DESIGN AND DEVELOPMENT OF A CHIPLESS RFID TAG-SENSOR FOR TEMPERATURE SENSING USING PCB

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronics Engineering Technology (Telecommunication) with Honours.

by

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2020/2021

DECLARATION

I hereby, declared this report entitled Design and Development of A Chipless RFID tag-sensor for Temperature Sensing using PCB is the results of my own research except as cited in references.

Signature: ………..……………………

Author : HENG JIA LER

Date: 14TH FEBRUARY 2021

APPROVAL

This report is submitted to the Faculty of Electrical and Electronic Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunication) with Honours. The member of the supervisory is as follow:

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ABSTRAK

Pada zaman kini, teknologi Radio Frequency Identification (RFID) telah menunjukkan peningkatan dalam penampilan baru-baru ini. Terdapat banyak aplikasi yang memanfaatkan teknologi RFID ini untuk membantu manusia menyelesaikan tugasan harian. Salah satunya adalah teknologi sensor RFID yang digunakan dalam pengesanan, pengenalpastian, dan penginderaan. Sensor adalah peranti atau komponen yang mampu mengesan dan bertindak balas terhadap perubahan parameter persekitaran seperti kepanasan, cahaya, pengerakan, dan kelembapan. Dengan gabungan dari kedua-dua RFID dan sensor dapat menghasilkan sensor jarak jauh tanpa wayar. Oleh itu, idea untuk merancang dan mensimulasikan sensor RFID tag tanpa chip untuk pengesahan suhu dicadangkan dalam projek ini. Walaupun begitu, terdapat beberapa kesukaran dalam mewujudkan sensor RFID tag tanpa chip untuk menggantikan kod Respons Pantas (QR code) dan kod bar yang ada untuk tujuan yang sama untuk mengesan dan mengenal pasti. Malahannya, terdapat beberapa batasan dalam mewujudkan kegunaan RFID tag sensor adalah jarak bacaan sensor RFID tag terbatas dalam beberapa meter sahaja dan kesukaran dalam penginderaan data untuk tujuan id pengenalan dan suhu pengesahan yang tepat. Untuk mengatasi masalah ini, tindakan diambil dalam bahagian metodologi untuk mengatasi batasan yang disebutkan. Dalam projek ini, sensor RFID tag tanpa cip yang bersegi V slotted (lubang) telah direka bentukkan, disimulasikan dan dibuat. Teg tersebut mengandungi maklumat 8-bit untuk tujuan pengenalan dan pengesanan. Ukuran teg adalah 25 × 25 mm^2 yang bersaiz kecil dan sesuai dengan kebanyakan produk. Pengekodan yang berbeza daripada kombinasi 8-bit juga dihasilkan untuk membenarkan kemampuan pengekodan teg ini. Di samping itu, reka bentuknya telah diuji pada substrat

fleksibel yang berbeza iaitu Kapton (Polyimide) dan Polyethylene terephthalate (PET). Reka bentuk ini telah menunjukkan ketahanan dan potensi dengan menunjukkan keupayaan pengekodan dalam substrat-sbustrat tersebut.

ABSTRACT

Nowadays, Radio Frequency Identification (RFID) technology has shown an increment in appearance this recently. There are many applications that adapt this RFID technology to aid human to accomplish daily activity. And one of them is the chipless RFID tag sensor technology that could use in tracking, identification, and sensing. Sensor is a device or component that capable to detect and respond to the environmental parameter's changes such as heat, light, motion, and moisture. With the combination from both RFID and sensor can produce a ranged sensor wirelessly. Therefore, the idea to design and simulate of a chipless RFID tag-sensor for temperature sensing is proposed in this project. Nevertheless, there are some difficulties in realising the chipless RFID tag-sensor to replace the existing Quick Response code (QR code) and bar code for the same purpose to detect, tracking and identify. The problems are the reading range of chipless RFID tag-sensor is limited in a few meters and the difficulties in both sensing all temperature change accurately and giving suitable bits for identification at the same time. To overcome these issue, respective action is taken in the methodology part to repair the disadvantage of the mentioned problems. In this project a V slotted chipless RFID tag-sensor has been designed, simulated and fabricated. The tag contains 8-bit information for identification and detection. The tag size is 25 × 25 mm^2 which is small in size and can fit with most of the products. Different Coding of 8-bit combinations are also generated to justify the coding ability of this tag. In addition, the design has been tested on different flexible substrates i.e., Kapton (Polyimide) and Polyethylene terephthalate (PET). The design show robustness by exhibiting coding capacities also on those substrates.

DEDICATION

To my beloved parents, I dedicate this project to my both beloved parents, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. They have been the source of my strength throughout this program. I also dedicate this work to all my friends who has encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started. To my classmates, who have been affected in every way possible by this quest. Thank you. My love for you all can never be quantified.

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LIST OF SYMBOLS

D, d	-	Diameter
F	-	Force
g	-	Gravity = 9.81 m/s
I	-	Moment of inertia
l	-	Length
m	-	Mass
N	-	Rotational velocity
P	-	Pressure
Q	-	Volumetric flow-rate
r	-	Radius
T	-	Torque
Re	-	Reynold number
V	-	Velocity
w	-	Angular velocity
x	-	Displacement
z	-	Height
q	-	Angle

LIST OF ABBREVIATIONS

PCA	Principal Component Analysis

LIST OF PUBLICATIONS

CHAPTER 1

INTRODUCTION

1.1 Background Study

Sensor is one of the important parts of the feedback mechanism which that the result studied object is used on the control of the system. This feedback mechanism is related to the SMART technology also known as the Internet of Thing (IoT) where the technology thing is connected to the internet and allowed the object to reply the result of its current state which can be used later to trigger the next following up process for the further processing such as instead trigger of water switch from the fire alarm system so that the process of extinguish fire can be done once the smoke of fire or the temperature reaches pre-set value. Hence, we can see that the first observer of this whole system is initial by the sensor therefore, the sensor should be designed ideally fitting the requirement of the system to be allowed further process.

With the various type of thermal sensor and temperature sensor, the problem is still noticeable in some cases especially come to the ability to produce in large scale and the cost and the complexity to design it. The existing temperature is used in malicious field of study from aerospace engineering (Harun, Cheng and Wibbelmann, 2008) to medical (Ajami and Rajabzadeh, 2013), biological science (Kimura *et al.*, 2018) to the microcomputer (Papić *et al.*, 2017) and IoT 4.0 (Zhong *et al.*, 2017; Ding and Jiang, 2018)(Jia *et al.*, 2012) industrial based. The feedback is a complex system type of topic since even the evolution and adaptation related to it. “Temperature sensing is one of the most sensitive properties or parameters for industries like petrochemical, automotive, aerospace and defence, consumer electronics, and so on. These sensors are installed into devices with the purpose of measuring the temperature of a medium accurately and efficiently in a given set of requirements." (Kumar, Mukherjee and Mishra, 2005). Although there are many temperature sensors out there, it is classified into four major types, Negative Temperature Coefficient (NTC) thermistor, Resistance Temperature Detector (RTD), Thermocouple and Semiconductor-based sensors. "4 Most Common Types of Temperature Sensor," (Ametherm, 2019). With the rise of IoT as the main trend for the growth of technology until fourth industrial revolution, the world is required more type of temperature sensor that can fulfil the desired of retrieving the wanted results from the studied field. Therefore, the proposed chipless Radio Frequency Identification (RFID) tag sensor as the presented as the new type of sensor (temperature sensor). A chipless RFID tag sensor can achieve all these factors easily compared to the currently available type of sensors.

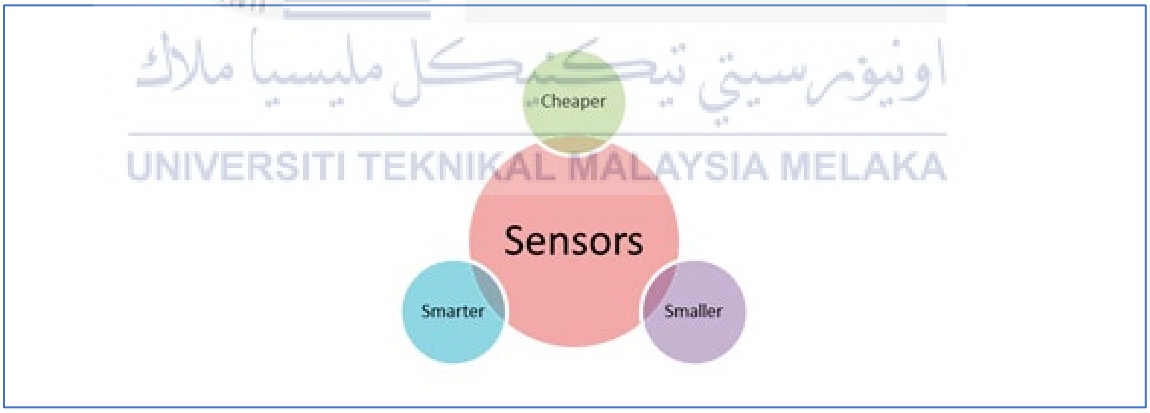


Figure 1.1: The advantage provided by chipless RFID sensor-tag

The first ever recorded built of RFID is the Mario Cardullo's device, patented on January 23, 1973, was the first true ancestor of modern RFID (Cardullo, 2003). But some early work may indicate Harry Stockman, (Stockman H., 1948), has proposed the concept of RFID in an earlier timeline. (Stark, K.,2019). With today's technology, the realisation of Wireless identification and sensing platform can be achieved (Moh et al., 2009). The research in RFID started to glow.

Among the current technology of RFID tag designs, it is classified into three majors, the active, semi-passive, and passive. An active RFID tag will be required electricity to be powered up while the passive does not, hence causing the chipless RFID tag to lead in the field for long term usage as it was used as sensor for physical environmental sensing. From passive RFID tag, there is another classification of with chip or chipless. The chipless passive RFID is chosen due to the reason of cost. The cost of production maybe directly affects the desire of factory to mass produce. Although, there are a few noticeable flaws in term of data encoding capability and strengths of the wave reflect back shatter through Radar Crossing Section, RCS that are less comparable to other type, but many studies have been researched and the pattern is improving day by day paper by paper.

There are two types of working principle for the passive chipless RFID tags, surface acoustic wave sensor and electromagnetic RCS back scattering (BS) frequency based chipless RFID sensor. The former utilised the micro-acoustic wave to encode and sense environment but is sided by the high fabricating cost and poor repeatability due to the complex sensing unit. The design based on the currently design ideas are simulated and the most optimal result data is used the target to be improved.

A few topologies of frequency-based scatterers are proposed by numerous research, such as C-shaped (Vena, Perret and Tedjini, 2012a), ACiSRR (Athauda and Karmakar, 2019), L-shape (Issa *et al.*, 2018), circular rings shape (Vena, Perret and Tedjini, 2012b), U-shape (Polivka *et al.*, 2016), ellipse shape (Jabeen *et al.*, 2019) and slotted based ring resonators (Islam *et al.*, 2012). Therefore, with the ability of temperature sensor tag and long-term consumption, this paper will improve exitance design of chipless RFID and compare the best choice of design with some modifications to obtain the best suit type of design for the objective to sense temperature of the object.

1.2 Objectives

The objectives of the project are as follows,

1. To design and simulate an RFID tag-sensor on different PCB
2. To design and simulate an RFID tag-sensor on different flexible substrates.
3. To fabricate the designed chipless RFID tag sensor on PCB.
4. To benchmark the fabricated tag with the existing design in previous study.

1.3 Problem Statement

The limitation of chipless RFID tag sensor to sense all the temperature (from 0-100 °C) and providing sufficient bit for identification. The difficulties of chipless RFID tag sensor to encode the maximum amount of bit coding for purpose of identification, while miniatures the size of the tag. Therefore, to create a long lasting and less costly chipless RFID sensor-tag is being designed for the function of sensing environmental temperature.

1.4 Scope of Research

The scope of this project is made to inform the features and components used in this project. The research will only focus on the design of the chipless RFID tag sensor that operate at Ultra-Wideband frequency (3.1 - 10.6 GHz) with the optimal performance by simulating the results through the software "CST DESIGN ENVIRONMENT –

2018/2019/2020". Next, material of ROGERS R3003 is being used as the material of substrate with dielectric constant of 3.0 and tangent delta of 0.001 (ε_r=3.0, tan δ= 0.0010) while perfect electric conductor (PEC) metal is used as the material for the sensor tag. Other than that, some substrate materials that worth mentioning is the Taconic TLX-8, Polyimide (Kapton) and Polyethylene terephthalate (PET). The dielectric constant of Taconic TLX-8 is ε_r = 2.55, while tan δ= 0.0019. For Polyimide, ε_r = 3.5 and tan δ= 0.027. Lastly, PET substrate material is ε_r = 3.2, while tan δ= 0.02. This project is meant to sense the temperature change around the chipless RFID tag sensor. Other than only a sensor, the chipless RFID tag sensor is encoded with bit data for identification purpose. However, due to the limitation of hardware for simulation, bit encoding number up to eight-bits will be simulated in this paper. The tag sensor will be tested along the transmitting antenna from the other research. With this, the transmission of the interrogated signal to the chipless RFID tag sensor to perform rescattering on the structural design of the tag. Then, the reader can be used to observe the bit encoded response and sense the temperature changes. Lastly, this project is dedicated to various fields related with the sensor requirement type of usage and also on the purpose of identification.

1.5 Thesis Organisation:

Chapter 1 provides an introduction to title and objective of this project with relative background of study. The problem initiating the project is mentioned and the objective of study has been stated. Beside this, the scope of study also being set up so that the result of this project will only toward solving of the stated existence problem.

Chapter 2 discusses about the literature review that involved in the study of this project. The research paper was being studied and reviewed so that the project can focus on the improvement of the similar project based on the problems faced.

Chapter 3 gives and overview of the whole project process. All results in this project obtained by using the mentioned methodology procedures from set up to the record of the desired value on the result. Details of results are provided in the next chapter.

Chapter 4 will be the important part of the project whereas it retrieves the result of this project and analyses along with discussion on the obtained result in previous part, so that the meaning of the result is converted into word.

Chapter 5 concludes the overall finding of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the overview for this project will be expressed based on the previous work and the literature studies that were related to this project. This project is focusing on the design of the chipless RFID tag sensor for sensing the temperature of an object. Starting with the concept used in RFID, the explanation will then provide to the concept of the of RFID tag, the type of RFID, type of passive RFID, the explanation of the electromagnetic spectrum design compared to time domain reflection-based design, the tag structure explanation toward previously researcher's designs and the comparison chart of different type of design. Therefore, this chapter will present some information and discussions about the application applied.

2.2 Radio Frequency Identification

The Radio Frequency Identification (RFID) was a technology that initially used as tags to take place of the barcodes for supply chains. This is clear that the advantages provided by RFID are much convenient for the identification and tracking of the item and object. It reads the information without the present of optical, the capacity of information is greater and having probability to identify multiple objects even it is quite a distance. (Herrojo *et al.*, 2019), (Etienne, 2014) (Vena et al., 2016) (Karmakar et al., 2016)

(Karmakar et al., 2019) (Rezaiesarlak et al., 2015) (Finkenzeller et al., 2010) (Herrojo *et al.*, 2019).

The concept of RFID is contactless of contact technique to gather the information data between two component, RFID tag and RFID interrogator device - RFID reader. This RFID system makes use of the reflected radio frequency (RF) sent from the information stored in the RFID tag, using the RFID read to capture this reflected RF, and then moved to analysation. The user will now capable to use the analysed information on real-time processing system for searching, identifying, and tracking purposes (Forouzandeh and Karmakar, 2015).

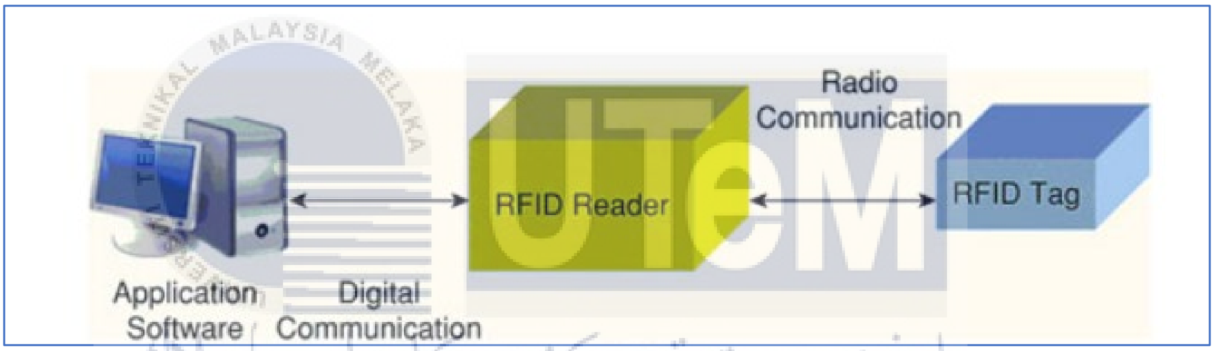


Figure 2.1: RFID system block diagram

With the ability of data receive and target identification through connectionless contact, RFID technology has been covered by a wide range of enterprises for its integration into information technology infrastructures, hence colourise the daily lifestyle of living creatures. RFID also helps to improve the transformation of enterprises for some improvement in work done such as the automatic identification and the tracking of objects. These can be done by the development RFID system mentioned earlier that only required RFID reader and RFID tag to make the process of identifying, tracking and authorising (Herrojo *et al.*, 2019) (Forouzandeh and Karmakar, 2015).

There are various types of RFID have been studied by the researchers to improvement the ability of it. One of them scored some potential with the features of low cost and the high manufacturability, due to the reason of battery-less and chip-less. These chipless passive RFID tags are as cheap as a few eurocents but with the probability beyond the other identification (ID) systems in present field. Thus, the growth of the related field research in this decade brings the lead to the chipless RFID technology. (Karmakar et al., 2016b) (Hunt et al., 2007) (Karmakar et al., 2016c) (Karmakar et al., 2012) (Karmakar et al., 2013) (Schussler et al., 2009). Therefore, in chipless RFID tags, sometimes the tag is equipped with a planar encoder containing the ID code or with an antenna for communication with the reader.

The direction of the research related to chipless RFID technology in these few years have leaning towards the field of bit data encoding ability and also the bit density can be provided by these tags. This is due to the lack in the chipless RFID tag sensor when the comparison drawn with the chipped-RFID. Therefore, the research was mainly in overcome the incapability of chipless RFID sensor tag while discussing along the structure in chipless RFID tag.

2.3 PASSIVE RFID

Figure 2.2: Type of RFID in current market

As mentioned in the earlier part, the RFID technology is only three type in major at this time. Even though that many types of RFID tag do present far from long time ago. “The three types of RFID transponder are active, semi-passive and passive.” was constantly being classified as the common type of RFID that live among us. The active RFID will always need a power source to continuously energise the life of it. Whether a chargeable battery or a built in permanent powered infrastructure will give the functionality of the active RFID transponders without many obstacles.

Therefore the lifetime of this device is totally dependent to the battery capacity and the usage frequency of the device (consumption of electric energy will cause drop in battery life) (Forouzandeh and Karmakar, 2015).

Next, the semi-passive (or sometimes is called semi-active) RFID transponders or tag where it benefits for the portable battery supply on the functionality of data transmission and receives. However, the limitation of reading range was noticed as it serves the longevity. Lastly, the Passive RFID tags which do not require any outer source for excitation, remains calm before any excitation energy signal was sent. It is said to be powered by the electromagnetic waves generated from the reader entirely. The passive RFID tag utilizes this energy for both communication and data processing purposes. Furthermore, passive transponders may or may not contain an integrated circuit (IC). (Forouzandeh and Karmakar, 2015).

However, it also to be lack of attenuation and reading range as compared to active RFID tag at the trade-off for lower built cost and no battery supply is demanding. (Forouzandeh and Karmakar, 2015). The implementation of chipless RFID systems and the relevant implementations such approaches include time domain systems and frequency domain systems will further be discussed (Herrojo *et al.*, 2019).

The following figure 2.3 shows the block diagram of the passive RFID tag. The overall process is similar to as mentioned RFID system, just that in the name of passive, it doesn't require a battery supply to active the devices.

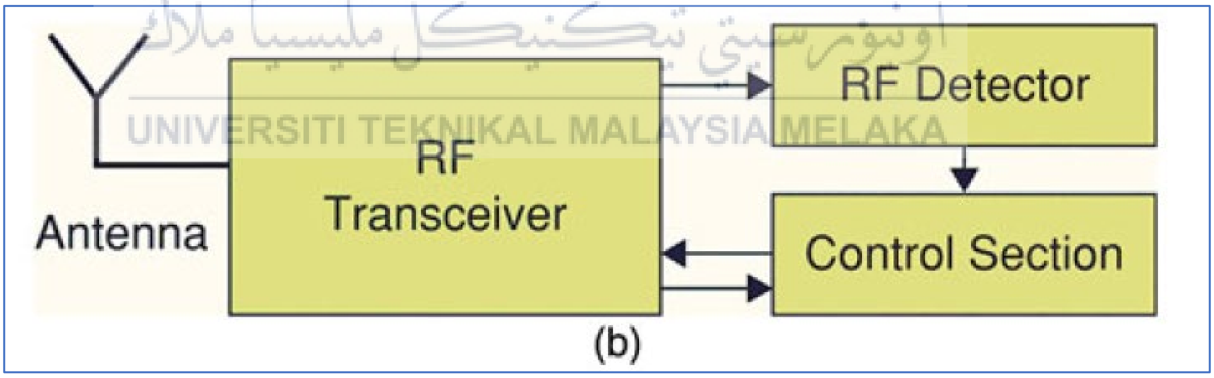


Figure 2.3: Passive RFID tag block diagram (Forouzandeh and Karmakar, 2015)

In summary, the passive RFID tag is selected as compared to the other type. This is due to the target of the functionality of this tag is to detect the temperature around the attached object. Thus, the criteria of passive RFID tag is much suitable for the objective of this project as to allocate bit for identification purpose and also sense the temperature around the attached object.

2.4 Chipless RFID Tag

After the basic understanding of the concept of RFID system especially the type of RFID such as Passive, Semi-Active and Active RFID, this section will tell more on the chipless RFID. Chipless RFID is basically the same functionality of passive as a chipless RFID tag for example, is called as passive RFID for the classification. The chipless RFID system is used to draw the comparison to the integrated circuit (IC) chip technology that are currently on the commercial. The reason that majority of the RFID tag in the current market shows the inclusive transponders of an antenna and IC is due to the much earlier initiation of this technology compared to the passive technology (Li *et al.*, 2020). Therefore, the popularity of this IC RFID has made a pretty good progression so far if the chipless RFID technology is absent. The main issue for this IC RFID is the high fabrication cost and the connection stability between the antenna and IC (Li *et al.*, 2020). The production cost per million pieces are 7-10 cents is much higher cost as compared to the 0.01 cent (Forouzandeh and Karmakar, 2015) of producing a chipless RFID tag. In replacement, the CRFID is being part of the study to improve the current technology.

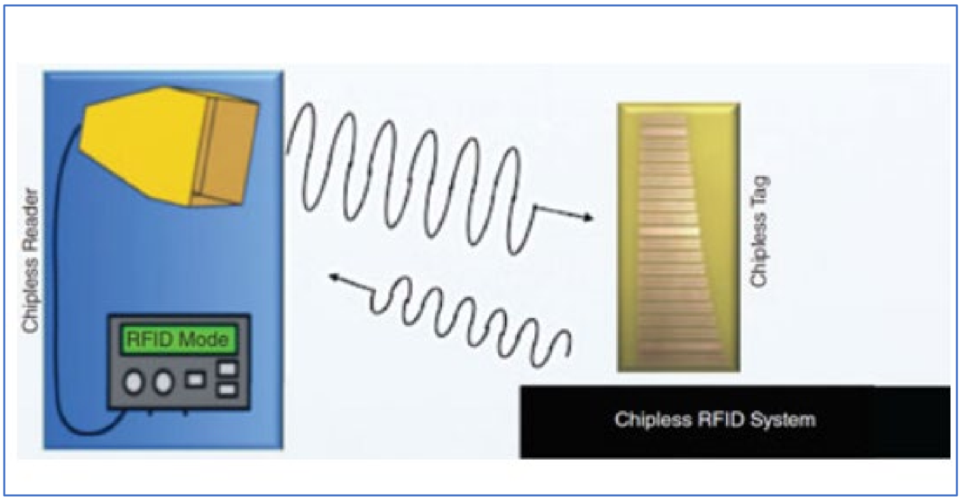


Figure 2.4: The example of the chipless RFID system (Forouzandeh and Karmakar, 2015)

The concept plays within the chipless RFID system is that the similarity of radar to show the information on the tag from the reflected electromagnetic wave. From figure 2.4, the information is encoded in the electromagnetic response of the tag. This electromagnetic signature response, mostly dependent on the tags passive physical architecture (Forouzandeh and Karmakar, 2015). With this process, it shows that no communication protocol is requires between this process which make it more easy to understand in the concept involvement with involving complex (Li *et al.*, 2020).

Chipless RFID tag comes with some principle to run with. Some basis idea behind the communication principle in these RFID tag technologies are the dependency on the backscattered signal retrieved from the tag. A wave of excitation was sent from the transmission horn antenna. The performance of the tag could be assessed by the Radar Cross Section (RCS) of the structure. Therefore some properties in scattering structure of the tag should be taken into consideration for the design of the tag (Forouzandeh and Karmakar, 2015).

