MICROWAVE MODELLING OF H.F. ANTENNAS OVER LOSSY EARTH

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ABSTRACT

The dielectric constant and loss tangent values of several mixtures of sand, water and salt are measured at 9.3 GHz, in order to investigate the feasibility of microwave modelling of H.F. antennas which operate over imperfectly conducting ground. A particular mixture is used for modelling a monopole antenna over a circular metal disk which is lying on a lossy half-space. Good agreement between theoretical and experimental results is obtained for both input impedance and radiation pattern as a function of the radius of the ground system.

Introduction

Scale modelling is a useful and economic technique to provide experimental information on any property of large antennas. A major problem is the modelling of ground at microwave frequencies since an ideal medium must not only have electrical parameters that are realistic in value, but must also facilitate independent control over each parameter. Recently, a mixture of sand, salt and water was used by Hall et al.[1] for properly modelling H.F. Yagi antennas over real ground at 2 GHz.

As an extension of Hall et al. work this paper presents an experimental research on the properties of several mixtures of sand, salt and water at 9.3 GHz in order to investigate the feasibility of microwave modelling of H.F. antennas at higher frequencies.

A particular mixture was used for modelling a monopole antenna over a circular metal disk which is lying on a lossy half-space. This antenna has been studied both theoretical and experimentally in the literature [2, 3]; however, the experimental results for input impedance and radiation pattern have been obtained from small models using ordinary tap water or brine as an imperfect ground.

As further investigation was desirable, now using a more realistic model of lossy earth, new experimental results for input impedance and radiation pattern of a monopole as a function of the radius of the metal disk are presented. The results confirm the validity of the approximate theory for the monopole and suggest that using sand, salt and water mixtures, several complex H.F. antennas operating over real ground could be microwave modelled in order to obtain reliable experimental data.

Microwave modelling of imperfectly conducting ground

Modelling conditions for simulated ground

The electrical parameters of real ground vary with different soil types and weather conditions. For this reason a flexible modelling medium constituted by a mixture of sand, salt and water has been chosen.

According to CCIR Report 229-1 typical values for the relative permittivity ε_r and conductivity σ of the ground at frequencies below 100 MHz are

$$3 < \varepsilon_r < 30$$
$$0.1 < \sigma < 20 \text{ mS/m}$$

To geometrically [1] model real ground the following relationships must be observed

$$\varepsilon' = \varepsilon$$
$$\sigma' = p\,\sigma$$

where ε and σ are the ground permittivity and conductivity measured at a frequency f_0, ε' and σ' are the corresponding parameters of the model at a frequency f' and p is the frequency scaling factor ($p = f'/f_0$).

Experimental procedure and results

The electrical parameters ε and σ of a mixture of sand, salt and water were measured at 9.3 GHz for various combinations of the constituents using the well known Hippel [4] and infinite sample waveguide reflection methods [4].

The measurements were performed using a microwave source, frequency meter, slotted waveguide with a square-law detector and a 10 cm. short-circuited waveguide containing the sample.

The experimental results for the relative permittivity ε_r and loss tangent $\tan\delta = \sigma/\omega\varepsilon$ are summarized in Fig. 1 where the indicated water and salt weight percentages are relative to the weight of the sand. Each point in the figure represents the average of four measurements which gave a standard deviation of less than 5% for the permittivity and less than 8% for the loss tangent.

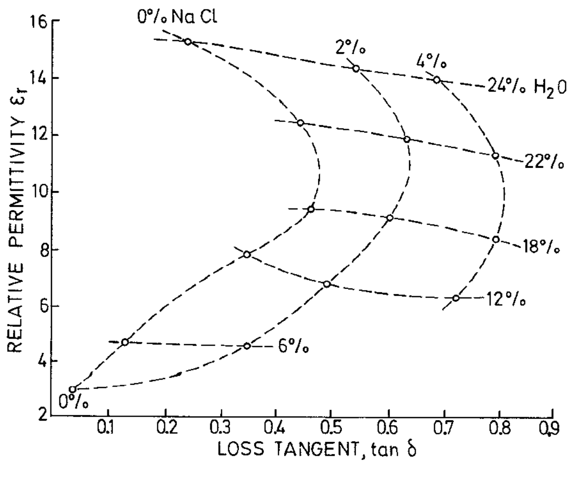

FIGURE 1: RELATIVE PERMITTIVITY AND LOSS TANGENT OF VARIOUS MIXTURES OF WET SALTY SAND.

