A Novel Method for Cluster Detection of RFID-Tags using Multilinear Polarized Antenna

HUSSAIN SALEEM SHEIKH[1], FAHIM GOHAR AWAN[2], ASIMA KIRAN[3]

[1]Center for Energy Research and Development, University of Engineering and Technology, Lahore, PAKISTAN
[2]Department of Electrical Engineering, University of Engineering and Technology, Lahore, PAKISTAN
[3]Department of Electrical Engineering LCWU Lahore, PAKISTAN

Abstract: Product identification using barcodes has gained good astounding, especially at the point of sale, where different products are being scanned individually before making the payment receipt. These products when at the warehouse meets issues like individual scanning demands significant time and labor to be involved in the human error. Barcodes have been in a process of replacement by Radio Frequency Identification (RFID). RFID is a technology that enables data transfer wirelessly and provides several advantages over barcodes which mandatory requires line of sight. Much of the work has been done on RFID tag antenna design, but efficient reader antenna design has been a major need of the hour for big warehouses, that came across bulk data to manage on daily basis. RFID reader antennas are unable to focus their RF energy on a desired zone. This paper proposes a novel multi-linear polarized RFID reader antenna design that utilizes the RF energy efficiently to meet the bulk reading application that will help in managing the tagged stock for industrial application.

Keywords: RFID, RF energy, warehouse management.

Received: March 10, 2021. Revised: June 28, 2021. Accepted: July 9, 2021. Published: July 16, 2021.

1. Introduction

Inventory in the warehouses is being stocked using manual procedures or labeled with a barcode in many cases. Now with barcoded stock when moved from one place to another, these barcodes were scanned before making any entry to a particular location or if the barcodes are not being used then manual entries are made against that particular product on provided worksheet or register [1]. Similarly, at the time of inventory out particular product was searched in registers. If not found, then the manual search continues for that particular product. It resulted in lots of wasted time and effort and consequently, company bear loss for not delivering the items on time.

Many companies are willing to adopt technology and are looking for proficient and active ways for the production process, picking process, storage of inventory and dispatching inventory [2]. The future generation of warehouses needs to manage their inventory via low power wireless technology that will provide more accuracy; RFID contain all these features. RFID now can even locate the location of the specific inventory in the warehouse based on the Received Signal Strength Indicator (RSSI) [3]-[4].

To manage the inventory, barcodes are now in the process of replacement by Radio Frequency Identification (RFID). It is simply the technology, which enables wireless transfer of information. As the barcode requires to be in the line of sight while detecting it, in case of RFID there is no need of RFID tags to be in the line of sight while detecting them [5]. Moreover, real time access to the inventory and meeting the changing customer demand is the need of the hour [6].

There are various frequency bands in RFID system consisting of low frequency, ranging from 100 KHz to 500 kHz, High Frequency at 13.56 MHz and Microwave band, which contain bands allotted to different applications i-e from 860 MHz to 960 MHz, 2.45 GHz and 5.8 GHz [7]. The band of 860 MHz to 960 MHz in the microwave has been dedicated to RFID Ultra High Frequency (UHF) for global use in accordance to ISO 18000-6.

RFID has gained well repute in the research field as it wide range of applications [8][9][10]. Most widely used application in UHF band of RFID is the traceability of inventory [11], trading of goods and in inventory management as shown in Figure 1. As UHF has the ability to read RFID tags fast and from long range, so much work has been done in the field of tag antenna design [12]-[13]. Most applications demand that tag size should be small, compact, cheaper and easily designable; all these characteristics lie in a customized Dipole antenna.

The problem faced by large warehouses using the RFID technology to manage their inventory is the inability of the RFID reader's antenna to bulk read the inventory tags at any desired zone.

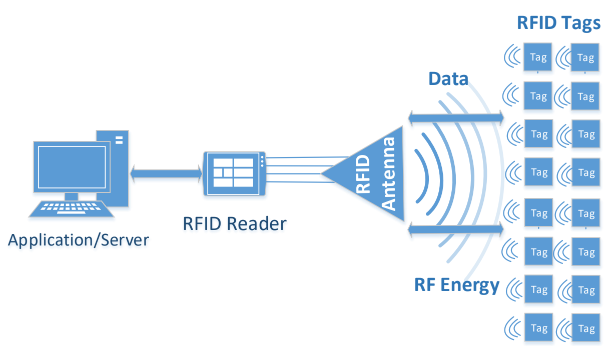


Fig. 1. General Structure of RFID System

To address the problem this research presents an efficient antenna for RFID reader that maximize the performance by efficiently using the RF energy in the intended zone. The newly designed antenna provides improved performance of upto 99.5% in comparison to previously used patch antennas which provides read performance of 79% in a given environmental condition. The main proposition of the research is that the efficiency of the system increases by the use of newly designed RFID antenna.

2. Literature Review

Multiple research papers have been reviewed in the course of building up this research. Much research work has been conducted on the identification of various products by transferring the data wirelessly. However, identifying a product separately on a unit level and in a bulk level requires a different approach. Also, there is much room for improvement in RFID technology such as the good design of the antenna and efficient software can maximize the RF energy and can provide accurate data respectively for managing the bulk stock in the warehouse and allocate the resources efficiently [14].

This research touches different sectors some of them involves industrial practices and some technological advances. Industrial practices include warehouse management, inventory management and some of the good standard operating procedures. Technological advances involve the use of RFID for product identification, components of RFID, best practices to use the technology, RFID reader antenna design. So, the research papers reviewed for this section touches each of the sectors.

When the industry is focused to improve its daily inventory management process flow, all the processes are listed and time analysis is conducted to note for the time taken for each process. It has been noted that most of the time has been spent on inventory management such as finding a particular product and then finding the empty space in the warehouse to put that product. Resultantly, Warehouse management can be improved by the use of RFID technology. Deployment of RFID in a warehouse can result in increased efficiency in utilization of rack space, faster loading/unloading speed, reduction in human error, increase in efficiency and reduction in operational cost [15]. Many RFID reader antennas with relatively high performance have been fabricated but each application in RFID system demands particular antenna design and its performance. The research deals with the solution for the problems that arise in antenna design, such as antenna size, operating mode, antenna structure, antenna type, operating frequency, the bandwidth, its radiation patterns, antenna scattering, polarization, and mutual coupling [16]. In a case study [17] a digital warehouse management system has been proposed based on RFID in the Tobacco industry. Storage and retrieval assigning approach have been implemented using Event Condition-based set of rules. Many operations and tasks in warehouses can be improved by the implementation of an RFID based system integrated with computer and by the use of wireless technology. Similarly, in a research [18], gaps in currently used RFID systems have been attempted to fill in. In the research requirements pertaining to designing a UHF based RFID tag antenna has been discussed. The research also described a design for passive UHF tag intended for a particular application. Y. Lee [19] has given the comprehensive insight of the antenna coils based on electromagnetic theories, methods for designing the coil of the antenna and for calculations and quantitative analysis of inductance, a method for antenna tuning, and mathematical calculations for calculating the read range in the RFID applications. The Application Note also focused on the basic configuration required for setting up RFID reader, RFID transponder and RFID tag antenna in various RFID applications and provided with mathematical equations to calculate antenna efficiency parameters. In a research [20], an automated warehouse management system has been proposed and focus on High Frequency to deal with single read at a time. Although the research was based on High-frequency communication band but the paper presented a framework of digital warehouse system based on RFID. The research proposes the future generation of warehouses implemented via an application and IT technologies including RFID and wireless communication to increase warehouse capacity, get the real-time update of the inventory. Use of Ultra High-Frequency band of RFID has its importance and more advantages over other frequency bands for a particular application. So, as a result, there is a growing use of RFID readers in many applications, including the use of RFID at airports, supermarkets malls, point of sales, warehouses [21].

