Fullwave Analysis of the Radiative Properties of Short-Circuit Discontinuities in Modified Coplanar Stripline

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Abstract

Spectral domain analysis is used to determine for the first time the radiation loss of short-circuit discontinuities in modified coplanar stripline. These results are compared with those for short-circuit discontinuities in coplanar waveguide and it is shown that, in the two cases analyzed, the radiation loss of the modified coplanar stripline short circuit is lower than that of the coplanar waveguide short circuit. The physical basis for this behavior is discussed.

Introduction

A new configuration for coplanar stripline (CPS) has been recently proposed and its dispersion and impedance characteristics have been analyzed[1]. In this configuration, a balanced pair of signal lines is bounded on both sides by semi-infinite ground planes as shown in Figure 1. This configuration of coplanar stripline combines the advantages of coplanar stripline and coplanar waveguide (CPW). It is a balanced line like CPS but it is shielded by lateral ground planes like CPW. These ground planes help reduce line-to-line coupling and reduce radiation loss into dielectric slab waveguide modes at discontinuities. 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 modified CPS, the ground planes eliminate the TE_0 dielectric slab waveguide mode and therefore reduce radiation losses at discontinuities.

Thus modified CPS is similar to CPW in that it has inherent shielding and that it suffers from only one parasitic surface wave mode which has no cutoff frequency. However, in addition to these advantages and the ones given in ref. [1], it is believed that this configuration of CPS will radiate even less at discontinuities than CPW. The reason for this will be given shortly.

In this paper, we have used the spectral domain technique to analyze short-circuit discontinuities in modifed CPS. From the spectral domain analysis the radiation loss at the discontinuity can be calculated. This radiation loss is compared to that of a coplanar waveguide short-circuit discontinuity and it is shown that in the case examined here, the modified CPS short circuit radiates less than does the CPW short circuit.

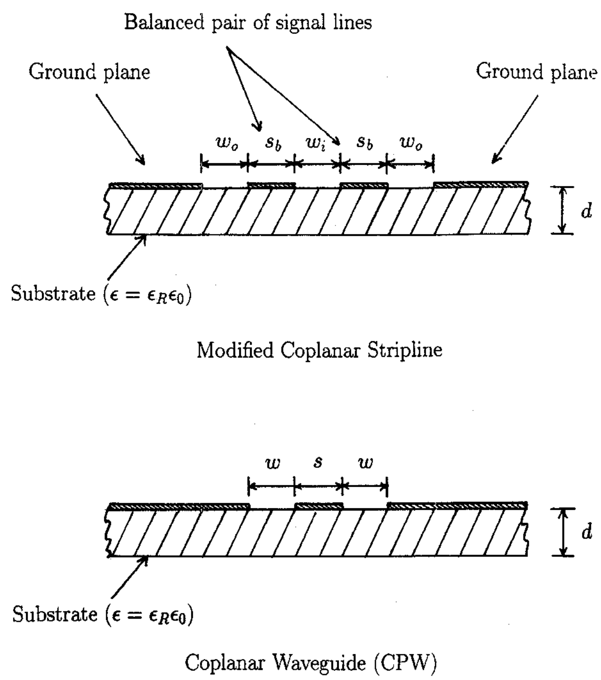

Figure 1: Modified Coplanar Stripline and Coplanar Waveguide

Numerical Method

The spectral domain analysis of the modified configuration of coplanar stripline shown in Figure 1 is similar to that used by Jackson [4] to analyze coplanar waveguide short-circuit discontinuities. 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. The details of this procedure can be found in ref. [5]. These coupled algebraic equations are then used with two different moment method formulations performed in the spectral domain. First, an eigenvalue formulation of the equations is performed to determine the characteristics of the fundamental mode of propagation on the line [5]. This information is used to derive a travelling wave source function which is used in the second part of the procedure in which a deterministic formulation of the equations is performed to determine the complex reflection coefficient of the discontinuity [4].

