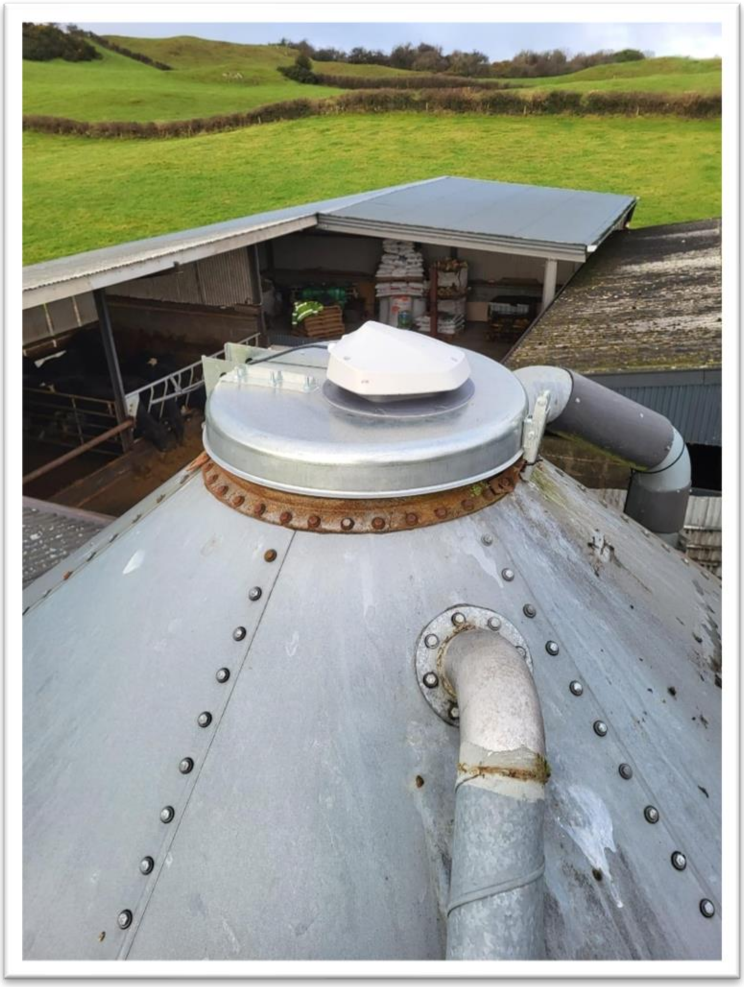
SiloSpi Satellite NTN Field Test Report



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1. Document overview

This test report includes the results and conclusions coming from field testing the Semtech (Formerly Sierra Wireless) HL7812 module, enabled with NTN communication (satellite link) with a Satellite NTN Sim card supplied by Skylo.

It details the testing carried out on the SiloSpi silo monitoring unit (from company LvLogics https://lvlogics.com/) to estimate if the technology has potential for use in current and future designs.

1.1. Version History

Version	Date	Description	Author
1.0	20-12-2023	First draft and document setup	Sławomir Tyborczyk
1.1	20-12-2023	Edits based on document review	Adrian Burns

Table 1 Document Revision History

1.2. References

Reference Doc	Name
REF1	SiloSpi Satellite NTN – Passive Antenna Chamber Testing v1.0

1.3. Definitions, acronyms & abbreviations

List of definitions, acronyms & abbreviations in alphabetical order.

Term	Description
DMP	Data Mobility Platform – cloud service from Skylo used to manage the communication with radio units equipped with Skylo Sim card that enables NTN connectivity
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
NIDD	Non-IP Data Delivery
NTN	Non-Terrestrial Network
RSRP	Reference Signal Received Power – value that estimates power based on the pilot signals coming from the current base station.
RSRQ	Reference Signal Received Quality – quality indicator of the received pilot signals from the current base station. The values of RSSI and RSRP are used for the calculation.
RSSI	Received Signal Strength Indicator – value of the signal strength received at the antennas of the device.
SINR	Signal Interference + Noise Ratio – the ratio between the desired signal and interference from outside sources.
TA	Timing Advance – value corresponding to the length of time a signal takes to reach the base station from a radio terminal

Table 2 Abbreviations and Acronyms

2. Test setup

Drawing below presents high-level illustration of the testing setup.

