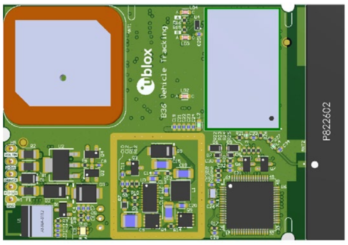
B36 vehicle tracking blueprint

Integration board with u-blox cellular, positioning and short range modules

Application note



Abstract

This document describes the features and performance of the B36 blueprint board, which integrates all the u-blox technologies (cellular, positioning and short range communication modules) in a single board with PCB-mounted antennas. The design is made available for u-blox customers as a blueprint, including schematics, bill of material and Gerber data.

Document information

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Product status	Corresponding content status	
In Development / Prototype	Objective Specification	Target values. Revised and supplementary data will be published later.
Engineering Sample	Advance Information	Data based on early testing. Revised and supplementary data will be published later.
Initial Production	Early Production Information	Data from product verification. Revised and supplementary data may be published later.
Mass Production / End of Life	Production Information	Document contains the final product specification.

This document applies to the following products:

Product name	Type number	Firmware version	PCN reference
EVA-M8Q	EVA-M8Q-0-10	3.01	N/A
EVA-M8E	EVA-M8E-0-11	3.01 UDR 1.21	N/A
SARA-R412	SARA-R412M-2B-01	M0.10.00 A02.04	N/A
SARA-G450	SARA-G450-00C-01	09.02 A03.15	N/A
ANNA-B1	ANNA-B112-01B-00	2.0.0	N/A

Contents

1 Introduction

Blueprint B36 is a solution to integrate u-blox technologies (cellular, positioning and short range) in a single board with PCB-mount antennas. The B36 board represents a tested and optimized design for vehicle tracking in a small form factor, whose main features are the following:

1. Small size so that it can be easily hidden
2. Providing a reference for combined integration of u-blox cellular, positioning, and short range modules
3. Giving an example of the component choice, placement, and layout
4. Addressing the RF and hardware challenges related to the integration of on-board antennas
5. Providing a power supply for both 12 V and 24 V vehicles, with protection and filters to comply with automotive regulations
6. Li-Po battery backup with a built-in charger

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

1. Guarantee the best performance with all the technologies
2. Minimize the interference among technologies (co-existence scenarios)

Blueprint B36 is designed to meet with the RF requirements imposed by the main North American and European certification schemes. To verify the performance, parameters like Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) have been tested in a fully anechoic chamber.

This application note provides indications about the hardware solutions implemented in the board and shows the results of the testing performed on the unit.

1.1 Variants

Table 1 shows the different variants of the blueprint B36 along with the list of integrated modules.

Variant	Cellular module	Short range module	Positioning module
B36-G450-1	SARA-G450	ANNA-B112	EVA-M8Q
B36-G450-2	SARA-G450	ANNA-B112	EVA-M8E
B36-R412-1	SARA-R412	ANNA-B112	EVA-M8Q
B36-R412-2	SARA-R412	ANNA-B112	EVA-M8E

Table 1: Blueprint B36 variants and integrated modules

All variants include the short range module ANNA-B112, which supports Bluetooth® 5 low energy.

All variants support concurrent reception of GPS, GLONASS, BeiDou, QZSS, SBAS and Galileo systems Variants G450-1 and R412-1 provide this with the EVA-M8Q positioning module. Variants G450-2 and R412-2 include the EVA-M8E positioning module, which also supports untethered dead reckoning.

Variants G450-1 and G450-2 provide global quad band GSM/GPRS service via the SARA-G450 module. Variants R412-1 and R412-2 utilize the SARA-R412 module which provides LTE Cat M1/NB1 and EGPRS technology for the global market.

For a complete description of the functionalities supported by each module, see the SARA-G450 System integration manual [1], SARA-R4 System integration manual [2], EVA-M8 Hardware integration manual [3], EVA-M8E Hardware integration manual [4] and ANNA-B112 System integration manual [5].