It can be seen in Fig. 1 that the medium gives a wide range of parameters when changing the relative percentage of its contituents thus allowing the microwave modelling of a large variety of soils.

Modelling a monopole centered on a circular conducting-disk ground system on the surface of a lossy half space

Theoretical analysis

The geometry of the problem is depicted in Fig. 2 where a vertical monopole of height h is centered on a circular metal disk of radius a which is lying on the surface of lossy half space of electrical constants (ε, μ_0, σ).

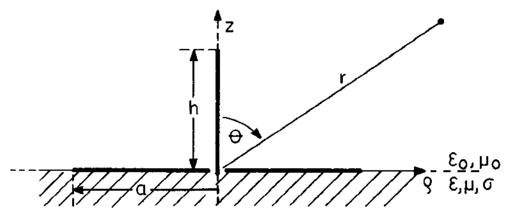

FIGURE 2: MONOPOLE ANTENNA WITH A CIRCULAR CONDUCTING-DISK GROUND SYSTEM ON THE SURFACE OF A LOSSY HALF-SPACE.

The antenna input impedance Z may be expressed as

$$Z = Z^{\infty} + \Delta Z \tag{1}$$

where Z^{∞} is the input impedance of the monopole over perfectly conducting ground.

The change in impedance ΔZ is given by [6]

$$\Delta Z = -\frac{1}{I(0)^2}\int_0^{\infty} H_{\phi}^{\infty}(\rho,0)\, E_{\rho}(\rho,0)\, 2\pi\rho \; d\rho \tag{2}$$

where H_{ϕ}^{∞} is the magnetic field at the surface of a perfectly conducting ground and $I(0)$ is the base current.

The field H_{ϕ}^{∞} is related to the current $I(z)$ on the antenna by

$$H_{\phi}^{\infty}(\rho,0) = -\frac{1}{2\pi}\frac{\partial}{\partial\rho}\int_0^h \frac{\exp[-j\,k_0(z^2+\rho^2)^{1/2}]}{(z^2+\rho^2)^{1/2}}\, I(z)\, dz \tag{3}$$

The tangential field $E_{\rho}(\rho,0)$ on the surface of the imperfectly conducting ground may be given approximately by

$$E_{\rho}(\rho,0) \cong -\eta\, H_{\phi}^{\infty}(\rho,0) \tag{4}$$

where $\eta = [\,j\omega\mu_0/(\sigma + j\omega\varepsilon)]^{1/2}$ is the surface impedance of the earth.

Since the surface impedance of the perfectly conducting disk is zero the integration of eq. (2) will be performed for $\rho \geqslant a$.

It is also important to determine the effect of the ground system on the radiated field. The electric far field E_{θ} of the antenna may be expressed as

$$E_{\theta} = E_{\theta}^{0} + \Delta E_{\theta} \tag{5}$$

where E_{θ}^{0} is the radiation field of the mopole over lossy earth in absence of the disk.

The relative field difference $\Delta E_{\theta}/E_{\theta}^{0}$ is given approximately by [6]

$$\frac{\Delta E_{\theta}}{E_{\theta}^{0}} \cong -\frac{k_0\,\eta \exp(-jk_0 r)}{r\,E_{\theta}^{\infty}}\int_{\rho=0}^{a} H_{\phi}^{\infty}(\rho,0)\, J_1(k_0\rho\sin\theta)\,\rho\; d\rho \tag{6}$$

where E_{θ}^{∞} is the radiation field of the monopole when the ground is perfectly conducting and J_1 is the Bessel function of the first kind.