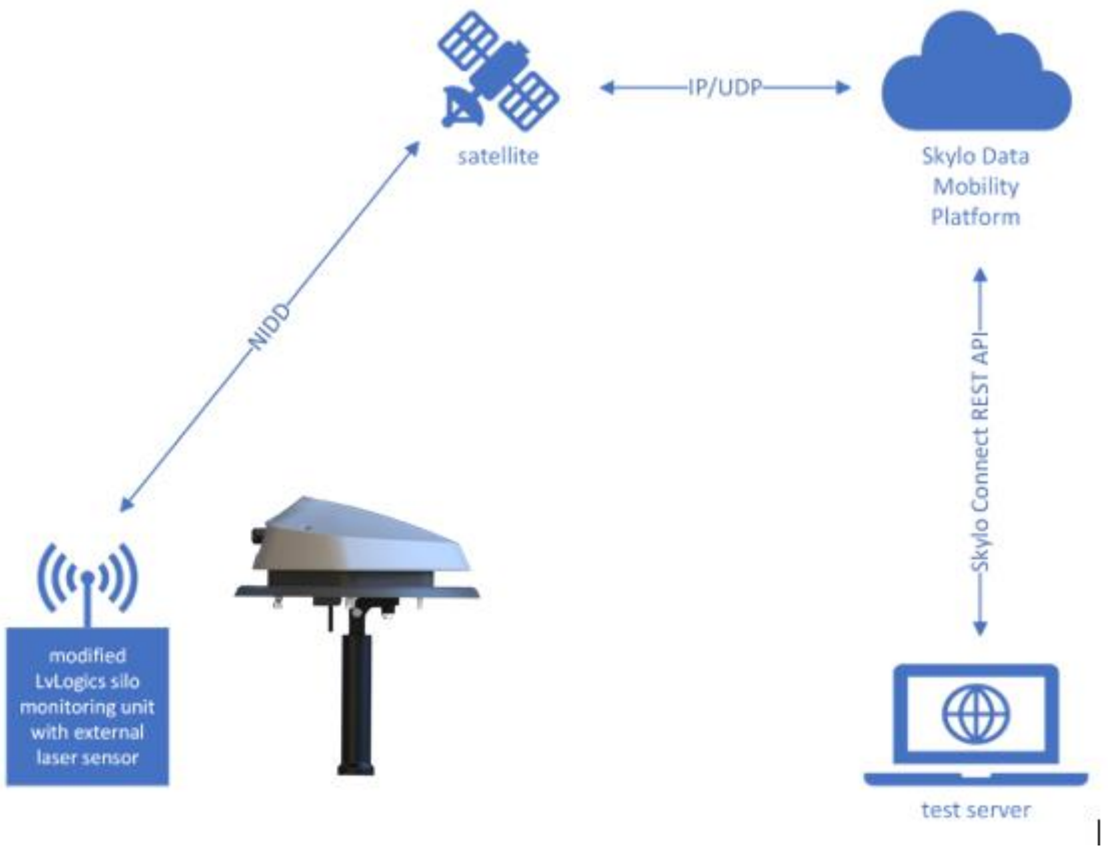

Figure 1 NTN testing setup

In order to enable Satellite NTN functionality, the existing SiloSpi device was upgraded from a Sierra Wireless HL7802 to a HL7812 module, with a firmware version enabling NTN communication.

2.1. Hardware

We main goal was to test the existing antenna on the product (PA.26A) and then compare with other antenna options and compare the performance and reliability of the hardware in the field.

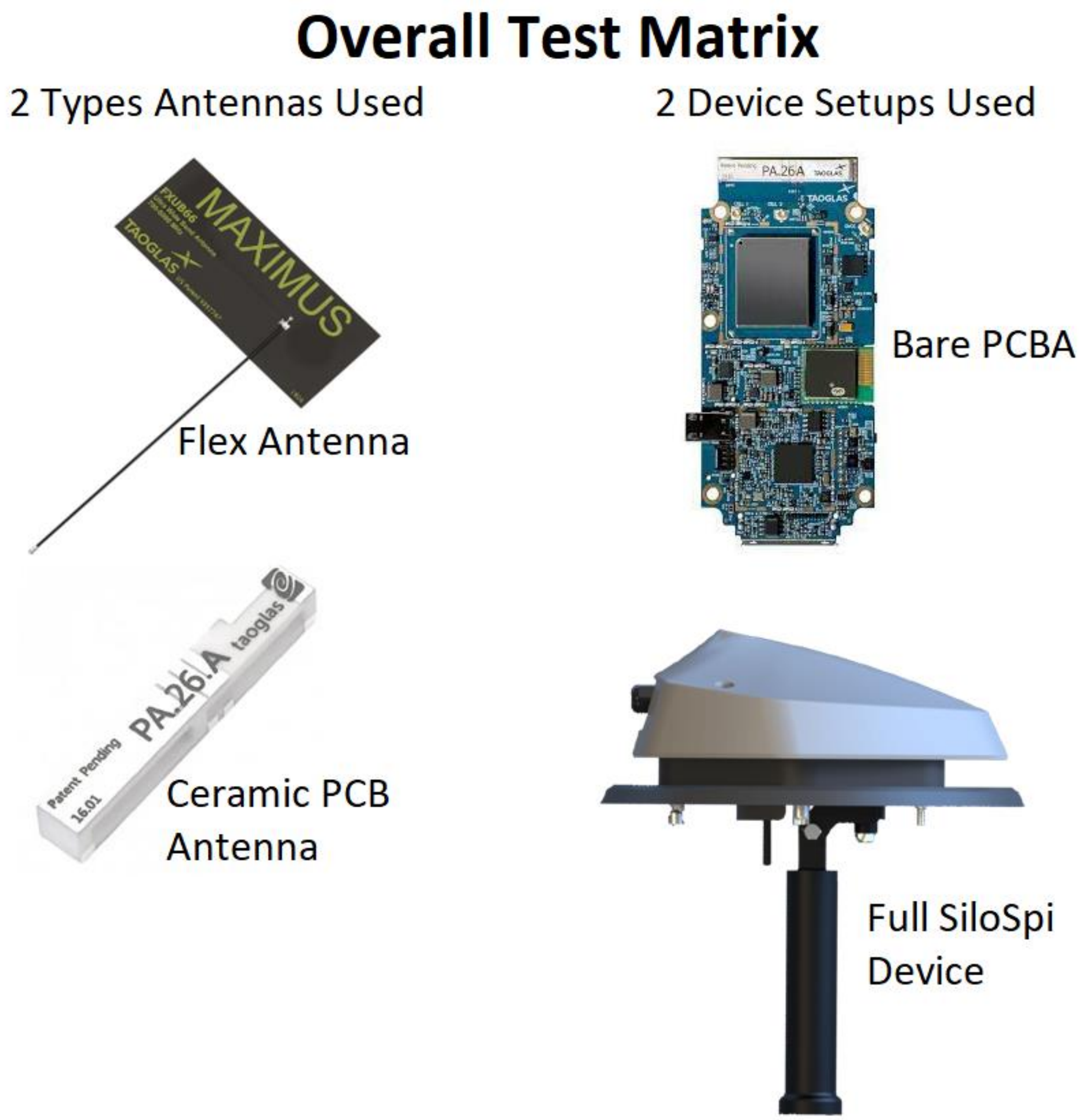

Figure 2 – High level pictures of the Antenna and Device setups used during the field testing

Two comparable hardware setups were used to conduct field tests:

Setup 1 – Bare PCBA

Contents Include

- Communications PCBA - EDGE4R BLE CELLULAR 01 REV. E PCBA
- Industrial Baseboard
- laser sensor
- Skylo Sim card
- Raspberry Pi 3B+ as a field test modem AT command driver
- (**no enclosure, bare PCBs, plastic bag to prevent from rain and snowfall**)

Figure 3 Photo of HW setup 1 (Bare PCBA) without enclosure

Setup 2 – Full Device

Contents Include

- Communications PCBA - EDGE4R BLE CELLULAR 01 REV. E PCBA
- Industrial Baseboard
- laser sensor
- Skylo Sim card
- Raspberry Pi 3B+ as a field test modem AT command driver
- (**fully assembled in original enclosure**)

Figure 4 Photo of HW setup (Full Device) in original enclosure

For the tests two different antennas were used:

Figure 6 Taoglas PA.26A ceramic PCB antenna

Figure 5 Taoglas FXUB66 flexible antenna

Based on recommendations from the Passive Antenna Chamber Testing (REF1), the RF matching circuit on EDGE4R board was updated to improve NTN communication radio performance.

