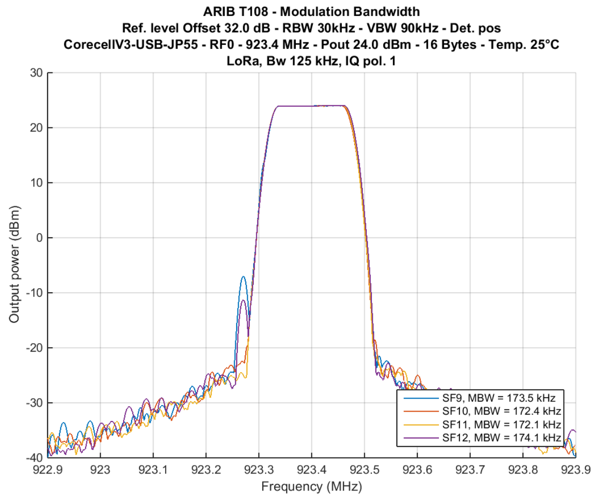


Figure 8.1: Modulation bandwidth vs frequency, Board JP55, SF7, Bw 125 kHz, 25°C

8.4 Spreading factor influence



(a) SF5-8



(b) SF9-12

Figure 8.2: Modulation bandwidth vs Spreading factor, Board JP55, 923.4 MHz, Bw 125 kHz, 25°C

8.5 Conclusion

→ **The occupied bandwidth is always lower than 200 kHz whatever the channel or the spreading factor.**

9 Adjacent channel leakage power

9.1 Description

The leakage power in both adjacent channels shall be measured and be lower than -5 dBm (see section 2.5).

Additionally, the spurious emission strength shall fall below the -29 dBm limit at fc $\pm$ 200 kHz in a bandwidth of 100 kHz. Finally, the spectral power at the edges of the radio channel shall be lower than +4 dBm.

9.2 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 board.

9.3 Frequency influence

Warning: The measurements of this section have been performed with the output power set to 24 dBm. This level can not allow to comply with the ACP regulation limit as well as the spurious one.

9.3.1 SF5

The figure 9.1 shows the adjacent channel leakage power on three channels, SF5 / Bw 125 kHz. The measurement is performed at ambient temperature (25 °C).

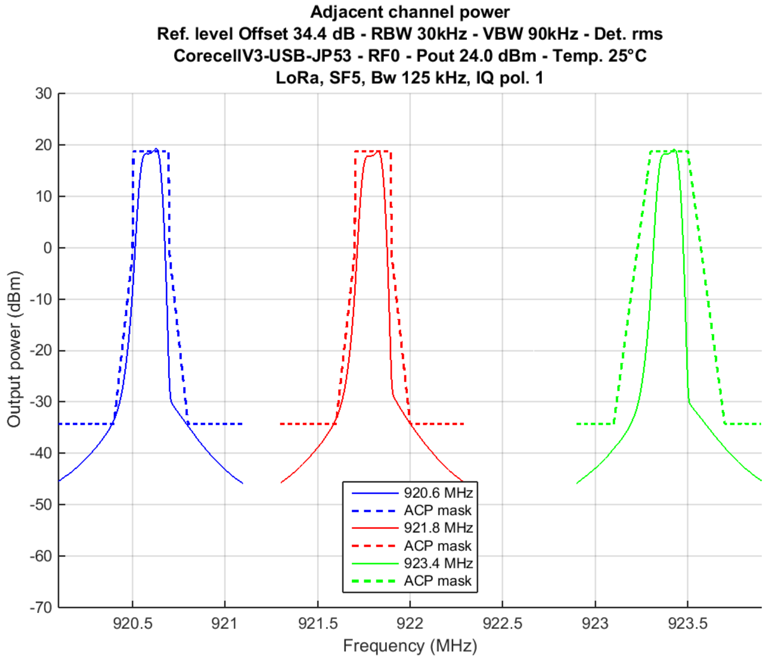


Figure 9.1: Adjacent channel leakage power vs frequency, Board JP53, +24 dBm, SF5, Bw 125 kHz, 25°C

The leakage power in the adjacent channels (lower and upper) is below the regulation limit of -5 dBm.

Channel	920.6	921.8	923.4
Lower Channel power (dBm)	-13.8	-14.3	-14.1
Channel power (dBm)	23.8	23.4	23.7
Upper Channel power (dBm)	-25.7	-24.9	-25.6

Table 9.1: Adjacent Channel Leakage Power vs frequency, Board JP53, +24 dBm, SF5, 25°C

9.3.2 SF9

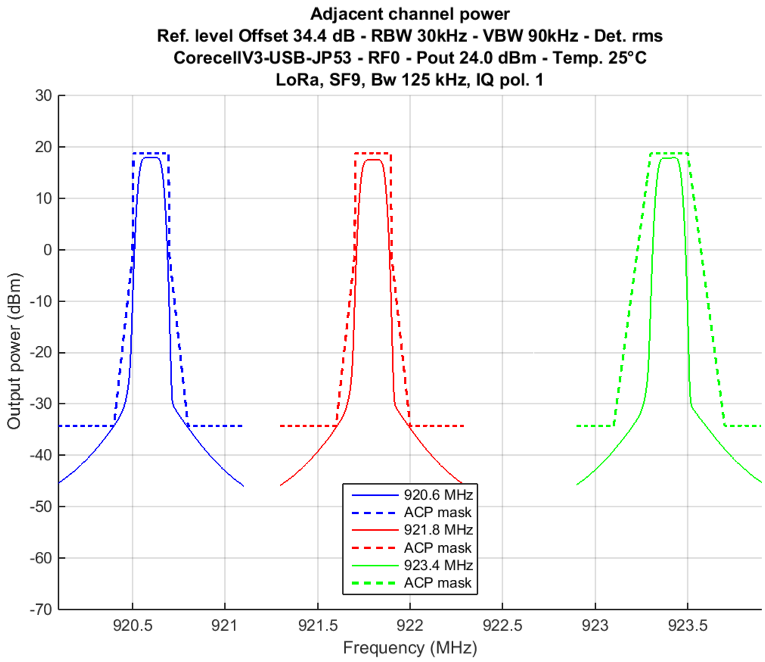


Figure 9.2: Adjacent channel leakage power, Board JP53, +24 dBm, SF9, Bw 125 kHz, 25°C

Channel	920.6	921.8	923.4
Lower Channel power (dBm)	-18.3	-18.7	-18.5
Channel power (dBm)	23.8	23.4	23.8
Upper Channel power (dBm)	-21.0	-21.4	-21.0

Table 9.2: Adjacent Channel Leakage Power, Board JP53, +24 dBm, SF9, Temp. 25°C

9.3.3 SF12

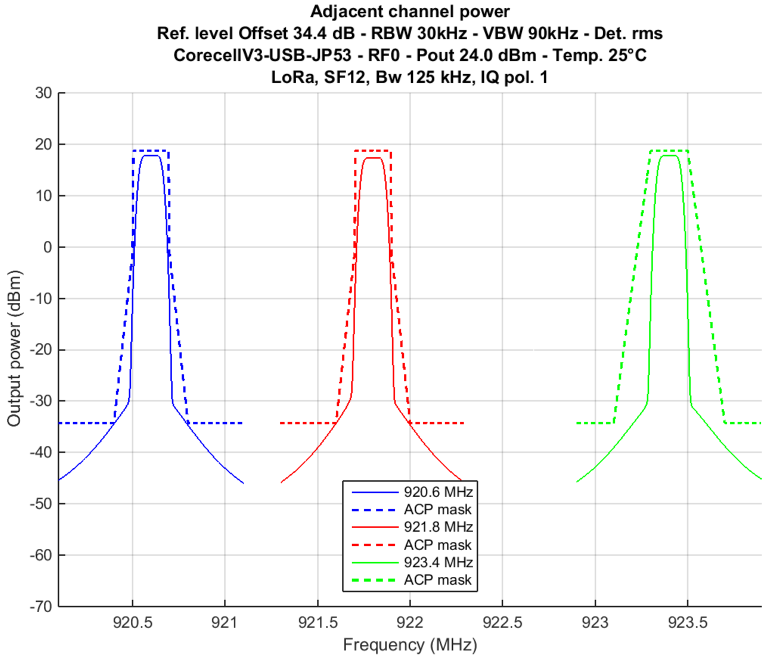


Figure 9.3: Adjacent channel leakage power, Board JP53, +24 dBm, SF12, Bw 125 kHz, 25°C

Channel	920.6	921.8	923.4
Lower Channel power (dBm)	-19.7	-19.8	-19.7
Channel power (dBm)	23.8	23.3	23.7
Upper Channel power (dBm)	-20.4	-20.6	-20.4

Table 9.3: Adjacent Channel Leakage Power vs frequency, Board JP53, +24 dBm, SF12, 25°C

9.3.4 FSK 50 kbits

The measurement of this section has been performed with the output power set to 18 dBm.

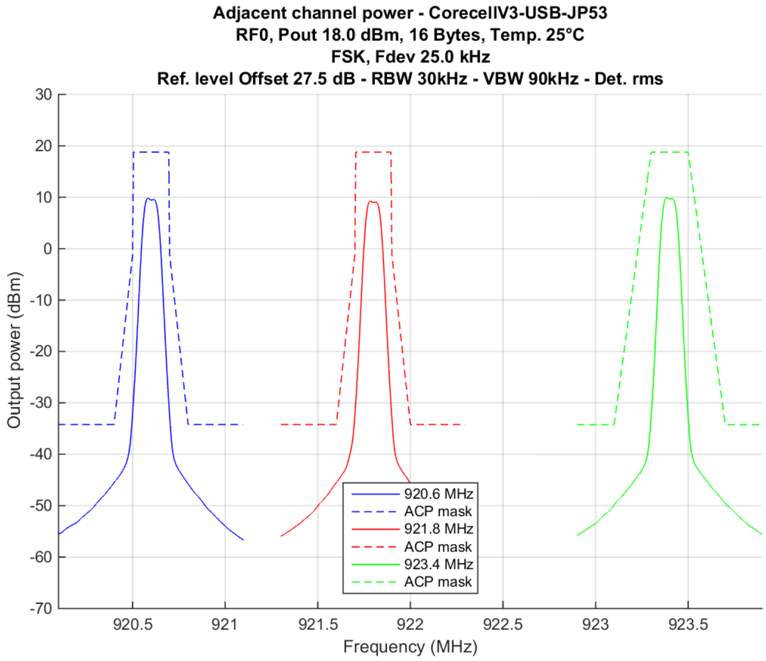


Figure 9.4: Adjacent channel leakage power, Board JP53, +18 dBm, FSK Fdev 25 kHz, 50 kbits, 25°C

9.4 Output power influence

9.4.1 Power +13 dBm

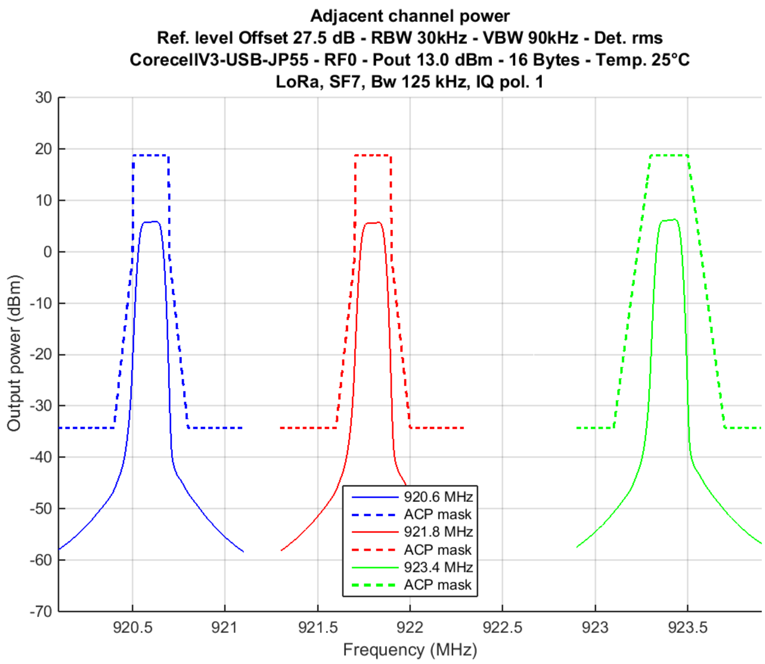


Figure 9.5: Adjacent channel leakage power vs frequency, Board JP55, +13 dBm, SF7, Bw 125 kHz, 25°C

9.4.2 Power +18 dBm

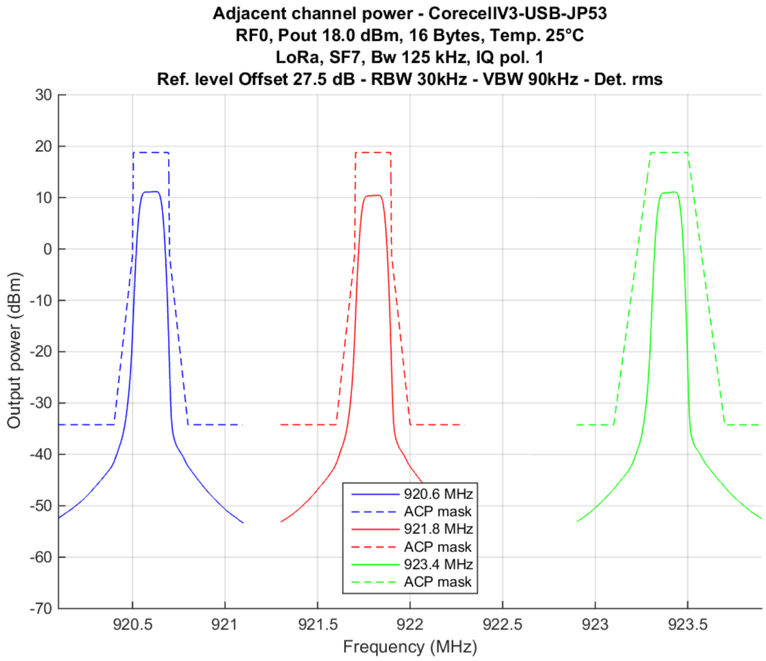


Figure 9.6: Adjacent channel leakage power vs frequency, Board JP53, +18 dBm, SF7, Bw 125 kHz, 25°C

9.4.3 Power +21 dBm

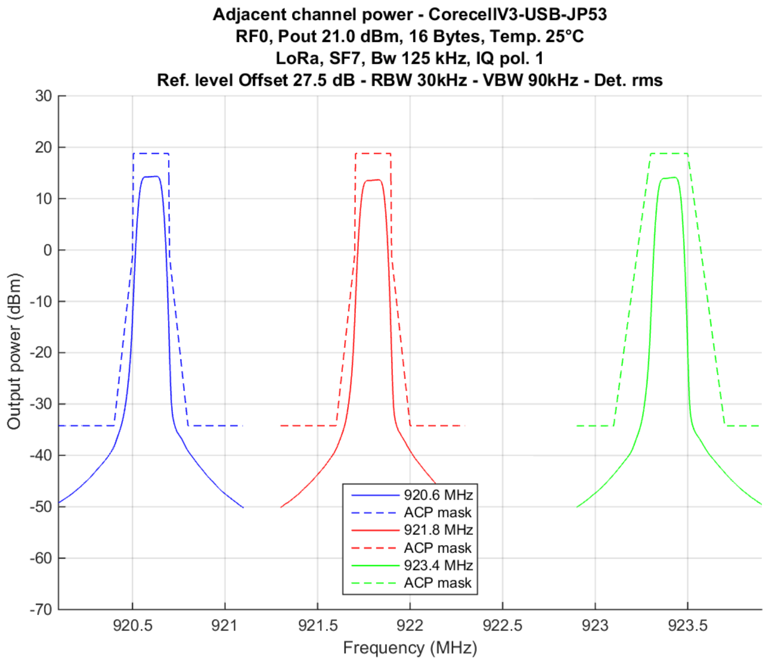
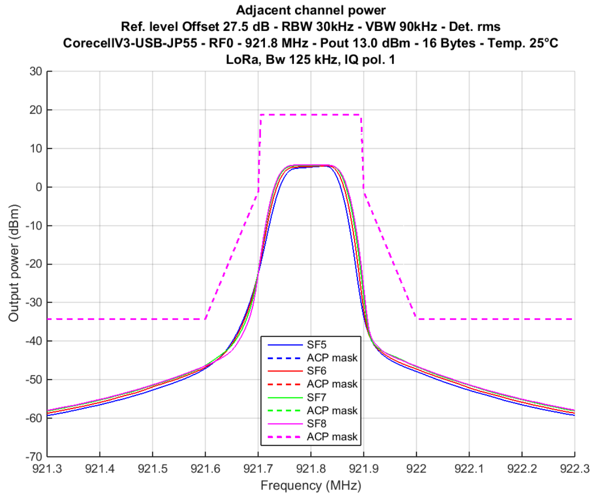


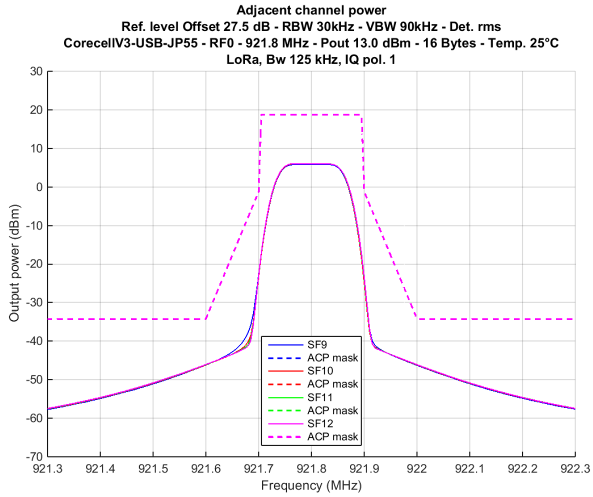
Figure 9.7: Adjacent channel leakage power vs frequency, Board JP53, +21 dBm, SF7, Bw 125 kHz, 25°C

9.5 Spreading factor influence

9.5.1 Output power +13 dBm



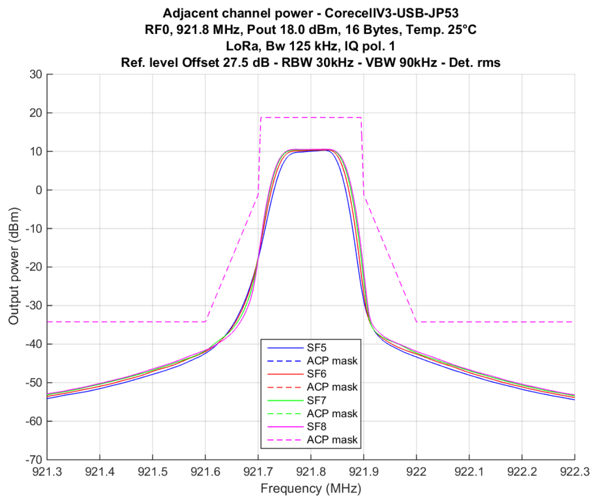
(a) SF5-8



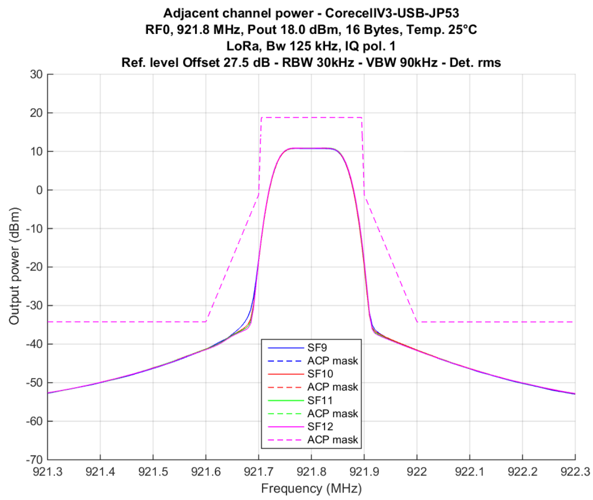
(b) 9-12

Figure 9.8: Adjacent Channel Leakage Power vs SF, Board JP55, +13 dBm, 921.8 MHz, 25°C

9.5.2 Output power +18 dBm



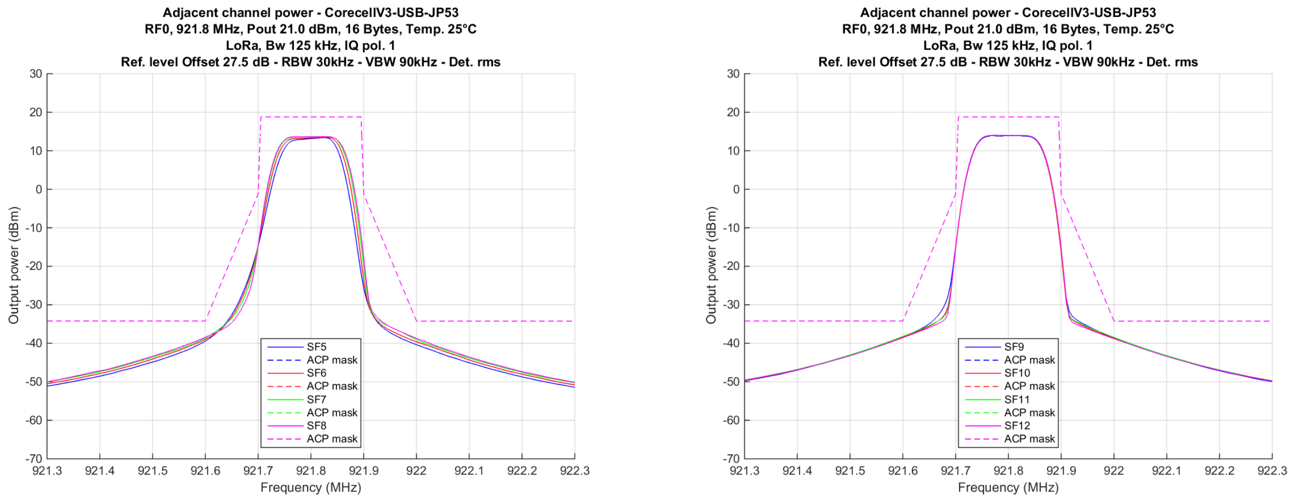
(a) SF5-8



(b) 9-12

Figure 9.9: Adjacent Channel Leakage Power vs SF, Board JP53, +18 dBm, 921.8 MHz, 25°C

9.5.3 Output power +21 dBm



(a) SF5-8 (b) 9-12

Figure 9.10: Adjacent Channel Leakage Power vs SF, Board JP53, +21 dBm, 921.8 MHz, 25°C

9.6 Temperature influence

Warning: The measurements of this section have been performed with the output power set to 24 dBm. This level can not allow to comply with the ACP regulation limit as well as the spurious one.

9.6.1 920.6 MHz

SF5

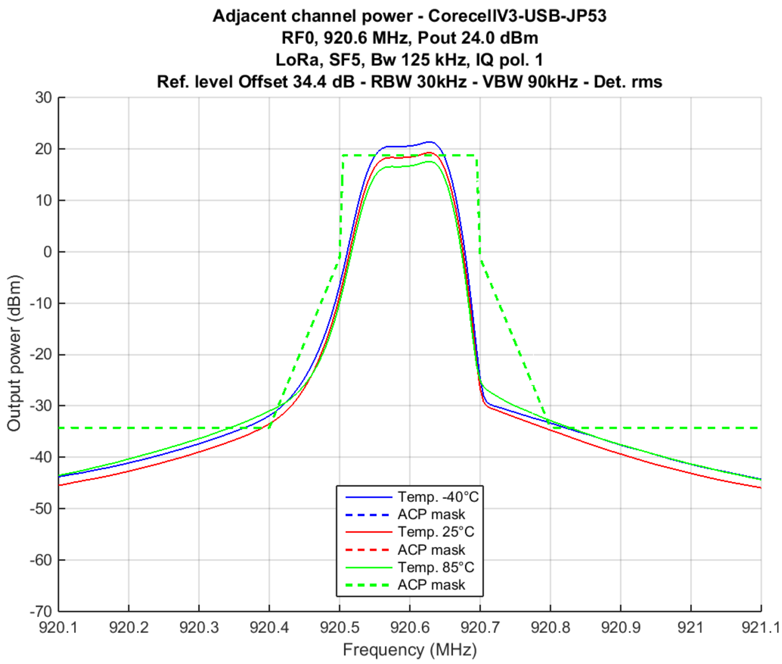


Figure 9.11: Adjacent channel leakage power vs temperature, Board JP53, +24 dBm, 920.6 MHz, SF5, Bw 125 kHz

SF9

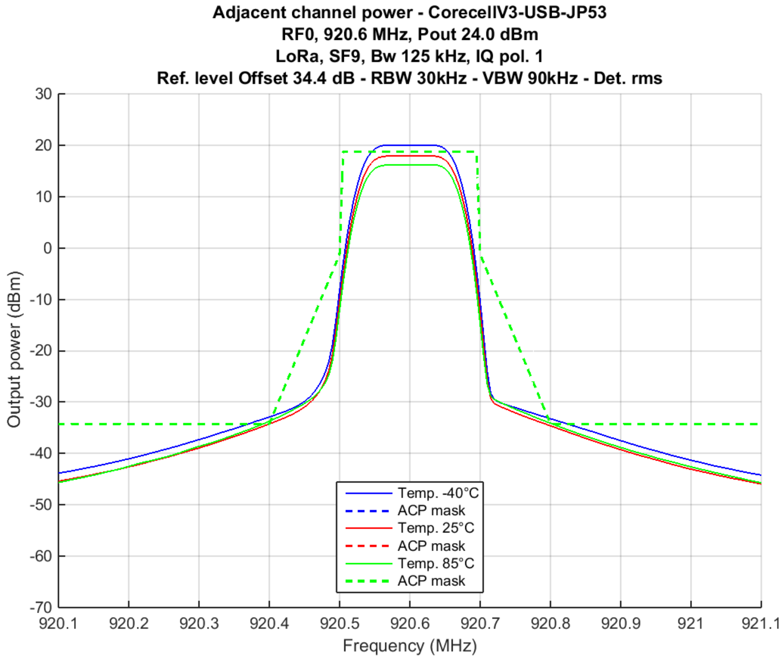


Figure 9.12: Adjacent channel leakage power vs temperature, Board JP53, +24 dBm, 920.6 MHz, SF9, Bw 125 kHz

SF12

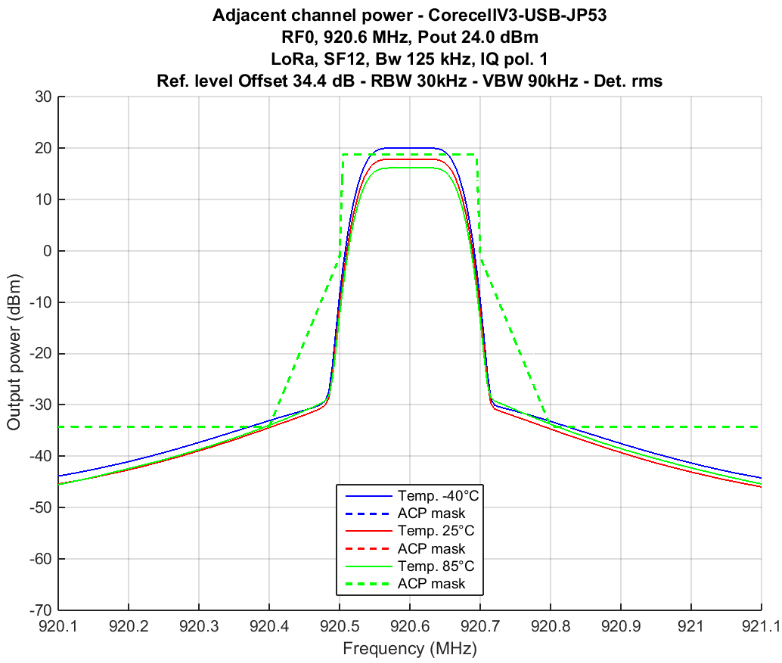


Figure 9.13: Adjacent channel leakage power vs temperature, Board JP53, +24 dBm, 920.6 MHz, SF12, Bw 125 kHz

9.6.2 923.4 MHz

SF5

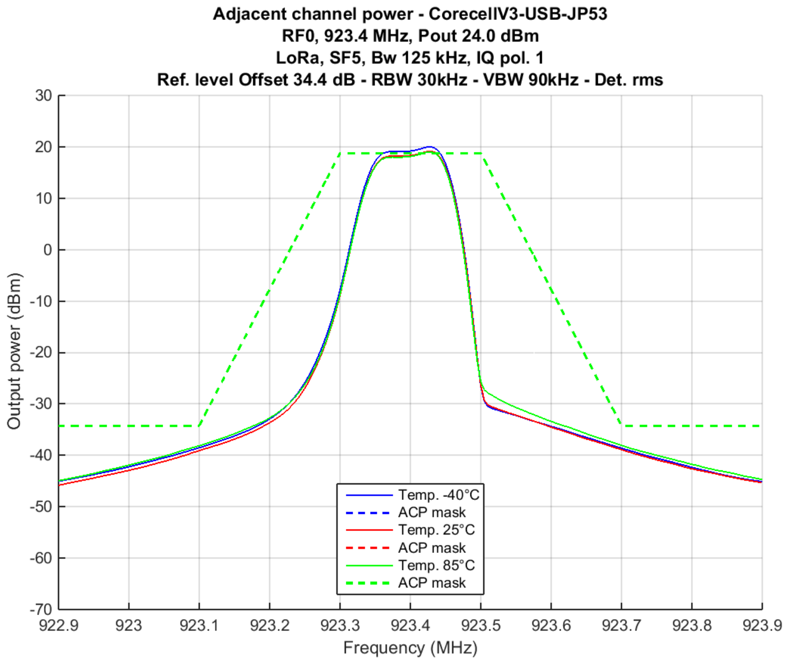


Figure 9.14: Adjacent channel leakage power vs temperature, Board JP53, +24 dBm, 923.4 MHz, SF5, Bw 125 kHz

SF9

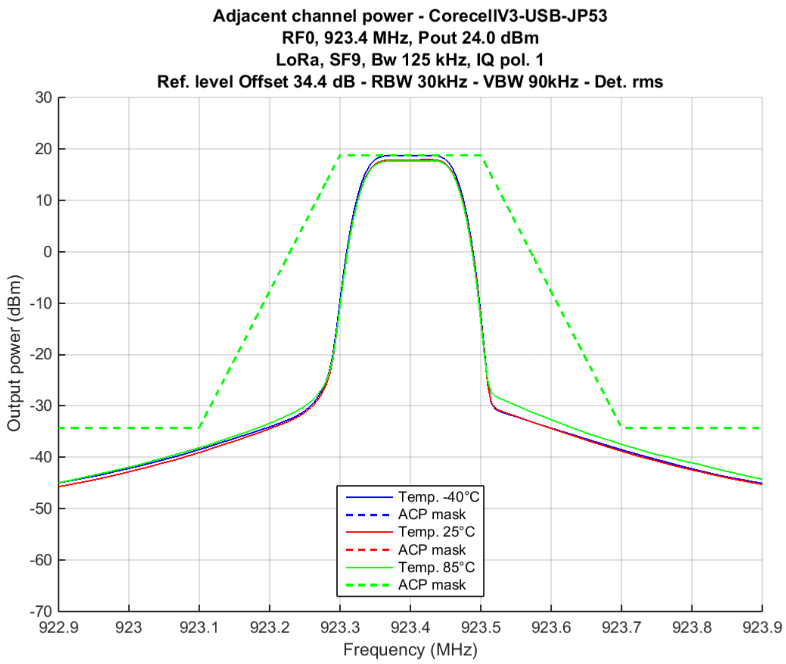


Figure 9.15: Adjacent channel leakage power vs temperature, Board JP53, +24 dBm, 923.4 MHz, SF9, Bw 125 kHz

SF12

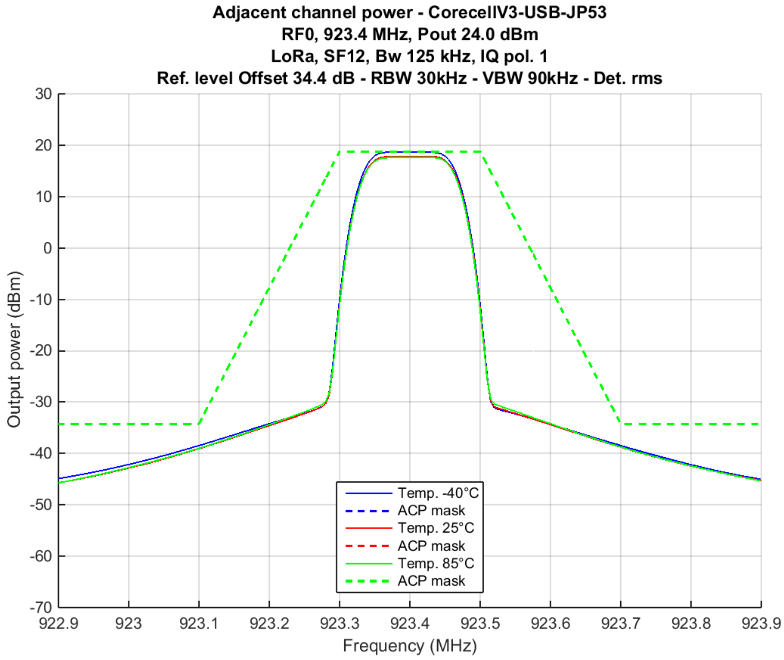


Figure 9.16: Adjacent channel leakage power vs temperature, Board JP53, +24 dBm, 923.4 MHz, SF12, Bw 125 kHz

9.7 Conclusion

→ **The Corecell gateway complies with the adjacent channel leakage power requirement if the output power is reduced to 21 dBm.**

10 Unwanted emission - Tx

10.1 Description

The spurious emissions while the gateway transmits shall be measured and be lower than levels mentioned in table 2.1. These measurements are performed in a conducted way on the antenna connector.

10.2 Setup

The setup used to measure spurious emissions is described in section 3.1. The output signal is measured on the SMA connector present on the interface board.

For spurious measurements below 1 GHz, a notch filter is manually tuned for each frequency. It allows rejecting the fundamental power to reduce the instrument reference level and then increase the measurement dynamic.

Warning: The notch filter shall not be used to measure spurious emissions from 900 to 930 MHz. Indeed, the insufficient narrowness of the notch filter bandwidth causes an error on the spectrum level close to the carrier. Then, the spurious measurement is split in two frequency ranges:

- A first one from 900 to 915 MHz performed with the notch filter tuned to the carrier frequency. The narrowness of the notch filter is sufficient to do not influence the measurement.
- Another one close to the carrier frequency i.e. in the range 915 to 930 MHz is performed using only the direct path without using the notch filter.

Away from the tuned frequency, 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.

