Single Elements and Arrays with a Reduced ground Plane Size

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ABSTRACT

This paper explores a unique method to reduce the overall size of an antenna. To compensate for the adverse effects of truncating a ground plane a non-planar cylindrical ring is placed around a shorted circular patch antenna. This ring allows the ground plane to be reduced from the commonly used radius of 0.6λ to a radius of 0.24λ while at the same time improving the impedance match and radiation performance. By comparing the radiation characteristics and current distribution of this new antenna to known antenna structures the principle behind its operation has been determined. The implementation of this new element into an array has also shown good results while at the same time having a small ground plane.

INTRODUCTION

Small size antennas are an important consideration for today's wireless Personal Communication Systems. Microstrip antennas are good candidates for these systems, and efforts to make them smaller have focused more on the reduction of the radiating patch size itself. Traditional methods of introducing shorting pins, slots, and the use of high dielectric substrates have all been used effectively. The problem is that size reduction must also concentrate on the reduction of the supporting ground plane, and this is the subject of this investigation. Ground plane size reduction is becoming more important given the limited area available on the intended device.

Truncating the ground plane has adverse effects on the antenna. The first is an increase in back lobe radiation due to diffraction. The second is a change in the impedance of the antenna, which will increase the return loss. To combat the negative effects that accompany the smaller ground plane two separate designs introducing either one or two cylindrical rings around the shorted patch are investigated as both a single element and in an array.

ANTENNA STRUCTURE

The reduction of the ground plane has two major detrimental effects. The first is an increase in back radiation due to diffraction. The second is a change in the impedance of the antenna, which will affect the matching. To combat these negative effects two separate designs introducing either one or two cylindrical rings around the shorted patch were investigated. Figure 1 shows the antenna configurations used in testing and simulation. It shows a shorted patch suspended 10mm over a 30mm ground plane; a 30 mm radius ring 14 mm high is attached to the perimeter of the ground plane and a 20 mm radius ring is suspended 1mm off the ground plane. Air is used as the substrate. The patch was designed using the procedure laid out in [1]. For a patch designed to radiate at 2.4 GHz a patch radius of 7.81 mm, 10 mm off of the ground plane was used. The shorting pin was placed at a radius of 7 mm and the probe feed is positioned at a radius of 5.4 mm and this produced a well-matched antenna (S11= -28 dB at 2.4 GHz). In [2,3] it was found that the gain of the antenna varied with the ground plane size. Using an un-shorted patch it was found that the maximum gain occurred using a circular ground plane of radius 0.63 λ. Figure 2 shows the effects on impedance by reducing the ground plane size. In agreement with [2and 3] the best match was achieved with a ground plane radius of 76 mm, 0.63 λ. By reducing the ground plane to 30 mm (0.23λ) the return loss deteriorated to –10 dB**,** the peak gain reduced from 4.5 dBi to 1 dBi and has an asymmetrical radiation pattern. The non-planar ring greatly improves the return loss to –27 dB and a 5 dB increase in gain is realized.

The height of the inner ring is an important facet of the design. Figure 2 shows that as the height of the inner ring increases so does the gain of the antenna. The increase in gain plateaus when wall height is approximately 0.1λ or 12 mm.

PRINCIPLES OF OPERATION

The present configuration was reached through extensive experimentation. As a result, it would be important to understand and explain how this unique structure is operating. Through further research it was observed that the current

distribution and radiation characteristics of this ring were very similar to that of a large loop antenna. In the following the theory of operation of a large loop antenna will be used to help explain the principles behind the operation of this antenna.
The first stage in the operation is the radiation of the patch itself. The RF source creates a current on the patch and in turn this induces a current on the ground plane. Without the presence of the ring on the ground plane, the current would flow to the edges of the ground plane. However, as it approaches the area under the ring, the presence of the ring forces the current to flow around the area below the ring (Figure 3a). This in turn induces a current on the ring in the opposite direction. The induced current on the bottom of the non-planar ring (Fig 3b) then becomes a large loop radiator. The cosine current distribution typical of a large loop antenna can be seen in Figure 3(b) obtained from simulations using HFSS.