The field component E_{θ}^{0} is given by

$$E_{\theta}^{0} = -j30k_0 \sin\theta\, \frac{\exp(-jk_0 r)}{r}\int_0^h I(z)\exp(jk_0 z\cos\theta) \cdot [\,1 + R_v \exp(-j2k_0 z\cos\theta)\,]\, dz \tag{7}$$

where R_v is the Fresnel reflection coefficient for vertically polarized waves.

When the ground is perfectly conducting, $R_V \to 1$ and the field E_{θ}^{∞} is readily obtained as $E_{\theta}^{\infty} = E_{\theta}^{0}\,(R_v=1)$

For thin antennas, especially near resonance, it may be assumed that the current distribution $I(z)$ is sinusoidal. More accurate formulas, which may be necessary for impedance calculations, include higher-order terms that complicate the evaluation of the fields. For antennas that are not too long ($k_0 h \leqslant 3\pi/2$) a quasi-zero-order (two terms) current distribution offers an attractive alternative [5].

Experimental equipment

In order to obtain experimental results it was used a monopole of height 0.28 λ and diameter 0.026 λ operating at 9.3 GHz over a lossy half space of parameters ε_r = 9.9 and tanδ = 0.6. The lossy earth was simulated be a mixture of sand, salt and water with 18% water and 2% salt, which was contained in a 16 λ diameter and 5 λ deep plastic tank housed in a microwave anechoic chamber.

The monopole was fed by a 30 cm. 50 Ω coaxial air line extending vertically through the bottom of the tank and terminated in a GR 874-C58A connector which gives an adequate adapted transition to excite the monopole with a small diameter coaxial line.

Measurements were made for copper disks whose radii ranged from 0.2 to 1.5 wavelengths.

Impedance measurements

The impedance measurements where made by conventional techniques using a coaxial slotted line placed directly beneath the plastic tank.

Measuring the reflection coefficient in the slotted line and using an impedance transformation, the monopole input impedance was found; the resistive and reactive components were plotted as a function of disk radius. From these plots the impedance Z^{∞} for an infinitely large disk was estimated by extrapolation, giving Z^{∞} = 95 + j72 Ω. This impedance then was substracted from the monopole input impedance to give ΔZ as a function of disk radius.

The experimental and theoretical results for the incremental resistence ΔR and reactance ΔX are plotted in Figs. 3 and 4 respectively. The theoretical results were obtained by numerical integration of eq. (2) considering an apparent electrical height h ≅ 0.32 λ which according to Schelkunoff and Friis [7] takes account of the end effect in our case. The results thus obtained were found to agree more closely with the measured data when using a sinusoidal current distribution.

The impedance calculations were repeated using a quasi-zero-order current distribution but no significative improvement was observed.

Examination of the curves of Figs. 3 and 4 indicates that the approximate method of impedance calculation yields results similar to the measured data in both amplitude and phase.

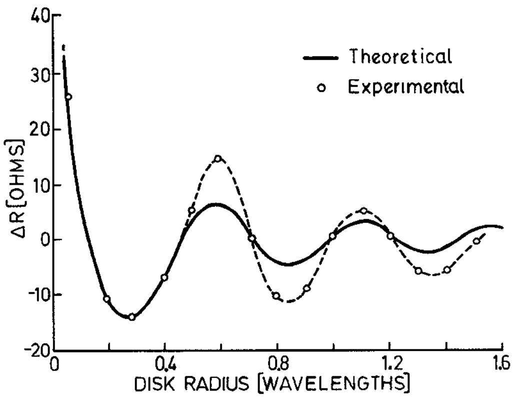

FIGURE 3. INCREMENTAL RESISTANCE OF A MONOPOLE OF HEIGHT 0.28 λ AND DIAMETER 0.026 λ ON A DISK GROUND SYSTEM AS A FUNCTION OF DISK RADIUS.