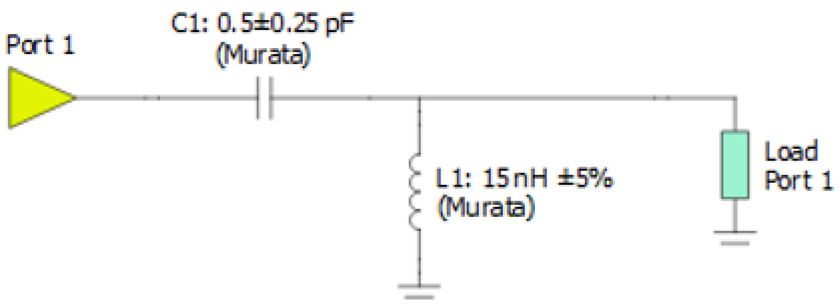

Figure 7 Matching circuit components used for PA.26A antenna

A common hardware component for both setups was a PC with a REST server script installed and running 24/7.

2.2. Firmware

EDGE4R BLE CELLULAR 01 REV. E was programmed with special test firmware whose only purpose was to provide a direct serial interface to HL7812 modem (pass-through mode), to control it using a Python script on a RPi.

The Sierra Wireless HL7812 was programmed with firmware version HL78xx.5.5.4.17.RK_03_02_01_00_32731_001.20230817.

2.3. Software

The Software part of the testing setup consisted of two Python scripts:

- modem driver – run on Raspberry Pi computer, used to control the HL7812 modem via serial port, manage the RX/TX of data packets, generate basic statistics regarding signal and data, read laser sensor;
- REST server – run on a local PC, used as a test echo server for testing bidirectional communication with the silo unit; provides interface for Skylo Data Mobility Platform using multiple endpoints for receiving data and notifications; capable of logging all the necessary parameters regarding communication status;

To be fully cooperative with the Skylo DMP, the REST server needs to be accessed from the public network (Internet). This was achieved by using an *ngrok* service, allowing connection to external networks in a consistent, secure, and repeatable manner without requiring any changes to network configurations.

The other important software component is Skylo DMP itself, this is the cloud service for managing the NTN communication between user equipment and user application. Skylo Connect APIs provide an interface to configure the endpoints for the DMP, which was essential for the data exchange.

2.4. Testing scenario

A simple test scenario based on a case study was proposed to get the closest results to the 'real-world' operation. The presented silo fill level monitoring device was used as the test unit.

1. The device reads the silo fill level using a laser distance sensor and the current parameters regarding the radio signal quality (RSRP, RSRQ, RSSI and SINR).

2. A small data packet (~35 bytes) with the above information is immediately sent to the remote test server, which records the information in a log, together with other useful information such as the number of packets, data size, number of ATTACH/DETACH/UNREACHABLE events.

3. The server sends the received packet back to the modem and verifies if the data has been delivered.

4. Steps 1-3 are repeated with configured interval. Default interval equals 1 minute.

3. Test results

Multiple tests have been carried out to verify the operation of different hardware setups in various weather conditions and locations. It is crucial for the radio module to know its location in order to calculate TA and other timing parameters necessary to establish a satellite link. During the tests the coordinates were manually fixed in modem as the testing was carried out without a GNSS antenna connected to the unit.

Below one can find data coming from conducted testing sessions.

3.1. Roof testing #1 (Poland) - PA.26A

3.1.1. Setup

HW: Setup 1 (Bare PCB)

Antenna: PA.26A ceramic antenna

SW: Python modem driver + Python REST test server

Description: 521 min test (8.6 hours), unit roof-mounted, modem transmits every 1 min data packet (ca. 35 bytes) via non-IP NTN to the server. The server immediately sends the data back to the modem. The packet consists of laser measurement value, signal parameters, registration status, packet and data counters.

Figure 8 Bare PCB setup tested on a roof

3.1.2. Statistics

Stats	
Total test duration in minutes	8.6 hours
Maximum packet length in bytes	36
Expected packets to be sent	521
Total packets sent from modem	422
Total packets received by server	404
Total echo packets received back by modem	209
Total echo packet loss	50.47%
Total bytes sent by modem	13875
Total bytes received back	6917
UNREACHABLE notification count	98
DETACHED notification count	18
ATTACHED notification count	105

Table 3 Statistics describing the quality of communication - roof testing #1 (Poland) - PA.26A

The test was conducted in difficult weather conditions (snowstorm), which probably significantly affected the final results. Over 95% of the packets sent from the modem reached the server, while only just over half of those sent from the server reached the unit. The downlink transmission must be described as unreliable.

