LEAKAGE EFFECTS IN BROADSIDE-COUPLED MICROSTRIP

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Abstract: Broadside-coupled microstrip with and without conducting side walls are studied using a full-wave spectral-domain analysis. Special attention is directed towards possible leakage to the parallel plate mode and its potential effects in practical integrated circuits. It is asserted that for appropriate geometrical parameters, broadside-coupled microstrip can be leaky at all frequencies. Instructive comparisons between the modes on broadside-coupled microstrip with and without side walls are made by means of dispersion curves.

I. INTRODUCTION

A leaky mode associated with a printed transmission line has electromagnetic fields which are not entirely confined to the strip region. Depending on the particular geometry, energy leakage can occur in the form of a surface wave [1]-[5], parallel plate mode [3],[6], and/or a space-wave [1],[2],[6]. Leaky-waves supported by printed transmission lines are of importance for several reasons. Leaked energy propagating throughout an integrated circuit results in undesirable and possibly catastrophic cross-talk. The leakage can cause a loss of energy from the strip region which for some cases may be far greater than that associated with conductor and dielectric loss [5],[6]. Of importance for analysis, such leakage and its associated cross-talk cannot be described using a conventional quasi-static treatment of the transmission line; rather, a full-wave analysis with special considerations for the non-spectral nature of leaky modes is essential. Once the leakage effect is properly understood, however, its undesirable effects may be minimized and it can also be used to advantage in the design of novel directional couplers (for example).

Previous work on leaky-waves associated with interconnects in high-speed integrated circuits and antenna feeds has focused on coplanar strips [1],[3],[5], coplanar waveguide [1],[3], conductor-backed slotline [3],[6], and microstrip [2],[4]. With the exception of conductor-backed slotline, the leakage associated with these structures occurs at high frequencies for practical geometrical parameters. However, there are more complex structures, such as broadside-coupled microstrip [7]-[10], for which leakage can occur at all frequencies. In broadside-coupled microstrip, as in conductor-backed slotline, the leakage is in the form of a parallel plate mode. Similar leakage to a parallel plate mode in a stripline configuration has been recognized [6] as a potential problem.

Broadside-coupled microstrip are commonly used as directional couplers in integrated circuits and have been analyzed extensively from both the quasi-TEM [7]-[9] and full-wave [10] points of view. The leakage effect associated with these structures, however, is reported here for the first time. In the analysis of leaky-waves on printed transmission lines, one must assume substrates of infinite. In previous analyses of broadside-coupled microstrip, however, the strips were assumed to exist inside a conducting box (rectangular waveguide) [7]-[10] and therefore the possible leakage effects went unnoticed. It is therefore of interest to compare the solutions found for an unbounded structure (transversely) with those found for a shielded structure. This comparison lends physical insight into the leaky-waves supported by broadside-coupled microstrip and also suggests a means of avoiding or suppressing them.

The spectral domain technique for the analysis of leaky modes on printed transmission lines has been discussed elsewhere [5],[6] and therefore it's discussion will be omitted here for brevity. Concentration will be placed on the new and practically important results. In Section II, results for broadside-coupled microstrip with and without side walls are presented and compared, with discussions of several important aspects. Important conclusions with an emphasis on the practical significance of the leakage effect are outlined in Section III.

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II. RESULTS

A. Unbounded Transversely

Recall that for an N conductor system, there are N-1 zero-cutoff-frequency modes [12]. The five modes supported by the six-conductor system in Fig. 1 are identified by two letters, which indicate the mode's symmetry in the vertical and horizontal directions (see Fig. 1). The first letter (E=electric wall or M=magnetic wall) identifies the symmetry about the horizontal dashed line in Fig. 1 while the second letter indicates the symmetry about the dashed vertical line. The modes with electric wall symmetry horizontally can be analyzed by dividing the original structure in two (about the horizontal dashed line). The new structure has four electrical conductors and can be viewed as shielded (on top and bottom) coplanar strips. There are therefore three modes with electric wall horizontal symmetry. By breaking the shielded coplanar strips in half (horizontally) with an electric wall along the vertical dashed line, two identical waveguides are obtained with semi-infinite transverse extent. Each consists of two electric conductors and hence there is only one mode with EE symmetry, which implies there are two modes with EM symmetry (denoted EM1 and EM2). Using similar considerations, it is readily deduced that the remaining two modes have ME and MM symmetry. The existence of two EM modes in the above transversely unbounded structure should be contrasted with shielded (by conducting side walls) broadside-coupled microstrip. In shielded broadside-coupled microstrip there are only four modes, one for each of the four symmetries

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discussed above [7]-[10]. The existence of an extra EM mode in the transversely unbounded structure will be important for the discussion to follow.

