DESIGN AND ANALYSIS OF HIGH-QUALITY FACTOR MULTI-RESONATOR CHIPLESS RFID TAG



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND ANALYSIS OF HIGH-QUALITY FACTOR MULTI-RESONATOR CHIPLESS RFID TAG

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2023

DECLARATION

I declare that this report entitled "Design and Analysis of High-Quality Factor Multiresonator Chipless RFID Tag" is the result of my work except for quotes as cited in the references. TEK IND EKNIKAL M/ UNIVERSI MEL Т Signature : . Author NUR SYAHIRAH AUNI BINTI JUMAIN : Date 20 JANUARY 2023 :

APPROVAL

I hereby declare that I have read this thesis, and, in my opinion, this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronics Engineering with Honours. TEK) INNO Signature: PROF. MA DYA. DR. MAISARAH BINTI ABU PROF. MADYA Pikulti Kejurutaraan Elektronik Dan Kejuruteraan Komputer UNIVERSITI Т Universiti Teknikal Malaysia Melaka (UTEM) Supervisor Name: Hang Tuah Jaya 76200 Eurian Tunggal Melaka Date: 20 JANUARY 2023

DEDICATION

This work is dedicated to my beloved family and those people who have guided and inspired me throughout my journey of education, I have also dedicated this work to my supervisor, Prof. Madya Dr. Maisarah Binti Abu who has been a constant source of knowledge and inspiration. Thank you for supporting me and for all the encouragement.

ABSTRACT

Nowadays, Chipless Radio Frequency Identification (RFID) tag has gained popularity due to lower-cost printing flexibility. Furthermore, chipless RFID tags also store information using electromagnetic features instead of memory chips. The technology comes through by focusing on a user-friendly RFID tag. According to the company's research into the technology, chipless tags have a significant bit of storage capacity. Therefore, the project presents a multi-resonator chipless RFID tag with a high-quality factor. The tags are designed and optimized using Computer Simulation Technology (CST) software and operated at 0-3 GHz with a high-quality factor with a high data capacity on a flexible substrate. This project also focuses on the performances of the chipless RFID tag such as radar cross-section in the response to the reflection from the environment. At the end of this project, the design is fabricated using a Fast Film substrate with permittivity, $\epsilon r = 2.7$ and thickness, h = 0.13 mm chipless RFID tags. The chipless RFID tags have been analyzed and measured the performance of the tag running through Vector Network Analyzer.

ABSTRAK

Pada masa kini, tag Pengecaman Frekuensi Radio Tanpa Cip (RFID) telah mendapat populariti disebabkan fleksibiliti percetakan kos yang lebih rendah. Tambahan pula, tag RFID tanpa cip juga menyimpan maklumat menggunakan ciri elektromagnet dan bukannya cip memori. Teknologi ini datang melalui dengan memfokuskan pada tag RFID yang mesra pengguna. Menurut penyelidikan syarikat dalam teknologi, tag tanpa cip mempunyai kapasiti penyimpanan bit yang ketara. Oleh itu, projek ini membentangkan tag RFID tanpa cip berbilang resonator dengan faktor kualiti tinggi. Tag direka bentuk dan dioptimumkan menggunakan perisian /ERSITI TEKNIKAL MALAYSIA MELAKA Teknologi Simulasi Komputer (CST) dan dikendalikan pada 0-3 GHz dengan faktor kualiti tinggi yang mempunyai kapasiti data yang tinggi pada substrat yang fleksibel. Projek ini juga memberi tumpuan kepada prestasi tag pengecaman frekuensi radio tanpa cip seperti radar kutub silang dalam tindak balas kepada pantulan dari persekitaran. Pada akhir projek ini, reka bentuk direka menggunakan substrat Filem pantas dengan kebolehtelapan, $\varepsilon r = 2.7$ dan ketebalan, h = 0.13 mm tag RFID tanpa cip. Tag RFID tanpa cip telah dianalisis dan mengukur prestasi tag yang dijalankan melalui Penganalisis Rangkaian Vektor.

ACKNOWLEDGEMENTS

First, I want to praise, and thank Allah almighty for blessing me, for giving me the courage to finish a study, and for providing me a chance. I would like to express my deepest gratitude and appreciation to my project supervisor Professor Madya Dr. Maisarah Binti Abu for their support and wise direction. My sincere appreciation for his attentive oversight, advice remarks as well as for taking the time to respond. This thesis would never have taken shape without his invaluable guidance and persistent help. Besides, I want to express my gratitude to my family for always being there for me to encourage me when the times got rough. I am overwhelmed to receive the kind words and all the assistance given. Next, to both panels of this project, Dr. Imran bin Mohd Ibrahim, and Mr. Azahari bin Salleh, always gave ideas and advanced during the presentation. Finally, I would like to thank all my fellow friends for their help and support. Their support was a great relief and comfort to push me to complete my project.

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LIST OF SYMBOLS AND ABBREVIATIONS



CHAPTER 1

INTRODUCTION



substantial growth. Radiofrequency identification device (RFID) technology offers many advantages over other methods like optical and radio frequency barcoding. They include non-line-of-sight reading, extended reading range, increased data capacity, and automation in item tracking, identification, and localization. Moreover, the next generation of bar code technology used for electronic product identification is radio frequency identification. RFID technology has demonstrated advantages over current bar code identification systems. Next, due to the existence of an application-specific integrated circuit (ASIC) chip, RFID tags with tiny chips cost more than barcode tags. The tag is used to encode product data in a variety of fieldsand can be programmed to operate in many different languages. The chipless tags use multiresonators to store and retrieve data fast. Without a data storage chip, chipless tags can be made. The method for creating a new type of tag includes RFID tags, middleware software, and a reader. The tag encodes information in the frequency spectrum, giving it its spectral signature. The RFID reader acquires the spectrum signature by interrogating the tag with a multi-frequency signal. The tag's spectral signature is encoded into the interrogation signal spectrum through a multi-resonator circuit. Moreover, multiresonators can be done by combining and matching resonator sizes and shapes. Multiresonators are structures that resonate at multiple frequencies over their operational range. Absence or presence can be used to encode data bits in their resonant peaks. The reader is connected to a host computer that performs additional signal processing and indicates the identity of the tag to interpret human readers. All RFID applications need to be inexpensive to compete with the cost of barcodes.