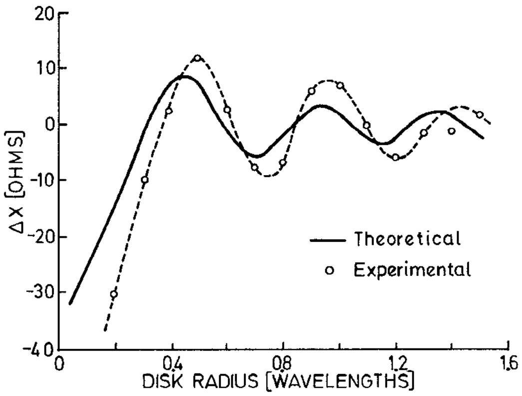

FIGURE 4. INCREMENTAL REACTANCE OF A MONOPOLE OF HEIGHT 0.28 λ AND DIAMETER 0.026 λ ON A DISK GROUND SYSTEM AS A FUNCTION OF DISK RADIUS.

Radiation pattern measurements

The radiation pattern measurements were made at 9.3 GHz. for the same antenna model described above. The monopole was used as a transmitter and its vertical radiation pattern was measured at a distance of 40 λ with a rectangular receiving horn mounted on a rotating wooden frame. The measurements were made using a network analyzer and an X-Y recorder.

In order to check the performance of the experimental set-up, a first measurement was made using a large 62 λ x 31 λ rectangular aluminium plate simulating perfectly conducting ground of infinite radius and very good agreement with the theoretical radiation pattern was obtained.

The experimental and theoretical vertical radiation patterns for three metal disks of radius 0.2 λ, 0.4 λ and 0.8 λ are included in Fig. 5. The experimental patterns were measured maintaining equal incident power to the antenna and the theoretical patterns were computed by numerical integration keeping constant the base current. Therefore, in order to refer all diagrams to the same input power they have been normalized using the experimental values of Z and Z^{∞} and setting the maximum power level of the radiation pattern of the monopole over perfectly conducting ground at 0 dB. The theoretical radiation patterns were calculated using a sinusoidal and a quasi-zero-order current distribution and the corresponding results did not differ more than 0.1 dB.

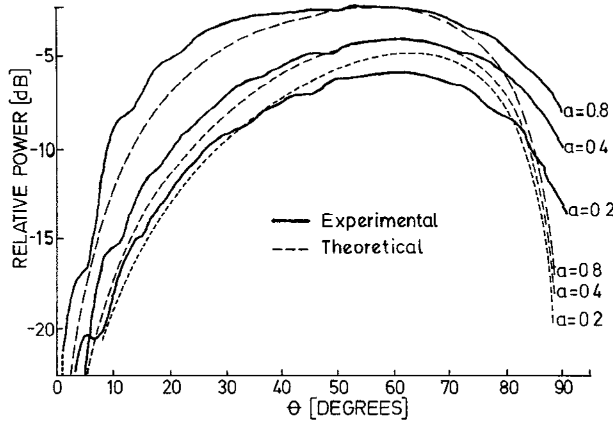

FIGURE 5. VERTICAL RADIATION PATTERNS OF A MONOPOLE OF HEIGHT 0.28 λ AND DIAMETER 0.026 λ ON A DISK GROUND SYSTEM WITH THE DISK RADIUS AS A PARAMETER.

The agreement between the theoretical and experimental radiation patterns included in Fig. 5, is quite good except near grazing angles most probably due to the finite extent of the lossy earth (8 λ in radius) and because the theoretical analysis did not consider the contribution of a surface wave. It is seen that the effect of an encreasing disk radius is to increase the maximum gain of the antenna.

Conclusions

The properties of a mixture of sand, salt and water have been obtained experimentally at 9.3 GHz. giving as a result a medium whose relative permittivity and loss tangent can be varied independently by changing the relative percentages of the mixture constituents, thus allowing the microwave modelling of a large variety of soils.

The feasibility of microwave modelling of H.F. antennas which operate over imperfectly conducting ground has been demonstrated by testing a monopole antenna over a circular metal disk which is lying on a lossy half space and obtaining good agreement between theoretical and experimental results for both input impedance and radiation patterns as a function of the metal disk radius.

References

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