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SIGFOX ALARM DEVICE

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SIGFOX HÄLYTYSLAITE

Nykyaikaiset liikenteenohjausjärjestelmät ovat yleensä liitetty valvontakeskuksiin internetin tai matkapuhelinverkon välityksellä. Käytössä on myös vanhempia ohjausjärjestelmiä, joissa ei ole etäyhteyttä, tai sitä ei ole hankintavaiheessa valittu toimitukseen. Ohjausjärjestelmien alkuperäisten laitevalmistajien tarjoamat etäyhteystoiminnot ovat erittäin kalliita, joten halvemmille etäyhteyksille, jotka voidaan integroida olemassa oleviin ohjausjärjestelmiin ja valvontakeskuksiin, on selkeä tarve.

Opinnäytetyön tarkoituksena oli valita yksinkertaisen hälytystiedon välittämiseen soveltuva verkkoteknologia, rakentaa pilottilaite ja testata laite asiakkaan järjestelmässä. Onnistuneen pilottivaiheen jälkeen oli tarkoitus kehittää lopputuote asiakkaan tarpeisiin. Tärkeimpänä tavoitteena oli kustannustehokkuus. Pitkistä viivytyksistä johtuen tämä työ rajattiin päättyväksi räätälöidyn modemin kehitykseen. Opinnäytetyön toimeksiantaja on RCP Software Oy.

Projekti aloitettiin palaverilla toimeksiantajan ja asiakkaan kanssa, käymällä läpi asiakkaan vaatimukset ja määrittelemällä projektille karkea aikataulu. Sen jälkeen valittiin käytettävä verkkoteknologia. Siirrettävä datamäärä on pieni ja laitteet ovat kiinteästi asennettu tiettyyn paikkaan. Muutamia vaihtoehtoja vertailtiin (Sigfox, LoRa, NB-IoT ja GSM/LTE) ja Sigfox teknologia valittiin, koska se täytti edellämainitut vaatimukset suhteellisen pienillä kustannuksilla.

Tarvittavat modulit, komponentit ja sopiva laitekotelo tilattiin pilottilaitetta varten. Kun kaikki osat oli toimitettu, pilottilaite rakennettiin valmiiksi parissa päivässä. RCP Software Oy kehitti laitteeseen ohjelmiston. Lisäksi kehitettiin mobiilisovellus ja pilvipalvelu konfiguroitiin hälytystiedon reitittämiseksi mobiilisovellukseen. Järjestelmän elektroniikan ja ohjelmistojen sekä pilvipalvelun testaamisen jälkeen laite asennettiin ja integroitiin asiakkaan järjestelmään.

Pilottilaite toimi hyvin ja hälytystieto välittyi luotettavasti mobiilisovellukseen. Mobiilisovellus perustuu karttanäkymään, jossa laitteiden sijainti ja hälytysten tilanne näkyvät reaaliajassa. Projektin aikana pilottilaitetta testattiin myös erilaisten hälytystietojen välityksessä, ja näissäkin tapauksissa todettiin, että järjestelmä on erittäin toimiva, luotettava ja edullinen.

Räätälöity Sigfox modemi perustui ON Semiconductor:in AX-SFEU-API järjestelmäpiiriin. Piirilevystä tehtiin yhteensopiva Arduino Nano:n kanssa, joten modulin voi tarvittaessa kytkeä suoraan Arduino Nano:n piikkirimoihin. Modemin ohjaus ja pakettien lähetys tapahtuu UART-väylän kautta AT-komennoilla. Järjestelmäpiirille voidaan kehittää myös oma ohjelmisto, joka tallennetaan piirin flash-muistille. Tällöin modulia voi käyttää itsenäisesti, eikä ns. isäntäprosessoria tarvita.

Opinnäytetyön tavoitteet täyttyivät hyvin ja asiakas oli tyytyväinen hälytysjärjestelmän toimintaan ja kokonaiskustannuksiin. Sigfox verkon toiminnassa oli alkuvaiheessa joitakin ongelmia, mutta ne olivat operaattorista johtuvia, koska jotkut tukiasemat olivat satunnaisesti poissa käytöstä. Vuoden 2018 lopussa luotettavuus ja verkon peitto Suomessa olivat paljon parempia. Kaupallinen lopputuote voidaan kehittää myöhemmin asiakkaan määrittelemän aikataulun mukaisesti.

ASIASANAT:

Sigfox, AX-SFEU-API, SoC, IoT

BACHELOR'S THESIS | ABSTRACT
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SIGFOX ALARM DEVICE

Modern traffic controllers are usually connected to supervision centers via the internet or mobile phone network. Also older traffic controllers are used, which don't have remote access, or remote access was not selected to the system delivery. Original equipment manufacturers can offer remote access installations, but they are very expensive, so cheaper solutions which can be integrated to current traffic controllers and supervision centers, are clearly needed.

The purpose of this thesis was to select the suitable network technology for simple alarm message delivery, build a pilot device and test it in customer's system. After a successful pilot phase the end product was planned to be developed for customer's needs. The main objective was cost. Due to long delays, this thesis was limited to ending to development of custom modem. Commissioner of this thesis is RCP Software Oy.

The project was started with a meeting together with commissioner and customer. Requirements were reviewed and a draft schedule defined. Used network technology was selected next. The amount of data to be transferred is small and devices are mounted in a fixed location. A couple of options were compared (Sigfox, LoRa, NB-IoT and GSM/LTE). Sigfox technology was selected, because it fulfilled the above requests with relatively low costs.

Needed modules, components and suitable enclosure were ordered for pilot device. When all the parts were delivered, pilot device was built in a couple of days. RCP Software Oy developed the software to the device. A mobile application was developed too and cloud service was configured to forward alarm information to the mobile application. After the testing of system's electronics, software and cloud service, the device was assembled and integrated to customer's system.

Pilot device was working well and alarm information was reliably transmitted to the mobile application. Mobile application is based on map view, where location of the devices and alarm statuses were viewed in real time. Pilot device was also tested with different alarm information during the project, and in those cases it was noticed that the system is functional, reliable and affordable.

Custom Sigfox modem was based on ON Semiconductor AX-SFEU-API system on chip. PCB was designed to be Arduino Nano compatible, so it can be connected directly to Arduino Nano pin headers. Modem control and packet transmissions are done via UART bus with AT commands. System on Chip can be programmed and the code will be stored to the flash memory. Then the module can be used independently without host controller.

The objectives of this thesis were fulfilled well and the customer was satisfied with the functionality and total costs of the alarm system. In the early phase there were some problems with the Sigfox network functionality, but they were operator related, because some base stations were occasionally offline. At the end of year 2018 network reliability and coverage in Finland were much better. Commercial end product can be developed later according to customer's schedule.

