

**DESIGN OF MULTIBAND CENTIMETRE WAVE
ANTENNAS FOR AN OFDM BASED RFID SYSTEM**

By

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MASTER OF SCIENCE IN INFORMATION AND
COMMUNICATION TECHNOLOGY

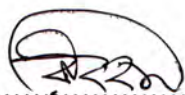


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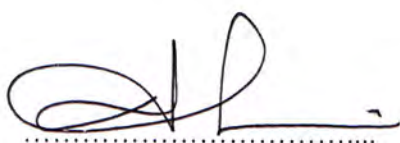
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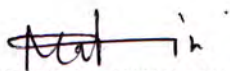
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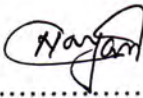
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A handwritten signature in black ink, appearing to read 'Nayan', written over a horizontal dotted line.

Nayan Sarker

DEDICATION

TO MY DEAREST PARENTS

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LIST OF ABBREVIATIONS

| Symbol | Meaning | Section |
|---------------|--|----------------|
| RFID | Radio Frequency identification | 1.1 |
| IoT | Internet of Things | 1.1 |
| IC | Integrated Circuitry | 1.1 |
| NLOS | No-Line-of sight | 1.1 |
| HF | High Frequency | 1.1 |
| UHF | Ultra-High Frequency | 1.1 |
| SHF | Super High Frequency | 1.1 |
| ISI | Inter Symbol Interference | 1.1 |
| ICI | Inter Carrier Interference | 1.1 |
| BER | Bit Error Rate | 1.1 |
| OFDM | Orthogonal Frequency Division Multiplexing | 1.1 |
| CW | Continuous Wave | 1.2 |
| IFF | Identification of Friend and Foe | 1.2 |
| EAS | Electronic Article Surveillance | 1.2 |
| PC | Personal Computer | 1.2 |

| | | |
|-------|--|-------|
| CMOS | Complementary Metal Oxide semiconductor (CMOS) | 1.2 |
| TDMA | Time Division Multiple Access | 1.3.2 |
| LOS | Line of sight | 1.6.1 |
| SNR | Signal to Noise Ratio | 1.6.4 |
| ASIC | Application Specific Integrated Circuit | 2.1.1 |
| BAP | Battery Assisted Passive | 2.1.1 |
| RF | Radio Frequency | 2.1.2 |
| DSP | Digital Signal Processor | 2.1.2 |
| VSWR | Voltage Standing Wave ratio | 2.2 |
| HPBW | Half Power Beam width | 2.2 |
| ISO | International Organization for Standardization | 2.3.2 |
| M-PSK | M-ary Phase Shift Keying | 2.3 |
| M-PAM | M-ary Pulse Amplitude Modulation | 2.3 |
| M-QAM | M-ary Quadrature Amplitude Modulation | 2.3 |
| FFT | Fast Fourier Transform | 2.3 |
| IFFT | Inverse Fast Fourier Transform | 2.3 |
| DAC | Digital to Analog Conversion | 2.3 |

| | | |
|------|---------------------------------|-----|
| ADC | Analog to Digital Conversion | 2.3 |
| LPF | Low Pass Filter | 2.3 |
| CP | Cyclic Prefix | 2.3 |
| MMID | Millimeter Wave Identification | 3 |
| MRC | Maximal Ratio Combining | 3 |
| UWB | Ultra-Wide Band | 3 |
| CST | Computer Simulation Technology | 4.1 |
| TEM | Transverse Electromagnetic Mode | 4.1 |
| LSLL | Lowest Side Lobe Level | 5.5 |

LIST OF SYMBOLS

| Symbol | Meaning | Section |
|----------------------|------------------------------------|---------|
| Ω | SI unit of electrical resistance | 2.1.4 |
| Γ | Reflection coefficient | 2.2 |
| Z_L | Load impedance | 2.2 |
| Z_{in} | Input impedance | 2.2 |
| D | Antenna directivity | 2.2 |
| G | Antenna gain | 2.2 |
| P_{rad} | Total Radiated power by an antenna | 2.2 |
| $U(\theta, \phi)$ | Antenna radiation intensity | 2.2 |
| σ | delay spread | 2.3 |
| CP | Cyclic prefix | 2.3 |
| N | Number of Subcarrier | 2.3 |
| T | Symbol period | 2.3 |
| R (θ, ϕ) | Radiation pattern | 2.7 |
| I | No. of array elements | 2.7 |

| | | |
|-------------------|---|-----|
| k | Wave vector of the incident plane wave | 2.7 |
| ϵ_r | Dielectric constant (Permittivity) | 4.2 |
| h | Substrate thickness | 4.2 |
| T | Copper material thickness | 4.2 |
| f_r | Antenna resonance frequency | 4.3 |
| W_g | Antenna ground plane width | 4.3 |
| L_g | Antenna ground plane height | 4.3 |
| ϵ_{reff} | Effective dielectric constant | 4.3 |
| ΔL | Extended length of the patch | 4.3 |
| W_t | Width of the feed line | 4.5 |
| L_t | Length of the feed line | 4.5 |
| S_{11} | Return loss | 5.1 |
| η_{rad} | Antenna radiation efficiency | 5.2 |
| f_d | Doppler spread | 5.6 |
| E_b/N_0 | received electrical energy per bit to single sided noise spectral density | 5.6 |

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ABSTRACT

In the era of object marking, radio frequency identification (RFID) has attracted wide attention. RFID is suitable not only for indoor but also for outdoor environment providing long distance object identification facilities. The major components of an RFID system are the RFID reader and the tag with the antenna for wireless data transfer between them. Little research has been done so far to analyze the fading effect for outdoor applications in the context of RFID. This research focuses on the development of an RFID reader antenna for outdoor scenarios. Two multiband patch antennas and an array antenna operating at centimetre band are proposed for an orthogonal frequency division multiplexing (OFDM) based radio-frequency identification (RFID) reader. The first one is a dual band antenna with centre frequencies of 7.30 GHz and 9.50 GHz, while the second one is a triple band antenna centred at 7.75 GHz, 9.70 GHz and 11.90 GHz. Both the patch antennas are designed with equal-width horizontal arms as radiating elements and a microstrip feeding line as the feeder. The simulated radiation efficiency of the multiband patch antennas is above 80% at each resonance frequency. The antennas are moderately small sized with dimensions of 40.30 mm by 35.10 mm. The designed double E-shaped array antenna provides resonance at frequencies of 7.23 GHz, 10 GHz, and, 11.748 GHz with dimensions of 86.584 mm by 35.117 mm. The spacing between the array elements of the proposed array antenna is 12 mm that minimizes grating lobe and mutual coupling between the array elements. The simulated antenna performance metrics such as (gain and directivity) of the designed array antenna at these three different frequencies are (9.81 dB and 10.13 dBi), (8.01 dB and 8.308 dBi) and (8.12 dB and 8.681 dBi) respectively. Simulations with Computer Simulation Technology (CST) Microwave Studio tool indicate that competitive values of different antenna parameters are achieved when compared with centimetre band antennas described in the literature. With the use of MATLAB tool, the bit error rate (BER) performance of the multiband antennas are simulated for outdoor Rayleigh and Rician fading channels. Simulation results for the proposed antennas indicate that for a given number of OFDM subcarriers, the larger the bandwidth of the signals received by the RFID reader, larger the BER degradation.

1 Chapter 1

INTRODUCTION

1.1 Introduction

In recent years, Radio-Frequency Identification (RFID) has become a promising technology in the field of object identification. A typical RFID system consists of a reader or interrogator, a reader antenna, a host computer, middleware software for the computer, and tag or transponder attached on items [1]. Connecting RFID reader to the terminal of Internet, the readers can identify, track and monitor the objects attached with tags globally, automatically, and in real time, if needed. This is the so-called Internet of Things (IoT). RFID technology, based on wireless communication between a reader and tags, has become the most popular technology for item identification and tracking, and thus the main enabler for the Internet of Things (IoT) vision. RFID is often seen as a prerequisite for the IoT [2]. Based on the availability of power RFID systems can be classified into active and passive, while depending on integrated circuitry (IC) or chip, systems are categorized into chip based and chip less. RFID uses electromagnetic fields to identify and track tags that store electronic information about objects they are attached to. For this purpose, the RFID reader and tag antenna plays an important role to transfer electromagnetic field between reader and tag to identify target object. A generalized block diagram of an RFID system is shown in Figure 1.1. An RFID reader or interrogator sends energy and data signal using reader antenna to the remote tag. The tag antenna receives the reader signal and electronically processed by tag microchip. After processing the reader signal it sends back to the reader via tag back scatter using tag antenna. The reader then receives the tag backscatter signal and collects required information. Finally, the retrieving information stored in the host computer that is attached with the reader section. RFID can read objects at a range up to 100 metres, can read considerable number of information at a time and can be usable for both outdoor and indoor environment. Unlike optical barcode systems, no-line-of sight (NLOS) communication is possible by RFID systems. RFID offers long distance and all weather reading and larger data carrying capacity than an optical barcode can offer. It is stated that some tags coupled with sensors can also provide data on

surrounding environment such as temperature, pressure, moisture contents, acceleration and location [3]–[5].

Figure 1.2 shows the applications of an RFID system. The several applications of an RFID system including library management, cattle identification, toll collection, flood level detection, parking access control, security, retail stock management, telemedicine and transportation logistic [6][7]. RFID also has potential applications in museums, art galleries, hospitals, and military. Various frequency bands are used worldwide for RFID such as high frequency (HF), ultrahigh frequency (UHF), super high frequency (SHF) also known as centimetre wave band (3 GHz – 30 GHz), and millimetre (mm) wave band. When RFID system designed in mm wave band then it is called Millimetre wave Identification (MMID). The frequency bands adopted in RFID system are shown in Table 1-1.

Usually the design of the RFID antenna in any frequency band is a complex task. Because of the wireless spectrum crunch, researchers are exploiting unused high frequencies in the centimetre and millimeter band due to its huge bandwidth for high speed wireless communications [8]. Moreover, the application of high frequency bands means high speed operation as the travel time of a signal becomes low with the increase in frequency (i.e. decrease in wavelength). Different countries of the world apply different frequencies for RFID communication. Moreover, different application scenarios within a country require different antenna requirements such as frequencies, gain, and directivity and so on. Therefore, there is a need of designing a single antenna having multiple resonance frequencies with high gain and directivity. To obtain, high gain as well as high directivity array is common choice. Resonance frequency of an antenna is one at which antenna impedance is matched with characteristics impedance of transmission line. When a single antenna operates at more than one resonance frequency then the antenna is called multiband antenna. For instance, having a dual band and triple band antenna allows these to be used in two or three different types of wireless application scenarios, respectively [9][10]. For improving RFID reading range, an antenna with high gain and high directivity is essential. In research work [11], [12], a microstrip array antenna is proposed for RFID applications. An RFID signal in the outdoor environment may experience multipath fading or distortion. In case of designing array antenna mutual coupling between array elements and grating lobe (a lobe with equal magnitude as main lobe in an unintended direction) are a major concern.

In the case of outdoor scenarios, Rayleigh or Rician fading and Doppler spread may occur if there is a relative speed between reader and tag [13]–[15]. These impairments cause inter symbol interference (ISI) as well as inter carrier interference (ICI). Therefore, in the presence of these impairments, the overall bit error rate (BER) increases and the reading range suffers. Similar to the case of 4G cellular communications, orthogonal frequency division multiplexing (OFDM) encoding technique may be used to combat multipath effects for outdoor RFID systems [16]–[19].

Table 1-1: Frequency bands adopted in RFID system

| Frequency band | Range | Data speed | Applications | Cost (\$) |
|-----------------------|--------------|-------------------|---------------------------|----------------------------|
| 120-150 KHz (LF) | 10 cm | Low | Animal identification | 1 |
| 13.56 MHz (HF) | < 1m | Low | Smart cards | 0.50 |
| 433 MHz | <10m | Moderate | Defense applications | 5 |
| 865-915 MHz | <12m | Moderate to high | EAN | 0.15 (passive) 25 (active) |
| 2450, 5800 MHz | 1-4 m | High | WLAN, Bluetooth standards | 2-3 |
| 3.1 – 30 GHz | <200 m | High | Long distance tracking | 5 |
| 57-66 GHz | <200-300 m | Very High | Long distance tracking | 5-10 |

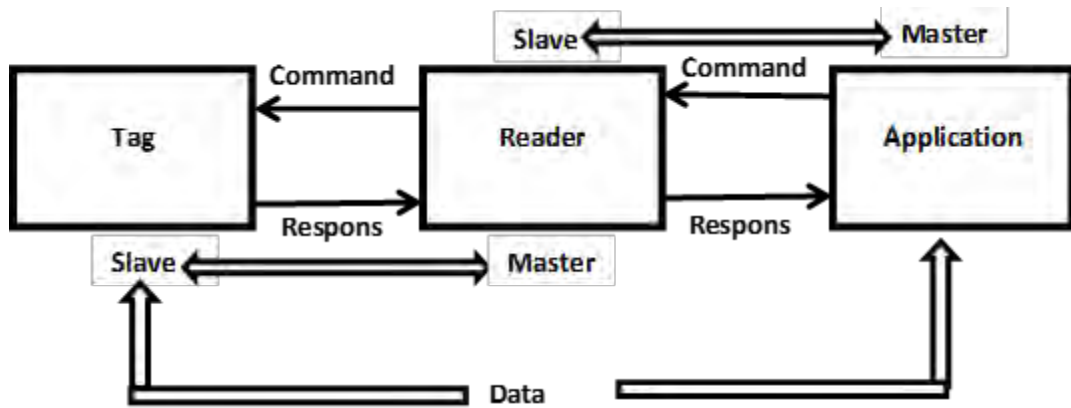


Figure 1.1: Generalized block diagram of a simple RFID system adapted from [20]



Figure 1.2: Applications of RFID systems adapted from [21]

Only the concept of OFDM based RFID system is proposed in a paper [22]. However, a detail investigation of OFDM based RFID scheme and the evaluation of BER is yet to be done. In this thesis, we focus on an OFDM based outdoor RFID system operating in the centimetre band.

1.2 Background history

Ernst F.W. Alexanderson argued the first continuous wave (CW) radio generation and transmission of radio signals which marked the beginning of modern radio communication in **1906**. In early of 20th century, the introduction of radar took place. Radar transmits radio waves for detecting and locating an object by the reflection of the radio waves. Thus in research work [23] the combination of radio broadcast technology and radar helped in emerging the idea of RFID.

In the **1930s** and **1940s** several technologies related to RFID were developed following the technical development of radar. Most of the significant histories of RFID trace the technology back to the radio-based identification system used by Allied bombers during World War II where early Identification of Friend and Foe (IFF) systems was introduced. Shortly after the war, an engineer named Harry Stockman came out with the idea of powering up a mobile transmitter completely from the strength of a received radio signal through his paper, “Communication by Means of Reflected Power” and thus the possibilities of passive RFID technology were introduced [24]. Commercial activities started by many companies manufacturing electronic article surveillance (EAS) equipment to counter the theft of merchandise [25]-[26]. The **1980s** became the decade for full implementation of RFID technology [26]-[27].

1.3 Advantages and limitations of RFID system

1.3.1 Main advantages of RFID

Though RFID is not likely to entirely replace commonly used barcodes in the near future, the following advantages may provide additional ways in improving the present tag identification system [28]–[30] :

- No line of sight required for reading i.e NLOS communication is possible in RFID system.
- Multiple items can be read with a single scan
- Each tag can carry a lot of data (read/write)
- Individual items identified and not just the category
- Passive tags have a virtually unlimited lifetime
- Active tags can be read from great distances
- Can be combined with barcode technology

Now, from an application standpoint, among the mentioned points of several advantages of RFID over barcodes three major categories are discussed below.

1.3.2 Limitations of RFID system

As RFID is advantageous than conventional barcode system it corresponds to few drawbacks. These limitations are minor as compared to its advantageous features. The limitations of RFID system are discussed below paper [28][31], [32].

- **Surface mounting effect**
- **Reader collision and Tag collision**
 - . Since they can be read in milliseconds, it appears that all the tags are being read simultaneously [33].
- **Lack of Standard.**
- **High cost.**
- **Security and Quick Technology Obsolescence**

1.4 Applications of RFID system

The application of RFID is branched out to countless number of sectors with its unlimited variety. However some of the very commonly observed applications of RFID system shown in Figure 2.3 are described [28]–[30],[34].

- Asset management
- Market Management
- Access control
- Transportation and logistics
- Infrastructure management and protection
- Hospitals and healthcare
- Library and Museums
- Sports and e-passport

1.5 RFID system and internet of things (IoT)

Radio frequency identification system (RFID) is an automatic technology and aids machines or computers to identify objects, record metadata or control individual target through radio waves. Connecting RFID reader to the terminal of Internet, the readers can identify, track and monitor the objects attached with tags globally, automatically, and in real time, if needed. This is the so-called Internet of Things (IoT). RFID is often seen as a prerequisite for the IoT. Passive RFID systems carry critical importance for IoT applications due to their energy harvesting capabilities. IoT first became popular through the Auto-ID Center and related market analysts publications. If all objects of daily life were equipped with radio tags, they could be identified and inventoried by computers. RFID based position estimation, in particular, is expected to facilitate a wide array of location based services for IoT applications with low-power requirements. The

RFID technology hence becomes a promising alternative for cost-effective, energy efficient indoor identification and localization for massively deployed IoT. Now-a-days, RFID technology is used in IoT-based personal healthcare systems [34]–[36] . RFID based IoT infrastructure is shown in Figure 1.3.



Figure 1.3: RFID based IoT communication infrastructure.

1.6 Factors affecting RFID communication

Some physical phenomena affect both indoor and outdoor RFID communication. These phenomena are briefly described here.

1.6.1 Multipath fading

Multipath Fading means rapid fluctuations of amplitudes, phases or multipath delays of a radio signal over a short travel distance or short period. Multipath fading occurs where different forms of propagation are present and the signals arrive at the receiver from a transmitter via multiple paths. Multipath fading effect depends on whether there is line of sight (LOS) component, between transmitter and receiver or not. Depending on LOS component multipath fading channel is classified as Rayleigh fading and Rician fading channel [37]. In RFID communication, multipath fading is more severe especially at outdoor communication. Due to the fading effect, ISI or ICI may occur so that RFID system performance is affected.

1.6.2 Path loss

The path loss describes a deterministic average attenuation of the signal strength depending only on the distance between the transmitter and receiver. Every RF signal experience a path loss at free space that is inversely proportional to the square of the distance which is similar to the inverse square law of intensity. Path loss includes all of the lossy effects associated with distance and the interaction of the propagating wave with the objects in the environment between the antennas [37].

1.6.3 RFID reader and tag collision

When the coverage area of one RFID reader overlaps with other, the radio signal of two or more readers may interfere with each other so that reader collision occurs in RFID communication. Same case may occur for RFID tag [38][39]

1.6.3.1 Interference

RFID is susceptible to interference generated by other wireless systems. Interference can cause a degradation of the signal to noise ratio (SNR) and increases the bit error rate (BER). In order to deal with this problem, it is essential to consider the presence of other wireless and electromagnetic devices in the space where the signal has to travel and try to install it apart from the range of other devices [40].

1.6.3.2 Doppler Spread

The performance an RFID system can be degraded due to the relative speed between RFID reader and tag. Due to Doppler spread multipath fading occurs and BER performance of RFID system is attenuated [37].

1.7 Motivation of the work

For the time being, RFID technology is very attractive technology in the area of object identification and in near future it will become more promising for both indoor and outdoor environment. However, more research work is required in this field to overcome the existing challenges especially in outdoor applications. The research work [9]–[11] only introduces the uses of antenna in RFID applications. A tri band antenna at frequencies 3.6/5.8/8.2 GHz [9] is presented for RFID reader applications. It is

mentionable that although the antenna [9] has fractal geometry with large size $90 \times 30 \text{ mm}^2$ but it provides comparatively lower gain. In [10] a multiband antenna is proposed with dimension $100 \times 70 \text{ mm}^2$ with resonance at 915 MHz, 1.60 GHz and 2.45 GHz respectively. A microstrip antenna and an array antenna are introduced in [11] provides high gain for RFID reader applications with relatively large dimension $341 \times 341 \text{ mm}^2$ at operating frequency 860 MHz – 960 MHz. So, reducing the antenna size as well as operates the antenna at higher frequency bands to solve the spectral crunch at lower frequency bands becomes a new research scope.

The detection probability and bit error rate performance of RFID system in various channel conditions are introduced in [22], [41]–[43]. The only BER and detection range for UWB band RFID system is evaluated in [22] [43] but the RFID reader antenna design is not evaluated in both the research. In existing research, the linkup between the bandwidth of the antenna used in RFID system and outdoor wireless channel is not mentioned. Nevertheless, details combined investigation of multiband antenna design and BER performance analysis of OFDM based RFID system in outdoor scenarios yet to be done.

Therefore, the previous research work only studies about the antenna required for RFID system and a little number of research work investigates the BER performance of the RFID system. Furthermore, the reported BER performance does not take the antenna parameters into BER calculation. Hence, the focus of this research is to design multiband antennas for RFID reader at centimetre and an OFDM based RFID system that will provide good BER performance while considering the antenna parameters.

1.8 Objectives with specific aims and possible outcome

The objective of this thesis is to develop an OFDM based RFID system for outdoor scenarios and designed multiband antennas. To fulfill the objective the following analysis will be performed:

- 1) The design of a dual band antenna is centred around 8-12 GHz for RFID reader section adapted from the design of a single band 10 GHz antenna described in [44].
- 2) A new triple band antenna is proposed centred around 8-12 GHz for RFID reader section.

- 3) A new 1×2 double E-shaped triple band array antenna centred around 7 GHz - 12 GHz is proposed with the help of triple band reader antenna.
- 4) The BER performance of the RFID communication system is evaluated based on the bandwidths of the proposed new antennas for the case where the transmitted signal bandwidth is equal to the reader antenna bandwidth.

The possible outcome after the successful completion of the research work will build a model for outdoor RFID system containing OFDM technique to mitigate multipath fading and designing multiband antenna for RFID reader applications.

1.9 Organization of the thesis

The rest of the thesis is organized as follows. In **Chapter 2**, an OFDM based RFID system is described. The literature review on different RFID systems is presented in **Chapter 3**. The design of a dual, a triple band antenna, and a triple band array antenna is introduced in **Chapter 4**. Simulation results on the bandwidths, gain, directivity, radiation efficiency, etc. for both antennas are also presented in **Chapter 5**. Next, **Chapter 5** presents the BER performance using designed antenna bandwidth, where the effects of fading channel (Rayleigh and Rician) are studied. In addition, a comparative study between dual, triple band and triple band array antennas with various reference antennas is also discussed. Finally, a summary, conclusion and future direction of the thesis work will be presented in **Chapter 6**.

2 Chapter 2

OFDM Based RFID System

2.1 Introduction

This chapter gives a comprehensive description of a RFID system particularly an active chip-based RFID system. As already mentioned in Chapter 1, a RFID system can be classified into active and passive, and then chipless and chip-based systems. A RFID system may be classified based on types of tags used in RFID system. This chapter mainly introduces the components RFID system, its classification and OFDM based RFID system for outdoor environment.

2.2 Advantages of an RFID system

2.2.1 Capability of tracking large number of objects:

Figure 2.1 shows that several products with individual RFID tag can be scanned with RFID reader instantaneously. When a mixed pallet of goods is received, then all individual products on the pallet need to be entered into a computer system to acknowledge receipt, then in the barcoding scenario, a worker needs to break the pallet, open the cases, and scan each product. If there were barcode labels on each case, and these barcodes were linked to the contents of each case, and the recipients were to trust that the cases had not been tampered with, then the number of barcode scans could be much lower.



Figure 2.1: Several goods with RFID tags [30].

This is both time-consuming and error-prone, and it means that the flow of goods into the warehouse needs to be interrupted in order to recognize what was received. In a scenario in which each product has an RFID tag attached to it, the pallet would simply be pulled through an RFID reader portal, and all products on the pallet would be identified almost instantaneously. As well as, this does not require line of sight facing of tag with scanner. This is due to the penetration capabilities of electromagnetic waves.

2.2.2 Unique object identifier:

The second advantage is that an RFID tag can give more information than today's barcode labels. (Advanced barcodes have been devised that can store more information, e.g. 2D-barcodes. However, the size of the barcode is a limiting factor for how much information can be encoded.) Consider for example a can of Coca Cola. The barcode on each can of Coke is the same—The barcode describes the class of the product. In an RFID scenario, each piece of coke will have its own unique identifier. This means that complete tracing of the origin of an individual product is possible for the first time. This enables new possibilities, for example, for handling product recalls, warranties.

The read/write capability of RFID tags may have additional benefits when a computer link to a network database cannot always be guaranteed. In this case, data about the item that is tagged with the read/write tag can be stored and changed on the tag itself, without requiring a change to the database record that corresponds to the tag's serial number. Military applications of RFID make heavy use of read/write tags.

2.3 Limitations of an RFID system

➤ Surface mounting effect

Naturally, there are limitations to RFID. Some limitations are due to the laws of physics. Metals and liquids, for example, effectively block radio waves. This is particularly true for UHF and Microwave frequencies. Thus, it is generally not possible to read RFID tags enclosed in metal or surrounded by liquids. There are some advances in tag and antenna design that allow for RFID tags to be placed on metal objects, as long as the tag is not fully enclosed. But in general, RFID does not work very well in environments where the product is surrounded by metals or liquids. A potential workaround to the problem of fluids and metals blocking RF is to use multiple readers, trying to read a tag from different angles. Antenna far field characteristics are highly

concerned in passive operation. Because of the variations in gain and directivity characteristics varies in angular plane. The tag attached in objects may not accurately position in the maximum gain or directivity coordinate in E plane as well as H plane. To overcome this problem, tag antenna radiation characteristic should inspire to be unidirectional or omnidirectional.

