Crosstalk in Parallel Slotlines

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***Abstract* — This paper deals with high-frequency crosstalk effects between two slotlines located in parallel on the same substrate. The analysis consists of a full wave integral equation formulation solved in the spectral domain using the method of moments, and accounts for both leaky modes and the residual wave excited on the structure. The numerical results thus obtained show how an electric field is induced in the passive slot line due to coupling with an adjacent slot line excited by a current source. Comparisons with measured data and with the results provided by a commercial simulator are also provided.**

***Index Terms* —Crosstalk, bound mode, leaky mode, full-wave analysis, coupled slotlines.**

I. INTRODUCTION

Planar transmission lines have been widely investigated in recent decades. Special attention has been devoted to microstrip lines [1]. The dispersion relation, field distribution and characteristic impedance of propagating modes in various types of planar transmission lines were studied using the eigenmode approach in [2]. Later, the actual amplitude of the different waves excited by a given source on a microstrip line was studied in [3, 4], using a full-wave approach based on integral equation techniques and spectral-domain analysis. By using this approach, the signal launched on the line can be decomposed into the bound modes, leaky modes and the so-called residual waves excited by the source. However, similar analyses were not available for the slotline, although a full-wave analysis of a slotline-like structure can be found in [5]. Finally, an approach similar to that previously used in [3, 4] for microstrip lines was applied to the slotline itself in [6, 7] to study both its modal spectrum and the characteristics of the signal excited on the line by a current source.

When two parallel transmission lines are located close to each other, they are coupled and thus the electromagnetic field excited on one line affects the other. This is known as crosstalk, and in most cases this effect is undesired as it deteriorates the performance of the guiding structure, particularly at high frequencies where leakage effects can be significant [8]. Since transmission line theory and quasistatic approaches lose accuracy as the frequency increases, a full-wave analysis is needed in order to address this issue properly. The crosstalk between two microstrip lines has been previously analyzed in [8, 9]. The purpose of the present paper is to study high-frequency crosstalk effects in slotlines. In the present paper, a pair of coupled slotlines is analyzed using a full-wave approach similar to that used for coupled microstrip lines. One of the slotlines is excited by a current source, and the voltage excited along this line, and also along the nearby slotline due to crosstalk, is studied for different frequency values. Finally, some comparisons with the commercial simulator CST Microwave Studio, and also with experimental data, are provided for validation purposes.

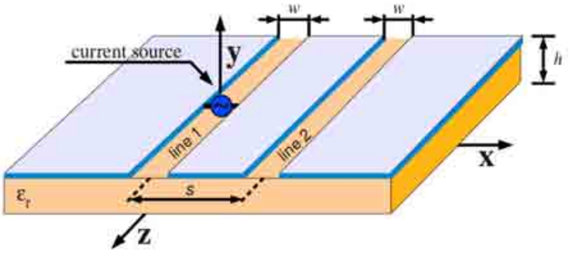


Fig. 1 Two parallel slotlines of infinite length. Line 1 is excited by a current source located at z = 0.

II. METHOD OF ANALYSIS

The structure under consideration is shown in Fig. 1. It consists of two identical parallel slotlines, one of which (the "active" line) is excited by a current source placed across the slot. The structure is assumed to be lossless, laterally unbounded, and the metallization is assumed to be of zero thickness.

The analysis is similar to the semi-analytical full wave approach used in [7] for a single slotline, which consists of an integral equation for the electric field in the slot that is solved by the Method of Moments (MoM) in the spectral domain. This formulation is extended to deal with the structure considered here, resulting in two coupled integral equations (one for the electric field in each slot) that are solved following a similar MoM procedure. This allows for the computation of the Fourier transform (in z) of the voltage signals excited along the slots. Their inverse Fourier transforms are then computed numerically, which yields the actual voltages as functions of the distance from the source. It is convenient to recall that the voltages thus obtained include all the possible high-frequency components, namely, all the bound modes, leaky modes, and residual waves excited on the structure at the working frequency. Finally, it should be mentioned that in the present case the electric field is not symmetric with respect to the center of the slots. Therefore, both even and odd basis functions are used to expand the electric field in each slot.

III. NUMERICAL RESULTS

A computer code has been developed based on the method expressed above. Three basis functions are used for the x

component of the electric field in the slots, and two for its z component.

