Application Note
Energy Harvesting Solution for NB-IoT Node

1. Overview

Energy Harvesting (EH) technology can be used for many types of wireless applications which can be for short range or long range purposes. Wireless communications that are cellular based, such as NB-IoT or LTE CAT/M, or LoRa, have higher power demands than non-cellular based protocols, like BLE and Zigbee. Even with such high power demand with cellular protocols, it is still possible to supply these modules to work autonomously.

Following is a reference design for an EH-based NB-IoT node. The node consists of 4 main blocks: Power, MCU, Sensor, and Wireless communication. The MCU sends proper AT commands to the NB-IoT module. To save energy as much as possible, the MCU is in sleep mode most of the time. It wakes up after a time interval, reads sensor data, and forwards the data to the NB-IoT module and then goes to sleep again. The power block is the EH-PMIC with its specific type of harvester; in this reference design PV is used. The EH-PMIC boosts the voltage enough to be able to charge a battery. The stored energy in the battery will be used later when there is no light to generate energy. Figure 1 shows the photo of the autonomous NB-IoT node.

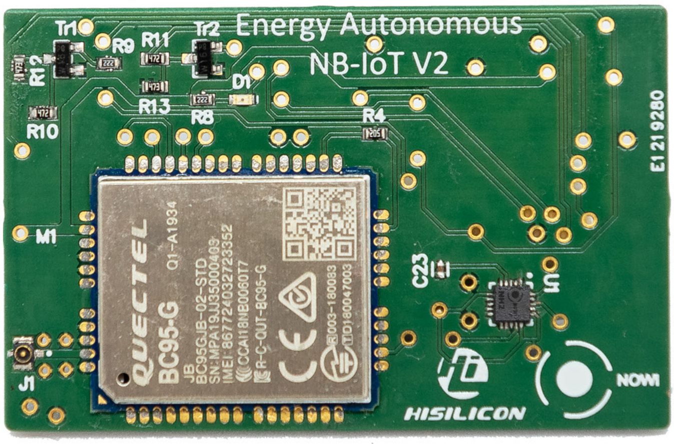


Figure 1: *Autonomous NB-IoT node.*

2. Design

In the Appendices A and B, the NB-IoT node design is presented in both systematic and schematic level. The top level design consists of different blocks. We will analyze each block in the coming sections.

2.1. Top Level

Each block of the system is represented in a block starting with *Mid*. The blocks have input and output pins to connect to their previous and next blocks. We will go through all the blocks explaining what each one does. The top level design is depicted in Appendix A. The first block is *Mid1*, which is the harvester. As mentioned before, this design uses PV as the harvester. Depending on the size limitations and required power, a PV can be selected. The output of PV is connected to the input of EH-PMIC.

Mid2, which is EH-PMIC, has an input named DC_IN. This pin is connected to the output of the harvester. EH-PMIC boosts this voltage and then the boosted voltage is on the VBAT pin. Battery is connected to this pin to be charged (The block of battery is not shown in this top-level design).

Since the voltage charged in the battery can go beyond the operating voltage of MCU and sensors, a LDO is being used to regulate the VBAT to 3.3V to offer fixed and clean power. *Mid3* refers to an LDO.

Mid4 is the microcontroller, which controls the whole system. The MCU reads the sensor data and forwards it to the NB-IoT Module. At the same time, MCU sends required AT-commands to the module to prepare for the sensor data transmission. The MCU needs to be programmed to stay in sleep mode and wake up when it is required to save harvested energy.

Mid5 is a modular block which has pin compatibility with PIC mikroBUS protocol™. In HW level, female pins are used to offer flexibility and give the ability to plug different types of sensors to the node. You can refer to the documentation of this protocole to understand better the function of each pin[1].

The last block is the wireless communication module (NB-IoT) represented by *Mid6*. The pins Rx and Tx are used to communicate with MCU using serial communication. The RI pin is a Ring Indicator, which sends interruptions when a message is received or data is transmitted. RSTPulse is the pin to RESET the module, which is connected to one of the GPIOs of MCU. VBAT is also the supply pin of the module.