Figure 1.1 General RFID system [1]

1.2 Problem Statement

Chipless RFID has the potential to be a useful monitoring and identifying technology. However, there are two critical challenges in the chipless RFID tags' design level which is a sensitive response to the reflection from the environment. It can impact the dynamic environment and the object associated with the tags responses, which obstructs the tag ID measurement technique. Furthermore, the distance performance of tags has low data capacity. The tag is used to label things made of elevated and greater substances, such as metals and liquids with a water base. These days, chipless tags can easily be given while remaining incredibly affordable, small, and suited for manufacturing things. This is because chipless tags can be produced with waveguide technologies or using the appropriate copper inks, custom printed on a range of dielectric materials [2]. Therefore, to overcome these issues, this project aims to design and optimize the multi-resonator chipless RFID tags.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA 1.3 Objectives

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- 1. To design and optimize the multi-resonator chipless RFID Tag.
- 2. To analyze the performance of the chipless RFID Tag.

1.4 Scope of Work

This project designed and analyzed the multi-resonator chipless RFID tag with high-quality factors. Other than that, the performance of the tag in terms of radar crosssection has been analyzed using Computer Simulation Technology (CST). The multiresonator circuits will consist of a single element and a modest design. Additionally, it might be printed with semi-conductive ink on bendable plastic or paper substrates for extremely affordable but increased RFID systems. The chipless tags can simply be equipped with sensing capabilities while staying affordable, small, and portable. Other than that, this project will simulate parameters that will be studied such as insertion loss. This project was fabricated on a substrate such as a flexible substrate.

1.5 📑 Importance / Significants

The printable passive RFID tags of chipless RFID systems have a few advantages over microchip RFID systems. This feature allows chipless RFID tags to be significantly less expensive than conventional RFID tags. Applications of chipless RFID tags can be the most promising technologies for the food business since they can meet all sensor and identification needs in food safety monitoring, package tracking, inventory control, early warning, and easy check-out. Other than that, this project of the chipless RFID tag with high-quality factor multi resonator is relevant to sustainability and environmentally friendly which can be used for potential impact and future revolution for a green project. This can be accomplished by creating a low-cost, durable, widely available, and simple-to-manufacture environmental sensor. Other than that, the concepts of chipless RFID tags appear to be promising for low- cost item tagging.

CHAPTER 2

LITERATURE REVIEW



This chapter contains the research results from a previous study that is relevant UNIVERSITITEKNIKAL MALAYSIA MELAKA to this project. These studies also serve as the primary source of information, with the theoretical, methodology, and interpretation of the studies assisting in the support of the project's material. The preferred journal objective was created by other people and related to the current project. The magazines or articles help the student to find new ideas and methods to fix a problem found in their project. A literature search is also helping students to find another way to solve the problem, even though they may have already done so and have a solution to a specific problem.

2.2 Multi-resonator chipless RFID tag

This research paper is about the design of chipless RFID tags based on multiresonator filters. This project used a type of broadband chipless RFID tagging based on a slot-linked tapered slot antenna (TSA) loaded with a collection of resonators (MRF). Other than that, this project used 8 bits of the MRF circuit. The spectral and temporal domain responses of MRF circuits operating in the frequency range of 4 to 9 GHz are measured under short and open terminations in this research. The pulse fidelity factor is calculated after discovering the cross-correlation between the signals [2]. The result has been proposed as an open stub resonator with either short circuit loads, or long circuit loads to generate distinct RFID codes. Next, the researchpaper is about the design of chipless RFID by using the Modified Complementary Split Ring Resonator (MCSRR) to produce a high data capacity and miniaturized flexible chipless RFID tag. The 48 mm x 48 mm, 19-bit, chipless RFID tag uses a frequency shifting approach and is made up and shows an MCSRR with a Different Width (MCSRR with DW) structure composed of five overlapping slots. The flexible (Polyethylene Terephthalate) PET substrate employed in this study had a permittivity TEKNIKAL MALAYSIA MELAKA RSITI of 0.2 aside from that [3]. The main objective is to operate the frequency of a wideband tag antenna and a rising reader antenna utilized to assess the material structures using a chipless RFID tag technology with a range of frequencies of 0.9 and 2.7 GHz. As a result, a low-cost RFID tag-based CSRR material structure with a bendable, larger efficiency, and compact size has been developed. The potential 19 bits frequency signature was generated using 5 overlaying of MCSRR with DW structures with dimensions of 48 mm × 48 mm.



Figure 2.1 A proposed transmission line with resonator structure; a) CSRR structure, b) MCSRR structure c) MCSRR with DW [3].



Figure 2.2 The simulated insertion loss for the proposed design; CSRR (green), MCSRR (red), and MCSRR with DW (blue) [3].

Next, the research paper is about the Dual band Modified Complementary Split Ring Resonator (MCSRR) Based Multi-resonator Circuit for Chipless RFID Tag. This project presented a small multi-resonator circuit that uses several modified complementary split-ring resonators (MCSRR) arranged along the transmission line as data bit encoding elements. Our suggested tag will increase the information density by roughly twofold, unlike the conventional resonance signature-based tags. Then, Dual-band MCSRR has been used in conjunction with innovative resonance detuning techniques to enable the spectral signature chipless RFID tag's overall space economy and information efficiency by transmitting bits with such a unique resonance [4].



Figure 2.3 The layout of the 8-bit is designed based on multi resonator circuit [4].