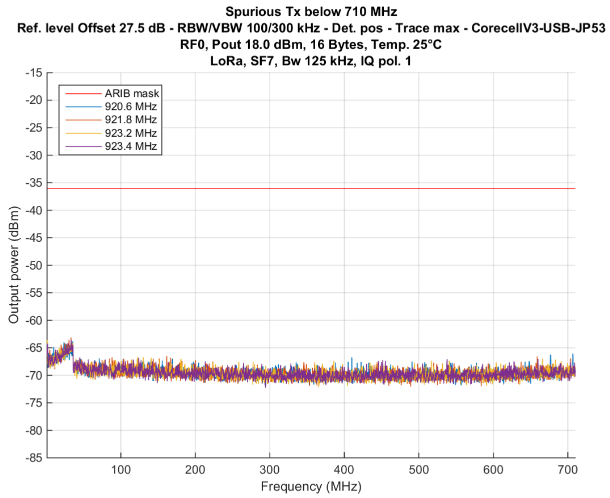
For spurious measurements above 1 GHz, the notch filter is bypassed and the high pass filter with a cut-off frequency at 1.2 GHz is used. Above the cut-off frequency, the attenuation is about 1 dB. So, loss is considered perfect and not compensated while the spurious are far to the regulation limit.

Finally, the loss of the direct path is measured and compensated in the spectrum analyzer (Ref. Level Offset).

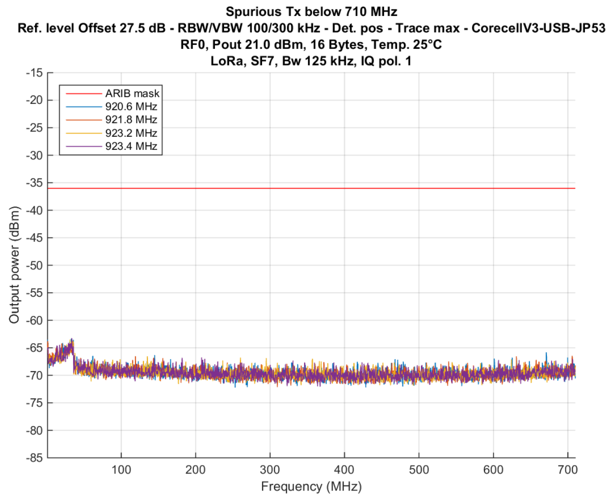
10.3 Results below 1 GHz

As seen in the following figure, no spurious is emitted by the gateway from 1 to 710 MHz. The level lower than -60 dBm is the instrument noise level.

The results is identical whatever the output power, the carrier frequency or the spreading factor.



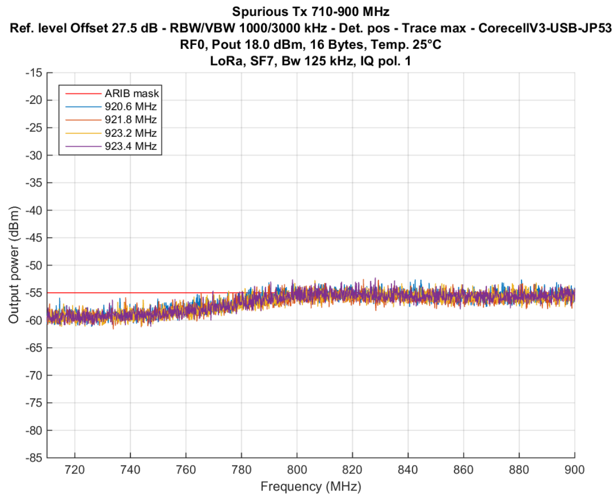
(a) +18 dBm



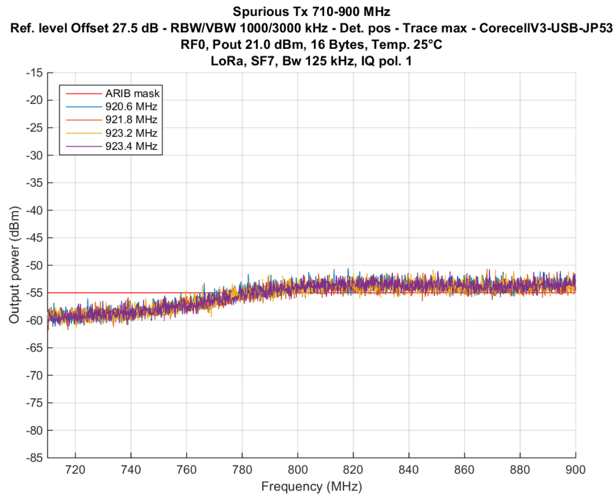
(b) +21 dBm

Figure 10.1: Spurious emission below 710 MHz, Board JP53, SF7, Bw 125 kHz, 25°C

From 710 to 900 MHz, the spectrum power is high and above the regulation limit of -55 dBm whatever the output power:

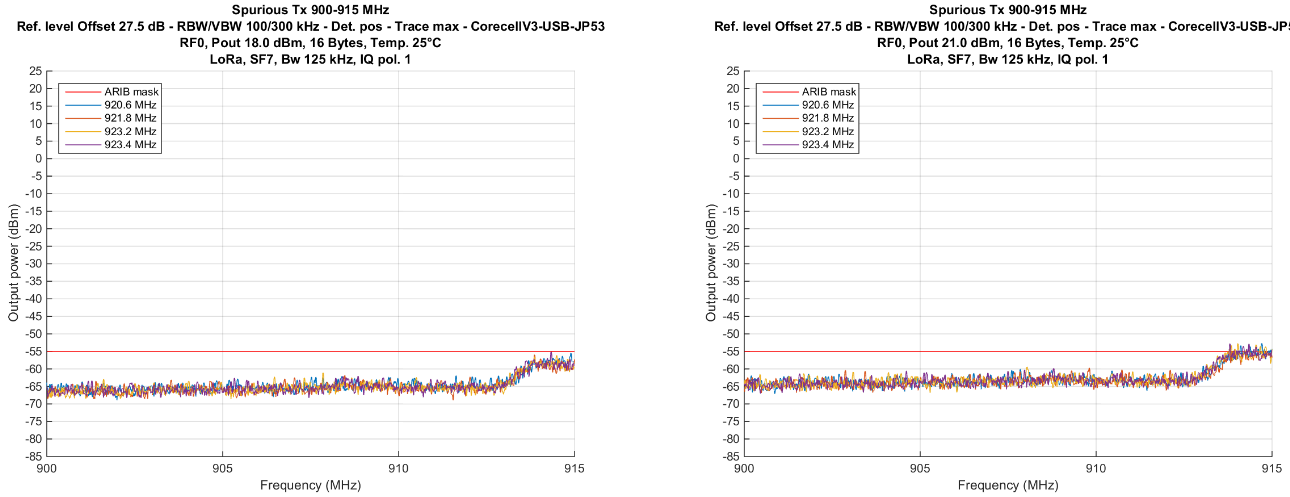


(a) +18 dBm



(b) +21 dBm

Figure 10.2: Spurious emission from 710 to 900 MHz, Board JP53, SF7, Bw 125 kHz, 25°C

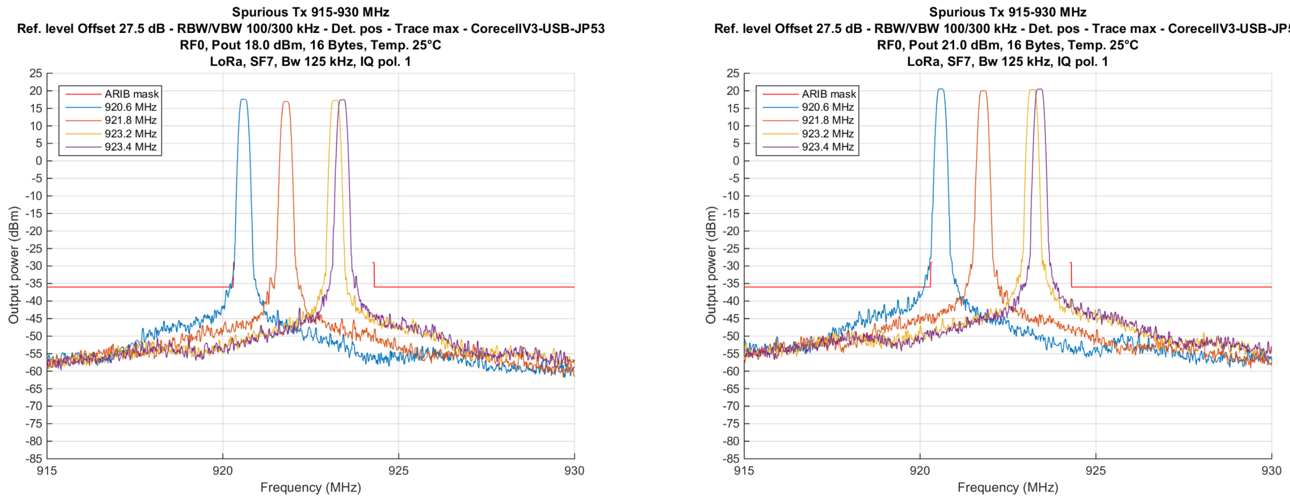


(a) +18 dBm

(b) +21 dBm

Figure 10.3: Spurious emission from 900 to 915 MHz, Board JP53, SF7, Bw 125 kHz, 25°C

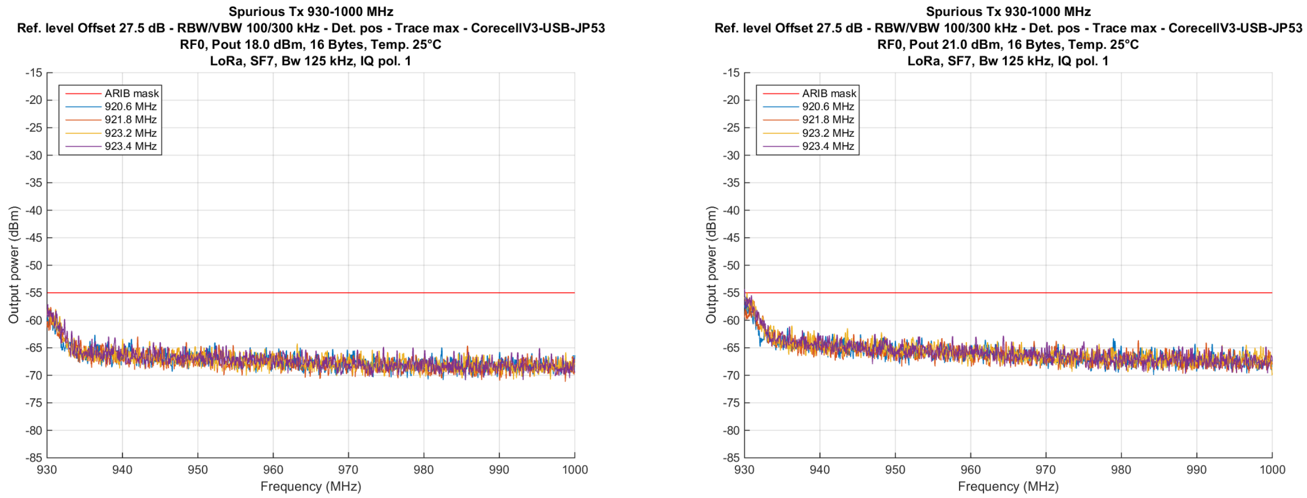
The difference of level at 900 MHz between the figures 10.2 (-50 dBm) and 10.3 (-60 dBm) is due to different reference bandwidth and the proximity of carrier. Indeed, in a RBW ten times higher, the signal is increased by 10 dB.



(a) +18 dBm

(b) +21 dBm

Figure 10.4: Spurious emission from 915 to 930 MHz, Board JP53, SF7, Bw 125 kHz, 25°C



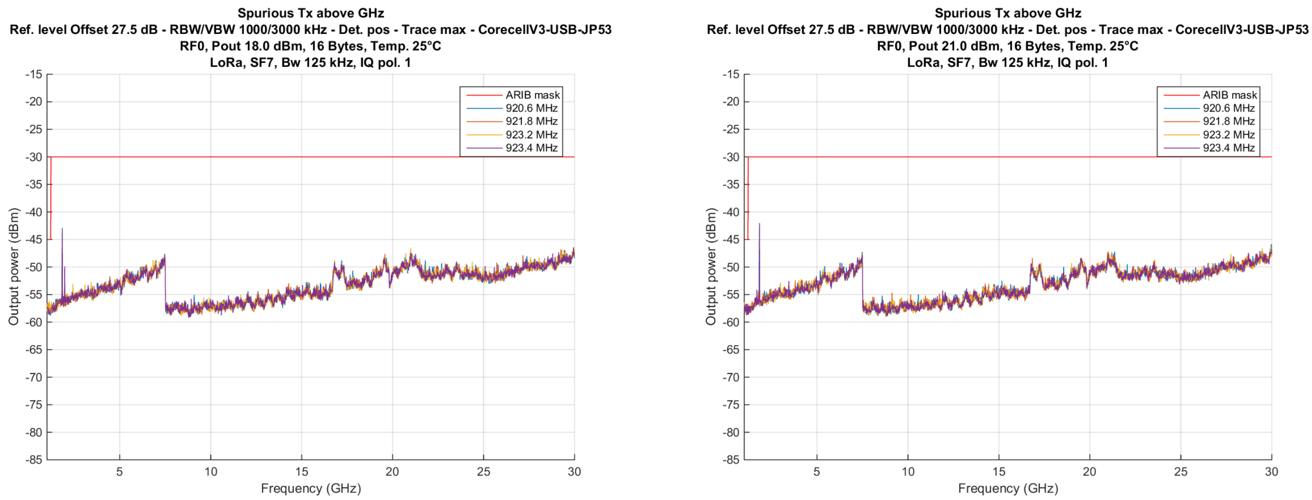
(a) +18 dBm

(b) +21 dBm

Figure 10.5: Spurious emission from 930 to 1000 MHz, Board JP53, SF7, Bw 125 kHz, 25°C

10.4 Results above 1 GHz

The figure 10.6 does not show any spurious emission above 1 GHz over the regulation limit.



(a) +18 dBm

(b) +21 dBm

Figure 10.6: Spurious emission above 1 GHz, Board JP53, SF7, Bw 125 kHz, 25°C

10.5 Conclusion

→ **The output power shall be reduced to a level lower than 18 dBm to comply with the ARIB regulation limit.**

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 [2], 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.

This test evaluates the system performances and the compliance to the LoRaWan specification regarding the Class B requirements.

$\rightarrow$ **The beacon emission time accuracy shall be better than** $1.5ms \pm 1\mu s$ **after the PPS signal rising edge.**

11.2 Setup

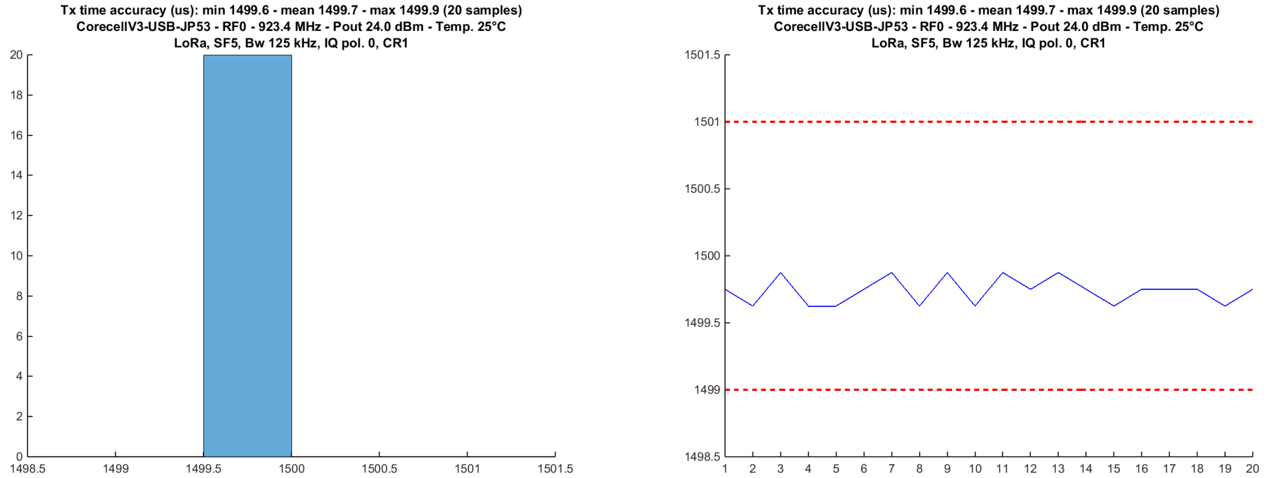
The setup shown in figure 3.1 allows to evaluate the beacon emission time accuracy. The packet emission is synchronized with the rising edge of PPS signal.

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 downloaded 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