1.2 Renderings

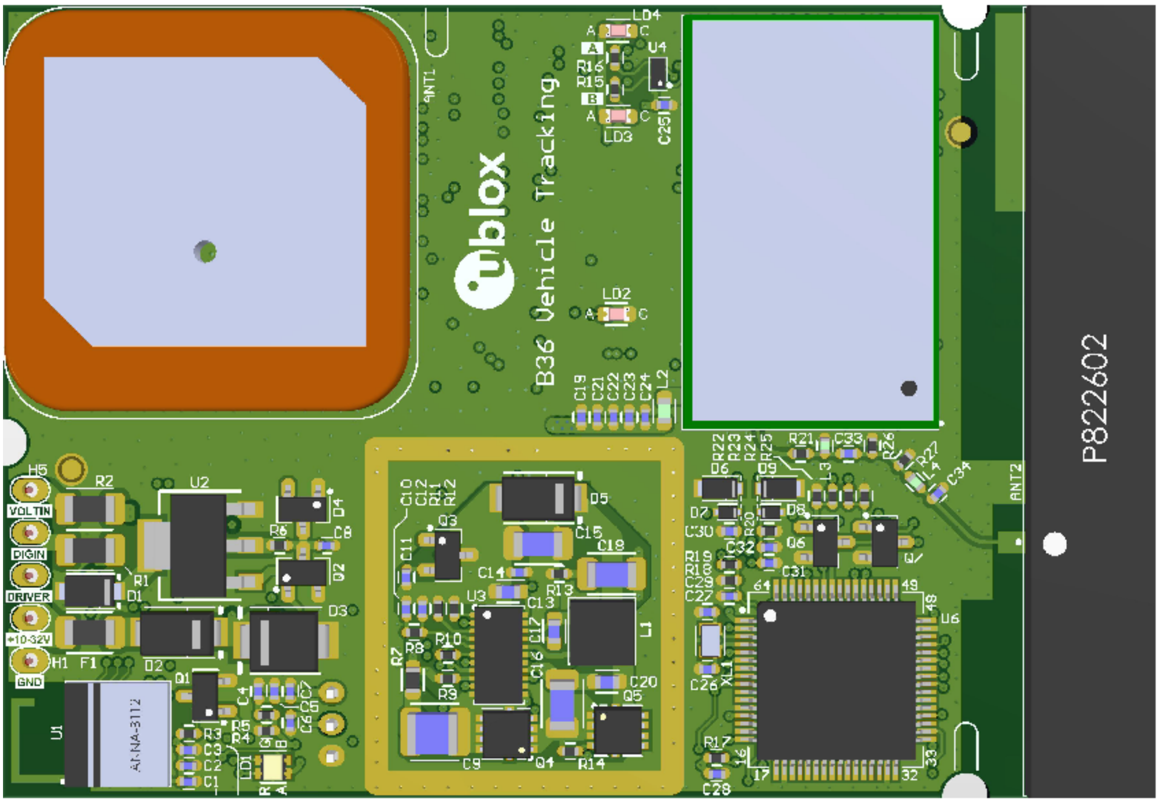


Figure 1: PCB top

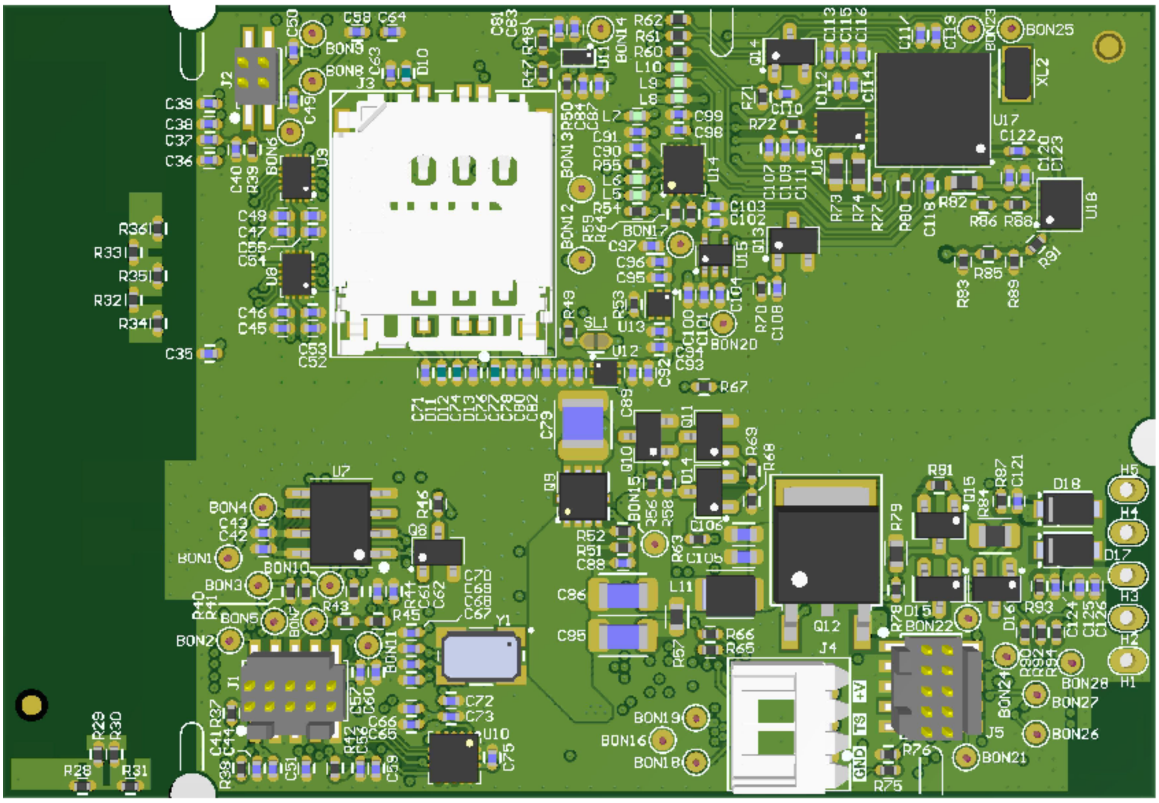


Figure 2: PCB bottom

2 Board description

2.1 Block diagrams

2.1.1 Variant G450-1

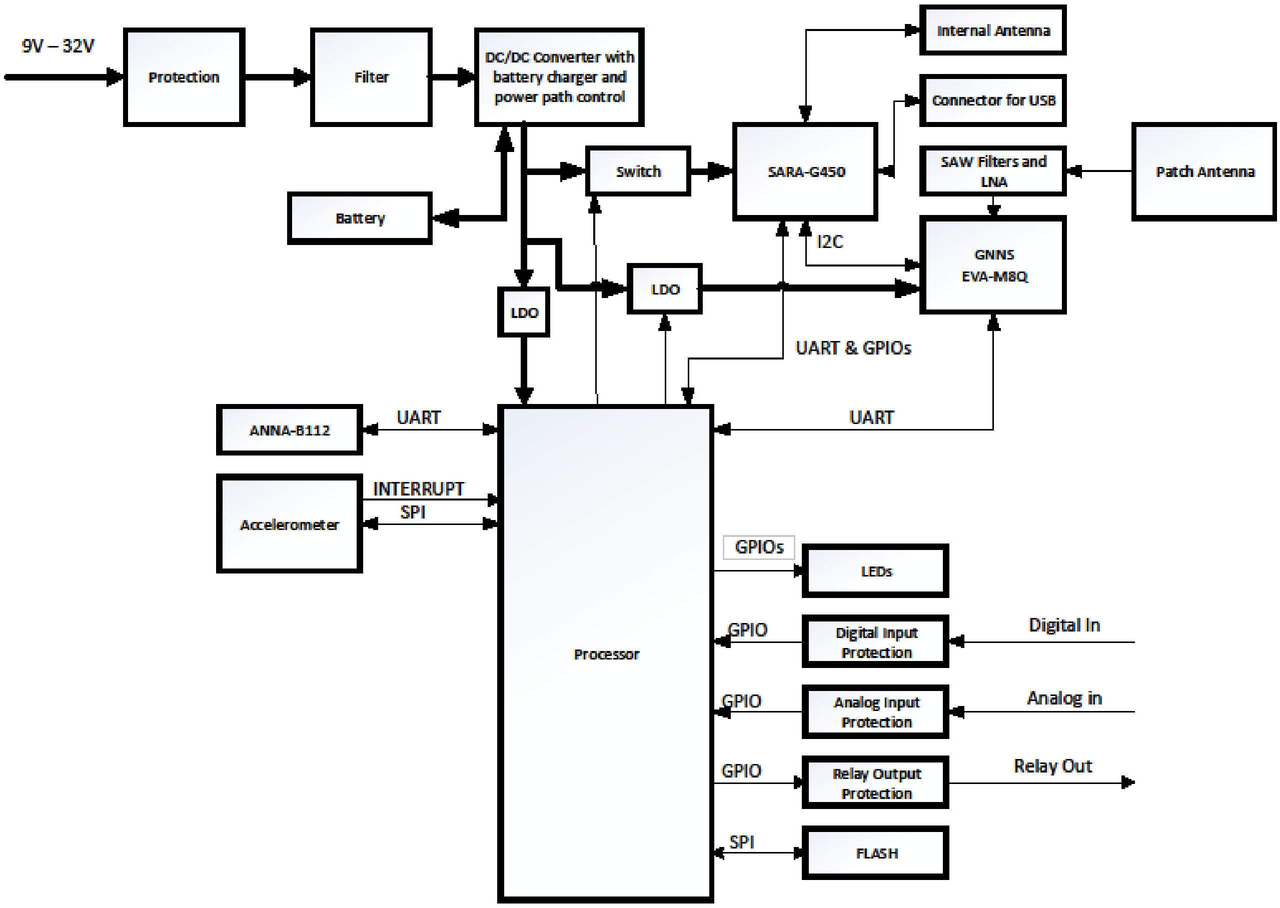


Figure 3: Variant G450-1

2.1.2 Variant G450-2

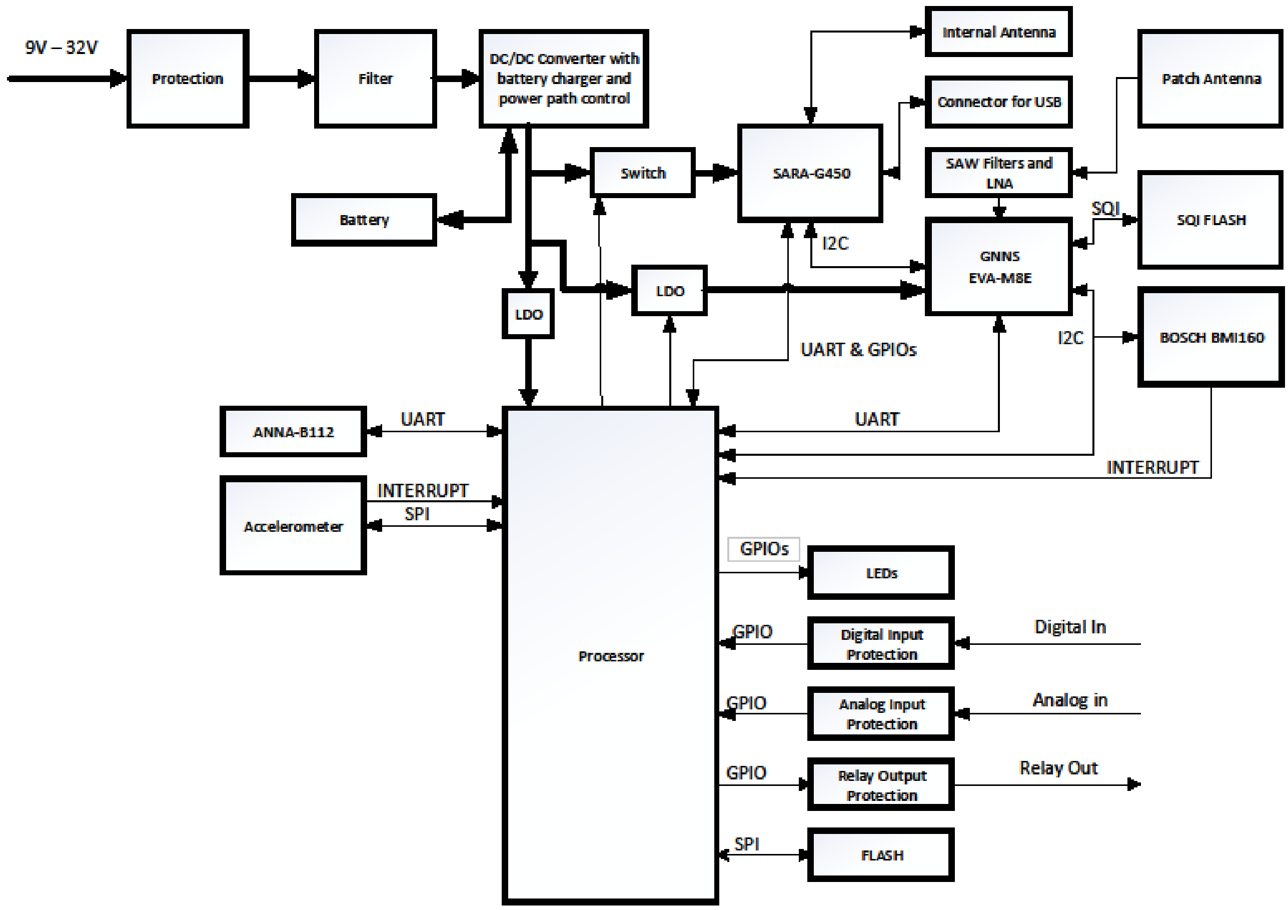


Figure 4: Variant G450-2

2.1.3 Variant R412-1

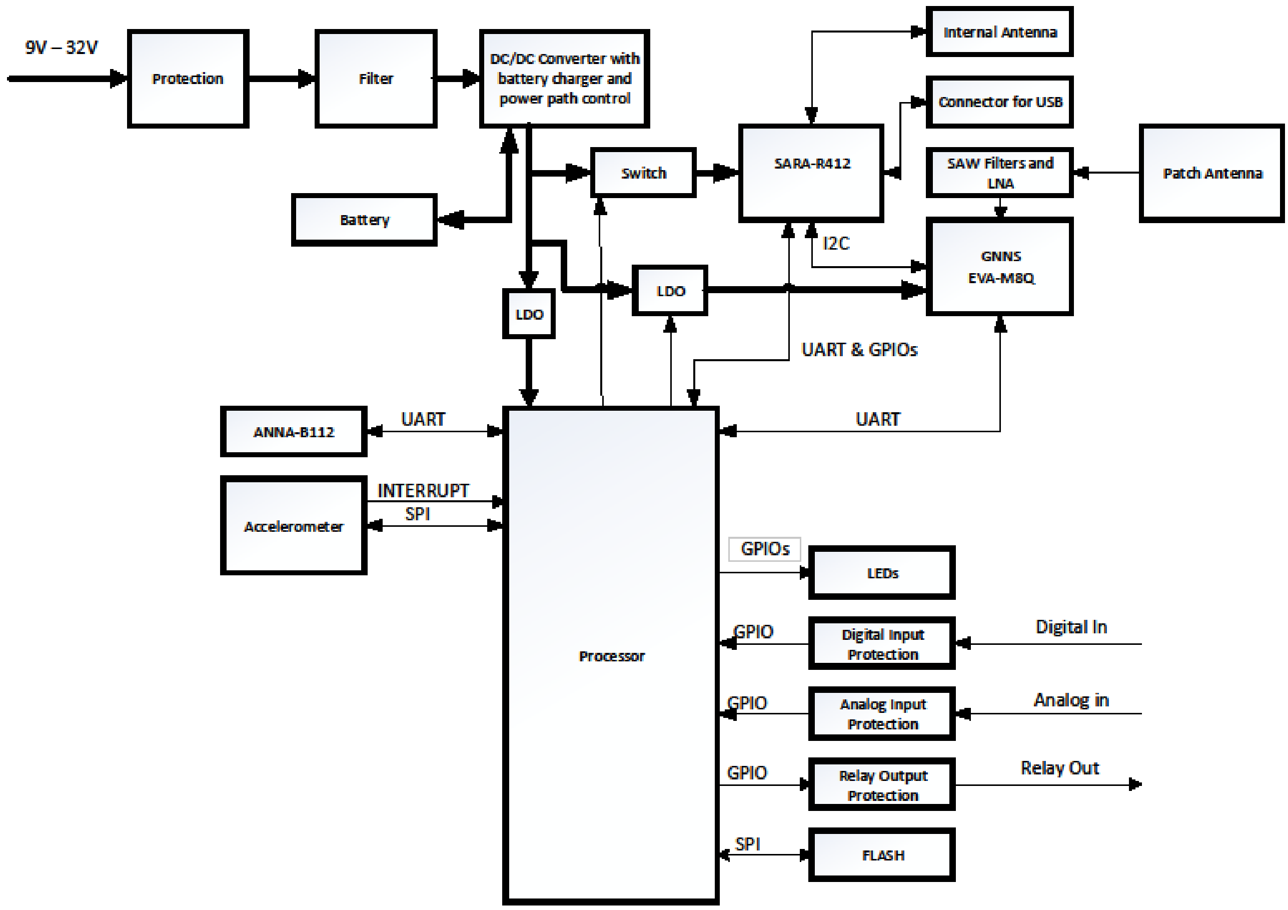


Figure 5: Variant R412-1

2.1.4 Variant R412-2

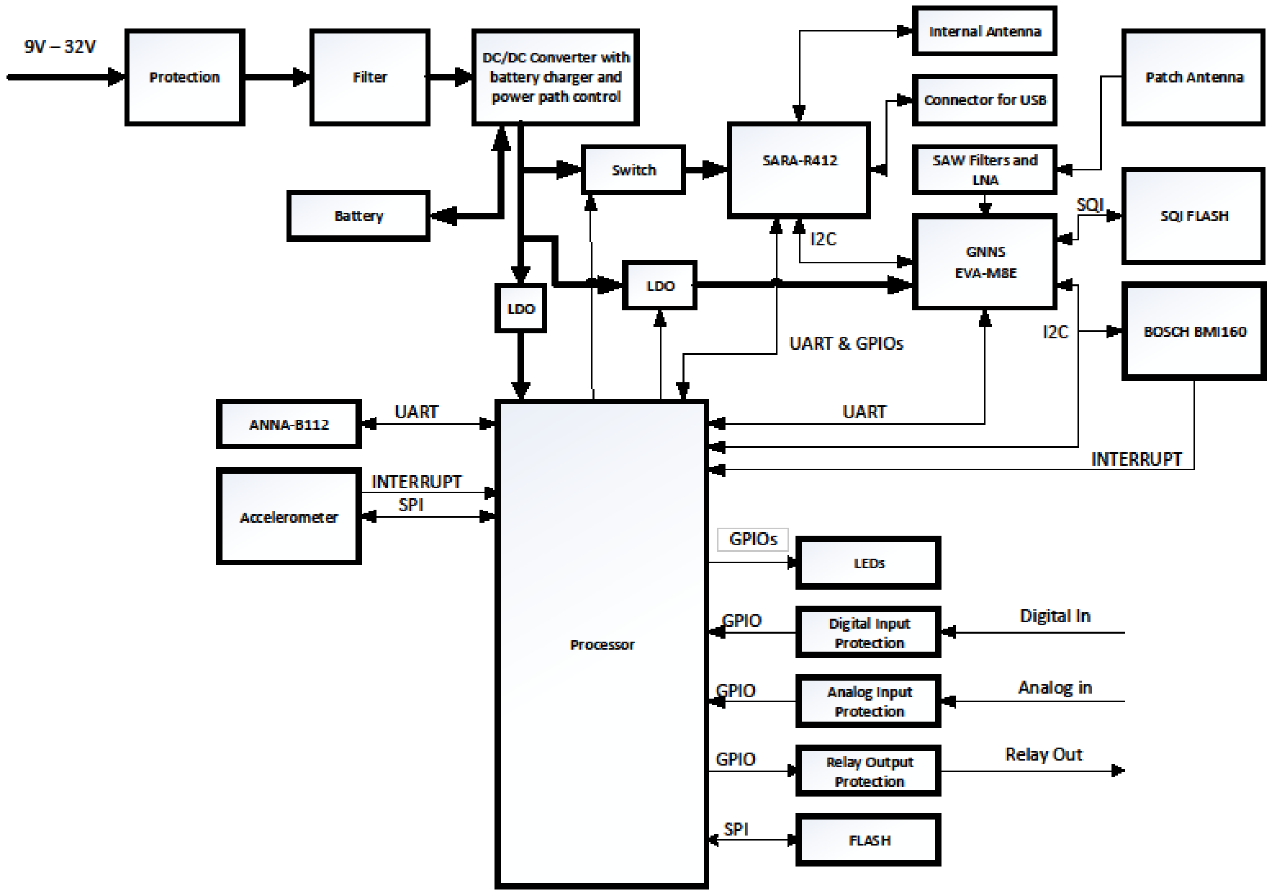


Figure 6: Variant R412-2

2.2 Environmental data

The blueprint board B36 is intended to be operated in the temperature range of –20 °C to 60 °C. The temperature range is a function of the battery specification.

2.3 Mechanical dimensions and PCB details

The form factor used by the blueprint B36 is 50 x 72.5 mm. These dimensions guarantee the optimal placement of the cellular antenna while being as small as possible.

The board size also allows the proper placement of the GNSS and BLE antennas, providing maximum levels of isolation among the radiating elements.

The PCB has an 8-layer stack-up, with most of the routing traced in the inner layers. This solution offers the best level of immunity against EMC and spurious emissions.

Components are placed on both sides of the board:

On the top layer are the antennas, the cellular and the BLE modules, the processor, the main power supply through-hole pads, LEDs, and programming connectors.

The bottom layer accommodates the GNSS module with LNA, bed of nails test points along with part of the supply circuitry, components related to the interfaces, and programming connectors.

2.4 Power supply

Blueprint B36 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 through-hole pads on the top of the PCB.

A main switching step-down regulator is used to provide a regulated voltage for the cellular module and for the low drop-out regulators that in turn supply the processor, short range and positioning modules. See section 2.1 and the design description in section 3.1 for more details on the block diagrams.

2.5 Data interfaces

2.5.1 Cellular data interfaces

The cellular interfaces externally available for the user are:

1. Full UART interface with voltage translation. This is the main interface for transferring data with a host application processor and can be used for AT commands and data communication.
2. SIM card interface; both 1.8 V and 3 V SIM types are supported.
3. A 4-pin 1.27-mm pitch pin header connected to the USB interface for FW upgrades.
4. An I2C interface to the GNSS module.

2.5.2 GNSS data interfaces

The externally available interface of the positioning module is:

1. An I2C interface for communication with u-blox cellular module, present on all board variants. This interface can also be accessed by the processor.
2. When using the EVA-M8E, an I2C interface is used to communicate with the inertial module.
3. When using the EVA-M8E, a quad SPI interface is used to communicate with the SQI flash.
4. The processor can also communicate with the GNSS module via a UART with no handshaking.

2.5.3 Short range data interfaces

1. An external interface connected to the BLE module is available for programming the module. This is via a standard ARM 9-pin 1.27-mm header. Only power (3 V), SWDIO, SWCLK and nRESET is available.
2. The module communicates with the processor via an UART.

2.5.4 Antenna interfaces

Blueprint B36 integrates two different SMD-mount antennas:

1. Two multiband ceramic antennas connected to the primary and secondary antenna pins of the cellular module.
2. One patch antenna working in the frequency range of the positioning systems.

