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Full Length Research Paper

UHF RFID antenna architectures and applications

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In order to use radio frequency identification (RFID) antenna for wireless communication and real world applications (e.g.) military and personal communication systems, mobile phones, personal digital assistant (PDA), blue-tooth systems, wireless local area networks (WLAN), railway vehicle identification, road tolling systems, fish tracking systems etc, studying the nature and characteristics of the antenna is an important use. The collective electrical signals acquired from RFID antennas require advanced techniques for feeding, gains and radiation patterns. The purpose of this paper is to review and discuss various algorithms and methodologies aimed at providing more flexible and efficient ways of analyzing RFID antenna. This paper further focused on the review of future implementation methodologies and performance comparison along with their applications. Some of the applications are illustrated at the end of the paper and recommended for further study is also outlined. This review serves as a comparative studies and reference beneficial for RFID antenna researchers, for future implementation of the technology. This review paper opens a corridor for researcher to perform future comparative studies between different architecture and model as a reference point for developing more powerful, flexible and efficient applications.

Key words: RFID, antenna, RFID reader, RFID transponder.

INTRODUCTION

Radio frequency identification (RFID) has become very popular in many services industries, distribution logistics, manufacturing companies and goods flow system. RFID reader transmits a modulated RF signal to the RFID tag consisting of an antenna and an integrated circuit chip. The chip receives power from the antenna and responds by varying its input impedance and thus modulating the backscattered signal. Modulation type often used in RFID is amplitude shift keying (ASK) where the chip impedance switches between two states: one is matched to the antenna (chip collects power in that state) and another one is strongly mismatched. The methods in which this is done and the type of equipment is used are the areas of ongoing research. RFID consists of three basic components, such as transponder (tag), interrogator (reader) and antenna. Based on the research, RFID has a number of standards such as international organization for standardization (ISO) in conjunction with the international electro technical commission (IEC), electronic product code (EPC) global and European telecommunications standard institute (ETSI). However, RFID follows some standard frequency ranges, which are low frequency (120 - 135 KHZ), high frequency (10 - 15 MHZ), ultra high frequency (850 - 950 MHZ) and microwave frequency (2.45 GHZ).

As the frequency of choice for RFID devices rises into the microwave region, the problem of designing antennas to match the devices on the projected object becomes more acute. The objective of any such antenna design is to maximize the transfer of the power in and out of the

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Abbreviation: RFID, Radio frequency identification; **PIFA,** planar inverted-F antenna.

device on the projected object. This requires careful design to match the antenna to free space and to the devices. From the system requirement and application point of view, a reader antenna should have the following characteristics: (i) compact; (ii) directional with higher gain; (iii) circular polarization; (iv) good impedance match (v) ease to integrate; (vi) low cost. However, in some cases, RFID system use two types of antenna such as dipole antenna for the reception of electric fields and loop antenna for reception of magnetic fields. The antenna uses a magnetic field known as inductive or near field, which looses its strength after a short distance, thus it is suited for RFID applications that allows the RFID transponders to be placed very near to the transceiver. RFID is already widely used, but demand is growing in the field of long-range identification, where electromagnetic waves and antenna are used for coupling (Ukkonen et al., 2004). However, there are many challenging feature that an antenna need to be incorporated, among them the antenna intended to be used in long-range RFID tags, the antenna has to be really small, preferably low-profile in order to be usable, the fabrication has to be inexpensive, since RFID tags are generally designed to be disposable.

Throughout the previous years many research methods for RFID antenna has been developed. Traditional system reconstruction methods have various limitations and considerable computational complexity and many show high variance. Ukkonen et al. (2004) proposed that a conductive surface metallic plate near antenna could act as a reflector causing the directivity to increase. Also a number of antenna types need a conductive ground plane to function properly. In these two cases a metallic surface can be used to improve the performance of the antenna. But, the incident wave is almost totally reflected by the metallic surface since metals are highly conductive. This will cause changes in the radiation frequency and the radiation pattern of antenna causes the radiation efficiency to be decreased. Foster and Burberry (1999) have performed basic measurements of an antenna near several objects. Raumonen et al. (2003) have studied a similar problem through simulation. Dobkin and Weigand (2005) have also experimentally shown a decrease in the read range of several RF tags near a metal plate and a water filled container along with changes in the RF tag antenna input impedance near metal. This is affected by electromagnetic properties of objects near or in contact with the tag antenna. Marrocco (2003) has investigated variations of meander-line dipole antenna configurations, attempting to achieve optimized gain within a given size. He showed that non-uniform meanders offer modest benefits in gain vs. the corresponding uniformly meandered antenna. However, while Marrocco provides an estimate of the radiation resistance and loss resistance, he does not discuss the reactive part of the impedance, the bandwidth, or the radiation pattern depictions. Based on the study, some of the common and most significant problems are: (i) the implementation of the methods shown earlier is complex and competitive; (ii) the antennas implementation become costly. So far, research and extensive effort have been made in the area, developing better algorithm, upgrading existing methodologies to reduce antennas interference. Recent advance technologies in different methods have made it practical to improve antennas performance and reduce interferences. Various techniques, methods and algorithm have received extensive attraction of many researchers, which includes genetic algorithm (GA), circularly polarized antenna, dual polarized antenna, inverted F-antenna, meander line antenna and many more.

Early UHF tags occasionally encountered problems around materials like metal and liquids. This led HF proponents to assert their technology was more reliable in those environments. Due to technology advances made in the last few years however, Gen 2 UHF tags now perform as well as or better than HF around these materials, with the added benefits of universality and costing less on a per-tag basis. Technically, near field HF RFID utilizes the magnetic field to power tags. Far field UHF RFID uses the electric field to power tags. While it is true that far field UHF electromagnetic waves tend to get absorbed by liquids directly in the reader field, the magnetic coupling of near field UHF is not subject to RF absorption. In the magnetic near-field applications, UHF Gen 2 tags work well adjacent to products filled with lotions, gels or liquids. Even challenging items in close proximity to one another such as small liquid filled 1 ml vials can be read within a case.

An effective pharmaceutical supply chain tracking and tracing system may require both near field item level scanning and far field case and pallet level applications. While passive HF RFID tags are readable from a few inches away and are effective for near field scanning, they are not suitable for the more demanding, long range case and pallet needs. Passive UHF tags can be read close up, or from several feet away and are very effective at item, case and pallet applications.

Low frequency and high frequency RFID systems (LF/HF, that is, 13.56 MHz) are short-range systems based on inductive coupling between respective antennas of a reader and a data-provider device through a magnetic field. Ultra-high frequency (UHF that is, 860-960 MHz) and microwave (that is, 2.4 and 5.8 GHz) RFID systems can be long-range systems that use electromagnetic waves propagating between respective antennas of a reader and data-provider device.

UHF RFID systems designed to operate over long distances through electromagnetic wave propagation have several advantages including range compared to LF/HF systems but their performance in general is more susceptible to the presence of various dielectric and conducting objects in the vicinity of the data-provider device.

HF and some UHF RFID systems are designed to operate using magnetic induction and perform over a relatively a short distance. These systems are less susceptible to the presence of various dielectric and conducting objects in the vicinity of the data-provider device, however their limited range severely restricts their broad application.

The nature of electromagnetic wave propagation and magnetic inductance are substantially different and consequently so are their respective tag and reader antenna designs. Due to this physical limitation, there has never existed a system which exhibits the performance characteristics of both near and far field RFID devices.

Near-field RFID may provide a possible solution for item level tagging (ILT) in various industries such as pharmaceutical and retailing industry. Near-field coupling is already being used in such areas of UHF RFID as printer coupler ((tag writer) and for conveyor belt applications. Other near-field HF, UHF and microwave applications, to name a few, include short range wireless communication, also known as near field communication (NFC), hyperthermia treatment, MRI imaging, detection of buried objects, measuring material properties and various modulated scattering probe techniques.

Far-field RFID is currently providing solutions to many logistics and tracking applications where upwards of hundreds of tags per second can be read over great distances.

