Leaky Waves on 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 and field plots. From the comparison, approaches for reducing the low-frequency leakage are proposed.**

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], [7], 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 [8]; 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 undersirable 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], [7], 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 [9]–[12], 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 [9]–[11] and full-wave [12] 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 lateral extent. In previous analyses of broadside-coupled microstrip, however, the strips were assumed to exist inside a conducting box (rectangular waveguide) [9]–[12] 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.

In Section II a brief review of the spectral domain technique is given for the analysis of printed strips on shielded and transversely unbounded substrates. A new efficient means of calculating the associated fields for transversely unbounded structures is also presented. In Section III, results for broadside-coupled microstrip with and without side walls are presented and compared, with discussions of several important aspects. Subtle relationships between the shielded and transversely unbounded solutions are addressed in Section IV. Important conclusions with an emphasis on the practical significance of the leakage effect are outlined in Section V.

II. Analysis

A. Spectral Domain Formulation

The spectral domain technique [13] has been described elsewhere for the analysis of leaky waves on printed transmission lines [5]–[7]. It is briefly reviewed here for completeness and because it will be needed in a new method presented subsequently for the efficient calculation of field distributions on transversely unbounded printed structures. The broadside-coupled microstrip of interest in this paper (see Fig. 1) will be analyzed in the spectral domain with an $e^{j\omega t}e^{-\gamma z}$ t- and z- dependence assumed and suppressed throughout. The l-directed electric field $E_l(x, y, \gamma)$ at any point (x, y) in the cross section can be expressed in terms of the spectral surface current and

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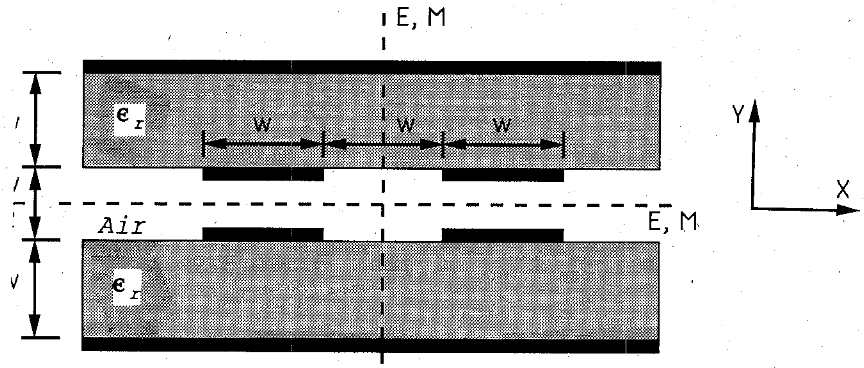


Fig. 1. Broadside-coupled microstrip structure to be considered. The E, M notation defines the symmetry of the modes and is discussed in the text.

Green's function [13]

$$E_l(x, y, \gamma) = \int_C \tilde{J}_k(k_x, y', \gamma)\, \tilde{G}_{lk}(k_x, y, \gamma; y')e^{-jk_x x}\, dk_x. \tag{1}$$

The spectral current $\tilde{J}_k(k_x, y', \gamma)$ is the Fourier transform (in x') of the k-directed surface current $J_k(x', y', \gamma)$ at (x', y'); and the spectral Green's function $\tilde{G}_{lk}(k_x, y, \gamma; y')$ is the Fourier transform (in x) of the l-directed electric field due to a k-directed $\delta(x')$ surface current source located at $y = y'$. For strips residing parallel to the x-z plane, the variables l, k can each represent either x or z. The contour of integration in (1) can be along the real k_x axis for fields bounded transversely (non-leaky). For leaky wave solutions, however, the fields grow exponentially for increasing transverse distance (x) from the strip and one must appropriately deform the integral path in (1) into the complex plane [5]–[7] to account for such non-spectral modes. How this deformation must be performed can be found by considering that $\tilde{G}_{lk}$ can be expressed as

$$\tilde{G}_{lk}(k_x, y, \gamma; y') = \frac{f_{lk}(k_x, y, \gamma, y')}{D_{\text{TE}}(k_x^2 - \gamma^2)D_{\text{TM}}(k_x^2 - \gamma^2)} \tag{2}$$