Speaking of challenge in tag design, although Chipless RFID technology has been overwhelmed in the industry and business market due to lower cost comparable with the barcode, it is in infancy stage. The reported chipless RFID that current shown are the prototypes and low number of commercial applications. With this, the real challenges are cost involving in fabrication and ability of sensing environmental parameter and encoding of bit data without the present of chips, IC. It is mentioned by (Li *et al.*, 2020) that not much of electromagnetic spectrum based on the Chipless RFID tags with recent approach of research.

More to add is that the chipless RFID tag structures have been demonstrated in sensing applications (Vena et al. 2012). The sensing capabilities can be shown by using a reader with the backscattered signal alterations, power variations, shifting on frequency (on the response frequency) or phase variations. The fully passive, accurate and low-cost performance of chipless RFID sensor tag shows a good response as the criteria fulfilled for sensing most environmental parameter even in harsh environments such as the absent of integrated electronics will extend the lifespan of the tag, hence present a robust of view of designed chipless RFID tag (McGee, Anandarajah and Collins, 2019).

For the application, temperature sensing as the part of the objective of this research paper, a few different reported demonstrations with the use of chipless RFID tag structures as temperature sensors were being studied. For instance, temperature sensors based on detuning resonance frequencies of a resonator has been proposed (Mandel et al., 2017) (Noor et al. 2016) (McGee, Anandarajah and Collins, 2019)

Although the chipless RFID technology is not yet compared as much as barcode scanning technology and the IC technology due to the state of this technology is still in infancy stage, where all of the research are still between the interval of discovering to developing. But this technology clearly show some possibility in good way to achieve milestone for the direction of development (Forouzandeh and Karmakar, 2015). In the follow part, the categories of chipless RFID tags based on the difference of data bit encoding methods or also knows as communication methods will be elaborate and explained specifically classify the tags based on the lead of usage in the structure design. Some of the viewpoint of chipless RFID tag researches may be look after for previous decade to dedicate the functionality of the method involved (Li *et al.*, 2020).

In summary, there are two type of passive RFID tag. The chipped tag is providing good capability in the bit size amount stored in the design and it can offer more information insertion based on the chip design. However, the chipless RFID tag is much more suitable for the objective of this project as to temperature sensing. Although it is important for as much as bit can the tag encoded as identification, but it is also important for the another purpose of temperature sensing ability. Moreover, the price providing by the chipless RFID tag is showing more possibility in the implementation to the application of tracking, identification and sensing of the item and object. Whereas these quantity of item and object is not in a small amount. This cause the selection of chipless tag to surpass chip tag to be design as the sensor tag for sensing temperature and bit encoding purpose.

2.5 Type of Chipless RFID Tag

In this classification of the type of chipless RFID tag, the type of chipless RFID will be made based on the technique to transmit and encode data information. Depending on the antenna to transmit data, reflected electromagnetic wave may carry the parameters of time, frequency spectrum and amplitude along with phase difference. The changes are then further analysed to be converted to data information of the tag and object. Therefore, the classification will then be divided based on these factors. Although the taxonomy of chipless RFID tag shows many variations, but only the related information encoding technique will be derived and discussed for the rest of this paper as much as fulfilling the objective.

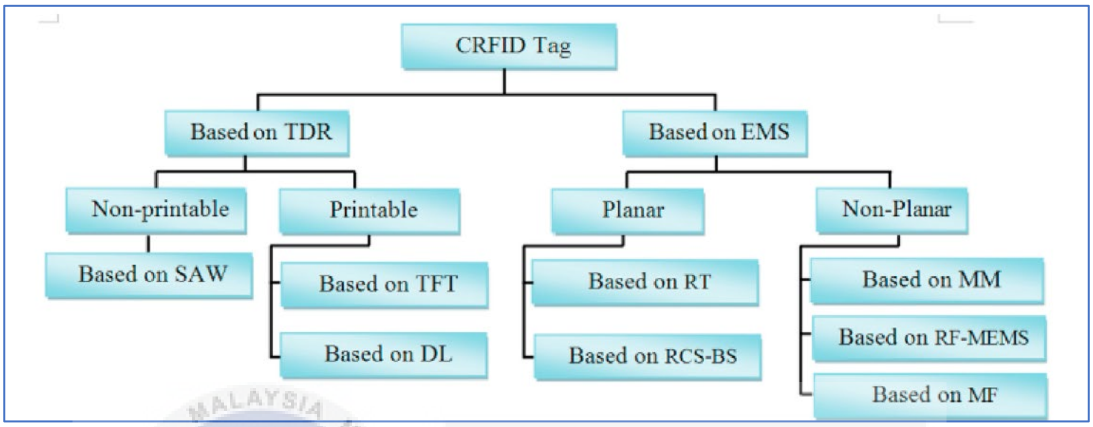


Figure 2.5: Taxonomy of chipless RFID tag (Li *et al.*, 2020)

There are two main sub-classes of chipless RFID tags that was currently classified base on the techniques of information encoding Communication techniques. These two are time domain reflectometry Time Domain Techniques (TDR)-based tags and spectral signature-based tags. In TDR-based system (Forouzandeh and Karmakar, 2015), the reader sends a pulse signal to the tag and then listens to the backward echoes of the pulse from the tag while the reflected pulse train demonstrates the bit data encoding information. Frequency-domain tags (Forouzandeh and Karmakar, 2015) utilised the response from the designed structural of the tag into the ability to encode bit data, responsive to the amplitude or the phase of the feedback result obtain from the RCS, in the frequency response of the resonant structure. The presence or absence of a resonant peak or specific phase in the spectrum will be used as each data bit at a predetermined frequency (Forouzandeh and Karmakar, 2015).

Before further discussion on the major classes, there is also system in minor type of chipless RFID class. Other than these two majors, the harmonic tag and hybrid tag are the minor classes around this chipless RFID system. The harmonic tag uses the reader to relay the signal at the original frequency, f_0, which is obtained at the transmitting portion of the tag; then, by means of a non-linear system (for example, a diode), the tag doubles the frequency of that signal to 2 f_0 and sends it back to the reader. The harmonic is therefore only produced and detected by the reader in the presence of the tag, (Forouzandeh and Karmakar, 2015). Then, the electromagnetic image is gathered to view the presence or absence of each polariser in the image represents 1-bit of data encoding (Forouzandeh and Karmakar, 2015). This approach takes more procedures than the major classes.

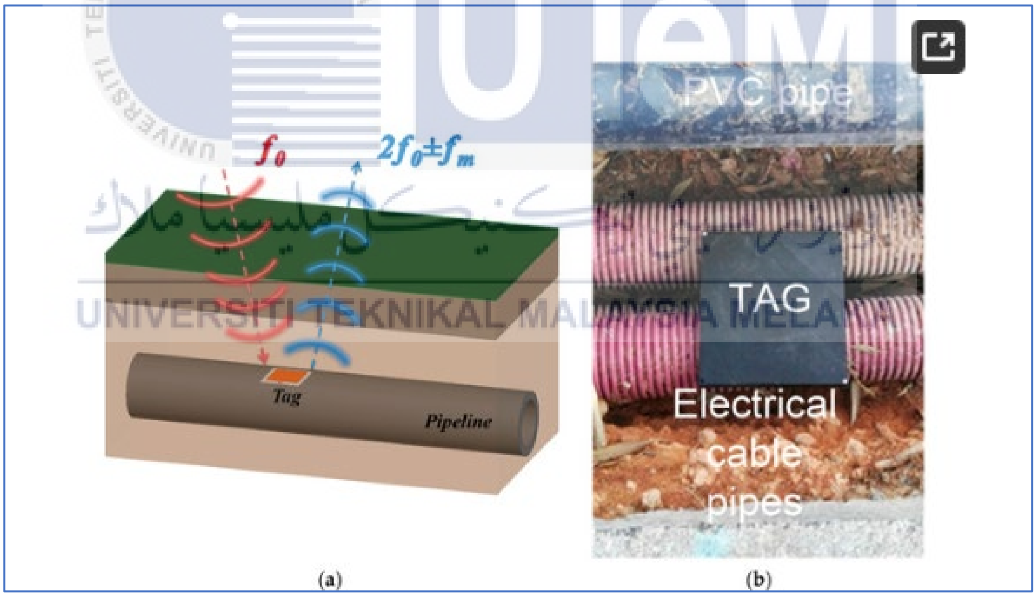


Figure 2.6: Harmonic system and an image of a typical installation. (Abdelnour *et al.*, 2018)

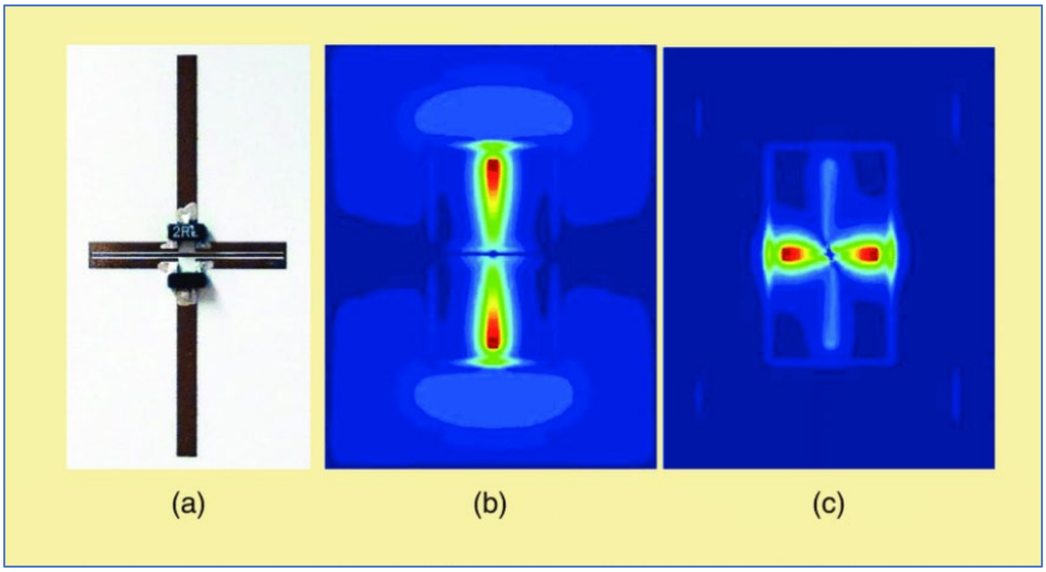


Figure 2.7: One-bit harmonic tag based on crossed dipoles and Schottky diodes frequency doubler. (Kim *et al.*, 2013)

Next, the hybrid systems capable to set up more than two logic states to a single resonant element. This approach gives a multistate behaviour by encoding the information in the frequency where each resonator can vary between different values within a predefined frequency window (Herrojo *et al.*, 2019). However, it is limited by the bandwidth assigned.

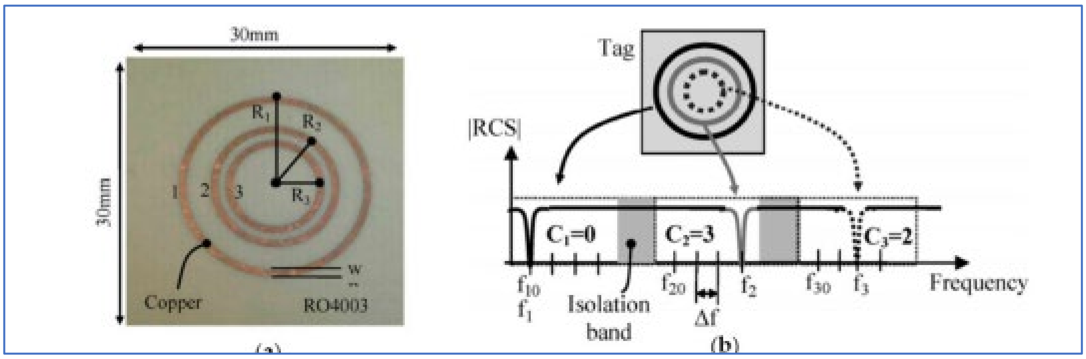


Figure 2.7: The coding principle of hybrid chipless-RFID tag constituted by three circular rings. (Herrojo *et al.*, 2019)

Back to the major class of chipless RFID's techniques of information encoding Communication techniques, the example of Time-Domain Techniques, TDR are surface acoustic wave, SAW. This SAW technology has been around for more than 40 years. The device with SAW TDR technique use the principle of piezoelectricity. SAW tags uses the advantage of high quality factor, Q of piezoelectric single crystals to store the request signal passively (no DC energy required) until all environmental echoes have died out (Plessky, Member and Reindl, 2010).

This piezoelectric crystal instead of semiconductor uses a single-metal-layer photolithographic technology. The SAW tags are generally fabricated in the 2.4 GHz ISM band. There are numerous research can be found in TDR RFID that present with SAW technology, as SAW provides a higher number of information densities than in other TDR tags (Forouzandeh and Karmakar, 2015). The main issue dealing inside of SAW technique is that the data capacity will always be compared to the others, as resulting the increase of research in this field (Plessky, Member and Reindl, 2010).

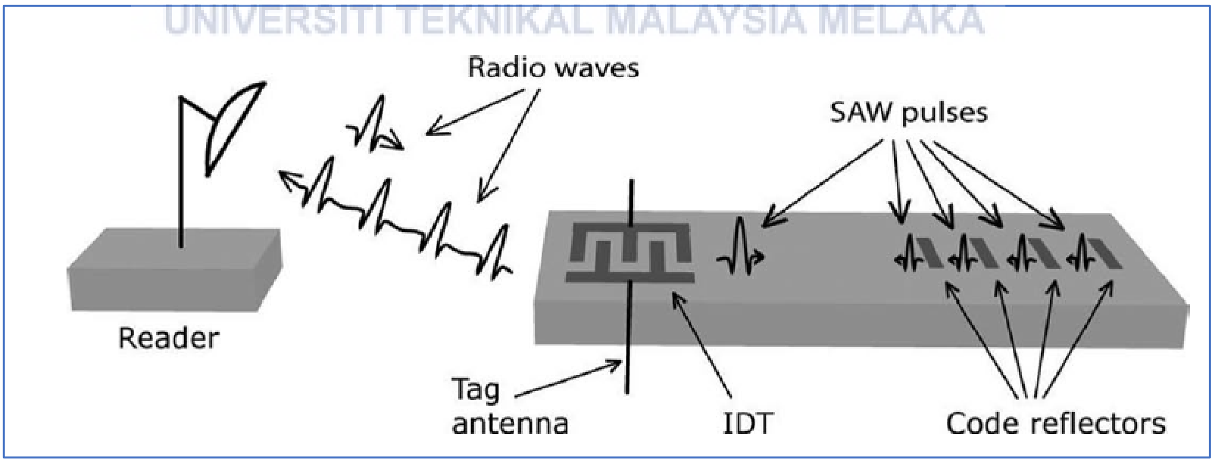


Figure 2.8: SAW chipless RFID tag system operation (Plessky, Member and Reindl, 2010)

Next, On-off keying (OOK) modulation is an easy method of data encoding in TDR-based chipless RFID systems. This modulation used the presence of a signal in a predetermined period of time to represents logic 1, on the other hand record the absence of signal as logic 0, these two-bit data are the most basic way to present the information encoding. In (Zhang et al., 2006) reported the first time-domain chipless RFID tag utilizing this technique. The reader sent a short-time pulse and the reflections due to capacitive impedance mismatches at certain intervals in the tag were transmitted back to the reader (Forouzandeh and Karmakar, 2015) (Herrojo *et al.*, 2019).

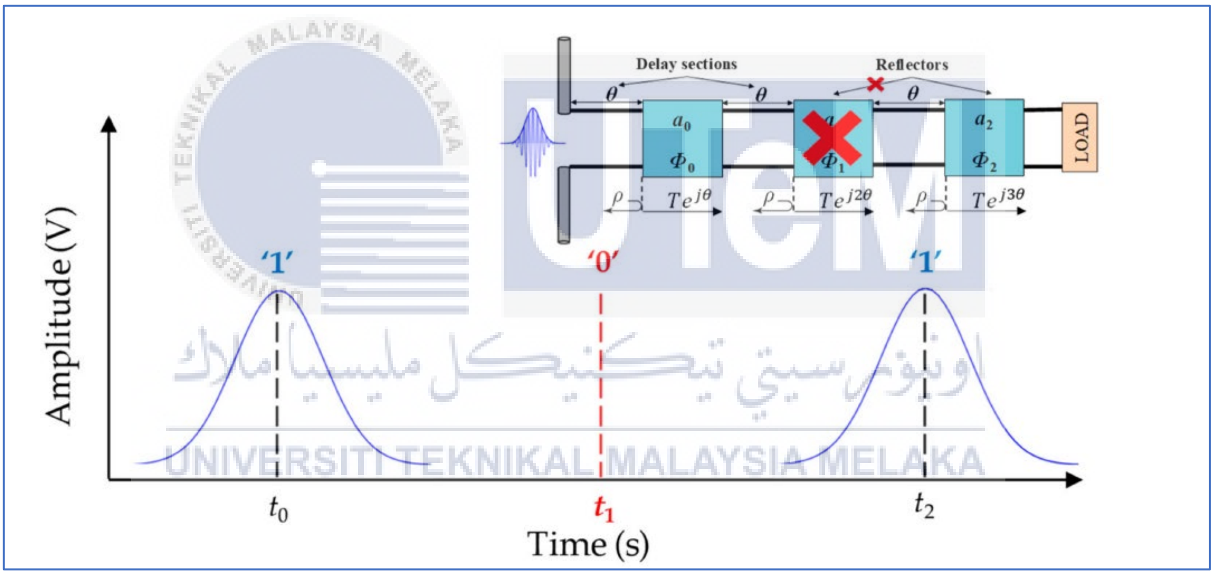


Figure 2.9: Working principle of OOK encoding (Herrojo *et al.*, 2019)

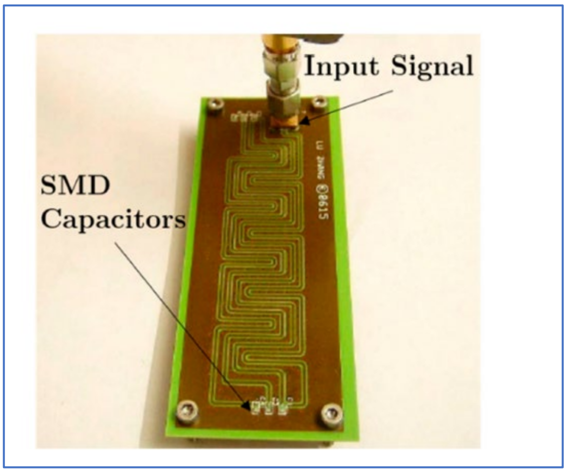


Figure 2.10: The chipless RFID tag proposed by Zhang et al.

The next TDR-based technique utilises the design of slot to further expand the information encode capability of the tag. This Pulse Position Modulation (PPM) uses an n-bit encoding could be provided by dividing each time slot into 2^n possible pulse position with a single pulse. With the locating of one reflector in each time slot, one and only one pulse will be reflected back to the interrogator (Forouzandeh and Karmakar, 2015). Hence, the encoded n bits with a single pulse will occupies one of the 2^n slots of a temporal window. This encoding technique shows a smaller number of reflectors (as less as one pulse reflected back) as directly compared to OOK encoding but with the longer time span in order to reach the same information of capacity. (Herrojo *et al.*, 2019)

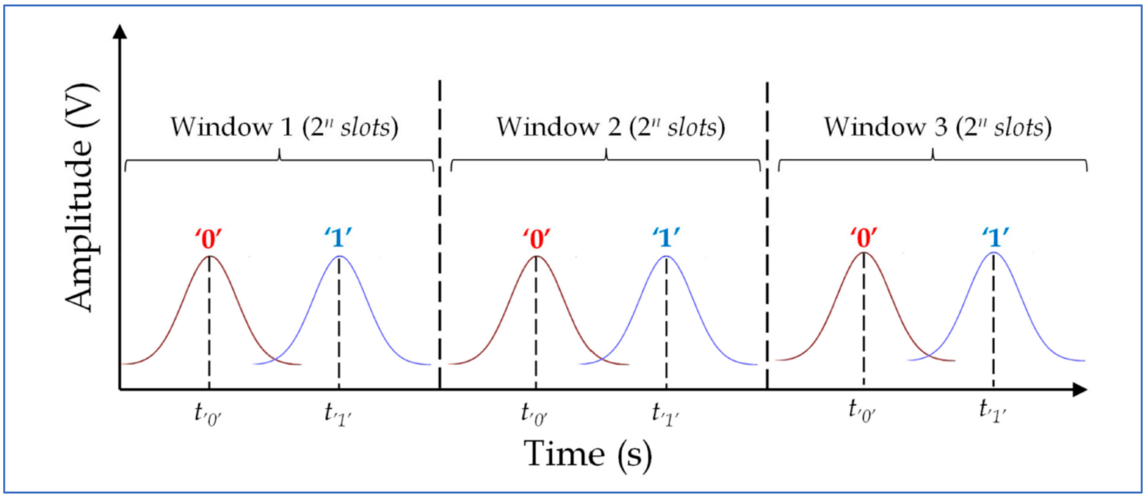


Figure 2.11: The working principle of PPM encoding (Herrojo *et al.*, 2019)

This method provides synchronisation for the reader to detect the pulse position of the tag response. As example in SAW tags, it starts a reflector to provide synchronise for the continuous of the following wave to make a connection as the same as the purpose. Another example can be taken into a look to visualise the concept of PPM. A 3-bit tag based on cascaded C-section dispersive structures was implemented for the first time by (Gupta, Nikfal and Caloz, 2011). This tag was built to maximise the in-group delay at three to five GHz. The two different positions of each pulse within a temporal window is depending on its encoding ('0' or '1') (Gupta, Nikfal and Caloz, 2011) (Herrojo *et al.*, 2019).

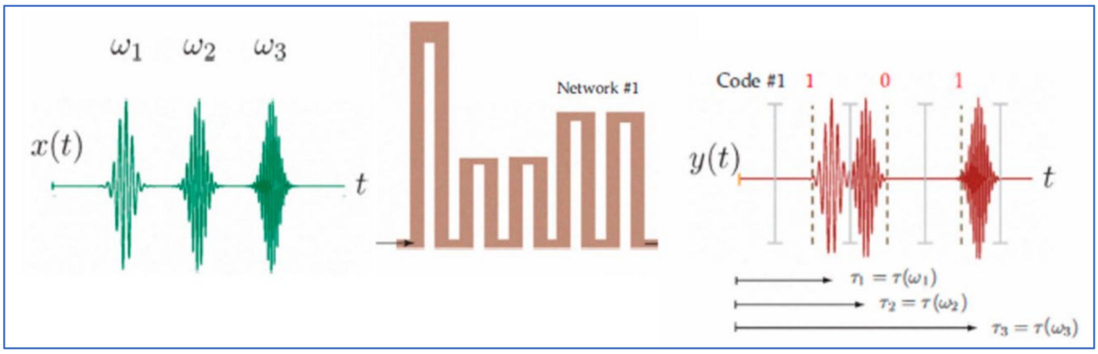


Figure 2.12: Tag proposed by (Gupta, Nikfal and Caloz, 2011) fed with three Gaussian pulses with frequency ω_1, ω_2, and ω_3 and an example of PPM encoding.

In chipless RFID tags, the backscattering modes produced by the tag antenna are considered for this synchronization. There are two modes reflected signal, first is the structural mode that induced current on the antenna's surface when it is terminated with the complex-conjugate impedance. The next one is the Antenna Mode that focus on the mismatch between the antenna impedance and the tag impedance (Nikitin et al., 2006) Because all tags applied the same the structural mode, this phenomenon can be used as reference value for time synchronization, hence the time difference between these two modes, Structural Mode and Antenna Mode can be utilized for encoding. After the study of different research study paper has shown that the slot usage are usually at number of one. (Forouzandeh and Karmakar, 2015)

The limitation on TDR is that the number of bits encoded on a tag as well as bits that can be decoded by the reader need to be considered to estimate the information content on a tag. (Forouzandeh and Karmakar, 2015). Although that some design of surface acoustic wave (SAW) tags shows a good chipless architecture, that capable to make up to 83 bits (Huang et al., 2002) and 128 bits (Hartmann et al., 2002) data have implemented in previous research studies, but the average number of bits are still in low number. The honourable mention available SAW tags in the current market features with 96 bits data capacity (Hartmann et al., 2015**).** Other than that, one undeniable factor of disadvantage that hinder the growth on TDR for the SAW technique is that the complexity of technology deployed, the high cost of printing individual codes, and the high attenuation levels due to the conversion of electromagnetic into acoustic wave and vice versa via piezoelectric transducers. (Scholl et al., 2003)

In conclusion, both the detection techniques and data encoding for chipless sensors and tags are the same. The frequency-based RFID systems and TDR-based RFID systems both have their own advantages and disadvantages, where the former has many research works and lack of solid work on the later (Forouzandeh and Karmakar, 2015). For the design used in this study, the frequency-based RFID systems will be chosen and discussed on the next part. This communication techniques were selected due to the advantages provided by this technique. The frequency-based chipless RFID system with planar designed sensor tag offers lower fabrication cost and wide area of coverage, compared to the bulky and complex design in SAW technique in TDR-based RFID system. However, the design related with TDR-based RFID system will also be displayed and discussed.

