Application note

RF certification process for NUCLEO-WL55JC

Introduction

Across the world, regulatory agencies manage their national spectra by assigning frequencies to specific uses and by establishing a system of technical requirements so that the devices which are intended to be used by multiple users can efficiently function together and limit overall interference.

Many types of devices are existing and in general regulatory agencies group devices under two major categories of operation: unintentional radiators and intentional radiators.

An intentional radiator includes any electronic that deliberately uses radio waves / RF to communicate. Common types of radio transmitters include cell phones, garage door openers, wireless microphones, remote controls, and various IoT sensors and other devices use throughout the home.

The NUCLEO-WL55JC STM32WL Nucleo-64 board (MB1389) is an intentional radiator as it contains a sub-GHz LoRa®/ Sigfox™ transceiver (transmitter and receiver) and then, must comply with various RF certifications.

The most common RF certifications are defined by the Federal Communications Commission (FCC) for the USA, Innovation, Science and Economic Development (ISED) previously Industry Canada (IC) for Canada, the radio equipment directive (RED) from the European Telecommunications Standards Institute (ETSI) for Europe, the type certification from the Association of Radio Industries and Businesses (ARIB) for Japan, and China Compulsory Certification (CCC), not covered in this document, for the People's Republic of China.

Many certification laboratories can handle and support such RF certifications. Among them, there are:

- SGS: https://www.sgs.com/en/certification
- LCIE: https://www.lcie.com/en/811-our-services/certification.html
- SMEE: http://smee.fr/en/contact/
- CETECOM: https://www.cetecom.com/en/testing/

To complete the various RF certifications, there are generally two types of boards called standard and engineering samples that must be prepared for RF certification tests.

Standard samples are boards as they are sold with the downloaded embedded demonstration software. RF engineering samples are boards where an AT command software is downloaded to manage the transceiver to perform transmit or receive patterns on a chosen channel, power, or modulation.

For better readability, the list of all the tests to perform for different RF certification countries are highlighted in color. When blue color is used in the test list, the considered test is done on normal samples. When yellow color is used in the test list, the considered test is done on RF engineering samples. When green color is used in the test list, this means that both normal samples or RF engineering samples can be used.

The purpose of this document is to provide help and guidelines to proceed with the certification of the user's boards. It is currently focusing on FCC (USA), ISED (Canada), RED (Europe), and ARIB (Japan) RF certifications.

Caution: This application note does not replace in any way the reference texts of the standards.

1 RF certification tests overview

This chapter does not replace in any way the reference texts of the standards but provides help and guidelines to proceed with the certification of the user's boards.

The indicated colors illustrate which kind of samples, either normal or RF engineering ones, are used for the considered test.

When the blue color is used in the test list, the considered test is performed on normal samples. When the yellow color is used in the test list, the considered test is performed on RF engineering samples. When the green color is used in the test list, this means that both normal samples or RF engineering samples can be used.

1.1 FCC certification

FCC certification tests are addressing the North American market.

Refer to the official regulation website https://ecfr.federalregister.gov/current/title-47/chapter-I/subchapter-A/part-15/subpart-C

RF certification tests to perform are FCC tests following:

- 47 CFR Part 15 - RADIO FREQUENCY DEVICES
- Subpart C - Intentional Radiators
- Chap § 15.207 Conducted limits,
- Chap § 15.209 Radiated emission limits; general requirements,
- Chap § 15.247 Operation within the bands 902 - 928 MHz, 2400 - 2483.5 MHz, and 5725 - 5850 MHz

The test summary is displayed in Table 1:

Table 1. Test summary

Item	Requirement	Test method	Limits
Antenna requirement	47 CFR Part 15 Subpart C 15.203 and 15.247	NA	Antenna directional gain less than 6 dBi
Frequency hopping, spread spectrum System hopping sequence	47 CFR Part 15 Subpart C 15.247 (a) (1), (g) (h)	NA	-
Conducted emissions at AC power lines (150 kHz - 30 MHz)	47 CFR Part 15 Subpart C 15.207	ANSI C63.10 (2013) Section 6.2	Refer to Table 2.
Conducted Peak Output power	47 CFR Part 15 Subpart C 15.247 (b) (2)	ANSI C63.10 (2013) Section 7.8.5	0,25W (24dBm) max for 25 ≤ hopping channels < 50
20 dB Bandwith	47 CFR Part 15 Subpart C 15.247 (a) (1) (i))	ANSI C63.10 (2013) Section 7.8.7	-
Carrier frequency separation	47 CFR Part 15 Subpart C 15.247 (a) (1)	ANSI C63.10 (2013) Section 7.8.2	minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater
Hopping channel number	47 CFR Part 15 Subpart C 15.247 (b) (1) (i)	ANSI C63.10 (2013) Section 7.8.3	50 channels for 20 dB bandwidth < 250 kHz 25 channels for 20 dB bandwidth ≥ 250 kHz
Dwell time	47 CFR Part 15 Subpart C 15.247 (b) (1) (i)	ANSI C63.10 (2013) Section 7.8.4	< 0.4 s within a 20 s period (when 20 dB bandwidth < 250 kHz) < 0.4 s within a 10 s period (when 20 dB bandwidth ≥ 250 kHz)
Conducted Band Edges Measurement	47 CFR Part 15 Subpart C 15.247 (d)	ANSI C63.10 (2013) Section 7.8.6	20 dB below in any 100 kHz bandwidth outside the frequency band
Conducted spurious emissions	47 CFR Part 15 Subpart C 15.247 (b) (1)	ANSI C63.10 (2013) Section 7.8.8	-
Radiated emissions which falls in the restricted bands	47 CFR Part 15 Subpart C 15.205 and 15.209	ANSI C63.10 (2013) Section 6.10.5	-
Radiated spurious emissions	47 CFR Part 15 Subpart C 15.205 and 15.209	ANSI C63.10 (2013) Section 6.4, 6.5, 6.6	Refer to Table 3.
Color code: the test is applied on		Normal samples	
		Engineering samples	
		Both normal and engineering samples	

Table 2. Conducted emissions at AC power lines (150 kHz - 30 MHz)

Emission frequency (MHz)	Conducted limit (dBµV)	
	Quasi-peak	Average
0.15 - 0.5	66 to 56(1)	56 to 46(1)
0.5 - 5	56	46
5 - 30	60	50

1. *Decreases with the logarithm of the frequency*

Table 3. Radiated spurious emissions

Frequency (MHz)	Field strength (µV/m)	Measurement distance (m)
0.009 - 0.490	2400 / f (kHz)	300
0.490 - 1.705	24000 / f (kHz)	30
1.705 - 30.0	30	30
30 - 88	100	3
88 - 216	150	3
216 - 960	200	3
Above 960	500	3

Note: The emission limits shown in Table 3 are based on measurements employing a CISPR quasi-peak detector except for the frequency bands 9 - 90 kHz, 110 - 490 kHz, and above 1000 MHz. Radiated emission limits in these three bands are based on measurements employing an average detector, the peak-field strength of any emission must not exceed the maximum permitted average limits specified above by more than 20 dB under any modulation condition.

1.2 ISED certification

ISED certification tests are addressing the Canadian market.

