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Full Length Research Paper

A quarter-wave Y-shaped patch antenna with two unequal arms for wideband Ultra High Frequency Radio-frequency identification (UHF RFID) operations

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The radio-frequency identification (RFID) system which has become pervasive in the auto identification technology has been noticed to have several limitations. These limitations can be broadly divided into two major areas namely; application specific problems and general RFID problems. Application specific problems are common to the environment in which RFID tags are deployed such as metal, aqueous and irradiation environments. Whilst, the general problem of RFID tags include low gain, regional specifications and so on. In this paper, a new antenna prototype has been design and stimulated. The proposed antenna showed tendency of exhibiting improved gain from the previous RFID UHF antenna which is 0-1 dBi to -3 dBi and impedance bandwidth of 140 MHz. The proposed antenna is Y shaped patch with unequal monopole arms which are responsible for the different frequencies that the antenna operates and a quarter wavelengths was adopted rather than the popular half wavelength for size reduction. The fractional return-loss bandwidth for S11<10 dB and radiation efficiency are about 95% was obtained.

Key words: Passive ultra high frequency radio-frequency identification (UHF RFID) tags, microstrip antenna, impedance bandwidth.

INTRODUCTION

The adoption of radio-frequency identification (RFID) technology in the supply chain industry and other fields of human endeavors have enhanced real time tracking of goods in the auto identification systems.The benefits derived from the real time tracking of goods has made RFID technology to be deployed in many fields such as logistics, information, commercial trade, manufacturing, traffic control manage-ment, etc (Ukkonen et al., 2006; Tikhov et al., 2007). All RFID systems be it passive - without battery, active - with battery and semi-passive-battery assisted make use RF in sending and receiving signals (Khan et al., 2009; Dobkin, 2007; Karmakar, 2010). However, passive UHF RFID tag which consists of a microchip and antenna as shown in Figure 1 uses additional technology known as back-scatter in communicating with reader antenna.

Advances in wireless communications and RFID have introduced tremendous demands in the antenna technology (Azim et al., 2010a, b; Islam et al., 2009a, g; Liu et al., 2011; Mobashsher et al., 2010a, b). It also the paved the way for wide usage of mobile phones in modern society resulting in mounting concerns surrounding its harmful radiation (Faruque et al., 2010a, b; Faruque et al., 2011a-e; Misran et al., 2010; 2011). (In addition to this, many parameters are considered when adoption RFID UHF systems. Of great importance to RFID system performance characteristic is tag range – the maximum distance at which RFID reader can either read or write information to the tag. Nikitin and Rao (2006) tag range is defined with respect to a certain read/write rate (percentage of successful reads/writes) which varies with a distance and depends on RFID antenna design and propagation environment. As a result of diverse materials and packages that need to be

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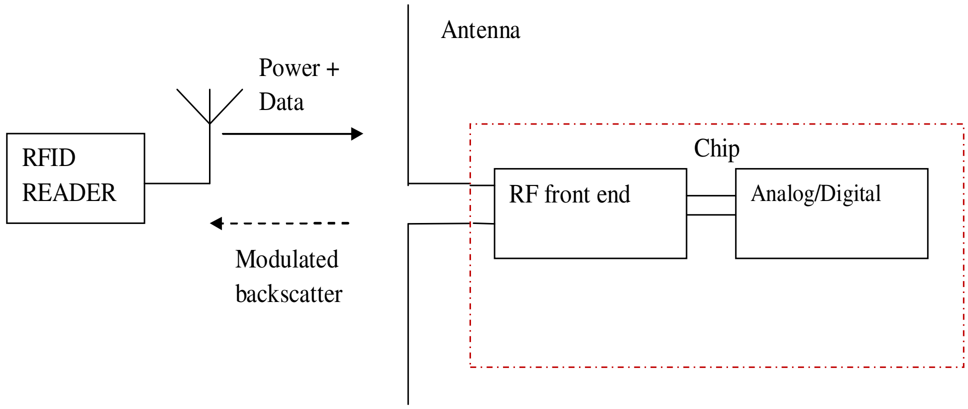

Figure 1. RFID system operation; Source: (Yu et al., 2006).

Table 1. Comparative study of different tag antennas.

