ISSN 2250-3153

Analysis of the Effects of Rectangular Ground Plane on Radiation Pattern of the Monopole Antenna

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Abstract- The aim of this paper was to analyze the impact of rectangular plane ground on the radiations pattern of the monopole antenna. Several simulations have been performed where the monopole antenna with wavelength 4m was placed on top of the rectangular plane ground and then radiations pattern was obtained in terms of directivity, electric field and gain, and finally the results were analyzed and concluded that large the ground plane is, the lower the direction of maximum radiation and as the ground plane approaches infinite size, the radiation pattern approaches a maximum in the x-y plane.

Index Terms- Directivity, Far field, Finite ground plane, Monopole antenna, Radiation pattern.

I. Introduction

Monopole antennas are half the size of their dipole counterparts, and hence are attractive when a smaller antenna is needed. Wire-type antennas are made of conducting wires and are generally easy to construct, thus the cost is normally low. Monopole antenna falls into this category of wire type antennas and it is the omnidirectional one in the sense that it has the same gain in every direction.

Many methods are used to improve the performance of monopole antenna[1] one of these methods can be varying the size and the type of ground plane for example you can employ finite or infinite ground plane, cylindrical, spherical or the rectangular sheet ground plane . In practice, monopole antennas are used on finite-sized ground planes. This affects the properties of the monopole antennas, particularly the radiation pattern[2].

The length of the monopole trace mainly determines the resonant frequency of the antenna, but because of the very wide gain bandwidth of a quarterwave monopole, the antenna length is not too critical. But like any other antenna types, the gain of a quarterwave monopole will vary if parameters in the surroundings, such as case/box materials, distance to the ground plane, and size of the ground plane are varied. If any of these parameters are changed, a retuning of the monopole trace length may be necessary for optimum performance in each application.

A quarterwave monopole is a ground plane dependent antenna that must be fed single-ended. The antenna must have a ground plane to be efficient, and ideally the ground plane should spread out at least a quarter wavelength, or more, around the feed-point of the antenna. The size of the ground plane influences the gain, resonance frequency and impedance of the antenna.[3]

II. Concepts and Theory

The monopole antenna is half of the dipole antenna and almost always mounted above some sort of ground plane, and the best way to investigate the monopole antenna is to utilize the image theory. The *image theory* states that if there is a current ***A/B/C*** above an infinite perfect conducting ground plane, the ground will act as a mirror to generate its image, ***A'/B'/C'*** [4].

The monopole antenna shown below, consists of a single leg perpendicular to a ground plane of height h =l/2. The monopole is fed at its base with respect to the ground plane. For purposes of analysis, the ground plane is considered to be infinite and perfectly conducting. In practice, this ideal ground plane is approximated[5].

Analysis of propagation pattern is of important before the deployment of any antenna. Propagation patterns of wireless systems may be affected by outside influences such as vegetation, solar radiation, climate conditions, interference from other RF sources, and ground reflection. As the RF waves propagate though space signal tend to reflect or absorbed in nearby objects and surfaces. Some RF waves would reflect off the ground surface while some would be absorbed by the ground. The amount of RF reflection and RF absorption depends on the earth's ground dielectric(ε_r) and ground conductivity(σ) properties[6]

The impedance of a monopole antenna is minimally affected by a finite-sized ground plane for ground planes of at least a few wavelengths in size around the monopole.[2]

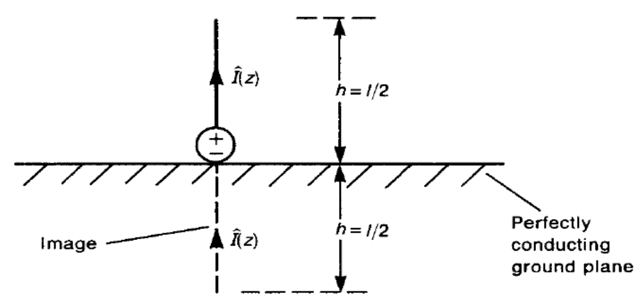


Figure 1: Illustration of the monopole antenna with perfectly conducting ground.[5]

The fields above the ground plane can be found by using the equivalent source (antenna) in free space. The monopole antenna fields below the ground plane in Figure 1 above are zero. So in practice the monopole antenna acts like dipole antenna with the concept of image the only change that needs to be noted is that the impedance of a monopole antenna is one half of that of a full dipole antenna. For a quarter-wave monopole (l=0.25* λ), the impedance is half of that of a half-wave dipole.