Some chipless RFID methods rely upon multiresonators and amazingly wideband (UWB) monopole antennas have also been researched. Instead of using radar cross-section (RCS) backscattering, the method relies on the transmission of the inquiry signal with the distinctive spectrum ID. To establish effective separation between the sent and received signals, the signals are cross-polarized. This is because the unique ID of the tag is encoded as a spectrum signature [5]. It demonstrates how the cross-polar tag's drawbacks make it troublesome for applications where the tag's orientation is not known. The reader antennas are cross-polarized to lessen crosstalk between the two antennas, which improves tag signal isolation [5]. This study also examined co-polar and cross-polar radiation patterns in both vertical and horizontal planes under near-field and far-field conditions, as well as return loss and gain versus frequency.







Figure 2.4 (a) Layout of a spiral resonator with defined layout parameters (b) Result insertion loss for simulated and measured [5].



Figure 2.5 Measured co-polar and cross-polar radiation patterns of UWB monopole at 2 GHz [5].

This project simulated and measured insertion loss versus frequency. It shows the uses of multi-resonators to encode data into the spectral signature. In other researched papers, the circuit is based on a multi-resonator circuit, which is made up of many stop-band spiral resonators to encode the data. The chipless tag was positioned in front of two cross-polarized reader antennae at up to 10 cm. The reader antennas were LPDA arrays of log-periodic dipoles. To effectively identify the chipless tag, the crosstalk between the transmitting and receiving signal must be reduced by the cross-polarized antennas [6]. Two optimization strategies are used to optimize the resonators' performance on flexible laminate.



Figure 2.6 Measured attenuation and transmission phase of 6-bit multi resonator [6].



Figure 2.7 Measured monopole radiation patterns from 4–6 GHz in both planes [6].

Moreover, this research paper is about the design of the chipless RFID tag based on retro-reflective structures. Self-steering tag antennas and retro-radiators are used to extend the reading range and maintain detection accuracy [7]. A y-polarized plane wave with a Gaussian signal coming from bore sight questions the tag. To simulate a chipless RFID tag, CST Microwave Studio's time domain is used. A ypolarized E-field probe is put at the bore sight, 200 mm from the tag, to detect the signal scattered by the tag. The result achieved, retro-array-based chipless RFID tags, which are linearly or circularly polarized, were introduced in the papers [7].

Next, the research paper is about Multiresonator Based Chipless RFID Tags and Dedicated RFID Readers. This project encodes data in the frequency spectrum, the chipless tag gives the spectrum a distinctive spectral signature. The RFID reader interrogates the tag with a multi-frequency signal to retrieve the spectral signature. The tag uses a multi-resonant circuit, or multi-stop band filter, to encode its spectral signature into the interrogation signal spectrum. The multi-resonator is a collection of cascaded spiral resonators intended to produce stop bands by resonating at specific frequencies. ADS Momentum 2008 is used to design the flexible chip-less tag on laminate Taconic TF-290 (ar=2.9, h=90µm, tan5=0.0028). The antenna and multiresonators are each created specifically for this function. The design specifications for the chipless RFID tag layout are printed on flexible TF-290 laminates [8].

The fundamental resonator is tiny, capable of separating harmonics, has a programmable architecture and is straightforward to construct. On a substrate made of RTDuroid (er=2.2, tan δ =0.0008) the tag is built and designed. The dimensions of the tag are 4.5 x 2 cm². Depending on the number of objects, either the presence/absence approach or frequency shift coding can be used. Laminated TF-290 [9].



Figure 2.8 Fabricated Multiresonator circuit with all the resonators aborted [9].



Figure 2.9 Simulated S12(dB) of the 6-bit multi-resonator circuit for two different codes [9].

2.3 The high-quality factor for chipless RFID tag

From the previous work, the paper has researched the Optimization of the Q Factorin Complementary Spiral Resonators for RFID Applications. Chipless RFID tags utilize optimized resonators as coding elements. On the top surface of the printable tag, an array of various resonators adjusted to resonate at different frequencies is inserted. SAW (Surface Acoustic Wave) is the most popular timedomain tag on the market [10]. The size of the spiral resonator is yet another crucial factor in reaching the correct resonance frequency. Although it is possible to determine a structure's quality factor by measuring the results of an experiment this form is not suitable for adjusting a structure's quality factor using geometrical parameters.

$$Q-factor, Q = \frac{F_0}{\Delta f}$$
(1)

In this project, an 8-bit typical tag has been created using spiral resonators to improve the quality of radio signals. The tag was made on Rogers's 5880 substrates with a 0.508 mm thickness and 0.8 mm thickness for maximum noise insulation.

Next, this research paper discusses how most RFID tags are produced at a higher frequency, generating high Q factors. The majority of RFID tag designs in the literature are created at high frequencies, although the spiral resonator used in this study has a decent Q factor of 24 at 0.9636 GHz [2]. The Q of a single-bit resonator can be calculated using the formula, where f0 is the center frequency and f is the reference bandwidth of 10 dB, which raises the Q factor values. Even though the low-frequency tags, the expected Q factor for such a spiral resonator at 0.9636 GHz is a good 24. In comparison to other designs, the spiral resonator's ability to store energy and be selective at the operating frequency is demonstrated by its high Q value of 24 at a frequency of less than 1 GHz. It also offers the least attenuation [11]-[12].



Figure 2.10 FR-4 epoxy-fabricated prototype (a) Resonator for such a fixed RFID tag (b), a 4-bit RFID tag (c), and an 8-bit RFID tag [12]

The utilization of chipless RFID systems to reduce strong reflections from objects behind the tag is the target of another study. The majority of common chipless RFID tags have a co-polar response, which is highly sensitive to the material properties of the object they are attached [13]. The main objective to combat the problem of this project at the tag design level is to use a cross-polar chipless RFID tag. A chipless RFID tag for item tagging that can recognize the passed tag at any 2D rotation angle of the tag is proposed as a result of this study [13]. It demonstrates how the pass tag's limitations make it unsuitable for applications where it tag's orientation is not known.



Figure 2.11 (a) (b) (c) (d) Tags were measured in various orientations, and metal tags were used as the raw material for the experiments [13].