Antenna	Pattern type	Free-space bandwidth (%)	Impedance (Ohms)	Polarization
Dipole	Ominidirectional	10-15	50-80	Linear
Folded dipole	Ominidirectional	15-20	100-300	Linear
Printed dipole	Directional	10-15	50-100	Linear
Printed patch	Directional	2-3	30-100	Linear/circular
Log spiral	Directional	100	50-100	Circular

identified, lots of challenges has been faced in developing tag antenna UHF RFID systems. Such challenges include but limited to the following; impedance match between tag antenna and the microchip so as ensure maximum power transmission coefficient, decrease the losses and improve the read range. Designing an efficient tag antenna has led many researches to come out with various design models such as; Traveling Wave Antennas (TWAs), Meander-line antenna, Dipole antenna, Monopole antenna or slight variations of the above methods (Son et al., 2006; Faruque et al., 2011a-e; Islam et al., 2010a,b; Shakib et al., 2009; 2010). None of the mentioned techniques has yielded a gain more than 0 and 1 dBi. RFID systems operating at ultra-high-frequency (UHF) bands are the preferred choice when longer interrogation range of several meters is needed, and high frequency (HF) is used when electromagnetic fields that exhibit good material penetration and sharp spatial field confinement such as metallic and aqueous environment are required and low system implementation cost is desired.

In low-frequency systems, copper wire is normally wounded in huge number of turns and in UHF frequencies, a different approach is taken. This approach involves using a single turn, dipole or patch antennas and Table 1 provides a comparative study of different tag antenna configurations. No matter what type of antenna being considered, some properties of tag antenna have to be considered (Finkenzeller, 2003; Raz et al., 1999; Tuttle, 1997; Azim et al., 2011a-c). These include:

1. Be small enough to be attached to the required object,
2. Have omnidirectional or hemispherical coverage to ensure non-line-of-sight operation of the tag,
3. Must provide maximum possible signal to the ASIC,
4. Have a polarization such as to match the enquiry signal regardless of the physical orientation of the tagged object,
5. Be robust and very cheap,
6. Frequency band. This is country specific as many countries or regions operates in a give frequency bandwidth,
7. EIRP. EIRP (effective isotropic radiated power) is also determined by local country regulations just like frequency band.

In this paper, a new wide slot microstrip antenna (MSA) prototype was designed and stimulated. The proposed antenna is a Y shaped patched antenna with an inverted F ground plane. The proposed antenna makes use of quarter wave length and thus has a considerably reduced total length. Moreover, the proposed antenna exhibit the fundamental benefits of MSA such as low cost, light weight and ease of fabrication.

RFID TAGS

RFID tag performance parameters

Finkenzeller (2003) RFID tag efficiency is defined in terms of tag factors with emphasis on tag performance characteristics such as: read range, directionality, sensitivity to materials also, combines with tag operating band to inhibit the maximum attainable antenna gain of the RFID tag. Impedance matching between the tag and the chip are crucial for the tag to perform in optimum capacity. Impedance matching for maximum tag range is usually done at the chip threshold power level which also depends on frequency and absorbed power of the RFID tags. There are numerous literatures on RFID tags optimum performance (Finkenzeller, 2004; Curty et al., 2007). Different form factors of RFID tags are commercially available (Shakib et al., 2010; Azim, 2010; Islam et al., 2009a, b). Ramakrishnan and Deavours (2006) have shown detailed comparative performance evaluations of various tags. The two most sensitive factors of tag performance and measurement are discussed as follows:

1. Tag sensitivity,
2. Tag range.

Tag sensitivity is defined as the minimum signal strength at the tag location needed to power up the tag (Curty et al., 2007). Unlike other tag parameters, this important tag characteristic is independent of the reader transmitted power or propagation environment. Rather, it is depends on the chip threshold power sensitivity, tag antenna gain, and match between tag antenna and high (power collecting) impedance state of the chip.

Tag field sensitivity tag E (V/m) and power sensitivity P_{tag} are directly related as shown in Equation 1 and visualized in Figure 2 (Nikitin and Rao, 2008). The power available at a perfectly matched antenna load (chip) can be express either through incident power P_i and tag antenna gain G or through incident power density P_{inc} and effective tag antenna A_{eff}:

$$P_{tag} G = S A_{eff} \quad (1)$$

Where S is the power density given as:

$$S = \frac{E^2}{120\pi} \quad (2)$$

Where E is the electric field of an incoming wave:

$$E_{tag} = \frac{4\pi}{\lambda}\sqrt{P_{tag}} \quad (3)$$

Thus tag power sensitivity can also be readily expressed as:

$$P_{tag} = Gp\,\tau P_{th} \quad (4)$$

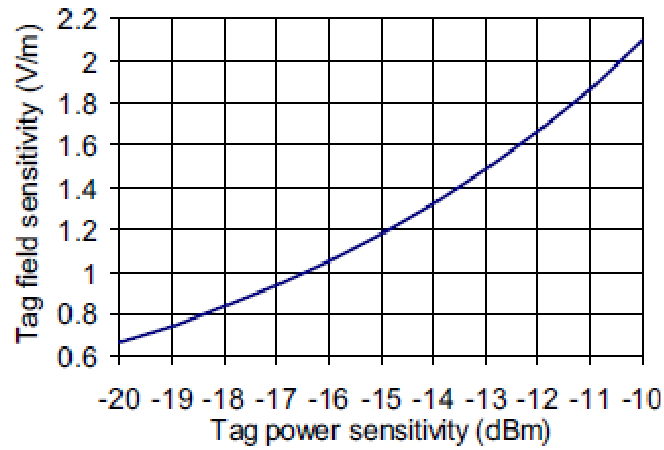

Figure 2. Tag field sensitivity (V/m) vs. tag power sensitivity (dBm), frequency is 915 MHz. Source: (Nikitin and Rao, 2008).