2.5.1 Frequency-Based Chipless RFID Tag

After the understanding of these classification of chipless RFID tag, this part will further discuss about the type of communication techniques that are carried out by the chipless RFID to achieve the ability to transmit and receive information. First of all, there are two types of techniques known as time-domain reflectometry and frequency signature coding. In the general, the time-domain reflectometry will take the interrogator to send a pulse and listens for echoes. Then, the receiver used the timing of pulse received at the end side of the object to encode these data.

As much as mentioned from the previous part, the frequency based chipless RFID tag will be further elaborated. The frequency based chipless RFID tag come along with different name such as frequency domain coding, frequency signature device, electromagnetic spectrum (EMS) and spectral signature barcode. Spectral signature-based chipless tag was referred to the data encode into the spectrum using resonant spectrum and it is classified into two such as chemical tags and planar circuit chipless

RFID tags. Due to overwhelming increase in trend of the frequency based chipless RFID tag, frequency based communication technique is then slowly take the position of the major class of chipless RFID system (Preradovic and Karmakar, 2011).

Although the variation of this frequency-based design of chipless RFID are quite big in the numbers, but this paper will not discussion much other type structure, so that the main type used in this research paper will be focused. This following figure 2.14 shows most of the type of the tag structure for the chipless RFID.

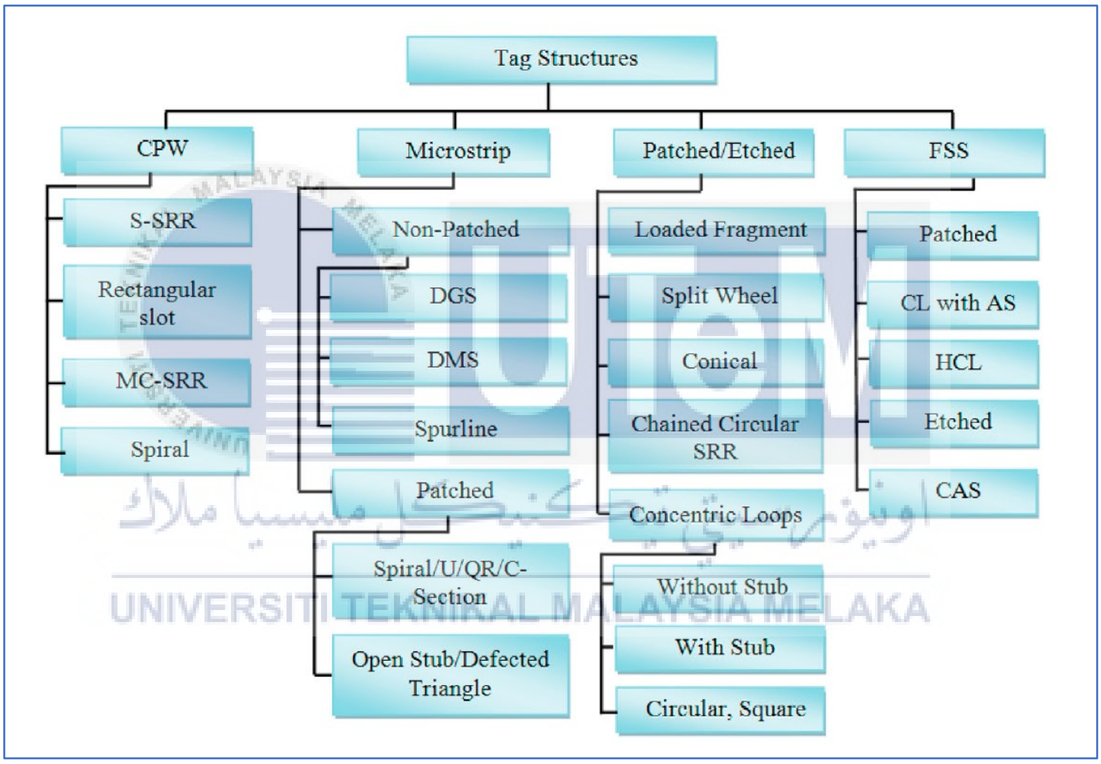


Figure 2.13: Tag structure tree diagram for chipless RFID tag

These frequencies based chipless RFID system will shows the result of a bit of information from the resonant frequency after the projection signal covered under the interrogation signal. Then, a range on distribution where the interrogation signal in distributed within a frequency band. The frequency is bounded due to the resonant characteristic of implemented resonant element. (Jalaly and Robertson, 2005a, 2005b).

For this project, the backscattered-based tags technique is used. The resonant elements generate the selected resonant frequency reflection when the tag is illuminated by an incident electromagnetic wave. The visibility of resonance peaks in frequency response of the tag radar cross section (RCS) can be encode by using as bit information “1” or “0” just by intercept the resonator with corresponding resonance. This technique enhances the ease of developing in term of the functionality without the present of the antenna, thus resulting in a smaller size.

In 2005, (Jalaly and Robertson, 2005a) proposed the first simple solution consisting of multiple dipoles with a variable capacity implemented on a substrate. By this research, it is helped to create multiple resonances in the bandwidth of the tag. Following the same strategy, same authors implanted another research, consisting of using dipoles with variable lengths (Jalaly and Robertson, 2005a), making the structure completely planar. From there, the tags show frequency ranges from 2.4 to 5.8 GHz and provide 5 bits of information capacity without a clear mention of size.

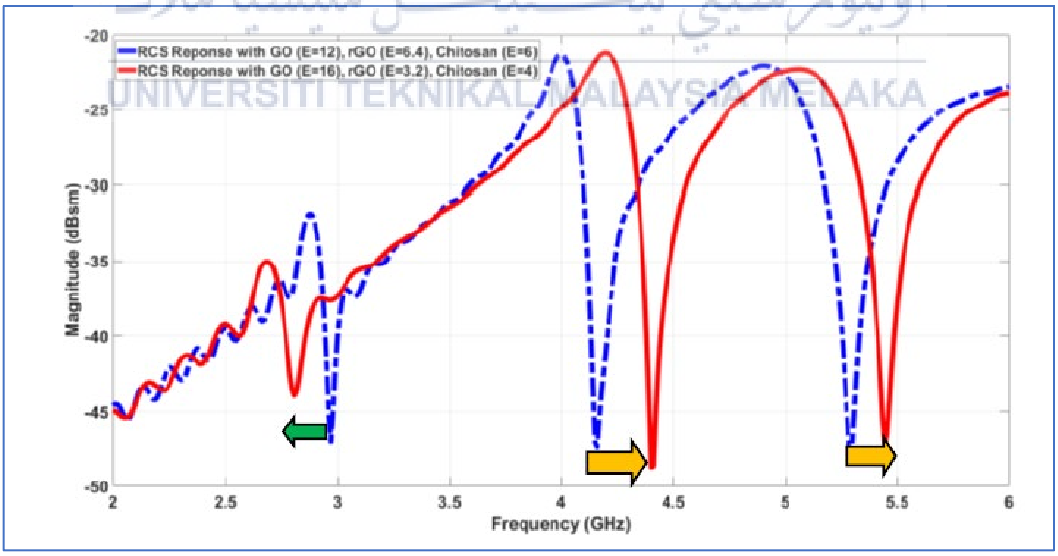


Figure 2.14: The simulation result in (Lazaro *et al.*, 2018) **show shifting in resonance frequency depending on the dielectric constant in substrate**

In summary, this research paper will propose the design of chipless RFID tag sensor with the ability to sense the temperature and make a shifting in resonant frequency of RCS. Also that the ability to bit encode data with the resonant frequency of RCS that provide in the feedback of the design of structure on the chipless RFID tag for identification purpose. Then, the encoded information in backscattering signal will be sent to the reader and further analysis at the processing area through the processing computer. As the rise in temperature will change the dielectric constant, permittivity of the substrate to conduct current and hence a shifting in the resonant frequency of RCS when the reader sent electromagnetic signal to the structure.

2.6 Design of Chipless RFID Tag Sensor

The design of the chipless RFID sensor tag by electromagnetic spectrum method and tag structure.

The design of chipless RFID tag is an electromagnetic based technique to send and receive information of Radar Cross Section (RCS) field. The scattering field of electromagnetic wave is generated by the inductive current flows. When the position of the designed chipless RFID sensor tag and the desired measure object are attached, the propagated electromagnetic wave will eventually hit (in touch with) the sensor tag. As the result, backscatter electromagnetic wave will be reflected and be read from the reader (receiver antenna), then the change of the resonant frequency (frequency resonant at contact) (Li *et al.*, 2020).

From this technique, the temperature was able to be collected from the direct contact between the designed chipless RFID sensor tag and the object of measurement. This electromagnetic backscatter is part of the previous explained frequency domain. It offers advantages of high quality of reflect rate and high pass filter for the low frequency interference such as noise (Li *et al.*, 2020) (Lu and Tan, 2018).

The system in the system of chipless RFID is consisting of three parts: tag, reader, and a computer data processing system. The chipless RFID tag totally dependent on the conductor printed on the top of the tag to store information and uses a type of frequency-domain coding. Electromagnetic waves are received or transmitted via a reader antenna. When the electromagnetic wave irradiates the chipless RFID tag, the tag will be coupled with the electromagnetic wave by the characteristics designed structure, and then the characteristic information of the structure is returned to the reader. Each tag will in a backscattering way reflect signals of different characteristics and the reader can recognize the target by interpreting the tag's structural information. The return signals are then processed by the computer data processing system. (Lu and Tan, 2018)

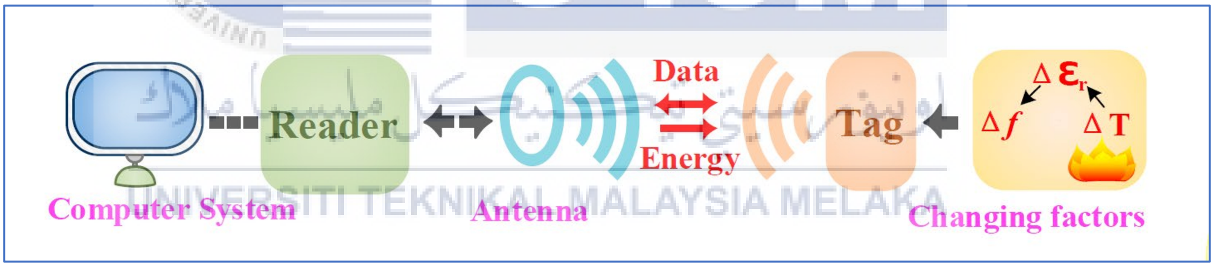


Figure 2.15: Principle of chipless RFID systems for temperature sensing

In this study, we design a structure of chipless RFID tag sensor with the Rogers-3003 material as the substrate layer. This material has dielectric constant of 3.0 and the dissipation factor of 0.0010. This structure is able to be printed with the current technology to form the sensing, so this indicates the feasibility to fabricate the chipless RFID tag. When the temperature of the environment changes, the dielectric constant inside of the substrate to be shifted accordingly. Lastly, the computer will be used to analyse the data with the computer data software to process the return signal, and hence showing the temperature sensing is achieved.

The chipless RFID tag is fully rely on the design structure printed on the tag to store the information and uses as a type of frequency-domain coding. A reader antenna is used to receive or transmit electromagnetic waves, also known as the interrogate signal. When the interrogate signal is propagate to the tag, the tag can be coupled with the electromagnetic wave through its own structure characteristics, and then the structure characteristic information is returned to the reader. In this case it is a response frequency of RCS, the response RCS is collected to show the ability of the tag to do sensing based on different temperature and provide enough bits for encode the resonant frequency to use as identification. The designed tag will reflect signals of different characteristics in a backscattering manner in this case it is called back scattering signal and the reader can recognize the target by interpreting the structural information of the tag. The computer data processing system then processes the return signals. This is the response due to normal condition, however when the temperature changes, the dielectric constant of the tag will be changes. Due to this, the response frequency of RCS will make a shift of resonant frequency when the backscattering signal in received at the antenna of the reader. Thus, making the a shifting of temperature as in the following figure 2.17 (Li *et al.*, 2020).

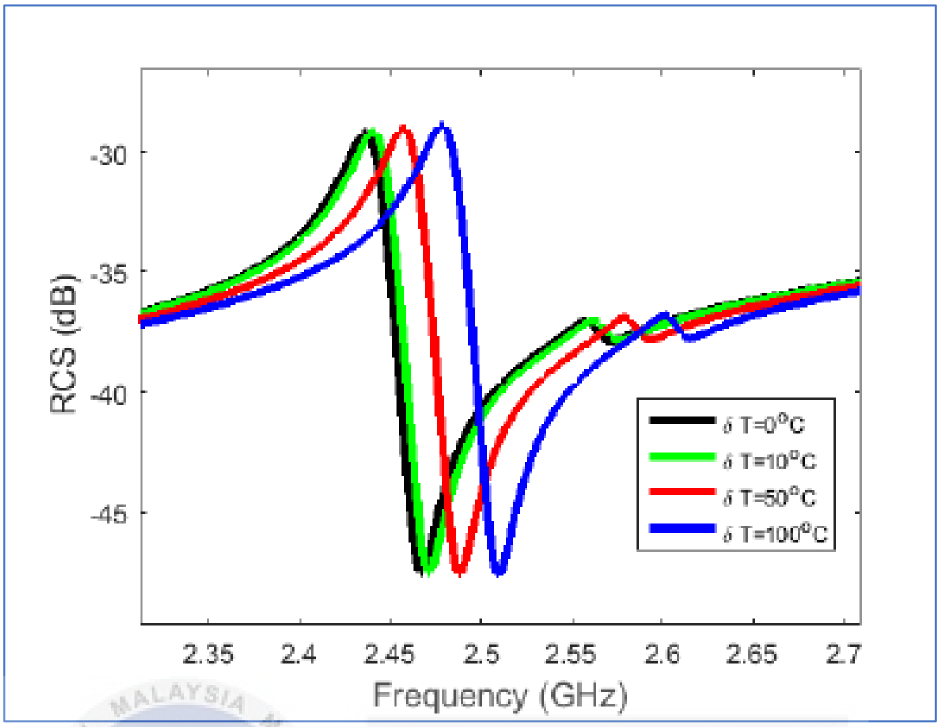


Figure 2.16: Measured RCS response frequency at different temperatures

The design of the chipless RFID sensor tag is a planar shaped structure. It consists of three layers, such as tag structure, substrate and ground plate. The ground plate is usually some copper or metallic material that attach at the bottom side. While the substrate is the material in between tag structure and ground plate. This layer is considered an important for the efficiency of the tag as it is the dielectric material that allow the flow of electrons. The dielectric constant of this material is 3.0 and the dissipation factor or tan δ of 0.0010. The structure tag design will affect the density of frequency and the bit size of the chipless RFID tag. These factors are some of the variables manipulate the resonant frequency obtained in this study.

The chipless RFID tag design and analysis is highly focused on maximizing the ratio of bit capacity to size. There are different approaches to structural design to deliver the desired result. The proposed shape tag structure provides enhanced performance in comparison with other shapes tag for temperature sensing. The following formula is used to calculate resonance frequency of a particular slot:

$$f_r = \frac{c}{2A}\sqrt{\frac{2}{\epsilon_r + 1}}$$

c = speed of light,

A = length of the largest slot (or the selected slot),

ϵ_r= relative permittivity constant of the substrate.

(By using rogers 3003, the dielectric constant of this material is 3.0)

Mutual coupling is one of the issue countering when designing the structure tag. Mutual coupling will occur on the closely reflected electromagnetic wave and cause the frequency spectrum to be messed up. This effect is avoided at all cost to prevent disturb of the resonant frequency that was required by the end of result.

On the section, a few designs noticeable design in previous study was selected and providing the functionality provided by these designs. Regarding of the topic of the design of chipless RFID tag sensor to sense the temperature with the enough amount of bit number (the resonant frequency of RCS) in the respond to provide higher limit for identification purpose. Therefore, this research study compares six previous research papers that are applying almost similar technology and performing similar purposes as a foundation to successfully achieve this objective of this paper of research study.

2.6.1 Asymmetric Circular Split Ring Resonator (ACiSRR) Design (Athauda, 2019)

This ACiSRR design used asymmetric circular split ring resonator (ACiSRR) shaped tag to measure multiple physical parameters without physical connection in ultra-wideband (UWB) frequencies while remain the origin of chipless RFID tag that capable to encode the actual data for product identification purposes.

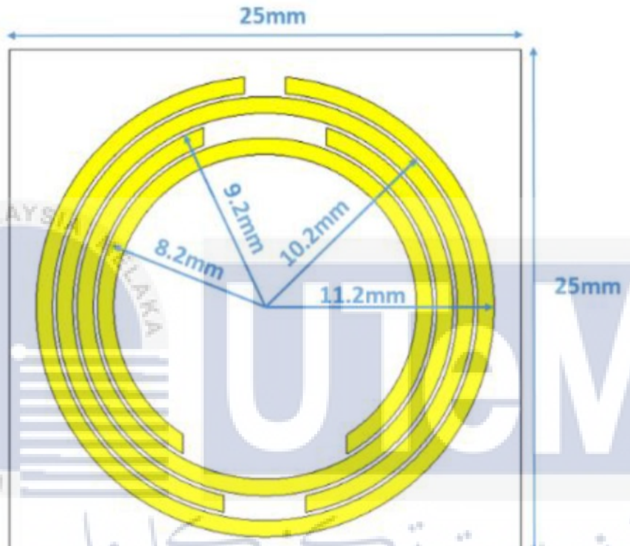


Figure 2.17: Asymmetric circular four split ring resonator

As the sensor tag proportional to the magnetic fields by the electromagnetic wave transferred through the reader antenna, the surface currents on the tag induced by the electrical will create a resonant frequency and can read by reader antenna.

In this paper of study, the understanding of different substrate shows differ dielectric properties. The change of temperature will eventually reflect changes in the resonant frequency, either in amplitude and/or shifting of the resonant frequency from referred resonance frequency. SRR was used in sensing application due to its symmetrical properties, capacitive behaviour, and negative refractive properties.

This design provides the ability to detect environmental changes such as pH, humidity and temperature. However, the research of bit encoding from the resonant frequency in this paper is less.

2.6.2 Elliptical Slot Based Design (Jabeen et al., 2019)

The design of elliptical slot is shown in the Figure 2.19.

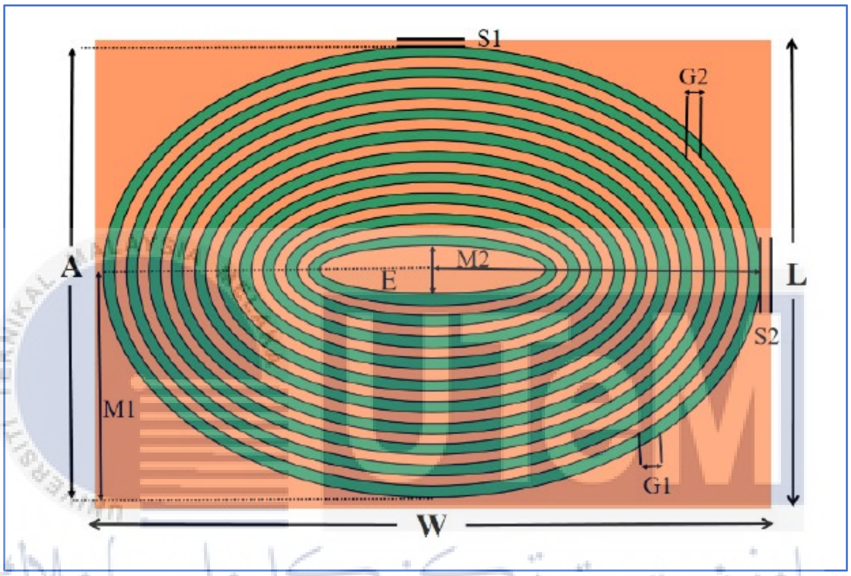


Figure 2.18: Elliptical Slot Based Design chipless RFID tag.

The study proposed the design to prove the sensing of moisture of the object as the sensor if 10-bit chipless RFID sensor tag was attached. The author of this study used backscatter mechanism of communication method to obtain the information on the chipless RFID tag.

2.6.3 Four Tip Dipole and Circular Patch Design (Mahmud *et al.*, 2018)

This design is focused on the capability to encode bit data at the other four tip dipole and a centre circular tag to send the information of the status on the object which is to sense the metal status behind the tag sensor.

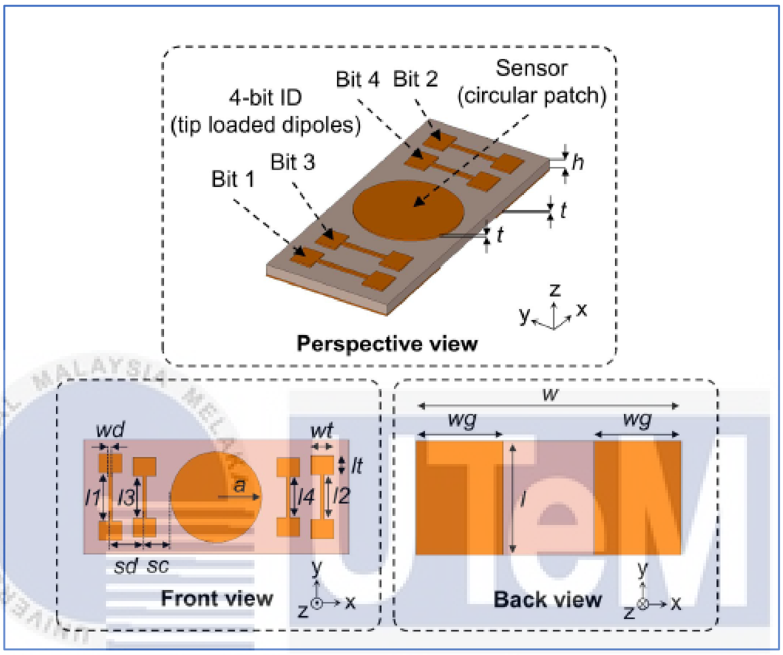


Figure 2.19: Structure and design of the chipless RFID sensor tag for metal crack detection and characterisation

In this case, the study shows the ability of the proposed design of sensor tag to detect the status of the metal behind of the sensor. The case was inspired by previously work done on TDR-based chipless RFID with delay-line tag structure, the frequency-selective surface-based sensor and the harmonic tag using band-stop filter structure, have been observed for detecting cracks on non-metallic structures. Therefore, the author was then proven the capability of frequency-based chipless RFID to both sensing the environmental parameter and while bit encode (4 bits).

2.6.4 Circular Design (Anum Satti *et al.*, 2018)

This design provide 27-bit linearly polarised chipless RFID tag with the size of 23 x 23 mm^2. It was then tested with different material of substrate to obtain the optimal performance to sense temperature. At the end of this design study is proposed a robust, flexible and miniaturised design of chipless RFID tag to sense temperature.

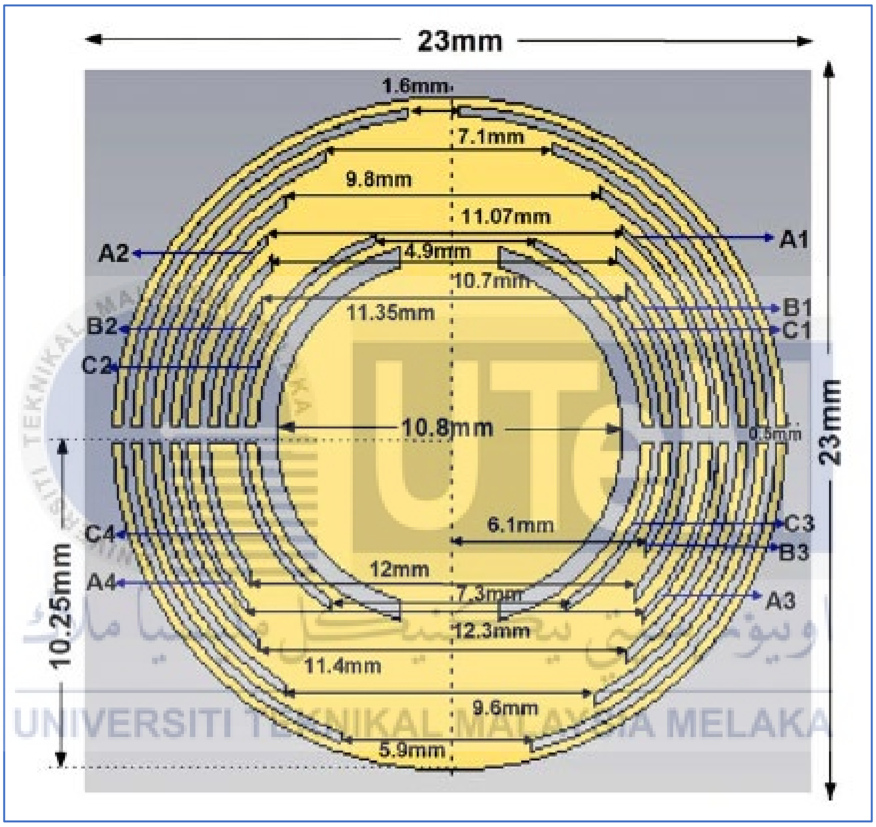


Figure 2.20: 27-bit chipless RFID tag design

2.6.5 Spiral Ring Resonator Design (Two SRRs) (Lu & Tan, 2018)

This design proposed two rings forming a dual-SRR. This design implements the chipless RFID with SRR structure as it is eased to be fabricated due to the simple structures.