The BLE module has a built-in antenna.

2.5.5 Processor

1. The processor communicates with the cellular module via an UART with full handshaking. Level translation is necessary for this interface.
2. An I2C interface to communicate with the inertial module.
3. An SPI interface to communicate with the accelerometer.
4. A UART without handshaking to communicate with the GNSS module.
5. A UART to communicate with the BLE module

2.6 LEDs

1. Two programmable red LEDs are available. They are controlled by the GPIO2 and GPIO3 pins of the cellular module as the processor does not have enough pins.
2. A tri-color LED is connected to the ANNA-B112 to provide status information.

3 Board design solutions

3.1 Power supply design

3.1.1 Protection

The Protection consists of a fuse, a diode for reverse polarity protection and overvoltage protection. The overvoltage protection has two components:

1. A MOSFET circuit that opens when the input voltage reaches about 32 V.
2. An 82 V TVS protects the MOSFET when the input voltage goes above 82 V. This is necessary for the ISO7637-2 test pulse 3b for 24 automotive systems. The test pulse amplitude is between 150 and 200 V.

3.1.2 Filter

The input filter ensures that the conductive emissions are kept at acceptable levels and comply with CISPR 25.

3.1.3 Main power supply

The main power supply of the board is a DC/DC step-down switching regulator, powered at an input voltage from 9 V to 32 V DC. The voltage level present at the output of the step-down regulator is used to supply the cellular module via a MOSFET controlled by the processor; this output voltage is typically set to 4.2 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 in terms of power efficiency and current draw.

For general design guidelines regarding the integration of the switching regulator, refer to SARA-G450 and SARA-R4 System integration manuals [1], [2].

The selected step-down switching regulator is the Linear Technology LTC4091 that guarantees high efficiency and comes with an integral battery charger and power path controller.

3.1.4 Cellular module supply

The power to the cellular module is directly supplied by the step-down regulator via a MOSFET controlled by the processor. The ceramic capacitors and a ferrite bead are placed on the VCC supply pins of the cellular module.

The 100 µF capacitor is used to avoid voltage drop undershoot and overshoot at the start and end of a transmit burst during a GSM call.

The other ceramic capacitors provide filtering against EMI in the frequency bands of the cellular module operation.

The ferrite bead (BLM18EG221SN1) is integrated in all the blueprint variants to “clean” the voltage line and suppress noise.

3.1.4.1 Switch-on and switch-off of the cellular module

To switch on the cellular module on any variant:

1. Switch on the module power by setting the CELLPWR signal from the processor (PB15) high.
2. Set CELLRST signal from the processor (PC7) low.
3. Set CELLPWRON signal from the processor (PC6) high.
4. Wait until the +1V8 stabilizes before communicating with the module.

To switch off the cellular module on any variant:

1. Send the AT+CPWROFF command wait for the OK and enough time for power down process to finish (i.e. until IOs are in tristate), then remove the main power supply from the board.
2. Set the CELLPWRON signal from the processor (PC6) low.
3. Switch off the module power by setting the CELLPWR signal from the processor (PB15) low.

For a complete description of all the operating modes of the cellular modules and the transitions from one state to another, see the SARA-G450 and SARA-R4 System integration manuals [1], [2].

3.1.5 Positioning module supply

Texas Instruments TPS72730DSE 3 V LDO is used to power the GNSS module. It can be switched on and off using the GNSSPWRON signal from the processor (PC11).

3.1.6 Short range module supply

The ANNA-B112 is powered by the same Texas Instruments TPS72730DSE 3 V LDO that powers the processor and this LDO is always on.

If needed, the module must be set into low power by firmware on the processor.

3.2 Connections among subsystems

3.2.1 Processor

Blueprint variants G450-1 and R412-1 implement connections between the processor and the cellular, positioning, and short range modules.

The processor controls the cellular module via an UART with full handshaking. There are also CELLPWRON and CELLRST lines between the processor and the cellular module. Level translation is necessary on the UART lines between the processor and the cellular module.

In the blueprint design, the short range module is fully controlled via the processor; with this solution designers have full access to the short range module via dedicated AT commands via an UART with partial handshaking.

The processor communicates with an accelerometer via an SPI interface. A second SPI interface is used between the processor and serial flash.

An I2C interface on the processor is used to communicate with the inertial module for the G450-2 and R412-2. This is an interface also used by the positioning module; make sure that the firmware does not have two I2C masters.

The processor communicates with the positioning module via a UART with only transmit and receive.

3.2.2 Cellular module

The cellular module communicates with the processor via a UART with full handshaking. Level translation is necessary between the processor and the cellular module.

The cellular module also communicates with the positioning module via an I2C interface. Level translation is also needed here.

3.2.3 Positioning module

The EVA-M8Q positioning module communicates with the processor via an UART with only transmit and receive lines.

The module communicates with the cellular module via an I2C interface with level translation.

The module communicates with an inertial module via an I2C interface and with SQI memory via a quad SPI interface.

The I2C interface to the inertial module is shared with the processor; make sure that the positioning module and the processor do not want to communicate with the inertial module at the same time.

3.3 Antenna design

The most important topic in the design of the Blueprint B36 is the optimization of the RF performance, specifically integrating three different antennas in a small PCB, maintaining good radiation properties with all the technologies. The sections below discuss the main design choices implemented.

3.3.1 Cellular antenna design

Board dimensions have been defined to minimize the PCB size and to guarantee RF performance of the cellular antenna.

As general guidelines, the antenna selection process must take into account the following parameters:

1. Operating band: it is usually expressed as the frequency span where the VSWR (or S11) at the antenna port is under a certain level. The recommended value is VSWR < 2, acceptable is VSWR < 3.
2. Efficiency: is the ratio of the radiated power to the power delivered to the antenna input; it is an average measure of how well an antenna receives or transmits. Efficiencies greater than 50% are acceptable, greater than 70% are recommended.
3. Gain: is the efficiency multiplied by the directivity; it is a measure of how the antenna is able to direct radiation towards a certain direction (usually the direction of maximum transmission / reception). The antenna’s maximum gain must not exceed the limiting values reported in the system integration manual of the cellular module and imposed by the regulatory certification schemes.
4. Antenna pattern: is 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 almost all the directions.

To maximize the parameters above, the antennas’ position on the board must be accurately defined. As a general guideline, separation distance of at least 1/4 of the wavelength of the minimum operating frequency should be provided, but this is not the only factor, and in most of the cases simulations and measurements are necessary to define the best antenna location on the PCB.

When integrating PCB-mount antennas or internal antennas with small RF coaxial cables, the effect of the board ground plane must be considered, since antenna parameters are affected by the ground plane size. Typically, the antenna gain and the antenna efficiency values drop when the PCB dimensions are reduced.

Finally, the antennas’ characteristic impedance must be matched with the matching network components that tweak the VSWR and prevent additional losses.

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:

1. Total radiated power (TRP) is a measure of how much power is radiated by the device (transmitter test)
2. Total isotropic sensitivity (TIS) is a measure of the minimum received power required to maintain a specific error rate (receiver test)
3. Radiated spurious emissions (RSE) takes into account the power emitted outside the RF operating band. Power limits are imposed by the regulatory authorities to avoid harmful interferences.

Blueprint B36 has been specifically designed to get good RF performance.

3.3.2 GNSS antenna design

The positioning module is either an EVA-M8Q or EVA-M8E. Both are concurrent GNSS receivers, able to receive and track multiple GNSS systems: GPS, GLONASS, BeiDou, QZSS, SBAS and Galileo. Because of the dual-frequency RF front-end architecture of the module, two of the three signals (GPS L1C/A, GLONASS L1OF and BeiDou B1) can be received and processed concurrently. By default, the positioning module is configured for concurrent GPS (including SBAS and QZSS) and GLONASS reception.

For these reasons the antenna integrated in the board is a ceramic patch antenna working in the GSP / GLONASS / BEIDOU frequency bands but tuned to better operate in the GPS – GLONASS frequency range of 1575 – 1608 MHz. The selected part number is:

Amotech A25-4800920-AMT18, 25 x 25 x 4 mm

The placement of the patch antenna on the board affects the RF performance. The GNSS antenna is placed on the top layer, as the battery is next to the bottom layer. To minimize the length of the antenna RF path and the associated losses, the positioning module is placed on the opposite side, directly beneath the patch antenna. A Qorvo QM14502 GNSS LNA with built-in SAW filters on both the input and output is used to improve gain and isolation. The frequency range of the LNA is 1550 – 16100 MHz.

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, take care to reduce the electrical noise that may interfere with the antenna performance. To minimize the inference / blocking effect of the cellular signals, the GNSS antenna is located far away from the cellular primary Tx/Rx antenna.

Since the GNSS sensitivity of the board is related to the ground plane size, the ground size on the top layer has been maximized; moreover, the area underneath the ceramic patch is fully covered by stitching GND vias.

3.3.3 BLE antenna design

The short range module ANNA-B112, integrated in all the blueprint variants, supports BLE functionalities in the 2.4 GHz radio band.

The module has an internal antenna.

4 Performance evaluation

4.1 Cellular evaluation

Blueprint B36 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. To verify the performance, parameters like total radiated power (TRP) and total isotropic sensitivity (TIS) have been tested in a fully anechoic chamber.

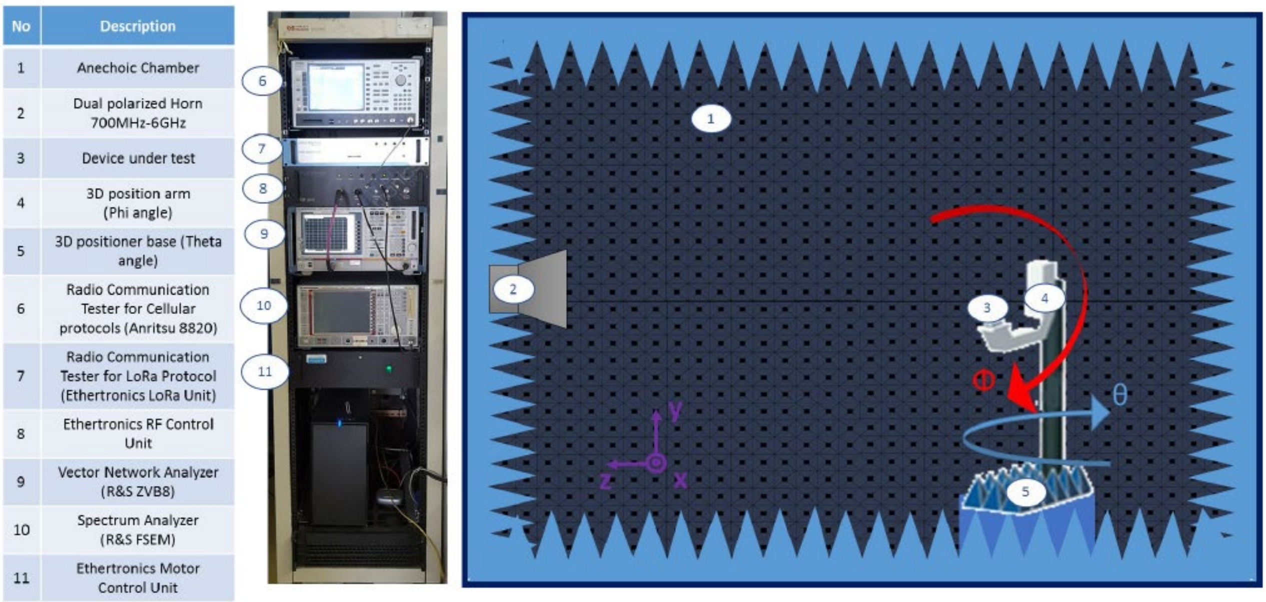
Tests were made by our partner Ethertronics/AVX at their facility. In the test, the P822601 allowed us to reach the targeted RF performance requirement on a small PCB size like the B36 without using an active antenna tuning and the corresponding RF switches.

The evaluation was done measuring LE-Cat M1 B12, B13, B20, B4 and B2 bands. The evaluation consisted of fine-tuning the matching of the cellular antenna P822601 in the B36.

The measurements presented in this report are TRP and TIS.

4.1.1 Cellular evaluation setup

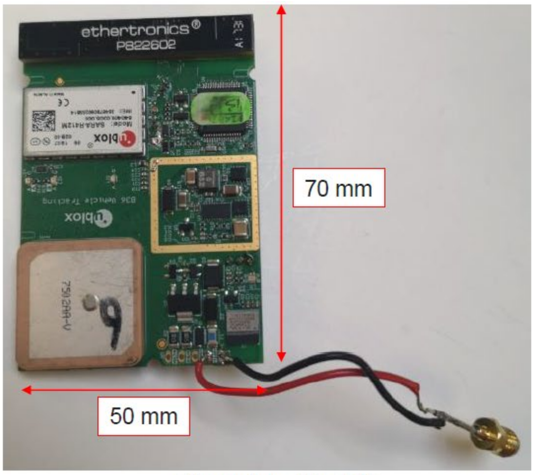
4.1.1.1 Environment



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 7: Schematic of the anechoic chamber system for efficiency, peak gain, and radiation pattern measurements

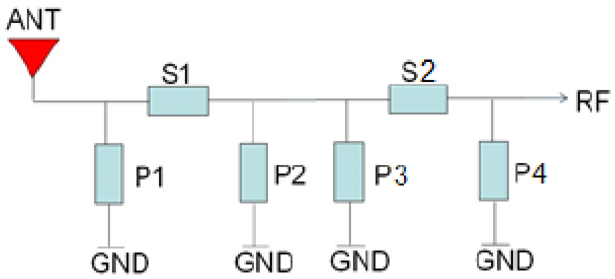
4.1.1.2 Device under testing



Dimensions of the PCB

The voltage biasing has been done through the RF Cable of the anechoic chamber

4.1.2 Ideal matching circuit



Matching	Value	Part number
P1	23 nH	LQW15AN56NG600D
S1	3 pF	04025J3R0BBS
P2	n/a	n/a
P3	n/a	n/a
S2	2.7 nH	L04022R7AHN
P4	1 pF	04021J1R0ABS

Table 2: Ideal matching circuit values and part numbers

4.1.3 AT&T TRP/TIS requirements for small form factor devices

A small form factor device is one that is less than 107 mm in the longest direction. LTE-M wearable devices within the small form factor limits need to be tested to adhere to the AT&T requirements, as shown in Table 3. The tests shall be done using the wrist phantom for wrist-worn devices or the body phantom for all other wearable device types.