Where p is the polarization efficiency, τ is the impedance matching coefficient between the tag antenna and the chip, and P is the chip power threshold sensitivity.

Equation (4) shows how much minimum incident power at the tag location is needed to make sure that the sufficient amount of it gets absorbed in the RFID chip and activates it.

Tag range

One of the frequent questions asked by supply chain users of the RFID tag is range of the tag. Tag range here is defined as the maximum range at which a tag can be read. Tag range measurement is not a complex experiment to undergo. It is much simpler to determine the read range of a single tag, which is mostly done in a large stationary anechoic chamber (Glidden et al., 2004).Tag range does not only depend on tag sensitivity but also on system parameters. The systems parameters in which these tags depends on are EIRP transmitted by the reader, propagation environment path loss, and tag sensitivity. Write range (maximum distance at which the tag can be written to) is usually lower than read range (approximately 70% of it) because RFID IC needs more power for performing write operation. If we assume that the maximum readable range of the tag is limited only by tag sensitivity, then tag read range can be calculated in an arbitrary propagation environment via link budget equation which equates signal strength at the tag to the tag power sensitivity.

$$P_t G_t L_{path}(d) = P_{tag} \quad (5)$$

There have been occasions where an inverse function of distance dependent path loss $Lpath^{-1}$(d) could be

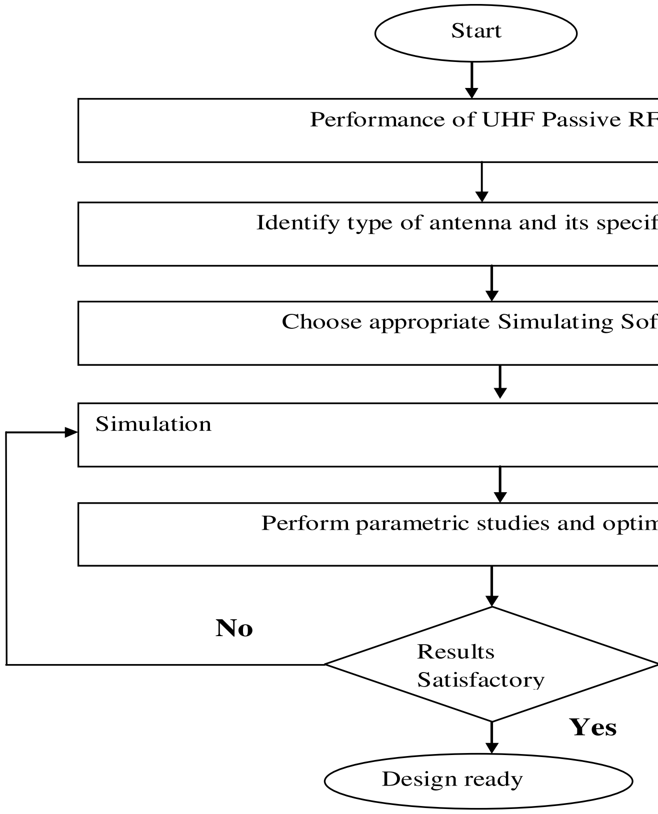

Figure 3. Flow chart on the simulation of the proposed antenna.

solved in an analytical form. Equation (5) could be analytically used to solve the problem of tag range. One of such occasions is the free space path loss occasions or friss equation, where the path loss is proportional to path d^{-2}(Nikitin and Rao, 2003; Son and Choi, 2006) and the tag range can be found to be:

$$r_{tag} == \frac{\lambda}{4th}\sqrt{\frac{P_{th}G_{th}p\tau}{P_{tag}}} \quad (6)$$

Equation (7) highlights the relationship between tag range in free space, tag field sensitivity and the tag power sensitivity.

$$r_{tag} = \frac{\lambda}{4\pi}\sqrt{\frac{30P_{th}G_{th}}{E_{tag}}} = \frac{\lambda}{4th}\sqrt{\frac{P_{th}G_{th}}{P_{tag}}} \quad (7)$$

RFID TAG ANTENNA STRUCTURE AND DESIGN

Antenna design

The performance of RFID is strongly dependent on many variables. Such variables includes but not limited to; frequency of operations, tag-chip impedance matching and so on. The tag range needs to be closely monitored in order to meet the design requirements of the RFID tag systems. In order to carry out a comprehensive study of RFID systems, a flow chart was designed and implemented Figure 3. The flow chart in investigates the problem statement and proceeds to describe the design.

