REFLECTION OF SURFACE WAVES ON A DIELECTRIC IMAGE LINE WITH APPLICATION TO "GUIDED RADAR"

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Abstract

The dielectric image line is treated as an example of a line that can support a surface-wave mode, and reflections from metallic obstacles on the line are considered. This problem finds its application in an obstacle detection scheme for guided ground transportation where the metallic obstacle may represent a preceding vehicle. An integral equation for the currents on the obstacle is solved by the moment method and the surface-wave reflection coefficient is obtained.

Introduction

Use of surface-wave structures to provide a communication system for railways has been discussed in the literature[1]. Detection of obstacles such as landslides, a preceding vehicle,..., etc., is also possible by launching signals along the surface-wave line from an installed trans/receiver set on the vehicle and signal-processing the returning echo to give a "Guided Radar System". Fig. 1 shows this concept of obstacle detection. In this figure, the contour of false alarm discrimination coincides with a constant power density contour of the attenuated surface-wave mode and it is assumed that any obstacle outside this contour will reflect a negligible amount of power and so will not be detected. Regions of probable false alarms and probable misses are shown and it is seen that these are smaller when the total attenuation between repeaters is low. Hence there is a necessary relationship between the attenuation rate on the line, the repeater span and the required probability of false alarm or miss.

A basic problem in the above application is the evaluation of reflection coefficients from typical obstacles on the surface-wave structure. Apart from the work of Gillespie and Gustincic[2] on reflections from symmetric metallic obstacles on the Goubau line, it appears that this problem has received little consideration. Moreover, the use of the Goubau line for guided ground transportation has the disadvantage of not being a self-supporting structure. Hence, radiation, due to the supports and line-sag between supports, adds to its losses. Lines that are self-supporting include the dielectric-image line, the slotted coaxial line, the loose braided coaxial line,..., etc. Among these, the image line is the one that is most accessible to rigorous analysis and hence can be favourably used for analytic evaluation of surface-wave reflection coefficients.

In this paper we consider the reflection from a thin metallic obstacle on the image line. The geometry of the problem is shown in fig. 2. The obstacle extends over the whole range of the circumferential dimension ($0 \le \phi \le \pi$). The dominant mode on the image line is the HE_{11} mode. For the particular shape of the obstacle in fig. 2, the scattered fields will have the same dependences on ϕ as the incident fields. The currents on the obstacle will have both radial and circumferential components. Green's functions for the image line are obtained by use of the transverse spectral representation for the fields[3] and are used in an integral equation for the obstacle current distribution from which the surface-wave reflection coefficient is obtained.

Theoretical Outline of the Solution

(i) Green's functions for the image line.

The element of current that is suitable as a unit source for the present problem is of infinitesimally small radial and axial extent and varies harmonically with ϕ; this is given by

$$J\rho(\rho_s)/_{\text{source}}^{\text{unit}} = \frac{1}{\pi\rho_s}\,\delta(\rho-\rho_s)\delta(z)\sin\phi$$

$$J_\phi(\rho_s)/_{\text{source}}^{\text{unit}} = \frac{1}{\pi\rho_s}\,\delta(\rho-\rho_s)\delta(z)\cos\phi$$

where ρ_s is the radial location of the source. The Green's dyad is defined by

$$\begin{bmatrix} E_\rho(\rho) \\ E_\phi(\rho) \end{bmatrix} = \int \begin{bmatrix} G_{\rho\rho}(\rho,\rho_s) & G_{\rho\phi}(\rho,\rho_s) \\ G_{\phi\rho}(\rho,\rho_s) & G_{\phi\phi}(\rho,\rho_s) \end{bmatrix} \begin{bmatrix} J_\rho(\rho_s) \\ J_\phi(\rho_s) \end{bmatrix} dV_s$$

where E, G and dV_s denote electric field, Green's function and differential volume respectively. A transverse spectral representation[3] is used to represent a general disturbance on the line; for instance, the radial field $E_\rho(\rho)$ at a certain cross-section is given by

$$E_\rho(\rho) = A_{sw}(e_\rho(\rho))_{sw} + \int_0^\infty B(k)e_\rho(\rho,k)dk \quad (1)$$

where A_{sw} is the coefficient of the surface-wave component and B(k) is the coefficient of the continuous spectrum over the transverse wavenumber, k. $(e_\rho(\rho))_{sw}$ and $e_\rho(\rho;k)$ are the normalised field functions of the surface wave and the continuous spectrum respectively.