KEYWORDS:

Sigfox, AX-SFEU-API, SoC, IoT

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LIST OF ABBREVIATIONS (OR) SYMBOLS

Abbreviation	**Explanation of abbreviation (Source)**
API	Application Programming Interface
AT	ATtention
BPSK	Binary Phase Shift Keying
DC	Direct Current
EIRP	Effective Isotopic Radiated Power
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FCS	Frame Check Sequence
GFSK	Gaussin Frequency Shift Keying
GND	Ground
GPIO	General Purpose Input/Output
GSM	Global System for Mobile Communications
HTTP	HyperText Transfer Protocol
HTTPS	HyperText Transfer Protocol Secure
IoT	Internet of Things
IPv6	Internet Protocol version 6
ISM	Industrial, Scientific and Medical
I2C	Inter-Integrated Circuit
LDO	Low-Dropout
LEP	LTN End Point
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LTE	Long Term Evolution
LTN	Low Throughput Network

M2M	Machine to Machine
MQTT	Message Queue Telemetry Transport
NB-IoT	Narrow Band Internet of Things
OEM	Original Equipment Manufacturer
RH	Relative Humidity
SNMP	Simple Network Management Protocol
SoC	System on Chip
UART	Universal Asynchronous Receiver/Transmitter
UNB	Ultra Narrow Band

1 INTRODUCTION

Commissioner's customer needs a cheap alarm system to send malfunction and alarm data from the field devices to their system and mobile phones. Older devices are not equipped with GSM or ethernet communication feature, and it is very expensive to add OEM communication system to those devices. So cheaper solution which can be integrated to existing old devices and systems is requested.

It is agreed to start the project with a pilot device which can be assembled to customer's system. Alarm information is needed to be routed only to the mobile phone application.

Following hardware requirements and enablers are fixed for pilot device:

- In pilot phase only one alarm signal is used
- Alarm signal is normally low (ground) and when alarm is activated, signal is pulled up to 12V or 24V DC
- 230V AC is available from the customer's device
- 35mm DIN rail is available for mounting the device
- All the customer's device electronics is inside a metal box
- Environmental conditions: Outside, but quite stable temperature and humidity.

In second phase after pilot testing the final modem/version is selected after comparison of available solutions (ready and certified modules, SoC's), and the whole alarm device is specified, including hardware, software and mechanical requirements.

Several alarm signals and environmental information are requested to be included in the alarm message. If the modem has temperature sensor, it may be used. Otherwise additional temperature and humidity sensor has to be added to the hardware. All the information has to be fitted to the message which can be used in different networks.

With the final alarm device the messages are sent to the customer's monitoring system and also to the mobile phone application.

This thesis is focused on selecting the suitable network technology, pilot device building & testing and custom modem hardware development.

2 SIGFOX

Sigfox is a French company rolling out a cellular type network infrastructure mainly for IoT and M2M purposes. Sigfox network provides a technology to connect a variety of applications (alternatives e.g. sensors, asset tracking or alarm systems etc.) where alternatives like GSM/3G/4G are too expensive or alternatives consume too much power. Sigfox network is a global wireless network system utilizing ETSI's specification for Low Throughput Networks (LTN) and Ultra Narrow-Band (UNB) modulation.

The Sigfox radio link uses unlicensed ISM radio bands listed in Table 1.

Table 1. Sigfox radio bands

Region	**Frequency**	**Regulation**
Europe, Middle East	868MHz	ETSI 300-220
North America	902MHz	FCC part 15
South America, Australia, New Zeeland	920MHz	ANATEL 506, AS/NZS 4268

Nodes can send short messages (up to 12 bytes) to the network. Messages received by the network become available via web backend (backend.sigfox.com). Maximum amount of uplink messages is 140 per day. The network can send replies when a message is received (up to 8 bytes). However, the downlink cannot be initiated by the network. Downlink message is possible only after uplink message. Maximum amount of downlink messages is 4 per day. [1]

Sigfox currently has a tiered option plan for how many uplink transmissions are allocated per day, as well as how many downlink transmissions can be sent from the main network station to the device. The amount of messages are listed in *Table 2*.

Table 2. Sigfox subscriptions and amount of messages

Level	Max uplink messages	Max downlink messages
Platinum	140	4
Gold	100	2
Silver	50	1
One	2	0

Sigfox technology is world wide and one subscription works in different countries without any actions or roaming fees. [1]

Network operator in Finland is Connected Finland, www.connectedfinland.fi. Company is running nationwide Sigfox-networks in Finland and Estonia and offers also devices, projects and IoT-platform with sub-brand Connected Solutions. Currently (status in December 2018) Sigfox network is present in 50 countries. Turku area is well covered (Picture 1). Total 85% of Finnish population is covered. [2]

Picture 1. Sigfox network coverage in Finland (end of year 2018)

2.1 Sigfox protocol

Following *Figure 1* describes the simple protocol stack of Sigfox wireless system.

Application layer
MAC layer
PHY layer
RF layer

Figure 1. Sigfox protocol stack

- RF layer takes care of frequency assignment and transmit/receiver power requirements at Sigfox end points and base stations.
- PHY layer takes care of preamble insertion (at transmit end) and removal (at receiver end). It uses BPSK modulation in the uplink and GFSK modulation in the downlink.
- MAC layer handles management of MAC messages. It prepares frames as per uplink and downlink formats defined in *Figure 2*. Sigfox system is mainly used for uplink transmissions. It can also be used for downlink transmissions using piggy backing concept.
- Application layer: Different applications are supported in this LTN technology. There are various interfaces/protocols between WAN (i.e. cloud) and servers to support the same e.g. SNMP, HTTP, MQTT, IPv6 etc.
  [3]

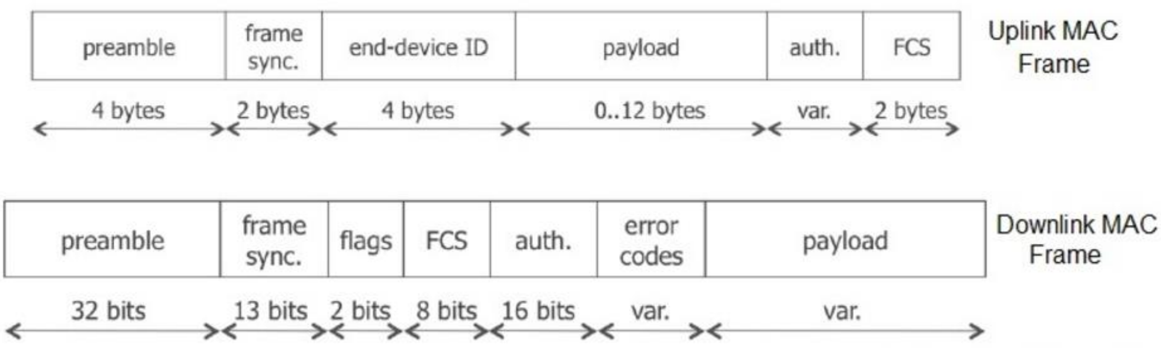


Figure 2. Sigfox frame structure [4]