The geometry of the proposed CPW – fed wide slot microstrip antenna for broadband high gain UHF tag is shown in Figure 3. The antenna will be fabricated on a Rogers RT 6202 substrate with thickness of 1.524 mm, a dielectric constant of εr of 2.94±0.04, and a loss tangent of tan δ = 0.0015 with an inverted F copper ground plane of 85 × 62.50 mm^2. The overall size of the antenna is 0.22λo × 0.20 λo. After several optimization, the following dimensions in millimeters gave the best results for the radiating patch (Pa= 3.0, Pb=42, Pc=36, Pd=2, Pf=38). For the ground plane, the following dimensions in millimeters were also used for the best result of the antenna (Ga = 2.8, Gb = 84, Gc = 57, Gd = 4.50, Ge = 60, Gf = 55). Coplanar Wave guide dimensions are also in millimeters (Wa= 16, Wb =3).

A CPW transmission line was used and it consists of a single strip length of 16 mm and a planar lower portion with a 4.50 mm thickness of the inverted F ground plane. The basis of the antenna structure is a wide slot patch, which has dimensions of 42 mm in the upper length of

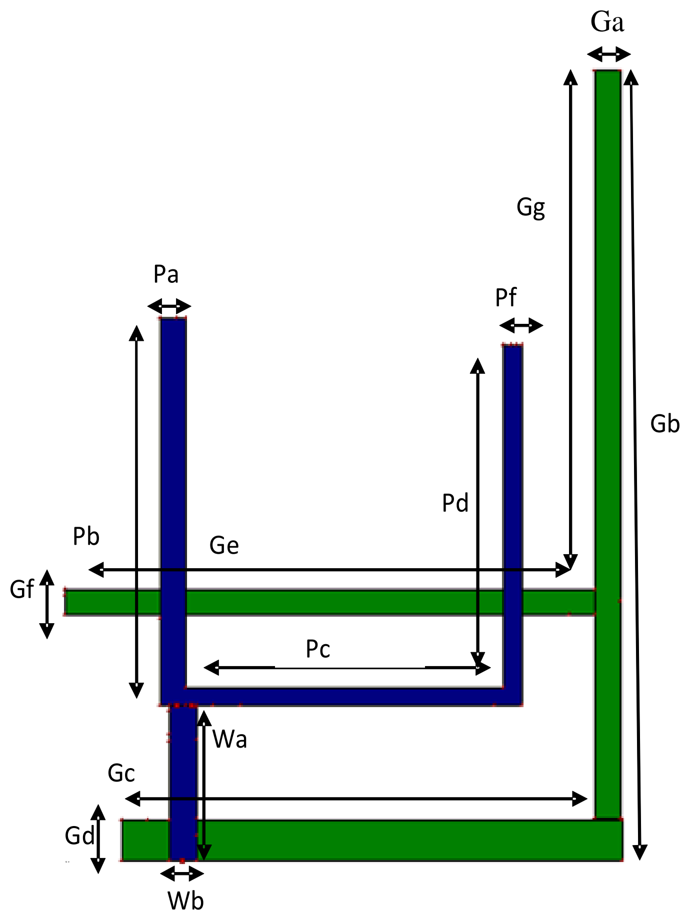

Figure 4. Proposed antenna geometry.

the Y patch and 38 mm in the lower length of the patch. Both arms are connected with a horizontal patch length of 38 mm. In addition, the proposed wide slot antenna is connected to the lower end of the inverted F ground plane in a distance of 5.6 mm for maximum gain. The use of large ground plane of 84 mm length by 57 mm in the lower section of the ground plane plays a major part in the achieved gain. The most significant portion of the ground plane is the middle arm with a dimension of 60 mm. This middle arm contributes tremendously to the overall gain of the wide slot monopole antenna. The blue color and green color in Figure 3 represents the patch and the ground plane respectively.

SIMULATIONS

The antenna was stimulated using IE3D which is a full wave simulation software based on method of moments (MoM). Figure 3 shows the stimulation frequency response of the return loss for the proposed wide slot microstrip antenna. The return loss of the slot antenna as presented in Figure 4 shows a BW of 150 MHz or 16%. The gain of the antenna is approximately 3 dBi at the resonant frequency of 930 MHz as shown in Figure 5. Microstrip antennas are well known for their inherent shortcoming of narrow bandwidth (Pozar, 1991). When a microstrip antenna is designed to operate in frequency ranges of 800 and 900 MHz, experiences have shown that it performs well but exhibit narrow bandwidth limiting the operation at one frequency. In as much as the patch and slot are designed to resonate at the same frequency, then the antenna will display a wide bandwidth at the design frequency. The aforementioned technique has been extensively used in microstrip technology to produce broadband antennas (Mobashsher et al., 2010). Many techniques have been used in patch antenna bandwidth enhancement (Islam et al., 2010). The most prevalent in these techniques is the impedance matching at the source (Finkenzeller, 2004). Multilayered structures are proposed in some techniques but this technique cannot be used in RFID technology due to the fact that it is bulky and non-planar in RFID applications sense (Widad et al., 2008; Mandeep and Hilary, 2010). The wide slot monopole RFID tag designed in a single planar layer as shown Figure 3 antenna exhibited a high gain