➤ **Reader collision and tag collision**

Reader collision and Tag collision in RFID communication are shown in Figure 2.2. The signal from one reader can interfere with the signal from another where coverage overlaps. This is called reader collision. One way to avoid the problem is to use a technique called time division multiple access, or TDMA. In simple terms, the readers are instructed to read at different times, rather than both trying to read at the same time. This ensures that they don't interfere with each other. But it means any RFID tag in an area where two readers overlap will be read twice. Another problem readers have is reading a lot of chips in the same field. Tag clash occurs when more than one chip reflects back a signal at the same time, confusing the reader. Different vendors have developed different systems for having the tags respond to the reader one at a time. Since they can be read in milliseconds, it appears that all the tags are being read simultaneously [33].

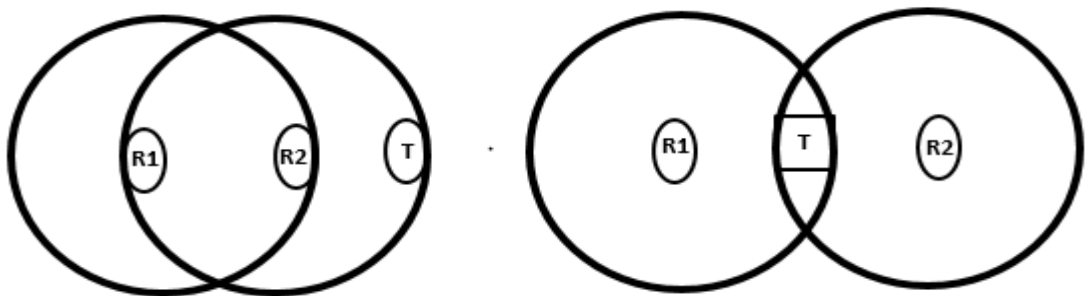


Figure 2.2: Reader collision (left) and tag collision (right).

➤ **Lack of standard.**

Though the characteristics of the application and the environment of use determine the appropriate tag, the sparse standards still leave much freedom in the choice of communication protocols and the format and amount of information stored in the tag. Companies transcending a closed loop solution and wishing to share their application with others may encounter conflicts as cooperating partners need to

agree in standards concerning communication protocols, signal modulation types, data transmission rates, data encoding and collision handling algorithms.

➤ **High cost**

Another disadvantage of RFID technology is its cost. A Tag consists of an antenna and microchip, whereas conventional barcode system consist some identical marks printed on paper. But the transceiver antenna along with microchip may raise the cost significantly high.

➤ **Security and quick technology obsolescence**

Depending on the field of application and in some cases, prescribed by law it may become necessary to prevent unauthorized persons from reading or writing data stored on or transmitted from tags. To this end, encryption must be ensured at all interfaces where data could be intercepted or transmitted. On the other hand, one of the common concerns of companies implementing RFID today is the rapid obsolescence of the technology, especially in view of the investment cost. Technology is continuously evolving and new protocol standards, faster and more fault-tolerant readers quickly out-date their predecessors.

2.4 Applications of RFID system

The application of RFID is branched out to countless number of sectors with its unlimited variety. A brief idea is already Section 1.1. However some of the very commonly observed applications of RFID system with Figure 2.3 are described below [28]–[30],[34].

➤ **Asset management**

RFID combined with mobile computing and Web technologies provide a way for organizations to identify and manage their assets. Mobile computers, with integrated RFID readers, can now deliver a complete set of tools that eliminate paperwork, give proof of identification and attendance. This approach eliminates manual data entry. RFID is being adopted for item level retail uses. Aside from efficiency and product availability gains, the system offers a superior form of electronic article surveillance (EAS), and a superior self-checkout process for consumers.

➤ **Market management**

RFID System can bring the attentions of “out of stock condition” and can immediately inform the market owner about refilling a certain product which is important for customer satisfaction.

➤ **Access control**

RFID tags are widely used in identification badges replacing earlier magnetic stripe cards. These badges need only be held within a certain distance of the reader to authenticate the holder. Tags can also be placed on vehicles, which can be read at a distance, to allow entrance to controlled areas without having to stop the vehicle and present a card or enter an access code.

➤ **Transportation and logistics**

Logistics and transportation are major areas of implementation for RFID technology. Yard management, shipping and freight and distribution centers use RFID tracking technology. In the railroad industry, RFID tags mounted on locomotives and rolling stock identify the owner, identification number and type of equipment and its characteristics.

➤ **Infrastructure management and protection**

Several countries have introduced RFID technology to identify and locate underground infrastructure assets such as gas pipelines, sewer lines, electrical cables, communication cables, etc. It is possible to detect pervasive surface crack in building infrastructure and provide necessary warning. This will reduce injuries and damages.

➤ **Human and animal identification**

RFID tags for animals represent one of the oldest uses of RFID technology. RFID tags are widely used in Australia for all cattle, sheep and goats and other animal identification. Implantable RFID chips designed for animal tagging are now being used in humans. In 2004 Conrad Chase offered implanted chips in his night clubs in Barcelona and Rotterdam to identify their VIP customers, who in turn use it to pay for drinks.

➤ **Hospitals and healthcare**

Adoption of RFID in the medical industry has been widespread and very effective. Hospitals are among the first users to combine both active and passive RFID technology. This includes patient tracking, medication authentication control, surgery asset management, wait time monitoring of patients etc.

➤ **Library and museums**

Libraries have used RFID to replace the barcodes on library items. In a library management system, RFID is implemented for increasing the efficiency of the staffs, self-service “check in” and optimizing the uses of space. The tag can contain identifying information or may just be a key into a database. RFID technologies are now also implemented in end-user applications in museums.

➤ **Sports and e-passport**

RFID technology has been widely adopted in sports managements and security. RFID can provide race start and end timings for individuals in large races where it is impossible to get accurate stopwatch readings for every entrant. In the race, the racers wear tags that are read by antennae placed alongside the track or on mats across the track.

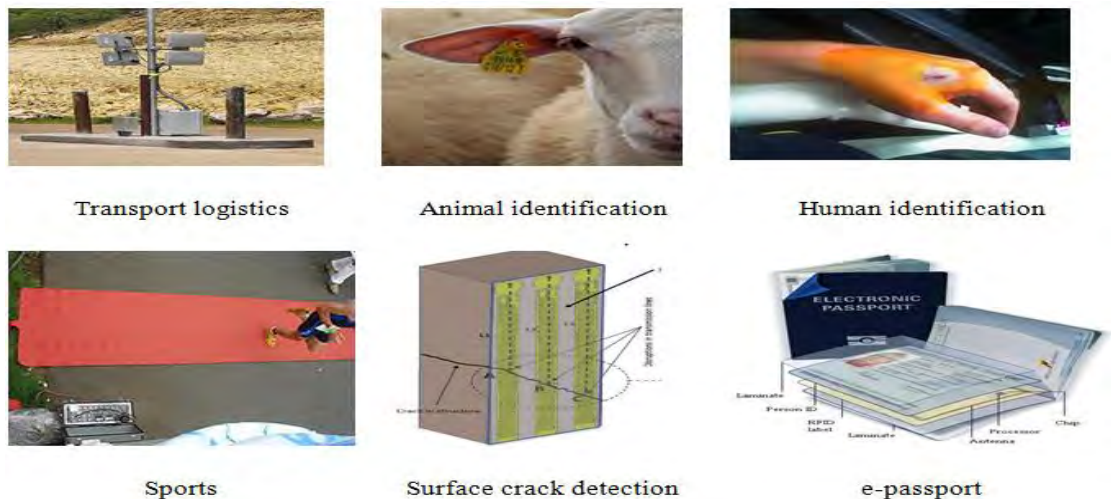


Figure 2.3: Specific applications of RFID on different areas adapted from [28]–[30],[45].

On the other hand, the first RFID passports known as "E-passport" were issued by Malaysia in 1998. In addition to information also contained on the visual data page of the passport, e-passports record the travel history (time, date, and place) of entries

and exits from the country. Now a day's e-passports technology has been adopted in most of the developed countries due to its unique features.

2.5 Components of RFID system

In its simplest form in common use today, an RFID system consists of four elements, as shown in Figure 2.4. The major hardware components of an RFID system are reader/interrogator, reader antenna and a RFID tag/transponder and a monitoring system. The RFID tag element also consists of an antenna integrated with a microchip. The RFID reader and antenna transmit an electromagnetic RF signal to the tag. This signal is received by the RFID tag via the tag's antenna .

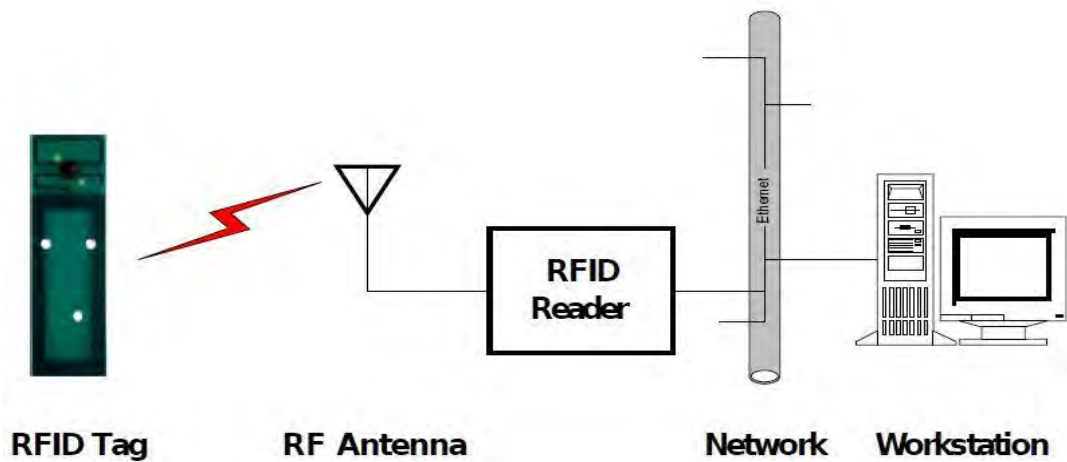


Figure 2.4: Generalized RFID system [46].

2.5.1 RFID tag

Figure 2.5 shows an RFID tag. Tag is the major component in sensing objects using RF backscatter. The device is made up an integrated circuit associated with antenna. These are usually attached to remotely located objects whose descriptions have to be extracted. RFID tags come in many shapes and sizes each suited to a specific application. RFID tags communicate in various ways with the RFID reader. The aerial (antenna) has to be designed to both collect powers from the incoming signal and also to transmit the outbound signal. RFID tags can be generally grouped based on its electromagnetic features and other parameters, regardless if they are encased, a sticky label or just a solid button like tag. RFID tags are either powered by the reader or

contain on-board power sources. Based on the power supply for sensing operation tag can be divided in two broad categories [47].

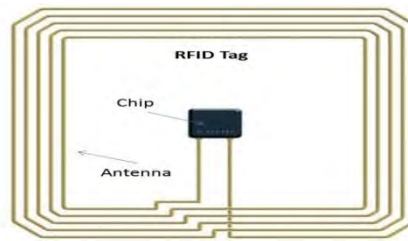
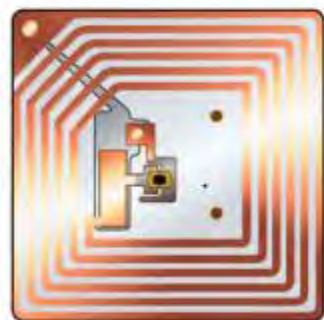


Figure 2.5: RFID tags used in tracking objects [48].

❖ Passive RFID tags

Figure 2.6 shows Chip less and Chip based passive RFID tag. The Passive tags do not have any internal source of energy. The IC is powered by the impinged electromagnetic waves radiated by the reader that also communicates with the tag in order to get its data. Communication in passive UHF RFID systems is based on backscattering of modulated electromagnetic wave: Reader transmits energy and commands to remotely placed tags. Tags microchip generates a response according to the reader command. This data from the microchip is then added to an RF signal that is “reflected” by the tag back to the reader through the reader antenna. This process is referred to as passive backscatter. The reader contains the electronics to receive this signal from the tag, extract the RFID tag’s code from the signal, and return it to its digital form, and provide that returned code to a host computer. Passive tags systems are reader talk first. The tags are mute until a signal is received from a reader.



(a)



(b)

Figure 2.6: Example of (a). Chip based passive RFID tag and (b) Chip less Passive RFID tag [49].

Based on the application specific integrated circuits (ASIC) in tag (transponder) section, RFID systems can be categorized as chip based and chip less RFID [47].

❖ **Chip less and chip based RFID tag**

A Chip less RFID tag is one that do not require a tag microchip in the transponder. It is more cost effective than chip based RFID tag. Active, Passive and BAP are the example of chipbased RFID tag.

❖ **Active RFID tags**

Unlike passive RFID tags, active RFID tags have their own internal power source which is used to power any integrated circuits that generate the outgoing signal. Figure 2.7 shows the Active and Semi active RFID tag. Active RFID tags are typically much more reliable than passive tags due to the ability for active tags to conduct a "session" with a reader. Due to their on board power supply, also transmit at higher power levels than passive tags, allowing them to be more effective in radio frequency challenged environments like water (including humans/cattle, which are mostly water), metal (shipping containers, vehicles), or at longer distances. Many active tags have practical ranges of hundreds of meters, and a battery life of up to 10 years. Various features of active and passive RFID tag are shown in Table 2-1.



Figure 2.7: Example of (a) Active RFID tag and (b) Semi active RFID tag [48].

Table 2-1: Features of passive and active RFID

| Specifications | Passive tag | Active tag | Battery assisted passive tag |
|-----------------------|-------------------------|---------------------------|--------------------------------------|
| Power source | RF energy from reader | Internal to tag | Has both internal and external power |
| Tag battery | No | Yes | Yes |
| Availability of power | Only in field of reader | Continuous | Continuous |
| Tag threshold | Very high | Low | High |
| Range | Less than 30 m | Greater or equal to 100 m | Above 30 m but less than 100 m |
| Production cost | Lower | Much | Moderate |
| Lifetime | Theoretically infinite | 2-4 years | around 5 years |
| Storage capacity | Few bits to 1Kbyte | Up to 512 Kbytes | 1 Kbyte to 10 Kbytes |
| Memory operation | Write once, read many | Read/write | Read/write |
| Size | Small | Big | Medium |
| Response | Weak | Strong | Moderate |

Beside these primary types of tags there is another type of tag often used in RFID systems. This one is known as Battery Assisted Passive (BAP) or semi active tag. It consists of a small battery for supplying necessary power required for sensing operation. It delivers power and emits modulated backscatter only in the presence of readers signal whereas active tags emits signal in absence of readers command. Semi active tag takes advances of both active and passive tag [1], [47].

2.5.2 Reader or interrogator

An RFID reader is basically a radio frequency (RF) transmitter and receiver, controlled by a microprocessor or digital signal processor (DSP). The RFID reader, using an attached antenna, captures data from RFID tags, and then passes the data to a computer for processing. As with tags, readers come in a wide range of sizes and offer

different features. Readers can be affixed in a stationary position (for example, beside a conveyor belt in a factory or dock doors in a warehouse), portable (integrated into a mobile computer that also might be used for scanning). Reader communicates with tag and receives commands from processor. The functions of RFID reader are pointed in below.

➤ **Reader functions:**

- Remotely power tags
- Establish a bidirectional data link
- Inventory tags, filter results
- Communicate with networked server(s)
- Interprets radio waves in digital form

2.5.3 Reader antenna

Generally, the position or the orientation of the identified object is random, and the manner for attaching the tag to the identified object is unfixed. In most cases, the tag antenna should have omnidirectional radiation or hemispherical coverage. This is due to the uncertainty of tag location in its azimuth and elevation plane as well as direction of electric and magnetic field characteristics. Thus, the reader antenna should be a circularly polarized antenna, in order to avoid the polarization loss when the orientation of the identified object is changed. Meanwhile, the reader antenna should have low profile and realize miniaturization, some of which should operate at more than one band. In some special cases, multiple antenna technology or smart antenna arrays for beam scanning will be employed. Depending on how many antennae are required, one or many multiplexers may be necessary. A multiplexer allows many antennae to be physically connected to a reader. Many readers contain built in multiplexers, and external varieties are also available. The combination of the reader, antennae, and multiplexer setup is sometimes referred to as a read point [50][51].

2.5.4 Tag antenna

The design of tag antennas are directly influenced by ASIC available in the market. Because in passive RFID tag microchip is attached directly to an antenna, proper impedance match between the antenna and the chip is crucial in RFID tag design. In conventional communication antenna bears input impedance 50Ω when looked from

the source or load sight. Generally, the impedance of the tag chip is not 50 Ω , and the antenna is connected to small microchip, which is considered as source or load of the antenna. The reader antenna transmits the electromagnetic energy to activate or awaken the tag, realizes the data transfer and sends the instructions to the tag. Meanwhile, the reader antenna receives information from the tag. In order to proper operation and supply the maximum power to the chip, antenna should be perfectly matched with microchip. In common applications, the tag antenna should be low cost and easy to fabricate for mass production [52].

2.6 RFID reader and tag antenna performance metrics:

The performance of Reader and tag antenna depends on several performance metrics. This metrics are S-parameter, Voltage Standing Wave ratio (VSWR), Half Power Beam Width (HPBW), antenna bandwidth, gain, directivity and radiation efficiency[51]. In this thesis, the antenna designs are evaluated by the following metrics:

- ❖ **Scattering parameter (S-parameter):** S-parameters represent the amount of power reflected back from the antenna. It is also called return loss (RL). RL is related to reflection coefficient (Γ). Equation (1) and (2) are used represent reflection coefficient and return loss of an antenna respectively.

$$\Gamma = \frac{Z_L - Z_{in}}{Z_L + Z_{in}} \quad (1)$$

$$RL = -20 \text{Log}(|\Gamma|) \quad (2)$$

where, Z_L is the load impedance (antenna impedance) and Z_{in} is the input impedance (or source impedance Z_S).

- ❖ **VSWR:** In a standing wave, the ratio of the maximum voltage to the minimum voltage is called VSWR. VSWR indicates impedance mismatch and higher the impedance mismatch, higher the value of VSWR. For effective radiation, the ideal value of VSWR is 1. But a VSWR value less than 2 is acceptable.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (3)$$

- ❖ **Directivity (D):** The antenna directivity is defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

$$D = \frac{4\pi U(\theta, \phi)}{P_{rad}} \quad (4)$$

where D is the directivity (dimensionless), P_{rad} is the total radiated power in Watt, $U(\theta, \phi)$ radiation intensity (W/sr).

- ❖ **Gain (G):** Gain is closely related to the antenna directivity and can be defined as the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

$$G = \frac{4\pi U(\theta, \phi)}{P_{in}} \quad (5)$$

- ❖ **Radiation Efficiency (η_{rad}):** Antenna radiation efficiency is related to the antenna gain and directivity.

$$\eta_{rad} = \frac{G}{D} \quad (6)$$

- **Antenna Beamwidth (HPBW):** Antenna beamwidth can be defined as the total angle (angular separation) in which the magnitude of the radiation pattern decreases by -3dB or 50% from the peak of the radiation main lobe. The range of the HPBW is from 1° to 360°.

2.7 RFID array antenna parameters

An array antenna is one which contains multiple radiating elements to improve antenna performance especially gain, directivity, signal to noise plus interference ratio (SNIP) and provides diversity reception. In an array antenna all the radiating elements are fed by a single feeding technique. Designing an array antenna, some factors such as mutual coupling among the array elements, grating lobe of the array antenna and array factor are very important consideration.

- ❖ **Mutual coupling:** It is necessary to maintain a standard separation among the radiating elements of an array antenna to avoid mutual coupling. If the spacing among the array elements is increased the mutual coupling is reduced.

According to the literature the spacing between array elements should not be larger than $\lambda/2$.

- ❖ **Grating lobe:** The lobe which has same magnitude as main lobe but directed in an unintended direction is called grating lobe. Grating lobe is an undesirable property of an array antenna. The higher the array elements spacing the greater the chance to produce grating lobe of an array antenna that adversely affects the array antenna performance. To avoid grating lobe as well as mutual coupling, it is important to maintain a standard separation of the array elements and it is $\lambda/8$ to $\lambda/2$.
- ❖ **Array factor (AF):** The array factor (AF) is a function of the positions of the radiating elements (antennas) in the array and the weights used. Consider, N identical antennas oriented in the same direction, each having radiation pattern $R(\theta, \phi)$ then the array antenna radiation (reception) pattern denoted by Y is written as,

$$Y = R(\theta, \phi) B_1 e^{j\mathbf{r}_1 \cdot \mathbf{k}} + R(\theta, \phi) B_2 e^{j\mathbf{r}_2 \cdot \mathbf{k}} + \dots + R(\theta, \phi) B_N e^{j\mathbf{r}_N \cdot \mathbf{k}} \quad (7)$$

where, B is the weighting function, \mathbf{k} is the wave vector of the incident plane wave and \mathbf{r} is the position of the individual antenna in the array antenna.

Equation (7) can be redrawn as,

$$\begin{aligned} Y &= R(\theta, \phi) \sum_{i=1}^N B_i e^{-j\mathbf{k} \cdot \mathbf{r}_i} \\ &= R(\theta, \phi) \text{AF} \end{aligned} \quad (8)$$

$$\text{Array factor, AF} = \sum_{i=1}^N B_i e^{-j\mathbf{k} \cdot \mathbf{r}_i}$$

It is noted that, if the elements are identical and have the same physical orientation, then the array antenna radiation or reception pattern is simply the multiplication of AF and $R(\theta, \phi)$. This concept is known as pattern multiplication.

2.8 RFID coupling method

The way in which the RFID tag and Reader-writer communicate to each other is described by the RFID coupling mechanism. The sort of coupling that is used depends upon the desired application, and in turn the type of RFID coupling used will affect the choice of frequency for the system. The RFID reader-writer can communicate with the

RFID tag in several number of ways. The main three RFID coupling mechanisms are classified as:

- RFID backscatter coupling
- RFID capacitive coupling
- RFID inductive coupling

The form of coupling used affects several aspects of the RFID system including the read range, operating frequencies needed and other equipment of the RFID hardware. The read range of the RFID system can broadly be categorized into three:

- Close range - within 1 centimetre
- Remote - between 1 cm and 1 metre
- Long range - more than 1 metre

Among these three types of RFID coupling, magnetic and capacitive types are typically used for close range links, while inductive coupling for remote links and RFID backscatter coupling for long range links [53]–[55]. Different types of RFID coupling with its operating range are shown in Figure 2.8.

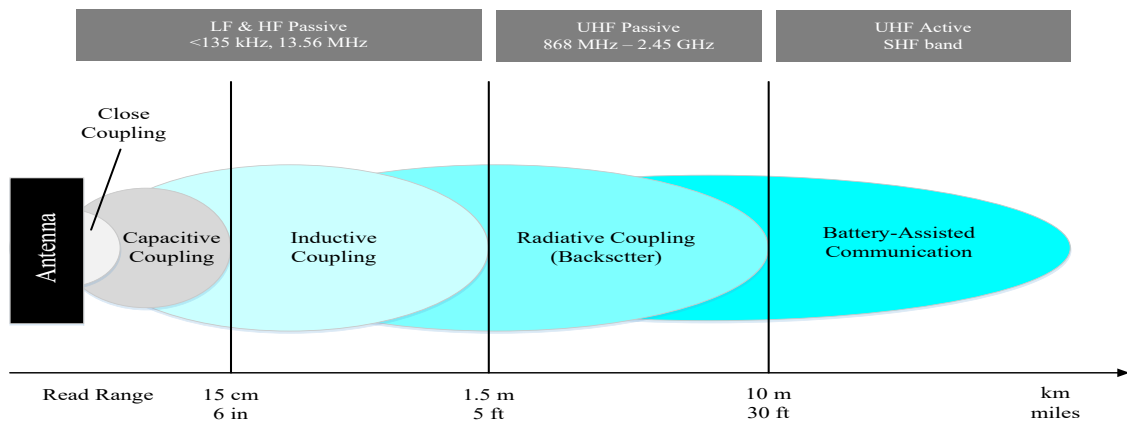


Figure 2.8: Different types of coupling mechanism used in RFID communication.

2.8.1 RFID backscatter coupling

In RFID backscatter coupling, the RF power transmitter by the tag reader is used to energize the tag microchip. In this coupling mechanism, the tag microchip reflect back some of the power transmitted by the reader called tag back scatter, but change some

of the properties, and in this way sends back information to the reader. Using RFID backscattering, some tags attain their data transmission by changing the properties of the tags themselves, while others switch a load resistor in and out of the antenna circuit. Outside the near field region, RFID backscattering operates and the radio signal propagates away from the RFID reader. When the RFID tag receives the incoming signal, this interacts with the incoming signal and some energy is reflected back towards the RFID reader in form of backscatter. This backscattering signal depends upon the properties of the tag (or any other object for that matter) such as the tag cross sectional area, and the antenna properties. Over short ranges RFID communication, the amount of power incoming the tag from the reader is enough to allow operation of small low current circuits within the tag. This small amount of power can be used to drive an electronic switch, for example a FET that can be used to switch an antenna load resistor in and out of circuit to successfully modulate the reflected signal and allow data to be passed back to the reader. In order to allow simultaneous transmission and reception, a directional coupler is usually used to allow the received signal to be separated from the transmitted one. In addition the RFID reader must be able to find out the modulation in the presence of a host of other reflections, although these will normally be stable and not modulated in any way [53][54].