The *Figure 2* depicts Sigfox frame structure. It structure both the uplink MAC frame and downlink MAC frame. As shown uplink frame consists of preamble, frame sync field, end device ID, payload, authentication field and FCS field. As shonw downlink frame consists of preamble, frame sync, flags, FCS, auth., error codes and payload. [4]

Preamble is a predefined pattern of symbols used for synchronization purpose. Using this pattern, various impairments are estimated at the receiver and corrected accordingly. This has become possible since a copy of this constant pattern is known at the receiver. Frame sync field carry frame type which differentiates different MAC frames. End device ID (32 bits in size) is used as unique identifier for each of the Sigfox end devices (or LEPs). FCS field is used for error detection. [4]

2.2 Sigfox cloud service

Sigfox routes all data from the devices through the Sigfox Cloud. The Sigfox Cloud then provides backend API and standards-based HTTPS callbacks so that server application can receive and send data from the devices. [5]

2.3 Pre-certification

To communicate on the Sigfox network, Sigfox Network Credentials need to be incorporated into the device. These credentials authenticate the device and ensure secure data transmission. For device makers who build their own modem, the outcome of the development phase is a final device that must pass the Sigfox Verified certification. To qualify for the Sigfox Ready certification, the device must then have its RF radiated performance validated. In order to allow device makers who want to perform live demonstration of their devices on the Sigfox network, Sigfox can provide Sigfox Network Credentials prior to the Sigfox Verified certification, under the following conditions:

- Device makers can ask for up to 20 Sigfox network credentials per device.
- Device-making organizations can ask for up to 100 Sigfox network credentials overall.

- These credentials allow device makers to register devices on Sigfox backend as prototypes only. Additional credentials are provided to registered devices on the Sigfox backend as Sigfox Ready devices.

When a device maker is building an own modem, it is maker's responsibility to flash the credentials into the device's memory. [6]

2.4 Certification

Every Sigfox device has to be certified before use (called Sigfox Ready™ certification). Sigfox Ready™ certification refers to radiated tests to assess the radiation performances of an end product. These radiation tests allow a classification for each end product in uplink. Tests reflect the efficiency of radiated power emitted by the end product. If the end product is based on a Sigfox Verified™ module or Sigfox Verified™ reference design, conducted tests are skipped. The certification costs (valid year 2018) and efforts are listed in *Table 3.* [7]

Table 3. Sigfox certification costs and efforts

RF component	**SIGFOX Ready certification cost for end product**	**Certification effort**
Compatible transceiver	10k€	• Full transceiver certification • End product certification
Compatible transceiver with reference design	7k€	• Transceiver delta certification • End product certification
Certified SoC	4.8k€	• Transceiver delta certification • End product certification
Certified SoC with reference design	2.5k€	• End product certification
SIGFOX ready module	2.5k€	• End product certification

2.5 Sigfox radio configuration and classes

Global operations are split into three geographical zones (listed in *Table 4*). Each zone has a different set of parameters which clearly define the device hardware implementation: mainly frequency range, maximum radiated power and radio front end specificities. Within a given Sigfox zone, local regulations may impose specific rules to operate in the unlicensed bands. [8]

Table 4. Sigfox zones

Zone	Region	Radio Configuration
1	Europe, Middle East	RC1
2	Americas, APAC1	RC2, RC4
3	APAC2 (Japan, South Korea)	RC3a, RC3c, RC5

Sigfox RC (Radio Configuration) defines the radio parameters in which the device operates: Sigfox operating frequencies, output power, spectrum access mechanism, throughput and coexistence with other radio technologies. Each radio configuration includes 4 uplink classes. RC1 (Europe, Middle East) classes are listed in *Table 5*. [8]

Table 5. RC1 uplink classes

Class	EIRP dBm
0	16 > EIRP ≥ 12
1	12 > EIRP ≥ 7
2	7 > EIRP ≥ 2
3	2 > EIRP

Sigfox's high limit EIRP recommendation is included in each column although regulation sometimes allows more radiated power than the Sigfox recommendation. [8]

Sigfox's recommendation is set to comply with the Sigfox technological approach of:

- Low current consumption
- Balanced link budget between uplink and downlink communication

3 MODEM SELECTION

There are several options to connect an alarm device to the network and cloud. GSM/LTE, NB-IoT, LoRa and Sigfox networks are considered in this case. The most important criteria to the customer is total costs, including device costs, data transfer costs, service costs and development costs.

The amount of data in alarm information case is really low, so mobile phone network (GSM/LTE) is too fast and powerful. The GSM/LTE hardware is also more complex and expensive. In battery powered cases the current consumption is pretty high, specially with 2G network. NB-IoT is using 4G/LTE networks, but it requires software updates to base stations. GSMA, the organization representing the interests of NB-IoT, LTE and other mobile networks claims that 40 countries are expected to roll out NB-IoT networks in the near future. At the moment at least finnish operators are not eager to update their networks to NB-IoT compatible. Apparently cells are updated according on request.

Because of those reasons Low Power Wide Area Networks (LPWAN) LoRa and Sigfox are considered more carefully.

LoRa is a radio network targeted to IoT solutions and has better link budget than other comparable radio technologies. But in order to connect to LoRaWAN networks or use LoRa at all, you need to deploy your own network gateway. LoRa is a good option if bidirectionality is needed, for example command and control functionality, because of symmetric link. LoRa hardware is cheaper than NB-IoT, but more expensive than Sigfox.

Sigfox is the most basic of these technologies. Sigfox device consumes very low amount of power. It works well for simple devices that transmit data infrequently, because it sends very small amounts of data and very slowly. It has bidirectional functionality, but it’s capacity to downlink is constrained and there is less link budget for downlink than uplink. This is because the receiver sensitivity on the end device is not as good as on the base station.

Due to requirements of the alarm device (cost, low amount of data, no mobility), Sigfox is the most suitable option. Network coverage in South-west Finland is also sufficient, so development is decided to be started with Sigfox modem.

4 PILOT DEVICE

A pilot device is built to start customer and system testing. It supports only one alarm signal input (General error/Yellow light). Target is to build the pilot device fast and with decent costs. Alarm information is routed to mobile application via Sigfox and RCPSW backend.

