B37 antenna tuning blueprint

Integration board with u-blox cellular modules supporting dynamic antenna tuning functionality

Application note

Abstract

This document presents the u-blox B37 blueprint board, showing how the dynamic antenna tuning feature supported by the u-blox SARA-R422M10S and SARA-R510M8S cellular / GNSS modules improves the RF performances using the off-the-shelf KYOCERA AVX 1004795 on-board antenna. Additionally, the B37 reference design shows RF co-existence between cellular and GNSS systems. The B37 design is available for u-blox customers as a blueprint, including schematics, bill of material and Gerber data, simplifying integration and innovation.

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Product name
SARA-R422M10S
SARA-R510M8S

Contents

1 Introduction

1.1 Overview

The u-blox B37 blueprint is a reference design that demonstrates the u-blox dynamic antenna tuning feature available with the u-blox SARA-R510M8S and SARA-R422M10S cellular modules, which also integrate u-blox's leading GNSS receiver technology.

The u-blox B37 blueprint includes two off-the-shelf KYOCERA AVX on-board antennas, specifically the 1004795 cellular antenna, with related tuning components, and the 1004322 GNSS antenna.

The B37 design is a tested and optimized example in a small form factor. The main features are:

- Having a small size (45 x 70 mm). comparable to a common tracking application.
- Providing a reference for integration of u-blox combo cellular modules with dynamic antenna tuning functionality.
- Presenting an example of the component choice, placement, and layout.
- Addressing the RF and hardware challenges related to the integration of on-board antennas.
- Providing a power supply for both 12 V and 24 V vehicles, with protection and filters following automotive regulations.

The RF characteristics of the board have been carefully analyzed and optimized to:

- Guarantee the best performance with all the technologies.
- Minimize the interference between GNSS and cellular technologies (co-existence scenarios).

The B37 blueprint is designed to meet the RF requirements defined by the Mobile Network Operators., The Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) figures have been tested in a fully anechoic chamber to verify the RF performances.

This application note provides valuable insights into the hardware solutions implemented on the board and presents the results of the testing performed on the unit.

1.2 BoM variants

The printed circuit board of the B37 blueprint is identified by the "KM_SR5_CS_397B00" code shown on the top side of the board. There are two Bill-of-Material variants, referred to as Hardware Release (HR) variants, for the same printed circuit board:

- The HR_397B**0**0 variant mounts the u-blox SARA-R510M8S module, supporting LTE-M / NB-IoT cellular technology, and integrating the u-blox M8 standard precision GNSS receiver supporting concurrent reception of up to 3 GNSS systems (GPS and Galileo + GLONASS or BeiDou)

- The HR_397B**A**0 variant mounts the u-blox SARA-R422M10S module, supporting LTE-M / NB-IoT and EGPRS cellular technology, and integrating the u-blox M10 standard precision GNSS receiver supporting concurrent reception of up to 4 GNSS systems (GPS, Galileo, GLONASS and BeiDou).

Table 1 shows the two variants of the blueprint B37 with the their integrated modules.

Variant	Cellular module
B37_HR_397B00	SARA-R510M8S
B37_HR_397BA0	SARA-R422M10S

Table 1: Blueprint B37 variants and integrated modules

For a complete description of the functionalities supported by each module, see the u-blox SARA-R5 series data sheet [1], and the u-blox SARA-R4 series data sheet [2].

1.3 Board pictures

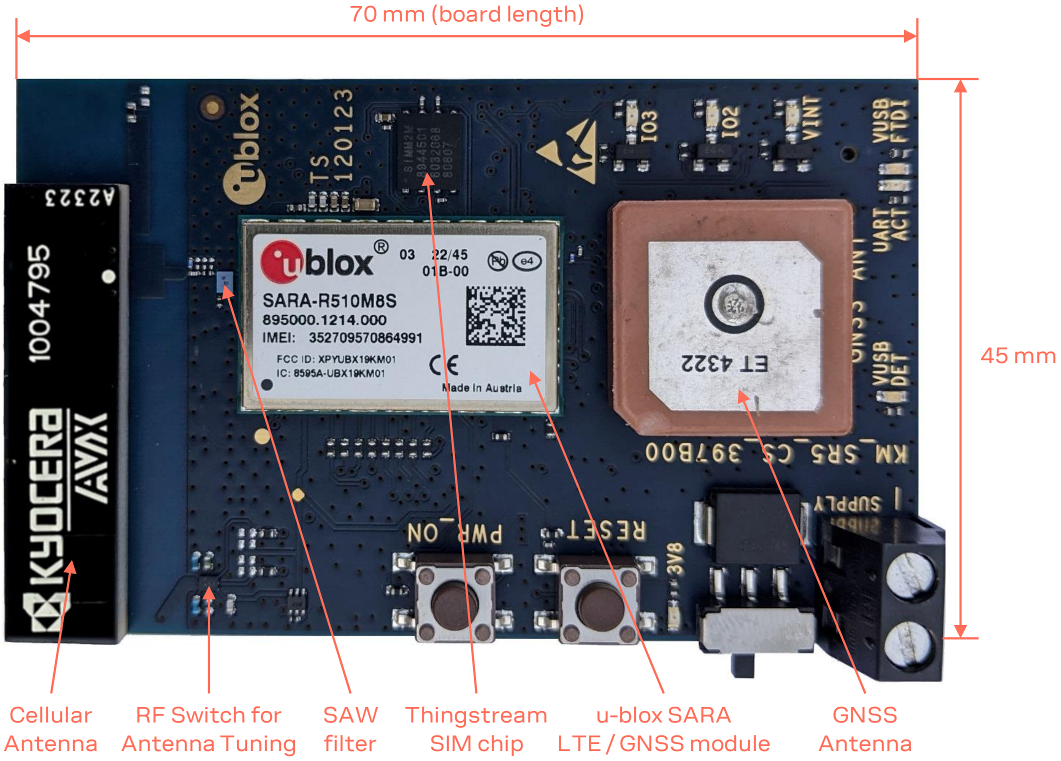

Figure 1: u-blox B37 blueprint top view

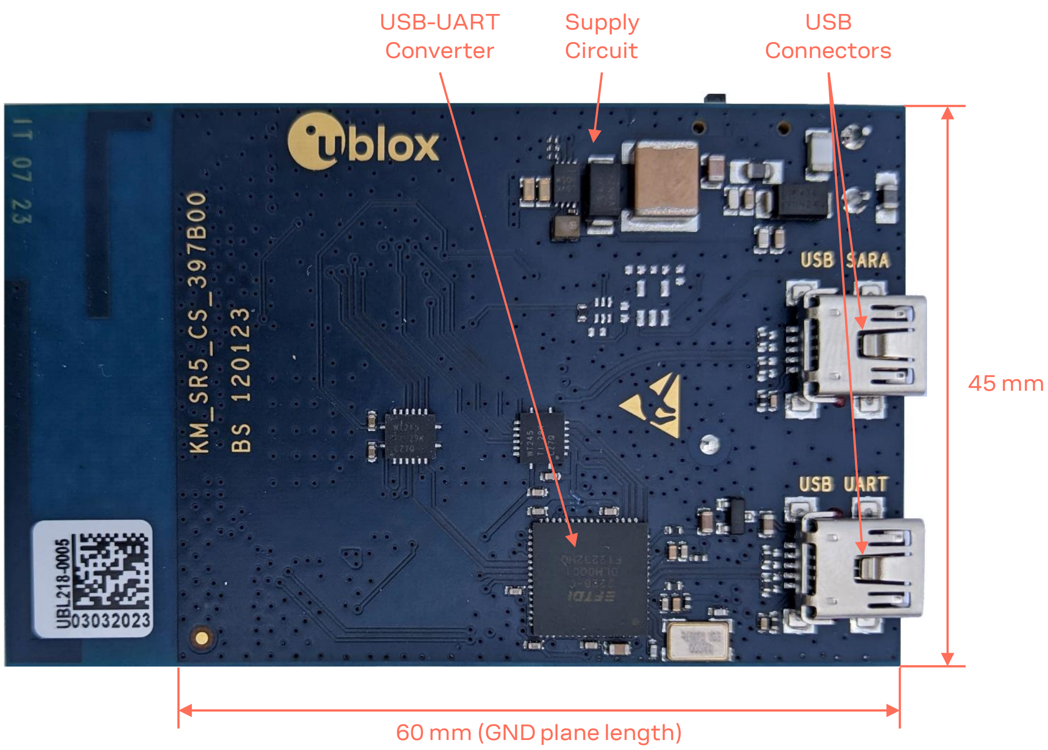

Figure 2: u-blox B37 blueprint bottom view

2 Board description

2.1 Block diagram

Figure 3 shows the block diagram of the u-blox B37 blueprint, illustrating the main parts included.