In Fig. 2 are shown dispersion curves for the five dominant (zero-cutoff-frequency) modes for the geometry in Fig. 1 with ϵ_r=10 . Note that the EM1 mode is leaky at all frequencies while all other zero-cutoff-frequency modes are non-leaky. The leakage rate for the EM1 mode is very high, with a peak value of loss in excess of 20 dB per wavelength.

In Fig. 3 are shown dispersion curves for the same structure considered in Fig. 2 except now the dielectric constant is 4. For this structure both the EM1 and EE modes are leaky at all frequencies. The other three zero-cutoff-frequencies modes (EM2, ME, and MM), as for the geometry studied in Fig. 2, are non-leaky for all values of w/λ_o studied. It is not clear at this point why the EE mode considered in Fig. 2 (ϵ_r=10) is non-leaky while the EE mode in Fig. 3 (ϵ_r=4) is leaky at all frequencies. However, the leakage rate of the EE mode in Fig. 3 is extremely low for small w/λ_o . Hence, for small w/λ_o , the EE mode in Fig. 3 is nearly a bound mode like its counterpart in Fig. 2. At larger w/λ_o , however, the leakage associated with the EE mode in Fig. 3 is appreciable. Further study is warranted on how geometrical and material properties effect the leakage characteristics of the modes.

It has been noted in the literature that numerical difficulties often occur when computing dispersion curves for leaky-waves on printed transmission lines [6]. This was the case for the EM1 mode in Fig. 3 for small w/λ_o . The actual computed data points are displayed in Fig. 3 for this mode in addition to a best-fit curve. Numerical difficulties were not found in the computations for larger values of w/λ_o for the EM1 mode in Fig. 3, nor for any other mode in Fig. 2 or 3.

It is interesting to note that the dispersion curves for the leaky-waves in Figs. 2 and 3 are very similar to those reported previously for leakage in conductor-backed slotline [3],[6]. As in conductor-backed slotline, the real part of the propagation constants for these leaky modes decrease in amplitude as the leakage rate increases. As will be discussed below, there are further similarities between leakage in broadside-coupled microstrip and leakage in conductor-backed slotline.

B. Bounded Transversely

Now consider the broadside-coupled microstrip structures studied in Section II.A bounded transversely by conducting side walls. The top and bottom conductors are now electrically connected by the side walls and effectively result in only one conductor. Hence, there are only 4 zero-cutoff-frequency modes of the new five-conductor geometry. The side walls were extended sufficiently far apart such that the low-frequency results (dispersion curves) were close to those computed for the open structures studied in Section II.A (the box width was 125w). For the shielded geometry with ϵ_r=10 , it was found that the zero-cutoff-frequency MM, ME, EM, and EE modes had dispersion curves nearly identical to those for the MM, ME, EM2, and EE modes, respectively, in the corresponding transversely unbounded structure (Fig. 2). The EM1 mode in the unbounded structure was found to have no corresponding zero-cutoff-frequency mode in the shielded structure. For the shielded geometry with ϵ_r=4 , it was found that the zero-cutoff-frequency MM, ME and EM modes had dispersion curves nearly identical to those for the MM, ME, and EM2 modes, respectively, in the corresponding unbounded structure (Fig. 3) for all w/λ_o . For small w/λ_o (low frequencies), the zero-cutoff-frequency EE mode in the shielded structure was found to have a dispersion curve nearly identical to that computed for the real part (β) of the propagation constant for the corresponding leaky EE mode in the transversely unbounded structure (Fig. 3). As for the geometry with ϵ_r=10 , the EM1 mode in the transversely unbounded geometry had no corresponding mode in the shielded structure. From these results, it can therefore be deduced that the EM1 mode requires the top and bottom conductors to be at different potentials (from the quasi-static point of view) and hence this mode is suppressed by the conducting side walls (which electrically connect the top and bottom conductors).

