Development of Contactless Sleep Monitoring System and Indoor Environment Sensor

A Project as a Course requirement for

Master of Technology in

Optoelectronics and Communications

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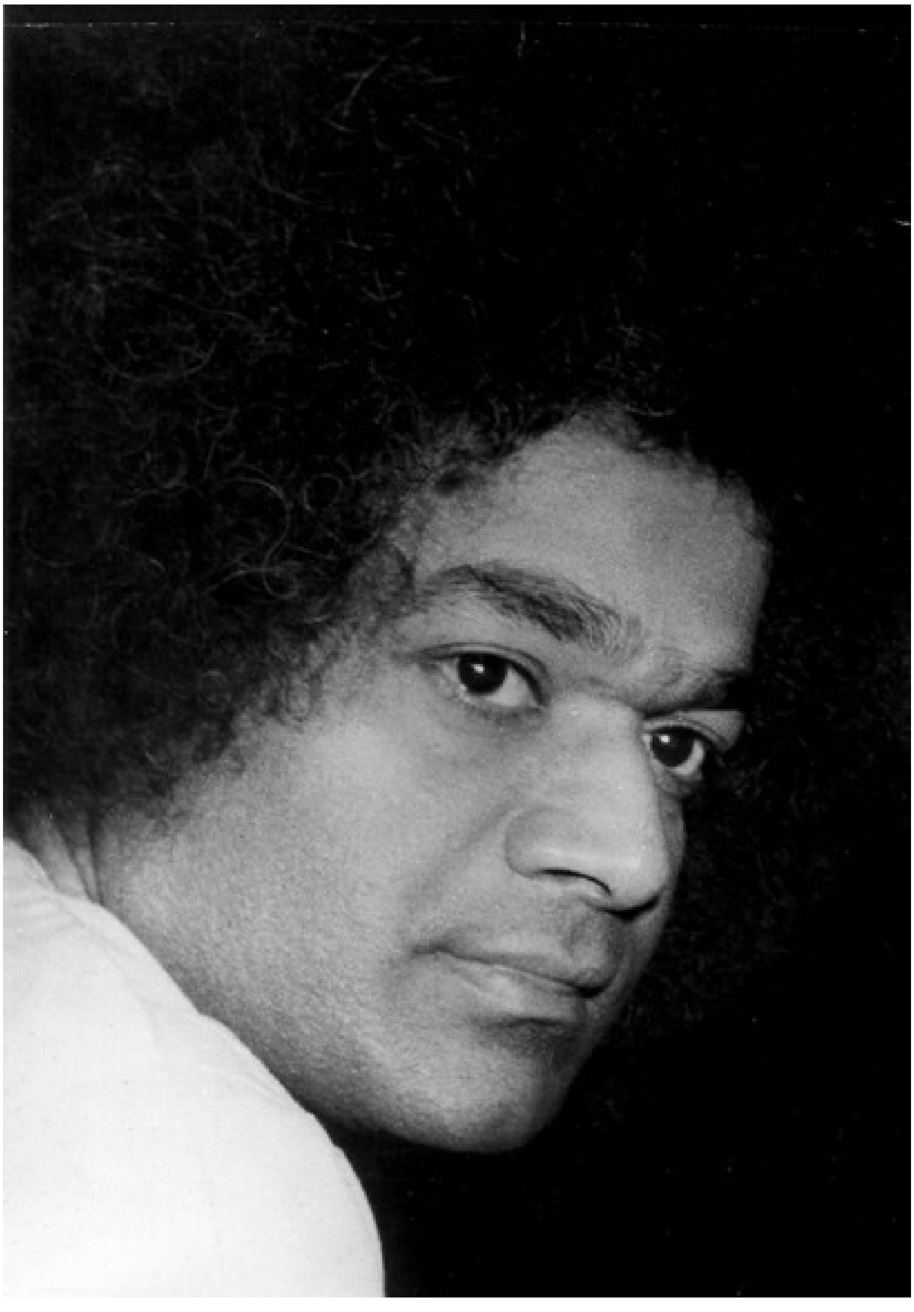

A HUMBLE OFFERING AT HIS LOTUS FEET

DECLARATION

The Project titled **Development of Contactless Sleep Monitoring system and Environment Sensor** was carried out by me under the supervision of Prof. Siva Sankara Sai, Department of Physics, Prasanthi Nilayam Campus, as a Course requirement for the Degree of Master of Technology in Optoelectronics and Communications and has not formed the basis for the award of any degree, diploma or any other such title by this or any other University.

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CERTIFICATE

This is to certify that this Project titled **Development of Contactless Sleep Monitoring system and Environment Sensor** submitted by Abhishek S R, 17701, Department of Physics, Prasanthi Nilayam Campus is a bonafide record of the original work done under my/our supervision as a Course requirement for the Degree of Master of Technology in Optoelectronics and Communications.

……………………………..
Prof. S Siva Sankar Sai
Director Prasanthi Nilayam Campus

Countersigned by

Place: ………………………………...

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Abstract

Sleep deprivation and related diseases are common in modern society. But most often goes unnoticed and neglected due to various reasons. Polysomnography (PSG) is a method of monitoring and analysing biophysiological changes that occur during sleep and is used to diagnose sleep-related disorders, such as narcolepsy and sleep apnea. PSG study requires you to wear multiple sensors for entire sleep duration, recording brain, eye and muscle activity, respiration, heart rate and blood oxygen saturation. But PSG cannot be used for infant monitoring, post-surgery patient monitoring and patients with skin diseases. The very process of PSG itself sometimes disturbs the normal sleep of a person. Since most of the symptoms related to sleep diseases occur during sleep, very often patients fail to realise the presence of symptoms. The requirement for a device which can resolve the above problems is really important. In this project, we develop a low-cost contactless sleep monitoring device which requires no physical connectivity to the sleeping person. The device is based on an Ultra Wide Band Impulse Radar which can detect vital signs and movements during the sleep. Since the ambient parameter plays a crucial role in determining the quality of sleep, we develop a multisensor board for ambient monitoring.
The design and hardware developement of the proposed device is completed and validation is underway.

Acknowledgements

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Contents

List of Figures

Chapter 1

Introduction

On an average adult human sleeps for around 6-8 hours, which means that we humans spend almost one -third of our lives in sleep, still, most of us don't know much about sleep. Sleep is a state of unconsciousness from which the person can be aroused by sensory or other stimuli. Before 1920s Sleep was considered to be an inactive state of the brain where it stops taking sensory inputs from the environment. Over the years, due to the advent of new technologies, there has been a huge improvement in understanding sleep and its importance in our daily life. Sleep is no more a passive state but a dynamic behaviour, in which the brain is highly active and stays busy, supervising biological maintenance which keeps our body in good condition.

The invention of EEG(Electroencephalography- a method using which electrical activity of the brain can be monitored) in the year 1924 by Hans Berger made a breakthrough in sleep studies.EEG helped to understand that, there are two types of sleep characterized by the electrical patterns in a sleeping persons brain. They are non-rapid-eye-movement (NREM) sleep and Rapid-eye-movement (REM) sleep.[1] The sleep episode begins with an NREM stage 1 progressing through stage 2, 3 and 4 representing an ongoing deeper sleep and finally to REM. This repeats in a cycle, normally, NREM sleep makeup about 75 to 80% of the total time that we spent in sleep, and the rest 20 to 25% is REM sleep. REM is a short sleep occurring approximately every 90 min and lasts for 5-30mins. During an NREM sleep, respiration rate and heart rate is 10% 30% less than the normal rate, whereas REM sleep has an irregular respiration and heart rate. Sleep patterns are affected by many factors, like age, the amount of sleep we had in previous days, individuals internal clock, other behaviours such as stress, exercise, external conditions such as temperature, humidity light etc.[2] Studying NREM and REM sleeps most ofetn used for sleep disorder studies and diagnosis.

1.1 Sleep disorder classification

Most sleep disorders can be classified into five categories of hypersomnia, insomnia, circadian rhythm disorders, parasomnia, and other disorder - related sleep problems.

1.1.1 Hypersomnia

Sleep disorder may not always be due to the deprivation of sleep, it may be due to sleep disorders such as sleep apnoea, narcolepsy, etc.

Obstructive sleep apnoea

Obstructive sleep apnoea (OSA) is one of the most common sleep disorders that cause hypersomnia during the day, affecting more than 2% of adult women and 4% of adult men. Middle-aged, overweight males are more vulnerable to OSA, but it can be seen even in children (3% in children), and lean individuals. In most of the cases, loud snoring can be always associated with OSA.[3] OSA occurs because of the relaxation of throat muscles, which support the soft palate, a piece of tissue hanging from the soft palate (uvula), the tonsils, tongue and the side walls of the throat. When these muscles relax, as we breath in airway narrows and slowly closes, resulting in an insufficient amount of air reaching the lungs, which will lower the oxygen level in blood. The inability to take a breath is sensed by the brain, thereby arousing us from sleep which can reopen the blocked airway. This awakening is generally so short that we may not remember it but We might choke or gasp for breath. This whole process can repeat up to five to thirty times or more each hour, which reduces our ability to achieve normal deep sleep. These short arousals happen without the knowledge of the individual, this can lead to day time drowsiness but more importantly long term effect on our cardiac rhythm.

Central sleep apnea
Breathing is involuntary during our sleep and is controlled by our brain, it can happen that the brain fails to send signals to breathing muscles meaning we do not make an effort to breathe. The moment body realizes the lack of oxygen we wake up from sleep. Even though this is less common it can still have after effect like OSA.
Complex sleep apnea
Complex sleep apnea syndrome (CompSAS) also known as treatment-emergent central sleep apnea, occurs when someone suffers from both central sleep apnea and obstructive sleep apnea. Loud snoring, episodes of breathless state during sleep and Gasping for air during sleep are the major symptoms of SAS but The first three symptoms are very important in the diagnosis of SAS but most of the time a person fails to remember these episodes from his sleep. This creates a requirement of a second person to observe the sleep and give feedback but its not practical every time.

Narcolepsy
Narcolepsy is basically a neurological disorder, one out of every 2,000 people in the world is affected by this. Narcolepsy patients have the tendency to fall asleep during the daytime, even after getting a satisfactory amount of sleep the night before.

1.1.2 Insomnia

Insomnia is one of the most common types of sleep disorder found in the modern population. It is characterized by the inability to sleep long enough to give the following day a feeling of relaxation or refreshment. Although insomnia is of a constitutional nature most of the time, there is evidence that untreated insomnia can be a risk factor for psychiatric problems, such as depression. Non-pharmaceutical methods like ambient parameters such as warm temperature are being suggested as a solution for these disorders.

1.1.3 Restless legs syndrome

Another common disorder that causes severe insomnia is the Restless Legs Syndrome (RLS). It is a sensory neurological movement disorder that affects 5% to

15% of the general population[4]. Patients with this syndrome have restlessness in their legs because the movement of the leg during sleep relieves the problem.

1.1.4 Circadian Rhythm Disorders

Due to the temporary mismatch between your sleep pattern and circadian rhythm, Circadian Rhythm Disorder occurs. The main symptom of circadian rhythm disorders is the inability to sleep during the desired sleep time. During sleep-/wake period, exposure to bright light has a potential effect on the circadian rhythm and can be used to treat the disease.

1.1.5 Parasomnias

The parasomnias are unwanted episodes of physical or experiential occurrence during sleep. These sleep disorders are not anomalies in the sleep and wake - up processes per se, but they are unpleasant phenomena that mostly occur during sleep[5]

1.2 Consequences of Sleep Deprivation

why quality sleep is important?. Most often we ignore having a bad sleep and continue with our day to day activities without knowing that our daily activities have a direct correlation with quality of sleep. One of the tragic effects of sleep deficiency is an increase in the risk of motor vehicle accidents in the general population. A report by [6] and [7] suggest that 19-22% of motor vehicle accidents are caused by drowsy driving.
It is a well-established fact that Sleep deficiency has a direct impact on the cognitive performance of a human being. Two of the most extensively studied cognitive domains within Sleep deprivation research are working memory and ability to concentrate which are very important parameters which define our progress in the work that we do. Below are some of the complication of sleep apnea
Daytime fatigue: The repeated rousing during sleep create severe daytime

drowsiness, fatigue and irritability resulting in lack of concentration, depression. Etc.
High blood pressure and heart problems: Sudden drops in blood oxygen levels due to sleep apnea increase blood pressure and create stress on the cardiovascular system. Obstructive sleep apnea also increases the risk of repeated heart attacks, strokes and abnormal heartbeats, such as atrial fibrillation. Multiple episodes of low blood oxygen levels (hypoxia or hypoxemia) may result in sudden death for a person suffering from an irregular heartbeat
Type 2 diabetes: Having sleep apnea adds to the risk of developing insulin resistance and type 2 diabetes.
Complications with medications and surgery:. OSA may create problems during general anaesthesia and medications. People with sleep apnea are more likely to experience complications after major surgery because they are more susceptible to respiratory problems, especially when lying on their back.
Liver problems: People suffering from sleep apnea are prone to have undesired results on liver function tests, and chances of showing signs of scarring are more (non-alcoholic fatty liver disease).