The authors in the literature survey have presented RFID based warehouse systems. They have been case studies and implementations that give the digital warehouse management system. The authors discuss the challenges that the system designer came across while RFID based system has been implemented. Much of the work presented has been more focused on RFID transponder (tag) side and almost all the authors focused on providing High or Low-frequency RFID inventory management systems. Therefore, over the past few years' antennas of the RFID tag have been proposed for different types of applications but RFID reader antenna has not been focused. Moreover, RFID UHF antenna for the purpose of utilizing the RF energy efficiently to meet the bulk reading applications has not been under much focus since the RFID technology advances. The research conducted in this paper aims to provide a fully RFID integrated warehousing with energy-efficient antenna design with the target to improve readability in the intended zone.

3. Theoretical Analysis

There are mainly two types of RFID system.

1. Active RFID
2. Passive RFID

RFID system that is referred to as active RFID system consists of an active tag which takes the power provided by the internal battery of tag, as a result, strong, reliable and long ranged communication of signal is established. Most common application using Active RFID system is real-time location system relating to identification and positioning of the animals in the zoo, inventory in warehouses and freight containers. [22]. Active RFID provides longer read distances as it makes use of internal battery power.

Tags in passive RFID system acquires the power from the signal generated by the external RFID reader. In a passive system, the RFID reader directs the RF energy to an antenna which converts it into RF waves which then creates the read zone for RFID tags to be detected when in that zone. The antenna in the tag performs energy capturing and sends its identification to the reader for further processing [23].

In this research, passive RFID has been selected due to its wide range of applications and cost-effectiveness. Passive technology is of great interest as the tags do not require any battery and hence no maintenance is required. Also, it has indefinite operational life and small form factor makes it the first choice for retail and warehouse management applications [24].

There are mainly 3 components of RFID system [25]

1. RFID reader
2. RFID Reader Antenna
3. RFID Transponder

3.1. RFID Reader

Communication between RFID tags and RFID antenna is made possible by RFID reader. Any simple RFID system cannot be structured without RFID reader as it plays a key role in communication. In the case of a passive RFID system, the role of reader is to supply the much-needed power supply to the reader antenna and then to tags. So a Master-Slave relation is established between the RFID Reader and tags. In this master-slave relation, RFID reader acts as the master whereas RFID tags act as slave, and RFID antenna providing them a solid mode of communication. However, if software governing the whole system is considered the part of RFID structure then RFID reader can be considered as the slave. In that case, the software, which sends commands to the reader to perform the directed function, will act as a master [26].

Fig. 2. Aerospace Innotech RFID UHF reader

3.2. RFID Transponder

RFID transponder, which is also known as RFID tag, consists of two parts RFID tag antenna and a chip containing the memory banks. The tag antenna performs two key functions; it gets itself charged by the RF waves, generated by the reader antenna which in turn allows the tag antenna to perform the function of sending the data stored in its chip to the RFID reader. As the tag is attached to a movable or immovable product so it is preferred to select a small tag antenna, it will also make it easier to move the tagged objects. Tags with 3D radiation or omnidirectional radiation pattern are preferred in many applications. Normally, the impedance of the RFID tag is 50 ohms. Ideally, the antenna impedance should match with tag chip and as a result, the antenna provides the maximum power needed to the chip to get itself all charged up and ready for communication. In most of the applications, low cost RFID tags that have the design which can be easily fabricated is preferred for the purpose of mass production [16]. These RFID tags can be used in low to high cost RFID systems depending upon the type of application.

Application demands the reusability of RFID tags, so tags are made in such a form that they can be reused repeatedly. Alien 9662 tag has been selected in this application as it provides good read results and it has been especially designed for bulk reading applications.

Fig. 3: RFID tag Alien 9662

However, the deployment of RFID tags in real life scenarios to tag different items is a big challenge as they can be very sensitive to the items they are being tagged with and their performance mainly depends upon the physical conditions which surround the tag [27]. For the purpose of covering more spatial zone, most of the antennas are dipole type antenna. Folded dipoles are ideal as they provide compactness. However, distributed elements can add up to enhance the tag performance [28].

Fig. 4: RFID tag in reusable form

3.3. Reader Antenna

The reader antenna receives power from the RFID reader converts it into electromagnetic energy then diffuses this energy to charge up the tag IC and activate it. The reader then sends the instructed commands to the tag through reader antenna. Likewise, the tag sends back the information to the reader through reader antenna. Hence, the reader antenna acts as a mode of communication between reader and tag. To make this communication more efficient and effective reader antenna design for right application plays a pivotal role. In most of the applications the positioning of the product, to which the RFID tag is attached, is not known. Because of the unknown product position, the orientation of the RFID tag also becomes unpredictable. Therefore, while designing the reader antenna polarization of the antenna should be carefully selected as it should be able to cover all the orientations of the RFID tag. This will result in less polarization loss if the position of the product changes [16].

In Passive RFID systems, energy for upholding the operations of the tag originates from the RFID antenna when it transmits electromagnetic waves. Thus, the design of the RFID antenna is the most important part of the RFID system when it comes to choosing the right antenna for the right application.

The ability of the RFID reader to acquire information from the RFID tag in less time depends upon antenna characteristics which include its gain and beam width. There are also number of factors, which determines the distance at which the RFID tag can be detected which mainly include polarization, gain, and orientation. MTI Wireless Edge RFID marketing director, Reuven Drori says that if there is an application, which results in less RFID tag detection rate, then one must change the RFID reader antenna as changing the antenna and choosing the right one for the application will improve the results [29].

The RFID reader antenna makes use of the backscattering coupling which enables to generate RF energy that will charge the tag to activate it, and as a result, it will modulate the information and energy left is sent back to the RFID reader antenna.

There are different types of antenna each for its specific application. This research is focused on designing an antenna, which will consume RF energy in more organized manner. Widely used RFID UHF antenna is Patch type antenna. These antennas generate RF energy in a beam way. As the RF energy propagates, it becomes weaker and weaker but it travels more as it reads the tags at distance. Typically, patch antenna operating at UHF 866 Mhz can read RFID tag as far as 5 meters but it does not provide consistent performance. When reading bulk tags these antennas cannot provide with good read results. There are many factors to consider while going for best performance in RFID system. These factors are basically the external environmental conditions that affects the performance of the tag.

To address the growing problem in RFID antenna sector to have consistent performance. This will open up the new doorway of technology to warehouse management. Having the antenna with consistent RF radiation, we can read the bulk tags in one go. This paper proposes RFID antenna design that will use the RF energy efficiently to read the bulk tags.

3.4. Antenna Design

There are many factors to consider while designing RFID antenna. Mainly which include frequency band, size, form, read range, application with mobility, cost, and reliability [18]. The aforementioned factors may be required for Tag antenna design some are required for Reader antenna design. In this, research we will deal only with the factors that are related to reader antenna design.

Patch antennas are most commonly used antennas in RFID system. They do provide long read ranges but what they lack is the consistent performance. Factories using patch antenna for their inventory often come across the problem non-intended reads. As RF energy produced by patch antenna is like a diffuse beam which covers long distance up to 7 meters but as this travel far it loses its intensity to read. Even tags near the antenna in bulk quantity are scattered so it is not possible for warehouses to manage the tagged stock such that all the tagged stock comes right in front of the RF energy beam. In most cases trying to get all the tags in that particular beam requires too much time and results in extra reads from the area where the tagged stock is present but RFID system should not have scanned these tags because these were not intended to get read.

In this research, dipole antenna has been designed considering the type of application in warehouse management, where bulk reads are required and long ranges upto 5 meters is not required.

3.5. Antenna gain

While designing an antenna its characteristics play a pivotal role in its design phase. Antenna gain determines the read distance required for any application. If more read distance is required antennas with higher gain should be used. Likewise, if less read range is required antennas with lower gain should be used.