A BRIEF HISTORY

In early times, electromagnetic and electricity was not wide observation around the world. It was electrostatic discharge and the magnetic properties of loadstones. The application was to make light with fire. There has been use of mirror for signaling and loadstone for navigation. However, probably the scientific understanding was progressed from 1600s. In 1846, Michel Faraday proposed that the light and radio waves are a form of electromagnetic energy. In 1864, Scottish physicist James Clerk Maxwell published his theory on electromagnetic. In 1887, German physicist Heinrich Rudolf Hertz used Maxwell's electromagnetic theory and invented electro-magnetic waves (radio waves) (Landt, 2005). In 1906, Alexander-son first presented the continuous waves (CW) radio generation and transmission of radio signals. Under Watson-Watt, the British developed the first active identify friend or foe (IFF) system. They put a transmitter on each British plane. When it received signals from radar stations on the ground, it began broadcasting a signal back that identified the aircraft as friendly. RFID works on this same basic concept. A signal is sent to a transponder, which wakes up and either reflects back a signal (passive system) or broadcasts a signal (active system) (Landt, 2001). From that time till 1960's was a theoretical exploration of RFID techniques with a number of pioneering research and scientific papers being published. In 1960's, various inventors and researchers developed prototype systems. Sensormatic and Checkpoint were launched with the electronic article surveillance (EAS) equipment used as an anti-theft device. The proposed systems were used for tags detecting in retail stores attached to high value items and clothing. The method was proved as an effective antitheft measure and was arguably the first and most widespread commercial use of RFID. In 1970s, there was an increasing research demand of RFID from researchers, developers and academic institutions including organizations like Los-Alamos scientific laboratory and the Swedish microwave institute foundation. Its main objective was to develop the animal tagging and later it became commercially viable. In 1980s, RFID applications extended into a number of areas. In Europe, animal-tracking systems became widespread and toll roads in Italy, France, Spain, Portugal and Norway were RFID equipped. In 1990s, electronic toll collection technology was invented first in the United States. In 1991, an electronic tolling system was operated in Oklahoma where vehicles could pass toll collection points at highway with speed without stopping at toll booths. There are now over 350 patents registered with the US Patent Office related to RFID and RFID applications. In the first manner, wireless communication systems were essential for making antenna. Many industries still developing antenna for wireless communication but only few years ago researchers started to give emphasis especially for RFID antenna. In 1999, Hui and Alphones first presented micro-strip antenna for RFID systems (Hui and Alphones, 2000). This antenna plays a significant role in the antenna field. An intelligent 2.45 GHz Beam-scanning array for RFID antenna was showed by Salonen et al. (2000). This antenna is used in RFID catered for paper industry. A novel tag design using inverted-F antenna presented by Ukkonen et al. (2004). This antenna was first used in metallic object in RFID antennas. One year later, Min et al. (2005) proposed meander line antenna using Magneto-dielectric material for RFID system. This antenna supports broadband, enough to operate in both UHF bands (433.92 MHz and 816-916 MHz) and ISM band (2.45 GHz). The proposed method also supports magneto-dielectric material to get broadband and miniature characteristics.

ANTENNAS ELECTRICAL CHARACTERISTICS

Nowadays the wireless technologies such as radio, cellular, RFID, depend on the existence and efficiency of

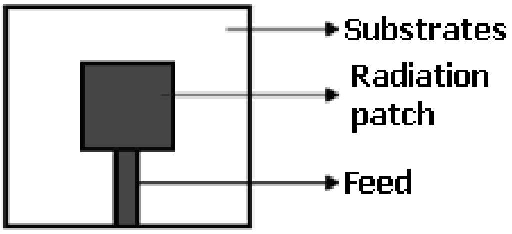

Figure 1. Micro-strip line feed (Nakar, 2004).

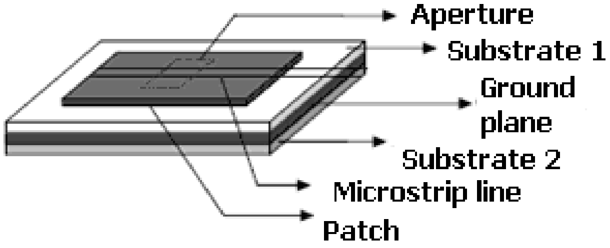

Figure 3. Aperture coupled feed (Nakar, 2004).

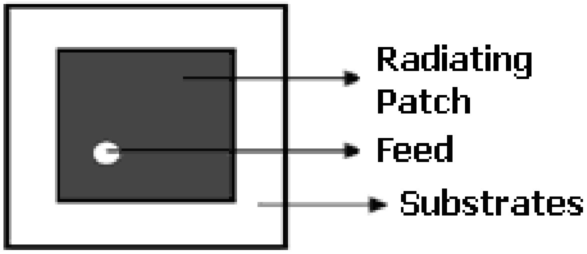

Figure 2. Coaxial probe feed rectangular micro-strip patch antenna (Nakar, 2004).

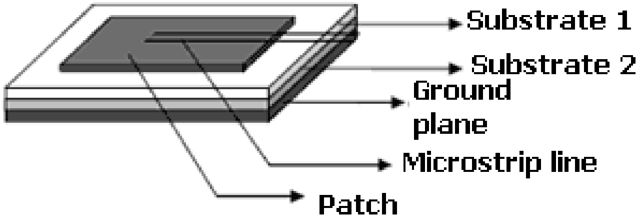

Figure 4. Proximity coupled feed (Nakar, 2004).

well-designed antennas to successfully communicate information through the air. Antennas are designed application-specific by enhancing certain antenna characteristics such as feed mechanism, resonant frequency and radiation pattern. In this section, we will describe the antenna parameters that designers use to enhance antenna efficiency.

Feed mechanism

A number of feed mechanisms have been developed for micro-strip antennas. Most often it is the feed mechanism that determines the complexity of the antenna design. Popular feed techniques can be classified into two broad categories are as follows.

Directly connected to antenna

A direct electrical connection is used to feed the radiating element such as micro-strip line, coaxial probe. Micro-strip line feed is one of the most commonly used feed techniques presented by Waterhouse (2003). A conducting strip is connected directly to the edge of the micro-strip patch. Inset feed is one in which the micro-strip line feed is inset into the patch to provide the right impedance match between the patch and the feed line. Figure 1 shows the micro-strip line feed. The advantage of this technique is that both of the feed and the patch lie on the surface of the substrate. This technique is efficient for thin substrates. However, the thick substrates should be avoided because of spurious feed radiation and cross polarization effects. The coaxial feed or probe feed has the inner conductor connection of the coaxial cable to the patch through a hole in the substrate and the outer shield grounded by connecting to the micro-strip ground plane. Figure 2 shows the coaxial probe feed. Though it is easy to place the feed in any location on the patch, the disadvantage with this technique is that it provides narrow impedance bandwidth and difficult to model.

Coupled to the feed

Electromagnetic field coupling is used to feed through antenna such as aperture coupling and proximity. An aperture coupled feed line is separated from the patch by the ground plane. Electromagnetic coupling is transferring the power from the feed line to the patch through a slot in the ground plane as shown in Figure 3. To avoid the cross-polarization, the coupling aperture is centered which are the top most layers from the patch. Among the multi-layered design, the efficiency of aperture coupling is lower compared to other techniques, but it is easy to model and presented in the proximity coupling feed in RFID antenna (Waterhouse, 2003). Proximity coupling feed has a feed line sandwiched between two different substrates as shown in Figure 4. The micro-strip antenna is on the top of the dielectric layer and the ground plane is on the bottom dielectric slab layer. The feed line is placed between the two dielectric slabs. The coupling is basically using capacitive in nature. The feed mechanism provides greater than 13% fractional bandwidth. However the fabrication complexity is better than previous methods. Kumar and Ray (2003) and Nakar (2004) came with the similar types of theory and saying that micro-strip antennas suffer from a number of disadvantages like narrow bandwidth, low efficiency, low gain, spurious radiation and surface wave excitation. While spurious radiation and surface waves can be eliminated by using the right feed mechanisms and substrate thickness but the major issues are poor bandwidth and low radiation efficiency. Micro-strip antennas inherently suffered from ohmic losses and dielectric losses making it a high quadrature *Q* device. In order to achieve greater bandwidth and gain, one must need to increase substrate thickness but this could result in surface waves, therefore alternate methods are explored.

Resonant frequency

UHF antennas typically "resonate" or operate at a particular frequency and are sized proportionally to the wavelength of the operating electromagnetic wave. A half-wave dipole for instance that operates at 915 MHz has a length of 15 centimeters which is approximately half of the operating wavelength.

