REDUCTION OF PROPAGATION LOSSES IN COPLANAR WAVEGUIDE

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ABSTRACT

Coplanar Waveguide (CPW) is finding increasing use in microwave and millimeter wave integrated circuits. CPW has several advantages over microstrip, but its ohmic loss tends to be larger because of the concentration of its currents near the metal edges. Two methods for reducing ohmic loss in CPW are proposed and studied using a numerical technique. It is shown that the propagation loss can be reduced by approximately a factor of four.

INTRODUCTION

Coplanar waveguide (CPW) is a planar guiding structure compatible with microwave and millimeter wave integrated circuit technology. CPW is relatively insensitive to variations in substrate thickness, has low radiation loss, and allows circuit elements to be connected in shunt as easily as in series.

At millimeter wave frequencies losses of both microstrip and CPW are dominated by conductor loss, which become more severe as the frequency increases. Herein lies the principal disadvantage of CPW, the ohmic loss of which is higher than that of microstrip. In this paper we propose two methods for reducing the propagation loss of CPW. The effects of these methods have been studied by means of a numerical technique.

In the first method, grooves are either etched or milled into the substrate, as shown in Fig. 1. For grooves with vertical walls, the loss of the guide is reduced by a factor of approximately four. Dielectric loss is also reduced. In the second method, a layer of a lower dielectric constant is deposited between the supporting substrate and the CPW, as also shown in Fig. 1. The loss of the guide can be reduced by a factor of nearly three using this technique.

With either method the dominant factor contributing to a reduction of conductor loss is a redistribution of the current on the metal electrodes. Other factors contributing to a reduction of conductor loss are a slight widening of the center conductor, which is necessary in order to maintain the desired characteristic impedance, as well as a small increase in the guide wavelength. Following the discussion of losses, we present design information for practical guides.

NUMERICAL METHOD

In order to analyze the guides shown in Fig. 1, the "quasi-TEM" approximation is employed, according to which the electric and magnetic fields are assumed to be transverse to the direction of propagation. Under this assumption the electric and magnetic fields can be derived from a single scalar potential which is a solution of Laplace's equation. As is shown in [1], the solution of Laplace's equation in the region of Fig. 2a can be found by means of a Schwarz transformation from Fig. 2b. The system of Fig. 2b is finite in extent and the fields are well behaved. Hence the 'transformed' problem can be solved by a simple relaxation method [2]. The analysis is valid if the conductors of the CPW are several skin-depths thick, possess a high but not infinite conductivity, have edges with radii of curvature large compared to the skin depth (to prevent divergent fields [3]), and are of a width which is small compared to a wavelength (to allow the 'quasi-TEM' approximation). These assumptions are good ones in most practical applications. In situations where the metal edges are not rounded compared to the skin depth the actual loss will be greater than that predicted by this analysis. The **relative** improvement in loss, however, will also be greater.

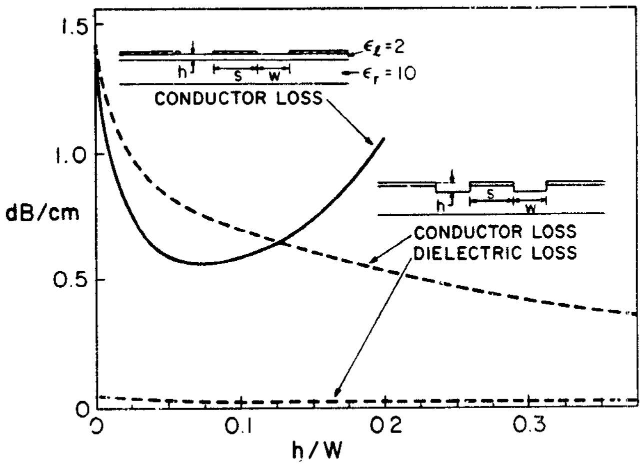
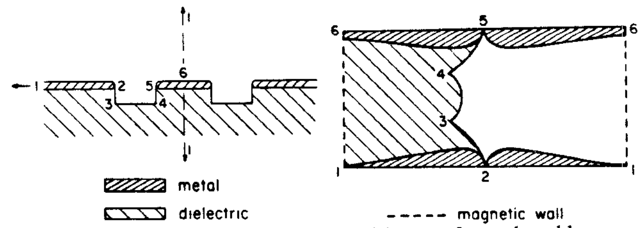


Fig. 1 Conductor and dielectric losses in 50 ohm CPW as functions of groove or layer depth h at 100 GHz from numerical calculations ($\epsilon_r=10$, $R_s=.0826\Omega/[]$, $\tan\delta = 2\times10^{-4}$, $S+2W=200\mu m$).



(a) Original problem. (b) Transformed problem.

Fig. 2 Coordinate systems of the original and transformed problems. The numbers denote points and their transformations.

