Development of Power Management Circuitry for Battery Less Body Patch

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LIST OF ABBREVIATIONS

NFC	Near Field Communication
RFID	Radio Frequency Identification
BLE	Bluetooth Low Energy
IoT	Internet of Things
IC	Integrated Circuit
SMT	Surface Mount Technology
TPU	Thermoplastic Polyurethane
GSR	Galvanic Skin Response
TS	Temperature Sensor
SNS	Sympathetic Nervous System
PCB	Printed Circuit Board
MCU	Micro-controlling Unit
ECD	Electrochromic Display

ABSTRAK

Apabila menceritakan perkara mengenai hubungan tanpa wayar, perkara pertama yang terlintas difikiran ialah sambungan Internet. Sambungan tanpa wayar menjadi gaya masa kini. Projek ini diilhamkan oleh sambungan tanpa wayar. Kajian ini berfokus mengenai pembangunan pengurusan tenaga tanpa menggunakan bateri untuk tampalan badan kegunaannya dalam memantau tekanan dan suhu pada badan manusia. Konsep litar projek ini adalah lebih kurang sama dengan konsep pengubah dimana gegelung utama mengalihkan tenaga ke gegelung sekunder, dalam projek ini telefon pintar yang mempunyai NFC akan menghantar tenaga kepada antena. Untuk menjayakan sambungan antara telefon pintar dan litar, frekuensi untuk kedua-dua peranti mestilah sama iaitu 13.56 MHz and induktor akan menghasilkan nilai voltan untuk dibekalkan kepada komponen-komponen dalam litar. Projek ini melibatkan reka bentuk induktor sebagai penyemai tenaga, kemudian akan disatukan dengan pengurusan tenaga litar bersepadu (IC) Texas. Litar ini akan dicetak di atas TPU substrat dengan komponen SMT.

ABSTARCT

When talking about wireless connection, the first thing come cross our mind is the wireless internet connection. Wireless connection is a trending thing, everything is wireless. This project was inspired by the wireless connection. The research is focusing on the development of battery less power management for body patch application in stress and temperature monitoring for human body. The concept of the circuit is same as transformers concept, the mutual inductance or inductive coupling, where the primary coil transfers the energy to the secondary coil. In this project the smart phone supported with NFC technology will transfer the energy to the antenna. In order to make a connection between smart phone and the circuit, frequency of both devices must be the same with the 13.56MHz and the inductor will generate curtain amount of voltage to supply to the circuit components. The project will involve inductor design as energy harvesting, then integrate with Texas power management IC.

Chapter 1

INTRODUCTION

1.1 Background

Human skin is the largest organ and it enveloped entire human body, it covers from head to toe. Skin is an outstanding organ in the human body that have numerous of functions, that is very important to preventing the organism from desiccating and protecting it from its environment, even while maintaining its in uninterrupted communication with the environment itself. Human skin surface is a contour structure as shown in figure 1. From the skin, various human diseases can be diagnosed such as temperature level and stress level.

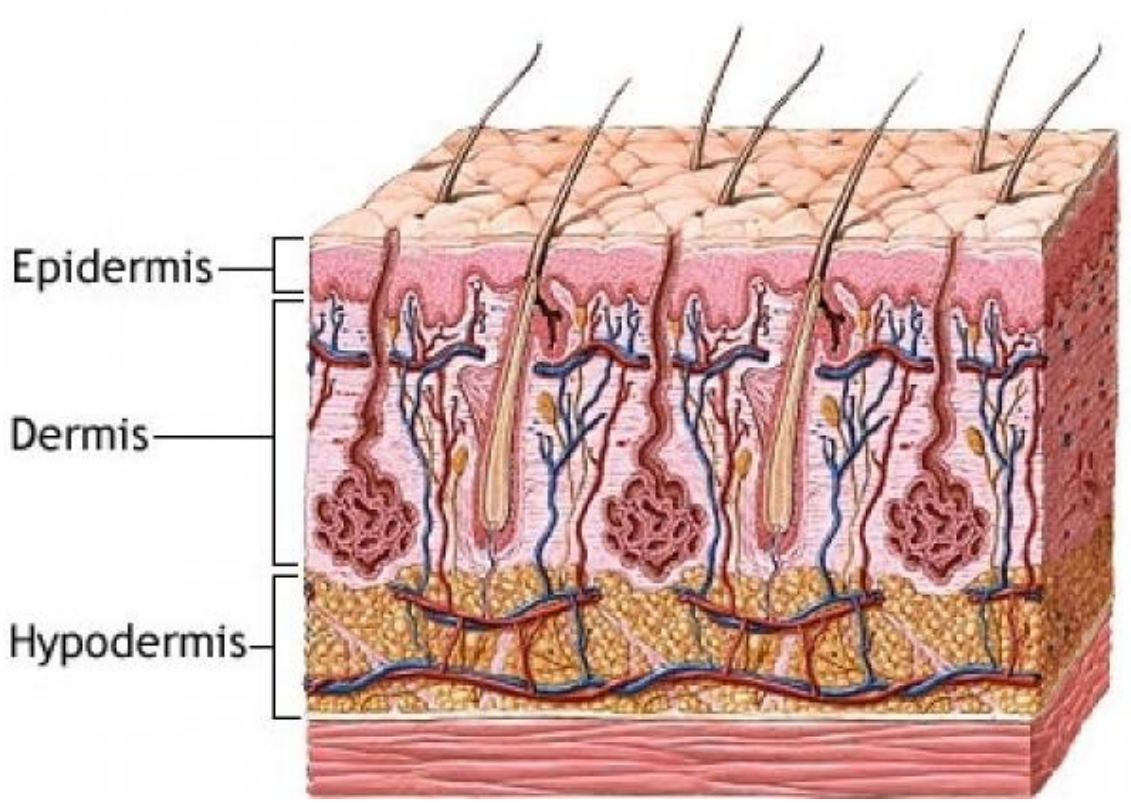

Figure 20: Human skin surface (source: google image)