From the concept that the size and type of ground affects the radiation intensity, the radiation intensity of the monopole antenna with the ground being finite and rectangular in shape can be derived through the following formulae:

The electric field intensity:

$$E_\theta \approx \frac{jnI_o e^{j\beta r}}{2\pi r}\left(\frac{\cos(\beta l\cos\theta)-\cos(\beta l)}{\sin\theta}\right) \quad (1)$$

Where:

$E_\theta = Electric\ field\ intensity$

$n = Intrinsic\ impedance = \sqrt{\frac{\mu}{\varepsilon}} = 120\pi\sqrt{\frac{\mu_o}{\varepsilon_o}}$

$\beta = phase\ constant\ or\ wave\ number = 2\pi/wavelength$

$r = radius$

$I_o = Maximum\ possible\ current$

$l = length\ of\ the\ monopole\ antenna$

Magnetic field intensity of the monopole antenna in ground plane is given by:

$$H_\emptyset = \frac{E_\theta}{n} = \frac{jI_o e^{j\beta r}}{2\pi r}\left(\frac{\cos(\beta l\cos\theta)-\cos(\beta l)}{\sin\theta}\right) \quad (2)$$

The average power density also known as Poynting vector is given by:

$$S_{av} = \frac{1}{2} * R_e\left(E_\theta \times H_\emptyset^*\right) = \hat{r}\,\frac{nI_o^2}{8\pi^2 r^2}\left(\frac{\cos(\beta l\cos\theta)-\cos(\beta l)}{\sin\theta}\right)^2 \quad (3)$$

Finally the radiation intensity is found from the following relation:

$$U = r^2 \times S_{av} = \frac{nI_o^2}{8\pi^2 r^2}\left(\frac{\cos(\beta l\cos\theta)-\cos(\beta l)}{\sin\theta}\right)^2 \quad (4)$$

Directivity is found by:

$$D = \frac{4\pi U(\theta,\emptyset)}{\int_0^{2\pi}\int_0^{\pi} U\sin\theta\, d\theta\, d\emptyset} \quad (5)$$

Where U= radiation intensity found on equation (4) above.

III. METHODOLOGY

A quarter wave monopole antenna on a finite rectangular ground plane is constructed and simulated. The rectangular plane ground was assumed to have a circumference of three wavelengths, and the wire has a radius of 1 × 10−5 of a wavelength. The free space wavelength was chosen as 4 m (approximately 74 MHz).

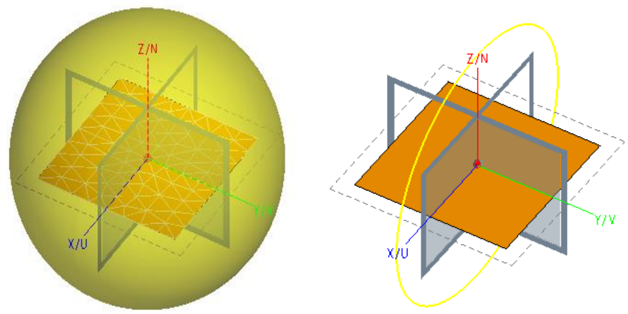


Figure 2: The rectangular ground plane and the monopole antenna placed above it.