where $D_{\text{TE}}(\Gamma^2) = 0$ and $D_{\text{TM}}(\Gamma^2) = 0$ constitute transcendental equations for the TE and TM modes (to y), respectively, supported in the source-free layered dielectric structure. For structures bounded on top and bottom by conducting plates, as in Fig. 1, these are the transcendental equations for parallel plate modes; whereas for unbounded structures (on top and/or bottom), these are the transcendental equations for surface waves. For the remainder of this paper, the discussion will be restricted only to structures bounded on top and bottom by conducting plates. If the dielectric between the plates is layered (the interest of this paper), it can be shown that all poles of $\tilde{G}_{lk}(k_x, y, \gamma; y')$ are due to the zeroes of $D_{\text{TE}}(k_x^2 - \gamma^2)$ and $D_{\text{TM}}(k_x^2 - \gamma^2)$. The transcendental equations $D_{\text{TE}}(\Gamma^2) = 0$ and $D_{\text{TM}}(\Gamma^2) = 0$ have an infinite number of roots at Γ_{ri} representing parallel plate modes with propagation constant Γ_{ri}, and correspondingly $\tilde{G}_{lk}(k_x, y, \gamma; y')$ has an infinite number of poles at $k_{xi} = \pm \sqrt{\gamma^2 + \Gamma_{ri}^2}$. For a lossless non-leaky structure, $\gamma = j\beta$ and $\beta^2 > \Gamma_{ri}^2$ for all i [2]. Therefore, all poles exist exclusively on the imaginary k_x axis. By using residue calculus, the real axis integral in (1) can be expressed alternatively in terms of an infinite sum of residues (see Fig. 2): for $x > 0$

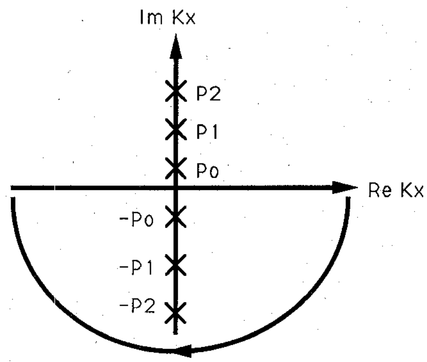


Fig. 2. Real axis integration can be expressed as an infinite number of residues which represent parallel plate modes. The poles exist exclusively on the imaginary axis for non-leaky modes. The path shown is for $x > 0$, the deformation would enclose the top half of the complex plane for $x < 0$.

$$E_l(x, y, \gamma) = 2\pi j \sum_i \text{Res}\,(k_{xi})e^{-|k_{xi}|x}, \tag{3}$$

where Res (k_{xi}) denotes the residue of $\tilde{J}_k(k_x, y', \gamma)\tilde{G}_{lk}(k_x, y, \gamma; y')$ at $k_x = k_{xi}$. From (3) the fields can be visualized as a superposition of an infinite number of evanescent parallel plate modes that satisfy the phase match condition at the strip. Note in Fig. 2 it has been assumed implicitly that no branch cuts exist in the complex k_x plane. This is always true for structures bounded on top and bottom by conducting plates [14].

Assume now that leakage occurs only to the dominant parallel plate mode with propagation constant Γ_{ro}, resulting in a complex $\gamma = \alpha + j\beta$ with $\beta < \Gamma_{ro}$ [2]. Due to phase match considerations, one expects the fields to grow exponentially in the $\pm x$ directions in the form of the parallel plate mode with propagation constant Γ_{ro}. The fields due to all other parallel plate modes must decay transversely under these conditions. It can easily be shown that under the assumption of a lossless dielectric and conduc-

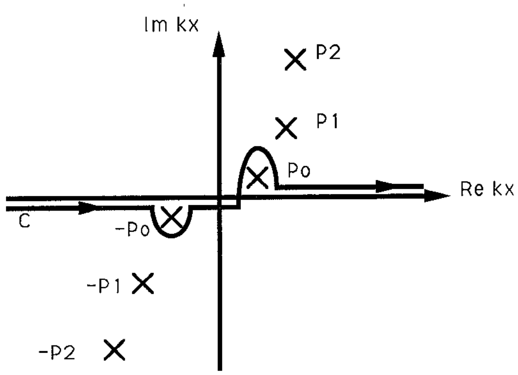


Fig. 3. Integral path required for leaky waves. The integral path is deformed around the poles which correspond to the parallel plate modes to which the broadside-coupled microstrip leak. In this figure, it is assumed that leakage is to a single parallel plate mode with corresponding poles at P_o and $-P_o$.