3.1.3. Signal quality graph

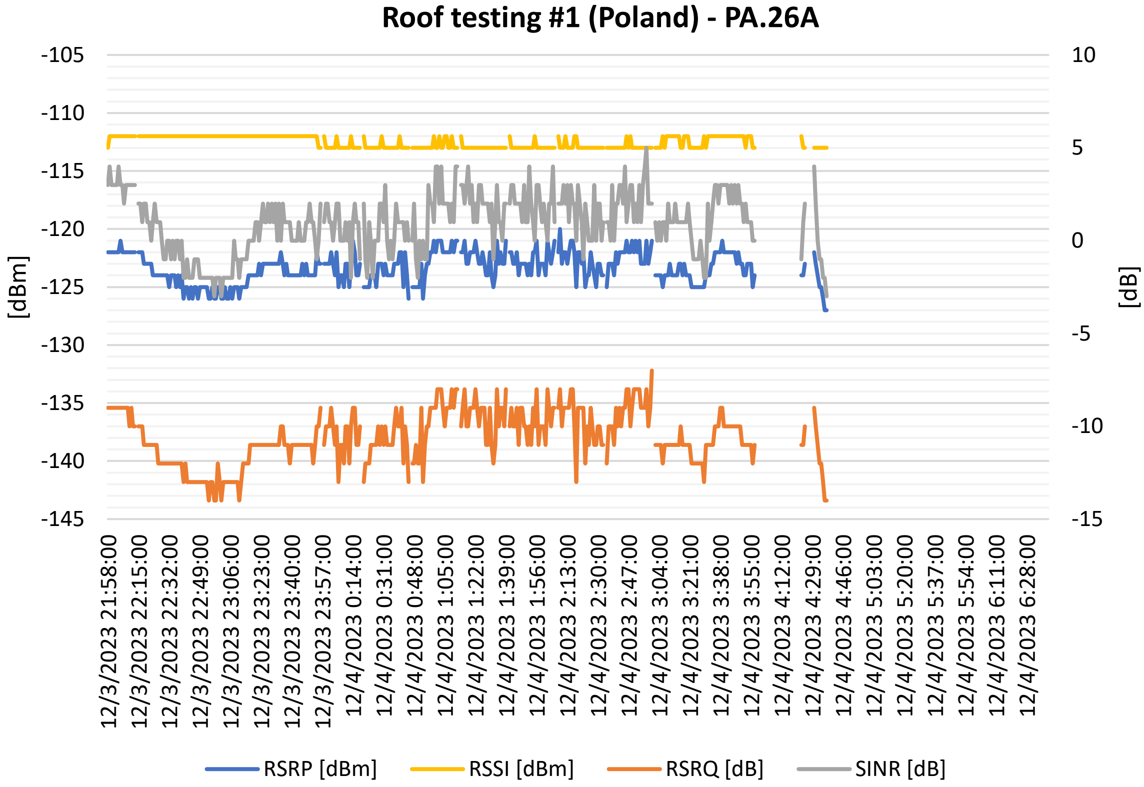

Figure 9 Signal quality parameters - roof testing #1 (Poland) - PA.26A

3.1.4. Conclusion

What is noticeable is the almost complete lack of communication with the satellite, starting at around 4am, which is probably related to the heavy snowfall. The signal quality is relatively poor.

3.2. Roof testing #2 (Poland) - PA.26A

3.2.1. Setup

<u>HW</u>: Setup 1 (Bare PCB)

<u>Antenna:</u> PA.26A ceramic antenna

<u>SW</u>: Python modem driver + Python REST test server

<u>Description</u>: 552 min test (9.2 hours), unit roof-mounted, modem transmits every 1 min data packet (ca. 35 bytes) via non-IP NTN to the server. The server immediately sends the data back to the modem.

The packet consists of laser measurement value, signal parameters, registration status, packet and data counters.

3.2.2. Statistics

Stats	
Total test duration in minutes	9.2 hours
Maximum packet length in bytes	36
Expected packets to be sent	552
Total packets sent from modem	524
Total packets received by server	488
Total echo packets received back by modem	426
Total echo packet loss	18.70%
Total bytes sent by modem	16483
Total bytes received back	13694
UNREACHABLE notification count	23
DETACHED notification count	23
ATTACHED notification count	44

Table 4 Statistics describing the quality of communication - roof testing #2 (Poland) - PA.26A

3.2.3. Signal quality graph

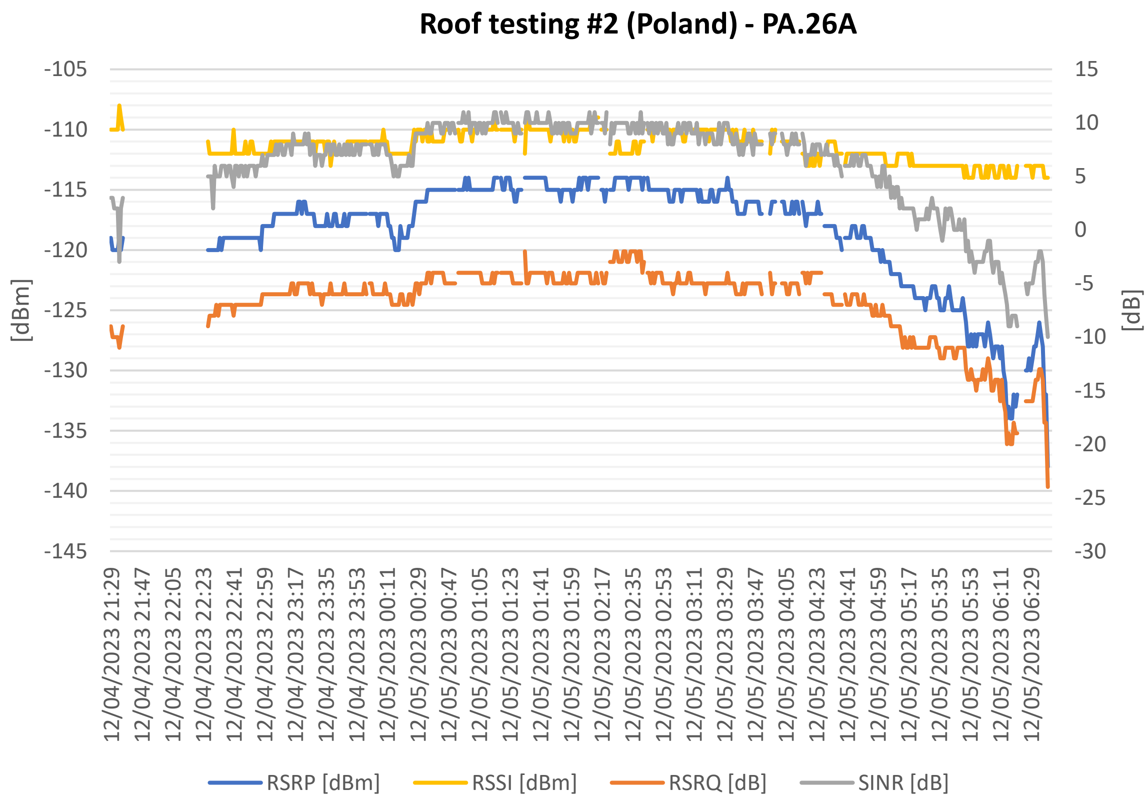

Figure 10 Signal quality parameters - roof testing #2 (Poland) - PA.26A

3.2.4. Conclusion

Another test with the same hardware configuration in better weather conditions performs better, with over 93% successful uplink transmissions and over 87% successful downlink transmissions.

3.3. Roof testing #3 (Poland) – FXUB66

Figure 11 Enclosed unit tested on a roof

3.3.1. Setup

HW: Setup 2 (Full Device)

Antenna: FXUB66 flex antenna

SW: Python modem driver + Python REST test server

Description: 805 min test (13.4 hours) , unit roof-mounted, modem transmits every 1 min data packet (ca. 35 bytes) via non-IP NTN to the server. The server immediately sends the data back to the modem. The packet consists of laser measurement value, signal parameters, registration status, packet and data counters.