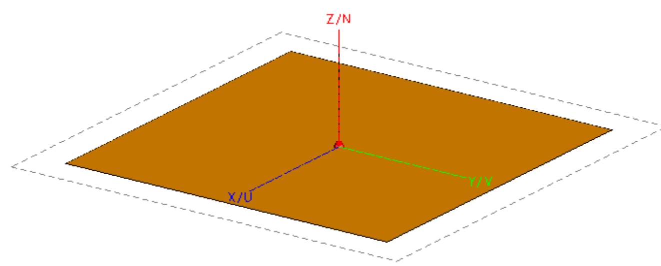


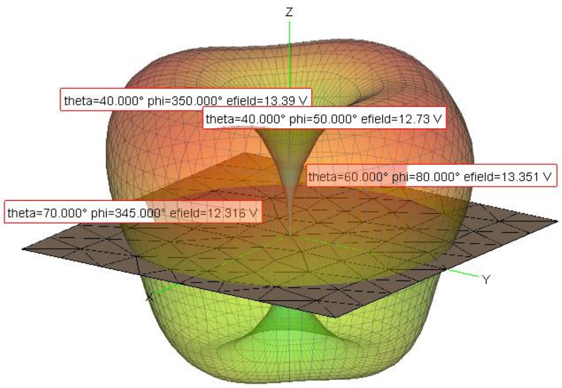
Figure 3: The rectangular ground plane with the monopole antenna placed at the center above it.

So the set up was done by considering the quarter wavelength monopole antenna with wavelength taken as 4m for free space and the frequency(f=c0/wavelength) was found with the dimensions of rectangle assumed and varied(height and width), the total source of power was set to 2W. And the pattern radiation analysis was taken for far field.

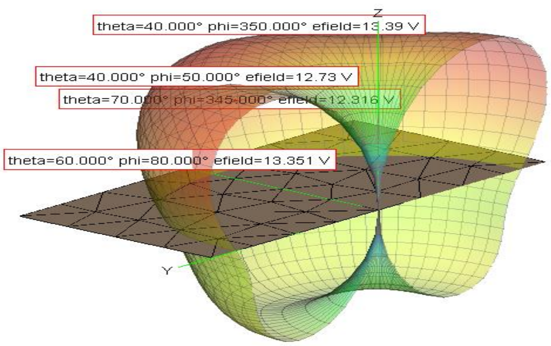
Two planes of magnetic symmetry were defined with x=0 and y=0 planes, while in Z-plane, no symmetry was defined because it the one in which our monopole antenna stands or pointing.

IV. RESULTS AND DISCUSSION

The following results were obtained after careful simulations using FEKO software in which the ground plane which was rectangular ground plane were defined.



(a)



(b)

Figure 4: (a) A full 3D plot of the radiated E-field. (b) A cut wave plane 3D plot of the radiated E-field

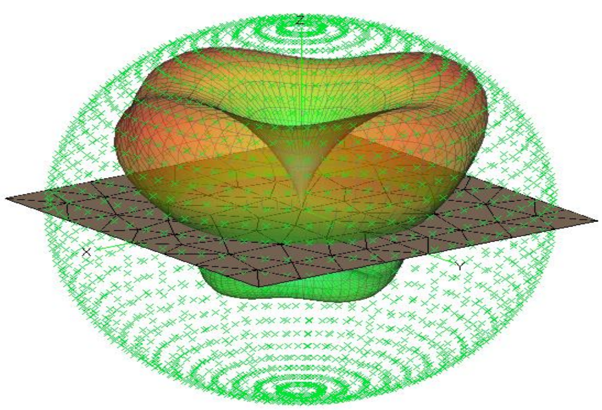
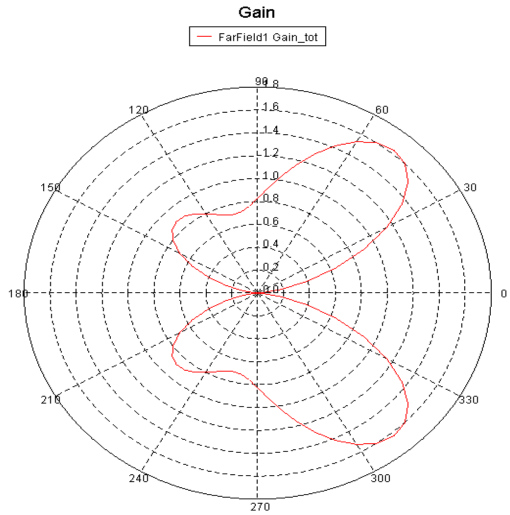
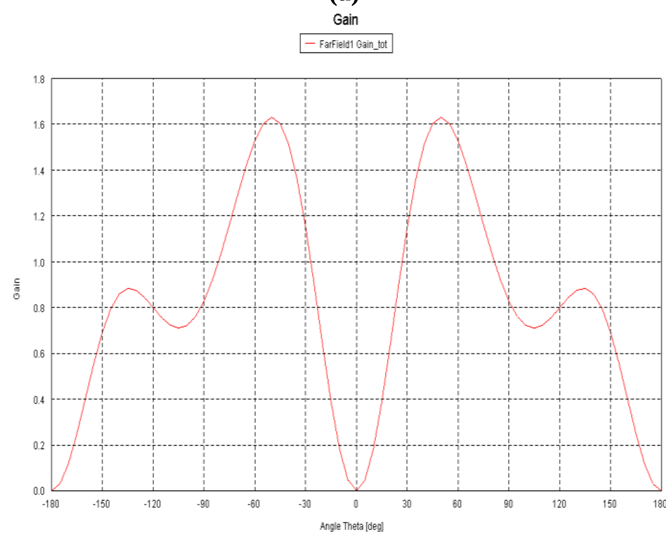