In 2002, Best has mentioned that the Koch fractal monopole antenna exhibit lower resonant frequency (Best, 2002). According to the researcher, the monopole geometry is inherently fixed for overall height and wire diameter. Thus, increasing the total wire length would lower the antenna’s resonant frequency. It is also apparent that if a fixed total wire length and height were change, the antennas geometry resonant frequency would also be change. Marrocco (2002) replaced the method because lower resonant frequency is not satisfactory for all kind of RFID system antennas. Marrocco showed that the UHF band printed dipoles or patch antenna has normally large resonant size especially for operating frequencies below 1 GHz. Li et al. (2004) represented folded shorted-patch (S-P) antenna. The simulated result for return loss of this antenna aggress well the measured result, which indicates a resonant frequency of 6.36 GHz and the electrical length of the folded patch antenna at the resonant frequency is approximately λ/16. But the disadvantage of this proposal is the folded shorted-patch (S-P) antenna resonant frequency, which is not perfectly matched to the antennas ground shape. Therefore, the obtained results are likely to be subject to further improvement if a perfect matching is performed. Keskilammi and Kivikoski (2004) presented a new approach of text as a meander line, which is used for size reduction of dipole antennas. According to Mikko, the resonant frequency of the proposed antenna’s simulated and measured return losses as a function of frequency for antenna 1 and 2. Researcher showed $f1$ = 940 MHz for antenna 1 and $f2$ = 870 MHz for antenna 2 having the same axial length. The shortening ratio SR = 0.28 and the gain g = 0.85dB. This structure has the best shortening ratio among these three proposed structures, which conclude that the shortening ratio is increased at the expense of antenna gain.

Radiation pattern

The antenna's radiation pattern is a graphical representation of the strength of the antenna's power density in space. The theoretical isotropic antenna has a spherical radiation pattern but physically do not exist. There are two types of radiation pattern such as E-plane and H-plane radiation in each RFID antennas.

Sinbad (1994) presented the effect of a finite ground plane and its role in directivity and radiation pattern [17]. The researchers concluding that the overall directivity decreases as the dimension of the ground plane is reduced and the current result in spurious radiation manifested in diffraction of both leaky and surface waves. Huff and Bernhard (2002) used edge currents in compact range reflectors for reducing current leakage. According to his theory, if the ground plane is truncated, the antennas frequency and radiation performance can be affected substantially. The most imperative property of the serrated ground plane occurs in the co and cross-polar radiation patterns. In order to un-serrate finite-ground-plane, E and H-plane patterns are equalized with a relatively equivalent shape of 90° angle from bore-sight. The effective dimension of the ground plane decreases when the length of serrations increases. So a slight decrease in H-plane beam width and increase in E-plane beam-width is observed. Another important development of proposed antennas is that the cross-polar radiation decreases in both the E- and H-plane patterns as well as an increase in the length of the serration. Padhi et al. (2003) proposed that the radiation patterns are directive and symmetric in both E- and H-planes. According to his research, the measured cross-polar levels are 28 dB lower than the co-polar levels. Back radiations are also found as the coupling aperture radiates in backwards. Comparatively proposed antenna is better because its back radiation can be suppressed with a metallic shield placed at a distance of quarter wavelength from the fed line. Chen and Hsu (2004) extracted and compared two types of feature, which measured in broadside and bidirectional in the E-plane and almost omni-directional in the H-plane. The most important matter is that if the substrate width is made narrower, then the radiation pattern will become more uniform in the H-plane.

Figure 5. The 3D polar radiation patterns of dipole antennas with lengths λ/2 (Chang et al., 2005).

Broadband and CPW-fed folded-slot monopole antenna presented by Liu and Hu (2005). The proposed antennas showed good radiation characteristics which is suitable for the RFID application at 5.8 GHz. Conical radiation patterns in the E-planes (x-z and y-z planes) and almost Omni-directional pattern in the H-plane (x-y plane) are observed in the research of Chen and Hsu (2004) and Liu and Hu (2005) respectively. Chang et al. (2005) developed an antenna using omni directional radiation pattern where the structure require current cancellation on the antenna, which was much less than the meander structures and the total current induces an identical magnetic dipole. Liu and Hu (2005) developed Broadband and CPW-fed folded-slot monopole antenna. It is much faster but takes bigger size as a cooperative to other (dipole) antennas. Therefore, Chang et al. (2005) presented a new small size spiral dipole antenna. The proposed antennas are inexpensive for mass production and have an Omni directional pattern to be detected independent to the direction. The simulated antenna and measured radiation patterns in E- and H- plane at 910 MHz are depicted. Figure 5 shows radiation pattern of dipole antenna.

CHALLENGES IN RFID ANTENNA

Though UHF RFID has become the standard in supply chain tracking for its fast response rates and long read ranges, UHF antennas suffer limitation and their design poses many challenges. According to the researchers, an RFID antenna should have the following characteristics such as: (i) it should be small enough to be attached to the required object, (ii) have to be omni-directional or hemispherical coverage, (iii) must provide maximum possible signal to the application specific integrated circuit (ASIC), (iv) have a polarization such as to match the enquiry signal regardless of the physical orientation of the protected object, (v) be robust and (vi) be very cheap. But they are still facing many problems, they are orientation-sensitive, radiating directions are still encountering problems, they are material-sensitive, penetrating easily through radiolucent materials but not at all through conductive or liquid materials and they are narrowband, functioning over a limited range of frequencies (Foster and Burberry, 1999). Bandwidth is the most important thing; it needs the attention because of the UHF RFID system operates at different frequencies around the world. The different region supports different frequencies, while 915 MHz is the UHF RFID standard in the United States, 867 MHz supports the system for Europe and the systems in Japan operate at around 960 MHz EPC-global. The global body for creating industry standards in RFID technology, which requires UHF tags to operate between 860-960 MHz as part of its latest generation 2 standards (Johnson and Samii, 1995).

Existing tag antennas are designed for specific applications. For example, the albino-dipole antenna is a three-dimensional folded dipole design that wraps around the corner of a box and is optimized to radiate omni-directionally. Despite its near omni-directional functionality, the albino-dipole design does not perform well in the presence of metal. It has a fairly limited bandwidth (900 – 930 MHz). The avoidance of grating lobes (particularly if scanning is required) places an upper limit on element spacing at each band, while maximum element space are preferred to minimize cost. This precludes the use of dual-band or wide-band elements, such as spirals or notches (Pozar and Targonski, 2001). Since 1886, when Hertz experimentally showed that a current-carrying element creates electromagnetic radiation, antenna design has evolved from a simple dipole antenna to antennas of all shapes, sizes and dimensions. Nonetheless, antenna design remains a demanding and mysterious feat. The simple straight wire antennas and arrays of those wire antennas mathematical calculations become very complicated but faster operation. Normally, an antenna designer would make a known antenna and manipulate its physical parameters (antenna materials and antenna size) to optimize a particular antenna parameter (bandwidth). This evolution of antenna design using intuition, empirical testing and a bit of luck, leads to functioning but imprecise antennas (Stace, 1997). Due to layout constraints, a single micro-strip feed substrate is limited to two independent feed networks. Thus, at least two substrate layers are required for dual polarization at two frequencies. Isolation requirements are not likely to be met unless these feed networks are separated by a ground plane (Johnson and Samii, 1995).

System considerations usually dictate comparable beam-widths at the two operating frequencies, so the radiating aperture at the higher frequency will be smaller than that at the lower frequency. This means that the dual-frequency array aperture will not be uniformly filled. The traditional techniques of optimal and precise antennas are near impossible. By using the search optimizer conjugate (gradient, newton and simplex) to optimize an antenna is not guaranteed because of such techniques, which are local optimizers. These techniques are looking for local extreme solution set by differentiating functions around a set of initial conditions (Stace, 1997). However, for a system whose solution space has many local maxima, these optimizing techniques are not ideal because they converge to local maxima instead of global maxima.

RFID SYSTEMS IN ANTENNA DESIGN

In the development of technology for industrial automation of RFID handling has been established recently and it is still rising. As part of the general identification procedure, radio frequency identification (RFID) is an essential field of research in the modern industrial automation. Radio frequency identification is among the most technically advanced methods of collecting data automatically. RFID technology plays an important role for controlling, detecting and tracking items and moving information efficiently with an item along its lifespan. Taking advantage of these modern RFID systems can make paper reel handling procedure faster, easier and more reliable. This section gives different method of antenna design for RFID systems.

Circularly polarized antenna

In last few years, researchers have looked into the designing of circular polarized antennas. Circular-polarization enables to receive or transmit through antennas without significantly changing the output voltage. In many applications, these antennas operating at low power density, when the transmitting power is low and the transmission distance is long. The following section has shown a brief review using various methods.

Boti et al. (2000) had a theory saying that circularly polarized passive antennas switching process is inserted in the antenna itself, with beam-led pin diodes soldered in the excitation slots. In the intermediate structure, Boti added the pairs of beam-led pin diodes for each coupling slot. But these pin diodes are not ideal for circular polarized antenna. Strassner and Chang (2003) came with a similar kind of proposal saying that circular polarized dual rhombic loop antenna (DRLA) combines highly efficient RF-to-dc diode conversion with high gain array to produce dc power regardless of the array's orientation. The use of this method is a high gain antenna array with the advantage of reducing the number of traditional components such as diodes, capacitors and many more. Aissat et al. (2004) proposed a circularly polarized antenna fed a coplanar waveguide line (CPW). The circular polarization (CP) is combining two non-orthogonal modes independently excited by an inclined slot and open termination at the end of the CPW line. For this reason, the proposed antenna can generate a linear polarization in any direction and also permit a symmetrical radiation pattern.