Band	Minimum TRP requirement power class 3	Minimum TRP requirement power class 5	Minimum TIS requirement (primary antenna)
2	+12.0 dBm	+9.0 dBm	–88 dBm
4	+12.0 dBm	+9.0 dBm	–90 dBm
12	+10.0 dBm	+7.0 dBm	–85 dBm

Table 3: AT&T TRP/TIS requirements

The reference design meets AT&T specifications for small form factor with at least 3 dB margin for TIS and TRP.

Band	Channel	TRP (Class 3)	TIS (720kHz)
LTE B2 (dBm)	Low	20.0	
	Mid	19.5	-105.6
	High	18.1	
LTE B4 (dBm)	Low	20.1	
	Mid	20.3	-104.2
	High	19.5	
LTE B12 (dBm)	Low		
	Mid	12.6	-94
	High		
LTE B13 (dBm)	Low		
	Mid	14.8	89.7
	High		
LTE B20 (dBm)	Low		
	Mid	14.5	-94.2
	High		

Table 4: TRP/TIS Measurement results

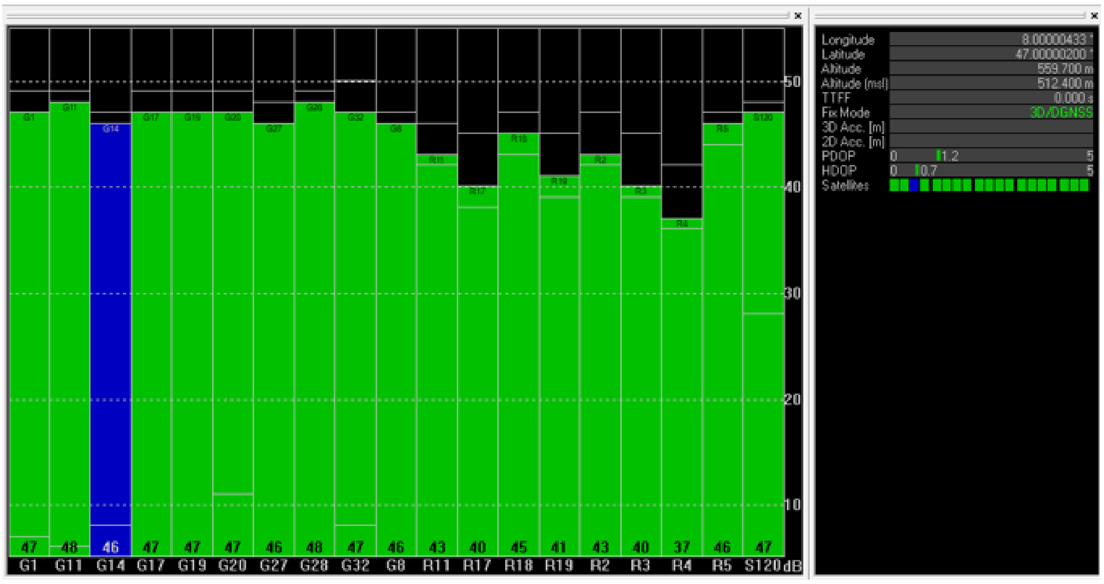
4.2 GNSS evaluation

Blueprint B36 is an integrated device with coexistence GNSS, cellular and BLE. The coexistence GNSS cellular is not to be neglected and can be challenging if not considered from the beginning. In the scope of the B36, schematic and layout have been optimized to obtain the best performance.

Section 4.2.1 describes the setup and testing realized in order to validate the optimal performance.

4.2.1 GNSS evaluation setup

4.2.2 Test GNSS ON, LTE OFF



Average C/N0	~43 dB
TTFF*	27 s

* Cold start without any AssistNow data

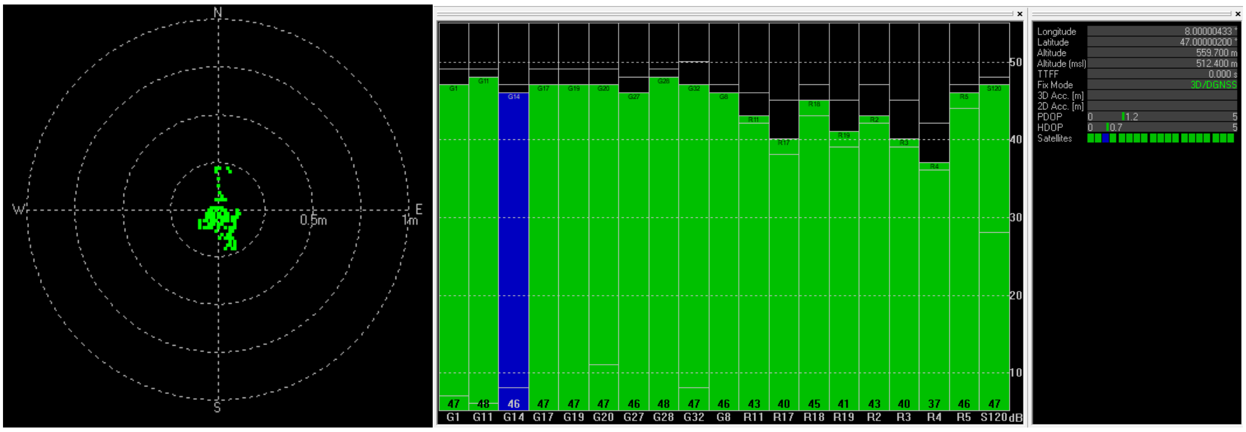
4.2.3 GNSS ON, LTE ON

The following test is made to see the possible degradation of the GNSS when the cellular module is emitting in full power on the B36.

CMW500 configuration:

- Signaling mode, RMC
- BW = 5 MHz
- TCP = 23 dBm
- CELL power = -100 dBm
- Att = 39 dB

4.2.4 Attenuation on C/N0



LTE band	2	3	4	5	8	12	13	20
Frequency, MHz	1900	1800	1700	850	900	700	750	800
Average C/N0, dB	40	40	43	43	43	43	43	43

Results:

- No degradation with respect to no LTE TX condition on bands 4, 5, 8, 12, 13, 20.
- About 3 dB degradation observed while using bands 2, 3.

The results are quite good given a 4-cm distance between cellular and GNSS antennas.

4.2.5 Sensitivity attenuation and time-to-first fix

LTE band	2	3	5	8	12	13	20
Sensitivity, dB	-140	-139	-143	-143	-143	-139	-143
TTFF*, s	36	38	27	27	27	37	27

*Cold start without AssistNow data

Results:

We observed no degradation on most of the tested bands, and the worst-case degradation of 4 dB when using band 3. This is all in all a quite good performance considering that the constraints imposed to the B36 were a worst-case scenario.

Appendix

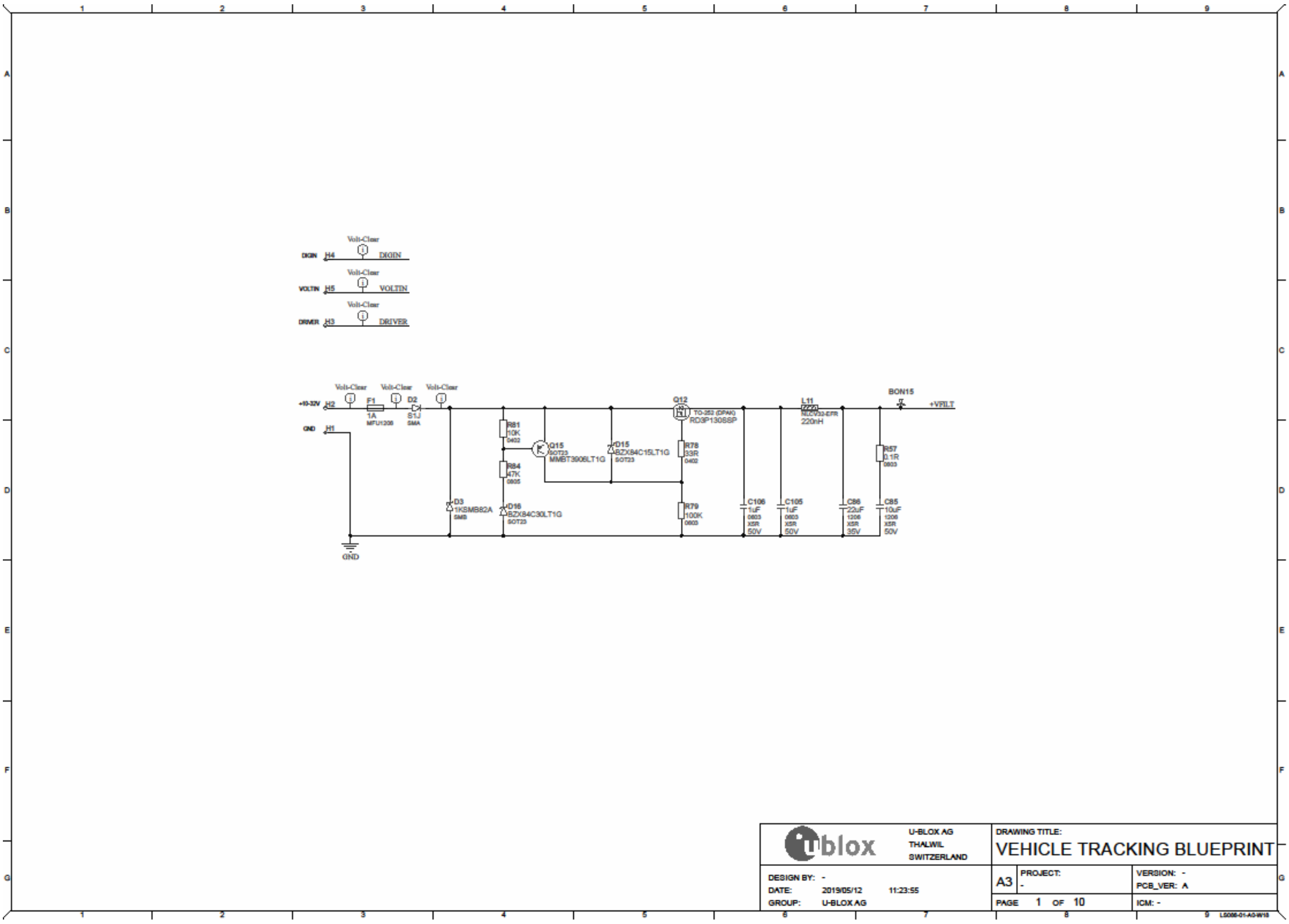
A Glossary

Abbreviation	Definition
ARM	Arm (Advanced RISC Machines) Holdings
PCB	Printed Circuit Board
BLE	Bluetooth Low Energy
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
I2C	Inter-Integrated Circuit
LDO Regulator	Low Dropout Regulator
LNA	Low Noise Amplifier
QZSS	Quasi-Zenith Satellite System
RF	Radio Frequency
SAW Filter	Surface Acoustic Wave Filter
SBAS	Satellite-based Augmentation System (civil aviation safety-critical system)
SIM	Subscriber Identity Module
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
SQI	Serial Quad Interface
UART	Universal Asynchronous Receiver-Transmitter
VSWR	Voltage Standing Wave Ratio

Table 5: Explanation of the abbreviations and terms used

B Schematics

B.1 Schematic 1: input protection circuit and filter circuit



B.1.1 Protection circuit

The protection circuit consists of a TVS that provides protection for above 82 V and a MSOFET that goes open circuit for protection up to 100 V.

The MOSFET protection circuit consists of a 1 A SMD fuse (F1) and a 36 V cutout circuit consisting of a Zener diode (D16), a PNP transistor (Q15) and a P type MOSFET (Q12). When the input voltage reaches about 32 V, the PNP transistor turns on because the Zener diode starts conducting. The result is that the MOSFET is turned off.

A 15-V Zener diode protects the MOSFET against the VGS going to high.

The MOSFET was selected for its high breakdown voltage and its low resistance.

A 1.5SMB82A (D3) is the TVS used to provide the protection above 82 V. This is needed to provide Level III protection for ISO 7637-2 Pulse 3b.

A S1J (D2) diode is used for reverse polarity protection.

Calculations:

The breakdown voltage of the BZX84C33 is from 30.8 V to 35 V at 1 mA.

The protection circuit is activated when the Vbe is from -0.3 V to -0.6 V.

The voltage across the two resistors is therefore from 1.71 V to 3.42 V.

The current at this voltage is between 30 µA to 60 µA.

Activation voltage at the source of the MOSFET is therefore between 32.5 V to 38.4 V.