Higher gain antenna when receives the power from RFID reader they tend to increase the power. If application demands for more read distance then higher gain antenna is used (For example 9 dBi, or higher).

There are certain wide range of applications that require low gain antennas. The environment does not suit for the long read distance. Moreover. There are many issues with long range antennas resulting in unnecessary reads such as outside from intended read zone. So the application in which the tags will pass through the antenna at relatively closer distance high gain antennas are not recommended.

Higher gain antennas with longer read range do not provide a uniform distribution of RF energy. The far the RF waves travel the weaker it gets and provides inconsistent results [30].

3.6. Antenna Polarization

Polarization is the key characteristic of the antenna design. It is classified into different types including Linear, Circular and Multi-Linear Polarization. The orientation and alignment of tagged product with the reader antenna determines the selection of the polarization type. If the tag orientation is the same as the orientation of the reader antenna, then Linear Polarized antenna will result in reading the RFID tags at a longer distance. However, if the orientation of the tag is not same as the orientation of the antenna (as it happens in most of the inventory management applications) circular polarized antenna will result in reading the RFID tag at a longer distance.

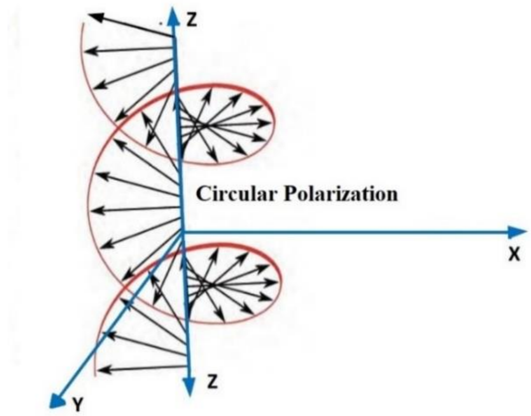


Fig. 5: Circular polarization schematic

Polarization determines the form of electromagnetic field that antenna is generating. It can be linear, circular or it can also be Multi-Linear. Linear polarization denotes the radiation generated along the single plane. On the other hand, in circular polarization the radiated RF energy is divided into two axis and then spins the radiated waves, which enable it to cover all the orientation planes of the tag. RFID Circular polarized antenna field can be pictured as a spinning cyclone produced from antenna surface. As a result of this, RFID tag antenna orientation becomes less important whereas in Linear polarized antenna field tag orientation hold much more importance. Moreover, in linear polarization the power radiated from the reader remain only in one axis and does not split into more than one, so antenna's field to charge up the tag travels more as compared to circular polarized antenna field provided the same gain [30]. Hence, linear polarized antenna provides much more read range than the circular polarized antenna. There are many applications to which circular polarized antennas are more suited, however general concept in field is that when a signal is received by circular polarized antenna it will lose the half of power received from the reader, so for effective RF energy channeling, linear polarization may be more suited to some applications [31].

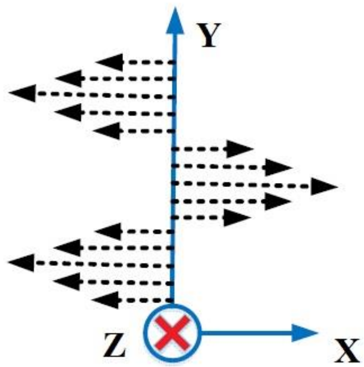


Fig. 6: Linear polarization schematic

As the tag orientation is not known at the time when the tagged item passes through the RFID reader antenna so it is necessary to use such a reader antenna that will cover all the angles of the tagged item which contain the RFID transponder. Multilinear polarization forms the basis of energy harvesting and provides more efficient way to use the RF energy in a more targeted way [32]. Multilinear polarized antenna generates multiple beams of RF energy that allows the antenna to communicate by covering variety of angles of the tags that are attached to the item.

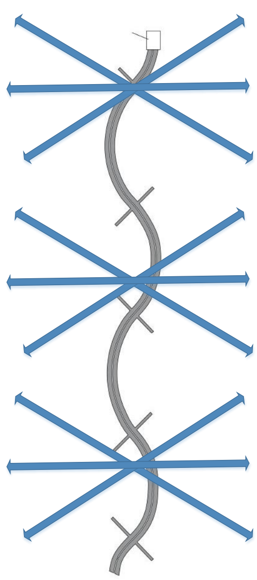


Fig. 7: Multilinear polarization beam diversity

In this research, multilinear polarized RFID reader antenna has been designed, as shown in Figure 7, the efficient antenna design allows it to generate multiple beams of RF energy making the region diversify and covering all the possible angles of RFID tag passing by. The transponder attached to the stocked item does not have fix position as it passes through the RFID pathway. So multilinear polarized antenna was able to read the RFID tag as the tags (transponder) attached to stock does not pass the pathway in the predefined position.

4. Comparative Analysis

4.1. Conventional Patch antenna

Patch antenna has been among the early developments in the history of electromagnetics. It lies in the group of printed antennas for example slot, tapered slot, and dipole. They are widely used because of their distinctive capabilities which include ease of integration, low cost of production [33].

Conventionally used patch antennas were designed almost 50 years ago. The purpose of these antennas was to read the tags from long distance which results in the detection of the tags which were not intended to get read i-e extraneous reads and above all it provide inconsistent read results.it works like a beam of light in flashlights which illuminates the region but it brightens the area well beyond the intended zone but as the light brightens farther region it gets dimmer and dimmer losing its capacity to illuminate. Figure 8 and Figure 9 depicts that patch antenna provides long read range but it gets faded away as RF rays travel further. The RF energy created by the patch antenna illuminates the region in a cylindrical pattern only.

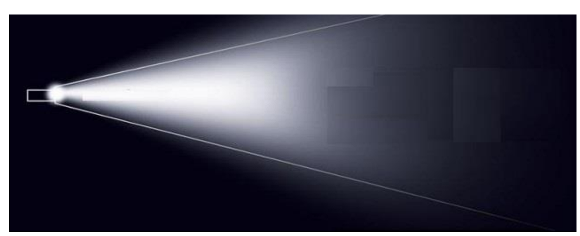


Fig. 8: Flashlight (depicting Patch antenna RF propagation)

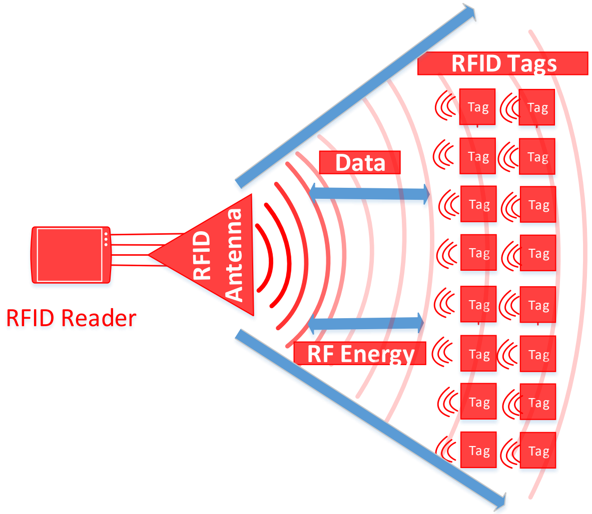


Fig. 9: Patch antenna RF radiation depiction in RFID system

Conventional patch antenna mainly covers the front side zone only. Figure 10 shows a typical 3D RF spectrum of conventional patch antenna.