The world is changing, and the ageing population is increased year by year [1]. Chronic related diseases have been corresponding due to this demographic change and the fast-growing elderly population makes human activity monitoring system gain their importance as increases demand for caretaking [2,3]. In many country, the self-care patients are increasing, they are being forced to manage their own disease, this is the current health system are struggling with [4]. The advancement in sensor technology, wireless communication and data information technology have opened a new opportunity to new models for providing healthcare or disease management device. A health monitoring in out-of-hospital condition has been catch interest to researchers and healthcare practitioners. They were concentrated on the health monitoring at home [5]. By providing the healthcare management tools, it will improve the quality of life for individuals and enable to extend the independent living at home [5].

The health monitoring related with this project use Near Field communication (NFC) as the power harvesting for the health monitoring device. NFC is the short-range and high frequency wireless point to point interconnection technology and it is a new technology that evolved from the combination of earlier Ratio Frequency Identification (RFID) contactless identification and networking technology such as Bluetooth as well as wi-fi [4]. By putting the two devices close to each other, NFC will enable the data transfer between the two devices. From a marketing perspective, it can be said that, the future devices interrogated with communication capabilities should be cheaper and less expensive, more complex to use, or provide significantly shorter operation time than those available now [4].

Inductor act as antenna to receive the signal from NFC antenna. The two antennas frequency must be the same, it follows the NFC frequency around 13.56 MHz, since NFC works at that frequency range. Antenna based inductor is use as the energy harvesting. NFC antenna will power up the inductor antenna since the inductor of the body patch is a passive antenna.

1.2 Problem Statement

As the world now leading in the technology, the recent technology advance in sensor system, low power integrated circuit and the wireless data transfer. The demand on the health monitoring device is increasing, but the devices were not efficient enough. In this part, it will state several obstacles regarding the issue.

Human skin is not a smooth surface, the skin has contours, wrinkles and curves. When the sensor is placed on top of human skin surface, it will not attach completely to the skin surface as the skin is not a smooth surface. The problem accounted is as the available body patch sensing system available has the problem in the case of contacting all the skin surface to the sensors. Because of all these obstacles, it makes the rigid printed circuit board (PCB) cannot be fully covered the skin surface.

Another issue regarding this is the PCB attached in the body patch is in rigid shaped and the printed circuit cannot follow the contour of the human skin surface, this will result in the patch cannot touch or couldn't sense certain part of the skin surface. This will cause the device cannot get the optimum data coming from the sensor and this will bring the inefficient in sensing output from the skin. However, insufficient data and standardized on flexible technology give a difficulty on enhancement flexible technology. As an

example, conductivity of conductive polymer ink can create unstable current flow on the flexible circuit trace lead to device failure. Thus, parameterized on current rating, voltage rating, performance on passive component on rigid PCB are needed as baseline for flexible technology development.

This type of device system still needs a wire-guided medium to get the power which is not suitable when comes to portable devices or it needs a battery or power supply to power up the sensing system such as a temperature sensor, stress sensor and Micro Controlling Unit (MCU). The body patch will be disturbed by the wires or the battery case and make it become big, heavy, less portable and difficult to test also difficult to make a measurement. The idea of the project is to make the body patch battery less, so it can be portable and user friendly with astatic elements implemented in the body patch.

1.3 Objective

The aim of this project to develop a full system battery less health body patch monitoring by integrated with near field communication on flexible polyimide (PI) substrate. Towards to final aim, the objective of this thesis to proof the design capability on integration between NFC and body patch sensor on rigid PCB as based line for development on flexible substrate. The objective:

i. To design and fabricate Near Field Communication (NFC) based body patch on FR4 substrate.
ii. To characterize current rating, voltage rating and frequency resonance of fabricated NFC antenna.

iii. To integrate temperature sensor and Galvanic Skin Response with Micro controller unit (MCU)Texas Instrument chip RF430RFL152H model on FR4 substrate.

iv. To characterize the sensing performance integration with Near Field Communication as energy harvesting.

1.4 Scope of Project

In this project will be focusses on the development of battery less power management for health body patch monitoring on human body. This project focus on body temperature and stress analysis. Toward to flexible system, a referring circuit need to be designed and developed to acquire the parameter and requirement baseline on monitoring temperature and stress from the human body before developing on flexible substrate. The circuitry will be designed by using Altium Designer.

The project will undergo three different stages of test, the first is the schematic design printed on rigid PCB and prove the concept of rigid PCB. Then the flexible board will be introduced as future work.

