calculations according to [2] and [4] grows very rapidly and the time necessary for the calculation of the line parameters becomes considerably longer, our calculation does not become more complicated, because it uses the same relations as given above.

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Analysis of a New Configuration of Coplanar Stripline

J. S. McLean and Tatsuo Itoh

***Abstract*—A new configuration of coplanar stripline is presented and analyzed. This configuration is derived by augmenting coplanar stripline with electrically wide lateral ground planes on either side of the balanced pair of signal lines. The ground planes should reduce line-to-line coupling in complex circuits and eliminate the TE_0 parasitic dielectric slab waveguide mode. Also, the spacing from signal lines to ground planes may be adjusted to change the characteristic impedance. Spectral domain analysis is used to calculate the dispersion characteristics of this transmission line. Furthermore, analytical expressions for quasi-static values of the propagation constant and characteristic impedance of the line are presented. This configuration of CPS should be useful for balanced high impedance lines in MMIC and high speed digital circuits.**

Introduction

Coplanar stripline (CPS), like coplanar waveguide (CPW), offers flexibility in the design of complex planar microwave/millimeterwave circuitry in that series and shunt connections can be made easily. In addition, CPS is useful in fabricating lines with high characteristic impedances as it is easier to realize a high impedance with CPS than CPW [1]. Furthermore, it is a balanced transmission line which is useful for balanced circuits such as mixers and with differential drivers such as those used in some high-speed digital applications. The main drawback to CPS is that, due to the lack of the shielding which is inherent in CPW, stray coupling to other lines can occur. Furthermore, in conventional CPS, the lack of a ground plane allows the existence of two parasitic dielectric slab waveguide modes, the TM_0 and the TE_0, which have no cutoff frequency [2]. The TE_0 mode couples strongly to the fundamental CPS mode at discontinuities (but not on uniform CPS line) causing losses and extraneous coupling [3]. This is because the electric fields of the TE_0 slab mode and the fundamental mode of CPS are both parallel to the dielectric interface. In this short paper, we examine the dispersion characteristics of a new configuration of coplanar stripline which eliminates some of the disadvantages of conventional CPS. In this configuration, the stripline is bounded on either side with semi-infinite ground planes as shown in Fig. 1. Thus, this CPS configuration is similar to CPW with laterally infinite ground planes. In practice, of course, the ground planes are of finite width. However, the analysis should be a very good approximation to the case in which the ground planes are electrically wide. One advantage provided by the ground planes is that line-to-line coupling, which is considered to be a drawback to conventional CPS, is reduced. Also, the TE_0 dielectric slab waveguide mode is eliminated by the ground planes, thus reducing losses at discontinuities. A TM_0 surface wave mode which has no cutoff frequency can still exist, but this is not a serious problem since the TM_0 fields are predominantly prependicular to those of the CPS mode. Finally, the spacing between the signal lines and the ground planes may be adjusted in order to modify the characteristic impedance of the line. The dispersion characteristics of this new CPS configuration have been calculated using the spectral domain technique. These dispersion characteristics are compared with those of conventional CPS which were also calculated using spectral domain analysis. Finally, analytical expressions for approximate quasi-static values of the propagation constant and characteristic impedance of this configuration of CPS are given. These expressions were derived from the conformal mapping analysis used by Ghione [4] to analyze finite ground plane coplanar waveguide.

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Numerical Method

The spectral domain analysis of the modified configuration of coplanar stripline shown in Fig. 1 is similar to that used by Itoh [5] to analyze coplanar waveguide with semi-infinite ground planes. The CPW analyzed in [5] can be visualized as two coupled slots in an odd mode whereas the modified CPS we consider here can be visualized as three coupled slots in an even mode. To briefly summarize, the electric field integral equation is transformed into the Fourier transform domain to yield two coupled algebraic equations relating the Fourier transforms of the components of the tangential electric field to those of the electric current density at the dielectric interface. That is:

$$\tilde{Y}_{xx}(\alpha, \beta)\tilde{E}_x(\alpha, \beta) + \tilde{Y}_{xz}(\alpha, \beta)\tilde{E}_z(\alpha, \beta) = \tilde{J}_x(\alpha, \beta) \quad (1)$$

$$\tilde{Y}_{zx}(\alpha, \beta)\tilde{E}_x(\alpha, \beta) + \tilde{Y}_{zz}(\alpha, \beta)\tilde{E}_z(\alpha, \beta) = \tilde{J}_z(\alpha, \beta) \quad (2)$$

where $\tilde{Y}_{xx}(\alpha, \beta) \cdots \tilde{Y}_{zz}(\alpha, \beta)$ are components of the spectral domain Green's function, $\tilde{E}_z(\alpha, \beta)$ and $\tilde{E}_x(\alpha, \beta)$ are the Fourier trans-