Of practical importance, the EM1 mode leaks at all frequencies for both structures studied in Section II.A. The results of this section indicate that if one excites the broadside-coupled microstrip in a symmetric fashion, such that the top and bottom conductors are at the same potential, the leaky EM1 mode will not be excited. Additionally, if one uses shorting screws (for example) to electrically connect the top and bottom conductors throughout a circuit, the dominant EM1 leaky mode should be largely suppressed. The EM1 mode for broadside-coupled microstrip has properties analogous to those found for the dominant zero-cutoff-frequency conductor-backed slotline mode [3],[6]. As for the EM1 mode, the dominant conductor-backed slotline mode is leaky at all frequencies. However, if the top and bottom conductors of the parallel plate region of conductor-backed slotline are electrically connected, the zero-cutoff-frequency conductor-backed slotline mode will not exist.

The EE mode in the shielded structure with ϵ_r=4 is now studied in greater detail since the corresponding EE mode in the open structure can be leaky. Dispersion curves for this mode are shown in Fig. 4. The real part of the propagation constant for the EE mode in the corresponding open structure is also shown in the plot for comparison. For small w/λ_o , the dispersion curve for the EE mode in the shielded structure agrees very closely with that for the real part of the propagation constant associated with the EE mode in the open structure. For larger values of w/λ_o , however, the dispersion curve of the shielded mode differs markedly from that of the leaky mode. One notes that at larger values of w/λ_o , the dispersion curves of the shielded EE mode interacts with the box modes in a mode-coupling-like fashion [13]. It has been demonstrated previously that such mode coupling behavior in a shielded structure can be related to leakage in an unbounded structure [14].

III. CONCLUSIONS

It has been demonstrated that for appropriate geometrical parameters, at least one zero-cutoff-frequency leaky-wave mode can exist in a four strip broadside-coupled microstrip geometry. However, by considering the broadside-coupled microstrip in a conducting box (rectangular waveguide), it was determined that this mode can be suppressed by two techniques. One should excite the structure symmetrically such that the top and bottom conductors are at (or approximately at) the same potential. Additionally, shorting screws (for example) can be used to electrically connect the top and bottom conductors.

It was found that a second mode on the four line broadside-coupled microstrip could also be leaky. The leakage rate, however, for the mode leaky at all frequencies was found to be negligibly small at small values of w/λ_o and can be safely neglected. One can conclude that with proper design, the low-frequency leakage effects discussed in this paper can be largely eliminated. At higher frequencies, however, leakage can be a significant problem, as has been found for several other printed interconnects [1]-[6].

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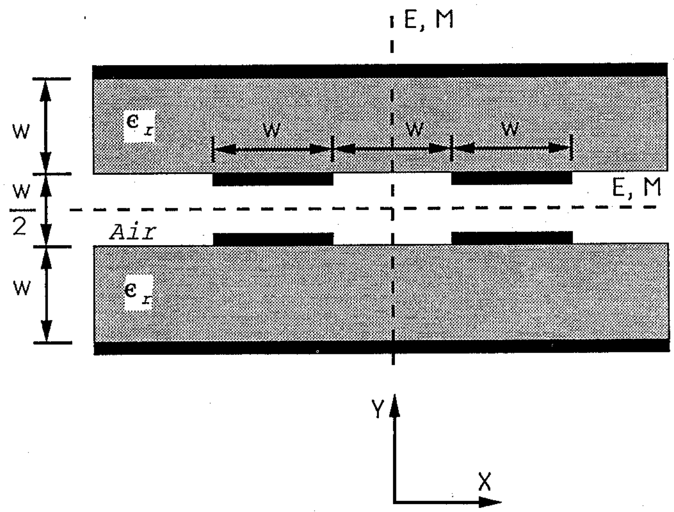
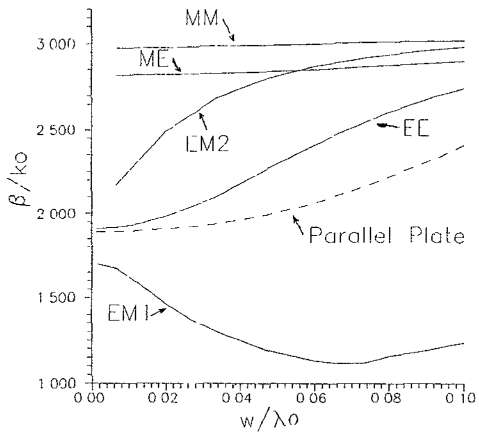