1.5 Thesis Organization

This thesis is divided into 5 major chapters. In chapter one, the introduction will explain on the overview of the whole project. In chapter 2, the literature review chapter will explain on the related research history, useful information, theory and experimetal and the topic regarding this FYP title. The focus is on the fundamental of wireless communication, sensor and enrgy harvesting.

Chapter 3, the methodology chapter will cover the method applied in this project. This chapter also will explain the process of the work from the start until the end, including tests and measurements that have been conducted during the experiment.

Chapter 4, result and discussion chapter will have all the measurement results and the results will be discuss in this chapter. The last chapter is chapter 5, conclusion and future work, it will conclude the all the discussion for this project and give suggestion for the future improvement.

Chapter 2

LITERATURE REVIEW

2.1 Overview

In this chapter, it will be describing the elements involved in this final year project. It can be said that mobile communication system continues to grow in popularity and have become an integral part for both personal and business communication. Through the wireless communication there are various of thing can be made. In this chapter it also describes the two parameters used in the health monitoring, temperature and stress level and the contribution of NFC technology in health monitoring field.

2.2 Background of Wireless Communication Research

NFC, RFID and BLE are Near Field Communication, Radio Frequency Identification and Bluetooth Low Energy respectively. The common about these three is it wireless technology, they were called so because all three are operated by transmitting data without using wires. Although they look similar, but there are differences between these three technologies. RFID is commonly used for tracking and tracing along the supply chain, many recent applications of NFC and BLE enhancing consumers' experiences in stores.

Near Field communication (NFC) is the latest technology compare with the other two. NFC is a very short-range wireless point to point interconnection communication technology, evolved from a combination of earlier RFID, the contactless identification and interconnection technologies (ISO 144443 A/MIFARE/FeLiCa) [4,6]. NFC was

introduced in 2004, the modern NFC was introduced after 10 years of invention, it has picked popularity because of it's cheap in price and extensive in use of smart phone as well as advanced in Internet of Thing (IoT) [7]. NFC allows users of handheld electronic devices just by holding them next to each other.

The communication of NFC is based on inductive coupling. NFC operates at 13.56 MHz carrier frequency and it provide speed up to 424 kbps [4,7]. NFC comes with two categories, passive mode and active mode, active mode device usually become power supply and passive mode device usually not suppling any power. When two devices communicate with each other there are 3 different configuration that can be made as shown in table 2.1.

Table 2.1: Communication Configurations

Device A	Device B	Description
Active	Active	When a device sends the data it generates a RF field. When waiting for the data a device does not generate an RF field. That is why the RF field is alternately generated by Device A and Device B
Active	Passive	The RF field is generated by Device A only
Passive	Active	The RF field is generated by device B only

The communication configuration is very important because the way of the data transmitted depends on whether the transmitting device is in active or passive mode. In an active mode the data will be sent using the amplitude shift keying (ASK) [8,9]. This means the base RF signal (13.56MHz) is modulated with the data according to a coding scheme. In the passive mode, the data is sent using a weak load modulation. The active

and passive mode are two different roles device can play in NFC communication. NFC is based on the message and reply concept, when the device A sends a message to device B, device B will respond back a reply. It is impossible for device B responds to device A without receiving any message from device A. In the table 2.2 it shows the list of all possible combination of the role with respect to active and passive mode. Only the combination Initiator and Passive is impossible [10].

Table 2.2: Possible Combinations Active/Passive with Initiator/Target

	Initiator	Target
Active	Possible	Possible
Passive	Not Possible	Possible

Radio frequency Identification or RFID is wireless communication technology. It is an automatic technology and aids machines or computers to identify object record metadata or control individual target using radio waves [11]. RFID technology was appeared in 1945, as an espionage tool for the Soviet Union, which retransmitted radio waves with audio information and it also similar to IFF (Identification Friend or Foe) transponder developed in the United Kingdom was routinely used by the allies in WWII to identify aircraft as allies or enemy [12]. There are several components of RFID as shown in figure 2.1. RFID is same as NFC it comes with two categories, active and passive. Active tag requires power source, they are either connected to a power socket or connected to an integrated battery [13].

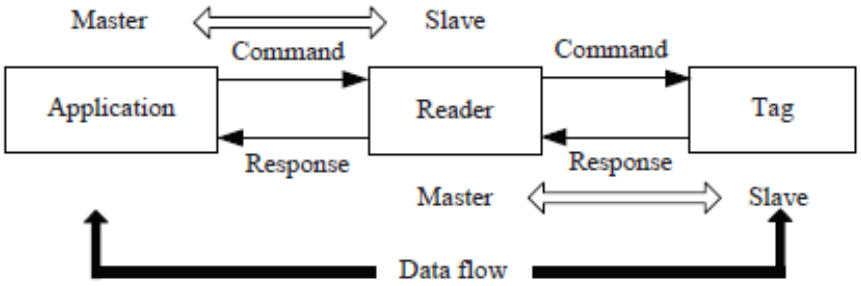

Figure 2.21: the component of RFID system [12]

Bluetooth wireless technology is an open specification that enable low-power and short-range wireless connections [14]. BLE is a low energy version of Bluetooth specified in the version 4.0 core specification [15]. BLE has designed as a low-power solution for control and monitoring application [16]. The advert of kcBLE has occurred while other low-power wireless solution such as ZigBee, 6LoWPAN or Z-Wave, have been steadily gaining momentum in application domains that requires multi-hop networking [17,18]. BLE technology can removed the inconvenience of wired transmission and eliminate the disadvantage that high power consumption of ordinary wireless transmission [19]. In figure 2.2, it shows that the device embedded with Bluetooth can be connected with other Bluetooth devices and control it by using smart phone.