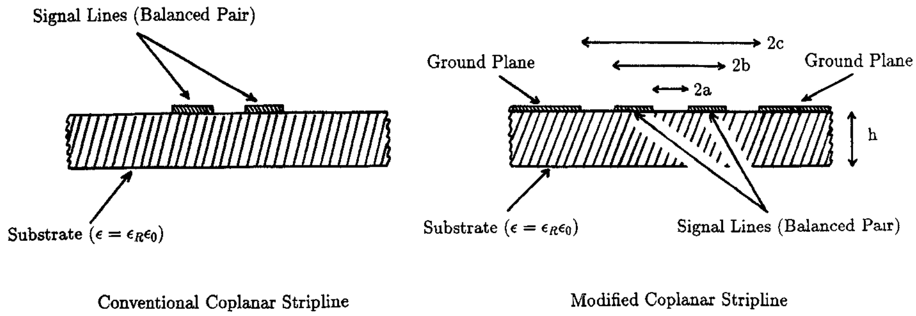

Fig. 1. Coplanar stripline configurations.

forms of the components of the tangential electric field at the interface, and $\tilde{J}_z(\alpha, \beta)$ and $\tilde{J}_x(\alpha, \beta)$ are the Fourier transforms of the components of the electric current density at the interface. In order to determine the propagation constant, the tangential electric field at the interface (which is the electric field in the slots) is expanded in terms of known functions as follows:

$$E_x(x, z) = \sum_{m=1}^{M} a_m E_{xm}(x) e^{-j\beta_z z} \tag{3}$$

$$E_z(x, z) = \sum_{m=1}^{M} b_m E_{zm}(x) e^{-j\beta_z z} \tag{4}$$

where $a_1 \cdots a_M$ and $b_1 \cdots b_M$ are unknown constants, $E_{x1}(x) \cdots E_{xM}(x)$ and $E_{z1}(x) \cdots E_{zM}(x)$ are known basis functions derived from Maxwellian functions [5], and β_z is the unknown propagation constant. The Fourier transforms of the expressions for the electric fields are substituted into (1) and (2) and the resulting equations are solved using Galerkin's method to determine β_z as was done in [5].

Analytical Expressions for Quasi-static Transmission Line Parameters

Analytical expressions for the quasi-static values of the propagation constant and the characteristic impedance may be determined by noting that the complementary line is copolanar waveguide with finite extent ground planes as shown in Fig. 2. This formulation has been analyzed using a conformal mapping technique [4]. Following the discussion presented by [7], we may assume that the propagation constant is the same for the complementary lines. Therefore, the quasi-static effective dielectric constant of the modified CPS structure is the same as that of the finite ground plane CPW structure and is given by Eqn. 17a of Ghione's analysis [4]:

$$\epsilon_{eff} = 1 + \left(\frac{\epsilon_R - 1}{2}\right) \frac{K(k_1)\, K(k')}{K(k_1')\, K(k)}, \tag{5}$$

where K denotes the complete elliptic integral of the first kind and

$$k = \frac{a}{b} \sqrt{\frac{1 - b^2/c^2}{1 - a^2/c^2}}, \tag{6}$$

$$k_1 = \frac{\sinh(\pi a/2h)}{\sinh(\pi b/2h)} \sqrt{\frac{1 - \sinh^2(\pi b/2h)/\sinh^2(\pi c/2h)}{1 - \sinh^2(\pi a/2h)/\sinh^2(\pi c/2h)}}, \tag{7}$$

$$k' = \sqrt{1 - k^2}, \tag{8}$$

and

$$k_1' = \sqrt{1 - k_1^2}. \tag{9}$$

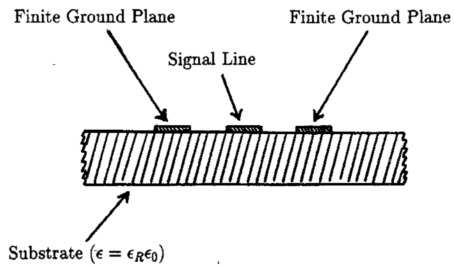

Fig. 2. Finite ground plane CPW.

The characteristic impedance is given by

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}}} \frac{K(k)}{K(k')}. \tag{10}$$

These expressions are approximate but should be useful for rapid estimates of the transmission line parameters.

Numerical Results and Discussion

To facilitate the discussion, we define the slow-wave factor (SWF) of a mode as the ratio of the phase velocity of the mode to that of plane wave propagation in free space. In Fig. 3, the slow-wave factor for the fundamental mode of a representative conventional CPS line on a 25 mil alumina ($\epsilon_R = 9.9$) substrate is plotted versus frequency. Also, in Fig. 3, the slow wave factors for a modified CPS structure with slot and conductor widths identical to those of the line mentioned above and three different outer slot widths are plotted versus frequency. The geometrical parameters of the CPS structures are given in Table I. It can be seen that the addition of the ground planes causes the CPS line to become less dispersive. Furthermore, decreasing the widths of the slots between the ground planes and the conductors decreases the dispersion of the CPS line.

