ON THE CHARACTERISTICS OF SPACE AND SURFACE WAVES IN A MULTILAYERED MEDIA,THE MECHANISM OF MUTUAL COUPLING IN MILLIMETER WAVE PRINTED ANTENNAS

Sassan Ahmadi (M.S.E.E.)Member IEEE
Shahrnaz Azizi (M.S.E.E.)
Electric Power Research Center(E.P.R.C.)
P.O.Box 15875-3474 Tehran,Iran.

ABSTRACT

Characteristics of space and surface waves excited by a surface electric current distribution in a multilayered structure are studied. Exact formulation of the input and mutual impedances and also radiation fields considering the effects of surface waves and the leaky modes is presented.These characteristics are investigated via the reaction concept. The subject may find application for theoretical analysis of the mechanism of mutual coupling in millimeter wave printed antennas.

I.INTRODUCTION

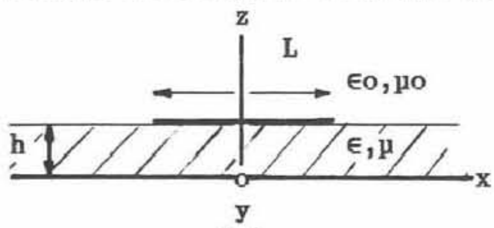
Radiation and impedance characteristics of a surface electric current distribution such as printed strip dipoles in stratified media are reported by a number of investigators.In the present investigation an attempt has been made to study the characteristics of space and surface waves excited by a surface electromagnetic source and the effects of them on the certain parameters of the antenna such as radiation pattern and input impedance[4].

The reaction concept is adopted as the main essence of this work. It will be shown in general that the impedance characteristics and radiation pattern of a printed antenna are affected not only by the space wave but also by the existence of surface waves and the leaky modes which are excited by the same electromagnetic source.The mechanism of mutual coupling and cross polarization patterns and any other certain parameter of a printed antenna will be exactly justified, especially in millimeter wave range.In the following sections basic features of our approach will be outlined.

II.FORMULATION OF THE PROBLEM

The geometry under consideration is shown in fig.1, a printed strip dipole on the upper surface of a grounded dielectric substrate is assumed to be the source of space and surface waves,but this assumption will not restrict the procedure.

The Hertz potential components Γ_α , Γ_z for $z \geq h$ are given in cylindrical coordinates as [2](a time dependence $\exp(j\omega t)$ is assumed):



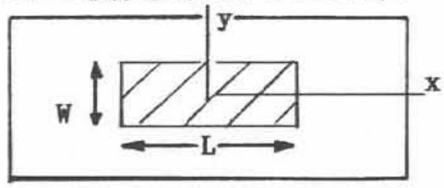


fig.1. a printed strip dipole with a longitudinal current distribution

$$\Gamma_{\alpha}=\frac{-j\omega\mu_o}{8\pi k^2}\int_{-\infty}^{+\infty}\frac{f(\Omega)}{De(\Omega)}\,e^{-u(z-h)}\,H_0^{(2)}(\Omega r)\,d\Omega \qquad (1)$$

and

$$\Gamma_{z}=\frac{-j\omega\mu_o}{8\pi k^2}\int_{-\infty}^{+\infty}\frac{g(\Omega)}{De(\Omega)Dm(\Omega)}\,e^{-u(z-h)}\,H_1^{(2)}(\Omega r)\,d\Omega \qquad (2)$$

where $k=\sqrt{\epsilon r}\,ko$ and

$$f(\Omega)=2\Omega(\epsilon r)\sinh(u'h)\ ;\quad g(\Omega)=\Omega^2(1-\epsilon r)(\epsilon r)\sinh(2u'h)\Phi\alpha \qquad (3)$$

and $\Phi x=\cos(\phi)$ while $\Phi y=\sin(\phi)$

$$De(\Omega)=\mu u\sinh(u'h)+u'\cosh(u'h) \qquad (4)$$

$$Dm(\Omega)=u(\epsilon r)\cosh(u'h)+\mu u'\sinh(u'h) \qquad (5)$$

with $u^2=(\Omega^2-ko^2)\ ;\ u'^2=(\Omega^2-k^2)$ (6)

The integrands in (1),(2) contain singularities in the range $ko<\Omega<k$ which correspond to either transverse magnetic(TM) surface wave modes($Dm(\Omega)=0$) or transverse electric (TE) surface wave modes($De(\Omega)=0$).In addition to the surface wave poles of the integrands in (1) and (2) which lie on the real axis,there are an infinite number of complex roots which give rise to a class of modes called leaky modes[3].