3.3.2. Statistics

Stats	
Total test duration in minutes	13.4 hours
Maximum packet length in bytes	36
Expected packets to be sent	805
Total packets sent from modem	606
Total packets received by server	568
Total echo packets received back by modem	428
Total echo packet loss	29.37%
Total bytes sent by modem	19663
Total bytes received back	13831
UNREACHABLE notification count	67
DETACHED notification count	27
ATTACHED notification count	103

Table 5 Statistics describing the quality of communication - roof testing #3 (Poland) – FXUB66

3.3.3. Signal quality graph

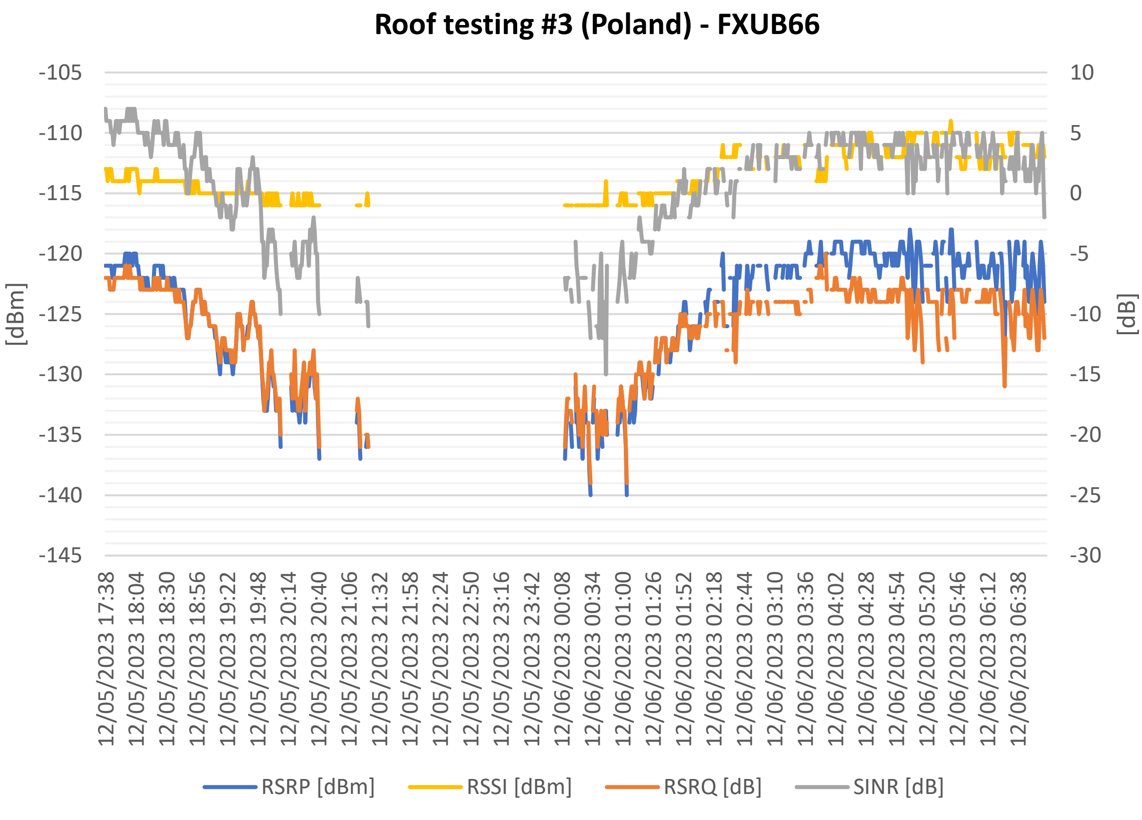

Figure 12 Signal quality parameters - roof testing #3 (Poland) - FXUB66

3.3.4. Conclusion

Over 3 hours of missing data suggests that the environmental conditions may have impacted the communication (TBD).

3.4. Outdoor testing (Ireland) - FXUB66

The outdoor testing took place between 15.12.2023 and 17.12.2023, over three consecutive days. The unit was installed approximately 600 m from the location indicated by the coordinates stored in the modem.

Figure 13 Enclosed unit tested outdoors

3.4.1. Setup

HW: Setup 2 (Full Device)

Antenna: FXUB66 flex antenna

SW: Python modem driver + Python REST test server

Description: 3 tests (24 hours each), unit mounted outdoors, modem transmits every 1 min data packet (ca. 35 bytes) via non-IP NTN to the server. The server immediately sends the data back to the modem. The packet consists of laser measurement value, signal parameters, registration status, packet and data counters.

3.4.2. Statistics

Stats	Date		
	15.12.	16.12.	17.12.
Total test duration in minutes	24 hours		
Maximum packet length in bytes	36		
Expected packets to be sent	1440		
Total packets sent from modem	812	801	713
Total packets received by server	699	709	550
Total echo packets received back by modem	570	573	373
Total echo packet loss	29.8%	28.46%	47.69%
Total bytes sent by modem	27492	27325	24173
Total bytes received back	19545	19715	12789
UNREACHABLE notification count	71	72	114
DETACHED notification count	20	19	12
ATTACHED notification count	91	91	126

Table 6 Statistics describing the quality of communication - outdoor testing #1-#3 (Ireland) – FXUB66