1.3 Motivation and problem statement

From the above contents, we can conclude that sleep-related diseases are common but never given importance unless it is severe and have an immediate effect on our life.what can be the reason for it?.
Polysomnography is a method or a diagnosing tool used for diagnosing a sleep-related disorder. it is considered as the gold standard diagnostic tool because of its reliability and accuracy. It is a combination of multiple diagnostic tools for monitoring our body for a complete sleep duration which includes:

- Electroencephalogram (EEG) for monitoring the electrical activity of the brain.
- Electrooculogram (EOG) for sleep stage classification
- Electromyogram(EMG) for monitoring leg movements.
- Thermistors

- Electrocardiogram (ECG) for heart monitoring.
- Pulse oximetry.
- Nasal air flow measurement.
- Video recording.

A patient undergoing a polysomnography test is required to place the above-mentioned sensors on the body parts like scalp, temples, chest and legs. The sensors are connected to a computer via wires. The data collected by the sensors are sent to this computer and stored there. A polysomnography technologist will be present in the next room for monitoring the patient throughout the night. The information collected by the sensors are analyzed later by the sleep technologist to chart sleep stages for diagnosing sleep diseases.
Even though there exists this highly accurate and reliable technique why most often these diseases go unnoticed?
A sleep study conducted in India shows that 6.4% of adult Indian population suffers from snoring and the prevalence of OSA was 3.42%. Subsequently, other community - based epidemiological studies from several parts of India confirmed that OSA is 2.4% to 4.96% in men and 1% to 2% in women.. This suggests that in India, up to about 34 million people may be suffering from OSAS. Despite being a common disease, a large number of OSAS cases, an estimated 82%, are not diagnosed due to lack of diagnostic facilities[2].
Even though PSG is a highly reliable technique, hospital testing is very costly for users to invest in on a daily basis and demands you to attach multiple electrodes over your body during the sleep, this stops users from having their normal peaceful sleep resulting in misinterpreting this as a sleep disorder. Even to go for a PSG patient should at least come to know that he/she suffers from sleep disorder this doesn't happen often due to the fact that most of the symptoms happen during the sleep especially in case of apnea and patient may not even realize it. So there is a requirement of a second person who should be awake near the patient to observe the symptoms. This answers the two questions asked previously. For these reasons, various products have been launched on the market for sleep stage analysis but most of them are contact based and people may not prefer wearing an electronic gadget while sleeping, doesnt assure a medically accurate data which prevents the user from using this for a sleep disorder diagnosis.

Few more important set back of the wearable device is that it may not be preferable for monitoring infants, post-surgery patients and people with skin allergies. Above reasons gives a strong requirement for a contactless polysomnogram which can be used to monitor sleep from a distance. So through this project work, we try to Develope an unobtrusive, non-invasive, contactless sleep/activity cum ambience monitoring system, for health care/wellness/home automation industry. With the following features:

- The device monitors ambient physical parameters and correlates with your sleep patterns.
- See through capabilities even after covered with blanket or bed-sheet.
- Low power device with wireless (BLE V5) data communication to a smartphone or remote server
- Lower cost suitable for the Indian market.

The thesis is organised as follows:
Chapter 1 which we have covered already discussed about the strong motivation behind the project.
Chapter 2 discuss about the selection of components for the hardware developemnt of the device.
Chapter 3 speaks on the hardware design of the device
Chapter 4 is on software implementation and the tools used in the project. The thesis is concluded with chapter 5 which consist of Result, discussions and future scope of the project.

Chapter 2

Hardware

2.1 Component selection parameters

Before coming to the components which are used in the project it will be worth explaining the general parameters and criteria which are used for selecting components for the hardware development of this project. Component selection is so critical in a product development cycle because selecting wrong components may create heavy losses in terms of money, time and other resources. It is the responsibility of a hardware designer to choose the right component for the design from all possible vendors by comparing multiple parameters.components can be compared mainly based on two things, technical parameters and non-technical parameters

2.1.1 Technical parameters

Functionality

Functionality depends on the application, unless component under consideration satisfy all the functional requirements it is not chosen. For example, if you require a temperature sensor for an application the range of operation, an accuracy of measurement etc.should be satisfied based on the need.

Electrical characteristics

It includes supply voltage and logical levels of the input-output lines of the component. This is crucial when it comes to systems which support multiple voltage levels, because voltage translators may be needed in order to include the component in the system.

Power consumption

In general power consumption is kept as low as possible, especially for components used in portable devices powered by the battery. A designer should look for special features like availability multiple operation modes like sleep mode idle mode etc.that enable low power consumption during an inactive state.

Operating Environment requirements

Every component is made to operate under specific ambient conditions like temperature, humidity etc. Based on these components are classified into different grades such as Military grade Industrial grade and Commercial grade. Therefore the component is chosen based on the environmental condition in which it's going to operate.

Regulatory Requirements

Depending on the country we live in there will be rules and regulations for using certain components, these rules are important when it comes to chemical-based sensors, devices which work in radio frequency range etc.

Reliability

Component reliability is essential while designing systems whose outputs are critical and cannot afford to be inconsistent, like Medical, devices and emergency alarm systems etc Performance degradation over a period of time, or Mean time between failure etc are few of the reliability parameters.

Intellectual property

When component under consideration is a microcontroller or processor it is important to compare based on the intellectual property that can be licensed from the vendor that is crucial for a faster reach of product into the market. It includes the operating system on a processor, other API's provided by the vendor etc.so that quicker development of the product happens.

Availability of Developer tools and support from the vendor
Quality development tools are critical when it comes to Programmable Logic devices, Microprocessors and Microcontrollers. There should be enough support from the vendor and product community so that troubleshooting becomes easier.

Physical size and Package
Portable and handheld devices are constrained by their size. Size, in turn, depends on the components selected. When it comes to IC's, package type of the component becomes crucial because it affects the size and ease of placement of the components on the PCB.

2.1.2 Non-Technical Parameters

Cost
Cost is an important constraint during component selection. There will be a cap on the price of the device decided by the development group. Especially when trying to develop a low-cost device without compromising on the quality of the product.

Multiple Sources
Having multiple suppliers and manufactures for the component is a highly desirable feature since it will reduce the cost due to competition and procuring the component becomes easier.

Stage of production
Every component will be having a stage of production depending on the phase of the component in the market. It can be in Engineering phase, active production phase, obsolete phase or not for the future design phase. It is obvious that one should go for a component in active production stage but there can be situations where we will be forced to go for components in other phases.while choosing a component in engineering phase it is important to verify that production schedule of it matches with that of the product being designed.

2.2 Product requirements

As mentioned in the previous chapter, our product consists of multiple sensors including ambient monitoring sensor, and a sensor for movement detection and vital sign monitoring that is connected to a Bluetooth chip which can send the collected data over BLE protocol to a mobile device.

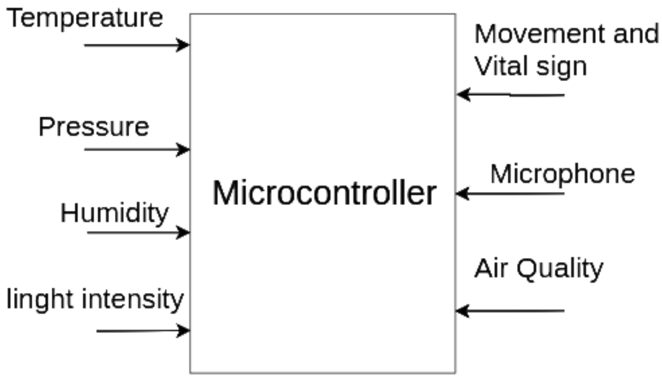

FIGURE 2.1: Simplified block diagram of the sensor integration.

Development of the hardware is divided into two parts: A sensor array board for ambient monitoring along with a BLE chip to transfer data and a movement and vital sign monitoring board with its own BLE chip.

2.2.1 Microcontroller

It is understood that the main requirement is that of a powerful microcontroller with the following requirements

1. Should have multiple interfaces so that it can integrate different sensors together.
2. In order to implement a sensor fusion algorithm microcontroller, must have data storage and processing capabilities.
3. Flexible power management system with low power operation and a wide supply voltage range.
4. Bluetooth Low Energy protocol support.
5. Availability of development tools.

Microcontroller	Transmit Power	Processor	Permanent Memory	Comments
Dialog DA14580/3	0 dBm	Cortex-M0	32kB / 128kB	Ultra low power.
Cypress PSoC	3 dBm	Cortex-M0	256kB	Cost effective solution
Qualcomm CSR101x	7.5 dBm	Proprietary	External	Best transmit power can be used for mesh network
Nordic nRF51822	4 dBm	Cortex-M0	512 kB	Very low current. High transmit power.
Nordic nRF52832	4 dBm	Cortex-M4	512kB	Fast MCU. Low current. High transmit power.
Nordic nRF52840	0 dBm	Cortex-M4	256kB	Based on old 8-bit MCU.
TI CC2650	5 dBm	Cortex-M3	128 kB	Good transmit power. Good MCU.
Atmel ATBTLC1000	3 dBm	Cortex-M0	External	Lowest power chip available.
Espressif ESP32	18 dBm	LX6	520KB	Fast .High power consumption

TABLE 2.1: Comparrisson of BLE mocrocontrollers in the market[8]

From the Table 2.1 it is evident that Nordic semiconductor chips satisfy all the parameters of the required MCU. The only MCU with a better processor is Espressif ESP32, but it consumes much higher power than nRF chipset. Since our product needs a low power consumption without compromising on the performance of the microcontroller nRF52832 is the best choice.
Nordic Semiconductor is a leading Bluetooth SoC solutions manufacturer. Both their chips are quite popular with nRF51822 and nRF52832. The core processor is a major difference between both of them. The nRF51822 uses a 16 MHz 32-bit ARM Cortex - M0 microcontroller while the nRF52832 uses a much faster, more advanced ARM Cortex - M4F 64 MHz microcontroller. It even supports DSP algorithms and includes a floating point unit (FPU). The nRF52832 is also ready for Bluetooth 5, while all other MCUs support only the Bluetooth 4 specification [9].

2.2.2 Vital sign and movement detection sensor

Vital sign and movement detection in polysomnography are highly accurate and reliable so in order to achieve the same standard, we should have a sensor which does this in a contactless way.
Many have explored ways to determine vital parameters from a distance without making any kind of contact. These include Optical based monitoring systems [10] which make use of Fiber optic grating which is used to project a bright spot on to the chest of the person sleeping and as the person breathes this spot moves accordingly, this is captured by a CCD camera and analysed.

In order to determine the respiration rate,[11] used a static camera to detect thoracic movements. The thorax surface projection was represented as a region with a range of intensities of brightness. Respiration was monitored by quantifying changes in image intensity locations over time .
A thermal sensor - based breathing rate monitoring system was reported in [12]. The sensor could detect breath - induced temperature changes near the nostrils and the data were then collected and analyzed simultaneously by a personal computer.
A method for monitoring respiration rates based on infrared imaging was developed by tracking algorithms that could follow respiratory - related facial features [13].
Non-contact respiration rate monitoring system based on radar was reported in [14]. The Radar Vital Signs Monitor (RVSM) was called the system. It was designed to monitor Olympic athletes ′ performance at distances of more than 10 meters. Using the Doppler phenomenon, the RVSM detected breathing-induced chest movements.

Since the proposed device is a portable and of small form factor, all the above methods except the radar-based are not suitable. Radar-based methods have a clear advantage over the others but it depends on what type of radar is used. There are mainly three types of Radar used for vital sign monitoring.

1. Continuous Wave (CW).
2. Frequency Modulated Continuous Wave (FMCW).
3. Ultra-Wideband Radar Impulse Radar (UWB IR).

Table 2.2 compares all the three types of radars mentioned above. UWB Radar clearly has an edge over the others except having a requirement of software controlled delay line. For our device we have chosen UWB IR for contactless vital sign and movement detection.

Continuous Wave Radar	**Frequency Modulated Continuous Wave**	**Ultra Wideband Radar Impulse Radar**
The technique is based on the detection of the reflected frequency echoes because of the movement of the chest wall.	Continuous modulated chirps are used. .	Based on Ultra Wideband impulses.
Cannot measure the Range due to lack of any timing mark. Only velocity can be measured.	The range is measured by the fact that when an echo signal is received, the change of frequency gets a delay depending on the distance from the target.	Range is obtained by measuring the arrival time of the pulses and change in amplitude of the received the pulse.
High resolution which is limited only by noise.	Resolution depends on the bandwidth	Resolution depends on the bandwidth
Circuitry complexity due to frequency conversion	Circuitry complexity due to frequency conversion	Lower circuit complexity since no frequency conversions are required.
Power consumption is more compared to UWB	Power consumption is more compared to UWB	Low power consumption due to less circuitry, Impulsive nature and Regulations.
No software controlling required	No software controlling required	Need to use a software-controlled delay line to define the gating and controlling the delay line.
Cannot detect target in cluttered environment	Clutter can be removed by using frequency gating.	Time gating allows detecting the target in the presence of clutter.

TABLE 2.2: Comparison of Different Radar types

Below are a few of the advantages of the UWB IR over the other methods which are not mentioned in Table 2.2

1. Ability to penetrate through an obstacle like clothing.

2. A target can be precisely located because of a very high downrange resolution.
3. A large bandwidth makes it possible to separate targets and clutter better.
4. It has a good immunity against interference with multipath, which is very strong within buildings.
5. Multiple targets can be resolved.
6. Privacy is protected, unlike camera-based monitoring.