The SARA module is supplied by a DC-DC step-down converter which can withstand a wide range of input voltages, from 7.5 V to 32 V. This range includes typical automotive voltages for both passenger vehicles and light trucks, as well as heavy trucks and earth-moving equipment.

To simulate an on-board MCU that sends AT commands to the module, a USB to UART converter allows communication over the module UART from an external host PC via dedicated USB connector. An additional USB port is provided for debugging and diagnostic purposes.

Given the small size of the board (see section 2.2), the dynamic antenna tuning pins on the cellular module control the KYOCERA AVX EC646 SP4T RF switch that changes the cellular antenna aperture to optimize the efficiency according to the actual RF cellular band in use. Moreover, to minimize the interference between cellular and GNSS technologies, the Qualcomm RF360 B8666 band-stop SAW filter has been added along the cellular RF path.

The cellular connectivity over mobile networks is granted using the on-board u-blox Thingstream M2M embedded SIM [3].

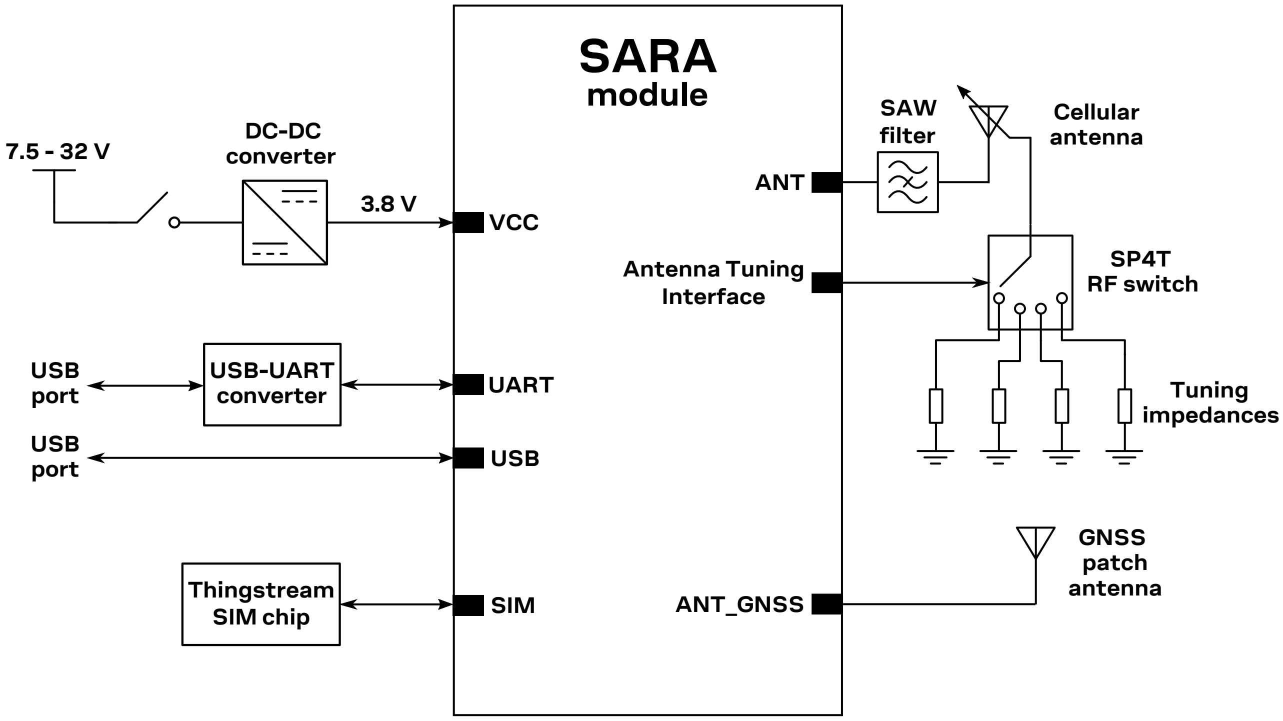

Figure 3: u-blox B37 blueprint block diagram

2.2 Mechanical dimensions and PCB details

As also illustrated in Figure 1 and Figure 2, the dimensions of the u-blox B37 blueprint are 45 x 70 mm. These dimensions guarantee the optimal placement of the cellular and GNSS antennas, while being as small as possible.

The PCB has a 4-layer stack-up. RF and signal routing runs on the top layer, USB traces and other signals on the bottom layer and the two inner layers are mainly for ground and power distribution. This solution offers the best immunity against EMC and spurious emissions.

Components are placed on both sides of the board:

- The top layer hosts the antennas and associated RF components, the SARA cellular / GNSS combo module, the switches and push buttons, the power connector, the SIM chip, test points and LEDs.
- The bottom layer accommodates the USB connectors, the power supply circuitry, the USB-UART converter and components related to the communication interfaces like the voltage translators.

2.3 Power supply

The B37 is supplied by a typical DC voltage of 12 or 24 V, and it accepts supply voltages up to 32 V. Power supply input is via screw terminals on the top of the PCB.

A main switching step-down regulator is used to supply a regulated voltage for the cellular module. For more details on the block diagrams, see section 2.1 and the design description in section 3.1.

2.4 Digital interfaces

The external digital interfaces for the user are:

1. Primary UART interface of the module (input / output data lines and HW flow control lines), converted as USB interface at the available mini-USB connector. This interface can be used for AT commands and data communication, and for the FW update of SARA-R5 modules.
2. Secondary UART interface of the module (input / output data lines and HW flow control lines), converted as USB interface at the available mini-USB connector. This interface can be used for tunneling of the GNSS data.
3. USB interface of the module, at the available mini-USB connector. This interface can be used for SARA-R5 / SARA-R42 modules diagnostic and for SARA-R42 modules FW update.

The primary UART interface of SARA-R5 and SARA-R42 modules also supports the multiplexer functionality as per 3GPP TS 27.010 [4]. For more details, see the mux implementation application note [5].

2.5 Antenna interfaces

Blueprint B37 integrates two SMD-mount antennas:

1. The KYOCERA AVX 1004795 LTE / LPWA broadband FR4 36.0 x 9.0 mm embedded antenna [6], for cellular signals transmission / reception.
2. The KYOCERA AVX 1004322 GPS / GLONASS / BeiDou / Galileo 18.0 x 18.0 mm patch antenna [7], for GNSS signals reception.

2.6 LEDs

For quick board status assessment, 7 LEDs are mounted on the top side of the board (Figure 4):

1. Two blue LEDs (DS105, labelled **VUSB FTDI** and DS212, labelled **VUSB DET**) near the USB connectors to signal that the B37 is connected to the respective USB bus
2. One green LED (DSD135, labelled **UART ACT**) near DS105 to signal USB to UART converter activity, both Tx and Rx
3. One green LED near the power switch (DL400, labeled **3V8**) to signal that the onboard DC-DC converter is active and generating 3.8 V for the SARA module
4. One green LED (DS213, labeled **VINT**) that turns on when the VINT voltage goes high, signaling that the cellular module is active
5. Two programmable green LEDs: DS207 (labeled **IO2**) and DS202 (labeled **IO3**) respectively controlled by the **GPIO2** and **GPIO3** pins of the module

Figure 4: PCB detail showing the LEDs on the top side.

2.7 Power-on/off and reset

The **PWR_ON** / **PWR_CTRL** and the **RESET_N** pins of the module are connected to externally accessible pushbuttons labeled as “PWR_ON” and “RESET” respectively, located as in Figure 5.

Figure 5: PCB detail showing the PWR_ON and RESET pushbuttons.

3 Board design solutions

3.1 Power supply design

3.1.1 Protection

To comply with 12 V and 24 V automotive supply voltages, input protection is required for battery power entering the board. The protection consists of a fuse, a diode for reverse polarity protection, and a TVS diode for overvoltage protection.

3.1.2 Input filter

The input filter is placed after the protection circuitry to maintain the radiated spurious emissions at acceptable levels. Moreover, long power leads may alter the antenna performance. Therefore, the ferrite beads in series with the positive and negative input terminals keep the RF currents confined within the board GND plane.

3.1.3 Cellular module supply

The main power supply of the board is a DC-DC step-down switching regulator, powered at an input voltage from 7.5 V to 32 V DC. The voltage level present at the output of the step-down regulator is used to supply the cellular module and is set to 3.8 V in all the blueprint variants.

The implemented solution is the typical choice when the available primary supply source has a nominal voltage much higher than the operating voltage of the intended load. In these cases, a switching step-down is the best solution regarding power efficiency and current draw.

The Analog Devices (former Linear Technology) LT3663 has been selected as the regulator IC because it guarantees high efficiency and 1.2 A maximum current handling capability. The **RUN** pin on this part is used for powering on or off the 3.8 V rail and is controlled by the S100 switch. In a real application, this pin can be controlled by the onboard MCU to apply to or remove power from the module.