Figure 1. Broadside-coupled microstrip structure to be considered. The E, M notation defines the symmetry of the modes and is discussed in the text.



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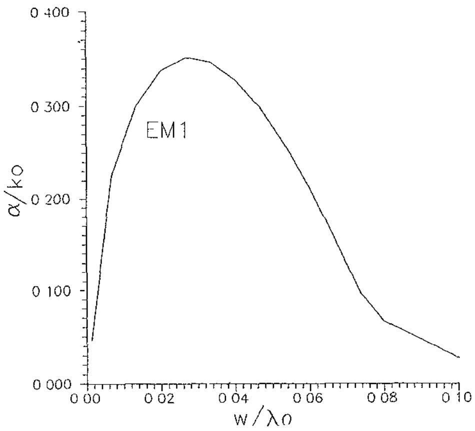
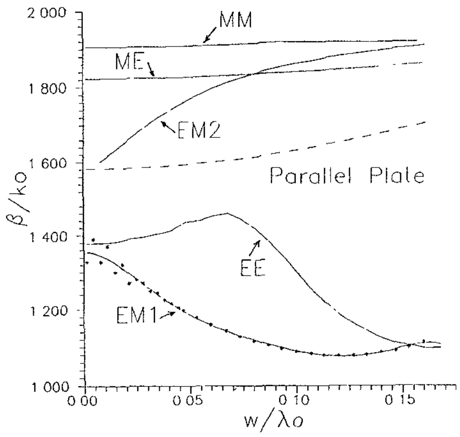


(b)

Figure 2. Dispersion curves for the five zero-cutoff-frequency modes supported in the structure in Fig. 1 with ϵ_r=10 . The dashed line is the dispersion curve for the parallel plate mode in this structure. Shown are (a) the real part , β , and (b) the imaginary part, α , of the propagation constant.



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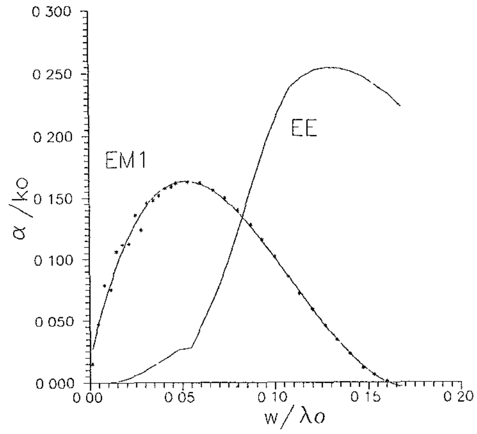

(b)

Figure 3. Dispersion curves as in Fig. 2 with ϵ_r=4 .

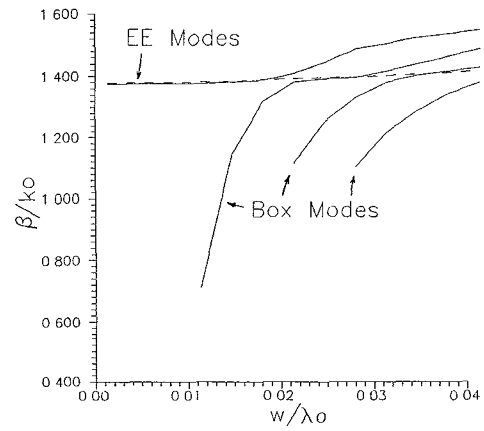

Figure 4. Comparison between the EE mode in Fig. 3 and the corresponding EE mode in a shielded structure with box width 125w. Also shown are box modes which interact with the EE mode in a mode-coupling-fashion. The dashed curve corresponds to the real part of the propagation constant for the EE mode in Fig. 3.