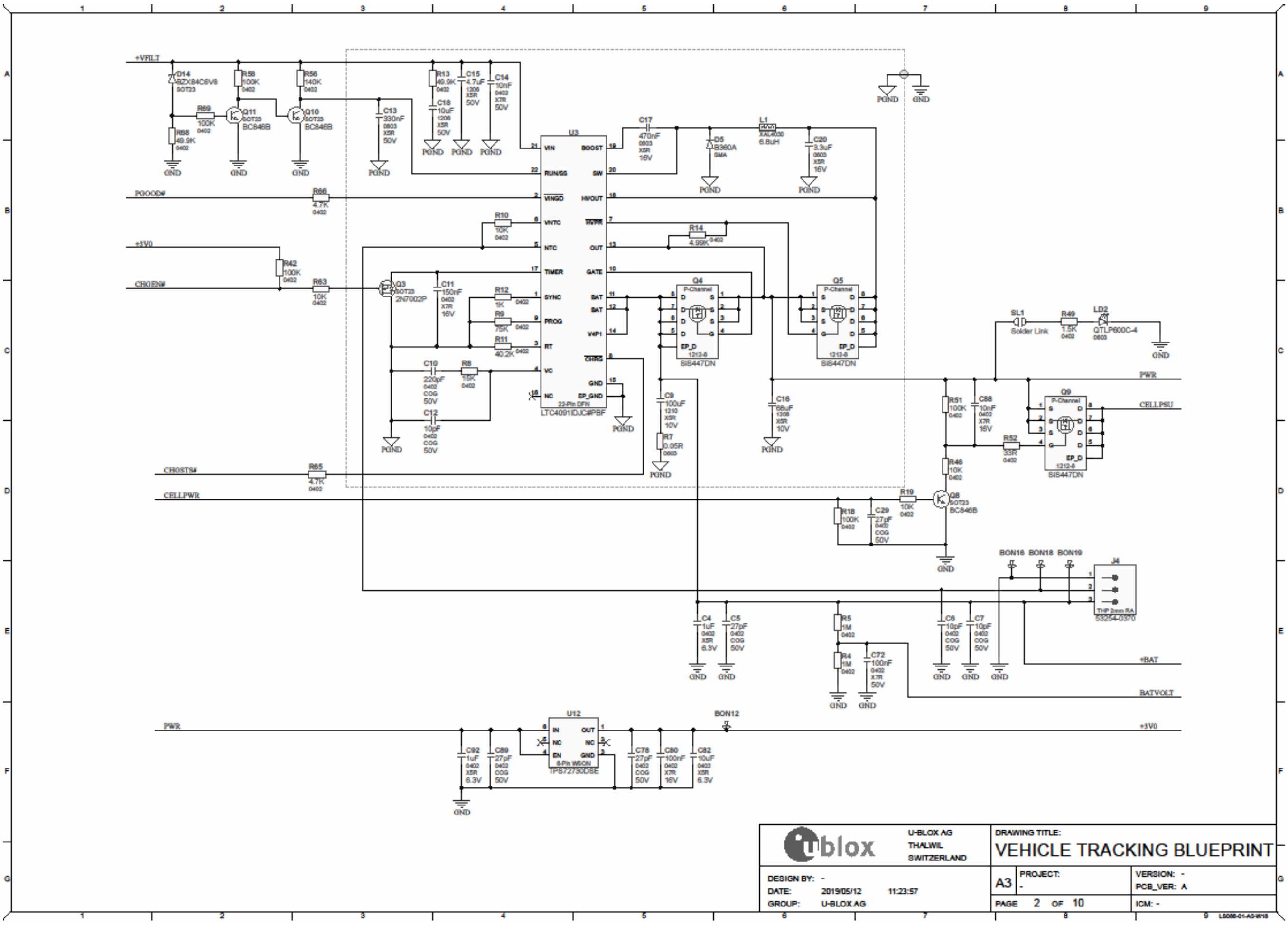
Because of the voltage drop across the S1J diode, the upper operational voltage of the unit is 33.2 V. (Minimum voltage drop across the diode is 0.7 V.)

The absolute maximum rating for the buck converter is 60 V.

B.1.2 Filter circuit

The filter circuit consists of an Inductor (L11) and capacitors C85, C86, C105 and C106. This filter is needed to comply with the EMC requirements.

B.2 Schematic 2: switch mode supply and battery connector



B.2.1 Switch mode supply

This is a 4.2 V 2 A power supply.

An Analog Devices LTC4091 buck converter (U3) is used. This device can handle an input voltage of up to 60 V. It uses an internal FET. An external inductor (L1), diode (D5) and an output capacitor (C20) are needed.

The device also has a battery charger and power path control built in. The battery charger supports battery temperature sensing which is necessary for automotive applications to protect the battery.

A Vishay SiS447DN P-channel MOSFET (Q5) is used to switch the output of the buck converter to the output of the power supply system. Another Vishay SiS447DN P-channel MOSFET (Q4) is used to switch the battery to the output of the power supply system. This FET is optional and is in parallel with an internal FET with a higher resistance.

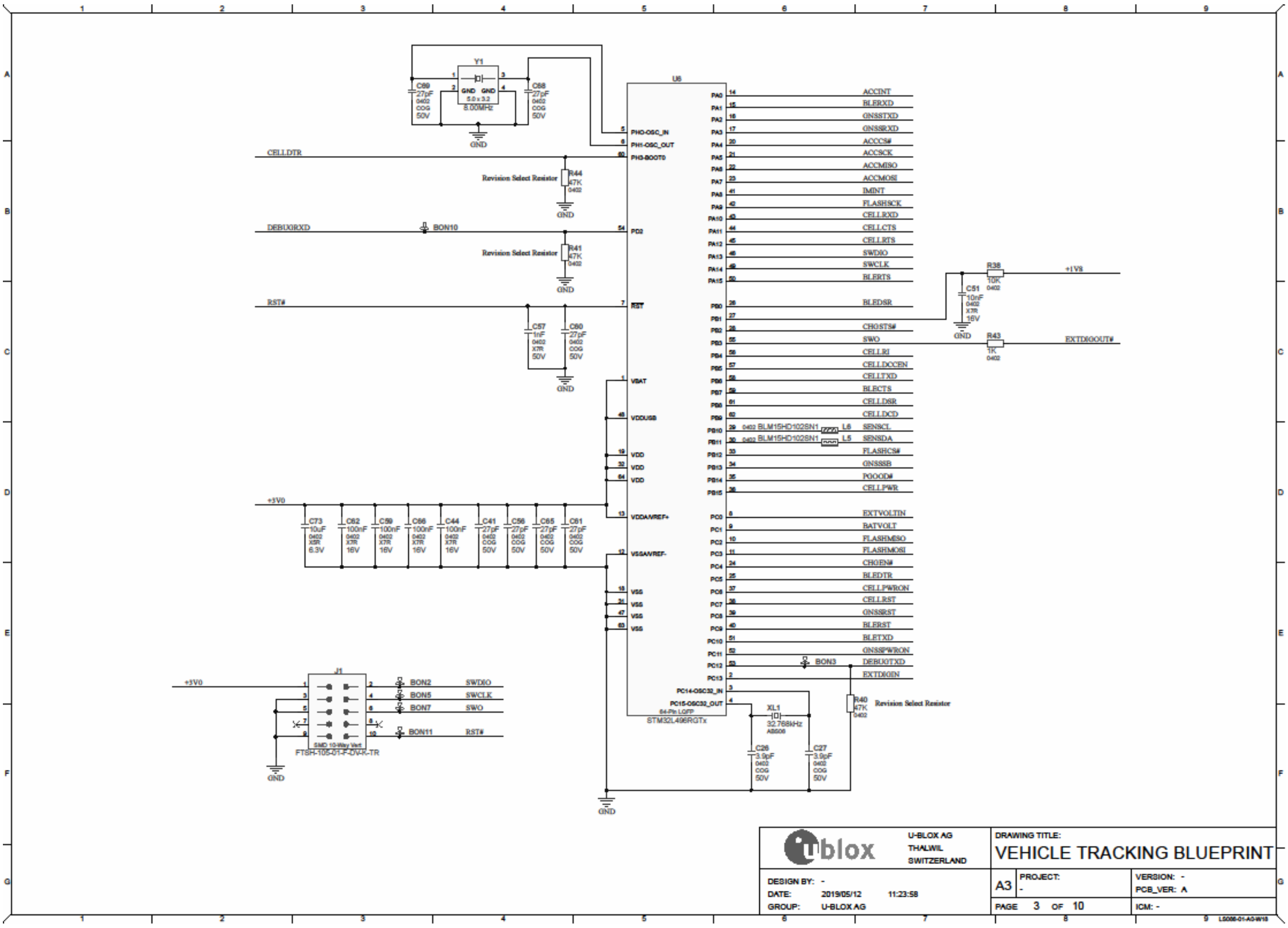
The Zener diode/transistor circuits D14, Q11 and Q10 provide cold-crank ride through functionality and prevent voltage overshoot on the output when there are voltage dips on the input of the buck converter.

The output is a nominal 4.2 V which is used to drive the cellular module and the 3.0 V LDOs.

A Vishay SiS407ADN P-channel MOSFET is controlled by the processor and is used to switch the power to the cellular module on and off.

The switching frequency is 800 KHz.

B.3 Schematic 3: processor



B.3.1 Processor

- SPI1 = Accelerometer
- SPI2 = Flash
- UART4 = BLE Module – with RTS and CTS
- UART5 = Debug
- USART1 = Cellular module
- USART2 = GNSS module – No RTS and CTS

The processor is an ST Microelectronics STM32L496RGT (U6). The pins are as follows:

Pin	Name	Description	Comment	Pin no
PA0	**ACCINT**	Accelerometer interrupt		14
PA1	**BLERXD**	BLE UART receive	UART4_RX	15
PA2	**GNSSTXD**	GNSS UART transmit	USART2_TX	16
PA3	**GNSSRXD**	GNSS UART receive	USART2_RX	17
PA4	**ACCCS#**	Accelerometer SPI chip select	SPI1_NSS	20
PA5	**ACCSCK**	Accelerometer SPI clock	SPI1_SCK	21
PA6	**ACCMISO**	Accelerometer SPI MISO	SPI1_MISO	22
PA7	**ACCMOSI**	Accelerometer SPI MOSI	SPI1_MOSI	23
PA8	**IMINT**	Inertial module interrupt		41
PA9	**FLASHSCK**	FLASH SPI clock	SPI2_SCK	42

Pin	Name	Description	Comment	Pin no
PA10	**CELLRXD**	Cellular module UART receive	USART1_RX	43
PA11	**CELLCTS**	Cellular module UART CTS	USART1_CTS	44
PA12	**CELLRTS**	Cellular module UART RTS	USART1_RTS	45
PA13	**SWDIO**	SWDIO of single wire	SYS_JTMS-SWDIO	46
PA14	**SWCLK**	SWCLK of single wire	SYS_JTMS-SWCLK	49
PA15	**BLERTS**	BLE UART RTS	UART4_RTS	50
PB0	**BLEDSR**	BLE interface DSR	GPIO output – active high	26
PB1	*+1V8*	Cellular module VINT measurement	ADC1_IN16	27
PB2	**CHGSTS#**	Charge status	GPIO input – active low	28
PB3	**SWO**	Debug port	Normally used as **EXTDIGOUT#**	55
PB4	**CELLRI**	Cellular module UART RI	GPIO input	56
PB5	**CELLDDCEN**	Enable cellular DDC interface	GPIO output	57
PB6	**CELLTXD**	Cellular module UART transmit	USART1_TX	58
PB7	**BLECTS**	BLE module UART CTS	UART4_CTS	59
PB8	**CELLDSR**	Cellular module UART DSR	GPIO input	61
PB9	**CELLDCD**	Cellular module UART DCD	GPIO input	62
PB10	**SENSCL**	Inertial module I2S clock	I2C2_SCL	29
PB11	**SENSDA**	Inertial module I2S data	I2C2_SDA	30
PB12	**FLASHCS#**	FLASH SPI chip select	SPI2_NSS	33
PB13	**GNSSSB**	GNSS safe boot	GPIO output– active high	34
PB14	**PGOOD#**	Power supply power input OK	GPIO input – active low – internal pullup enabled	35
PB15	**CELLPWR**	Enable power to cellular module	GPIO output – active high	36
PC0	*EXTVOLTIN*	External analog measurement input	ADC1_IN1	8
PC1	*BATVOLT*	Battery voltage measurement input	ADC1_IN2	9
PC2	**FLASHMISO**	FLASH SPI MISO	SPI2_MISO	10
PC3	**FLASHMOSI**	FLASH SPI MOSI	SPI2_MOSI	11
PC4	**CHGEN#**	Charge enable	GPIO output – active low – open drain	24
PC5	**BLEDTR**	BLE module status output	GPIO input – active high	25
PC6	**CELLPWRON**	Cellular module on	GPIO output – active high	37
PC7	**CELLRST**	Cellular module reset	GPIO output – active high	38
PC8	**GNSSRST**	GNSS module reset	GPIO output – active high	39
PC9	**BLERST**	BLE module reset	GPIO output – active high	40
PC10	**BLETXD**	BLE module UART transmit	UART4_TX	51
PC11	**GNSSPWRON**	Enable GNSS power	GPIO output – active high	52
PC12	**DEBUGTXD**	Debug UART transmit	UART5_TX	53
PC13	**EXTDIGIN**	External digital input	GPIO input – active high	2
PC14	Crystal	32.768 KHZ oscillator	RCC_OSC32_IN	3
PC15	Crystal	32.768 KHZ oscillator	RCC_OSC32_OUT	4
PD2	**DEBUGRXD**	Debug UART transmit	UART5_RX	54
PH0	Crystal	8 MHz oscillator	OSC_IN	5
PH1	Crystal	8 MHz oscillator	OSC_OUT	6
PH3	**CELLDTR**	Cellular module UART DSR	GPIO output	60

B.3.2 DMA channels

DMA 1 request mapping

Peripherals used:

CxS[3:0]	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
0000	ADC1						
0001		SPI1_RX	SPI1_TX	SPI2_RX	SPI2_TX		
0010						USART2_RX	USART2_TX
0011							
0100							
0101							
0110							
0111							

- SPI1 = Accelerometer
- SPI2 = Flash
- USART2 = GNSS module

DMA2 request mapping

Peripherals used:

CxS[3:0]	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7
0000							
0001							
0010	UART5_TX	UART5_RX	UART4_TX		UART4_RX	USART1_TX	USART1_RX
0011							
0100							
0101							
0110							
0111							

- UART4 = BLE module
- UART5 = Debug
- USART1 = Cellular module

B.3.3 I/O interrupts

The processor can use the following I/O interrupts to leave the low power mode.