Next, numerical results obtained using this code are shown for the structure with $_r$ = 9.9, h = 1 mm, w = 0.25 mm, and s = 0.75 mm. A single slotline with these same parameters has been analyzed in detail in [6]. In this reference, the following three different regimes were described. First, at 10 GHz only the bound mode propagates, so the voltage along the line is constant. At about 30 GHz, a physical leaky wave starts to propagate together with the bound mode. As a consequence, the voltage decreases rapidly close to the source due to strong leakage effects, but stays constant at further distances, where only the propagating bound mode is present. Finally, above 50 GHz two leaky waves propagate along the line [6], and the field is completely attenuated due to the leakage.

If a second, "passive" line is located near the "active" line, the voltage distributions along these lines are modified due to crosstalk. Fig. 2 shows these voltages at 10 GHz. It can be seen how the nearly constant amplitude of the bound wave voltage predicted on the single line is severely changed, showing strong oscillations. It can be observed that the voltage along the passive line (line 2) is very similar to that in the active line. This means that the amplitude of the bound mode excited in both lines is approximately the same. The oscillations are due to the coupling between the two modes, and it is interesting to note that the position of the maxima in line 1 coincides with the minima in line 2, and vice versa. These results are in full accordance with the results presented in [8, 9] for the current excited on coupled microstrip lines.

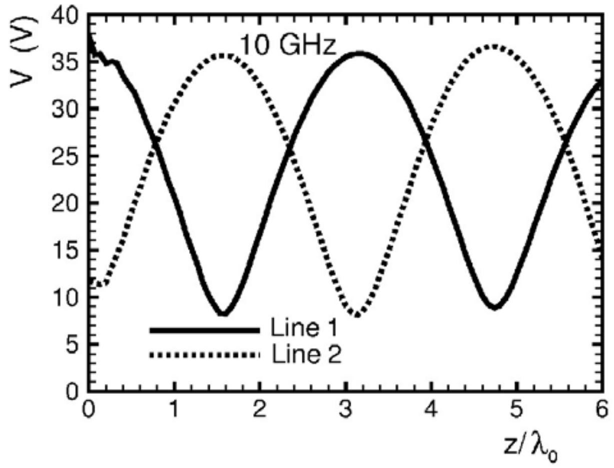


Fig. 2 Voltage along the parallel slotlines at 10 GHz (see the text for the values of the structure parameters). The amplitude of the current source is 1 A.

Fig. 3 shows the voltage distributions on both lines at 30 GHz. The energy starts to leak on the slotline in the form of a leaky wave at about this frequency, which is reflected in the fast decrease in the voltage signals close to the source. For distances from the source larger than approximately $\lambda_0/2$, the non-attenuated bound mode becomes dominant. It should be pointed out that, unlike in the case shown in Fig. 2, the signals propagating along the two lines are not similar in amplitude in this working regime. The amplitude is lower in the passive line, but a significant percentage of the energy still propagates along this line due to the coupling with the active line.

Finally, the results obtained at 50 GHz are plotted in Fig. 4. It can be observed that the voltage along both lines decreases rapidly, because there is no bound mode at this frequency and therefore all the energy is radiated due to leakage [6, 7]. The voltage excited on the active line is significantly larger in the close vicinity of the source. However, for distances above $\lambda_0/2$ the voltage in the passive line becomes comparable to that in the active line.

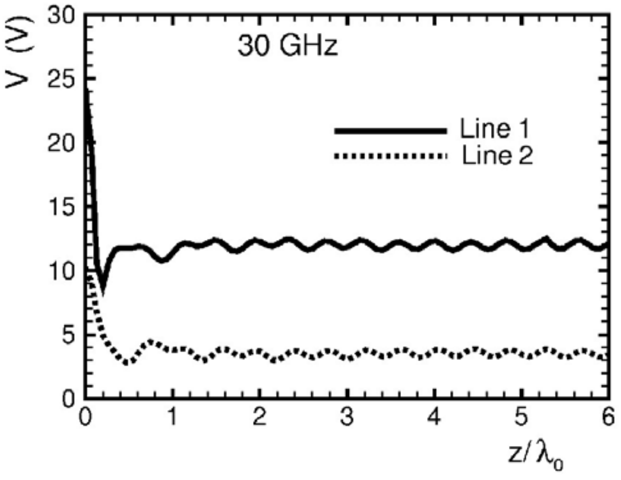


Fig. 3 Voltage along the parallel slotlines at 30 GHz.