Based on Boti et al. (2000) theory, Heikkinen and Kivikoski (2004) have used a novel circularly polarized shorted annular ring-slot rectenna (rectifying antenna). The proposed antenna is bidirectional; the radiation patterns are nearly identical on both sides of the antenna plane. The advantage of this antenna over a linearly polarized antenna is that it has nearly constant dc output and it can achieve the rectenna's rotation angle, relative to the transmitter changes. One year later, Ali et al. (2005) presented circularly polarized (CP) antennas with sensors. It helps the same dc voltage irrespective of the rotation of the rectenna. The conversion efficiency for the CP rectenna can be calculated by equation 1.

$$\eta R = \frac{V^2{}_D / R_L}{P_t G_t G_r \left(\frac{\lambda_0}{4\pi r} \right)^2 L_{Pol}} \tag{1}$$

Where P_t and G_t represent the transmit power and the gain of the transmitting array, G_r represents the gain of the rectenna, V_D is the voltage across the load resistor R_L of the rectenna. The distance between the transmitter and the rectenna is r.

Qing and Yang introduced the circularly polarized antenna, which are on the adjacent sides of a hybrid coupler and single strip line or coaxial line. Hybrid coupler can give isolation between the two feed ports, the branch line hybrid coupler or ring hybrid coupler. Li et al. (2005) presented a new theory of circular polarized (CP) loop antenna. A single-loop antenna has only one minimum axial ratio (AR) point while the two-loop antenna can create two minimum AR points. It will be demonstrated that the AR bandwidth of a CP loop antenna can be significantly increased by adding a similar loop inside the original loop. The addition of a parasitic element can produce two minimum AR points that lead to a considerable enhancement for the AR bandwidth. According to Rong Lin's theory, if a gap is introduced on the loop than loop antenna can radiate circularly polarized wave. Compared to conventional center-fed planar spiral antennas, the CP loop antennas have two important advantages: (i) the loop antenna is fed on its perimeter, making it possible to directly integrate an antenna array in a coplanar strip-line circuit; (ii) the sense of the circular polarization can be easily switched from left-hand to right-hand and vice versa.

Dual polarized antenna

The design of dual polarized antenna is suitable for passive 5.8 GHz in RFID applications. These types of antenna are very useful for receiver; it can receive the data and send back the identification information.

Padhi et al. (2001) presented dual polarized aperture coupled micro-strip patch antenna. It can be used for RFID transponder (tag) and interrogator (reader) unit. It also can be used for transmission (TX) and reception (RX). As can be seen, the circular patch is etched on the top substrate and the dual orthogonal apertures feed lines are etched on the top and bottom sides of the bottom substrate. The proposed antennas height and lengths and positions of the coupling apertures are optimized. This is done to increase the bandwidth of the antenna. The antenna's broad beam width and low front-to-back ratio in both planes are very useful for wide-angle coverage. Therefore, the performance of the developed antenna is very suitable for RFID applications. Most dual polarized antennas based on micro-strip or stripline technology are generally of the 'patch' or 'slot' variety. Rectangular patch dual polarized antennas have the disadvantages over equivalent linearly polarized arrangement such as high cross-polarization and low isolation. Rao and Bhartia (1989) have carried out experiments to investigate this problem on a multi-port dual polarized square micro-strip patch. To overcome these types of problem, Sangster et al. (2003) presented a stripline fed dual polarized antenna based on the use of slots, but here the slots are used as radiation, rather than parasitically exciting a patch radiator. It has shown high isolation and low cross polarization characteristics. The proposed antenna main advantage is that in a single frequency application, such as a transceiver or a range finder, a ferrite circulator is normally employed to connect, transmit and receive circuits to a common antenna. Pozar and Targonski (2001) have found the problem of coplanar fed micro-strip patch antenna and saying that it operates the limited bandwidth to a few percent at C band and the X-band slot elements, which are required for reflecting ground plane.

Pozar and Stephen overcame this problem using shared aperture dual band dual polarized antenna. The proposed antenna used different prototype, including scanning without grating lobes because of time and cost constraint, the prototype was built as fixed-beam broadside array. Padhi et al. (2001) evaluate his previous method and selected a dual polarized aperture coupled circular patch antenna using a C-Shaped coupling slot. It is preferred to distinguish feeding mechanisms as it offers greater design flexibility. According to his proposal, two popular techniques of achieving dual polarization using aperture-coupled micro-strip antennas are: (i) two off-center orthogonal coupling slots and (ii) crossed slots located at the center of the patch. The proposed antenna used relatively complicated feed arrangement or multilayer construction to reduce the coupling between the two feed lines. Broadband dual polarized printed array antenna proposed by Gao and Sambell (2004) has received a new approach of noble design. It uses the slot-coupled feed for one polarization, while the micro-strip line feed with slotted ground plane is used for different polarization. In Gao and Sambell antenna design, two feed network circuit for each polarization are placed on the same layer. It is very difficult to find enough space to accommodate two sets of feed networks on the same layer. To overcome this problem, Gao put the feed networks on different layers under the ground plane. Vallecchi and Gentili (2005) came with similar kind of proposal saying that dual polarized micro-strip fed linear arrays having a four port slot coupled cross patch as a basic element. The proposed antenna structure has been adopted as the best solution for cross-polarization reduction. To increase the operating bandwidth and minimize possible dielectric losses, the micro-strip patches and the feed lines are realized on a multilayer structure where relatively thick layers of foam material are employed.

Inverted F-antenna

Inverted F-antenna (IFA) has been used in RFID, mobile and wireless systems due to its compact size and low profile. The ability to vary its impedance, gain and polarization characteristics makes the IFA a potential candidate for many applications. Inverted F-antenna presents a very suitable method for the RFID systems.

Taga and Tsunekawa (1987) constructed the planar inverted-F antenna (PIFA) by replacing the linear radiator element of linear inverted F antennas with a planar radiator element. The characteristics of the PIFA on the infinite ground plane are projected to be the same as to those of the linear inverted F antenna. However, the characteristics of PIFA mounted on portable radio cases are different from those PIFA on the infinite ground plane. It also depends on both the antenna position and dimensions of the radio case, because of the existence of surface currents on the radio case. Virga and Samii (1997) found that planar inverted F antenna (PIFA) is another alternative to develop several compact broadband radiators suitable for RFID application. The proposed antenna structures have specific advantages over current methods because the bandwidth increases while maintaining low profile geometry and without additional internal matching. This antenna is attractive for RFID or wireless systems where the space volume of the antenna is quite limited. Liu et al. (1997) discovered that the planar inverted F antenna in dual frequency mode could also be used in RFID and cellular communication systems. According to the research, Liu tried to reduce the radiating edges and reducing any possible interaction. The size of a planar inverted F antenna can be determined approximately from equation 2.

$$f_0 = \frac{c}{4(a+b)} \tag{2}$$

Where c is the velocity of light, a and b are the width and length of the radiating element andf_0 is the operating frequency.

Based on Virga and Samii (1997) method (Enhanced bandwidth planar inverted F-antenna), Salonen et al. (2000) have used dual band planar inverted F antenna (PIFA) with U-shaped slot. The length l and width w of the PIFA determines the lower resonant frequency, which can be approximated by the equation 3.

$$f_w = \frac{c}{4(w+l)} \tag{3}$$

Where c is the velocity of light, l and w are the length and width of the radiating element, f_w is the lower operating frequency.

The upper resonant frequency for a U-shaped slot PIFA can be determined approximately from equation (3) in which length l and width w are replaced by l_2 and w_2, respectively.

Hirvonen et al. (2004) showed a number of disadvantages of particular antenna such as printed dipole antennas might be used in RFID application, but their performance is highly platform dependent. Conversely, micro-strip patch antennas are more tolerant to the effects of the platform, but are very large in size. Hirvonen et al. (2004) tried to overcome these types of problem and presented a planner inverted F-antenna (PIFA) structure for RFID applications. By using this antenna structure, smaller size may be achieved, but generally at the cost of reduced tolerance to the environment. RFID microchip may be directly matched to the antenna. More importantly, new platform independent impedance behavior can be achieved. See et al. (2006) presented inverted-F antenna (IFA) for RFID contact tracing system. The proposed antenna tracing system can evaluate the performance and protect the coverage of the systems. The coverage is defined as the maximum distance from the bottom of the IFA to the point where transmitted signal used by the beacon. The main advantage of this antenna is to provide the maximum coverage without any null regions for a limited output power.