Refer to the official regulation website https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10971.html

RF certification tests to perform are FCC tests following:

- RSS 247 - Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and Licence-Exempt Local Area Network (LE-LAN) Devices
- RSS GEN - General Requirements for Compliance of Radio Apparatus

The test summary is displayed in Table 4:

Table 4. Test summary

Item	Requirement	Test method
Antenna requirement	RSS GEN clause 6.8	indicates the maximum permissible antenna gain (in dBi) and the required impedance for each antenna type
Conducted emissions at AC power lines (150 kHz - 30 MHz)	RSS GEN clause 8.8	Refer to Table 5.
Conducted Peak Output power	RSS 247 clause 5.4 a)	The maximum peak conducted output power must not exceed 0.25 W and the effective isotropic radiated power (EIRP) must not exceed 1 W if the hopset uses less than 50 hopping channels
99% OBW and 20 dB BW	RSS 247 clause 5.1 a) RSS GEn clause 6.7	-
Carrier frequency separation	RSS 247 clause 5.1 a)	-
Hopping channel number	RSS 247 clause 5.1 c)	50 channels for 20 dB BW < 250 kHz 25 channels for 20 dB BW ≥ 250 kHz
Dwell time	RSS 247 clause 5.1 c)	< 0.4 s within a 20 s period (when 20 dB BW < 250 kHz) < 0.4 s within a 10 s period (when 20 dB BW ≥ 250 kHz)
Conducted Band Edges Measurement	RSS 247 clause 5.5	20 dB below in any 100 kHz BW outside the frequency band
Radiated emissions which falls in the restricted bands	RSS 247 clause 5.5 RSS GEN clause 8.9	-
Radiated spurious emissions	RSS 247 clause 5.5 RSS GEN clause 8.10	Refer to Table 6/Table 7.
Color code: the test is applied on		Normal samples Engineering samples Both normal and engineering samples

Table 5. Conducted emissions at AC power lines (150 kHz - 30 MHz)

Emission frequency (MHz)	Conducted limit (dBμV)	
	Quasi-peak	Average
0.15 - 0.5	66 to 56	56 to 46
0.5 - 5	56	46
5 - 30	60	50

1. *Decreases with the logarithm of the frequency*

Radiated spurious emissions

Table 6. **General field strength limits at frequencies above 30 MHz**

Frequency (MHz)	Field strength (µV/m at 3 m)
30 - 88	100
88 - 216	150
216 - 960	200
Above 960	500

Table 7. **General field strength limits at frequencies below 30 MHz**

Frequency	Magnetic field strength (H-field) (µA/m)	Measurement distance (m)
9 - 490 kHz(1)	6.37 / Frequency (Frequency in kHz)	300
490 - 1705 kHz	63.7 / Frequency (Frequency in kHz)	30
1705 kHz - 30 MHz	0.08	30

1. *The emission limits for the ranges 9 - 90 kHz and 110 - 490 kHz are based on measurements employing a linear average detector.*

1.3 RED certification

RED certification tests are addressing the European market.

The document is the Directive RED 2014/53/EU.

1. RF certification tests to perform are CEM qualification tests:
   - ETSI 301 489-1 (V2.2.3)
   - ETSI 301 489-3 (V2.1.1)
   - The tests are done on both Nucleo boards NUCLEO-WL55JC1 and NUCLEO-WL55JC2.
     - Spurious emission 30 MHz - 6 GHz / EN55032 class B)
     - ESD immunity / EN61000-4-2
     - Radiated immunity 80 MHz - 6 GHz / EN61000-4-3
2. RF certification tests to perform are radio qualification tests:
   - ETSI 300-200: Short Range Devices (SRD) operating in the frequency range 25 MHz to 1000 MHz.
     - ETSI 300-200 part 1: Technical characteristics and methods of measurement
     - ETSI 300-200 part 2: Harmonised Standard for access to radio spectrum for non-specific radio equipment
   - The tests are done on both Nucleo board order codes NUCLEO-WL55JC1 and NUCLEO-WL55JC2.
3. RF certification tests to perform safety are security qualification tests:
   - Directive RED 2014/53/EU Article 3.1a)
     Human exposure to electromagnetic fields (EMF) / EN62311 (2008)
4. RF certification tests to perform are safety security qualification tests:
   - Directive RED 2014/53/EU Article 3.1a)
     Electrical security / EN62368-1 (2014)

1.4 ARIB certification

ARIB certification tests are addressing the Japanese market.

The document is the ARIB STD-T108, Part 2 Specified low-power radio stations. https://www.arib.or.jp/english/std_tr/telecommunications/std-t108.html

The test summary is displayed in Table 8:

Table 8. Test summary

Item	Requirement	Limits
Antenna power	ARIB STD-T108 – clause 3.2.1	3 dBi or less (absolute gain)
Tolerances for antenna power	ARIB STD-T108 – clause 3.2.2	It must be 20 mW or less
Frequency tolerance	ARIB STD-T108 – clause 3.2.4	It must be within 20 x 10^{-6} (20 ppm)
Permissible value for Occupied Bandwidth	ARIB STD-T108 – clause 3.2.5	It must be (200 x n) kHz or less
Adjacent channel leakage power	ARIB STD-T108 – clause 3.2.6	Refer to Table 9.
Permissible values for spurious emission or unwanted emission intensity	ARIB STD-T108 – clause 3.2.8	Refer to Table 10.
Secondary radiated emissions	ARIB STD-T108 – clause 3.3	Refer to Table 11.
Transmission line control equipment	ARIB STD-T108 – clause 3.4.1	According to clause 3.4.1 chapter
Carrier sense	ARIB STD-T108 – clause 3.4.2	Carrier sense time must be 128 µs or more. Carrier sense level, amount of received power at all of unit radio channels included in the radio channel to emit must be -80 dBm at the antenna input.
Skipping carrier sense in a response	ARIB STD-T108 – clause 3.4.3	According to clause 3.4.3 chapter
Interference prevention fonction	ARIB STD-T108 – clause 3.4.4	The radio equipment must automatically transmit/receive identification codes.
Color code: the test is applied on		Normal samples
		Engineering samples
		Both normal and engineering samples

Table 9. Adjacent channel leakage power

Frequency	Power	Power at the edge	Spurious emission strength (915 MHz to 930 MHz)
From 915.9 MHz to 916.9 MHz	0 dBm (1 mW)	–20 dBm or less	–36 dBm / 100 kHz
From 916.9 MHz to 920.5 MHz	13 dBm (20 mW)	–7 dBm or less	–36 dBm / 100 kHz
From 920.5 MHz to 922.3 MHz	0 dBm (1 mW)	–20 dBm or less	–36 dBm / 100 kHz
From 922.3 MHz to 928.1 MHz	13 dBm (20 mW)	–7 dBm or less	–36 dBm / 100 kHz
From 928.1 MHz to 929.7 MHz	13 dBm (20 mW)	–7 dBm or less	–36 dBm / 100 kHz

Table 10. Permissible values for unwanted emission intensity (antenna input)

Frequency band	Spurious emission strength (average power)	Reference bandwidth
f ≤ 710 MHz	-36 dBm	100 kHz
710 MHz < f ≤ 900 MHz	-55 dBm	1 MHz
900 MHz < f ≤ 915 MHz	-55 dBm	100 kHz
915 MHz < f ≤ 930 MHz(1) (Except for |f-fc| ≤ (200 + 100 × n) kHz if bandwidth of unit radio channel is 200 kHz, except for |f-fc| ≤ (100 + 50 × n) kHz if bandwidth of unit radio channel is 100 kHz. Except for |f-fc| ≤ (100 + 100 × n) kHz if frequency band is 915.9 MHz ≤ f ≤ 916.9 MHz and 920.5 MHz ≤ fc ≤ 922.3 MHz. Where n is the number of unit radio channels constituting the radio channel and is an integer from 1 to 5)	-36 dBm	100 kHz
930 MHz < f ≤ 1000 MHz	-55 dBm	100 kHz
1000 MHz < f ≤ 1215 MHz	-45 dBm	1 MHz
1215 MHz < f	-30 dBm	1 MHz

1. *Permissible values for unwanted emission intensity in 915 MHz < f ≤ 925 MHz must be 55 dBm / 100 kHz, before July 24, 2012.*

Table 11. Adjacent channel leakage power

Frequency band	Limit on secondary radiated emissions and others (antenna input)	Reference bandwidth
f ≤ 710 MHz	-54 dBm	100 kHz
710 MHz < f ≤ 900 MHz	-55 dBm	1 MHz
900 MHz < f ≤ 915 MHz	-55 dBm	100 kHz
915 MHz < f ≤ 930 MHz	-54 dBm	100 kHz
930 MHz < f ≤ 1,000 MHz	-55 dBm	100 kHz
1000 MHz < f	-47 dBm	1 MHz

2 Boards preparation

This section deals with what is prepared and performed on the ST side in a certification framework before Nucleo boards commercialization.