2.2. Schematic Level

The NB-IoT node design is also explained at a schematic level (Appendix B). Like the top-level design, schematic is also divided into different sections. Below each section is described in details.

2.2.1. Power

The power section consists of two blocks: EH-PMIC and 3V3 LDO. EH-PMIC boosts the voltage received from the harvester to be able to charge a battery. The LDO is used to provide a clean fixed voltage for the MCU.

2.2.2. Energy Harvesting PMIC

The circuitry of Nowi energy harvesting PMIC is very simple. The only external component is C3, which is connected to Vdd1V8 pin. C1 and C2 are both decoupling caps for VBAT and DC_IN, respectively.

The schematic also shows the male connection header to connect the harvester and the male header for storage connection.

In this design, MCU from XLP series of Microchip is used. This MCU offers very low leakage current, which saves battery consumption. The sensor module header follows mikroBUS™ configuration. The 5V pin is removed as the maximum operating voltage in this design is 3.3V.

2.2.3. NB-IoT Wireless Communication

The wireless communication module 1 is BC-95G module, which is an NB-IoT chip. The design of this part is based on the reference design from Quectel[2]. NB-IoT is one of the protocols to connect objects to the internet. Quectel offers BC-95G as a low power NB-IoT module, which supports different bands. The schematic presented in Appendix B is from the BC-95G reference design. The module communicates with MCU to get both the data for transmission and also AT commands.

2.2.4. SIM Card

The schematic in Appendix B depicts the design for the SIM Card. J1 is a sim card holder and U10 is an ESD Protection chip to protect SIM Card.

2.2.5. Battery Decoupling Caps

To avoid any voltage fluctuations affecting other blocks and components, decoupling caps are used. Decoupling caps also damp the unwanted noise and spikes from the line offering more clear voltage, which is a requirement for the components like MCU and the NB-IoT module to operate properly.

2.3. Power Profile

The power provided by the source and consumption by the load determine how long the load by that provided source can be run. To be able to understand the relationship between these two, first we need to define some values. Consumption consists of two parts: Dynamic consumption and static consumption. Dynamic consumption is the consumption that the load consumes during its activity. For instance, the dynamic consumption of MCU is determined while it does computation, for a sensor while it measures until the measurement is done, and for a transmitter from when it starts the process of transmission until it ends. Dynamic consumption, generally in comparison to static consumption, has higher peaks of consumption, but for a shorter time. On the other hand, static consumption as the name offers, is about the current, which is almost constant over time. Dynamic consumption is due to activities and static consumption is due to leakage of the components of a system. The power consumption can be formulated as below:

Total consumption = Static Consumption + Dynamic Consumption = Leakage (MCU + Module + Sensor) Consumption + (Computing + Transmission + Sensing) Consumption

The following sections explain and depict the consumption of each block. Each block is measured using joulescope[3] tool.

2.3.1. MCU Power Consumption

The steps that MCU does are as follows. Also, Figures 2 and 3 reveal the power consumption of MCU in dynamic and static mode.

Sleep mode > Wake-up > Reads sensor data > Forwards data to NB-IoT module > Goes to sleep

The MCU resets (POR) itself every time it wakes up from the deep sleep. The deep sleep time interval is configured according to the deep sleep watchdog timer. In this application, the deep sleep time is kept as 16 seconds for testing the MCU behaviour and measurements, however in the real applications, the MCU will sleep around 19.2 hours.

