EXCITATION OF LEAKY MODES ON MULTILAYER STRIPLINE

Carlo Di Nallo[1], *Francisco Mesa*[2], *and David R. Jackson*[3]

[1] Department of Electronic Engineering, University of Rome "La Sapienza"
Via Eudossiana 18, 00184 Rome, Italy

[2] Microwave Group, Department of Electronics and Electromagnetism, University of Seville
Avd. Reina Mercedes s/n. 41012, Seville, Spain

[3] Applied Electromagnetics Laboratory, Department of Electrical and Computer Engineering
University of Houston, Houston, TX 77204-4793 USA

ABSTRACT

The practical issue of excitation of leaky modes on multilayered stripline structures is analyzed. The excitation is studied by calculating the current on the strip conductor due to a source. The GPOF method is used to investigate the physical meaning of the leaky modes.

I. INTRODUCTION

The existence of leaky modes on printed circuit lines is an important subject that has received considerable attention in recent [1]-[6]. A leaky mode on a printed transmission line radiates into the fundamental background mode of the structure, which is a parallel-plate mode in the case of a stripline (covered) structure, or a surface wave in the case of a microstrip (open) structure. The existence of a leaky mode on a printed line is important because such modes can have very undesirable consequences. The radiation into the background mode results in power loss on the line, and can lead to crosstalk between the line and adjacent circuit elements [1].

In previous studies to date, investigations of leaky modes on printed circuit lines have focused on the properties of the modes on *infinite* lines. In particular, the dispersion characteristics have been studied in detail for a variety of structures. However, none of these studies have investigated the *excitation* of the leaky modes by practical feeds. Studying the excitation of a leaky mode is important because it allows for a direct examination of the physical significance of the leaky mode. In fact, the physical significance of a leaky mode can be *defined* by the degree of correlation between the actual fields on the structure when excited by a feed and the fields of the leaky mode alone. In this presentation the excitation of leaky modes on multilayered stripline structures is investigated, and the physical significance of the leaky modes is studied. Two different multilayered stripline structures are used in the investigation: the two-layered stripline shown in Fig. 1a, and the air-gap stripline structure of Fig. 1b. The dispersion characteristics of the leaky modes on the air-gap structure have been reported in [1]-[2].

II. METHODOLOGY

The method of investigation involves first calculating the total current on the infinitely long conducting strip when the structure is excited by a feed. Several canonical feed models have been used, including a delta-gap feed and a vertical dipole underneath the strip (modeling a vertical probe connector). Figure 2 shows these two types of feeds.

The current is calculated by numerically constructing a Green's function for the feed source in the presence of the strip (referred to here as a 3D Green's function). Because the strip is assumed infinite, the 3D Green's function may be calculated from the more customary 2D Green's function

0-7803-3246-6/96/$5.00 © IEEE

(representing the field from an infinite line current) by using a spectral-domain method, in which the source is Fourier transformed in the z direction. The 3D Green's function is in the form of a spectral integral in the wavenumber k_z. (The spectral integral in k_z for the 3D Green's function is different from the path of integration in the transverse wavenumber (k_x) plane that is used to calculate the propagation constant of a leaky mode [1], [5].) The integrand has poles at the values k_{zn} corresponding to the propagation constants of the modes (bound or leaky) that propagate on the printed circuit line. Branch points also appear in the k_z plane at the values k_{pp} corresponding to the propagation wavenumbers of the background modes. The residues at the poles of the 3D Green's function define the *excitation amplitudes* of the guided modes (bound or leaky).

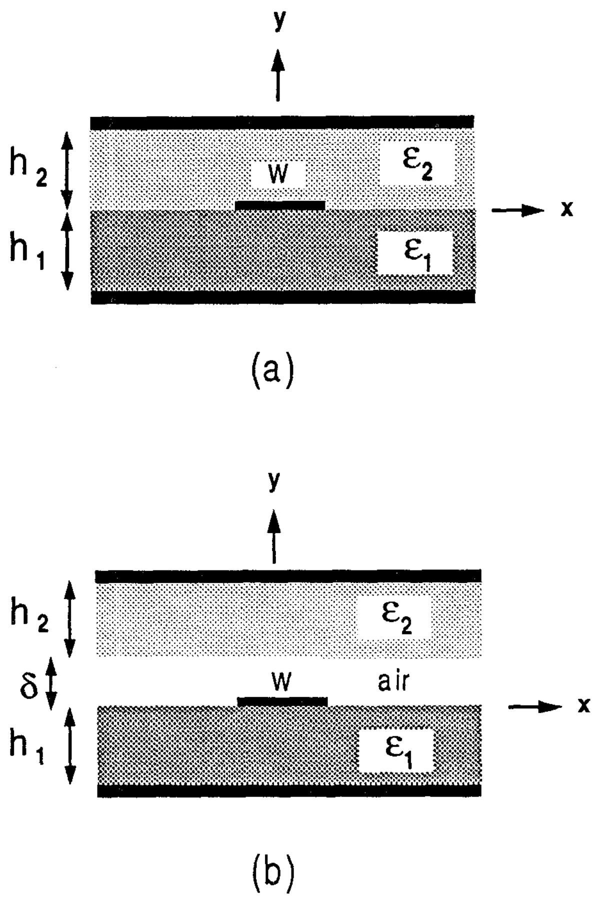

Fig. 1. Endview of the two stripline structures. (a) Two-layered stripline. (b) Air-gap stripline.