The power to the cellular module is directly supplied by the step-down regulator. The ceramic capacitors and a series ferrite bead are placed on the **VCC** supply pins of the cellular module for EMI filtering in the frequency bands of the cellular module operation.

For general design guidelines about the integration of the switching regulator and VCC supply circuit design, see the SARA-R5 series system integration manual [8] and the SARA-R4 series system integration manual [9].

3.2 RF design

3.2.1 General concepts

Optimizing the RF performance is among the crucial considerations when integrating a cellular module into an application. Given that the B37 blueprint has both a cellular and a GNSS antenna, not only the performance of the individual radiating elements must be considered, but also their coexistence. Moreover, the performance of PCB-mount antennas is significantly affected by the size of the ground plane and their placement. Therefore, placement and routing of the RF elements has the highest priority when designing a board using cellular / GNSS combo modules.

☞ Follow thoroughly the antenna and RF design-in guidelines and recommendations of the selected antenna manufacturer, in addition to the guidelines in the SARA-R5 series system integration manual [8] and the SARA-R4 series system integration manual [9].

3.2.2 Ground plane size and cellular antenna

The size of the B37 blueprint is 70 x 45 mm, of which 60 x 45 mm are dedicated to the ground plane. Board dimensions have been defined to minimize the PCB size and to guarantee adequate RF performance of the cellular antenna.

As general guidelines, consider the following parameters in the antenna selection process:

- **Operating band**, usually expressed as the frequency span where the VSWR (or S11) and antenna efficiency are acceptable. Ensure that the antenna operating bands cover the frequency ranges in use in the countries of deployment. The higher the efficiency and the lower the VSWR, the better the antenna performance.
- **Gain**, the efficiency multiplied by the directivity. It is a measure of how the antenna directs radiation towards a certain direction (usually the direction of maximum transmission / reception). The antenna's maximum gain must not exceed the limits imposed by the regulatory certification schemes.
- **Antenna pattern**, the variation of the power radiated by the antenna as a function of the direction. For cellular applications it is convenient to select antennas with a "doughnut-shaped" or toroidal radiation pattern. This guarantees a good reception in nearly all directions.

To maximize the parameters above, the antenna characteristic impedance must be matched to 50 Ω to prevent additional losses.

Moreover, the antennas position on the board must be accurately defined. If the design uses an off-the-shelf antenna, like this blueprint does, follow the antenna datasheet and the manufacturer to choose the best placement. Otherwise, simulations and measurements are necessary to decide the best antenna location.

PCB-mount antenna performance depends greatly on the size and shape of the ground plane. Any metallic element placed near the antenna will also change the RF behavior of the device. For example, batteries position must be carefully evaluated during the design of an application and the battery must never cover the antenna clearance as dictated by the manufacturer.

Usually, the longest direction of the PCB that will influence the performance the most. The ground plane of the application PCB can be reduced to a minimum size that must be approximately one quarter of the wavelength of the minimum radiated frequency. The B37 blueprint offers a numerical example, where the lowest supported frequency band is the LTE Band 71, so:

Minimum frequency = 617 MHz → Wavelength ≈ 48 cm → Minimum GND plane size ≈ 12 cm

This requirement conflicts with the size of the board which is 70 mm in the longest direction.

Radiation efficiency with small devices can be improved by a technique called antenna aperture tuning. It aims to increase the antenna electrical dimension to make it appears bigger than it is.

A resonant circuit is inserted to tune the antenna aperture (i.e., the portion of a plane surface near the antenna, perpendicular to the direction of maximum radiation, through which the major part of the radiation passes). This creates a peak in the efficiency at a certain frequency that improves the performance at the expense of bandwidth.

The dynamic antenna tuning feature of all the modules supported by the B37 blueprint allows moving this peak according to the current operating frequency of the application. This leads to maximum antenna performance in the low frequency LTE bands with the addition of an RF switch and a few tuning components. Dynamic antenna aperture tuning is depicted in Figure 6.

To implement the dynamic antenna tuning feature, the 36.0 x 9.0 mm embedded KYOCERA AVX 1004795 cellular antenna is paired with the EC646 switch by the same manufacturer. The value of the tuning components have been determined with the help of KYOCERA AVX, by testing the application performance in their anechoic chamber.

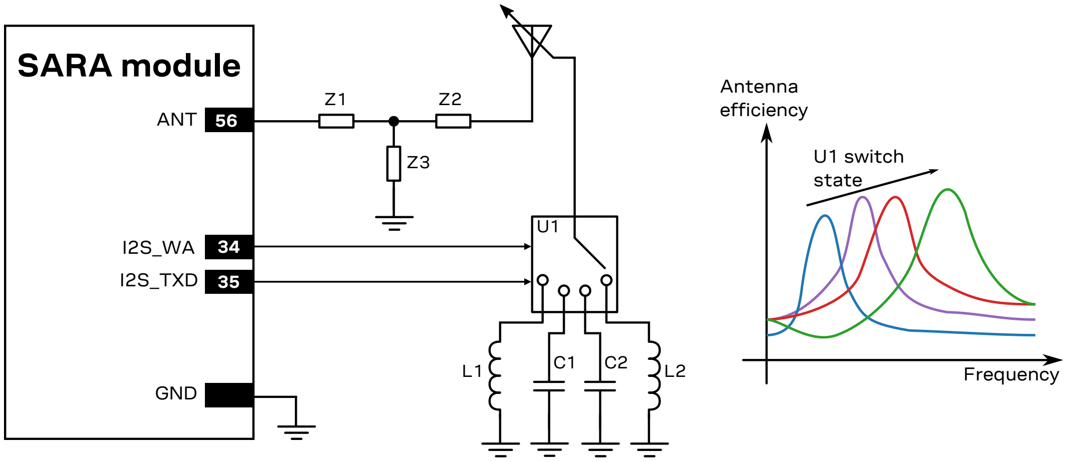

Figure 6: Dynamic antenna aperture tuning conceptual diagram.

3.2.3 Dynamic antenna tuner functionality

The modules in all the B37 blueprint variants support cellular frequencies from 600 MHz to 2.2 GHz. To allow more efficient antenna designs over a wide bandwidth, **I2S_TXD** and **I2S_WA** pins can be configured to change their output value in real time according to the current operating LTE band. See the corresponding module data sheet [1] [2] and system integration manual [8] [9] for more details.

The **I2S_TXD** pin is labelled **ANT_TUNA** in the schematic, while **I2S_WA** is labelled **ANT_TUNB**. The two lines change state with the module operating band, as shown in Figure 7, Figure 8, Figure 9 and Figure 10.

Figure 7: Dynamic antenna tuning pins configuration for LTE Band 71 (ANT_TUNA = 0, ANT_TUNB = 0)

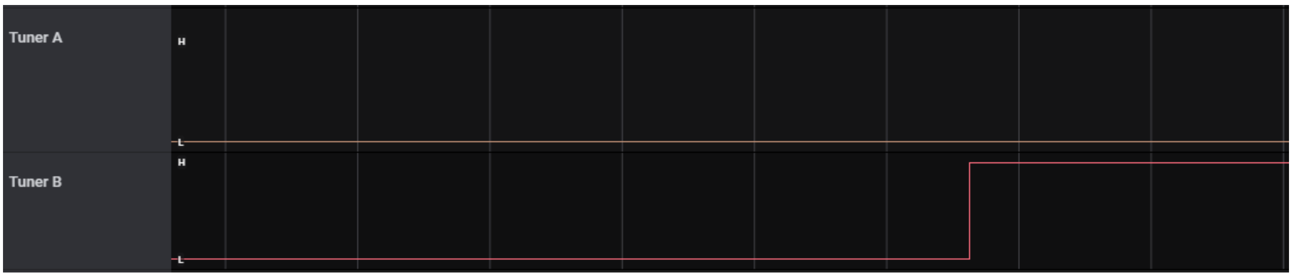

Figure 8: Dynamic antenna tuning pins configuration for LTE Band 12 (ANT_TUNA = 0, ANT_TUNB = 1)

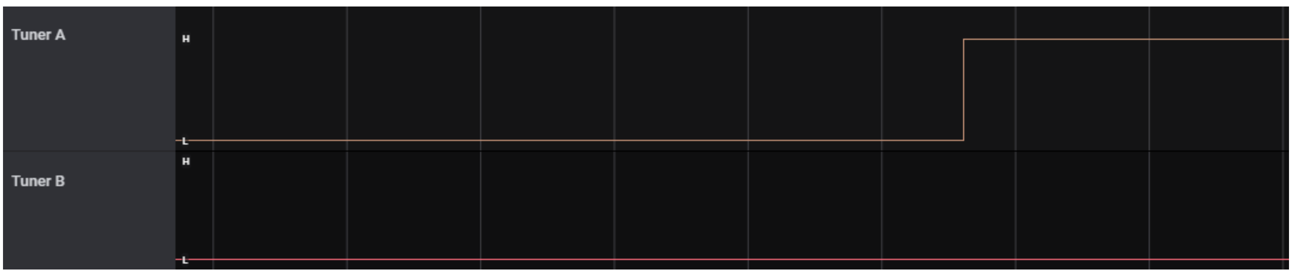

Figure 9: Dynamic antenna tuning pins configuration for LTE Band 20 (ANT_TUNA = 1, ANT_TUNB = 0)