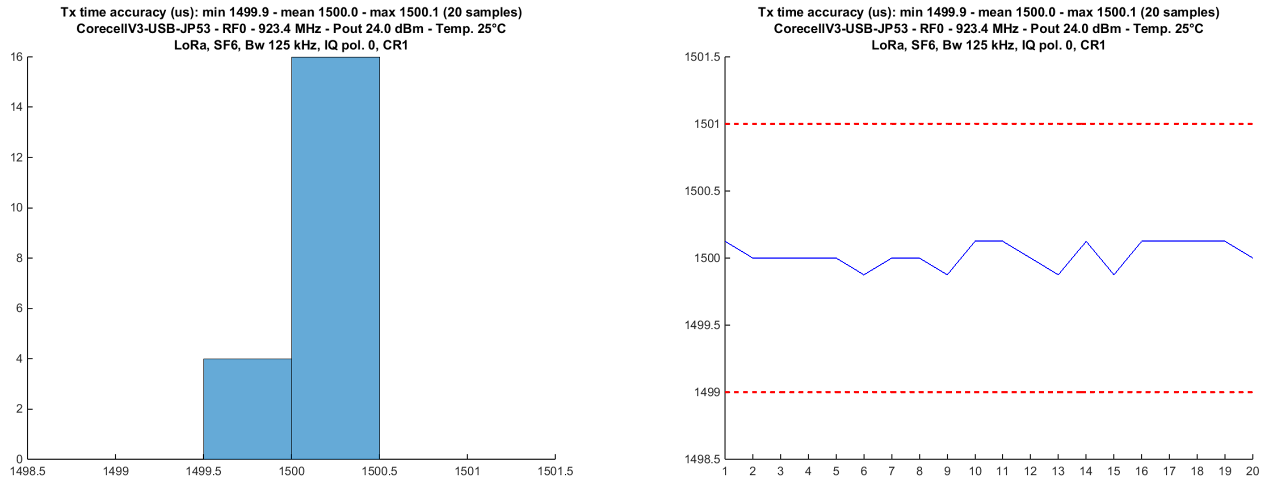
11.3.1 SF5



(a) Histogram (b) Samples

Figure 11.1: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF5, Bw 125 kHz

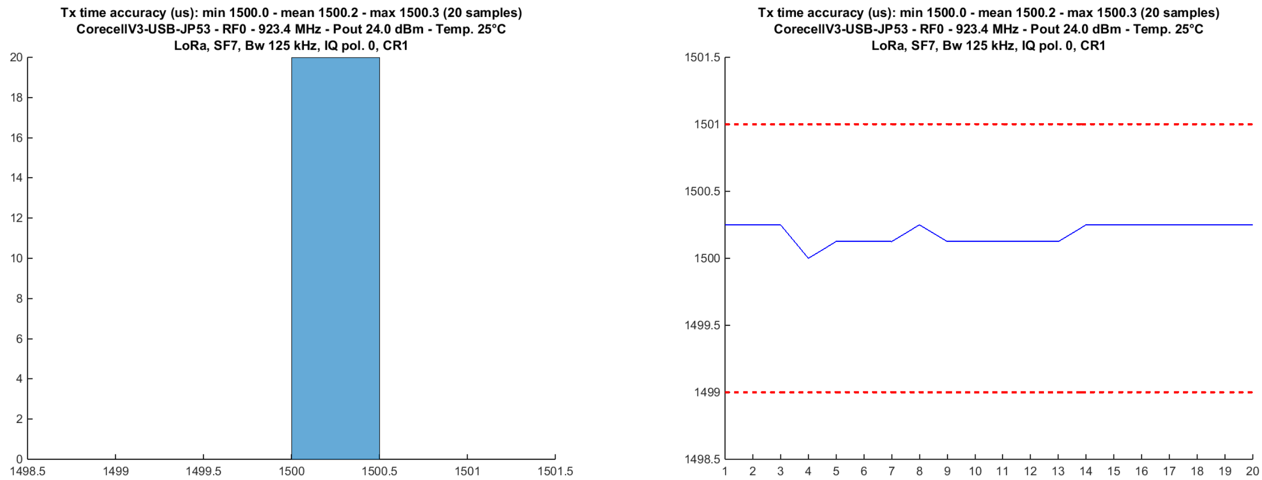
11.3.2 SF6



(a) Histogram (b) Samples

Figure 11.2: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF6, Bw 125 kHz

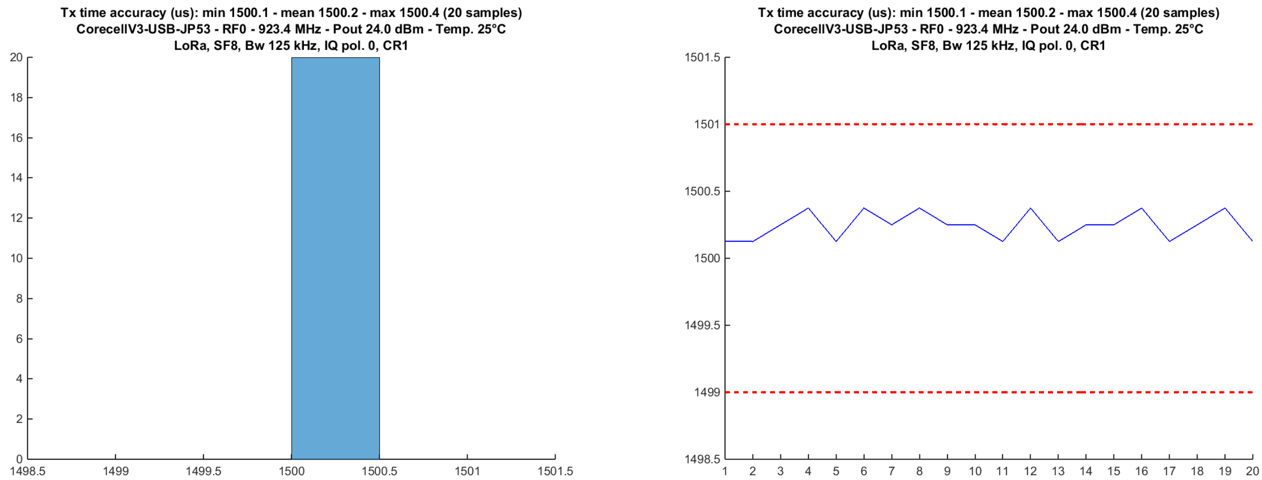
11.3.3 SF7



(a) Histogram (b) Samples

Figure 11.3: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF7, Bw 125 kHz

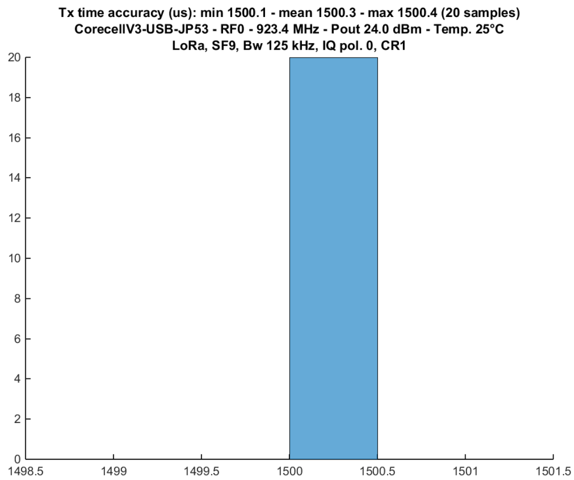
11.3.4 SF8



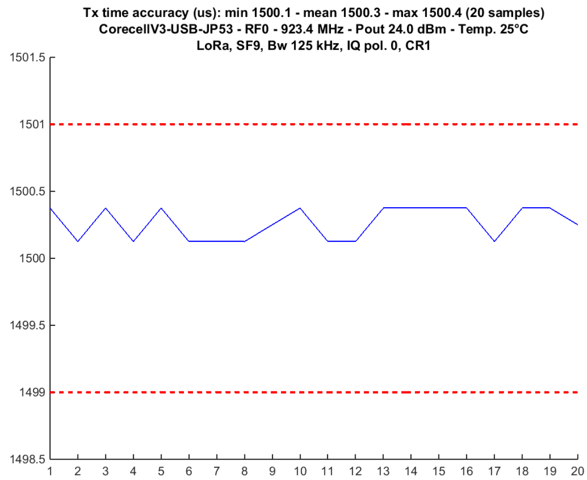
(a) Histogram (b) Samples

Figure 11.4: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF8, Bw 125 kHz

11.3.5 SF9



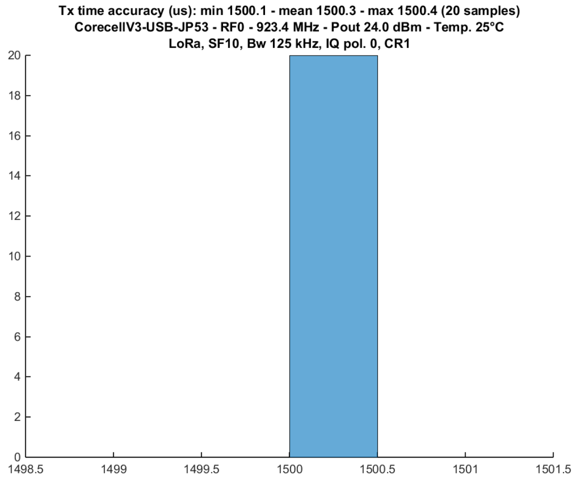
(a) Histogram



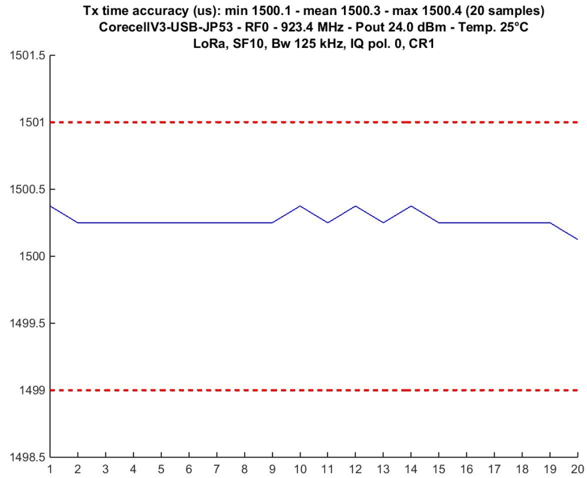
(b) Samples

Figure 11.5: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF9, Bw 125 kHz

11.3.6 SF10



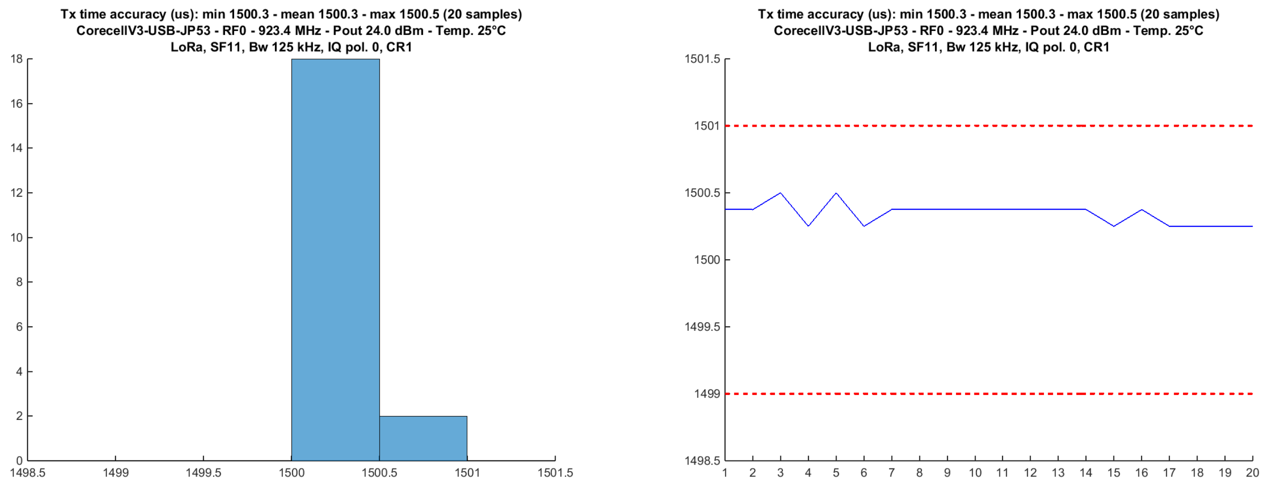
(a) Histogram



(b) Samples

Figure 11.6: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF10, Bw 125 kHz

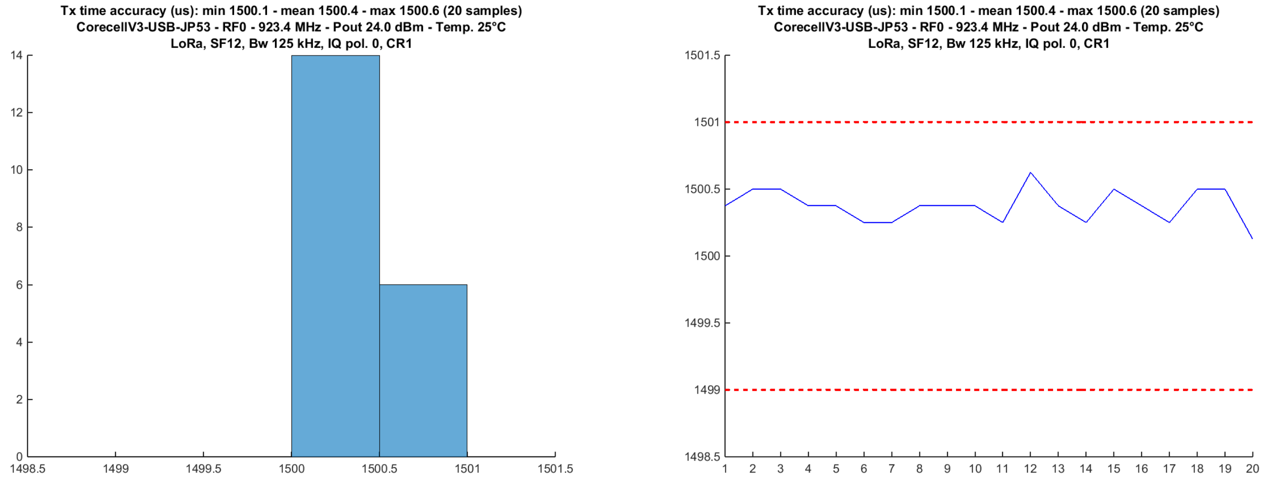
11.3.7 SF11



(a) Histogram (b) Samples

Figure 11.7: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF11, Bw 125 kHz

11.3.8 SF12

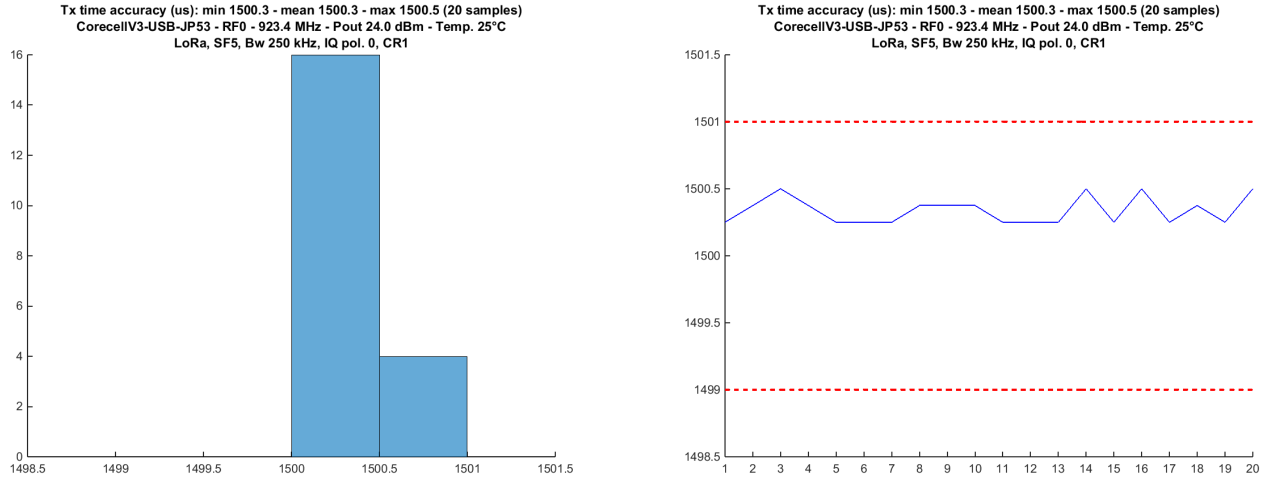


(a) Histogram (b) Samples

Figure 11.8: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF12, Bw 125 kHz

11.4 Bandwidth 250 kHz

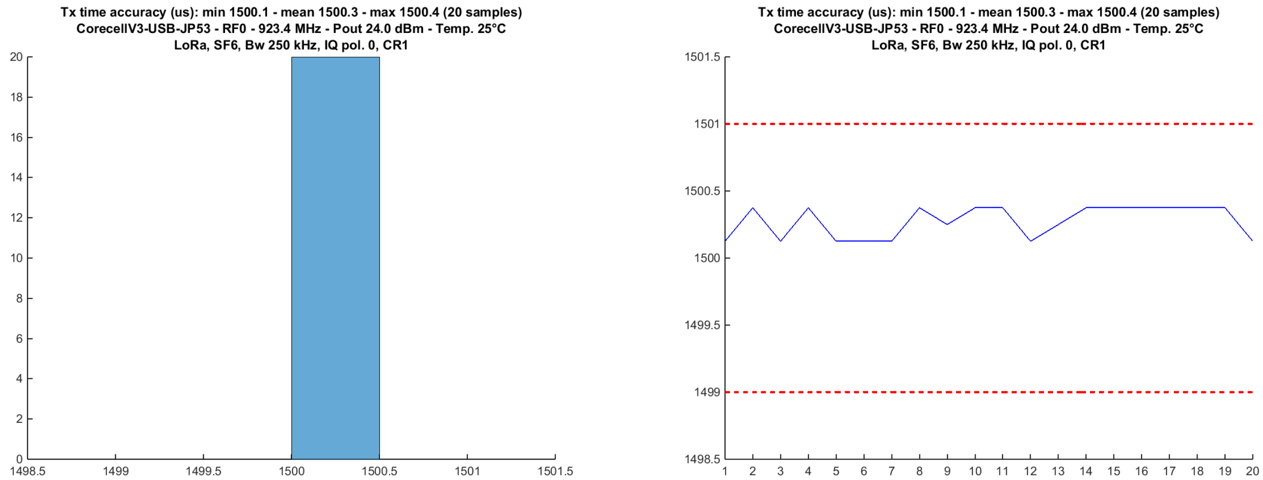
11.4.1 SF5



(a) Histogram (b) Samples

Figure 11.9: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF5, Bw 250 kHz

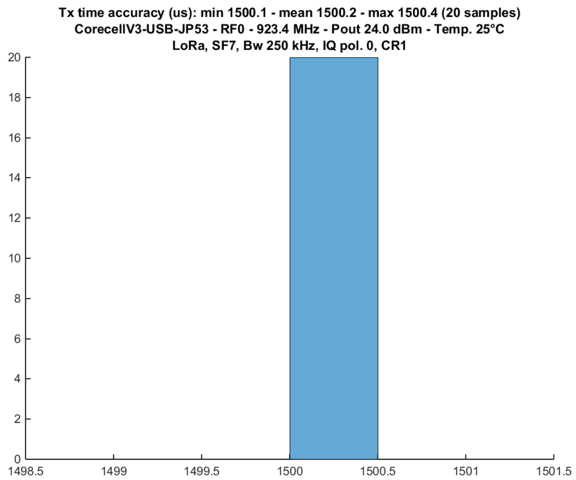
11.4.2 SF6



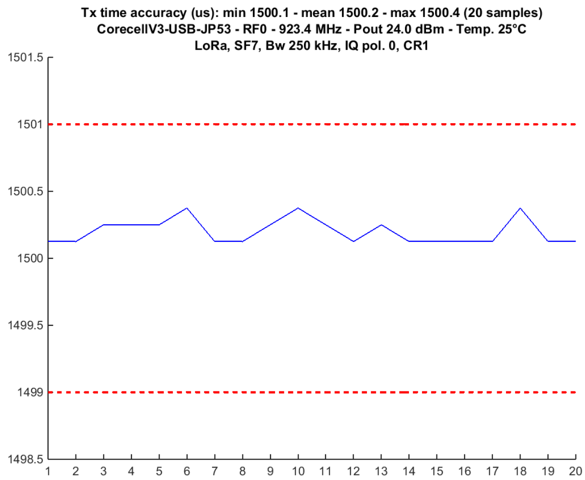
(a) Histogram (b) Samples

Figure 11.10: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF6, Bw 250 kHz

11.4.3 SF7



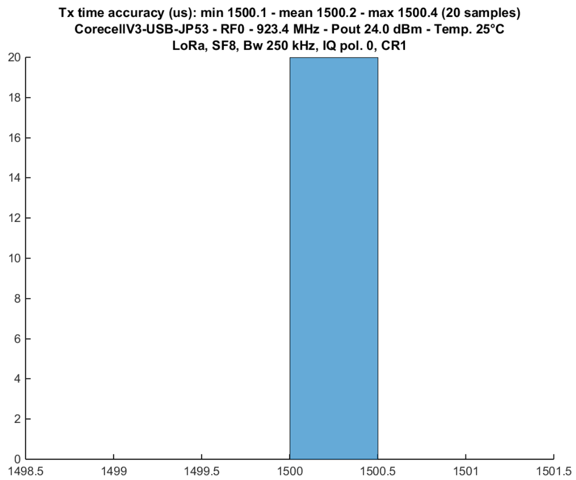
(a) Histogram



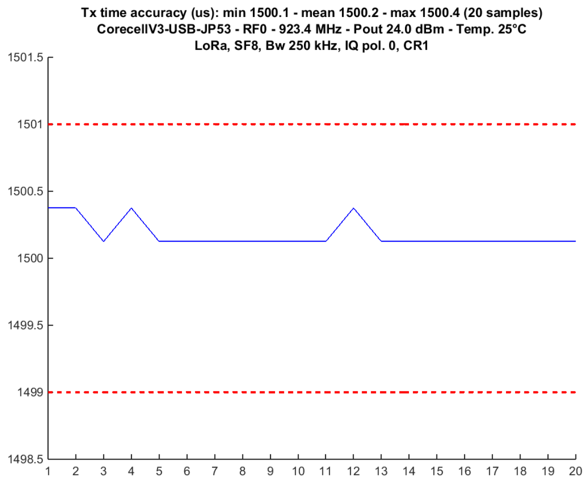
(b) Samples

Figure 11.11: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF7, Bw 250 kHz

11.4.4 SF8



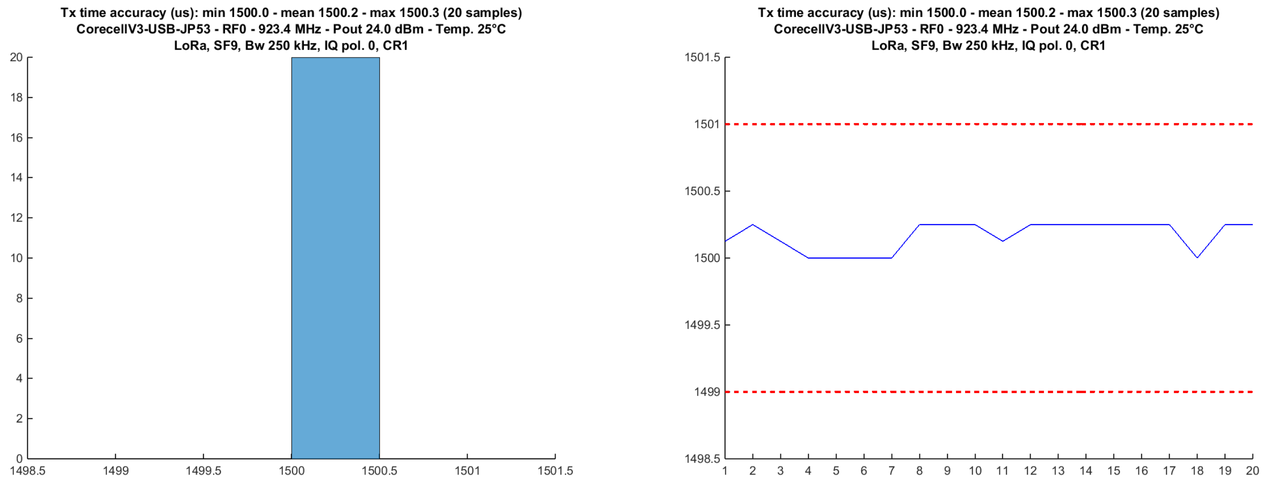
(a) Histogram



(b) Samples

Figure 11.12: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF8, Bw 250 kHz

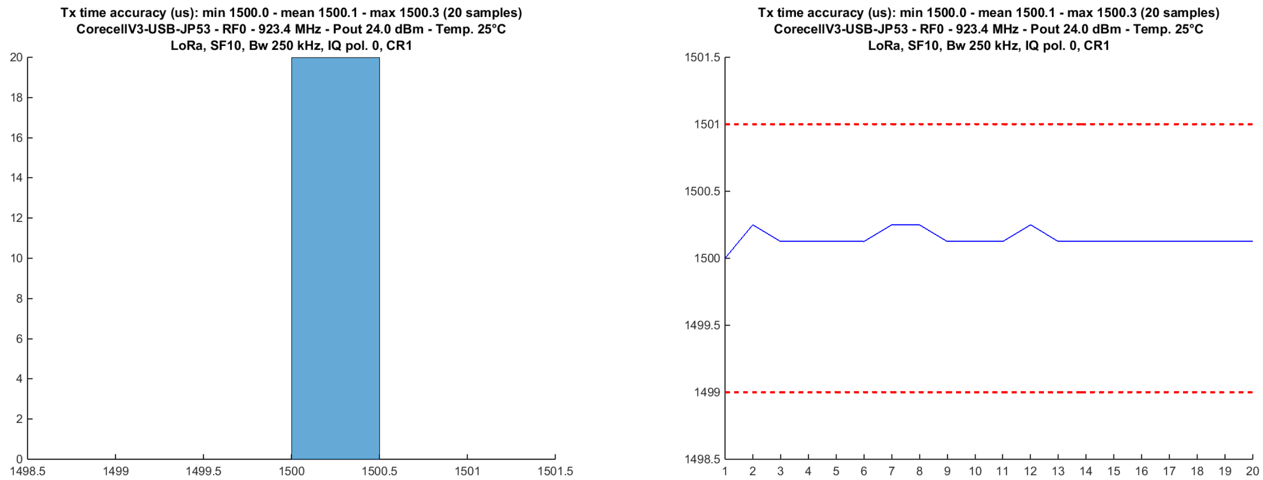
11.4.5 SF9



(a) Histogram (b) Samples

Figure 11.13: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF9, Bw 250 kHz

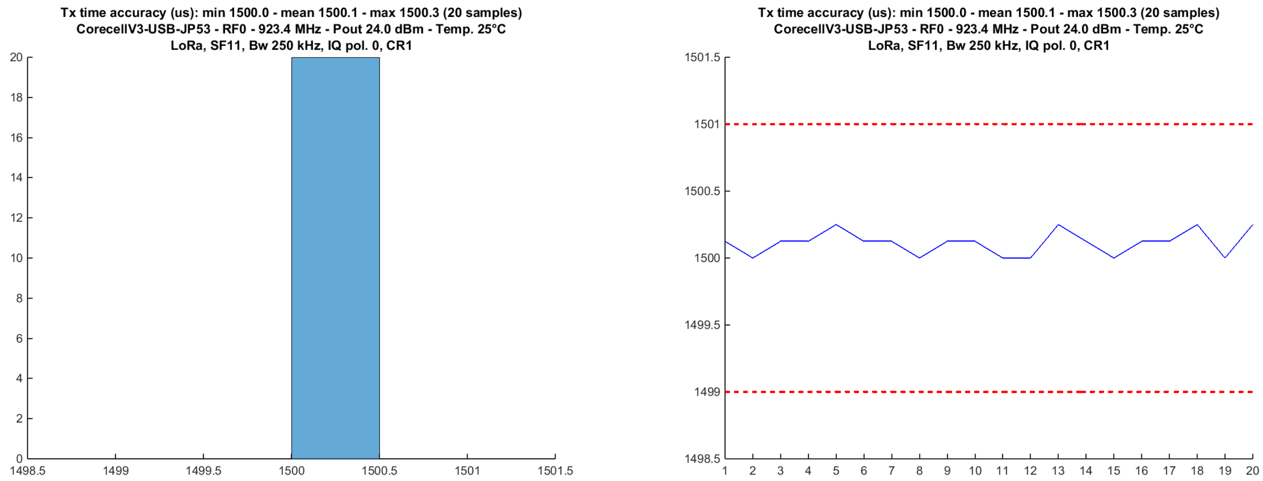
11.4.6 SF10



(a) Histogram (b) Samples

Figure 11.14: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF10, Bw 250 kHz

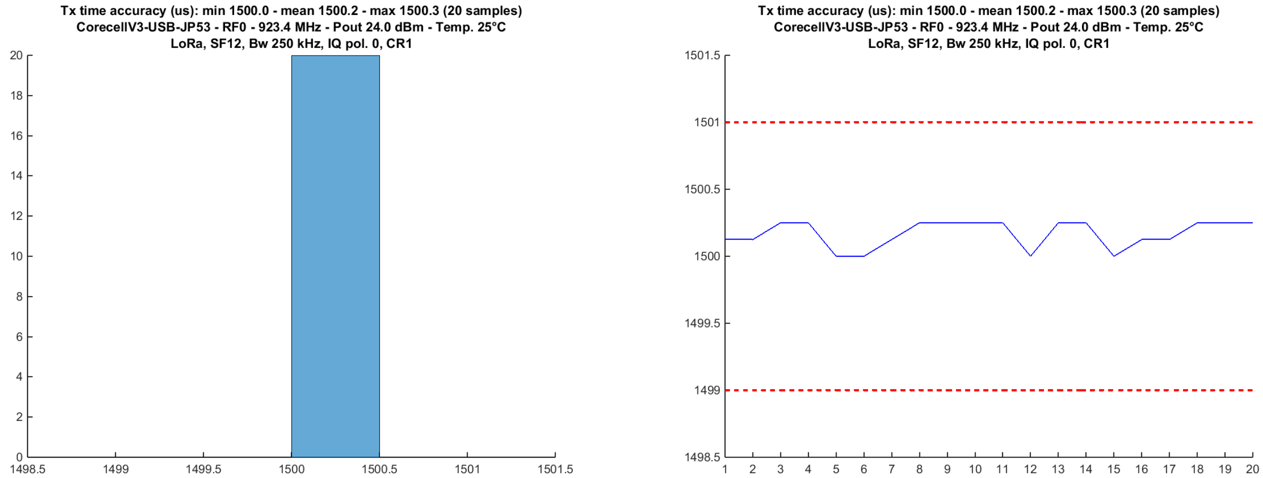
11.4.7 SF11



(a) Histogram (b) Samples

Figure 11.15: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF11, Bw 250 kHz

11.4.8 SF12

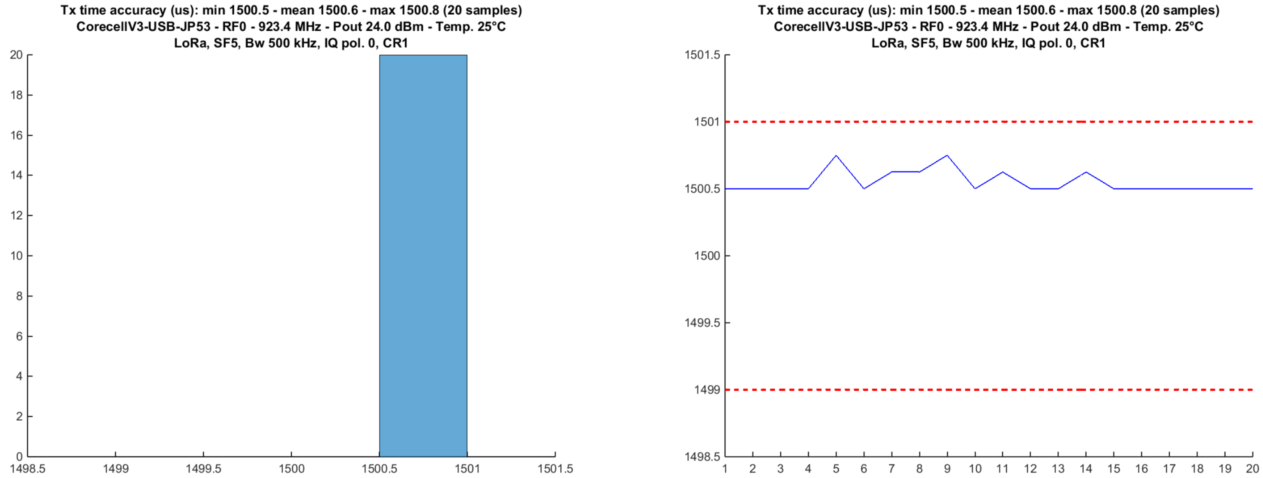


(a) Histogram (b) Samples

Figure 11.16: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF12, Bw 250 kHz

11.5 Bandwidth 500 kHz

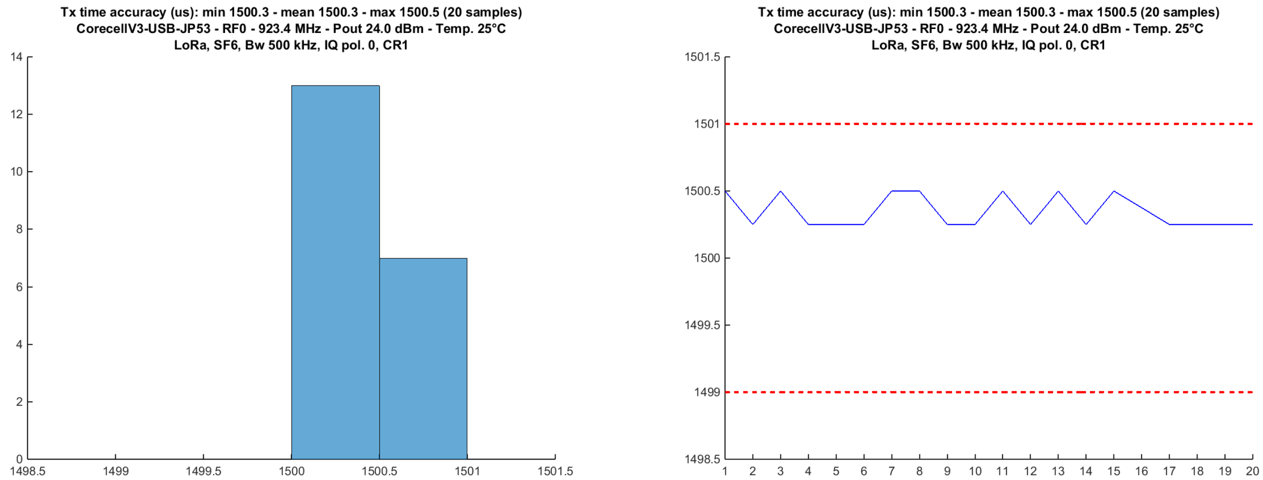
11.5.1 SF5



(a) Histogram (b) Samples

Figure 11.17: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF5, Bw 500 kHz

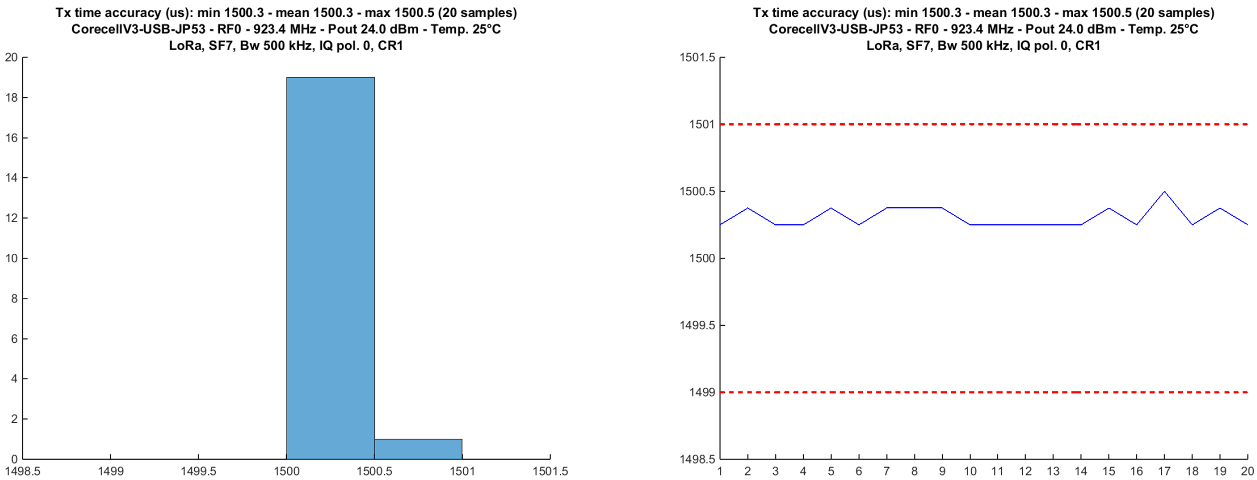
11.5.2 SF6



(a) Histogram (b) Samples

Figure 11.18: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF6, Bw 500 kHz

11.5.3 SF7

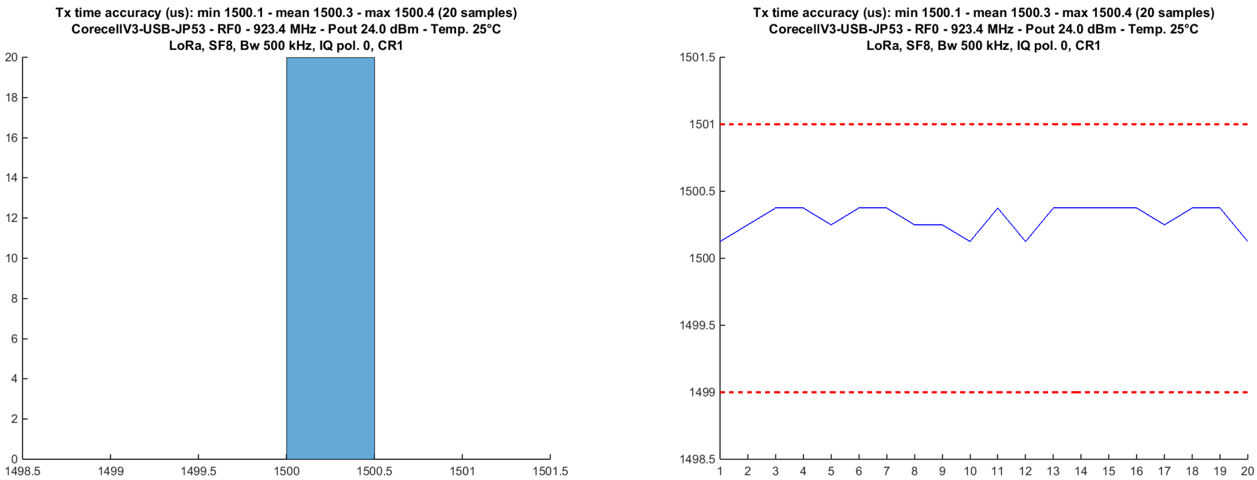


(a) Histogram

(b) Samples

Figure 11.19: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF7, Bw 500 kHz

11.5.4 SF8

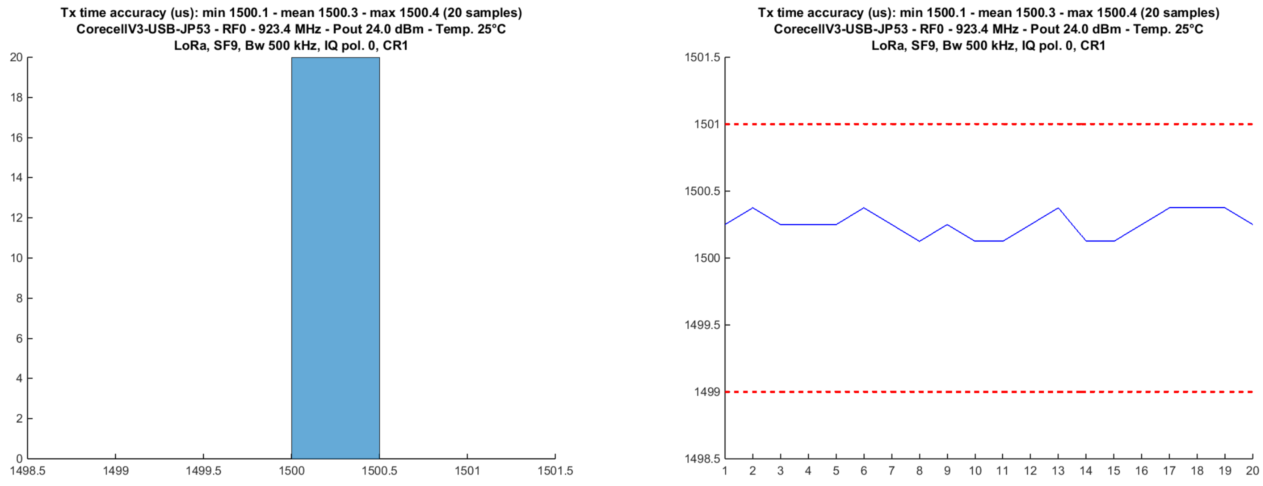


(a) Histogram

(b) Samples

Figure 11.20: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF8, Bw 500 kHz

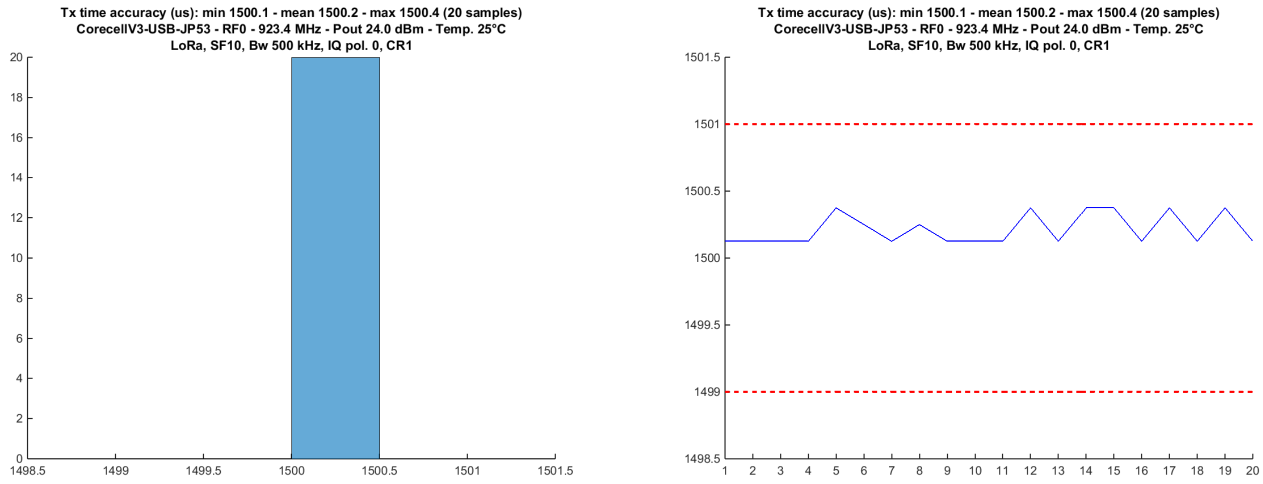
11.5.5 SF9



(a) Histogram (b) Samples

Figure 11.21: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF9, Bw 500 kHz

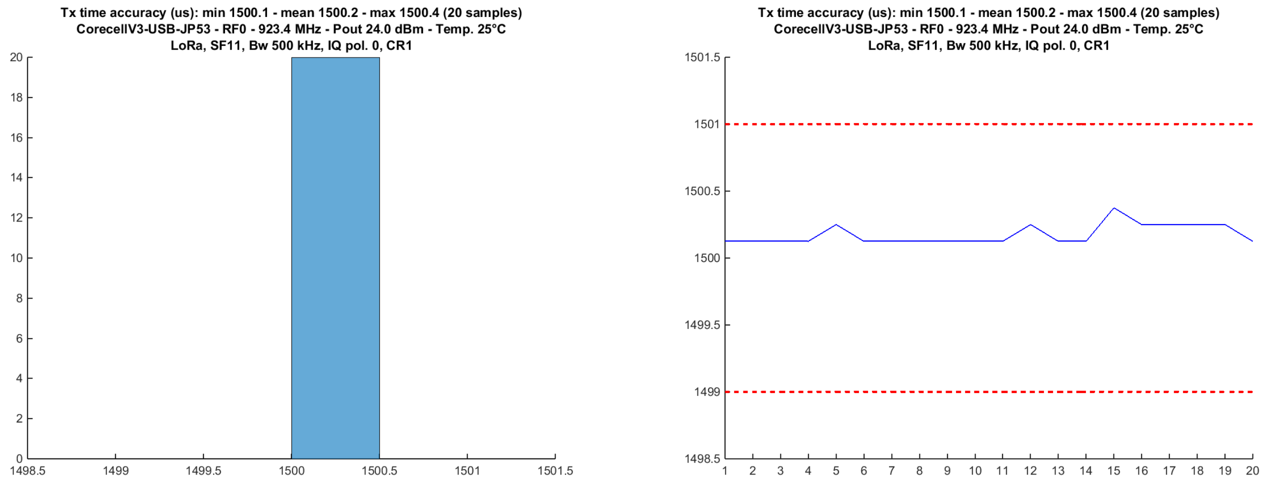
11.5.6 SF10



(a) Histogram (b) Samples

Figure 11.22: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF10, Bw 500 kHz

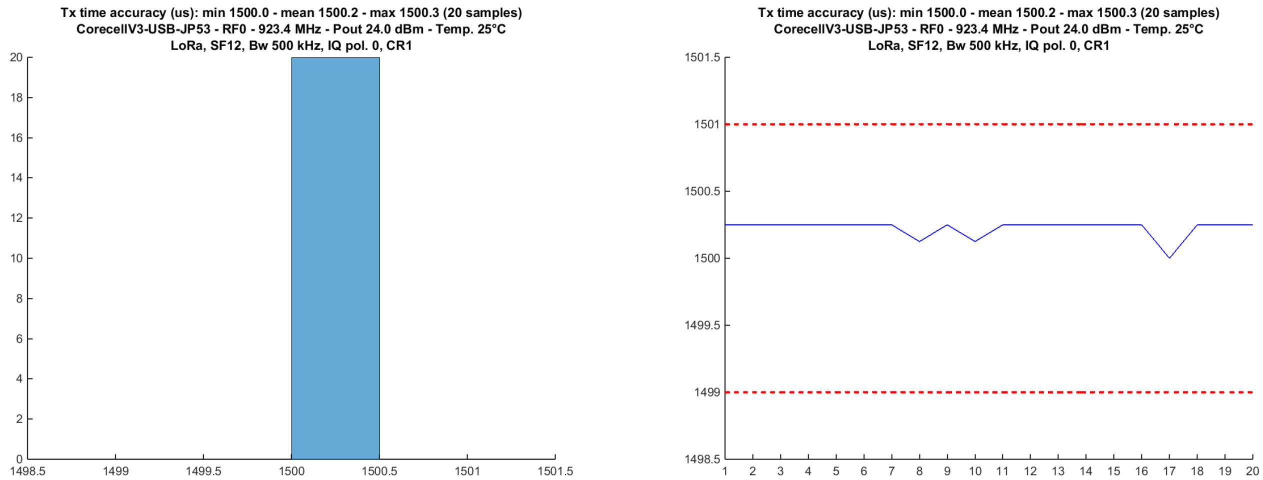
11.5.7 SF11



(a) Histogram (b) Samples

Figure 11.23: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF11, Bw 500 kHz

11.5.8 SF12



(a) Histogram (b) Samples

Figure 11.24: Beacon emission time accuracy, Board JP53, 923.4 MHz, 24 dBm, SF12, Bw 500 kHz

11.6 Conclusion

→ **The beacon emission time complies with the LoRaWan class B requirement of 1500 ± 1µs whatever the bandwidth or the spreading factor.**

12 Downlink PER

12.1 Description

This measurement allows to verify that downlink packets emitted by the gateway are correctly received by an end-device 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 end-device (here a SX1262 shield).

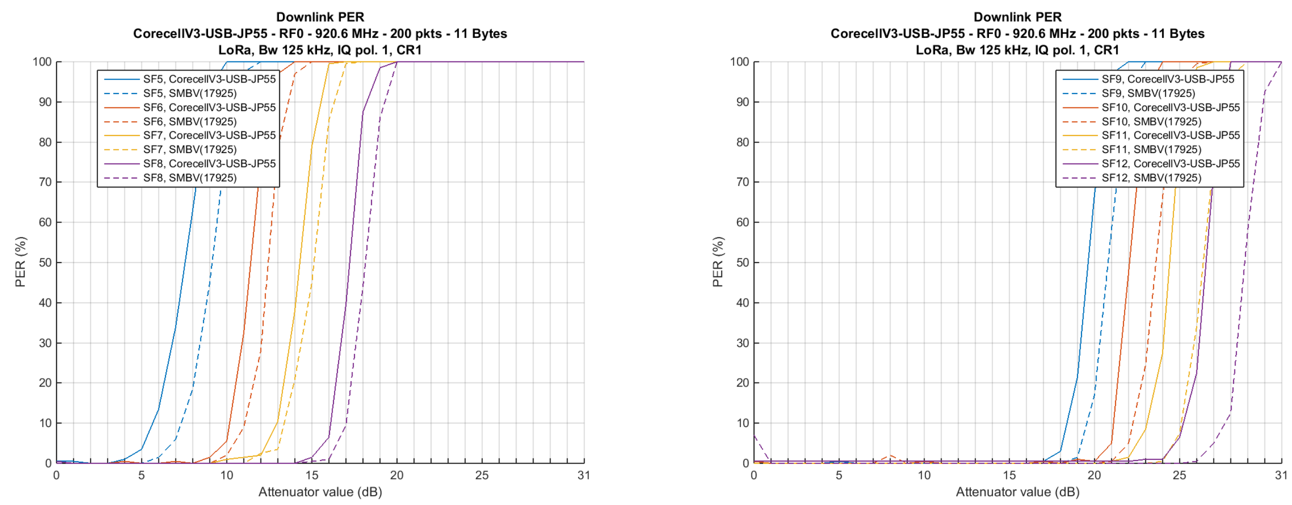
The attenuation is divided in two parts, one part being inside a Faraday box with the end-device inside, the second part outside the box. This reduce the radiated signal across that could reach at the end-device input at a higher level than the sensitivity one.

The signal generator output level is set to compensate the path loss difference between both RF chains and 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

Note: All these measurements have been performed using a maximum transmit time of 4s.

12.3.1 920.6 MHz

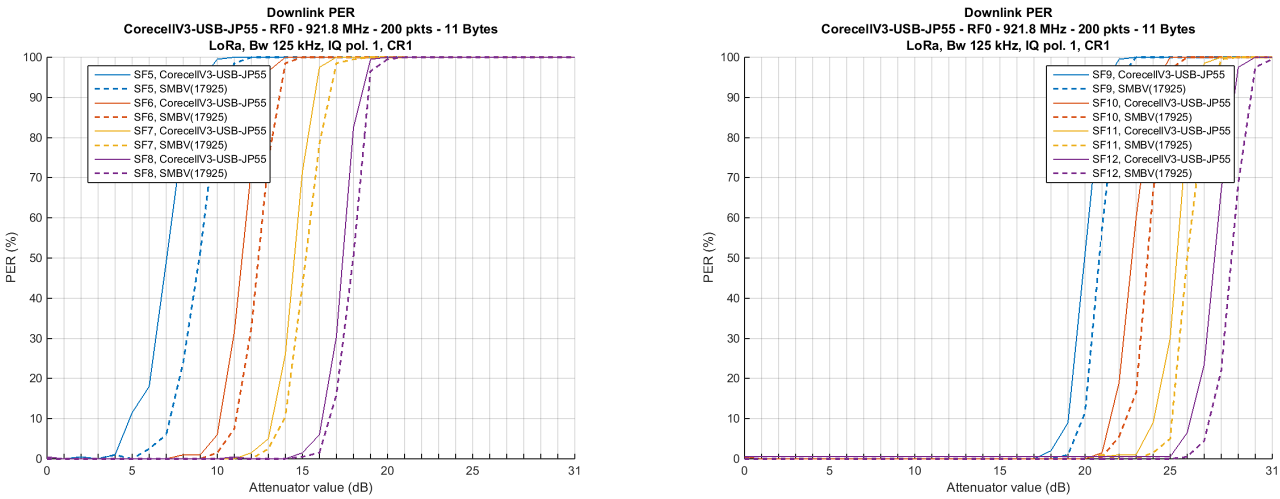


(a) SF5 to 8

(b) SF9 to 12

Figure 12.1: Downlink PER vs Spreading factor, Board JP55, 920.6 MHz, Bw 125 kHz, Pout 24 dBm

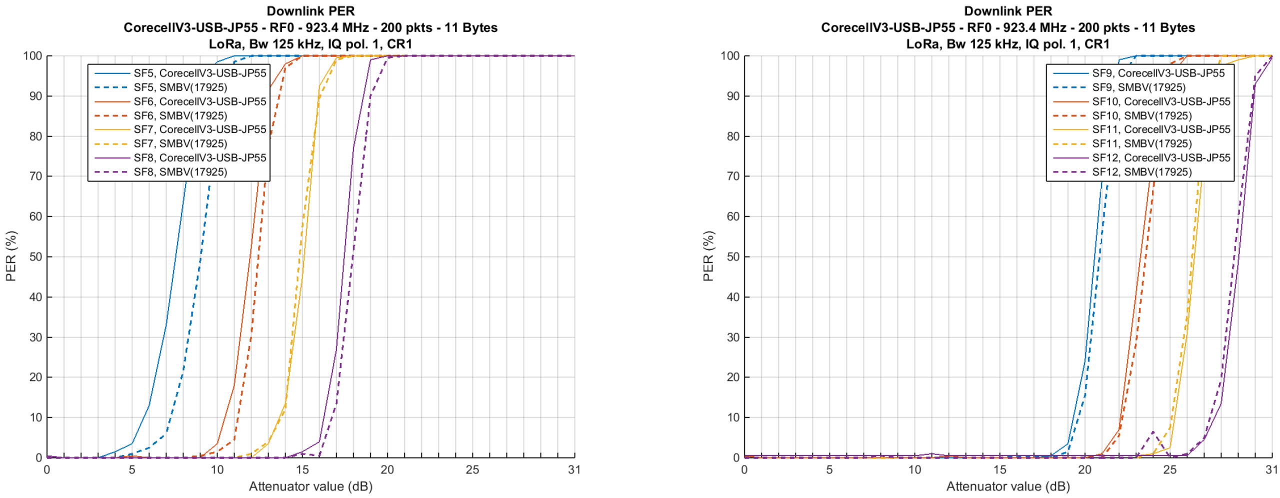
12.3.2 921.8 MHz



(a) SF5 to 8 (b) SF9 to 12

Figure 12.2: Downlink PER vs Spreading factor, Board JP55, 921.8 MHz, Bw 125 kHz, Pout 24 dBm

12.3.3 923.4 MHz



(a) SF5 to 8 (b) SF9 to 12

Figure 12.3: Downlink PER vs Spreading factor, Board JP55, 923.4 MHz, Bw 125 kHz, Pout 24 dBm

12.4 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 II

Receiver

13 Unwanted emission - Rx

13.1 Description

The spurious emission while the transmitter is turned off shall be measured and be lower than levels mentioned in table 2.2 (see section 2.7.2).