I/O	Signal	Description	Comment
PA0	ACCINT	Accelerometer interrupt	When exceeding a programmed level in the accelerometer
PB1	PGOOD#	Interrupt when input power from the vehicle is removed	
PB4	CELLRI	Ring indicate from cellular module	
PC5	BLEDTR	Interrupt from the BLE module	
PA8	IMINT	Interrupt from the inertial module	When exceeding a programmed level
PC13	EXTDIGIN	External digital input	

Note that the I/Os are given in numeric order to ease the use of the interrupt vectors.

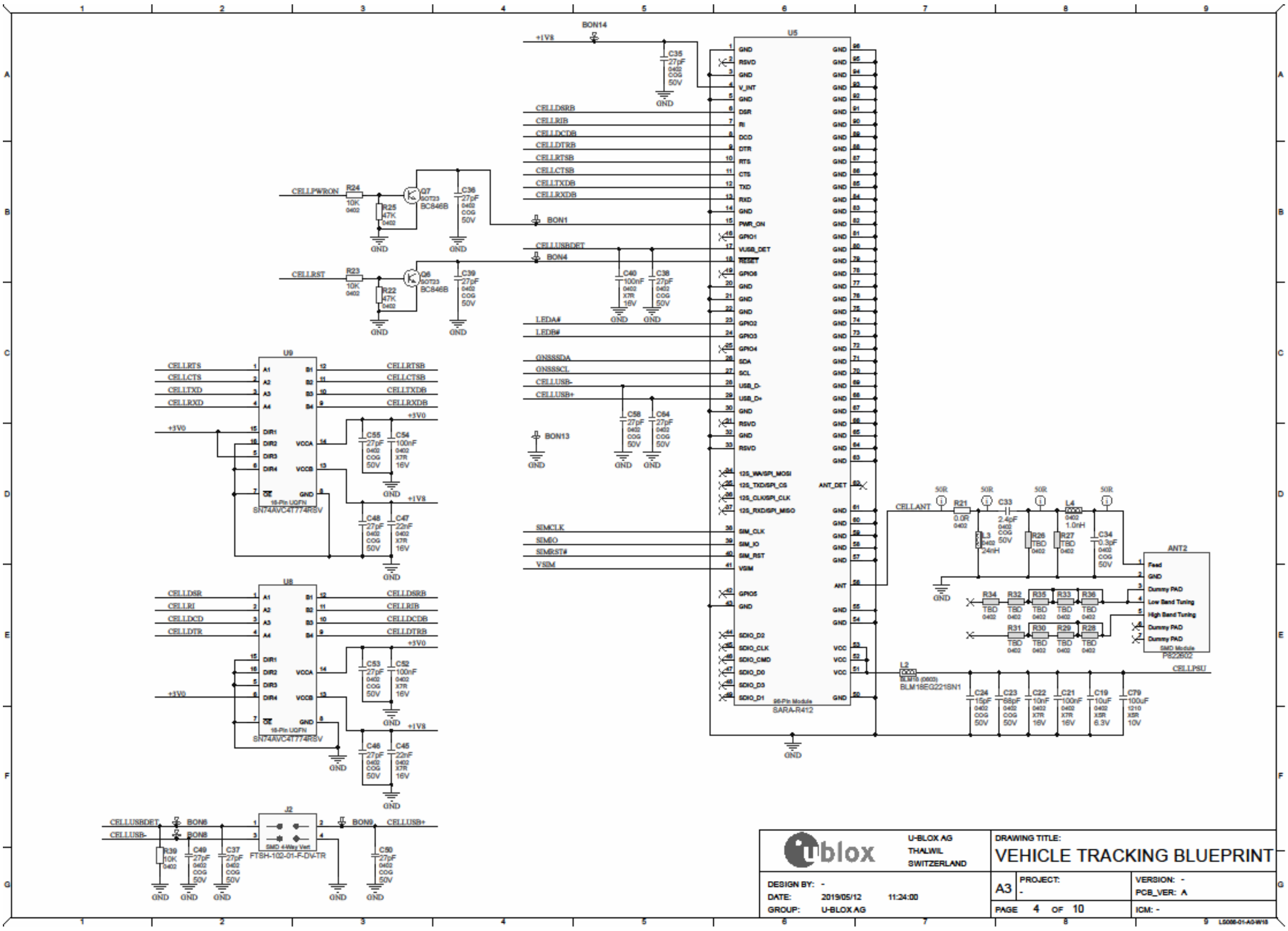
J1 is a programming port and it conforms to the ARM standard. Use an Olimex ARM-JTAG 20-10 Adapter or A Segger J-link 9-pin Cortex-M adapter.

J1 pin connections are as follows:

Pin	Signal
1	VTref
2	SWDIO
3	GND
4	SWCLK
5	GND
6	SWO
7	Key position
8	Not used
9	Not connected
10	nRESET

XL1 is a crystal for the processor RTC and YL1 is a crystal for the processor system clock.

B.4 Schematic 4: cellular module



B.4.1 Cellular module

The cellular module can be either a SARA-G450 or a SARA-R412M.

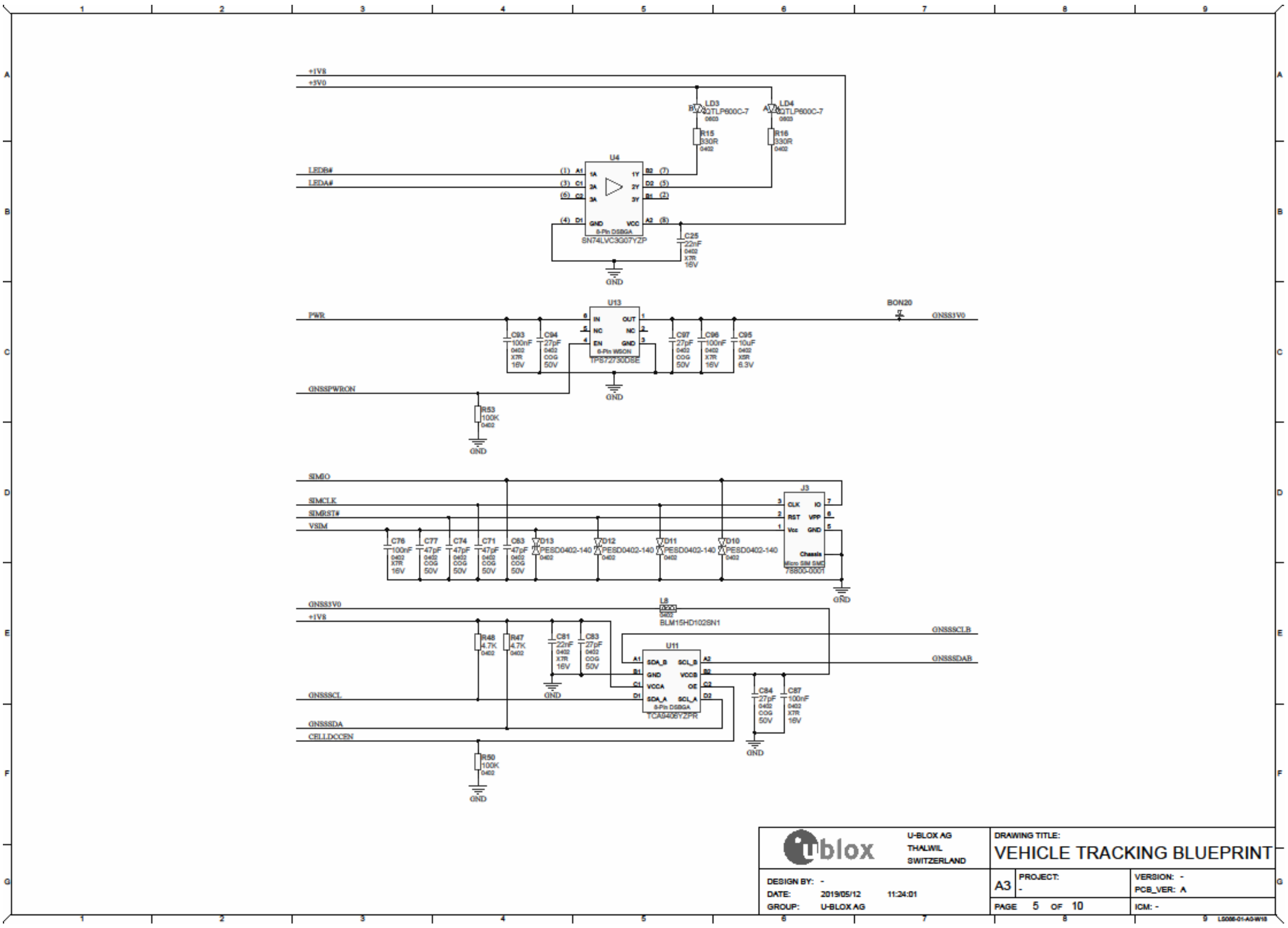
- Provision on the power supply is made to supply the peak current needed for 2G.
- The module communicates with the processor via serial bus and with the GNSS module via I2C bus.
- The PWR_ON and RESET_N lines are driven by open collector transistors.
- GPIO2 and GPIO3 are used to drive two LEDs.
- Two Texas Instruments SN74AVC4T774RSV (U8 and U9) level translators are used for the level conversion of the UART between the processor and cellular module.
- A PCB mount Ethertronics P822602 antenna (ANT2) is used for the cellular module.
- A Samtec FTSH-102-01-F-DV-TR connector (J2) is used as an USB interface for the SARA-R412 and a UART interface for the SARA-450.

J2 pin connections showing their signals:

SARA-R412 pins	Signal according to USB version 2.0 specification	SARA-G450 pins	Signal, 1.8 V logic
1	VUSB_DET	1	Not used
2	USB_D+	2	TXD_FT
3	USB_D-	3	RXD_FT
4	GND	4	GND

B.5 Schematic 5: LEDs, micro SIM, SPL translator, LDO

This page contains information on the LEDs, micro SIM connectors, serial port level (SPL) translator and LDO for the GNSS module.



B.5.1 LEDs

The LEDs are driven from the cellular module via open drain gates provided by a 74LVC3G07 (U4). Only two of the three gates on this device are used.

B.5.2 LDO for the GNSS module

A Texas Instruments TPS72730 LDO provides the power for the GNSS module as well as the SQI flash and the inertial module via a 2.7 V LDO.

B.5.3 Micro SIM connector

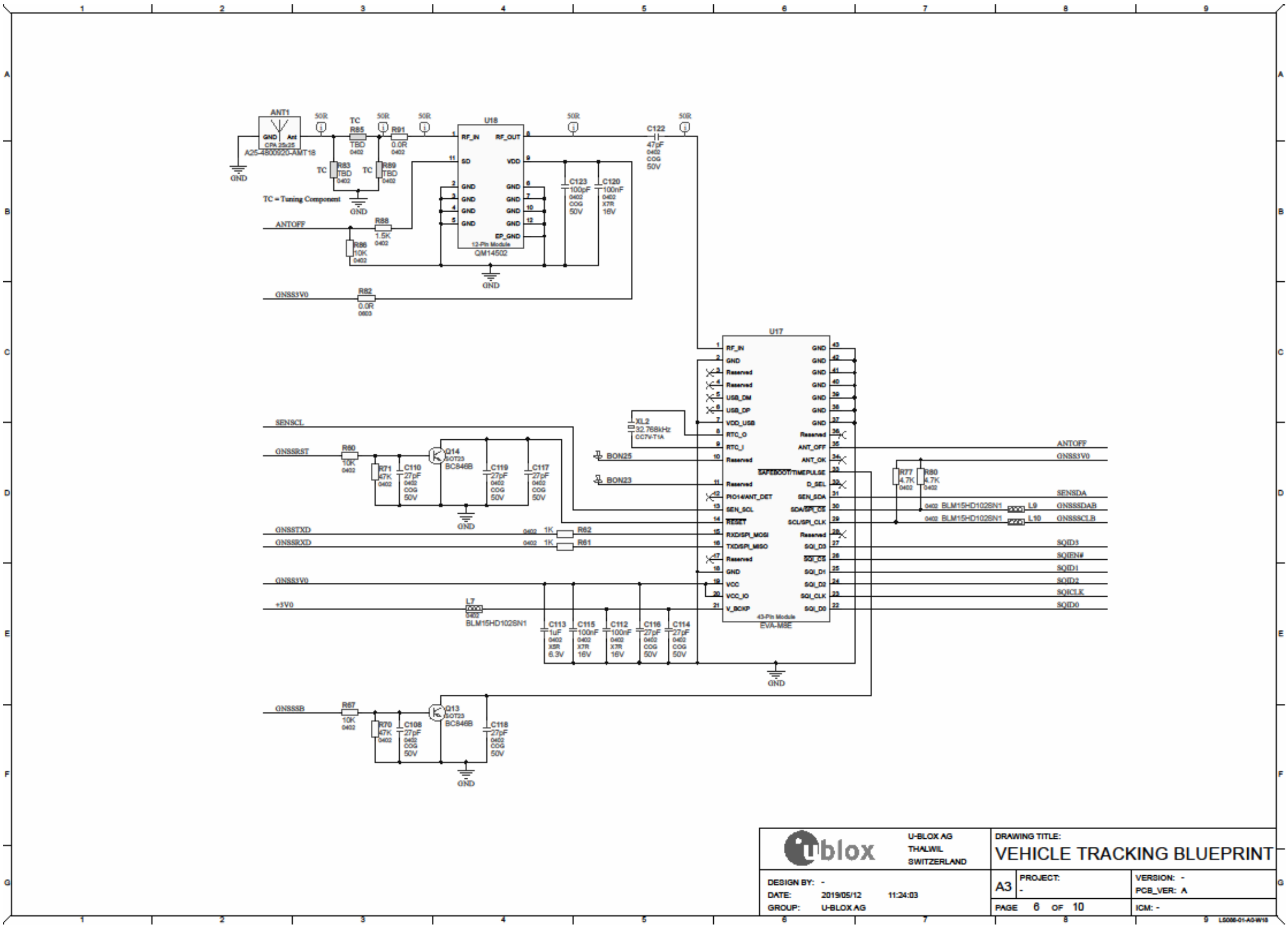
A flip-up Micro SIM connector is used. ESD protection is provided for the SIM connector with PESD0402-140 TVS devices.