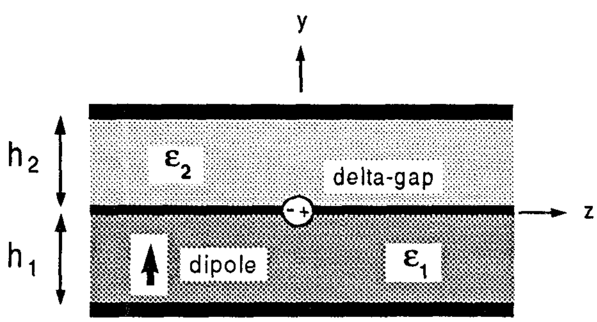

Fig. 2. A side view showing two types of feeds: the delta-gap feed and the vertical dipole (shown for the two-layered structure).

After the total current excited on the strip is calculated, the GPOF method is used to numerically fit the current by a set of exponential waves. The degree to which these exponential waves matches the exponential current wave of the leaky mode alone (as defined by the leaky mode propagation constant and excitation amplitude) defines the physical significance of the leaky mode.

In addition to the numerical study mentioned above, an analytical investigation into the physical significance of the leaky mode excited by a feed is carried out by studying the properties of the 3D Green's function. By investigating the proximity of the poles to the path of integration that is used to calculate the total strip current, the physical significance of the excited leaky modes may be examined. In particular, it is concluded that the *condition of leakage* introduced previously as a possible criterion for the physical significance of a leaky mode [2] is indeed a *necessary* condition for the mode to be physically significant (a leaky mode may satisfy the condition of leakage and still not have much physical significance, however). The condition of leakage states that the phase constant β of the leaky mode must be *consistent* with the path of integration in the k_x plane that is used to calculate the propagation constant of the leaky mode. The term ``consistent" means that β is less than the wavenumbers of the background modes into which leakage is occurring, and greater than the wavenumbers of those background modes which do not participate in leakage. The condition of leakage was introduced in [2] as a speculative criterion for physical significance, based on physical reasoning.

The analytical investigation presented here confirms this criterion as a necessary condition. Results are also presented to confirm this.

In addition to the study of the infinite line excited by a feed, results will be presented for a *finite* length line excited by a feed. The current excited on a finite length of line is calculated numerically using the method of moments. These results confirm the conclusions obtained from the infinite line analysis, and demonstrate the degree to which leaky mode excitation is observed on practical circuits of finite length.

III. RESULTS

The dispersion curve for one particular two-layered structure (Fig. 1a) is shown in Fig. 3. This structure has been deliberately chosen to give a dispersion curve where the phase constant of the leaky mode remains widely separated from, and less than, the phase constant of the proper mode and the propagation constant of the TM_0 background mode over a wide frequency range. In this case the leaky mode is expected to have physical significance, and also to be clearly discernible from the proper mode that is also excited by the feed. Table 1 shows a comparison between the currents of the bound and leaky modes calculated from the residues of the 3D Green's function (theoretical) and the current waves calculated by the GPOF method (GPOF), for a delta-gap excitation on the line. The first few exponential waves found by the GPOF method are listed for each frequency. The agreement is very good for the bound mode at all frequencies. That is, the GPOF method always yields a wave that matches extremely well with the theoretical bound-mode propagation constant and amplitude. This is to be expected, since the bound mode has physical significance at all frequencies. The agreement for the leaky mode propagation constant and amplitude is good above 2 GHz, and is better at higher frequencies. For frequencies above 4 GHz only two GPOF waves are significant, corresponding to the bound and leaky modes. At 2 GHz the agreement becomes quite poor for the leaky mode. No GPOF wave is found that matches the theoretical leaky mode amplitude. At this lower frequency the leaky mode is close to the boundary of the spectral gap [4], as can be seen from the dispersion plot (Fig. 3).

ACKNOWLEDGMENT

Prof. Francisco Mesa wishes to acknowledge the financial support provided by a NATO Fellowship during the course of this research.

REFERENCES

[1] D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner, ``Leakage of the Dominant Mode on Stripline with a small Air Gap," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-43, No. 11, pp. 2549-2556, November 1995.