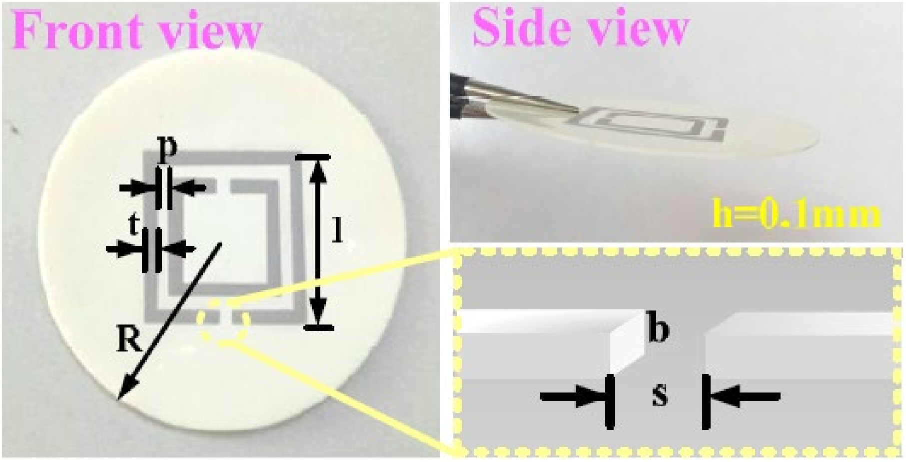


Figure 2.21: Overview of the fabricated design tag

This basic arrangement helps the vector to shift to the desired resonant frequency in the SRR duration and parameter. The smaller the resonant frequency is because the range of the exterior ring side is higher. The tag is mounted on the heat pad, whose temperature is controlled by the temperature controller. For signal reception and transmitting, a horn antenna is used. As the external context variables change, each ID's resonance frequency will change within a certain range. This system can identify targets at the same time and detect environmental information. Using the following equations:

$$f_s = \frac{1}{2\pi(L_s \times C_s)^{-\frac{1}{2}}}$$

$$C_s = C_i + C_g$$

$$C_s \propto \epsilon_0 \times \epsilon_r$$

$$\epsilon_r = \frac{E}{E_e}$$

From these equations, a clear relationship was drawn for $f_s, C_s, E_e, \epsilon_r$ and T :

$$T \uparrow \rightarrow\rightarrow \epsilon_r \uparrow \rightarrow\rightarrow E_e \downarrow \rightarrow\rightarrow C_s \downarrow \rightarrow\rightarrow f_s \downarrow$$

When temperature increases, the dielectric constant will increase over time as temperature increases. Then, the electric field intensity decreases due to the inversely proportional relation, and hence decreases both f_s and C_s. (Lu and Tan, 2018)

The design of this paper shows the basic and simple design while providing clear suggestion of the method to approach temperature sensing by the designed tag.

2.6.6 U-Shaped Design (Polivka et al., 2016)

In this research, the author proposed a 20-bit chipless tag as is inspired by the design structure in (Vena et al., 2012).

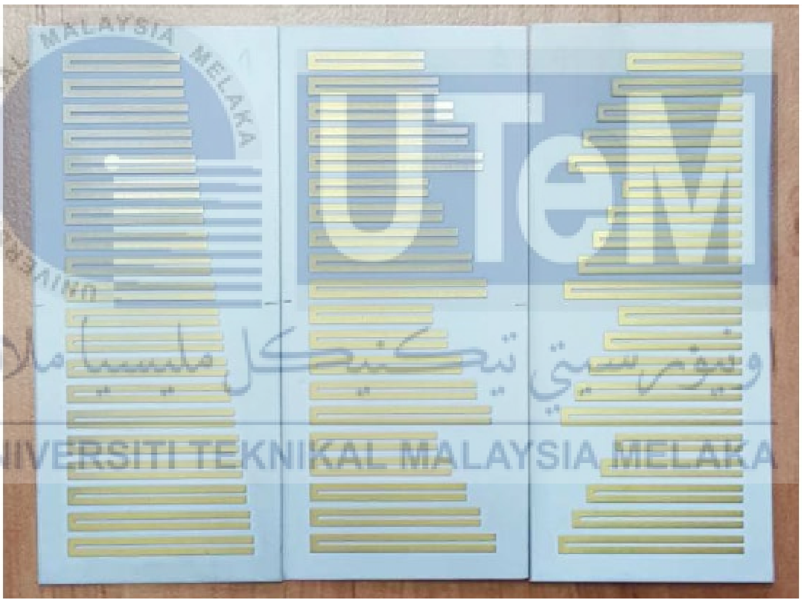


Figure 2.22: 20-bit chipless tag, composed of array of the U-shaped strip scatterers

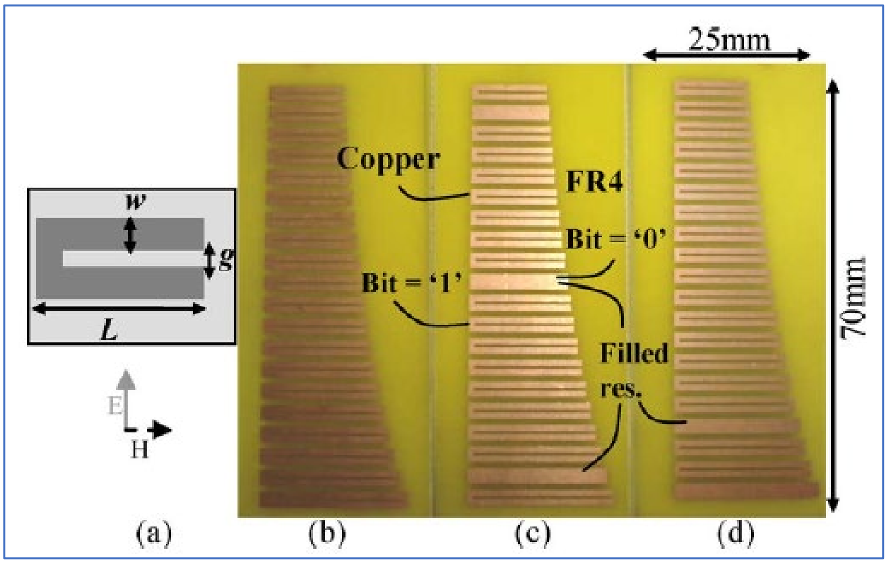


Figure 2.23: 20-bit chipless tags with different state of data set up on bit

The design was U-shaped and arranged in array. From the sentences, the mutual coupling between the resonant frequency and direct adjoining scatterers were the holdback for the improvement for the design. Since the designed arrangement would be able to bring the best condition for the robustness of the RCS curve. Therefore, the solution for this problem brought to the change it structures alignment and reformation without remove the number of bits of structure nor increase in the size of tag.

(Polivka et al., 2016) The mutual coupling effect should be taken care if the design was meant to compose to array of the structured strip scatterers.

In this design of paper, the author shows the capability of the chipless RFID tag to provide a very high bit of data encoding with the repeated U-shape design. However, the array design has caused some mutual coupling effect to be affecting the overall performance. The problem was carefully overcome with the good design structure. Although the ability of sensing temperature was not provided, but the idea of design for maximum bit encode in identification is suggested.

2.7 Previous Research Studies

The study of the related previous project is essential to have a better understanding of the project. In this chapter, the ideology of the related previous project will be mentioned so that a direct comparison can be drawn between product and the direction of design shall be taken into. Therefore, this research study compares a few previous research papers that are applying almost similar technology and performing similar purposes as a foundation to successfully achieve this objective of this paper of research study.

This project required the effective type of design to maximise the properties of maximum encoding information and while located under a minimum size. The limitation of the chipless RFID tag sensor to encode information from the bit provide in the resonant RCS frequency of the design. Moreover, the information capacity of the tags increment will implies increasing the number of resonant elements and the size. (Polivka *et al.*, 2016). Thus, suitable design should be selected for the function to sense temperature while providing great number of bit size (under smaller size).

Several design of the frequency domain based scatterers and RCS techniques in previous studies have been studied, among them e.g. C-shaped (Vena et al., 2012), multiple C-shaped (Vena et al, 2012) (Amin et al., 2014) strips, concentric strip rings forming polarization independent tags (Vena et al., 2012), or other polarization independent tags (Reaiesarlak et al., 2014) (C. Feng, 2015), dual polarized tags (Islam et al., 2015), tags based on stepped impedance resonators (C. M. Nijas, 2014) or complementary slots-in-plate (Polivka et al., 2014). During the design of scatterers arrangement according to their resonant length, there is some draw back on it as it creates a mutual coupling of neighbouring elements. As the number of resonant slot increased, the effect of mutual coupling will also increase. This cause a harder for a good depth of attenuation of RCS resonant frequency to be formed.

There are few main challenges for general case in chipless RFID tag such as maximise information in the minimum possible area (to allow more RCS resonant frequency to be obtained) and to sense the temperature around the designed chipelss RFID tag sensor. Below the table 2.1 is the comparison that have similar functionality as the objective of this project to sense temperature while bit encoding for identification. Table 2.1 shows that the development in data bit encoding is usually not coming along with the ability to the tag to be sensor for temperature or environmental parameter. However, there is an improvement in the number of research conducted to the environmental parameter sensing in the recently year.

Table 2.1: Comparison of Design of Previous Study on the Topic of Project

Author/ Years	Bits	Area (cm^2)	Bit Density (bit/cm^2)	Data Bit Encoding	Temperature Sensing
E-shaped (Sumi *et al.*, 2015)	8	17.7	0.45	Yes	No
(Svanda et al., 2016)	20	17.5	1.14	Yes	No
U shaped (Polivka, et al., 2016)	20	2.6 x 7.0	1.099	Yes	No

L-shape, (Habib *et al.*, 2017)	8	7.14	1.120	Yes	No
Hexagonal (Iqbal *et al.*, 2017)	14	2.3 x 1.0	6.087	Yes	No
Circular (Anum Satti *et al.*, 2018)	27	2.3 x 2.3	5.1	Yes	Humidity & Temperature
Rectangle (Adbulkawi and Sheta, 2018)	6	3.387	1.771	Yes	No
(Muhamud et al., 2018)	4	3.5 x 1.5	0.762	Yes	No (Metal crack detection)
Asymmetric circular split ring resonator (Athauda, 2019)	3	2.5 x 2.5	0.48	No	Yes (Humidity, temperature, pressure and pH)
Ellipse Shape (Jabeen *et al.*, 2019)	10	3.648	2.74	No	No (Humidity)

2.8 Summary

Some academic papers based on proceedings and journals have been reviewed in this chapter. The literature review is essential for the development of the idea to design the project using various method that cited which could show the usage and capability of the project. Hence, the vision in order to design the project in sophisticated yet simple way possible. The design of the frequency based chipless RFID sensor tag with the communication technique will be explained moreover in the following part. In summary, the overall idea and concept of this project is shown clearly after the overview on this chapter.

CHAPTER 3

METHODOLOGY

3.1 Chipless RFID Tag Concept

Introduction to research methodology provides comprehensive overview of a broad range of research paradigms and methodologies, as well as associated methods and techniques. The chapter focuses on the methodology design as well as process flow of the entire research. The overview of the research explaining the methods and the proposal to analyse data templates for design comparison.

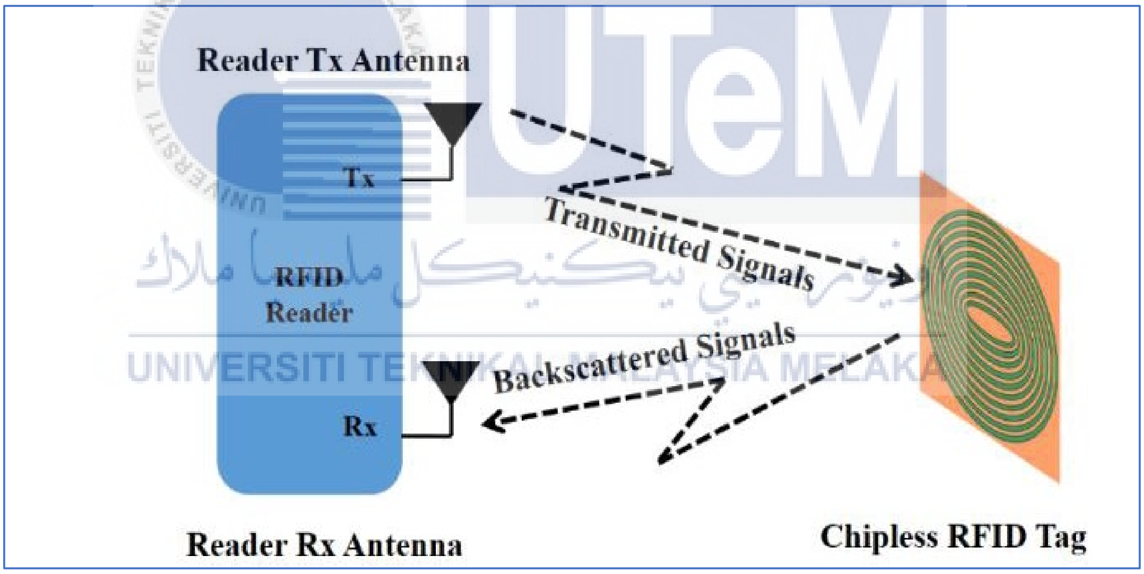


Figure 3.1: The process of chipless RFID tag system in sensing environmental parameter (Jabeen *et al.*, 2019)

The chipless RFID tag sensor will first require a well-designed structure pattern to maximise the bit number to encode the ID for the chipless RFID tag sensor under the Ultra-

Wideband frequency range (3.1 GHz – 10.6 GHz). While maximise the data bit per area, the area should also be minimised.

Other than that, the most important part of this tag sensor is to sense the temperature around the object. The chipless RFID tag sensor is meant to be implanted on the surface of the object. This will be allowing the object that the RFID tag sensor attached to, to be sensible for the temperature around the object. Referring to figure 3.1, to obtain this value of temperature change, the RFID reader transmitter antenna to transmit an interrogate signal to the proposed design of chipless RFID tag sensor. Interrogate signal was then irradiated the structural design of the slot and pattern of the tag. The chipless RFID tag sensor is then reflecting the information inside of design structure as a backscattering signal to the receiver antenna of the RFID reader. Then the RCS spectrum of the tag with resonant frequency is shown. Assuming that the condition of the mentioned process to be in a standard room temperature of 25 degree Celsius, and now by changing the temperature of the surround of the designed RFID tag sensor, the permittivity (dielectric constant, ϵ = 3.0 and loss tangent of 0.0010, δ) of the substrate material of the tag will be affected and the transmission of electrons will be differed than the normal condition. Also, that the change in the dielectric constant of the substrate material will then affect the flow of electrons on the surface of metal copper of the designed chipless RFID tag sensor. This variation of permittivity will cause the flow of current on the surface of the metal on the top of substrate to be differ. The reflected wave will provide different RCS resonant frequency when the backscattering signal is received at the RFID reader antenna. The designed tag will then play role in here to be the deflector of the transmitted EM wave (backscattering signal) to the receiver antenna to make the reflection of the RCS resonant frequency has being shifted in the resonant frequency due to the change in the temperature that eventually cause the dielectric constant to be changed. This shifting was then captured by the RFID reader receiver and then was sent to the processing system to further analyse.

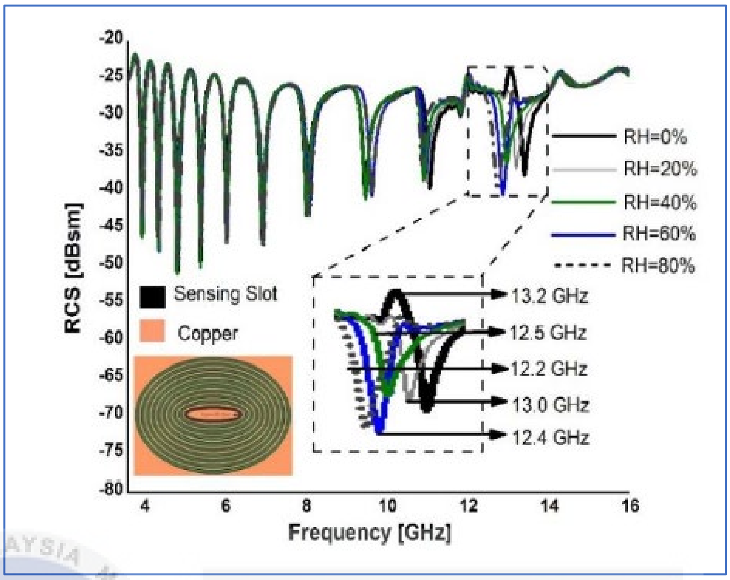


Figure 3.2: RCS resonant frequency from humidity sensing

The figure 3.2 shows the change in RCS according to different level of humidity of the tag sensor. Referring to this, the similar result such as figure 3.3 but with higher bit value will be expected at the result part of this project with the suitable proposed design of chipless RFID tag sensor to sense temperature.

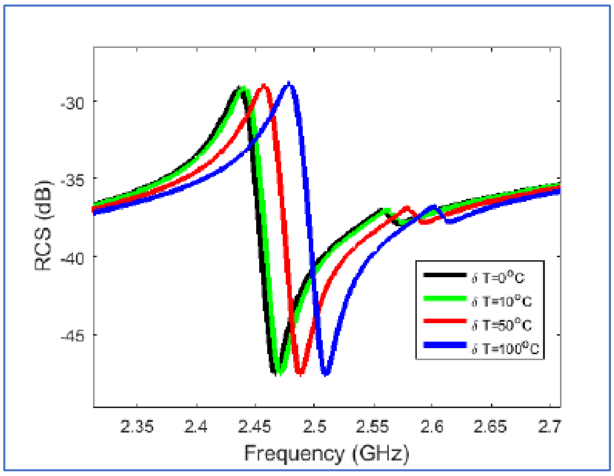


Figure 3.3: RCS response frequency of one bit for different level of temperature in the previous studied research

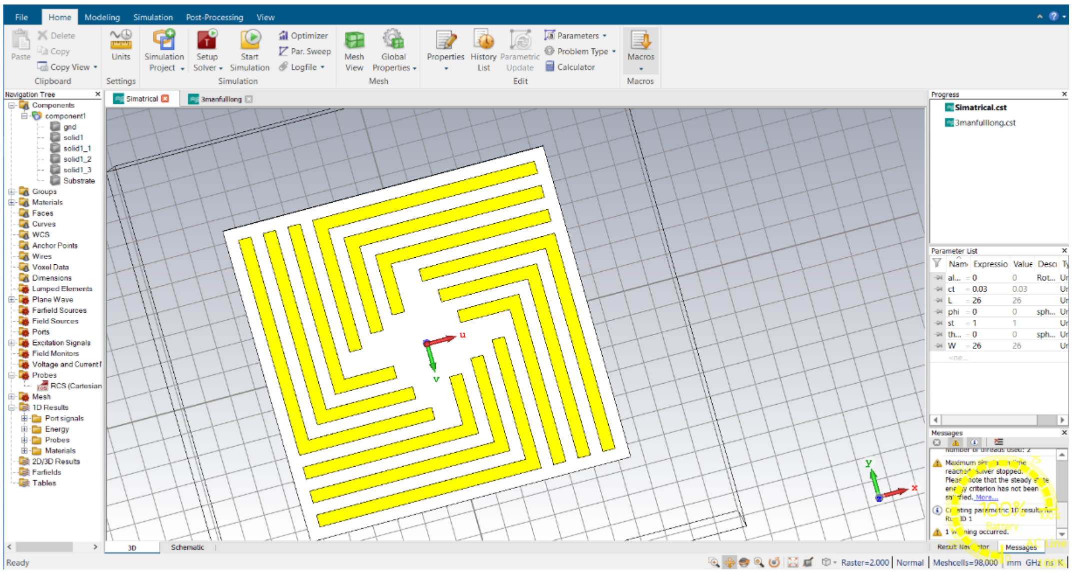


Figure 3.4: The preliminary design of the chipless RFID tag sensor (4-bits)

Figure 3.4 shows the preliminary design of the chipless RFID tag sensor based several design factors such as sizing, structure of slot and the arrangement of the length of slotted design. This proposed design of RFID tag will firstly be simulated and tested in software CST 2018. The proposed design of tag will be repeated for several time to have a optimised performances on the temperature sensing ability and the RCS response frequency for bit encoding ability. These are the objectives of this paper, to develop a good visual and clear visual on the RCS response curve when the tag being simulated. With the theoretical and some experiments run on different temperatures, it shows that the changes in the temperature is affecting the dielectric constant of the substrate material. Due to the change in this permittivity, the RCS response curve will slightly be being shifted to the left-hand side or right-hand side of the original spike of RCS response.

However, due to multiply complex parameters, this temperature change condition on the back side of designed tag cannot be fulfilled with the simulation on CST MWS software. Therefore, the temperature changes can only be measured after the fabrication process of the design process was done. Then, the proposed design will be moved to the hardware development after the verification from the supervisor.

Next, the fabricated result will be brough to the anechoic chamber laboratory in UTeM for the real environment measurement to done. Other apparatus and equipment such as the transmitter and reader (receiver antenna) are included to measure the result. Based on the simulated outcome and measured value, its will be made into a line to show a clear comparison between the fabricated and the predicted result.

Finally, the result shall be revised, analysed and compared between simulations and fabricated results of chipless RFID tag sensor to accomplish the objective of temperature sensing and bit encode of the tag identification.

3.2 Apparatus and Material

3.2.1 Software CST 2018

Software CST 2018 to be used as the simulation software for the chipless RFID tag sensor to sense temperature.

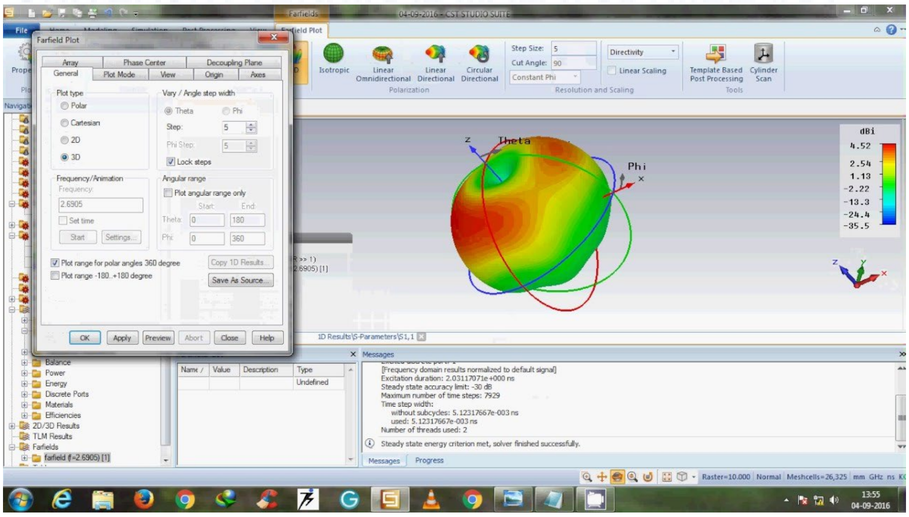


Figure 3.5: CST Microwave Suite Studio Software 2018 (Source: Internet)

3.2.2 Substrate – RO 3003

The material ROGERS 3003 with the dielectric constant of 3.0 and the loss tangent of 0.0010 will be used as the substrate for the chipless RFID tag. This substrate plays an important role in sensing the temperature change due to the characteristic of the material with ability to shift the resonant frequency on reflection after the permittivity to vary.

Figure 3.6: RO3003 (Source: rogerscorp)

Property	RO3003
Dielectric Constant, ε_r Process	3.00 ± 0.04
(2) Dielectric Constant, ε_r Design	3.00
Dissipation Factor, tan δ	0.0010
Thermal Coefficient of ε_r	-3
Dimensional Stability	-0.06 0.07
Dimensional Stability	-0.06 0.07
Volume Resistivity	10^7
Surface Resistivity	10^7
Tensile Modulus	930 823
Moisture Absorption	0.04
Specific Heat	0.9
Thermal Conductivity	0.50
Coefficient of Thermal Expansion (-55 to 288 °C)	17 16 25
Td	500
Density	2.1
Copper Peel Strength	12.7
Flammability	V-0
Lead Free Process Compatible	YES

Figure 3.7: Properties of ROGERS 3003 based on data sheet

3.2.3 Copper material

Copper etched on the surface of substrate to allow the information to be stored and reflected to the reader after the wave excitation of antenna.