To ensure the complete test list of various RF certifications, two types of boards must be prepared for RF certification tests:

2.1 Normal or standard samples

This kind of board is the board in the condition in which it is sold. This means with the screwed SMA antenna and with the associated demonstration software. With this sample, the certification laboratory is evaluating the dynamic behavior of the samples as it is in a real-life environment.

2.1.1 Demonstration set-up overview

There are one concentrator and multiple sensors. The concentrator is silent until it gets a command from the connected PC to start sending a beacon on one of the beacon frequencies. The frequency is selected depending on the region.

The sensor is continuously scanning, it is sweeping on all supported beacon frequencies (one region) until it finds a beacon.

Once it finds a beacon, it listens for the synchronization to know which time slots are free. The sensor chooses one of the free time slot to respond to both control information and sensor data to the MB1389 concentrator.

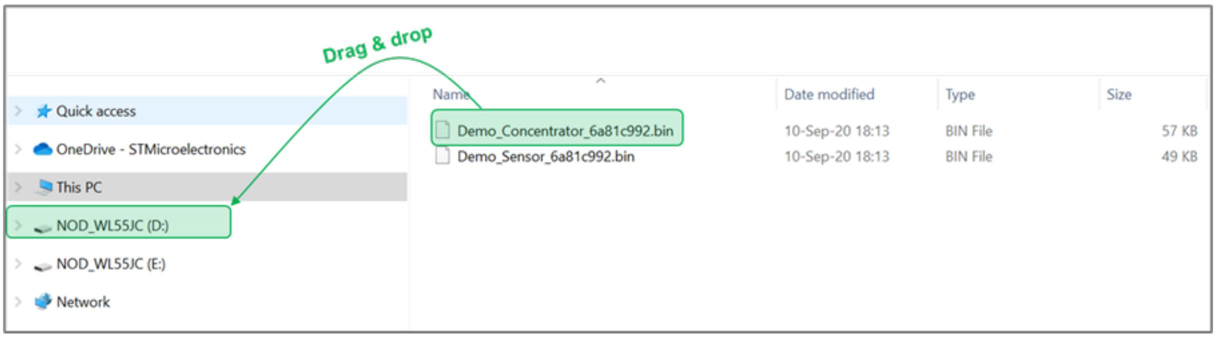
Sensors scan for beacons, then connect to the concentrator and start transmitting their sensor readouts.

In our case, at least two Nucleo boards (MB1389) are necessary:

- One Nucleo board (MB1389) acting as the concentrator (this is the device to test). The .bin file to download on the MB1389 concentrator is: `Demo_Concentrator_6a81c992.bin`
- One Nucleo board (MB1389) acting as the sensor. The .bin file to download on the MB1389 sensor is: `Demo_Sensor_6a81c992.bin`

The way to flash the demonstration software inside the MB1389 is easy. This is simply done with a drag-and-drop, as depicted in Figure 1.

Figure 1. Demonstration software drag-and-drop flashing procedure



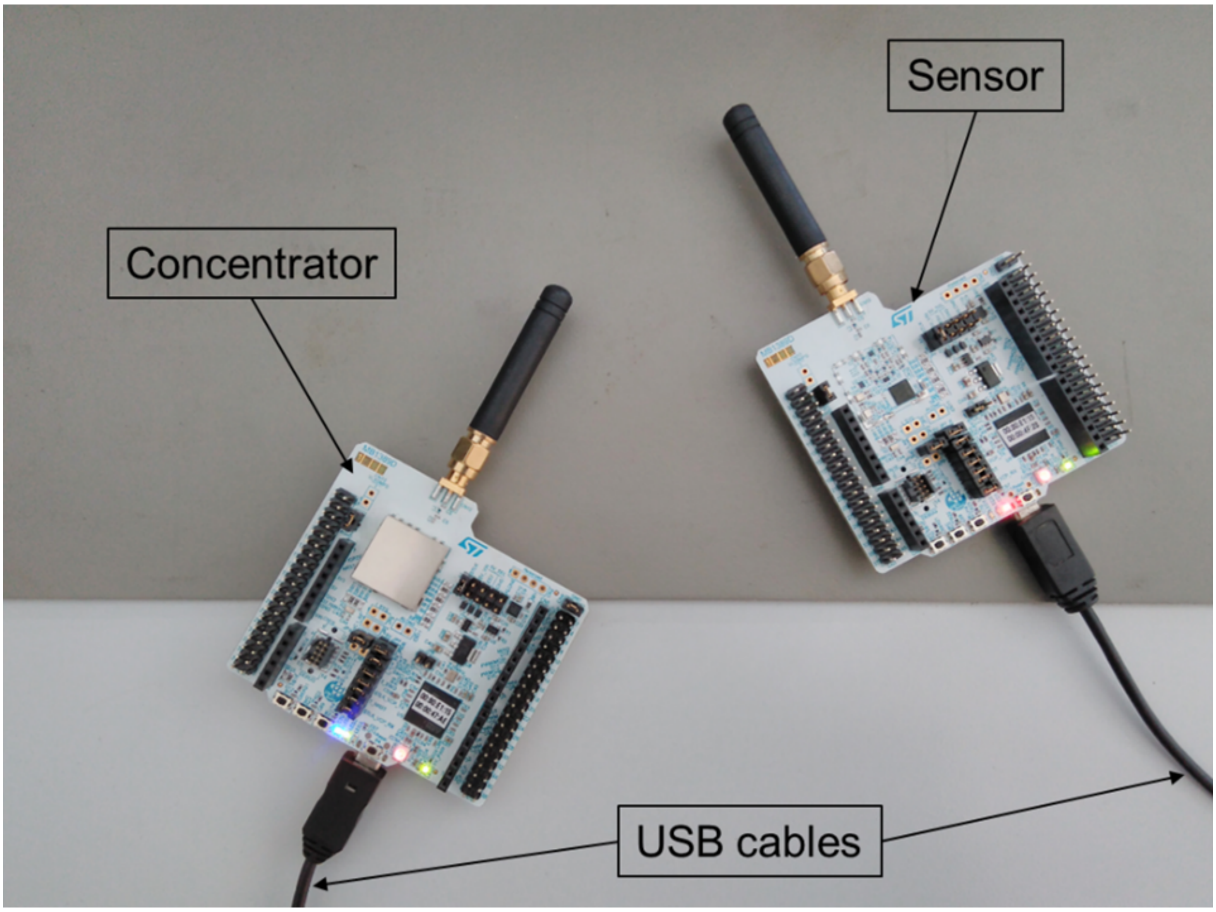
Note:
1. *The drag-and-drop action is only feasible with .bin files.*
2. *NOD_WL55JC is the concentrator (MB1389 board).*
3. *The other NOD_WL55JC is the sensor (MB1389 board).*

Power both sensor and concentrator devices, by supplying them with the USB cable. At least two Nucleo boards (MB1389) are necessary:

- One MB1389 board acting as the concentrator (this is the device to test),
- One MB1389 board acting as the sensor.

The PC software is only a user interface. All radio management is performed in the concentrator.

Figure 2. **Nucleo boards acting as concentrator and sensor**



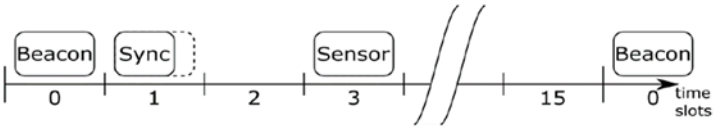
Note that there is only one concentrator but there may be multiple sensors (up to 14 sensors). In the presented set-up, only one sensor is used.

2.1.2 Demonstration details

Slot configurations:

There are 16 1-second long slots. Slot 0 is concentrator beacon, slot 1 is for concentrator synchronization, the rest is for sensors. Depending on the subregion, slots 1 through 15 may use frequency hopping. The synchronization packet is usually shorter than the full slot. So the 16-second superframe is divided into 16 1-second slots.