13.2 Setup

The setup shown in figure 3.1 **is not used for this measurement**. Indeed, the excessive test bench loss reduces the measurement dynamic; the signal analyzer noise floor is higher than the expected measured level.

→ **The DUT is connected to the signal analyzer through only a 6dB attenuator and a 1m cable.**

Finally, the packet forwarder is launched before performing the measurement.

13.3 Results

As shown in figures 13.1 to 13.4, no spurious is generated at the Rx antenna input while the HAL and the packet forwarder are running.

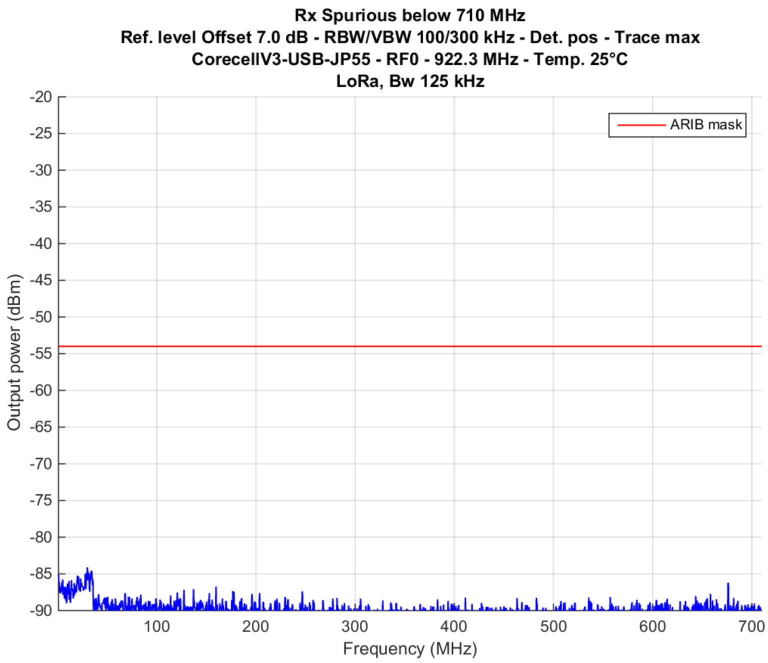


Figure 13.1: Rx Spurious from 1 to 710 MHz, Board JP55, 25°C

In figures 13.2 and 13.4, the instrument noise level rises by 10 dB due to the resolution bandwidth changed from 100 kHz to 1 MHz.

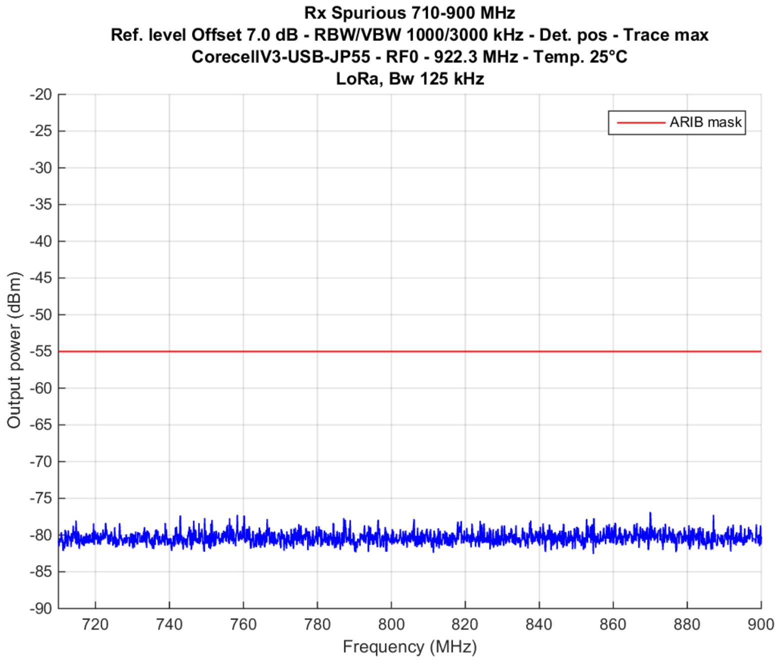


Figure 13.2: Rx Spurious from 710 to 900 MHz, Board JP55, 25°C

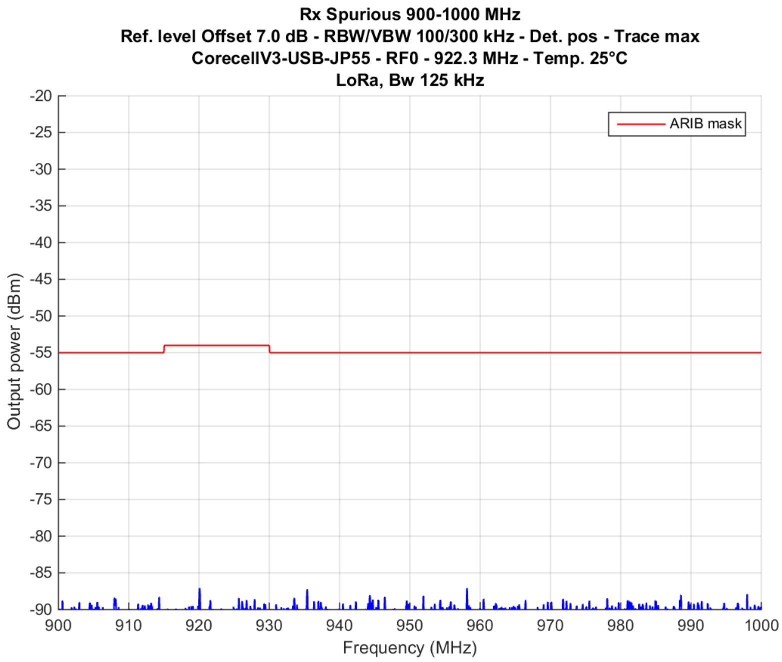


Figure 13.3: Rx Spurious from 900 MHz to 1 GHz, Board JP55, 25°C

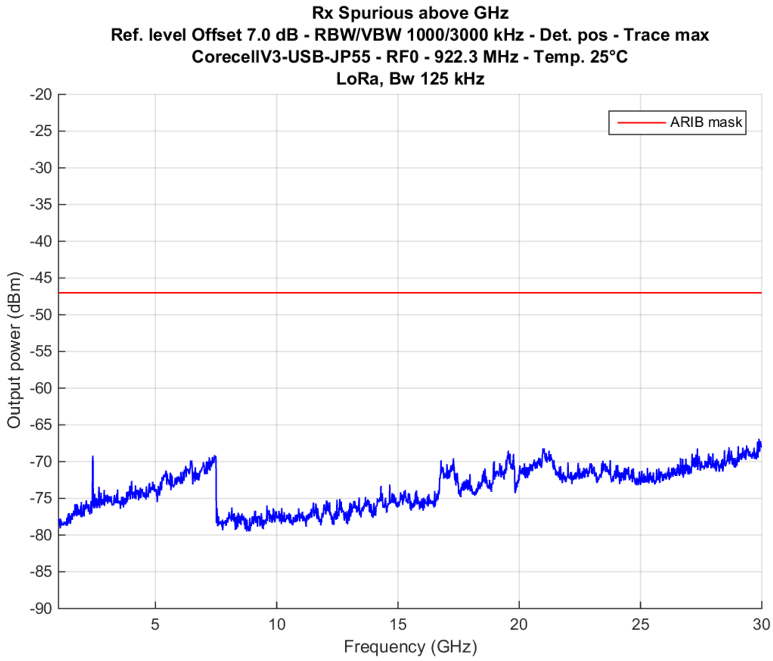


Figure 13.4: Rx Spurious above 1 GHz, Board JP55, 25°C

13.4 Conclusion

→ **The LoRa gateway complies with the Unwanted emission in Rx mode limits mentioned in the table 2.2.**

14 Sensitivity level and PER

14.1 Description

This measurement determines the sensitivity level i.e. the minimum RF input power needed to demodulate the received packet. It is determined for a PER of 1%. It also verifies the PER remains null for input power above the sensitivity level i.e. the AGC works well and no saturation occurs.

14.2 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.

14.3 Theoretical Noise Floor computation

The Friis formula (eq. 14.1) allows to calculate the cascaded noise figure and to combine the stage contributions:

$$Fin = F1 + \frac{F2-1}{G1} + \frac{F3-1}{G1 \times G2} + ... \quad (14.1)$$

The theoretical noise level is computed using the following assumption:

- 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, the US915).
  - 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

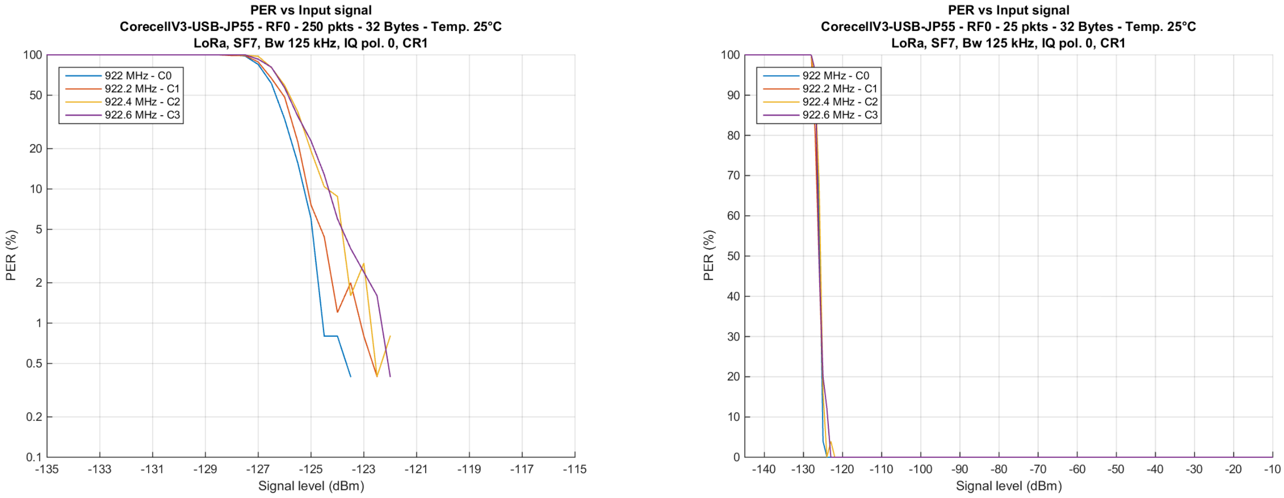
The equivalent input noise figure is:
Fin = 1.48 + (1.41-1)/0.68 + (1.48-1)/(0.68*63.1) + (2-1)/(0.68*63.1*0.68) + (6.31-1)/(0.68*63.1*0.68*0.5) = 2.5 or 4 dB

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

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

14.4 Frequency influence

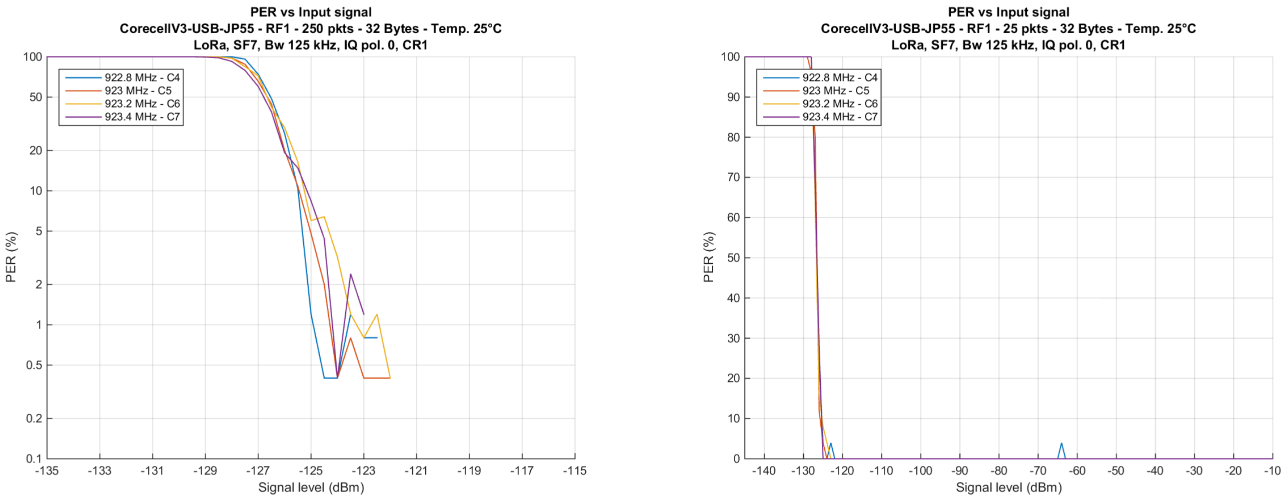
14.4.1 MultiSF modems (lower band)



(a) Sensitivity level (b) High level

Figure 14.1: Sensitivity level and PER vs channels (Lower band), Board JP55, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

14.4.2 MultiSF modems (Higher band)

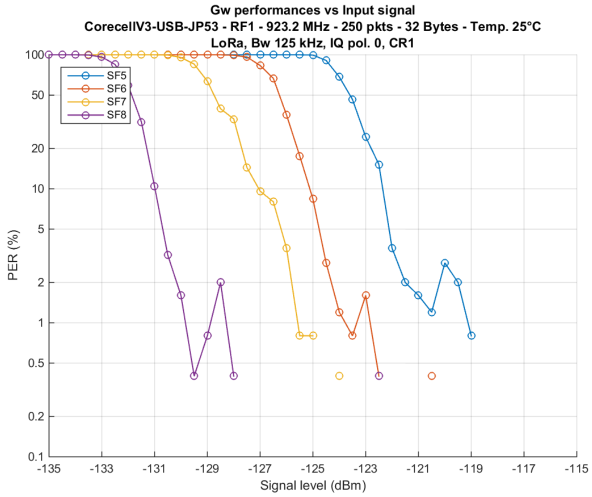


(a) Sensitivity level (b) High level

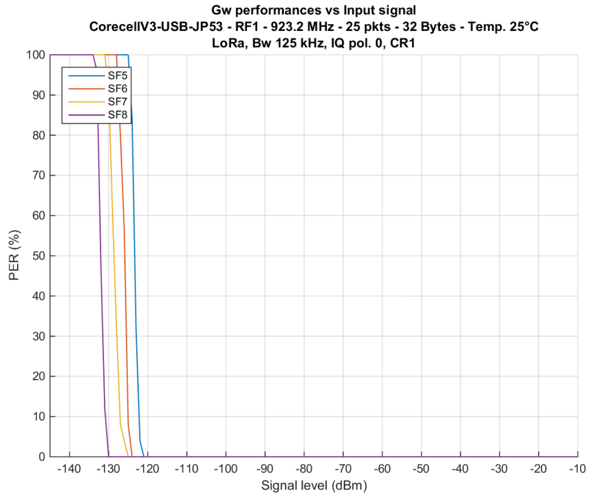
Figure 14.2: Sensitivity level and PER vs channels (Higher band), Board JP55 , MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

14.5 Spreading Factor influence

14.5.1 MultiSF modem (923.2 MHz)

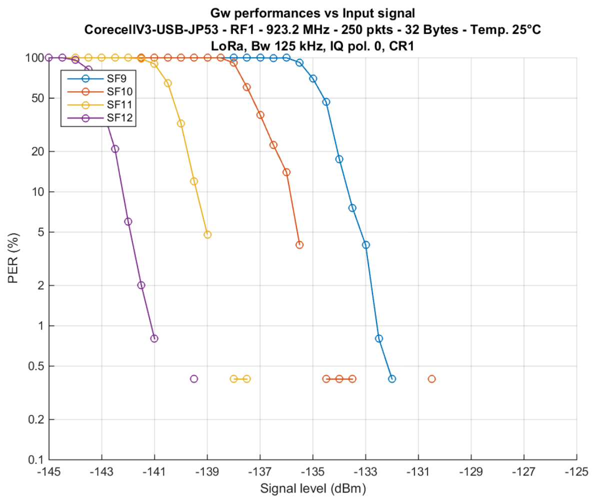


(a) Sensitivity level

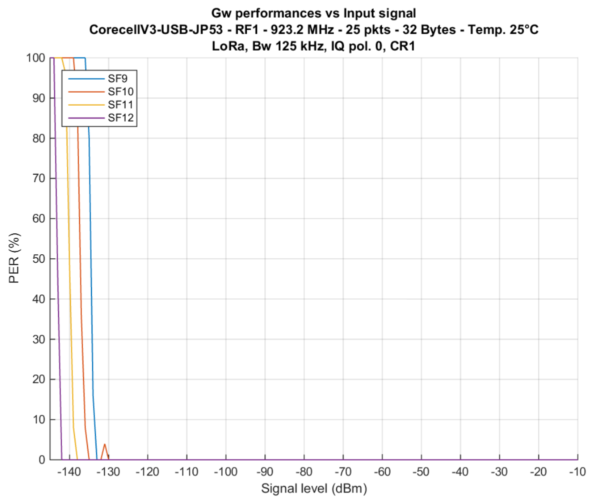


(b) High level

Figure 14.3: Sensitivity level and PER vs SF (5 to 8), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 32 bytes, 25°C



(a) Sensitivity level

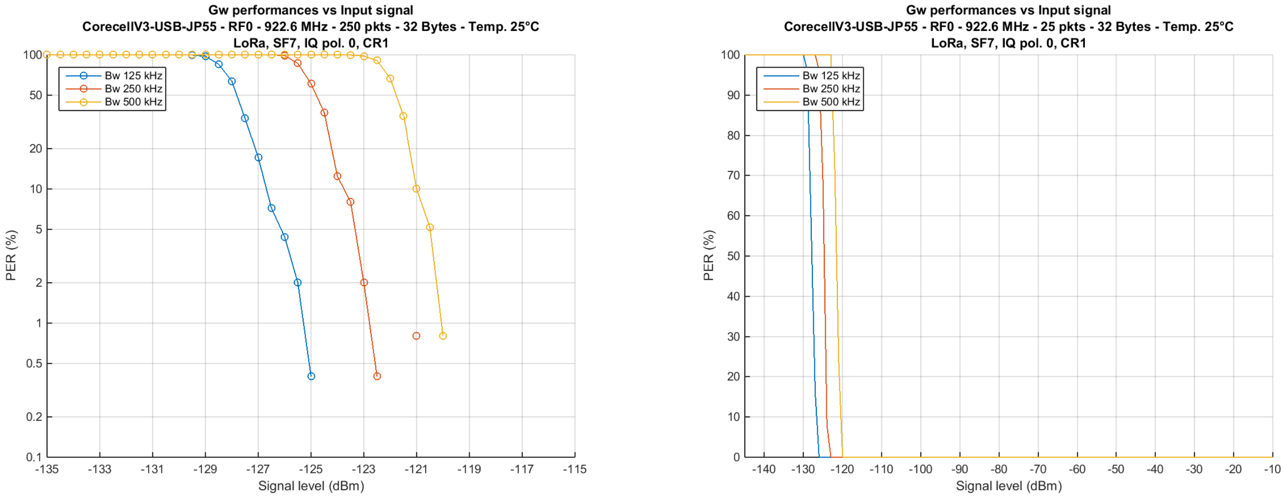


(b) High level

Figure 14.4: Sensitivity level and PER vs SF (9 to 12), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 32 bytes, 25°C

14.6 Bandwidth influence

14.6.1 SingleSF modem (922.6MHz)



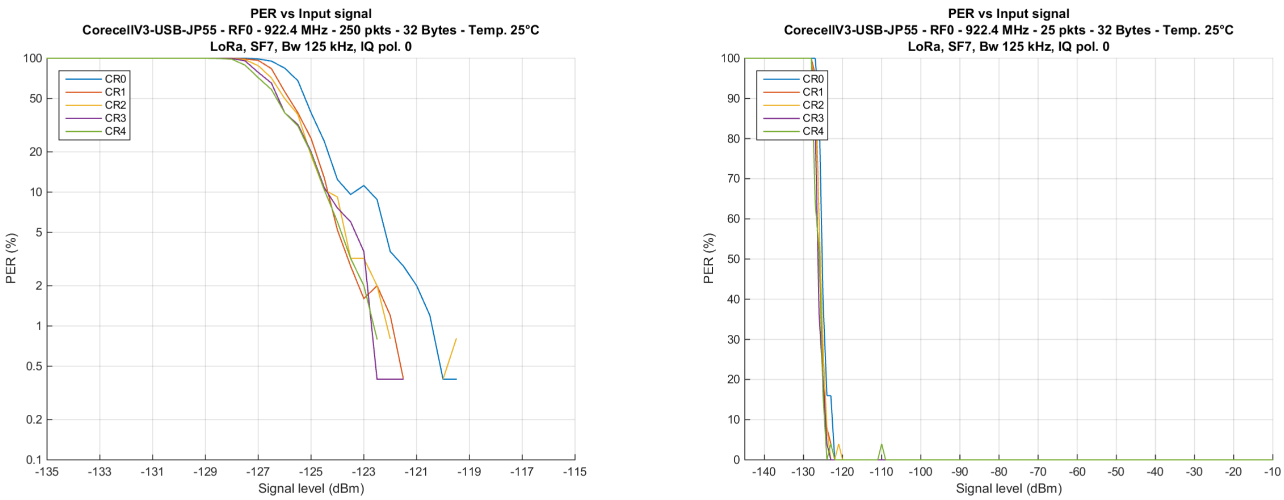
(a) Sensitivity level

(b) High level

Figure 14.5: Sensitivity level and PER vs bandwidth, Board JP55, SingleSF modem, 922.6 MHz, SF7, Bw 125 kHz, 32 bytes, 25°C

14.7 Coding rate influence

14.7.1 MultiSF modem (922.4 MHz)



(a) Sensitivity level

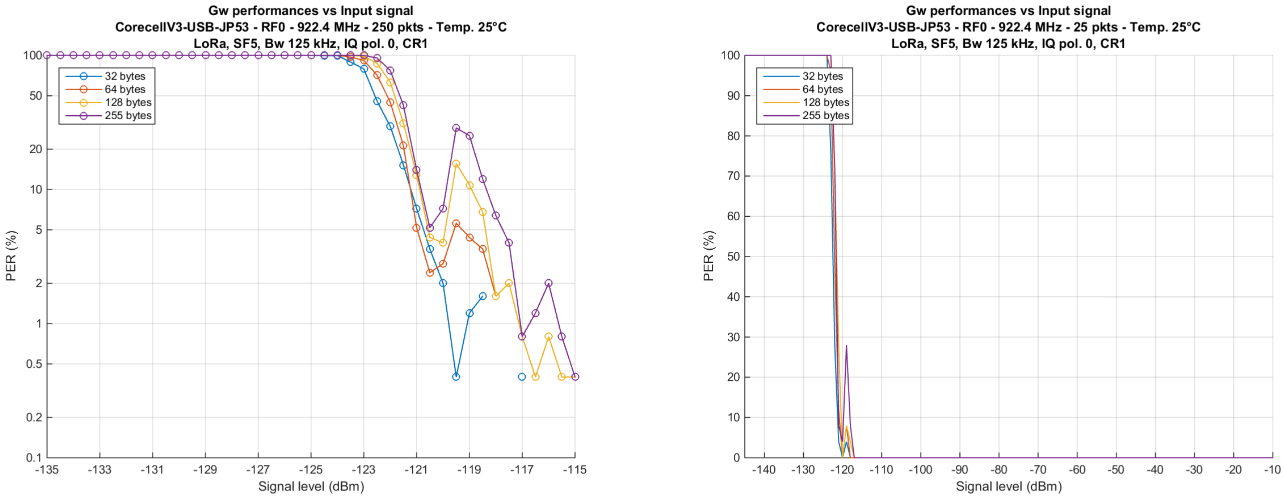
(b) High level

Figure 14.6: Sensitivity level and PER vs coding rate, Board JP55, MultiSF modem, 922.4 MHz, SF7, Bw 125 kHz, 32 bytes, 25°C

14.8 Payload length influence

14.8.1 MultiSF modem, Bw 125 kHz

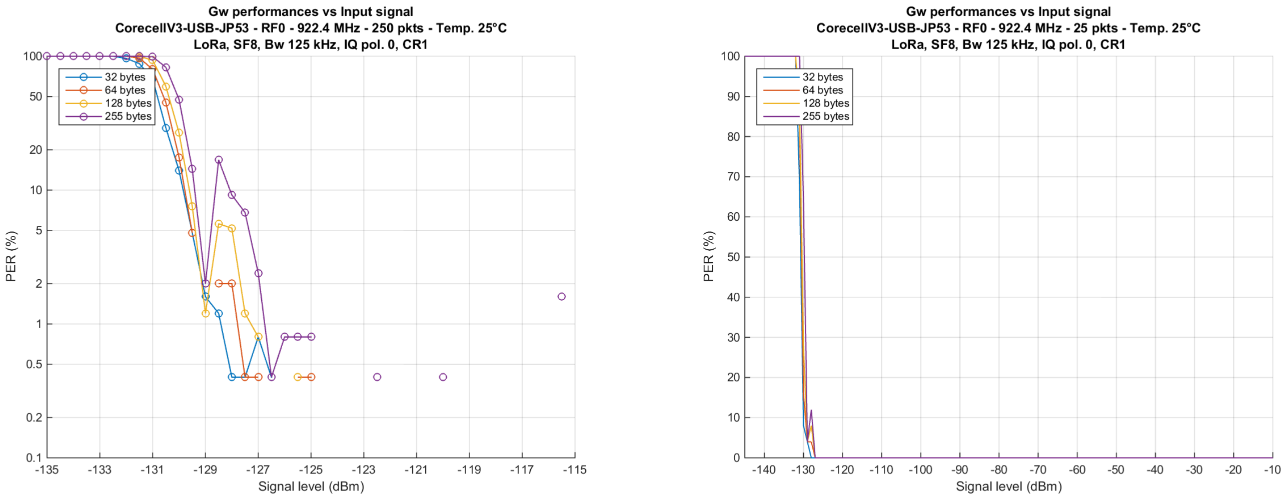
SF5



(a) Sensitivity level (b) High level

Figure 14.7: Sensitivity level and PER vs payload length, Board JP53, 922.4 MHz, SF5, Bw 125 kHz, CR1, 25°C

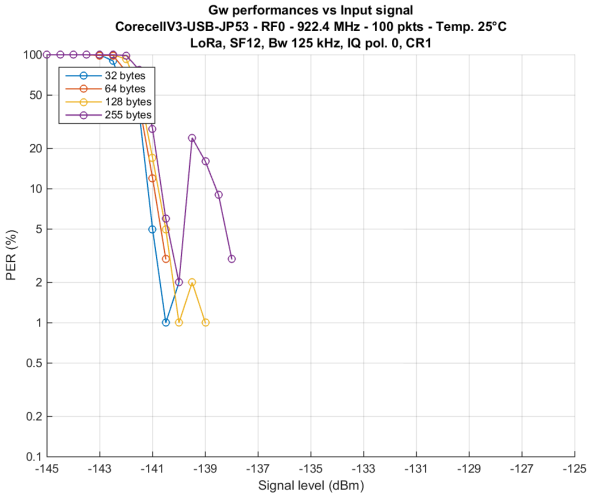
SF8



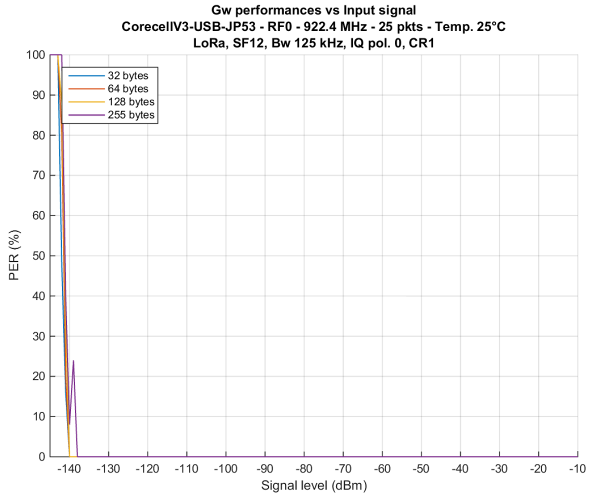
(a) Sensitivity level (b) High level

Figure 14.8: Sensitivity level and PER vs payload length, Board JP53, 922.4 MHz, SF8, Bw 125 kHz, CR1, 25°C

SF12



(a) Sensitivity level

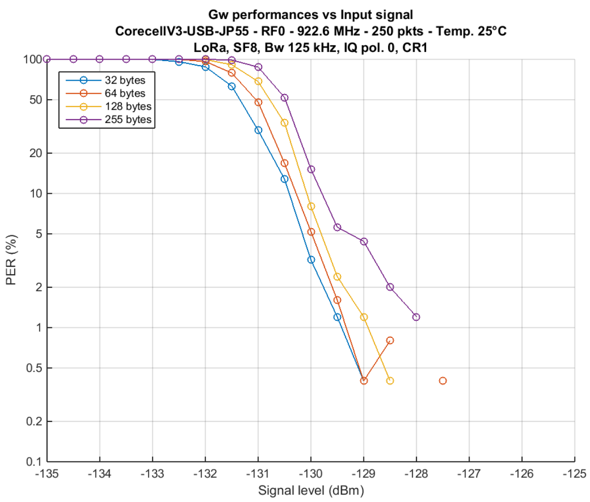


(b) High level

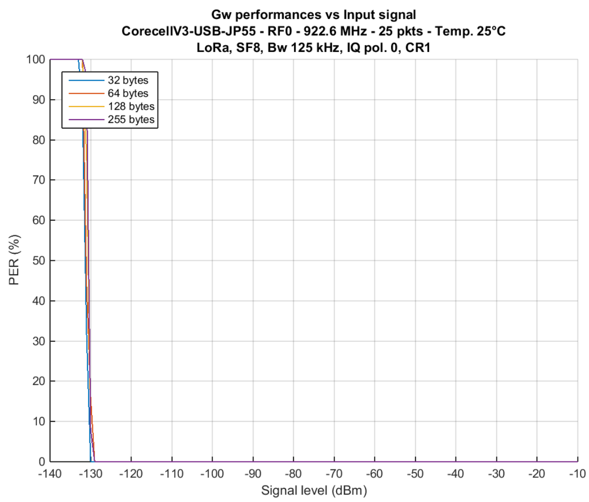
Figure 14.9: Sensitivity level and PER vs payload length, Board JP53, 922.4 MHz, SF12, Bw 125 kHz, CR1, 25°C

14.8.2 SingleSF modem, Implicit header (922.6 MHz)

Bandwidth 125 kHz



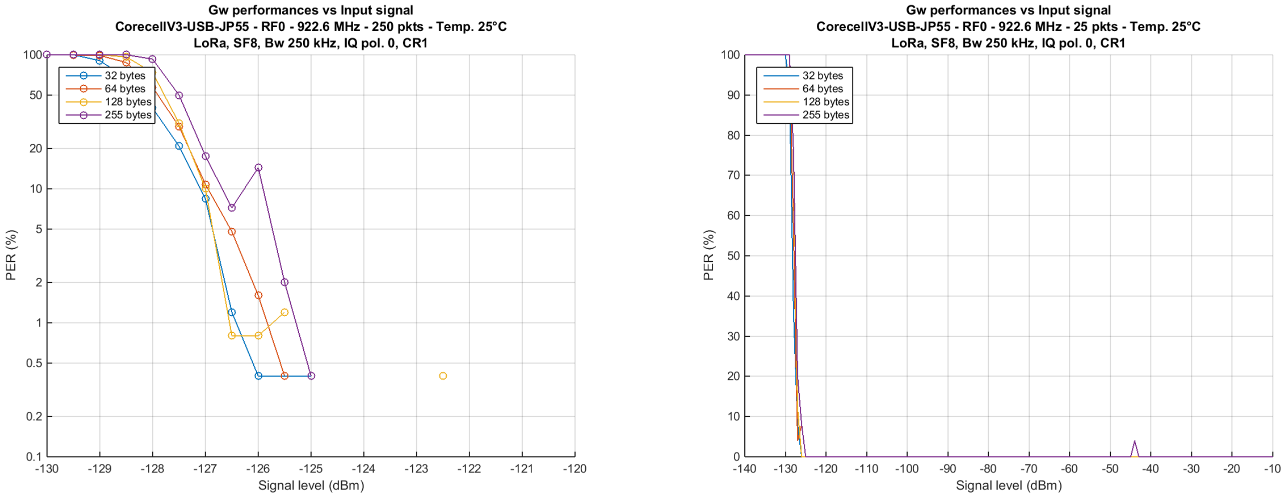
(a) Sensitivity level



(b) High level

Figure 14.10: Sensitivity level and PER vs pl len., Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 125 kHz, 25°C