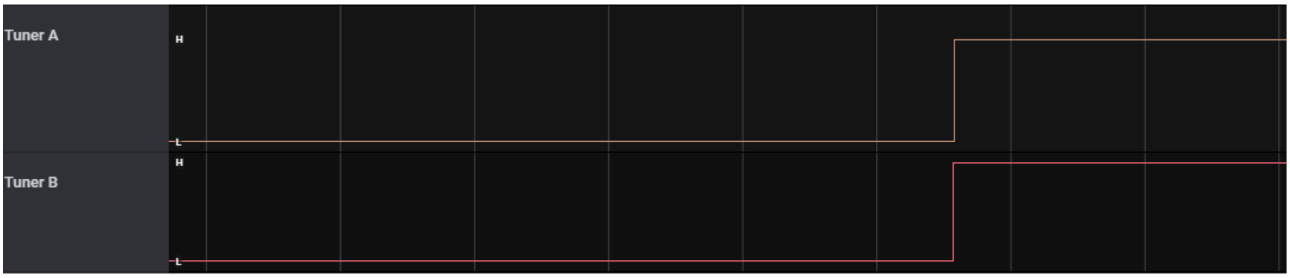

Figure 10: Dynamic antenna tuning pins configuration for LTE Band 2 (ANT_TUNA = 1, ANT_TUNB = 1)

3.2.4 GNSS antenna design choices

The positioning module integrated in the cellular module can receive and track multiple GNSS systems: GPS, GLONASS, BeiDou, QZSS, SBAS and Galileo. For more details of concurrent GNSS operation, see the SARA-R5 / SARA-R4 positioning and timing implementation application note [10]. The antenna integrated in the board is a 18x18x4 mm ceramic patch antenna working in the GPS / GLONASS / BEIDOU frequency bands (1559…1610 MHZ). The selected part is the KYOCERA AVX 1004322.

As discussed in u-blox GNSS antennas application note [11], with patch antennas the placement on the board affects the RF performance. Ideally, patch antennas shall be positioned at the center of the widest possible ground plane to achieve maximum gain and optimal matching. Note that if the antenna is offset from the center, an additional matching circuit may be required. However, in the case of the B37 blueprint, even though the antenna is slightly offset from the exact center of the PCB to accommodate the small device size and minimize RF losses caused by lengthy transmission lines, this antenna placement still offers reliable GNSS reception performance in both simulated and real-world environments.

A GNSS passive antenna requires a careful evaluation of the layout of the RF section. Typically, a passive antenna may be located near electronic components. Therefore, it is essential to reduce the electrical noise that may interfere with the antenna performance. To minimize the interference of the cellular signals (see SARA-R5 and SARA-R4 system integration manual [8][9]), the GNSS antenna is placed on the opposite side of the cellular antenna and does not share the ground plane with any noisy return currents.

Additionally, a band-stop SAW filter has been added to the cellular antenna RF path to further improve the isolation between the embedded antennas. For this application, a Qualcomm / RF360 B8666 has been chosen. As outlined in the system integration manuals [8][9], many other options can be considered for such a filter. However, its addition has to be carefully evaluated, considering that the additional insertion loss of such filter may affect the cellular TRP and/or TIS RF figures.

Finally, a notch filter centered at ~787 MHz implemented as shown in Figure 11 improves the GNSS immunity to LTE band 13 high channel.

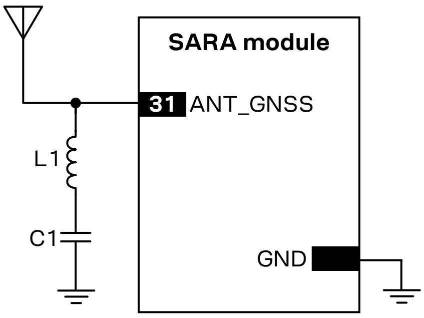

Figure 11: Notch filter for improved out-of-band jamming immunity.

4 Performance evaluation

4.1 Cellular evaluation

4.1.1 General concept

Radiation performance is subject to measurements according to approval requirements of specific network operators (mainly in the North American market) or regulatory authorities. In these cases, additional certification requirements apply, and the customers are typically asked to evaluate their device in terms of:

- **Total radiated power (TRP):** a measure of how much power is radiated by the device (Tx test)
- **Total isotropic sensitivity (TIS):** a measure of the minimum received power needed to keep a specific error rate (Rx test)
- **Radiated spurious emissions (RSE):** a measure of the power emitted outside the RF operating band. Power limits are imposed by the regulatory authorities to avoid harmful interferences.

Blueprint B37 is designed to meet with the RF requirements imposed by the main North American and European certification schemes, as well as AT&T specifications for small form factor devices. To verify the performance, parameters like total radiated power (TRP) and total isotropic sensitivity (TIS) have been tested in a fully anechoic chamber.

Tests were made by our partner KYOCERA AVX at their facility. The evaluation was done by measuring the antenna efficiency and the TRP in LTE Cat M1 bands 12, 13, 5, 4 and 2.

4.1.2 Cellular evaluation setup

The measurements in Section 4.1.5 and 4.1.7 were performed using the setup shown in Figure 12: the vector network analyzer (VNA) is used for measuring return loss and radiation efficiency, while the radio communication tester is used to evaluate active LTE performance.

No	Description
1	Anechoic Chamber
2	Dual polarized Horn 700MHz-6GHz
3	Device under test
4	3D position arm (Phi angle)
5	3D positioner base (Theta angle)
6	Radio Communication Tester for Cellular protocols (Anritsu 8820)
7	Radio Communication Tester for LoRa Protocol (Ethertronics LoRa Unit)
8	Ethertronics RF Control Unit
9	Vector Network Analyzer (R&S ZVB8)
10	Spectrum Analyzer (R&S FSEM)
11	Ethertronics Motor Control Unit

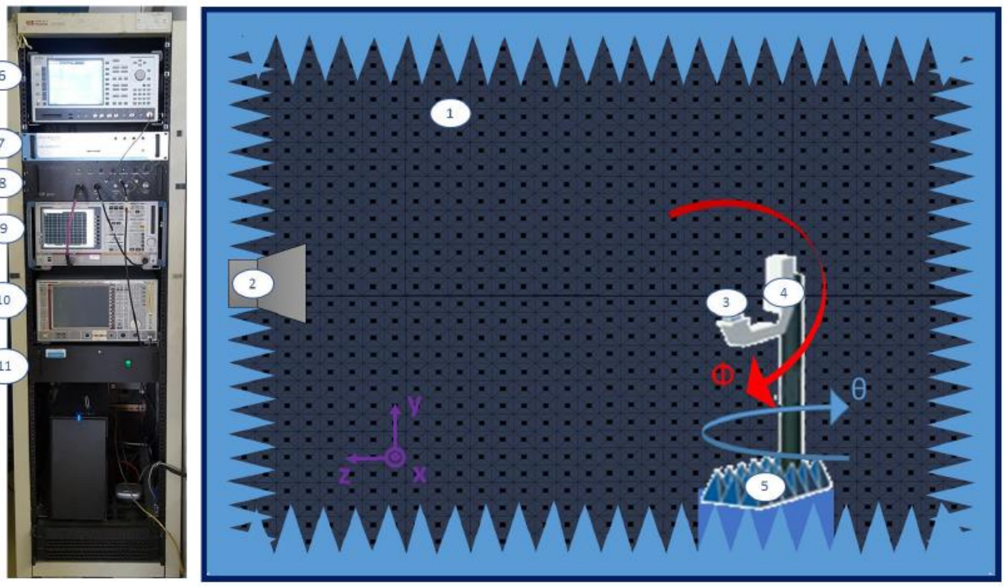

Figure 12: Schematic of the anechoic chamber system for return loss, radiation efficiency and active LTE measurements.

Figure 13 shows the B37 blueprint prepared for RF testing. Figure 14 shows how the board has been placed inside the anechoic chamber.