3.4.3. Signal quality graph

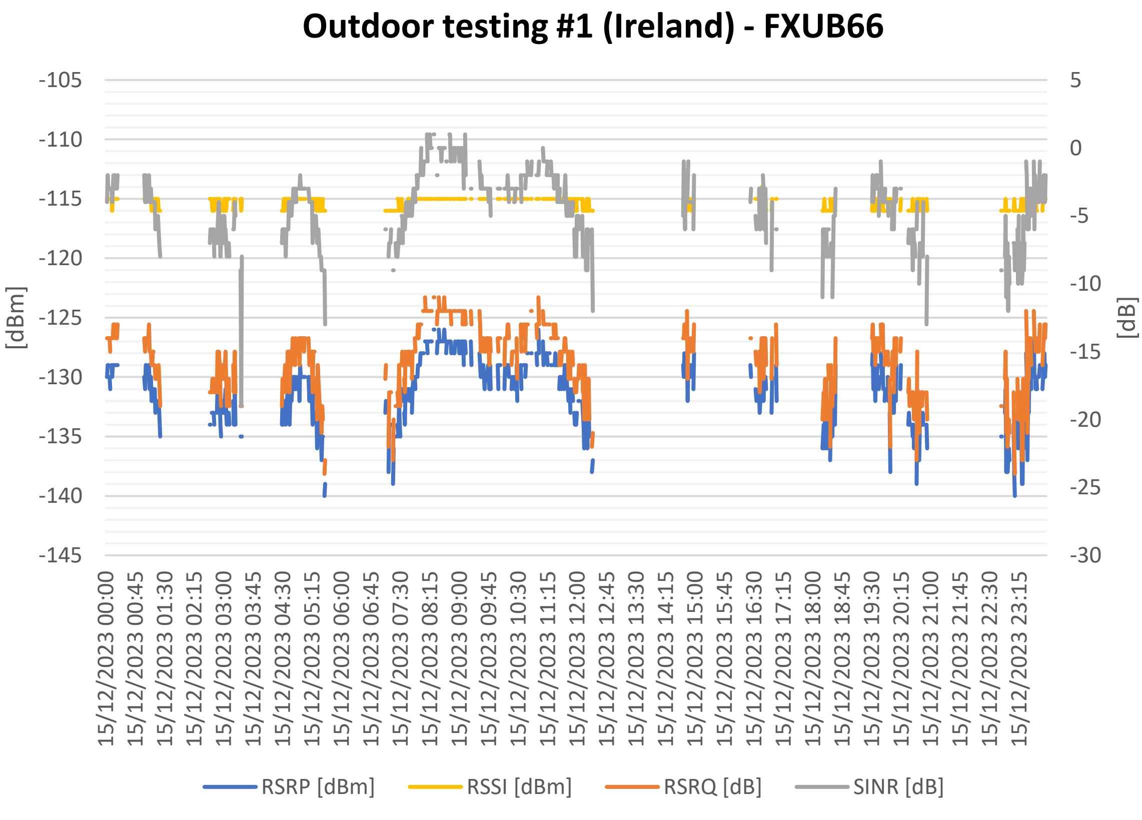

Figure 14 Signal quality parameters - outdoor testing #1 (Ireland) - FXUB66

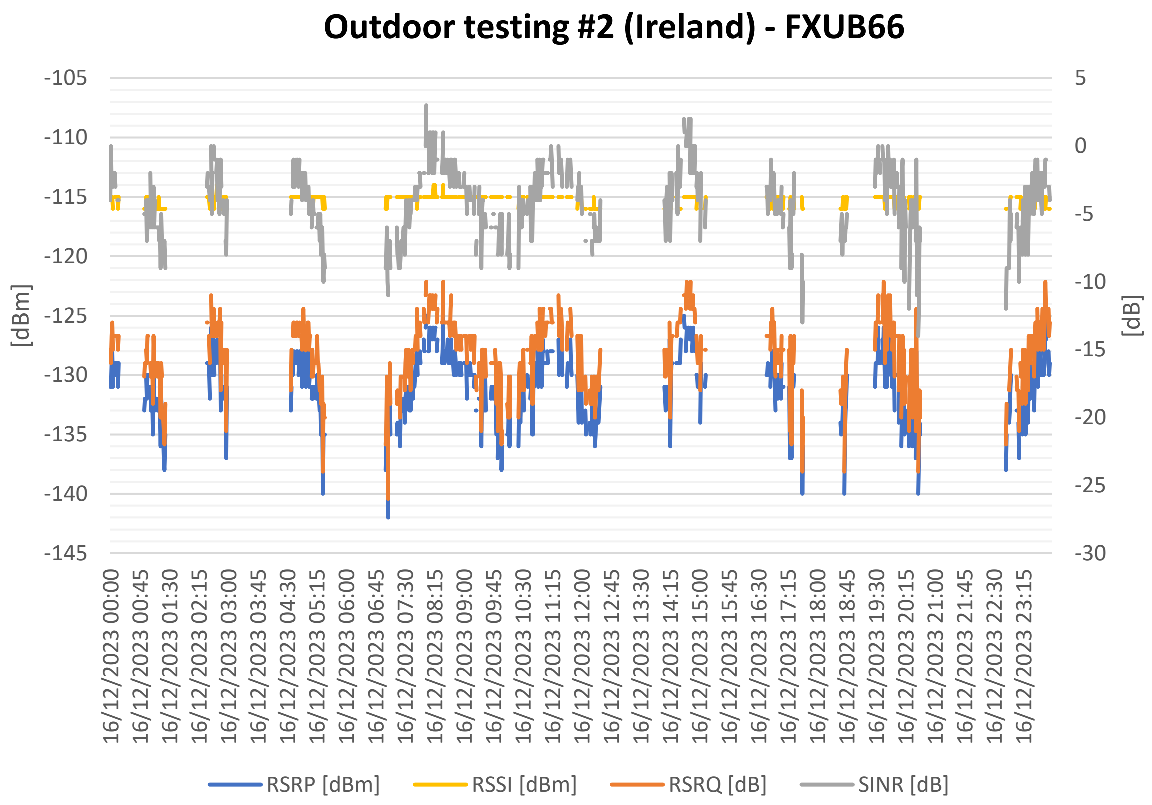

Figure 15 Signal quality parameters - outdoor testing #2 (Ireland) - FXUB66

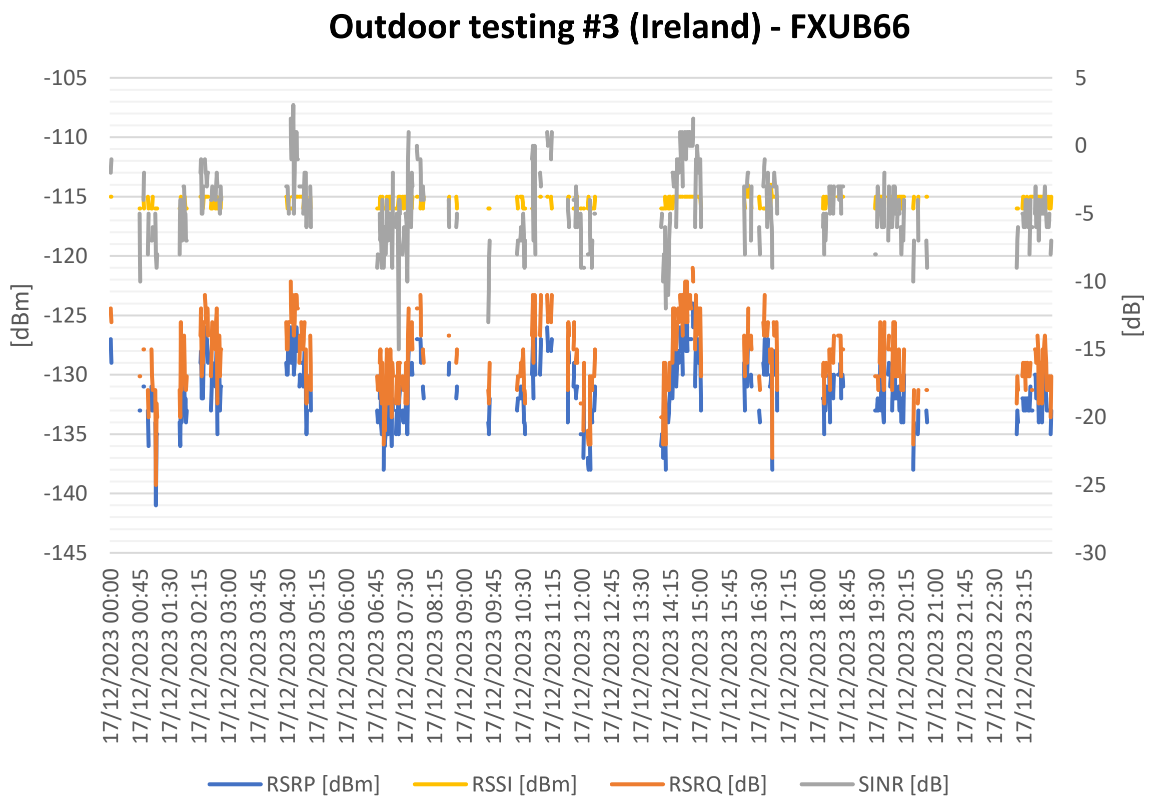

Figure 16 Signal quality parameters - outdoor testing #3 (Ireland) - FXUB66

3.4.4. Conclusion

Testing for 3 consecutive days and comparing the graphs shows that there are repeated periods of missing data, due to inaccurate geographical coordinates set in modem. It is worth mentioning that the original installation site of the unit was approximately 40 km away from the location indicated by the geographical coordinates, in which case correct NTN communication could not be established. It's important to notice that devices need to know their exact location in order to operate on the NTN network.

3.5. Top of the silo testing #1 – (Ireland) – FXUB66

Testing the unit on top of the silo took place between 18.12.2023 and 19.12.2023. The unit was installed at the location indicated by the exact coordinates stored in the modem.

Figure 17 Silo fill level monitoring

3.5.1. Setup