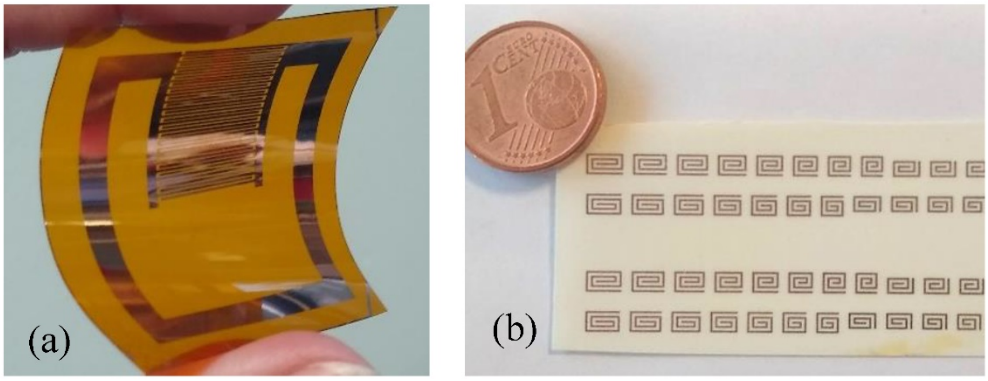


Figure 3.8: Copper material etched tag with the size less than one-euro cent (Source: Mulloni, Viviana; Donelli, Massimo. 2020)

3.2.4 Thermoelectric Peltier Power Generator

This tool will be used to generate heat behind the fabricated tag for the study on the effect of temperature changes toward the RCS response frequency.

Figure 3.9: TEG SP1848-27145 Thermoelectric Peltier Power Generator

3.3 Formulae

The formulas in designing the chipless RFID tag sensor are as following:

$$f_r = \frac{c}{2A}\sqrt{\frac{2}{\epsilon_r + 1}}$$

f_r, Resonant Frequency

c, speed of light

A, length of the slotted design

ϵ_r, permittivity of the substrate material in tag ($\epsilon_{ro3003} = 3.00$)

$$d \geq \frac{2D^2}{\lambda}$$

d, Far field distance

D, Maximum length of the tag

λ, wavelength

$$\sigma^{tag} = \frac{(S_{11}^{tag} - S_{11}^{iso})}{(S_{11}^{ref} - S_{11}^{iso})} \times \sigma^{ref}$$

σ^{tag}, RCS of the measured tag

S_{11}^{tag}, reflection coefficient to the tag

S_{11}^{iso}, reflection coefficient without the tag

S_{11}^{ref}, reflection coefficient to a reference object (replacing tag)

$$\sigma^{ref} = \frac{4\pi(a^2b^2)}{\lambda^2}$$

σ^{ref}, RCS of the reference scatterer

a & b, length and width of the object

3.4 Block Diagram

This block diagram presents the implementation of chipless RFID tag sensor based on the theory in this project.

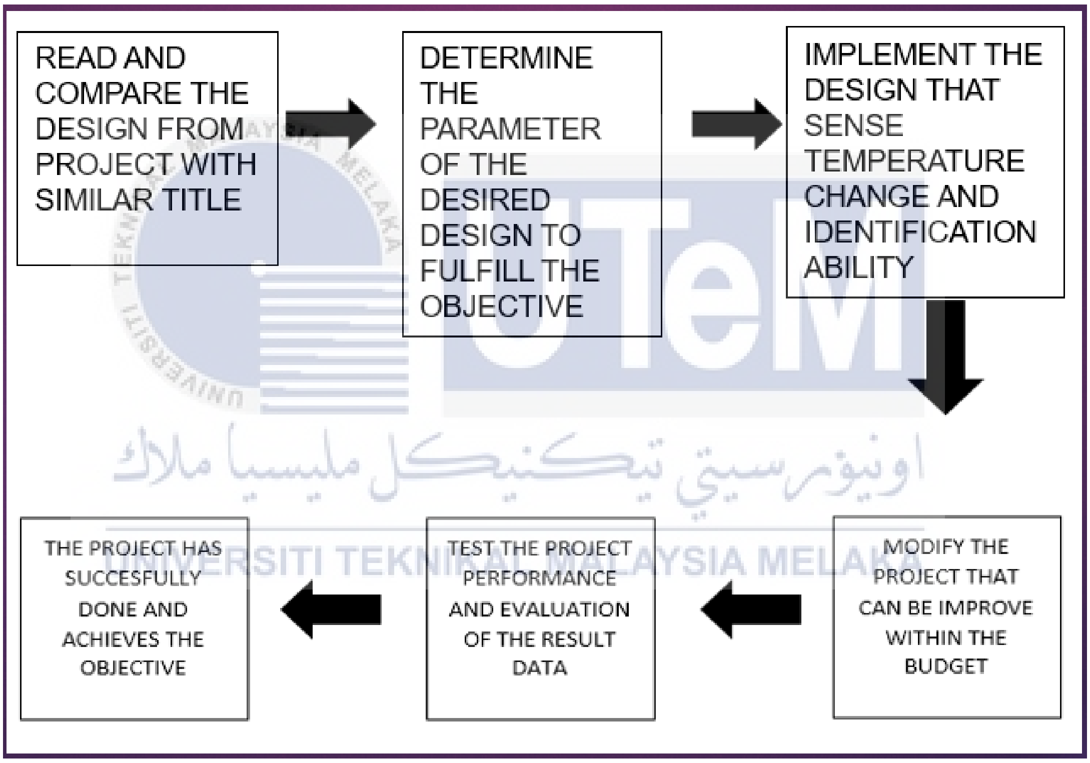
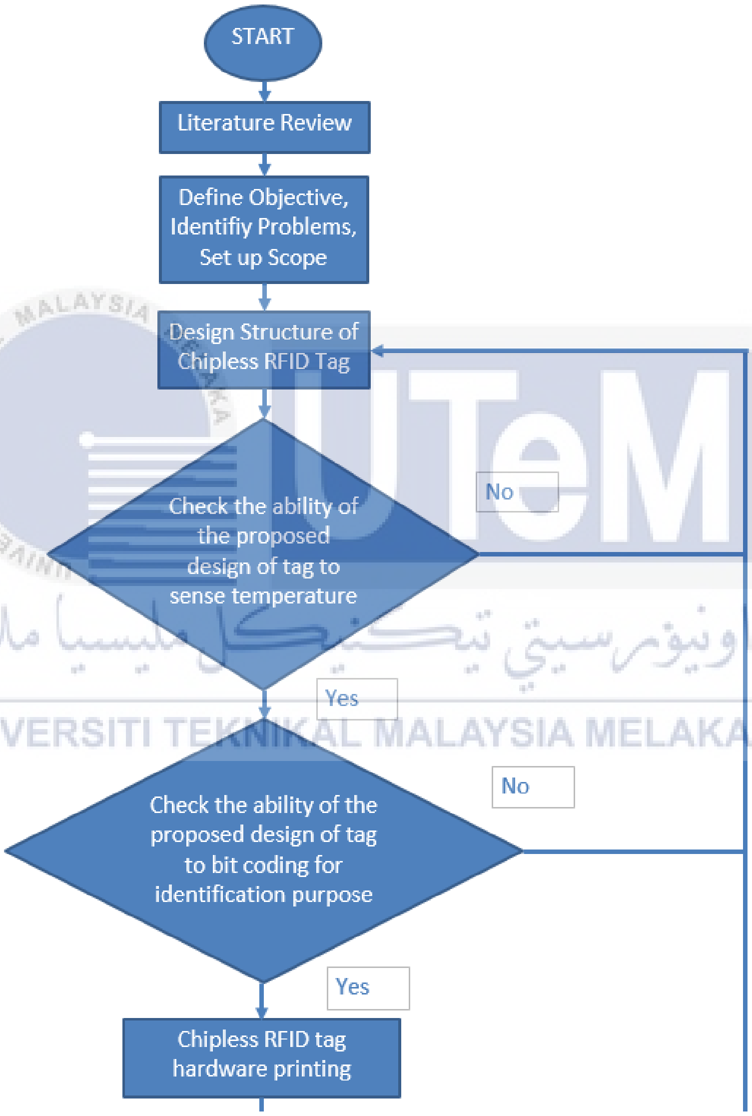


Figure 3.10: Block Diagram of Implementation Based on Theory

3.5 Flow Chart

The process to develop project system will be illustrated with an operation flow chart. The operation flow chart will show the process on working of both hardware and software to achieve the objectives. This flow chart includes the procedure on the design of the chipless RFID tag that able to overcome the challenge on bits encode per area and the ability to shifting the resonant frequency based on the segregation of level of temperature of the object. A few decisions will be made based on the adjusting of the correctness to embark the desired result at the outcome. The following is the figure 3.10 that present flow chart of this project.



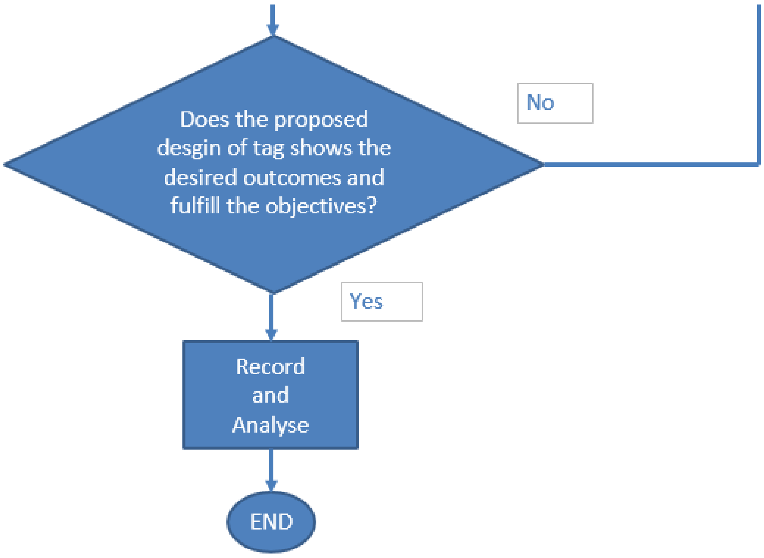


Figure 3.11: Flow chart of whole project

3.6 Summary

This chapter summarised the methodology part consist of the mechanism and the components used for the project. The components of the project cited along with the explanation of the features and advantages. Therefore, the mechanism of the project method explained in the simple way in flow chart diagram for the guidance to express the idea of the project.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will explain about the result and analysis of this paper. This project is related to the chipless RFID tag sensor that capable to sense temperature with the ability to produce an eight bit of bit encoding. In this session, it has two part will be the results of analysis on the performance of the designed chipless RFID tag sensor is observed. Next is about the compared between expected result and the actual result based on the scenario.

4.2 Results and Analysis of Chipless RFID tag sensor

4.2.1 The structural design of Chipless RFID tag sensor

There are three type of designs being taken into consider for this project. The follow is the type of design being put into compare while discussed when the direction of the type of design of the sensor tag. As presented in the figures, those shapes are common shape that present in daily life, starting with hexagonal, circle and lastly V-shape. Among these shape for the design of the chipless RFID sensor tag on the application to bit encoding and thermal sensing, the V-shape design was being chosen. There are two reasons for this action, one of it is the capability to encode bit data. As presented in the figure, the requirement for each bit to exist in the RCS response frequency of the design

RFID tag sensor is the slots designed in the tag sensor. The RCS response frequency can be calculated through the formula mentioned in the chapter 3, the RCS response frequency. The increment of the bit encoding will eventually make the shapes of design to be increase or decrease with the difference of slow width taken. For this case, a slot width of 0.5 mm was taken to the design of this project. This measurement was taken by a research conducted by Ma & Jiang (2019), where the width of the slot can tighten the RCS response frequencies stimulated, through the back scattering of the interrogated signal after the signal hit the designed surface which the slot of tag sensor located. The size dimension of the chipless RFID sensor tag that was about to be designed is in the dimension of 25 mm × 25 mm × 0.545 mm $(Length \times Width \times Height)$.

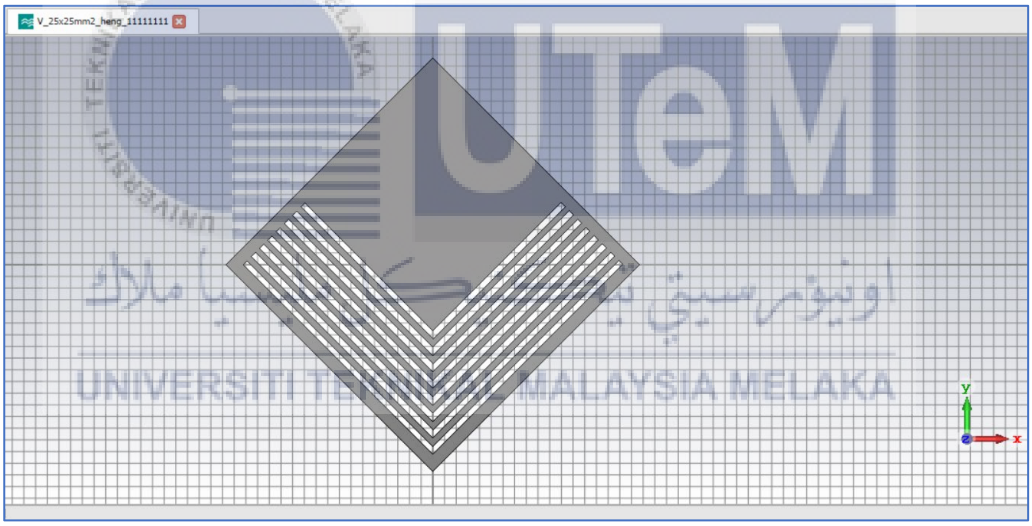


Figure 4.1: The design of 8 bitse V-shaped chipless RFID tag sensor for bit encoding and temperature sensing

This is the designed V-shaped structural of the chipless RFID tag sensor that will be analysed, fabricated and simulated. This design was first simulated with different parameter of dimension to obtain the optimised performance. Then, it is simulated comparing with different material design of substrate and their relationship. Next, the fabrication will be started on the selected printed circuit board (PCB) factory for the measurement undergoes in real word. The laboratory anechoic chamber at campus of UTeM will be used as the location for testing the fabricated tag. The result was then compared to the simulation result on CST MWS Suite Studio for comparison. Lastly, the fabricated result can move to last testing on effect of environmental temperature change towards the shifting in the RCS response frequency curve.

Now, the optimised parameter of the dimension is listed on the table 4.1, for a clear parameter figuring. For better explanation, the figure 4.2 provides one bit of bit number from the slotted dimension on the tag.

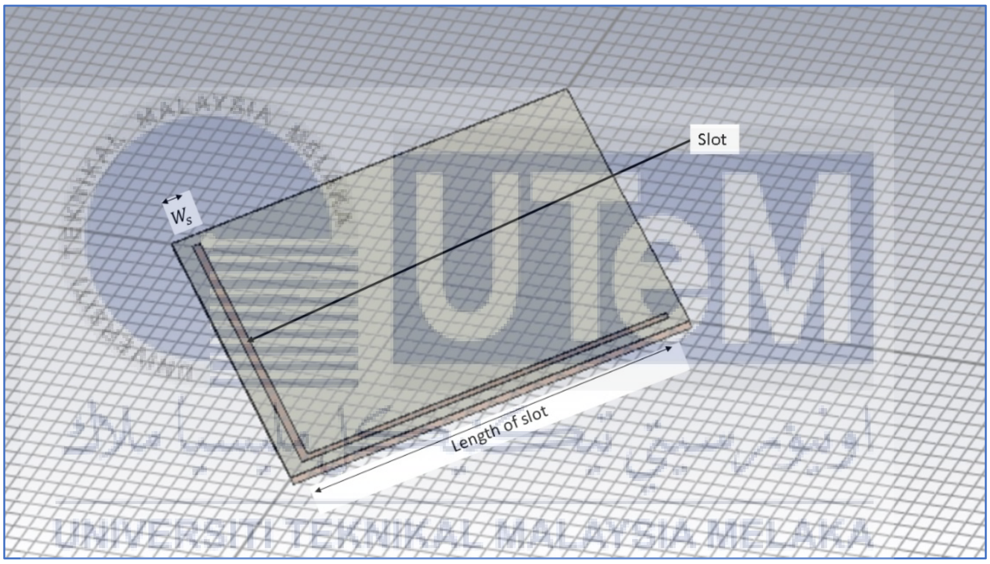


Figure 4.2: The indicator to the related parameter of dimension on the design of RFID tag sensor

As shown in figure 4.2, the two different dimensions of the slot of tag are W_s and L_n. As the length of the slot decrease, the frequency response value is higher. Therefore, the largest value of parameter dimension for the length of the slot, will have the lower value of bit number in arrangement order of bit. The width of slot could be altered for different sizes, however, the width was limited to 0.50 mm. This approach was taken for the relationship drawn between the length of slot, and the respective location for the bit numbers under the length's response frequency.

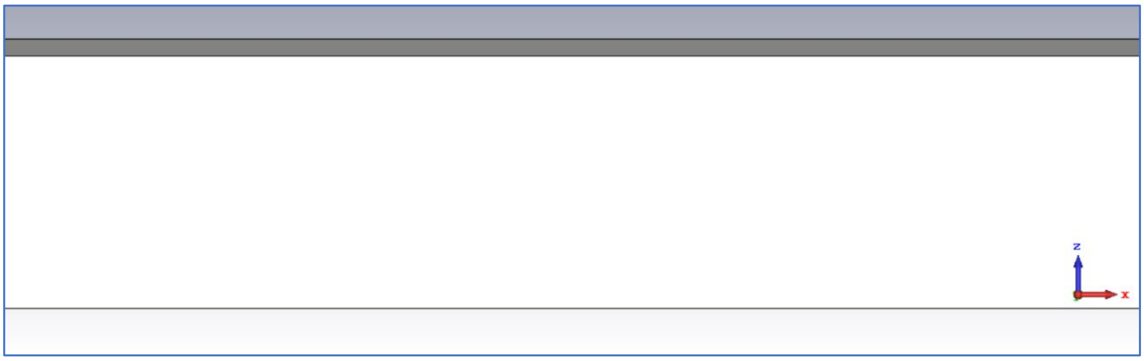


Figure 4.3: Layer of designed chipless RFID tag sensor

The design is as following figure 4.3 shows that the component consists of two layers, the first layer is the Perfect Electric Conductor (PEC) metal with thickness, *ct* of 0.035 mm. Then, the second layer is the rogers 3003 material with dielectric constant of 3.0 (ϵ_r = 3.0) and thickness of substrate at 0.51 mm (t = 0.51 mm). The dimension of this chipless RFID tag sensor is 25 mm × 25 mm × 0.545 mm. The parameter of overall designed tag sensor is tabulated in the following table 4.1.

Table 4.1: Parameter of design chipless RFID tag sensor with 8 bits of encoding size and substrate of rogers RO 3003

Parameter	Value
Side length of primary slot (L_1)	23 mm
Wide of slot (W_{slot}) (W_s)	0.50 mm
Distance of adjacent slot (d)	0.50 mm
The inner most side length of inner most slot (L_8)	15.5 mm
Height of substrate (h)	0.51 mm
Thickness of PEC (t)	0.035 mm
Area of tag	25 x 25 mm^2

Table 4.1 shows the optimised parameters in the tag design, all of these parameters play important role to obtain the desired results. The 8-bits RCS response can clearly show in the simulation inside CST software.

4.2.2 Formula applied

The formula that was taken into calculation for the design of the structure and shape of the chipless RFID sensor tag are as following:

$$f_r = \frac{c}{2L_n}\sqrt{\frac{2}{\epsilon_r + 1}}$$

where the L indicates the slot length of the RFID sensor tag. This formula was applied to calculate the value of resonance frequency for the slot. Then, the resonant frequency of that slot can be alternated to desired data value of “0” or “1”. When the slot is present, the spectrum of RCS will indicate a resonant frequency which as in this case, 2.41 GHz was the resonant frequency. Whereas the absentee of slot proves no resonant frequency in the reference frequency value.

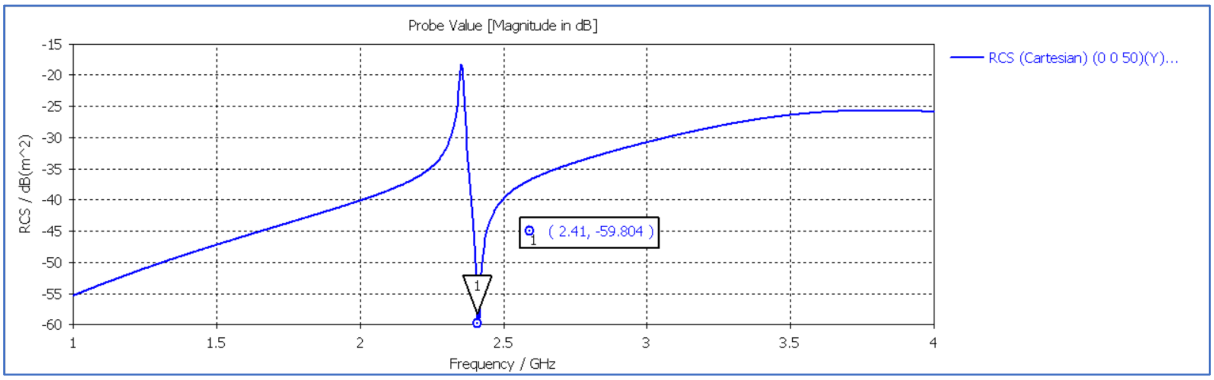


Figure 4.4: Spectrum of RCS response frequency of one slotted designed (“10000000”) (Figure 4.2 and 4.36) at 2.41 GHz

Then, follow by this formula of far field:

$$d \geq \frac{2D^2}{\lambda}$$

For the calculation of RCS to be completed, the far-field should be considered. The designed tag needs to be allocated at the far-field region from the transmitter/ receiver (antenna) at not less than the distance (d). Failing to do so will resultant that the tag still be in the nearfield region which RCS response cannot be shown as mentioned. Since the tag was reflecting a back scattering of interrogate signal from antenna, the optimal distance between tag and the transmitter antenna can be determined using the formula mentioned above. Notation that the D is the largest dimension of the design chipless tag (substrate part), 25 mm. And the wavelength, λ for a selected centre frequency of 6.5 GHz in UWB is 46.15 mm. Therefore, the minimum distance for the RCS to be observable (in far-field region) is 11.01 mm.

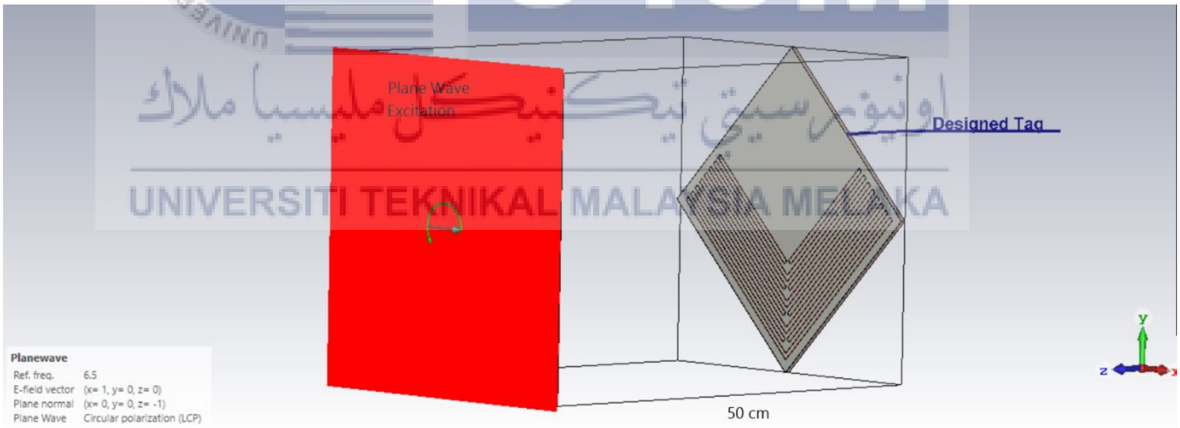


Figure 4.5: The setup setting for simulation in CST MWS Suite Studio for the designed chipless tag sensor.

4.2.3 Frequency spectra of the designed chipless RFID tag

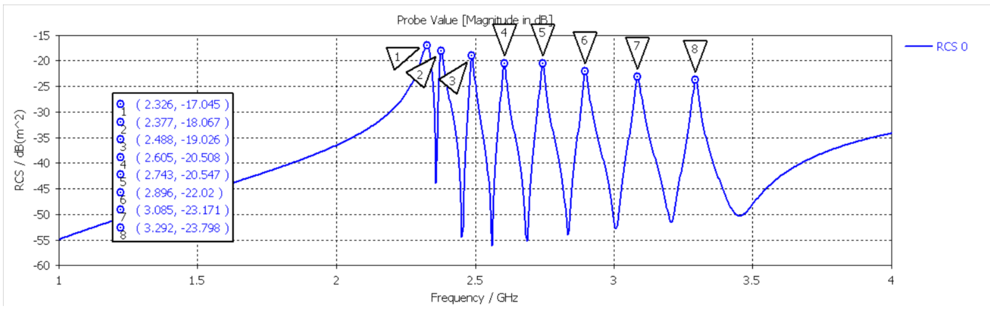


Figure 4.6: The RCS response frequency of designed V-shape tag in figure 4.1

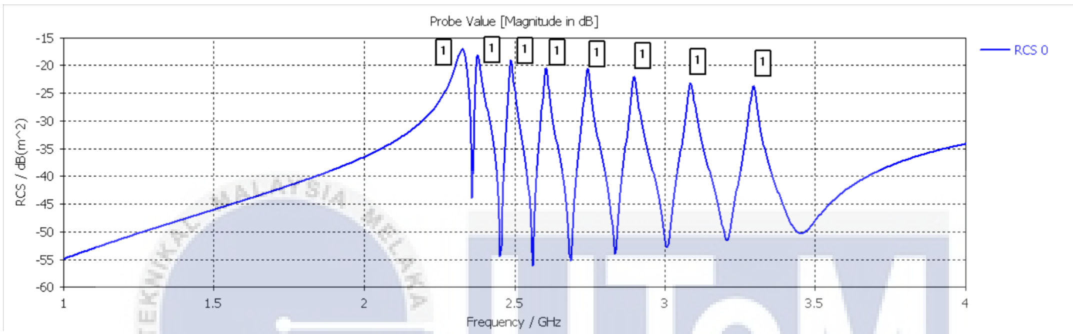


Figure 4.7: The RCS response of bit for V-shaped design tag in figure 4.1

The figure 4.6 shows the RCS response frequency of the designed tag sensor ("11111111") in figure 4.1 at frequency range between 0 to max frequency. There are eight bits available in the resonance frequency presented in the plotted result. By filling the slot, the value of data responses in zero, this will the make the resonance frequency of respective slot to unseen in the graph presented. Therefore, this is used to create a unique bit code for the identification of the tag sensor among other chipless RFID tag sensor attached items. Figure 4.7 shows the bits coding for each peak in the bit of "11111111". This indicate the rise in curve response is corresponding to the bit of one as present value.