4.1 Pilot device hardware

Pilot device hardware system block diagram is described in *Figure 3.* Arduino Nano is used to read the alarm signal from customer's system and control the Sigfox modem with UART interface. F143-MINI-DVK-SMA Sigfox modem is controlled with AT commands using UART interface. Alarm input is connected to Arduino Nano D4 digital I/O pin. Internal pull-up is activated, and when alarm signal is active, it drives the pin to GND. MIC2920A is used to regulate the alarm signal to 5V, because the actual alarm signal level from customer's device is unknown (OEM is not willing to confirm it). N4078-2C-5V-0.2 relay is used to select/change the signal polarity.

The pilot device is getting +5V DC power from USB charger. Rest of the hardware is powered with Arduino Nano +3.3V and +5V power outputs.

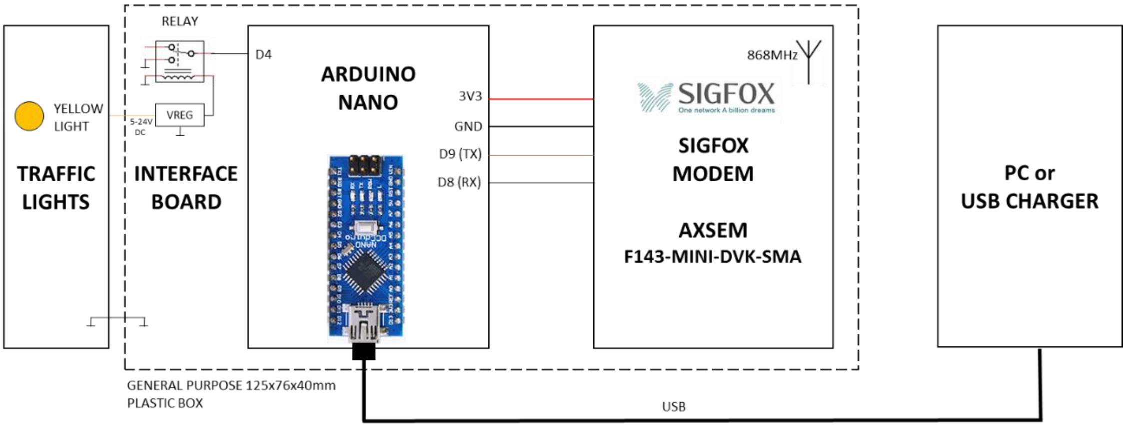


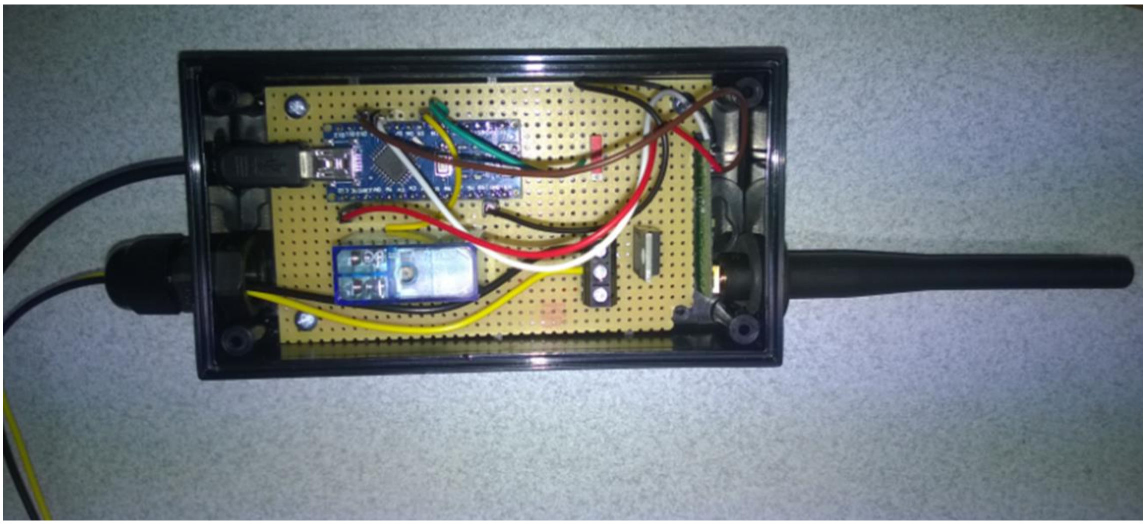
Figure 3. Pilot device hardware block diagram

Pilot device part list:

- ON Semiconductor F143-MINI-A-MOD-GEVB Sigfox transceiver module. (Part of DVK-SFEU-1-GEVK development kit)
- 868MHz antenna (50ohm)
- Arduino Nano
- MIC2920A 5V regulator
- 10uF / 35V capacitors
- N4078-2C-5V-0.2 relay
- 3-pin screw terminal connector
- PWB (breadboard)
- USB charger
- General purpose plastic box
- DIN rail mounting clip
- 3 grommets for the cables and antenna
- Connection cables

All the parts and wires are assembled and soldered to breadboard. Sigfox transceiver module is located on the top of the box. Antenna can be screwed directly to module's SMA connector. A hole is drilled to get antenna out of the box. There are two holes on the bottom of the box to get USB charger and signal + ground wires inside the box.

Picture about the pilot device without cover part can be seen in *Picture 2*.



Picture 2. Pilot device

Pilot device is assembled to Kaarina, roads’ 110 and 180 crossroads traffic lights (*Picture 3*). Traffic lights system is controlled with Swarco ITC-2 traffic controller. Due to metal cabinet, an external antenna is needed to get good enough RF performance.

Picture 3. Pilot device connected to Swarco ITC-2

4.2 Pilot device alarm system

Pilot device alarm system is dercribed in *Figure 4.* Alarm device is sending the message thru Sigfox network to Sigfox cloud. When a message is received by Sigfox cloud, the callback sends it over to RCPSW cloud. Callbacks are HTTP requests which are one way only, as they are generated by Sigfox server and sent to RCPSW server instantly upon receipt of a message from the alarm device. Customer/end user gets the message to the mobile application from RCPSW cloud. Device location and alarm status are shown in mobile application's map view.