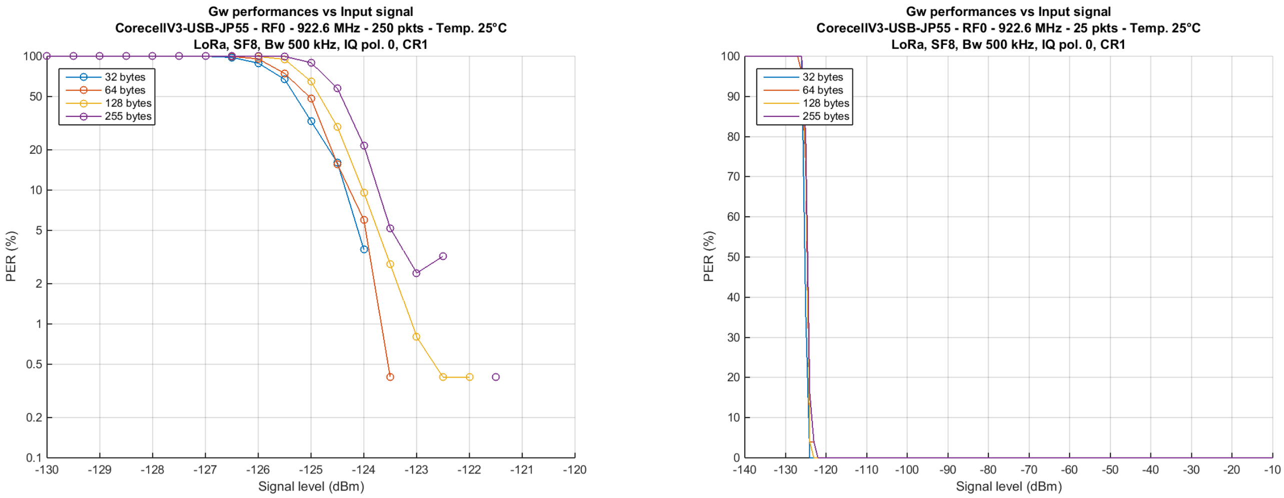
Bandwidth 250 kHz



(a) Sensitivity level (b) High level

Figure 14.11: Sensitivity level and PER vs pl len., Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 250 kHz, 25°C

Bandwidth 500 kHz

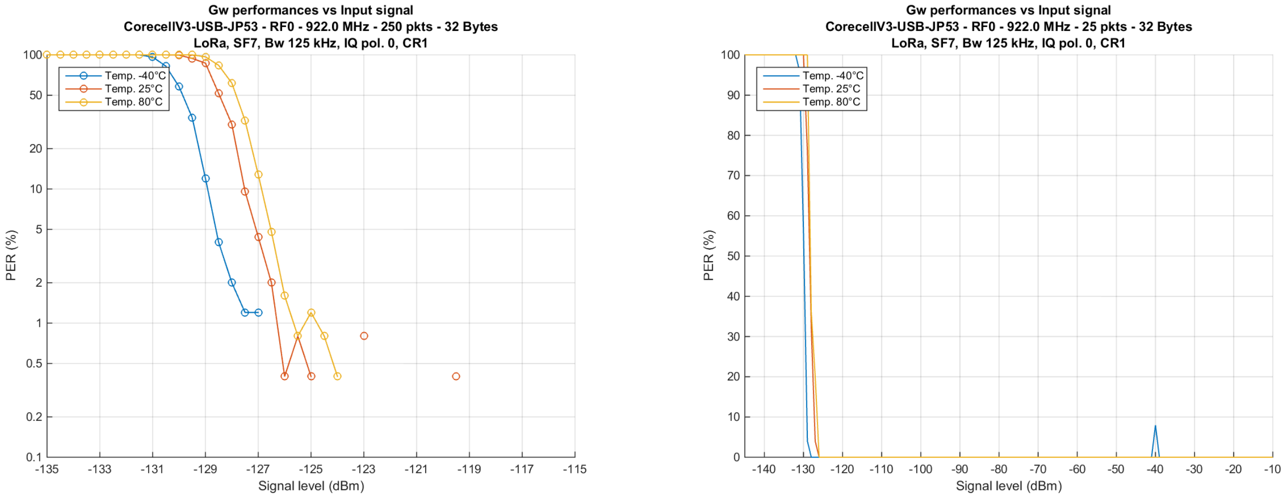


(a) Sensitivity level (b) High level

Figure 14.12: Sensitivity level and PER vs pl len., Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 500 kHz, 25°C

14.9 Temperature influence

14.9.1 MultiSF modem (922.0 MHz)

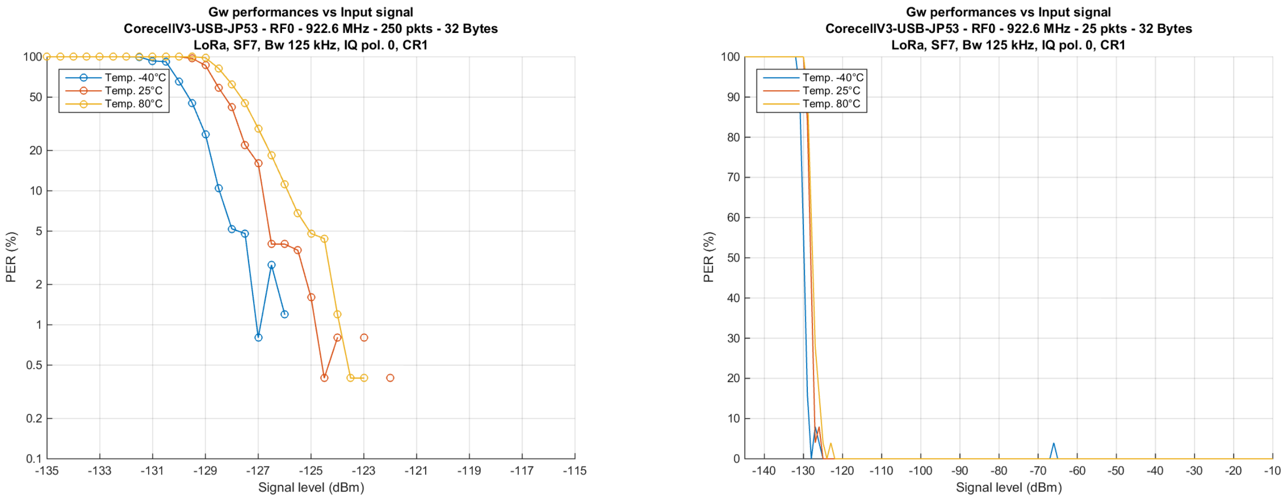


(a) Sensitivity level

(b) High level

Figure 14.13: Sensitivity level and PER vs temperature, Board JP53, MultiSF modem, 922.0 MHz, SF7, Bw 125 kHz, CR1

14.9.2 MultiSF modem (922.6 MHz)

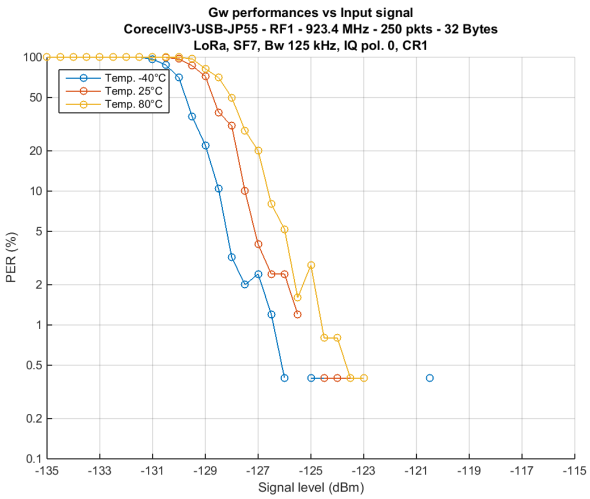


(a) Sensitivity level

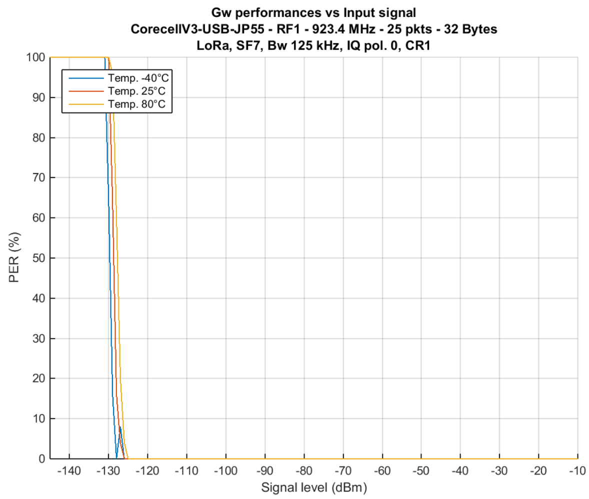
(b) High level

Figure 14.14: Sensitivity level and PER vs temperature, Board JP53, MultiSF modem, 922.6 MHz, SF7, Bw 125 kHz, CR1

14.9.3 MultiSF modem (923.4 MHz)



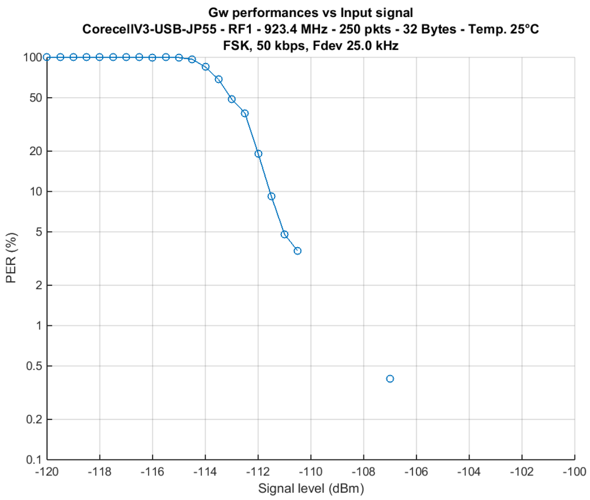
(a) Sensitivity level



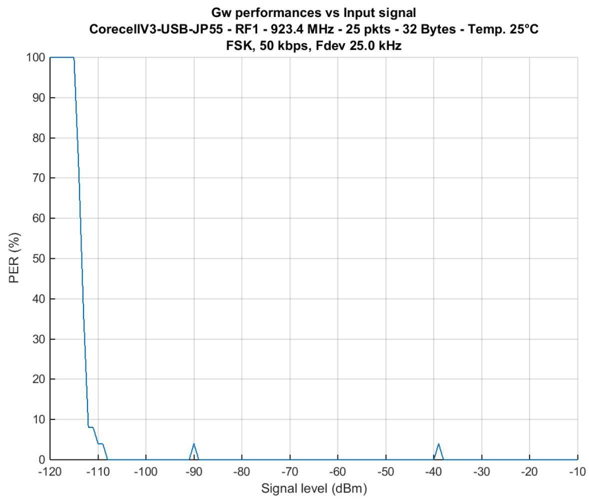
(b) High level

Figure 14.15: Sensitivity level and PER vs temperature, Board JP55, MultiSF modem, 923.4 MHz, SF7, Bw 125 kHz, CR1

14.10 FSK modem



(a) Sensitivity level



(b) High level

Figure 14.16: Sensitivity level and PER, FSK modem, Board JP55, 923.4 MHz, 50 kbps, Fdev 25 kHz, 25°C

14.11 Conclusion

→ The sensitivity level and the PER for higher signal input levels comply with the expected performances mentioned in section 14.3

15 RSSI

15.1 Description

The LoRa modems returns two indicators of the received signal level: the 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.

15.2 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.

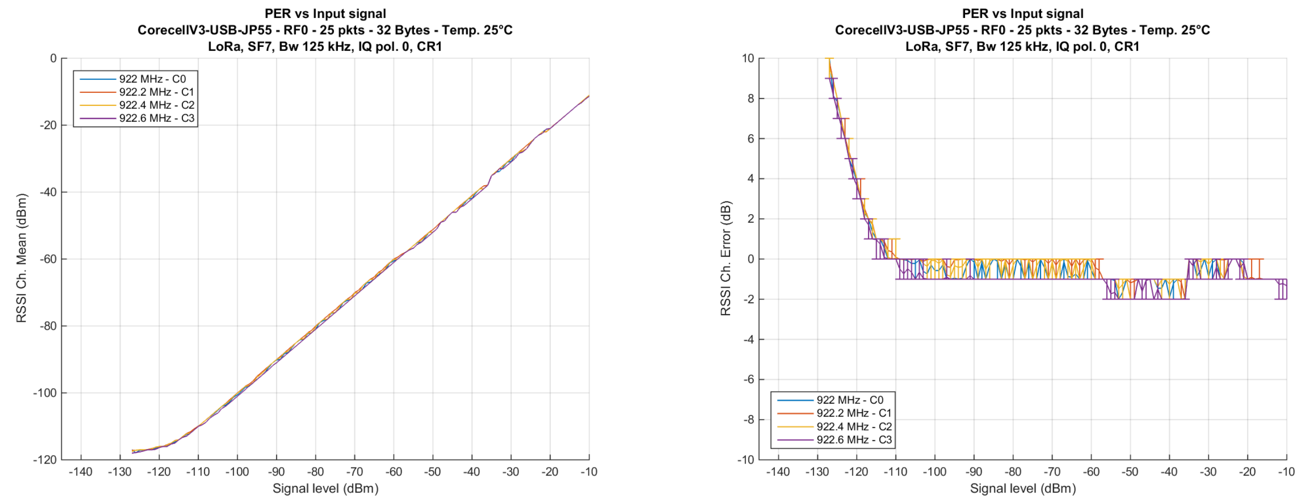
The **packet forwarder** software running on the host pulls data from the gateway by the USB bus and send them to the computer through UDP protocol.

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.

15.3 Frequency influence

15.3.1 MultiSF modems (Lower band)

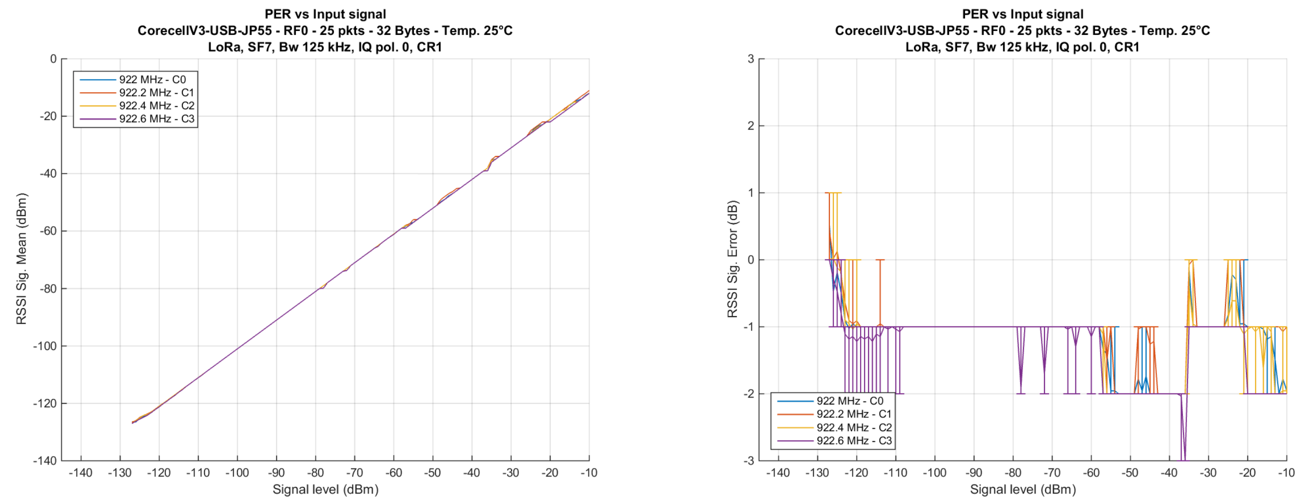
RSSI channel



(a) RSSI mean (b) RSSI error

Figure 15.1: RSSI channel vs channels (Lower band), Board JP55, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

RSSI signal

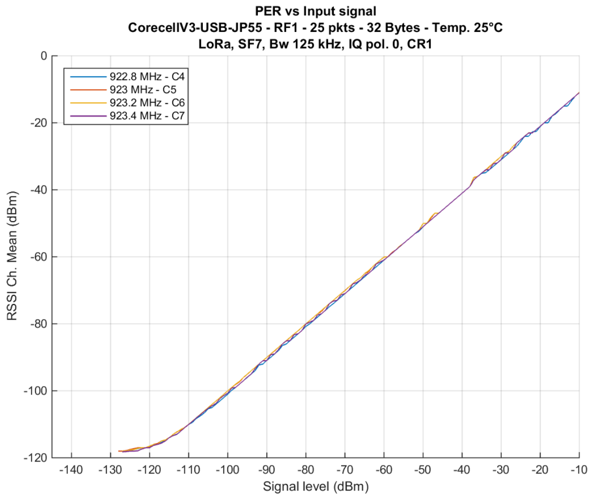


(a) RSSI mean (b) RSSI error

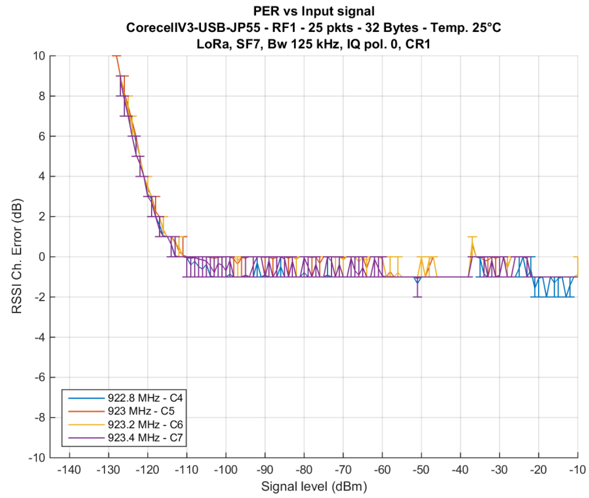
Figure 15.2: RSSI signal vs channels (Lower band), Board JP55, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

15.3.2 MultiSF modems (Higher band)

RSSI channel



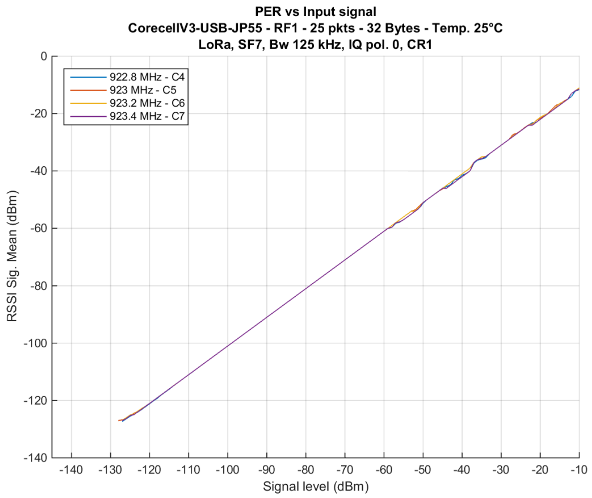
(a) RSSI mean



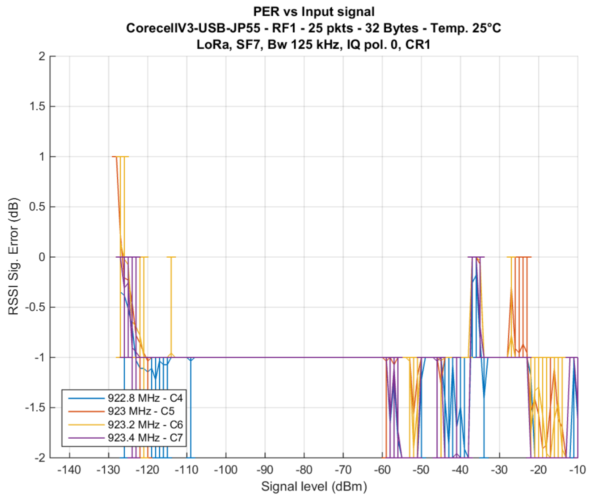
(b) RSSI error

Figure 15.3: RSSI channel vs channels (Higher band), Board JP55, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

RSSI signal



(a) RSSI mean



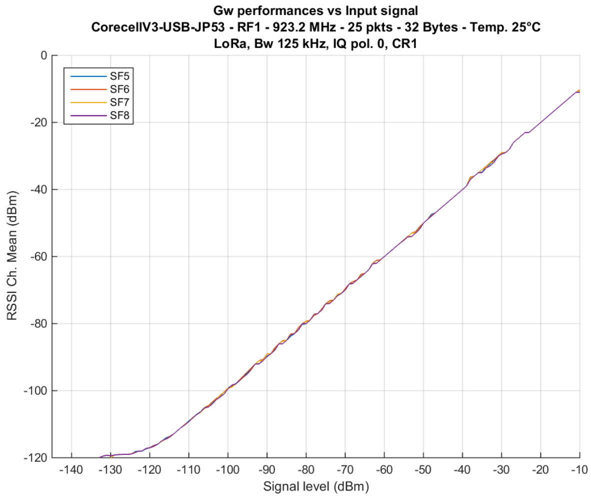
(b) RSSI error

Figure 15.4: RSSI signal vs channels (Higher band), Board JP55, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

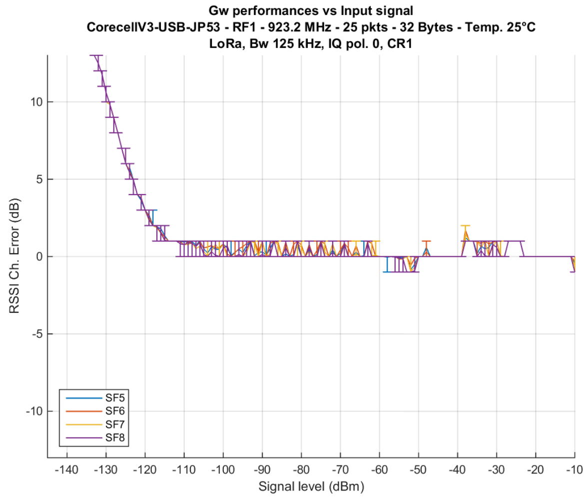
15.4 Spreading factor influence

15.4.1 MultiSF modem (923.2MHz)

RSSI channel



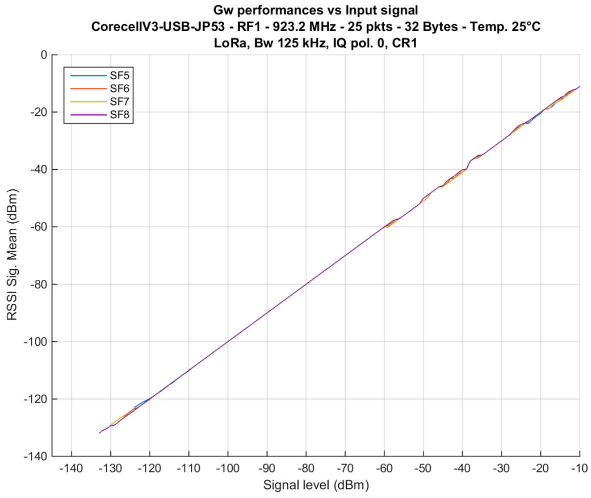
(a) RSSI mean



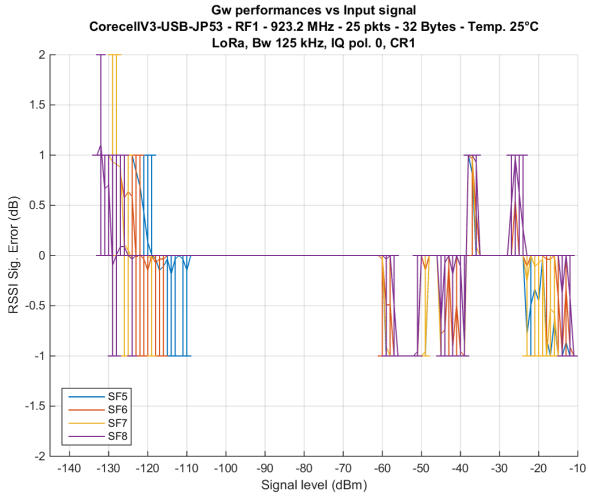
(b) RSSI error

Figure 15.5: RSSI channel vs temperature, Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, CR1, 32 bytes, 25°C

RSSI signal



(a) RSSI mean



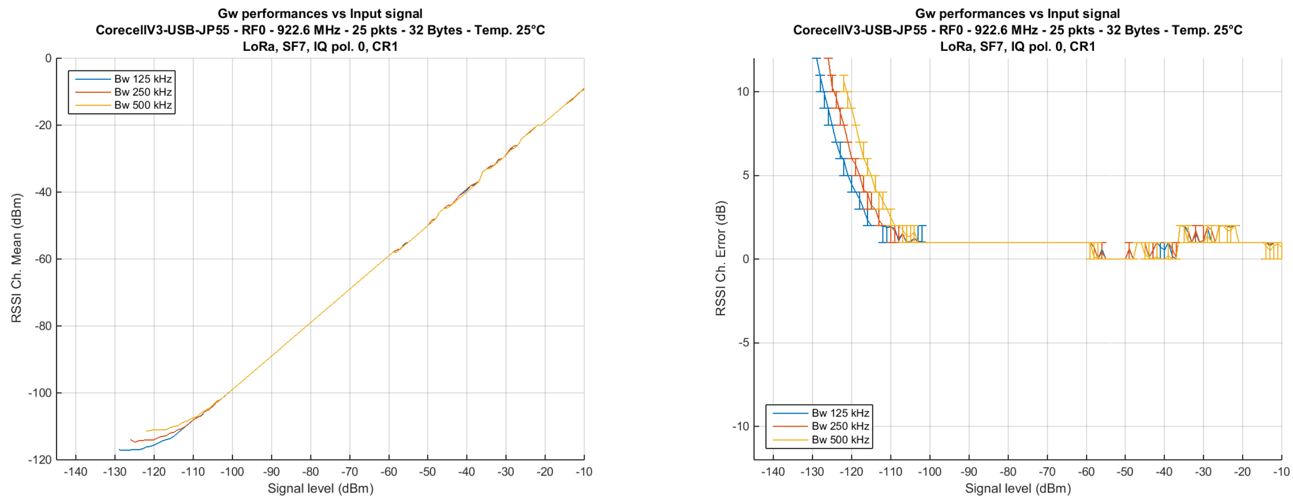
(b) RSSI error

Figure 15.6: RSSI signal vs temperature, Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, CR1, 32 bytes, 25°C

15.5 Bandwidth influence

15.5.1 SingleSF modem (922.6MHz)

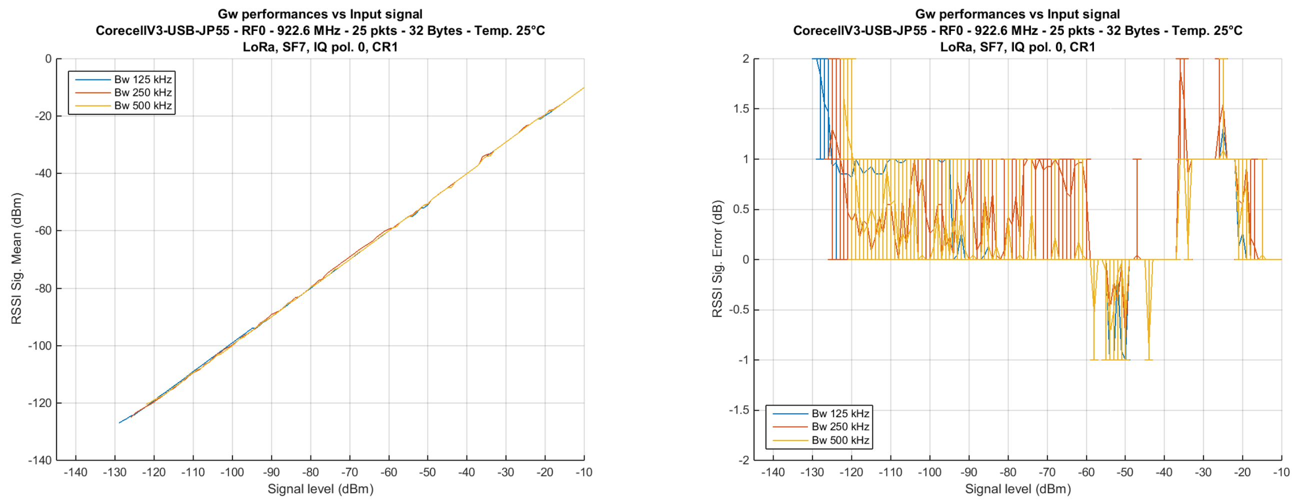
RSSI channel



(a) RSSI mean (b) RSSI error

Figure 15.7: RSSI channel vs bandwidth, Board JP55, SingleSF modem, 922.6 MHz, SF7, CR1, 32 bytes, 25°C

RSSI signal



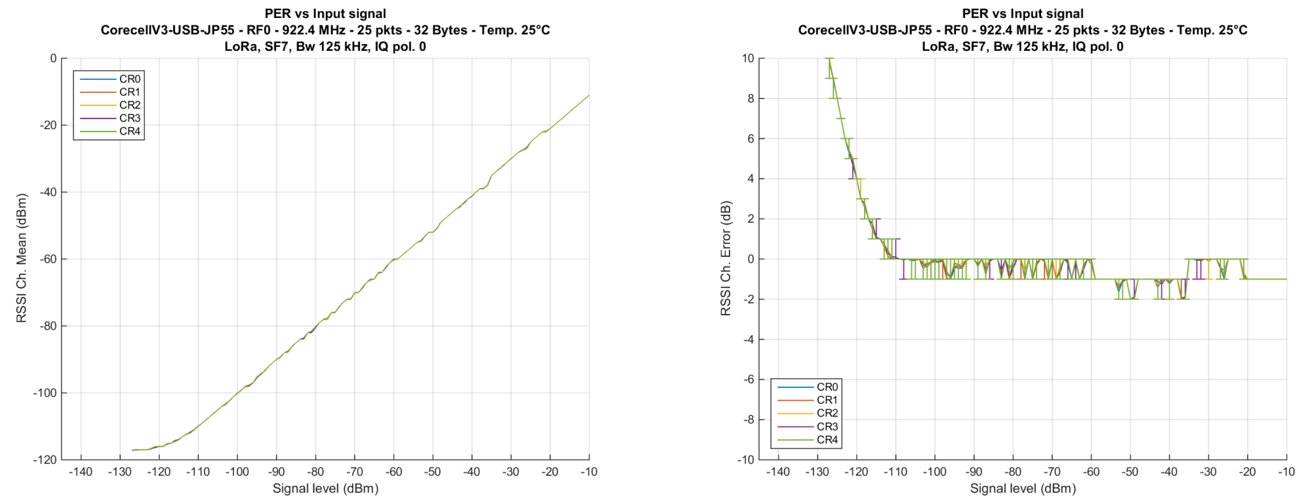
(a) RSSI mean (b) RSSI error

Figure 15.8: RSSI signal vs bandwidth, Board JP53, SingleSF modem, 922.6 MHz, SF7, CR1, 32 bytes, 25°C

15.6 Coding rate influence

15.6.1 MultiSF modem (922.4 MHz)

RSSI channel

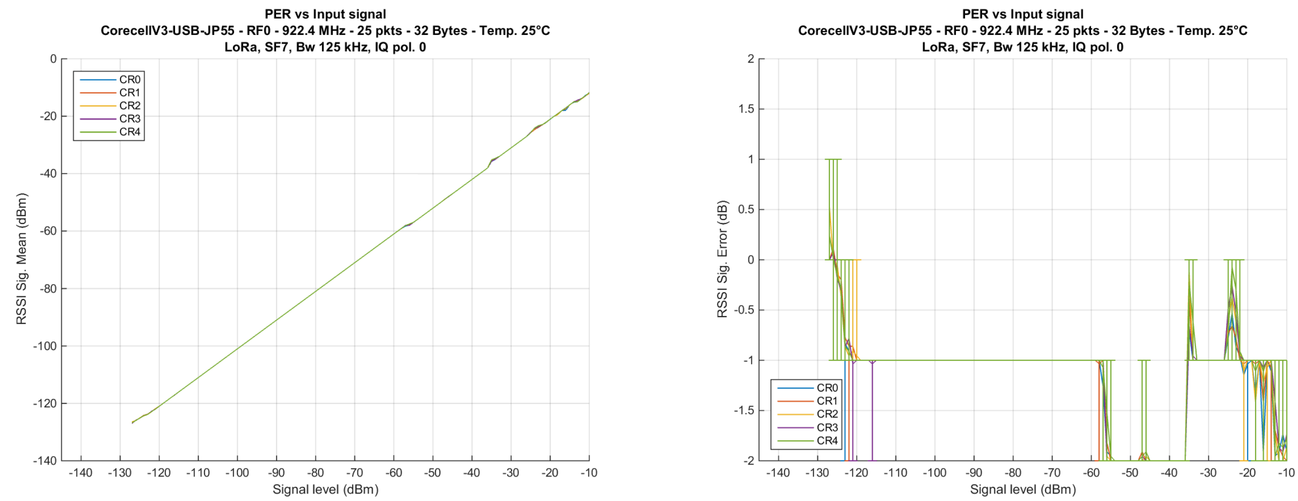


(a) RSSI mean

(b) RSSI error

Figure 15.9: RSSI channel vs coding rate, Board JP55, MultiSF modem, 922.4 MHz, SF7, Bw 125 kHz, 32 bytes, 25°C

RSSI signal



(a) RSSI mean

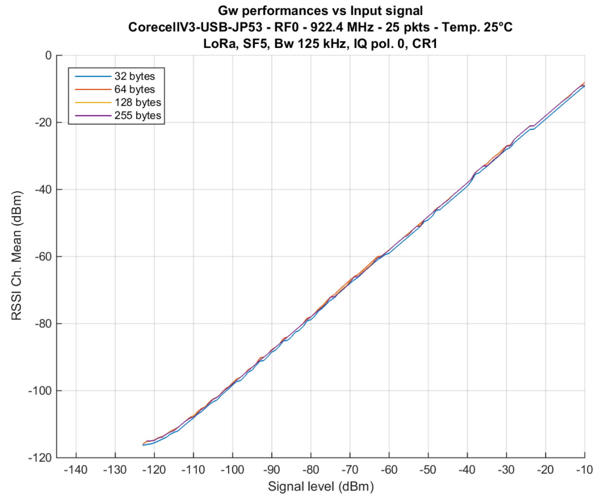
(b) RSSI error

Figure 15.10: RSSI signal vs coding rate, Board JP55, MultiSF modem, 922.4 MHz, SF7, Bw 125 kHz, 32 bytes, 25°C