Figure 13: B37 dynamic antenna tuner blueprint prepared for RF testing

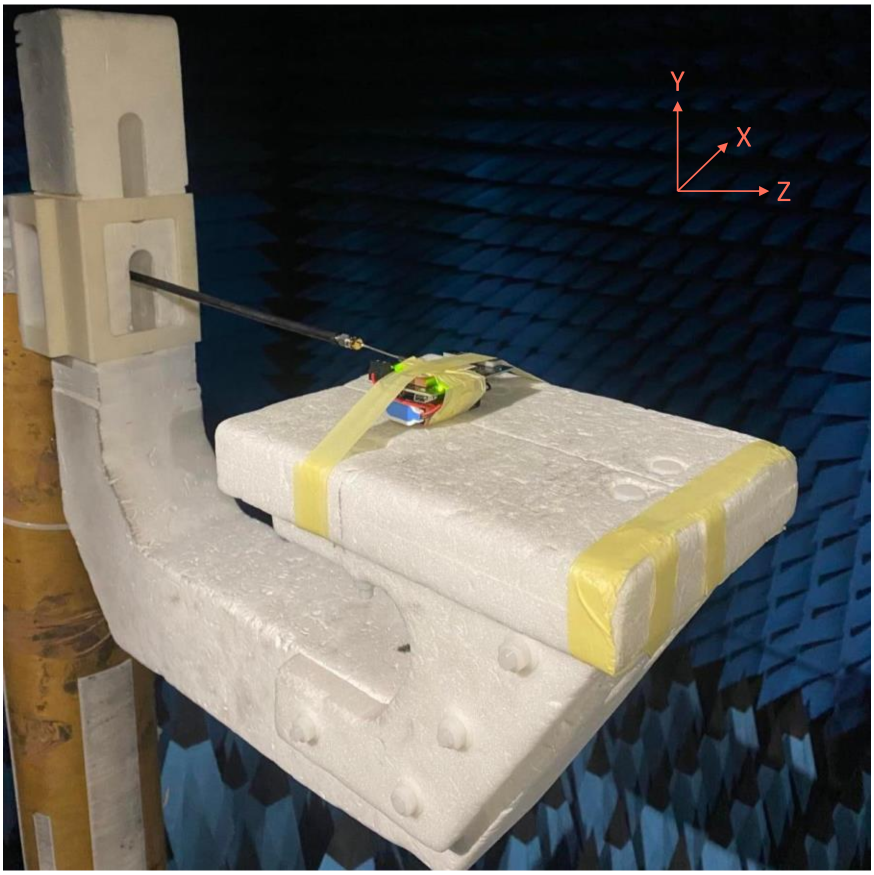

Figure 14: DUT inside the anechoic chamber

4.1.3 Antenna matching circuit

Figure 15 shows the antenna matching circuit schematic. The matching component values have been optimized using the setup described in Section 4.1.2, and are summarized in Table 2.

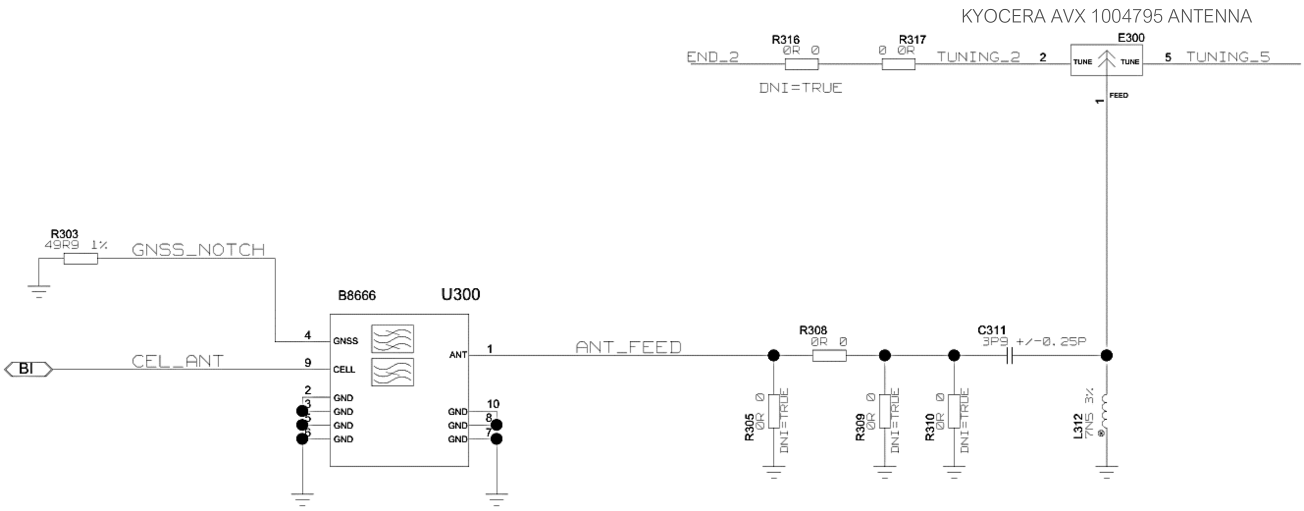

Figure 15: Antenna impedance matching circuit

Matching component	Value
P1 (L312)	7.5 nH
S1 (C311)	3.9 pF
P2 (R309)	open
P3 (R305)	open
S2 (R308)	0 ohm

Table 2: Antenna matching circuit component values

4.1.4 Dynamic antenna tuning circuit

The **I2S_TXD** and **I2S_WA** pins of the module are connected to the KYOCERA AVX EC646 RF switch. The switch center pin is coupled to the RF structure of the antenna and allows tuning of the resonant frequency of the radiating element to a different frequency. This frequency is decided by the impedance selected by operating the switch via its GPIO input pins.

Antenna measurements have shown that, for the current design, it is not possible to optimize the performance in LTE band 12 and LTE band 13 at the same time. Therefore, Table 3 reports the impedance values at each port of the switch offering two different options for the RF2 impedance: one optimized for AT&T networks and the other for Verizon. The schematic and a PCB detail of the RF switch section of the board are in Figure 16.

Tuning impedance	Value	Frequency range covered
RF1	6.8 nH	Below 700 MHz
RF2 (optimized for Verizon)	open	Between 700 MHz and 800 MHz
RF2 (optimized for AT&T)	2pF	
RF3	18 nH	Between 800 MHz and 960 MHz
RF4	2.2 nH	Above 1 GHz

Table 3: Dynamic antenna tuning impedance values

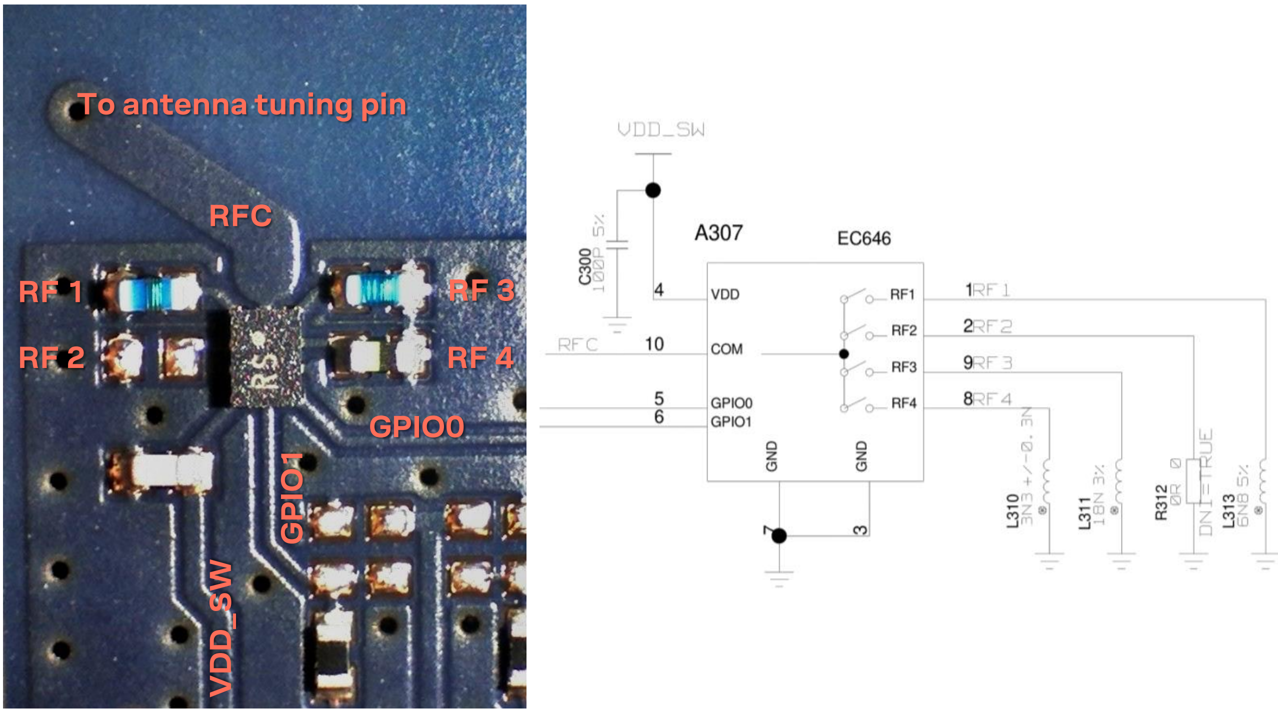

Figure 16: PCB detail and schematic of the EC646 dynamic antenna tuning circuit

4.1.5 Passive antenna performance

Passive antenna measurements are executed during the R&D process to give guidelines about the expected antenna performance when connected to the module. This application note reports the following figures of merit:

- **Antenna return loss**: the ratio between the power delivered into the antenna and the power reflected on the transmission line due to RF mismatches. This is another way to express the standing wave ratio (SWR) value.
- **Antenna radiation efficiency**: the ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter. It measures how well an antenna converts the RF power accepted at its terminals into radiated power.