HW: Setup 2 (Full Device)

Antenna: FXUB66 flex antenna

SW: Python modem driver + Python REST test server

Description: 12 hour test, unit mounted on a silo, modem transmits every 1 min data packet (ca. 35 bytes) via non-IP NTN to the server. The server immediately sends the data back to the modem. The packet consists of laser measurement value, signal parameters, registration status, packet and data counters.

3.5.2. Statistics

Stats	
Total test duration in minutes	12 hours

Maximum packet length in bytes	36
Expected packets to be sent	720
Total packets sent from modem	720
Total packets received by server	715
Total echo packets received back by modem	668
Total echo packet loss	7.22%
Total bytes sent by modem	24112
Total bytes received back	22414
UNREACHABLE notification count	10
DETACHED notification count	22
ATTACHED notification count	32

Figure 18 Statistics describing the quality of communication - silo testing #1 (Ireland) – FXUB66

3.5.3. Signal quality graph

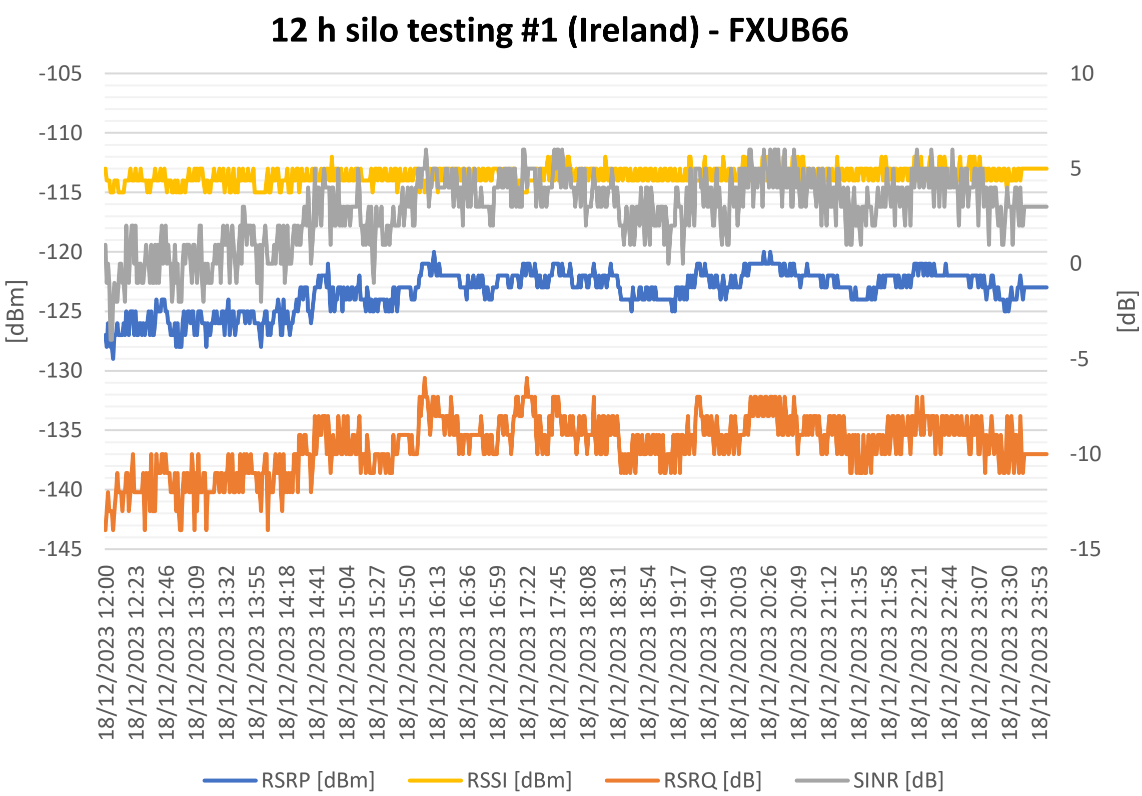

Figure 19 Signal quality parameters - silo testing #1 (Ireland) - FXUB66

3.6. Top of the silo testing #2 – (Ireland) – FXUB66

3.6.1. Setup

HW: Setup 2 (Full Device)