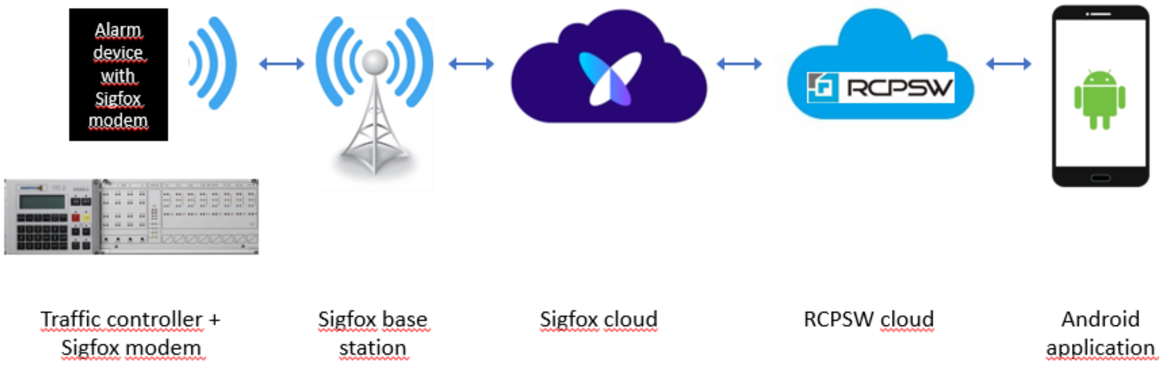


Figure 4. Pilot device alarm system

5 CUSTOM SIGFOX MODEM

Custom Sigfox module is developed for the customer end product. *Table 6* represents the compared commercially available Sigfox modules and one SoC.

Table 6. Sigfox SoC and module options

Manufacturer	Type code	SoC/Module	Size (mm)	RF power
ON Semiconductor	AX-SFEU-API	SoC	7.0 x 5.0	14dBm
ON Semiconductor	AX-SFEU-MINISTAMP	Module	22.0 x 18.2	14dBm
Wisol	SFM10R1	Module	15.0 x 13.0	14dBm
TD next	TD1207	Module	25.4 x 12.7	16dBm
Lite-ON Technology	WSG303S	Module	22.5 x 16.5	14dBm

There is no need for WiFi, BLE or sensors (except temperature), so Sigfox only modules are taken into account. Main criterias for the selection are low cost, small form factor and high RF power. Based on cost and small size, ON Semiconductor AX-SFEU-API SoC is selected.

The one and only target for the custom Sigfox modem is RC1 uplink Class 0 (16 - 12dBm). RF path layout from application note is maintained as well as possible and same tuning components are used to get the best possible RF performance.

5.1 AX-SFEU-API SoC

ON Semiconductor AX−SFEU−API SoC (*Figure 5*) is a ultra−low power single chip solution for a node on the Sigfox network with both uplink and downlink functionality. AX-SFEU-API SoC is delivered without firmware. The Sigfox protocol library needs to be purchased. Firmware has to be programmed to the flash memory to transmit and receive data from the Sigfox network in Europe. [9]

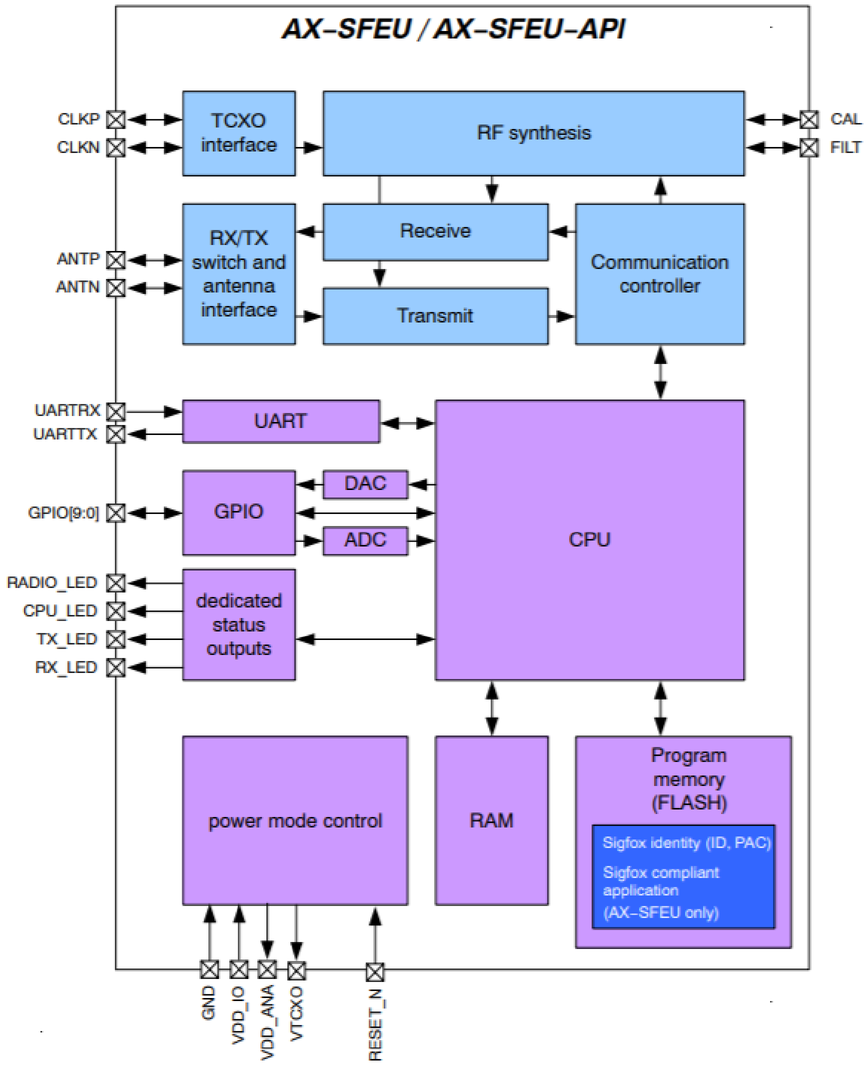


Figure 5. AX-SFEU-API block diagram [9]

AX-SFEU-API general features:

- QFN40 7.0mm x 5.0mm package
- Supply voltage range: 2.1 − 3.6 V
- Operating temperature range: −40°C to 85°C
- Internal temperature sensor
- Supply voltage measurements
- 10 GPIO pins
  - 4 GPIO pins with selectable voltage measure functionality, differential (1 V or 10 V range) or single ended (1 V range) with 10 bit resolution
  - 2 GPIO pins with selectable sigma delta DAC output functionality

- 2 GPIO pins with selectable output clock
- 3 GPIO pins selectable as SPI master interface
- Integrated RX/TX switching with differential antenna pins

The AX-SFEU-API variant is intended for customers wishing to write their own application software based on the AX−SF−LIB−1−GEVK library. [9]

5.2 AX-SFEU-API reference design

AX-SFEU-API reference design schematics *Figure 6* and layout *Figure 7* can be found from ON Semiconductor AX-SFEU-API datasheet [9] and application notes [10].

