Effect of a Dielectric Overlay in a Microstripline on a Circular Cylindrical Surface

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Abstract—**The effect of a dielectric overlay on the propagation constant of a microstripline on a circular cylindrical surface is examined here, using dyadic Green's functions. The results show that this effect is substantial when the values of the relative dielectric permittivity and thickness of the overlay are increased.**

I. Introduction

The analysis of electromagnetic problems in multilayered dielectric media, waveguides and other structures have received an increased attention after the publication of the work done by Tai [1], on the application of dyadic Green's functions in electromagnetic theory. Since microstriplines on multilayered dielectric media are finding several important applications, their analysis is relevant and the use of dyadic Green's functions is a natural choice.

The study of microstriplines on circular cylindrical substrates is of particular importance for applications with microstrip antennas on these substrates, however, not much is available in the specialized literature. A theoretical analysis using a dynamic model for the microstrip elements on cylindrical substrates was developed by Alexopoulos and Nakatani [2], however, only single layer substrates were considered. To the authors knowledge there is no work published on microstriplines with multilayer circular cylindrical dielectric substrates.

Dyadic Green's function of the electric type for a four-layered cylindrical-concentric media were obtained here, when the inner layer is a perfect conducting cylinder [3]. This function was used for the analysis of an infinite microstripline mounted on a circular cylindrical substrate and its propagation constant was calculated. Numerical results are presented and the effect of a dielectric overlay on the propagation constant of a microstripline is examined.

II. Calculation of the Propagation Constant

A four-layered circular-cylindrical concentric dielectric medium is shown in Fig. 1. For the solution of this problem the dyadic Green's functions for the dielectric media were initially obtained, using Ohm–Rayleigh method [1]. These functions have to satisfy the boundary conditions for the fields at the interfaces between the media [1].

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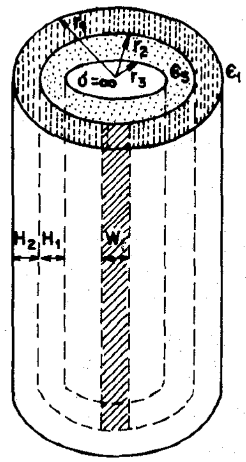

Fig. 1. Microstripline on a circular cylindrical substrate with a dielectric overlay.

The electric field in medium 2 is given by [1]:

$$\overline{E}_2(\overline{R}) = i\omega\mu_2 \iiint_{v'} \overline{\overline{G}}_{e2}^{(22)}(\overline{R}/\overline{R}') \cdot \overline{J}(\overline{R}')\, dv' \qquad (1)$$

where $\overline{J}(\overline{R}')$ is the electric current density on the metal strip.

For the infinitely long microstripline as shown in Fig. 1, the fields are assumed as having a harmonic time dependence, $\exp(-i\omega t)$ and propagating with a z dependence $\exp(ik_e z)$, where k_e is the desired propagation constant along the line. The ϕ component of the electric current density is small and assumed here to be equal to zero. This is an approximation, particularly valid at lower frequencies [2]. Thus, the electric current density has only the component along the z direction, since the metal strip is assumed to have infinitesimal thickness. In addition, J_z will be assumed to be a function of z only. How good is the approximation, of neglecting the dependence of J_z on ϕ remains to be investigated. Note, however, the agreement observed in Fig. 2 of the results of this analysis with that by Alexopoulos and Nakatani [2], in which not only J_z was assumed to be a function of ϕ but also J_ϕ was assumed different from zero. This electric current density, $\overline{J}(\overline{R}) = J_z(z)\hat{z}$, is introduced in (1) and, as a result, the spectral integral that appears in the dyadic Green's function is discretized in terms of k_e, that may be assumed as being purely real for lossless propagating modes.

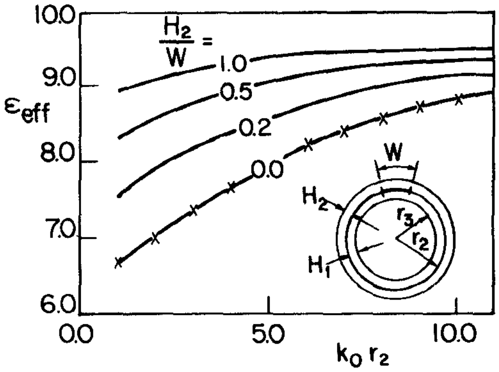

Fig. 2. Effective dielectric constant, ε_{eff}, as a function of $k_0 r_2$, for various values of H_2/W and for $\varepsilon_1 = \varepsilon_0$, $\varepsilon_2 = \varepsilon_3 = 9.6\,\varepsilon_0$, $H_1 = W$ and $(r_3/r_2) = 0.9$. Results from Alexopoulos Nakatani [2] are also shown with x marks.