Figure 3. **Superframe format**



We then have slot 0 to 15:
- Slot 0 is reserved for concentrator beacon at 925 MHz.
- Slot 1 is reserved for concentrator synchronization at 924 MHz if no sensor is connected but can vary within the channel list if one or more sensor is connected.
- Slot 2 to 15 are reserved for data exchange (from the sensor to concentrator).

Channel maps and hopping

Region 0, European Union

The beacon frequency is 869.525 MHz. The sensor frequency is the same for modulations narrower than 250 kHz. This channel has a 10% duty cycle. Maximum power of 22 dBm EIRP can be used.

Region 1, The United States

The beacon is not part of the hopping. The beacon is at 925 MHz with a 500 kHz bandwidth. The synchronization and sensor transmit channels are part of the frequency hopping. The frequency hopping uses 45 channels for sync and sensors. Channels are separated by 0.5 MHz, starting on 902.5 MHz and going down to 914.5 MHz.

The synchronization frequency hopping sequence is randomly predetermined following PRBS9. Sync channel is controlled entirely by seed.

The Beacon Seed is also used to generate the frequency-hopping sequence of the sensor transmit channels depending on the time slot allowed (between time slot 2 and 15) for the sensor. For the frequency-hopping sequence, the slot channel relations for sensor packets are given entirely by a mask of occupied slots and seed.

The seed is an input to a pseudorandom generator.

Each slot, starting with slot2, has one pseudorandom number generated. The generator range must be much larger than the number of available channels.

The generated number is taken modulo number of occupied slots (counting synchronization) and gives a channel number for the slot.

Depending on the slot used by the TX sensor the hopping sequence is pre-determined and listed below:

Figure 4. US frequency-hopping per slot in MHz versus superframe table

nbchannel 45

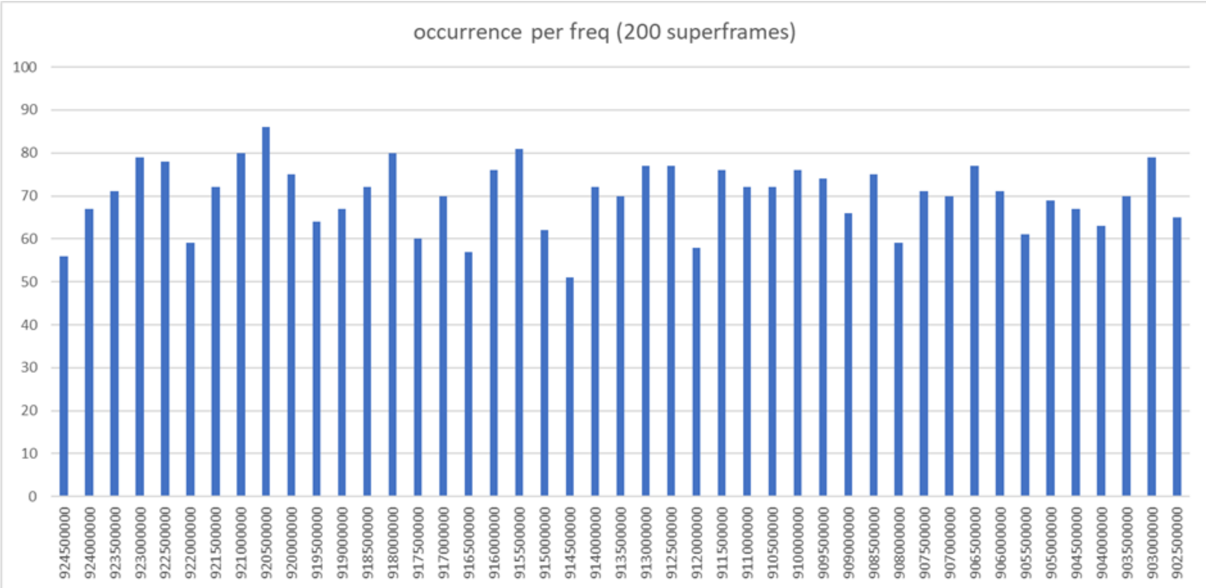
prbsinit (do not change) 85

table freq Hopping US per slot and superframe inMHz

	PRBS9	seedHex	seedDec	sync	slot1	slot2	slot3	slot4	slot5	slot6	slot7	slot8	slot9	slot10	slot11	slot12	slot13	slot14
superframe1	171	AB	171	906.5	913	913	908	907.5	920	917	905.5	904	919	903	919	923	923	904.5
superframe2	342	56	86	904	921	921.5	911	915.5	916	912.5	923.5	907	910	907.5	917	907.5	911	907
superframe3	172	AC	172	906	917.5	914.5	916	906.5	907.5	923	922.5	912	918	909	909.5	909	916	912
superframe4	344	58	88	903	907.5	920.5	908.5	913.5	913.5	906	916.5	923	908	919.5	920.5	920.5	911.5	903.5
superframe5	176	B0	176	904	909	912.5	911	902.5	902.5	910	904.5	921.5	914	910.5	912.5	916.5	921	923.5
superframe6	353	61	97	921	903	918	910.5	908.5	909.5	912.5	924	905	921.5	910	917	907	914.5	911.5
superframe7	195	C3	195	917	904.5	913	923	914	904.5	910.5	918	916	917.5	924	922.5	916.5	912	924.5
superframe8	390	86	134	902.5	908	917.5	918.5	910	903.5	903.5	903.5	904.5	907	904.5	920	913	907.5	906
superframe9	269	0D	13	918	915.5	924	921.5	919.5	915.5	922	918	916	915.5	920.5	905.5	918.5	910	921.5
superframe10	27	1B	27	911	911	902.5	904	909.5	916.5	903	924.5	915.5	924	922.5	918	921	907	907.5
superframe11	55	37	55	919.5	920.5	923	914	912	914.5	906	919	910.5	918.5	904	924.5	922	923.5	916.5
superframe12	111	6F	111	914	917	919	915.5	921	910.5	916	908	904.5	907.5	912	907	905.5	911.5	916
superframe13	222	DE	222	903.5	909.5	909.5	902.5	917.5	915	907.5	914	903	913	922	912	909	917	907.5
superframe14	445	BD	189	920	922.5	912	908	920	916	907.5	920.5	913	923.5	906.5	916	910.5	902.5	920.5
superframe15	378	7A	122	908.5	921.5	915.5	911	914	904	916	908.5	902.5	919	918.5	907	905	915	920.5
superframe16	244	F4	244	915	914.5	906.5	920	903.5	924.5	907.5	911	921.5	913.5	908.5	912	908	924	912.5
superframe17	489	E9	233	920.5	914	910	920.5	910.5	908.5	907.5	914.5	923.5	924.5	924.5	912	908.5	920.5	908
superframe18	467	D3	211	909	905	909	903	906	921.5	907.5	917.5	905	924	915.5	916	909.5	913.5	903
superframe19	422	A6	166	909	913	913.5	923.5	908.5	919	920	902.5	913	924	914	903	903	906.5	908
continue....																		

The occurrence of the Tx sensors channels (over 200 superframes) shows that the channel occupancy is quite uniform when the frequency hopping sequence is used for the United States.

Figure 5. **Occurrence of Tx sensor channels per frequency over 200 superframes**



Beacon configuration

The beacon is mostly a preamble for the sensors to find the network. The beacon modulation needs to be specific for the US and the rest of the world.

For the US region: Beacon needs to fit inside the US 0.4 s dwell time. For that reason, the US region-specific settings for LoRaWAN do not allow for the slowest LoRa communication. For the US network, SF12/500 kHz is selected.

There are 4 bytes for data. There is subregion information that informs the sensor about the details of the communication modulation. There is a seed used in some regions for hopping. There is a behavioral major version to prevent incompatible devices to connect. The concentrator behavioral version is 0 (other values are reserved). There is an offset number to calibrate the time frame in sensors. Lastly, there is a primitive checksum as the beacon packet does not use the header and LoRa CRC.

In the EU, the 10% frequency band does not fit 250 kHz modulation. Some other regions require 200 kHz or less bandwidth. The packet length is 790.5 ms (4 bytes payload SF=11, no CRC, coding rate = 4/5, 36 preamble symbols, 125 kHz bandwidth).