The ohmic loss is estimated from the perturbation formula [2,4]

$$\alpha_c = \frac{R_s \int_C J^2\, dl}{2ZI^2} \tag{1}$$

where the line integral on C is preformed around the metal boundary, J is the current density on the metal surface, I is the total current, R_s is the surface resistance of the metal, and Z is the guide impedance. Care is taken in the numerical evaluation [5] to ensure

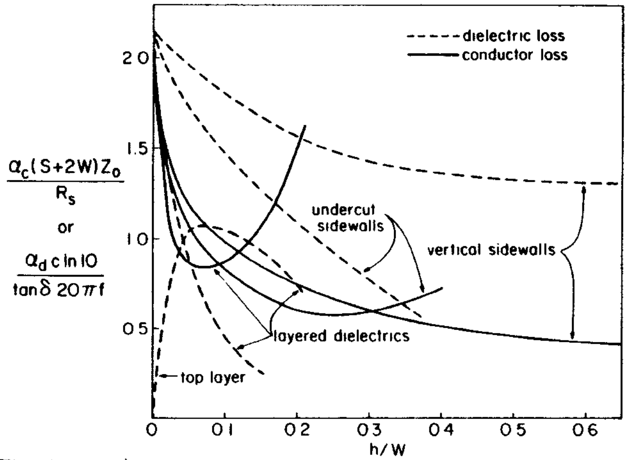


Fig. 3 Normalized propagation losses as a function of groove or dielectric layer depth for 50 ohm lines. Data from numerical calculations.

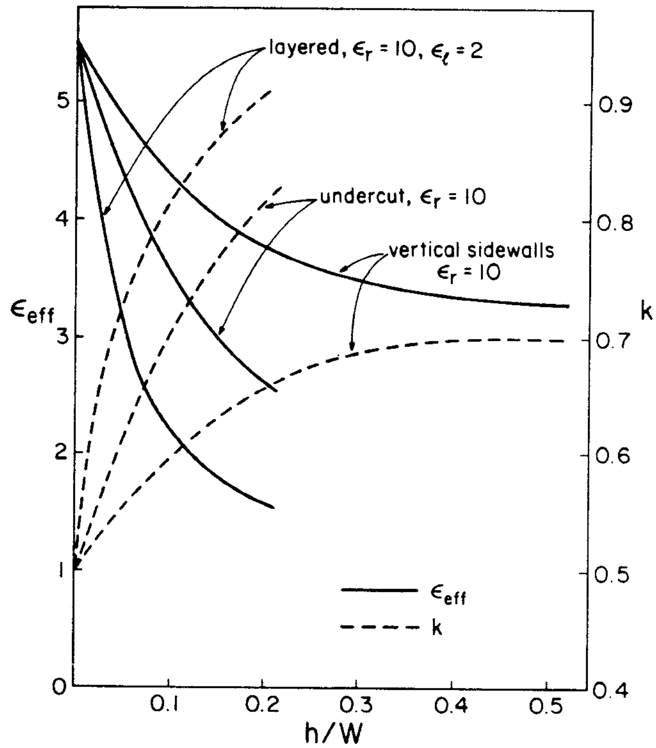


Fig. 4 Effective dielectric constant and k=S/(S+2W) as functions of groove or layer depth for 50 ohm impedance.

that the resulting sum accurately approximates the desired result. Because the fields are well behaved in the 'transformed' region of Fig. 2b, the fields can be determined with a relatively course two-dimensional grid there. These field quantities are transformed back to the region of Fig. 2a and the integral found by numerically summing the currents thus determined over very small intervals along the conductor surface. The dielectric loss is estimated from [4]

$$\alpha_d = \frac{20\pi f}{\ln 10 c\sqrt{\epsilon_{eff}}}\sum_i \epsilon_i \tan\delta_i \left[\frac{\epsilon_{eff}'-\epsilon_{eff}}{\epsilon_i'-\epsilon_i}\right] \quad (2)$$

where ϵ_{eff}' is the value of the effective dielectric constant ϵ_{eff} for the structure when ϵ_i, the dielectric constant of material i, is perturbed to some slightly different value ϵ_i'.

NUMERICAL RESULTS

Fig. 1 shows the reduction of loss possible for typical guides at 100 GHz. Fig. 3 shows normalized plots of conductor and dielectric loss, respectively, as functions of groove depth and dielectric layer depth for 50 ohm guides. Losses for two different groove profiles are shown. The plots for grooves with vertical walls might be appropriate for grooves fabricated by ion-beam milling (at millimeter wave frequencies) or machine milling (at microwave frequencies). The grooves with recessed sidewalls are typical of the shapes that result when isotropic etching is employed. Use of either groove type results in a substantial reduction of both ohmic and dielectric loss. Calculations were also performed for a third profile with sidewalls slanted at an angle of 45 degrees, similar to what would be obtained with an anisotropic etch. In this case, however, the loss reduction was less than 50 percent for the deepest groove possible.

The situation is more complicated for the layered case. Both dielectrics contribute to the propagation loss, and so the normalized loss due to each dielectric is separately plotted in Fig. 3. This technique may find use in situations where the dielectric loss is much smaller than the ohmic loss, not an uncommon situation at millimeter wavelengths. It may also find use when dielectric films with loss tangents lower than those of the supporting substrate are available, a situation which may occur when the substrate is a semiconductor.

In Fig. 4 the value of k [=S/(S+2W)] required to obtain a 50 ohm impedance guide is plotted as a function of groove and layer depth for the cases discussed above. The effective dielectric constant is also plotted.

CONCLUSION

Two types of modified CPW have been studied. The investigation shows that ohmic loss can be reduced by a factor of four and dielectric loss reduced by a factor of two. CPW is just one of a class of guides with similar loss mechanisms. The methods outlined in this work should also be useful with coplanar strips, slotline, and finline with narrow slots. Current also concentrates to some extent at the edges of a microstrip conductor. Hence it may be possible to reduce microstrip losses by a technique similar to that proposed here.

ACKNOWLEDGEMENTS

This research was sponsored by National Science Foundation Grant ECS-8116018. D. F. Williams is supported by an ARO Graduate Fellowship under grant DAAG 29-83-G-0014.

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