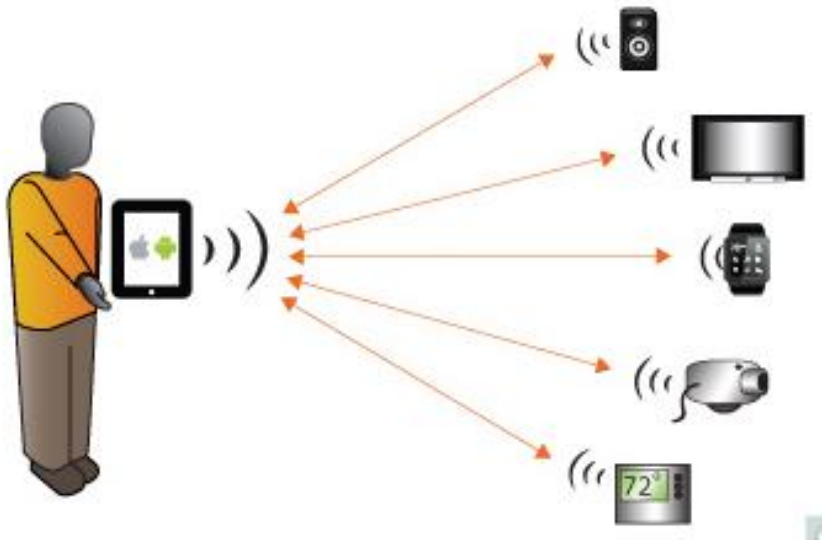

Figure 2.22: Bluetooth Low Energy

2.2.1 Comparison Between NFC with RFID and BLE

The main advantage of NFC over BLE and RFID is that NFC requires mush lower power consumption rather than BLE and RFID, since NFC is slower in speed and short-range, NFC doesn't need much power. This low power consumption also has drawback of shorter range and slow speed compare with BLE and RFID. NFC has a range of around 10 cm while BLE can transmit data more around 10 m and RDIF can transmit data more than 10m distance. When it comes to speed, NFC has faster connectivity compare with BLE. As NFC uses inductive coupling and there is no normal pairing, it takes not more than one tenth of a second for a connection between two devices [20]. Whereas, BLE it needs to be turn on first, find the device and pair them together then it can start to work.

The differences of these three wireless communication technologies are simplified and tabulated as shown in table 2.3. NFC provide a data transmission rate up to 424 Kbps with short-range of 10 cm. The short-range is the major feature of NFC technology

because it will enable much faster and easy communication between two devices by bringing the devices closed together. Because of this advantage, it is enhancing feature NFC is bounded to be integrated into numerous type of consumer devices, especially in handled devices such as smart phone [21].

Table 2.3: Comparison between NFC with Bluetooth and RFID

	NFC	Benefits of NFC	Bluetooth	RFID
Network Type	Point-to-point	Easy setup pairing = bringing close	Point-to-point Multipoint	Point-to-point
range		Safe, suitable for crowded area	10m	>10m
speed	424kbps		721kbps	640kbps
Set up time	<0.1s	Fast transaction e.g. for public transport, money	6s	
Modes	Active Mode Passive Mode	Reader mode and card like mode	No	Active Mode Passive Mode
Cost	Low	Affordable for most devices	Moderate	Low

NFC is an advance from RFID technology and it is still compatible with certain parts of the existing RFID infrastructure. NFC enables a convenient short-range communication between electronics devices and smart object.

2.2.2 Related work of NFC in Health Monitoring.

NFC is a high-potential technology for short-range connectivity between health monitoring device and mobile terminals. The range of work for NFC is maximum 20cm.

NFCIP-1 is an NFC specific communication mode, defines in the ECMA-340 standard. This mode is intended for peer-to-peer data communication between devices [4]. The NFCIP-1 has two mode variants, one is active mode and the other one is passive mode. In an active mode, both participants generate their own carrier while transmitting data. Where in the passive mode it called as NFC tag which contain information that can be read by other devices but cannot read any information by itself [20], only the initiator will generate the carrier during the communications, and the target device uses load modulation when communicating back to the monitor, it is similar to passive RFID tag behavior [22].

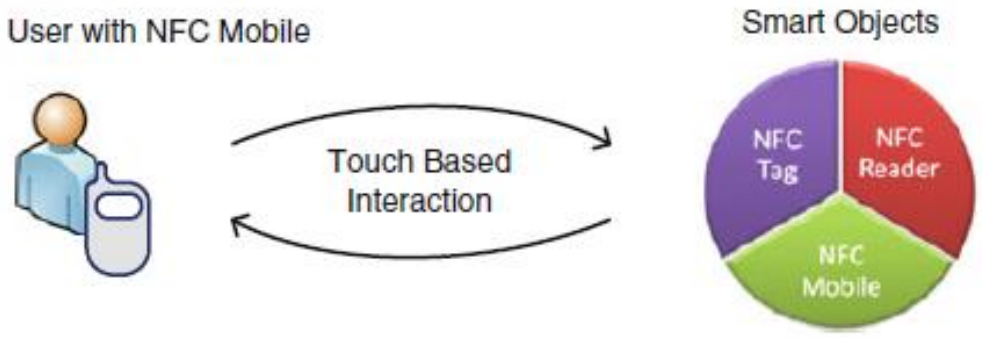

Figure 2.23:Touch based Paradigm for NFC. [6]

Currently the new way of interaction approach by NFC technology, which is touching paradigm as shown in figure 2.3. This interaction can be identified as “the deliberate bringing together of two devices, for the purpose of obtaining services [21].