tor, all poles of $\tilde{G}_{lk}$ now exist in the first and third quadrants of the complex k_x plane. To satisfy the aforementioned conditions, and using similar residue calculus considerations discussed above, the integral path needs to be deformed as shown in Fig. 3. Note that for $x > 0$, if the integral along the path shown in Fig. 3 is evaluated by enclosing poles below the contour (in a manner similar to that in Fig. 2), the integral is represented alternatively as an infinite sum of decaying (transversely) parallel plate modes plus one exponentially increasing parallel plate mode. The one parallel plate mode which corresponds to exponential growth is the mode to which leakage occurs. The procedure can be extended to the case of leakage to more than one parallel plate mode, similarly.

B. Moment Method Solution

The unknown surface currents on the strips $J_k(x', y', \gamma)$ at different $y = y'$ planes are expanded in a known set of basis functions with unknown coefficients. The boundary condition that the tangential electric fields must vanish on a perfect electric conductor (conductor loss is neglected in this discussion) is enforced using a Galerkin testing procedure. This leads to a matrix equation from which the propagation constant γ and basis function coefficients can be found. Each component of the matrix involves a spectral integral which is performed along the real axis for non-leaky modes and along a deformed contour in the complex plane (around appropriate poles) for leaky solutions, as discussed.

C. Field Computations

The fields are computed (after finding γ and the surface currents) by evaluating spectral integrals of the form in [1]. As $|x|$ increases, this integral becomes increasingly oscillatory and a standard Gaussian-type numerical integration is therefore CPU intensive. This is particularly important for this study since the fields of leaky waves are not confined to the strip region and therefore fields must be computed relatively large distances from the strip region. The integral is evaluated in this work (for $x \neq 0$) by using the alternative representation as in (3) in terms of a superposition of residues corresponding to parallel plate modes. These residues can be evaluated in closed form. This approach for computing the fields is much more efficient than computing the contour integral in (1) since (as demonstrated subsequently) usually only a small number of residues (parallel plate modes) are required to obtain convergence. As will be discusssed below, field plots are important for mode identification and for gaining physical insight into the leakage mechanism.

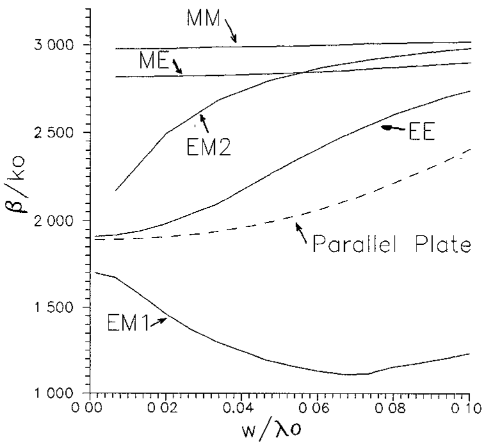
D. Shielded Structures

The preceding analysis assumed printed strips on dielectric layers of infinite width. As discussed previously, this paper will also involve the study of shielded (by a conducting box) broadside-coupled microstrip. For such structures the Fourier integral in (1) is inappropriate and one must use a Fourier series representation [15]. Accordingly, the technique discussed above for the field computations is of course not valid for a shielded structure. However, for such geometries the fields can be efficiently computed using the fast Fourier transform algorithm.

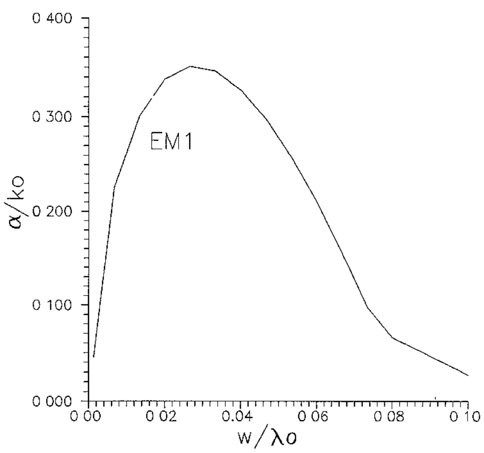
III. Results

A. Unbounded Transversely

Recall that for an N conductor system, there are $N - 1$ zero-cutoff-frequency modes [16], [17]. 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 horizontal electric wall symmetry can be analyzed by dividing the original structure in two identical halves by placing an electric conductor along the horizontal dashed line. The new equivalent structure that has four electrical conductors can be viewed as shielded (on top and bottom) coplanar strips. There are therefore three modes with horizontal electric wall symmetry. By further breaking the equivalent shielded coplanar strips by placing an electric wall along the vertical dashed line, two identical waveguides are obtained with semi-infinite transverse extent, each consisting of only two electric conductors. Accordingly, 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 discussed above [9]–[12]. The existence of an extra EM mode in the transversely unbounded structure will be important for the discussion to follow.

