MULTILAYER COPLANAR WAVEGUIDE FOR HIGH SPEED DIGITAL APPLICATIONS

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Abstract

This paper presents measurements of pulse distortion, coupling, and loss due to discontinuities of the coplanar waveguide (CPW) on single and multilayer structures. The CPW compares favorably to the microstrip line in terms of low coupling and distortion. A novel metal-backed coplanar waveguide (CPW) on multilayer structure is introduced to minimize or eliminate pulse distortion due to overmoding. The new CPW structure also has the advantage of relatively low loss at discontinuities. For a T circuit, the loss per bend in the new structure is about 0.2 dB less than a similar microstrip line.

I. Introduction

There are four main problems associated with high speed, high density digital circuit interconnects. These are cross-talk due to coupling between lines, pulse distortion due to dispersion, signal loss due to reflection or radiation at discontinuities, and susceptibility to external electromagnetic interference. These problems are not independent; for example, cross-talk and reflection at a discontinuity can both cause pulse distortion, and radiation from a discontinuity can corrupt the signal in another part of the circuit.

Presently, the most common configurations of digital interconnects are the microstrip line and the strip line [1-3]. Modern digital boards can consist of several microstrip and/or strip line layers with ground planes to isolate different metalization layers. Although the ground planes partially shield the lines from external interference, the microstrip lines are still vulnerable to cross-talk and pulse distortion due to coupling between different lines on the same metalization layer [4]. In addition, the microstrip line has the inherent disadvantage of strong radiation at discontinuities [5,14].

Two different approaches have been introduced to minimize cross-talk between adjacent microstrip lines. The first approach is to use multilayer structure [4], where the dielectric layers have been optimized in order to minimize coupling between the lines. In [4], no experimental work is presented and the effects of discontinuities are not examined. The second approach is to use grounded isolation lines [17] which converts the microstrip line into coplanar waveguide with finite size side strips. In this work, the effects of shielding or adding a ground plane were not investigated and the impact of metal discontinuities was not discussed.

Other researchers have investigated pulse distortion due to microstrip discontinuities [9,10]. However, no work has been reported on reducing the radiation at discontinuities or increasing the immunity to external interference, and these remain serious limitations to the use of microstrip transmission lines in high density, high speed digital circuits.

Coplanar waveguide (CPW) [5-7,11-14] has the advantage of small radiation at discontinuities [5,13,16], low dispersion as compared to the microstrip line [13] (i.e., less dispersive distortion than the microstrip line), reduced coupling between different lines in the same metalization layer [6], and for the same dielectric substrate a CPW circuits has less delay time than the microstrip circuit. Due to the odd symmetry of the CPW fields (see Fig. 1a), it weakly couples to external fields [15] which increases line immunity to interference. In addition, there is easy access to the ground plane which makes it useful in applications where frequent connections to the ground plane are required. However, CPW can still couple to other lines on different layers of metalization. With the increased complexity of modern digital integrated circuits and modules, the use of multilayer metalization is imperative. Also, CPW circuits require more metalization than microstrip circuits. Thus, conventional CPW is not widely used in digital circuits.

Some attempts have been made to investigate metal-backed CPW [13] (see Fig.1b). The ground plane in this type of CPW can be useful in the isolating different metalization layers. Unfortunately, due to the close proximity of the ground plane to the printed line, the metal-backed CPW is overmoded [13,14]. The effects of overmoding on pulse propagation have not been thoroughly investigated. Because metal-backed CPW has many desirable features that would enhance the performance of digital circuits, it is useful to develop a technique to remedy the problem of overmoding. To date, no research in this area has been reported.

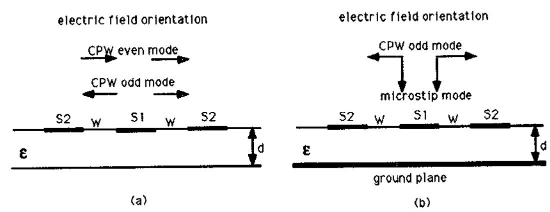

Figure. 1 Geometry of a) coplanar waveguide, and b) metal-backed coplanar wave guide, including electric field orientation of each mode

In this work, a spectral domain analysis has been used in the design of different transmission lines. CPW measurements are described in Sec. II, including a novel CPW configuration to eliminate the effects of overmoding. The effects of discontinuities in the metal-backed CPW and the microstrip line are presented in Sec. III and the paper is concluded in Sec. IV.