B.5.4 Serial port level translation

Texas Instruments TCA9406 level translator (11) is used as a level translator on the I2C bus between the processor and the GNSS module. The CELLDCCEN from the processor signal enables and disables the ports on this device.

B.6 Schematic 6: GNSS module, antenna, and LNA

This page contains information on the GNSS module, antenna and LNA.



B.6.1 GNSS module

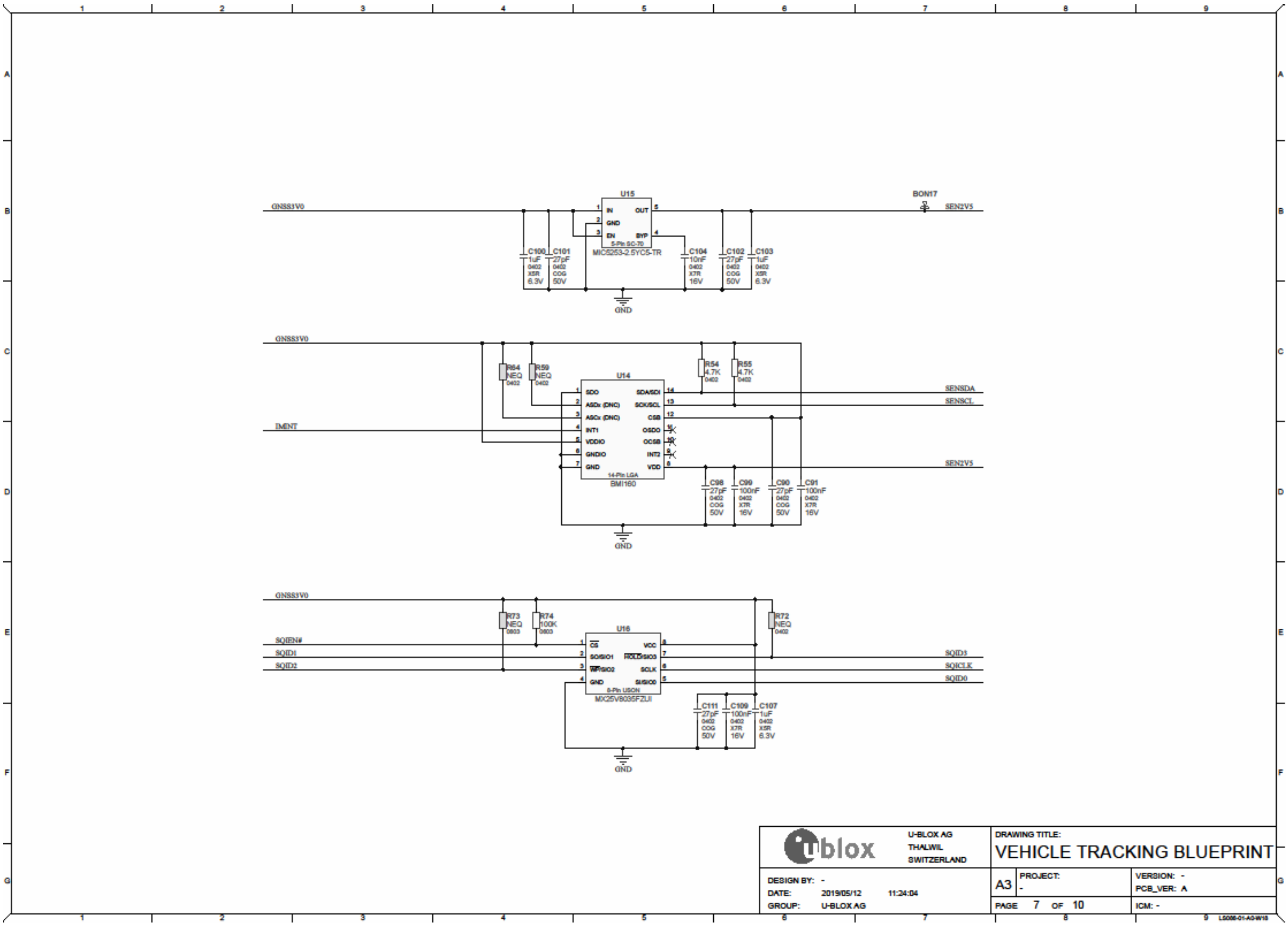
An EVA-M8 or EVA-M8E is used. When using the EVA-M8E, provision has been made for an inertial device and a SQI flash device to facilitate dead reckoning.

The GNSS module can be reset from the processor. The processor can also communicate with the GNSS module via the serial port.

B.6.2 Antenna and LNA

A 25 mm by 25 mm patch antenna is used. Its signal is amplified via a matching circuit by a Qorvo QM14502 GNSS LNA. This LNA has SAW filters on both the input and output to provide better isolation between the cellular antenna and the GNSS antenna. The same applies to the BLE and GNSS antennas. Provision is made for matching components.

B.7 Schematic 7: UDR Option



B.7.1 Inertial module

The Bosch BMI160 inertial device has both an accelerometer and a gyroscope and it is used with the EVA-M8E.

This device is powered by a 2.7V LDO.

B.7.2 LDO

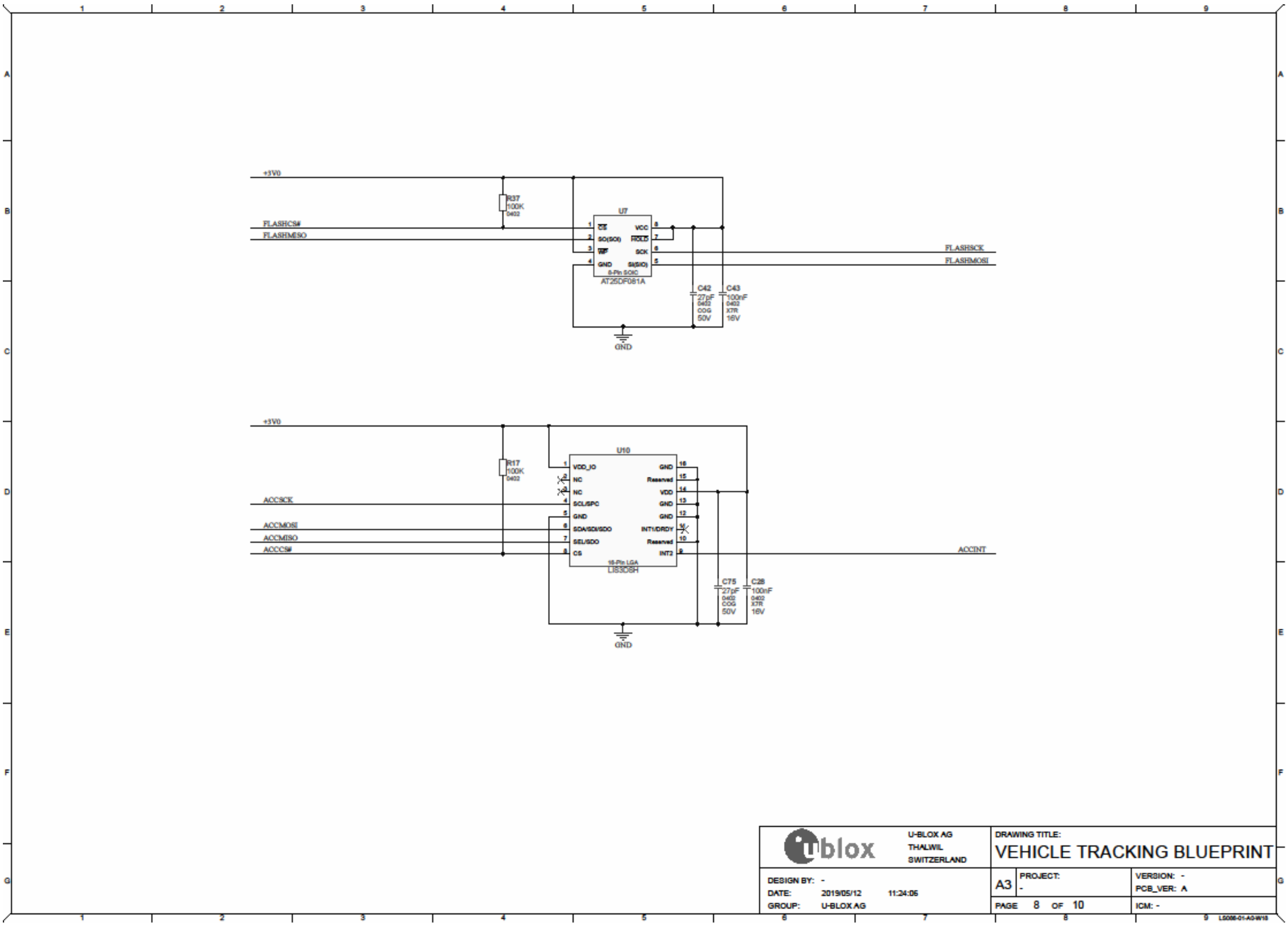
A Micrel MIC5253-2.7BC5 is used to provide the power for the inertial device.

B.7.3 SQI flash

A Macronix MX25V8035F SQI flash is also connected to the EVA-M8E via an SQI bus.

B.8 Schematic 8: external flash

This page contains information on the external flash for the processor and the accelerometer.



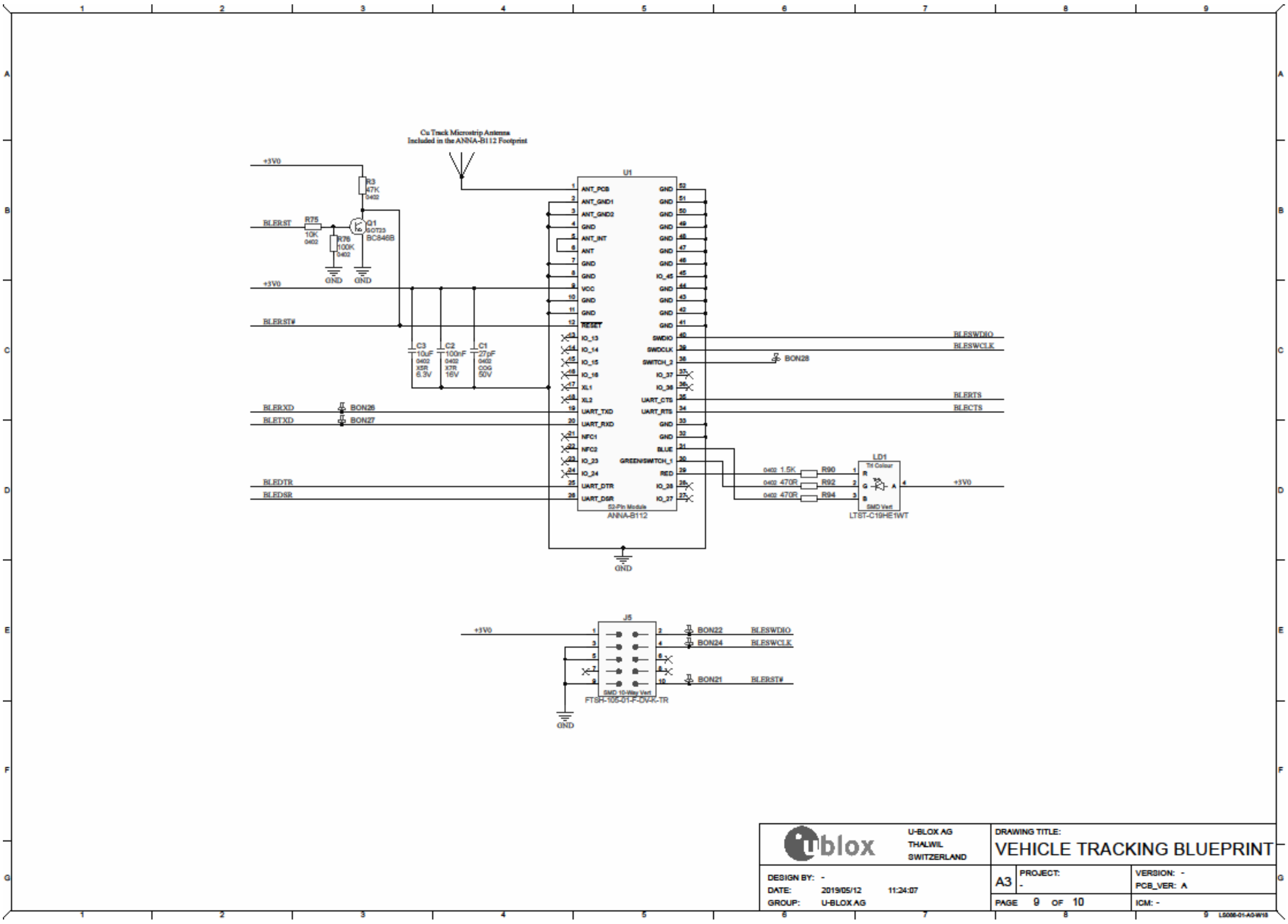
B.8.1 Flash

The Adesto AT25DF081A flash is connected to the processor via an SPI bus.