[2] D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner, "Proper and Improper Dominant Mode Solutions for Stripline with an Air Gap," *Radio Science*, vol. 28, no. 6, pp. 1163-1180, Nov. - Dec. 1993.

[3] A. A. Oliner and K. S. Lee, "The Nature of the Leakage from Higher-Order Modes on Microstrip Lines," *IEEE Intl. Microwave Symp. Digest*, pp. 57-60, June 1986.

[4] H. Shigesawa, M. Tsuji, and A. A. Oliner, "The Nature of the Spectral Gap Between Bound and Leaky Solutions when Dielectric Loss is Present in Printed-Circuit Lines," *Radio Science*, Vol. 28, no. 6, pp. 1235-1243, Nov.-Dec. 1993.

[5] F. Mesa and R. Marques, "Integral Representation of spatial Green's Function and Spectral Domain Analysis of Leaky Covered Strip-Like Lines," *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-43, pp. 828-837, April 1995.

[6] L. Carin and N. K. Das, "Leaky Waves on Broadside-Coupled Microstrip," *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-40, pp. 58-66, Jan. 1992.

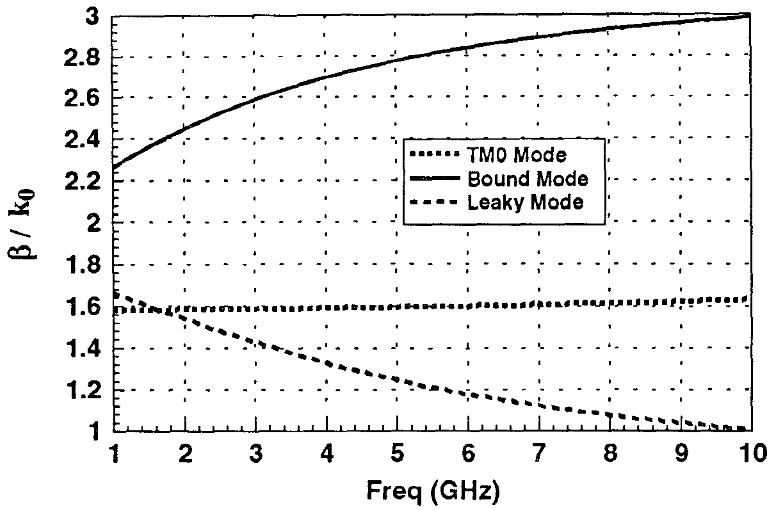

Fig. 3. Dispersion plot for the two-layered structure of Fig. 1a versus frequency. $h_1 = 1.0$ mm, $h_2 = 0.5$ mm, $\varepsilon_{r1} = 10.0$, $\varepsilon_{r2} = 1.0$, $w = 7.0$ mm.

Table 1. Comparison between the theoretical propagation constants k_{z0} (real, imaginary) and excitation amplitudes (real, imaginary), and those determined by the GPOF method, for the structure of Fig. 3. TM_0 denotes the mode of the background structure, B.M. denotes the bound mode excited by the source, and L.M. denotes the leaky mode excited by the source.

f (GHz)			Propagation Constant	Excitation Amplitude
8	Theory	TM_0 B.M. L.M.	(1.6119, 0) (2.9277, 0) (1.0800, -0.3228)	 (0.04234, 0) (0.03897, -0.0077)
8	GPOF		(2.9274, 0.000014) (1.0828, -0.3220) (1.5974, -0.2387) (1.6110, -0.0474)	(0.0424, 0.000054) (0.0399, -0.0133) (0.0013, 0.0025) (0.00065, 0.00030)
6	Theory	TM_0 B.M. L.M.	(1.5980, 0) (2.8393, 0) (1.1821, -0.6192)	 (0.0615, 0) (0.0571, -0.00075)
6	GPOF		(2.8391, 0.000011) (1.1842, -0.3542) (1.5736, -0.2274) (1.5959, -0.0457)	(0.0682, 0.0104) (0.0615, 0.000086) (0.000034, 0.0039) (-0.00093, 0.00077)
4	Theory	TM_0 B.M. L.M.	(1.5885, 0) (2.6936, 0) (1.3336, -0.3688)	 (0.1044, 0) (0.0939, -0.0016)
4	GPOF		(2.6935, -0.000054) (1.3520, -0.3248) (1.5938, -0.0832)	(0.1043, 0.000034) (0.0725, 0.0425) (-0.0411, 0.0049)
2	Theory	TM_0 B.M. L.M.	(1.5830, 0) (2.4453, 0) (1.5441, -0.2827)	 (0.2486, 0) (0.1957, 0.0059)
2	GPOF		(2.4452, 0.000059) (1.4663, -0.2198) (1.5699, -0.0545)	(0.2485, 0.00035) (0.0503, 0.0234) (-0.0046, 0.0148)