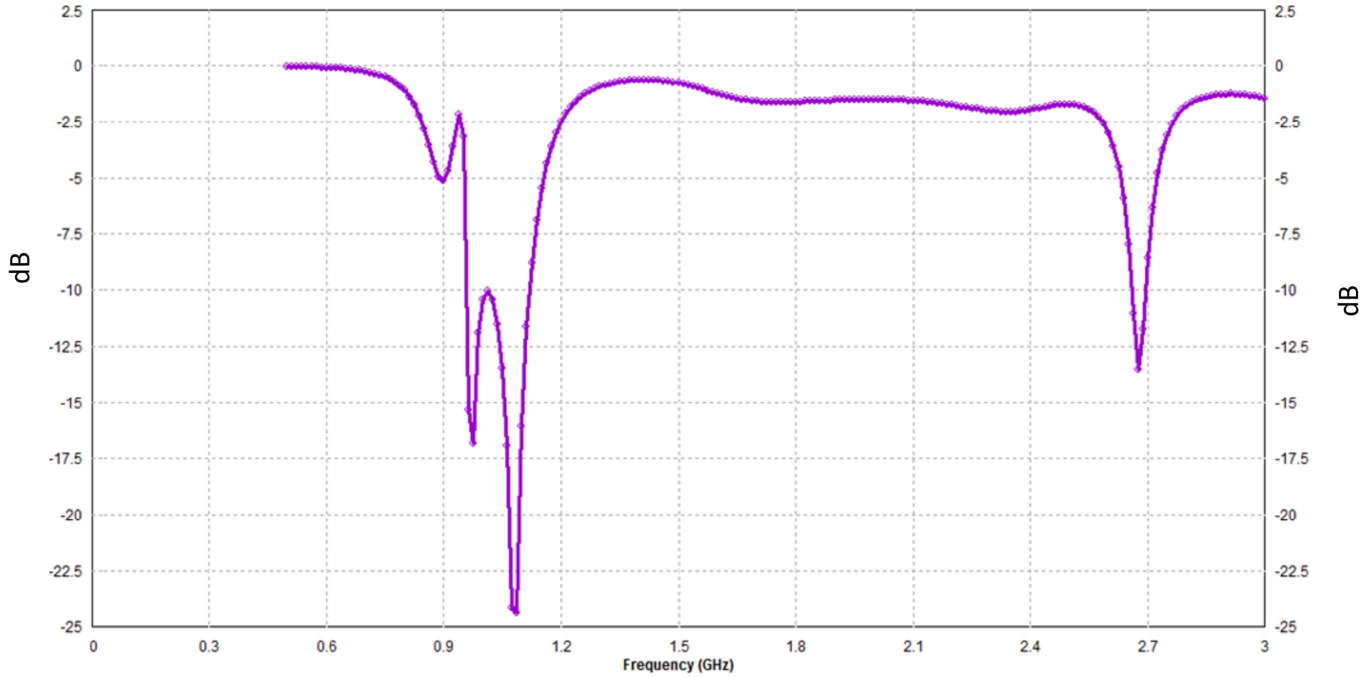

Figure 5. Return loss of the proposed wide slot MSA.