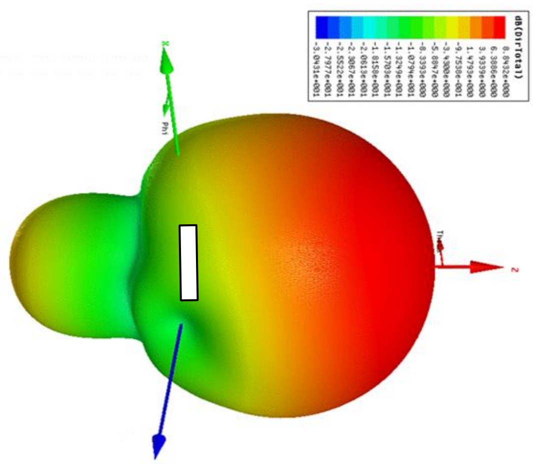


Fig. 10: Patch antenna 3D RF spectrum

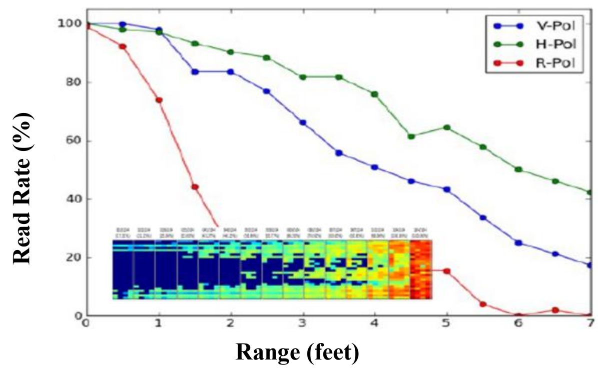


Fig. 11: Deteriorating power density at Maximum power input

Figure 11 shows the typical patch antenna performance at maximum input power. The graph shows that when the patch antenna is placed right before the RFID tags (0 feet), the Vertical Polarization (V-Pol), Horizontal Polarization (H-Pol), and Right Hand Polarization (R-Pol) of the antenna displays 100% read percentage. However, as the patch antenna moves away from the tags the read percentage deteriorates.

In this research, Patch antenna has been used to compare the results with the newly designed antenna. Efficiency is calculated by comparing the read results of both antennas provided the same conditions.

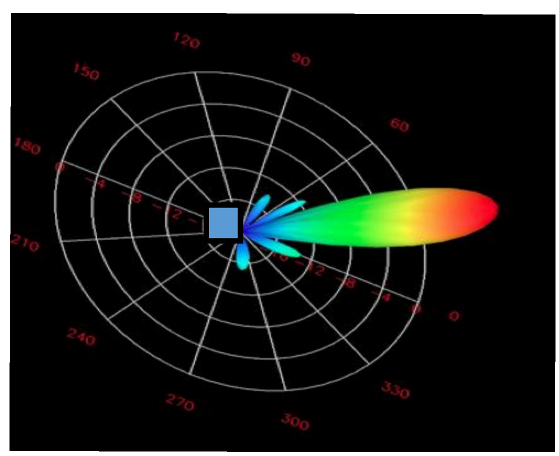


Fig. 12: Patch antenna volumetric pattern

Figure 12 shows the volumetric patterns of the patch antenna by giving the RF energy beam direction, field size, intensity, range and shape of the RF illumination pattern.

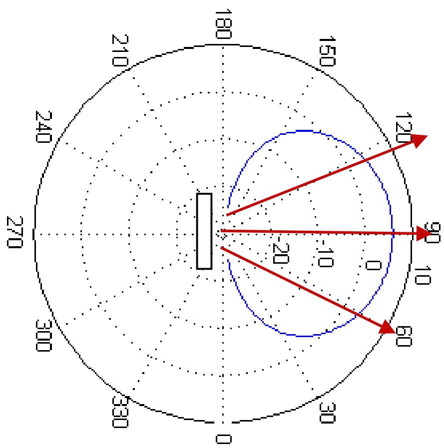


Fig. 13: Patch antenna Radiation Pattern, Narrow telephoto lens effect

Patch antenna radiation pattern shows that it creates telephoto lens effect, which covers the front read zone only in the cylindrical beam with many fading RF energy regions as depicted in Figure 13, Figure 14 (a) and Figure 14 (b). Moreover, Figure 14 (a) and (b) shows that the top and side view of the patch antenna RF radiation is the same.

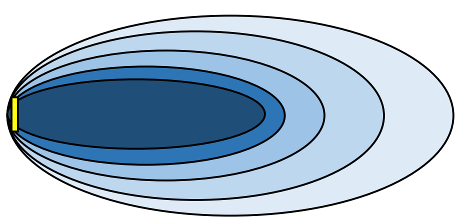


Fig. 14 (a): Top view of Patch antenna RF Radiation

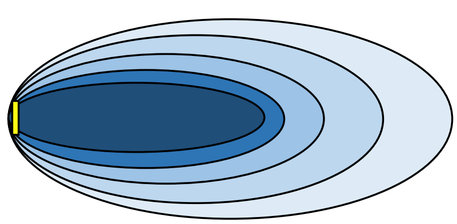


Fig. 14 (b): Side view of Patch antenna RF Radiation

4.2. Energy efficient RFID reader antenna

The designed RFID reader antenna a new model in RFID antenna design. As an alternative to using an antenna, which radiates a beam of RF energy in a single direction, this newly designed antenna distribute the RF energy uniformly and creates an illumination zone in a volume of space. This designed antenna is specially designed for item level bulk reading purpose. As required in warehouses with large stock to manage while stocking in and out of the warehouse, it has to pass through the RFID pathway where each item in the stock get read by RFID antenna.

The newly designed antenna is capable of generating a constant RF energy spectrum around its inlay. It works like a fluorescent light. Figure 15 gives the depiction of the fluorescent light illumination pattern.

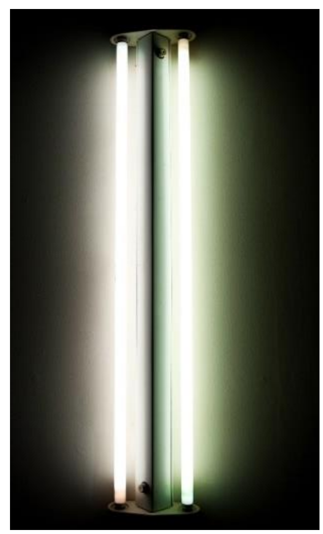


Fig. 15: Fluorescent Light (Depicting Antenna RF propagation)

The newly designed antenna is capable of generating multiple RF energy beams instead of a single beam (in patch antenna), this allows it to illuminate a volume of space of RF energy around its length.

Hussain Saleem Sheikh,
Fahim Gohar Awan, Asima Kiran

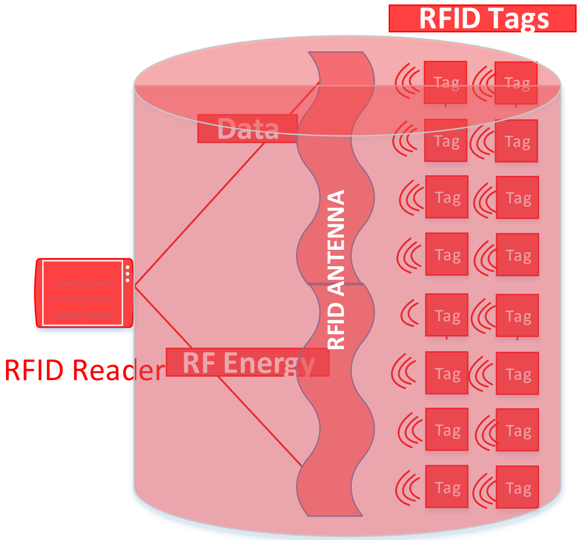


Fig. 16: Graphical representation of RFID system with energy efficient antenna

The newly designed antenna is specially designed keeping in view the item level readability required in warehouses. As this antenna illuminates a uniform volume of RF energy around its length to provide the front and back readability as shown in Figure 16. Figure 17 shows the 3D RF spectrum of the newly designed energy efficient antenna.