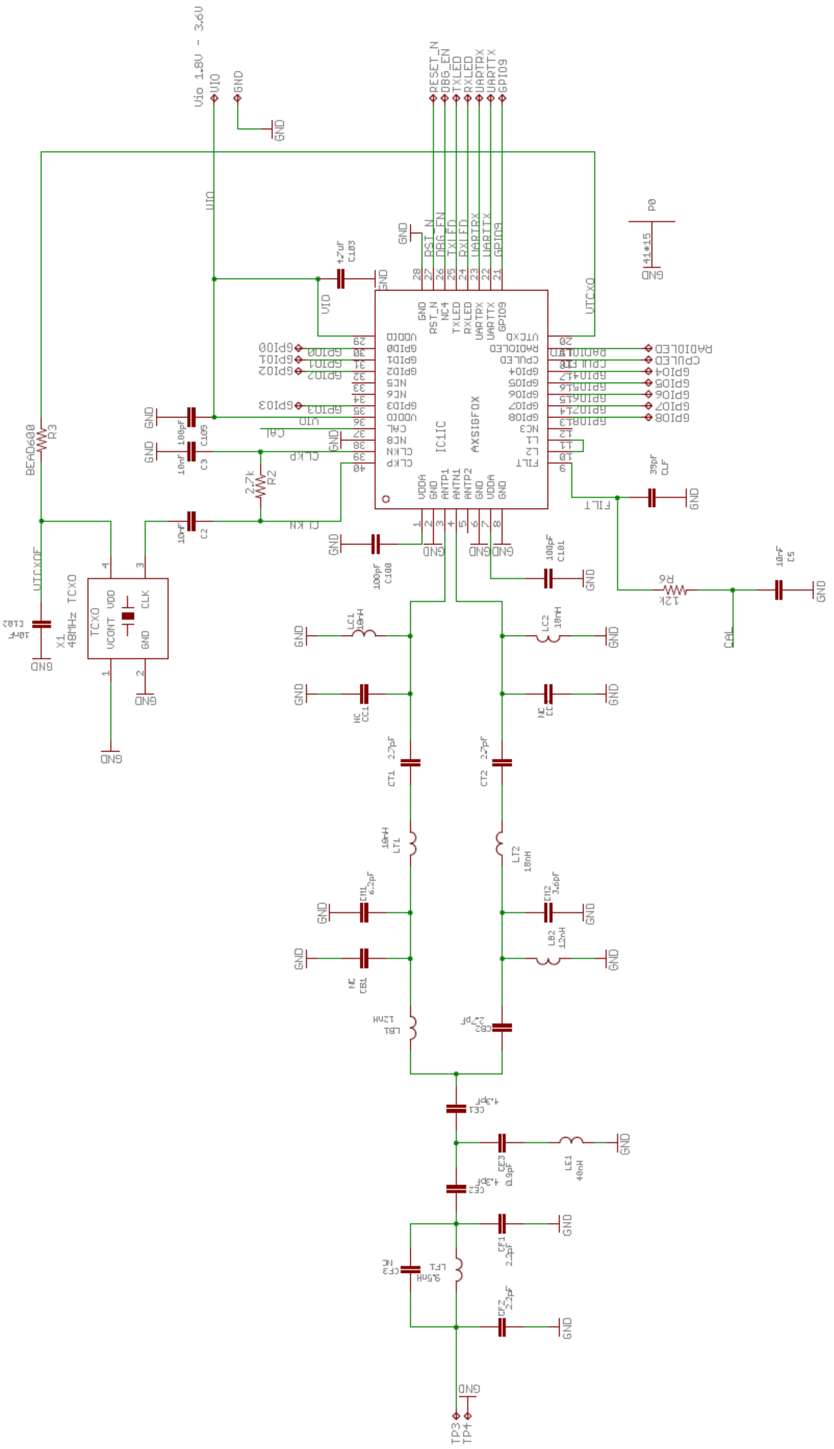


Figure 6. AX-SFEU-API reference schematics [9]

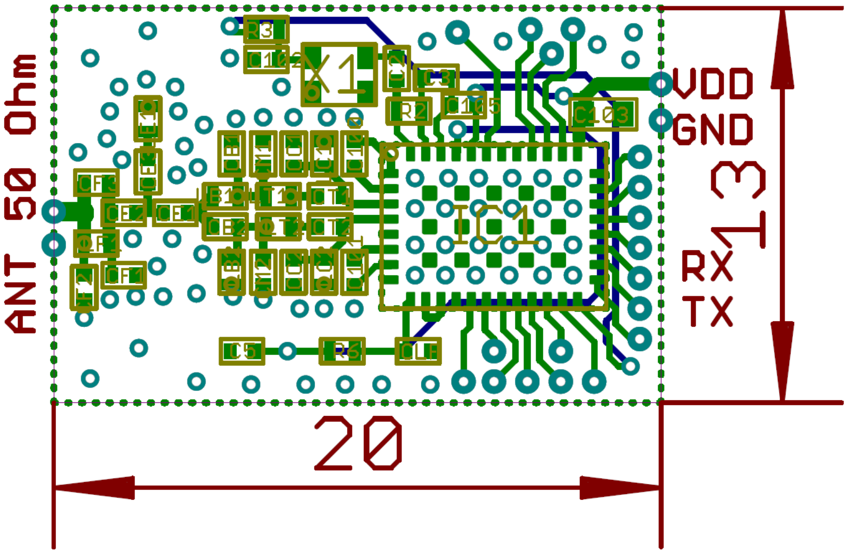


Figure 7. AX-SFEU-API reference layout [10]

5.3 Custom modem schematics

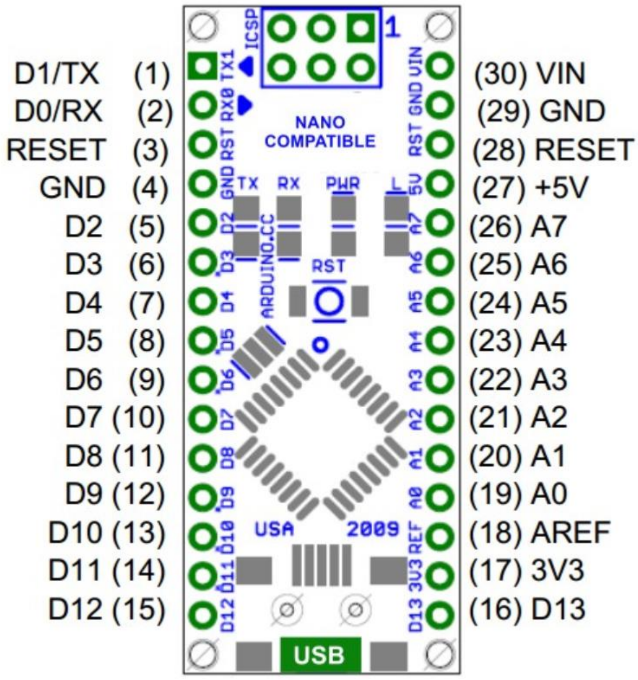
AX-SFEU-API reference schematics is copied to the custom modem design and following extra parts are added and connected:

- 2pcs 15-pin female headers for Arduino Nano interface
- LP2981 3.3V LDO regulator for AX-SFEU-API VDD_IO voltage
- 1u capacitors for LP2981
- 2x5-pin male header for GPIO interface
- 4pcs indicator LEDs
- Push button for reset
- 2x5-pin male header for flashing interface
- SMA connector for RF interface
- Test points to needed signals
- Mics pheripheral components

Final schematics is added to this thesis as Appendix 1.