II. Coplanar Waveguide Structures

a. Single Layer Structures

This section describes the results of time domain measurements of single and coupled CPW on a single dielectric layer. Three identical CPWs were etched on a single layer of 1.27-mm-thick RT Duroid 6010.5 (ε_r=10.5). The lines were designed for 50 Ω impedance (S=2.0 mm and W=0.9 mm) to allow a good coax to CPW match. The side strips have the same width as the center strip. Two of the CPWs shared a side strip. One of the CPWs was connected to ground at both ends while the other was connected to the test ports of the HP8510B network analyzer through SMA coaxial connectors. In the test, the low pass time domain option of the HP8510B was used and the bandwidth of the measurements was set to 10 GHz. This bandwidth corresponded to a measured time domain 3 dB pulse width of about 70.0 ps. Fig. 2 shows the input pulse launched at a calibrated time equal to zero with a calibrated level of zero dB. To compare pulse propagation in coupled lines versus single lines, the third CPW was built about two inches apart from the other two lines as shown in Fig. 3a. The length of the three lines was 10.2 cm. Fig. 3b shows the insertion loss of an isolated CPW line. The line has a delay time of about 0.86 ns and an insertion loss of about 0.8 dB. Fig. 3c shows the insertion loss of one of the two coupled CPW lines mentioned above. The insertion loss increased to about 1.6 dB due to coupling. However, the pulse remained almost undistorted. This shows that the coupling between adjacent lines in CPW circuits is not significant. Other CPW lines of different strip widths have been built and the above conclusion regarding low coupling remained the same.

Measurements of the microstrip line show that the microstrip line on the same dielectric substrate has more delay (1.01 ns for the microstrip line compared to 0.86 ns for the CPW) and less insertion loss than the CPW (0.7 dB for a single microstrip line compared to 0.8 for CPW). The effects of coupling in microstrip circuits are much worse than that of the CPW. In a similar arrangement to that described above, coupling between two microstrip lines resulted in the following:

a) increased losses (more than 4 dB insertion loss) and distortion on the signal line (the pulse width almost doubled)

b) additional pulses on the signal line due to reflections on the sense line. This can result in false trigger of the digital circuit.

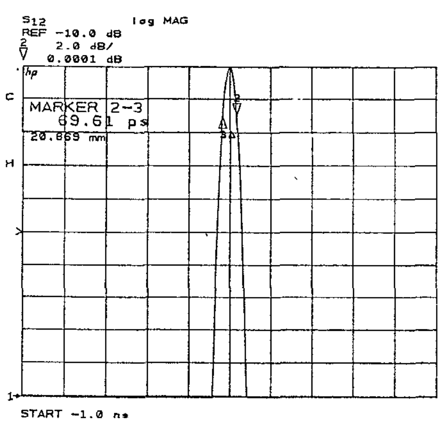

Figure. 2 Input pulse using the low pass time domain option of the HP8510 network analyzer.

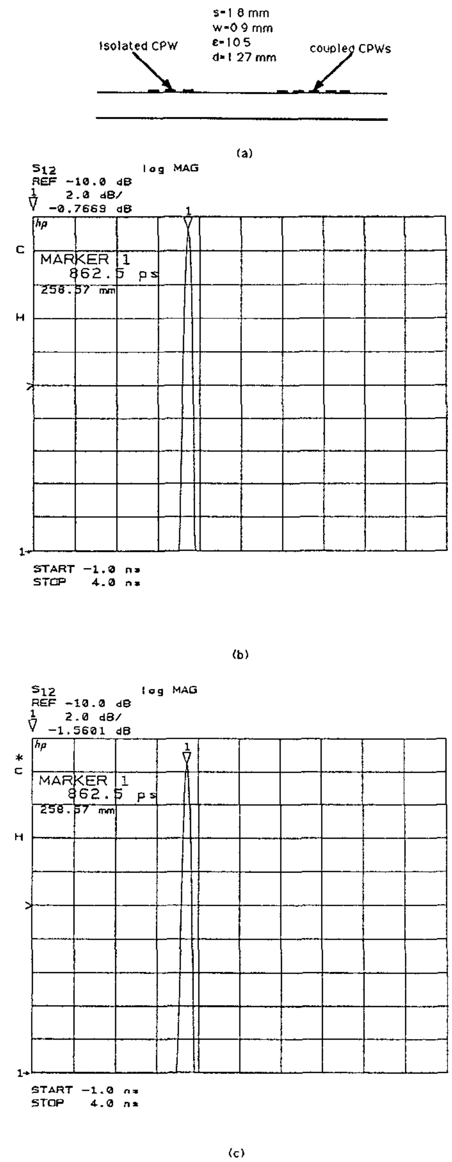

Figure. 3 a) Geometry and insertion loss measurements of b) isolated CPW and c) coupled CPWs on a single layer dielectric substrate.

As mentioned above it would be very useful to isolate different layers of CPW interconnects with a ground plane. This ground plane will result in two different modes; the CPW-like mode and the microstrip-like mode [14]. The electric field orientation of both modes is shown in Fig. 1b. Since the fields of the CPW-like mode is more concentrated near the air-dielectric boundary, it is expected that the CPW-like mode is faster than the microstrip-like mode. Hence, a pulse launched at the source end of the line is distorted and (if the line is long enough) arrives as two separate pulses at the sense or receiving end. Fig. 4 shows the geometry and pulse insertion loss measurements of a metal-backed CPW. The effects of overmoding resulted is pulse loss of about 3.5 dB and distortion in the form of a second peak. In addition, due to the difficulty of matching both the microstrip mode and the CPW mode, multiple reflection may be unavoidable. This shows that metal-backed CPW without any form of compensation or elimination of one of the two modes is unsuitable for digital applications. In CPW multi-metalization layers, other metalization layers will be at best equivalent to a ground plane. At worst, the number of possible modes will increase with the number of metalization layers and the number of conductors per layer. Therefore, multi-metalization will result in overmoding effects similar to that described above.