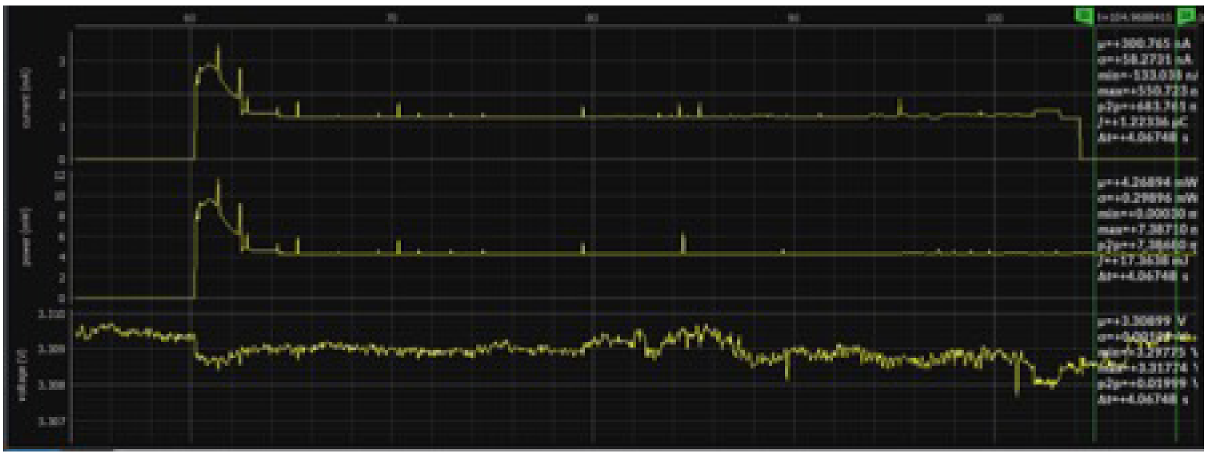


Figure 2: *MCU current pofile in "Sleep Mode".*

The MCU draws 300 nA of deep sleep current and it wakes up from the deep sleep with the deep sleep watchdog timer, which uses Low Power RC oscillator (31 kHz).

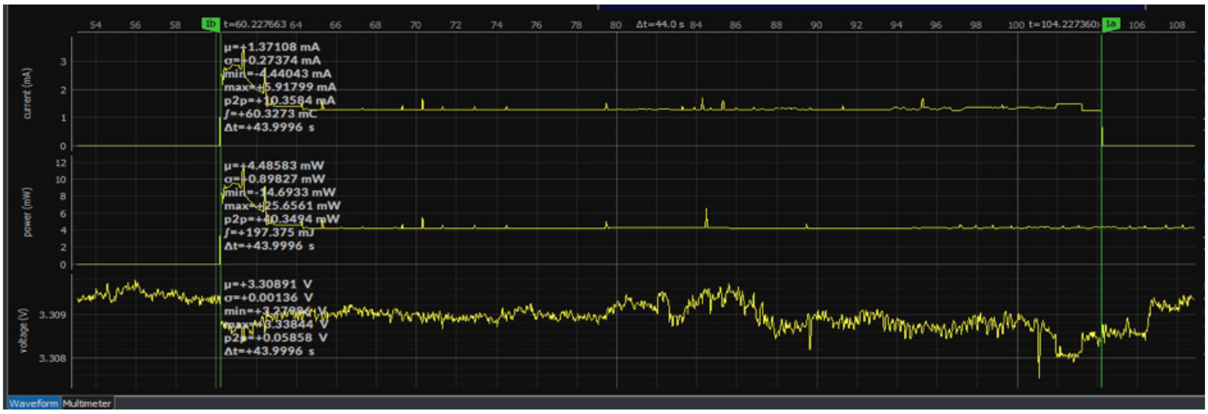


Figure 3: *MCU current consumption for one cycle of active operation (1.37 mA of average current).*

3.3.2. NB-IoT Power Consumption

The graph below reveals the power consumption of the BC-95 Quectel NB IoT module. The spikes represent the AT commands that were sent to the module to connect it to the network.