5.4 Custom modem layout

Custom Sigfox module is designed to be Arduino Nano hardware/mechanically compatible, so it can be directly attached as Arduino Nano shield.



Picture 4. Arduino Nano layout [11]

Layout planning is started with inspecting the Arduino Nano layout (*Picture 4*). Custom modem PCB outline (43.175mm x 17.775mm) is almost the same as Arduino Nano outline. 2pcs of 15-pin female headers are placed according to Arduino Nano 15-pin male headers. AX-SFEU-API IC and pheripherals are placed between the 15-pin headers and the reference layout is followed as closely as possible. Programming interface pin header is placed on the bottom side of PCB. Extra 2x5-pin female header for GPIO interface, reset button, LEDs, regulator + pheripherals are placed on the top side. SMA connector is placed on the edge of the PCB to allow connecting antenna or antenna cable without touching neither the components nor the PCB. 4-layer PCB is needed to get all the signals routed without changing the reference layout too much.

Final layout and component placement are added to this thesis as Appendix 2.

5.5 Final custom modem

Final assembly (*Picture 5*) is done by Sorv-Elektro, Salo. All the needed PCB gerber files and manufacturing documents are delivered to Sorv-Elektro, and they are sourcing PCB, stencil and components and making the assembly work for 20pcs proto series.

Picture 5. Assembled custom modem

A quick visual inspection is done for assembled modules to see that there are right components assembled and to detect short cuts or open solder joints. Then they are powered up and flashed. After booting-up, a basic hardware testing is done for couple modules. VDD_IO voltage levels, 48MHz clock, 32kHz clock and UART signals are measured with oscilloscope. RF power is also measured with spectrum analyzer. Everything seem to be according to AX-SFEU-API specification.

6 CONCLUSION

In this thesis four different network technologies were studied, and the conclusion was that in this case Sigfox meets the customer's requirements best. As a result of this thesis a pilot alarm device was developed and tested in customer's system, and a custom Sigfox modem hardware was developed. The final alarm device specification is open and it will be defined after getting an offer request from the customer. For the final device an additional interface board will be developed, where custom Sigfox modem can be connected and all the needed external connectors are placed.

At the moment Sigfox certification is not applied for the custom modem, because the device can be added to Sigfox connectivity into development solutions. There is no need to apply for Sigfox certification when the solution is based on a Sigfox Verified™ module or reference design, and the device is not used to operate on Sigfox network for commercial purposes. Any development solution that is not based on a Sigfox Verified™ module or reference design must apply for the Sigfox Verified™ certification with conducted tests.

The pilot device has already been used in a couple of different systems sending alarm information and sensor data. It is very easy to modify the pilot device to be used in different systems and environments. External sensors can be connected with I2C bus. Mobile application can be used with minimal changes for different demonstration purposes.

Sigfox network is developed purely for IoT needs. It is very useful and competitive option for transferring small amounts of data. Data can be get from sensors e.g. temperature, relative humidity, ambient light, air pressure or as in this case, just simple alarm (On/Off) information. At the moment the network coverage may be limiting the usage of Sigfox, but operators are continuously expanding the network to new locations.

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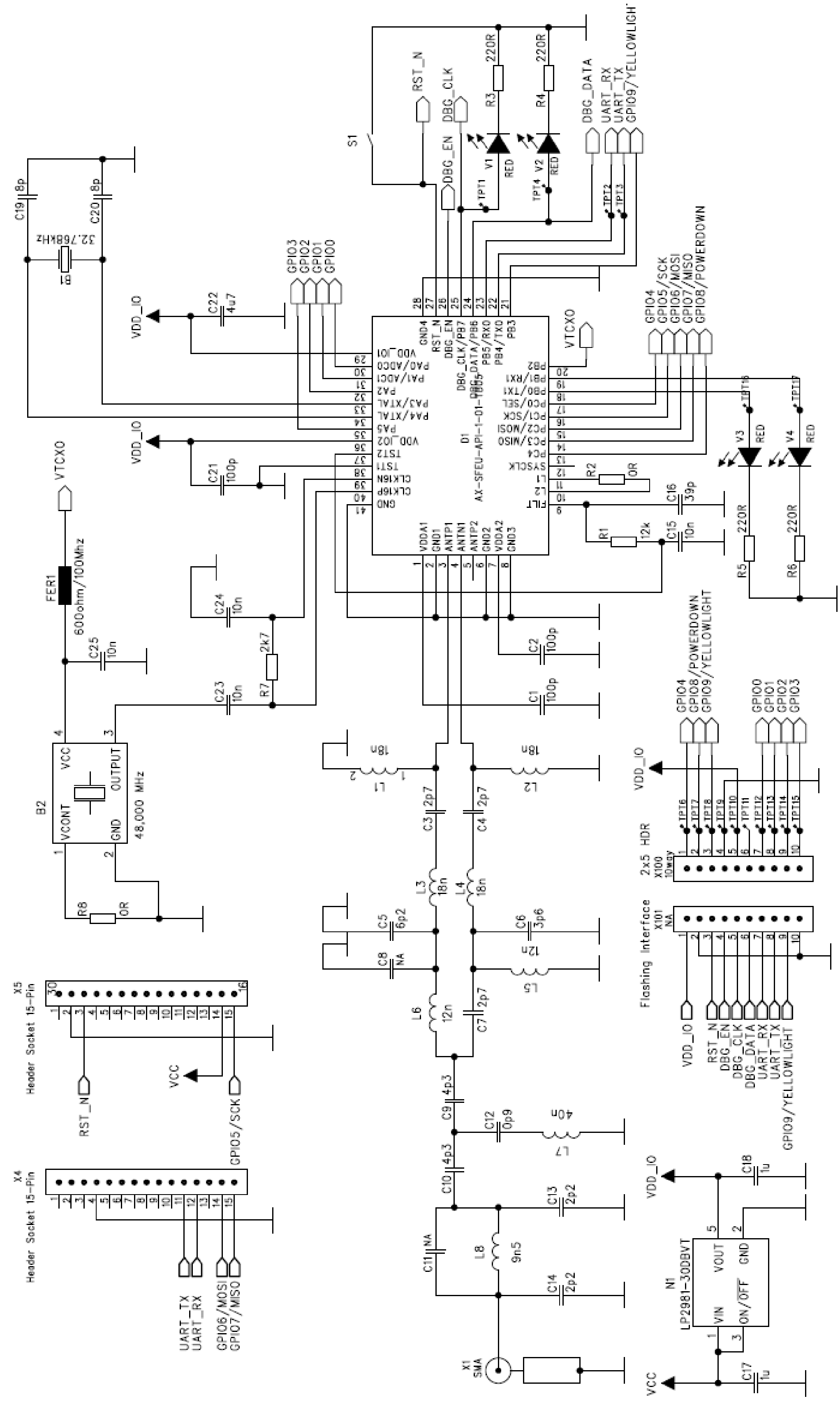
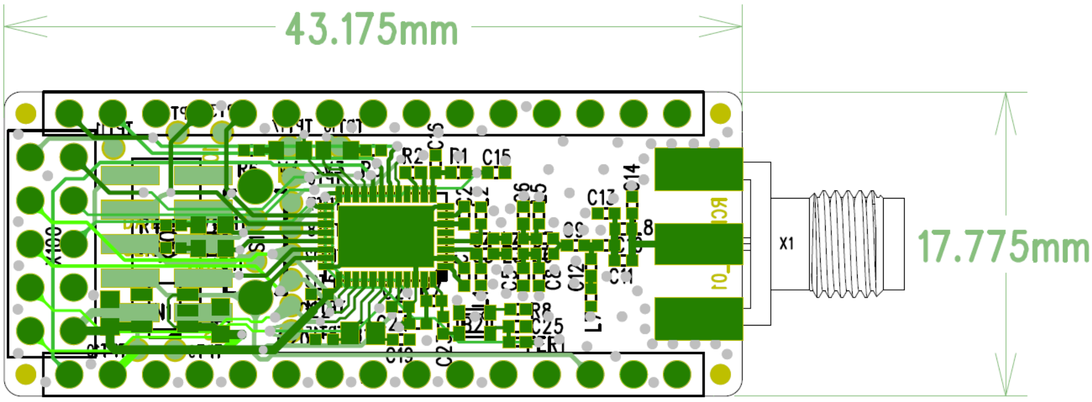
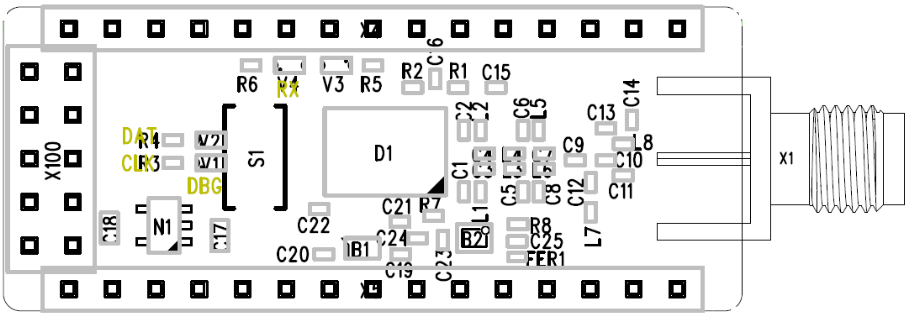
Appendix1: Custom modem schematics