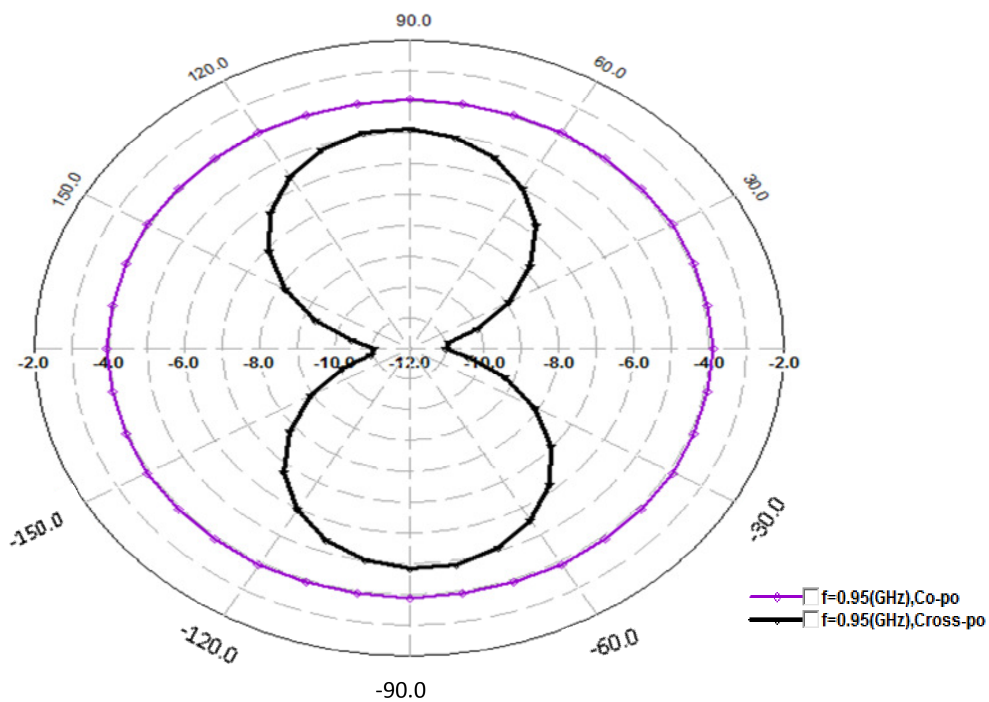

Figure 6a. Azimuth pattern gain display at 0°.

and broadband width. The wide bandwidth from 930 to1170 MHz is as the result of the wide U slot adopted because microstrip antenna has an inherent disadvantage of narrow bandwidth.

Figure 6(a) and (b) plot the measured the radiation pattern at 0.95 MHz for the proposed antenna. The patterns observed to be stable for operating at the said frequency. It is also noted that, at the operating

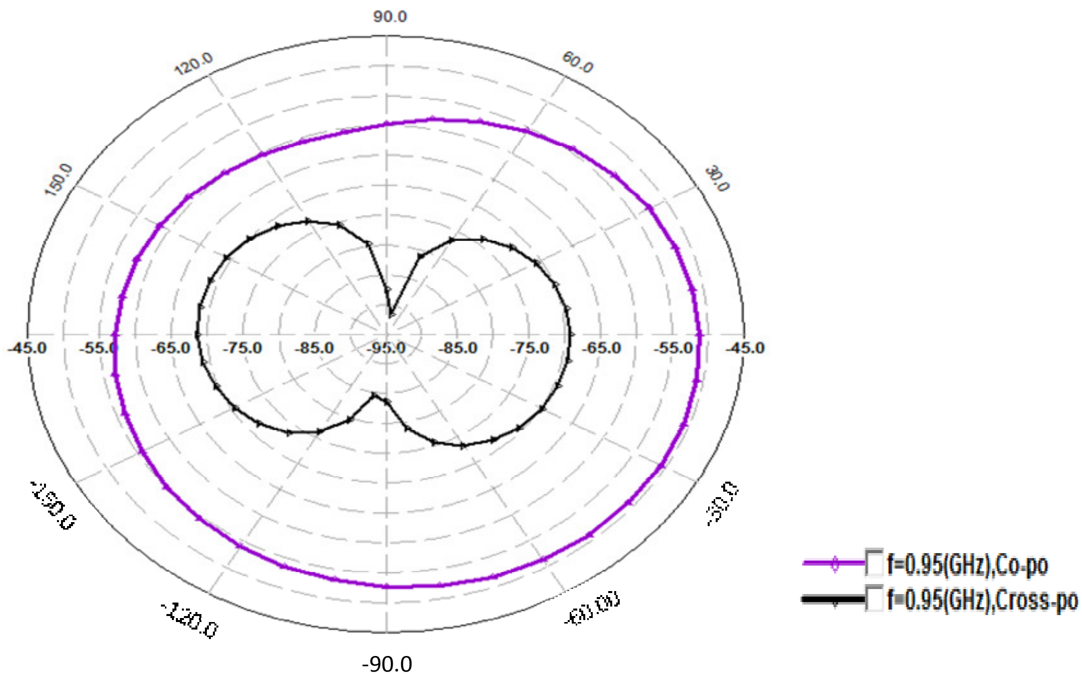

Figure 6b. Azimuth pattern gain display at 90°.

Table 2. Effects of ground plane reduction by 5 mm.

Ground plane	Optimized	5 mm short
Ga	2.8	2.8
Gb	84	84
Gc	57	57
Gd	4.50	4.50
Ge	60	55
Gf	3.0	3.0

frequency, the patterns in E plane are nearly omni-directional and those of H plane are in symmetry with respect to the antenna axis ($\theta = \theta^{\circ}$) since the antenna's structure is in symmetry. However, in the E plane, the peak radiations are positioned at about 30° right and left shifts from the center ($\theta = \theta^{\circ}$) according to the appropriate positions of the dominant frequency which is 0.95 MHz.