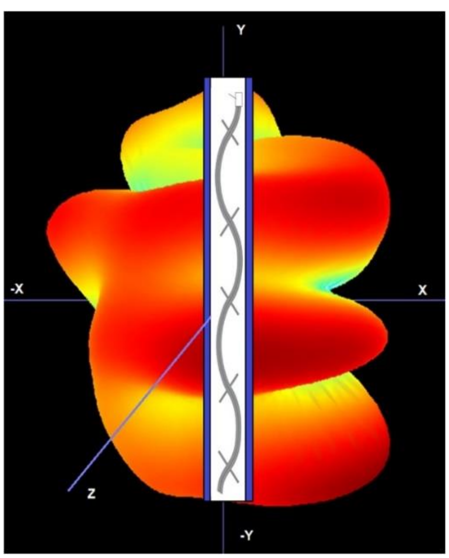


Fig. 17: Energy efficient antenna 3D RF spectrum

Pakistan Telecommunication Authority has allotted frequency band of 865-868 MHz to Ultra High-Frequency RFID applications [34]-[35]. The designed antenna has an operating frequency of 866 MHz.

The designed antenna is a dipole type antenna. The wavelength (λ) of the antenna can be calculated using equation (1) [36].

$$\lambda = \frac{c}{fc} \qquad (1)$$

Where c denotes speed of light and f_c denotes operating frequency of the antenna, which is 866 MHz so λ is 346 mm.

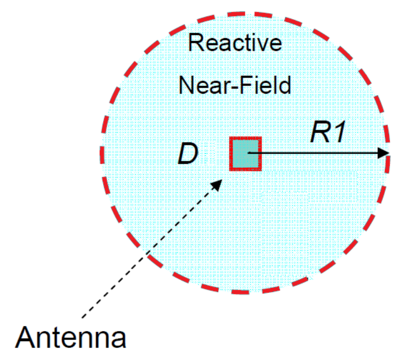


Fig. 18: Field region around an antenna

Figure 18 shows Reactive Near-Field region which is the most integral region in terms of RF energy, it is the region immediately surrounding the antenna in which the reactive field dominates.

$$R_1 \leq 0.62\sqrt{\frac{D^3}{\lambda}}$$

Where R_1 denotes radius of Reactive Near Field region, D denotes the dimension of the newly designed antenna which is largest in length [36] (D is 1446 mm) . The reactive near-field region (R_1) for the designed antenna is calculated to be 1832 mm.

The free space transmission normally comprises of the transmission antenna, receiving antenna and transmission path. Parameters of all the components determine the functionality of the system. Therefore, the main parameters to consider here are transmitted power, antenna parameters, wavelength, the distance between the receiver and transmitter antenna. Friis equation (2) gives the relation.

$$P_R = P_T \left(\frac{\lambda}{4\pi R}\right)^2 G_T G_R \qquad (2)$$

Where P_R denotes Received power, P_T is transmitted power, R denotes the distance between Reader antenna and RFID tag antenna, G_T denotes Gain of transmitting antenna, G_R is Gain of receiving antenna [37].

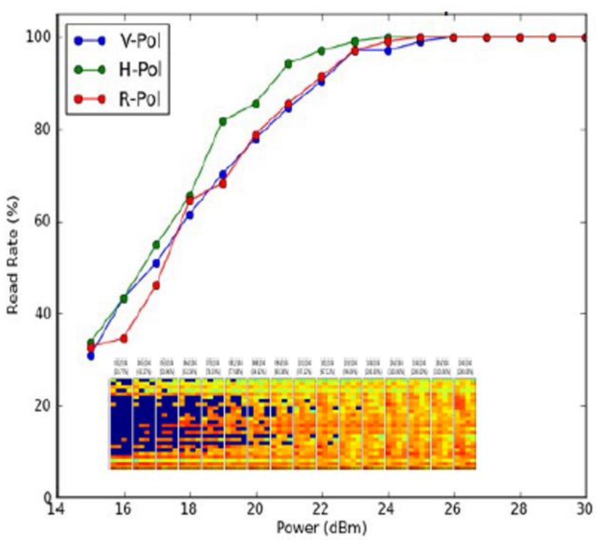


Fig. 19: Uniform Power density achieved at Minimum power input

Figure 19 shows that the designed antenna provides the maximum read percentage, even at minimum input power. The details of hardware used given in Table 1. RFID reader used in this research provides the total power of 30 dBm. At this power of 30 dBm, almost 100% read rate is achieved.

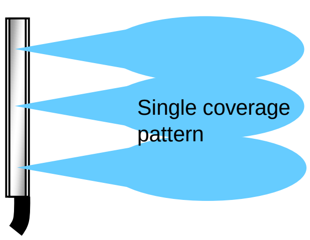


Fig. 20 (a): Single antenna beam effect illustration

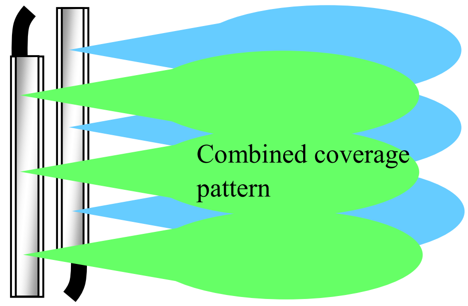


Fig. 20 (b): Double antenna beam effect illustration

Figure 20 (a) shows the effect and coverage zone of the single antenna but if two antennas Figure 20 (b) were used it will result in combined coverage pattern which will fill in spatial and polarization nulls of the first antenna hence as a result, a better read rate for item-level readability is achieved. By inverting and shifting the antennas, the newly designed antenna will produce a complementary coverage pattern. The inverted antenna is cross-polarized with respect to its partner in the pair.

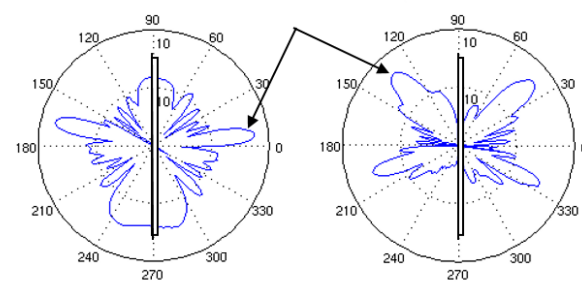


Fig. 21: Horizontal Polarization (Left), Vertical Polarization (Right)

Figure 21 shows polarization beam diversity, it depicts that beams are complimentary which will provide reduced null regions. Any single inlay of antenna when used in the RFID system to cover a given region with its RF energy, will provide fading nulls caused by multi-path interference. The newly designed antenna, when used in pairs, will overcome the fading patterns as shown in figure 22.