The radiation pattern for a large loop antenna is bi-directional with its maximums normal to the plane of the loop. By placing a ground plane parallel to the plane of the loop the radiation pattern becomes unidirectional. In [4] Ilzuka, King and Harrison investigated the effects of the proximity of a ground plane to a loop. By placing the ground plane behind the loop, an image of the loop is created. However, the proximity of this loop to the ground plane has an effect on the current distribution of the ground plane. In [4] it was found that for small separation distances, the surface currents induced in the ground plane are confined to the vicinity of the loop and correspond to an almost perfect image. In agreement with [4], Figure 3(a), obtained from simulations using HFSS, shows that the current distribution on the ground plane is maximized under the ring and the amount of current reaching the edge of the ground plane is minimized.

Another property of this antenna that was noticed during experimentation was that the gain of the antenna increased as the height of the cylindrical rings increased (Figure 2). As the ring height reached 12 mm, the increase in gain was maximized. This height corresponds to a distance of 0.1λ and is comparable to the optimum spacing for a Yagi-Uda array of loops [5]. It was hypothesized that the cylindrical ring was behaving like a Yagi-Uda array of coaxial loops. To confirm this hypothesis, a simulation was conducted, this time replacing the cylindrical ring with two planar rings where the top and bottom of the non-planar ring was located. The simulated results for the two planar loops were identical to those using the single non-planar ring. Experimental results show excellent agreement to simulation (Figure 4). The H-plane pattern has a peak gain of 6.38 dBi and a beam width of 78 degrees. The E-plane pattern has a peak gain of 6.09 dBi and a beamwidth of 82 degrees. This is an improvement of over 6 dBi compared to the shorted patch antenna on the small ground plane without using the rings. Similar measurements without using the outer ring were conducted. Results show the forward gain is reduced to 5.4 dBi and there is a slight increase in back lobe radiation.

In comparison to a Yagi-Uda array of loops the induced current on the bottom of the non-planar ring (or on the bottom ring of the planar ring pair) (Figure 3b) behaves as a large loop radiator or exciter as we have discussed above. Because of the presence of the ground plane the radiation will be in the forward direction only. The ground plane is behaving like a reflector. The top of the non-planar ring (or the top ring in the planar ring pair) then behaves as a director and provides an increase in the gain of the antenna.

2x2 Array

The incorporation of this antenna into an array is also examined. The reduction in element size has enabled us to space the elements with a closer spacing than that which is normally attainable with microstrip antennas. This configuration also has the advantage of very low levels of mutual coupling. The low levels of mutual coupling are primarily attributed to the fact that the rings deviates the ground plane current and as a result the current from one element has minimal interaction with the ground plane current of adjacent elements. Good radiation results with low back lobes have been obtained while still maintaining a small ground plane size.

CONCLUSION

In this paper a novel idea to significantly reducing the size of the ground plane of a shorted microstrip antenna is introduced. In particular it was found that by introducing a cylindrical ring around the shorted patch and another cylindrical ring on the perimeter of the ground plane an excellent improvement in performance was realized.

Experimental results with this new configuration achieved very good agreement with simulations. This new antenna reduces the size of the ground plane to a radius of 0.24λ while at the same time showing large reductions in the back radiation and up to a 5 dB increase in the forward gain when compared to the same antenna without the use of rings. This is in a fact better performance than the shorted patch on a ground plane with a radius of 0.63λ or greater.

This has allowed an 87 % decrease in the area of the ground plane and therefore makes it a suitable antenna for PCS devices and other applications.

In the absence of exact theoretical analysis, an alternative approach was adopted to explain the principle of operation of this antenna. By comparing the new antenna performance with that of other existing antennas and carefully examining the behaviour of the currents on the fields, it was concluded that it is performing like a Yagi-Uda coaxial array of loops. It was shown that the presence of the ring close to the ground plane forced the ground plane current to flow in the area underneath the ring. A current in the opposite direction to the ground plane current was induced on the ring. This current is responsible for the majority of the radiation of the antenna. The top of the non-planar ring performed in a similar manner to that of a director loop in a Yagi-Uda Array. From this explanation another antenna variant was designed. This antenna uses two wire loops in place of the non-planar cylindrical ring. The two loops were placed where the top and the bottom of the cylindrical ring were placed. Simulation and experimentation was conducted on this configuration. It performed better than the cylindrical ring by obtaining a 6 dB improvement in gain over the same antenna with out rings on a small ground plane. Analysis of this element in an array showed that the same size reduction was possible.