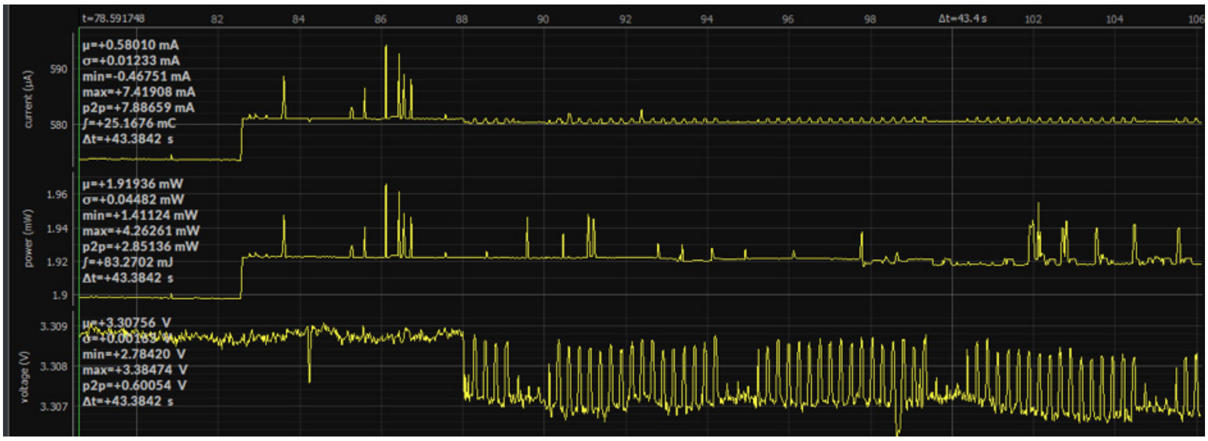


Figure 4: *Measured current of NB-IoT module in active mode.*

The average current consumption of the NB IoT module is 584 uA when it receives AT commands from the MCU, attaches to the network and sends data.

3.3.3. Sensor Power Consumption

The BME680 sensor work flow can be written as below:

Wakes-up -> Senses the data -> Goes to sleep

The leakage current of the sensor is 0.098 uA. The average dynamic current of the sensor is 579 uA.

The graphs below show the current consumption of the sensor when it wakes up, transmits the measured temperature data and goes to sleep:

Figure 5: *BME680 Sensor Current Profile.*

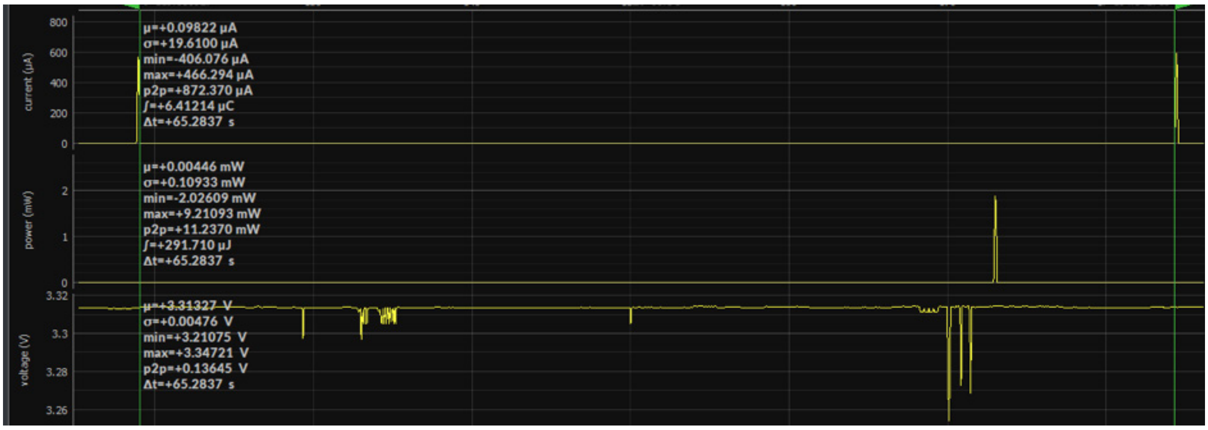


Figure 6: *BME680 Sensor Sleep Mode current profile (0.098 uA of leakage current).*

The sensor talks to the MCU with I2C (Inter-Integrated Circuit) communication. The gathered data belongs to temperature measurement but it can also be arranged for gas and pressure measurements as well.

Table 1 summarizes the average energy consumption of each block:

COMPONENT	STATIC (uA) (LEAKAGE)	DYNAMIC (uA) (AVERAGE)	AVERAGE TOTAL (uAh)
Nowi EH-PMIC	1	25% input power	25% input power**
NB-IoT BC-95G*	0	18000	500
XLP MCU	0.3	1208	33.85
Sensor (BME680)	0.098	579	0.119

Table 1: *Energy consumption of each block per hour.*

** This consumption is for one transmission.*
*** 25% of input current is consumed by the PMIC.*

The daily energy consumption will depend on the total number of the transmissions that are sent via NB-IoT module.