The transverse spectral representation has been preferred to the longitudinal one because the excitation coefficients for a known source are then more straightforwardly obtained. An orthogonality relationship is derived between the surface-wave mode and the pseudo-modes (components of the continuous spectrum[3]), as well as among the latter modes. By use of this relationship, the excitation coefficients, A_{sw} and B(k) due to a unit current source are obtained, thus yielding the Green's functions for this source.

The path of integration in eqn. (1) is deformed in the complex k plane and then performed semi-numerically.

(ii) The current distribution and the surface-wave reflection coefficient.

An integral equation for the current distribution is obtained by use of the Green's dyad, $\bar{\bar{G}}$ and imposing the boundary condition of zero tangential electric field on the obstacle; this is given by

$$\int_{\text{obstacle}} \bar{\bar{G}}(\rho,\rho_s).\bar{J}(\rho_s)dV_s+\bar{E}_i(\rho)=\bar{0} \quad \text{on the obstacle.}$$

where $\bar{E}_i(\rho)$ is the incident radial and circumferential components of the incident surface-wave mode; more specifically, $E_i(\rho)$ is the column

$$\begin{bmatrix} E_{i\rho}(\rho) \\ E_{i\phi}(\rho) \end{bmatrix}$$

with a similar meaning for $\bar{J}(\rho_s)$.

The above integral equation can be solved by the moment method by using pulse function approximation for the currents and point-matching for the fields. Alternatively the current can be expanded into a finite Fourier series of sine and cosine functions defined on the obstacle. The coefficients of this series are obtained by point-matching the fields. This method is proved to be more reliable than the use of pulse functions since it filters out the higher spatial harmonics of the current, which are liable to be in error because of the unavoidable numerical inaccuracies of the Green's functions. The number of terms in the Fourier series of the current are increased until the resulting surface wave reflection coefficient shows no significant change. It is worth mentioning that an attempt to include more spatial harmonics for the current than a certain critical number results in an inaccurate reflection coefficient that oscillates about the correct value.

A variational procedure using the Raleigh-Ritz method is also attempted. The current is again approximated by a finite Fourier series and the surface-wave reflection coefficient, (R) is computed from a formula that is stationary with respect to the series coefficients.

Some Preliminary Results

Table 1 shows a comparison of the predicted magnitudes of reflection coefficient (obtained by the moment method and the use of a finite Fourier series for the current) with those measured. The frequency is 2.05 GHz and the dielectric semi-rod has a radius of 2.5 cm and a relative permittivity of 2.56. It may be noted that the corresponding reflection coefficients obtained by the variational procedure differ from those in table 1 by only 2.5 to 9%, which gives increased confidence in these results. The discrepancies between theoretical and experimental results are believed to be partially due to an inaccurate recording of the frequency during the experiment along with the fact that the transverse decay coefficient is highly sensitive to the frequency. The last two columns in the table show an attempt to fit the obtained results by use of a simple empirical formula. Such a formula should be very useful when dealing with more complex shapes of the obstacle or the line itself.

Conclusion and Further Work

In this paper, we have briefly described the concept of "Guided Radar". The dielectric image line is taken as an example of a surface-wave structure that is accessible to rigorous analysis. Surface wave reflection coefficients from metallic semi-annular obstacles on the line are considered and a method is presented for their prediction in magnitude and phase, as well as the prediction of the current distribution on the obstacle.

