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Review Article

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Electromagnetic Field on the Earth's Surface along a Thin Wire Using Wave Propagation

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Abstract

In this paper, the wave propagation on the earth's surface in medium 1 (air) along a thin wire is presented and the electromagnetic field determined, which is represented by a finite set of horizontal plane layers characterized by conductivities. The electromagnetic properties of the electromagnetic field reviewed, and a solution will be given for the boundary value problem of a wave propagating. The displacement current in free space is negligible. The electric and magnetic fields are obtained in terms of the propagation constant of the transmission current on the wire at the origin.

Keywords: Electromagnetic field; Antenna and propagation; Wave propagation

Introduction

The wave propagation along a thin wire on the earth's surface is an interesting topic and very fundamental problem in electromagnetic theory. All treatments of the phenomenon of the wave propagation took the earth surface as a perfectly smooth (planar or spherical) interface between the air and ground or water.

Zheng [1] studied the wave propagation theories and application, and Manjunath et.at. [2] Studied the wave propagation in random granular chairs.

Carson [3] and Wise [4] solve the problem were based on transmission line analogies that led to useful results, particularly at the low frequency end of the spectrum, with the high frequency behavior studied with kikuchi [5].

Kuester and Chang [6] presented the first use of full wave theory for a wire above a two - layer medium. Mahmoud and Wait [7] obtained Wave propagation along a thin wire located inside a rectangular waveguide with imperfectly reflecting boundaries, and Coleman [8] found the wave propagation for the case of a thin wire on the interface between two semi-infinite homogeneous media. Robert [9] studied the electromagnetic wave propagation on a thin wire above earth. Yingkang et.at. [10] Obtained the wave propagation along a thin vertical wire antenna placed in a horizontally layered.

In addition, Ghada, et al. [12] studied the Electric Field Strength along a Thin Vertical Wire, The wire is assumed to be placed vertical to the earth's surface in a stratified homogeneous medium and in Ghada et.at. [13], The modal equation used for the propagation constant to obtain the wave propagation along a thin vertical wire which located at y = h.

The objective of this paper is to study the wave propagation field in the air along a thin wire on the earth's surface at y = 0. In addition, The electric and magnetic fields are obtained in terms of the propagation constant of the transmission current on the wire at the origin represented graphically. Moreover, a solution will be given for the boundary value problem of a wave propagating along a thin wire on the earth's surface.

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Formulation of the Problem

We consider the problem as shown in Figure 1, we assume that the wire is on the earth's surface, and it is very thin compared to its length l. In medium (1), the permittivity and permeability are $\in_1$ and μ_1, respectively. In medium (2), the permittivity and permeability are $\in_2$, μ_2, respectively.

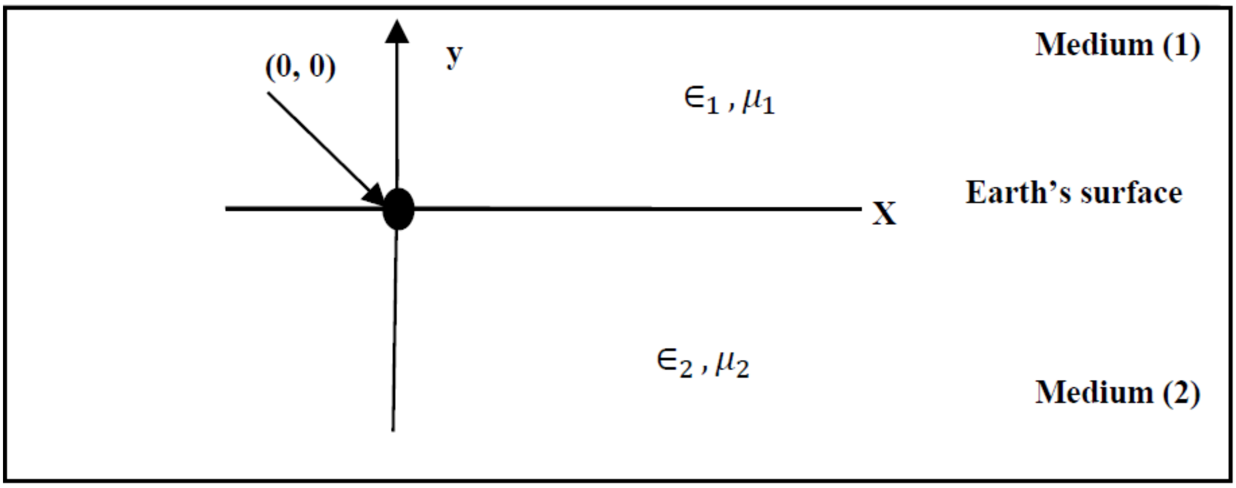

Figure 1: Geometry of the problem.