Considering the time constraint, developing a UWB -IR radar is far from the scope of this project. A radar module which can satisfy our requirement will be a better option. Performance of UWB IR depends on many interrelated parameters. Depending on the application, the developer should have to do a trade-off between the parameters to get the best performance. The following are some of the key specifications which determine the performance of UWB IR .
Frequency Content of UWB Signals: An ultra - wideband signal's frequency content is specified by its centre frequency and bandwidth. A large bandwidth implies good spatial resolution. In order to achieve good penetration through dense materials, low frequencies are desirable. But a larger antenna is needed to create lower frequency signals, increasing the device's overall size.
Power: Instant peak signal power, average signal power, and average system power consumption can describe the power characteristics of a UWB system. A high peak power results in more penetration, long operating distances and high SNR but increases the power consumption. But as per telecommunication rule Maximum mean EIRP density should be below - 41 dBm//MHz.
Pulse Repetition Rate (PRR):PRR decides the operating range because, in order to avoid interference between transmitted and reflected pulse, time of flight should be less than the inverse of PRR. Responsiveness of motion detection is more at faster PRR so that high-frequency movement can be detected. textbf-Pulse width and Range resolution: Both are interrelated parameters which determine the ability to distinguish closely spaced targets.

$$\tau = \frac{2\Delta R}{C} \tag{2.1}$$

Receiver Window Size and integration time: The size of the receiver window corresponds to the sampling time window. A small window enables increased spatial resolution and increased sensitivity to small movements. Multiple pulses are integrated over a time period which determines the SNR of the received signal[15].
A radar module in which the above parameters can be configured will allow the developer to get the best performance. There are only a few companies which produce UWB IR modules like ARIAsensing-LT10 Xseries UWB modules, UWB-Radar108R, Xethru X4M04 series and The Time Domain PulsON P410 module.
Among all the above radar modules, Xethru X4M03 radar development kit module seems to be most suitable for us. Apart from satisfying technical parameters one of the major advantage is that Xethru provides different components of the development kit like main radar chip, its antenna and MCU separately so that developer can build his own the module from scratch once he is comfortable with the Radar development kit. Xethru X4M03 is based on Xethru X4 IR-UWB radar system on a chip. X4 transmits is configurable within two different frequency bands 6-8.5 GHz and 7.25-10.2 GHz. The radar sends out an electromagnetic impulse through the Tx antenna which is reflected from an object in front of it. Reflections are sampled through a receiver antenna. Radar can sample the received signal at a sampling rate of 23.328 GS/s that can sample up to 1536 samples. This collection of samples make up a radar frame. Each sample in a frame is called a range-bin which corresponds to a particular distance. In X4, we can choose to read either a 1536 sample frame or an on-chip down-converted frame with 180 range bins. Down conversion decimates the frame with a factor of 8. The sampler system can be configured to get radar frames suitable for an application[16].

2.2.3 Ambient monitoring sensors

The proposed device will be designed to monitor the following ambient parameters:

- Temperature
- Humidity

- Pressure
- Light intensity
- Indoor Air Quality (IAQ)
- Microphone

Above parameters are selected based on the fact that all have a direct impact on our sleep cycle.
Coming to the first parameter that is temperature, we have multiple options starting from an analog thermistor, Infrared based sensors to digital sensors. For a digital electronic device like the proposed one, It will be better to go with a Semiconductor based digital output temperature sensor. There are numerous choices for a digital output temperature sensor which gives the same performance. Among all, we boiled down to Boche BME680. The main reason behind the selecting this particular sensor is that it is a digital 4-in-1 sensor with gas(Volatile Organic Compound), humidity, pressure and temperature measurement.
This helps us to reduce the form factor of the product considerably. The following are some of the specifications of BME680 sensor as given in [17]

- Input Voltage: 3.3V 5.0V
- Operating Current: 5mA (25mA in VOC).
- Interface: I2C (up to 3.4 MHz) and SPI (3 and 4 wire, up to 10 MHz).
- Temperature Measurement Range: $-40°C\ +85°C$.
- Temperature Measurement Precision: $1.0°C(0\tilde{6}5°C)$.
- Humidity Measurement Range: 0-100%r.H
- Humidity Measurement Precision: 3%r.H.(20-80% r.H.,25C).
- Atmospheric Pressure Measurement Range: 300-1100hPa.
- Atmospheric Pressure Measurement Precision: 0.6hPa(300-1100hPa,0$\tilde{6}$5C).
- Module Size: 30 22(mm) / 1.18 x0.87(inches) .
- Response time ¡ 1 s (for new sensors)

Lighting in the room is also a factor which affects the quality of sleep. Both the intensity and the wavelength plays a role in this. Higher wavelength light like red has shown less disruptive to sleep than other light wavelengths. So keeping these in mind we have chosen a digital colour sensor BH1745NUC from Rohm Semiconductor which can determine the intensity of three different colours, Red green and blue along with white light. Below are the main specifications of the product[18].

- Voltage Range: 2.3V to 3.6V
- Maximum Sensitivity:0.005Lx/step
- Current Consumption:130A (Typ)
- Standby Mode Current:0.8A (Typ)
- Operating Temperature Range:$-40°C\ +85°C$.

Coming to the Indoor Air Quality Sensor, the product requires a sensor which can detect the presence of a range of poisonous gas rather than measuring the quantity. In general gas, Sensors comes with single or few target gases but we could find an IAQ sensor which matched exactly with our application. It's SPEC Sensors RESP_IRR_20 IAQ sensor which is a Screen Printed ElectroChemical sensor board particularly made for broad detection of breathing irritant gases. There is a wide range of target gases which include:
Carbon Monoxide, Hydrogen Sulfide, Ozone, Nitrogen Dioxide, Sulfur Dioxide, Ethanol, Nitric Oxide, Chlorine, n-Heptane, Ammonia, Methane, Saturated Hydrocarbons.
Below are few of its Specifications:

- Measurement Range: 0 to 20 ppm (calibrated as NO2 equivalents)
- Response Time to 90%: ¡ 60 seconds typical
- Sensitivity: -50 +/- 25 nA/ppm (NO2 equivalents)
- Expected Operating Life: greater than 5 years (10 years @ 23+/-3C; 40+/-10% RH)
- Operating Temperature Range: $-10°C\ +40°C$. ($0°C$ to $40°C$ continuous)

- Operating Humidity: non-condensing 0 to 100% RH (15 to 95% continuous)
- Power Consumption: less than 50 microW circuit and ambient gas dependent
- Resolution: 20 ppb NO2 (depends on the gas electronics).

RESP_IRR_20 IAQ sensor works best when operated in Potentiostat mode details of the potentiostat circuit is discussed in chapter3.
Including a microphone in the sensor board gives two advantages. First to monitor the noise level in room and second to monitor the snoring level. There two kinds of microphone technologies Electret Condenser Microphones (ECM) and MEMS (Micro-Electro-Mechanical System). We chose MEMS over ECM for the following reasons: Ideal for applications in electrically noisy and high vibration environments
MEM reduce the level of unwanted noise introduced by the mechanical vibration, temperature stable Performance, small package sizes available.
MP34DT06J, a MEM microphone from STMicroelectronics was chosen for the proposed project.
Some of the features of MP34DT06J given in [19]includes:

- Single supply voltage
- Low power consumption
- AOP = 122.5 dB SPL
- 64 dB signal-to-noise ratio
- Omnidirectional sensitivity
- 26 dBFS 1 dB sensitivity
- PDM output

Chapter 3

Circuit design

As mentioned in chapter two hardware implementation is divided into two parts:

1. A multisensor board integrating ambient all the ambient parameter sensors.
2. Radar BLE board consisting of Xethru X4M03 radar module and nRF52832 BLE chip.

Since the design is centred around nRF52832 it will be wise to describe the design considerations related to nRF52832 first then proceed to other sensors.

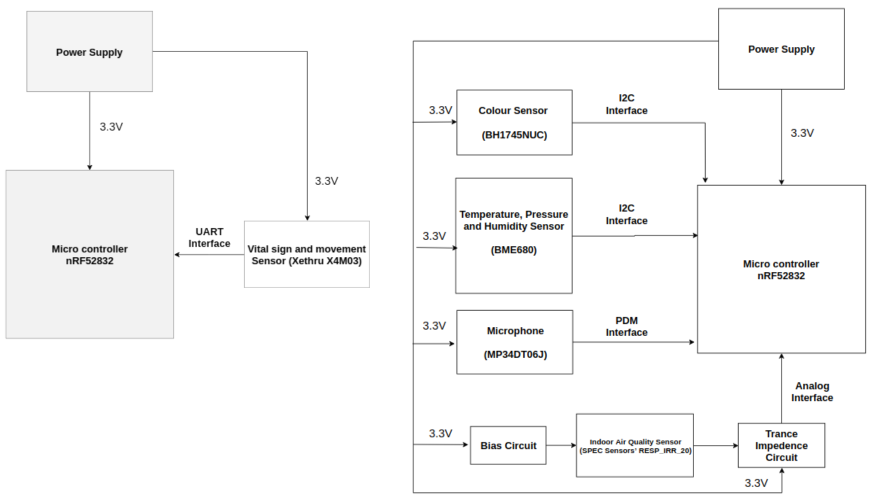

FIGURE 3.1: Block diagram of the proposed hardware[17].

3.1 nRF52832

nRF52832 has got multiple interfacing options like:

- Up to 3x SPI (Serial Peripheral Interface) master/slave.
- Up to 2x I2C (Inter-Integrated Chip) compatible 2-wire master/slave.
- I2S (Integrated Inter-IC Sound Bus).
- UART (Universal Asynchronous Receiver-transmitter) with CTS/RTS.
- PDM (Pulse Density Modulation)

And there are 32 general purpose input output pins which can be configured and used as different interfaces mentioned above[9]. For our design, we are using an analog input, PDM, I2C and UART protocols to interface with different sensors, this will be discussed as the chapter proceeds.

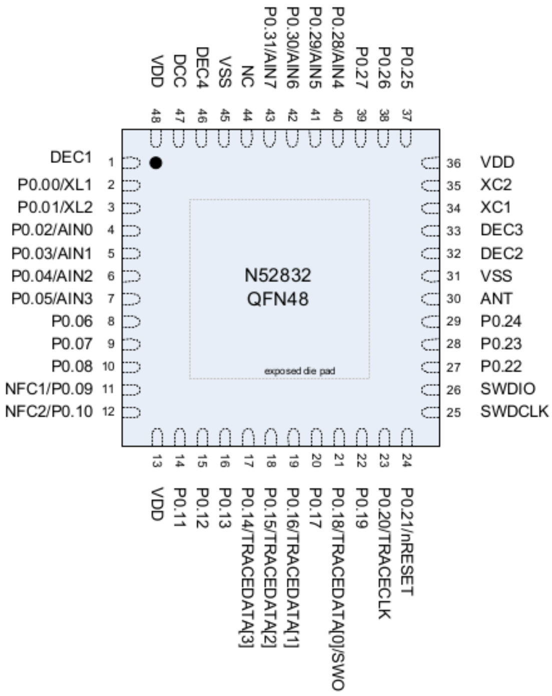

FIGURE 3.2: Pin layoyt diagram of nRF52832[17].

Nordic gives multiple reference circuits for a developer to choose from so that it can achieve the best performance.nRf52832 supply voltage ranges from 1.7V - 3.6V and has two power supply features, on-chip LDO and DC/DC regulators to down convert voltage for internal operations[9]. Depending on the application we have to choose between LDO or DC/DC. Using the DC/DC regulator will reduce current consumption compared to when using the LDO regulator. Why this happens because in LDO the energy for lowering the voltage from the supply voltage down in order to obtain the correct input voltage for the peripherals on the chip. Whereas DC/DC will use much of the energy obtained by lowering the voltage to actually increase the current. So the tradeoff is to have DC/DC only enabled at the moments the MCU is drawing high current, then disable it when the chip is using low current. This switching can be achieved by changing the DCDCEN register value.

Now, our system is intended for data streaming (Radar data) and occasional data transfer (Sensor data) with some data processing done on the Cortex M4F, which can be considered as high current consumption operation. So in order to bring down the current consumption, we used internal DC/DC. DC/DC requires an external LC filter to be connected between the DEC and DEC4 both L1 and L2 in Figure correspond to this.

nRF52832 has two internal RC oscillators at 64MHz and 32.768KHz[9] but the disadvantage with internal oscillators is the lack of precision and frequency stability especially when you using BLE radio. For this reason, there is an option on the chip to use two external crystal oscillator at 32 MHz and 32.768KHz. The external HF clock is critical for data timing and more critical to keep the Bluetooth radio on the correct frequency. All the 2.4GHz channels are derived from the 32MHz crystal. The use of external crystal oscillator further reduces the power consumption because internal RC oscillator must be calibrated every 4 seconds to be accurate enough. Two external crystals .32.768 kHz and 32 MHz are used for the design along with its load capacitors. A 2.4GHz antenna from Johanson Technology was used in the design, which has a frequency range of 2.4GHz to 2.5GHz. Remaining connections to the microcontroller are discussed in the coming sections

3.2 Multisensor board design

3.2.1 BME 680

BME680 has two protocol options I2C and SPI for interfacing with other MCU. We have chosen the I2C protocol because of two reasons.first being that SPI is much faster compared to I2C which is not at all required for our application and other is Single I2C bus can handle multiple sensors without increasing the wiring. Figure 3.3 shows the pin layout diagram of BME680.