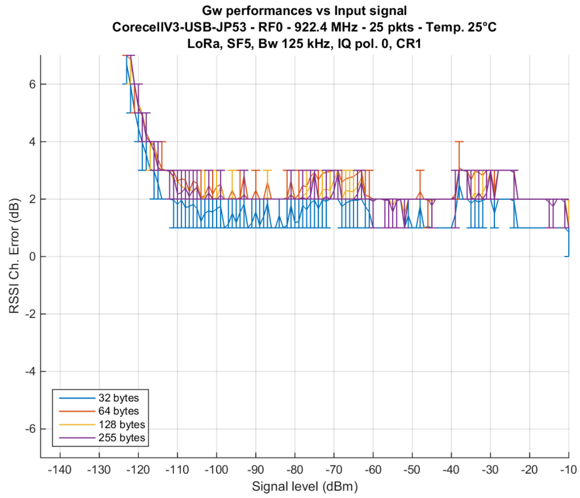
15.7 Payload length influence

15.7.1 MultiSF modem, SF5, Bw 125 kHz

RSSI channel



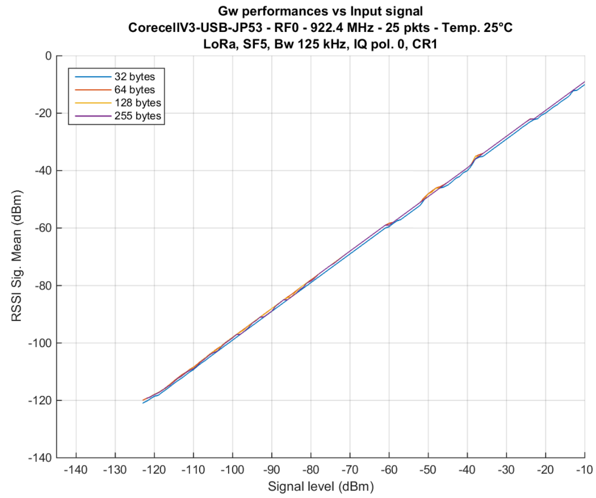
(a) RSSI mean



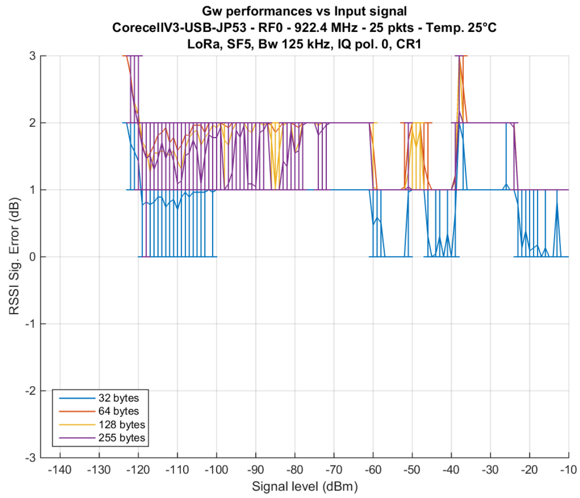
(b) RSSI error

Figure 15.11: RSSI channel vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF5, Bw 125 kHz, CR1, 25°C

RSSI signal



(a) RSSI mean

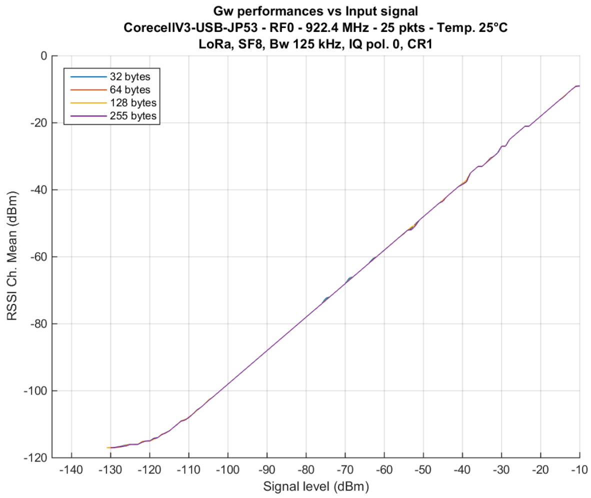


(b) RSSI error

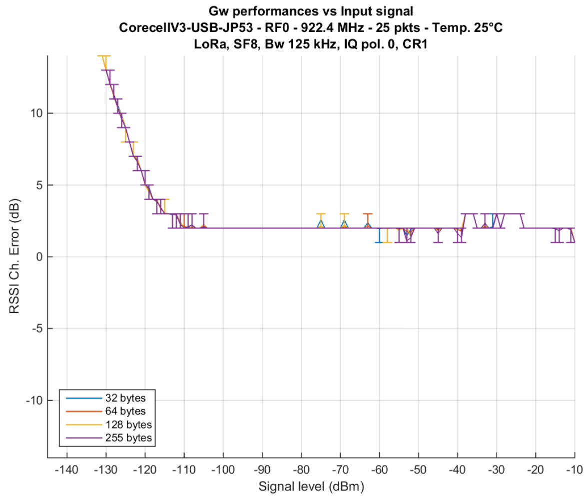
Figure 15.12: RSSI signal vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF5, Bw 125 kHz, CR1, 25°C

15.7.2 MultiSF modem, SF8, Bw 125 kHz

RSSI channel



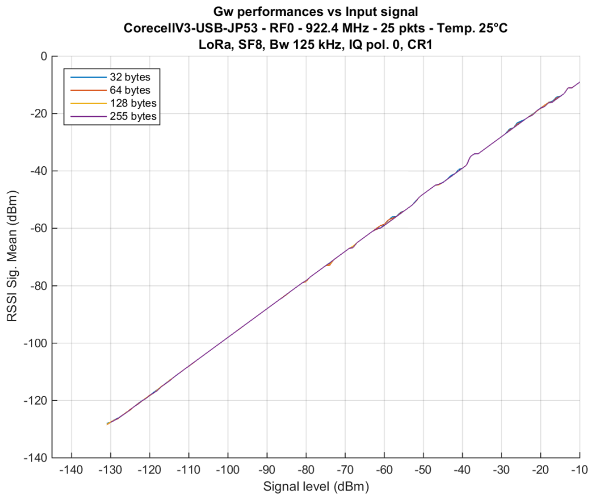
(a) RSSI mean



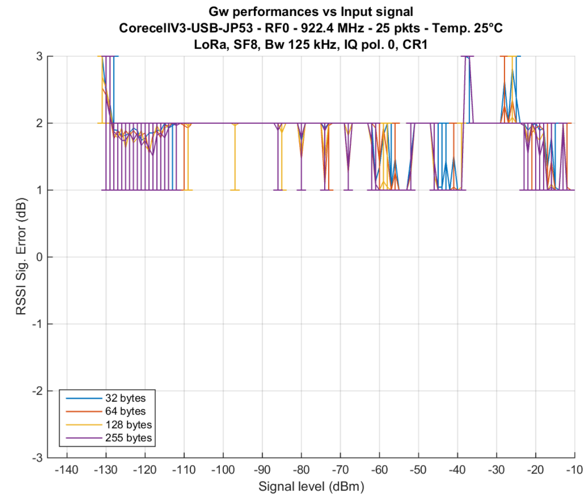
(b) RSSI error

Figure 15.13: RSSI channel vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF8, Bw 125 kHz, CR1, 25°C

RSSI signal



(a) RSSI mean

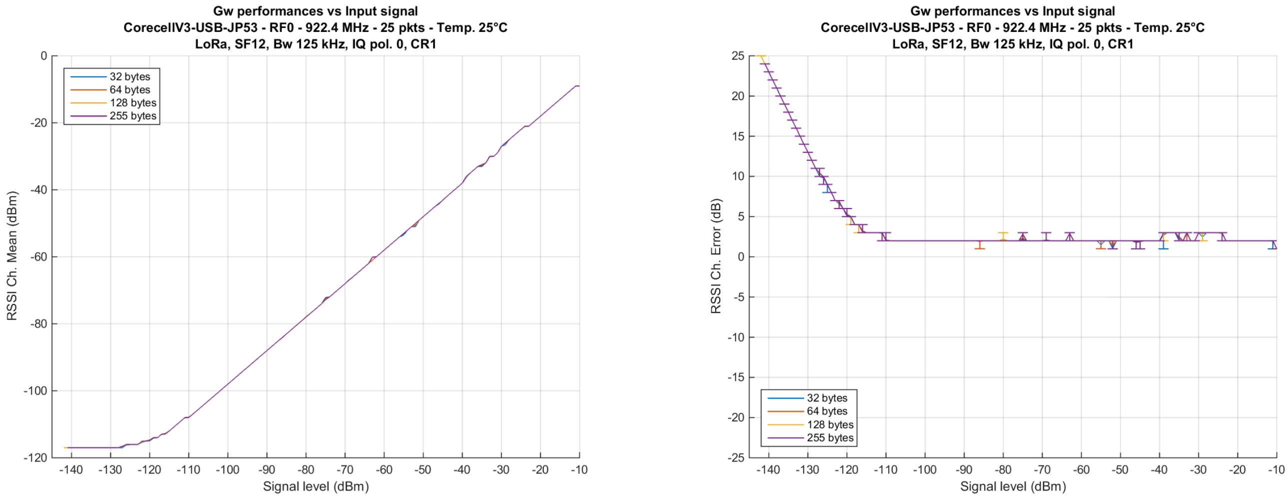


(b) RSSI error

Figure 15.14: RSSI signal vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF8, Bw 125 kHz, CR1, 25°C

15.7.3 MultiSF modem, SF12, Bw 125 kHz

RSSI channel

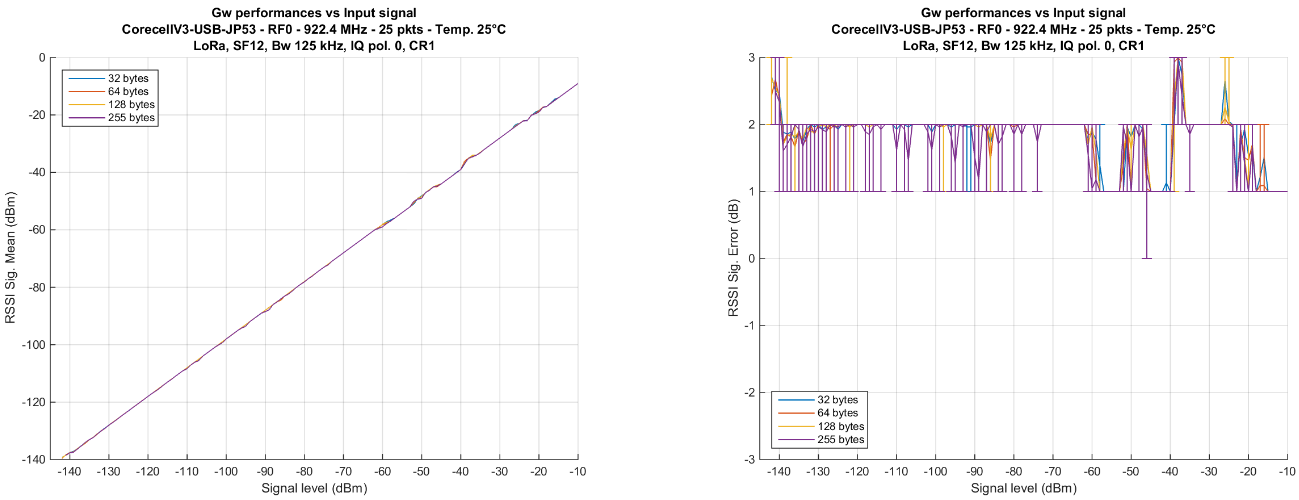


(a) RSSI mean

(b) RSSI error

Figure 15.15: RSSI channel vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF12, Bw 125 kHz, CR1, 25°C

RSSI signal



c

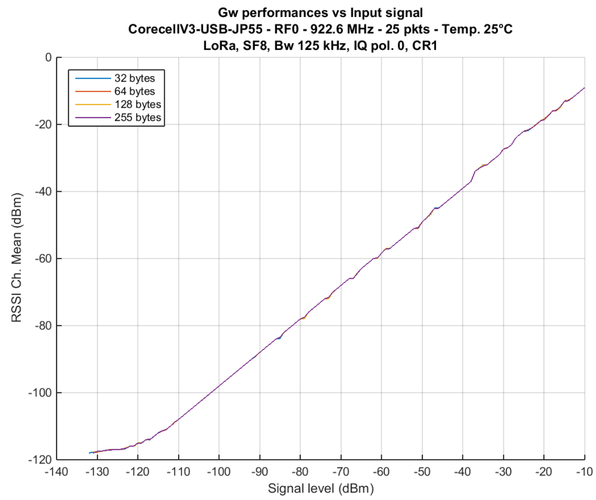
(a) RSSI mean

(b) RSSI error

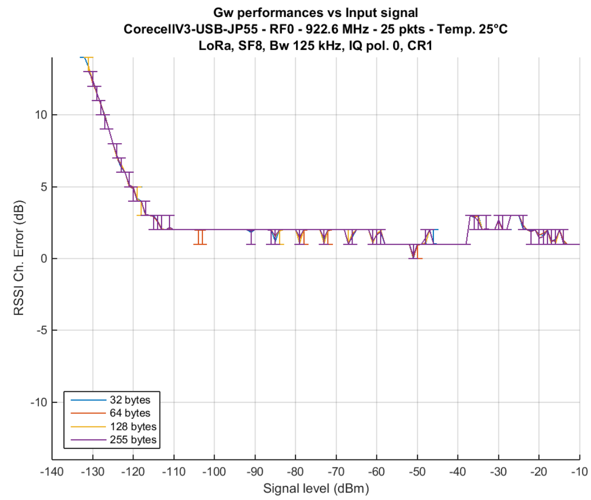
Figure 15.16: RSSI signal vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF12, Bw 125 kHz, CR1, 25°C

15.7.4 SingleSF modem, Implicit header (922.6 MHz), Bw 125 kHz

RSSI channel



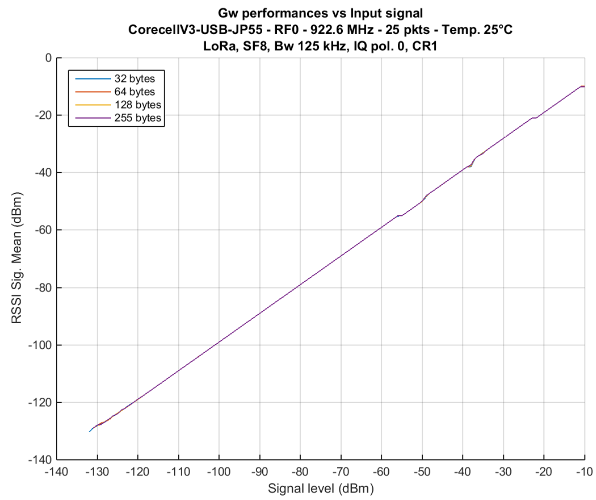
(a) RSSI mean



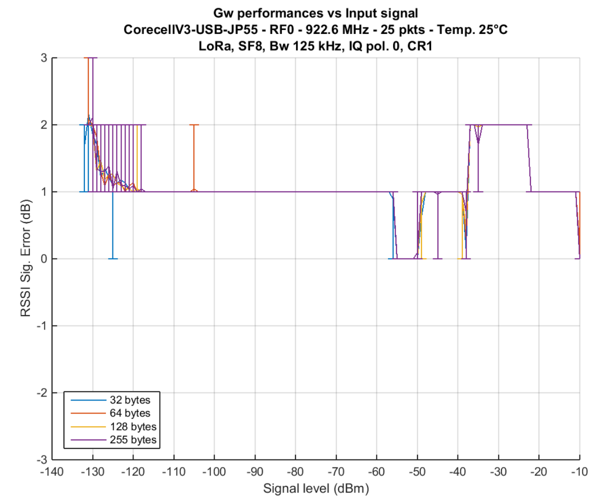
(b) RSSI error

Figure 15.17: RSSI channel vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 125 kHz, CR1, 25°C

RSSI signal



(a) RSSI mean

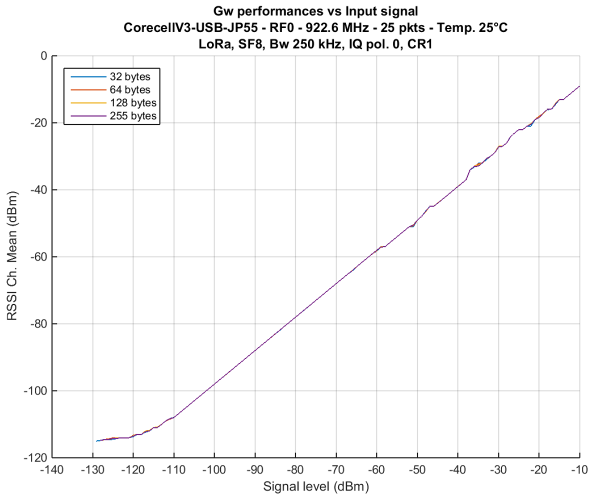


(b) RSSI error

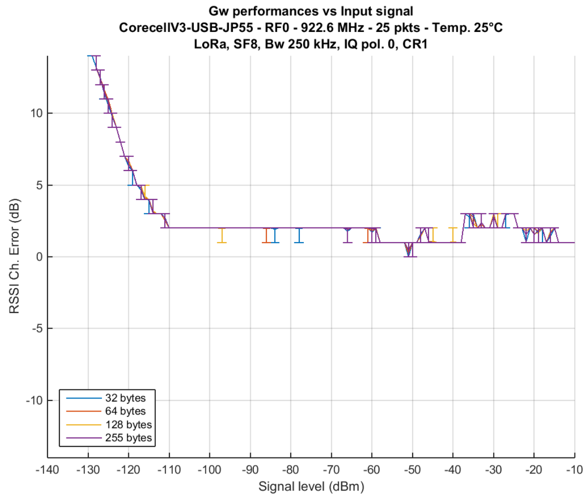
Figure 15.18: RSSI signal vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 125 kHz, CR1, 25°C

15.7.5 SingleSF modem, Implicit header (922.6 MHz), Bw 250 kHz

RSSI channel



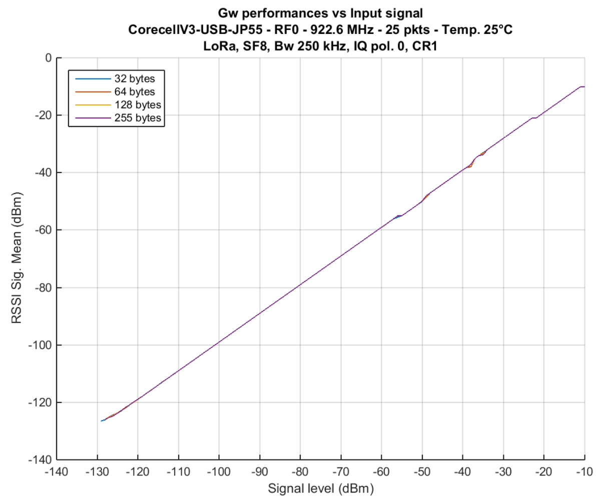
(a) RSSI mean



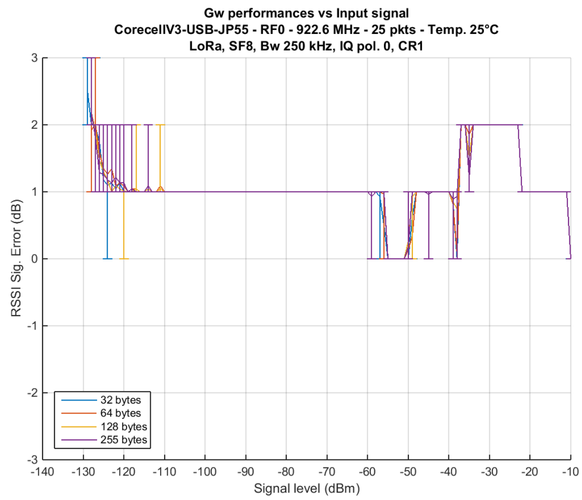
(b) RSSI error

Figure 15.19: RSSI channel vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 250 kHz, CR1, 25°C

RSSI signal



(a) RSSI mean

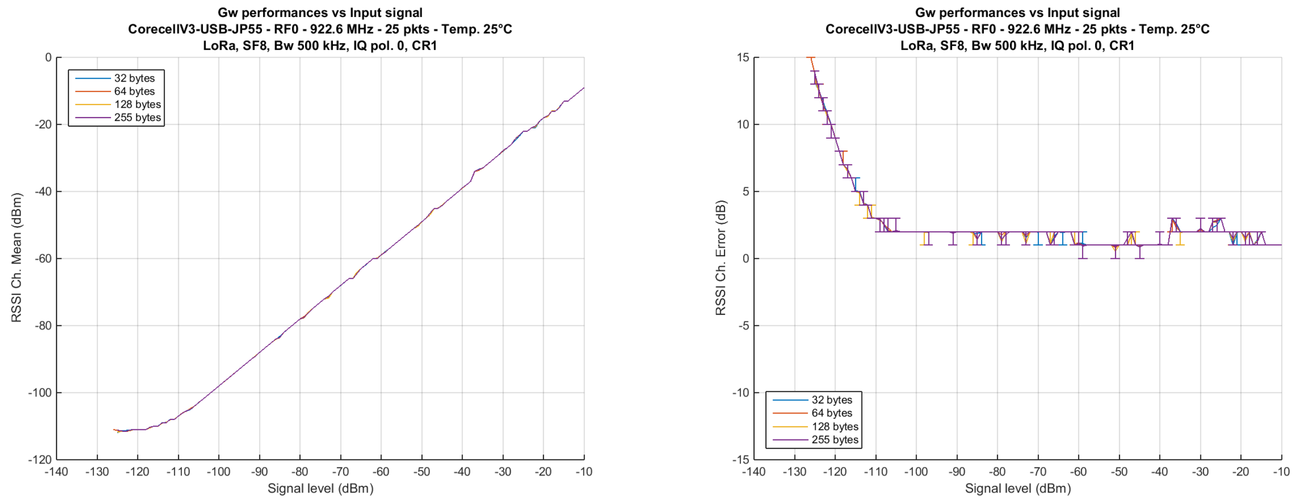


(b) RSSI error

Figure 15.20: RSSI signal vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 250 kHz, CR1, 25°C

15.7.6 SingleSF modem, Implicit header (922.6 MHz), Bw 500 kHz

RSSI channel

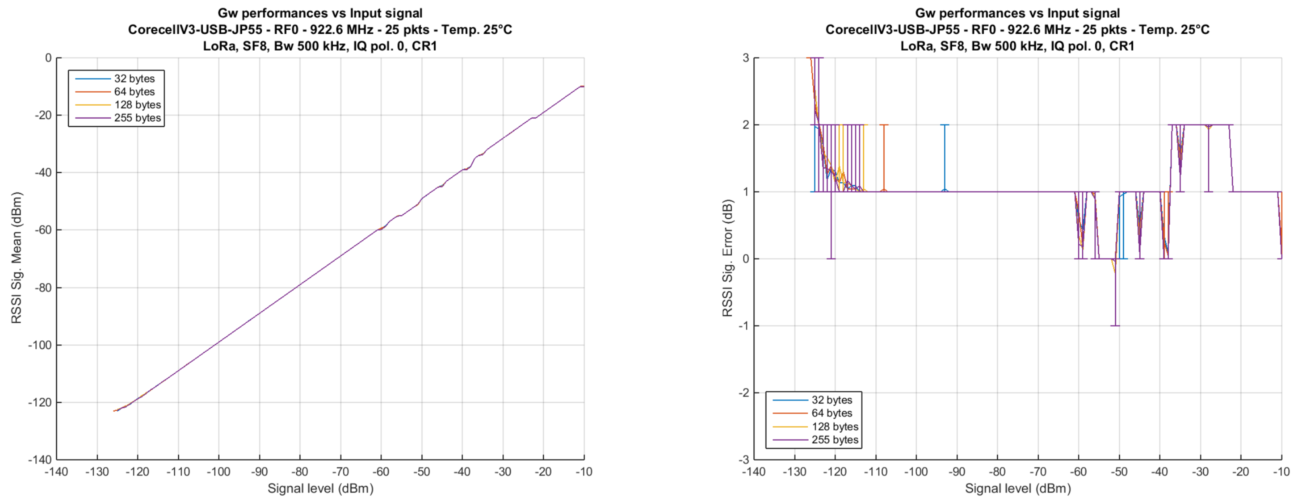


(a) RSSI mean

(b) RSSI error

Figure 15.21: RSSI channel vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 500 kHz, CR1, 25°C

RSSI signal



(a) RSSI mean

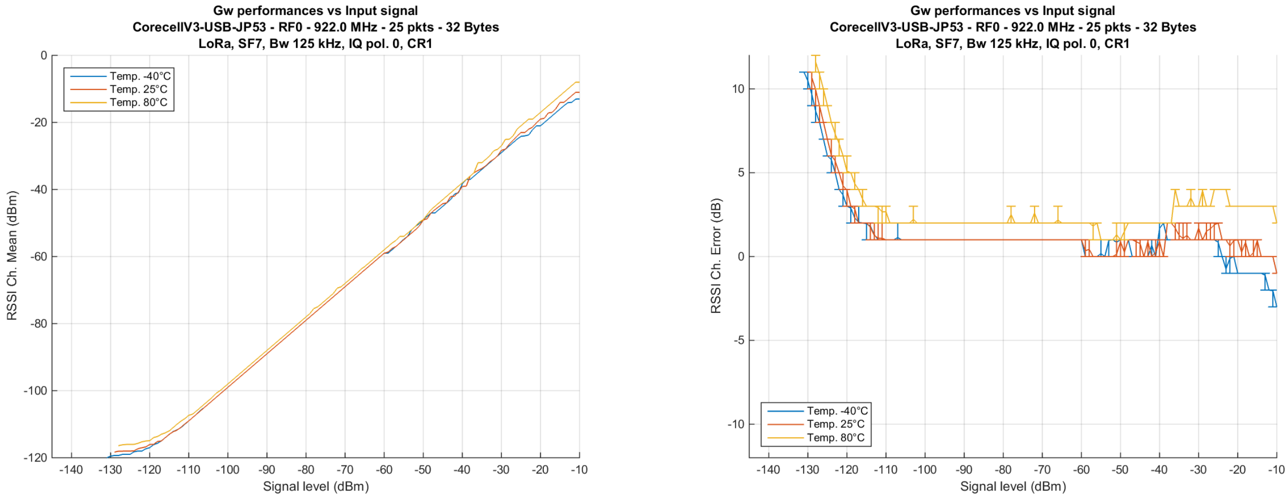
(b) RSSI error

Figure 15.22: RSSI signal vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 500 kHz, CR1, 25°C

15.8 Temperature influence

15.8.1 MultiSF modem (922.0MHz)

RSSI channel

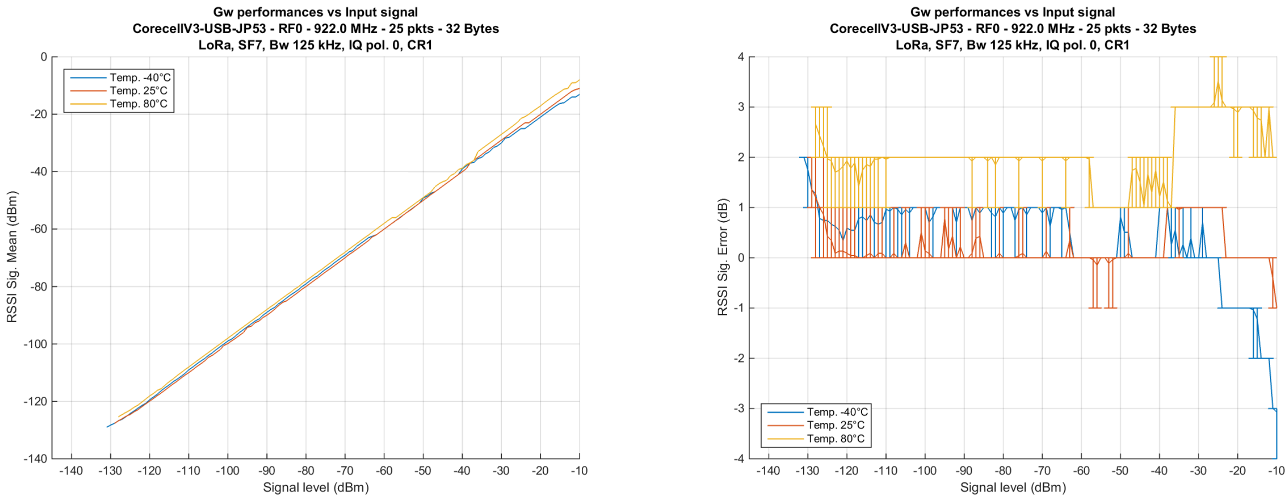


(a) RSSI mean

(b) RSSI error

Figure 15.23: RSSI channel vs temperature, Board JP53, MultiSF modem, 922.0 MHz, SF7, Bw 125 kHz, CR1

RSSI signal



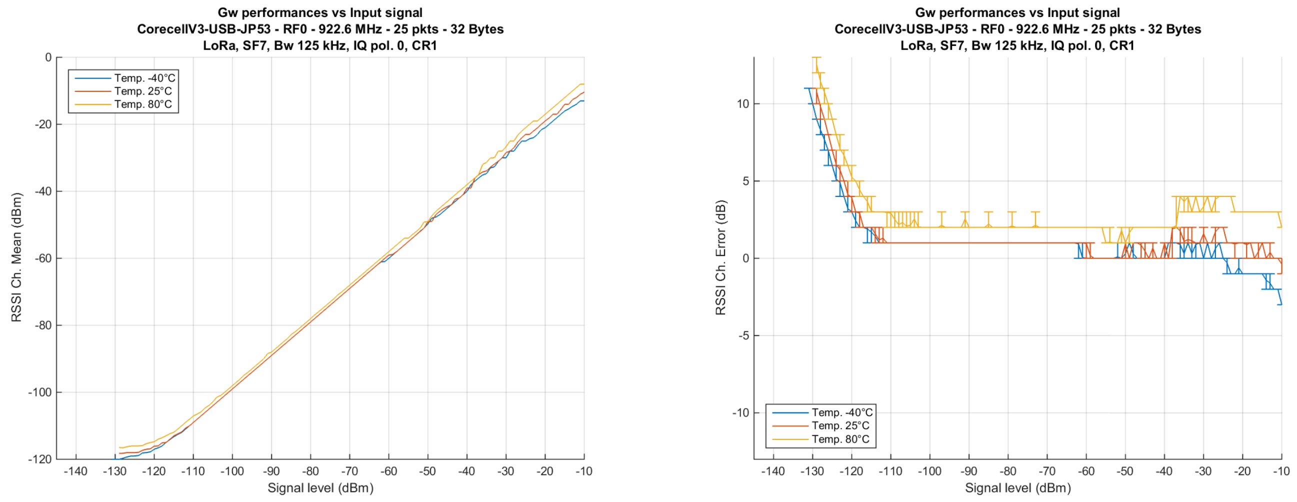
(a) RSSI mean

(b) RSSI error

Figure 15.24: RSSI signal vs temperature, Board JP53, MultiSF modem, 922.0 MHz, SF7, Bw 125 kHz, CR1

15.8.2 MultiSF modem (922.6MHz)

RSSI channel

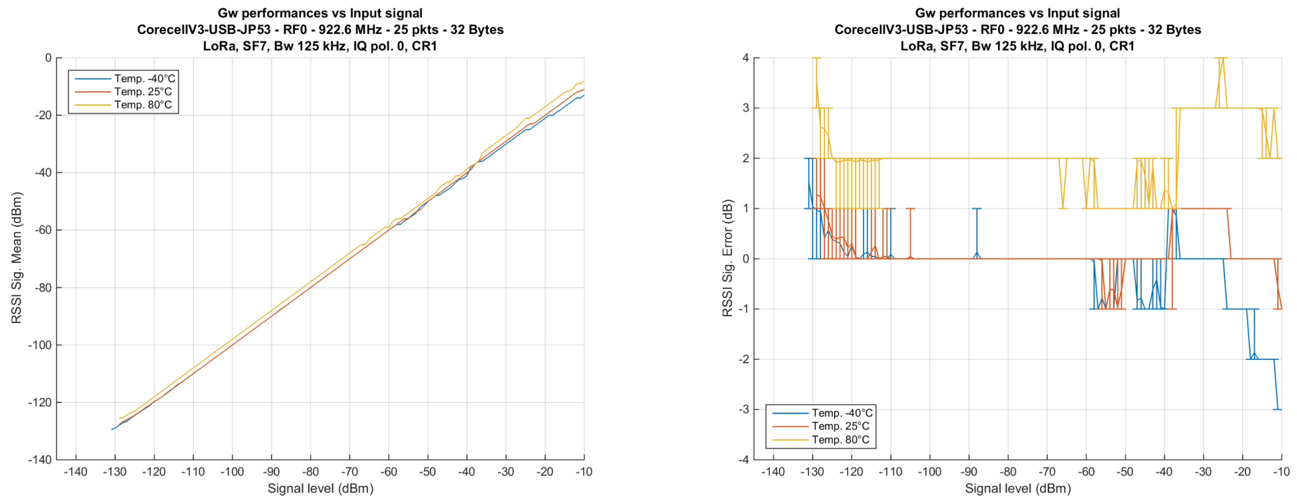


(a) RSSI mean

(b) RSSI error

Figure 15.25: RSSI channel vs temperature, Board JP53, MultiSF modem, 922.6 MHz, SF7, Bw 125 kHz, CR1

RSSI signal



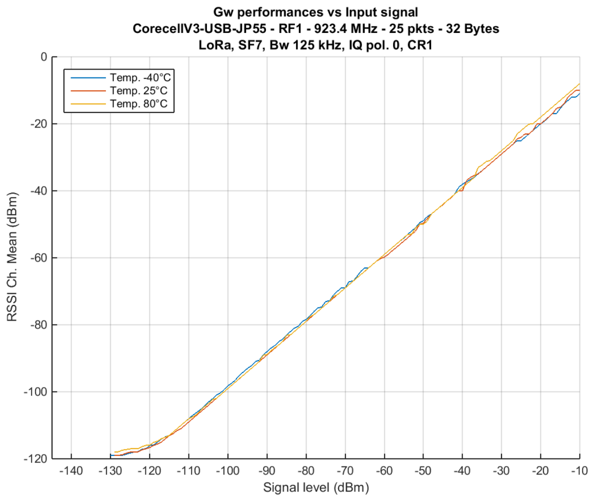
(a) RSSI mean

(b) RSSI error

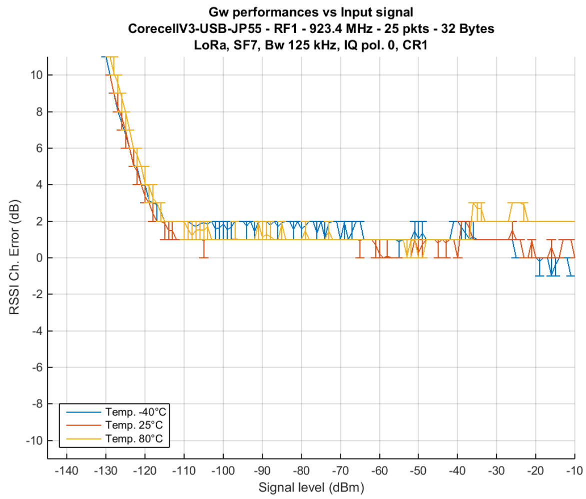
Figure 15.26: RSSI signal vs temperature, Board JP53, MultiSF modem, 922.6 MHz, SF7, Bw 125 kHz, CR1