3.3.4. Miscellaneous Components

These components are not directly related to an EH-System, but they are necessary for the functioning of the system.

COMPONENT	STATIC	DYNAMIC
ESD protection IC	0.1 uA	-
Storage (Battery)	1% to 2% of capacity per year*	-
3V3 LDO	25 uA	-
Load switch	0.1 uA	-

Table 2: *Power consumption of miscellaneous blocks.*

Notes:
1. A load switch is used to disconnect the NB-IoT module from the power to save more power.
2. It is recommended to remove LED to decrease the power consumption, as it is not a necessary component for operation of the system.

**Considering a 800 mAh battery, the leakage would be 1 uAh.*

2.4 Formulating The Consumption

We can formulate at the end the consumption as below:

Static Consumption + Dynamic Consumption (for each transmission) + Conversion Consumption

The Static Consumption + Dynamic Consumption is 54.5 uAh for one transmission per day. The harvester current needs to compensate for this consumption. Since in this design NH2D0245 with 2 times boosting factor is used, this means that the current halves from the input. Therefore, there should be at least 2 times 54.5 uAh multiplied (which is 109 uAh) to have at input (at around 2 volts) to be able to charge a 3.7 volt, 800 mAh battery. However, in this calculation, the conversion efficiency is not counted yet. To compensate for the conversion efficiency, 25% more current should be provided by the harvester. It means that:

Total current provided by the harvester = (Static+Dynamic) Consumption + 0.25 of (Static+Dynamic) Consumption = 1.25 of (Static+Dynamic) Consumption = 1.25 x 109 uAh = 137 uAh