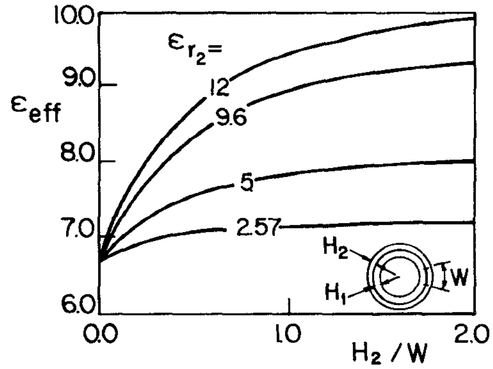

Fig. 3. Effective dielectric constant, ε_{eff}, as a function of H_2/W, for various values of ε_2 and for $\varepsilon_1 = \varepsilon_0$, $\varepsilon_3 = 9.6\,\varepsilon_0$, $H_1 = W$, $k_0 r_2 = 1$ and $(r_3/r_2) = 0.9$.

The tangent component of the electric field is imposed to be equal to zero on the metal strip since we are assuming a perfect conducting strip. From this condition an integral equation is obtained and the values of k_e are calculated. The effective dielectric constant is thus obtained from $\varepsilon_{\text{eff}} = (k_e/k_0)^{1/2}$, where k_0 is the free-space wave number.

III. Numerical Results and Conclusion

The dependence of the effective dielectric constant on $k_0 r_2$, and for various heights of the dielectric overlay, is shown in Fig. 2. In Fig. 3 the effective dielectric constant is shown as a function of H_2/W, for various values of the overlay dielectric permittivity, ε_2.

The results of Alexopoulos Nakatani [2] are also shown Fig. 2 and agreement is observed when the overlay thickness is reduced to zero ($H_2 = 0$). Note that, with the choice of $\varepsilon_3 = 9.6\,\varepsilon_0$, the effect of the dielectric cover on the effective dielectric constant is appreciable even for small values of $k_0 r_2$. Note also in Fig. 3 that, for $k_0 r_2 = 1$, the curves of ε_{eff} approach the asymptotic values for H_2 larger than 1.9 W and for all the used values of ε_2.

The influence of the dielectric overlay on the pole location of the surface wave and on the propagation constant of a microstripline, with $W = 0.477$ cm, on a circular cylindrical substrate with $r_3 = 2.5$ cm and $H_1 = 0.159$ cm, and having $\varepsilon_1 = \varepsilon_2 = \varepsilon_0$ and $\varepsilon_3 = 2.57\,\varepsilon_0$ was calculated. In this case, the pole $= 1.009\,k_0$ and $k_e = 1.471\,k_0$. If $H_1 = H_2 = 0.159$ cm, $\varepsilon_1 = \varepsilon_0$ and $\varepsilon_2 = \varepsilon_3 = 2.57\,\varepsilon_0$, the pole $= 1.023\,k_0$ and $k_e = 1.549 k_0$. Substantial changes are noted, even considering an overlay with a low dielectric permittivity value and a small thickness of the dielectric overlay. Since k_e is larger than the pole location and because a uniform microstripline is assumed, no surface wave power is generated. Transmission line discontinuities, however, may excite surface waves as well as higher order propagation modes [4].

It is important to note that there are not many experimental data available, particularly concerned with the effect of a dielectric overlay on microstrip elements on circular cylindrical substrates, for comparison with the theoretical results from this work. However, the use of dyadic Green's functions for the solution of electromagnetic problems and the comparison of the numerical results obtained for a microstripline with those from Alexopoulos and Nakatani [2], that show agreement when the overlay thickness is reduced to zero, are helpful for the conviction that the obtained results are very reliable.

The analysis was done for nonmagnetic dielectrics such that $\mu_1 = \mu_2 = \mu_3 = \mu_0$, where μ_0 is the free-space magnetic permeability.

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