We chose a Cartesian coordinate system *(x, y, z)* and oriented along the positive z-axis and located at *(x, y) = (0, 0)*. The interface separating the two media is the plane *x=0*, between two homogeneous half - spaces. The solution of the boundary value problem, we let the current have the form $I\ e^{-\Gamma z}$, where $\Gamma = i\ \beta$ is the propagation constant [14].

The boundary conditions require for the electric and magnetic fields at y = 0, as

$$\vec{E}_{1x}(\vec{r}) = \vec{E}_{2x}(\vec{r}) \qquad (1)$$

$$\vec{E}_{1Z}(\vec{r}) = \vec{E}_{2Z}(\vec{r}) \qquad (2)$$

$$\vec{H}_{1x}(\vec{r}) = \vec{H}_{2x}(\vec{r}) \qquad (3)$$

$$\vec{H}_{1Z}(\vec{r}) = \vec{H}_{2Z}(\vec{r}) \qquad (4)$$

The Integral Representation of the Field on the Earth's Surface

For the region $y>0$, (in medium (1)),

$$E^{\rightarrow}\ \vec{E}_{1x} = \frac{\partial^2 \vec{\pi}_1}{\partial x \partial z} + i\mu_1 \omega \left(\frac{\partial \vec{\pi}_1^*}{\partial y} \right) \qquad (5)$$

$$E^{\rightarrow}\ \vec{E}_{1y} = \frac{\partial^2 \vec{\pi}_1}{\partial y \partial z} - i\mu_1 \omega \left(\frac{\partial \vec{\pi}_1^*}{\partial x} \right) \qquad (6)$$

$$\vec{E}_{1Z} = \left(k_1^2 - \beta^2 \right) \vec{\pi}_1 \qquad (7)$$

Similarly, we can write the components of the magnetic field as

$$\vec{H}_{1x}(\vec{r}) = \frac{\partial^2 \vec{\pi}_1^*}{\partial x \partial z} - i \in_1 \omega \left(\frac{\partial \vec{\pi}_1}{\partial y} \right) \qquad (8)$$

$$\vec{H}_{1y} = \frac{\partial^2 \vec{\pi}_1^*}{\partial y \partial z} + i \in_1 \omega \left(\frac{\partial \vec{\pi}_1}{\partial x} \right) \qquad (9)$$

and,

$$\vec{H}_{1Z} = \left(k_1^2 - \beta^2 \right) \vec{\pi}_1^* \qquad (10)$$

For the region $y < 0$, (in medium 2) same equations hold, but we add a subscript two to all relevant quantities.

We get that the primary fields of the infinite wire can be derived from the potential π^p on the earth's surface is given by Wait [15]

$$\vec{\pi}^p = -\left(\frac{i\mu_1 \omega I}{4\pi k_1^2} \right) e^{-i\beta z} \cdot \int_{-\infty}^{\infty} \frac{e^{-i\lambda x}}{u_1} \cdot e^{-u_1 y}\ d\lambda \qquad (11)$$

Hence, the integral representation for the resultant Hertz potentials takes the form

$$\vec{\pi}_1 = e^{-\Gamma z} \int_{-\infty}^{\infty} \left\{ e^{u_1 y} + R(\lambda) e^{-u_1 y} \right\} \left[\frac{e^{-i\lambda x}}{u_1} \right] d\lambda, \quad y > 0 \qquad (12)$$

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$$\vec{\pi}_2(x,y,z)=e^{-\Gamma z}\int_{-\infty}^{\infty}T(\lambda)e^{u_2 y}\left[\frac{e^{-i\lambda x}}{u_1}\right]d\lambda,\ \ y<0 \qquad (13)$$