The reason why NFC is implemented in heath monitoring application because of the low-power consumption, easy to use and low cost wireless sensor for medical sensors and instruments. The integrates of NFC into health monitoring devices and mobile terminals, enabling Touch Me-based interaction with heath monitoring devices, which

possible even though through clothing. Touch can trigger a data transfer operation between the devices via NFC. Touching also establish a connection between devices that use another wireless technology, such as Bluetooth.

An application using NFC to track patients with some disease has been deployed in Karachi [23]. For reducing medical errors NFC tags are used for identification of medicines, when the tag is placed on the medicine [24]. NFC technology can be very helpful in tracking patient information by collecting and transferring in real-time from variable health related devices such as heart monitors, body temperature sensors and blood pressure sensors to the patient's NFC tag [25].

2.3 Galvanic Skin Response (GSR)

A serious health problem may cause from the long-term exposure to mental stress and chronic stress would disrupt nearly every system in human body. In the recent studies states that stress could result in a significant rewiring of brain circuitries alteration in neuronal morphology and changes in neurogenesis, making one more exposure to stress [26,27,28,29]. Skin has a numerous function and from skin we can detect the stress level based on the skin conductivity. The skin conductance varies because of physiological arousal (stress) and physiologist have Galvanic Skin Response as for measures and evaluate stress, affective and arousal states [30,31]. Skin conductance is not a conscious control, it is modulated naturally by the present of feeling activity that can change human behaviour, cognitive, emotion, and decision making on subconscious level [32].

Skin conductance is one of the most sensitive markers of arousal. It modulates the mount of sweat secretion from sweat glands. The number of sweat glands varies across the human body, about 200 to 600 per cm^2 were found in hand and food make it these two regions are the highest region of sweat glands. While sweat secretion plays a major role for thermoregulation and sensory discrimination, changes in skin conductance in hand foot regions are also triggered quite impressively by emotional stimulation, the higher the arousal, the higher the galvanic skin response [33]. Therefore, a real time personal stress level monitoring is needed that would benefit many people by providing a continuous feedback about their stress levels and make the physicians easier to evaluate stress exposure between the patients.

Galvanic Skin Response (GSR) is used to determine the stress level. GSR is a measure of conductivity of human skin and can improve an indication of changes in human skin sympathetic nerve system (SNS) [30]. As a person becomes stressed, GSR will increases or decreases respectively depending on the levels of stress of the individual. The circuit for the GSR sensor is shown in figure 2.4. The circuit use a non-inverting amplifier design to monitor the skin impedance during the sense cycle. The output signal is sensed by the 14-bit sigma delta converter on the RF430FRL152H devices (micro-controlling unit) [10].

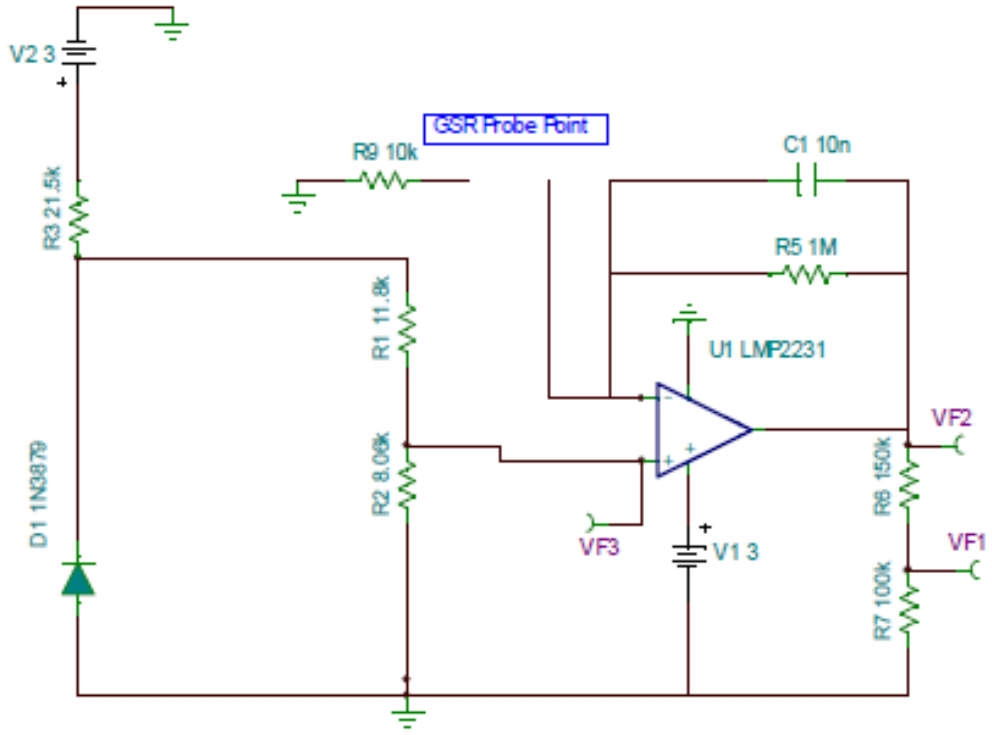

Figure 2.24: GSR Circuit [10]