From the quasi-static formulas we can calculate the approximate values of the propagation constant of CPS line. Although these values are approximate, they are reasonably accurate at low frequencies, as can be seen in Table II where the quasi-static approximations of the CPS slow-wave factors are compared to those calculated by spectral domain analysis for the structures given in Table I. Finally, the quasi-static formula for characteristic impedance has been used to calculate the variation of the characteristic impedance of modified CPS with changes in the outer slot width. In Fig. 4, the characteristic impedance of modified CPS with an inner slot width of 25 mil (.635 mm), substrate thickness of 25 mil, and substrate dielectric constant of 9.9 is plotted versus the outer slot width. As can be seen, as the outer slots are made very wide, the characteristic impedance approaches that of conventional CPS line. If the outer slot width approaches infinity, the expressions for the

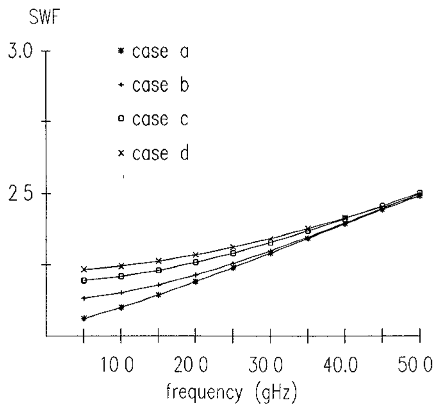

Fig. 3. Slow-wave factors versus frequency for modified CPS with 3 different outer slot widths and conventional CPS (substrate: $\epsilon_R = 9.9$, thickness: 25 mil).

TABLE I
CPS DIMENSIONS

	Case a	Case b	Case c	Case d
Inner slot width (mm)	.635	.635	.635	.635
Conductor width (mm)	.635	.635	.635	.635
Outer slot width (mm)	∞	1.27	.635	.3125

TABLE II
COMPARISON OF SLOW WAVE FACTORS CALCULATED BY QUASI-STATIC AND FULL WAVE ANALYSES

	Case b	Case c	Case d
Quasi-static value	2.12	2.16	2.20
Fullwave Analysis (5 GHz)	2.13	2.19	2.23

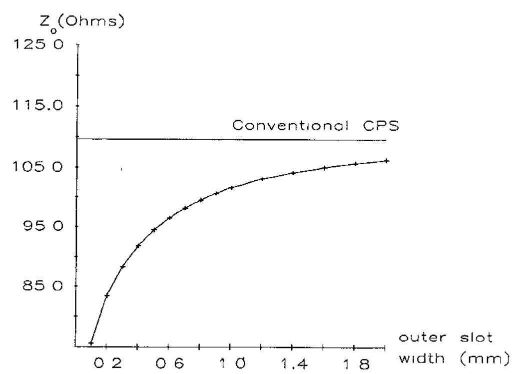

Fig. 4. Variation with outer slot width of the characteristic impedance of modified CPS. (Inner slot width: .635 mm, substrate thickness: .635 mm, ϵ_R: 9.9)

quasi-static values of the propagation constant and characteristic impedance reduce to those given for conventional CPS [7]. While it is not completely consistent, it may be more accurate to replace ϵ_{eff} in the quasi-static expression for characteristic impedance with the value of ϵ_{eff} calculated using the spectral domain approach as was done in [8].

CONCLUSION

A new configuration of coplanar stripline has been proposed and analyzed using both quasi-static and fullwave analysis. The modified configuration offers several advantages over conventional CPS. First, line to line coupling is reduced because of the isolation provided by the ground planes. Second, the parasitic TE_0 dielectric slab waveguide mode, which plagues conventional CPS, is eliminated. Finally, flexibility in obtaining lower characteristic impedances is added by the possibility of adjusting the outer slot width. This configuration of CPS should be useful in the realization of balanced lines with high isolation.

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A Dispersive Boundary Condition for Microstrip Component Analysis Using The FD-TD Method

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***Abstract*—A dispersive absorbing boundary condition (DBC) is presented, which allows the dispersion characteristics of waves to be used as a criterion for designing absorbing boundary conditions. Its absorbing quality is superior to that of the presently used Mur's first order boundary condition for microstrip component analysis, and, as well, its implementation is much simpler when compared to that of the "super boundary condition" treatment. Due to the significant performance improvement of the new boundary condition, the memory requirement can be reduced greatly when applying this boundary condition to microstrip component analysis.**

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