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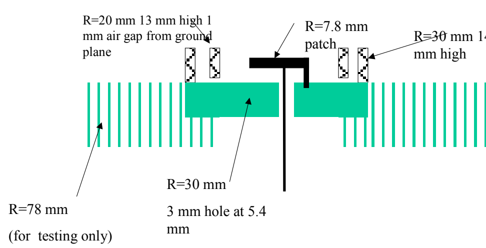


Figure 1: Antenna with optional 78 mm Ground Plane Extension

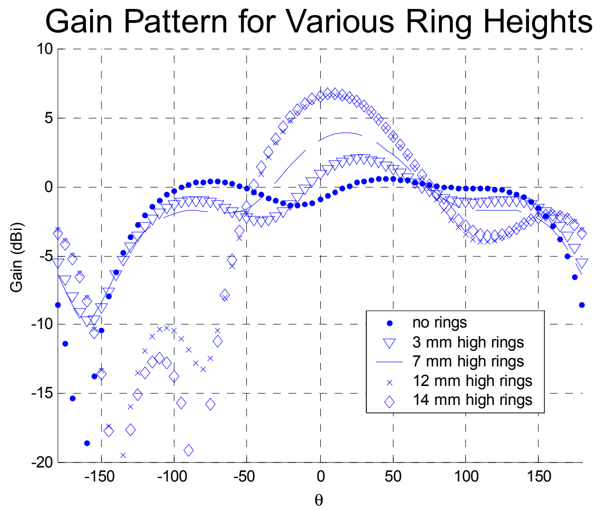
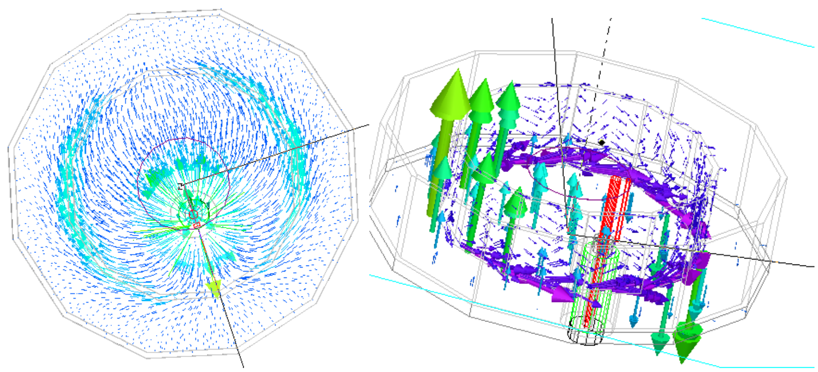


Figure 2: Gain Pattern for various Ring Heights



a. Ground Plane Current **b. Current on Ring**

Figure 3. Ground Plane Current Density

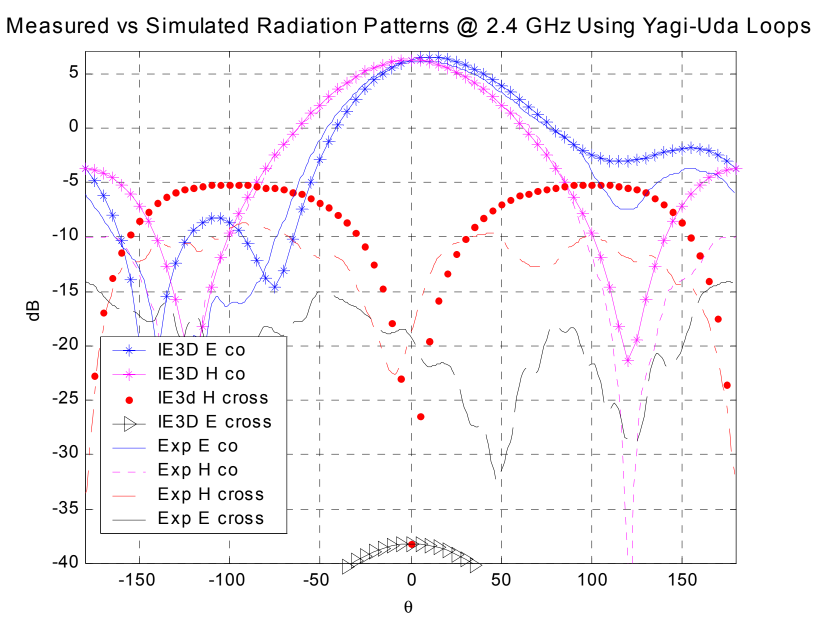


Figure 4: Experimental vs Simulated Radiation Patterns