The number of modes excited depends upon the thickness h of the substrate, its dielectric constant ϵr,and the frequency of operation.The Sommerfeld-type integrals given by (1) and (2) contain the two radicals given by u and u' which are double-valued functions of the complex variable Ω.However the sign of the radical represented by u' does not affect the single-valuedness of the integrands,since the terms involving u' are even functions of Ω.This implies then that only the branch points contributed by u need be considered[1]. Thus the integrands in (1) and (2) are two-valued functions of Ω because of the two branches of the function u.The branch points occur at: $\Omega=\pm ko$ (7)

The convergence of the integrals and outward-propagating or attenuated wave character require ($Re\ \Omega>0$) and ($Im\ \Omega<0$) [3].The choice of the branch cuts and the path of integration are shown in fig.2. Although the branch cut is arbitrary,as far as the original integrals along C are concerned,it must be chosen more carefully if the integrals along C1 are to vanish.Also it is only on the proper branch that the integrals (1) and (2) will converge at infinity.The original integral along C is thus equal to:

$$\int_C = -\int_{C1} - \int_{C2} -2\pi j\sum_n \text{residue at } \Omega Ro^{TM(n)} - \qquad (8)$$

$$-2\pi j\sum_n \text{residue at } \Omega Ro^{TE(n)}$$

$\Omega Ro^{TM(n)}$ and $\Omega Ro^{TE(n)}$ are the n-th zeros of $Dm(\Omega)$ and $De(\Omega)$ respectively. Provided we assume that ko has a small imaginary part,that is, $ko=ko'-jko''$, corresponding to a small loss in the medium.If the integral along the semicircle C1 vanishes,then the original integrals are equal to the branch

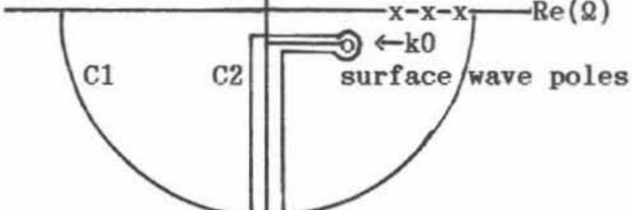


fig.2. path of integration

cut integral plus the residues contributed by the enclosed poles. The branch cut integral represents the radiation field with a continuous eigen value spectrum [3]:

$$\Gamma_\alpha = \frac{j\omega\mu_o}{8\pi k^2} \int_{C2} \frac{f(\Omega)}{De(\Omega)} e^{-u(z-h)} H_o^{(2)}(\Omega R)\, d\Omega - \quad (9)$$

$$- \frac{\mu_o\omega}{4k^2} \sum_n \text{residue at } \Omega R_o^{TE(n)}$$

and

$$\Gamma_z = \frac{j\omega\mu_o}{8\pi k^2} \int_{C2} \frac{g(\Omega)}{De(\Omega)Dm(\Omega)} e^{-u(z-h)} H_1^{(2)}(\Omega R)\, d\Omega - \quad (10)$$

$$- \frac{\omega\mu_o}{4k^2} \sum_n \text{residue at } \Omega R_o^{TE(n)} - \frac{\omega\mu_o}{4k^2} \sum_n \text{residue at } \Omega R_o^{TM(n)}$$

The surface wave field for the n-th surface wave mode is obtained as:
for TM modes:

$$\Gamma_{z,s}^{(n)} = -\frac{\omega\mu_o}{4k^2} \left. \frac{g(\Omega)\, e^{-u(z-h)} H_1^{(2)}(\Omega R)}{De(\Omega)\ \partial Dm(\Omega)/\partial\Omega} \right|_{\Omega=\Omega R_o^{TM(n)}} \quad (11)$$

for TE modes:

$$\Gamma_{\alpha,s}^{(n)} = -\frac{\omega\mu_o}{4k^2} \left. \frac{f(\Omega)\, e^{-u(z-h)} H_o^{(2)}(\Omega R)}{\partial De(\Omega)/\partial\Omega} \right|_{\Omega=\Omega R_o^{TE(n)}} \quad (12)$$

$$\Gamma_{z,s}^{(n)} = -\frac{\omega\mu_o}{4k^2} \left. \frac{g(\Omega)\, e^{-u(z-h)} H_1^{(2)}(\Omega R)}{Dm(\Omega)\ \partial De(\Omega)/\partial\Omega} \right|_{\Omega=\Omega R_o^{TE(n)}} \quad (13)$$

The space and surface wave fields of a printed strip dipole are determined. Notice that we have assumed the current distribution on the strip dipole. Derivation of this current distribution has been discussed in the literature[5],[6],[7]. Therefore we have shown that total fields due to the radiation of an electromagnetic source can be decomposed into three separate parts. Contribution of them on the radiation pattern, cross polarization and sidelobe levels depend upon the conformity between their polarization and the direction of current distribution.