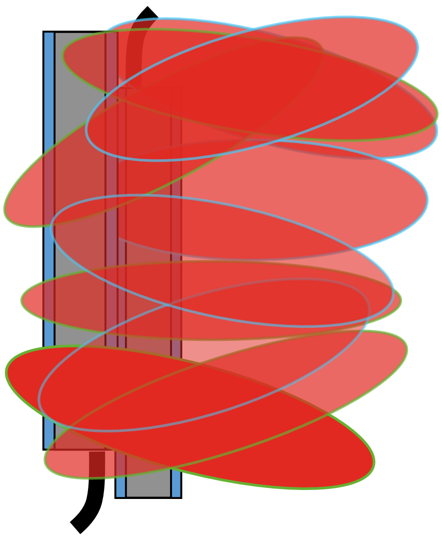


Fig. 22: Double antenna beam diversification illustration

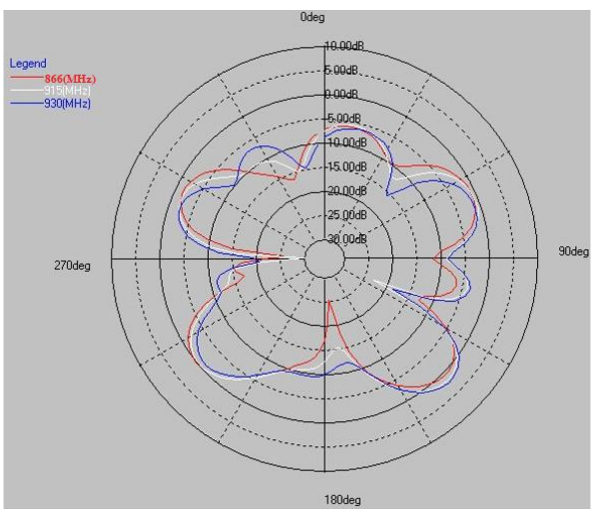


Fig. 23: Combine effect of two antennas with gain 4.5dBi

Figure 23 shows the combined effect for two antennas gives a wide angle lens effect providing more read range and covers the intended area with full RF energy strength. The gain of the antenna is calculated to be 4.5 dBi.

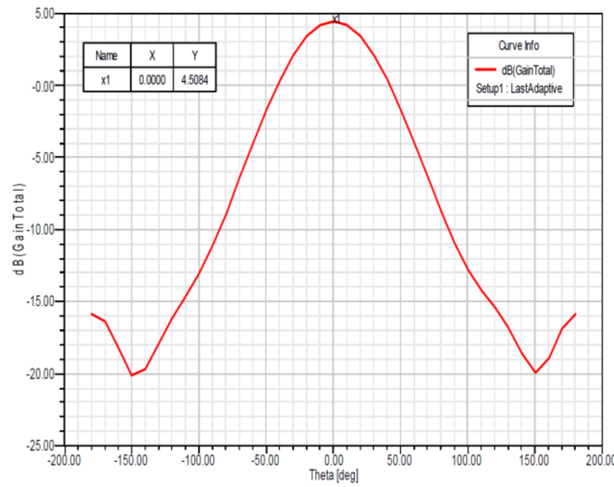


Fig. 24: Antenna gain of 4.5 dBi

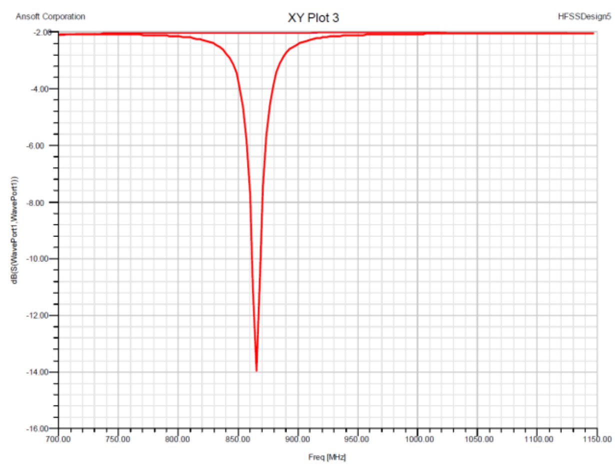


Fig. 25: Dipole antenna S11 of -13.98 dB

ANSOFT HFSS has been used to simulate the antenna behavior and its various parameters. As expected, gain of the antenna is simulated to be 4.5 dBi, which was calculated before as well as shown in Figure 24. The 5 feet length of the antenna is designed keeping in view the application needs, so resultantly a low gain antenna will also restrict it from radiating its RF energy to far field. Similarly, the return loss, S11, of the antenna is simulated to be -13.98 dB at 866 MHz as shown in Figure 25, which is good return loss. However, the return loss of patch antenna is sometimes much lower than that, upto -36 dB [21] but our application of reading bulk tags in a near field zone of around 4 to 5 feet suits to have the calculated return loss of -13.98 dB.

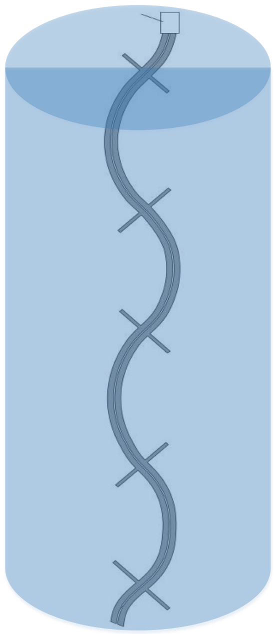


Fig. 26: 360 Degree RF radiation pattern

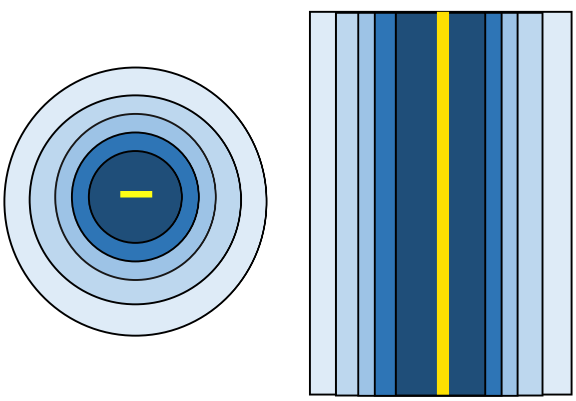


Fig. 27 (a): Top view Antenna coverage zone (Left)

Fig. 27 (b): Side view of the coverage zone (Right)

The newly designed antenna provides 360 Degree RF energy coverage zone hence it provides full reading capability around its whole length. So it's clear that it provides more coverage zone than patch antenna as depicted in Figure 26, Figure 27 (a) and (b) of the newly designed antenna and Figure 14 (a) and (b) of the patch antenna.

5. Experimental Setup

Experiment is conducted in a well-known textile company of Pakistan at its dyeing and finishing unit. All the testing equipment has been setup at the warehouse where all the fabric rolls are kept in their pallets. For the purpose of reusability such form factor of the RFID tags was developed so that they can be reused after the complete cycle of fabric dispatch. Similarly, two RFID pathways have been constructed to make two types of transactions Check-IN and Check-OUT as shown in Figure 28 and 29.

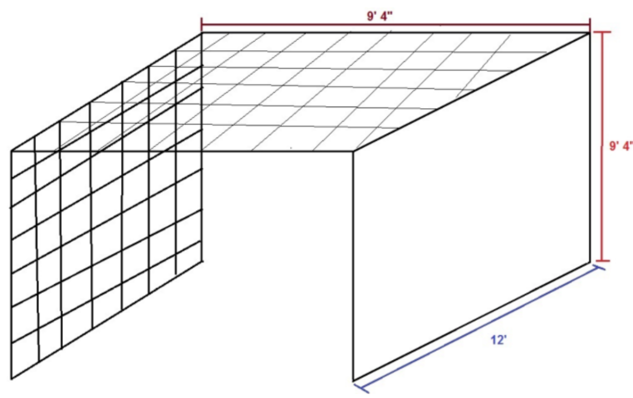


Fig. 28: Check In/Out Layout

Fig. 29: Actual Check In pathway

Check-In/Out pathways allow the fork lifter to pass the pallet/trolley containing tagged fabric on a fork lifter.

To contain and limit the RF rays in constructed pathway, concept of faraday's cage is used such that the front portion of the pathway is covered with aluminium foil to avoid any stray reads from the antenna as depicted in Figure 30. It will restrict the electromagnetic rays within our pathway.

Fig. 30: Styrofoam with aluminium foil

Belts containing RFID tags are being rolled over the fabric and then this tagged fabric is placed on the pallet, which is then lifted by a fork lifter to be passed through the constructed RFID pathway.

