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Electrical and Computer Engineering

01 Aug 2000

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Recommended Citation

Experimental and Numerical Study
of the Radiation from Microstrip Bends

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Abstract: This paper investigates the radiation from microstrip lines with 90-degree bends. A 1-GHz TEM cell is used to measure the radiation from microstrip lines with different kinds of bends. A full wave hybrid FEM/MoM code is used to compute the radiation. Both experimental and numerical results show that there is no significant difference between the radiation from right angle bends and bends with two 45-degree corners at frequencies and trace dimensions that are likely to be found on printed circuit boards.

I. Introduction

With the increasing density of digital circuit layouts, discontinuities in microstrip traces that were previously considered insignificant have now been shown to introduce noticeable signal degradation for very short rise time pulses. For example, Douville and James [1] demonstrated that the way in which a bend is mitered affects the equivalent electrical length of the bend. This can be significant for very fast signals, particularly in meander line configurations that employ a large number of bends. Several models were developed to describe the effect of bends in a microstrip configuration and these models were validated with measurements. However, these models neglected the effect of radiation from the bends, which the authors concluded was "essentially negligible."

Moore and Ling [2] further investigated the effects of unmitered 90-degree bends using an FDTD technique. Their results indicate that significant reflections can occur from unmitered bends when the incident pulse width is on the order of the propagation delay through the bend. The models used in [8] neglected the effects of radiation, but still agreed with the experimental results of Douville and James.

N. Ishibashi et al. [3] reported that a transmission line with a bend radiates some of the input power and may sometimes result in radiated EMI problems. The problem configuration they studied is illustrated in Figure 1 (with h=0.08 λ). The authors determined that the radiation loss was on the order of 10% of the input power. Their model results showed that the radiation loss increased with sharper bend angles (α). For α =0 (a straight line without a bend), the radiation loss was about 6~7% of the input power. As the bend angle approached 90 degrees, the amount of loss was about 11% , nearly twice that for a straight line without a bend. Of course 0.08λ is

relatively thick compared to most printed circuit board geometries. A board with a typical 10-mil trace-plane spacing in FR4 is 0.08λ thick at approximately 47 GHz.
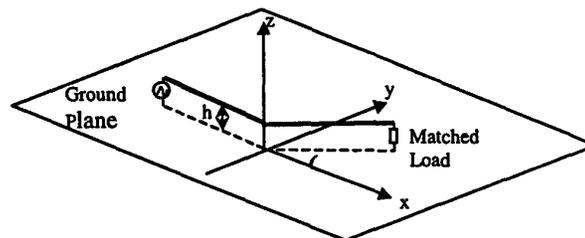

Figure 1. Configuration studied in [3]

II. Measurement

Figure 2 shows two microstrip lines with different bends. The first microstrip line has an unmitered 90° bend. The second microstrip line has two 45° bends. Two 10-cm × 8-cm × 1.3-mm boards were built with these trace geometries. The traces on the top layers are 3 mm wide and 7 cm long. The bottom layers are solid metal planes. The dielectric has a relative permittivity of 4.5. Both microstrip lines are terminated with 47-ohm resistors. Figure 3 shows the pictures of these two printed circuit boards (top view).
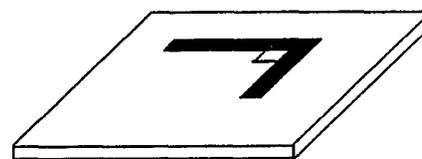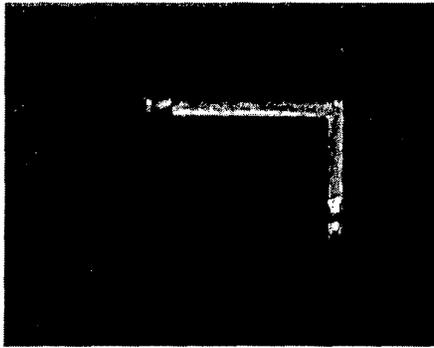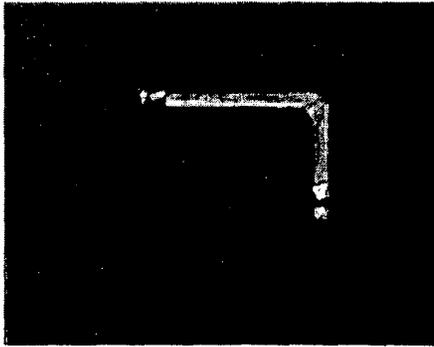