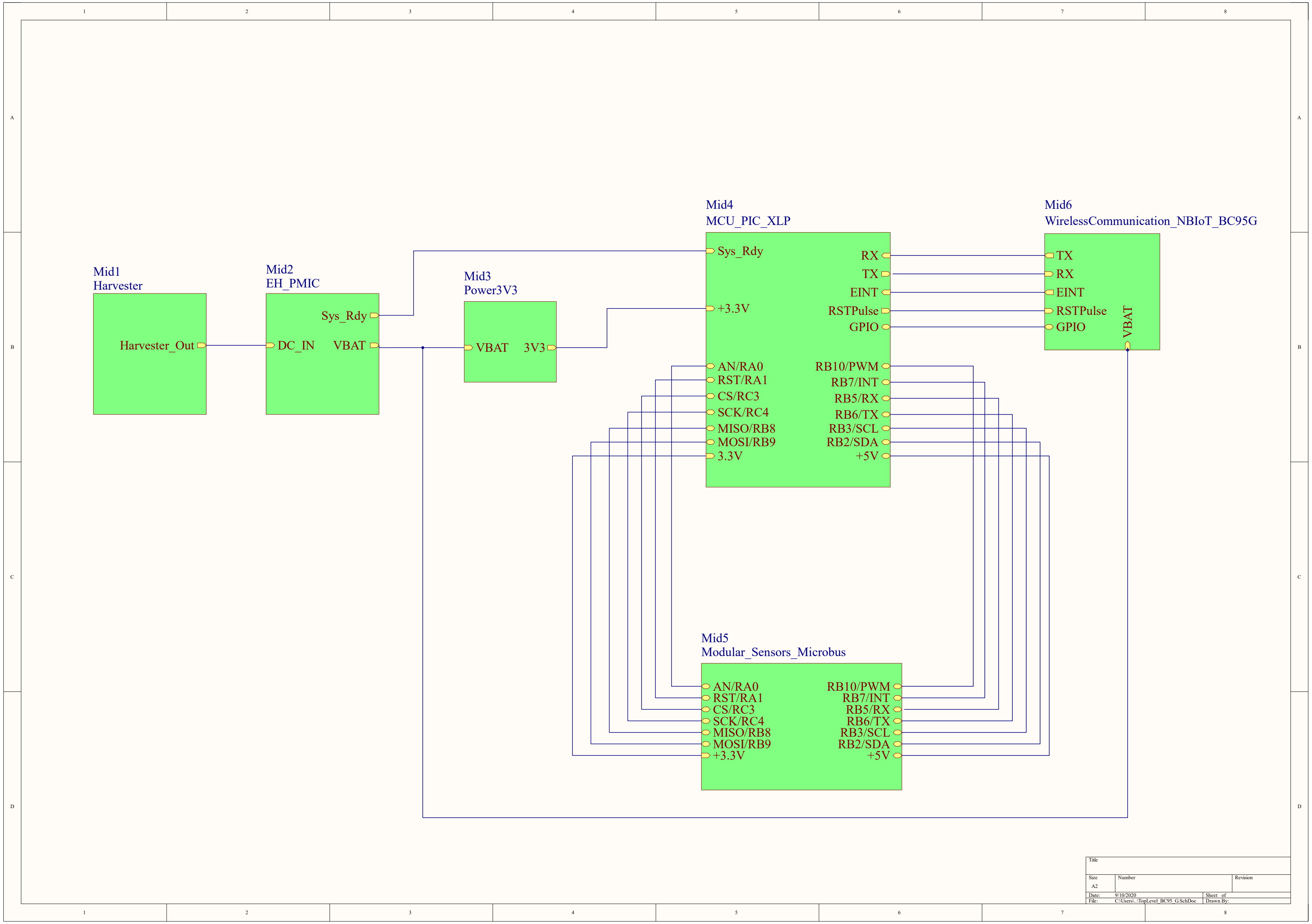
3. Conclusion

The purpose of this application note is to present a low power NB-IoT node powered by Energy Harvesting technology using Nowi NH2D0245 PMIC. Using Nowi energy harvesting PMIC technology, it is possible to supply a node autonomously, which can sense temperature, movement, humidity, etc. and update the cloud repository. This helps businesses and companies to gather data with less maintenance cost and use this data for their decision making and analysis in their businesses. To show one of possible application cases, we measured and calculated the total energy consumption of the node. For one transmission per day, the harvester needs to provide 137 uAh of current at 2 volts. This power is enough to compensate the sleeping, leakage, and active current of the whole NB-IoT node.