B.8.2 Accelerometer

An ST Microelectronics LIS3DSH accelerometer provides movement detection and information for accident reconstruction. It has an interrupt output that can be programmed to trigger the processor when programmable acceleration levels are exceeded. The accelerometer communicates with the processor via an SPI bus.

B.9 Schematic 9: Bluetooth low energy module



B.9.1 Bluetooth low energy module

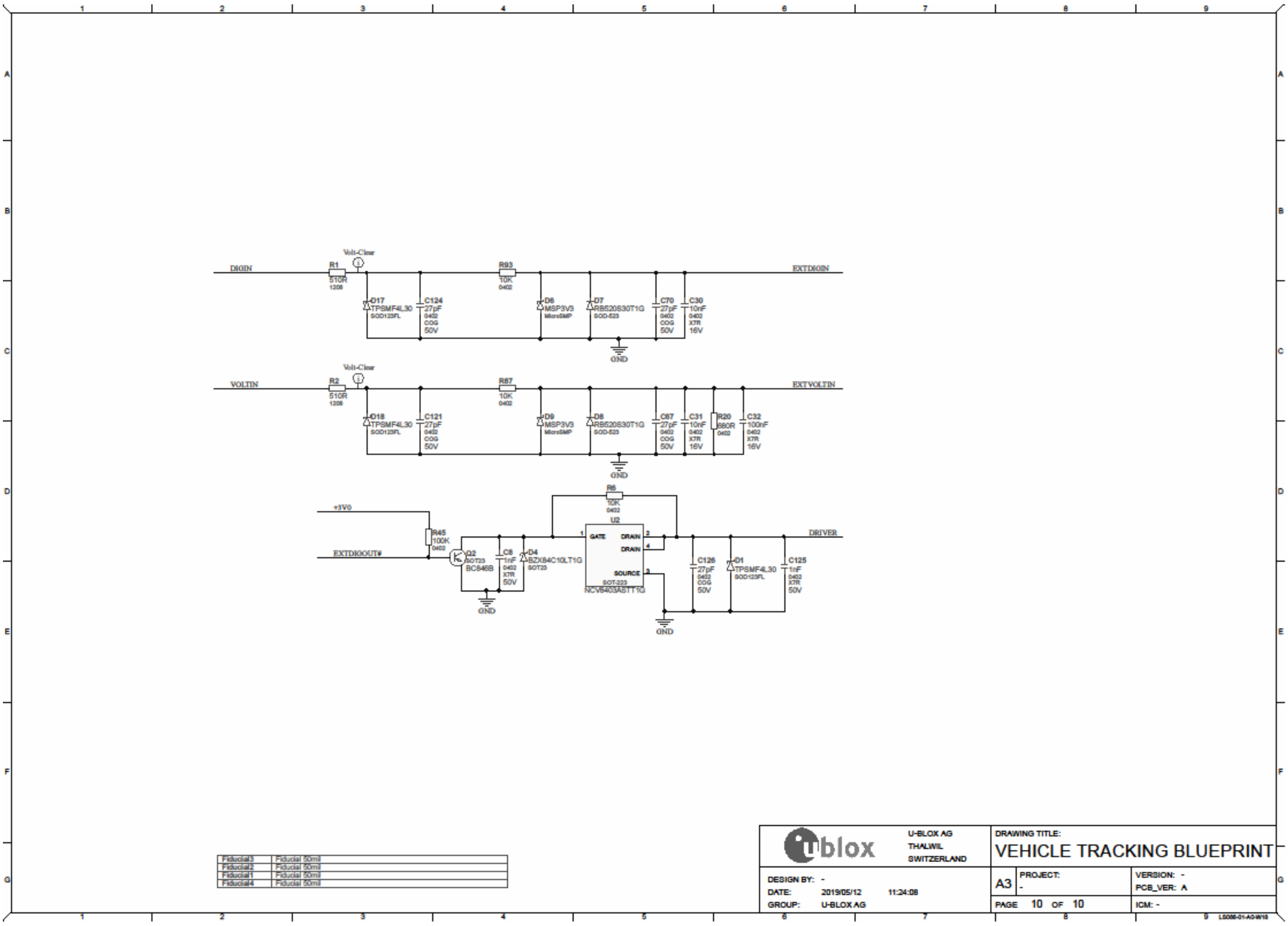
The ANNA-B112 module communicates with the processor via a UART with CTS/RTS handshaking.

- The module has a built-in antenna.
- A tri-color LED provides a visual indication of the module status.
- J5 is a programming port for the module.
- Use an Olimex ARM-JTAG 20-10 Adapter or A Segger J-link 9-pin Cortex-M adapter.

J1 Pin connections are as follows:

Pin	Signal
1	VTref
2	SWDIO
3	GND
4	SWCLK
5	GND
6	Not used
7	Key position
8	Not used
9	Not connected
10	nRESET

B.10 Schematic 10: external I/O ports



B.10.1 Digital input

ESD and overvoltage protection is provided in the form of a 510R resistor and a TPSMF4L30A TVS as well as a 10 K resistor and a MSP3V3 TVS. A Schottky diode RB520S30T1G is used for reverse polarity protection. A 27 pF capacitor is used to filter RF noise.

A 10 nF capacitor is used for lower frequency noise and to charge the internal capacitor of the sample and to hold the circuit inside the processor's analog to digital converter.

B.10.2 Analog input

ESD and overvoltage protection is provided in the form of a 510R resistor and a TPSMF4L30A TVS as well as a 10K resistor and a MSP3V3 TVS. A Schottky diode RB520S30T1G is used for reverse polarity protection. A 27 pF capacitor is used to filter RF noise and a 10 nF capacitor is used for lower frequency noise.

A 680R resistor with the 10 K protection resistor provides a voltage dividing function to attenuate the input voltage. A 100 nF capacitor is used to charge the internal capacitor of the sample and to hold the circuit inside the processor's analog to digital converter.

B.10.3 Driver output

An On Semiconductor NCV8403 (U2) is a self-protected low side driver that can drive an external relay. A TPSMF4L30A TVS is used for overvoltage protection and a 27 pF is used as a filter for RF frequencies. A transistor circuit is used to ensure that the gate voltage is high enough.

B.11 Firmware

The goal of the firmware is to give the user an understanding of flash/RAM usage and to demonstrate the typical power usage of the blueprint board.

B.11.1 Toolchain requirements

The firmware is written in C and the Keil toolchain is used.

B.11.2 Firmware framework description

The firmware is based on the STM32 HAL libraries. Freertos is used as the operating system. All drivers to peripherals are implemented to at least the state where the peripheral can be put in low power mode.

B.11.3 Firmware application description

The firmware initializes the hardware, allows the cellular module to log on to the cellular network and then put the hardware in low power mode. Upon receiving a mobile-terminating SMS message, a Google Earth link with the current unit location will be sent to the mobile number from which the SMS was received.

B.11.4 Accelerometer

On boot the unit will initialize the accelerometer with configuration to monitor for motion. Once motion is detected it will wake the MCU.

B.11.5 BLE

The ANNA module will be configured to use SSP (Just works) to accept incoming connections. A u-blox SPS instance will be created, onto which information can be transparently published over the air (BLE).

Once configured, the ANNA will be put into a low power mode and will be woken up when motion is detected via the accelerometer.

B.11.6 Power circuitry

When 12 V is detected on the power input, the unit will start to charge the battery.

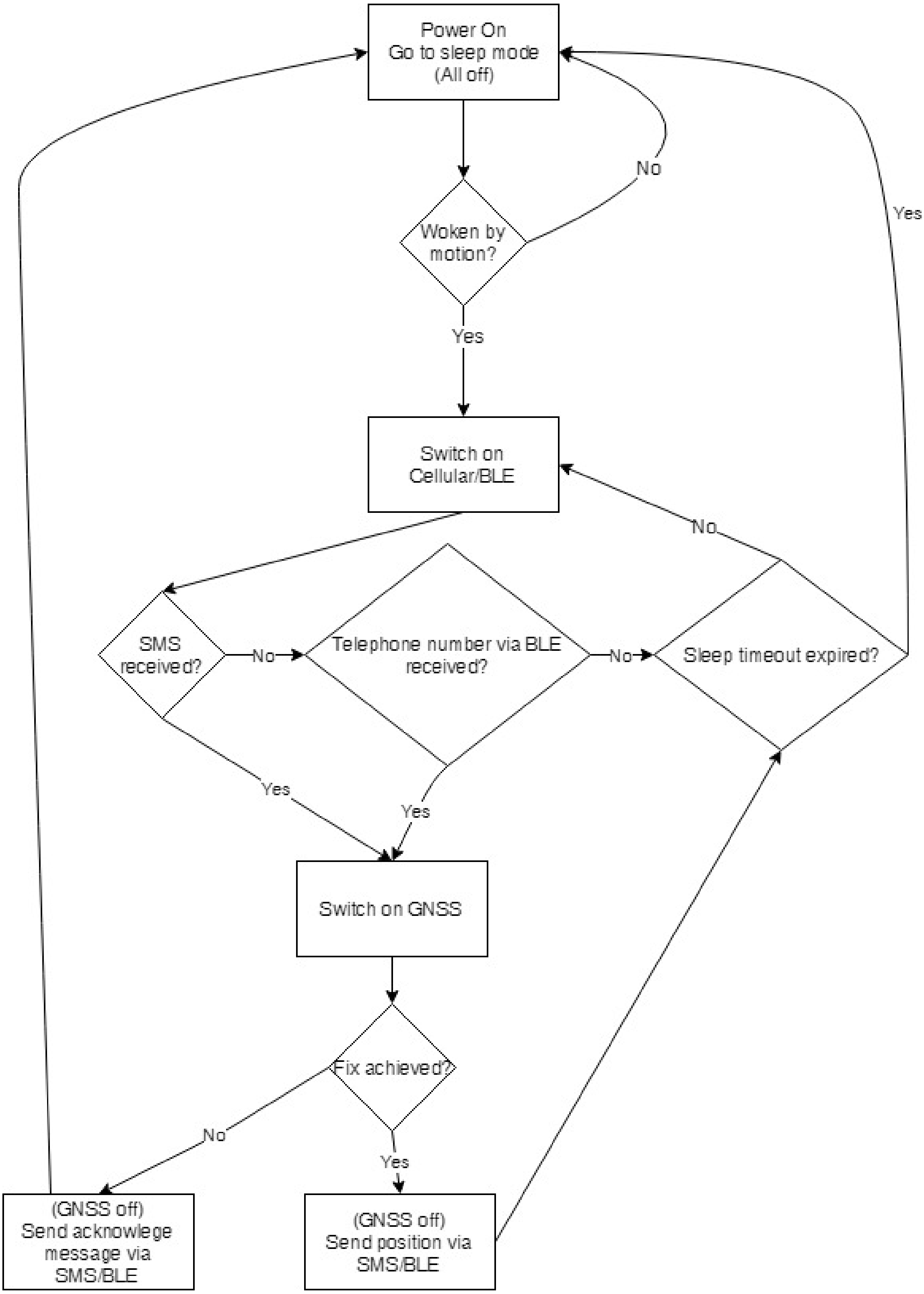


Figure 8: Firmware flow diagram

Related documents

[1] SARA-G450 System integration manual, doc. no. UBX-18006165
[2] SARA-R4 System integration manual, doc. no. UBX-16029218
[3] EVA-M8_Hardware integration manual, doc no. UBX 16010593
[4] EVA-M8E Hardware integration manual, doc no. UBX-15028542
[5] ANNA-B112 System integration manual, doc. no. UBX-18009821
[6] u-blox AT Commands manual, doc. no. UBX-13002752
[7] u-blox Package information guide, doc. no. 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	19-Mar-2020	alel	Initial release
R02	27-Mar-2020	alel	Fine tuning before public release

Contact

For complete contact information, visit us at www.u-blox.com.

u-blox Offices

North, Central and South America

u-blox America, Inc.

Phone: +1 703 483 3180
E-mail: info_us@u-blox.com

Regional Office West Coast:

Phone: +1 408 573 3640
E-mail: info_us@u-blox.com

Technical Support:

Phone: +1 703 483 3185
E-mail: support@u-blox.com

Headquarters
Europe, Middle East, Africa

u-blox AG

Phone: +41 44 722 74 44
E-mail: info@u-blox.com
Support: support@u-blox.com

Asia, Australia, Pacific

u-blox Singapore Pte. Ltd.

Phone: +65 6734 3811
E-mail: info_ap@u-blox.com
Support: support_ap@u-blox.com

Regional Office Australia:

Phone: +61 2 8448 2016
E-mail: info_anz@u-blox.com
Support: support_ap@u-blox.com

Regional Office China (Beijing):

Phone: +86 10 68 133 545
E-mail: info_cn@u-blox.com
Support: support_cn@u-blox.com

Regional Office China (Chongqing):

Phone: +86 23 6815 1588
E-mail: info_cn@u-blox.com
Support: support_cn@u-blox.com

Regional Office China (Shanghai):

Phone: +86 21 6090 4832
E-mail: info_cn@u-blox.com
Support: support_cn@u-blox.com

Regional Office China (Shenzhen):

Phone: +86 755 8627 1083
E-mail: info_cn@u-blox.com
Support: support_cn@u-blox.com

Regional Office India:

Phone: +91 80 405 092 00
E-mail: info_in@u-blox.com
Support: support_in@u-blox.com

Regional Office Japan (Osaka):

Phone: +81 6 6941 3660
E-mail: info_jp@u-blox.com
Support: support_jp@u-blox.com

Regional Office Japan (Tokyo):

Phone: +81 3 5775 3850
E-mail: info_jp@u-blox.com
Support: support_jp@u-blox.com

Regional Office Korea:

Phone: +82 2 542 0861
E-mail: info_kr@u-blox.com
Support: support_kr@u-blox.com

Regional Office Taiwan:

Phone: +886 2 2657 1090
E-mail: info_tw@u-blox.com
Support: support_tw@u-blox.com