Figure 2.12 Simulation of different effects with Nonperiodic configurations
[13]

Other than that, a chipless sensor can estimate the orientation of an object attached to it. The method is based on a single scatterer's cross-polarization response, and it is more resistant to unknown objects in the environment than other methods. Then, the paper researched the High Bit Encoding of Chipless RFID Tag Using Multiple E-Shaped Microstrip Resonators. A new 8-bit chipless RFID tag with a 650 MHz bandwidth was created because of this study. Eight E-shaped microstrip resonators in the frequency range of 3.12 to 3.77 GHz are used in the multi-resonating circuit of the proposed tag, which also includes two cross-polarized transmitting and receiving monopole antennas [13].

Next, the research paper that has been researched is Chipless tag design utilizes a high-Q slotted resonance. To create the retransmission chipless tag, which is the main goal of this research, many adjacent U-shaped slotted configurations with variable lengths are published on the microstrip feed line. The substrate of the 6-bit tag is 30 mm2 by 19.5 mm2. The U-shaped slot resonance has a narrow resistivity range and high Q values. Two cross-polarized antennae and a data-storing multiresonator make up the retransmission chipless tag [14].



Figure 2.13 Structure of U-shaped resonators chipless tag: (a) Top view; (b) Side view [15]



Figure 2.14 Simulation and measurement results of U-shaped slot resonator chipless tags: (a) ID111111; (b) ID101010; (c) ID010101; (d) ID111000 [15]

2.4 Summary

All the reviews of the background study above are important to this project research. The review was necessary as it will be the key to supporting the current project to design the chipless RFID tag. The design mostly will be referred to the method of the previous research with the addition of the new technique and good improvement.



CHAPTER 3

METHODOLOGY



project. The main important elements involved in the research methods are the development of dynamic modeling for the electric vehicle system, active steering control based on for wheel active steering system, and its controller. Next, the method of how this project explains the flow of the project and methods used throughout this research to make this project successful. Every process or step that was done to complete the project will be discussed. Besides, the development of this project includes hardware and software, design of the circuit, simulation of the circuit, fabrication of the circuit, and programming used in this project are explained in more detail such as functions, steps work, and process of components used to perform the project successfully.

The detail of the workflow of the project has been discussed including the device design and program development. Furthermore, the tags are beginning to become quite popular in the sector, use less power, are more durable, and are less expensive. Other than that, producing active tags include power. the financial cost of this project is also shown.

3.2 Project Planning

The project research is started by reviewing the study background of the previous research to make a new design or improvement of the older design. By doing so, it was to achieve the multi- resonator chipless RFID tag with a high-quality factor of X and Y bits, with 6 bits. Moreover, to start creating the model, need to use a mathematical calculation to figure out how big the multi-resonator circuit needs to be. The multi-resonator circuit is designed on CST Studio Suite. The substrate used in this project is a fast film with a permittivity of 2.7 and a thickness of 0.13 mm. In the designing process, the dimension for creating a cylinder with orientation W parameters is calculated to know the input value and the description until the shape of the designis done.

After that, the simulation is run and optimized until the desired result is obtained. The result is analyzed its parameters in terms of the S-Parameter and Radar Cross Section (RCS). Finally, the fabrication part is conducted to get the physical hardware of the project. The testing section runs through Vector Network Analyzer (VNA) in the laboratory. The measurement is being analyzed to compare the simulated and actual results obtained. Once a good result is achieved, that means the model is well performed for the application.
3.3 Research Methodology Flow Chart

To achieve the objectives, some steps need to be considered for the research. The explanation of the process flow of the project is described step by step in the following order.



3.4 Research & Study the design

The research related to the issues of this project are the specifications, result, and structure of the low-cost RFID tag in terms of multi-resonator of high-quality factors, and analyzed the performance of tags with RCS. Furthermore, the shape and design antenna contributed to its performance gain the antenna. Before designing, the multi-resonator chipless RFID the mathematical formula equation that is needed to be calculated. The equation is to determine the dimension required for the design model. Firstly, before calculating the dimension, a parameter such as a permittivity, frequency, type, and height of the substrate needs to be specified.



Figure 3.1 Dimension of the multi-resonator chipless RFID circuit [4]

3.4.1 Design and simulation of the multi resonator of the chipless RFID tag with the high-quality factor

The multi-resonator chipless RFID tag operated at 0 - 3 GHz was designed using Computer Simulation Technology (CST) software on the flexible substrate which is a fast film with a permittivity of 2.7 and thickness of 0.13 mm. Furthermore, from 300 MHz to 3 GHz is the ultrahigh frequency range. In addition, being more sensitive, it transfers data more quickly. The application for chipless RFID tags that operated at 0 - 3 GHz is ranging from retail inventory management to pharmaceutical anti-counterfeiting, to wireless device configuration. The target of the design is a quality factor above 24 and with 6 bits or frequency resonances. The other simulated parameters that have been studied are insertion loss, Radar cross-section using a probe.



Figure 3.2 Responses to insertion loss (S21) for an MCSRR configured to create allfour 2-bit binary ID combinations.

When the outer and inner rings of a bell ring vibrate at various frequencies can a two-bit binary ID = "11" be encoded then a stop band forms at the frequency response when the binary state "1" is connected to resonance. When the binary condition "0" is observed, resonance is absent.

3.4.1.1 Step to design the chipless RFID Tag using Computer Simulation

Technology (CST) Studio

Three main parts of the multi-resonator tags need to be considered before starting to design.

i. Substrate

The substrate is a vital component of the operation of a microstrip patch (metallic sheet) antenna. It is primarily utilized in microstrip antennas to mechanically support the antenna. Because the electrical performance of the antenna, circuits, and transmission line may be impacted, a substrate should be built of a dielectric substance.