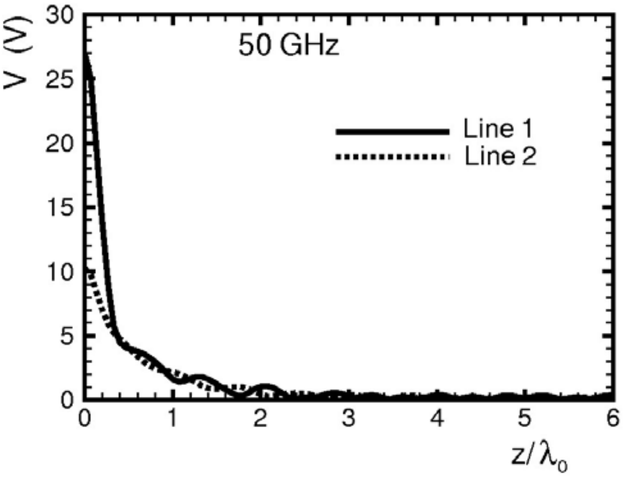
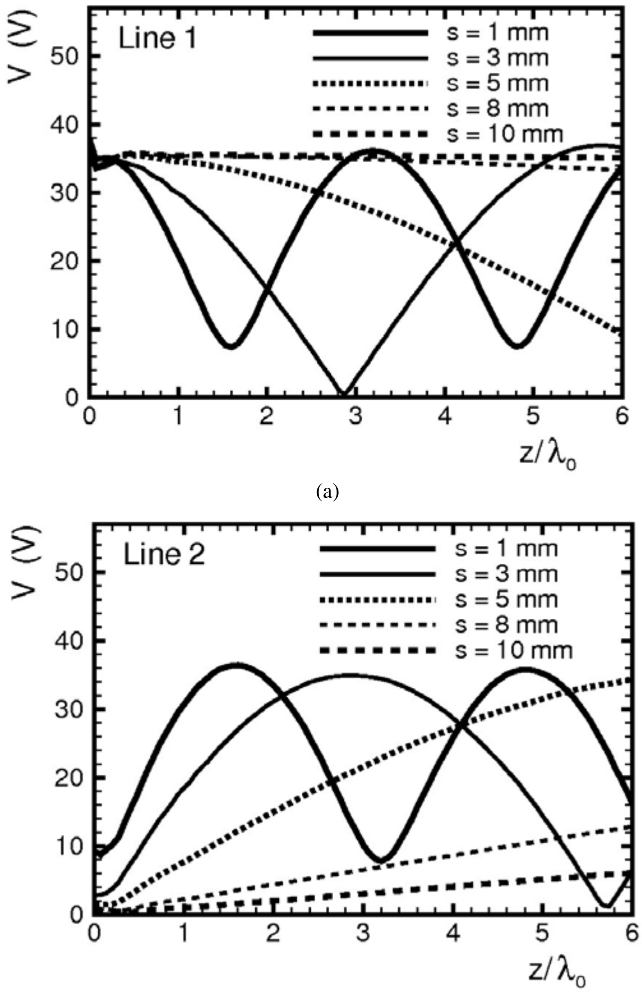


Fig. 4 Voltage along the parallel slotlines at 50 GHz.

Among the three cases analyzed above, the one shown in Fig. 2 (10 GHz) is perhaps the most interesting from a practical point of view, since only bound modes propagate and the coupling between the two signals is the strongest. It would be interesting to study the effect of increasing the distance between the slotlines at this same frequency. Thus, Figs. 5(a) and (b) show, respectively, the voltage along lines 1 and 2 for different distances between the slots. It is shown that the wave excited along line 1 is strongly affected by the presence of the passive line for distances of 1, 3, and 5 mm. The influence of the second line is much lower when placed at a distance of 8 and 10 mm. For larger distances (not shown), it is found that the voltage excited on line 1 is basically the same as that excited by the same source on a single slotline. Concerning the voltage excited on the passive line, Fig. 5 (b) shows that its magnitude is comparable to that in the active line for s = 1, 3 and 5 mm (strong coupling). For s = 8 and 10 mm, the voltage excited in the passive slot decreases, which is consistent with the low coupling observed in the signal along line 1. For distances larger than 10 mm (not shown), the voltage excited on the passive line is negligible, as expected. It is interesting to note that the voltage distributions along the two coupled lines are complementary, in the sense that the location of the maxima in one of them corresponds to the minima in the other.



(a)

(b)

Fig. 5 Voltage along (a) line 1 and (b) line 2 for different distances between the slots. The frequency is 10 GHz.