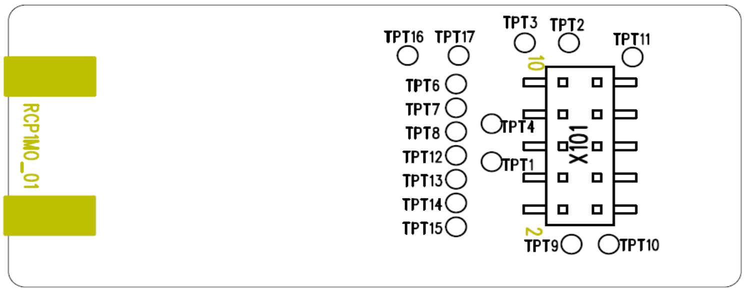


Appendix2: Custom modem layout and component placement

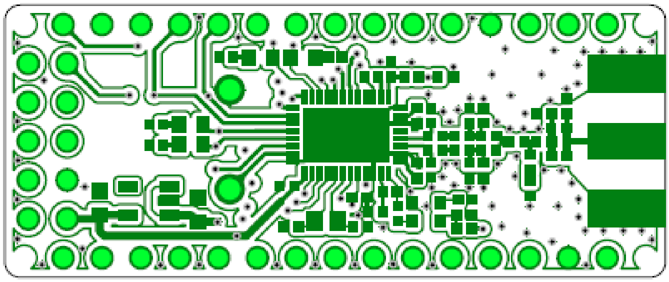




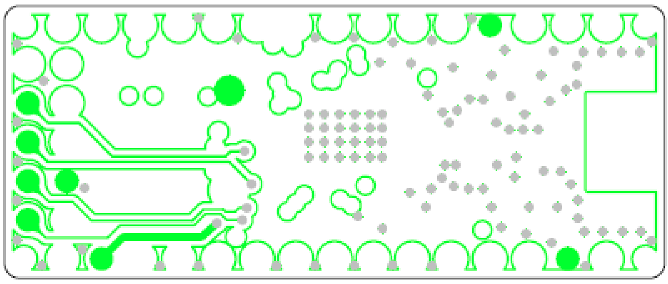
Component placement (Top side)



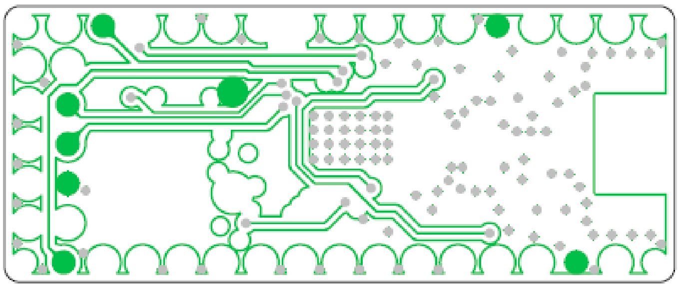
Component placement (Bottom side)



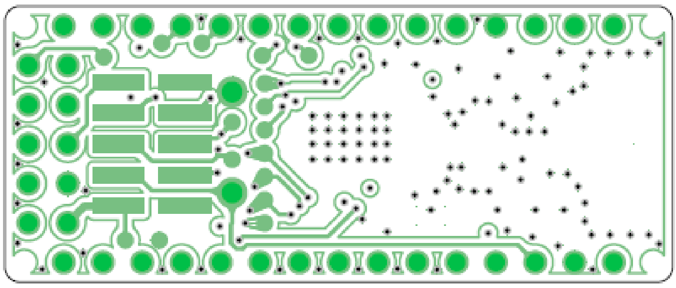
Layer 1



Layer 2



Layer 3



Layer 4