Ground Plane

TENH A ground-plane antenna is a dipole antenna that uses an unbalanced feed line.It is a popular antenna in communication systems because of its ease of production and low cost. A monopole antenna is half of a dipole and is positioned above the ground plane. This function can be simulated by replacing the real earth with a conductive plane. The conducting surface must extend at least a quarter wavelength from the antenna base to operate as an antenna ground plane.

iii. Patch

An antenna patches any flat surface is suitable for a radio antenna. Over larger sheet metal, a ground plane, a polygon, rectangular, circular, triangular, or any other geometrical sheet or "patch" of metal.

3.4.1.2 Software Simulation

The project template is created. The project template under the Microwave and RF Optical is chosen, and the antenna and workflow RFID is selected. Next, there is frequency selection which needs to be decided for the antenna operation.

| New Template | Project Template Create a project template with settings tailored to your application area. |
|--|--|
| Anter MW 8 | nna - Chipless RFID Tag 一屆 k RF & OPTICAL, Time Domain |
| MW 6 | nna - Testing -III RF & OPTICAL, Time Domain |
| Anter MW 8 Anter MW 8 | INA - Planar_2 RF & OPTICAL, Time Domain RRF & OPTICAL, Time Domain |
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Figure 3.4 Setting the frequency minimum and maximum.



The dimension for the material of the chipless RFID tag for the substrate and patch were defined and designed using the 'brick' or 'cylinder' from Modelling Tab. Next, to achieve the best multi resonator at 0-3GHz an Octagon with 8 sides is designed and created by using a cylinder with orientation W parameter.

| 1 6 8 V | 0 (P 🗋 ÷ | | | Untitled_0 - CST Studio Suite | | | | | | | | | - 6 | e x |
|---------------------------|---|-----------------------|--------------------|--|----------------------------------|------------------|--|--------------------|-------------------------|---------|---------------------|------------------|--------------|------|
| File Hom | ne Modeling Simul | ation Post-Processing | liew | | | | | | | | Search | n (Alt+Q) | Q, | ^ (? |
| Import/Export Exchange | Background Material Library • New/Edit • Materials | Shapes | Transform | Align Blend • Boolean • Tools | Send Tools • Modify Locally • | Curves Curves | Y Pick Points → Picks → Q Clear Picks Picks | Edit Properties | History List Edit | ₽· 0 | Local WCS • LOCA | Cutting Plane | I: X n: 0 | -+ |
| Navigation Tree | | × 🛛 🔀 Untitled_0* 🔯 | RFID design (PSM_r | new) • (original | .8sisi)* 🖸 | | | | | | _ | | | |

Figure 3.6 Brick or cylinder selection from CST.

| Name: | | OK |
|------------|-------|---------|
| Substrate | | |
| Xmin: | Xmax: | Cancel |
| 4 | L | Preview |
| Ymin: | Ymax: | Help |
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| Zmin: | Zmax: | |
| -st | 0 | |
| Component: | | |
| component1 | | × |
| Material: | | |
| FastElm | | 0 |

Figure 3.7 Brick dimension to represent the thickness of the substrate

The CST Microwave Studio software was utilized to create and simulated the suggested tag. Figure 3.8 depicts the tag's shape along with its characteristics. The largest hexagon resonator's radius is L21, the lowest resonator's radius is Rn, the spacing among resonators is Ss, and the length of the slotted resonant frequency, Ws, is the same as Ss. The patch's radius is L1. Bits are represented by the number of Octagon resonators, where the longest resonator represents the lowest frequency and vice versa. The logic switched from expressing logic "1" to representing logic "0" when the resonator or slot was removed.



The tags were created to operate in the frequency ranges of 0 GHz to 3.0 GHz, this one was modeled on thin films substrates with a dielectric permittivity of 2.7, a copper thickness of 0.035 mm, a substrates height of 0.13 mm, and a loss tangent of 0.0019. The tag's dimensions for the bottom band were as follows: Ws = Ss = 2.2 mm, L1 = 90.5 mm, and L21 = 73.5 mm. The lengths of the resonators were numbered, and slot number 1 is the longest and lowest frequency, which is known as the most significant bit (MSB). The bit designated as "least significant" has the maximum frequency in the ring number "n." (LSB).

Then, the tag in the shape of a cylinder should fit the scale parameters of X and Y respectively. After integration, the running frequency typically changed either higher or lower than 0.4 GHz. The resonator should be scaled lower than 1, and if the frequency rises over 0.4 GHz, the resonator structure must be scaled larger than 1 until

the lowest insertion loss goes inside that range. The thickness of the material not be transformed, and the scale vector must be 1.

| Transform Selected Object | × |
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| Settings Source: and Loads Monitor: Probe Source: Probe Source: Probe Source: Sou | Global Intersection Electrical Properties - Check Connections - Mesh Gheck |
| Settings Sources and Loads Monitors Solver Picks | |

Figure 3.10 Boundaries selection from CST

Next, select boundaries from the simulation tab and define their conditions. Then, edit the boundaries in the simulation set to open (add space) for Zmin and Zmax because this design does not have a ground plane and passes through to the receiver.

| Boundar | ies | Symmetry Planes | | | | |
|---------|--------|------------------|---|-------|-------------------|---------|
| App | oly in | all directions | | | | |
| Xmin: | ma | agnetic (Ht = 0) | ~ | Xmax: | magnetic (Ht = 0) | ~ |
| Ymin: | ele | ectric (Et = 0) | ~ | Ymax: | electric (Et = 0) | ~ |
| Zmin: | op | en (add space) | ~ | Zmax: | open (add space) | × |
| Cond | 10 | 00 | | S/m | Open Boundary. | <i></i> |



The waveguide port is set up after choosing the port location as seen in Figure 3.12, the Waveguide Port option under the Simulation tab was selected. The port placement at the front and after the tag is chosen before the dimension of the virtual port is defined.

Figure 3.12 Waveguide Port (final port structure)

3.4.2 Fabrication of the multi-resonator of the chipless RFID tag

The fabrication process is carried out in the laboratory by using a flexible substrate for the material design to construct the proposed tag. The substrate is used like flexible copper laminate that consists of five-layer material. Layout printing, pattern transferring, and copper etching were the three steps of the fabrication process.