Synchronization configuration for the US region

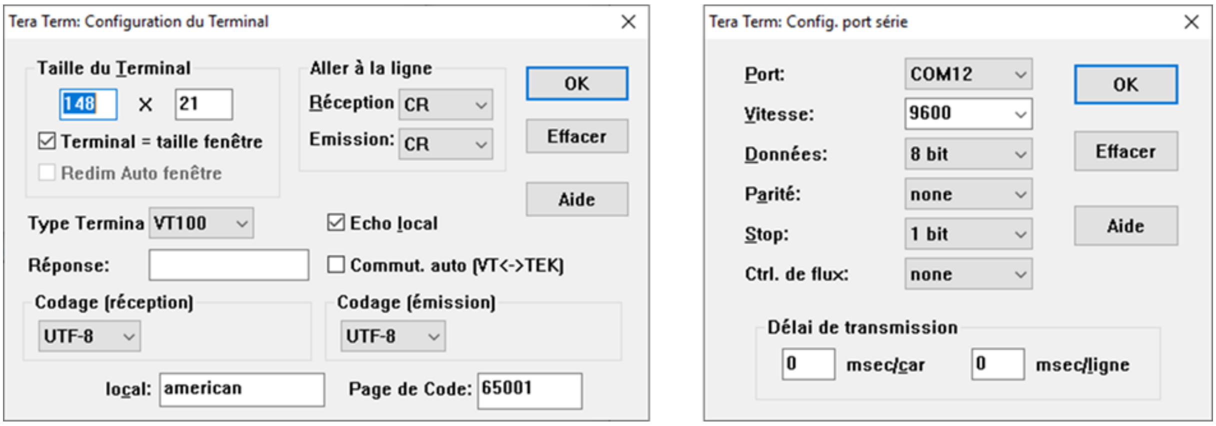
The purpose of synchronization is to provide more information about the network, to verify beacon information in the CRCed packet, and to publish coding changes (changes of used coding rate and modulation parameters) for sensor uplink packets. The synchronization continues with the same modulation as the beacon, but the packet format is different. The preamble length is the default one, where there is an explicit header and a CRC. The synchronization length is 210 ms.

2.1.3 Demonstration procedure

Tera Term set-up

Once the sensor is supplied, the LD3 red LED is blinking. Once the concentrator is supplied, all the LEDs (LED1, LED2 and LED3) are scrolling. A Tera Term session can be opened with the following parameters.

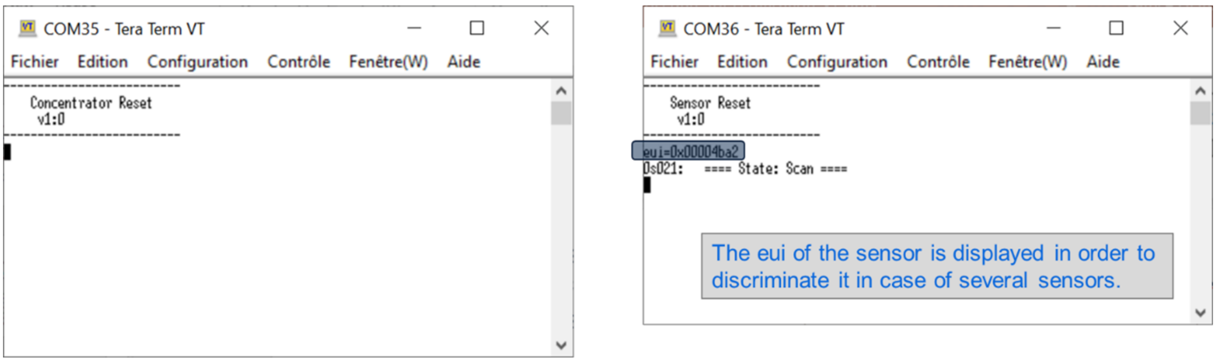
Figure 6. Tera Term parameters



Initialization

The Tera Term windows are respectively the following ones once the sensor and the concentrator have been reset (B4 buttons on sensor and concentrator). The concentrator window is on the left and the sensor window on the right.

Figure 7. Tera Term windows



Concentrator behavior

The concentrator is silent until it receives a command from the connected PC to start sending a beacon on one of the beacon frequencies. The frequency is selected depending on the region.

After version check, the first three commands to send to PC to start the concentrator (MB1389D) must set region, subregion, and start the beacon. For the European Union, it is AT+REGION=0, AT+SUBREGION=0 and AT+BEACON_ON. The first two commands select the format of the transmitted beacon. The third command starts sending the beacon. For a list of available regions refer to annex “Regulations applicable to the Demo” or run AT+LIST_REGIONS.

Then the concentrator starts flashing green LED on each time slot of the network. When the concentrator transmits a beacon or synchronization packet, it lights up the red LED for the duration of the transmit. When the concentrator receives something, it flashes the blue LED at the end of the received packet.

PC software is only a user interface. All radio management is done in the concentrator.

Sensor behavior

Sensor packets are sent between synchronization and the next beacon. The sensor can transmit only if it successfully received a beacon and synchronization of the current period. The default coding is the same as the concentrator beacon uses.

The sensor starts in the scan state. In this state, the sensor flashes the red LED quickly. Once it finds one beacon, it can never return to the scan state except for reset.

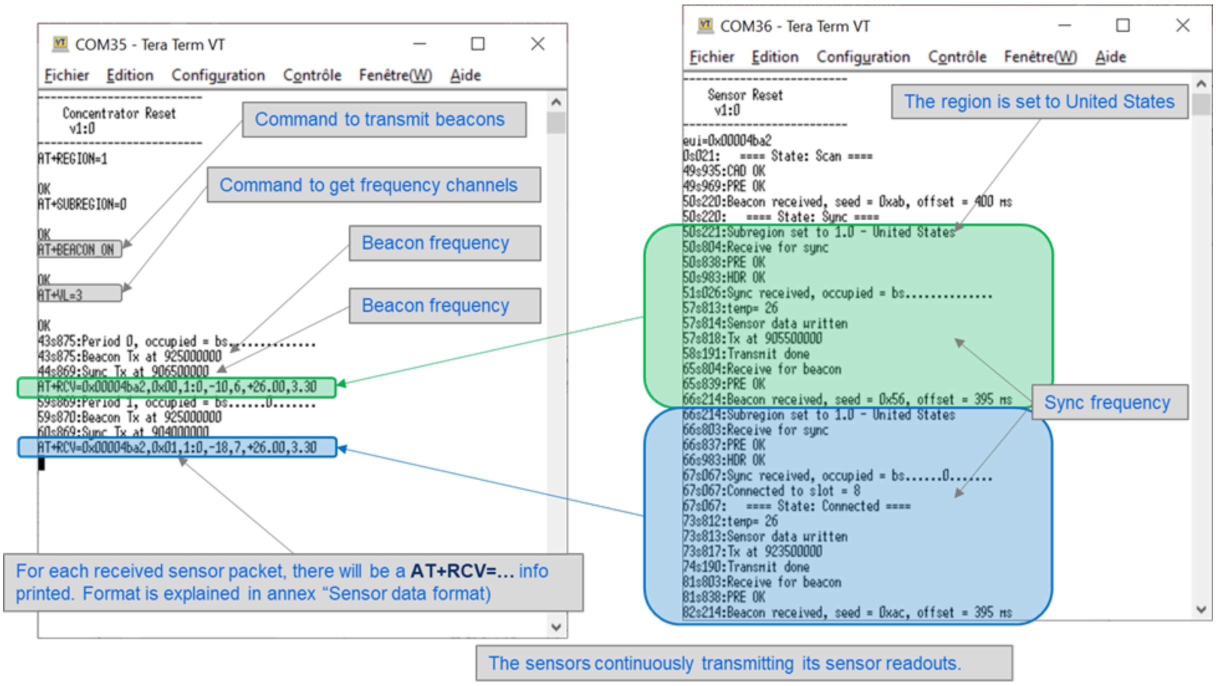
In the synchronization state, the sensor tracks beacons but is not connected. It can transmit in a random empty slot. In this state, any activity (receive or transmit) makes the blue LED flash.