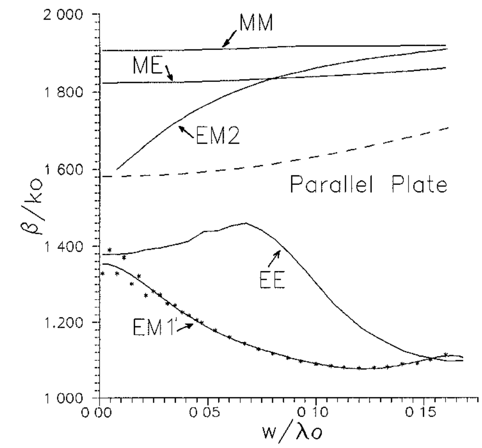


(a)

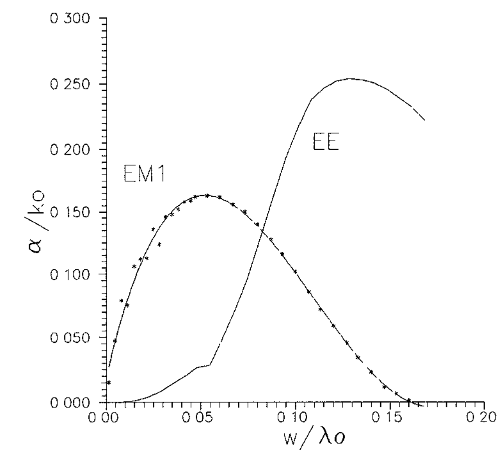


(b)

Fig. 4. Dispersion curves for the five zero-cutoff-frequency modes supported in the structure in Fig. 1 with $\epsilon_r = 10$. 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.



(a)



(b)

Fig. 5. Dispersion curves as in Fig. 4 with $\epsilon_r = 4$.

In Fig. 4 are shown dispersion curves for the five dominant (zero-cutoff-frequency) modes for the geometry in Fig. 1 with $\epsilon_r = 10$. 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. 5 are shown dispersion curves for the same structure, but now with $\epsilon_r = 4$. For this case, unlike that of Fig. 4, both the EM1 and EE modes are leaky at all frequencies. The other three zero-cutoff-frequencies modes (EM2, ME, and MM) of Fig. 5, like in Fig. 4, are non-leaky for all values of w/λ_o studied.