15.8.3 MultiSF modem (923.4MHz)

RSSI channel



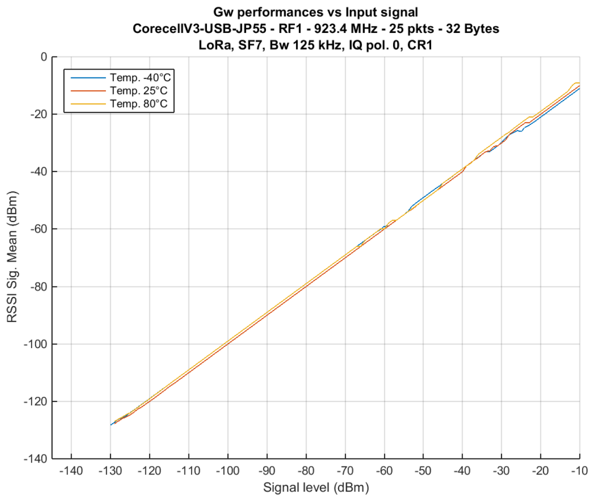
(a) RSSI mean



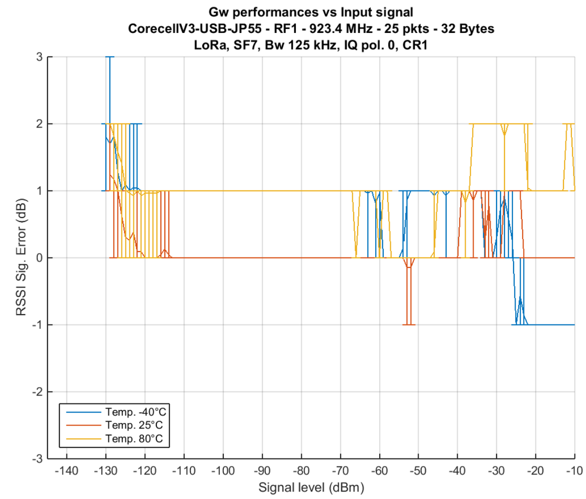
(b) RSSI error

Figure 15.27: RSSI channel vs temperature, Board JP55, 923.4 MHz, SF7, Bw 125 kHz, CR1

RSSI signal



(a) RSSI mean



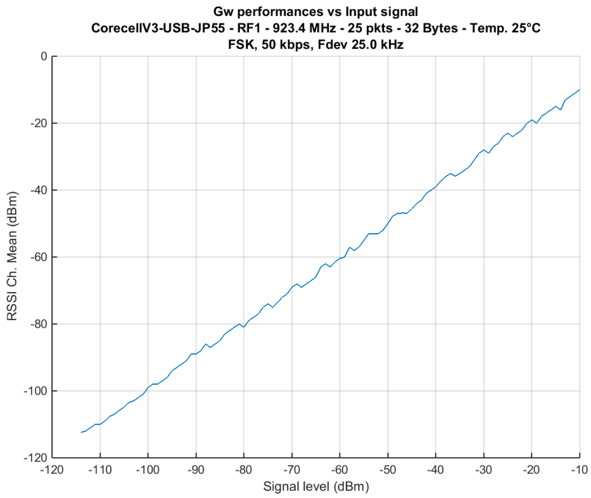
(b) RSSI error

Figure 15.28: RSSI signal vs temperature, Board JP55, 923.4 MHz, SF7, Bw 125 kHz, CR1

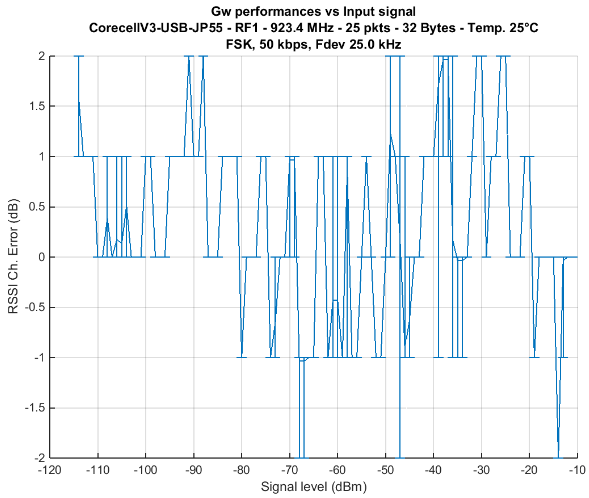
15.9 FSK modem

The following polynomial coefficients are used to linearise the RSSI from the FSK modem:

```
/* polynomiam coefficients to linearize FSK RSSI */
#define RSSI_FSK_POLY_0         90.636423
#define RSSI_FSK_POLY_1         0.420835
#define RSSI_FSK_POLY_2         0.007129
#define RSSI_FSK_POLY_3         -0.000026
```



(a) RSSI mean



(b) RSSI error

Figure 15.29: RSSI channel FSK modem, Board JP55, 923.4 MHz, 50 kbps, Fdev 25kHz, 25°C

15.10 Conclusion

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

16 SNR

16.1 Presentation

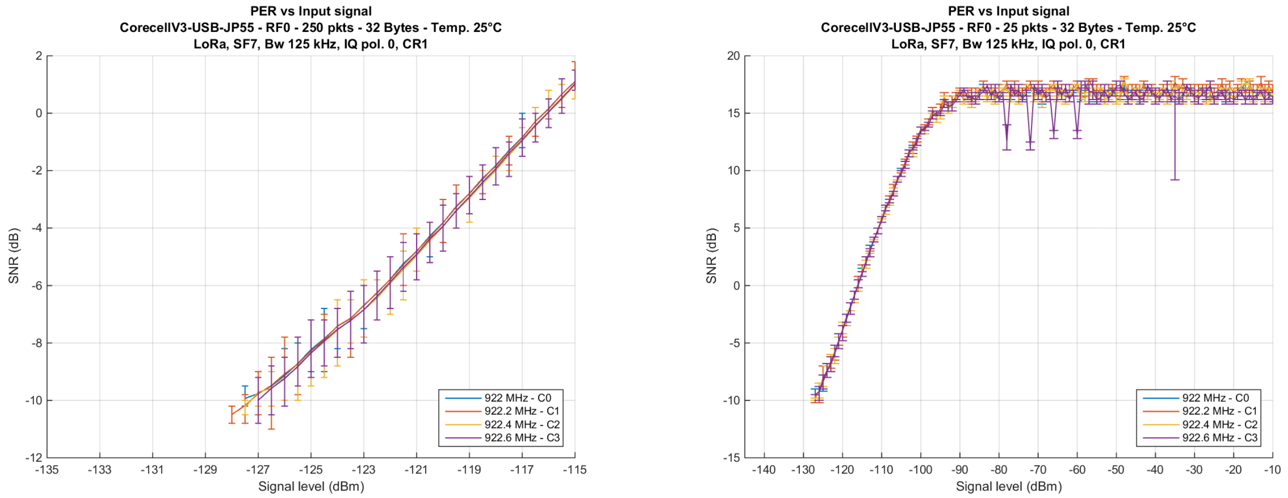
In conjunction with the RSSI value, the LoRa modem determines the Signal-To-Noise Ratio while receiving packets. This test verifies the accuracy of this indicator according the packet parameters (Carrier frequency, Spreading Factor, payload length, ...)

16.2 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.

16.3 Frequency influence

16.3.1 MultiSF modem (Lower band)

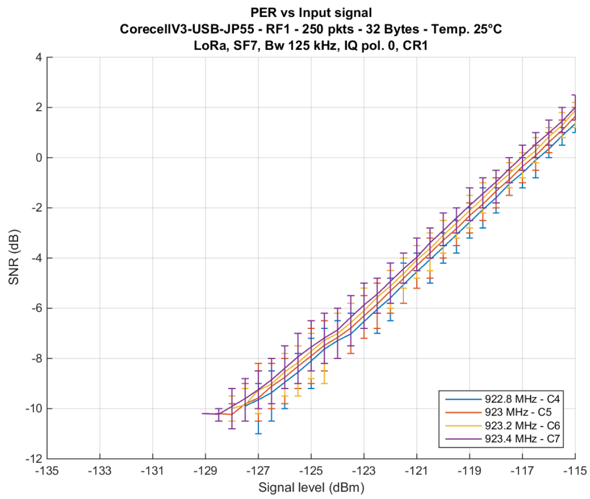


(a) Sensitivity level

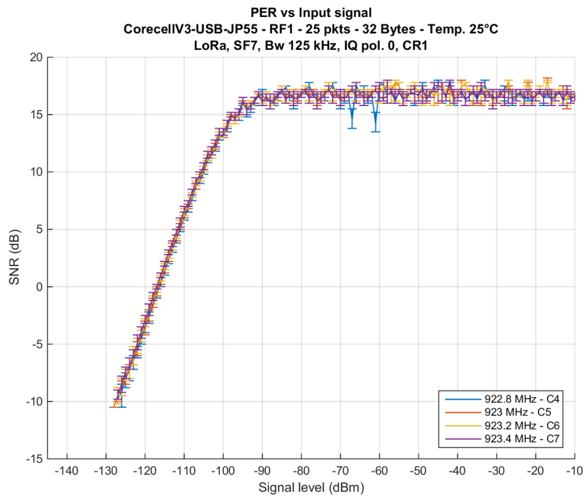
(b) High level

Figure 16.1: SNR vs channels (Lower band), Board JP55, MultiSF modem, SF7, Bw 125 kHz, 32 bytes, 25°C

16.3.2 MultiSF modem (Higher band)



(a) Sensitivity level

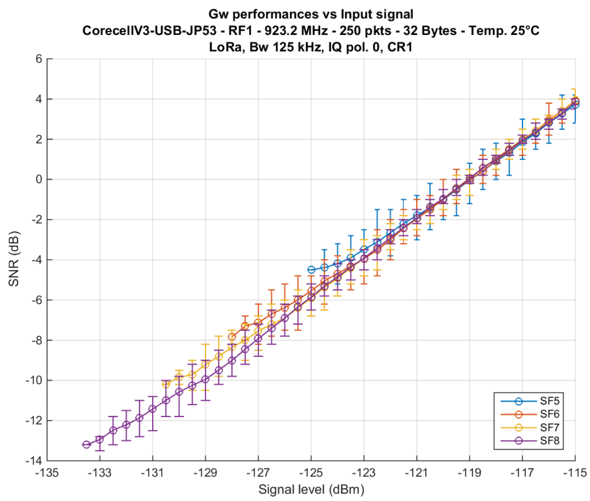


(b) High level

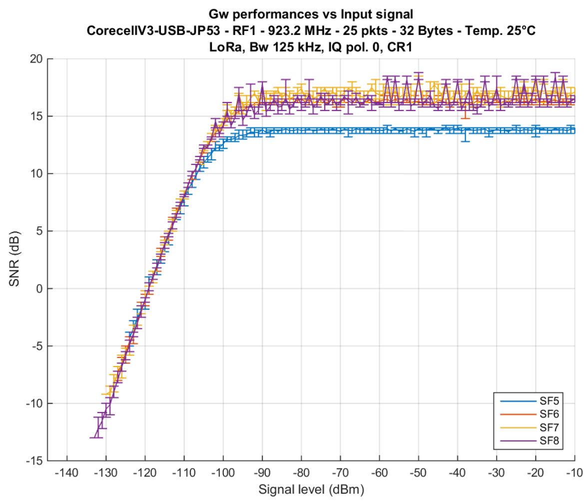
Figure 16.2: SNR vs channels (Higher band), Board JP55, MultiSF modem, SF7, Bw 125 kHz, 32 bytes, 25°C

16.4 Spreading Factor influence

16.4.1 MultiSF modem (923.2 MHz)

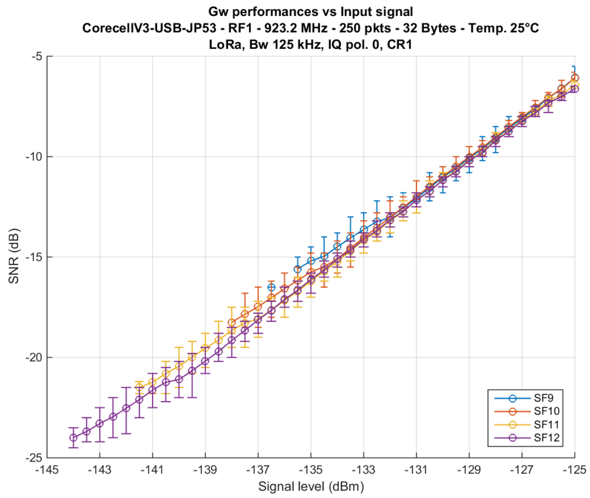


(a) Sensitivity level

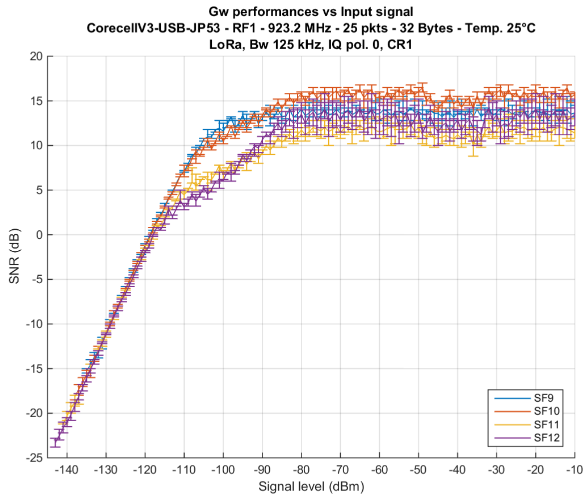


(b) High level

Figure 16.3: SNR vs SF (5 to 8), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 32 bytes, 25°C



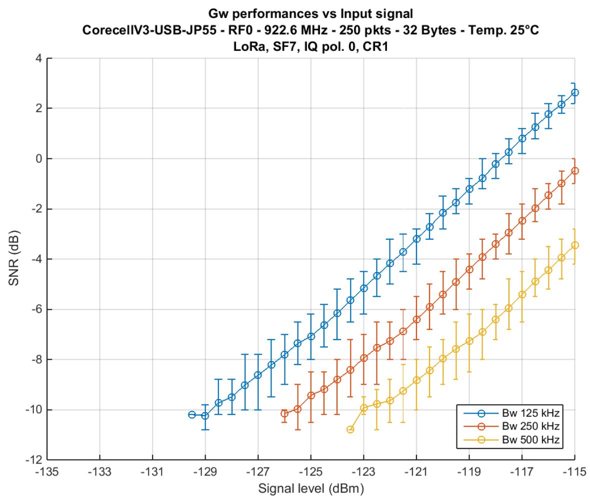
(a) Sensitivity level



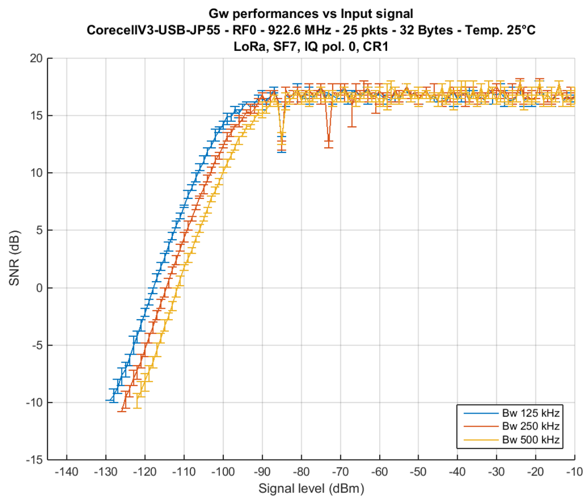
(b) High level

Figure 16.4: SNR vs SF (9 to 12), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 32 bytes, 25°C

16.5 Bandwidth influence



(a) Sensitivity level

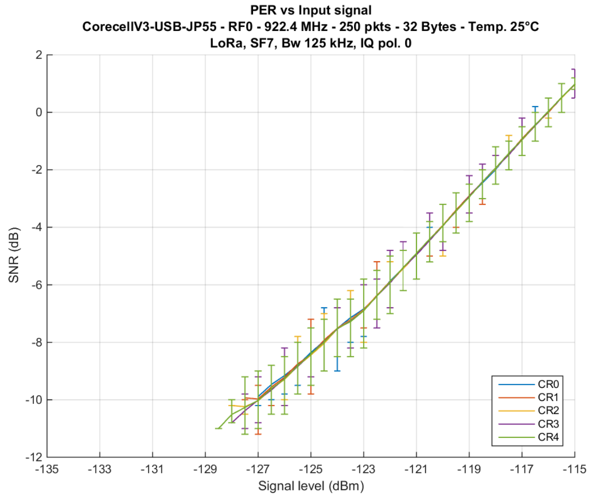


(b) High level

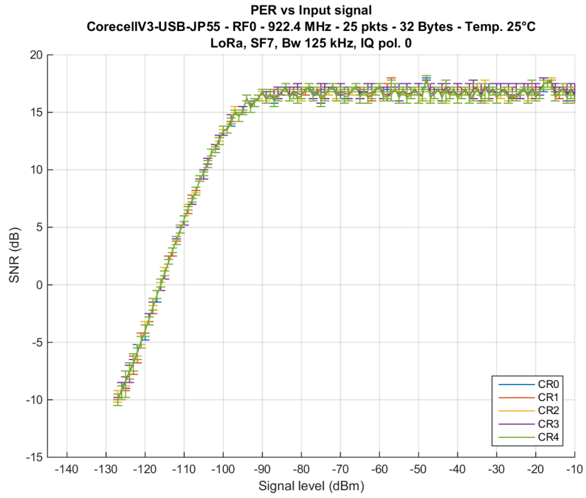
Figure 16.5: SNR vs bandwidth, Board JP55, SingleSF modem, 922.6 MHz, SF7, Bw 125 kHz, 32 bytes, 25°C

16.6 Coding rate influence

16.6.1 MultiSF modem (922.4 MHz)



(a) Sensitivity level



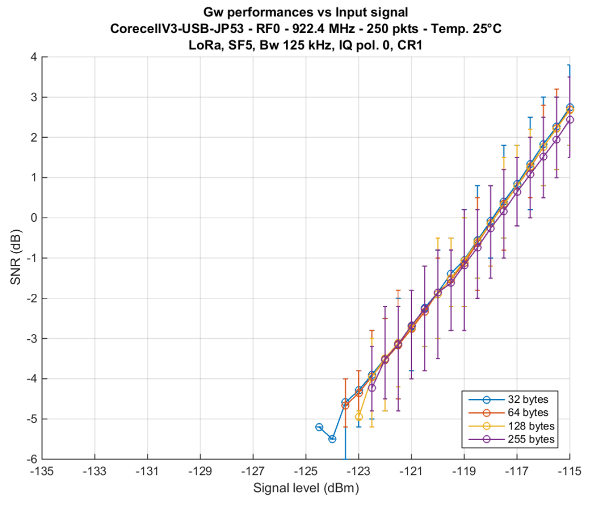
(b) High level

Figure 16.6: SNR vs coding rate, Board JP55, MultiSF modem, 922.4 MHz, SF7, Bw 125 kHz, 32 bytes, 25°C

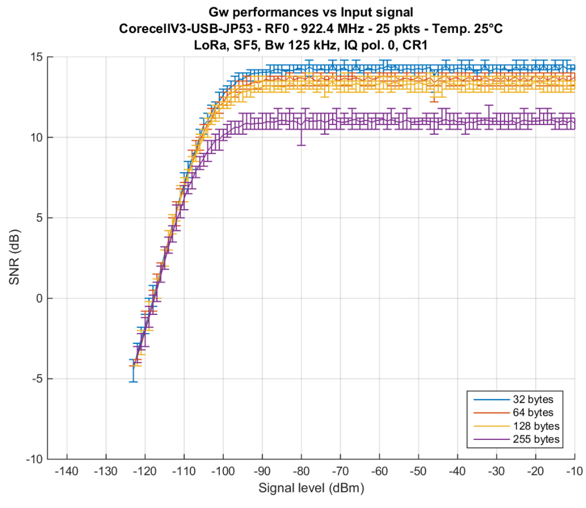
16.7 Payload length influence

16.7.1 MultiSF modem, Bw 125 kHz

SF5



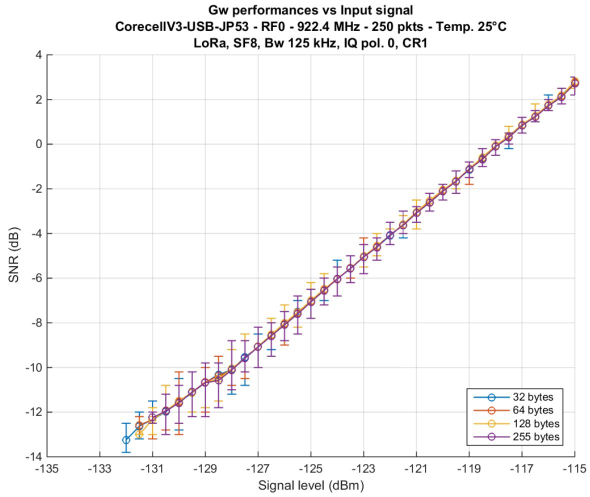
(a) Sensitivity level



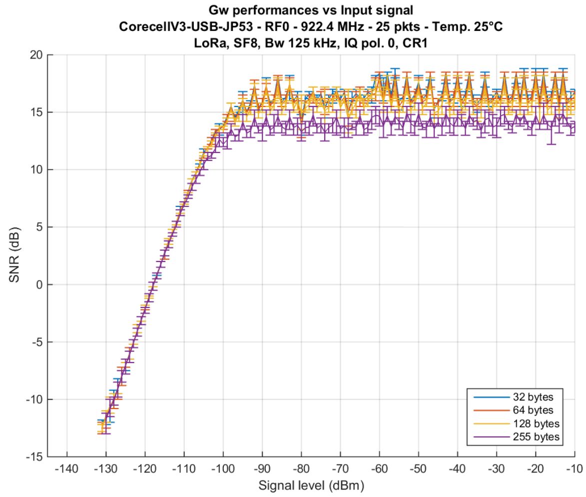
(b) High level

Figure 16.7: SNR vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF5, Bw 125 kHz, CR1, 25°C

SF8



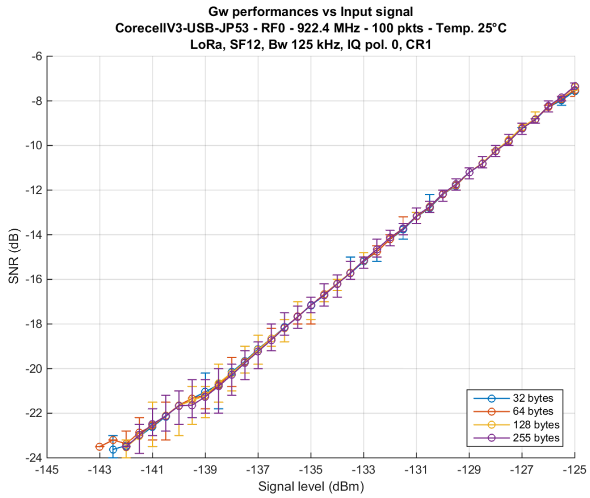
(a) Sensitivity level



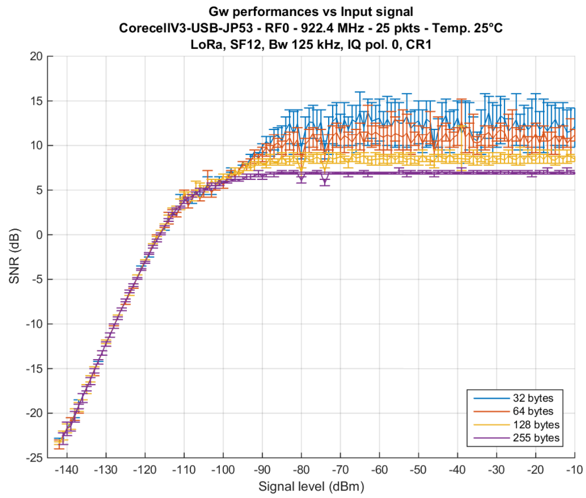
(b) High level

Figure 16.8: SNR vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF8, Bw 125 kHz, CR1, 25°C

SF12



(a) Sensitivity level

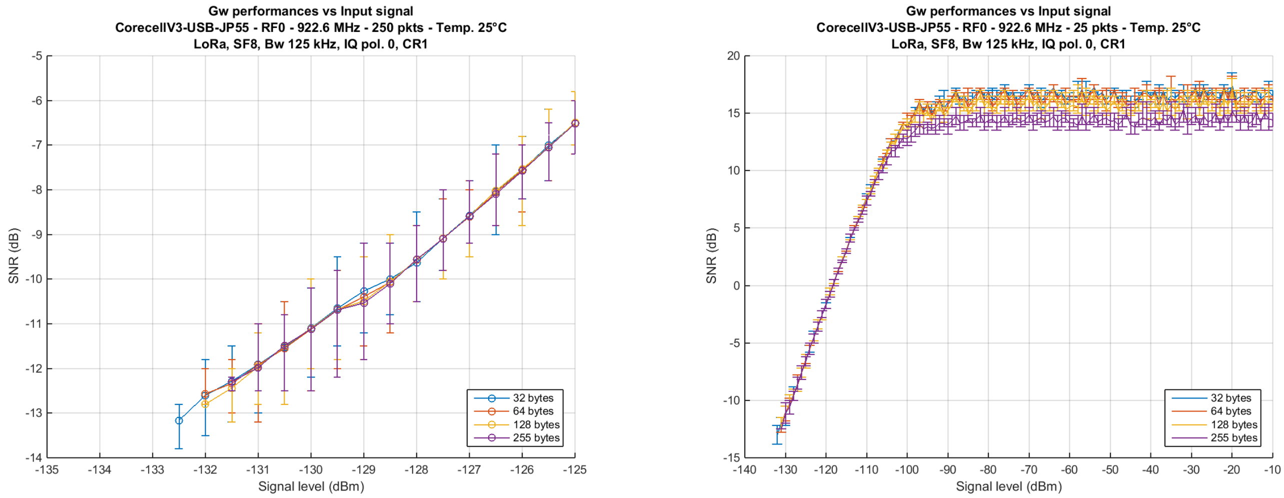


(b) High level

Figure 16.9: SNR vs payload length, Board JP53, MultiSF modem, 922.4 MHz, SF12, Bw 125 kHz, CR1, 25°C

16.7.2 SingleSF modem, Implicit header (922.6 MHz)

Bandwidth 125 kHz

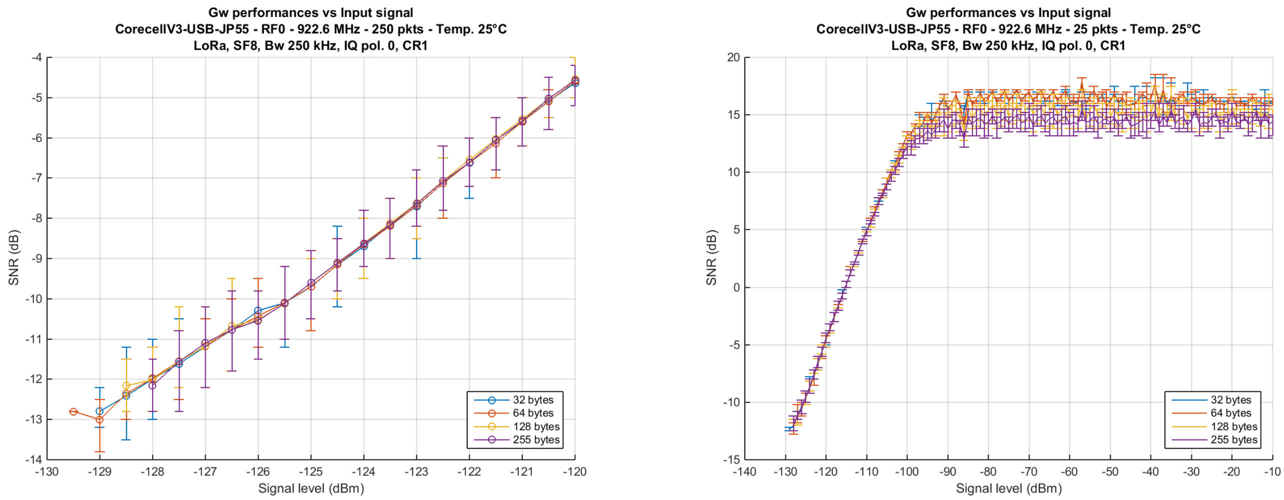


(a) Sensitivity level

(b) High level

Figure 16.10: SNR vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 125 kHz, CR1, 25°C

Bandwidth 250 kHz

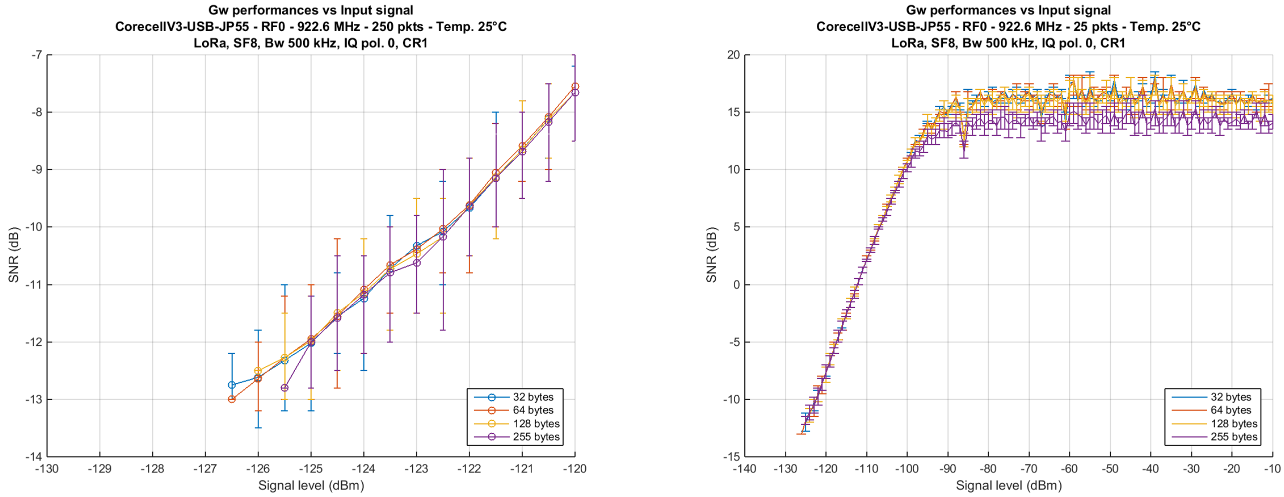


(a) Sensitivity level

(b) High level

Figure 16.11: SNR vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 250 kHz, CR1, 25°C

Bandwidth 500 kHz

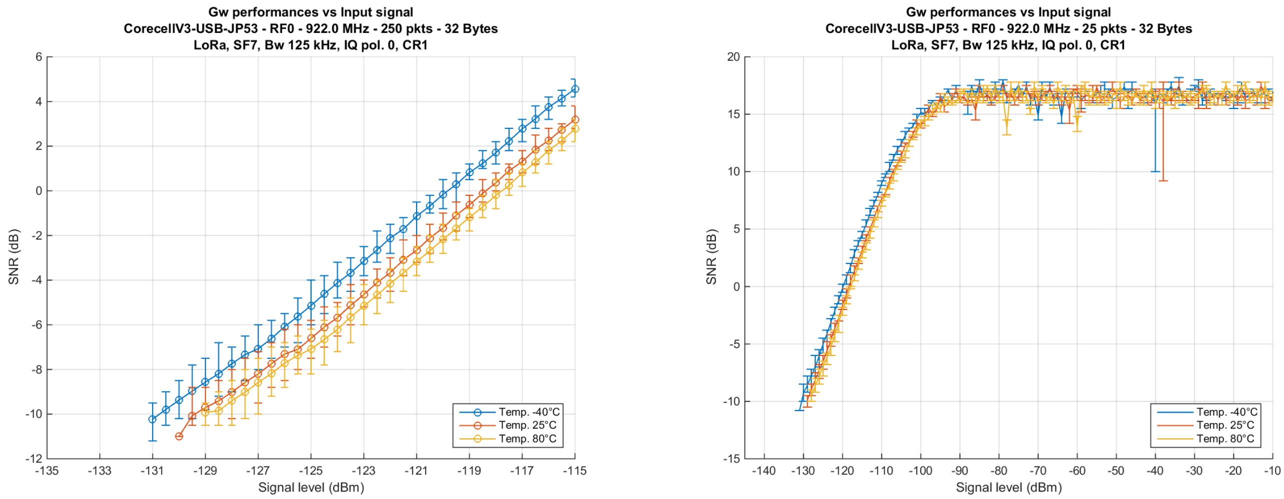


(a) Sensitivity level (b) High level

Figure 16.12: SNR vs payload length, Board JP55, SingleSF modem (Implicit), 922.6 MHz, SF8, Bw 500 kHz, CR1, 25°C

16.8 Temperature influence

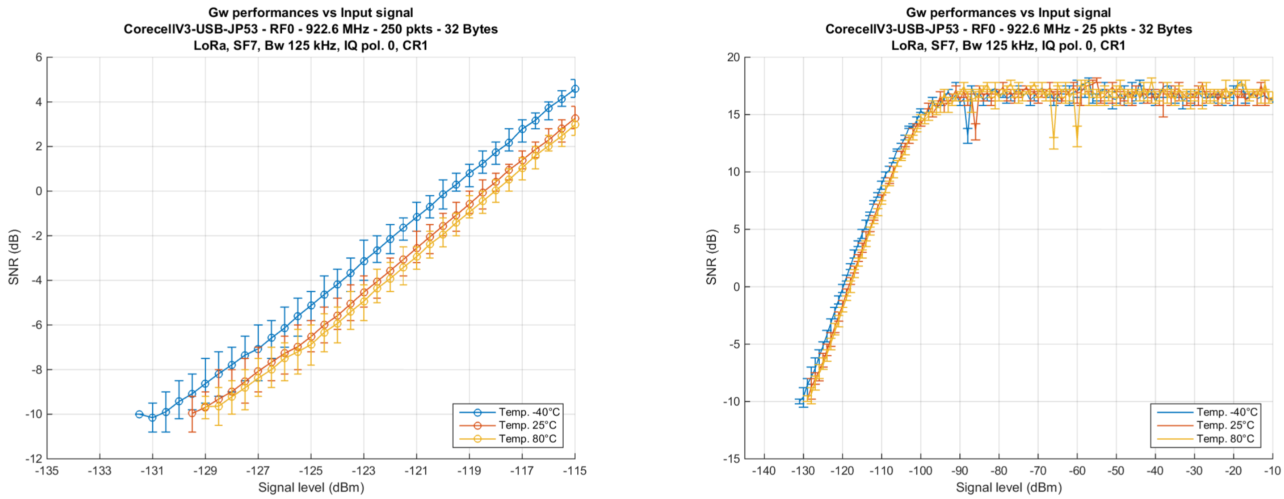
16.8.1 MultiSF modem (922.0 MHz)



(a) Sensitivity level (b) High level

Figure 16.13: SNR vs temperature, Board JP53, MultiSF modem, 922.0 MHz, SF7, Bw 125 kHz, CR1

16.8.2 MultiSF modem (922.6 MHz)

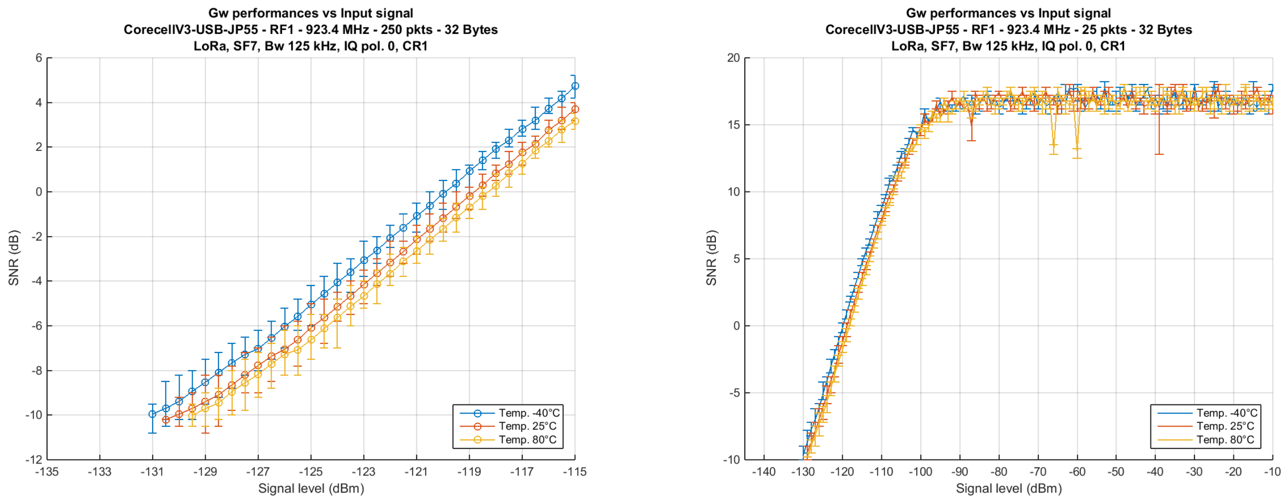


(a) Sensitivity level

(b) High level

Figure 16.14: SNR vs temperature, Board JP53, MultiSF modem, 922.6 MHz, SF7, Bw 125 kHz, CR1

16.8.3 MultiSF modem (923.4 MHz)



(a) Sensitivity level

(b) High level

Figure 16.15: SNR vs temperature, Board JP55, MultiSF modem, 923.4 MHz, SF7, Bw 125 kHz, CR1

16.9 Conclusion

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

17 Blocking and Immunity to interferer

17.1 Description

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

17.2 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.