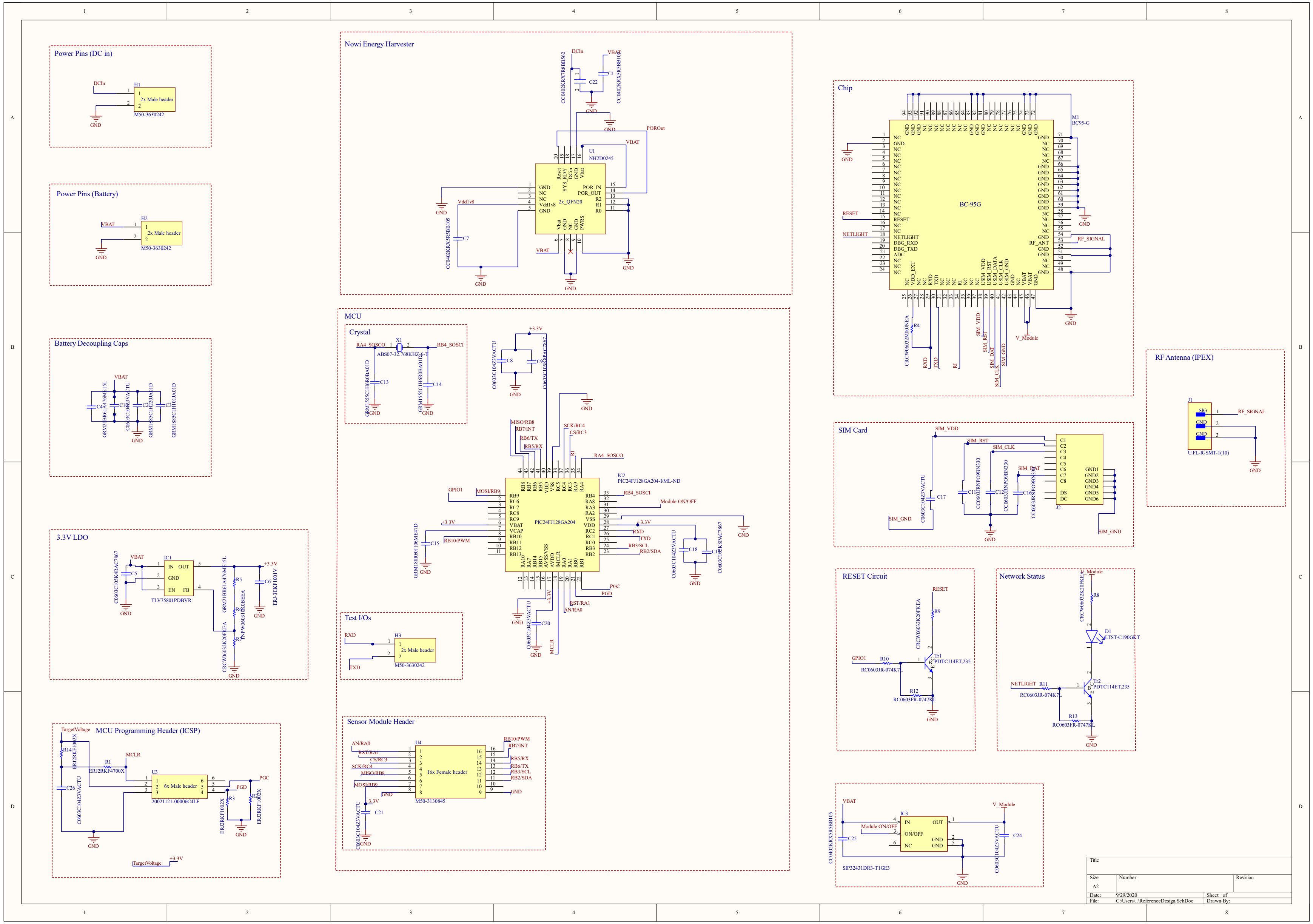
References

[1] https://www.mikroe.com/mikrobus
[2} BC95 Hardware Design - NB-IoT Module Series - Rev. BC95_Hardware_Design_V1.3
https://www.quectel.com/UploadImage/Downlad/Quectel_BC95_Hardware_Design_V1.3.pdf
[3] https://www.joulescope.com

Appendix A - Schematic Diagram, TOP Level



Appendix B - Schematic Diagram, Whole_system



Appendix C - BOM List

COMMENT	DESCRIPTION	DESIGNATOR	FOOTPRINT	LIBREF	QUANTITY
CC0402KRX5R5BB105	Chip Capacitor, 1 uF, +/- 10%, 6.3 V, -55 to 85 degC, 1005 (0402 Metric), RoHS, Tape and Reel	C1, C7, C25	CAPC1005X55X25ML5T10	CMP-2100-03591-1	3
GRM1885C1H220JA01D	Chip Capacitor, 22 pF, +/- 5%, 50 V, -55 to 125 degC, 0603 (1608 Metric), RoHS, Tape and Reel	C2	CAPC1608X90X35ML10T15	CMP-2000-04945-1	1
GRM1885C1H101JA01D		C3	CAPC1608X90X35NL10T15	CMP-2006-02595-1	1
GRM21BR61A476ME15L	Chip Capacitor, 47 uF, +/- 20%, 10 V, -55 to 85 degC, 0805 (2012 Metric), RoHS, Tape and Reel	C4, C6	CAPC2013X145X45LL20T25	CMP-2000-06341-1	2
C0603C105K4RAC7867		C5	CAPC1608X90X35LL15T15	CMP-2006-02298-1	1
C0603C104Z3VACTU		C8, C10, C17, C18, C20, C21, C24, C26	CAPC1608X87X35NL15T15	CMP-2006-03069-1	8
C0603C105K8PAC7867		C9, C19	CAPC1608X90X35ML15T15	CMP-2006-02287-1	2
CC0603JRNPO9BN330	Chip Capacitor, 33 pF, +/- 5%, 50 V, -55 to 125 degC, 0603 (1608 Metric), RoHS, Tape and Reel	C11, C12, C16	CAPC1608X90X40LL10T20	CMP-2000-06072-1	3
GRM1555C1H6R0BA01D		C13, C14	CAPC1005X55X25ML05T10	CMP-2008-04410-1	2
GRM188R60J106ME47D		C15	CAPC1608X90X35NL10T15	CMP-2006-02792-1	1
CC0402KRX7R8BB562	CAP CER 5600PF 25V X7R 0402	C22	FP-CC0402-MFG	CMP-03422-000637-1	1
LTST-C190GKT	LED GREEN CLEAR CHIP SMD	D1	FP-LTST-C190GKT-MFG	CMP-22017-000005-1	1
M50-3630242	CONN HEADER SMD 2POS 1.27MM	H1, H2, H3	1.27mm male 2pos	Header 2x 1.27mm	3
TLV75801PDBVR	IC POWER MANAGEMENT SUPERVISORY	IC1	SOT95P280X130-5L	TLV758P	1
PIC24FJ128GA204-I/ML-ND	IC MCU 16BIT 128KB FLASH 44QFN	IC2	PIC24FJXXXGA204	PIC24FJ128GA204	1