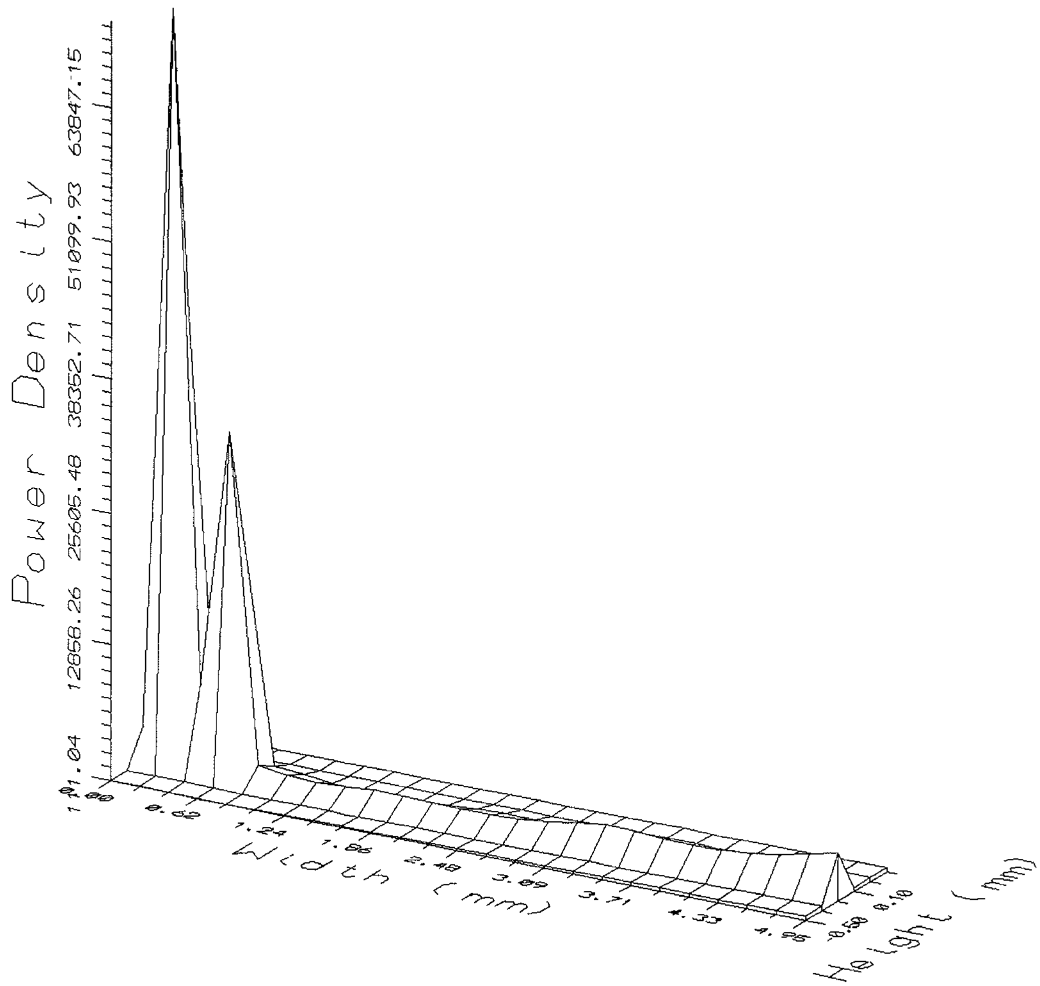
It is interesting to note that the EE mode considered in Fig. 4 ($\epsilon_r = 10$) is non-leaky, while the EE mode in Fig. 5 ($\epsilon_r = 4$) is leaky. One can readily derive a quasi-static expression for the parallel plate propagation constant, $\Gamma = k_o\sqrt{\epsilon_{ep}}$, in the partially filled structure of Fig. 1:

$$\epsilon_{ep} = \frac{\epsilon_r(1 + 2\Delta)}{\epsilon_r + 2\Delta}, \tag{4}$$

where Δ in general is the ratio of the dielectric thickness to air gap ($\Delta = 2$ in Fig. 1). As can be seen from (4), ϵ_{ep} increases from unity for $\epsilon_r = 1.0$ to a saturation value of $1 + 2\Delta$ for large ϵ_r. On the other hand, all other parameters remaining fixed, the EE mode effective dielectric constant, ϵ_{es}, usually increases without saturation for increasing ϵ_r. Hence a transition effect from the leaky ($\epsilon_{es} < \epsilon_{ep}$) to non-leaky ($\epsilon_{es} > \epsilon_{ep}$) state should generally be expected with increasing ϵ_r, which occurs in the present case between $\epsilon_r = 4$ and $\epsilon_r = 10$.

As seen from Fig. 5, the leakage rate of the EE mode for $\epsilon_r = 4$ is extremely low for small values of w/λ_o. This is because the parallel plate mode is excited by the left and right strips, and for EE symmetry the strip currents on a given layer are equal in magnitude but opposite in direction. Therefore for small w/λ_o the effects of the two strips nearly cancel, resulting in a very small leakage rate. For small w/λ_o, the EE mode in Fig. 5 is nearly a bound mode like its counterpart in Fig. 4. At larger w/λ_o, however, the leakage associated with the EE mode in Fig. 5 is appreciable.

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. 5 for small w/λ_o. The actual computed data points are displayed in Fig. 5 for



(a)

Fig. 6. Truncated power density plots for the right side of Fig. 1 with dielectric constant 10. (a) and (b) are for the leaky EM1 mode and (c) is for the non-leaky EM2 mode. In (a) the power density is shown for $0 < x < 5$ mm. To emphasize the exponential transverse growth in the leaky wave, (b) shows the power density over $1 < x < 5$ mm (away from strip edge singularities). Physical parameters: $w = 0.4$ mm and $f = 20$ GHz ($w/\lambda_o = 0.027$).

