The Far Field of Antennas in Practical Scenarios

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***Abstract*— The far field of an antenna is generally considered to be the region where the outgoing wavefront is planar and the antenna radiation pattern has a polar variation and is independent of the distance from the antenna. This paper intends to illustrate that $2D^2/\lambda$ formula, where D is the maximum dimension of the antenna and λ is the operating wavelength, is not universally valid, it is only valid for antennas operating in free space where $D \gg \lambda$. Also, in this paper we try to study the far field of antennas operating over a PEC ground plane and over an imperfect ground plane, in these cases we show that the far field's starting distance depends on the transmitting and receiving antenna's heights over the ground plane.**

Keywords*— *Far Field, Near Field, Radial, Transverse.

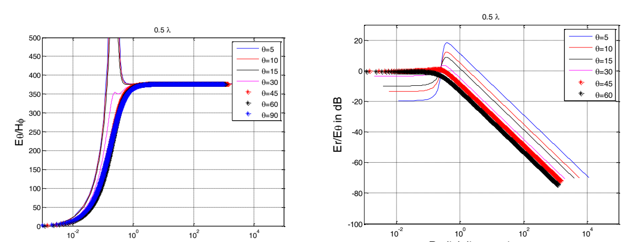
I. Introduction

To generate a locally plane wave in the far field the radial component of the electric field must be negligible compared to the transverse component. Also, the ratio of the electric and the magnetic far fields should equal the intrinsic impedance of the medium. These two requirements must hold in all angular directions from the antenna. The radial and the transverse components of the fields are space dependent so to determine the starting distance of the far field we need to examine the simultaneous satisfaction of these two properties for all θ and φ angular directions, where θ is the angle measured from z-axis and φ is the angle measured from the x-axis.

Here, we use the analytical expressions given in [1, equations 10-74, 10-75, and 10-76] to compute the fields for a z-oriented dipole antenna of various lengths operating in free space. For each specific length of the dipole antenna we provide two plots, one is for the ratio of $|E_\theta / H_\phi|$ as a function of the radial distance in meters for various angular directions θ (for $\theta = 5^o$, 10^o, 15^o, 30^o, 45^o, 60^o, and 90^o), and the second plot is for the ratio $|E_r / E_\theta|$ in dB as a function of the radial distance in meters for various angular directions θ as before.

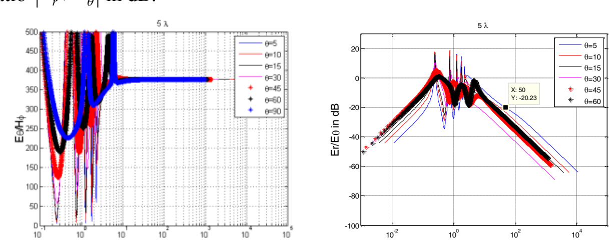
The first z-oriented dipole antenna we consider is 0.5 λ long. The frequency is 300 MHz for all examples in this paper. If we calculate $2D^2/\lambda$ for this case, it gives 0.5 λ which is 0.5 m. Figure 1(a) shows that the ratio of $|E_\theta / H_\phi|$ is 377 after 2 m for all θ directions. Figure 1(b) plots the ratio $|E_r / E_\theta|$ and it is observed that to have the ratio of $|E_r / E_\theta|$ less than –20 dB for all θ directions one has to be away 80 m or 80 λ. In Figure 1(b), the plot for $\theta = 90^o$ does not appear because the radial component is zero along that specific direction. In this case, 80 λ is the correct starting distance where the far field starts to evolve.

The second example deals with a dipole antenna that is 5λ long. If we calculate $2D^2/\lambda$ it results in 50λ which is 50 m. Figure 2(a) shows that the ratio of $|E_\theta / H_\phi|$ is 377 after 20 m for all θ directions. Figure 2(b) shows that the ratio $|E_r / E_\theta|$ takes considerable more distance to reach a negligible value. However the small value of the ratio is reached for most angles after 50λ which is the same distance predicted by the $2D^2/\lambda$ formula, this means that the $2D^2/\lambda$ formula provides the correct result for the location of the far field in this case because $D \gg \lambda$. This proves that the $2D^2/\lambda$ formula applies only if simultaneously $D \gg \lambda$ condition is satisfied.



(a) (b)

Figure 1. (a) The ratio of $|E_\theta / H_\phi|$ for a 0.5 λ z-oriented dipole antenna as a function of the radial distance in meters for various directions in θ. (b) The ratio $|E_r / E_\theta|$ in dB.



(a) (b)

Figure 2. (a) The ratio of $|E_\theta / H_\phi|$ for a 5 λ z-oriented dipole antenna as a function of the radial distance in meters for various directions in θ. (b) The ratio $|E_r / E_\theta|$ in dB.

In [2], it is mentioned that if $D \geq 2.5\lambda$ then it is safe to use

$2D^2/\lambda$ to locate the starting distance of the far field. However, authors of [2] referred to [3] which does not include a derivation for the limits from which the conclusion in [2] was drawn. In our work, we actually provided some analytical results to show that we need $D \geq 5\lambda$ to assure that the far field criteria is satisfied at a distance given by $2D^2/\lambda$.