INFLUENCE OF THE GROUND PLANE

It is well known that monopole-type antenna performance isdependent on ground-plane effects (Arkko, 2003) and an evaluation of the dependence of printed strip mono-pole performance on ground-plane size has been carried out (Ammann and John, 2005). The shaped ground plane has recently been investigated for increased impedance and pattern bandwidth (Zhang and Fathy, 2006). The bandwidth of wide-slot antennas have been enhanced using a microstrip fork-like feeds (Sze and Wong, 2001; Qing et al., 2001). From the Table 2, it was evident that when the middle arm length of the ground plane was decreased by 5 mm, the resonance frequency of the shifts 930 to 960 MHz in the lower frequency band and there is a decrease in bandwidth of the proposed antenna. We decided to choose 5 mm short in ground plane to show the intricate nature of the ground plane and how a small change may affect and shift the total gain of the proposed antenna.

It is evident that the lower the ground plane, the lower the gain of the antenna as can be seen Figure 7. It can be seen from the graph within that the ground plane of a monopole antenna plays a crucial part in the overall gain of the antenna. The maximum game in the lower region which is 930 to 960 MHz decreases from approximate 3 dBi to 2.5 dB as can be seen in Figure 8. The current distribution as shown in Figure 9 shows that current is uniformly distributed both in radiating patch and ground

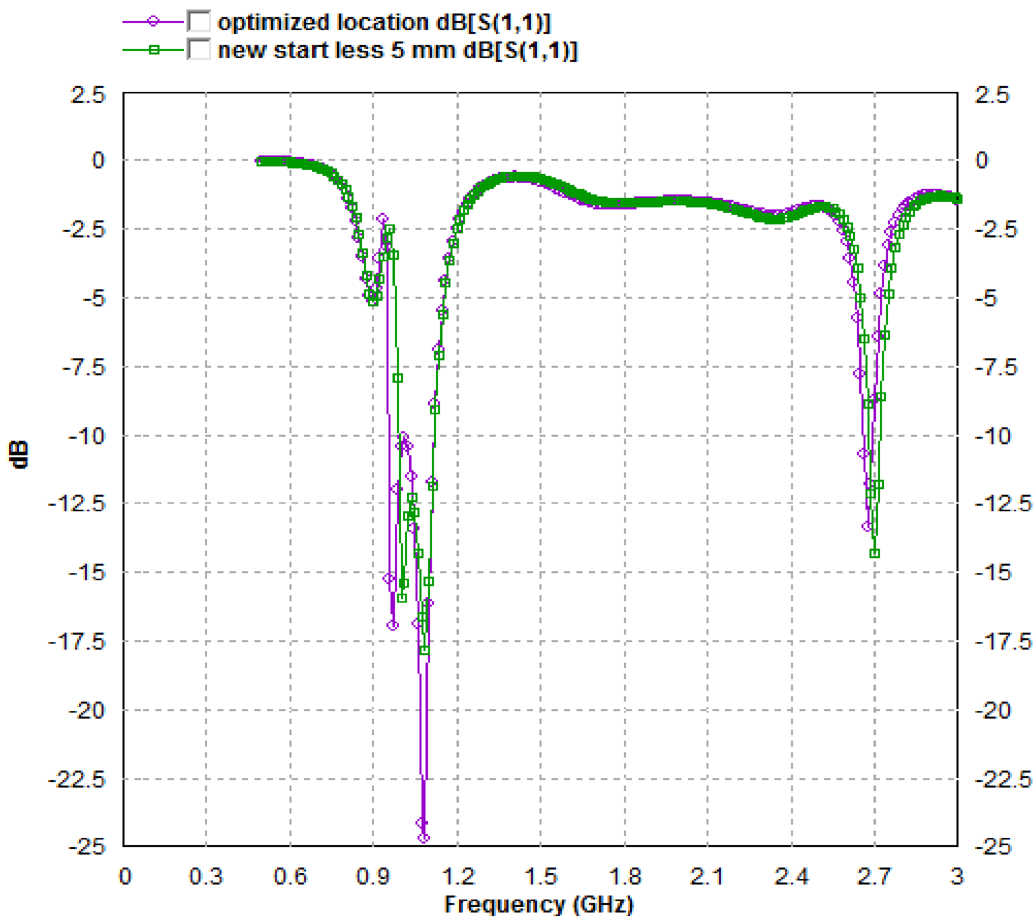

Figure 7. Return loss graph of reduced ground plane.