2.8.2 RFID capacitive coupling

Capacitive coupling is used for short range of communication where RFID close coupling is needed. According to the name capacitive coupling, the coupling between the tag and the reader, the system uses a capacitive effect. This coupling is often used for smart cards for which the standard International Organization for Standardization (ISO) 10536 may be applied. In RFID communication, RFID capacitive coupling operates best when items like smart cards or other devices containing chip are inserted into a reader so that the card is in very close proximity to the reader. Instead of having coils or antennas, capacitive coupling uses electrodes and the plates of the capacitor to provide the required coupling. The RFID reader and card tag provide a capacitor, which is useful for signal transmission, although an earth return is required. The reader generated AC signal, which is picked up, rectified within the RFID tag, and used to power the devices within the tag. Then by the modulating load the data is returned to the RFID reader [54].

2.8.3 RFID inductive coupling

RFID inductive coupling is used for what are termed vicinity coupled cards. RFID inductive coupling is defined in ISO 15693 standards. In terms of operation, inductive coupling is the transfer of energy from one circuit to another via the mutual inductance between the two circuits. For RFID inductive coupling to be used, both the tag and the reader will have induction or "antenna" coils. When the tag is placed close enough to the reader the field from the reader coil will couple to the coil from the tag. A voltage will be induced in the tag that will be rectified and used to power the tag circuitry. To enable data to be passed from the tag to the reader, the tag circuitry changes the load on its coil and this can be detected by the reader as a result of the mutual coupling. RFID inductive coupling is a near field effect. Accordingly the distance between the coils must be kept within the range of the effect - normally this is taken to be about 0.15 wavelength of the frequency in use. RFID inductive coupling is normally used on the lower RFID frequencies - often LF, i.e. below 135 kHz or at 13.56 MHz. The choice of the best form of RFID coupling will depend upon the intended application. Capacitive RFID coupling is used for very short ranges, inductive RFID coupling for slightly longer ranges and RFID backscatter coupling or RFID backscattering is normally used where longer distances are needed [55].

2.9 OFDM based RFID system description

It is mentioned in Chapter one that in outdoor RFID applications multipath fading may occur so that ISI or ICI may occur. Multipath fading can be classified as shown in Figure 2.9.

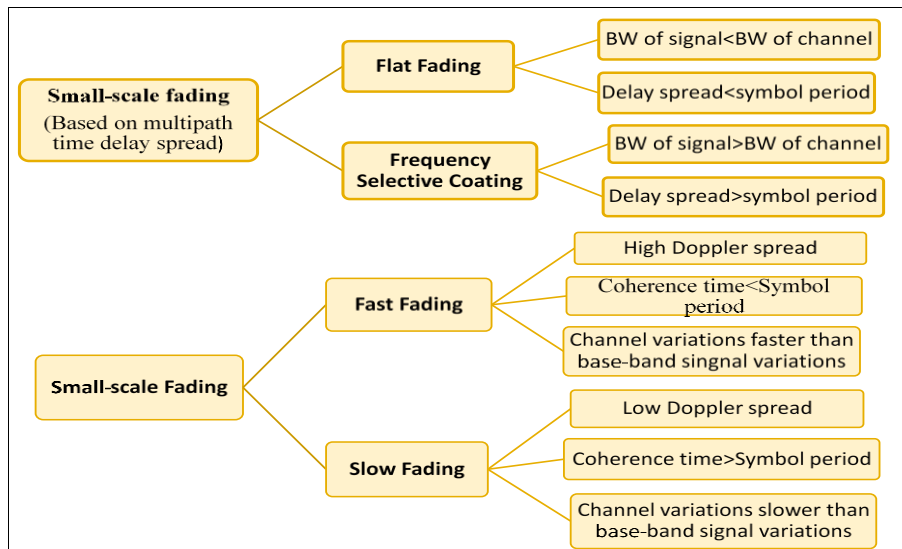


Figure 2.9: Classification of Multipath Fading

Due to the presence of multipath fading, the RFID system BER performance is degraded hence overall system performance may be degraded. OFDM is useful to combat multipath fading. For this reason, OFDM based RFID system is proposed in outdoor applications to improve the overall system performance. The complete OFDM based RFID system is shown in Figure 2.10.

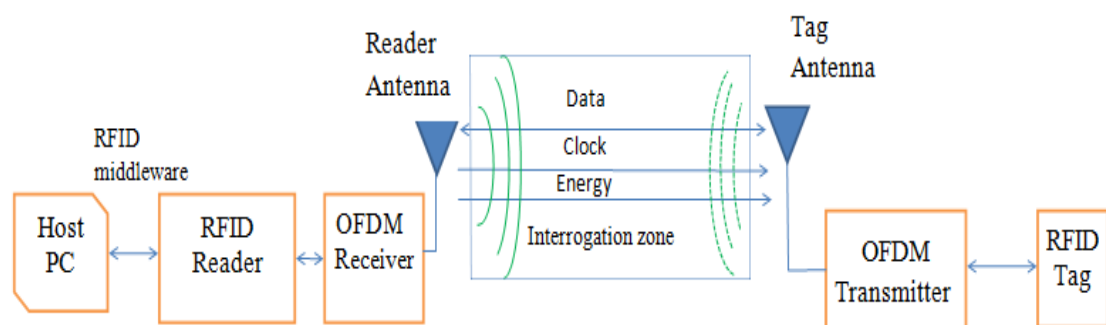


Figure 2.10: Block diagram of an OFDM based RFID system.

First of all, the RFID reader antenna transmits energy signal as well as clock signal to the tag system. The tag antenna receives energy signal to power up the tag microchip. Then reader sends data signal to the tag. The tag antenna receives the reader signal and processes it. After processing, the tag microchip retransmits a backscatter signal associated with data signal to the reader. The backscatter signal is more strengthened if

tag antenna's inductive impedance is perfectly matched with tag microchip capacitive impedance. Finally, the reader decodes tag backscatter signal and sends it to the destination host or central monitoring system via RFID middleware. It is notable that the read range of RFID system depends on several parameters such as either the tag is active or passive, reader and tag antenna gain, directivity, obstacles between reader and tag and the wireless channel overall. It has already been mentioned that in a practical outdoor wireless channel, multipath fading causes inter symbol and inter carrier interference to degrade the system performance. The use of OFDM waveform can combat this effect. Therefore, OFDM transmitter can be used at the tag section and OFDM receiver at the reader section. In the following, the OFDM transmitter and receiver useful in outdoor RFID system are described.

Figure 2.11 shows the typical block diagram of an OFDM transmitter and receiver system [16]–[19],[56]. At the OFDM transmitter, channel coding and interleaving are performed. High speed serial data streams are then mapped onto complex numbers from the constellation being used such as M-array pulse amplitude modulation (M-PAM), M-array quadrature amplitude modulation (M-QAM) or M-array phase shift keying (M-PSK). The complex constellations are converted into N number of lower speed parallel data streams using serial to parallel (S/P) conversion block. These parallel data streams are converted into time domain complex numbers from the frequency domain using N -point inverse fast Fourier transform (IFFT) block. The complex time domain samples at the output of the IFFT are given by following expression

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=1-\frac{N}{2}}^{\frac{N}{2}} X_k \exp\left(\frac{j2\pi tk}{T}\right) \text{ for } 1 - N/2 \leq k \leq N/2 \quad (9)$$

where k is the subcarrier index, T is the symbol period before adding cyclic extensions, and the smaller case letters denote time domain and the upper case letters denote frequency domain samples. After converting the parallel signals to serial sequence using parallel to serial (P/S) converter at the output of the IFFT, a cyclic extension known as cyclic prefix (CP) is added. By adding a CP, the symbol period is increased which is higher than the delay spread (σ) and thus minimizes multipath fading effects. A digital to analog converter (DAC) is then used to convert the samples of this extended OFDM symbol to continuous time domain analog signals and filtered by a low pass filter (LPF) to avoid unwanted signal frequency and finally are up-converted to the desired frequency before transmission [16]–[18].

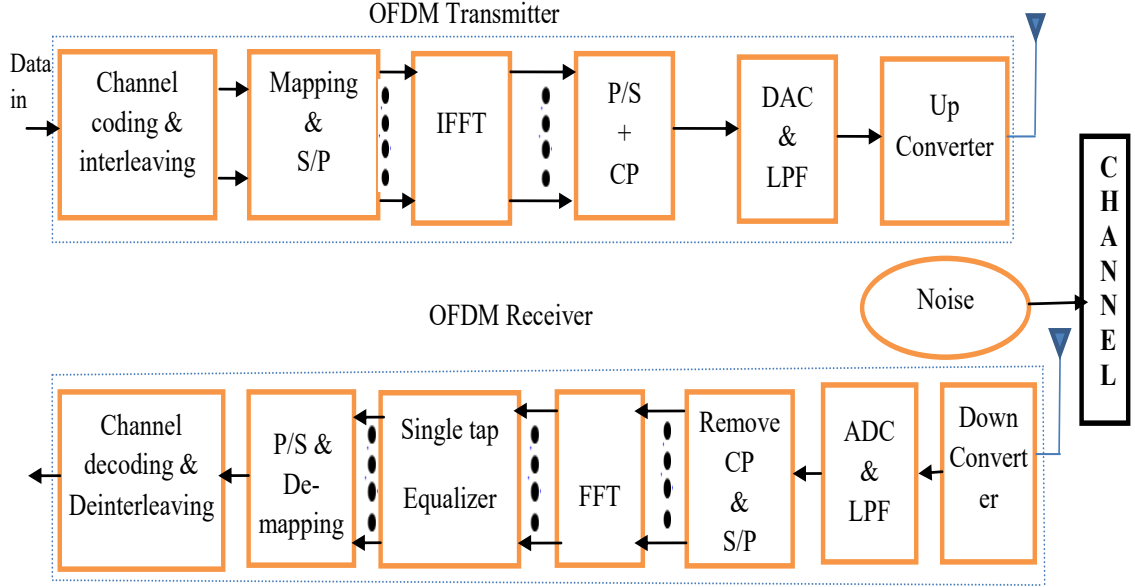


Figure 2.11: Block diagram of an OFDM transmitter and receiver.

At the OFDM receiver, the received signal is first down converted to base band signal. The base band signal is then converted to discrete signals by passing through a LPF and analog to digital converter (ADC). The received discrete base band time domain signal is fed to an N -point FFT block after the removal of CP and the S/P conversion. The FFT output is described by the given equation

$$X_k = \frac{1}{\sqrt{N}} \sum_{t=1-N/2}^{N/2} x(t) \exp(-\frac{j2\pi kt}{T}) \text{ for } 1-N/2 \leq t \leq N/2 \quad (10)$$

After that the FFT output is equalized to obtain the desired frequency domain signal by a single tap zero forcing equalizer. Finally, the original information is recovered by channel decoding and de-interleaving using the demodulation block [18], [19], [56], [57].

2.10 Conclusion

The limitations, applications and components of an RFID system is discussed in this chapter. Moreover, OFDM based RFID system is investigated in this chapter. In next chapter, literature review on RFID systems is introduced.

3 Chapter 3

Literature Review on RFID Systems

3.1 Introduction

A number of research works have been carried out in the field of RFID communication. Some research papers focus on the single band antenna and some others discuss about the multiband antenna. Interference occurring in RFID system is also reported in some previous work.

3.2 Literature review

The existing work on RFID systems can be divided into three subsections based on the antenna design for effective data transfer between reader and tag. The first category introduces the research works which evaluate the single band antenna for RFID systems and establish the relationship between RFID and IoT. The second one contains the research work about multiband multi service antennas for RFID systems. RFID antenna parameters optimization and multipath fading related issues are investigated in the third category.

3.2.1 RFID single band antenna and IOT

❖ Rectangular Patch antenna

Several researchers are investigated for single band antennas for RFID communication. The work in [44] reports RFID systems where antennas operate in centimetre band. The authors [44] state that the antenna operates in 10 GHz with bandwidth 384 MHz. A circularly polarized antenna with dimensions of $130 \times 130 \text{ mm}^2$ provides resonance at UHF band (922 MHz) and gain of this antenna is limited to only 4.3 dB [58]. Planar endfire antenna with circular polarization for RFID reader applications is investigated in [59] at resonance frequency of 5.8 GHz with bandwidth restricted to 111 MHz. The authors in [60] describe vertically polarized omnidirectional antenna having resonance at 450 MHz with very thick substrate of 6.35 mm to increase BW. However, due to the use of high thickness substrate, the antenna efficiency is degraded. A multiservice antenna at resonance frequency of 2.4 GHz is applicable in RFID, Wi-Fi, LTE with large dimensions of $170 \times 130 \text{ mm}^2$ [61]. The authors of the paper [62] propose an array

based reader antenna for RFID system having high gain with circular polarization (CP). The antenna is excited with an inset feed line and it operates in ISM band with resonant frequency of 2.4 GHz for health care applications with a large antenna size 120×73.12 mm². A single antenna useful in both near field and far field with centre frequency of 860 MHz is presented in [63]. The near field and far field antenna dimensions are 83×83 mm² and 220×180 mm².

❖ L and F shaped antenna

The author [64] describes that biconical shaped antenna provides high gain as well as high bandwidth. Moreover, the bending antenna arm also provides broadband characteristics. F and L shape antennas are not moderately biconical but these antennas provide large BW and gain than rectangular patch antennas. The research papers [65], [66] present two L shaped patch antennas with centre frequency of 5.8 GHz and 808 MHz, respectively. The first one provides 383 MHz impedance bandwidth with dimension of 50×50 mm², while the second one provides 47 % impedance bandwidth with size 120×120 mm². An inverted F antenna with centre frequency 10.5 GHz is reported in [67] for active RFID applications. The antenna provides -10 dB impedance bandwidth at 15% of the centre frequency, but the antenna has 3.08 dB low directive gain.

❖ RFID and IoT

The work in [34] discusses the applications of RFID. Connecting RFID reader to the terminal of Internet, the readers can identify, track and monitor the objects attached with tags globally, automatically, and in real time, if needed. This is the so-called Internet of Things (IoT). RFID is often seen as a prerequisite for the IoT. If all objects of daily life were equipped with radio tags, they could be identified and inventoried by computers [34].

3.2.2 Multiband and multiservice antenna in RFID systems

❖ Multiband multipurpose antenna

A multiband antenna is one which operates more than one frequency bands. Because each nation or wireless carrier uses different frequency bands, a multiband antenna is desirable [68]. A considerable number of techniques are investigated to achieve an antenna with multiple frequency bands. Some previous research works for multiband

antennas are exploiting fundamental as well as higher order modes, implementing an antenna with defected ground plane, or by the use of split ring resonator (SRR). To realize miniaturized multiband antenna, the radiation patterns are non-stable at different frequency and very hard to realize multiband resonance frequency. Another difficulty in previous work is that to obtain multiband operation the designed antenna structures are very complex [69], [70]. Although [69] provides multiband with relatively small antenna size, but the peak gain of this work is 1.85 dBi and the antenna structure contains circular ring with Y-shape-like strip and a defected ground plane that makes the overall antenna structure more complicated. A multi-service antenna reported in [61] which is useful in RFID, Global System for Mobile Communication (GSM), Long Term Evolution (LTE), and Wireless- Fidelity (Wi-Fi) communication infrastructure. In the research work [71], a multipurpose near-far-field switched multiband planer reader antenna for RFID applications is introduced. Authors explain that this antenna has three different resonance frequencies: 915 MHz, 2.45 GHz, and 5.8 GHz useful for RFID and GSM, and LTE applications. At present, miniaturized microstrip patch antenna has become more promising as well as become a suitable candidate for various wireless applications such as RFID to MMID, Radar system, GPS system and so on. This is due to its compact size, light weight and easy fabrication process. Some researchers have deployed dual or triple band antennas, but they have some limitations including overall antenna volume and gain [72], [73]. The simulated gain of [72] at resonance frequency 2.41 GHz -2.13 dB while at resonance frequency 3.79 GHz gain is 5.04 dB. The simulated gain of [73] at resonance frequency 1.36 GHz is -5.12 dB while at resonance frequency 2.88 GHz gain is -6.4 dB.

❖ Multiband antenna at UHF band

Multiple research works have been done to design multiband antenna at UHF frequency band for RFID communications. The authors of [74] [75] presented multiband antenna for RFID applications. The antenna provides resonance at 433MHz/ 923MHz/2.45 GHz is presented in [74], while the antenna [75] provides resonance at 13.56 MHz for near field and 920 MHz for far field. Both of the antennas have the relatively large dimension and the size of [74] is $120 \times 120 \text{ mm}^2$. In [76] authors have presented a switched dual-band coil antenna working in NF at HF and FF at UHF with peak gain 2.2 dB and 2.71 dB at NF and FF respectively, where another non-uniformly distributed turns coil antenna [77] for a maximum H-field in the HF RFID is presented. Authors in [78] present a dual-band dual-sense single-feed circularly polarized (CP) stacked patch

antenna with a small frequency ratio is proposed for Chinese 842.5/922.5-MHz radio frequency identification (RFID) reader applications. In this antenna, two elliptical-ring patches are configured orthogonally to operate at different frequency bands with different senses of circular polarization. Measured impedance bandwidth is very low about 2.99% (824–849 MHz) for the lower band and 2.72% (908–933 MHz) for the upper band, and measured antenna gain is 4.5 dBi in both of the resonance frequency with a large dimension $150 \times 150 \text{ mm}^2$. A two layered dual band antenna with (6-8dB) gain is presented in [79] with size $155 \times 230 \text{ mm}^2$. The limitations of this research work due to two layering the fabrication process is relatively complex and the size of the antenna is comparatively large.

❖ Multiband antenna at SHF band

A dual band antenna for RFID applications at SHF band with resonance frequencies 2.45 GHz and 5.8 GHz are proposed in [80]. A compact dual band antenna operating around the range of 2.4 GHz and 5.0 GHz is proposed for RFID systems in [81], [82]. The authors of [83] describe a dual band antenna at resonance frequencies of 2.44 GHz and 5.77 GHz, and a triple band antenna at resonance frequencies of 2.44 GHz, 3.55 GHz and 5.79 GHz. Although the antenna is M shaped but the simulated gain as well the bandwidth of the first two resonance frequencies are comparatively small (110 MHz, 1.65 dB) and (140 MHz and 3.73 dB). Similarly, the authors of [84] present high bandwidth high gain dual band and triple band antennas at 2.4 GHz and 5.8 GHz bands, but these antennas are extremely large with dimensions of $250 \times 250 \text{ mm}^2$ which is less feasible for RFID applications. A multiband compact size RFID reader antenna with considerable gain, stable radiation pattern and circular polarization is needed due to improve reader/tag performance as tag antenna orientation is not fixed. A several number of reader antennas are designed at UHF, Microwave or SHF band. A dual-band antenna for 2.4/5.8 GHz [85] and a tri band 3.6/5.8/8.2 GHz [9] were presented for RFID reader applications. It is mentionable that although the antenna [9] has fractal geometry with large size $90 \times 30 \text{ mm}^2$ but it provides comparatively lower gain.

3.2.3 RFID antenna parameters optimization and multipath impairments

❖ Antenna optimization

It is necessary to reduce the size of the antenna to meet the requirements of Application Specific IC (ASIC) especially for RFID systems. A number of techniques have been

introduced and investigated to reduce the antenna size. Some of these techniques are using loading capacitors, inductors, or loading shorting structures [86]–[88]. On the other hand, to adapt in different application scenarios like as different RFID or MMID frequency band or Radar system, antennas operating with multiple frequency band is very essential. In the research work [89], an on-chip dual-band rectangular slot antenna, is proposed and demonstrated for a new generation of high data-rate, battery-free, yet active millimeter-wave identification (MMID) system. The single antenna solution proposed in this work addresses the overall system compactness, the cost, and the underlying technical challenges related to multi-frequency reader-tag MMID system, such as the alignment between the reader's and tag's antennas (accurate line-of-sight, especially in a short-range communication system). All of these research works are limited to large in size, complex structure and use much thicker substrate or use multilayer structure to obtain high gain as well as high bandwidth. Authors in [90], [91] claim that for the same permittivity, if the substrate thickness increases the BW increases, or if the substrate permittivity increases the BW also increases with sacrificing efficiency. In [92], a dual-port, dual-band and linearly polarized RFID reader antenna is designed to simultaneously operate at ultra-high frequency (UHF) and ultra-wideband (UWB) bands for positioning systems. Patch and slot structure are used to obtain high gain and wideband. The measured impedance bandwidth of the UHF antenna ranges from 0.890 to 0.907 GHz with a minimum antenna gain of 9.0 dBi and the total size of the antenna is $200 \times 200 \times 10 \text{ mm}^3$. Slot antennas are another candidate to operate over a wideband [93]. However, the slot antenna has a bi-directional radiation pattern and low antenna gain, which may not be suitable for reader applications [94]. Placing a bi-directional antenna over a ground plane is a simple and effective way to achieve a unidirectional radiation pattern [95], [96]. The increase of the antenna gain is a sacrifice of the antenna bandwidth because of a reduction in the radiation resistance, which results from the induced short for the incident wave owing to the low surface impedance of a conducting ground [97].

❖ Millimeter wave antenna design

To achieve higher resonant frequency (millimeter wave, SHF band), multilayer structures, higher permittivity and higher thickness are required [8] [91]. It is notable that, single layer antennas are comparatively easy to fabricate, are more cost effective and are of lower complexity. In addition, the use of thicker substrate to enhance gain

and bandwidth for single layer antenna, results in the antenna radiation efficiency to degrade.

❖ Multipath impairments

Although, antenna (reader/tag) is key components in RFID system for efficient communication, but in case of outdoor scenario, multipath fading as well as Doppler spread becomes a big challenge in RFID and other wireless communications. Little research has been done to combat such kind of challenge. In [98], it is analyzed that the combination of interference coming from the self-radio, from other radio systems such as mobile phone or other RFID reader, affect the appearance of multiple tag antenna interfering each other. A method based on simulation using tag antenna design, is presented to evaluate inter-tag interference in a variety of cases. There are studies devoted to explain the causes and effects of interference for RFID as for example self-leakage, happening when continuous carrier is sent by the reader while receiving circuit is activated and, may desensitize the receiver. Due to its strong influence, some authors [99] propose methodologies for its compensation within the own chip. Local oscillator phase noise, also influences read range, since it will leak to the receiver passing through the power amplifier and isolator, overshadowing thermal noise component from receiver. The detection probability and performance evaluation of passive UHF RFID system is examined with considering cascaded fading channels (Rayleigh/ Rician) and interference effects [41], [42]. The authors in [43] try to measure detection range in outdoor environment of active RFID system using receiver diversity with maximal ratio combining (MRC). BER performance of RFID system is evaluated based on the FFT size, distance for reader to tag, reader antenna diversity, and one way distance between reader and tag. Furthermore, effect of transmit power on RFID read range is also investigated in [43]. Moreover, the BER performance of battery assisted active RFID system is investigated based on single input multiple output (SIMO) to communicate between reader and tag is reported in [22]. By increasing the use of number of receiving elements in the reader section BER performance and read range of RFID system are improved. Sometimes, small-scale fading alone can cause significant reductions in range and reliability and is most pronounced on the modulated-backscatter signal received at the reader. The fading on this signal often follows a product-Rician distribution resulting in deeper fades than those found on the signal received by the RF tag [13]. One way to reduce fading in the backscatter channel is through antenna diversity which uses multiple antennas at the reader and RF tag to provide spatially-separated diversity branches. This technique was first explored for backscatter radio by

Ingram et al. [100] and others [101], [102] have used multiple antennas at the reader for this purpose. Multiple antennas can also be used on the RF tag and it has been shown that modulating backscatter with multiple, spatially separated RF-tag antennas can reduce small-scale fading on the modulated-backscatter signal [103]. All the reference papers discussed above only study the antenna design or fading/interference issues in RFID communications. However, a detail investigation of OFDM based RFID scheme and the evaluation of BER using simulated antenna bandwidth is yet to be done. Summarized results of the different antennas are presented in Table 3-1.