Meander line antenna

In the ultra-high frequency (UHF) band, especially lower than 1 GHz, meander line antennas (MLA) are an attractive choice for the purpose of reducing the antenna sizes. The characteristics of the antennas are the optimized MLA shape converges to a top-loaded antenna as the available height increases.

Marrocco et al. (2002) first introduced the new design of miniaturized meander line antennas for RFID applications. It is a proper shaping of the conductor in order to the best utilization of the wire current and improves the antenna gain while keeping the size small. The proposed antenna is based on Genetic algorithm (GA) and a method of moment (MoM) to design the best length for each meander line segment. According to Gaetano theories, GA applies algorithm of selection, crossover and mutation to obtain new population, which better match a fitness function depending on a non linear combination of the antenna parameters.

One year later, Marrocco (2003) proposed the optimized self-resonant meander line antenna (MLA) using the same algorithm (genetic algorithm) for RFID application. In his design, the length of each segment of the MLA is encoded into 7 bits and each antenna is solved by the method of moment.

The frequency can be chosen to meet the particular requirement of each system. Therefore, it is difficult to apply RFID globally, as the system has different frequencies in each region and areas. To solve these type of problems, Min et al. (2005) presented the meander line antenna using broadband and miniaturizetion characteristics. Here, the magneto-dielectric material is used to achieve broadband frequency. The proposed antenna supports both UHF band (433.92 – 916 MHz) and ISM band (2.45 GHz). To achieve high bandwidth performance, magneto-dielectric materials are used as substrate for planner antennas. These substrates are used to miniaturize antennas while maintaining a relatively high bandwidth and efficiency. To survey the frequency analysis, Min et al. (2005) like Ali et al. (1995) found the similar types of proposal to support different frequencies. But Ali et al. (2005) updated his antennas formulation to new approaches. Since this antenna has been meandered on both sides and also has two sleeves, so, this antenna called a dual meander sleeve antenna. The main advantage of this antenna is unlike other (Bailey, 1984; Friedman, 1985; Dye et al., 2007) wideband antennas. It has no complicated impedance matching or tuning arrangements except the two sleeves. Michishita and Yamada (2005) presented dielectric material loading for a piled type antenna. The proposed antenna works as short dipole antenna. It is becoming input impedances of the pilled, near the frequencies and frequency changes very fast.

Lee et al. (2006) applied meander line structure, coupler line theory and stacking technique with low temperature co-firing ceramic (LTCC) processing method for compact triple band antenna. The common benefits achieved from the capacitance and inductance components of radiation elements adjusted by controlling the spacing between the coupled and meander lines. Using these methods, the proposed compact triple-band LTCC chip antenna can be used for the communication handsets.

Micro-strip antenna

Micro-strip antennas have attractive features such as lightweight, small volume, low profile and low production cost which is very wide. Now micro-strip antennas and antenna arrays are being used in many applications such as WLAN, RFID, point to point wireless communication and many more.

Hui and Alphones (2000) showed a number of limitations in micro-strip antennas imposed by printed technology. Hui addressed that the major operational disadvantages of micro-strip antenna are their low efficiency, low power, high *Q*, poor polarization purity, poor scan performance, spurious feed radiation, surface wave losses and very narrow frequency bandwidth. Hui et al. presented a new micro-strip patch antenna with annular ring photonic band-gap (PBG) for RFID application which may solve these types of problem. The proposed annular ring PBG structure appears to be promising solution to suppress higher harmonic and surface-waves in patch antenna. In addition, the improvements in antenna performance make the new design approach useful for a wide range of applications in microwave and mm-wave frequencies. Huff and Bernhard (2002) presented micro-strip antenna through ground plane edge serrations. Huff and Bernhard used serrations as an edge treatment for a micro-strip antenna ground plane of reducing the diffracted fields caused by the truncation. The importance of the serrations is that any data can demonstrate using the impedance match and fundamental resonant frequency.

The proposed antenna's important development is the decrease in cross-polar radiation in the E and H-plane patterns as the length of serration is increased. Chen and Chia (2003) presented center-fed (CF) micro-strip antenna for RFID application. This antenna is comprised of a coaxial probe and shorting pin separated by narrow rectangular slot centrally cut in the patch. The drawbacks of proposed antenna are feeding system, which centrally excites the patch through a narrow slot. Chen could not properly solve the narrow slot to his proposal. So, it was replaced by an equivalent center-fed magnetic line source of equivalent magnetic current. To overcome these types of problem Rao and Johnston updated Chen's proposal. To solve the narrow slot ground plane, Rao and Johnston (2004) proposed aperture coupled micro-strip antenna. The attractive feature of proposed antenna has many degrees of freedom for impedance matching and adjustment of the operating frequency. The new method of antenna arrays known as collinear array (CoA) are based on in-phase feeding of radiating elements that lie in the straight line and their radiation is typically broadside perpendicular to the axis of collinear elements presented by Franklin (1924). Polivka et al. (2005) came with a similar kind of proposal where the collinear micro-strip patch antenna (CoMPA) array is based on the slot loaded micro-strip patch operates with transverse magnetic (TM_{0x}) modes. Where *0* indicates metal waveguide for zero tangential electric field amplitude and *x* determines the number of half current wavelengths in the resonant longitudinal dimension.

Due to the collinear arrangement of in-phase source current areas, the beam-width in E plane with directivity can be enhanced by increasing the order of operational mode with enlargement of patch resonant dimension. Aziz et al. (2005) showed the effect of different scaling

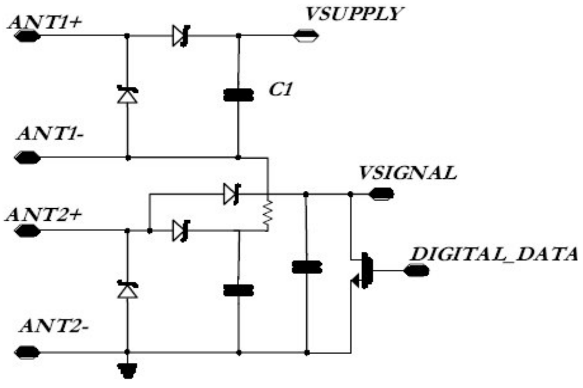

Figure 6. Front-end circuit diagram for test-chip (Pillai et al., (2004).

factor to micro-strip log periodic antenna. The proposed antenna has attractive features such as lightweight, small volume, low profile and low production cost. In the contrary, Aziz saying that this antenna has a limitation, which is the narrow bandwidth of the basic element. Chen and Chia (2003) updated the micro-strip antenna proposed by Padhi et al. (2001). Chen and Chia modified micro-strip antennas balanced feeding structure. The modified structure is good in impedance matching and radiation performances.

Pasha et al. (2000) presented micro-strip fed slot antenna to be used in millimeter wave RFID system. The antenna is fabricated precisely with very low tolerance and time domain gates are implemented in measurements to see any mismatch in the micro-strip feed line and the slot micro-strip antenna (SMA) launcher.

Other methods

There are a number of methods proposed by various researchers for the purpose of RFID antennas. Some of these methods are briefly explained here. Cichos et al. (2002) mathematically formulated performance analysis of polymer equation based on RFID coils as shown in equation 4.

$$H = \frac{I.N.r^2}{2\sqrt{(r^2 + x^2)^3}} \tag{4}$$

Yang et al. (2006) modified the above expression data, which leading to:

$$Ra = \frac{(2\pi f_0 M)^2}{R_{rb}} + R_{loop} \tag{5}$$

$$Xa = 2\pi f_0 L_{loop} \tag{6}$$

Where R_{ib} and R_{loop} are the individual resistances of the radiating body and the feeding loop. M is the mutual inductance and L_{loop} is the self- inductance of the feeding loop.

Since the components of impedance can be predicted in R_{loop} is typically small, therefore, M and R_{rb} mainly control resistance. The reactance is dependent only upon L_{loop}. This is taken as the resonant frequency formulation for the novel inductively coupled RFID antenna. Padhi et al. (2004) introduced a method based on a miniaturized slot ring antenna. The proposed antenna presented microwave RFID system design that operates in their dominant mode and characterized by lowest frequency of operation. The use of such method operation results in large size antennas, which are predominantly responsible for an increased size of an RFID system. Pillai et al. (2004) considered stacked antenna for broadband RFID front-end circuit. The proposed circuit employing schottky diodes, which have very little leakage characteristics and also exhibits little leakage at evaluated temperatures. The drawbacks of this circuit are parasitic capacitors coupled through the substrate and might increase the front-end capacitance and decrease the *Q* of the circuits. If no power supplied to one of the antennas, then the corresponding capacitor on V-supply will act as an open for the chip load current and over periods of time, voltage to the chip may reduce. Figure 6 shows a schematic of the front end for Test-chip.