Figure 17 and Figure 18 show the antenna return loss in the low-frequency bands and in the high-frequency bands for each switch state and for a version of the blueprint without dynamic antenna tuning. Figure 19 and Figure 20 offer the same comparison between dynamic antenna tuning and a version of the board with fixed tuning but for the radiation efficiency. The frequency range covered by each switch state is summarized in Table 4.

Switch state	Frequency range covered	Tuning impedance
State00	Below 700 MHz	RF1
State01	Between 700 MHz and 800 MHz	RF2
State10	Between 800 MHz and 960 MHz	RF3
State11	Above 1 GHz	RF4

Table 4: Dynamic antenna tuning truth table

To compare the results, a version of the same board without the dynamic tuning has been created. In this board the antenna tuning pin is left open, and the antenna matching is achieved through a broadband matching network. In contrast to the active tuning solution, both the return loss and the radiation efficiency are improved. For frequencies below 700 MHz the average efficiency without dynamic antenna tuning is 12 %, while with the dynamic antenna tuning, it can reach 13.5 %. Between 700 MHz and 800 MHz, the efficiency improves from an average of 20 % to 22 %. Given the small size of the board (45 x 70 mm), at low frequency the efficiency is approaching the physical limit. The dynamic antenna tuning feature is most effective at higher frequencies: between 800 MHz and 1 GHz the efficiency improves from 17 % to 25 % while above 1700 MHz the same figure of merit goes from 29 % to 45 %.

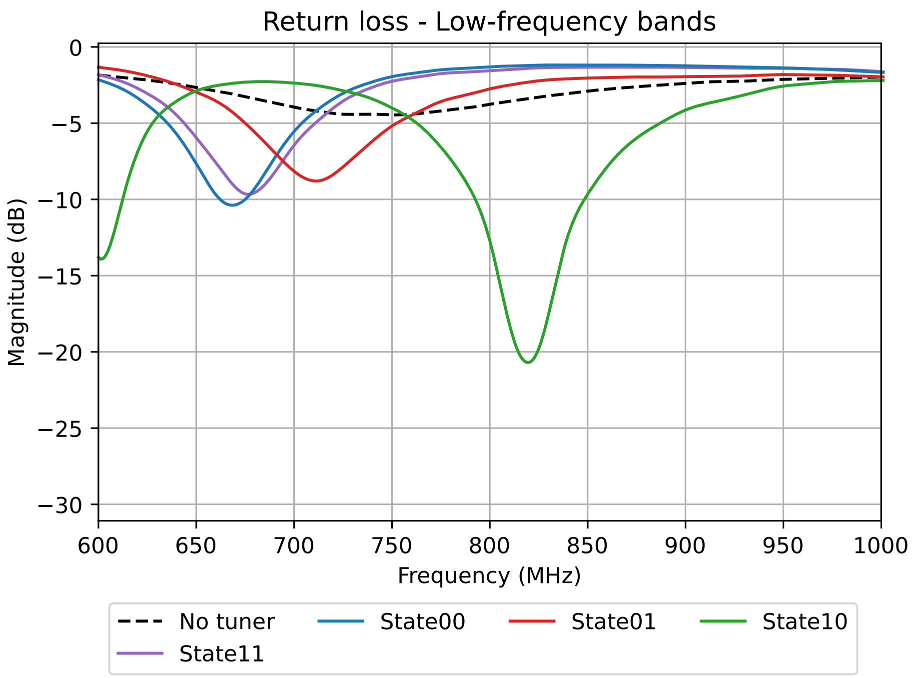

Figure 17: LTE antenna return loss in the low frequency bands (600 MHz - 1000 MHz).

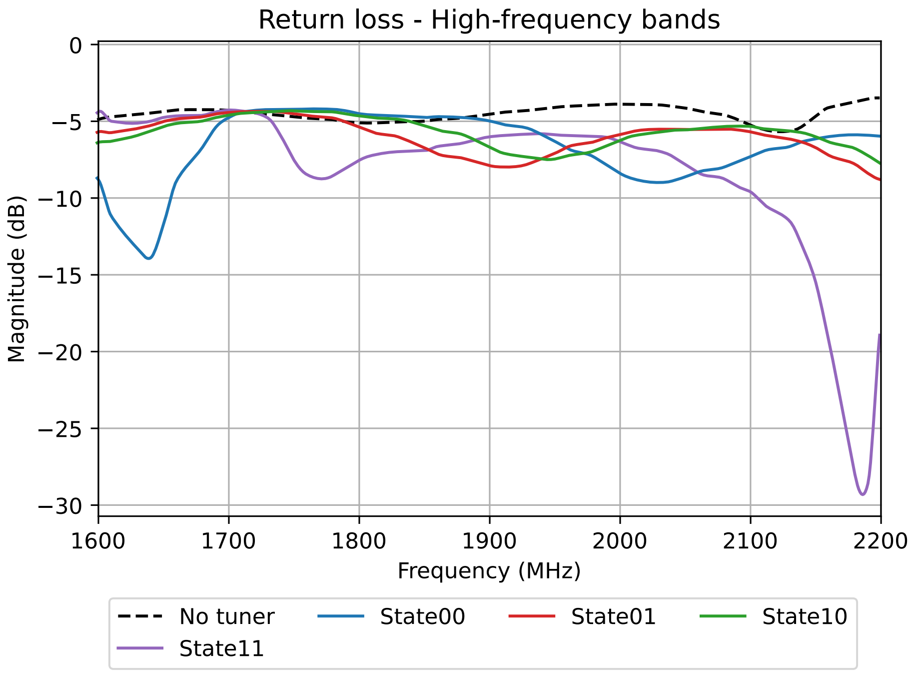

Figure 18: LTE antenna return loss in the high frequency bands (1600 MHz - 2200 MHz).

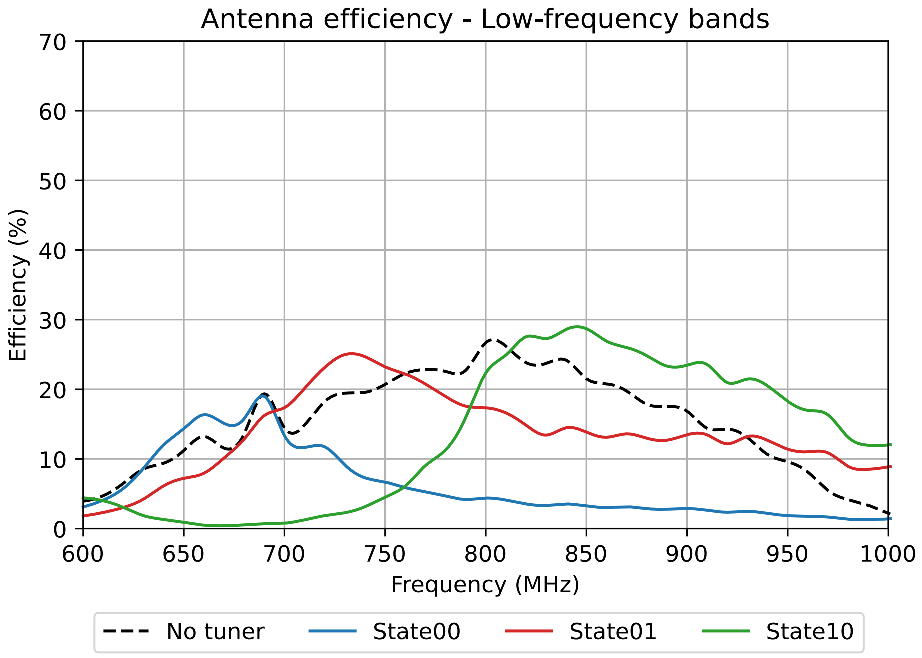

Figure 19: LTE antenna radiation efficiency in the low frequency bands (600 MHz - 1000 MHz).