(a) 90° bend case
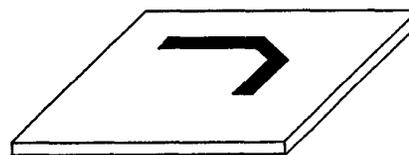
(b) two 45° bends case

Figure 2. Two implementations of a 90-degree bend in a microstrip trace

(a)

(b)

Figure 3. Pictures of the two microstrip lines (top view)

(a) 90° bend case (b) Two 45° bends case

Figure 4 illustrates the experiment setup. A 1-GHz TEM cell is used here. The topside of the microstrip line board is mounted in the TEM cell. Port 1 of a network analyzer is connected to the source end of the microstrip line. Port 2 of the network analyzer is connected to one of the terminations of the TEM cell. In this configuration, the device under test has a negligible effect upon the cell characteristics [4].
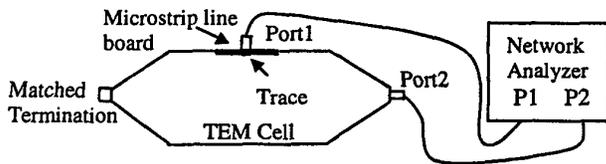

Figure 4. Experiment setup

S21 parameters were measured to compare the radiation from microstrip traces with different bend angles. The radiated power is approximately proportional to the magnitude of S21 according to the equations below,

$$S_{21} = \frac{V_2^-}{V_1^+} \qquad (1)$$

$$P_{rad} = k \mid S_{21} \mid^2 \qquad (2)$$

where P_{rad} is the radiated power from the microstrip line and k is a constant coefficient that depends on the TEM cell construction. Expressed in dB,

$$\mid S_{21} \mid dB = 20 \log_{10} \frac{V_2^-}{V_1^+} \qquad (3)$$

$$P_{rad} = 20 \log_{10} k + \mid S_{21} \mid dB \qquad (4)$$

Figure 5 shows the measured results. Although the upper-limit frequency of the TEM cell was 1GHz, the results up to 3GHz are presented The higher frequency results are still useful for making relative measurements comparing the radiation from different boards. Note that the radiated power from the trace with two 45° bends is not less than the emissions from the trace with one 90° bend. In fact, the measured radiation from the trace with two 45° bends is slightly (<2dB) higher. This slight increase is within the measurement repeatability from board to board and is not significant.
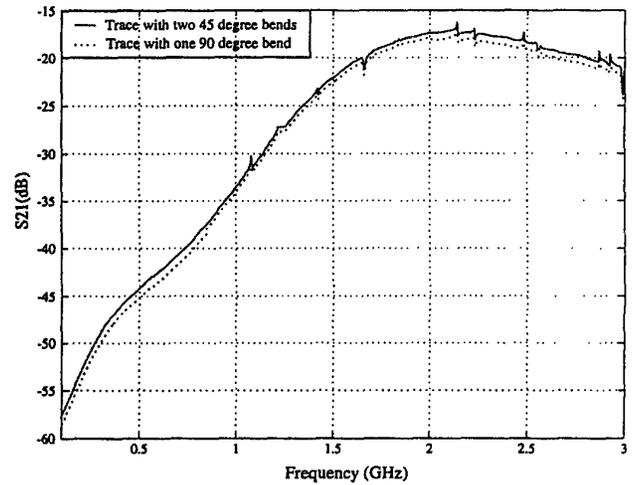

Figure 5. Measured results

III. Simulation

The full wave hybrid FEM/MoM numerical code EMAP5 was employed to model the geometries in Figure 1. Full-wave hybrid FEM/MoM methods are well suited for solving problems that combine inhomogeneous regions with small structures and larger radiating conductors. They have been successfully applied to the analysis of radiation from printed circuit board geometries [5]. The finite element method (FEM) is employed to analyze the interior part of the boards and the method of moments (MoM) is used to analyze the exterior parts of the boards. The two equivalent problems are related by forcing the continuity of tangential fields on the boundary of the boards. Because the traces are very thin, they are treated

as perfect electric conductors (PECs) with infinitesimal thickness.