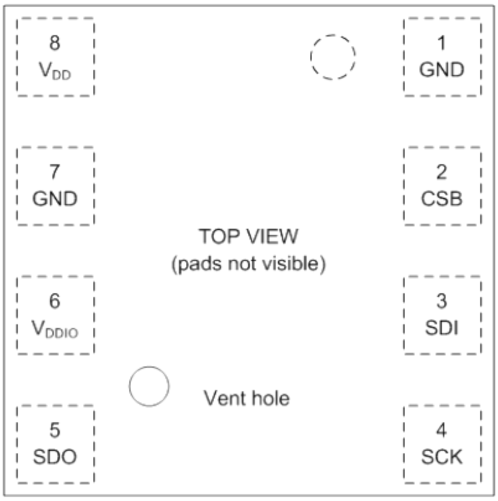

FIGURE 3.3: Pin layoyt diagram of BME680[17].

Pin	Name	I/O type	Description	nRF52832 pin connection
1	GND	Supply	Ground	-
2	CSB	In	Chip select	-
3	SDI	In/Out	Serial data input/ SDA for I2C	P0.07
4	SCK	In	Serial clock input	P0.08
5	SDO	In/Out	Serial data output	
6	VDDIO	Supply	Digital / Interface supply	-
7	GND	Supply	Ground	-
8	VDD	Supply	Analog Supply	-

TABLE 3.1: BME680 pin assignment and connection to nRF52832[17]

Interface type selection is done based on the CSB (chip select) status. If CSB is connected to VDDIO, then I2C interface is active and If CSB is pulled down to the ground then SPI interface is activated. The I2C interface pins SDA (Serial Data) and SCK(serial clock) are connected to VDDIO via 4.7 Kohm pull up resistors. As given in Table 3.1 pin number P0.07 and P0.08 of nRF52832 is connected to SDA and SCl pin of BME680 respectively. BME680 can have a 7-bit address in which 6 MSB bits are fixed 7th bit can be changed by connecting the SDO pin to either GND or VDDIO. We have connected it to GND which resulted in a slave address of 1110110 (0x76). 100nF bypass capacitors are used for the VDD and VDDIO connection. Figure 3.4 shows the schematic of BME680.

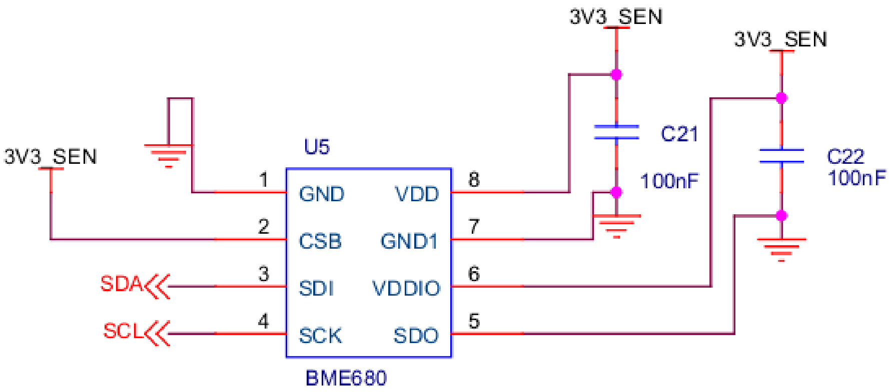

FIGURE 3.4: Schematics of BME680 sensor.

3.2.2 BH1745NUC

BH1745NUC is a digital colour sensor IC with the I2C bus interface.It can sense Red, Green and Blue lights (RGB) and converts them to digital values.

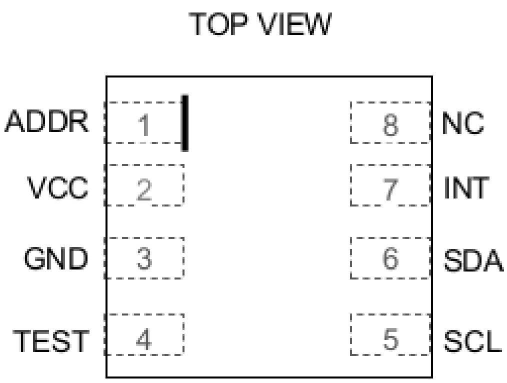

FIGURE 3.5: Pin layoyt diagram of BH1745NUC[18]

There is an Interrupt function which compares the measurement result selected from RGBC data by INT SOURCE register to the preset interrupt threshold level. INT pin monitors the status of the interrupt function[18]. Three 4.7Kohm pull up resistors should be connected to each SDA(Data), SCK(clock) and INT(Interrupt) pin because INT pin is Nch open drain terminal so this terminal should be pull-up to some kind of voltage source by an external resistor, similar reason holds for SDA and SCL. But since we are going to use the same I2C bus used by BME680 and there is already pull-up resistors connected to the SDA and SCL lines, so we don't have to connect again. So only INT pin requires a pull-up resistor. A 100nF bypass capacitor is connected to Vcc. Address pin ADD is connected to GND to get an address of bin -0111000.

Pin No	Pin Name	Function	nRF52832 pin connection
1	ADDR	Slave address for I2C	
2	Vcc	Power supply pin	
3	GND	GND terminal.	
4	TEST	For testing .Connect to GND.	
5	SCL	SCL interface for I2C.	P0.08
6	SDA	SDA interface for I2C.	P0.07
7	INT	INT pin for interrupt Status monitoring	P0.31
8	NC	Non connect (Open).	

TABLE 3.2: BH1745NUC pin assignment and connection to nRF52832[18]

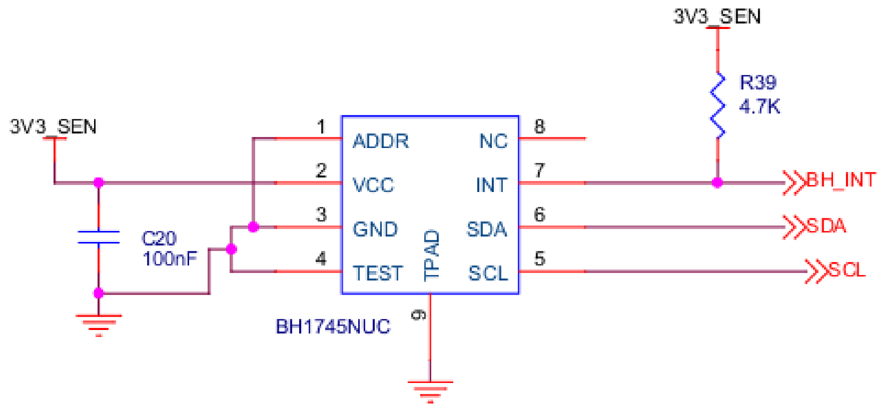

FIGURE 3.6: Schematics of BH1745NUC sensor

3.2.3 MP34DT06J

The MP34DT06J is an ultra-compact, low-power, omnidirectional digital MEMS microphone. It has PDM (Power Density Modulated) output synchronised with a clock.

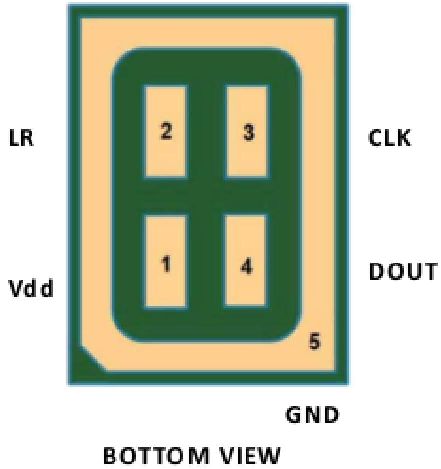

FIGURE 3.7: Pin layoyt diagram of MP34DT06J [19].

From the Figure 3.7 and Table 3.3 we can see that there is an option for selecting left or right channel. To select between them we have to connect the LR pin to either GND or Vdd. L/R pin is connected to ground in our design for selecting the right channel. A 100nF and 1microF capacitors are connected in parallel to pin Vdd.

Pin	**Pin name**	**Function**	**nRF52832 connection pin**
1	Vdd	Power supply	
2	LR	Left/Right channel selection	
3	CLK	Synchronization input clock	P0.26
4	Dout	Left/Right PDM data output	P0.25
5	GND	Ground	

TABLE 3.3: Pin asssignment and connection of MP34DT06J to nRF52832[19]

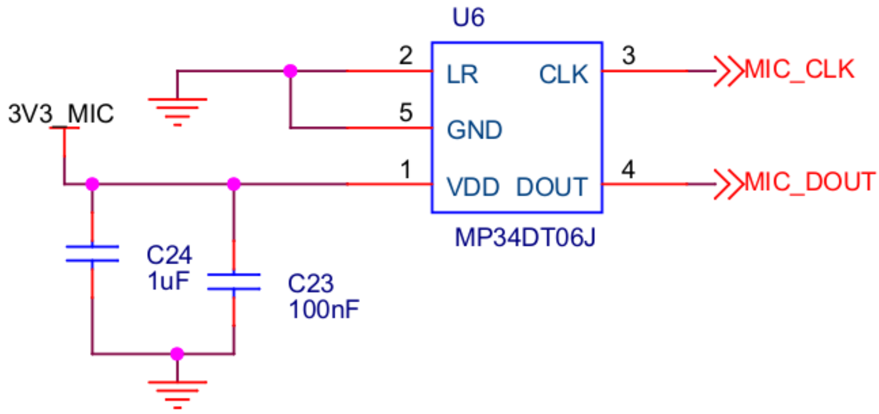

FIGURE 3.8: Schematics of MP34DT06J sensor .

3.2.4 RESP_IRR_20 P Package 110-901

As we have discussed in the previous chapter, SPEC Sensors RESP_IRR_20 is a Screen Printed ElectroChemical sensor. The sensor contains mainly three pins corresponding to 3 electrodes namely Reference Electrode (RE), Working Electrode, Counter Electrode(CE). There are two unused pins and two WE pins which can be shorted and used. Like any other electrochemical cell this sensor to performs best when operated at a fixed bias potential. The working of the sensor is as follows.Due to Electrochemical Reaction with the target gas sensor produce electrons which flows to or from WE through an external circuit. A counter-electrode is provided to complete the circuit of the electrochemical cell. The addition of the third electrode, called the reference electrode, improves the stability, signal-to-noise ratio, and response time of the 2-electrode design by providing a stable electrochemical the potential in the electrolyte. Texas Instruments's LMP7721 is used as opamp for the circuit, We operate the sensor in zero bias mode by connecting the V+ to ground through a 10 Kohm resistor. A transimpedance amplifier is used to convert the small current from the sensor to a voltage. The gain of the transimpedence amplifier is determined by the resistor R46, which is 1.2Mohm in our design (Refer Figure 3.9) . For example, a 10 ppm carbon monoxide sample produces a typical signal current of approximately 500nA, which gives an output voltage of 600mV. The output voltage is given to the ADC of nRF52832 through pin P0.28. A PMOS is used to keep the WE and RE at the same potential when the sensor is not powered.

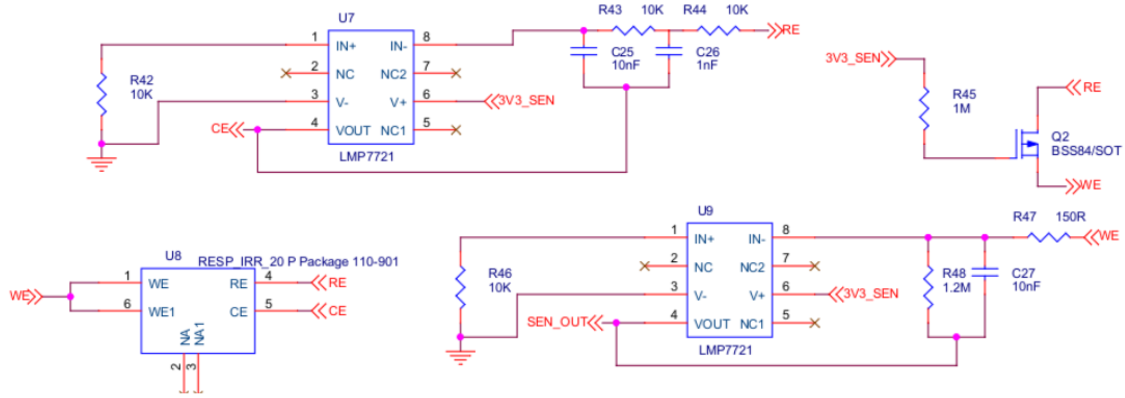

FIGURE 3.9: Schematics of RESP_IRR_20 P Package 110-901 sensor .

3.2.5 Power supply design

Table 3.4 gives the operating voltage and current consumption of individual sensors and microcontroller. These values depend on the mode of operation, so we have considered extreme cases.

Sensor	Current consumption	Supply voltage range
BME 6810	3.7 microA at 1Hz and .09-12 mA (when all sensors are used (P,T, H and gas)	1.71 - 3.6V.
MP34DT06J	650microA in Normal mode operation	
BH1745NUC	130microA	2.3 - 3.6 V
nRF52832	9.2mA at peak	1.7 - 3.6V.

TABLE 3.4: Powwer cunsumption and supply voltage of individual sensors

IAQ monitor is a zero power sensor. but the opamp used have a Supply Voltage 1.8 V to 5.5 V. Below are the components used for power supply design:

Power supply Components.