The bits are differentia by the Most Significant Bit (MSB) and Least Significant Bit (LSB). The MSB is matched to the largest dimension of length for the slotted design of the tag. Then, LSB is for the smaller length of slot on the tag. The MSB also indicate to the front part of the resonance frequency, while the back was contributed by the LSB.

4.3 Adjustment for optimisation of parameters

After the simulation result of the designed tag was generated, it is required to build the optimised dimension of parameter for the tag fabrication. While preparing the optimised value, a few aspects are needed to be stated. The value of resonance frequency is usually preferred in lower value of frequency, as this provides a large space for the afterward bit encoding for the less significant bit. However, there maximum value of bit encoding is set to 8 bits in this paper of research. Then, the dimension is better to be a smaller size, as it fulfils the paper research opportunity to be taken as part of identification purpose. Although, the size is recommended to be smaller, but the resonance frequency that used for identification on the bit encoding and temperature sensing should not be in a state of blur, during the finding of suitable parameters for the tag.

Under different value parameter, some of the adjustable factors such as thickness of substrate, length of the designed V-shape and material for substrate. All of these plays an important role in the performance by designed tag during the RCS response when sending the interrogate signal back to the reader. The follow will the result of simulation for the designed V-shaped chipless RFID tag sensor (passive) with default material of Rogers RO 3003 at the dimension in table 4.1. And the tag for the following results will only be using 11111111-bit tag as in figure 4.1.

4.3.1 Thickness of substrate

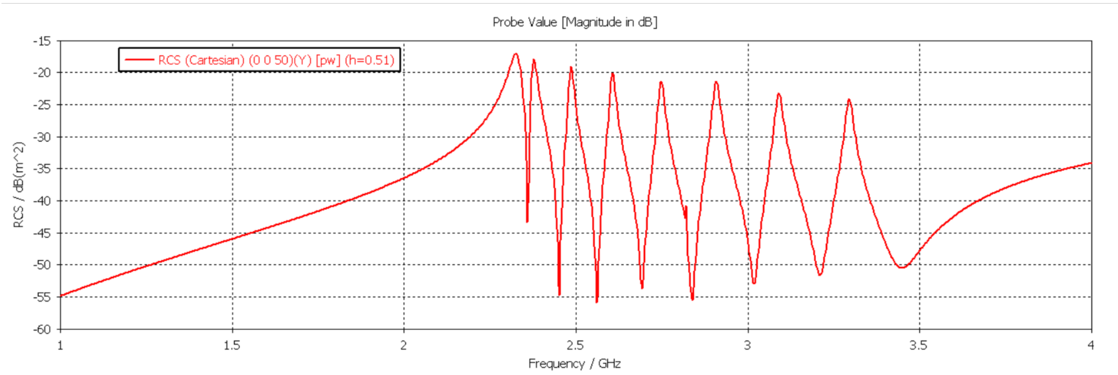


Figure 4.8: RCS response frequency for thickness of substrate at 0.51 mm

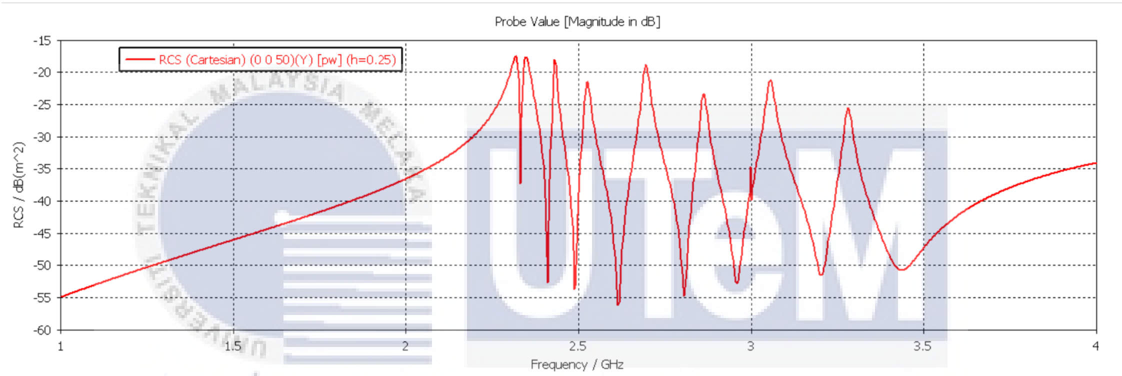


Figure 4.9: RCS response frequency for thickness of substrate at 0.25 mm

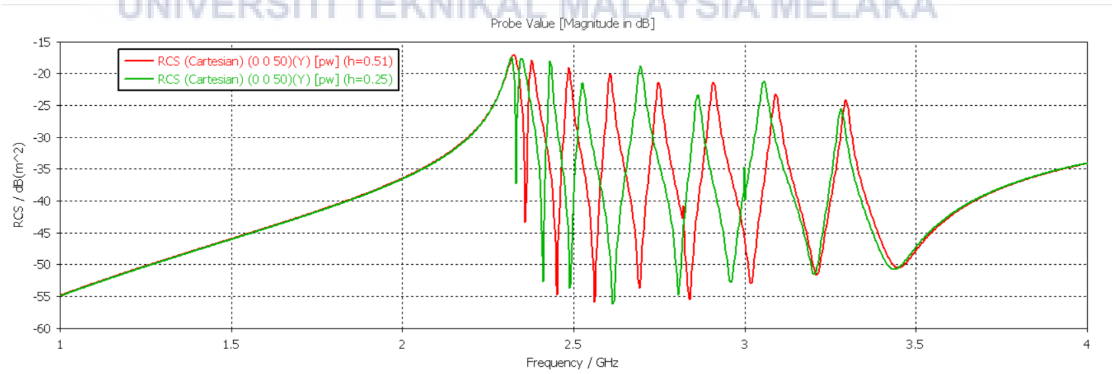


Figure 4.10: Comparison of RCS response frequency for thickness of substrate at 0.25 mm and 0.51 mm

As shown in figure 4.10, the lower the thickness of substrate provide a smaller value of resonance frequency for the front part of the resonance frequency. The value of frequency is better to be lower value, so that it allows more bit encoding space for the less significant bit. However, with the substrate thickness reduce to 0.25 mm, the figure 4.9 shows response frequency of the first bit and second are too close to be identify. Therefore, the optimise value of substrate height is 0.51 mm.

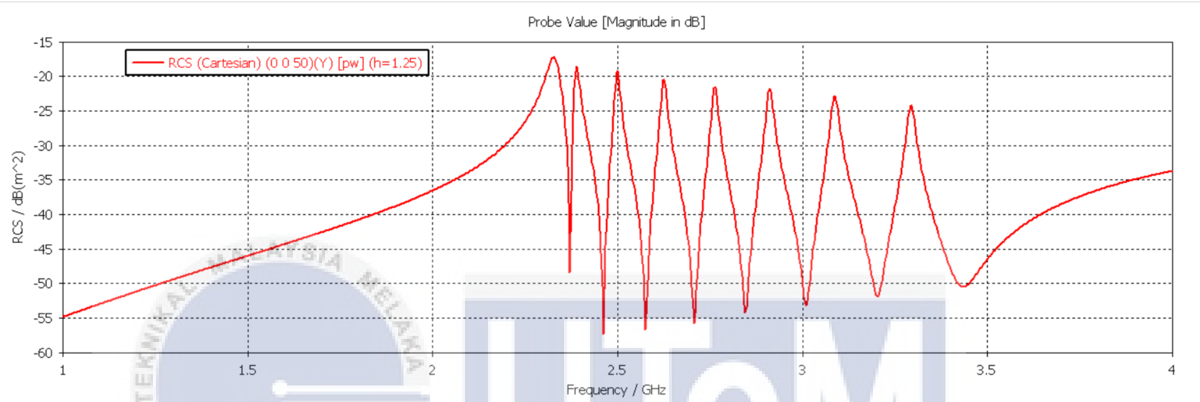


Figure 4.11: RCS response frequency for thickness of substrate at 1.25 mm

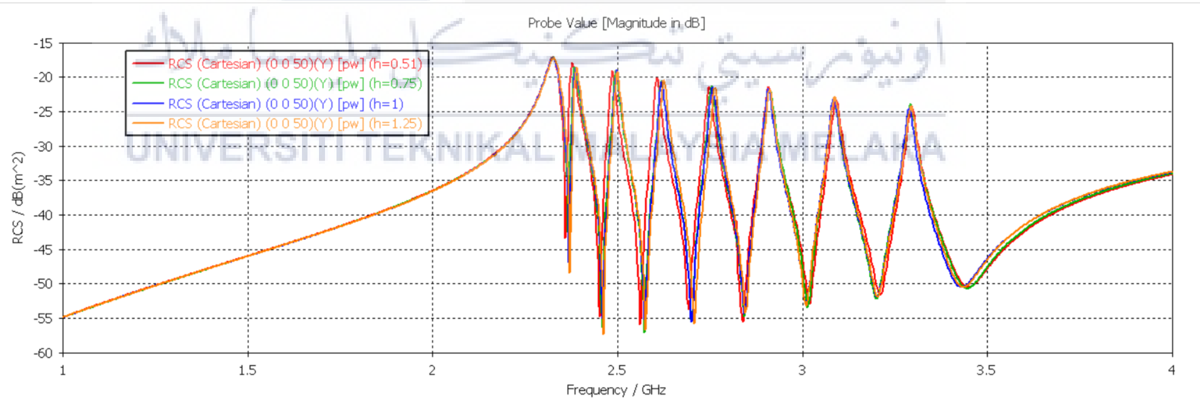


Figure 4.12: RCS response frequency for thickness of substrate at 0.51, 0.75, 1.0, 1.25 mm

In figure 4.12, four of the waveforms for resonance frequency showing the similarity when compared. It shows that all of them are providing the same resonance frequency. Therefore, the lowest size of parameter (0.51 mm) was chosen as the optimised thickness for substrate in the material of Rogers RO 3003.

4.3.2 Material comparison

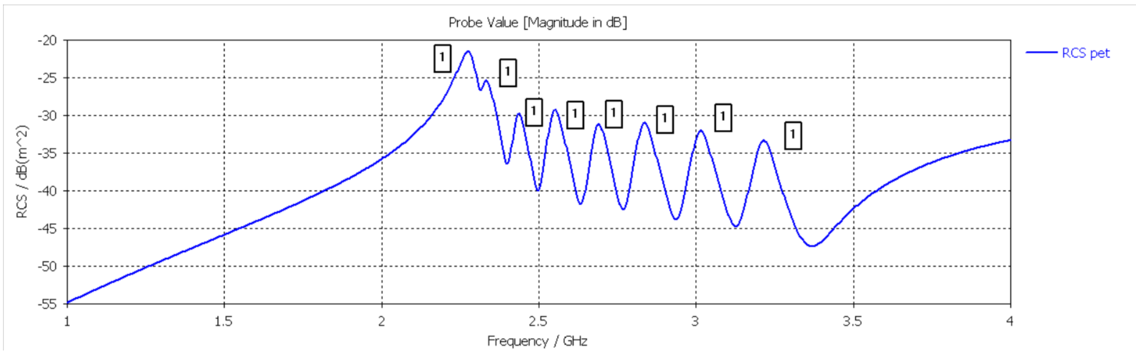


Figure 4.13: The RCS response frequency of designed tag under Polyethylene terephthalate (PET) substrate material.

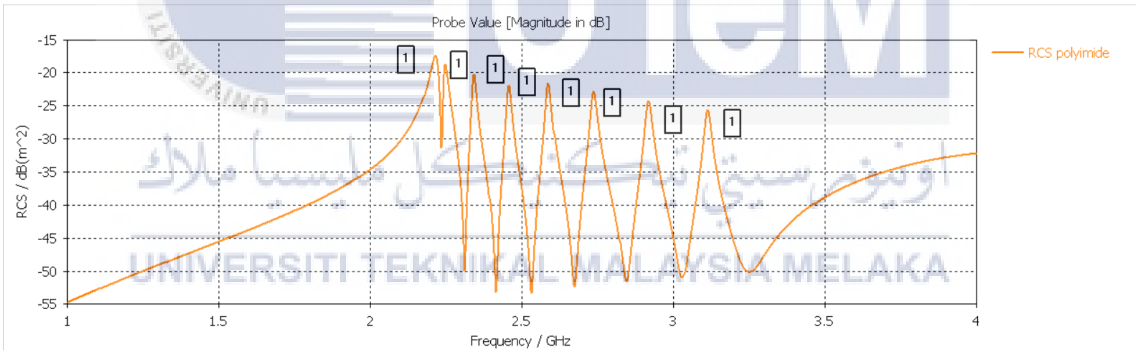


Figure 4.14: The RCS response frequency of designed tag under Polyimide substrate material.

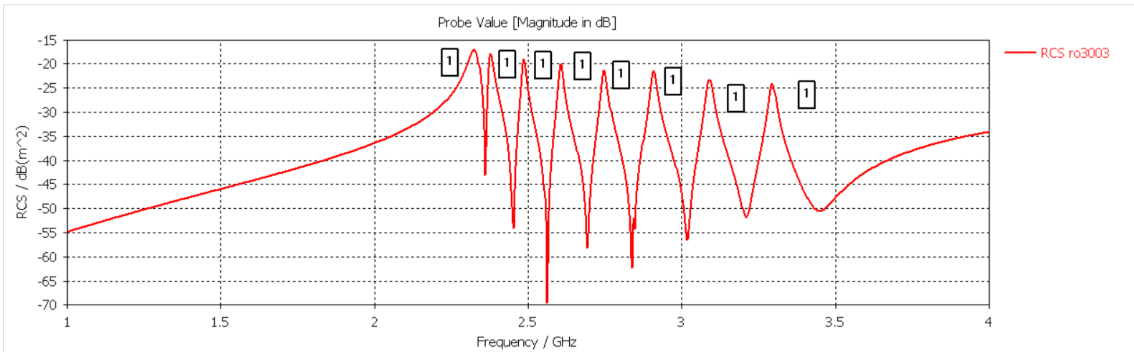


Figure 4.15: The RCS response frequency of designed tag under Rogers 3003 substrate material.

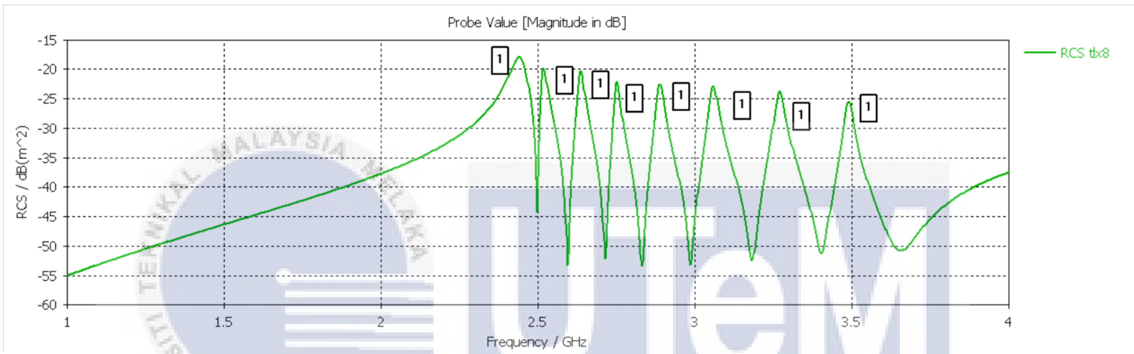


Figure 4.16: The RCS response frequency of designed tag under Taconic TLX-8 substrate material.

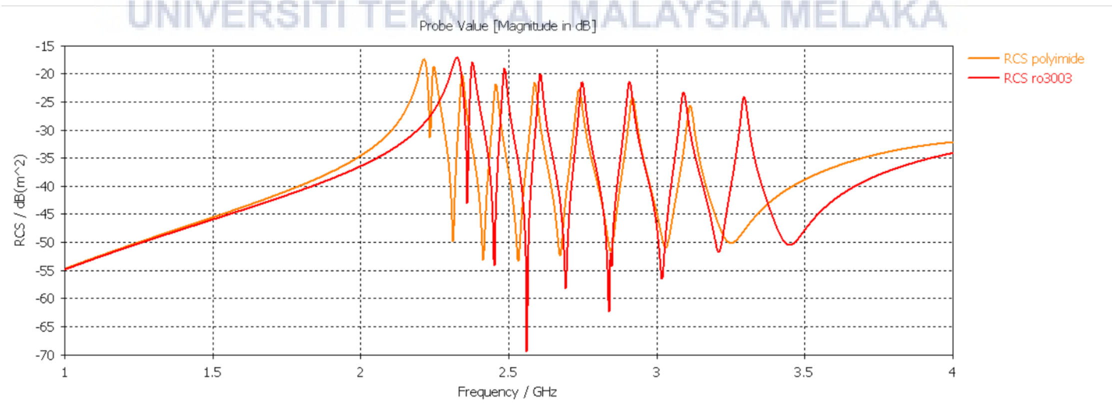


Figure 4.17: Comparison between RCS response frequency of designed tag under Rogers 3003 and Polyimide substrate materials.

Figure 4.17 shows the differences between two substrate materials, Polyimide and Rogers 3003. The polyimide substrate materials show a better resonance frequency in terms of the frequency value allocation. It has a slightly smaller value of resonant frequency value, which allows more potential in dealing with greater bits number at less significant bits. However, the drawback from this material also visible. The first bit of RCS response frequency is unviewable in a clear vision. This may be due to the rescattering signal is in good position for the receiver to be observed. Therefore, this material was lag by the material of Rogers 3003, in terms of RCS response visualisation visibility.

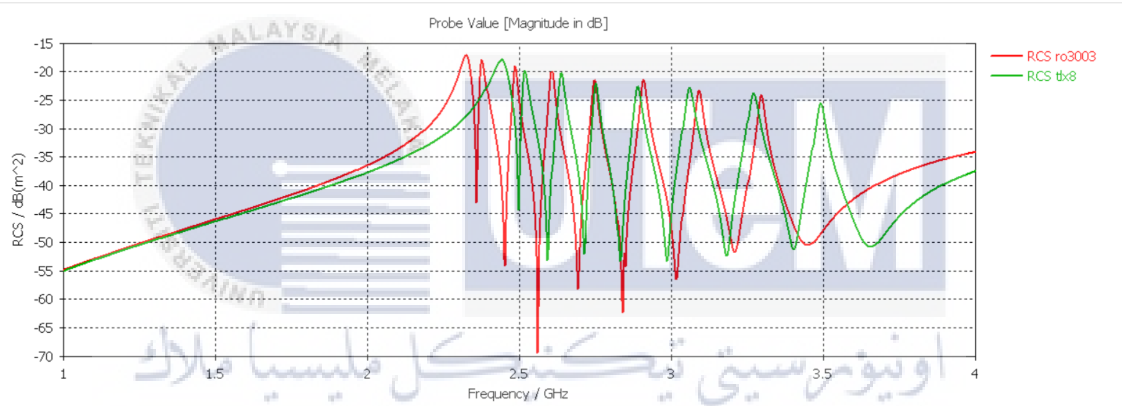


Figure 4.18: Comparison between RCS response frequency of designed tag under Rogers 3003 and Taconic TLX-8 substrate materials.

In this figure 4.18, it is clear, that substrate material of Rogers 3003 was being chosen as the better performance as it led the RCS respond frequency, when compared to the green waveform (Taconic TLX-8). Thus, Rogers 3003 is a suitable substrate material to design the tag sensor for a reliable performance.

Lastly, the substrate material such as the polyimide and PET are common substrate on the flexible substrate categories. This is just the average result in inflexible type of RFID tag. Taking more factors such as flexibility as result, may return a good RCS response frequency in the further design of the RFID tag sensor.

4.4 Analysis of bit encoding

4.4.1 The polarisation angles

The antenna transmission to the tag may induce different type of scattering on different level of angle of polarisation of the tag. Due to the advantages provided by the radio frequency radiation transmission, the angle polarisation angle should be considered. Therefore, it is required to observe the angle of polarisation effect to the designed tag. To focus on the effect, the tag 11111111-bit coding was taken as the example for polarisation angle simulation. At certain polarised angle, the bit encode of the tag will degraded to other bit coding or even worst to 00000000, which none of the bit will be response toward the end reader side. Therefore, a simulation of polarisation angle is required to avoid the angle that acts as polariser (be filtered out).

The observation of the tag is checked under the following angle of polarisation (rotate clock-wisely), 45º, 90º, 135º, 180º, 225º, 270º, and 315º. The negative degree is indicating a negatively rotation (clockwise) at the degree of rotation at the centre of tag design. It is also checked with different bit number on the effect of polarisation, toward the angle of rotation of the designed tag. The combination bit of 11111111, in total 8-bits. This designed tag as in figure 4.1 will be simulated as the visualisation of the credibility for this tag play an uni-polarised tag. The RCS response frequency of the tag under various angle of polarisation is then measured. The following are the results of designed tag under different angle of simulation with their respective RCS response frequency.

Table 4.2: The resonance frequency of different angle.

Bit numbers / Angle of rotation	Resonance frequency (GHz)							
	1	2	3	4	5	6	7	8
0° / 360°	2.359	2.452	2.56	2.686	2.833	3.007	3.205	3.451
45°	2.380	2.485	2.606	2.731	2.887	3.085	3.286	-
90°	-	-	2.588	-	2.747	-	-	-
135°	2.374	2.491	2.611	2.743	2.905	3.085	3.289	-
180°	2.356	2.449	2.56	2.686	2.827	2.986	3.226	3.439
225°	2.377	2.488	2.605	2.743	2.905	3.091	3.295	-
270°	-	-	2.608	-	2.905	-	-	-
315°	2.38	2.488	2.608	2.752	2.911	3.097	3.295	-

Table 4.3: The RCS response for each bits of different angle.

Bit numbers / Angle of rotation	RCS Resonance Bit							
	1	2	3	4	5	6	7	8
0º / 360º	1	1	1	1	1	1	1	1
45º	1	1	1	1	1	1	1	1
90º	0	0	0	0	0	0	0	0
135º	1	1	1	1	1	1	1	1
180°	1	1	1	1	1	1	1	1
225°	1	1	1	1	1	1	1	1
270°	0	0	0	0	0	0	0	0
315°	1	1	1	1	1	1	1	1

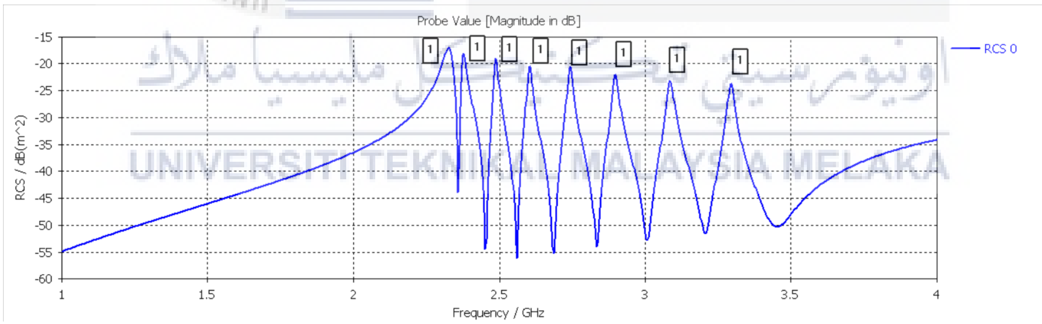


Figure 4.19: The RCS response for altering the clockwise rotation angle from 0º to 0º on the bit "11111111" designed tag.

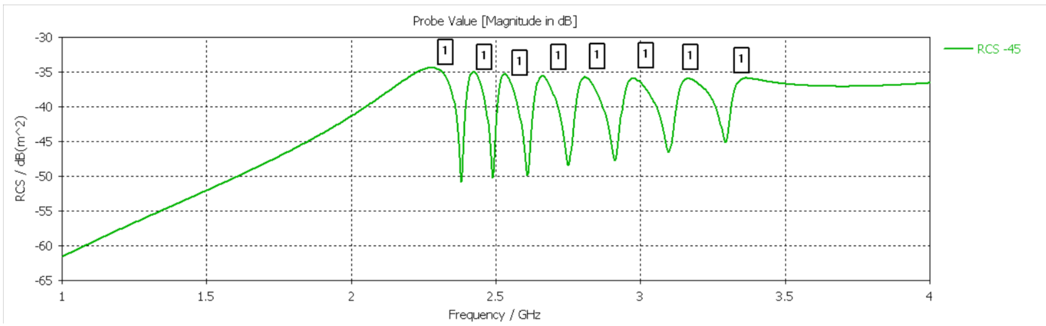


Figure 4.20: The RCS response for altering the clockwise rotation angle from 0º to 45º on the bit "11111111" designed tag.