In the lost state, the sensor is unable to track beacons. It periodically switches between a long sleep period and a long receive one, trying to find a beacon while saving battery. In this mode, the activity is reported by the red LED.

In the connected state, the sensor is fully connected and transmits measured data in one constant slot. In this state, any activity flashes the green LED.

Demonstration execution

Figure 8. Demonstration execution



Available Concentrator commands and responses

AT commands

- Get means AT+command=?<cr><lf>
- Set means AT+command=param<cr><lf>
- Run means AT+command<cr><lf>

All parameters are decimal numbers unless stated otherwise.

Table 12. Command list

AT command	Actions	Description
Z	Run	Reset
+VER=?	Get	Get the version of the firmware in format v X:Y, where X is the major version, and Y the minor one. The major version is incompatible with others, regions and subregions may be changed. For example, the minor version may change sensor data format.
+LIST_REGIONS	Run	Print list of all available regions and subregions
+DE=de	Get, Set	Register to change LowDataRateOptimize [0 .. 1], recommended when symbol length is greater than 16 ms
+CR=cr	Get, Set	Register to change the LoRa code rate[1 .. 4] = [4/5 .. 4/8]
+SF=sf	Get, Set	Register to change the LoRa spreading factor[6 .. 12]
+BW=bw	Get, Set	Register to change the LoRa bandwidth [0 .. 9] 0 - 7.81 kHz; 1 - 10.42 kHz; 2 - 15.63 kHz; 3 - 20.83 kHz; 4 - 31.25 kHz; 5 - 41.67 kHz; 6 - 62.5 kHz; 7 - 125 kHz; 8 - 250 kHz; 9 - 500 kHz
+RISE=rise	Get, Set	Register to change the FSK power ramp [0 .. 7] 0 - 10 µs; 1 - 20 µs; 2 - 40 µs; 3 - 80 µs; 4 - 200 µs; 5 - 800 µs; 6 - 1700 µs; 7 - 3400 µs
+BR=br	Get, Set	Register to change the FSK bitrate[600 .. 300,000 bits/s]
+BT=bt	Get, Set	Register to change the FSK Gaussiansymbol shapingBT[0 .. 4] 0 - off, no shaping; 1 - 0.3, biggest effect; 2 - 0.5; 3 - 0.7; 4 - 1, smallest effect
+MOD_LORA=eui	Set	Set modulation for sensor to LoRa/FSK.Parameter eui is hexadecimal `0xabcd1234`.
+MOD_FSK=eui	Set	Modulation parameters are taken from DE, CR, SF, and BW for LoRa® from RISE, BR, FDEV, and BT for FSK. Some combinations are not allowed. It may return AT+MOD_LIM=period,data_lim if the modulation limits the period or length of received data.
+MOD_TEST_LORA	Run	Same as AT+MOD_XXX=eui, but test only. It returns AT+MOD_LIM=period,data_lim every time.
+MOD_TEST_FSK	Run	-
+REGION=r	Get, Set	Set region and subregion. Affects only after the next AT+BEACON_ON.
+SUBREGION=s	Get, Set	-
+BEACON_ON Get, Set,	Get, Set	Turn beacon on and off (Run equals to Set=1).

Table 13. Command response

Response	Description
OK	Command processed successfully.
AT_ERROR	Error while processing command.
AT_PARAM_ERROR	Wrong parameters for the command.
AT_TEST_PARAM_OVERFLOW	Parameters are too long.
AT_RX_ERROR	UART receives an error.
MOD_NOT_ALLOWED	Selected modulation is not allowed.
AT_EUI_NOT_CONNECTED	The requested sensor is not available.

Table 14. Spontaneous messages

Spontaneous messages	Description
AT+RCV=eui,counter,version_major: version_minor, RSSI, SNR, data, data.	Received sensor packet. Data are described in Sensor data format section. The counter is incremented in each transmitted packet, RSSI is the signal strength [dBm], SNR is the signal-to-noise ratio [dB].
AT+MOD_LIM=period,data_lim	The modulation is accepted (OK is returned as usual), but period or data are limited: • period gives the number of skipped periods, 0-transmit once in 16 s, 1-transmit once in 32 s. • data_lim gives the number of bytes sent (including 6 bytes of eui, counter, and version), 26 bytes is maximum.
AT+MOD_OK=eui	The modulation change is successful. This can appear at any time if the sensor loses synchronization, connects again and the modulation is changed again.
AT+LOST=eui	When a sensor is lost

Sensor data format

Table 15. Sensor data format

Data	Description	Format on Air	Format in AT+RCV	Unit in AT+RCV
Temperature	Influenced by ST-LINK	int16_t [0.01 `C]	+22.41	°C
Voltage	Voltage on MCU	uint8_t [0.05 V]	3.15	V

Figure 9. Sensor data format

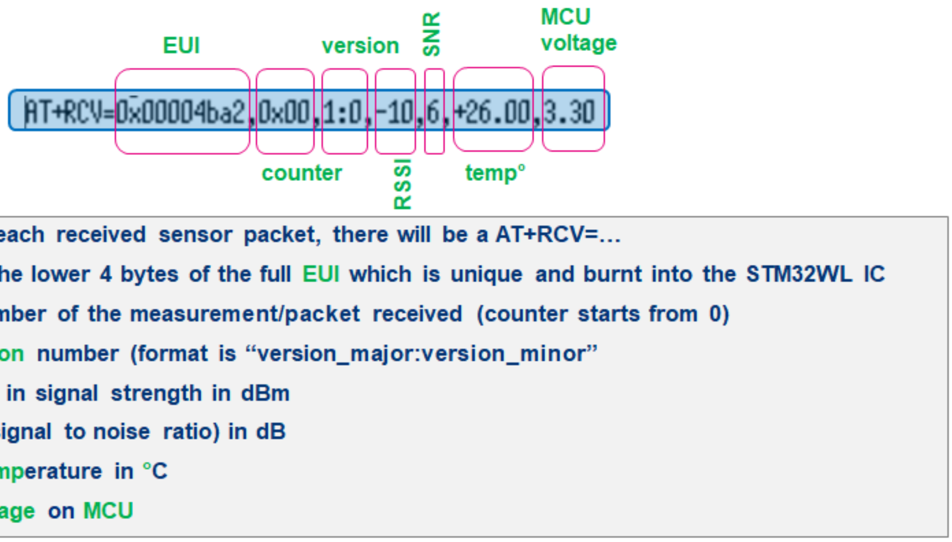


Figure 9 is a description of data measured, sent, and printed in AT+RCV. A letter E can be printed instead of the value if the data are not available due to payload data limit or error in measurement.

Regulations applicable to the software demonstration

Region0, the European Union

- Regulated by [ERCRecommendation70-03] and [EN300220]. Beacon frequency is 869.525 MHz.
- Duty cycle of 10% and 29.15 dBm EIRP are limits on h1.6, 869.4 - 869.65 MHz. Only 125 kHz LoRa modulation fits there.
- Duty cycle of 1% and 16.15 dBm EIRP are limits on h1.4, 868 - 868.6 MHz.

Region1, the United States

- Subregion1.0, the United States: Regulated by [CFR Title47, §15.247] and explained in [558074 D01 15.247 Meas Guidance v05r02]. Beacon is sent at 925 MHz.
- Subregion1.1, Australia Regulated by [Radiocommunications (Low Interference Potential Devices) Class Licence 2015]. Digital modulation transmitters are limited by 30 dBm EIRP, the radiated peak power spectral density in any 3 kHz must not exceed 25 mW (14 dBm) per 3 kHz on 915 – 928 MHz.

Region2, Asia

Beacon is transmitted at 923.4 MHz.

- Subregion2.0, Republic of Korea
- Subregion2.1, Japan
- Subregion2.2, Generic Asia

Region3, Mainland China

- Transmitter is limited to 19.15 dBm EIRP on 470 - 510 MHz.The transmission never lasts more than 5000 ms. Bandwidth is less than 200 kHz, which means LoRa 125 kHz bandwidth only.
- All communication use 470.3 MHz (The first LoRaWAN® channel).