Table 3-1: Literature Review Table

| References | Antenna Size in mm^2 | Antenna Shape | Operating freq. Band | f_r in GHz | BW in GHz | Gain in dB | Return Loss | Substrate Material | η_{radef} (%) |
|------------|----------------------------------|---|----------------------|------------------------|--------------------------|----------------|--|--------------------|--------------------|
| Ref [44] | 34.35×2 9.52 | Rectangular Microstrip patch | X band and 57-66 GHz | 10, 60 | 0.384 | 12.84 | -31 | RT/Duroid5880 | 92 |
| Ref [58] | 130× 130 | Circular split ring | UHF band | 0.922 | 0.18 | 4.9 | ≤ -37 | FR4 substrate | - |
| Ref [59] | 38× 33.5 | Planer end fire CP antenna | Centimetre band | 5.8 | 0.11 | 4.9 | -20 | Printed substrate | 63 |
| Ref [61] | 170× 130 | Ring and Y shaped | ISM band | 1.04, 2~4.77 | 2.77 | 4.15 | ≤ -35 | FR4 substrate | 88, 76 |
| Ref [62] | 120× 73.12 | Rectangular Microstrip patch | ISM band | 2.4 | - | 6.1 | -17.4 | FR4 substrate | - |
| Ref [66] | 120× 120 | Square patch with circular ground plane | UHF band | 0.808 | 0.38 | 2.96- 3.41 | ≤ -24 | FR4 substrate | 86 |
| Ref [67] | 52×37 | Inverted F anteaann (IFA) | Centimetre band | 10.5 | 1.575 | 3.08 | -24 | Taconic TLY-5-0620 | - |
| Ref [74] | 118× 120 | Rectangular Microstrip patch | UHF and ISM band | 0.433, 0.923 | 0.006, 0.033, 0.07 | - | -20, -33, -24 | FR4 substrate | - |
| Ref [75] | Quadrifilar spiral antenna (QSA) | spiral-shaped loop and | HF and UHF | 0.01356, 0.915 | - | 2.5 | | FR4 substrate | - |
| Ref [76] | 98× 98 | Loop shaped | UHF, ISM band | 0.915, 2.45, 5.8 | 0.03, 0.07, 0.34 | 1, 4.1, 4.3 | ≤ -47 , ≤ -50 , ≤ -30 | FR4 substrate | - |

| References | Antenna Size in mm^2 | Antenna Shape | Operating freq. Band | f_r in GHz | BW in GHz | Gain in dB | Return Loss | Substrate Material | $\eta_{rad\text{eff}}$ (%) |
|------------|------------------------|---|----------------------|--------------------|---------------------|------------------|--------------------------------------|--------------------------|----------------------------|
| Ref [78] | 178.04×178.04 | Elliptical ring patch | UHF | 0.8425, 0.9225 | 0.025, 0.025 | 4.5, 5.5 | -19, -30 | FR4 substrate | 60 |
| Ref [79] | 155 × 230 | Aperture coupling two-layered with four notches | UHF and ISM | 0.970, 2.45 | 0.124, 0.68 | 6~8 | -30, -22 | FR4 substrate | - |
| Ref [81] | 43×26 | Dual E shaped patch | Centimetre band | 2.45, 5 | 0.11, 2.1 | ~8,9-10 | ≤ -24 , ≤ -40 | RT/Duroid5880 | 95 |
| Ref [82] | 57.7 × 70.9 | Rectangular Microstrip patch | Centimetre band | 3.763 | 3.94 | 2.4 | -43.84 | FR4 epoxy | 38.3 |
| Ref [83] | 64×62 | M shaped Patch | Centimetre band | 2.44, 3.55, 5.79 | 0.11,0.14,0.63 | 1.65, 3.73, 6.32 | ≤ -25 | RT/Duroid5880 | - |
| Ref [84] | 250 × 250 | Coin shaped | UHF band | 0.797-0.962 | 0.194 | 9.1-9.8 | ≤ -21 | Thick air | - |
| Ref [89] | 2.5×2.5 | Rectabgular Slot | Millimetre wave | 24, 40 | 5, 7 | -1, 0 | -16, -19 | Bulk silicon substrate | 41, 31 |
| Ref [92] | 200 × 200 | Hybrid design using patch and slot | UHF and UWB band | 0.89, 2.45 | 0.017, 1.99 | ~9 | -28 | RT/Duroid 5880 substrate | 99, 96 |
| Ref [104] | 54×37 | Rectangular Microstrip patch | UHF band | 0.33, 0.755, 0.955 | 0.33, 0.024, 0.03 | -16.7, -6.2, -1 | -10, -37 | FR4 substrate | - |
| Ref [105] | 74×70 | Multi layer monopole | Centimetre band | 2.45, 5.2 | 0.65, 0.99 | 3.04,2.6 | ≤ -20 , ≤ -30 | Rogers RT/duroid 5880 | ≥ 95 |
| Ref [106] | 19×25 | F shaped | Centimetre band | 2.40, 5.20, 5.80 | 0.76, 0.964, 0.80 | 1.5, 1.7, 3.05 | ≤ -20 , ≤ -42 , ≤ -30 | FR4 substrate | ≥ 87 |
| Ref [9] | 60×40 | Fractal Geomerty | Centemetre band | 3.6, 5.8, 8.2 | 0.248, 0.398, 0.405 | - | -19.4, -20.4, -20.6 | FR4 substrate | - |

3.3 Conclusion

Various antennas for RFID systems with different parameters such as resonance frequencies, gain, bandwidth, dimensions, and corresponding shapes are discussed in this chapter and presented in tabular form. Moreover, multipath impairments in RFID communication are also introduced in literature review.

4 Chapter 4

Antenna Design for RFID system

4.1 Introduction

Antenna is the key component for any kind of wireless communication. So designing an perfect antenna is a very challenging task as well very essential for communication. In this chapter the overall design methodology of the proposed antennas that are useful for RFID reader section. The Section 4.3 presents the design procedure of dual band antenna while Section 4.4 presents triple band antenna design procedure. The double E-shaped triple band array antenna are designed in Section 4.5.

4.2 Design of three antennas in the centimetre band

Both the antennas are designed based on a single band microstrip antenna shown in [44]. Computer Simulation Technology (CST) Microwave Studio is used for antenna simulation and optimization. Commercially available Rogers RT5880 substrate with permittivity, $\epsilon_r = 2.2$, loss tangent, $\tan \delta = 0.0009$, substrate thickness, $h = 0.787$ mm, and copper thickness, $t = 0.018$ mm is used for the antenna design. The initial length and width of the two antennas are obtained by taking 10 GHz resonance frequency. In order to obtain the dual band and the triple band, the length and the width are adjusted to maximize the antenna performance. In addition, a double E-shaped array antenna is designed using CST Microwave Studio. The array antenna is designed based on the triple band RFID reader antenna that is described in section 4.4.

❖ Existing Two element antenna

The antenna reported in [44], uses two horizontal Arms with overall antenna dimension 34.35×29.52 mm². The Rogers RT5880 substrate with permittivity 2.2 and thickness of the substrate 0.787 mm and 1.57 mm for 10 GHz resonance frequency is introduced in Figure 4.1. In this thesis modify structure of dual band antenna for RFID reader section is obtained from the antenna introduced in [44]. The proposed antenna has slightly larger dimension than the antenna in [44] and it is 40.292×35.117 mm². Although the dimension of the proposed antenna is larger but it provides dual operating frequency

which is the main objective of this thesis while the antenna in [44] provides resonance at only 10 GHz.

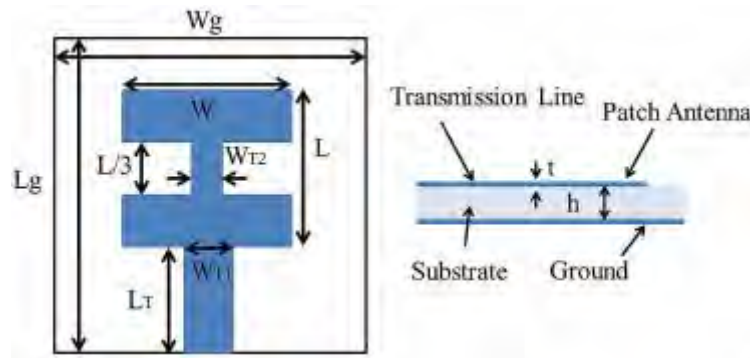


Figure 4.1: Existing two elements antenna [44].

4.3 Dual band antenna design

Plan view and 3-D perspective view of the dual band centimetre wave microstrip patch antenna are shown in Figure 4.2. Here, the modify structure of dual band antenna is designed and optimized with resonance frequencies $f_{r1} = 7.30$ GHz and $f_{r2} = 9.50$ GHz on Rogers RT5880 substrate. The optimized dimensional parameter values of the dual band antenna are shown in Table 4-1.

Table 4-1: Specifications of dual band antenna.

| Antenna Parameters | Length in mm |
|-------------------------|--------------|
| W_g | 40.29 |
| L_g | 35.12 |
| $W_1 = W_2$ | 36.29 |
| L_3 | 5 |
| L_4 | 15.56 |
| L_1 | 6.56 |
| L_2 | 7 |
| W_3 (Width of L_3) | 7 |
| W_4 (Width of L_4) | 3 |

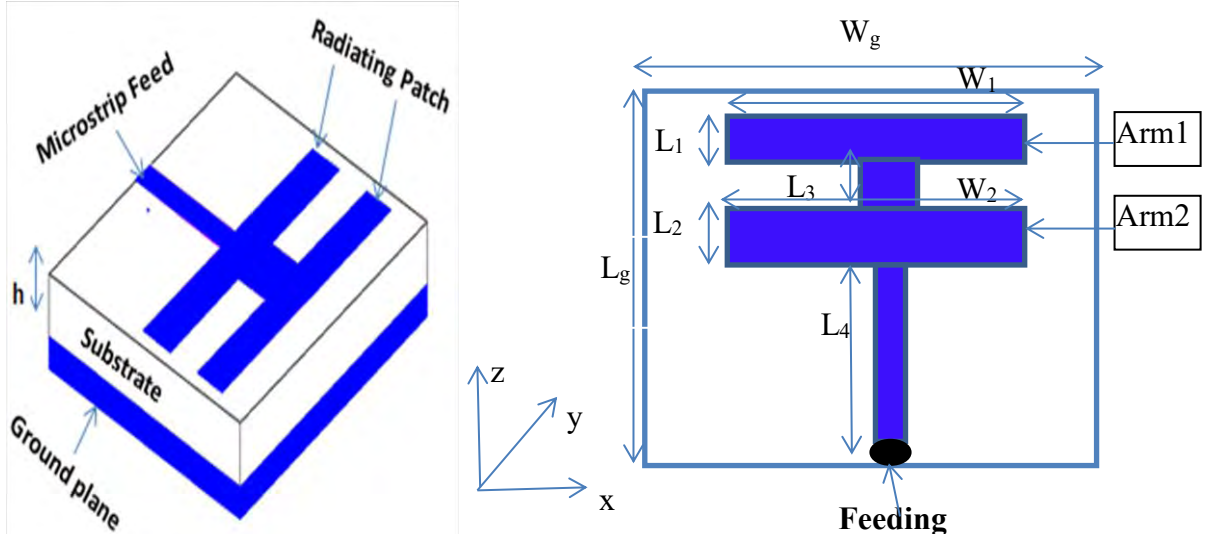


Figure 4.2: A 3-D and a 2-D view of dual band RFID reader antenna.

Here, two horizontal metal plates denoted as Arm1 and Arm2 with the same width ($W_1 = W_2 = 36.29$ mm) are used as the main radiating element of the designed dual band antenna. The length of radiator arms Arm1 (L_1) and Arm2 (L_2) are 6.56 mm and 7 mm, respectively. A single microstrip feeding line is used to feed this antenna so that it is comparable to an array of two extra wide microstrip patch elements [44]. The width and the length of radiator that connects Arm1 and Arm2 is $W_3 = 7$ mm and $L_3 = 5$ mm, and the width and the length of the microstrip feedline is $W_4 = 3$ mm and $L_4 = 15.56$ mm, respectively. Finally, a copper ground is placed on the opposite side of the antenna substrate to complete the design. The length of the radiator that connects Arm1 and Arm2 is initially obtained using the procedure and expressions given in (9)-(10) [107]. In order to obtain the antenna's higher order Transverse Electromagnetic Modes (TEM) whose attributes are very closely matched with the fundamental mode, a technique is introduced to calculate the proposed antenna's length and width. This technique is commonly known as size extension method [108]. According to the size extension method, the extended patch antenna width 'W' and length 'L' can be expressed as [108]:

$$W = \frac{(2N+1)}{\sqrt{(2\epsilon_r+1)/2}} \times \left(\frac{\lambda}{2}\right) \quad (11)$$

$$L = \frac{(2N+1)}{\sqrt{\epsilon_{eff}}} \times \left(\frac{\lambda}{2}\right) - 2\Delta L \quad (12)$$

where λ is the proposed antenna's operating wavelength, ϵ_r is the relative permittivity (dielectric constant) and N is a positive valued integer number (in this antenna design we assume $N=1$). Due to the fringing field effect, the physical dimensions of the microstrip patch antenna would look electrically wider. The extended length of the patch ΔL on each side is a function of antenna width to substrate height ratio (W/h) and the effective dielectric constant ϵ_{eff} [64]. So, ΔL and ϵ_{eff} are obtained by the following equations

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3)(0.264 + W/h)}{(\epsilon_{eff} - 0.3)(0.8 + W/h)} \quad (13)$$

where effective dielectric constant,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \left(\frac{\epsilon_r - 1}{2}\right) \left(1 + 12 \frac{h}{W}\right)^{-\frac{1}{2}} \quad (14)$$

To feed the proposed antenna microstrip transmission line length, $L_4 = L_T$, and its input impedance Z_{in} are obtained by the expression introduce in [104]:

$$Z_{in} = 29.9 \frac{\lambda_0}{W} \quad (15)$$

$$L_T = \frac{(2M+1)}{2} \times \left(\frac{\lambda}{2}\right) \quad (16)$$

where M is assumed as a positive valued integer number (in the designed antenna $M=1$) and λ_0 is the operating wavelength at free space in desired frequency.

The equations described above are used to design a dual band (one band at frequency 7.30 GHz and other band at 9.50 GHz) linearly polarized antenna. Initially the transmission line length L_4 and width W_4 are obtained using equations given in

[107]. The ground plane width and length ' $W_g = W + 6h$ ' and ' $L_g = L + 6h$ ' are initially set respectively from the method described in [44]. For better antenna performance, the length and width are adjusted using optimization tools of CST Microwave Studio. Using optimization tools of CST, the length of Arm2 is adjusted as $L_2 = 7$ mm, and the lengths of connector Arm1 and Arm2 are adjusted to $L_3 = 5$ mm. Desired impedance matching, acceptable gain, directivity, resonance frequency at centimetre band, S_{11} parameters, lowest side lobe level (LSLL), radiation efficiency are achieved by final optimization using CST of the designed dual band antenna for RFID reader applications.

4.4 Triple band antenna design

By modifying the dual band antenna structure described in the previous section, a novel triple band antenna at centimetre band is designed in this section. Plan view of the triple band antenna design is shown in Figure 4.3. The design mechanism of the proposed triple band antenna at centimetre band with three resonance frequencies is almost similar to the dual band antenna which is described in Section 4.3. The main difference between the modify structure of dual band antenna (adapted from [44]) and the triple band antenna is the number of horizontal arms as well as the variation in length of the horizontal arms. The length and the width of various radiator elements of triple band antenna are obtained by the same equations that are described in Section 4.3. Three horizontal metal plates denoted as Arm1, Arm2, and Arm3 with the same width ($W_1 = W_2 = W_3 = 36.30$ mm) are used as the main radiator element of this proposed antenna. The lengths of Arm2 and Arm3 are the same, $L_2 = L_3 = 5$ mm, and the length of Arm1 is $L_1 = 3$ mm. A single microstrip feeding line is used to feed this antenna so that it is comparable to an array of three extra wide microstrip patch elements. The length of radiator that connects Arm1 and Arm2 and the length of microstrip feedline is $L_4 = 5$ mm and $L_T = L_6 = 10.12$ mm, respectively. Better antenna performances are achieved by optimizing antenna's various parameters using optimization tools of CST Microwave Studio. The optimized dimensional parameters of the triple band antenna are shown in tabular form in Table 4-2.

Table 4-2: Specifications of triple band antenna.

| Antenna parameters | Length in mm |
|-------------------------|--------------|
| W_g | 40.29 |
| L_g | 35.12 |
| $W_1=W_2=W_3$ | 36.30 |
| $L_4=L_5$ | 5 |
| L_6 | 10.12 |
| L_1 | 3 |
| $L_2=L_3$ | 5 |
| W_4 (Width of L_4) | 5 |
| W_5 (Width of L_5) | 8 |
| W_6 (Width of L_6) | 4 |

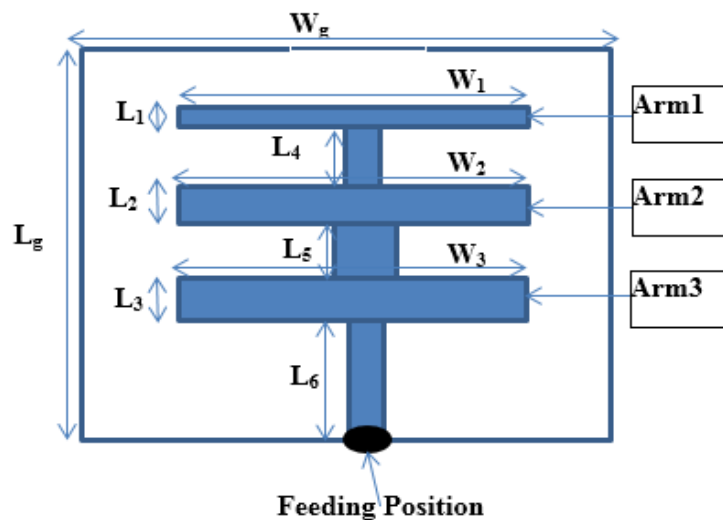


Figure 4.3: Triple band RFID reader antenna.

Since, individual Arm of the triple band antenna act as a radiating element so it is similar to the three element (horizontal metal arm) array antenna as mentioned in previous section. As a result, it is necessary to avoid antenna grating lobe and mutual coupling between antenna Arms. If the spacing among the antenna elements increases then mutual coupling decreases but grating lobe is more significant. It is good practice to adjust grating lobe and mutual coupling, the spacing among the antenna elements should be less than $\lambda/2$. In this thesis, spacing between Arm1, Arm2 and Arm 3 is $L_4 = L_5 = 5$ mm to reduce the effect of grating lobe and mutual coupling on the antenna performance.

4.5 Double E-shaped triple band array antenna design

The 2-D structure of the proposed double E-shaped triple band array antenna at centimetre wave is shown in Figure 4.4. The proposed triple band double E-shaped array antenna design is designed and optimized with resonance frequencies $f_{r1} = 7.23$ GHz, $f_{r2} = 10$ GHz and $f_{r3} = 11.748$ GHz on Rogers 5880 substrate. The optimized dimensional parameter values of the proposed triple band array antenna is shown Table 4-3.

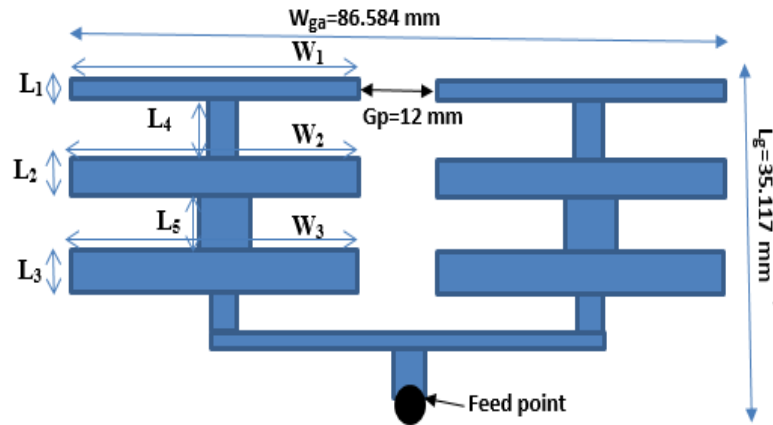


Figure 4.4 : 2 D view of the double E-shaped triple band RFID reader array antenna.

Table 4-3: Dimension of the proposed array antenna structure

| Antenna parameters | Length in mm |
|--------------------|--------------|
| Wga | 86.584 |
| Lg | 35.117 |
| $W_1=W_2=W_3$ | 36.29 |
| L4 | 5 |
| L5 | 8 |
| L1 | 3 |
| $L_2=L_3$ | 5 |
| W4 (Width of L4) | 5 |
| W5 (Width of L5) | 8 |
| Gp | 12 |

The simulation and optimization of the proposed array antennas are done by Computer Simulation Technology (CST) Microwave Studio. Similar to the triple band reader antenna shown in Figure 4.3, the antenna is designed using Rogers RT5880 substrate having permittivity of $\epsilon_r = 2.2$, thickness of $h = 0.787$ mm, loss tangent of $\tan \delta = 0.0009$, and copper metal thickness of $t = 0.018$ mm. The dimension of the array antenna is 86.584×35.117 mm². To avoid grating lobe and mutual coupling, the spacing (G_p) between two array elements is less than half wavelength and it is 12 mm. By final optimization with CST, the desired impedance matching, resonance frequency, gain, directivity, s_{11} level, radiation efficiency, and lowest side lobe level (LSLL) are obtained.

4.6 Conclusion

The details design procedure of the proposed antennas are presented in this section. All the antennas are designed using CST Microwave Studio. All the three antennas have the same substrate, which is Rogers RT5880, and the dimensional parameters of the proposed antennas are obtained using various reference equation. The simulated results of all the antennas are mentioned in the next chapter.

5 Chapter 5

Performance of Proposed Antennas on OFDM Based RFID Systems

5.1 Introduction

The simulation results of the optimized dual band and triple band microstrip patch antennas for OFDM based RFID reader using CST Microwave Studio are described Chapter. The various simulated results such as S_{11} , 3-D, 2-D, polar plot of radiation pattern, VSWR, gain vs frequency curve and so on are shown in the Section 5.2 and Section 5.4. The parametric study of dual band antenna is also presented in Section 5.3. In addition, Section 5.5 describes the simulated results of the double E-shaped triple band array antenna. On the other hand, the Section 5.6 is used to describe the BER performance of the proposed model using the designed antenna bandwidth while the Section 5.7 presents the comparison of three distinct antennas.

5.2 Simulation results of the optimized dual band antenna

The simulation results of the designed dual band antenna using waveguide ports are at resonance frequencies $f_{r1} = 7.30$ GHz and $f_{r2} = 9.50$ GHz are presented in this section. The simulated return loss at f_{r1} is -32.25 dB and at f_{r2} is -41.0 dB, which are shown in Figure 5.1, whereas VSWR at these resonance frequencies are 1.05 dB and 1.02 dB, respectively as shown in Figure 5.2. This indicates antenna impedance is considerably matched with the waveguide port impedance as less amount of power is reflected back from the input terminal of the antenna.

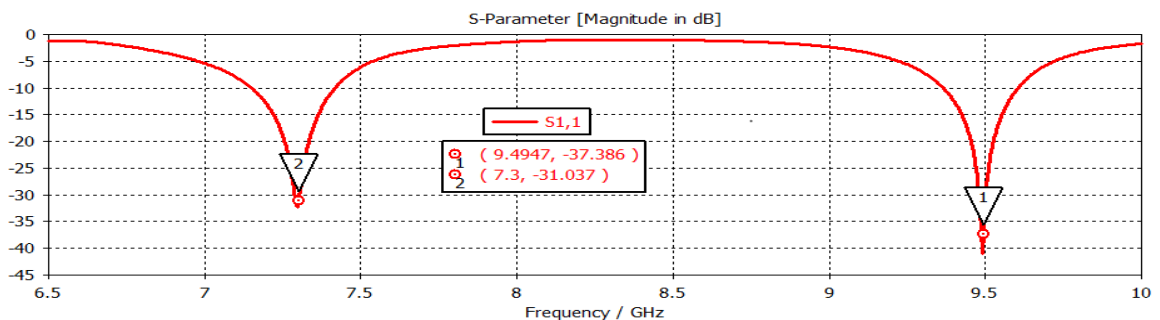


Figure 5.1: Reflection co-efficient (S_{11}) of the dual band reader antenna.

3 D and 2 D radiation pattern of dual band antenna at resonance frequencies f_{r1} and f_{r2} are shown in Figure 5.3 ((a) and (b)) and Figure 5.4 ((a) and (b)) respectively. Figure 5.5 and Figure 5.6 show the simulated E-plane ($\varphi=0^0$) and H-plane ($\varphi=90^0$) far field radiation patterns at f_{r1} and f_{r2} , respectively indicating side lobe level, 3 dB angular beam width, main lobe magnitude and main lobe direction.