The effect of space and surface wave modes on input impedance can be shown by using the concept of self reaction [8]. Decomposition of electric field into space, TE surface wave modes and TM surface wave modes yields:

$$Zin = C_1 \langle s_{TE}, a\rangle + C_2 \langle s_{TM}, a\rangle + C_3 \langle r, a\rangle \quad (14)$$

where $\langle s,a\rangle$ is the reaction of surface wave fields on the corresponding surface current source and $\langle r,a\rangle$ is the reaction of radiated field on the same source. The effect on mutual impedance can also be shown as follows:

$$Zab = B_1 \langle s_{TE}, b\rangle + B_2 \langle s_{TM}, b\rangle + B_3 \langle r, b\rangle \quad (15)$$

The far field due to the elementary horizontal dipole at z=h is given in spherical coordinates by [2]:

$$E_\theta \approx ko^2[\cos(\theta)\cos(\phi)\Gamma_x - \sin(\theta)\Gamma_z] \quad (16)$$

and

$$E_\phi \approx ko^2[-\sin(\phi)\Gamma_x] \quad (17)$$

According to previous discussions, it can be observed that radiated fields are affected not only by space waves but also by TE surface wave modes and TM surface wave modes.

The surface wave amplitude for the TE1 and TM2 modes of a x directed electric dipole are plotted in figs.3 ,4 respectively. The parameters were h=1.27 mm, ϵ_r=2.33, and f=30GHz. Fig.5 shows the variation of the radiated field components due to the radiation of a x directed electric dipole with the same parameters. These space and surface wave components are plotted in the vicinity of the source.

III.CONCLUSION

This paper has presented an accurate method for the evaluation of the effects of space and surface wave modes on the certain parameters of a surface electromagnetic source such as a printed dipole via the concept of reaction. The present investigation may find applications in the studying of the mechanism of mutual coupling in millimeter wave printed antennas.

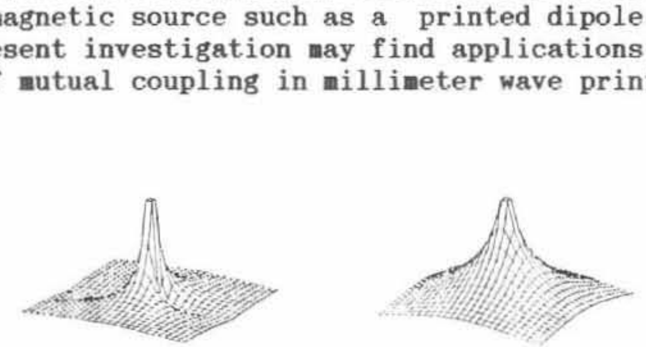


fig.3.Variation of normalized surface-wave amplitude for the TE1 mode components (Γ_z-left, Γ_x-right) with radial distance in the vicinity of a x-directed electric dipole.

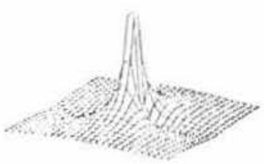


fig.4.Variation of normalized surface-wave amplitude for the TM2 mode Γ_z-x directed dipole with radial distance.

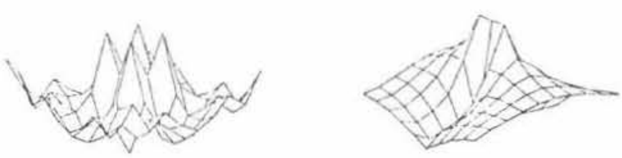


fig.5.Variation of space wave amplitude (Γ_x-left, Γ_z-right) for a x-oriented electric dipole with radial distance.

REFERENCES

[1] I.E.Rana, N.G.Alexopoulos,"Current distribution and input impedance of printed dipoles,"IEEE trans. Antennas propagat.,vol AP-29 Jan.1981
[2] N.G.Alexopoulos, D.R.Jackson , P.B.Katehi , " Criteria for nearly omnidirectional radiation patterns for printed antennas," IEEE trans. Antennas propagat., vol. AP-33 Feb.1985
[3] R.E.Collin,"Field theory of guided waves,"MCGraw-Hill book company 1960
[4] A.K.Bhattacharyya ," Characteristics of space and surface waves in a multilayered structure,"IEEE trans.Antennas propagat.,vol.AP-38 August 1990
[5] P.B.Katehi,"A generalized method for the evaluation of mutual coupling in microstrip arrays,"IEEE trans.Antennas propagat.,vol AP-35 Feb.1987
[6] P.B.Katehi,N.G.Alexopoulos," On the modeling of electromagnetically coupled microstrip antennas-the printed strip dipole,"IEEE trans.Antennas propagat., vol AP-32 Nov.1984
[7] P.B.Katehi,"mutual coupling between microstrip dipoles in multielement arrays,"IEEE trans. Antennas propagat.,vol AP-37 March 1989
[8] R.F.Harrington,"Time harmonic electromagnetic fields,"MCGraw-Hill book company 1961