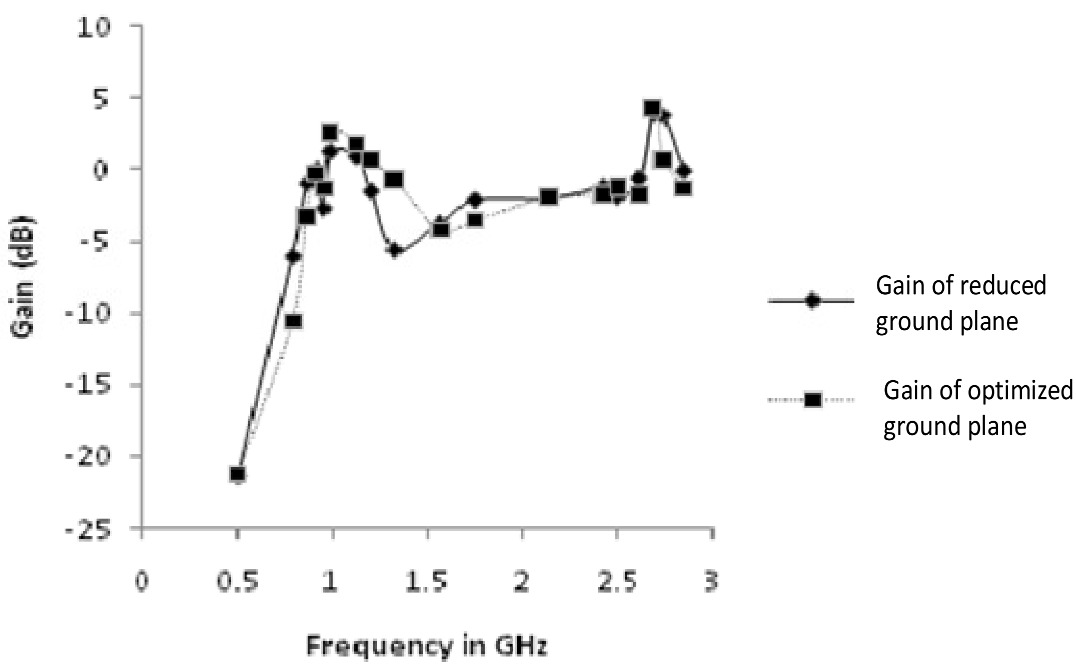

Figure 8. Change in gain as a result of change in ground plane.

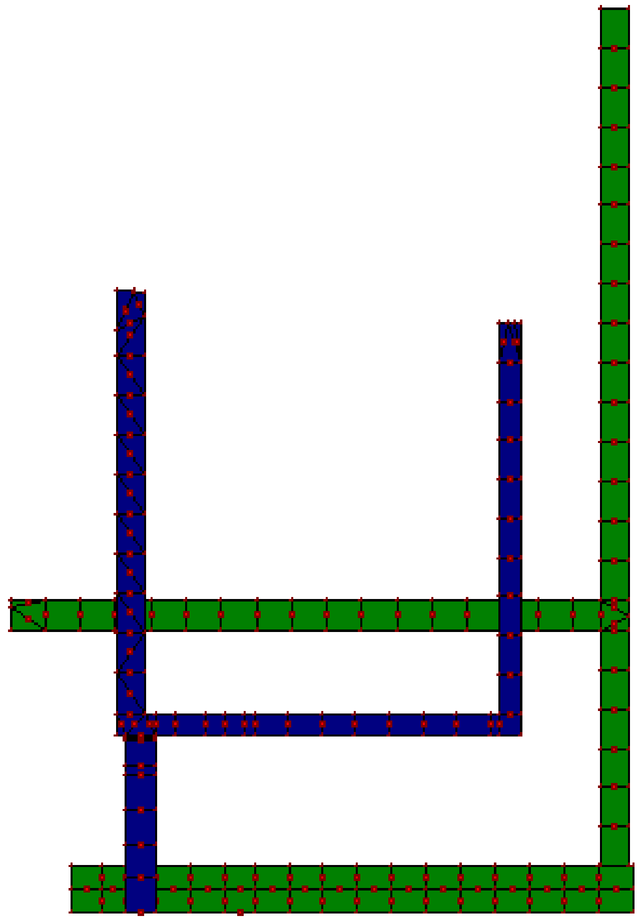

Figure 9. Current distribution of the proposed antenna.

plane. The conciseness of the antenna contributed in no small measure to decrease the movement of electrons to the surrounding space and helps in the high gain as exhibited in the proposed antenna. Conclusions could be drawn that the longer the ground plane, the lower the resonant frequency of the proposed antenna while the shorter the ground plane, the tendency for the upper frequency to be the key resonant frequency.

Conclusions

Broadband wideband frequency operations of a simple CPW fed- planar monopole antenna suitable for UHF RFID tag antenna has been studied. By embedding wide slot in the form of U in the radiating patch and adoption of inverted F ground plane, a wide impedance bandwidth of 140 MHz or over 10% were achieved. From the radiation pattern, it shows that the antenna radiates in all directions and this omnidirectional capability has made the antenna suitable for RFID tag antenna. The antenna design fulfilled the bandwidth requirement needed to operate in wideband ultra high frequency band spectrum.

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