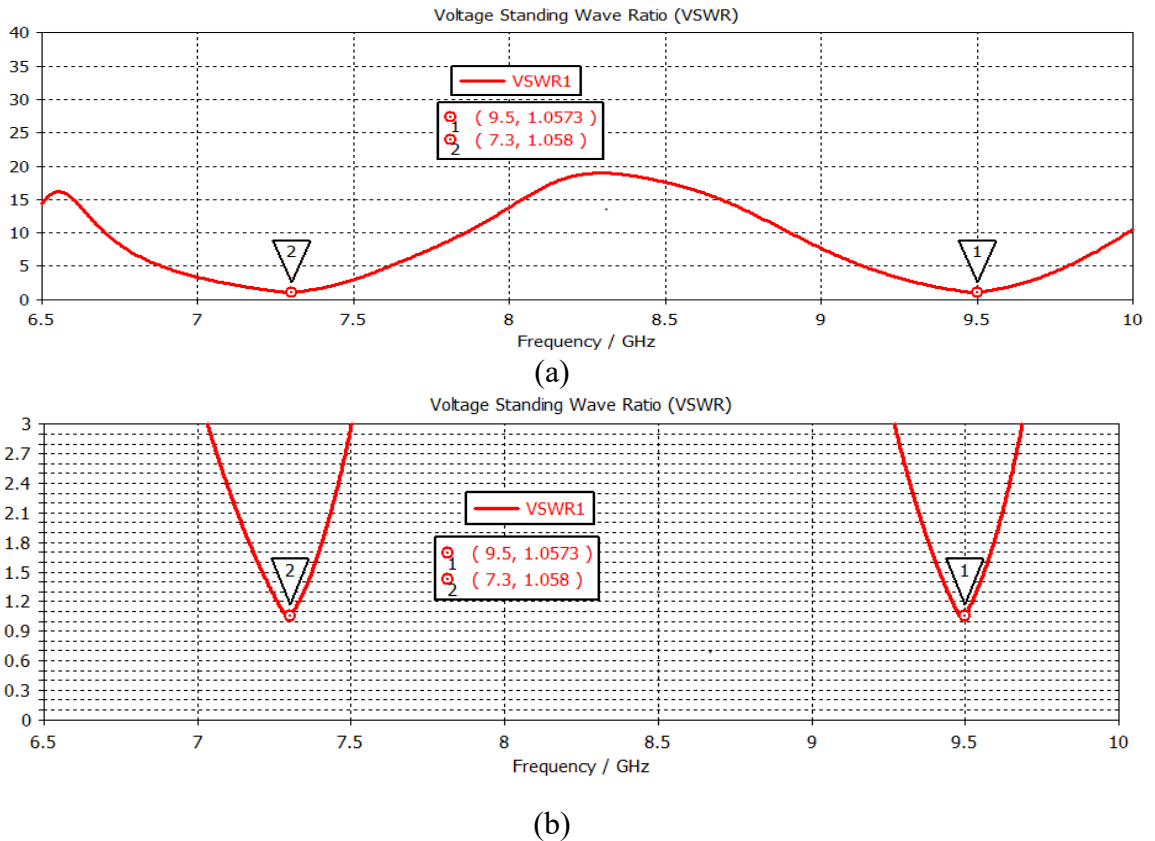
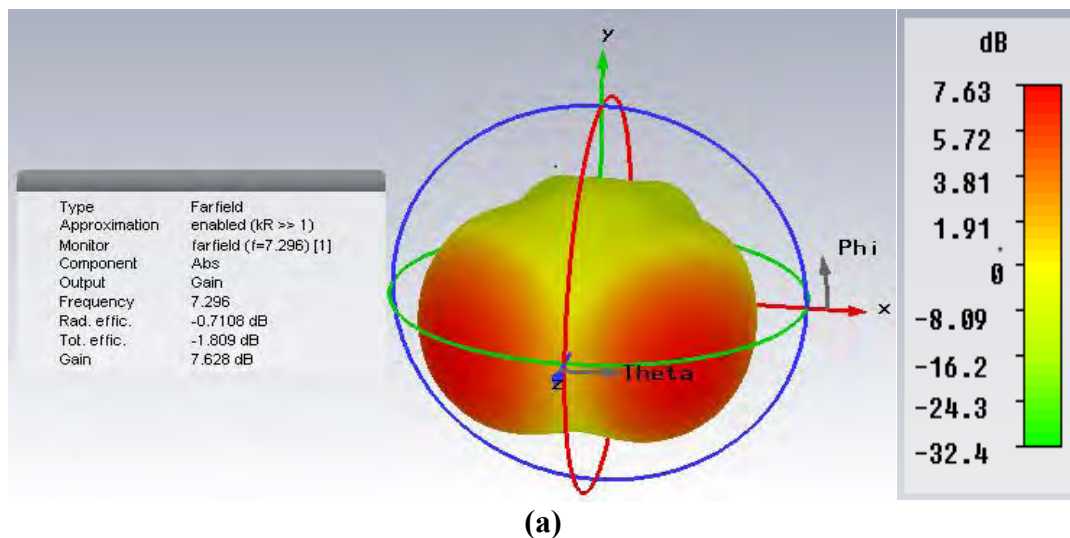
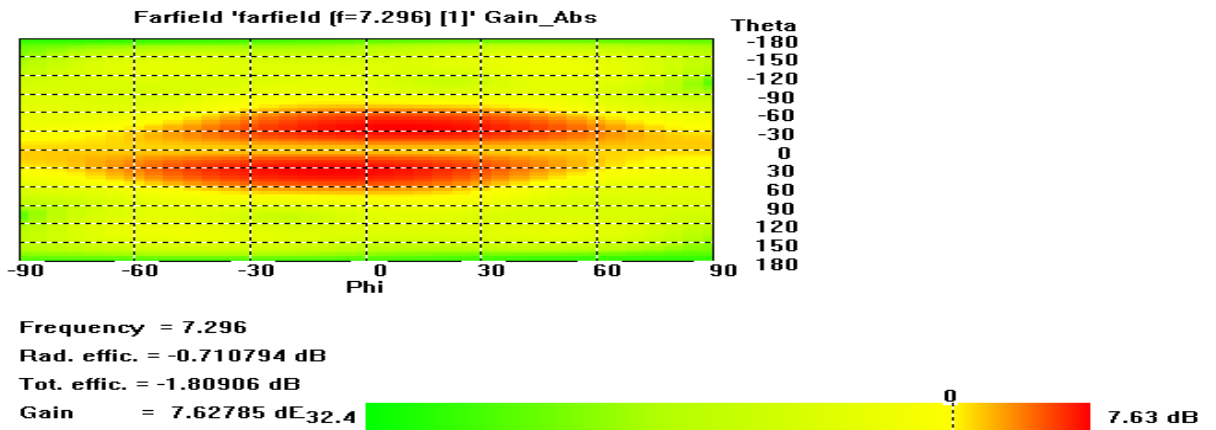


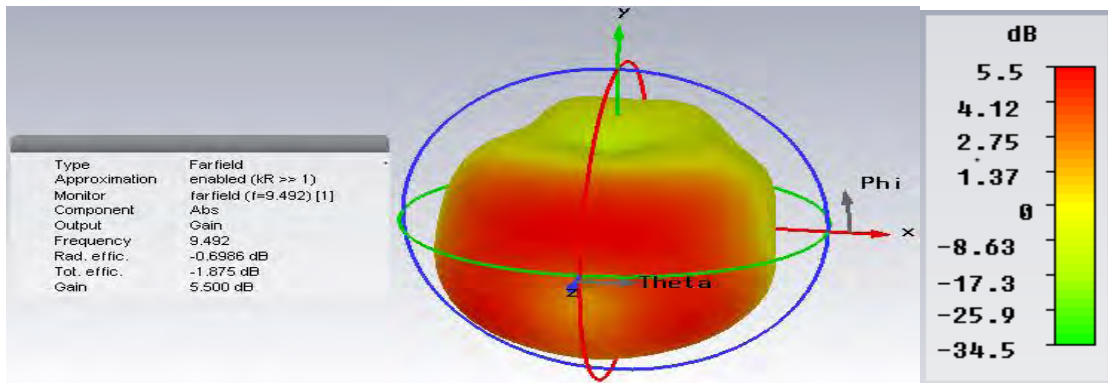
Figure 5.2: VSWR curve of the dual band reader antenna (a) Full view and (b) Short view.



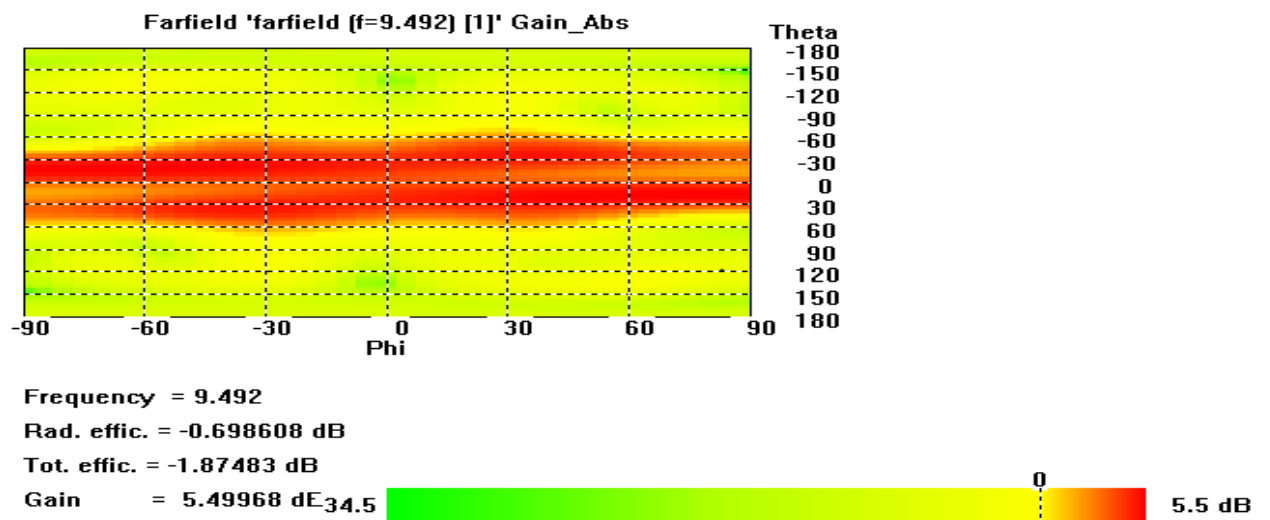


(b)

Figure 5.3: (a) 3-D and (b) 2-D radiation pattern for dual band reader antenna at $f_{r1} = 7.30$ GHz.



(a)



(b)

Figure 5.4: (a) 3-D and (b) 2-D radiation pattern for dual band reader antenna at $f_{r1} = 7.50$ GHz.

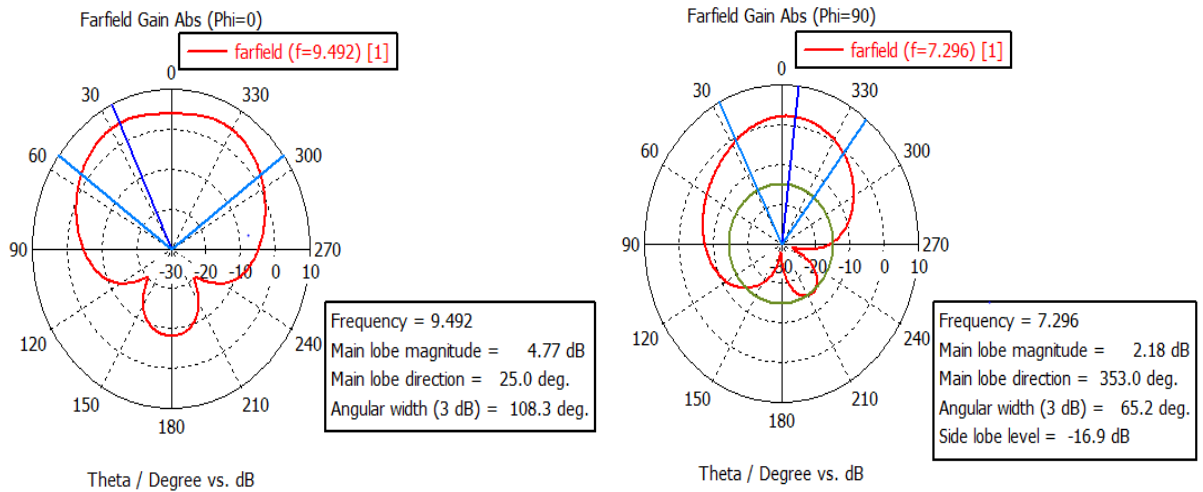


Figure 5.5: E and H-plane radiation pattern for dual band reader antenna at $f_{r1} = 7.30$ GHz.

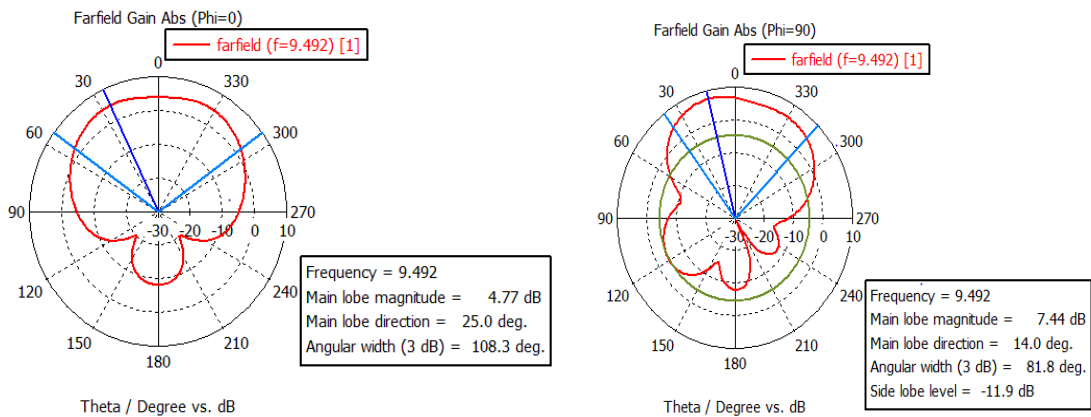


Figure 5.6: E and H-plane radiation pattern for dual band reader antenna at $f_{r2} = 9.50$ GHz.

It can be seen from Figure 5.5 and Figure 5.6 that the side lobe levels at both resonance frequencies are above -11dB which ensures that maximum power is concentrated at main lobe so that tag antenna receives more power from the reader. The gain versus frequency plots, and the radiation efficiency versus frequency curves of this dual band antenna are shown in Figure 5.7 and Figure 5.8 respectively.

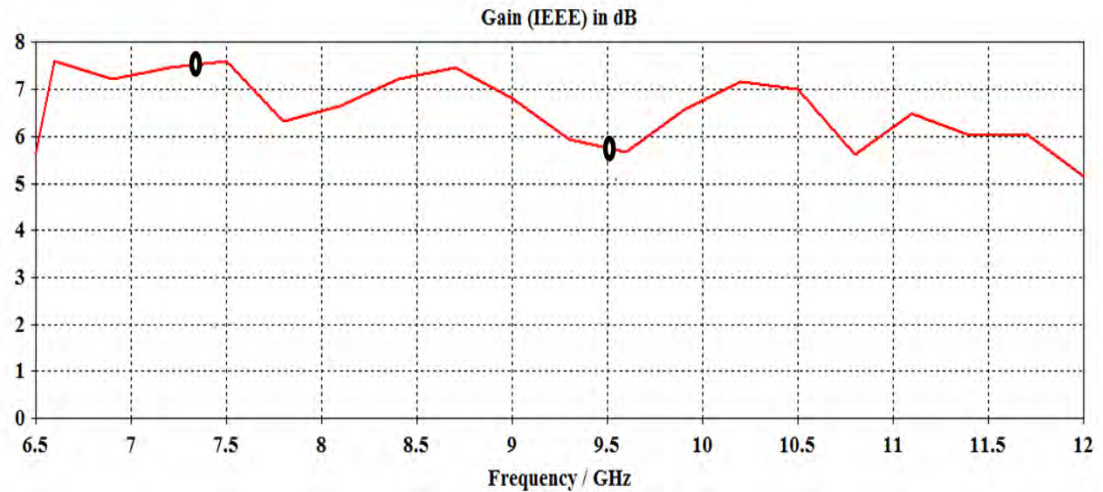


Figure 5.7: Gain vs frequency for dual band reader antenna.

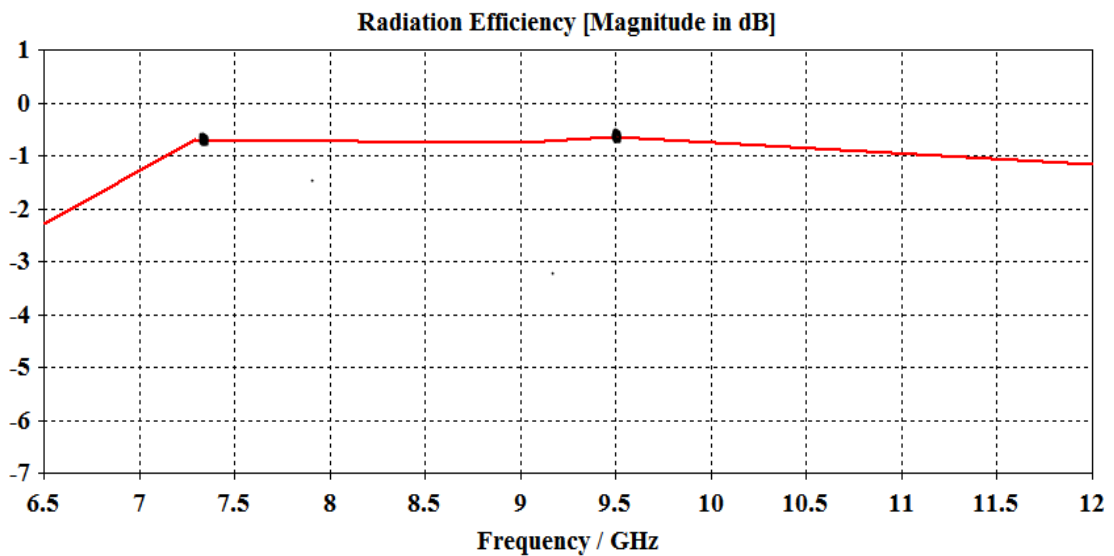


Figure 5.8: Radiation efficiency for dual band reader antenna.

It can be seen from Figure 5.7 and Figure 5.8 that gain at resonance frequency f_{r1} is slightly higher than the gain at resonance frequency f_{r2} , but the radiation efficiency at both of the resonance frequencies is almost same. The antenna gain (G) and directivity (D) at f_{r1} are 7.628 dB and 8.339 dBi, respectively. Moreover, the antenna gain and directivity at f_{r2} are 5.60 dB and 6.198 dBi, respectively. The antenna radiation efficiency is related to the gain and directivity and it can be written as $\eta_{rad} = G(dB) - D(dB)$. So, the antenna radiation efficiency at 7.30 GHz is 85.00% and at resonance frequency of 9.50 GHz is 87.14%. The reflection coefficient curves in Fig. 5 show that the -10dB bandwidth at resonance f_{r1} is 300 MHz (4.11% of resonance

frequency) ranging from 7.138 GHz to 7.438 GHz. The bandwidth decreases to 270 MHz (2.85% of resonance frequency) at f_{r2} ranging from 9.354 GHz to 9.624 GHz.

5.3 Parametric study for the dual band antenna

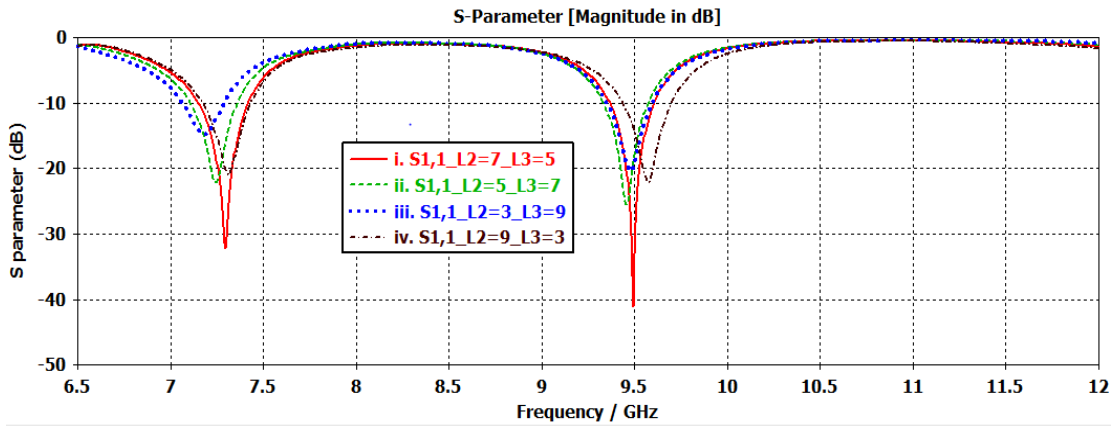
The effects of length variation of Arm2 (denoted as L_2) and the length of the vertical line (denoted as L_3) that connects horizontal Arm1 and Arm2 on the simulation result are observed. Due to the variation of lengths of L_2 and L_3 , both the resonance frequencies of the designed dual band antenna are changed. The effects of width variations are shown in Table 5-1.

Table 5-1: Specifications of dual band antenna with variation in width.

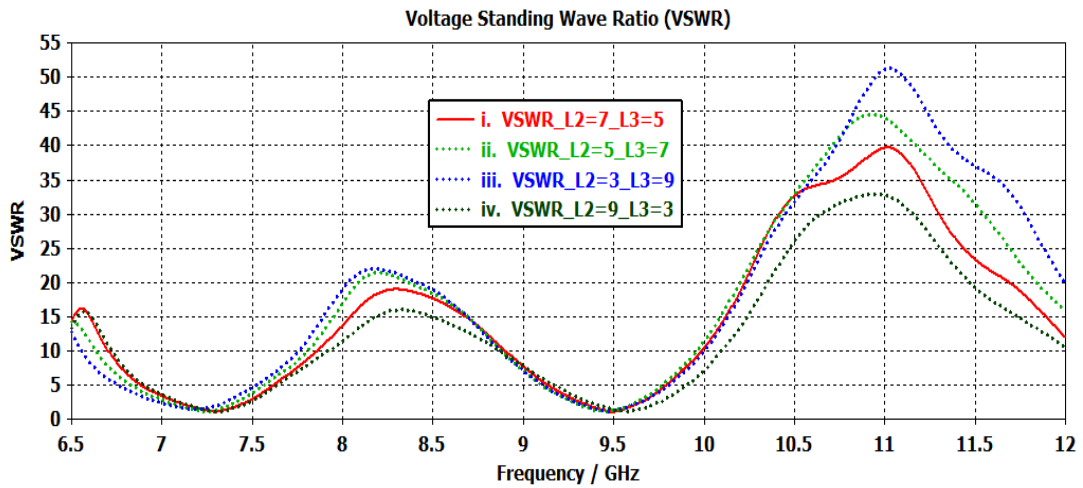
| SL No. | Arm2 (L ₂ in mm) | L ₃ in mm | Resonance frequency GHz | | S-parameter S ₁₁ in dB | | VSWR | | Radiation Efficiency (η_{rad}) | |
|--------|-----------------------------|----------------------|-------------------------|----------|-----------------------------------|-----------------------------|------------------|------------------|---------------------------------------|------------------------------|
| | | | f_{r1} | f_{r2} | S ₁₁ at f_{r1} | S ₁₁ at f_{r2} | VSWR at f_{r1} | VSWR at f_{r2} | η_{rad} (%) at f_{r1} | η_{rad} (%) at f_{r2} |
| i. | 7 | 5 | 7.30 | 9.50 | -32.250 | -41.011 | 1.05 | 1.02 | 85.00 | 87.14 |
| ii. | 5 | 7 | 7.245 | 9.46 | -22.129 | -25.435 | 1.17 | 1.11 | 84.14 | 83.17 |
| iii. | 3 | 9 | 7.185 | 9.48 | -14.770 | -20.348 | 1.44 | 1.22 | 80.16 | 81.85 |
| iv. | 9 | 3 | 7.316 | 9.58 | -20.826 | -22.055 | 1.20 | 1.17 | 85.31 | 86.00 |

Table 5-1 shows the variation of lengths L_2 and L_3 , and corresponding effects on S-parameter, VSWR, and resonance frequencies. The overall impact on S-parameter, VSWR and radiation efficiency are shown in Figure 5.9 ((a), (b), and (c)) respectively. From Table 5-1 it can be seen that when L_2 decreases and L_3 increases, the S-parameter and VSWR increases, which means the antenna performance degrades. For all of the cases, the values of VSWR at both resonance frequencies are less than 1.50 which indicates that the antenna impedance is reasonably matched with the waveguide port impedance. The best result is achieved when $L_2=7$ mm and $L_3=5$ mm,

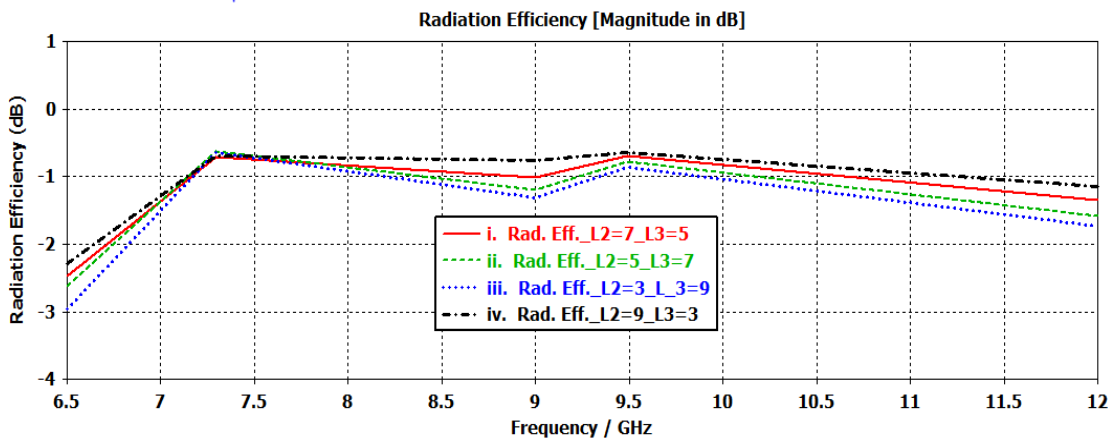
at which $S_{11} = -32.250$ and -41.011 and $VSWR = 1.05$ and 1.02 for f_{r1} and f_{r2} , respectively.



(a)



(b)



(c)

Figure 5.9: Effects of length variation of L_2 and L_3 on S-parameter, VSWR and Radiation efficiency are shown in (a), (b) and (c) respectively.

5.4 Simulation results of the optimized triple band antenna

This designed antenna provides resonance at three separate frequency bands. The antenna dimensional parameters are almost similar to the dual band antenna discussed in the previous section except that the horizontal radiator width that is introduced in Section 4.4. Various simulation results including return loss (S_{11}), VSWR and radiation pattern (both E and H field) and gain versus frequency curves are shown in this section. Figure 5.10 shows the reflection co-efficient (S_{11}) of the triple band reader antenna and Figure 5.11 shows the VSWR curve of this antenna.