An analytical expression for the measurement of RFID antenna using conductive ink on plastic presented by Bechevet et al. (2005). The proposed method of antennas lies on three steps: (i) determination of the electromagnetic properties of low cost substrates; (ii) to take into account of the conductive part of the planar antenna; (iii) the design of optimization and antennas measurements in free space. A modified triangular or half-bowtie shape ultra-wide band monopole antenna etched on a thin substrate with a staircase shape to achieve a wide bandwidth proposed by Cho et al. (2005). The proposed antenna is applied to the impedance matching methods, which utilizes two slits near the feeding region and an extended ground plane on the bottom side of the antenna. The tuning parameters also affected by antenna performances. The extended ground plane and two slits in the vicinity point can easily control capacitance and inductance. By adjusting them, a wide impedance bandwidth can be achieved. Liu and Hu (2005) came with a similar kind of proposal of the same antenna (monopole) but some updated version such as broadband coplanar waveguide (CPW)-fed patch monopole antenna for 5.8 GHz RFID application. This antenna is mechanically robust and easy to fabricate and integrate with the application-specific circuit. The

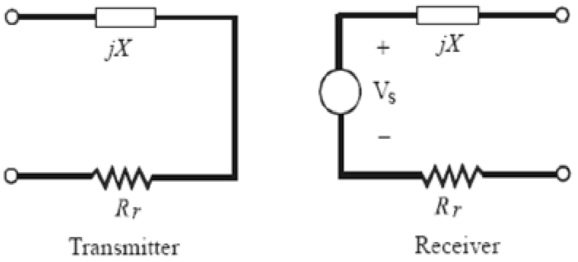

Figure 7. RFID label antenna equivalent with a lossless antenna (Cole and Ranasinghe, 2006).

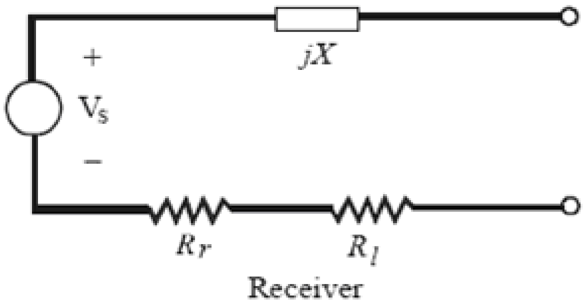

Figure 8. RFID label antenna equivalent with accounting for ohmic losses (Cole and Ranasinghe, 2006).

advantage of proposed antenna is that the total length of the folded slot and total wavelength to the resonant frequency size can be reduced by using the slot-folding technology. Cole and Ranasinghe (2006) proposed a method to show the effectiveness of small antennas for UHF RFID labels using coupling volume theory and radiating antenna theory. Radiating antenna theory commonly used in antenna radar calculations. It is appropriate in the context in which labels are placed in the far field and when the label antenna size is large. Coupling volume theory was devised for situation in which labels are placed in the near field and the energy storage field of a transmitter antenna. The proposed antenna has been shown for ideal lossless and electrically small antennas. Figure 7 shows the RFID label antenna equivalent with a lossless antenna. Figure 8 shows the RFID label antenna equivalent with accounting for ohmic losses.

COMPONENTS OF RFID SYSTEM

RFID system consists of three components such as reader, tag and antenna. The system of RFID antenna also can be classified into two ways, such as, interrogator (reader) antenna and transponder (tag) antenna.

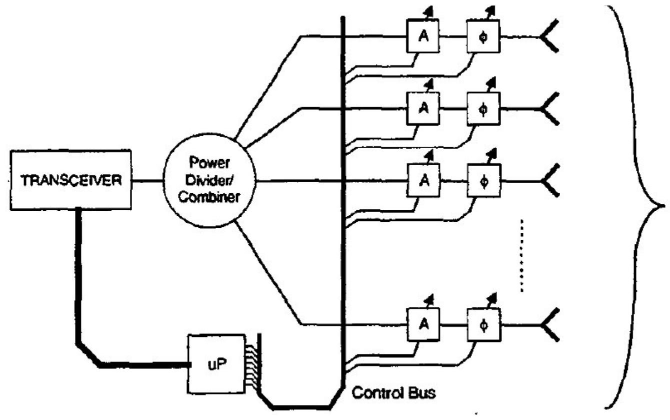

Figure 9. Block diagram of the control network of digital beam-forming antenna (Salonen and Sydanheimo, 2002).

RFID reader antenna

A wave development of large and well-established players in antenna design and manufacture has led to tremendous technical advances in the performance of reader antennas for RFID. RFID reader antennas have some characteristics such as: (i) good data transfer rate, (ii) freedom from environmental reflections that can plague UHF systems, (iii) frequency band available worldwide as an ISM frequency, (iv) on-chip capacitors for tuning tag coil can be easily realized, (v) cost effective antenna coil manufacturing, (vi) robust, (vii) inexpensive, (viii) high radiation efficiency (ix) low side-lobe to reduce interference.

Salonen et al. (2000) developed an intelligent five-element rectangular patch antenna array for modern array beam-scanning RFID reader. For any element pattern, Pekka presents a common theory of array factor. The current distribution feeding the elements of the array is symmetrical.

Salonen and Sydanheimo (2002) used the beam-forming antenna for RFID reader using 4-bit pin diode phase shifters. Figure 9 shows the control network of digital beam-forming antenna. The similar method of adaptive antennas is also based on antenna arrays in which the radiation pattern can be controlled electrically by defining the weights for feed current amplitudes and proper phase shift for each of them. According to the research, the proposed antenna has three basic phase shifter circuit that use pin diodes as the switching device: i) switched line, (ii) loaded-line and (iii) hybrid coupled (circuits.

Padhi et al. (2003) presented a shared aperture dual polarized coupled micro-strip patch antenna in C-band (5.8 GHz) and S-band (2.4 GHz). According to the design of proposed antennas two coupling apertures are placed in right angle under the radiation patch to generate two

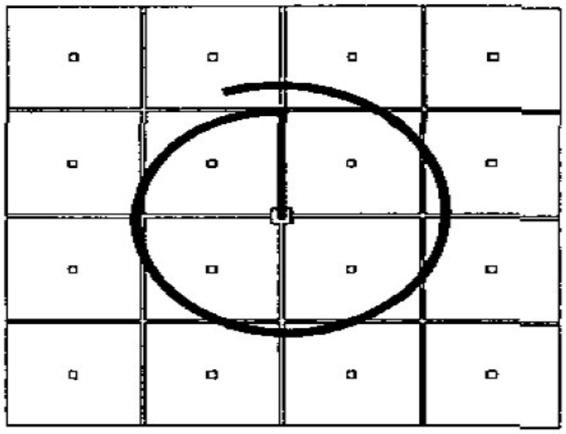

Figure 10. A compact and very low profile spiral curl antenna Raumonen et al. (2004).

orthogonal polarizations such as T_x and R_x. High gain and high isolation between the two coupling aperture input ports make the array very much suitable candidate for RFID reader module for 2.4 GHz band. Qing and Yang (2004) presented aperture coupling feeding technique for RFID reader antenna design. This antenna is reasonably compact because the feed circuit is fabricated on a separate substrate under radiating patch. In addition, this feed technique has following advantages: (i) the feed circuit is isolated from the radiating element by the ground plane which prevents spurious radiation; (ii) active devices can be easily fabricated in the feed substrate for system size reduction; (iii) there are more degrees of freedom for the designer. The little disadvantage of this proposal is that it is very sensitive to the slot dimensions, to overcome this problem; their position, length and width should be selected carefully. Raumonen et al. (2004) presented a compact and very low profile spiral curl antenna. This method is using the electromagnetic band gap (EBG) structure. But, the drawbacks of this method are the axial ratio bandwidth; the input match bandwidth and the reduced gain. Figure 10 shows a compact and very low profile spiral curl antenna. In the metallic ground plane, the horizontal wire antenna cannot be placed very near the ground plane. Therefore the overall height of the antenna structure must be increased due to the reverse phase of the reflected waves. Whenever the antenna is very near to the ground plane, the reflected wave will cancel the fields in the antenna. Therefore, the antenna radiation is very poor and radiation resistance is very low. On the contrary it means a poor impedance matching. To overcome these types of problem, Pasi Raumonen used finite element method (FEM). Using this structure, proposed antenna might get high impedance surface, which has a desirable feature, compact reduced size demands of the application at hand.

Weigand (2005) discovered that compact micro-strip antenna could be used in PCMCIA for RFID reader cards. According to his theory, a bent micro-strip dipole antenna that meets the PC card, which has size constraint, is a preferred radiation property and also matched to a 50 Ohm transmission line. Steven shows the outlines how this theory considers the effects of varying individual dimensions. The shunt inductance resonates with the impedance of the antenna arm anyway shorter than λ/4 and thus capacitive and large currents flow in the inductive shunt. Since most of the current flows through the horizontal inductive shunt, the resonant length is measured from the center of the shunt rather than the center of the feed.