2.4 Antenna Design

The wireless power transfer is invented, or the concept originally came from an Austrian engineer Nikola Tesla in 1890s. the energy is transmitted from a power source to a destination over the wireless medium. The wireless power transfer would enable the computer, sensors network and so on. The antenna is one of the most important parameters in wireless technology. To get the optimum power supply to the circuit wirelessly, the wireless power transfer via magnetic resonant coupling. The antenna is used for the transmission of a signal, the radio frequency in the form of electrical energy from a transmisster is converted into the electromagnetic energy by the antenna. An antenna captures or transmit radio electromahnetic waves.

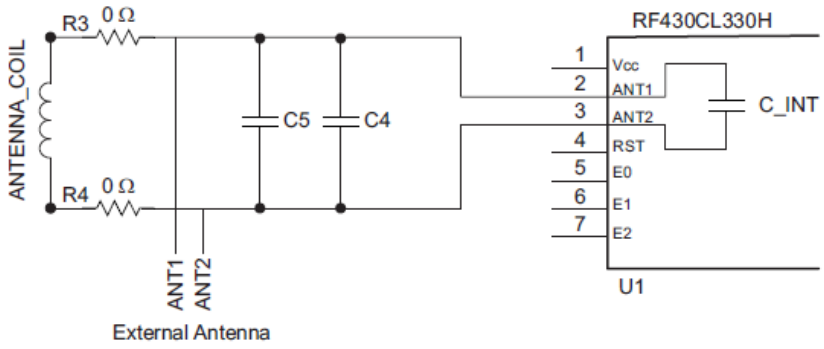

Figure 2.25: Target Board Antenna Connection

The antenna uses the concept of inductive coupling that uses magnetic field which naturally part of current's moving through a wire. In figure 2.5 it shows that the basic input circuit of the RF430CL330H. The antenna coil with the internal parallel capacitor (C_{int}) will creates a resonant frequency where the formula for resonance capacitor (C_{res}) as shown in equation 2.1. The resonant between source and load coil is achieved with lumped capacitors termination the coil, C4 and C5 as shown in figure 5 [23].

$$C_{res} = C_{int} + C_4 + C_5 \quad (2.1)$$

The source drives a primary coil, creating a sinusoidally varying magnetic field, which induces a voltage across the terminals of the secondary coil, and thus transfer the power to the load. The mechanism is same as the mechanism for transformer, where the magnetic field is typically confined to a high permeability core and functions when the region between the primary and secondary coils is simply air [23]. The figure 2.6 shows the illustration of the inductive coupling wireless power transfer.

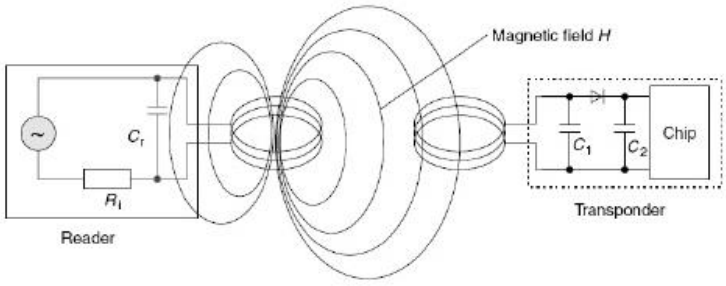

Figure 2.26: Inductive Coupling

2.5 Surface Mount Technology (SMT)

The present methods of manufacturing conventional electronics assemblies have essentially reached their limits as far as weight, cost, volume and reliability are concerned. Surface mount technology (SMT) makes it possible to produce more reliable assemblies at low cost, weight, and volume. SMT is one of the most common technology used in producing PCB. SMT is used to mount the electronics components on a PCB or substrate [34]. By using SMT, it will speed up the production process, but as a result the risk of defect in increases.