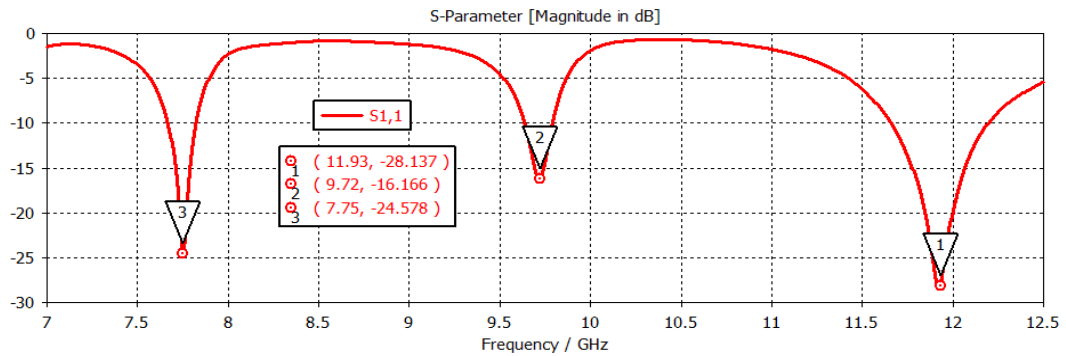
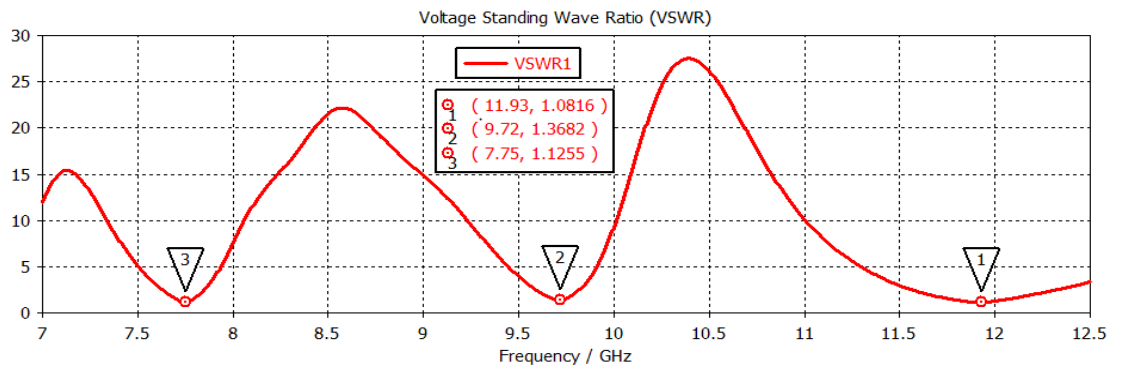
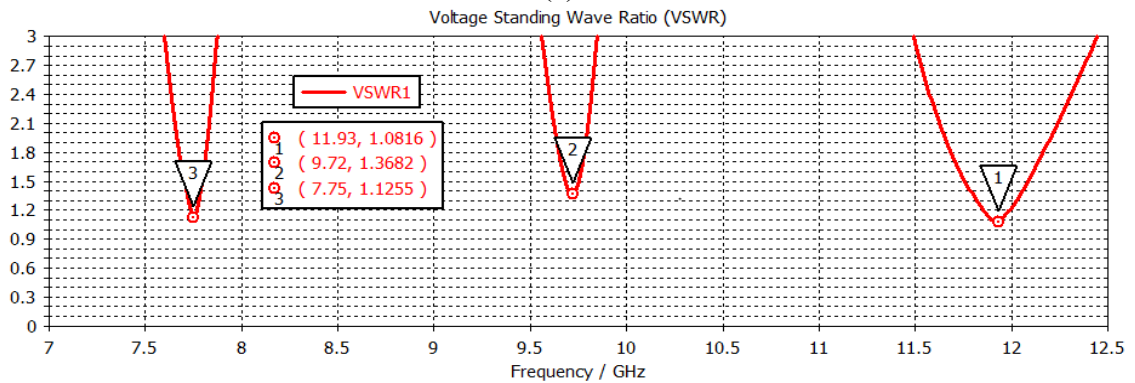


Figure 5.10: Reflection co-efficient (S_{11}) of the triple band reader antenna.



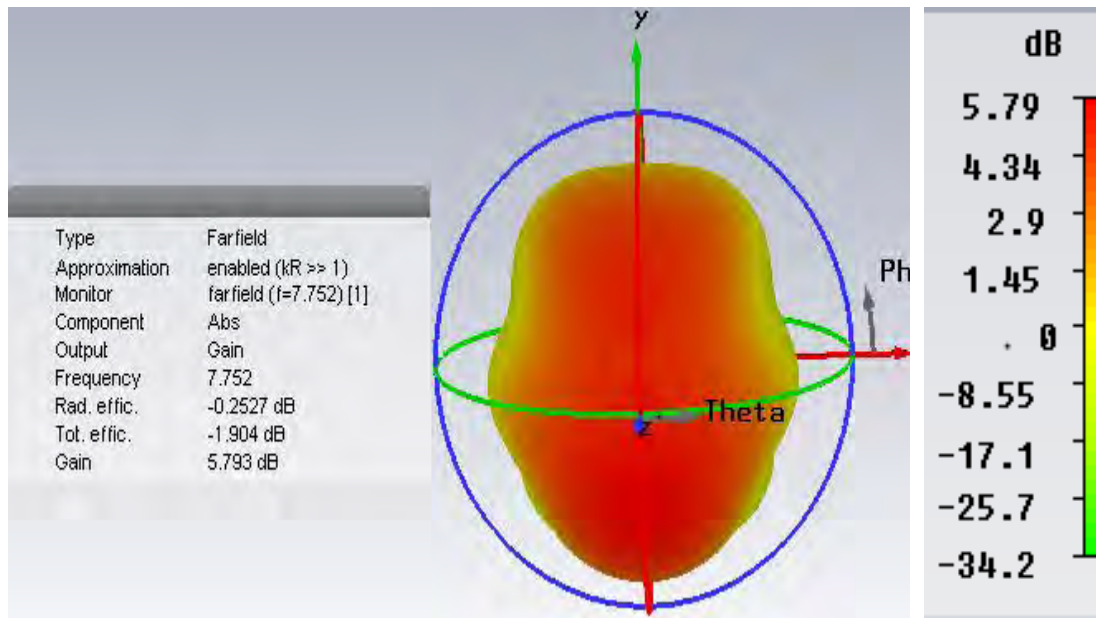
(a)



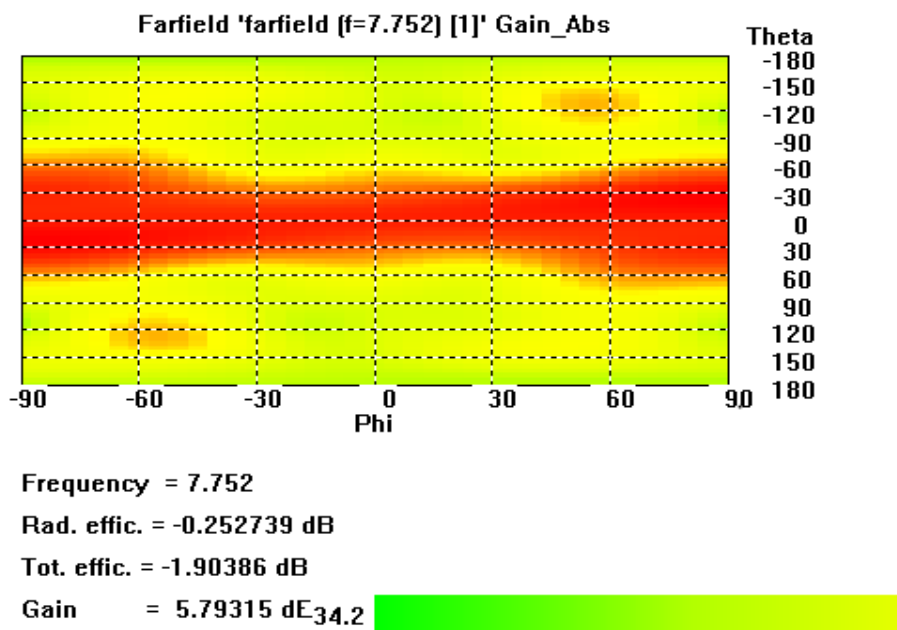
(b)

Figure 5.11: VSWR curve of the triple band reader antenna (a) Full view and (b) Short view.

3 D and 2 D radiation pattern of triple band reader antenna at resonance frequencies f_{r1} , f_{r2} and f_{r3} are shown in Figure 5.12 ((a) and (b)), Figure 5.13 ((a) and (b)), and Figure 5.14 ((a) and (b)) respectively.

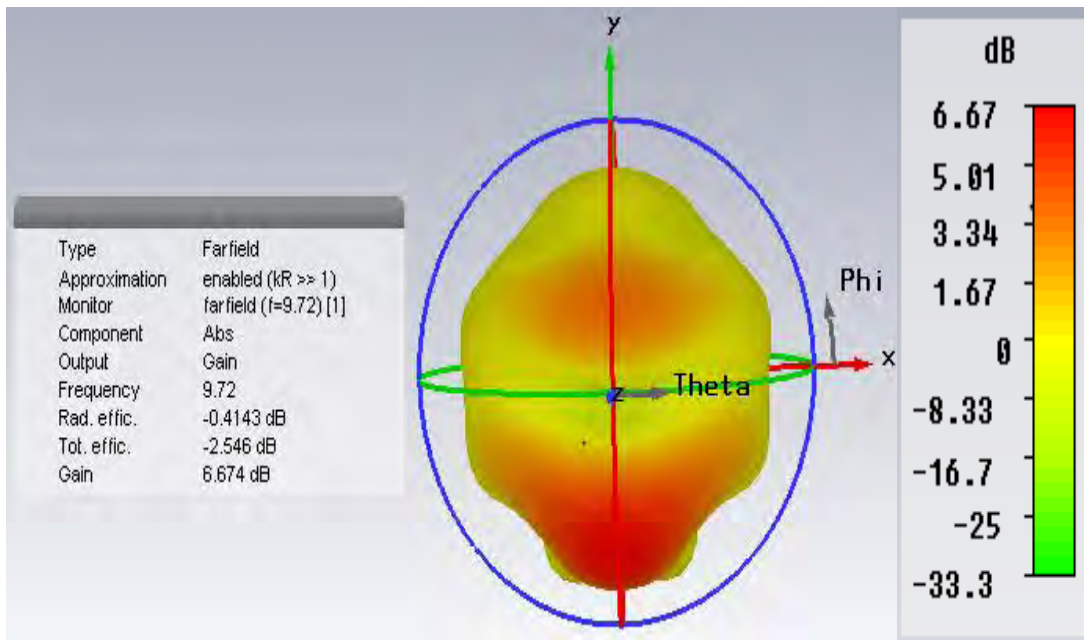


(a)

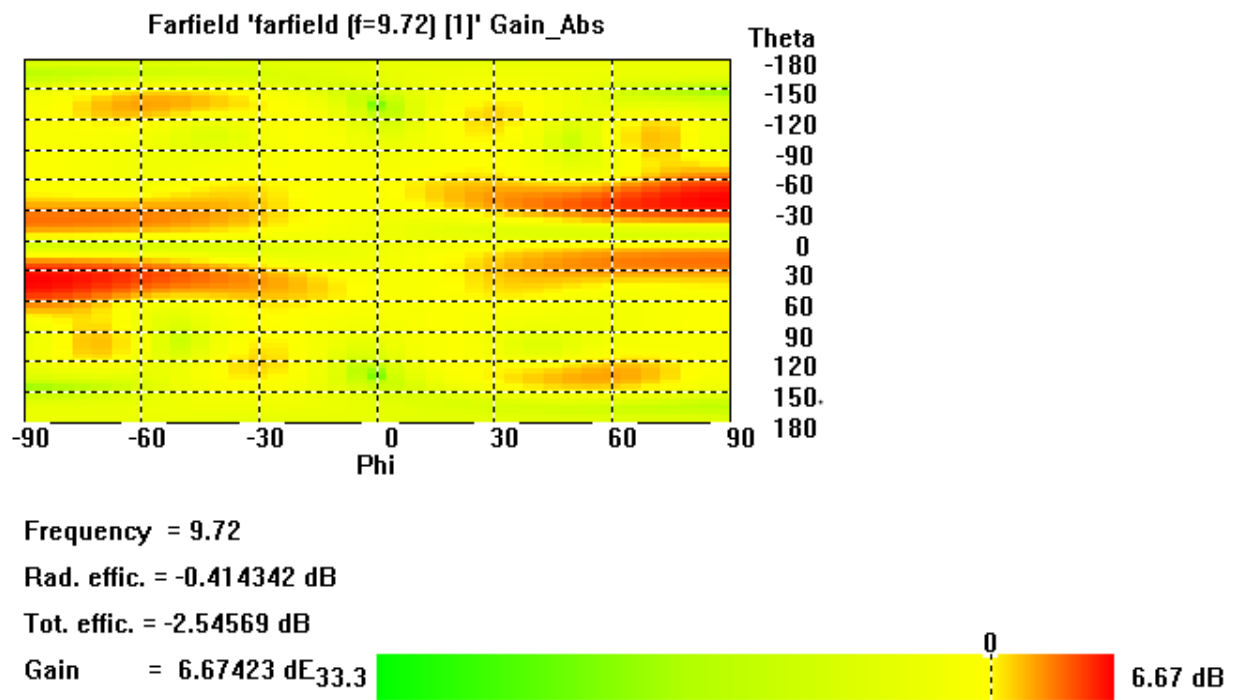


(b)

Figure 5.12: (a) 3-D and (b) 2-D radiation pattern for triple band reader antenna at $f_{r1} = 7.75$ GHz.

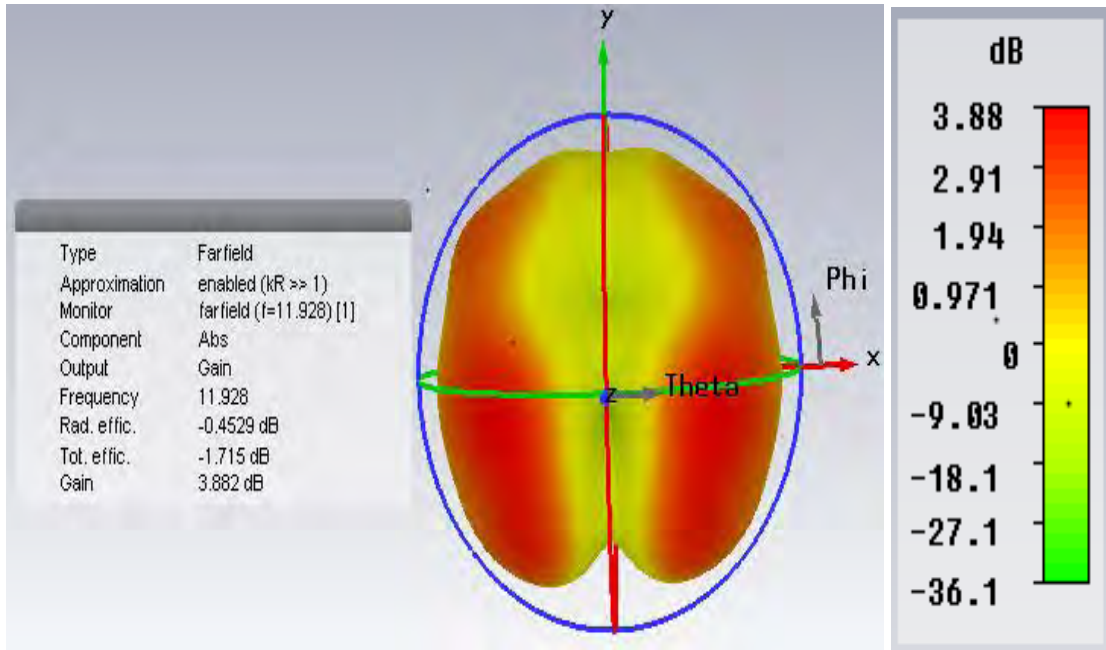


(a)

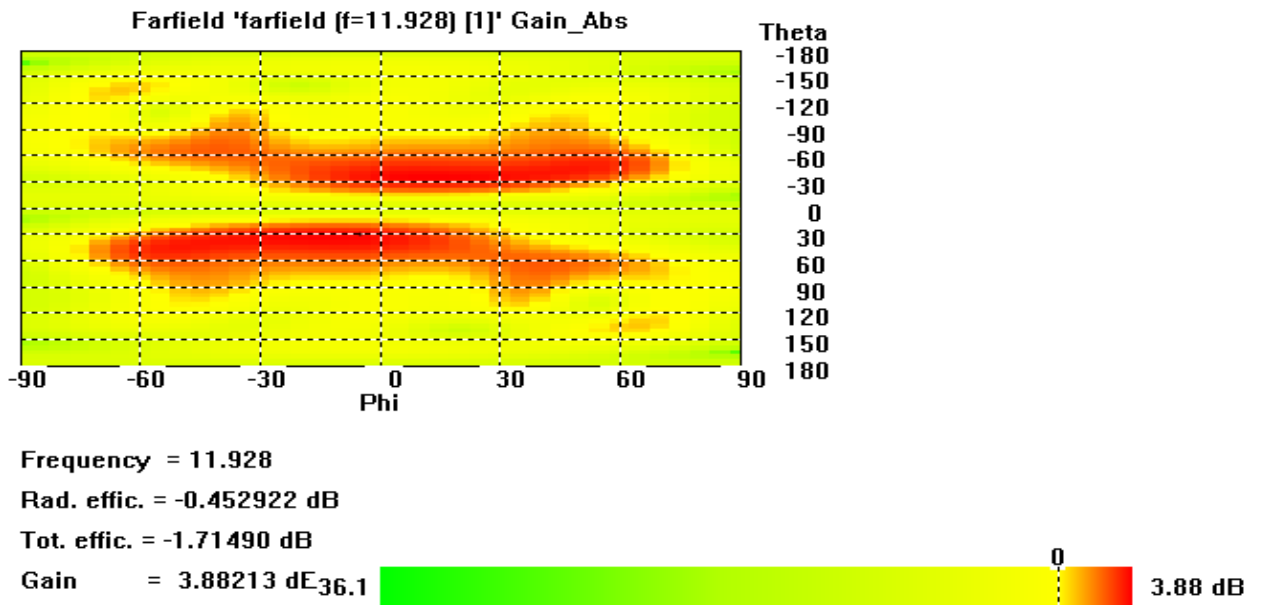


(b)

Figure 5.13: (a) 3-D and (b) 2-D radiation pattern for triple band reader antenna at f_{r1} = 9.72 GHz.



(a)



(b)

Figure 5.14: (a) 3-D and (b) 2-D radiation pattern for triple band reader antenna at $f_{r1} = 11.93$ GHz.

Furthermore, Figure 5.15, Figure 5.16 and Figure 5.17 show the radiation patterns of the antenna at f_{r1} , f_{r2} and f_{r3} , respectively. The simulated radiation pattern at every resonance frequency band shows the main lobe magnitude, 3 dB angular beam width, LSSL, and main lobe direction. The lowest side lobe level is -12 dB achieved at f_{r1} .

The (gain and directivity) at three resonance frequencies are: (5.79 dB and 6.04 dBi), (6.67 dB and 7.09 dBi), and (3.88 dB and 4.33dBi) at f_{r1} , f_{r2} and f_{r3} , respectively. So, the radiation efficiency of this triple band proposed antenna are 94.34%, 90.88% and 90.09% at f_{r1} , f_{r2} and f_{r3} , respectively. The -10 dB return loss bandwidth at these three resonance frequencies are 180 MHz (2.33% of resonance frequency) ranging from 7.66 GHz to 7.84 GHz, 177 MHz (1.83% of resonance frequency) ranging from 9.63 GHz to 9.80 GHz, and 587 MHz (4.93% of resonance frequency) ranging from 11.630 GHz to 12.217 GHz.

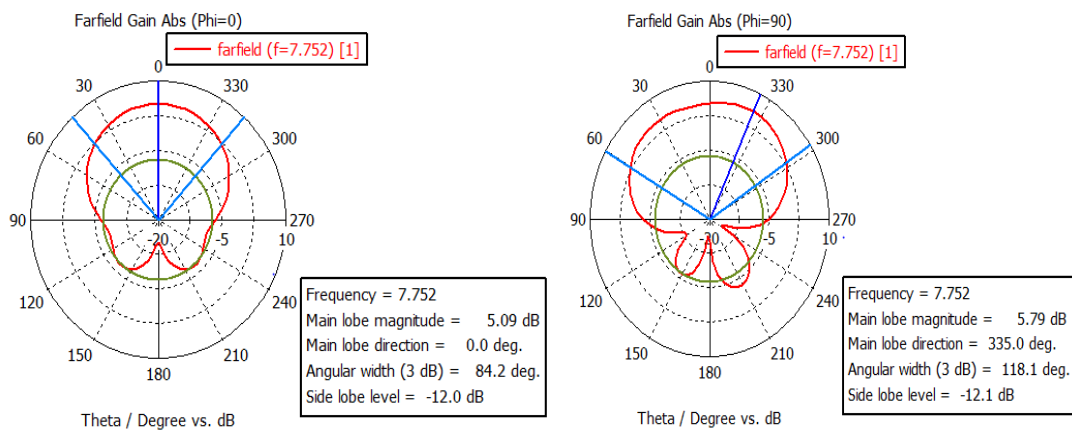


Figure 5.15: E and H-plane radiation pattern for triple band reader antenna at f_{r1} =7.75 GHz.

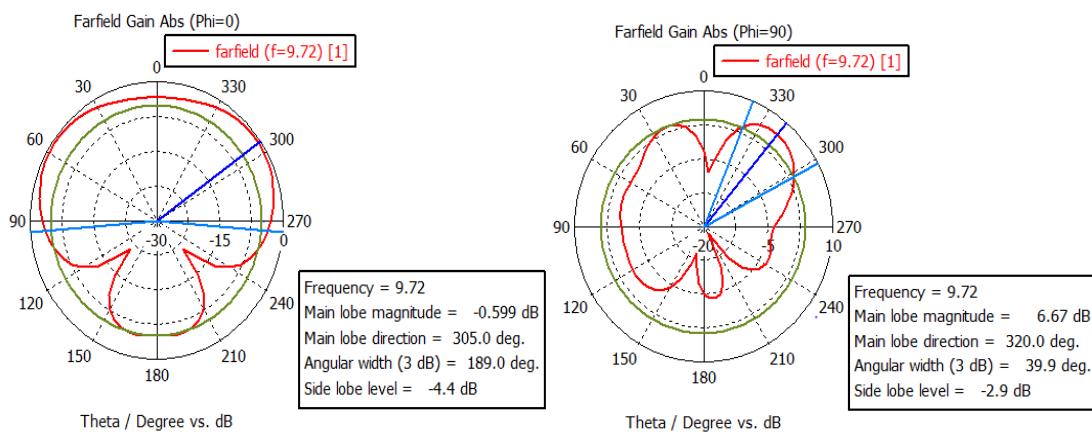


Figure 5.16: E and H-plane radiation pattern for triple band reader antenna f_{r2} =9.72 GHz.

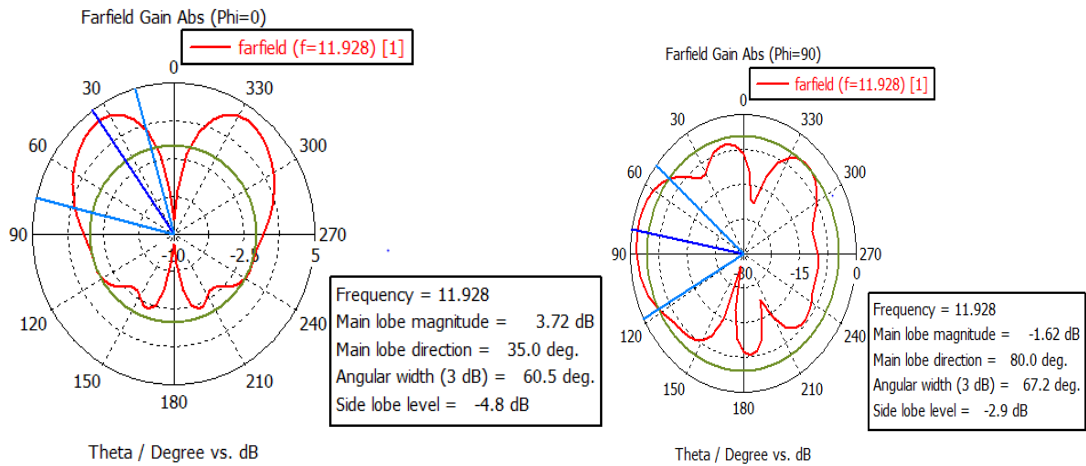


Figure 5.17: E and H-plane radiation pattern for triple band reader antenna at $f_{r3}=11.93$ GHz.

5.5 Simulation results of the double E-shaped triple band array antenna

The simulation results of the proposed array antenna using waveguide ports are at resonance frequencies $f_{r1}=7.23$ GHz, $f_{r2}=10$ GHz and $f_{r3}=11.748$ GHz are presented in this section. The simulated return loss at f_{r1} is -21.16 dB, at f_{r2} is -40.52 dB and at f_{r3} is -34.63 dB, which are shown in Figure 5.18, whereas VSWR at these resonance frequencies are 1.19 dB, 1.02 dB and 1.03, respectively as shown in Figure 5.19.