Lee et al. (2005) found a number of limitations using a dielectric substrate, single feed single-element patch antenna, which is usually narrow circular polarized (CP) bandwidth of about 2% or less. It greatly limits their practical applications. Figure 11 shows circularly polarized metallic patch antenna. To overcome these types of limitation, Lee et al. presented a single feed circularly polarized metallic patch antenna for RFID reader applications. The proposed antenna's main advantage is the feed structure with the probe feed placed in between the antennas radiating patch and ground plane. The proposed feed structure, a cone-truncated square patch antenna with a thick air-layer substrate, which can be excited with good impedance matching and good CP radiation characteristics.

Polarization and space diversity antenna using inverted-F antenna proposed by Kim et al. (2006) has received considerable attention, particularly in RFID reader applications. Figure 12 shows inverted F-antenna. The benefits of the use of polarization and space diversities at the transmitter or receiver was found to reduce the error rate for two to four orders of magnitude in most cases, thus leading to the higher detection capability of RFID readers. The drawbacks of the polarization and space diversities antenna radiation directions are limited to the broadside direction of the micro strip patch. To overcome this problem, Jong-Sung added an inverted-F antenna, which is very popular in portable handsets of mobile communications, particularly in planar types due to its simple design, flexibility, low cost and reliable performance. A path loss model that can be applied to predict the signal strength at a certain distance away from a transmitting antenna is presented by Leong et al. (2006). According to his theory, the power transfer ratio for a pair of lossless antennas in free space with optimum orientation is given by Equation 7.

$$\frac{P_r}{P_t} = g_t g_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{7}$$

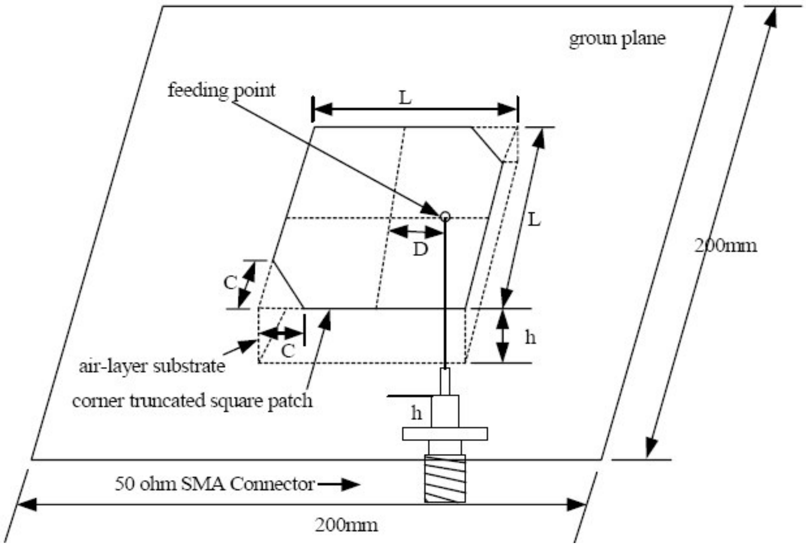

Figure 11. Circularly polarized metallic patch antenna Lee et al. (2005).

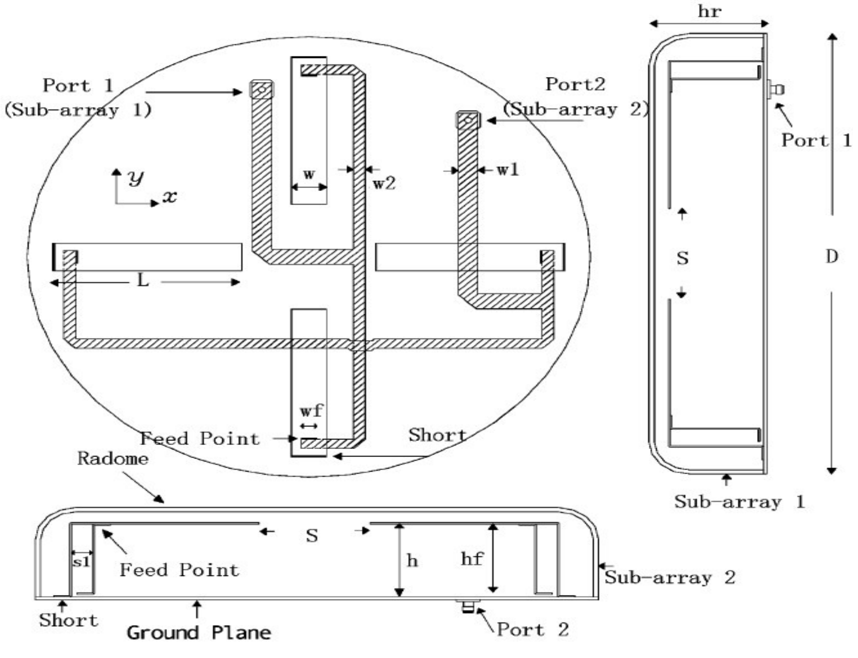

Figure 12. Inverted F-antenna Kim et al. (2006).

Where λ is the wavelength; P_t is transmitted power; P_r is received power; g_t is the receiver antenna gain; d is the separation distance between antennas.

RFID tag antenna

Generally, tag antenna is preferred to ensure identification from all directions. Because of their lightweight, low profile and their ability to conform to non-planar structures, antenna can be applied in these RFID applica-tions. An antenna for an RFID-tag should satisfy the following requirements: (i) the antenna element should be thin; (ii) it should be a flexible with a simple shape; (iii) the impedance bandwidth should be wide; (iv) the antenna feed point should be composed of two

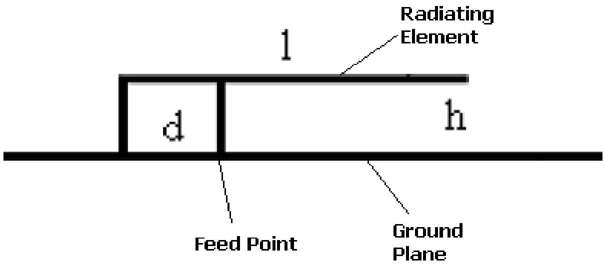

Figure 13. Basic structure and dimensions of inverted F-antenna for RFID tag application Ukkonen et al. (2004).

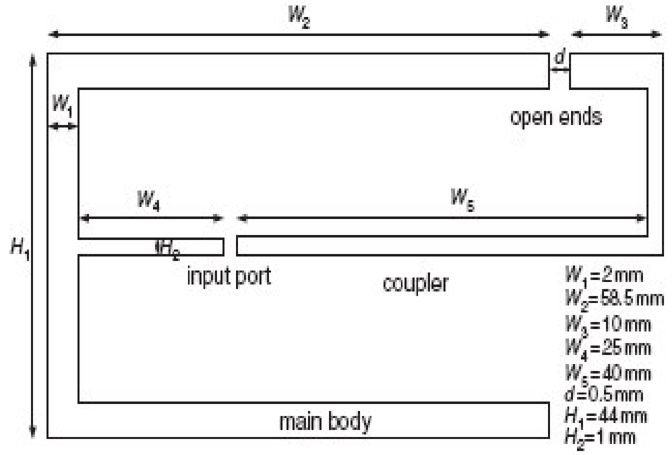

Figure 14. Architecture of the capacitive coupled RFID tag antenna (Chang and Lo, 2006).

terminals on the plane because the I/O terminal of the IC-tag chip is composed of two adjacent electrodes. Ukkonen et al. (2004) introduced a novel inverted-F antenna (IFA) designs for RFID tag application. According to his theory, one of the biggest challenges is tagging an object that consists of metal or other conductive material. Because of directivity increase, the metal plate near antenna can perform better reflector. There are also a number of antenna types that needs a conductive ground plane to function properly. The metallic surface can also be used to improve the performance of the antenna.

On the other hand, since the metals are highly conductive therefore the incident wave is almost totally reflected by the metallic surface. This will cause the changes in the radiation frequency and the radiation pattern of an antenna. Therefore the radiation efficiency decreases. These negative effects are bigger when the antenna is very near to the metallic surface. Figure 13 shows the proposed antenna for RFID tag application. Meander dipole tag antenna proposed by Rao et al. (2005) has received considerable attention, particularly in antenna design. Tag antennas are usually analyzed with electromagnetic modeling and simulation tools, typically with method of moments (MoM) for planar designs and with finite-element method (FEM) or finite-difference time-domain method (FDTD) for more complicated three-dimensional designs. To have a better control over the antenna resistance, one loading bar has been added with the same time width as the meander trace. To provide a better match for the chip capacitive impedance an additional inductance is also being added. This antenna can be easily tuned by trimming. Lengths of meander trace and loading bar can be varied to obtain optimum reactance and resistance matching.