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COMMENT	DESCRIPTION	DESIGNATOR	FOOTPRINT	LIBREF	QUANTITY
SIP32431DR3-T1GE3	IC PWR SWITCH P-CHAN 1:1 SC70-6	IC3	SIP32431DR3-T1GE3	SIP32431DR3-T1GE3	1
U.FL-R-SMT-1(10)	CONN U.FL RCPT STR 50 OHM SMD	J1	FP-U_FL-R-SMT-1_10-MFG	CMP-11598-000001-1	1
0786463001	CONN MICRO SIM CARD PUSH-PULL	J2	MOLEX_78727-0001		1
BC95-G	BC95-G, Compact NB-IoT Module Multiband	M1	Quectel_BC-95G	Quectel_BC95-G	1
ERJ2RKF4700X		R1	RESC1005X40X25ML05T05	CMP-2002-01153-1	1
ERJ2RKF1002X	Chip Resistor, 10 KOhm, +/- 1%, 0.1 W, -55 to 155 degC, 0402 (1005 Metric), RoHS, Tape and Reel	R2, R3, R14	RESC1005X40X25LL05T05	CMP-2000-07588-1	3
CRCW06032M00JNEA		R4	RESC1609X50X30NL10T20	CMP-2000-03190-1	1
ERJ-3EKF1001V		R5	RESC1608X55X30LL15T15	CMP-2000-00180-1	1
TNPW060310K0BEEA		R6	RESC1609X55X30NL10T20	CMP-2000-03691-1	1
CRCW06032K20FKEA		R7, R8, R9	RESC1609X50X30NL10T20	CMP-2000-03167-1	3
RC0603JR-074K7L	Chip Resistor, 4.7 KOhm, +/- 5%, 100 mW, -55 to 155 degC, 0603 (1608 Metric), RoHS, Tape and Reel	R10, R11	RESC1608X55X25ML10T15	CMP-2000-05024-1	2
RC0603FR-0747KL	Chip Resistor, 47 KOhm, +/- 1%, 0.1 W, -55 to 155 degC, 0603 (1608 Metric), RoHS, Tape and Reel	R12, R13	RESC1608X55X25NL10T15	CMP-1659-00055-1	2
PDTC114ET,235	TRANS PREBIAS NPN 250MW TO236AB	Tr1, Tr2	SOT23_ZLLS500	PDTC114ET	2
NH2D0245	2x Energy Harvesting PMIC	U1	2x_Nowi_QFN20	NOWIQFN20	1
20021121-00006C4LF	CONN HEADER SMD 6POS 1.27MM	U3	1.27mm Header	Heaeder 6x	1
M50-3130845	CONN RCPT 8POS 0.05 GOLD SMD	U4	16x Female Header	Header Female 16x	1

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COMMENT	DESCRIPTION	DESIGNATOR	FOOTPRINT	LIBREF	QUANTITY
ABS07-32.768KHZ-6-T	Low Profile Crystal, 32.768 KHz, 6 pF, -40 to 85 degC, 2-Pin SMD, RoHS, Tape and Reel	X1	ABRA-ABS07_V	CMP-2000-05735-1	1