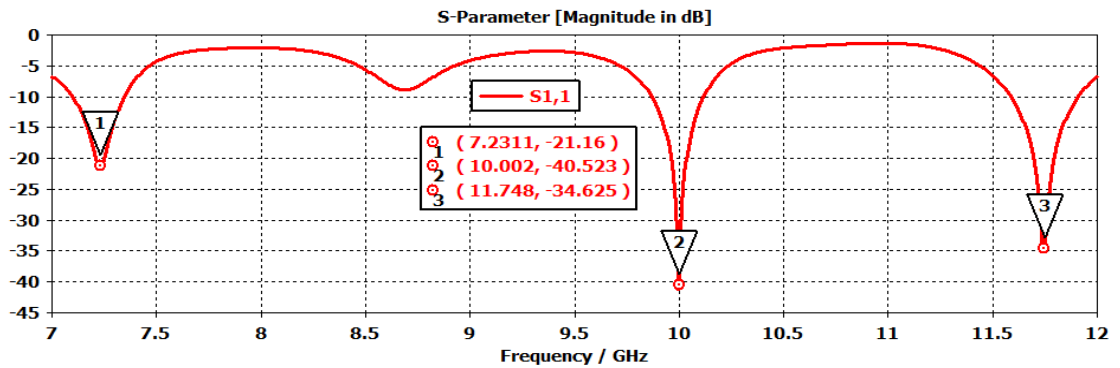
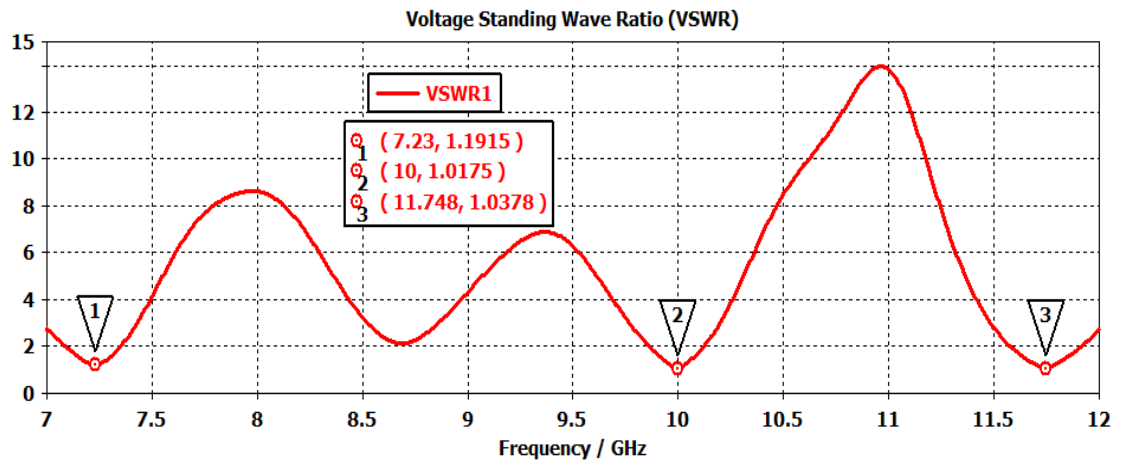


Figure 5.18 : Reflection coefficient (S_{11}) of the double E-shaped triple band array antenna.

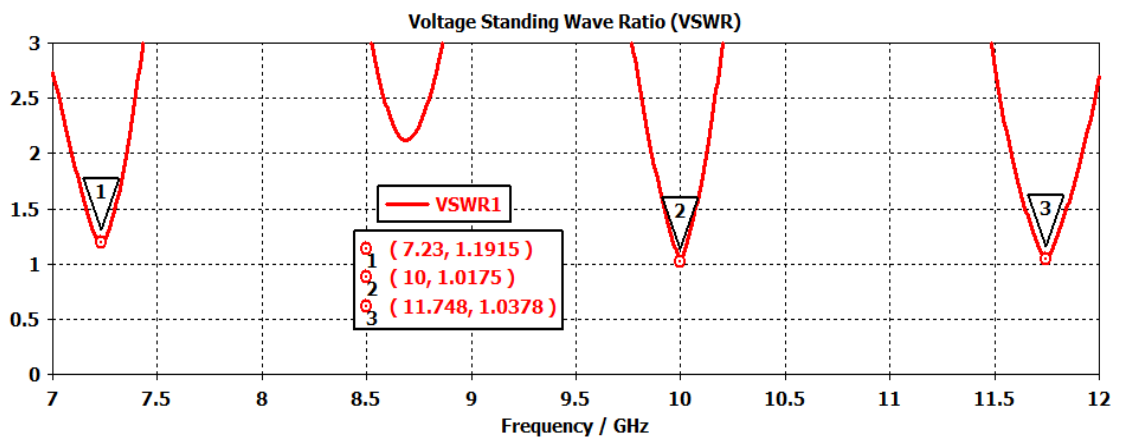
This indicates antenna impedance is considerably matched with the waveguide port impedance as less amount of power is reflected back from the input terminal of the antenna.

The -10 dB return loss bandwidth at these three resonance frequencies are 264 MHz ranging from 7.09 GHz to 7.35 GHz, 270 MHz ranging from 9.86 GHz to 10.13 GHz,

and 362 MHz ranging from 11.574 GHz to 11.936 GHz. The antenna radiation efficiency is the ratio of the gain to the directivity. The radiation efficiency at these three resonance frequencies are 93.97%, 93.45%, and 87.92%, respectively.

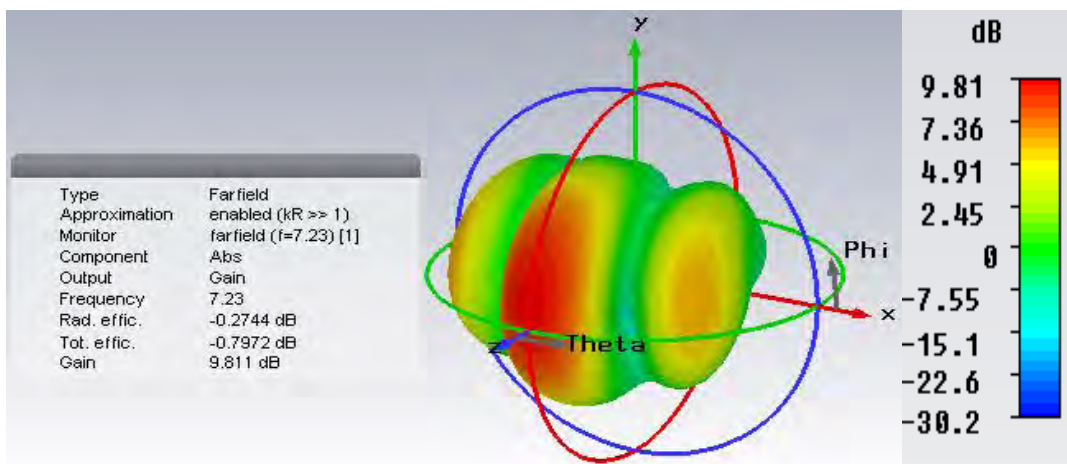


(a)

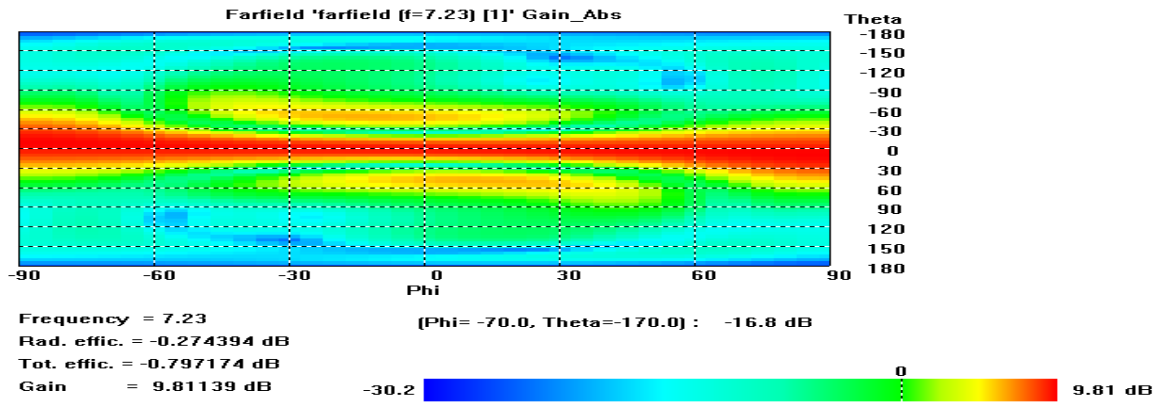


(b)

Figure 5.19: VSWR curve of the double E-shaped triple band array antenna (a) Full view and (b) Short view.



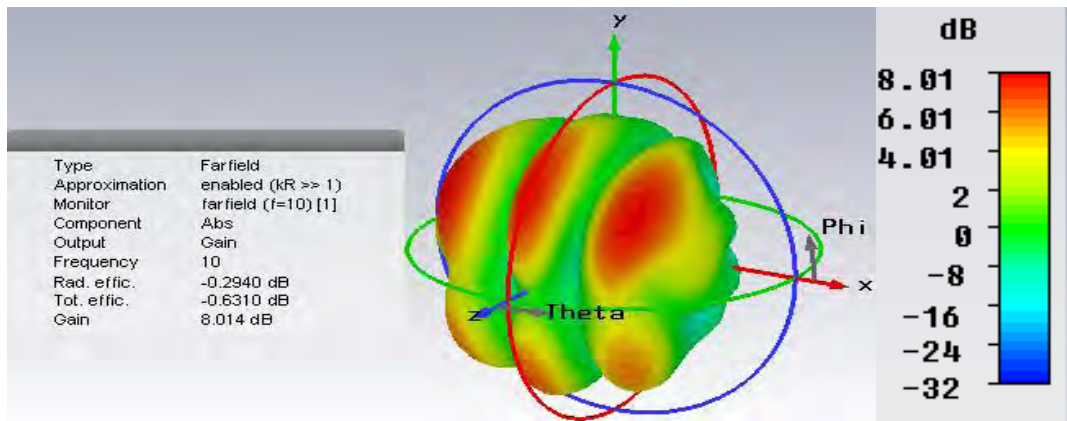
(a)



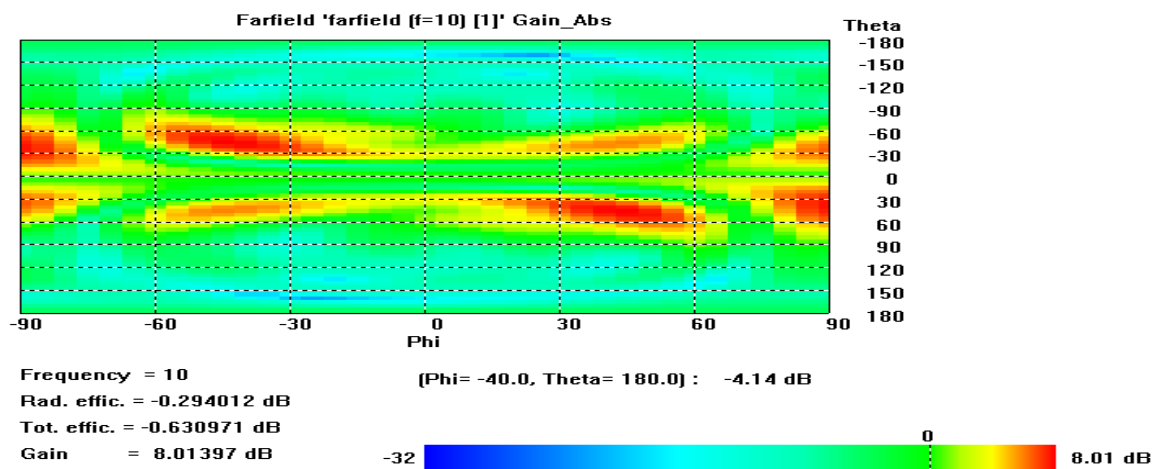
(b)

Figure 5.20: (a) 3-D and (b) 2-D radiation pattern for double E-shaped triple band array antenna at $f_{r1} = 7.23$ GHz.

3 D and 2 D radiation pattern of the double E-shaped triple band array antenna at resonance frequencies f_{r1} , f_{r2} and f_{r3} are shown in Figure 5.20 ((a) and (b)), Figure 5.21 ((a) and (b)), and Figure 5.14 ((a) and (b)) respectively.

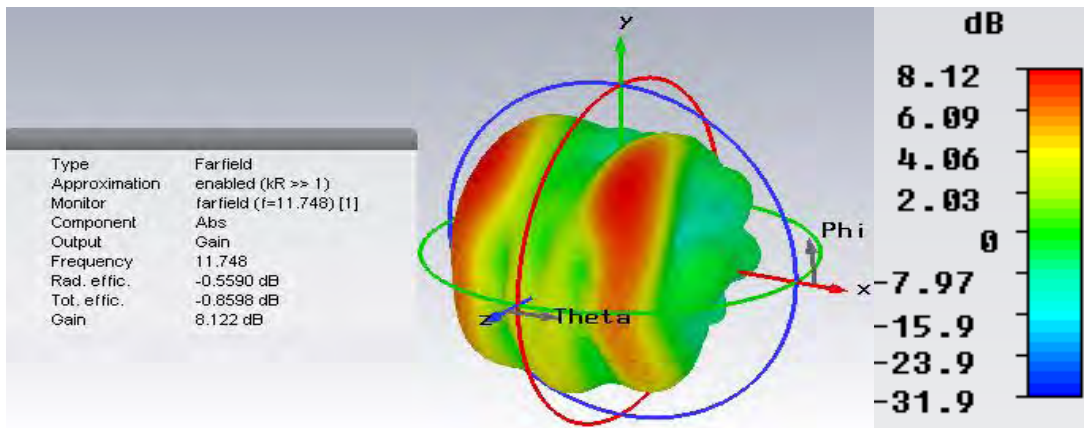


(a)

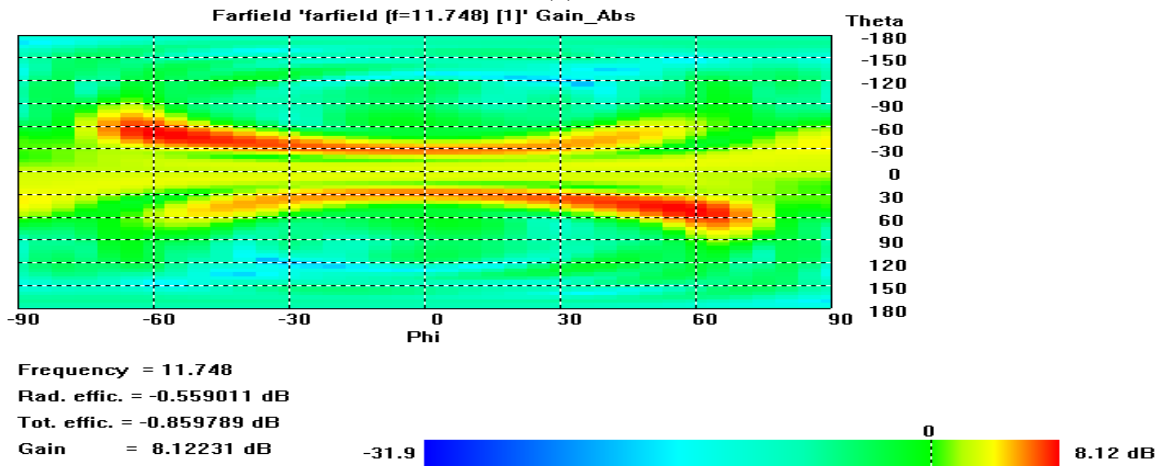


(b)

Figure 5.21: (a) 3-D and (b) 2-D radiation pattern for double E-shaped triple band array antenna at $f_{r2} = 10$ GHz.



(a)



(b)

Figure 5.22: (a) 3-D and (b) 2-D radiation pattern for double E-shaped triple band array antenna at $f_{r3} = 11.748$ GHz.

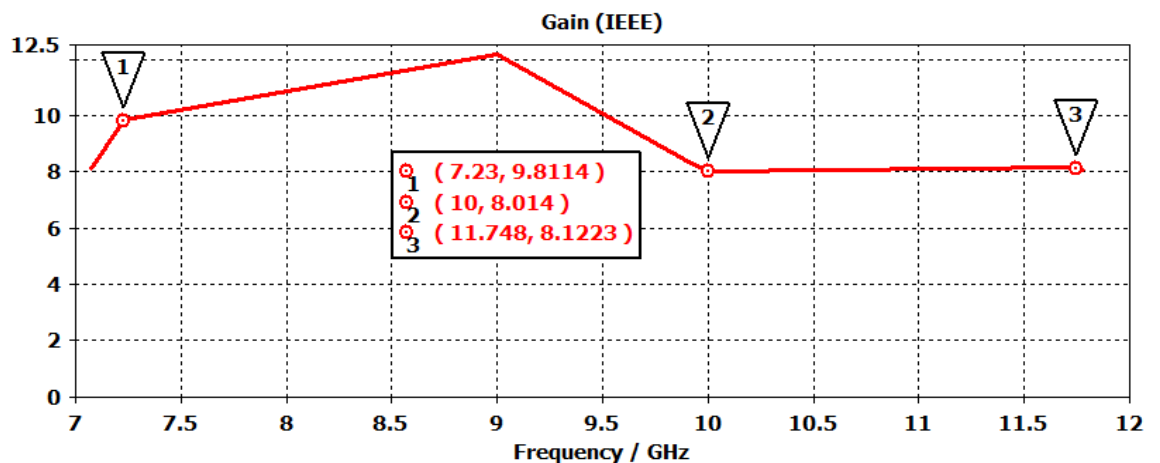


Figure 5.23: Gain vs frequency for double E-shaped triple band array antenna.

Figure 5.23 shows that the gain vs frequency curve of the double E-shaped triple band array antenna. it can be seen that the array antenna has increased gains of 9.81 dB, 8.01 dB and 8.12 dB, while the triple band reader antenna introduced in Section 4.4 has gains of 5.79 dB, 6.67 dB and 3.88 dB at resonance frequencies around 7.50 GHz, 9.75 GHz

and 11.75 GHz, respectively. So, the gain of the double E-shaped triple band array antenna is significantly improved than the triple band reader antenna. The simulated results of triple band reader antenna and double E-shaped triple band array antenna are shown in Table 5-3.

Figure 5.24, Figure 5.25, and Figure 5.26 show the simulated E-plane ($\varphi=0^\circ$) and H-plane ($\varphi=90^\circ$) far field radiation patterns at f_{r1} , f_{r2} , and f_{r3} respectively indicating side lobe level, 3 dB angular beam width, main lobe magnitude and main lobe direction. The simulated parameters at E-plane such as (main lobe magnitude, 3 dB beam width, and LSSL) at these three resonance frequencies are (9.57 dB, 27.3° , and -3.4 dB), (3.77 dB, 42.4° and -2.3 dB), and (6.31 dB, 18.1 dB and -2.9 dB), respectively.

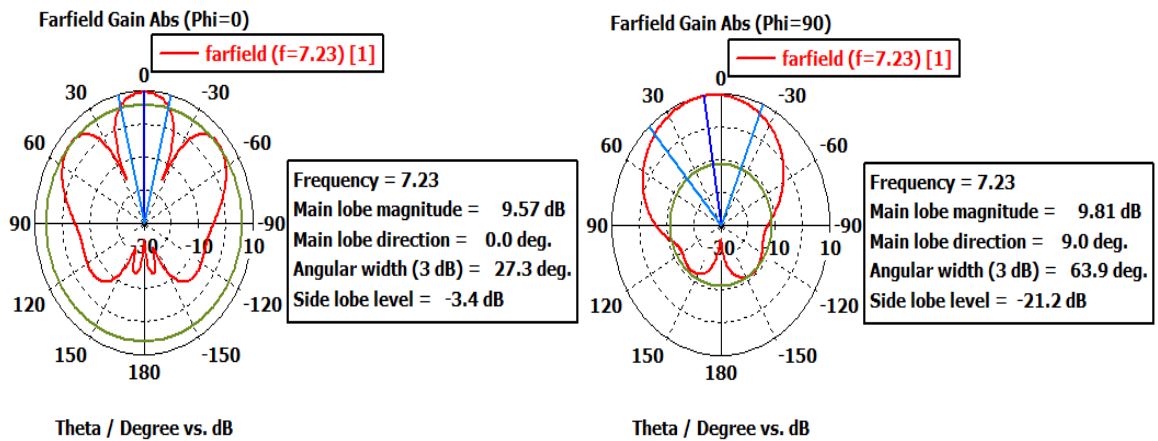


Figure 5.24: E and H plane radiation pattern of the proposed array antenna at $f_{r1}=7.23$ GHz.

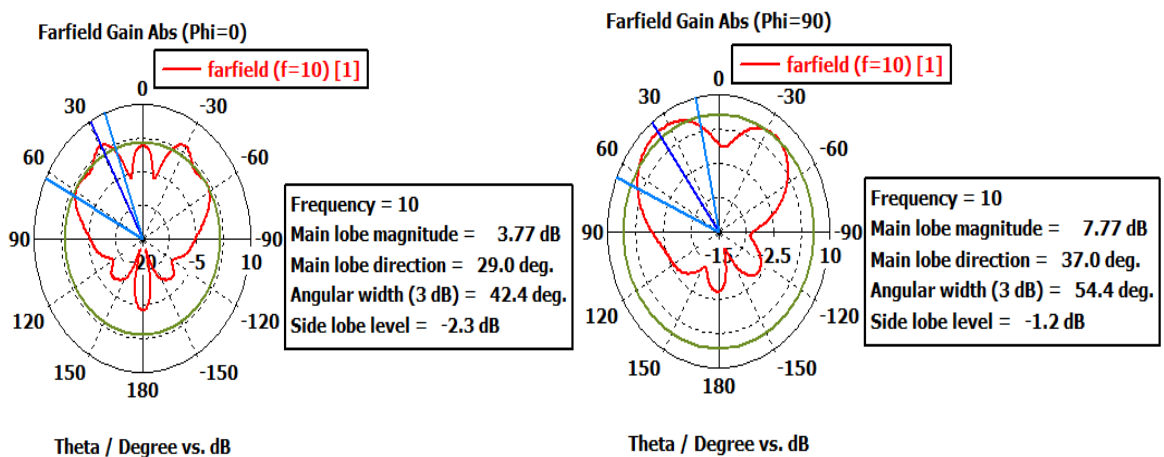


Figure 5.25: E and H plane radiation pattern of the proposed array antenna at $f_{r2}=10$ GHz.

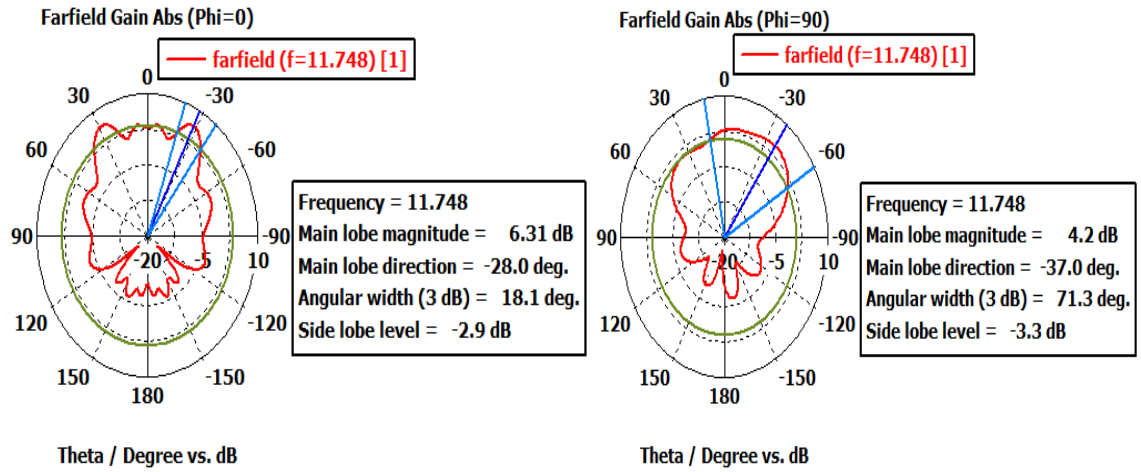


Figure 5.26: E and H plane radiation pattern of the proposed array antenna at $f_{r3}=11.748$ GHz.

5.6 BER performance of the proposed antennas in the centimetr band

In this section, the BER performance of an RFID system is simulated via MATLAB tool. The detail simulation parameters are shown in Table 5-2. Various simulated performance metrics of the three proposed antennas are shown in Table 5-3. Table 5-4 shows the comparison of the Proposed Antennas with the literature.

Table 5-2: Parameters for BER simulations.

| Parameters | Quantity/Level |
|---------------------------------|-----------------------------|
| Fading Channel | Rayleigh/ Rician |
| Baseband Modulation | QAM |
| Constellation Points | 4, 16 |
| Subcarrier Number | 128, 256 |
| Cyclic Prefix (CP) | 25% |
| Doppler Spread (f_d) | 100 Hz |
| Delay Spread (σ) | 0.005×10^{-12} Sec |
| Antenna Bandwidth (Triple Band) | 180 MHz, 177 MHz, 587 MHz. |
| Antenna Bandwidth (Dual Band) | 270 MHz, 300 MHz |

The practical RFID system at outdoor may suffer many environmental effects such as multipath Rayleigh or Rician fading, Doppler spread (f_d) due to the relative motion of the object with respect to RFID reader along with path loss. It has been mentioned in

the Introduction Section that OFDM is applied in this research to reduce the effects of multipath fading that exists in outdoor scenarios. In order to evaluate the BER performance for OFDM based RFID systems, the bandwidths of the transmitted signals are considered. It can be noted that the total bandwidth of the signal is divided into the OFDM subcarriers. The OFDM symbol duration which is the reciprocal of the bandwidth of a subcarrier should be greater than the channel delay spreads (σ). Therefore, the BER performance is a function of the bandwidth of each subcarrier [17]–[19] [56]. An antenna with a large bandwidth can effectively receive a signal of the same bandwidth. In the following, it is considered that the transmitted signal bandwidth is equal to the reader antenna bandwidth. Due to multipath fading, the power received by receiving antennas through line of sight (LOS) and non-line of sight components (N-LOS) are different and corresponding σ are also different. Single tap zero forcing equalizer is taken into account at the RFID reader section. In the simulations, an uncoded target BER of 10^{-4} is considered. This target BER of 10^{-4} is approximately equivalent to 10^{-9} when channel coding is applied.