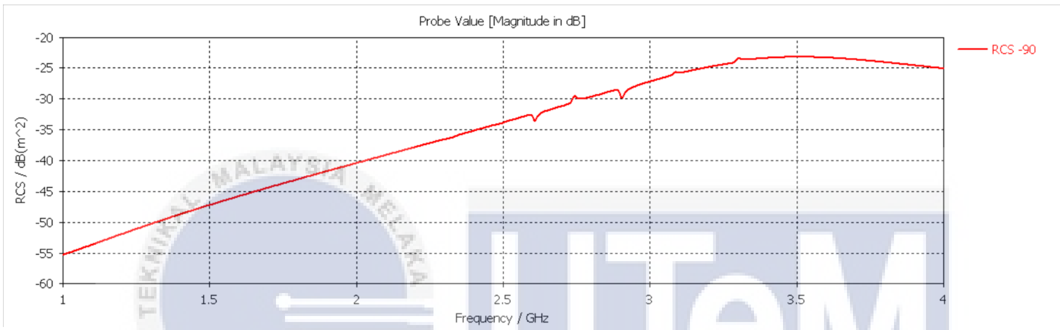


Figure 4.21: The RCS response for altering the clockwise rotation angle from 0º to 90º on the bit "11111111" designed tag.

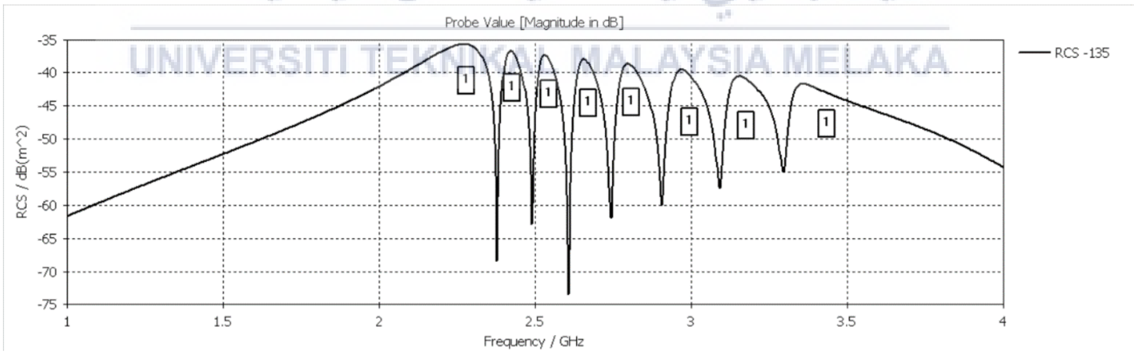


Figure 4.22: The RCS response for altering the clockwise rotation angle from 0º to 135º on the bit "11111111" designed tag.

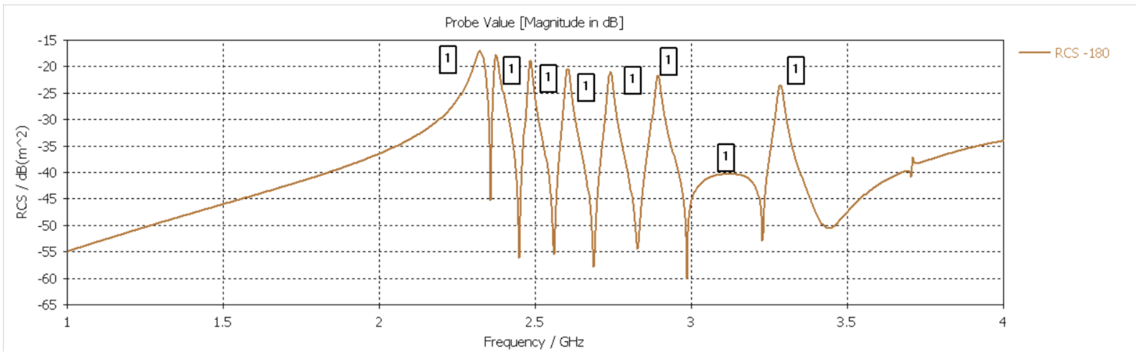


Figure 4.23: The RCS response for altering the clockwise rotation angle from 0º to 180º on the bit "11111111" designed tag.

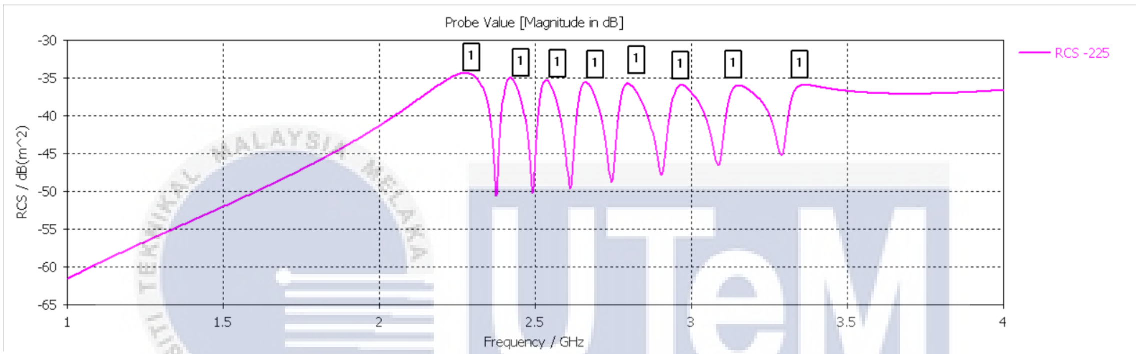


Figure 4.24: The RCS response for altering the clockwise rotation angle from 0º to 225º on the bit "11111111" designed tag.

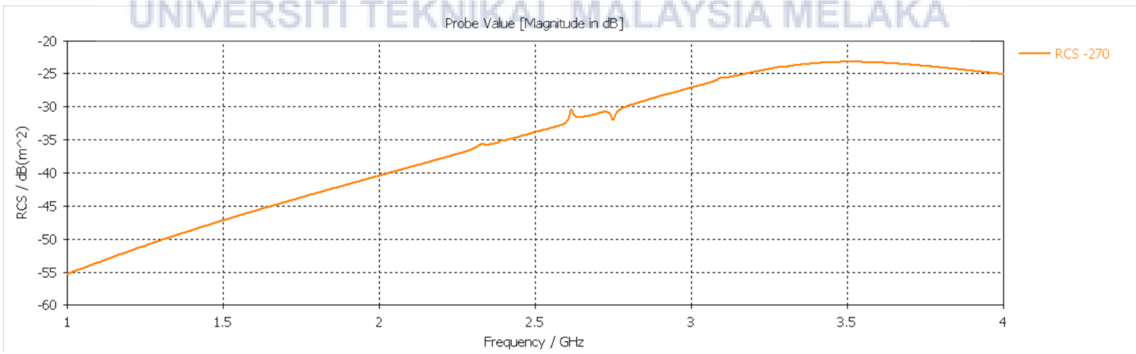


Figure 4.25: The RCS response for altering the clockwise rotation angle from 0º to 270º on the bit "11111111" designed tag.

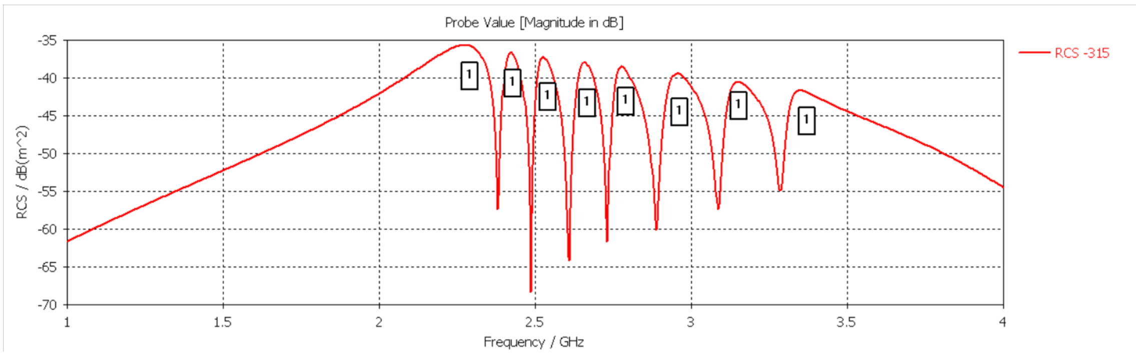


Figure 4.26: The RCS response for altering the clockwise rotation angle from 0º to 315º on the bit "11111111" designed tag.

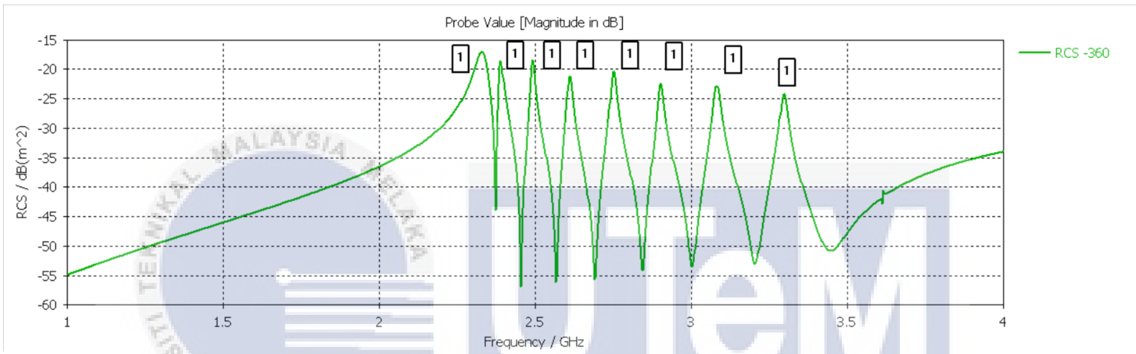


Figure 4.27: The RCS response for altering the clockwise rotation angle from 0º to 360º on the bit "11111111" designed tag.

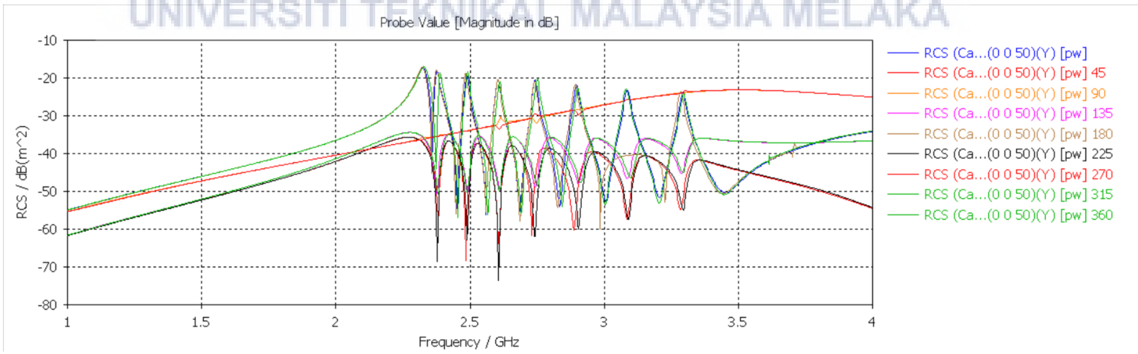


Figure 4.28: The RCS response for altering the clockwise rotation angle from 0º to 45º, 90º, 135º, 180º, 225º, 270º, and 315º of bit coding "11111111" designed tag.

In the polarisation angle for the tag with bit encoded of "11111111", it can be seen that in some polarisation angle, there are some absentee in the detection for the RCS response frequency. This indicate the low signal of RCS is being reflected to the reader(receiver) side during transmission, as part of them are filtered out from the characteristics of polariser. Thus, at the angle such as 270 º and 90 º (indicated respectively in figure 4.30 and 4.31) should be avoided during the attachment of the tag to the object in reality scenarios. And the process of sending interrogate signal from transmitter should avoid these two angles and adjusted to the other angle to prevent unavailable RCS response frequency received, which could not be used for identification.

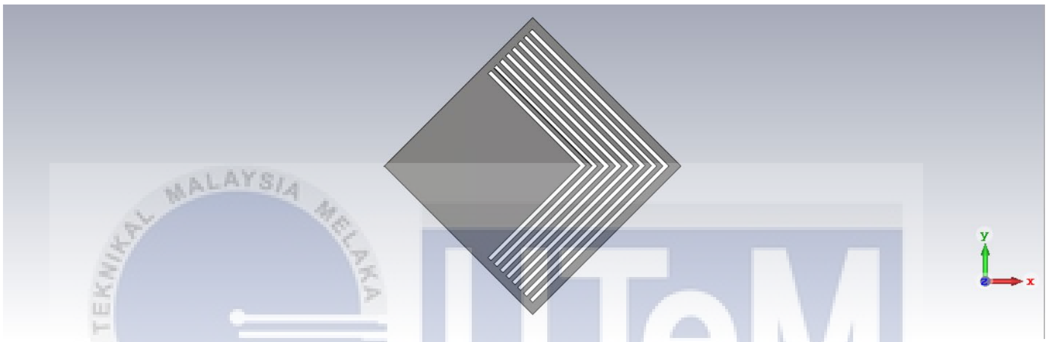


Figure 4.29: Structural design of tag with bit (11111111) at 270 º (clockwise rotation from 0 º of V)

Figure 4.30: Structural design of tag with bit (11111111) at 90 º (clockwise rotation from 0 º of V)

4.4.2 Bit combination

In terms of bit combination, two type of combinations are formed. First one is the arranged combination type. There combinations are systematically formed, for examples: 00000000, 11111111, 10101010, and 01010101. All of these combinations are in 8-bits and arranged in order. The second type is the random combination, where the combinations are random generated for the simulation. Both bit combinations are simulation and observed at the RCS response of each combination. This was to locate a reference for the frequency response in RCS for the related bit encoded. Therefore, bit combinations of both types will be simulated and analysed. All tag will be simulated at the parameter in table 4.1 and substrate of Rogers 3003. Each structural design of tag will be presented at 0 º.

4.4.2.1 Systematic bit combination

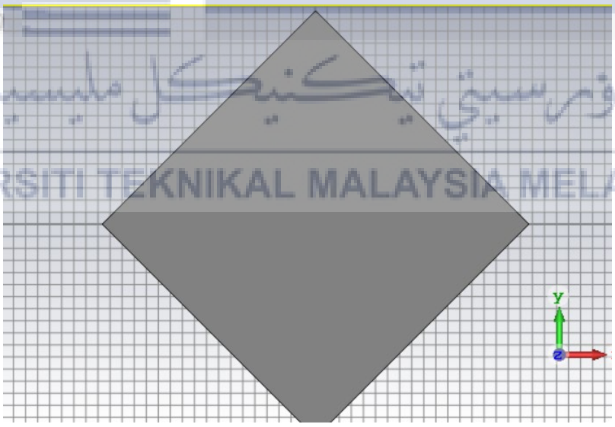


Figure 4.31: Structural design of tag with bit (00000000)

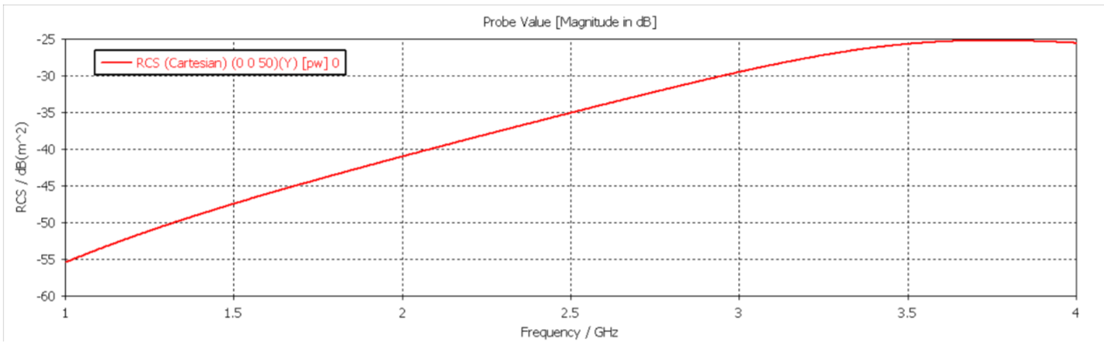


Figure 4.32: The RCS response for 00000000-bit designed tag at 0 º

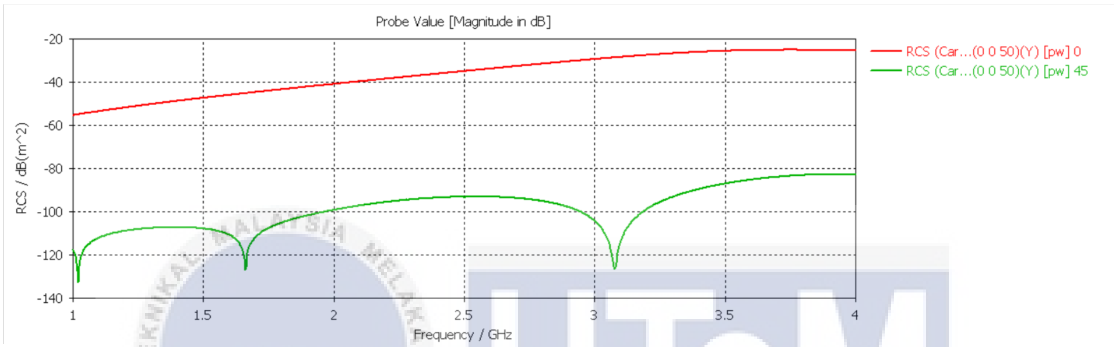


Figure 4.33: The RCS response frequency for "00000000" designed tag at 0º, 45º of clockwise rotation angle.

From figure 4.32 and figure 4.33, the difference is not big as there is not slotted design under 0000000 bit of tag. This tag was used as reference tag in the further calculation. Also that, from the angle of 45 º, the three small clouds of RCS response can be ignored, whereas it is too small to be considered as one big of response bit in RCS.