Figure 5: Requested far field directivity of the monopole antenna on rectangular ground plane.

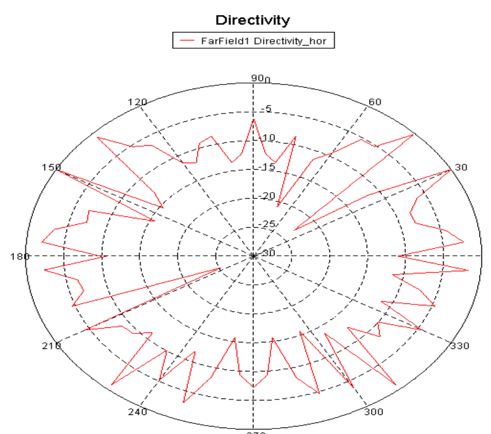


(a)

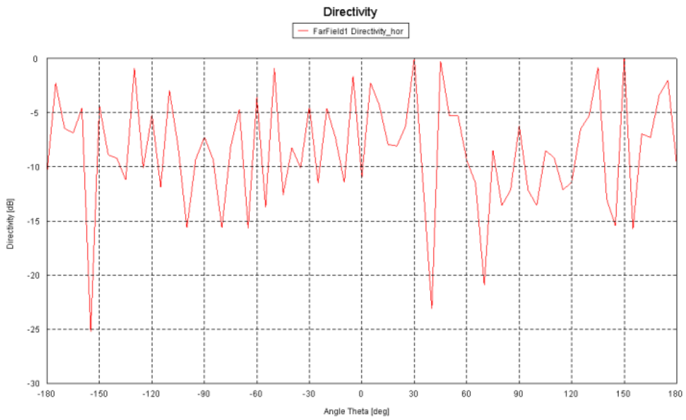


(b)

Figure 6: (a) Polar plot for total Gain in horizontal cut. (b) A graph of Total gain against angle theta.



(a)



(b)

Figure 7: (a) Polar plot of far field directivity pattern in horizontal (b) Graph of Directivity against angle theta in horizontal.

From the above results it can be easily seen that there is great variations in terms of gain, directivity, and electric field intensity of the monopole antenna when the rectangular plane ground is placed, so the size of the plane ground also affects the radiations pattern the antenna as seen in figure 7 where the directivity patterns follows the size of the ground plane placed together with the height of the antenna, the resulting radiation pattern radiates in a direction, away from the horizontal plane and the resulting radiation pattern for this monopole antenna is still omnidirectional. However, the direction of peak-radiation has changed from the x-y plane to an angle elevated from that plane.

V. CONCLUSION

The monopole antenna works generally on finite sized ground which affects the radiation patterns of the antenna strongly as it can be observed on different figures above. So the large the ground plane is, the lower the direction of maximum radiation and as the ground plane approaches infinite size, the radiation pattern approaches a maximum in the x-y plane.

ACKNOWLEDGMENT

I would like to send my appreciation to the FEKO software developers as it helped to come up with the simulated results, also Ruaha University College (RuCo), Dr. Sylvano Kitinya and Carl Mmuni for their support during the preparation of this paper.

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