Chang and Lo (2006) presented the broadband RFID tag antenna using two bent dipoles and a modified double T-matching network. Three main design goals have been considered for the desired tag antenna: (i) a small and planar profile, (ii) a high efficiency and band-width product (EB) and a quasi-isotropic radiation pattern. Figure 14 shows the architecture of capacitive coupled RFID tag antenna.

Chang et al. (2005) discovered that the small sized spiral dipole antenna can be used for the expected application of UHF RFID systems, such as supply chain integration, industrial automation, track and trace and so on. According to the research, the proposed antenna is designed to reduce the antenna size and to minimize the efficiency. The readable range of the tag with the proposed antenna is 230 cm. However, the measured readable range is only 110 cm. The range difference is caused by the mismatching between the antenna impedance and the tag chip impedance. Figure 15 shows the small-sized spiral dipole antenna for UHF RFID transponder.

Choi et al. (2005) proposed a planar inverted-F antenna (PIFA) which is an example of single shorting pin that can reduce the antenna size and improve the bandwidth. Figure 16 shows PIFA with the loop-shaped stub and meander line antenna. Min et al. (2005) discovered that, the small size and bandwidth of the antenna design by Choi does not satisfy all the desired properties for RFID tag application. Min et al. updated his theory and presented two types of antenna for RFID tag applications such as printed dipole antenna and loop antenna with parasitic element. Nikitin et al. (2005) discovered that straight dipole (left) and meander dipole (right) antennas from silver link can be used in RFID tag application.

Choi et al. (2005) came with a similar kind of proposal saying that a planar inverted-F antenna (PIFA) can be stuck to metallic objects to create a passive RFID tag in the UHF band. A PIFA consists of a ground plane and radiating patch, as well as a feed wire and shorting plate. The PIFA is fed by a feed wire at the point where the wire connects to the ground plane. The addition of the

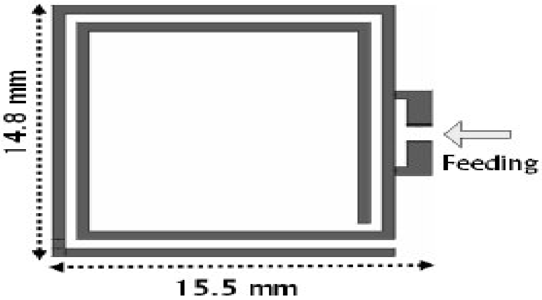

Figure 15. Configuration of the small-sized spiral dipole antenna for UHF RFID transponder (Chang et al., 2005).

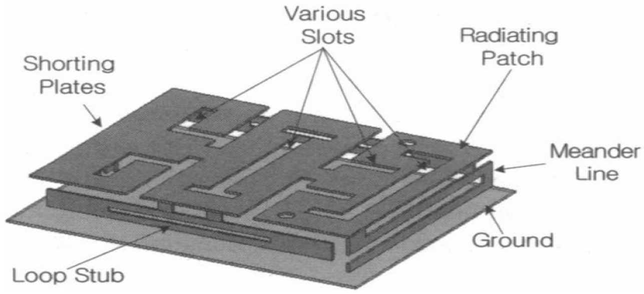

Figure 16. The proposed PIFA with the loop-shaped stub and meander line Choi et al. (2005).

shorting plate allows for a good impedance match to be achieved with the radiating patch, which is typically less than λ/4 long Figure 16

RFID ANTENNAS APPLICATION

Nowadays wireless communication technology as like RFID antenna has lad to increase the use of military and personal communication systems. Presently, the trend is that of providing a wireless antennas link to every kind of electronic device such as mobile phones, personal digital assistant (PDA), blue-tooth systems and wireless local area networks (WLANs). Among these systems antenna link are used for transmitting and receiving voice, images and data. However, RFID antennas not only indispensable but also play an important role in the quality of service in wireless communication systems.

RFID antennas are also used in embedded communication system, which is composed with digital, analogue and RF parts with specific characteristics for each one. RFID have become very popular in many service industries, distribution logistics, manufacturing companies and goods flow systems (Nikitin et al., 2005). In these applications data are contact-less transferred to a local querying system (reader) from a remote transponder (tag) including an antenna. The antenna size is very small, low cost, low profile and especially the bandwidth requirement is less critical. Recently RFID antenna is using for railway vehicle identification. The proposed antenna measured by 4 unit's micro-strip antenna array as transmitting/receiving antenna of the RFID system. It operates at 915 MHz frequencies. The information transmission between high frequency RFID card and RFID equipments mainly depends on magnetism coupling of loop antenna and in this case, the operating distance is very near, generally within 1 m. So this system only could identify low speed target. However, microwave identification usually operates at 915, 2450 or 5800 MHz and so on. Therefore, the identification distance of this case is far, even could be 10 m and it is suitable for identifying high-speed target. So it can be used as railway vehicle identification system, road tolling system and the automatic identification management of container wharf and goods yard (Canadian, webpage). RFID antenna is also used in fish tracking systems.

In 1980s, Colombia Basin Bonneville power authority (BPA) took an interest in fish tracking via RFID antenna. They did experiment in salmon fish tracking and achieved success. That kind of tracking was already underway with livestock and some officials realized the same might work for salmon and steelhead, another endangered river fish. According to their research, the area is measured at least 10 feet across because of its size alone. The speed at which the salmon will pass the reader antenna tag reader will scan using an antenna. This antenna is the world's largest RFID antenna system. This antenna is reading RFID tags inside the salmon up to 3 feet away as they pass at up to 60 miles per hour on their way to the ocean (Swedberg, 2005). Earlier Scientists were worried about the cost of RFID antenna. QinetiQ, a science and technology company based in Farnborough, England, has linked with Sun's Coates screen business unit and produced low cost metal for their antennas. The antennas are typically made by sheet copper and etching away layers until getting required thickness.

A typical UHF antenna is about 2 microns thick and a 13.56 MHz antenna is usually about 15 to 20 microns thick. To make the antenna thicker, QinetiQ takes the antennas out of the electro-less solution and uses electroplating to add 5 microns of metal to the antenna per minute (Roberti, 2004). RFID antenna also takes a part for paper industry applications. For these purposes the possibilities of the use of a broadband bow-tie-RFID antenna is most preferable (Schaffrath et al., 2005). It supports UHF frequency region around the center frequency of 915 MHz.

CONCLUSION

The review provides various methodologies to design

RFID antenna. Various electrical characteristics of RFID antenna, challenges in RFID antenna, RFID systems in antenna design, components of RFID system, were discussed along with their advantages and disadvantages. It has been shown that the circular polarized dual rhombic loop antenna (DRLA) is better than switching process with beam-led pin diodes soldered in the excitation slots because of their traditional components such as capacitors, diodes and many more. For RFID, circularly polarized shorted annular ring-slot antenna is alternative to other frequency response band. The advantage of this antenna over a linearly polarized antenna is that it has nearly constant DC output and it can achieve the antennas rotation angle, relative to the transmitter changes. It has also been shown that a measure advantages of strip-line fed dual polarized antenna is that in a single frequency applications, such as a transceiver or a range finder, a ferrite circulator is normally employed to connect, transmit and receive circuits to a common antenna.

The drawback of broad-band dual polarized printed antenna is that it is very difficult to find enough space to accommodate two sets of feed networks on the same layer. The study shows that the planar inverted F-antenna (PIFA) is alternative to develop several compact broadband radiators suitable for RFID application. This antenna structure has specific advantage over other methods because of the increased bandwidth while maintaining low profile geometry without additional internal matching. Inverted-F antennas are also used for RFID contact tracing system. The problem of this antenna is to provide the maximum coverage without any null regions for a limited output power. The most common and popular genetic algorithm and method of moment (MoM) is used in meander line antenna for RFID application. It has been shown that the major disadvantages of micro-strip antennas are low efficiency, low power, high *Q*, poor polarization purity, poor scan performance, spurious fed radiation, surface wave losses and very narrow frequency bandwidth. Stacked antenna circuit employs schottky diodes, which have very little leakage characteristics and exhibits little leakage at evaluated temperatures. For RFID reader antenna, the drawbacks of a compact and very low profile spiral curl antennas are the axial ratio bandwidth; the input match bandwidth and the reduced gain. For RFID tag antenna such as, meander dipole tag antennas have a better control over the antenna resistance and inductance. This antenna can be easily tuned by trimming.

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