Numerical Results and Discussion

A fullwave, spectral domain analysis of CPW short-circuit discontinuities in which the radiation loss of such discontinuities was calculated has previously been presented [4]. The spectral domain analysis given here has been used to analyze one of the CPW short-circuit discontinuities presented in reference [4] and a short-circuit discontinuity in modified CPS with a similar geometry. The inner slot and each of the outer pair of slots in the modified CPS has the same width as does each of the slots in the CPW line. Also, each of the pair of signal conductors in the modified CPS line has the same width as the inner conductor of the CPW line. A substrate dielectric constant ϵ_R of 12.8 was used. The results of the calculations for the CPW short here are in good agreement with those given in ref. [4], as far as those can be read from the graph given in ref. [4], and therefore should verify the analysis. In Figure 2, the magnitude of the reflection coefficient and the power loss for both the CPW and the modified CPS short-circuit discontinuities are plotted as functions of substrate electrical thickness. It can be seen that for these geometries (the geometrical parameters of the lines are given in Figure 2), the modified CPS short-circuit discontinuity exhibits lower radiation loss than does the CPW short-circuit discontinuity. A similar comparison was made between a CPW and a modified CPS short circuit discontinuity on an alumina-like substrate with $\epsilon_R = 9.9$ and a thickness of .635 mm or 25 mils. The geometries of the CPW and modified CPS were related as in the above comparison in that they had similar slot and conductor widths (the geometrical parameters of the lines are given in Figure 3). In Figure 3, the magnitude of the reflection coefficient and the power loss for these discontinuities are plotted versus frequency. As in the first case, the radiation loss of the modified CPS short is lower than that of the CPW short.

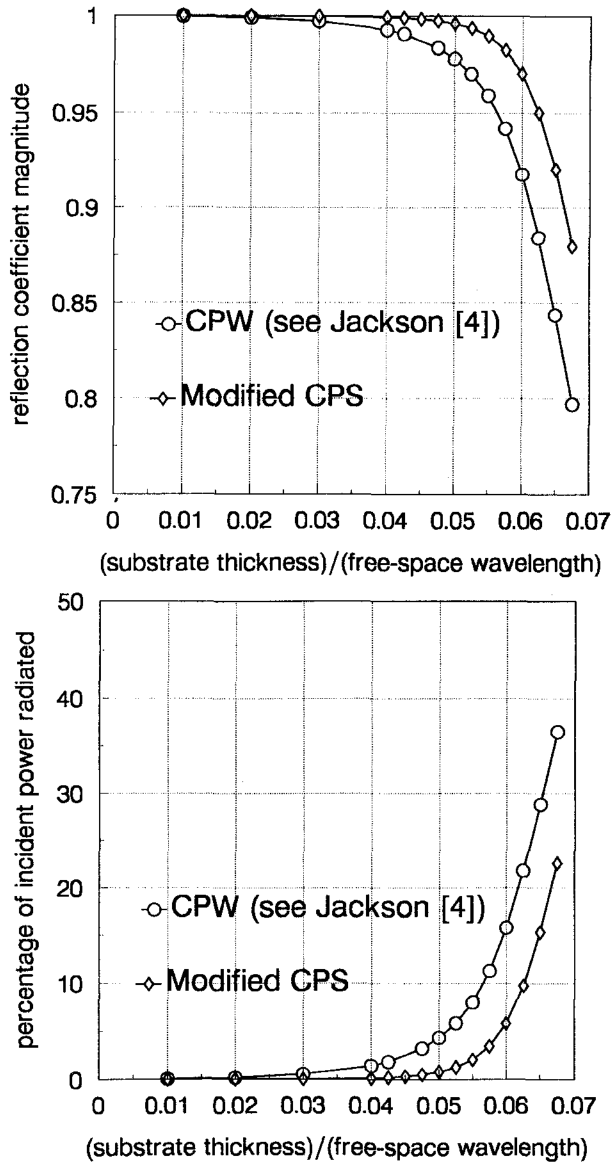

Figure 2: Comparison of the radiative characteristics of CPW and modified CPS short-circuit discontinuities: substrate dielectric constant: $\epsilon_R = 12.8$; CPW dimensions: $s/d = 1.4$, $w/d = 1$; modified CPS dimensions: $s_b/d = 1.4$, $w_i/d = 1$, $w_o/d = 1$.

While the differing geometries of the lines makes direct comparison difficult, we believe that the cases presented here are reasonable choices for comparison. It may perhaps be useful to compare the characteristic