II. Dipole Antennas Over ground plane

For the characterization of an antenna operating over PEC ground plane, we will not use $2D^2/\lambda$ to predict the starting distance of the far field. However, if one tends to use $2D^2/\lambda$ then D is defined in terms of the height of the antenna located over the ground, which is related to the effective aperture size and not necessarily to the dimension of the antenna. To predict the starting distance of the far field for antennas operating over PEC ground, we use the formula given in [4] where it has been shown that for the case of antenna operating over PEC ground, the far field starts at a distance d, given by:

$$2\pi \frac{H_{Tx}^2 H_{Rx}}{\lambda d^2} = \frac{1}{\Psi}\ ; \quad \Rightarrow d = H_{Tx}\sqrt{\frac{2\pi H_{Rx}\Psi}{\lambda}} \tag{1}$$

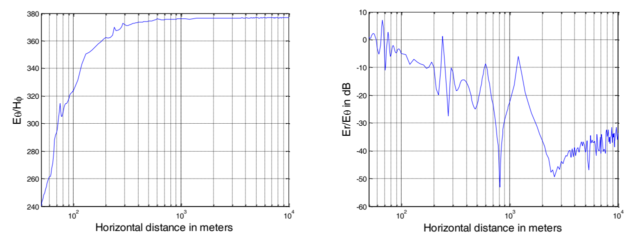
where Ψ is the ratio of the transverse component of the electric field with respect to the radial component. H_{Tx} and H_{Rx} are the height of the transmitting and the receiving antennas over Earth, respectively.

For antennas operating over imperfect ground plane, we use the electromagnetic analysis code Analysis of Wire Antennas and Scatterers (AWAS) [5]. As an example, we simulate a z-oriented dipole antenna of length 10λ radiating over an urban ground with relative permittivity $\varepsilon_r = 4$, conductivity $\sigma = 2\times10^{-4}$ Siemens/m, the height of the transmitter antenna is 60 m above the ground, the height of the field point is 10 m from the ground. Figure 3(a) plots the ratio of $|E_\theta / H_\phi|$ as a function of the horizontal distance in meters, the ratio of $|E_\theta / H_\phi|$ is 377 after 700 m. Figure 3(b) plots the ratio $|E_r / E_\theta|$ in dB as a function of the horizontal distance in meters, the ratio $|E_r / E_\theta|$ is less than –35 dB after a distance of about 2000 m, this distance increases when we check other θ directions. Using the expression in (1) one would expect the far field, if the ground was a PEC, to start approximately at $d = 3567$ m while if we use the formula $2D^2/\lambda$ blindly assuming D to be 10λ, one calculates $d = 200$ m which is nowhere close to the correct far field's starting distance value.

As a last example, consider a z-oriented dipole antenna of $\lambda/2$ length radiating over an urban ground located at a height of 30 m. All other simulation parameters were the same as the first example. Figure 4(a) shows that the ratio of $|E_\theta / H_\phi|$ is 377 after 700 m. Also, Figure 4(b) shows that ratio $|E_r / E_\theta|$ is approximately a locally plane wave after about 950 m. We can calculate the predicted value as to where the far field will start if the ground was a PEC using (1), $d = 18.8 H_{Tx}\sqrt{\frac{H_{Rx}}{\lambda}} = 18.8*30*\sqrt{10} \approx 1783$ m.

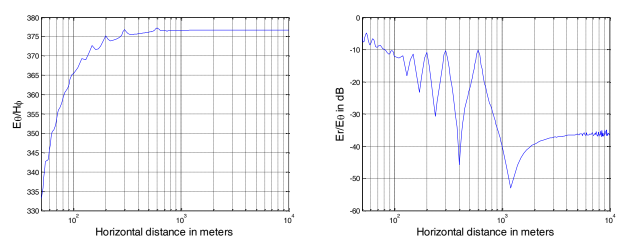
III. Conclusion

We must pay attention to the constraint under which it is safe to use $2D^2/\lambda$ to predict the starting distance of the far field. If $D \geq 5\lambda$ then it is safe to use $2D^2/\lambda$ to predict the starting distance of the far field for an antenna radiating in free space. Locating the starting distance of the far field using $d = H_{Tx}\sqrt{\frac{2\pi H_{Rx}\Psi}{\lambda}}$ is sufficient for antennas operating on top of PEC ground plane. We can use simulation tools that can treat antennas operating over an imperfect ground plane to locate the starting distance of the far field by examining the criteria of the far field. An example of such simulation tools is AWAS [5]. When the antenna is operating over a ground plane then the far field's starting distance depends on the transmitting and receiving antenna's heights over the ground plane.



(a) (b)

Figure 3. (a) The ratio of $|E_\theta / H_\phi|$ for a 10λ z-oriented dipole antenna located at a height of 60 m above an urban ground. (b) The ratio $|E_r / E_\theta|$ in dB.



(a) (b)

Figure 4. (a) The ratio of $|E_\theta / H_\phi|$ for a $\lambda/2$ z-oriented dipole antenna located at a height of 30 m above an urban ground. (b) The ratio $|E_r / E_\theta|$ in dB.

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