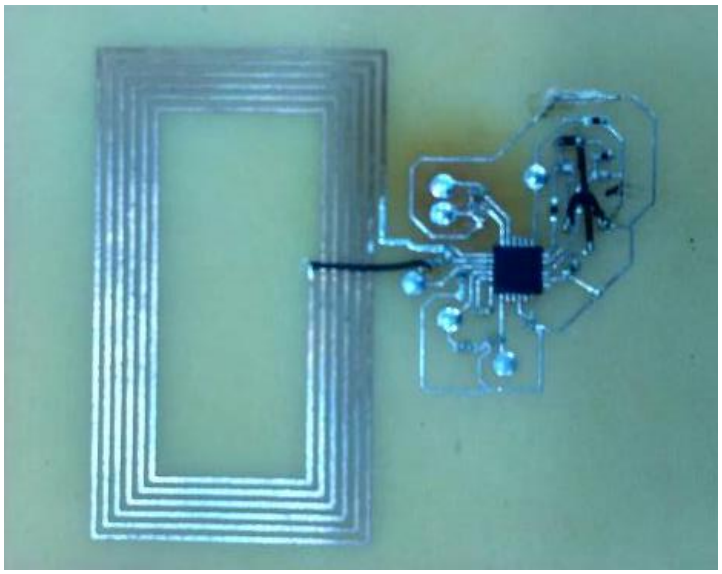

Figure 2.27: Surface Mount Technology PCB

The electronics assembly originally used point to point wiring and no substrate at all. The first semiconductor packages used radial leads which were inserted in through the holes of the single-sided circuit boards already used for resistor, capacitor and inductor [34]. The productive process consists of 3 main steps 1) solder printing; 2) pick and place; 3) reflow. In the solder printing step, a solder paste layer is printed on the surface of the PCB. In pick and place step, each component is positioned on the PCB. And lastly in reflow step, the solder joints take shape by the reflowing of the solder paste [35]. At every step of production process defect might occurs. For instance, paste missing and paste bridges in the solder printing step; missing parts and misoriented parts in the pick and place step; and faulty solder joints in the reflowing step [36].

There is another method to mount components on PCB by using traditional or conventional technology which is drill the hole on the board surface and insert the components feet through the holes then solder the component using lead on the opposite site of the board. This process is called through-hole mounting. The through-hole concept as shown in figure 2.8. The through-hole mounting is much reliable because the components are tightly attached with the board. On the other hand, the drilling process making the production of board much more expensive. Moreover, the present of the drilled holes on the board will limit the routing area for the tracing on the layers which are immediately beneath the top layer on multi-layer board.

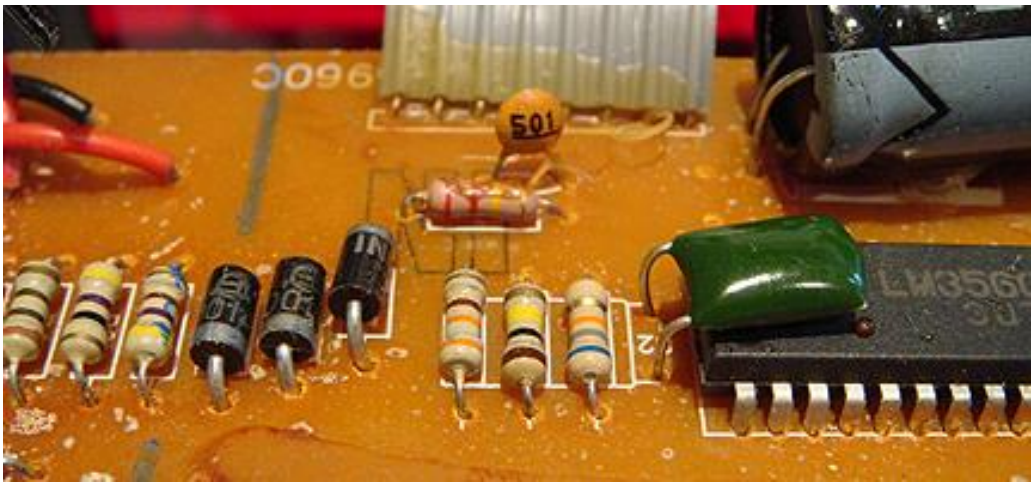

Figure 2.28: Through-hole Technology

When comparing between the two mounting techniques SMT and Through-hole Technology, it can be said that SMT gives a lot of benefit comparable with the through - hole technique. SMT can solve the limitation of through-hole space problem with multi-layer function. SMT also makes the production at low cost, weight and volume. Another thing is SMT will speed up the process, so that is why SMT is chosen to mount the electronic components on the PCB and substrate.

2.6 Flexible Substrate

The flexible substrate is originally designed as a replacement for traditional wire harness. The flexible substrate comparisons to the rigid PCB are the flexible substrate will reduce the wiring error and reduce the error in component assembly because of the accurate design and automated production. Unlike rigid PCB, flexible circuit are not limited to two layers. Because its flexibility during installation the circuit allows a third dimension to work because they can interconnect between two or more panes during execution.

2.7 Chapter Summary

This chapter describes the wireless communication technology that leading today, also the comparison between three wireless communication technologies, NFC, BLE and RFID. As the wireless communication technology receive high in demand and the IoT is introduced making the function for wireless communication become wide and varied especially in health monitoring devices.

Chapter 3

METHODOLOGY

3.1 Overview

This chapter will explain all the processes, or the steps involved in this project. From the software design for the schematic circuit to hardware implementation for rigid PCB. In this chapter will discussing on the methodology of this project and related current topic to understand and to get some knowledge and idea on how this project be conducted. The first step to start this project is to get the information on related topic purposed.

Next is make the draft for the circuitry. This project use Altium Designer 2016 to design the schematic circuit. The rigid PCB with schematic diagram then fabricated with SMT method. The circuit is fabricated on FR4 substrate. When the fabrication is complete, simulate the electrical characteristic of the sensing system. Later, proving the concept of the rigid PCB on the data collected. The flow chart of this project is shown in figure 3.1.