The two coupled lines can in fact be represented by one fictive line transmitting the total wave excited by the same source. The total voltage of this wave can be defined as the sum of the complex voltages excited at the two actual slots. We represent in Fig. 6 the sum of the two voltage signals in the coupled slotlines. They are compared with the voltage excited on a single slotline with the same parameters. It is shown that the two voltage waves fit together very well.

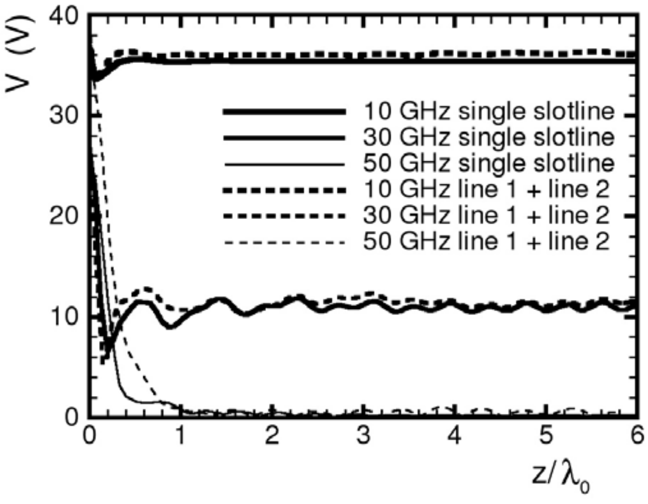


Fig. 6 Voltage along the single slotline with w = 0.25 mm, h = 1 mm, and r = 9.9 plotted together with the sum of the two waves along line 1 and line 2 with s = 5 mm.

IV. EXPERIMENTAL VERIFICATION

In order to provide experimental verification of our results, we fabricated a pair of parallel slotlines of width *w* = 5.6 mm, separated by a distance *s* = 20 mm and printed on a dielectric substrate with $_r$ = 2.6 and *h* = 14.6 mm. Fig. 7 shows a picture of the experimental setup. The active line is fed using a coaxial cable and a probe is used to measure the electric field along the slots. The position of the probe is controlled by a computer system and the data is automatically collected and saved into the computer.

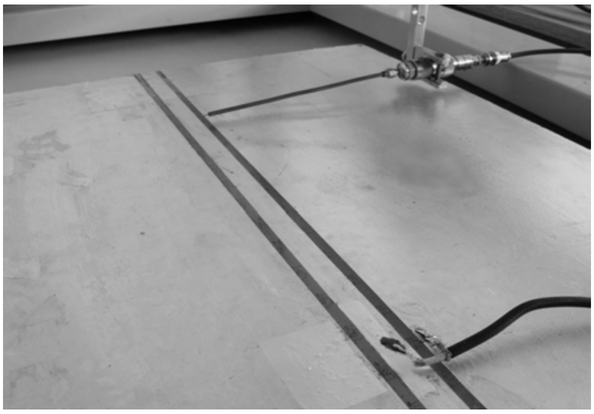
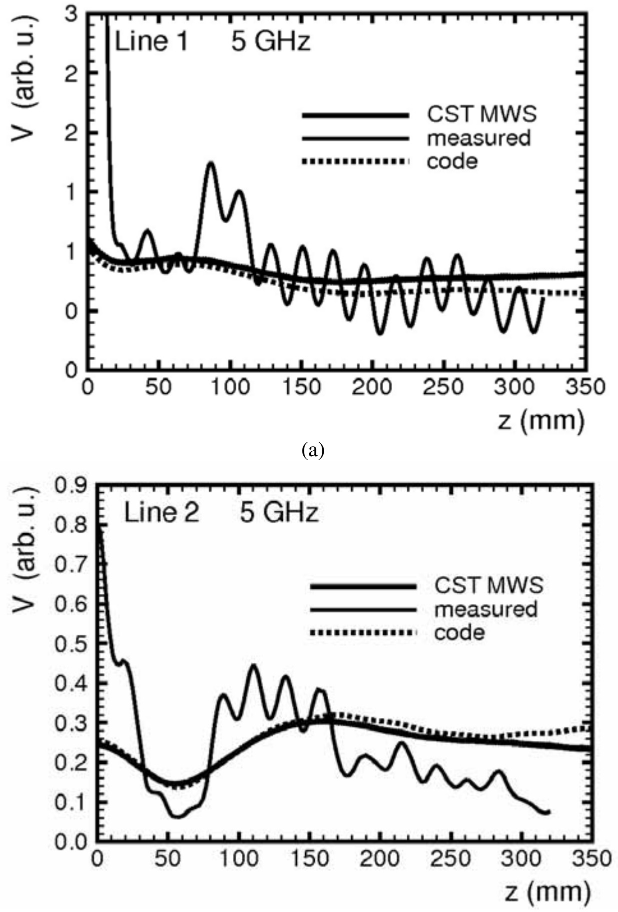