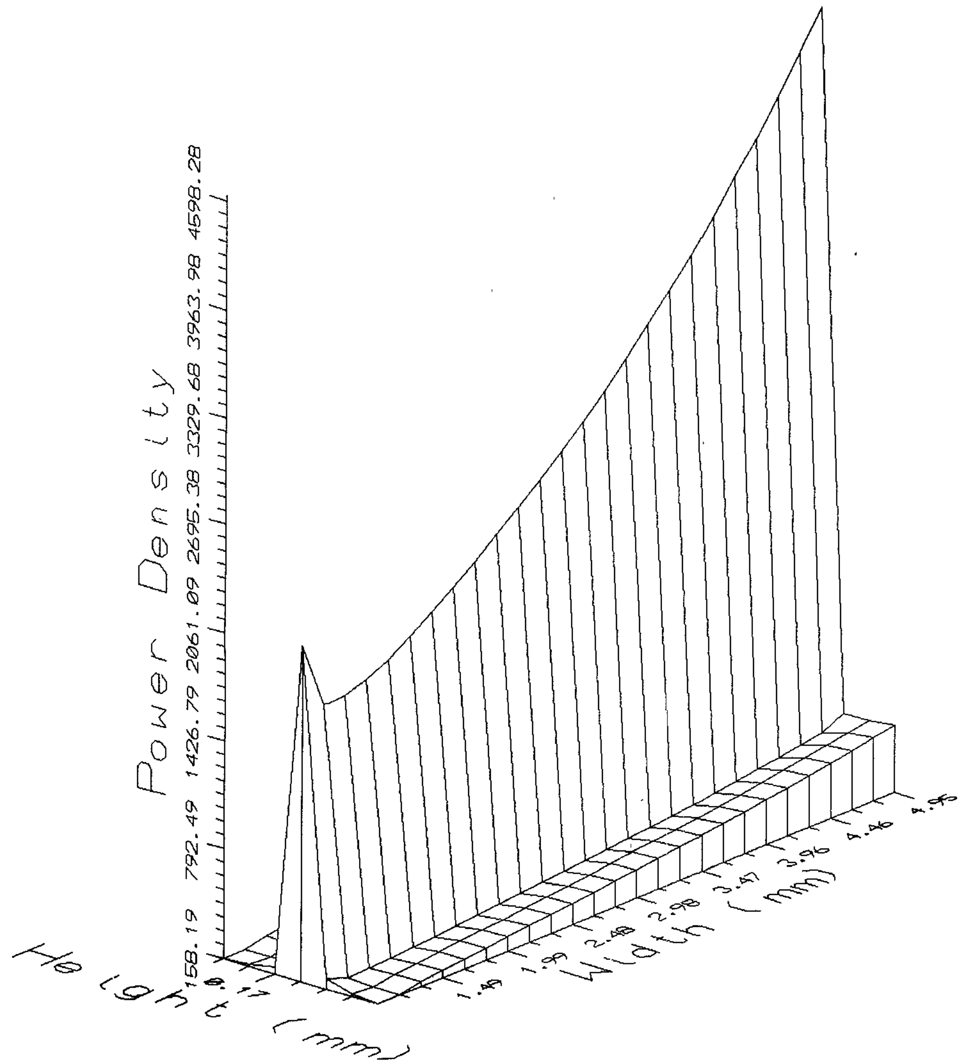
this mode in addition to a best-fit curve. Numerical difficulties were not found in the computations for larger values of w/λ_o for the EM1 mode in Fig. 5, nor for any other mode in Figs. 4 or 5.

It is interesting to note that the dispersion curves for the leaky waves in Figs. 4 and 5 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.

It is useful to consider field plots associated with the various modes investigated above. Plotted in Fig. 6 are power density plots ($\boldsymbol{E} \times \boldsymbol{H}^*$) over the cross section for the EM1 and EM2 modes considered in Fig. 4 (for $w/\lambda_o = 0.027$). Power density plots for the modes in Fig. 5 are similar to those shown in Fig. 6. Note, as expected, that the EM2 mode has power confined about the conducting strips (non-leaky). The field singularities at the strip edges are quite evident in these figures. Also as expected, the fields of the leaky EM1 mode grow as the transverse distance away from the strips (x) increases. The residue calculus method discussed above was used in the computations of these figures for all $x > 0.05\lambda_o$ (10 parallel plate modes were used to guarantee convergence).