Fig. 31: RFID tagged fabric

Fig. 32: RFID Tagged fabric passing through pathway

Testing was conducted using two types of antenna

1. Patch Antenna
2. New designed antenna

The pallet was made of metal, RF rays does not perform well in the presence of metal, glass or liquid [38], so special RFID tags called anti-metal tags were used to tag the pallets. They were fixed with each of the pallet and Fork Lifter.

6. Results

Both types of antennas were tested under the same environmental conditions and same input power. Following are the parameters that were same for both types of the antennas.

Table 1: RFID Reader specifications

Technical Parameter	Description
Operating Frequency	ETSI 865-868 Mhz
Tag Protocol	ISO18000-6C
Antenna RF input power	+20dBm~ +30dBm @50Ω load, 1dBi each step

6.1. Results from Patch Antenna

Patch antenna was tested in check IN/OUT pathway. 4 patch antennas were used Tagged fabric in a pallet was passed through it and read results were noted.

Constant Parameters for each test

Number of Antennas: 4

Polling Time between Antenna: 200 ms

Input Power: 30 dBm

Table 2: Patch antenna results

Test No.	Tags in Pallet	Tags Detected	Time Taken (sec)	Read Rate%
1	26	20	18	77
2	35	28	22	80
3	29	22	20	76
4	39	32	23	82
5	34	27	20	79
6	37	29	22	78

Total Tags: 200

Tags Detected: 159 ; Total Time Taken: 125 seconds

Detection Rate: 79%

6.2. Results from New Designed Antenna

The newly designed antenna was tested in pairs as two of the antennas were grouped in a metallic cover.

Fig. 33 (a): Putting antenna inlay in cover

Fig. 33 (b): Antenna Final form

Constant Parameters for each test

Number of Antennas: 2

Polling Time between Antenna: 400 ms

Input Power: 30 dBm

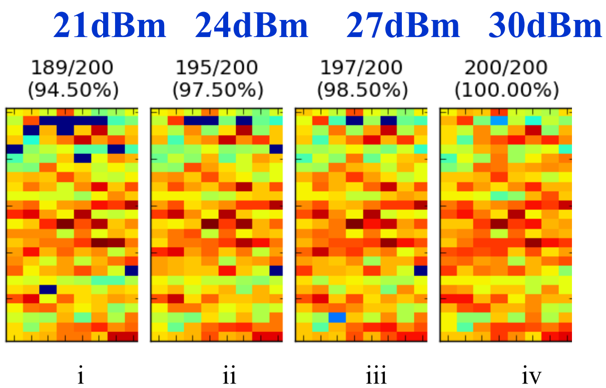
Table 3: New designed antenna results

Test No.	Tags in Pallet	Tags Detected	Time Taken (sec)	Read Rate%
1	26	26	10	100
2	35	35	11	100
3	29	29	11	100
4	39	38	12	97
5	34	34	10	100
6	37	37	10	100

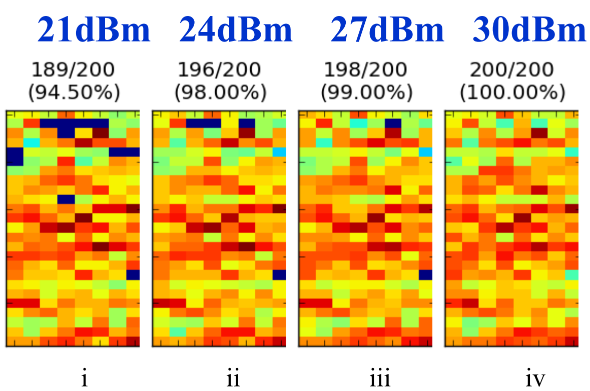
Total Tags: 200

Tags Detected: 199 ; Total Time Taken: 64 seconds

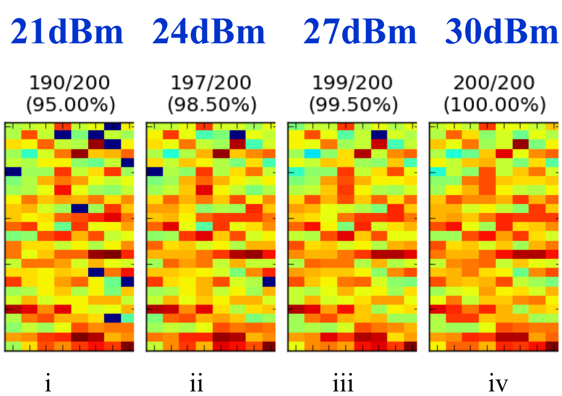
Detection Rate: 99.5%



(a) Case 1



(c) Case 2



(b) Case 3

Fig. 34 (a), (b), (c) Read Results at different input power

Figure 34 gives the results obtained after testing the newly designed antenna. The test was conducted using 200 tags under different cases and different input powers. Each case represents four testing instances i, ii, iii, and iv. Each of the instance i-iv contains 200 small boxes which represent 200 tags. Blue color small box represents the tags which were not detected. All the cases were tested at 4 stated input powers.

Results obtained also align with the recent researches carried out for RFID based proposed inventory management where efficiency of the system has been increased by the use of RFID and the tags which enters the RFID read zone first are read first [39].

7. Conclusion

The conclusion of this research will be derived from the result section.

Case 1 results concludes that when a single box containing 200 of tightly packed RFID tagged items were detected using two antenna inlays as shown in figure 33 (a). This case was tested at three input powers and the results showed that at 30 dBm, 100% read rate was recorded.

Fig. 35: Two boxes containing 200 RFID tagged baby clothes

Case 2 results concludes that when two boxes containing 200 of loosely packed RFID tagged items as shown in figure 35 were detected using two antenna inlays. As the tagged baby clothes were spaced out the detection rate increases a bit as shown in Figure 34 (case 2).

Fig 36: Fork Lifter containing 200 Tagged baby clothes

Case 3 results concludes that when 200 tagged items were placed in on the pallet carried by the fork lifter as shown in Figure 36. So in that case as the tagged items were more spaced out it shows improved detection rate as shown in Figure 34 (case 3).

The newly designed antenna shows much more efficient results as the detection rate is almost 100% the one tag which was not detected making the rate to be 99.5%, is because proper SOP's needs to be followed while filling the pallet with fabric rolls having RFID belt on them, the RFID tag in the belt should not touch the metallic base of the pallet as it will block the RF rays coming from Reader antenna. However, the patch antenna shows the detection rate to be 79 % and takes much more time for the tags to be detected.

References

[1] L. Yuan, "Research and Practice of RFID-Based Warehouse Logistics Management System," 2019 International Conference on Smart Grid and Electrical Automation (ICSGEA), Xiangtan, China, 2019, pp. 514-519, doi: 10.1109/ICSGEA.2019.00123.

[2] S. Alyahya, Q. Wang, N. Bennett, "Application and integration of an RFID- enabled warehousing management system – a feasibility study", Elsevier Journal of Industrial Information integration, Vol. 4, pp. 15-25, December 2016.

[3] T. Adiono, H. Ega, H. Kasan and C. S. Harimurti, "Fast Warehouse Management System (WMS) using RFID based goods locator system," 2017 IEEE 6th Global Conference on Consumer Electronics (GCCE), Nagoya, 2017, pp. 1-2, doi: 10.1109/GCCE.2017.8229410.

[4] C. S. Choong, A. F. A. Nasir, A. P. P. A. Majeed, M. A. Zakaria, and M. A. M. Razman, "Automatic Identification and Categorize Zone of RFID Reading in Warehouse Management System", Advances in Mechatronics, Manufacturing, and Mechanical Engineering pp 194-206, August 2020.