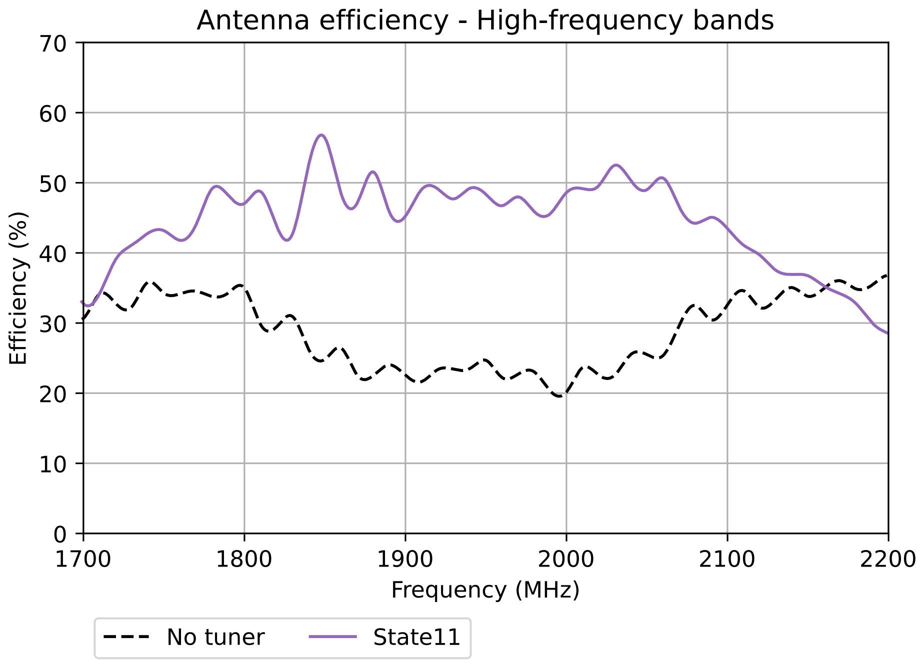

Figure 20: LTE antenna radiation efficiency in the high frequency bands (1700 MHz - 2200 MHz).

4.1.6 US MNOs TRP/TIS requirements for LTE Cat-M devices

AT&T and Verizon mobile network operators (MNOs) in the United States impose stringent requirements about antenna performance for devices operating on their network. To allow the reduced antenna efficiency when the available ground plane size is limited, the operators define the “small form factor” devices for which the limits are relaxed.

According to AT&T [12], a small form factor device is one that is less than 107 mm in the longest direction. AT&T LTE-M small form factor device TRP/TIS limits are shown in Table 5.

LTE Cat M1 Band	Minimum TRP requirement (power class 3)	Minimum TIS requirement (primary antenna)
2	+12.0 dBm	–88 dBm / 720 kHz
4	+12.0 dBm	–90 dBm / 720 kHz
12	+10.0 dBm	–85 dBm / 720 kHz

Table 5: AT&T small form factor TRP/TIS requirements for the B37 blueprint

Verizon names an application a “small form factor” device if it has no surfaces that individually exceed 2500 mm^2 in area [13]. Given that the B37 blueprint size is 45 x 70 mm, the surface area is 3150 mm^2. Therefore, this blueprint is not considered a small form factor device by Verizon and normal free-space radiation requirements apply. Verizon free-space TRP/TIS limits are shown in Table 6.

LTE Band	Minimum TRP requirement (power class 3)	Minimum TIS requirement (primary antenna)
4 (Cat-M1)	+19 dBm	-100 dBm
4 (NB-IoT)	+19 dBm	n/a
13 (Cat-M1)	+18.0 dBm	–97 dBm
13 (NB-IoT)	+18.0 dBm	–105 dBm

Table 6: Verizon free-space TRP/TIS requirements for the B37 blueprint

4.1.7 Active LTE antenna performance

The final device performance evaluation is made with a fully functional unit. This reveals if there is some interference caused by the device itself which couples into the antennas, disrupting normal operation. In active measurements, one measures the total radiated power (TRP) and total isotropic sensitivity (TIS) of the device. These figures combine the antenna performance with the device radio capability. TRP value indicates the power level that the device radio can deliver through the antenna to the surrounding space. TIS indicates the radio's capability to sense incoming signals with a low power level.

For the B37 blueprint, Table 7 and Table 8 respectively show TRP and TIS measurements in the mid channels of LTE bands 2, 4, 12, 13 and 5. When the respective tuning components are used as discussed in Section 4.1.4, the device meets AT&T specifications for small form factor devices. Verizon free-space requirements are also met, with the marginal exception of LTE band 4 where the device is 1 dB below the limit. To achieve the Verizon requirements, the board can be made either slightly smaller to reduce the area below 2500 mm^2 thus reducing the limit, or bigger to increase the radiation efficiency.

LTE Cat M1 Band	TRP middle channel [dBm] AT&T dynamic ant. tuner	TRP middle channel [dBm] Verizon dynamic ant. tuner	TRP middle channel [dBm] No dynamic antenna tuner
2	21.0		16.4
4	18.0	18.0	17.3
12	16.4		14.9
13		18.5	18.3
5	17.8		14.6

Table 7: B37 blueprint TRP measurement results

Table 7 and Table 8 also offer a comparison with a version of the B37 blueprint without the dynamic antenna tuner. These results confirm the observation in Section 4.1.5: in band 13, the lowest frequency band supported, the antenna efficiency is approaching the physical limit and the dynamic tuner is of little benefit. At higher frequencies instead, the improvement in TRP and TIS is consistent.

Specifically, the TRP RF performance improvements due to antenna dynamic tuning are the following:

- +2.5 dB in LTE band 12,
- +3.2 dB in LTE band 5,
- +0.7 dB in LTE band 4,
- +3.6 dB in LTE band 2.

Similarly, the TIS RF performance improvements due to antenna dynamic tuning are the following:

- +1.9 dB in LTE band 12,
- +2.7 dB in LTE band 5,
- +1.0 dB in LTE band 4,
- +3.6 dB in LTE band 2.

Additionally, the B37 blueprint demonstrates improvements for other major MNOs in the US, such as the LTE band 71 for T-Mobile, and for European MNOs, including the LTE bands 20 / 8 / 3 for Deutsche Telekom, Orange, Vodafone, Telefonica, and others. These enhancements showcase the versatility and adaptability of the B37 blueprint across various networks and regions.

LTE Cat M1 Band	TIS middle channel [dBm] AT&T dynamic ant. tuner	TIS middle channel [dBm] Verizon dynamic ant. tuner	TIS middle channel [dBm] No dynamic antenna tuner
2	-103		-99.4
4	-104	-104	-103
12	-97.0		-95.1
13		-97.5	-97.7
5	-95.7		-93.0

Table 8: B37 blueprint TIS measurement results

4.2 GNSS evaluation

4.2.1 General concept

The coexistence between cellular and GNSS technologies is crucial and can pose challenges if not addressed from the first design stages, in both the schematic design and the layout design.

To avoid desensitization of the GNSS receiver due to the interference of the cellular transmitter, it is crucial to place the GNSS and LTE antennas away from each other to maximize the isolation [10] [11].

In the case of this B37 blueprint, the isolation is further improved with the addition of the Qualcomm RF360 GNSS SAW extractor filter, and its measurement is reported in Figure 21. The LTE to GNSS antenna isolation depends on the EC646 RF switch state and, in the worst case, it amounts to 30 dB. As it will be shown in Section 4.2.4, this value is more than adequate to prevent any noise generated by LTE transmission from interfering with the reception of GNSS signals.

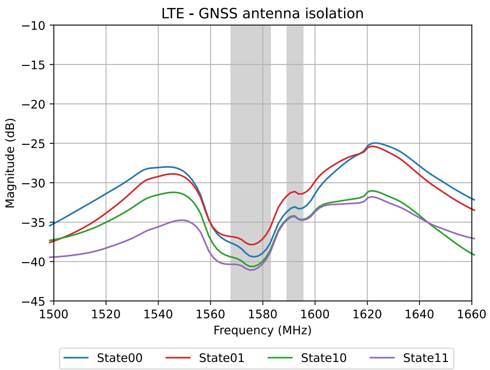

Figure 21: Measured isolation between GNSS and cellular antennas. In grey are the GPS and the GLONASS L1 bands.

4.2.2 GNSS evaluation setup

The measurements in Section 4.2.3 and 4.2.4 were carried out using the setup outlined in Figure 22. The blueprint is placed inside a diagnostic chamber where it receives both a GNSS signal and an LTE signal. Upon connection to the LTE network simulator, the device is instructed to transmit continuously at its maximum power level, and the GNSS time to first fix (TTFF) is measured.