- USB 5 pin Micro B connector.
- Transient Voltage Suppressors (TVS)
- LiPo battery charger (Bq21040)
- 3.7V LiPo Battery.
- P-MOS Transistor(BSS54)

- Voltage regulator (TPS63000)

Since all the sensor operates below 3.6 we decided to power the full circuit with a common supply voltage of 3.3 V derived from a 3.7 V LiPo battery which can be charged from a 5V Micro USB adapter. An option is given to power the device directly from the wall adapter while charging the Lipo battery. This achieved by adding a PMos transistor to multiplex the power from a wall adapter and battery.
Proper battery management is one of the major requirements when integrating Li - Poly batteries into design. Unless properly designed, these types of batteries carry a risk of fire and explosion. A LiPo battery charger (Bq21040) is used to address this problem. Sometimes the voltage of the LiPo gets above 4V so we use a Voltage regulator (TPS63000) to reduce the voltage to 3.3V. For USB 5 pin Micro B connector transient Voltage suppressors (TVS) are used in parallel with the Vbus to clamp the temporary spikes in the voltage and D+ and D- are left open.

3.2.5.1 Bq21040 design requirements.

The bq21040 device is a highly integrated linear battery charger Li - Ion and Li - Pol that targets portable applications with limited space. The device runs either from a USB port or from an AC adapter. The high input voltage range with protection against input over voltage supports unregulated adapters that are low cost[20].

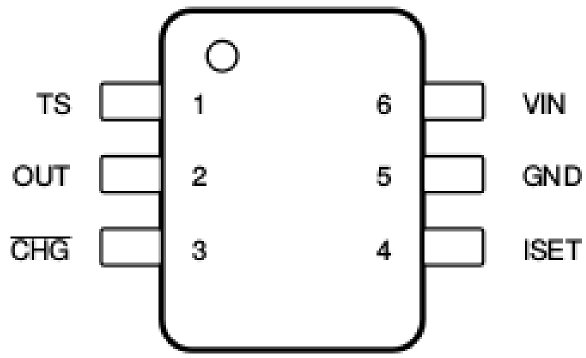

FIGURE 3.10: Schematics of Bq21040[20]

3.10 show pin layout of the chip, functions and connections of each pin are given below.

Pin $\overline{CHG}$ pin - Low indicates charging and open drain indicates no charging or Charge complete. A pull up resistor of 10 kohm is connected to this pin.
Iset pin - Programs the fast-charge current setting. The external resistor from ISET to VSS defines fast charge current value ranging from 10.8kohm(50mA) to 675ohm (800mA). we have chosen a resistor value of 1Kohm to get the fast charge value of 540mA.
OUT pin - To which battery connection is made, a bypass capacitor of 1microF is also connected.
Ts- Pin for temperature sensing using NTC thermister to monitor battery. we have connected a 10Kohm thermister to Ts pin. Vin - Input power connected to external DC supply AC adapter or USB port. A bypass capacitor of value 1microF is used. An LED is connected through a 1.5Kohm resistor to Vout to indicate power out.

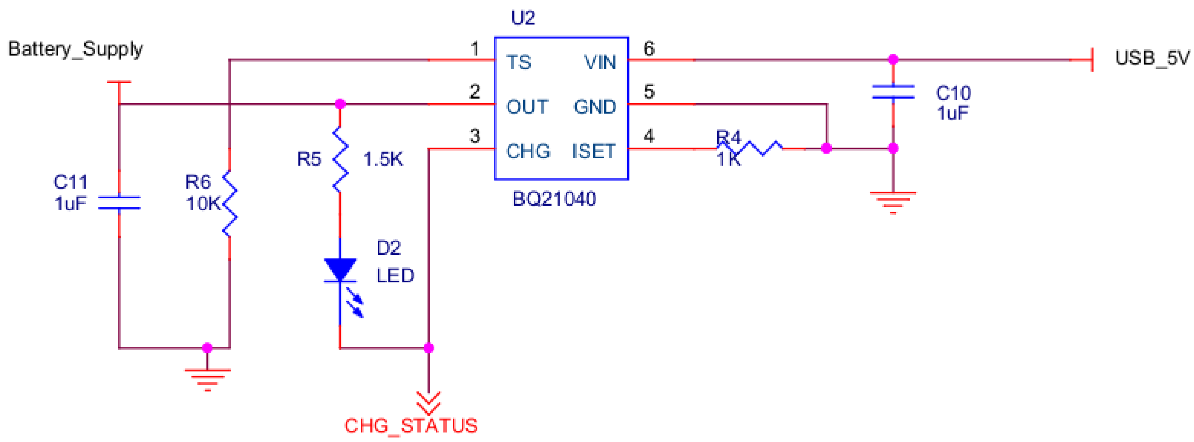

FIGURE 3.11: Schematic diagram of BQ21040

3.2.5.2 TPS63000 design requirements

TPS63000 DC/DC converters are designed for single - cell Li - ion or Li - polymer battery - powered systems with a typical voltage between 2,3 V and 4,5 V. Figure 3.12 gives the pin layout of TPS63000, the following are pin functions and connection in our design. Pin En is Enable pin for activating the chip.EN is connected to VIN so that TPS63000 is put into operation when VIN is high. Power save mode is disabled when VIN is high by connecting PS/SYNC to VIN pin. The supply voltage for control Stage is given through VINA which is also connected to VIN pin.
Pin Fb is a feedback pin which decides the output voltage. We require a fixed

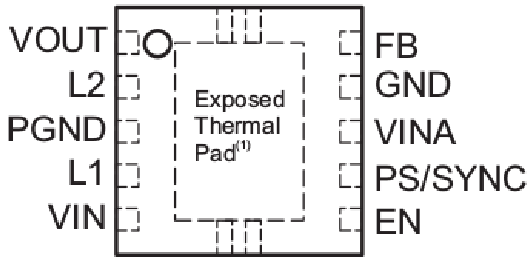

FIGURE 3.12: Pin layout diagram of TPS63000 [21]

3.3V output voltage. For this, a resistor divider is connected between VOUT, FB and GND. The typical value of the voltage at FB is 500 mV and typical current into the FB pin is 0.01 A. Based on these values, the recommended value of R2 is below 500Kohm but the manufacturer recommends a value below 200 Kohm. Value of R1 is calculated based on the equation.
R1 = R1 $\times$ ($\frac{V_{out}}{V_{in}}$ - 1). Choosing R2 as 178 Kohm results in R2 = 1M ohm.
As mentioned in the previous chapter all DC-DC converter requires an external inductor and TPS63000 provides pin L1 and L2 for connecting it. A 2.2 microH inductor is connected between them for our design.

3.3 Radar BLE board

For Radar BLE design nRF52832 reference circuit remains the same

3.3.1 Interfacing X4M04 with nRF52832

X4M03 comes with multiple interfacing options, a 16 pin port which includes multiple I/O pins which can be used to control the Atmel SAM S70 MCU and SPI/UART interface for data transfer, a USB interface for communicating with the computer and 10 pin debugging serial wire interface. Inorder to connect X4 with nRF52832 we have used the 16 pin interface,Table 3.5 gives complete connnection information.

Sl. No.	Name	Type	NRF PIN No.
1	VDD_EXT	Power, 3.3 - 5.5V	
2	GND	Power	
3	MOSI/RX	I/O	P0.04
4	MISO/TX	I/O	P0.29
5	SCLK	I/O	P0.03
6	nSS	I/O	P0.28
7	nRESET	Input with pull-up	P0.06
8	IO7/WAKEUP	I/O	P0.17
9	IO8/SWCLK	I/O	P0.19
10	IO9/SWDIO	I/O	P0.20
11	IO1	I/O	P0.11
12	IO2	I/O	P0.12
13	IO3	I/O	P0.13
14	IO4	I/O	P0.14
15	IO5	I/O	P0.15
16	IO6	I/O	P0.16

TABLE 3.5: X4M03 16 pin out interface conection with nRF52832

3.3.2 Power supply design

Radar BLE board is designed to power from a USB connector. We have used TPS61201 DC-DC regulator for supplying a fixed 3.3 V to both nRF52832 chip and X4M03.

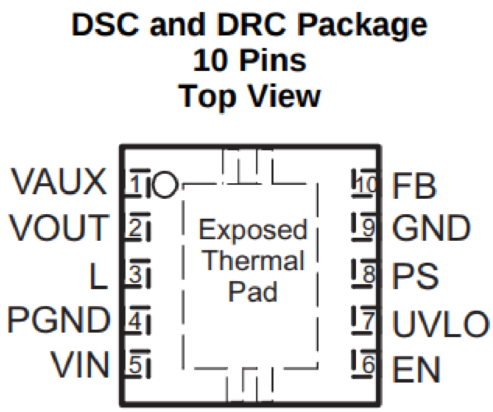

FIGURE 3.13: Pin layout diagram of TPS61201 [22]

Circuit for TPS61201 is similar to that of tps63000. It too has an Enable (En) pin we have connected it to 5V.

Fixed and adjustable versions of output voltage are available within the TPS6120X family. The FB pin is used to detect the output voltage to properly configure the fixed output voltage devices. This means it needs to be directly connected to the VOUT. An external resistor divider is used to change the output voltage for the adjustable output voltage version..we have needed a 3.3 fixed output voltage so it's directly connected to VOUT.

If the supply voltage is too low, the UVLO input can be used to shut down the main output. Typically, the internal reference threshold is 250 mV. So for the supply voltage to cause shutdown when it drops below 250 mV, VIN should be directly connected to the UVLO pin. Else if the shutdown should occur at higher voltages, we can use a resistor divider.In our configuration we have connected UVLO to VIN. To make sure that the TPS6120X devices can operate, an inductor must be connected between the VIN and L pins. We have used a manufacturer suggested value of 2.2 micro. 10 microF and 0.1 microF bypass capacitors are used for VIN and VOUT. Figure 3.14 shows the schematics of the design.

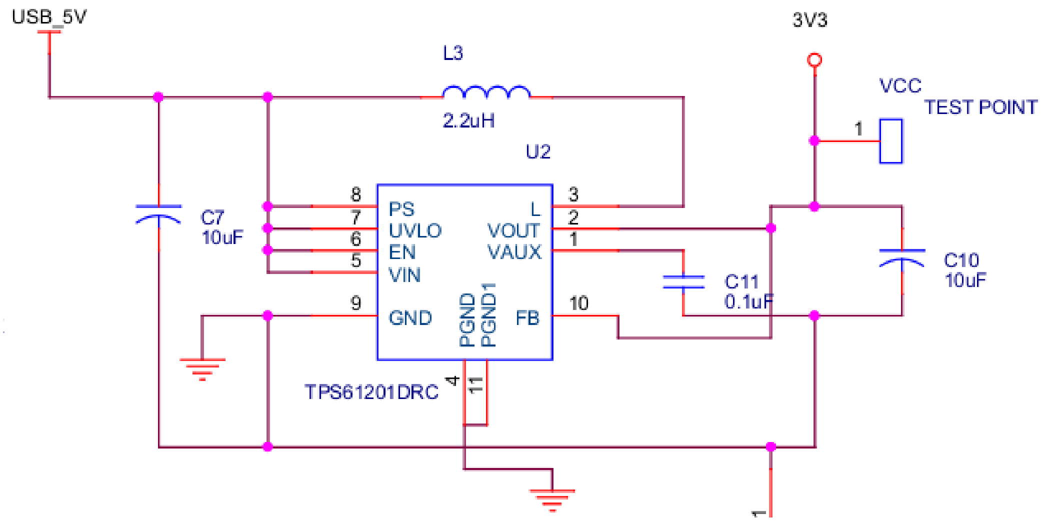

FIGURE 3.14: Schematic diagram of TPS61201 [22]

Chapter 4

Basic software implementations

This chapter discusses the software implementations done for the project at different levels, starting from Xethru X4 radar data acquisition, nRF52832 BLE chip programming, mobile app development, movement and breathing detection algorithm implementation.

4.1 Radar Data aquisition

Xethru X4M03 comes with Xethru Embedded platform(XEP). XEP provides the low-level building blocks of a XeThru Embedded application and serves as a firmware platform for the XeThru module products. It provides all necessary features to interact with the XeThru radar X4, running application code, and interact with a host through serial communication. It contains two important functional layers: Module Communication Protocol X4M03 for communicating with the host [23].

X4 driver layer provides the developer with direct access to all XeThru X4 SoC functionalities. The host can use the Module Connector provided by Xethru to send instructions such as setting X4Driver configuration and start radar frame streaming. Module connector is provided only for Computer system (Ubuntu and Windows) and Raspberry Pi [23]. In order to interface with an MCU Xethru provides a Module communication protocol Wrapper(MCPW) which is implemented on the host MCU. In our case host is the nRF52832 chip

Before interfacing directly with the BLE chip we wanted to understand the radar output data frames and connecting to a PC is the easiest way to interface with X4M03. A python code was written on top of the Xethru proprietary code to stream the data point from radar to PC and log it to a file.

4.2 nRF52832 chip BLE programming

We used Segger Embedded Studio for ARM, Linux, 64-bit V4.12 IDE for code development and nRF5 Software Development Kit v15.2.0 for APIs. We have used a BLE peripheral example provided in the software development kit program as the base to build our BLE program. Here we give a brief introduction to all these tools.