Figure 3.13 Fabricated resonator using thin and bendable substrate

3.4.3 Analysis and measured the performance of the tag in terms of Sparameters and radar cross-section (RCS)

The proposed tag has been fabricated in the 6-bit ideal size. The resonator was made from a thin, flexible substrate. A horn antenna in front of the tag served as a transmitter, while a second horn antenna behind the tag served as a receiver as shown in Figure 3.14. The S21 magnitude was then determined using the Vector Network Analyzer (VNA).



Moreover, for the measurement select a suitable cable and verify that it's connected to VNA properly; if not, a serious mistake might occur. Then, select the measurement frequency range, perform the distance for measuring the results and make sure the cable is not relocated, as this could result in mistakes. The result has been analyzed for the multi-resonator chipless RFID tag with high-quality factors which have high data capacity. Furthermore, it also observes to know the performance of the tag. In the measured part, the need to measure the insertion loss S2,1. Then, do a comparison of the simulation result and measured result. The simulation setup is shown in Figure 3.15 below. The tag was stimulated using a linearly polarized plane wave, and following the lowest frequency, the radar sectional (RCS) probe was positioned somewhere at the base of the building. There isn't a ground plane in the structure. Then, the furthest diffracted signal from the tag was detected by these probes.



Figure 3.15 Simulation Setup RCS for the octagonal 6 bits resonator Chipless Tag

In the simulation, RCS used the measure of the ability to reflect radar in the direction radar receiver, i.e., it is a measure ratio power steradian in direction radar power density by the target. Moreover, a target can be viewed as a comparison strength signal a target signal is a perfectly smooth sphere of the cross-sectional area of $1 m^2$. An RCS is most easily visualized as product three are projected cross-section, reflectivity, and directivity.

3.5 Summary

This chapter represents the proposed methodology for designing the multiresonator chipless RFID tag. The flow in designing an 8-bit multi-resonator chipless RFID tag is illustrated in the flow chart. A 6-bit multi-resonator chipless RFID tag has been designed using CST Studio. Based on the above mathematical equation and characteristic, the design of a 6-bit multi-resonator chipless RFDI tag has optimized the parameter to get the best result of S21 for the design using Computer Simulation Technology (CST) Studio. Other than that, the parameter needed to measure the *S*21 corresponds to RCS.



3.6 **Project Planning**

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Mark "X" on the Gantt chart for the expected milestones (Hint: Completion of major activities)

CHAPTER 4

RESULTS AND DISCUSSION



bit multi-resonator chipless RFID tag that was obtained based on the response S-Parameters insertion loss S21. Moreover, this chapter has a preliminary design and simulation result from the previous paper for use as a reference design. Utilizing the entire electromagnetic modeling software Computer Simulation Technology (CST) studio, the 6-bit multi-resonator has been created and optimized.

4.2 Preliminary Result (Design 1)

This is an initial design from the previous paper to use as a reference. Moreover, this preliminary result has two designs with different simulation results which are about the distance of the feed line, and split rings. The first step, realizing the design of the 2-bit multi-resonator circuit and optimizing using full-wave electromagnetic simulation software Computer Simulation Technology (CST) Studio. This project was designed as a 6-bit multi-resonator. For the preliminary result, used a 2-bit multi-resonator as an initial for simulation. Here is the first design that has used a 2-bit multi-resonator circuit and has a feed line. In this design, the simulation result has a not good result for encoding data bits using resonators in chipless RFID tags.



(i) Design 1

Figure 4.2 Simulated insertion loss (S21 magnitude) results for the design 1 2-bit multi-resonator circuit

Next, the third design has the same design as the first one, but the feed line isnear the outer ring of a complementary split rectangular ring resonator (CSRR). The second design has different from the feed line in that the result has become better than the first one. In this design, create the inner ring of a complementary split rectangular ring resonator (CSRR) the sections from both the inner and outer rings are located on the same side to optimize utilization. Unfortunately, this design still cannot get the best result because of references from the previous researchpaper, and still looking for improvements to this design.



Figure 4.3 Generated 2-bit multi-resonator circuit design 2



Figure 4.4 Simulated insertion loss (S21 magnitude) results for design 2 for 2-bit multi-resonator circuit

Moreover, this design created the splits of the two rings situated on two opposite sides of the resonator in the typical CSRR. In the CSRR, the inner ring serves as a loading element for the outer ring, and both rings are combined to form a single-stop band.

4.3 Design 3 (Single element tags)

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Here, the longest resonator in the tag produces a frequency signature at the lowest frequency, although the maximum frequency spectrum signature is produced by the lowest resonance. Resonators can be present or absent, which denotes a "1" or "0," respectively. a comparable design to the first and second designs for a comparable range of frequencies.

Based on the slot ring tag, a chipless tag with an octagonal resonator was created. The frequency ranges from 0 GHz to 3.0 GHz were intended for use by the tags. Due to the rising need for wearable systems, Tag was constructed into a thin and flexible substrate.

| Parameters, s | Value, mm | - |
|--|-----------|---|
| Chipless Tag length, L | 100 | - |
| A gap in the resonator | 15 | |
| The entire length of the resonator, L1 | 90.5 | |
| The separation between resonator, Ss | 2.2 | |

Table 4.1 Structural parameters for the proposed octagonal resonator chipless RFID Tag



Figure 4.5 6-bit proposed chipless RFID tag (a) Tag design, (b) simulated response of insertion loss (S21)

Additionally, the limited resonance makes it possible to encode several bits in the same frequency band. With a wider spacing between the resonators than the first design, this design also lessens the effects of mutual coupling. This architecture may be advantageous for complex IoT applications are given all these fascinating features. However, when the number of bits grows, the design's size will also grow significantly.

4.3.1 High-quality Factor

Af entire width at 3dB above the minimum at the resonance frequency. By measuring the result in an experiment, it can determine the quality factor of a structure, although the form does not help adjust the quality factor geometrically. Next, to implement quality factor optimization, a circuit analytical expression is required. Q factors increase when the thickness has the ohmic loss and is utilized in investigation or variation in metal thickness. Other than that, no impact on resonance frequency.