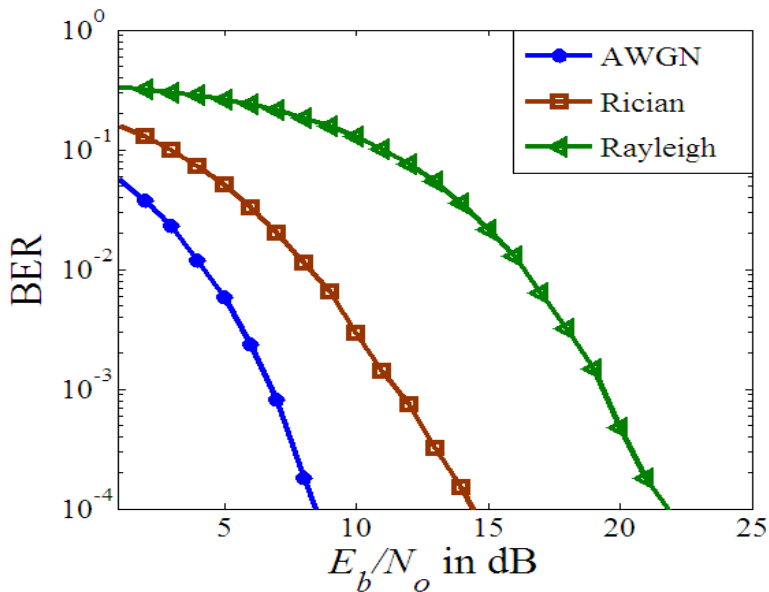


Figure 5.27: BER performance of different channel at fixed bandwidth 270 MHz.

Figure 5.27 represents the BER as a function of E_b/N_0 , the received electrical energy per bit to single sided noise spectral density for the dual band antenna at f_{r2} . At f_{r2} the antenna bandwidth is 270 MHz, so the transmitted and the received signal bandwidths

are also assumed to be 270 MHz. It can be seen that for both Rayleigh and Rician fading channels, E_b/N_0 penalty is occurred in comparison with AWGN channels. In case of no fading (i.e. AWGN channel), E_b/N_0 of 8 dB is required to achieve a BER of 10^{-4} . The E_b/N_0 requirement for Rician fading channel is 14 dB and for Rayleigh fading channel is 24 dB at a given BER of 10^{-4} . So, an extra 10 dB level of E_b/N_0 is required for Rayleigh fading than Rician fading, since in Rician fading a LOS path exists between RFID reader and the tag. In comparison to AWGN channels, at a fixed BER of 10^{-4} , additional 6 dB and 16 dB E_b/N_0 are needed for Rician and Rayleigh fading channels, respectively.

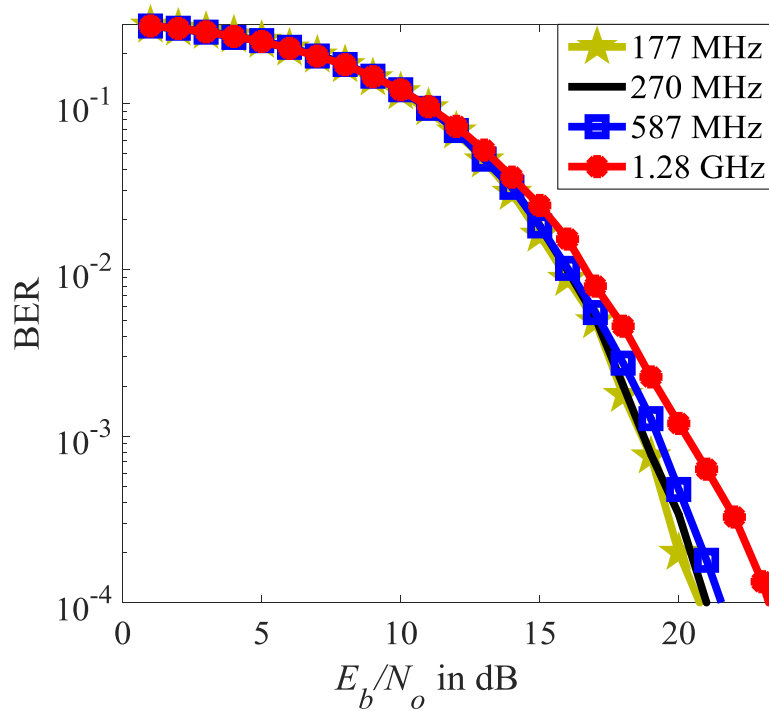


Figure 5.28: BER performance at different resonance frequencies of the proposed antennas.

Figure 5.28 shows the BER as a function of E_b/N_0 by using the bandwidths (177/270/587 MHz) of the proposed antennas and the bandwidth (1.28 GHz) of the antenna in [44]. It is seen that due to the variations of the antenna bandwidths (also the transmitted/received signal bandwidths), the E_b/N_0 requirement is varied for the same target BER. The graph presents that the E_b/N_0 requirement increases when bandwidth of the transmitted/received signal (per subcarrier) increases. For the same BER (10^{-4}),

the E_b/N_0 requirements for bandwidth 177 MHz and 587 MHz are 20.8 dB and 21.5 dB, respectively. So, for a bandwidth 587 MHz, approximately 0.7 dB more E_b/N_0 is required than a bandwidth of 177 MHz. This is because as the bandwidth is lower, the symbol period is greater which means that the delay spread has less influence. Figure 5.28 also shows that the BER performance is 1.8 dB better for a signal bandwidth of 587 MHz (equal to the bandwidth of the proposed triple band antenna) compared to a signal bandwidth of approximately 1.28 GHz which is equal to the bandwidth of the antenna proposed in [44].

The BER performance of an RFID system is shown in Figure 5.29 can further improved with the application of channel coding. In this case, rate 1/2 convolution coding with Viterbi soft-decision decoding is considered. The encoding operation is done by means of a trellis structure for the generator polynomial with a constraint length of 7 and feedback taps located at the octal numbers 171 and 133. Note that rate 1/2 means the ratio of the number of input bits to the number of output bits is 1 to 2. Moreover, constraint length 7 means the number of delay elements in the convolutional coding is 6. Furthermore, the generator polynomials of 171 and 133 are used for wiring of the input sequence with the delay elements to form the encoded output. Figure 5.29 shows the plots for AWGN and Rician fading channels with antenna bandwidth of 390 MHz. The plots indicate that at an E_b/N_0 of 15 dB, the BER for an uncoded Rician channel is 10^{-4} , whereas the BER for a convolutionally coded Rician channel is 10^{-7} .

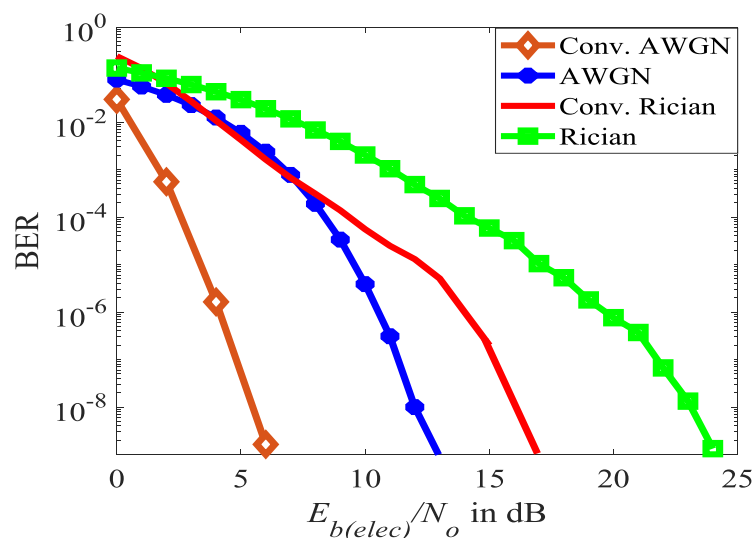


Figure 5.29: BER performance of AWGN and Rician fading channels with and without convolutional coding

5.7 Comparative study of antennas

In all of the proposed dual band, triple band and dual band microstrip array antennas, the S_{11} is always less than -10 dB at the resonance frequencies, which indicates that the designed antenna impedance is considerably matched with waveguide port impedance. The overall simulated results of the three proposed antennas are shown in Table 5-3. In case of dual band antenna, the bandwidth at $f_{r1}=7.30$ GHz is 300 MHz which is slightly higher than the bandwidth of 270 MHz at $f_{r2}=9.50$ GHz. At f_{r1} , the S-parameter is -32.25 dB, whereas at f_{r2} , the value of S-parameter is -41.01 dB. The lowest side lobe level (LSLL) at H-plane for f_{r1} and f_{r2} are -16.90 dB and -11.90 dB, respectively. The radiation efficiency values for dual band antenna are 85.00% and 87.14% for f_{r1} and f_{r2} , respectively. Although large bandwidth is more desirable for antennas, a smaller bandwidth means more robustness to multipath fading effects. Therefore, in terms of BER performance, radiation efficiency and S-parameters, f_{r2} is more preferable than f_{r1} for RFID communication in outdoor applications. In case of triple band antenna, the bandwidths at the three resonance frequencies (f_{r1} , f_{r2} and f_{r3}) are 180 MHz, 177 MHz and 587 MHz, respectively. The S-parameter and radiation efficiency levels at f_{r1} are -25.99 dB, and 94.34%, respectively. On the other hand, the S-parameter and radiation efficiency levels at f_{r2} are -15.85 dB and 90.88%, respectively. These two parameters have values of -29.34 dB and 90.09%, respectively at f_{r3} . The LSLL of the proposed triple band antenna at f_{r1} , f_{r2} and f_{r3} are -12.1 dB, -2.9 dB and -2.9 dB, respectively. The LSLL for dual band antenna at f_{r1} is -13.90 dB and -16.90 dB for E and H-plane, respectively. However, for triple band antenna, the LSLL at f_{r1} is -12.0 dB and -12.1 dB for E and H-plane, respectively. Consequently, the LSLL values are less in dual band compared to triple band where the lowest side lobe level indicates that maximum power radiates through the main lobe.

The double E-shaped triple band array antenna provides resonance at $f_{r1}=7.23$ GHz, $f_{r2}=10$ GHz and $f_{r3}=11.748$ GHz. Bandwidth of the proposed array antenna are 264

MHz, 270 and 362 MHz at frequencies f_{r1} , f_{r2} , and f_{r3} respectively. The (gain and directivity) of the antenna at these three different frequencies are (9.81 dB and 10.13 dBi), (8.01 dB and 8.308 dBi) and (8.12 dB and 8.681 dBi) respectively. The (radiation efficiency, and bandwidth) at these three resonance frequencies are (93.97%, 264 MHz), (93.45%, 270 MHz), and (87.92%, 362 MHz), respectively.

In this section, the proposed dual band, triple band and triple band array antennas are compared with the antennas described in the relevant literature. An important feature of the proposed dual band, triple band and dual band microstrip array antennas is that the sizes of the designed antennas are smaller than the antennas reported in [10], [11], [58], [81], [83], [109], [110]. However, the proposed dual band, triple band and dual band microstrip array antenna sizes are larger than the antennas reported in [44], [111], [112] where the centre frequencies are less than those of the proposed antennas. Table 5-4 shows that the gain values of the proposed dual band antenna, triple band antenna and triple band array antenna antennas are higher than those of the reference antennas except the work in [44], [81], [83]. Table 5-4 also shows that triple band antenna has a resonance frequency at 11.93 GHz and triple band array antenna has a resonance frequency 11.748 GHz which are larger than any frequency described in [58], [67], [81], [83], [109]–[112]. This makes the proposed triple band antenna attractive since RFID technology is moving towards centimetre and millimetre wave band [113] to solve the problem of the spectrum crunch. It can also be noted that, both the dual and triple band antennas have bandwidths lesser than the ones reported in [44], [67]. However, it has been shown in Section 5.6 that bit error increases when the received signal bandwidth increases in a multipath fading channel.

Table 5-3: Performance metrics of dual band antenna, triple band antenna and double E-shaped triple band array antenna.

| Antennas | Dual Band | | Triple Band | | | Triple Band Array | | |
|---------------------------------|---------------|---------------|---------------|---------------|----------------|-------------------|-------------|-----------------|
| Resonant Frequency (GHz) | $f_{r1}=7.30$ | $f_{r2}=9.50$ | $f_{r1}=7.75$ | $f_{r2}=9.72$ | $f_{r3}=11.93$ | $f_{r1}=7.23$ | $f_{r2}=10$ | $f_{r3}=11.748$ |
| S-parameters (dB) | -32.25 | -41.01 | -25.99 | -15.85 | -29.34 | -21.16 | -40.52 | -34.625 |
| Bandwidth | 300.00 | 270.25 | 184.50 | 177.75 | 587.00 | 264 | 270 | 362 |

| Antennas | | Dual Band | | Triple Band | | | Triple Band Array | | |
|---|---------|-----------|-------|-------------|--------|-------|-------------------|-------|-------|
| Rad. Efficiency (%) | | 85.00 | 87.14 | 94.34 | 90.88 | 90.09 | 93.97 | 93.45 | 87.92 |
| Gain (dB) | | 7.628 | 5.06 | 5.793 | 6.674 | 3.882 | 9.81 | 8.01 | 8.12 |
| Directivity (dBi) | | 8.339 | 6.198 | 6.046 | 7.089 | 4.335 | 10.13 | 8.308 | 8.681 |
| Main lobe magnitude (dB) | E-plane | 7.51 | 4.77 | 5.09 | -0.599 | 3.72 | 9.58 | 3.77 | 6.31 |
| | H-plane | 2.18 | 7.44 | 5.79 | 6.67 | -1.62 | 9.81 | 7.77 | 4.2 |
| LSLL (dB) | E-plane | -13.90 | -10.5 | -12.0 | -4.4 | -4.8 | -3.4 | -2.3 | -2.9 |
| | H-plane | -16.90 | -11.9 | -12.1 | -2.9 | -2.9 | -21.2 | -1.2 | -3.3 |
| SNR requirement (dB) to achieve 10^{-4} BER | | 21.70 | 21.0 | 20.85 | 20.8 | 21.5 | - | | |
| 3-dB Beam width | E-plane | 108.3 | 108.3 | 84.2 | 189.0 | 60.5 | 27.3 | 42.4 | 18.1 |
| | H-plane | 65.2 | 81.8 | 118.1 | 39.9 | 67.2 | 63.9 | 54.4 | 71.3 |

Table 5-3 is used to represent the various simulated parameters of the proposed three antennas in tabular form.

Table 5-4: Comparison of the Proposed Antennas with the existing antennas available in the literature.

| Reference Antennas | Size in mm ² | Operating Bands in GHz | Bandwidth in GHz | Gain (dB) |
|--------------------|-------------------------|---------------------------|------------------|--------------------|
| Ref [10] | 100×70 | 0.915, 2.45 | - | - |
| Ref [11] | 341×341 | 0.86 to 0.96 | 0.1 | 9.5 |
| Ref [44] | 34.35×29.52 | 10, 60 | 0.384 | 13.84 |
| Ref [67] | 52×37 | 10.5 | 1.575 | 3.08 |
| Ref [83] | 64×62 | 2.44, 3.55, 5.79 | - | 1.65, 3.73, 6.32 |
| Ref [81] | 100×60 | 2.4, 5.00 | 0.12, 2.10 | 8, 9 |
| Ref [58] | 130×130 | 0.922 | 0.106 | 4.9 |
| Ref [109] | 120×40 | 2.40, 5.20, 5.80 | 0.51, 1.01 | 1.48, 2.30, 3.05 |
| Ref [110] | 63×125 | 0.7-0.8, 1.6-2.8, 3.3-3.8 | - | 0.10-0.60, 0.8-2.3 |
| Ref [111] | 27.5×13 | 2.40, 3.50, 5.50 | - | 0.71, .95, 2.36 |

| Reference Antennas | Size in mm² | Operating Bands in GHz | Bandwidth in GHz | Gain (dB) |
|---|-------------------------------|-------------------------------|---------------------------|---------------------|
| Ref [112] | 13×12 | 2.98, 4.73, 5.70 | - | 2.59, 3.58, 2.29 |
| Modified structure of [44] (Dual Band) | 40.292× 35.117 | 7.30, 9.50 | 0.27, 0.30 | 5.50, 7.628 |
| Proposed Triple Band | 40.292× 35.117 | 7.75, 9.72, 11.93 | 0.185, 0.177, 0.587 | 5.793, 6.674, 3.882 |
| Proposed Triple Band Array | 86.584× 35.117 | 7.23, 10, 11.748 | 0.264, 0.270, 0.362 | 9.81, 8.01, 8.12 |

The proposed antennas size, gain, bandwidth, and resonance frequencies are compared with the various reference antennas are shown in Table 5-4.

5.8 Conclusion

The overall simulation results of the proposed antennas are described in this chapter. Various performance metrics of the antennas are compare with each other. On the other hand, simulated results of these antennas are also compared with the reference paper that are described in the Literature section of this thesis. Concluding remarks as well as impairments and future scope of this thesis are discussed in the next chapter.

6 Chapter 6

Conclusion

6.1 Introduction

In modern era, RFID is a technology for automated identification of objects and people, which is the good replacement of barcode technology. The main features of RFID are that these provide both LOS and N-LOS communication. RFID can communicate with tracking objects both in indoor and outdoor whereas barcode technology is applicable for only indoor LOS communication. In addition, RFID is the pre-requisite of IoT. Fundamentally, RFID systems consist of four elements: RFID reader, RFID tag, the antennas for both reader and tag and the computer network that is essentially connect with RFID readers. Due to use of RFID both in N-LOS and outdoor scenarios its performance is deteriorated by many parameters such as multipath fading, Doppler spread and other environmental obstacles. Different frequency bands are used to the deployment of RFID communication and the performance of RFID system depends on the used frequency band, reader/ tag antenna performance, and fading effects. Therefore, effective antenna design and the use of OFDM can improve the performance of RFID communication.

6.2 Outcome of this thesis

The contributions of the thesis are summarized as follows.

6.2.1 An OFDM based outdoor RFID communication system

This thesis introduces an OFDM based RFID system. For this purpose, an OFDM receiver is used in RFID reader section and an OFDM transmitter is used in RFID tag section. The BER performance of the OFDM based RFID system using the proposed antennas is evaluated for Rayleigh and Rician fading channels.

6.2.2 Two RFID patch antennas

Two antennas are proposed for the OFDM based RFID Communication system. A dual and a triple band microstrip patch antenna. These two antennas are simulated using CST Microwave Studio for RFID reader section at centimeter band. The designed dual band

antenna provides resonance at frequencies $f_{r1} = 7.30$ GHz and $f_{r2} = 9.50$ GHz. The return loss (S_{11}), gain, directivity, radiation efficiency and bandwidth at f_{r1} is -32.25 dB, 7.628 dB, 8.339 dBi, 85.00% and 300 MHz respectively. The beam width at this frequency is 46° for E-plane and 65.2° for H- plane. In case of f_{r2} for dual band antenna, the return loss (S_{11}), gain, directivity, radiation efficiency and bandwidth is -41 dB, 5.60 dB, 6.198 dBi, 87.14% and 270 MHz respectively. The beam width at this frequency is 108.3° for E-plane and 81.8° for H- plane. In this thesis, it is also shown that the variation of lengths L_2 and L_3 , causes change in the corresponding effects on S-parameter, VSWR and resonance frequencies. In addition, it is explicit that when L_2 decreases and L_3 increases, the S-parameter increases, which means the antenna performance degrades. For all of the cases, the values of VSWR at both resonance frequencies are less than 1.50 which indicates that the antenna impedance is reasonably matched with the waveguide port impedance. The best result is achieved when $L_2 = 7$ mm and $L_3 = 5$ mm, at which $S_{11} = -32.25$ and -41.011 for f_{r1} and f_{r2} respectively. On the other hand, triple band antenna provides resonance at $f_{r1} = 7.75$ GHz, $f_{r2} = 9.72$ GHz and $f_{r3} = 11.93$ GHz. The return loss (S_{11}), gain and directivity are: -25 dB, 5.79 dB, 6.04 dBi at f_{r1} ; -12.5 dB, 6.67 dB, 7.09 dB at f_{r2} and -28.5 dB, 3.88 dB and 4.33 dB at f_{r3} . The bandwidth and radiation efficiency are: (180 MHz, 94.34 %), (177 MHz, 90.88 %) and (587 MHz, 90.09 %) at f_{r1} , f_{r2} and f_{r3} respectively. The beam width at this three resonance frequencies are 84.2° , 189° and 60.5° . It is manifested that the minimum side lobe level for dual band antenna is -16.9 dB and for the triple band antenna it is -12.1 dB. Among the three proposed antennas, the highest bandwidth 587 MHz is achieved in case of triple band antenna at f_{r3} . The size of the dual band and triple band is equal and it is 40.292×35.117 mm².

6.2.3 Double E-shaped triple band array antenna

A double E-shaped triple band array antenna is also proposed in this thesis. The size of the array antenna is 86.584×35.117 mm². The array antenna is designed using two triple band RFID reader antenna. Moreover, using CST the simulation results of the proposed dual band microstrip array antenna is evaluated. The simulated S_{11} , gain, directivity, and bandwidth of this antenna are (-21.16 dB, -40.52 dB, and -34.625 dB), (9.81 dB, 8.01 dB and 8.12 dB), (10.13 dBi, 8.308 dBi, and 8.681 dB) and (264MHz,

270 MHz, and 362) at frequency $f_{r1}=7.23$ GHz, $f_{r2}=10$ GHz and $f_{r3}=11.748$ GHz respectively. It is manifested that the minimum side lobe level for the dual band microstrip array antenna is -21.2 dB at f_{r1} . The comparative study of the proposed antennas with the reference antennas are also demonstrated in this research.

6.2.4 BER performance of the antennas

The BER performance of proposed OFDM based RFID system is evaluated using the bandwidth of designed antennas. To evaluate the BER of the proposed RFID system, 100 Hz Doppler spread is considered and QAM modulation is used to mapping the signal. The BER vs E_b / N_0 graph is obtained using MATLAB tools. Considering the bandwidth for transmitted and received signal is equal to the bandwidth (270 MHz) of the dual band antenna at resonance frequency f_{r2} . Using this consideration the BER vs E_b / N_0 is drawn which shows that for same bandwidth and same BER (10^{-4}), larger amount of E_b / N_0 is required for both Rayleigh and Rician fading channels in compare with AWGN channel. It is apparent that the required amount of E_b / N_0 for AWGN channel, Rician fading and Rayleigh fading channel are 8 dB, 14 dB and 24 dB respectively for 10^{-4} BER. Consequently, the compensation of E_b / N_0 for Rician and Rayleigh fading channel is 6 dB and 16 dB respectively in resemble with AWGN channel. An extra 10 dB of E_b / N_0 is required to achieve 10^{-4} BER for Rayleigh fading than the Rician fading channel because there exists a LOS component in Rician fading channel whereas Rayleigh fading does not have. It is clearly exhibited that due to the variations of the antenna bandwidths (also the transmitted/received signal bandwidths), the E_b / N_0 requirement is varied for the same target BER. For the same BER (10^{-4}), the requirements for bandwidth 177 MHz and 587 MHz are 20.8 dB and 21.5 dB, respectively. The BER performance is 1.8 dB better for a signal bandwidth of 587 MHz (equal to the bandwidth of the proposed triple band antenna) compared to a signal bandwidth of approximately 1.28 GHz, which is equal to the bandwidth of the antenna proposed in [38]. This is because as the bandwidth is lower, the symbol period is greater which means that the delay spread has less influence.

6.3 Future work

In foreseeable future, the ubiquity of RFID technology and other enabling technologies, combined with high standards and customer demand for unique products based on this infrastructure, will lead to a revolutionary change in the way we perceive the relationship between information and physical objects and locations. For this purpose, an efficient antenna design as well as its hardware implementation is very essential. Hereafter, in this thesis, the proposed antennas provide better result than some of the reference antennas but in some cases especially for gain and antenna dimensions the proposed antennas are slightly inferior to the reference antenna introduced in [10, 38, 50] and [38,106,107] respectively that will be solve in future. The proposed double E-shaped triple band array antenna provides resonance slightly different than the resonance frequencies of the triple band reader antenna. The performance of array antenna can be evaluated further using CST optimization tools. In future, the simulated results of the proposed antennas will be compared with the experimental results. Hereafter, an antenna may be designed that provides high gain. This is because RFID read range is proportional to the antenna gain according to the Friis free space transmission equation. So, antenna with high gain will be highly desirable to rectify RFID read range. Moreover, an antenna at mm wave especially at unlicensed 57 - 66 GHz frequency band can be designed for high speed MMID communication which can be useful not only for RFID but also for IoT and other high speed wireless communications. In future, methods will be explored to combat the effect of Doppler spread on the BER performance of OFDM based RFID system.

6.4 Summary

The proposed OFDM based RFID system will be good candidate for outdoor applications. Due to the use of OFDM technique, most of the obstacles that may arise in outdoor environment can be minimized effectively. Moreover, most of the simulated results of the proposed antennas are in the acceptable range so that they will be a good contestant for RFID reader applications. It is notable that for the same BER, the required SNR will be varied depending on multipath fading channels. However, because of the use of OFDM, the proposed system exhibits better BER performance than conventional RFID system. Compared with the recent research reported in the literature, the multiband antennas are shown to have better gain operating at higher spectrum, without significantly increasing the physical dimensions.

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