B. Bounded Transversely

Now consider the broadside-coupled microstrip structures studied in Section III-A bounded transversely by conducting side walls. The two conductors on top and bottom are now electrically connected by the side walls, effectively resulting 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 III-A (the box width was 125 w). For the shielded geometry with $\epsilon_r = 10$, it was found that the zero-cutoff-frequency MM, ME, EM, and EE

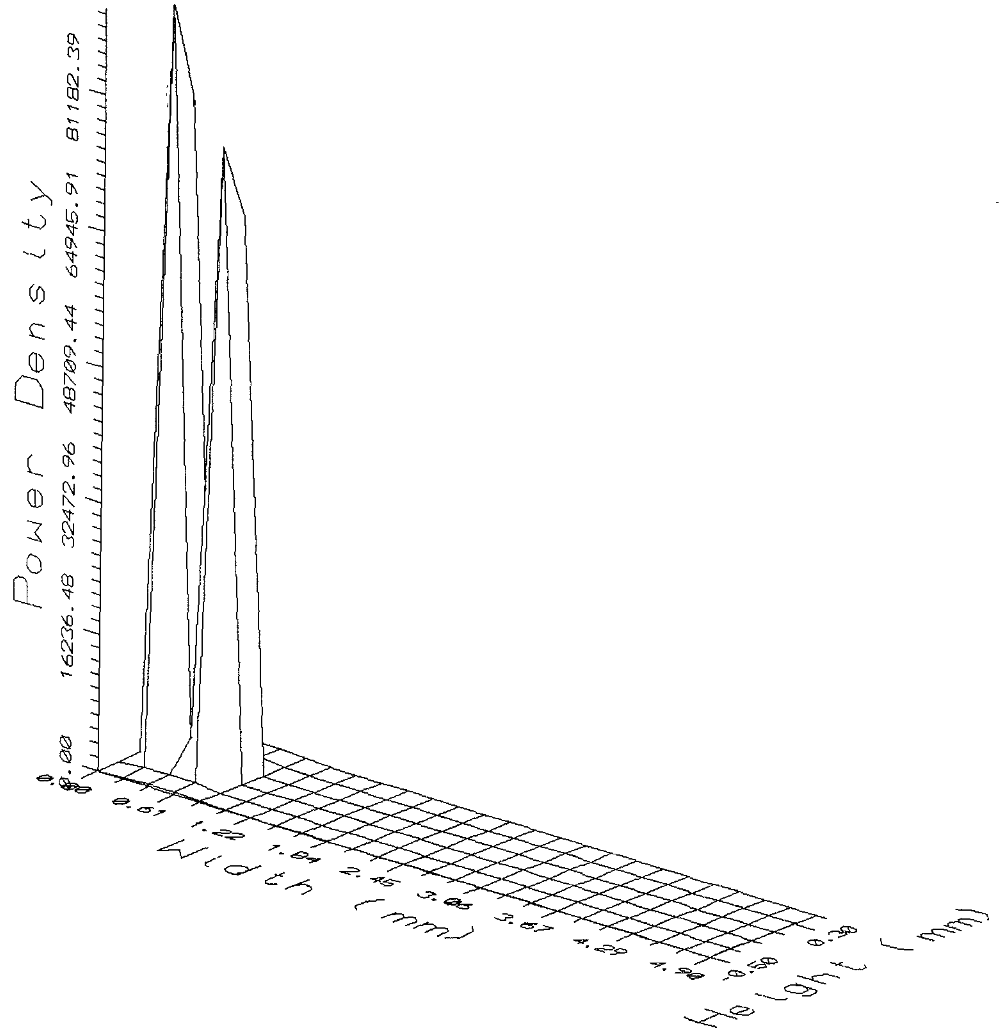


(b)

Fig. 6. (Continued).

modes had dispersion curves nearly identical to those for the MM, ME, EM2, and EE modes, respectively, in the corresponding transversely unbounded structure (Fig. 4). 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. 5) 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. 5). 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 III-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. Also, if the top and bottom conductors of the parallel plate region of conductor-backed slotline are electrically connected, like the EM1 mode, the zero-cutoff-frequency conductor-backed slotline mode will not exist.



(c)

Fig. 6. (Continued).