Also,

$$\vec{\pi}_1^*=e^{-\Gamma z}\int_{-\infty}^{\infty}M(\lambda)e^{-u_1 y}\left[\frac{e^{-i\lambda x}}{u_1}\right]d\lambda,\ \ y>0 \qquad (14)$$

$$\vec{\pi}_2^*(x,y,z)=e^{-\Gamma z}\int_{-\infty}^{\infty}N(\lambda)e^{u_2 y}\left[\frac{e^{-i\lambda x}}{u_1}\right]d\lambda,\ \ y<0 \qquad (15)$$

and

$$u_i=\left[\lambda^2+\beta^2-k_i^2\right]^{1/2}, \qquad for\ i=1,2$$

The wave numbers k_1 and k_2 for the two media, are

$$k_i^2=\in_i\mu_i\omega^2, \qquad for\ i=1,2$$

In the equation (11), we have omitted the factor $\frac{-i\mu_i\omega I}{4\pi k_1^2}$ on the right-hand side. From equations, (12)-(15), with the boundary conditions can applied to obtain the unknown functions *R(λ), T(λ), M(λ)* and *N(λ)*

$$R(\lambda)=\frac{\lambda^2\beta^2(1-K)^2+\left(\in_1\omega u_1-\in_2\omega u_2 K\right)\left(\mu_1\omega u_1+\mu_2\omega u_2 K\right)}{\left[-\lambda^2\beta^2(1-K)+\left(\in_1\omega u_1+\in_2\omega u_2 K\right)\left(\mu_1\omega u_1+\mu_2\omega u_2 K\right)\right]} \qquad (16)$$

In the case of $\mu_1=\mu_2=\mu$, equation (16) leads to

$$R(\lambda)=-1+\frac{2k_1^2\left(\lambda^2-u_1u_2\right)}{\left(k_1^2-\beta^2\right)\left(k_1^2u_2+k_2^2u_1\right)}u_1 \qquad (17)$$

$$T(\lambda)=\frac{2K\in_1\omega^2u_1\left(\mu_1u_1+\mu_2u_2K\right)}{\left[-\lambda^2\beta^2(1-K)^2+\left(\in_1\omega u_1+\in_2\omega u_2K\right)\left(\mu_1\omega u_1+\mu_2\omega u_2K\right)\right]} \qquad (18)$$

$$M(\lambda)=\frac{i\lambda\beta\omega\left(k_2^2+k_1^2\right)}{k_1^2u_1\left(k_2^2-\beta^2\right)+k_2^2u_2\left(k_1^2-\beta^2\right)} \qquad (19)$$

And

$$N(\lambda)=K\frac{i\lambda\beta\omega\left(k_2^2-k_1^2\right)}{k_1^2u_1\left(k_2^2-\beta^2\right)+k_2^2u_2\left(k_1^2-\beta^2\right)} \qquad (20)$$

where,

$$K=\frac{\left(k_1^2-\beta^2\right)}{\left(k_2^2-\beta^2\right)}$$

The z-component of the electric field directed along a thin wire on the earth's surface can be written as

$$\vec{E}_{1Z}(x,y,z)=\frac{-i\mu_1\omega I}{4\pi}e^{-i\beta z}B(\beta) \qquad (21)$$

where, B

$$B(\beta)=2\int_{-\infty}^{\infty}\frac{\left(\lambda^2-u_1u_2\right)}{\left(k_1^2u_2+k_2^2u_1\right)}e^{-u_1 y}\cos(\lambda x)\,d\lambda$$

The z-component of the magnetic field directed along a thin wire on the earth's surface can be written as

$$\vec{H}_{1Z}(x,y,z)=\frac{\mu_1\lambda\omega^2\beta I}{4\pi}\left(k_2^2-k_1^2\right)e^{-i\beta z}D(\beta) \qquad (22)$$

where,

$$D(\beta)=\int_{-\infty}^{\infty}\left(\frac{e^{-u_1 y}}{k_1^2u_1(k_2^2-\beta^2)+k_2^2u_2(k_1^2-\beta^2)}\right)e^{-u_1 y}\cos(\lambda x)\,d\lambda$$

Conclusion

A theoretical analysis of the electric and magnetic fields along a thin wire on the earth's surface have been studied. We choice the matching point on the wire at the origin, The imaginary part of the current depends on the rate of variation of the phase of the waveβ, which is the rate of variation of the phase of the wave along the z coordinate. The waves have only z-component of the electric and magnetic fields. The displacement current in free space is negligible.

A solution will be given for the boundary value problem of a wave propagating. It is related to the wavelength and to radian frequency, and it is measured in rad/m. The result of imaginary part of the electric field component $\vec{E}_{1Z}$ and $\vec{H}_{1Z}$ has been calculated due to the imaginary part of the propagation constant.

Acknowledgement

None.

Conflict of Interest

No conflict of interest.

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