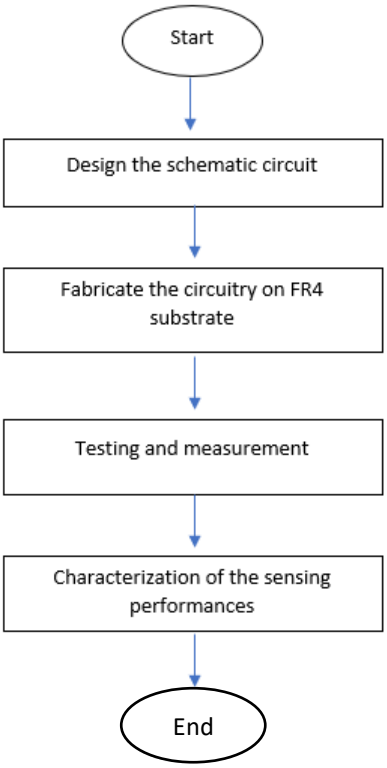

Figure 3.29: Flow Chart of the project

3.2 List of Hardware

There are several components being implemented in this project with their own specification. In the table 3.1 shown the list of components used in this project.

Table 3.1: List of Components

No.	Component	Quantity
1	Smart Phone supported with NFC	1
1	RF430RFL152H Micro Controlling Unit	1
2	EC Display	2
3	CD74HC4511 Decoder	2
4	LMP2231	1
5	Skin Temperature Thermistor	1
6	Sensor Reference Potential	1

3.2.1 NFC Smart Phone

For the NFC mobile terminal, the mobile that or smart phone that being used is Xiaomi Note 3 because it was supported with NFC. In figure 3.2 shows the interface of application use to detect the temperature and stress level.

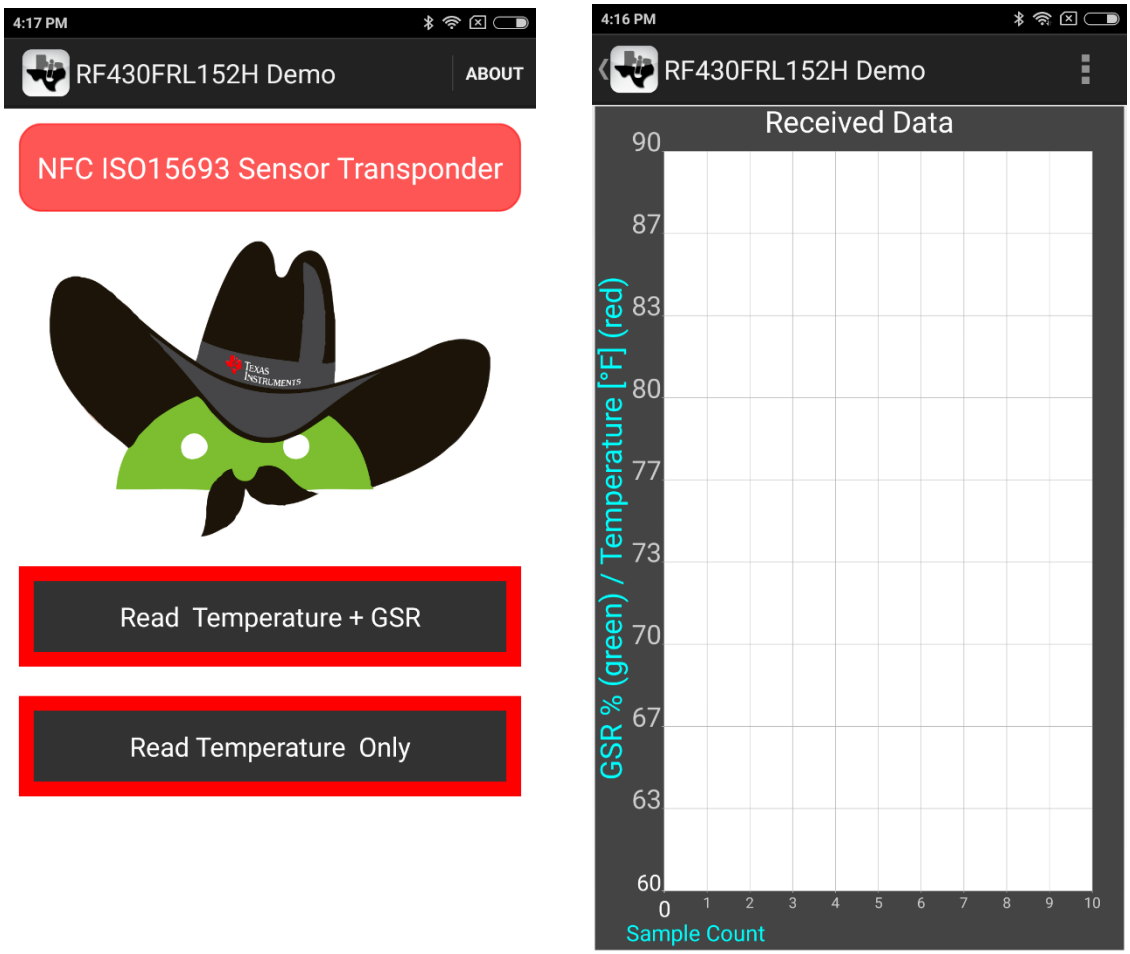

Figure 3.30: Temperature & GSR reader Apps Interface