Additionally, virtually every RFID tag design uses high frequencies and offers higher Q factor values. Because the ability to store energy at frequencies greater than UNIVERSITY EXAMPLE AND ADDITIONAL ADDITION

The Q-factor is calculated by using the following relation:

$$Q = \frac{Fo}{\Delta f} = \frac{Fo}{f2 - f1}$$







Figure 4.6 (a) the values of frequency, f1 (b) the values of frequency, f2

(c) the values of frequency, fo

Calculation:

$$Q = \frac{F_0}{\Delta f} = \frac{F_0}{f^2 - f^1}$$
$$\Delta f = f^2 - f^1$$
$$f_0 = 1.547 \text{ GHz} \ f_1 = 1.52 \ GHz \ f_2 = 1.58 \ GHz$$
$$Q = \frac{1.547 \ GHz}{1.58 \ GHz - 1.52 \ GHz} = 25.78$$

4.4 Three elements of RFID tags design

Three elements of the design of an RFID tag are shown in figure 4.7. It is intended that the addition of slots will improve antenna performance while also making the design more manageable. The aggregate effect of slots is unpredictable when there are numerous patches involved, which in this case altered the resonance frequency. The optimizer in the CST software automatically generates all the parameters, including the patch width and slot dimension. This optimization's configuration is intended to improve insertion loss and place it at 1.56 GHz. The optimization does not, however, perform as anticipated. The amplitude of S21 over frequency is shown in Figure 4.8, with a minimum S21 of -35 dB and a resonant frequency of 1.56 GHz.



Figure 4.7 Generated three-element RFID tags design



Figure 4.8 Simulated insertion loss (S21 magnitude) results for three-element tags design

4.5 Analysis and discussion of the multi-resonator chipless RFID tags

The suggested resonator-based chipless tag is further examined utilizing a variety of simulations run by CST Microwave Studio. Here, the chipless tag is discussed in an incident on a plane wave with linear polarization, and a far-field probe is positioned to receive the tag's diffracted signal. The efficiency of the tags has then been investigated and analyzed concerning substrate qualities, spacing among resonators, The Rx arrangement, and the side of the substrate.

4.5.1 Impact of the ground plane UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The proposed tags are capable of being encoded from both sides (front and back). On one side of the tag, the ground plane has been added to examine this property. A design without a ground plane has a higher received signal power level than a design with a ground plane. This will undoubtedly result in a more precise reading of the tag without a basis.



Figure 4.9 (a) front of the tag (b) back of the tag with ground plane

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Next, the ground plane also reduces the impact of material or item tags. Additionally, that tagging isn't available in all locations when there is ground present, which limits where the reader may be installed. It is significant to note the application context ground necessary. In context, a basis may be necessary for identification cards, a ground may be helpful like a bank card that requires security.

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| | | | | Frequen | cy / GHz | | | | | | | | | |

Figure 4.10 Simulation response to the presence of ground plane of proposed chipless tags

4.5.2 Impact of Rx probe placement

For some purposes, viewing these tags from either the front or rear may be necessary. As seen in figure 4.11, the illustration of both the front and back rear, the probes are to evaluate the readability of tags. Figure 4.12 displays the outcomes for the two scenarios. This makes it obvious that the replies' resonance frequencies and power levels match perfectly. This implies that both sides will provide accurate readings that are identical.



(a) Front





Figure 4.12 Simulated RCS magnitude responses on different positions of the probe

4.5.3 Impact of substrate properties

The tags will be on various substrate heights and related permittivity. The resonant will alter as a result, as seen in Figure 4.13 and Figure 4.14. The real bandwidth may require a change. In the worst situation, the potential for the inaccurate reading tag, the seeming effect will be more resonant. Furthermore, it is seen that sheet substrates with a thickness of 0.13 mm could potentially provide the necessary bit encoding. It will signal paper substrate tag; a reader with extremely high sensitivity will be needed signal strength quite low in comparison to others.

| Substrate | Thickness, h | Permittivity / |
|-----------|--------------------|-------------------------|
| | | Dielectric constant, er |
| | 0.13 mm (original) | 2.7 (original) |
| Fast Film | 0.78 mm | 3.8 |
| Γ | 1 mm | 4.8 |

Table 4.2 Comparison of thickness substrate and dielectric constant



Figure 4.13 Proposed different thickness



thicknesses and permittivity and be achieved a different result. From the above analysis, the size of the antenna was reduced but antenna performance degraded a substrate material with a dielectric constant used in the simulation of a patch antenna. Resonance frequency decreases but the bandwidth of substrate thickness has been increased. A material's capacity to store energy is gauged by its permittivity.

4.5.4 Impact of bending the substrate

Radius, r is the main point of the bending substrate. The bend radius is the maximum bend angle that a cable may take without being damaged (including kinking). The material's needed flexibility increases as the radius gets narrower. Furthermore, it can be reducing the cost of production for a large area. Based on the bending theory of thin films, the surface strain can be estimated when bending a substrate of thickness t on a certain radius.

Moreover, can serve as leading IoT enablers in terms of the creation of sensors, circuits, and the incorporation of flexible electronics components into ordinary items. An example of an application is for continuous monitoring of a person's body temperature, respiration rate, electrooculogram, electromyogram, and heart rate, wearable sensors for bio-signals have gained a lot of attention in recent years.



UNIVE Radius = 60m, 100m, and 130 meters SIA MELAKA

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(2)





Figure 4.15 (a) view the perspective of the tag (b) view the side of the tag



As in figure 4.16, it can conclude the increase of the radius because of the capacitance and the thickness of the dielectric layer could fluctuate because of the flexible substrate bending.

4.6 Measurement Result

Figure 4.17 shows the testing method utilized to evaluate the performance of the tags. The tags are using two horn antennas from transmit and receive with bandwidth 1-3Ghz. An antenna system like a radar system uses one antenna to interrogate a target another picks up scattered signal targets. Since the lack, of a ground plane, disperse radiation in front rear directions.