In EMAP5, triangular elements are used in the MoM part and tetrahedral elements are used in FEM part. Figure 6 shows a top view of the mesh created using a commercial mesh generator for the configuration of the microstrip trace with 45° bends.
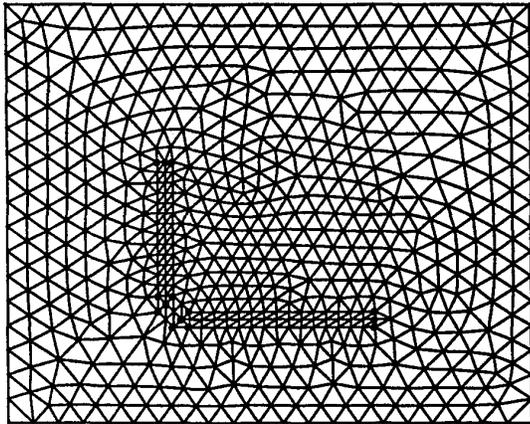

Figure 6. Mesh used to model the microstrip trace With two 45° bends (top view)

Figure 7 illustrates the simulation results. Since the measured results were obtained in a TEM cell (near field) and numerical results are far filed, the measured and simulated results cannot be compared directly. However the simulated results show the same frequency dependence as the measured results below 1GHz. There is very little difference between emissions from the trace with the 90-degree bend and emissions from the trace with two 45-degree bends up to 3 GHz.

IV. Conclusion

The radiation from two microstrip lines with different bends was investigated by means of measurement and numerical modeling. The comparison showed that the radiated emissions from the trace with two 45° bends is virtually identical to the emissions from the trace with one 90° bend.

Although we cannot conclude that radiation from 90-degree bends is never significant based on this one example, these results are consistent with the conclusions of other investigators. Douville and James [1] cite an example based on radiated power formulas obtained from Lewin [6] as modified by Hammerstad [7]. Their calculations indicate that for the fairly extreme example of a 25-ohm line on a 25-mil substrate with $\varepsilon_r \approx 2.5$, the radiation loss (ratio of power radiated to power incident on bend) would be about 0.35 dB at 12 GHz.

Sometimes, the argument is made that although the radiation from one bend may be negligible, that bend geometries may be important on a board with thousands of bends. However, as the results presented in [1-3] and this paper indicate, the radiation from the bends is generally insignificant relative to the emissions from the rest of the trace. Therefore, no matter how many bends there are, the radiation from the bends is not likely to be significant relative to the other EMI sources on the printed circuit board.
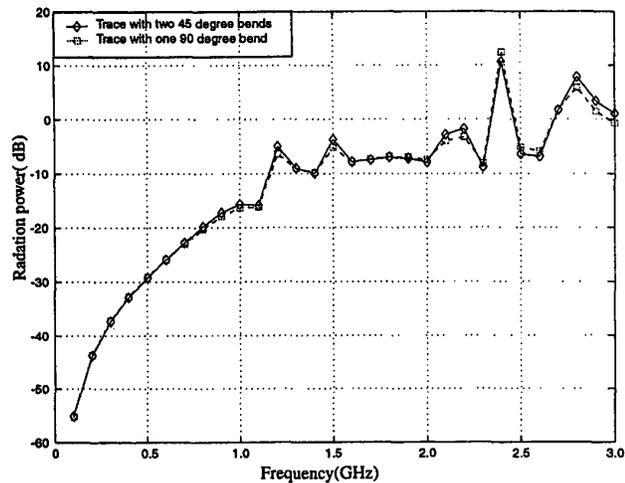

Figure 7. Numerical model results

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