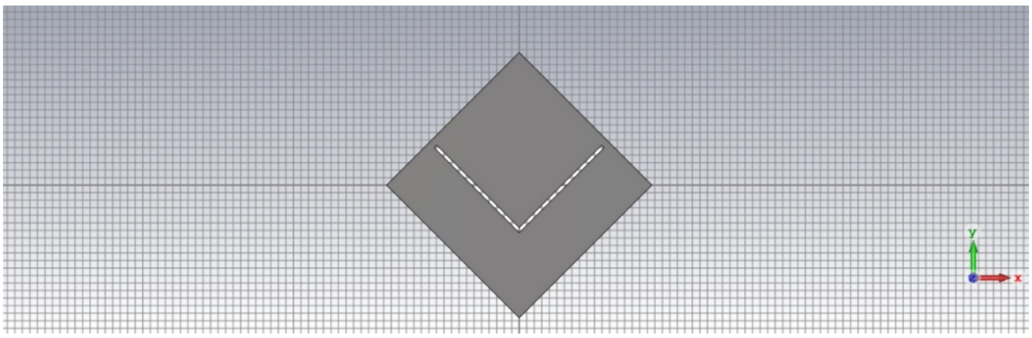


Figure 4.34: Structural design for 0000 0001-bit tag

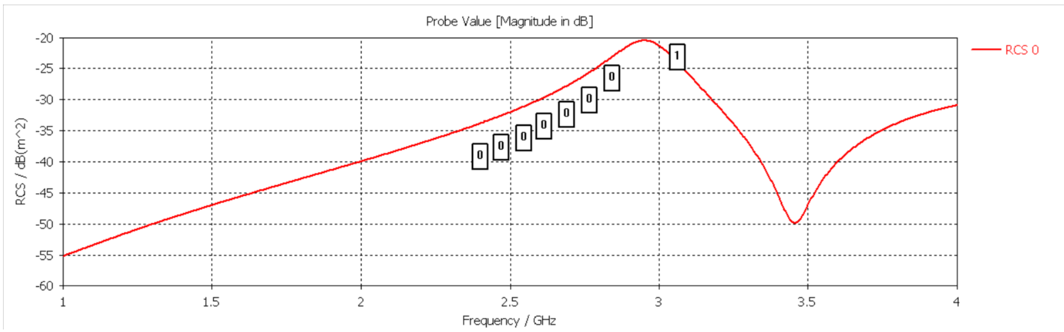


Figure 4.35: The RCS response for 00000001-bit designed tag

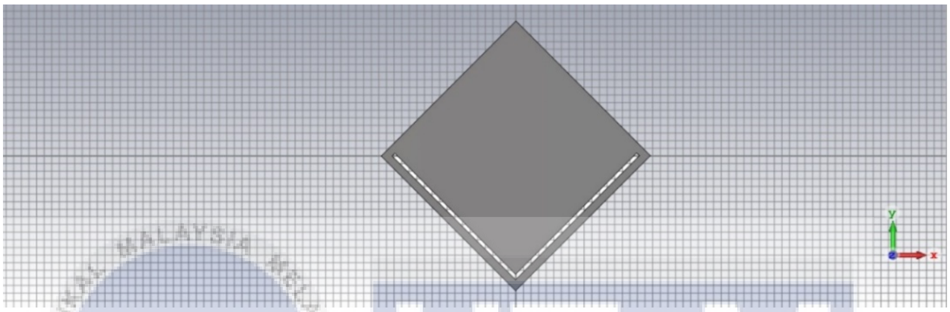


Figure 4.36: Structural design for bit 1000 0000 tag

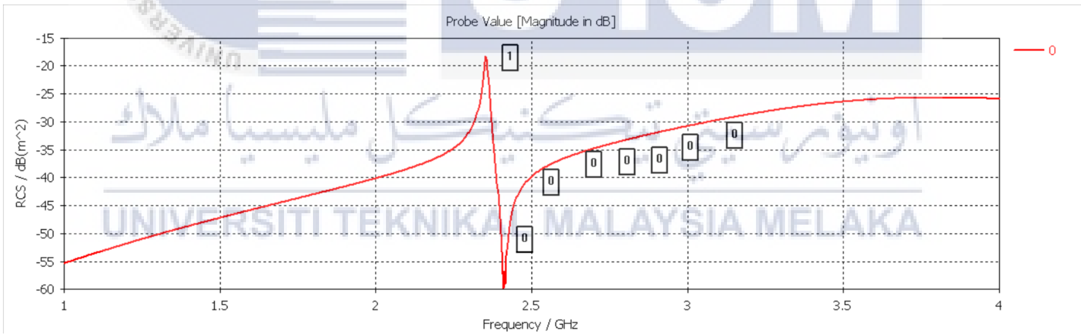


Figure 4.37: The RCS response for 10000000-bit designed tag

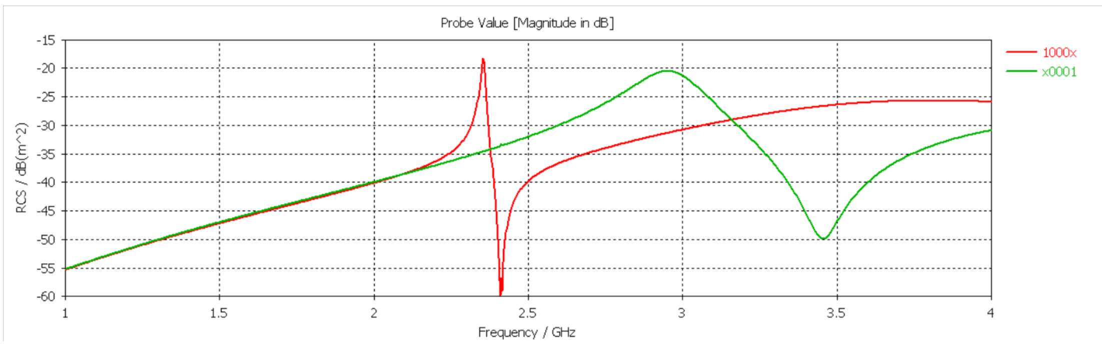


Figure 4.38: Comparison between 00000001 and 10000000 on the bit encoding

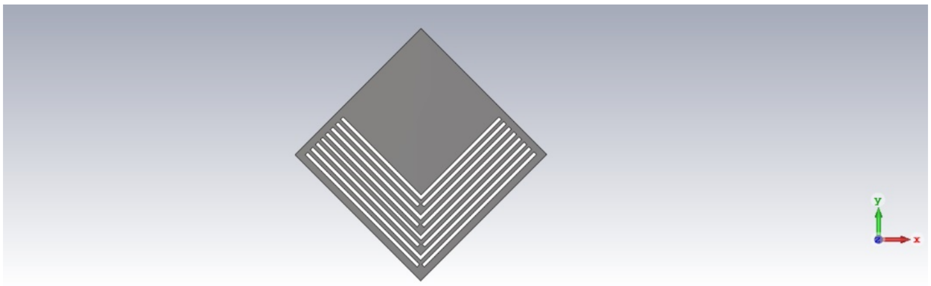


Figure 4.39: Structural design for 0101 0101-bit tag

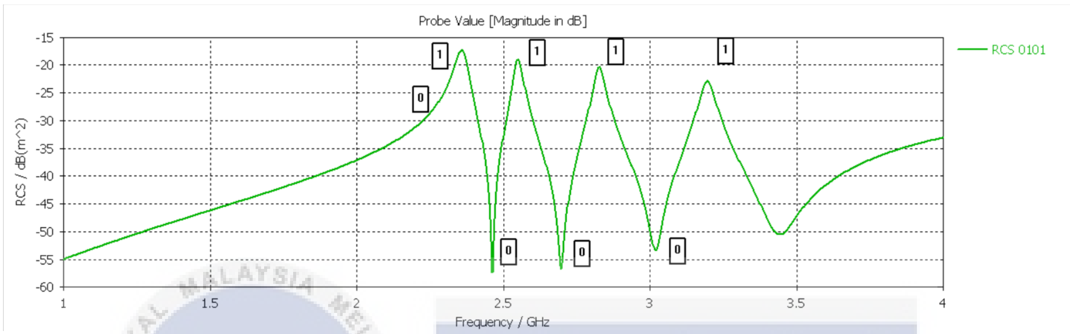


Figure 4.40: The RCS response for 01010101 -bit designed tag

Figure 4.41: Structural design for 1010 1010-bit tag

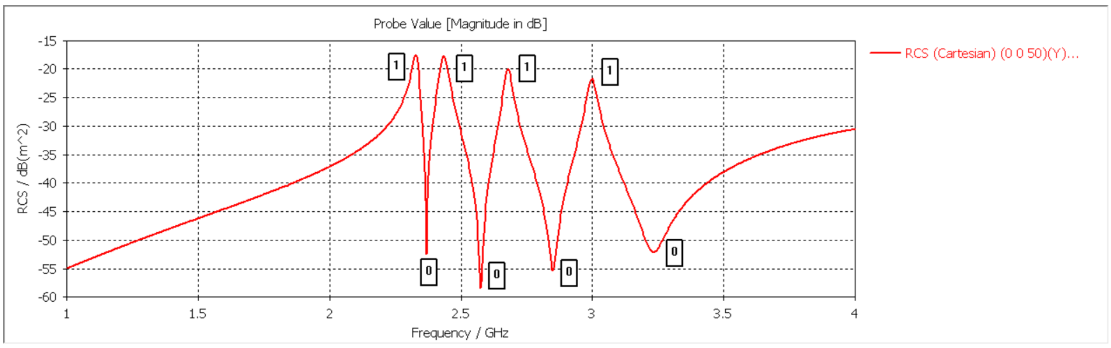


Figure 4.42: The RCS response for 1010 1010-bit designed tag

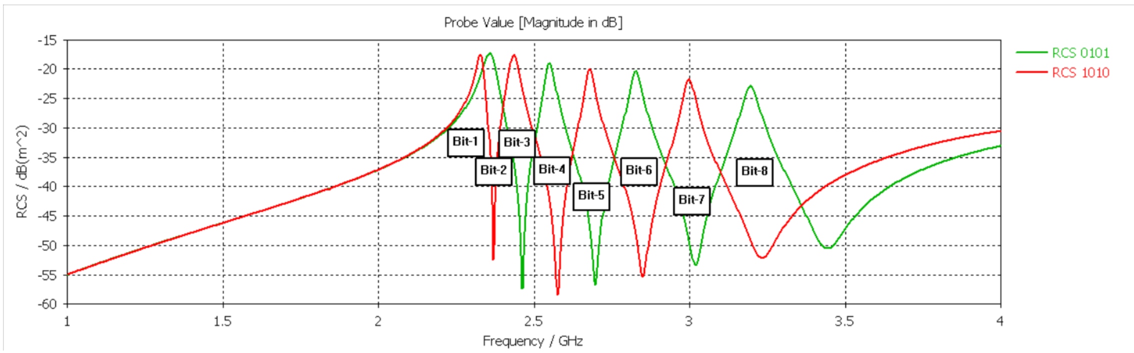


Figure 4.43: Comparison between 01010101 and 10101010 on the bit encoding frequency

4.4.2.2 Random bit combination

Figure 4.44: The RCS response for 1100 0001-bit designed tag

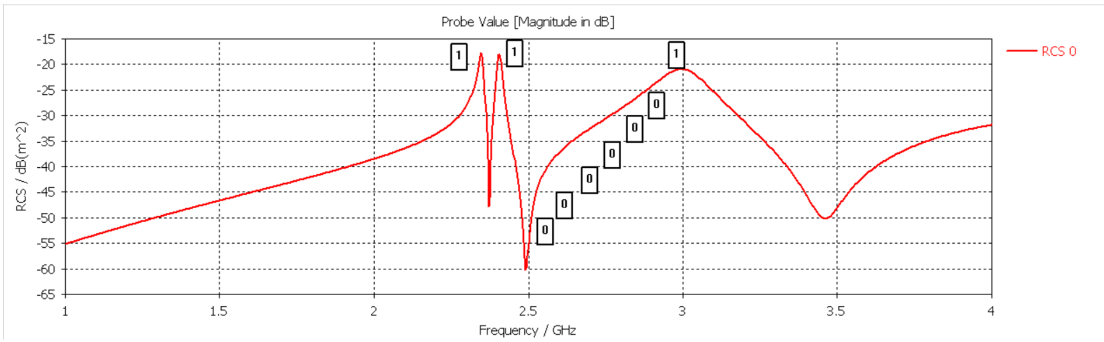


Figure 4.45: The RCS response for 1100 0001-bit designed tag

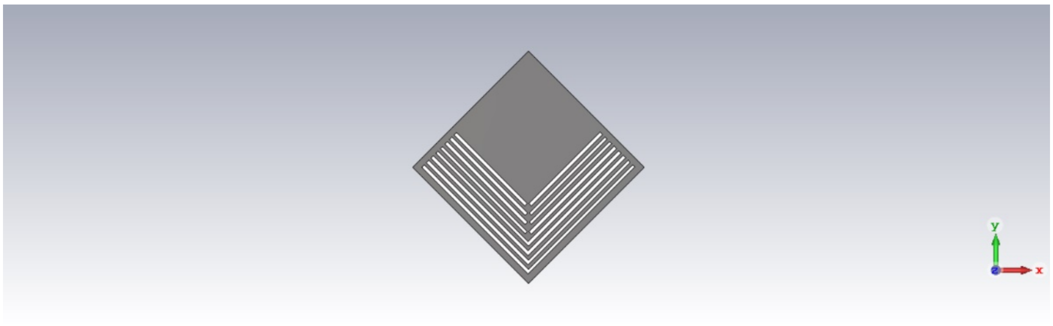


Figure 4.46: The RCS response for 1111 0000-bit designed tag

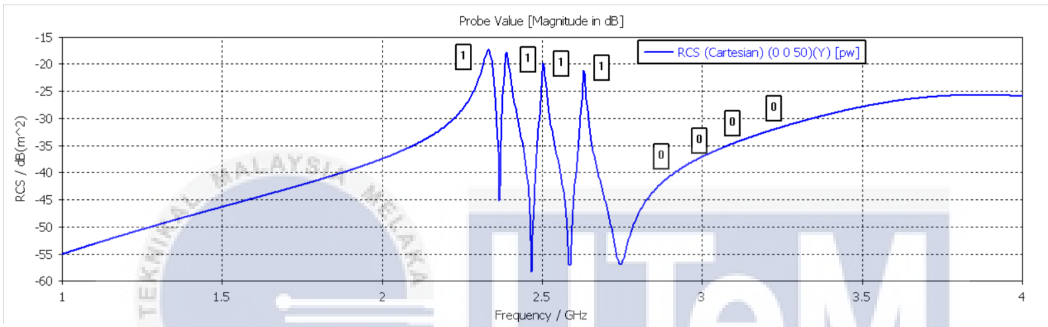


Figure 4.47: The RCS response for 1111 0000-bit designed tag

Figure 4.48: The RCS response for 0000 1111-bit designed tag

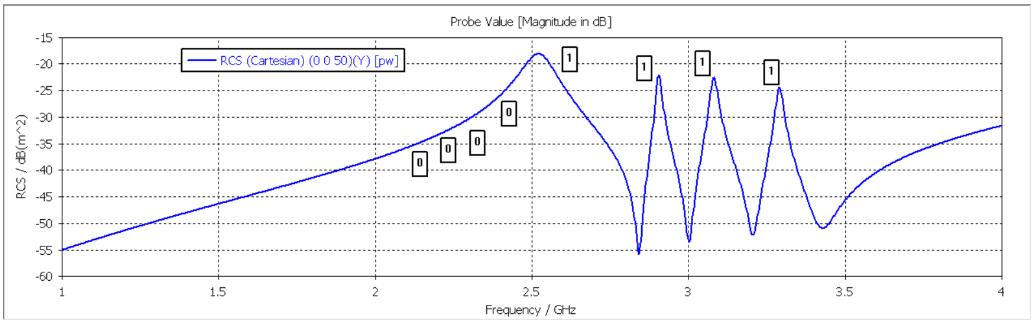


Figure 4.49: The RCS response for 0000 1111-bit designed tag

Figure 4.50: The RCS response for 1100 0011-bit designed tag

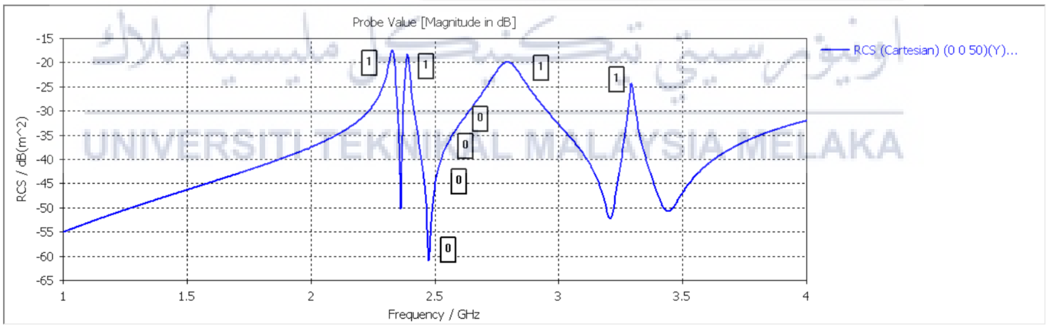


Figure 4.51: The RCS response for 1100 0011-bit designed tag

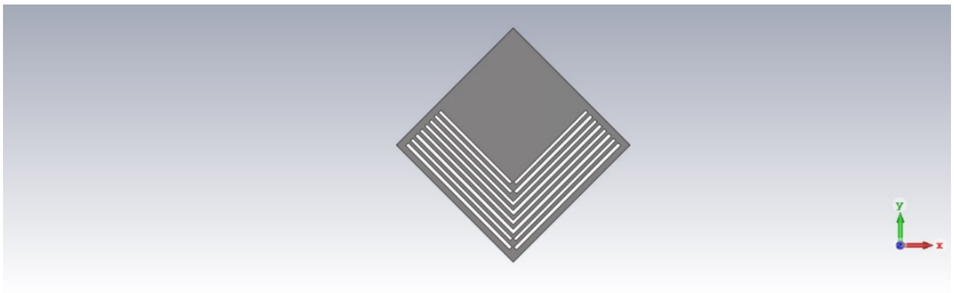


Figure 4.52: The RCS response for 0011 1100-bit designed tag

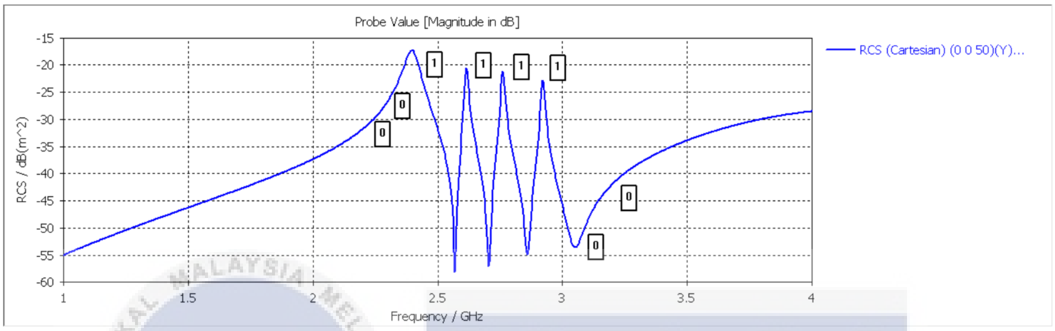


Figure 4.53: The RCS response for 0011 1100-bit designed tag

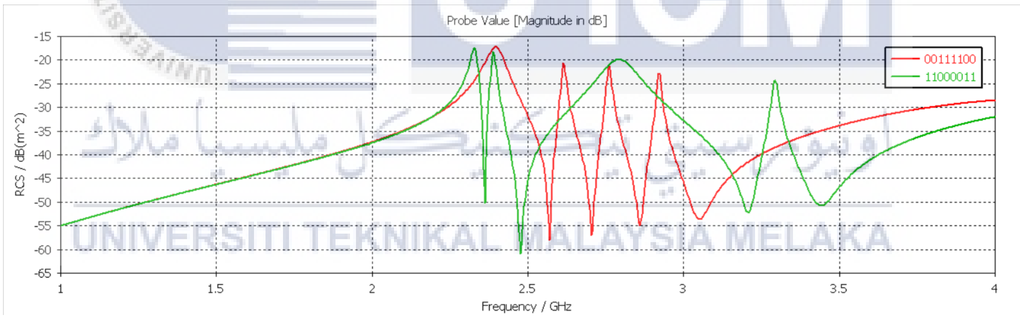


Figure 4.54: Comparison between 0011 1100 and 1100 0011-bit designed tags

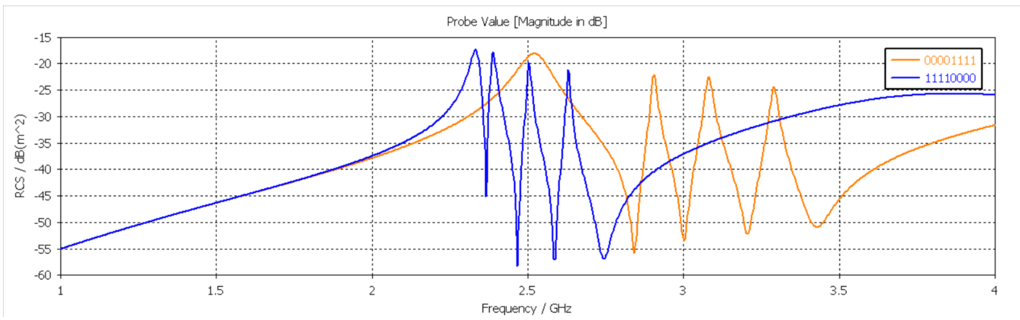


Figure 4.55: Comparison between 0000 1111 and 11110000 -bit designed tags

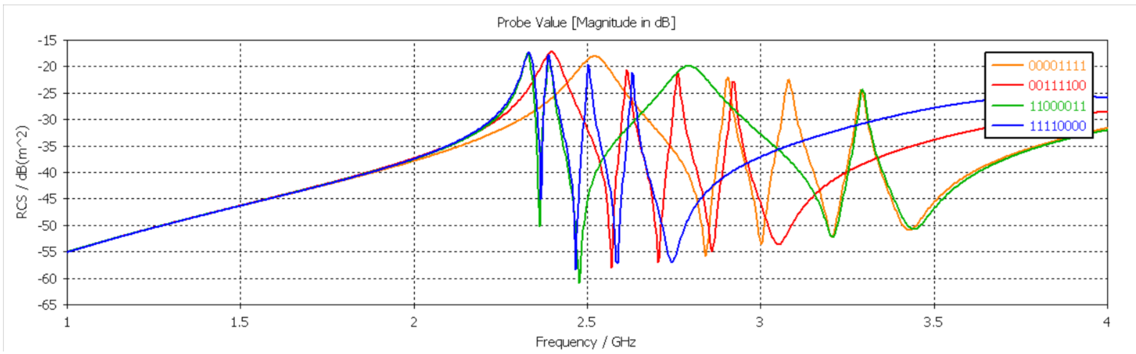


Figure 4.56: Comparison between 0011 1100, 1100 0011, 0000 1111 and 11110000 - bit designed tags

From these systematic arrangements of combination bit and rand combination bits, it shows the RCS response may slightly moving forward in one to two bits value. This analysis brings out the possibility of taking the wrong assumption as the reference frequency point for the bit response in RCS. Other than that, the response from systematic combination provided a better visualisation than the random combination. These simulations provide a clear vision that the tag in not a unpolarised tag design. In order to obtain good RCS response frequency curve, it is required to attach the tag sensor in V shape (zero degree) to allow a good reflection on scattering. Thus, the tag can performance the ability of tag to the real value.

4.5 FABRICATED CHIPLESS RFID TAG SENSOR

4.5.1 The fabricated chipless RFID tag sensor

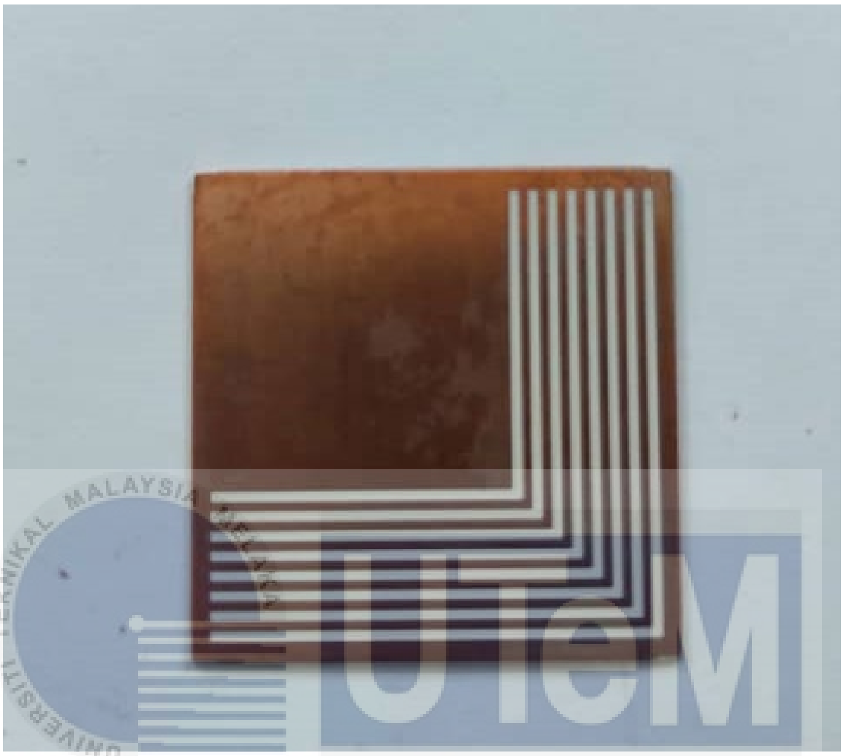


Figure 4.57: Fabricated chipless RFID tag sensor

Figure 4.57 shows the fabricated design of chipless RFID tag sensor with the proposal material of Rogers 3003 as substrate and PEC as conducting matrial at surface. The designed shape is the same as in figure 4.1, but with slightly different on the angle (Figure 4.57 shows a counter clockwise rotation of 45 degree at V-shape). The dimension design of the tag is 25 mm x 25 mm, and also other parameter dimensions are listed as in table 4.1.

4.6 SUMMARY

In summary for this chapter, the analysis of the objective of this paper has been obtained through the multiple method. Firstly, the type of shape that is suitable for the design of this chipless RFID tag sensor. Through numerous days of research paper studied, one of the designs that provide high bit encoding density while sensing the temperature, is that the L-shaped or V-shaped. This is due to the tolerable of back scattering of the interrogate signal that produce less interference between each of them, during scattering of each slotted design on the signal back to the reader. Then, suitable material for substrate and other parameter in the design of tag was concluded. In decision making, the rogers 3003 shows a better simulation result as compared to the others. The length of designed slot on the tag is optimised to archive the great performance for the objectives. Lastly, the fabrication result was done and proven the ability of the tag to sense temperature while giving the bit encoding ability to the structural design.

The fabricated design of the chipless RFID tag sensor should be taken to a real time measure in laboratory, however due to the condition of epidemic outbreak for COVID-19 is getting worse, the action of benchmarking and measuring are halted with the implementation of Malaysia Control Order 2 on partial of Malaysia. With this extreme situation, all of the follow process after the fabrication could not be completed and was hindered. The presented result in this chapter is the best outcome achieved in this current situation and wish that, the condition for this epidemic outbreak of COVID-19 can be restored back to normal.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter discusses about the conclusion and the future work for the design of the chipless RFID tag sensor. The performance of design of the chipless RFID tag sensor has been determined and recommendation for this project was suggested in this chapter.

5.2 CONCLUSION

In conclusion, both hardware and software are presented in this paper, where the software is the CST Microwave Suite Studio for the simulation of the designed chipless RFID tag sensor, while the hardware involved in the fabrication of the designed chipless RFID tag sensor. A V-shaped of structure for the usage in the passive chipless RFID tag sensor type of design is being designed and studied in this paper. The tag designed and simulated for the maximum size of bit encoding of eight. With the tag designed in this paper, the bits increase greatly while giving the temperature sensing. This paper on the design of the passive chipless RFID tag sensor is potential in the bit encoding ability while provide temperature sensing. This will be helpful the development of related field. Hopefully that the other research papers can focus more on the deployment, for more bits on the passive tag and capable to outreach the performance of the existing optical barcode system. And also with the secure transferring of the bit encoding RCS interrogating signal.

5.3 RECOMMENDATION AND FUTURE WORK

This section provides the suggestions for developed and fabricated chipless RFID tag sensor.

For the design of the tag used in the RFID for tagging and sensing purpose, any type of shape of design is welcome to be designed. Based on different type of shape of design. For example, this paper proposes the V-shaped design from the research paper in previously being studied. However, it is important to maintain a good number in bit encoding density. The higher the number of bits being design will consume on size of the designed tag. Therefore, an equilibrium should be achieved from these two factors, which are sizing of tag and the design of structure on the surface of the tag.

Then, all dimensions should be tuned to optimise for the good performance of tag. This step is necessary to achieve desired waveform graph of RCS response frequency. With the features in the CST MW Suite Studio Software, the ability to do parameters sweep give the analysis and comparison of various length based on setting. The resonance frequency graphs are needed to be separated at a suitable distance for clear identification for each unique bit's response. The future will be required to analyse this part, as it takes the longest time to optimise the design to obtain desired result of RCS response frequency. Other than that, the material of substrate is functioning as the main component for the technology to be continued grows. The possibility lays on other substrate element may still be potential in the design, especially in the flexibility categories. The ability of sensing and provide the RCS response frequency toward the incoming interrogate signal. All of this is due to dielectric property of the substrate materials used in this tag. For this paper, the Rogers 3003 material is maximised in the effect of tracking, identifying, and sensing purpose. And also, the cost of this material is at reasonable state to be considered for bulk producing at future. Therefore, future work should provide good and reasonable material to be used as substrate for the tag.

Next, the angle of polarisation for matching both the sender and the tag in a suitable reason. The designed tag is proven to be a non-unpolarised tag, due to the RCS response frequency obtained from the simulation shows a unsuccessful result in providing good RCS response frequency back the received to capture. Therefore, future work may focus on the improve on the design to become a unpolarised tag sensor.

Lastly, the research presented in this paper has succeeded in contributing to design of chipless RFID tag sensor technology. Although the ability to sense the temperature changes was not shown in this paper, but as the previous studies proven, this ability for the design tag sensor was undenied. Therefore, for the improvement of recommendation on the future work, similar setup for the design of the chipless RFID tag sensor was wished, to be completed to realise the functionality of the designed RFID tag sensor to sense temperature change while providing bit encoding ability. With these abilities of tracking, identifying, and sensing in the attach item or object, the chipless RFID tag shows the advantages in many aspects. Therefore, the chipless RFID tag sensor provides quite a number of potentials in the suggested future research can be built.

5.4 PROJECT POTENTIAL

This paper produces the passive chipless RFID tag sensor that is useful in many ways. As mentioned in earlier of the paper, the tracking ability of the designed tag is definitely good attachment to the object. Whereas it could use to identify the object with the RF radiation through the spaces such as storage place for the object. Since the tag sensor is encoded with multiple bits. It could provide wide range of ID for variety of items. Other than that, the sensing ability of the tag can be used on multiple physical environmental parameter sensing. In this case, the temperature is being sensed. When the temperature of the item increases or decrease, the RCS response frequency curve could move forward or backward with the changes in temperature regarding of the changes. The design of passive chipless RFID tag sensor is focusing on the aspect such as cheap in production, bulk producible, passive tag, and the lightweight designs. For a usage of private industrial, the next step should be investigated to find an approach to protect the security of the chipless tag.

Name: HENG JIA LER Matrix No.: B071710676 Gantt Chart for PSM 1

PSM 1 Design and Development of A Chipless RFID tag-sensor for Temperature Sensing using PCB																
Task / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Briefing								MID SEMESTER HOLIDAYS								REVISION WEEK
Workshop PSM																
Discuss project with SV																
Chapter 1: Introduction																
Chapter 2: Literature Review																
Submission of 1st Progress																
Discuss with SV bout project																
Chapter 3: Methology																
Design Plan																
Design the Project																
Chapter 4: Expected Result																
Submission of 2nd Progress																
Prepare Slide and Recheck Report																
Presentation PSM 1																

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APPENDIX

Appendix 1 Example Appendix