4.2.1 Software development kit

The development kit v15.2.0 is a collection software API for microcontrollers of the nRF52 series that can be used freely in the development of BLE applications. We have used the softdevice API version 132 for our project. SoftDevice is a wireless protocol stack library for building System on Chip (SoC) solutions provides by Nordic Semiconductors. The kit provides the entire BLE protocol stack, premade projects supporting different IDE including Segger studio, keil etc. Binary files of each of the example projects are also given[24]. A good approach for a developer is to select a readily available build project which matches closest with the application, the developer has in mind and to modify the relevant parts. Our BLE project is a modification of the BLE UART project.

4.2.1.1 SoftDevice

SoftDevice consists of three main components:

1. SoC Library: Ensures Application and SoftDevice coexistence with secure sharing of common Chip System (SoC) resources.
2. The SoftDevice Manager (SDM): This Application Programming Interface (API) allows the SoftDevice to be managed at the top level. It controls the

state of the SoftDevice and configures the behavior of some core functionality of the SoftDevice.

3. Bluetooth 5 Low Energy protocol stack: This set of the component allows fast implementation of BLE 5 on the chip [24].

The Bluetooth 5 compliant host and controller implemented by the SoftDevice comes with multi-role support such as Central, Observer, Peripheral and Broadcaster. It allows applications to implement standard low energy Bluetooth profiles and proprietary application case implementations. The Application Programming Interface (API) is defined above the Generic Attribute Protocol (GATT), Generic Access Profile (GAP), and Logical Link Control and Adaptation Protocol (L2CAP). Other protocols, such as the Attribute Protocol (ATT), Security Manager (SM), and Link Layer (LL), are managed by the higher layers of the SoftDevice as shown in the Figure 4.1. [24].

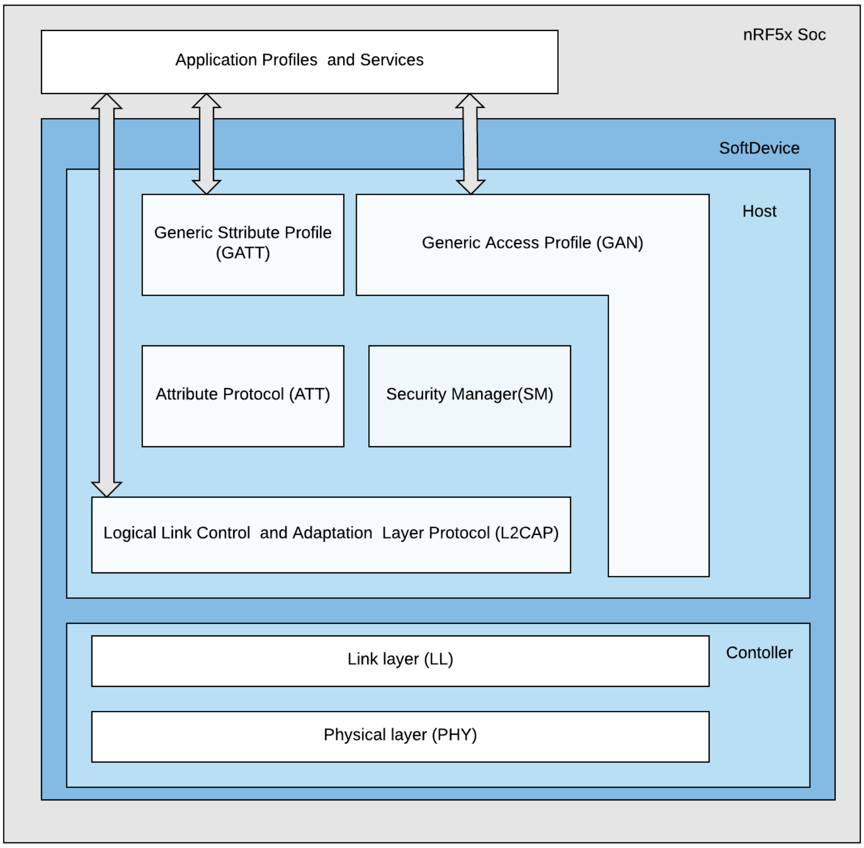

FIGURE 4.1: SoftDevice stack architecture.

4.2.2 Code implementation

Below code is for streaming Data points received by the nRF52832 chip from a UART device to mobile phone. A basic python program was written in the PC to implement Serial communication over USB. A USB to UART converter was used to connect to nRF52832 UART pins.
Now coming to the BLE programming, as mentioned above it is always good to selected an existing example and customize it based on our application.we have selected a BLE UART example. The program commences from the main function placed in the Application main.c file. All the initialisation of the different hardware and software are done in main.c by calling different functions.
uart_init(): The first function in main.c which initiates the UART communication parameters like baud rate, set CTS, RTS, Rx and Tx pins of UART and initialise a FIFO buffer for Tx and Rx.
timers_init(): The function is called for initializing the timer module. It enables the application to create multiple timer instances based on the RTC1 (Real-time Clock1) peripheral.
ble_stack_init(): This function initializes the SoftDevice and the BLE event interrupt, configure the BLE stack using the default settings, fetch the start address of the application RAM.
gap_params_init This function will set up all the necessary GAP (Generic Access Profile) parameters of the device like Device name and connection parameters. It also sets the permissions and appearance.
gap_conn_params.min_conn_interval = MIN_CONN_INTERVAL
gap_conn_params.max_conn_interval = MAX_CONN_INTERVAL
gap_conn_params.slave_latency = SLAVE_LATENCY
gap_conn_params.conn_setup_timeout = CONN_SUP_TIMEOUT
gap_conn_params is a structure variable containing Gap parameters and its values are defined as Macros in the beginng of the main.c Simillarly there are Structure vaiable for security parameters and appearences and are defined in ble_gap.h.
gatt_init() is the next function called in main which initiates GATT library and calls functions defined in nrf_ble_gatts.c which set parameters for GATT like:
p_gatt → evt _handler = evt_handler
p_gatt → att_mtu_desired_periph = NRF_SDH_BLE_GATT_MAX_MTU_SIZE
p_gatt → att_mtu_desired_central=NRF_SDH_BLE_GATT_MAX_MTU_SIZE

p_gatt $\rightarrow$ data_length = NRF_SDH_BLE_GAP_DATA_LENGTH

services_init(): Service function does two things. First to Initialize Queued Write Module which handles prepare write, execute write, and cancel write. Then to initialize UART services. Nordic provides a UART service under nRF_BLE_Services which helps us to develop proprietary UART services and characteristics for sending and receiving UART data to a client using BLE. Below are few of the functions ble_nus.c contains
Function for handling the BLE_GAP_EVT_CONNECTED event from the SoftDevice.
Check the hosts CCCD value to inform of readiness to send data using the RX characteristic
Function for handling the BLE_GATTS_EVT_WRITE event from the SoftDevice.
Function for handling the BLE_GATTS_EVT_HVN_TX_COMPLETE event from the SoftDevice
advertising_init(): Function is called for initializing the Advertising functionality.
conn_params_init(): Function for initializing the Connection Parameters module.
nus_data_handler(): This function will process the data received over BLE Service and send it to the UART module. It takes a structure pointer as a parameter which points to ble_nus_evt_t containing Event type, A pointer to the instance, Connection handle and Rx data.
uart_event_handle():It Handles the data received over UART. This function receives a single character from the app uart module and attaches it to make up a string. The string will be sent over BLE when the last character received was a 'new line' $\backslash n$ (hex 0x0A) or if the string has reached the maximum data length.

4.2.3 Mobile BLE App

A mobile app is necessary for receiving the data that we sent over BLE. Developing an Android app is not an option due to time constraint. So we decided to make use of an open source workbench from EvoThings called Evothing studio. It consists of three connected parts, Evothings Workbench, the application that runs on the desktop, the Evothings Viewer app which runs on mobile

device and cloud servers to connect the Workbench and the Viewer application. Evothing workbench contains BLE app templates and example written in javascript language and can be modified according to our needs. To put the BLE app on the mobile phone, we need to connect the workbench to the mobile View app. For this workbench gives an option to generate a one-time key that can be fed into the mobile viewer and both Desktop and mobile are connected. Now clicking on the run option against example app or custom made app will transfer the code to mobile and will run like a normal mobile app.
We customised an existing example app by making changes according to our requirement which enabled us to transfer the Data points sent from the nRF52832 chip to mobile phone. The app was made such a way that it can transfer the data points to a server for further processing. Figure 4.2 shows the interface of the app generated and 4.3 shows the data sent to a web server which is displayed on the HTML page.

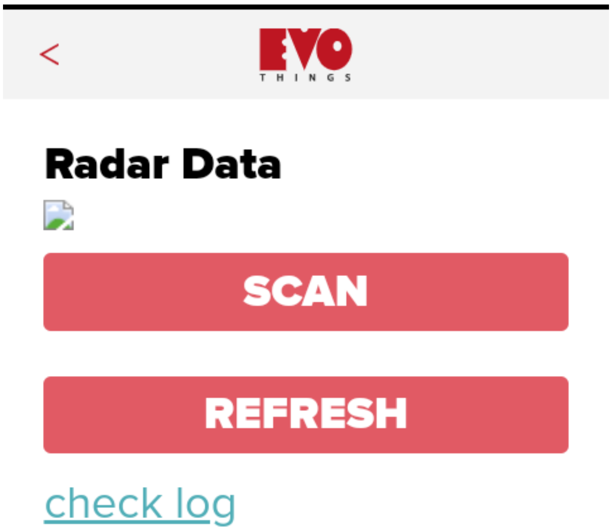

FIGURE 4.2: User interface of the mobile app.

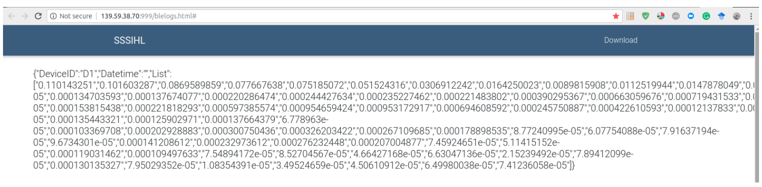

FIGURE 4.3: Data points displayed on the web.

4.3 DSP algorithm implementation for movement detection and breathing rate measurement

The Raw radar data contain reflections from multiple objects within 9.9m.This is calculated from the Sample rate of the radar which is 23.328GS/s and total the number of samples it can take that is 1536 samples. The down converted data contain 180 data points which means that each range bin represents a distance of 5.5cm. We have programmed the X4M03 to output 17 Frames per second.
The algorithm implementation was done using python language for which python packages like Numpy, Scipy and Mtplotlib were used. The breathing data stored in the web page was extracted block by block to implement the algorithm. Each block corresponds a specific number of frames. We have used a block size of 34 frames corresponding to 2 seconds of data. These blocks of frames were arranged in to a matrix of size MXN. M is the number of frames and its 34 in our case. Value of N is the number of samples in the frame that is 180 and M represents the Slow axis and M represents Fast axis. In order to

$$\begin{array}{c|ccccc}
 & \multicolumn{5}{l}{\text{FAST AXIS................}} \\
\text{S L} & D_{11} & D_{12} & \ldots\ldots & \ldots\ldots & D_{1N} \\
\text{O W} & D_{21} & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\
 & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\
\text{A X} & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\
\text{I S} & D_{M1} & \ldots\ldots & \ldots\ldots & \ldots\ldots & D_{MN}
\end{array}$$

detect the movement we have used variance based algorithm. The algorithm is framed based on the fact that reflected radar signal is amplitude modulated by the chest movement of the breathing person. By looking at the variance of range bin amplitude through time we can detect the presence of a moving target and estimate the distance from the radar. If there is a large movement like a person moving, the variance would spread across the range bins but if there is a small movement like the breathing of a stationary person, Variance will be constrained to a single bin.
The variance along the slow axis is calculated for each of the bin for a particular

block of a matrix. The range bin (Rmax) which give rise to the largest variance corresponds to a target which is moving. The value of the range bin is added to an array. If the range bin corresponding to the largest variance remains constant over a K number of times (Value of K used in our case was 2 corresponding to 4 seconds) then that represents a small periodic movement within a range bin. Then FFT of the corresponding bin is found, the highest peak corresponds to the breathing rate of the person. The block diagram of the algorithm is given in Figure 4.4

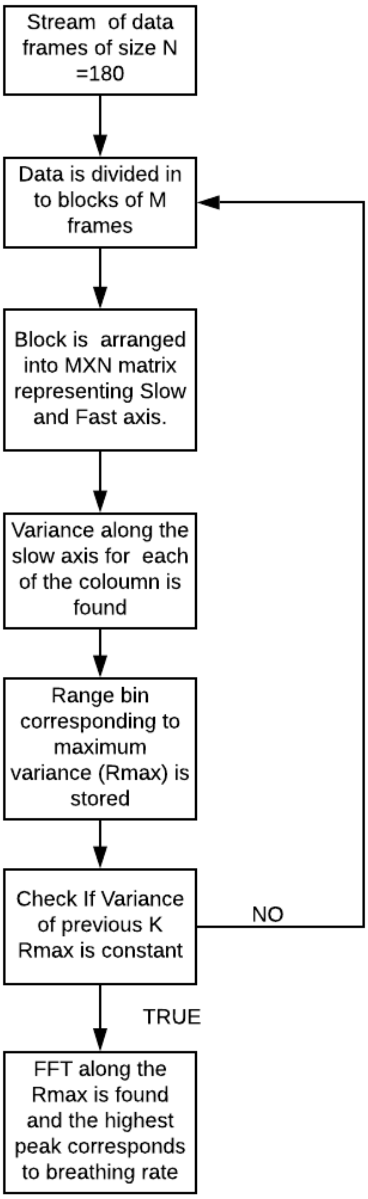

FIGURE 4.4: block diagram of the implemented algorithm.