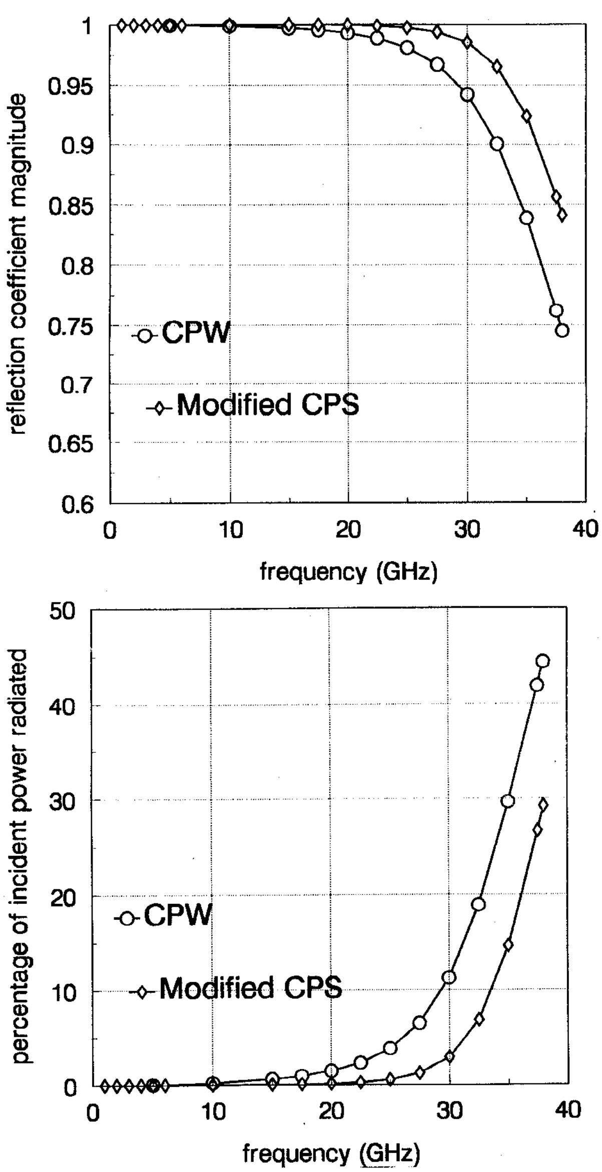

Figure 3: Comparison of the radiative characteristics of CPW and modified CPS short-circuit discontinuities: substrate dielectric constant: $\epsilon_R = 9.9$; CPW dimensions: $s = w = d = .635$ mm; modified CPS dimensions: $s_b = w_i = w_o = d = .635$ mm.

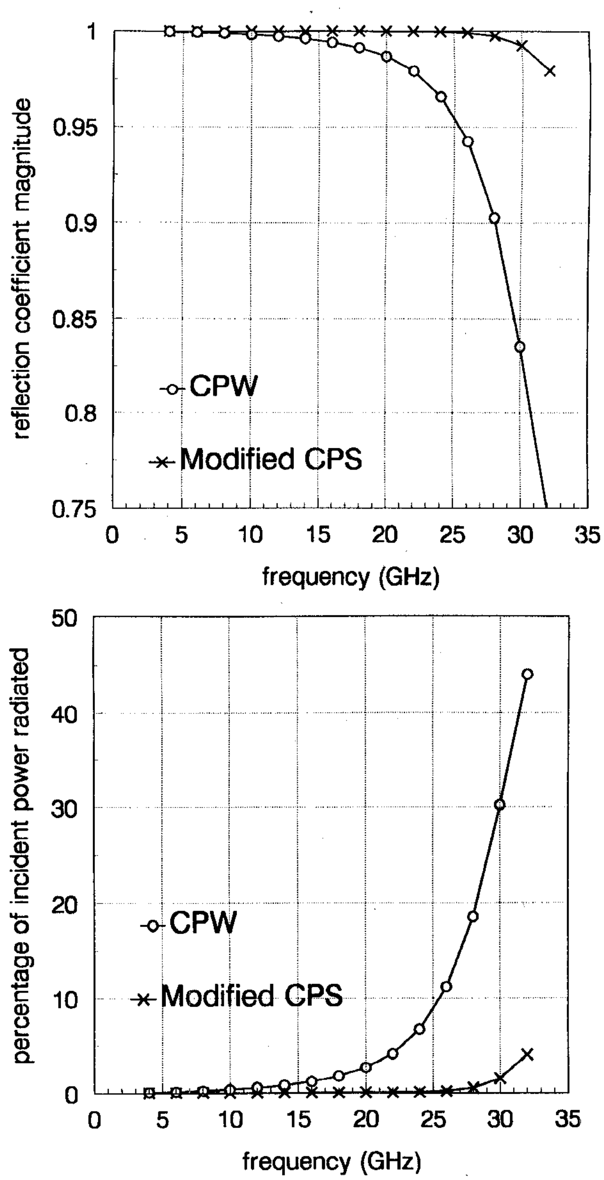

Figure 4: Comparison of the radiative characteristics of CPW and modified CPS short-circuit discontinuities: substrate dielectric constant: $\epsilon_R = 12.8$; substrate thickness: $d = .635$mm; CPW dimensions: $s/d = 2$, $w/d = 1$; modified CPS dimensions: $s_b/d = 1.$, $w_i/d = 1/3$, $w_o/d = 1/3$.