Extension of the analysis to other shapes of obstacle is found to increase the computational complexity very much, since modes with higher harmonics in the circumferential direction are then introduced. However, some approximation might be in order. It is helpful here to consider that the field of an element of current on the obstacle has three components: (i) the direct radiation, as if in free space, (ii) the indirect radiation due to reflections from the guiding structure and (iii) the surface wave mode. It is due to the indirect radiation that the Green's functions are more complicated than those involved in the usual free-space radar. In the present problem, it is found that great simplification is attained if the dielectric semi-rod is removed, or replaced by free space while computing the indirect radiation component. This removal should be justified if the obstacle is not too near to the line. With this simplification, the use of cylindrical coordinates becomes unnecessary or of no particular advantage; hence extension is possible to obstacles of arbitrary shape. Investigation of this extension is underway.

References

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Acknowledgement

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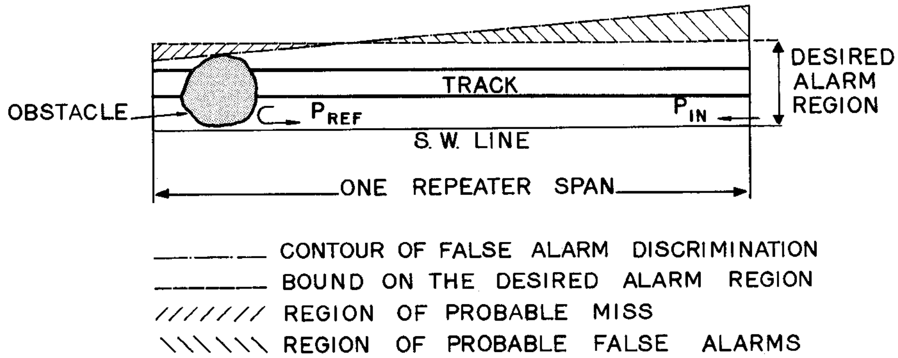


FIG 1 CONCEPT OF GUIDED RADAR

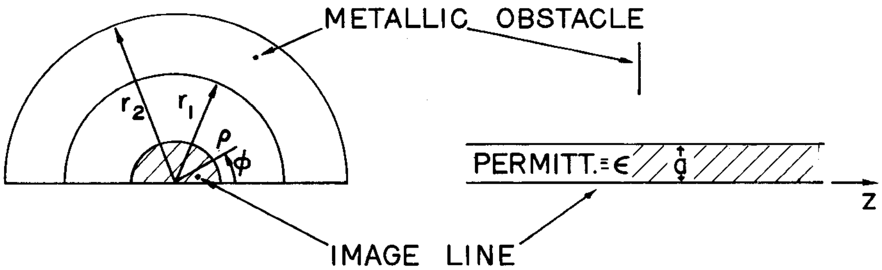
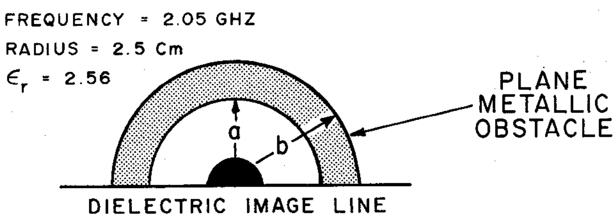


FIG 2 GEOMETRY OF THE PROBLEM



OBSTACLE		REFLECTION COEFFICIENT			
a cm	(b−a) cm	MEASURED $\lvert\rho\rvert$	PREDICTION $\lvert\rho\rvert$	SIMPLIFIED PREDICTION $\lvert\rho\rvert$	
				n = 2	n = 3
3.5	2.0	0.28	0.181	0.168	0.200
4.0	2.0	0.15	0.146	0.150	0.150
4.5	2.0	0.13	0.120	0.132	0.128
3.5	3.0	0.30	0.190	0.186	0.214
4.0	3.0	0.16		0.162	0.172
4.5	3.0	0.13		0.144	0.136

"PREDICTION" — FROM DETAILED THEORY
"SIMPLIFIED PREDICTION" — FROM EMPIRICAL LAW

$$|\rho|^2 \propto \int_{AREA} (\text{INC PWR DENSITY})^n \, dA$$

TABLE 1: SOME PRELIMINARY RESULTS