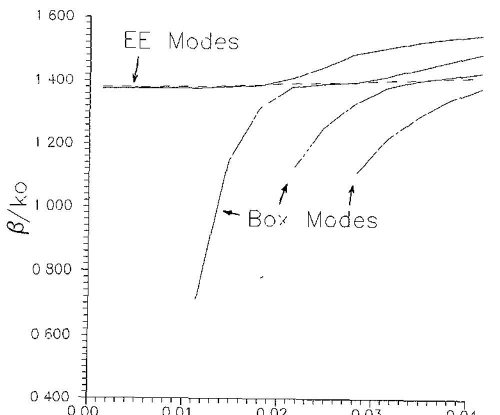


Fig. 7. Comparison between the EE mode in Fig. 5 and the corresponding EE mode in a shielded structure with box width 125 w. Also shown are box modes which interact with the EE mode in a mode-coupling-fashion. The dashed curve corresponds to the real part of the propagation constant for the EE mode in Fig. 5.

The EE mode in the shielded structure with $\epsilon_r = 4$ 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. 7. 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 [18]. It has been demonstrated previously that such mode coupling behavior in a shielded structure can be related to leakage in an unbounded structure [19].

IV. Discussion

The two examples considered above represent special cases of a general phenomenon that was found for all broadside-coupled microstrip studied. Consider a symmetric structure (unbounded transversely) as in Fig. 1 with dielectric substrates on top and bottom and air in between. If the air region had a thickness less than twice that of either dielectric (each with equal thickness), at least one zero-cutoff-frequency leaky wave mode should be expected for suitable dielectric constants [6]. Similarly, zero-cutoff-frequency leaky waves were also found for symmetric structures with dielectric in between and air above and below. For such structures, at least one leaky wave mode should be expected for suitable values of the dielectric constant if the dielectric layer is greater than twice that of either (symmetric) air region. However, as discussed previously, care must be taken in evaluating the significance of the zero-cutoff-frequency leaky waves. As described above, by considering the zero-cutoff-frequency modes in a shielded structure, one gains insight into the excitation dependence of the leaky waves; and with proper excitation, leakage can often be avoided.

During the course of this work, a direct relation between mode coupling and leakage was also found. Let $M1$ be a zero-cutoff-frequency mode in an open (transversely) broadside-coupled microstrip structure and let $M2$ be a zero-cutoff-frequency mode in the corresponding shielded structure. Assume further that $M1$ and $M2$ have low-frequency dispersion curves that are nearly identical. Under these conditions, it was found that at frequencies for which $M1$ was leaky, $M2$ always displayed mode-coupling-like behavior [18] with box modes. The frequencies at which strong coupling-like behavior occurred in the dispersion curve of $M2$ depended on the box width as well as on when $M1$ was leaky. By making the box width smaller, for example, one pushes the regions of strong mode coupling to higher frequencies by cutting off box modes. By making the box width large, the mode coupling occurred at frequencies very close to those at which leakage occurred in the corresponding open structure.

The leaky-wave-based (open transversely) and coupled-mode-based (shielded) analyses of broadside-coupled microstrip provide different but related descriptions of how electromagnetic energy leaks away from the vicinity (the strips) of a printed transmission line. Consider semi-infinitely long broadside-coupled microstrip excited at the point $z = 0$ and extending to $z = \infty$. In a practical structure of finite transverse extent, the leaked energy (in the form of a surface wave or parallel plate mode) will encounter the end of the substrate and reflect back to the strip from which it was excited. The energy in the vicinity of the strip will initially decay (after excitation at $z = 0$) as energy leaks into the substrate, and will increase when the energy comes back upon reflection at the substrate edge. Such a situation, in which the fields in the cross-section of the waveguide vary longitudinally by other than just a simple phase term, must be described by more than one mode. One must apply coupled mode theory to the analysis of such a problem and the modes considered in Fig. 7, which have dispersion curves displaying coupled-mode-like behavior [18], appear to be excellent candidates for such an analysis. Although the shielded structure models a practical circuit accurately, the attendant physical effects are comouflaged since all modes have real propagation constants. The open (transversely) structure, although unrealistic, gives a clear picture of the dominant physical effects using a single nonspectral mode (rather than coupled proper modes). The leaky wave description clearly describes the key physical effect of energy loss (in the form of surface waves or parallel plate modes) away from the strips, but is unable to describe practical effects due to realistic substrates of finite width.

V. Conclusion

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 this leaky mode is negligibly small for small values of w/λ_o and could 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]–[7].

This paper has studied the leakage effect in a broadside-coupled microstrip, choosing a restricted set of parameters in order to demonstrate the possible leakage phenomenon. Specific behavior for different parameter sets could also be interesting and warrants further study.

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