Antenna: FXUB66 flex antenna

SW: Python modem driver + Python REST test server

Description: 24h test, unit mounted on a silo, modem transmits every 1 min data packet (ca. 35 bytes) via non-IP NTN to the server. The server immediately sends the data back to the modem. The packet consists of laser measurement value, signal parameters, registration status, packet and data counters.

3.6.2. Statistics

Stats	
Total test duration in minutes	1440
Maximum packet length in bytes	36
Expected packets to be sent	1440
Total packets sent from modem	1440
Total packets received by server	1440
Total echo packets received back by modem	1381
Total echo packet loss	4.1%
Total bytes sent by modem	48524
Total bytes received back	46545
UNREACHABLE notification count	0
DETACHED notification count	51
ATTACHED notification count	51

Figure 20 Statistics describing the quality of communication - silo testing #2 (Ireland) – FXUB66

3.6.3. Signal quality graph

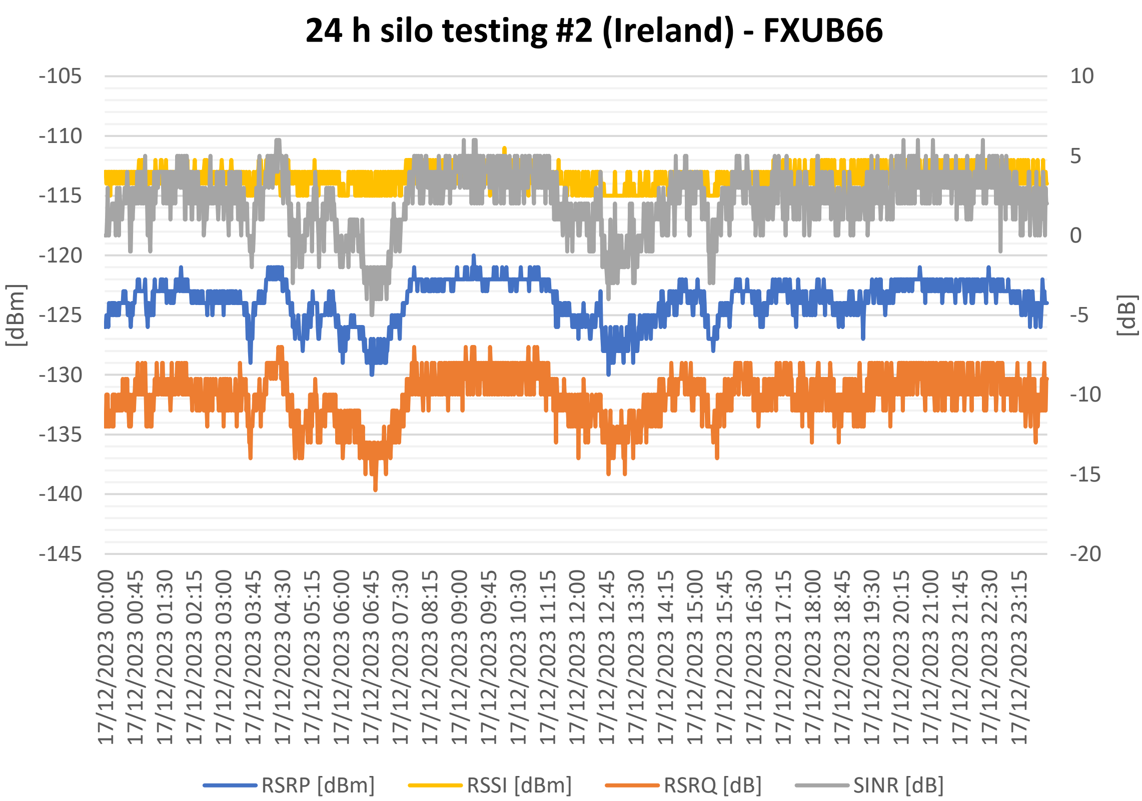

Figure 21 Signal quality parameters - silo testing #2 (Ireland) - FXUB66

4. General remarks and conclusions

- For this field test, we did not enable the GNSS capability of the HL7812 module due to time constraints but accurate location of the devices location is essential for it to establish successful communication on the NTN network. Location needs to be precisely determined, either manually (as done during this field test) or obtained with the integrated GNSS radio/antenna. Incorrect/inaccurate coordinates will result in poor or no service at all.
- The signal quality can depend on weather conditions (snowstorm, heavy clouds, rain).
- Both the legacy PA.26A antenna and newer FXUB66 antenna worked in the silo monitoring application. This confirms that only the unit's modem may be upgraded to make the device 'NTN communication ready'. Various antenna options exist as seen in the Passive Antenna Chamber Testing report (REF1).
- It seems that the larger the data packet, the less chance it has of being delivered to the server; some of the previous tests included even 256 B dummy data packets. The delivery success ratio increased when sending smaller packets.
- Non-IP communication is connectionless, so data packets are neither automatically retransmitted nor acknowledged. Control planes are used for user data transport.
- The maximum single data packet for Skylo NTN is 256 B.
- The modem sometimes reports that the data has been sent correctly, even though no notification of uplink data comes from the cloud side -> some packets went missing after sending.
- The uplink communication seems to be more reliable than in the downlink direction.

5. Next steps

- Enable GNSS for realtime location updates (avoid manual co-ordinate setting)
    - This would of course be essential for a mobile product (non stationary)
- Re-test the legacy PA.26A antenna on top of the Silo to measure improvement in operation (from ground/roof dataset)
- Re-test with the most recommended/optimal antenna (FXUB64) to show best possible performance, FXUB64 was recommended in the Passive Antenna Chamber Testing phase (REF1).