Fig. 7 Measurement setup, showing the coaxial cable feeding (down right) and the computer controlled probe used to measure the field (top right).

Fig. 8 shows the measured data together with the results obtained with our code and the data provided by a CST Microwave Studio simulation. The frequency is chosen as 5 GHz because at this frequency the voltage excited along the slots consists of the superposition of a bound mode and a leaky mode [6]. The slotlines were simulated in the CST Microwave Studio using "open" boundary conditions at the substrate edges to avoid reflections from the substrate edges. In the case of the fabricated line, there are some reflections due to non-perfect termination by an absorbing material at the substrate edges. This deteriorates the measured results, which show noticeable oscillations due to the interference of the signal excited along the slots with the waves reflected at the substrate edges. However, the agreement between all three curves in Fig. 8 is fairly good (the data is conveniently normalized and represented in arbitrary units for comparison purposes).



(a)

(b)

Fig. 8 Comparison between measured voltage, voltage simulated by the CST Microwave Studio, and calculated voltage along (a) line 1 and (b) line 2. The frequency is 5 GHz (see the text for the values of the structure parameters).

V. CONCLUSIONS

This paper has studied the crosstalk between two parallel slotlines using a full wave integral equation approach. Three different working regimes of the slotline were analyzed. In the first one, only a bound mode propagates in the single slotlines. In the second, a leaky mode propagates together with the bound mode, whereas in the third only leaky waves propagate. The results obtained here show that the voltage distributions along the coupled lines are substantially modified by crosstalk. Strong maxima and minima appeared in the voltage distributions, and these two voltage distributions are complementary. Naturally, crosstalk effects lose relevance for increasing distances between the slots.

An interesting additional result shown here is that the sum of the complex voltages excited on the two lines (active and passive) is very similar to the voltage wave excited along a single slotline with the same structure parameters.

Finally, our results have been partially verified by measurements and by comparison with the commercial simulator CST Microwave Studio.

ACKNOWLEDGEMENT

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REFERENCES

[1] K. C. Gupta, R. Garg, and I. J. Bahl, “*Microstrip Lines and Slotlines*,” Dedham, Artech House, 1979.

[2] J. Zehentner, J. Mrkvica, and J. Machac, “Spectral Domain Analysis of Open Planar Transmission Lines,” *Microwave Review*, vol. 10, no. 2, pp. 36-42, November 2004.

[3] F. Mesa, C. Di Nallo, and D. R. Jackson, “The theory of surface-wave and space-wave leaky-mode excitation on microstrip lines,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 2, pp. 207-215, February 1999.

[4] F. Mesa, D. R. Jackson, and M. Freire, “High frequency leaky-mode excitation on microstrip line,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 49, no. 12, pp. 2206-2215, December 2001.

[5] A. Neto, and S. Maci, “Green’s Function for an Infinite Slot Printed Between Two Homogeneous Dielectrics—Part I: Magnetic Currents,” *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 7, July 2003.

[6] V. Kotlan, J. Machac, and F. Mesa, ”Comparative Analysis of the Dispersion Characteristics of a Slotline and a Microstrip Line,” *2009 Asia Pacific Microwave Conference,* Singapore, December 2009.

[7] V. Kotlan, F. Mesa, and J. Machac, “Numerical and experimental study of the voltage excited by a current source,” *Radio Science*, 45, RS1004, January 2010.

[8] J. Bernal, F. Mesa, and D. R. Jackson, “Crosstalk between two microstrip lines excited by a gap voltage source,” *IEEE Transaction on Microwave Theory and Techniques*, vol. 52, no. 8, August 2004, pp. 1170-1179, August 2004.

[9] J. Bernal, F. Mesa, and R. Rodriguez-Berral, “High frequency crosstalk between two microstrip lines,” *IEEE MTT-S International Microwave Symposium 2003*, vol. 2, pp. 813-816, June 2003.