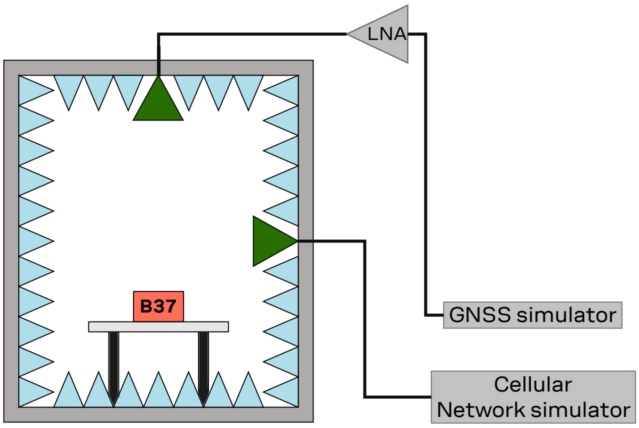

Figure 22: GNSS performance measurement setup

4.2.3 GNSS performance evaluation with LTE Tx disabled

To obtain a baseline measurement, the `AT+CFUN=0` command was used to disable the module cellular subsystem. In this scenario, Figure 23 shows the carrier to noise ratio C/N_0 (the ratio between the amount of signal power and the amount of noise power density entering the GNSS receiver) for each satellite and the position accuracy. Table 9 reports the average C/N_0 ratio and the TTFF.

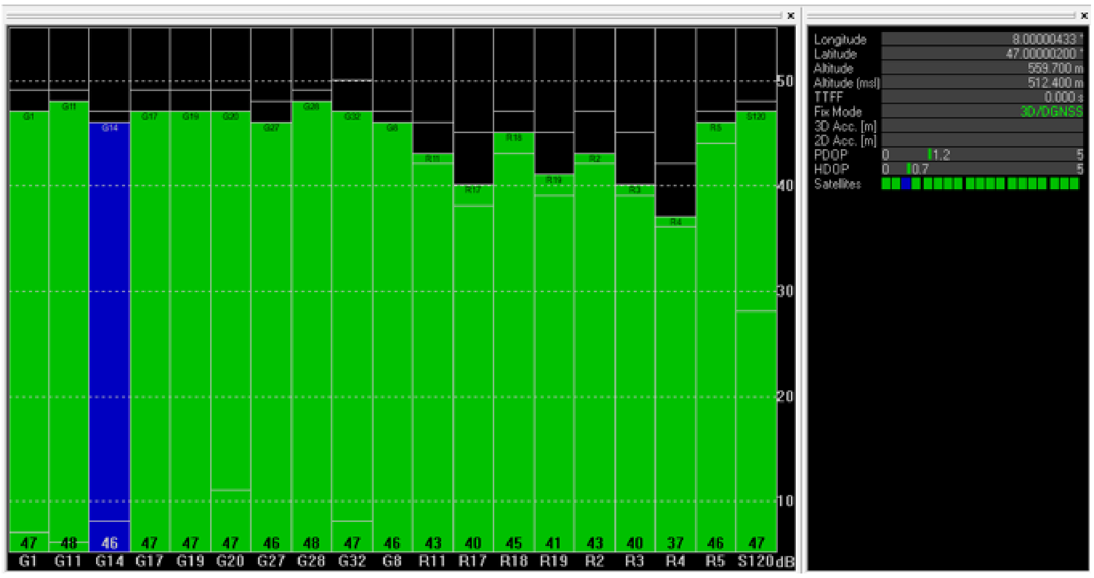

Figure 23: C/N_0 for each satellite and position accuracy with cellular transmitter disabled

Figure of merit	Measured value SARA-R510M8S	Measured value SARA-R422M10S
Average C/N_0	~43 dB	~43 dB
TTFF[1]	26 s	23 s

Table 9: C/N_0 and time to first fix with cellular transmitter disabled

[1] Cold start without any AssistNow data

4.2.4 GNSS performance evaluation with LTE Tx enabled

The following test reveals the possible degradation of the GNSS when the cellular module is transmitting. Since the spurious emissions depend on the device operating band, Table 10 reports the TTFF results when the module is continuously transmitting at its maximum output power level (~23 dBm) on a Cat-M1 simulated network in LTE band 2, 4, 12, 13 and 5. Note that this is the absolute worst-case scenario: in a real network, the typical transmission power is around 0 to 3 dBm, and the module does not transmit continuously. As shown in Table 11, for a more typical output power of 3 dBm, no degradation was observed in the TTFF, compared with Table 9, in any of the bands tested.

For the measurements in Table 10 and Table 11, the cellular network simulator was configured as follows:

- Cell type: LTE Cat-M1 (eMTC)
- Signaling mode: RMC
- BW = 5 MHz
- CELL power = -100 dBm
- DUT Tx power: MAX power / 3 dBm target power

Considering measurement uncertainty, at maximum Tx power, the TTFF degradation due to LTE transmission is negligible, confirming that the isolation obtained in Figure 21 is enough to maintain good coexistence performance during LTE transmission.

LTE band	UL frequency [MHz]	TTFF[2] [s] SARA-R510M8S	TTFF[2] [s] SARA-R422M10S
2	1850 - 1910	27	24
4	1710 - 1755	31	30
12	699 - 716	28	24
13	777 - 787	27	23
5	824 - 849	28	25

Table 10: TTFF with LTE module transmitting at maximum power (~23 dBm)

LTE band	UL frequency [MHz]	TTFF[2] [s] SARA-R510M8S	TTFF[2] [s] SARA-R422M10S
2	1850 - 1910	27	24
4	1710 - 1755	27	25
12	699 - 716	28	24
13	777 - 787	27	23
5	824 - 849	27	24

Table 11: TTFF with LTE module transmitting at ~3 dBm output power

[2] Cold start without AssistNow data

Appendix

Glossary

Abbreviation	Definition
C/N_0	Carrier-to-noise ratio
DC	Direct Current
eMTC	Enhanced Machine To Machine
FR4	Flame Retardant 4 (grade designation for glass-reinforced epoxy laminate Printed Circuit Board material)
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
GNSS	Global Navigation Satellite System
GPIO	General-purpose Input Output
GPS	Global Positioning System
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
LDO Regulator	Low Dropout Regulator
LED	Light Emitting Diode
LNA	Low Noise Amplifier
LTE	Long-term Evolution
MCU	Micro-Controller Unit
MNO	Mobile Network Operator
PCB	Printed Circuit Board
QZSS	Quasi-Zenith Satellite System
RF	Radio Frequency
RSE	Radiated Spurious Emissions
SAW Filter	Surface Acoustic Wave Filter
SBAS	Satellite-based Augmentation System (civil aviation safety-critical system)
SIM	Subscriber Identity Module
SMD	Surface Mount Device
SP4T	Single-pole 4-Throw
SPI	Serial Peripheral Interface
SQI	Serial Quad Interface
TIS	Total Isotropic Sensitivity
TRP	Total Radiated Power
TTFF	Time To First Fix
Tx	Transmission
UART	Universal Asynchronous Receiver-Transmitter
UL	Up-Link
US	United States
USB	Universal Serial Bus
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

Related documents

[1] u-blox SARA-R5 series data sheet, UBX-19016638
[2] u-blox SARA-R4 series data sheet, UBX-16024152
[3] u-blox Thingstream M2M Embedded SIM product summary, UBX-20044784
[4] 3GPP TS 27.010 – Terminal Equipment to User Equipment (TE-UE) multiplexer protocol
[5] u-blox mux implementation application note, UBX-13001887
[6] KYOCERA AVX 1004795 broadband embedded cellular antenna data sheet, https://datasheets.kyocera-avx.com/ethertronics/AVX-E_1004795-1004796.pdf
[7] KYOCERA AVX 1004322 GPS / GLONASS / BeiDou / Galileo patch antenna data sheet, https://datasheets.kyocera-avx.com/ethertronics/AVX-E_1004322.pdf
[8] u-blox SARA-R5 series system integration manual, UBX-19041356
[9] u-blox SARA-R4 series system integration manual, UBX-16029218
[10] u-blox SARA-R5 / SARA-R4 positioning and timing implementation application note, UBX-20012413
[11] u-blox GNSS antennas application note, UBX-15030289
[12] AT&T Radiated Performance Requirements, https://iotdevices.att.com/networkready.aspx
[13] Verizon Open Development Certification Process, https://opendevelopment.verizonwireless.com/open-access/article/Open-Access-Specifications
[14] u-blox LEXI-R4 / SARA-R4 series AT commands manual, UBX-17003787
[15] u-blox SARA-R5 series AT commands manual, UBX-19047455
[16] u-blox Package information guide, UBX-14001652

☞ For regular updates to u-blox documentation and to receive product change notifications, register on our homepage (www.u-blox.com).

Revision history

Revision	Date	Name	Comments
R01	30-Oct-2023	psca	Initial release

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