[5] C. R. Medeiros, J. R. Costa and C. A. Fernandes, "RFID Reader Antennas for Tag Detection in Self-Confined Volumes at UHF," in IEEE Antennas and Propagation Magazine, vol. 53, no. 2, pp. 39-50, April 2011, doi: 10.1109/MAP.2011.5949323.

[6] C.K.M. Lee, Yaqiong Lv, K.K.H. Ng, William Ho & K.L. Choy (2017) Design and application of Internet of things-based warehouse management system for smart logistics, International Journal of Production Research, 56:8, 2753-2768, DOI: 10.1080/00207543.2017.1394592.

[7] K. Finkenzeller, RFID Handbook, 2nd edition, Wiley ,New York, 2003.

[8] A. Lazaro, R. Villarino, F. Costa, S. Genovesi, A. Gentile, L. Buoncristiani, and D. Girbau, "Chipless Dielectric Constant Sensor for Structural Health Testing", IEEE Sens. J. 2018, 18, 5576–5585.

[9] D. Betancourt, M. Barahona, K. Haase, G. Schmidt, A. Hübler, and F. Ellinger, "Design of Printed Chipless-RFID Tags With QR-Code Appearance Based on Genetic Algorithm", IEEE Trans. Antennas Propag. 2017, 65, 2190–2195.

[10] M. Svanda, J. Havlicek, J. Machac, and M. Polivka, "Polarization independent chipless RFID tag based on circular arrangement of dual-spiral capacitively-loaded dipoles with robust RCS response", IET Microwaves Antennas Propag. 2018, 12, 2167–2171.

[11] G. Alfian, M. Syafrudin, U. Farooq, M. R. Ma'arif, M. A. Syaekhoni, N. L. Fitriyani, J. Lee, and J. Rhee, "Improving efficiency of RFID-based traceability system for perishable food by utilizing IoT sensors and machine learning model", Food Control, Vol. 110, April 2020.

[12] Y.-C. Lee, J.-S. Sun, "A fractal dipole tag antenna for RFID dual-band application," Microwave and Optical Tech.L ett., Vol. 50,1963–1966,2008.
[13] S.H. Ting, C. K. Wu, and C. H. Luo, "Design of Dual Mode RFID Antenna for Inventory Management and IV Fluid Level Warning System", International Journal of Antennas and Propagation, vol. 2017, Article ID 2470291, 7 pages, 2017.
[14] T. Zhen, Y. Zhu, and Q. Zhang. "A RFID Logistics Resource Management System for the Warehouses" Proceedings of the International Conference on Environmental Science and Information Application Technology (ESIAT), vol. 2, pp. 63 – 66, 2009.
[15] G. Liu, W. Yu, and Y. Liu, "Resource management with RFID technology in automatic warehouse system," in Intelligent Robots and Systems, IEEE/RSJ International conference, pp. 3706-3711, October 2006.
[16] M. Zhang, Y. Jiao, M. Koyuturk, F. Zhang and W. Wang, "Design of Antennas for RFID Application" Book edited by: Cristina TURCU, pp. 554, ITech, Vienna, Austria, February 2009.
[17] H. Wang, S. Chen and Y. Xie, "An RFID-based digital warehouse management system in the tobacco industry: a case study," International Journal of Production Research, vol. 9, no. 48, pp. 2513–2548, 2010.
[18] K. V. S. Rao, P. V. Nikitin, and S. M. Lam, "Antenna design for UHF RFID tags: A review and a practical application," IEEE Trans. Antennas Propag., vol. 53, no. 12, pp. 3870–3876, Dec. 2005.
[19] Y. Lee, "Antenna circuit design for RFID applications," Microchip Technol. Inc., Chandler, AZ, Appl. Note AP7 10, 2003.
[20] Q. Wang, S. Alyahya, N. Bennett, H. Dhakal, An RFID-Enabled Automated Warehousing System, International Journal of Materials, Mechanics and Manufacturing, Vol. 3, No. 4. November 2015.
[21] D. D. Donno, L. Catarinucci, and L. Tarricone, "An UHF RFID Energy-Harvesting System Enhanced by a DC-DC Charge Pump in Silicon-on-Insulator Technology," IEEE Microwave and Wireless Components Letters, vol. 23, no. 6, pp. 315-317, June 2013.
[22] H. Cho, Y. Baek, "Design and Implementation of an Active RFID System Platform" In Proceedings of the International Symposium on Applications and the Internet Workshops (SAINTW'06), Phoeniz, AZ, USA, 23–27 January 2006.
[23] N. Sklavos, M. Hubner, D. Goehringer, P. Kitsos, System-Level Design Methodologies for Telecommunication, NY: Springer, 2014.
[24] R. Want, "An Introduction to RFID Technology," IEEE Pervasive Comput., vol. 5, no. 1, p. 25, 2006.
[25] J. Mi, and Y. Takahashi, 2016, "Design of an hf-band rfid system with multiple readers and passive tags for indoor mobile robot self-localization", Sensors, 16(8), p.1200.
[26] S. Preradovic, N. Karmakar, "RFID readers - a review", International Conference on Elec. and Comp. Eng., pp. 100 – 103, December 2006.
[27] H. Chaabane, E. Perret, S. Tedjini, "A methodology for the design of frequency and environment robust UHF RFID tags," IEEE J. AP, Vol. 59, No. 9, 3436–3441, 2011.
[28] X. L. Bao and M. J. Ammann, "Dual-frequency circularly-polarized patch antenna with compact size and small frequency ratio," IEEE Trans. Antennas Propagation, vol. AP-55, pp. 2104–2107, Jul. 2007.
[29] J. Zaino, 'What You Need to Know About RFID Reader Antennas', 2011 [Online]. Available: http://www.rfidjournal.com/articles/view?8982/3
[30] S. Armstrong, '6 Factors that Affect RFID Read Range', 2013. [Online]. Available: https://blog.atlasrfidstore.com/improve-rfid-read-range
[31] D. Schemmel and P. Nayeri, "A smart wireless energy harvesting system with adaptive beamforming and power management," IEEE APS/USNC-URSI National Radio Science Meeting, California, U.S., Jul. 2017.
[32] A. Desai and P. Nayeri, "A multi-linear polarization reconfigurable plus shaped dipole antenna for wireless energy harvesting applications," International Applied Computational Electromagnetics Society (ACES) Symposium, Colorado, U.S., Mar. 2018.
[33] R.A.R. Ibrahim, M.C.E.Yagaub, R.W.Y. Habash, "Microstrip Patch Antenna for RFID Applications", Electrical and Computer Engineering CCECE Canadian Conference, PP 940-943, 2009.
[34] Pakistan Telecommunication Authority, 'RFID Spectrum for Pakistan', 2008. [Online]. Available:

https://www.pta.gov.pk/index.php/en/media-center/single-media/framework-for-rfid-applicationsequipment-in-pakistan

[35] Pakistan Telecommunication Authority, 'Guidelines for Use of RFID Equipment in Pakistan', 2008. [Online]. Available: https://www.pta.gov.pk/index.php/en/media-center/single-media/framework-for-rfid-applicationsequipment-in-pakistan

[36] NXP Application Note, "AN 1629 UHF RFID label antenna design, UHF antenna design," Sep. 2008 [Online]. Available: http://www.nxp.com

[37] C. A. Balanis, Antenna Theory: Analysis and Design. Hoboken, NJ: Wiley, 2005.

[38] M. Węglarski, P. J. Mihułowicz, M. Chamera, J. Dziedzic, P. Kwaśnicki, "Designing Antennas for RFID Sensors in Monitoring Parameters of Photovoltaic Panels" Micromachines. 2020;11:420. April 2020, doi: 10.3390/mi11040420.

[39] Q. Liu, "Automated logistics management and distribution based on RFID positioning technology", Telecommunications and Radio Engineering, vol. 79, no. 1, pp. 17-27, 2020.