impedances of the CPW and modified CPS lines in the above discussion. In the first comparison ($\epsilon_R = 12.8$ substrate), the CPW line has a characteristic impedance of about 60 ohms and the modified CPS line has a characteristic impedance of about 80 ohms as calculated by quasi-static methods [1], [6] (full-wave spectral domain analysis for characteristic impedance is possible but was not used here). In the second comparison ($\epsilon_R = 9.9$), the CPW line has a characteristic impedance of about 74 ohms and the modified CPS line has a characteristic impedance of about 97 ohms.

It might be more useful to compare CPW and modified CPS short circuit discontinuities in lines of similar characteristic impedances. Unfortunately, there is a multiplicity of modified CPS and CPW structures which have the same characteristic impedance. On a given substrate, the characteristic impedance of modified CPS line can be lowered by decreasing the width of the inner slot, by decreasing the width of the outer slots [1], or by increasing the signal line widths. Likewise, on a given substrate, the characteristic impedance of CPW can be reduced by either decreasing the slot width or by increasing the conductor width. Decreasing the outer slot widths in a modified CPS line tends to make the modified CPS line appear more like a slot line and therefore more dispersive. Reducing the inner slot width in a modified CPS line increases the likelihood that a CPW-like parasitic mode will be present. Therefore, it would appear that a reasonable modified CPS geometry would use inner and outer slots of nearly equal widths. Furthermore, it seems that, for both CPW and modified CPS, the radiation loss at a short-circuit discontinuity increases with the overall line width. Therefore, a CPW line and a modified CPS line on the same substrate with similar characteristic impedances and overall widths were compared. The modified CPS line has similar inner and outer slot widths. A substrate dielectric constant of $\epsilon_R = 12.8$ was used. The substrate thickness was .635 mm or 25 mils. The characteristic impedance of both the CPW and the modified CPS line was about 57 ohms. As can be seen, the radiation loss of the modifed CPS line was much lower than that of the CPW line in this case.

In order to understand the low radiation loss of the modified CPS short-circuit discontinuity, it is enlightening to compare the configuration of modifed CPS to that of two other forms of planar transmission line. In Figure 4, three forms of planar transmission line which are derived from slots are shown. The first is a slot line which simply consists of a single slot in a ground plane. The second is CPW which can be thought of as two coupled

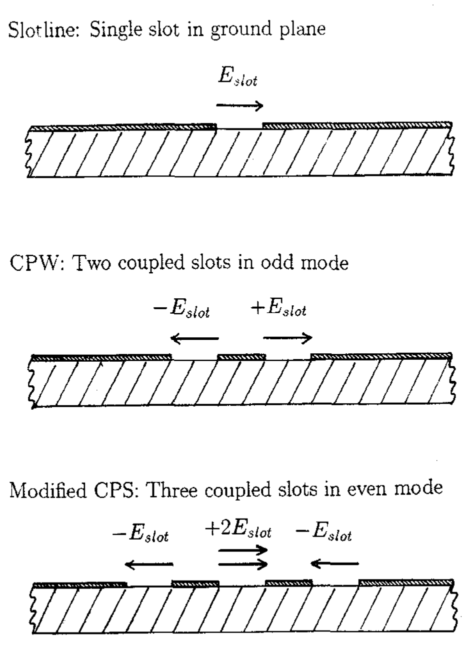

Figure 5: Comparison of modified CPS with other coplanar transmission lines

slots excited in the odd mode. This odd mode configuration gives a cancellation of the slot electric fields in the farfield region. Therefore, the short-circuit discontinuity in CPW does not radiate as much as that of slot line. It should be noted that two shorted slots excited in an even mode radiate more than a short-circuited slotline [2]. The third configuration shown is modified CPS. This configuration can be thought of as three coupled slots excited in a even mode. Therefore, an even more complete cancellation of the slot electric fields occurs in the farfield region. Because of this field cancellation, the modified CPS short-circuit discontinuity radiates the least of the three configurations given.

While CPW discontinuities admittedly already exhibit lower radiation loss than many other planar transmission lines, it is felt that modified CPS offers significant improvement in this area. When this advantage is considered along with the others given in ref. [1] such as reduced line-to-line coupling, modified CPS appears to be a very promising planar transmission line configuration.

Acknowledgements

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