Chapter 5

Results and future work

5.1 Results and discussions

The project mainly concentrated on hardware design and development of the sensor modules and basic software implementation to verify the working of the hardware.
Two different hardware modules were designed: A radar BLE board which interfaces with X4M03 and Sensor BLE board integrating multiple sensors for ambient monitoring. The complete Schematics of the design is Shown in Appendix A. PCB layout (Bottom and Front View) of the radar BLE module is shown in Figure 5.1. Fabrication of the above module was carried out by SmartX Connected Products Pvt.Ltd. Chennai, fabricated hardware is shown in Figure 5.2.

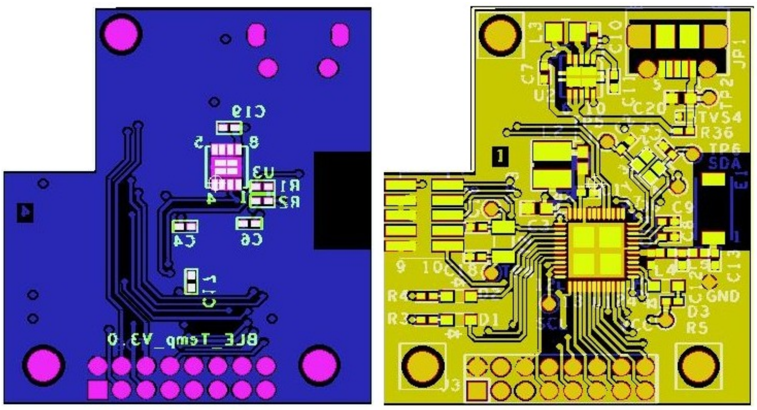

FIGURE 5.1: PCB layout of the Radar BLE board,Bottom and front view respectively.

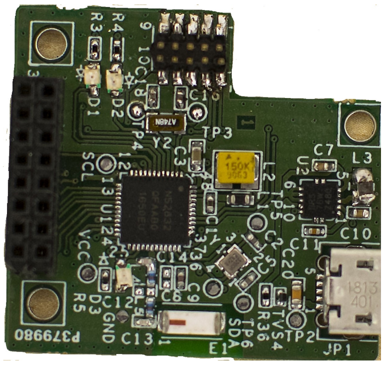

FIGURE 5.2: Image of the fabricated Radar BLE board.

Figure 5.3 and Figure 5.3 shows the PCB layout and Silk Screen Top and Bottom of the multisensor board. The Fabrication of this PCB board is underway.

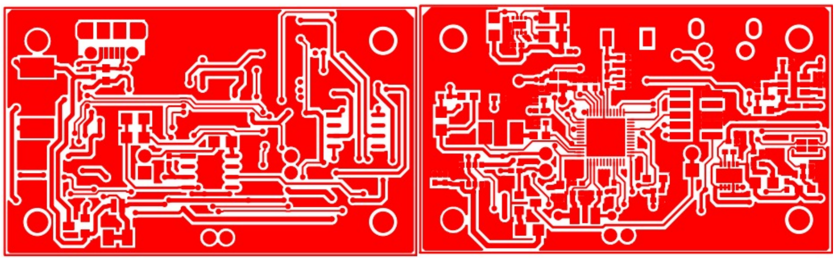

FIGURE 5.3: PCB layout of the Multisensor board ,Bottom and Top view respectively.

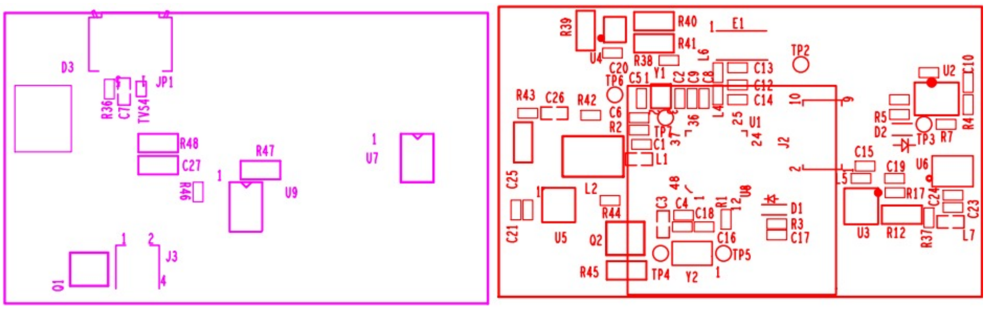

FIGURE 5.4: Silk Screen Bottom and Top of the Multisensor board respectively.

To verify the working of the develpoed Radar BLE module a Bluetooth program was written into the nRF52832 chip to transfer data received from a UART device to a mobile phone and then the data was logged to a server. Figure 5.5 shows the interface of the app generated and 5.6 shows the data sent to a web server which is displayed on the HTML page.

Radar data points were successfully streamed from X4M03 to a PC. The plot of the down-converted raw radar data is shown in Figure 5.7. X-axis of the

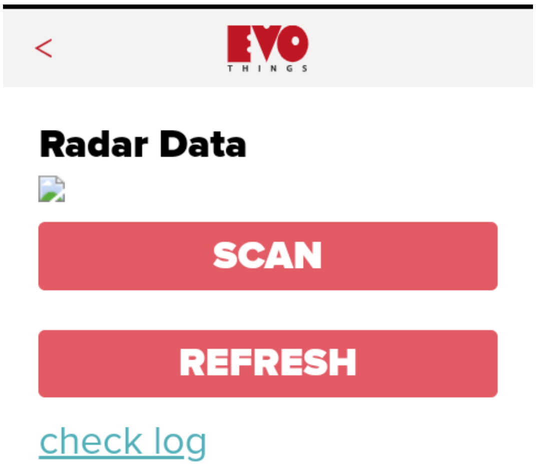

FIGURE 5.5: User interface of the mobile app.

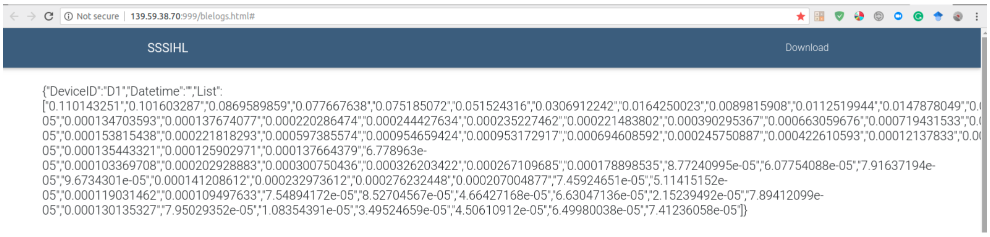

FIGURE 5.6: Data points displayed on the web.

plot corresponds to rangebins representing distance from the radar and Y-axis corresponds to the normalized intensity of reflection from multiple objects.

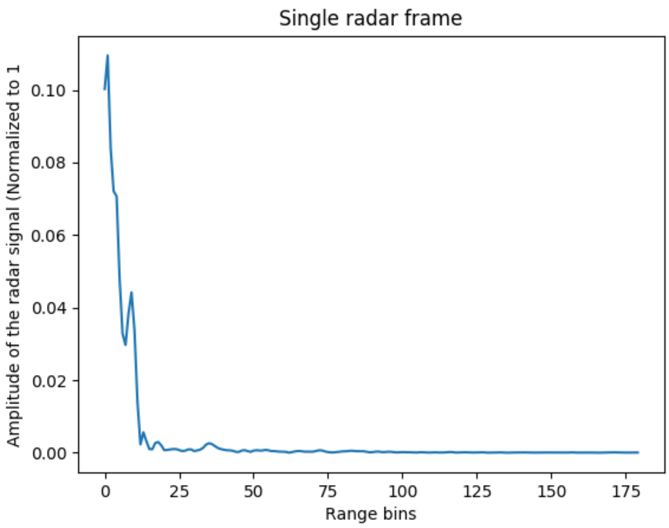

FIGURE 5.7: Plot of a single radar frame. Each range bin corresponds to a sample.

Radar data logged in to the server was extracted and DSP algorithms where implemented on it for movement detection and respiration rate estimation. Figure 5.8 shows the graph of variance along the slow axis, the highest peak corresponds to the distance at which maximum movement is detected and in our case this is at .37 meters and correspond to the breathing of a person at that distance.

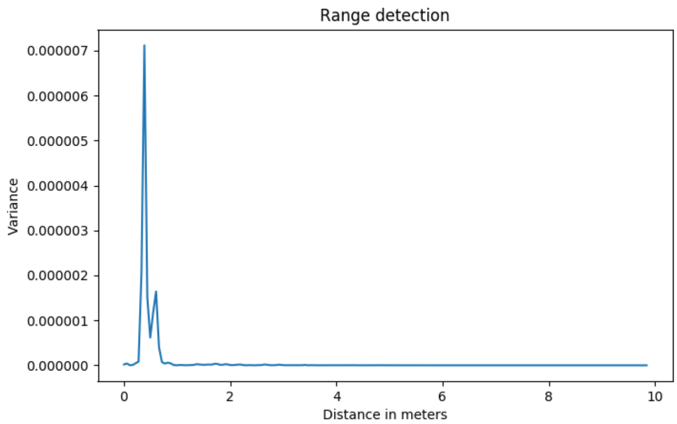

FIGURE 5.8: Range detection using variance method. The highest peak corresponds to the presence of a moving target.

Once the range of the breathing person is detected an FFT along the slow axis was carried out to detect the breathing rate of the person. Figure 5.9 shows the FFT of the rangebin corresponding to the breathing pearson and inset shows the peak at .72Hz which is the breathing rate of the person.

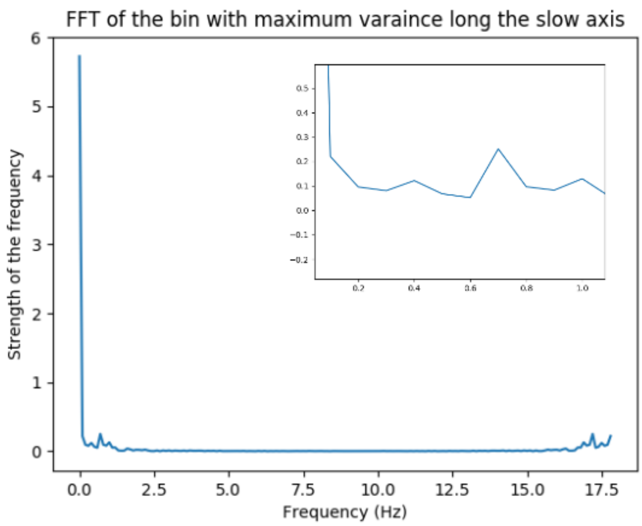

FIGURE 5.9: FFT of the breathing signal. The peak corresponds to the breathing rate

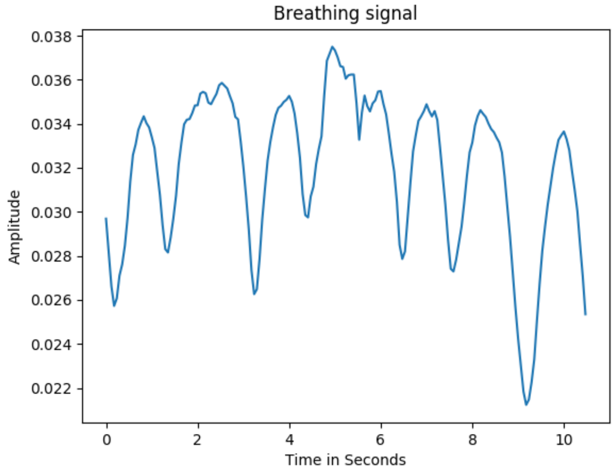

FIGURE 5.10: Plot of the breathing signal for a period of 10 seconds.

A plot of amplitude variation of the rangebin corresponding to the breathing person gives the breathing signal and is shown in the 5.10. All the above results are obtained at 17 Frames per Second.

5.2 Future work

- Interfacing X4M03 radar module with nRF52832 through UART or SPI protocol so that real-time radar data can be streamed to a mobile phone.
- Firmware development and implementation for multi-sensor data collection.
- The developed algorithm for respiration rate and motion detection has to be tested under different conditions and should be modified to meet the medical standards.
- Sleep classification and disease detection from the vital parameters and correlate with the external parameters monitored using the multi-sensor board.