The ADVANTEST R3767CG vector network analyzer from Agilent was used to obtain the results of the measured two-port S-parameters. 5 bits of data were encoded by the multi-resonator. As a result of the 5 different types of resonators, the results are displayed in Figure 4.19 – Figure 4.22 with different distances. Demonstrate five separate resonant peaks in the attenuation (which correspond to magnitude nulls) and five phase jumps. A specific resonance is created by each spiral resonator and is then used to encode data.



Figure 4.17 View from horn antenna (transmit) to the tags

Analysis of the distance from the horn antenna transmission to the tag and from the horn antenna receiver to the tag:-

Free space measurement

It discovered free space measurement effective technique for the dielectric, particularly flat need to be measured being damaged. As placed between for a measurement, the method is straightforward, quick, and precise.



Distance, d (1 meter)





Distance, d (50 centimeters)



Figure 4.20 Measurement result for insertion loss S2,1 (50 centimeters)



Figure 4.21 Measurement result for insertion loss S2,1 (30 centimeters)

• Distance, d (10 centimeters)





4.6.1 Comparison between simulation and measurement result

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The comparison of the simulation and measurement findings is shown in Table 4.3. This slightly off reading happened because of the surroundings for observations. This is a result of the measurement being done outside or open space.

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. . . .

| | Simulat | ion | Measurement | | | | | | |
|--------|-----------------|-----------|-----------------|-----------|--|--|--|--|--|
| Marker | Frequency (GHz) | Magnitude | Frequency (GHz) | Magnitude | | | | | |
| 1 | 1.5448 | -38.192 | 1.54 | -17.999 | | | | | |
| 2 | 1.8011 | -32.427 | 1.72 | -15.376 | | | | | |
| 3 | 1.9845 | -25.803 | 1.92 | 18.956 | | | | | |
| 4 | 2.2144 | -30.679 | 2.15 | 18.894 | | | | | |
| 5 | 2.537 | -31.590 | 2.46 | -17.302 | | | | | |

| Table 4.3 Compariso | n between | simulation | and | measurement | results |
|---------------------|-----------|------------|-----|-------------|---------|
|---------------------|-----------|------------|-----|-------------|---------|

 ± 10

4.6.2 Comparison existing research

In table 4.4, a comparison between the suggested chipless tags' various features and the current literature has been made. The suggested chipless tag designs provide the desired characteristics.

| Chipless RFID | Bandwidth | No. of | Printable | Structure | Substrate | Q-factor |
|-------------------------|-------------------|---------|-----------|-----------|-----------|----------|
| types | requirement | Bit | | | types | |
| | | encoded | | | | |
| Design, analysis, and | 3 GHz – 6 GHz | 8 bits | yes | L | Rogers | - |
| realisation of chipless | MC | | | resonator | RT 5880 | |
| RFID tag for | PX | | | | | |
| orientation | 2 | | | | | |
| independent | | | | | | |
| configurations [1] | | | | | | |
| Bendable Hexagonal | 2.5 GHz – 3.3 GHz | 3 bits | yes | Hexagonal | Fast Film | |
| Resonator Designs | N/N - | | | | | |
| for Chipless Tag [15] | 1.1.10 | 1 | | resonator | * | |
| This paper | 0 GHz – 3 GHz | 5 bits | yes | Octagonal | Fast Film | yes |
| UN | VERSITI TEKI | | MALAYS | resonator | AKA | |

Table 4.4 Comparison of an existing chipless RFID tag on different parameters

4.7 Discussion

The measurements were done in a room setting as a proof of concept under several setup configurations. The antenna was initially calibrated based on the surroundings of the room. When measuring tags, it eliminates noise and interference caused by antennae and other materials. In the initial chipless RFID design, as illustrated in Figure 4.17, both horn antennas were positioned in front of the tags, and the antennas were positioned in front. The tags are positioned at four distinct distances in each of these cases: 1 m, 50 cm, 30 cm, and 10 cm. The frequency of the tags remained constant across all studies. A vector network analyzer transmits at a strength of 1 W at 30 dBm and subsequently, the transmission coefficient (S21) is measured. Other than that, the measurement result for 10 cesntimeters is similar to the result from the simulation result. The resonance is quite the same as the simulation. The higher resonance frequency is 2Ghz with -19dB.

4.8 Summary

In summary, it can be concluded resonant slightly alter as substrate height, the position of Rx, and relative permittivity all change. These are small, though, and the reader may easily be adjusted for. Improve magnitude of resonant for precise reading can also be on a paper substrate using highly for a mass affordable. Next, application space within broad will in end, dictate the selection of all criteria. Finally, a comparison between various literature in existence.

The suggested chipless tag designs show the desired characteristics, including high bit density and orientation independence. The recommended designs are a great choice for emerging technology because of their greatly improved features.
CHAPTER 5

CONCLUSION AND FUTURE WORKS



paper/plastic. Data spectral signature by the operating system using multiresonators. It is feasible to identify in strength phase of the received tag signal and decode the ID by a signal. The simulation experimental supports concept prototype design.

The challenges that were faced in designing this system are discussed in this project. Overall, this project has been successful to a certain extent.

5.2 Future Works

Next, two types of Sustainable Development Goals (SDG) can be related to this project which are SDG 9 and SDG 12. SDG 9 is industry, innovation, and infrastructure. SDG 9 can be related to this project is the data can be stored permanently and the tracking system is easy, cheapest also can be confirmed immediately. Other than that, SDG 12 is responsible for consumption and production. The main goals of SDG 12 will be related to this project are also the use of the natural environment can improve the quality of life.

Finally, enhancing the tag on a less expensive substrate, such as paper or plastic is the main of future study. Moreover, tickets and library tagging software can all employ fake tags. The technique has a lot of potentials if transparently placed on a plastic substrate for inexpensive item tracking. The focus of future research will be on improving reading accuracy.

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