Region4, India

- Maximum power of 22 dBm EIRP is compliant for all modulations.
- All communication use 865.1 MHz and bandwidth is limited to 200 kHz.

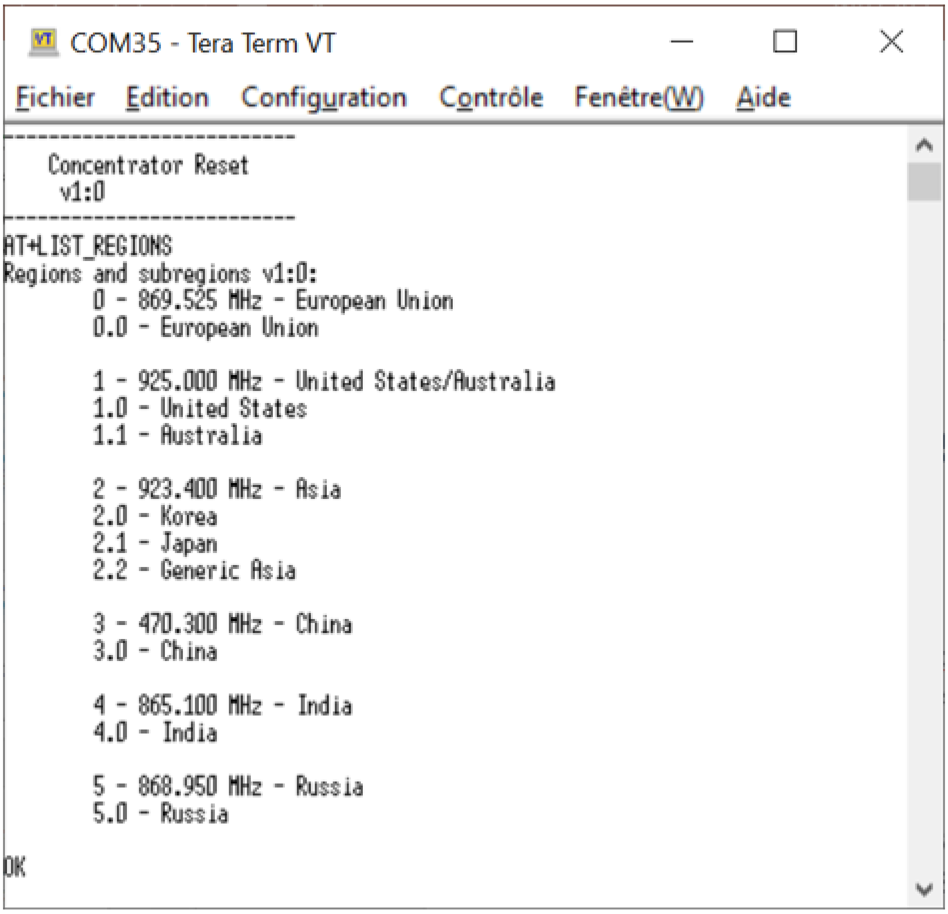
Region5, Russia

The following comes from [Report ITU-R SM.2153-2 (06/2011)]:

- On frequencies 864 -865 MHz, the maximum power is 16.25 dBm EIRP with duty cycle 0.1% or LBT.
- On frequencies 868.7 - 869.2 MHz, the maximum power is 16.25 dBm EIRP.
- All communications use 868.95 MHz.

Frequency values per region are reported in Figure 10.

Figure 10. **AT+LIST region frequencies**



Modulation settings changes

Change the coding to LoRa on the sensor (via concentrator Tera Term windows)

The first step is to put the coding parameters in the corresponding registers. To get a LoRa 250 kHz with spreading factor SF9 and code rate 4/5 it is `AT+DE=0, AT+CR=1, AT+SF=9`, and `AT+BW=8`.

The second step is to apply the new modulation. To change sensor `0x12345678`, the command is `AT+MOD_LORA=0x12345678`. The register values are persistent and can be used to set multiple sensors to the same modulation.

The modulation is acknowledged by `OK`, but the actual change happens at best in the following period. When the modulation is changed, the concentrator sends a notification `AT+MOD_OK=0x12345678`.

Change the coding to FSK on the sensor (via concentrator Tera Term windows)

The process is similar to the previous chapter. To set sensor `0x12345678` to 40 kBd GMSK, use `AT+RISE=1, AT+BR=40000, AT+FDEV=10000, AT+BT=2` and `AT+MOD_FSK=0x12345678`.

2.2 RF engineering samples

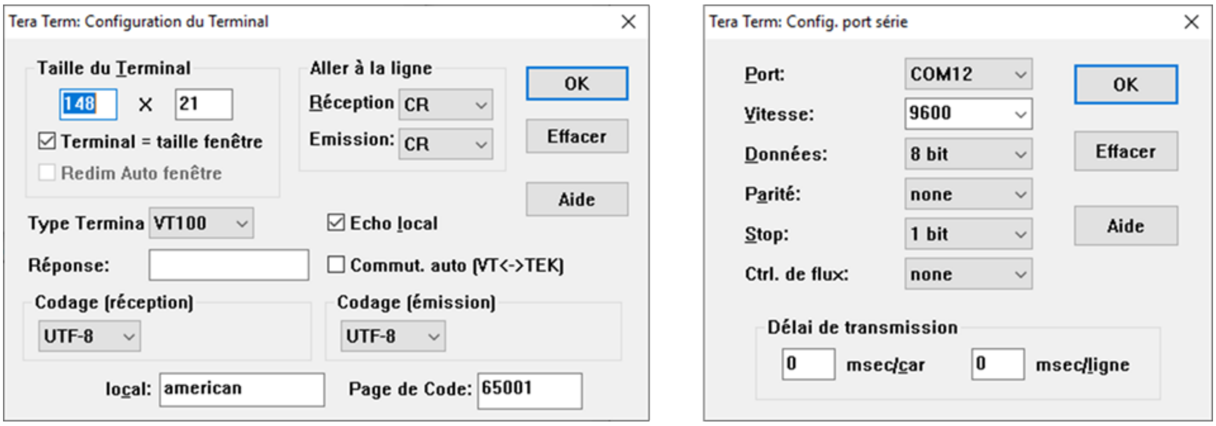
This kind of board is a board where the hardware aspect is the same as the normal or standard samples, but with special embedded software that can set the board in transmission mode only. Some RF Tx parameters must be managed such as carrier frequency, output power, and modulation.

2.2.1 MB1389 board control

To control the MB1389 board (either in Rx or Tx), once the AT slave software is loaded (drag-and-drop action) and AT commands can be used.

So, a Tera Term session can be opened with the following parameters.

Figure 11. Tera Term parameters



2.2.2 AT commands

The most important AT commands to use are the following ones:

`AT?` Get all available AT commands

`AT+<CMD>?` Help on <CMD>

`AT+<CMD>=<value>` : Set the value

`AT+SNR` Get the SNR of the last received packet

`AT+TRSSI` Starts RF RSSI tone test

`AT+<CMD>` Run <CMD>

`AT+<CMD>=?` Get the value

`AT+RSSI` Get the RSSI of the last received packet

`AT+TTONE` Starts RF Tone test

`AT+TTLRA` Set Nb of packets sent with RF Tx LORA test

`AT+TRLRA` Set Nb of packets received with RF Rx LORA test

`AT+TTX` Starts RF Tx test: N= Nb of packets sent

`AT+TRX` Starts RF Rx test: N= Nb of packets expected

`AT+TTH`Starts RF Tx hopping test: Fstart, Fstop, deltaf, nbTx Fstart, Fstop and deltaf in Hz

`AT+TOFF` Stops on-going RF test

`AT+TCONF` Config RF test

[Freq]:[Power]:[Bandwith]:[SF]:4/[CR]:[Lna]:[PABoost]:[modulation]:[payloadLen]:[fskdDeviation]:[lowDrOpt]:[Btproduct]