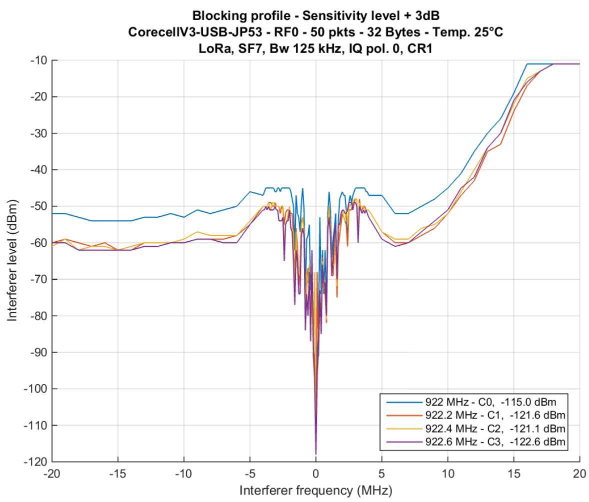
The interferer is a continuous carrier wave swept from -20 to +20 MHz in comparison with the carrier frequency, with a variable step in order to find sensitive frequencies.

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

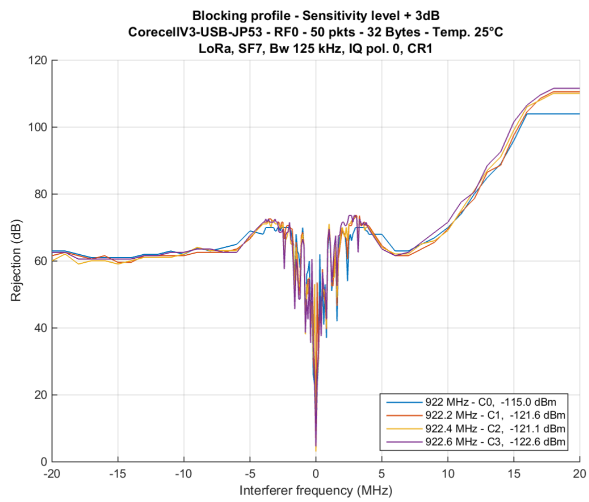
17.3 Frequency influence

→ **All the following measurements have been performed using SAW filters suitable for US band and not for the AS923 band. The blocking profile shall be improved with the suitable SAW filter.**

17.3.1 MultiSF modem (Lower band)



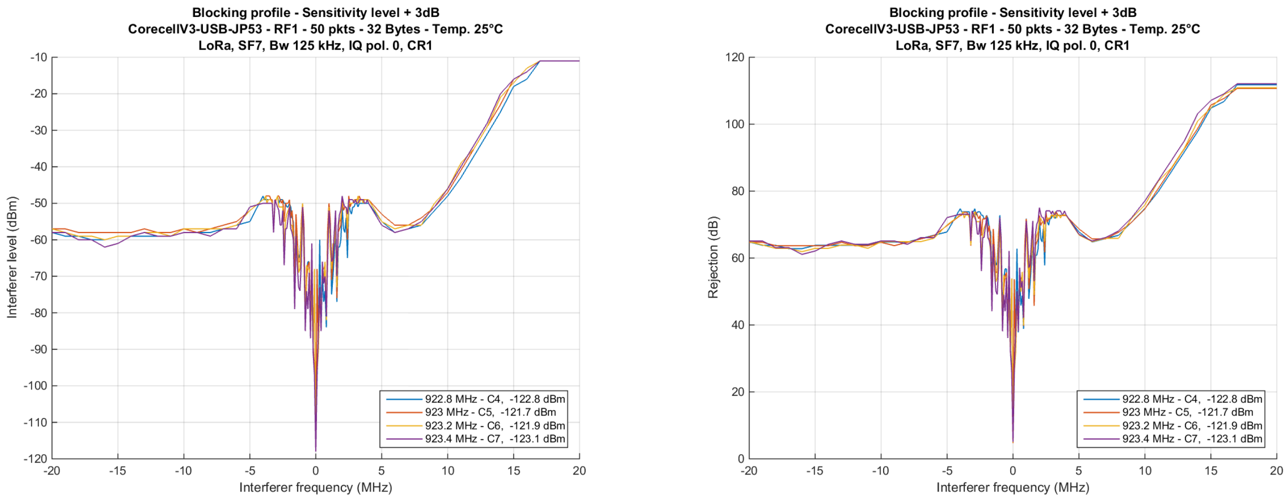
(a) Interferer level (dBm)



(b) Rejection (dB)

Figure 17.1: Blocking profile vs channels (Lower band), Board JP53, MultiSF modems, SF7, 25°C

17.3.2 MultiSF modem (Higher band)



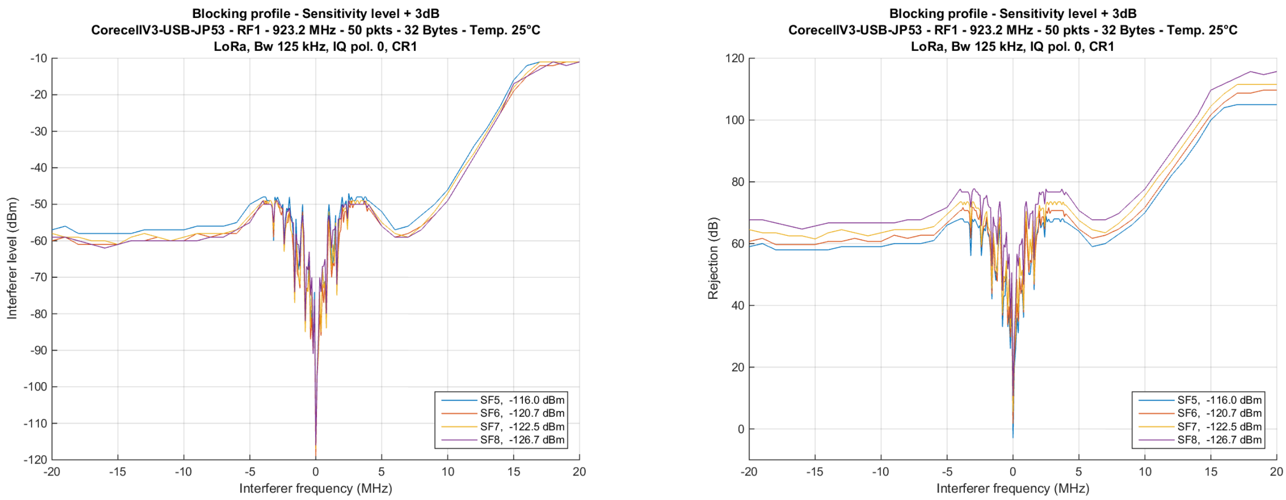
(a) Interferer level (dBm) (b) Rejection (dB)

Figure 17.2: Blocking profile vs channels (Higher band), Board JP53, MultiSF modems, SF7, 25°C

17.4 Spreading factor influence

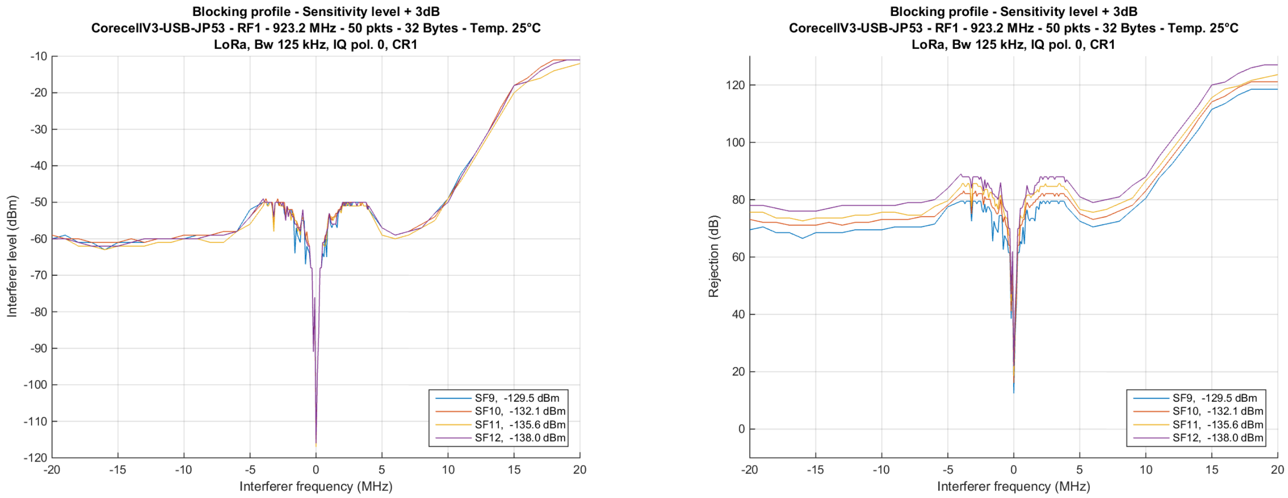
17.4.1 MultiSF modem (923.2 MHz)

Wideband



(a) Interferer level (dBm) (b) Rejection (dB)

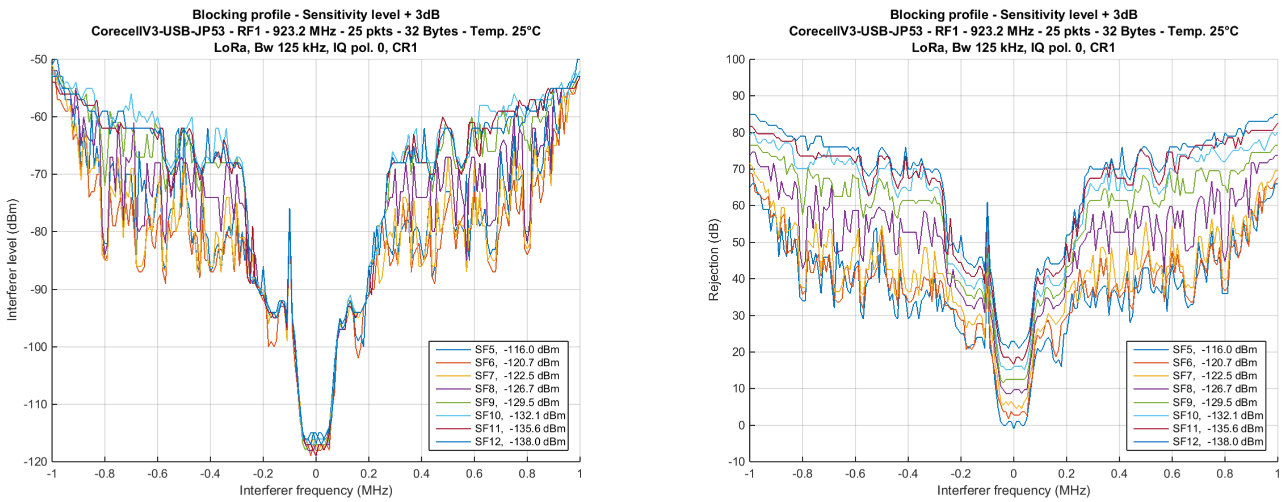
Figure 17.3: Blocking profile vs SF (5 to 8), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 25°C



(a) Interferer level (dBm) (b) Rejection (dB)

Figure 17.4: Blocking profile vs SF (9 to 12), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 25°C

Zoom around the center frequency



(a) Interferer level (dBm) (b) Rejection (dB)

Figure 17.5: Blocking profile vs SF (5 to 12), Zoom, Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 25°C

→ As expected the rejection at the SX1250 PLL center frequency (Offset -100 kHz) is increased thanks to the DC notch.

17.5 Conclusion

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

18 Frequency error tolerance

18.1 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.

18.2 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 are updated simultaneously with the evaluated error.

18.3 FSK modem

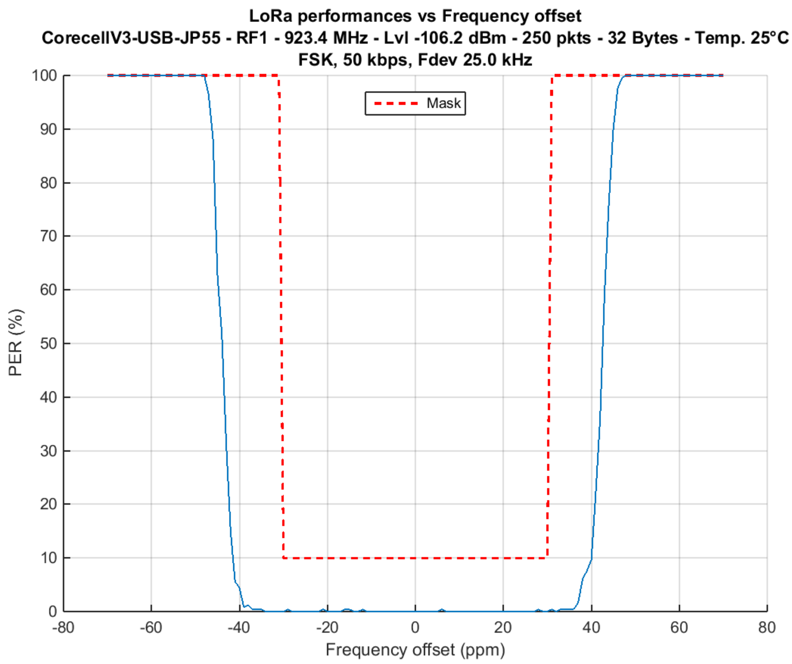
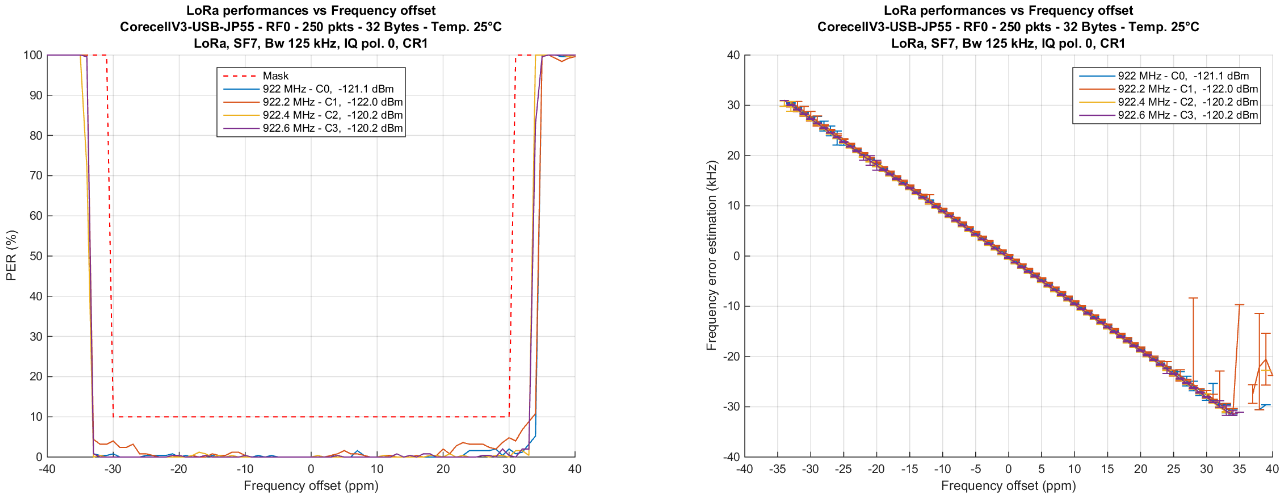


Figure 18.1: Frequency error tolerance, Board JP55, FSK modem, 923.4 MHz, Fdev 25 kHz, 32 bytes

18.4 Frequency influence

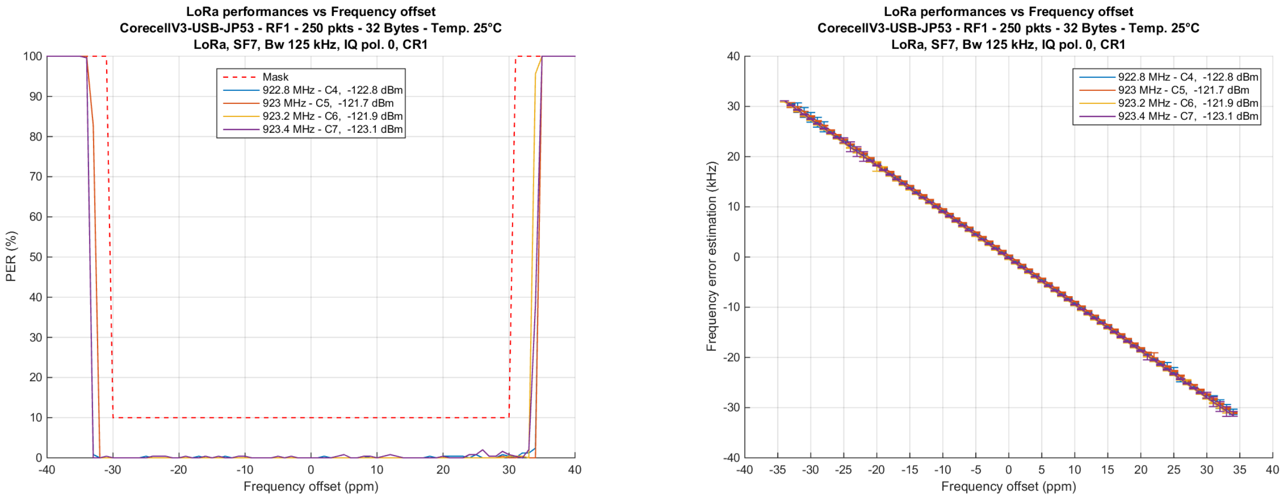
18.4.1 MultiSF modems (Lower band), Bandwidth 125 kHz



(a) Tolerance (b) Freq. Estimation

Figure 18.2: Frequency error tolerance vs channels (Lower band), Board JP55, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

18.4.2 MultiSF modems (Higher band), Bandwidth 125 kHz

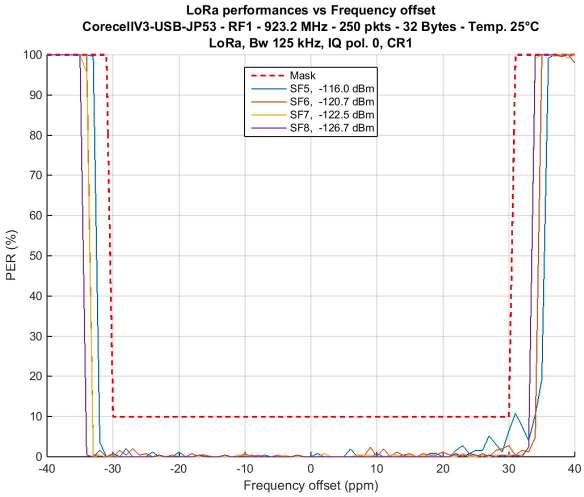


(a) Tolerance (b) Freq. Estimation

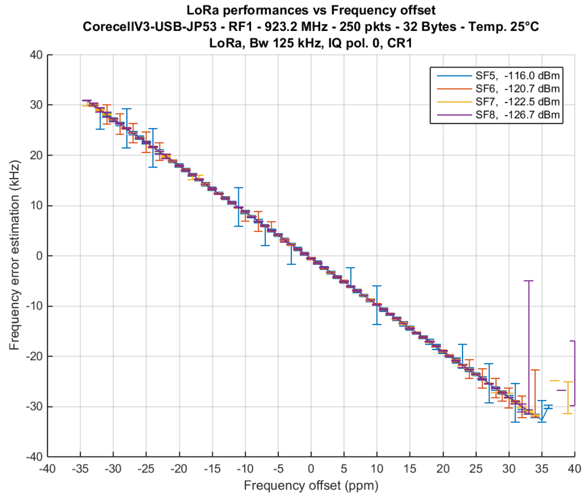
Figure 18.3: Frequency error tolerance vs channels (Higher band), Board JP53, MultiSF modems, SF7, Bw 125 kHz, 32 bytes, 25°C

18.5 Spreading factor influence

18.5.1 MultiSF modem (923.2 MHz)

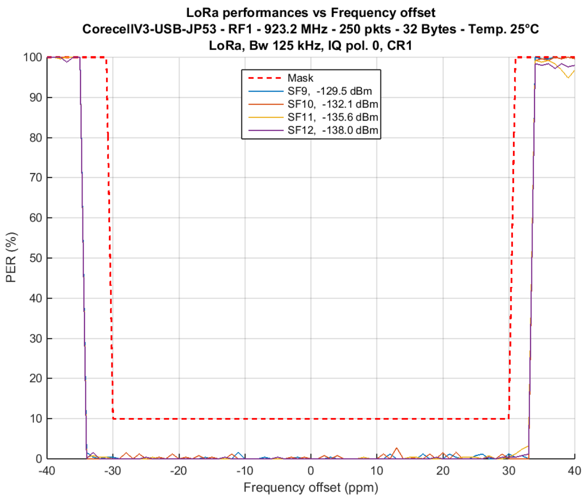


(a) Tolerance

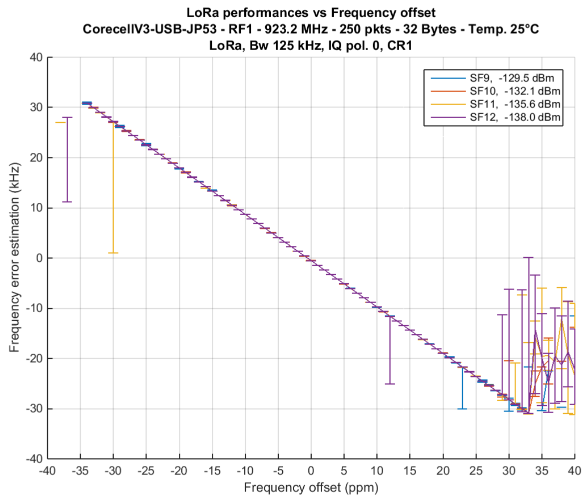


(b) Freq. Estimation

Figure 18.4: Frequency error tolerance vs SF (5 to 8), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 32 bytes, 25°C



(a) Tolerance



(b) Freq. Estimation

Figure 18.5: Frequency error tolerance vs SF (9 to 12), Board JP53, MultiSF modem, 923.2 MHz, Bw 125 kHz, 32 bytes, 25°C

18.6 Conclusion

→ **The MultiSF, the SingleSF and the FSK modems are tolerant to a Xtal frequency error between ± 30ppm.**

19 Frequency drift tolerance

19.1 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 and specifically the sensitivity level in function of the frequency drift and allows to determinate the range for which the SX1302 is able to track.

19.2 Setup

The setup used for this measurement is shown in figure 3.1; Only one signal generator is 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.

19.3 Results

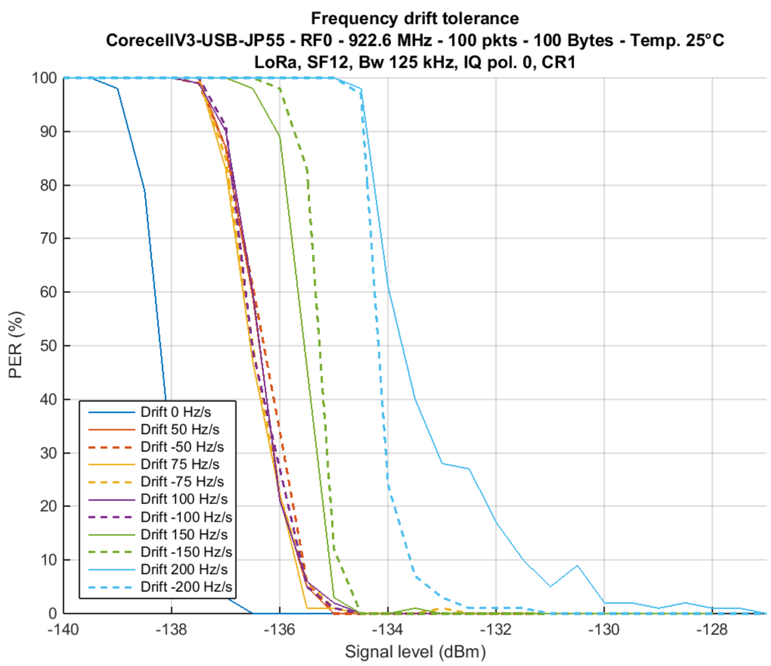


Figure 19.1: Frequency drift tolerance, Board JP55, MultiSF modem, 904.7 MHz, SF10, Bw 125 kHz, 64 bytes, 25°C

19.4 Conclusion

The sensitivity level of the MultiSF modem (125 kHz bandwidth) is degraded by 3dB when the frequency drift reaches ±150 Hz/s.

20 Carrier sense / LBT feature

20.1 Description

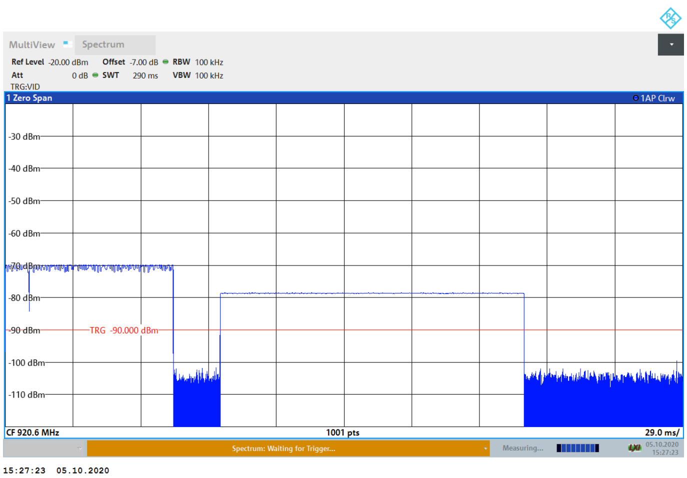
The gateway implements a carrier sense / LBT mechanism in order to assess if the channel is clear before transmit. This features is requested by the ARIB regulation.

The content of this chapter evaluates the mechanism and its compliance with the regulation.

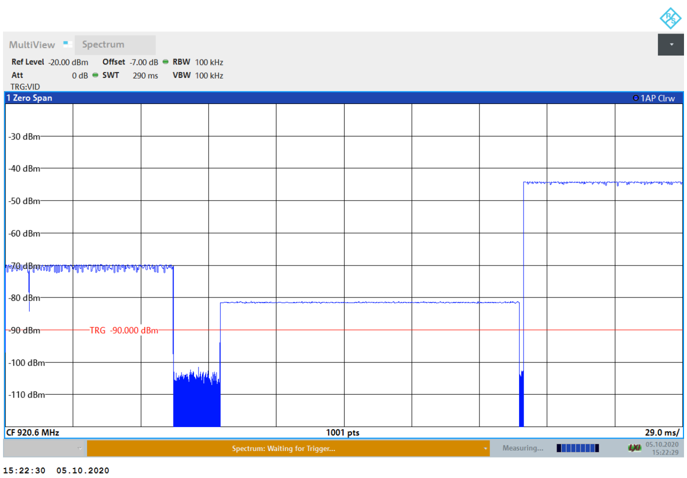
20.2 Setup

The setup used for this measurement is described in the section 3.1. A signal generator sends an uplink packet to the gateway which forwards it to the server (Matlab script). The last requests a downlink about 150 ms after the uplink.

Just after the uplink packet, an interferer is generated and up to the instant just before the downlink. The gap between the interferer end and the beginning of the downlink emission time is configurable as well as the level of the interferer.



(a) Downlink forbidden



(b) Downlink allowed

Figure 20.1: LBT Setup: after the uplink packet, an interferer is added just before the downlink

20.3 Threshold over channel bandwidth

This measurement checks variation of the threshold over the receiver bandwidth.

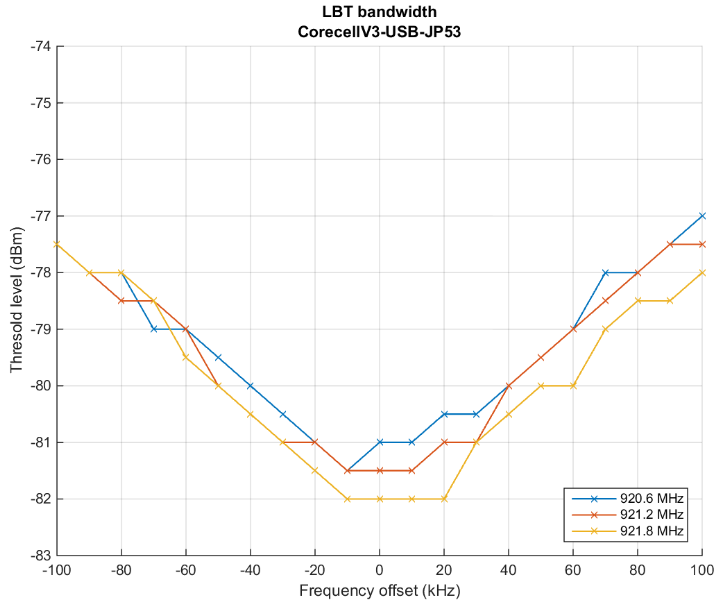


Figure 20.2: LBT, Threshold over channel bandwidth, Board JP53

At the channel band edges, the threshold is increased by 3 to 4 dB in comparison with the channel center frequency. This is coherent with the Rx channel bandwidth set in the SX1261 which perform the LBT function. Furthermore, this behaviour is similar to the one measured on the LoRaLoc gateway V2.

20.4 Threshold over channel

This measurement checks the threshold over several channels.

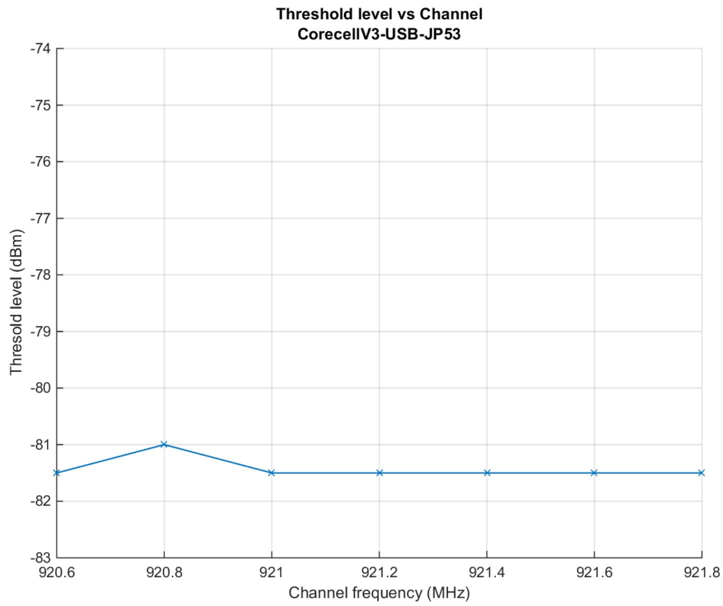


Figure 20.3: LBT, Threshold over channel, Board JP53

20.5 Scan duration

This measurement determines when the presence of the interferer is performed.

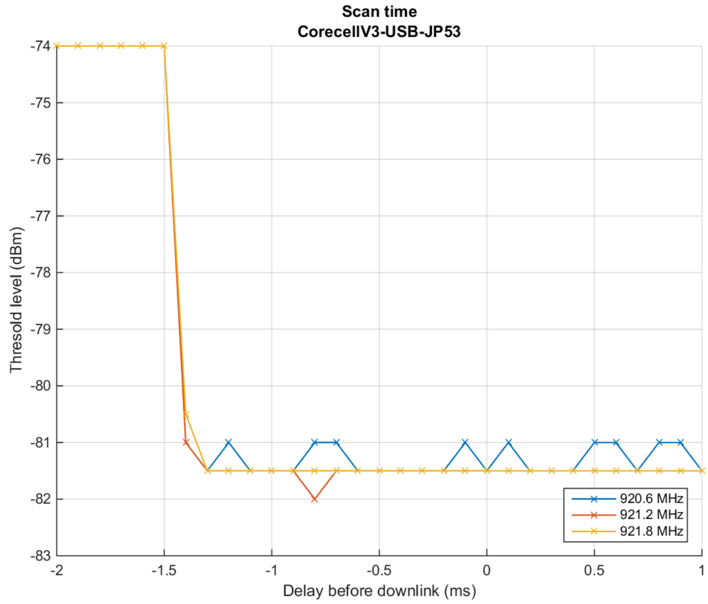


Figure 20.4: LBT, Scan duration, Board JP53

The clear channel assessment is performed 1.4 ms before the start of packet.

20.6 Conclusion

→ **The LBT algorithm implemented in the SX1261 works as expected and complies with the ARIB standard requirements.**

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

Contact Information

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