Appendix A

Circuit schematics

A.1 Radar BLE module

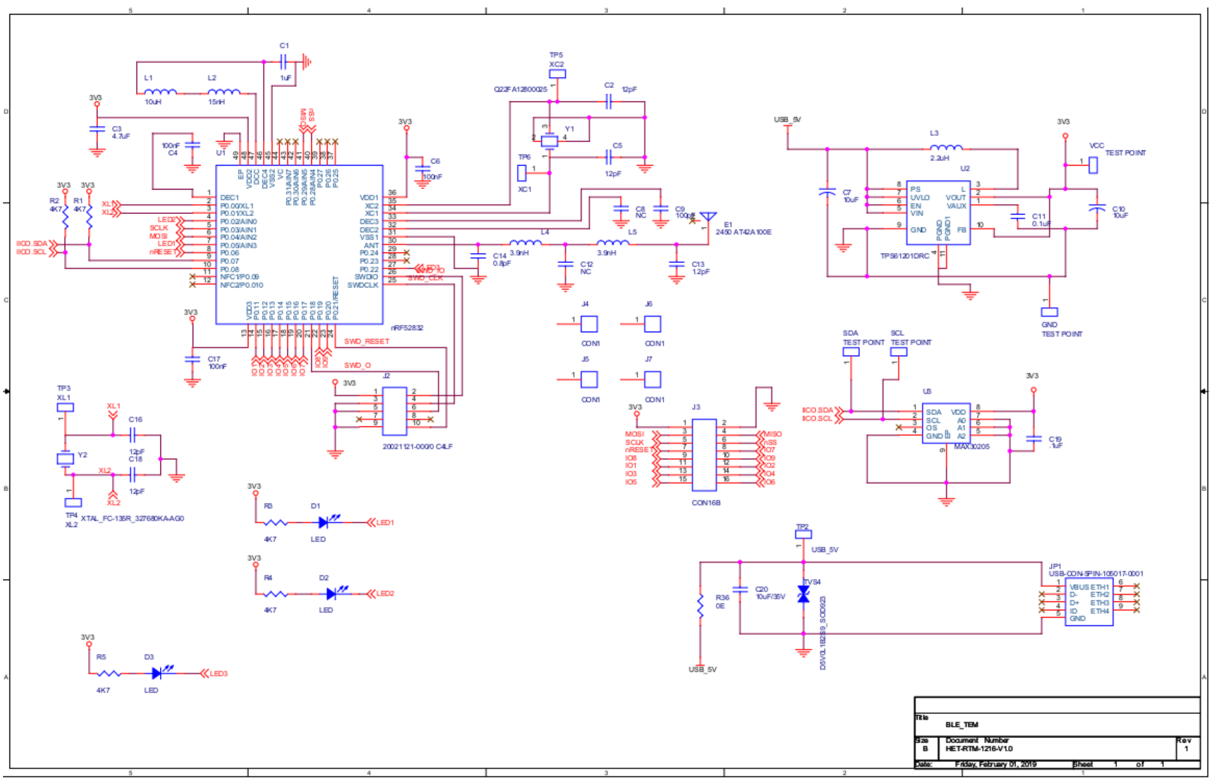

FIGURE A.1: Schematic diagram of Radar BLE module part

A.2 Multisensor BLE module

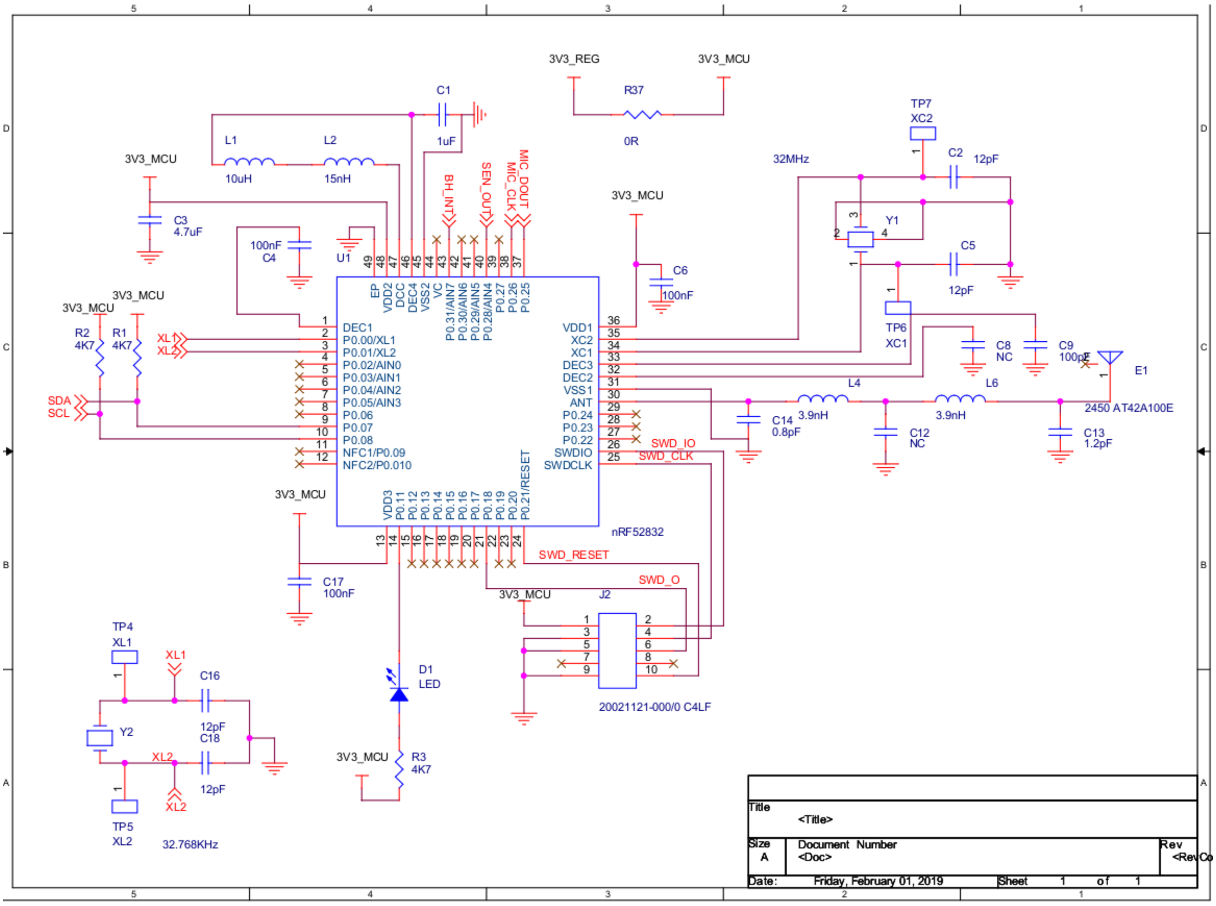

FIGURE A.2: Schematic diagram of Multisensor module part 1

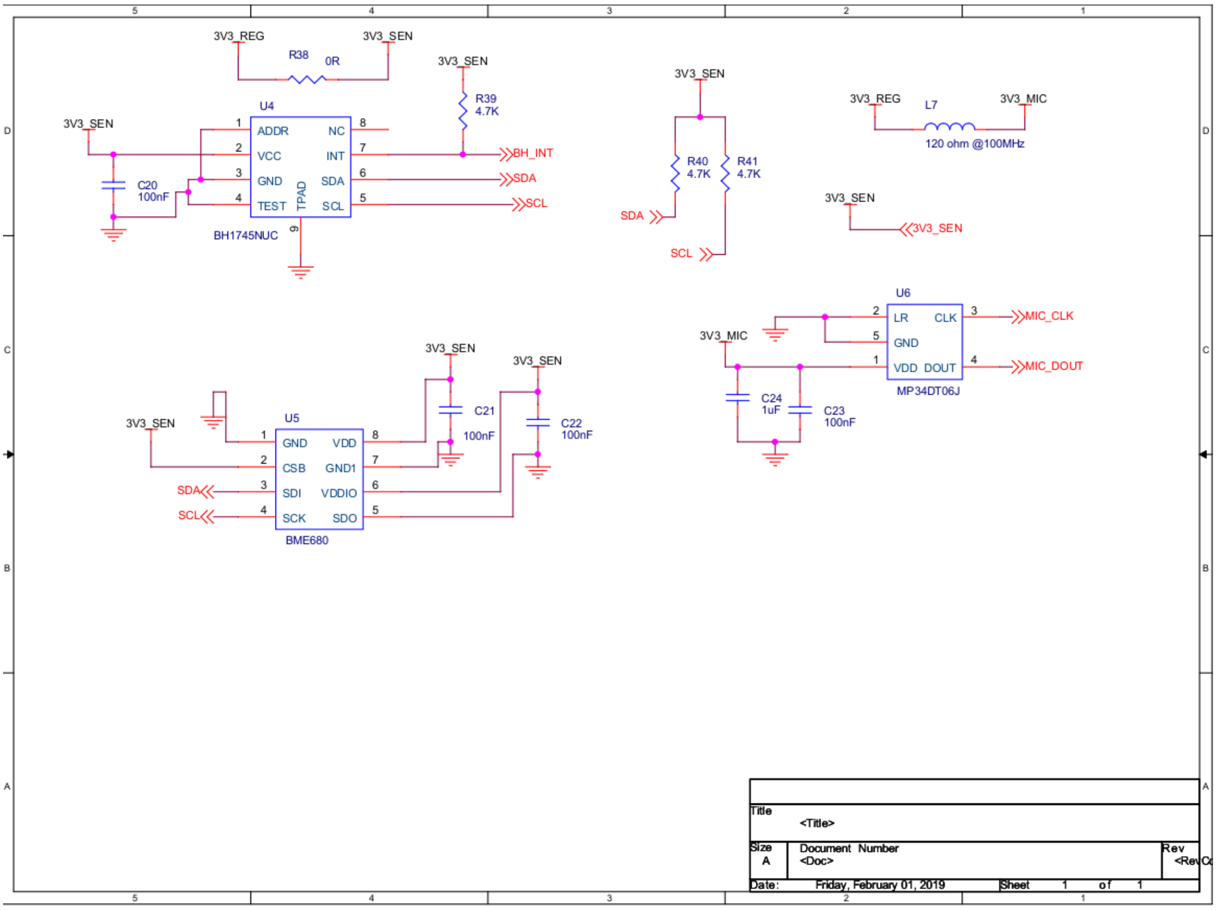

FIGURE A.3: Schematic diagram of Multisensor module part 2

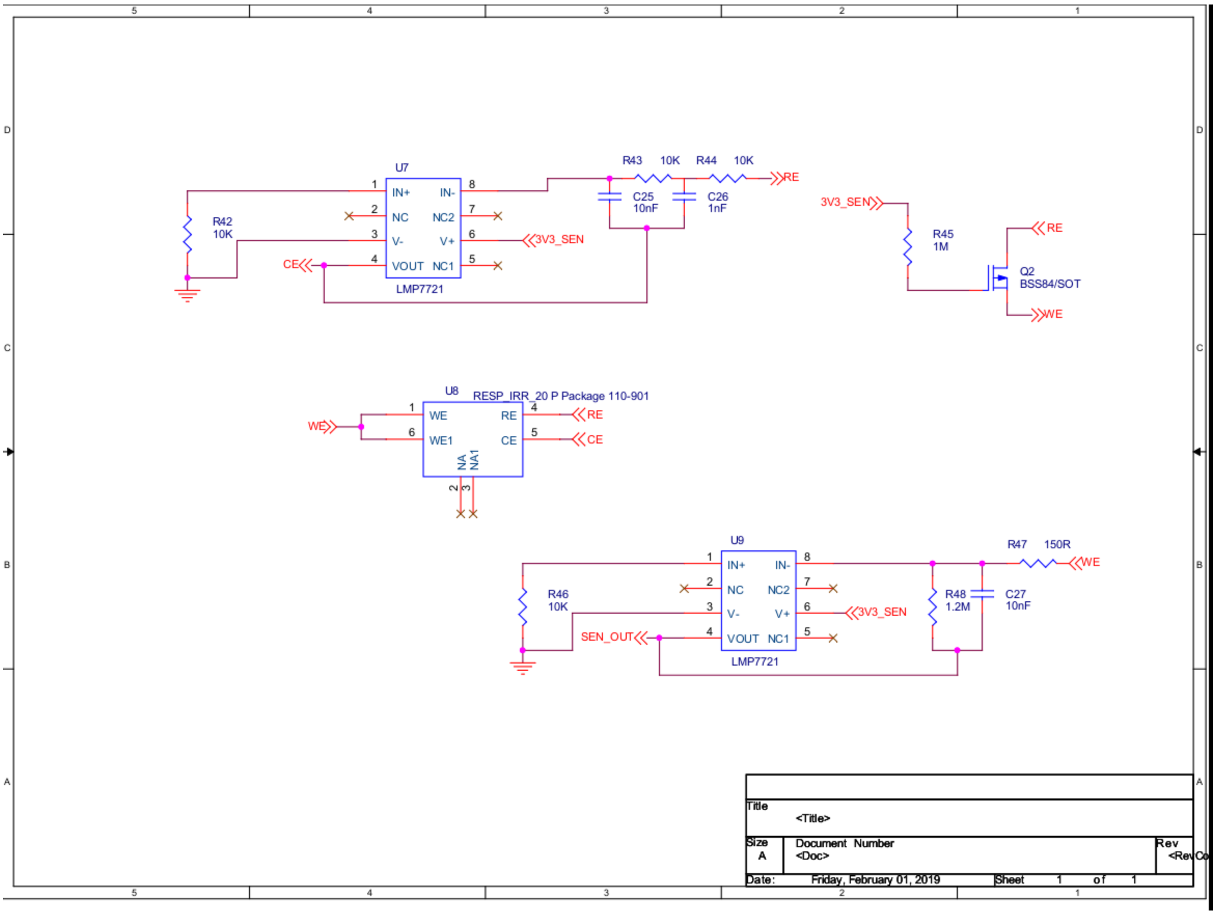

FIGURE A.4: Schematic diagram of Multisensor module part 3

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