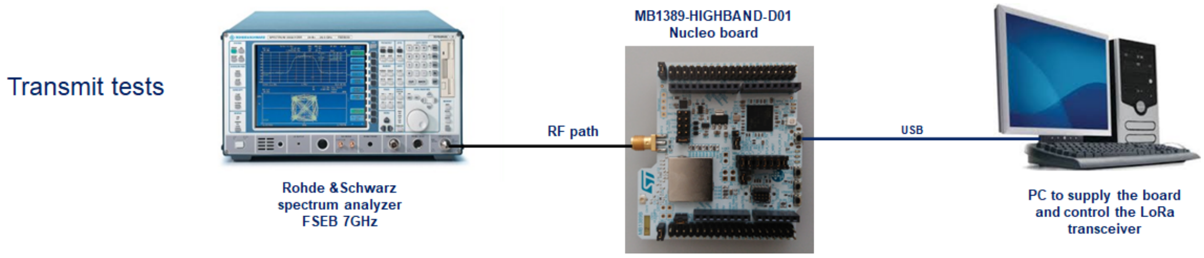
2.2.3 Parameter description of AT+TCONF command

```
uint32_t freq;                 /* in Hz */
uint32_t power;                /*[-9 :22]dBm*/
uint32_t bandwidth;            /* Lora [0:7.8125, 1: 15.625, 2: 31.25, 3: 62.5, 4: 125,
                                  5: 250, 6: 500]kHz FSK : [4800Hz :467000 Hz]*/
uint32_t loraSf_datarate;      /* Lora[SF5..SF12] FSK [600..300000 bits/s]*/
uint32_t codingRate;           /* Lora Only [1: 4/5, 2: 4/6, 3: 4/7, 4: 4/8] */
uint32_t lna;                  /* 0:off 1:On */
uint32_t paBoost;              /* 0:off 1:On */
uint32_t modulation;           /* 0: FSK, 1: Lora, 2: BPSK(Tx)*/
uint32_t payloadLen;           /* [1:256] */
uint32_t fskDev;               /* FSK only [4800:467000]
Note: no check applied wrt bandwidth. Commom practice is to have bandwidth>1.5*fskDev*/
  uint32_t lowDrOpt;           /* Lora Only 0: off, 1:On, 2: Auto
                                  (1 when SF11 or SF12, 0 otherwise)*/
  uint32_t BTproduct;          /* FSK only [0 no Gaussian Filter, 1: BT=0.3,
                                  2: BT=0.5, 3: BT=0.7, 4: BT=1]*/
```

2.2.4 RF transmit tests

The set-up is the following one:

Figure 12. RF transmit test set-up



For LoRa® modulation:

The AT commands to use are:

- AT+TCONF configures LoRa® RF test.
  - AT+TCONF=915000000:22:4:10:4/5:0:0:1:16:25000:2:3 (915 MHz, 22 dBm, 125 kHz BW, 10 SF, 4/5 coding rate, LNA off, PA boost off, LoRa® modulation, 16 payload length)
- AT+TTX=N starts the RF Tx test: N is the number of sent packets. It analyzes the spectrum shape on the spectrum analyzer.
- AT+TOFF stops the on-going RF test.

For Sigfox™ modulation:

The AT commands to use are:

- AT+TCONFconfigures Sigfox™ RF test.
  - AT+TCONF=915000000:22:100:100:4/5:0:0:2:16:25000:2:3 (915 MHz, 22 dBm, 100 Hz bandwidth, 100 bps, LNA off, PA boost off, Sigfox™ modulation)
- AT+TTX=N starts the RF Tx test: N is the number of sent packets. It analyzes the spectrum shape on the spectrum analyzer.
- AT+TOFF stops the on-going RF test.

For FSK modulation:

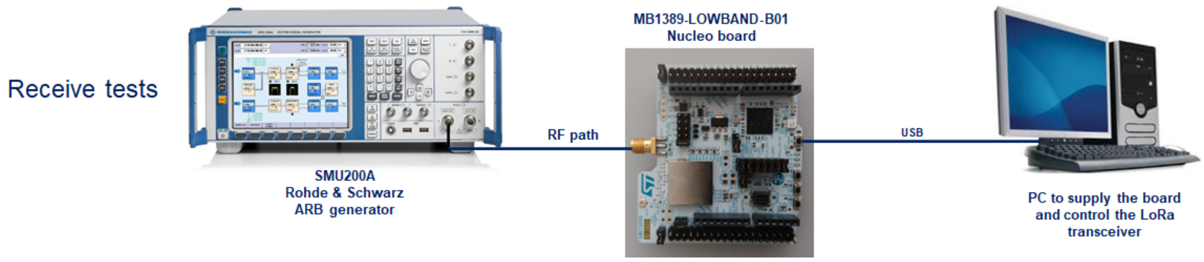
The AT commands to use are:

- `AT+TCONF` configures FSK RF test.
  - `AT+TCONF=915000000:22:75000:50000:4/5:0:0:0:255:25000:2:3` (915 MHz, 22 dBm, 75 kHz bandwidth, LNA off, PA boost off, FSK modulation, 255 payload length, 25 kHz FSK deviation, 0.7 BT)
- `AT+TTX=N` starts the RF Tx test: N is the number of sent packets. It analyzes the spectrum shape on the spectrum analyzer.
- `AT+TOFF` stops the on-going RF test.

2.2.5 RF receive tests

The set-up is the following one:

Figure 13. RF receive test set-up



The AT commands to use are:

`AT+TCONF`: Config LoRa® RF test

`AT+TCONF=915000000:22:4:10:4/5:0:0:1:16:25000:2:3` (915 MHz, 22 dBm, 125 kHz bandwidth, 10 SF, 4/5 coding rate, LNA off, PA boost off, LoRa® modulation, 16 payload length)

`AT+TRX=N`: Starts the RF Rx test: N is the number of expected packets. The firmware counts PER on 50 packets.

`AT+TOFF`: Stops the on-going RF test

The SMU200 Rohde & Schwarz RF generator is configured as followed:

The firmware default settings `sf12_crc1_cr1_hdr1_pl10_ppm1_pr8.wv` file is loaded in the SMU200.

The sampling frequency in the Rohde & Schwarz ARB generator must be changed:

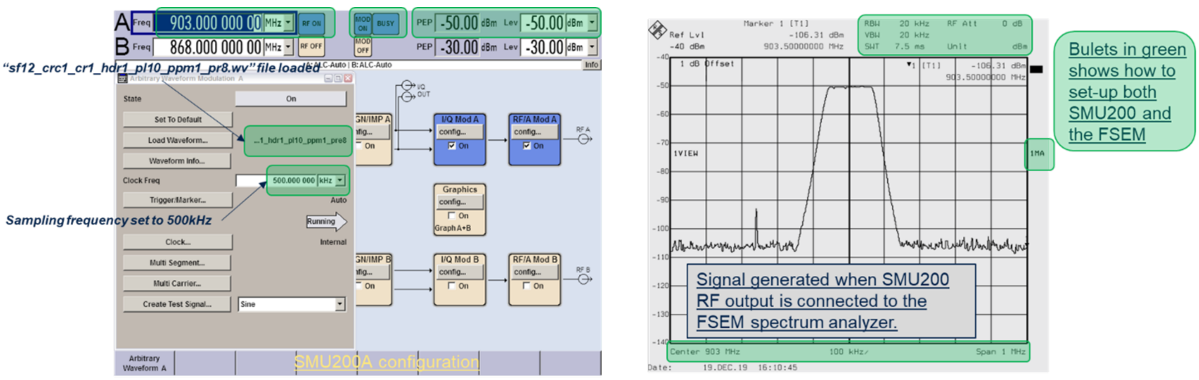
The sampling frequency formula is:

$$F_S = (6.5\ M \div 1.625\ M) \times LoraBW$$

Example:

$$LoraBW = 125\ kHz \Rightarrow Fs = 500\ kHz$$

Figure 14. SMU200 Rohde & Schwarz RF generator configuration



Revision history

Table 16. **Document revision history**

Date	Version	Changes
4-Dec-2020	1	Initial release.

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