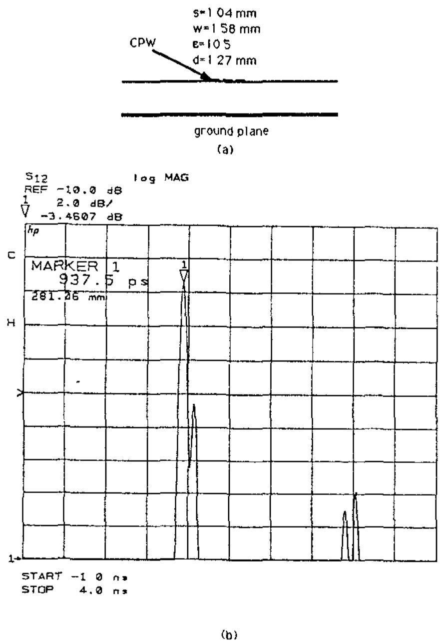

Figure. 4 a) Geometry and b) insertion loss measurements of single layer metal-backed coplanar waveguide.'

b. Multilayer Structures

As discussed above the group velocity of the microstrip-like mode in a single layer shielded CPW is somewhat slower than that of the CPW-like mode. In a multilayer structure, it is possible to equalize the group velocities of the two modes by making the top layer of high dielectric constant material to slow down the CPW-like mode, and the bottom layer of low dielectric constant material to speed up the microstrip mode. The required dielectric constants and thicknesses of the layers may be determined using the spectral domain approach. For the geometry shown in Fig. 5a, choosing the thickness and the dielectric constant of the top dielectric layer to be 0.254 mm and 10.5 respectively, and the thickness and the dielectric constant of the bottom layer to be 0.508 mm and 2.2, will equalize the effective dielectric constants of the CPW and the microstrip like modes of the shielded CPW to about 3.0. Fig. 5b shows the measured pulse response of this shielded CPW. The pulse insertion loss was about 0.6 dB and no significant distortion was observed. Furthermore, the insertion loss of coupled shielded CPWs with a common side strip (similar to that on a single dielectric layer) was almost identical to the isolated CPW. This shows that the multilayer structure was also

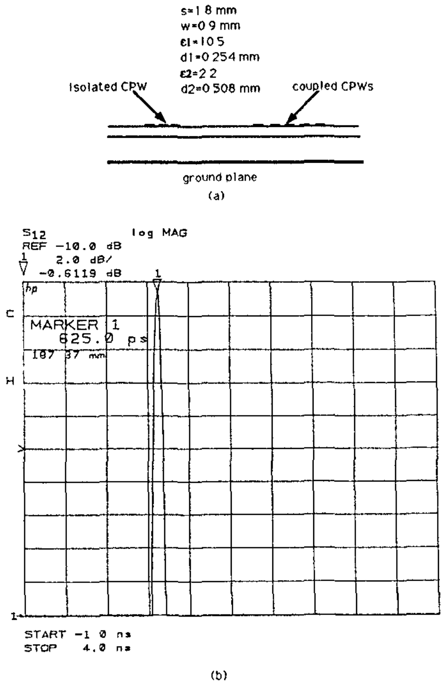

Figure. 5 a) Geometry and b) insertion loss measurements of multilayer metal-backed coplanar waveguide

effective in compensating for overmoding as well as reducing the coupling between adjacent lines. Similar multilayer microstrip structures (the same microstrip width and the same dielectric substrates as the multilayer CPW structure) have been built and gave somewhat lower loss (0.4 dB) but the coupling effects were similar to that of the multilayer CPW.

III. CPW and Microstrip Discontinuities

As discussed above the insertion loss of the metal-backed CPW can be reduced by using a multilayer structure to compensate for overmoding. In practical circuits losses at discontinuities may represent a significant part of the overall losses. To examine losses at discontinuities in the new CPW structure as compared to microstrip discontinuities, a T metal-backed multilayer CPW circuit and a T microstrip circuit were built on the same dielectric substrate as shown in Fig. 6. Despite the fact that microstrip line has less loss than CPW, measurements of pulse insertion loss of microstrip bends (port 1 to port 2 or port 1 to port 3) were consistently higher than CPW bends (port 4 to port 6 or port 5 to port 6). The loss was about 4.3 dB for the microstrip bends compared to 4.1 dB for the CPW bends. (This loss should be ideally 3.5 dB including reflection at the T joint.) The insertion loss of the straight junctions (port 2 to port 3 for the microstrip and port 4 to port 5 for the CPW) were very similar (about 4.1 dB). Clearly, CPW confines its fields better than the microstrip line. This may be attributed to the odd symmetry of the CPW fields as mentioned above. Previous work on microstrip and CPW discontinuities [9,10,13,16] gave the same conclusion.

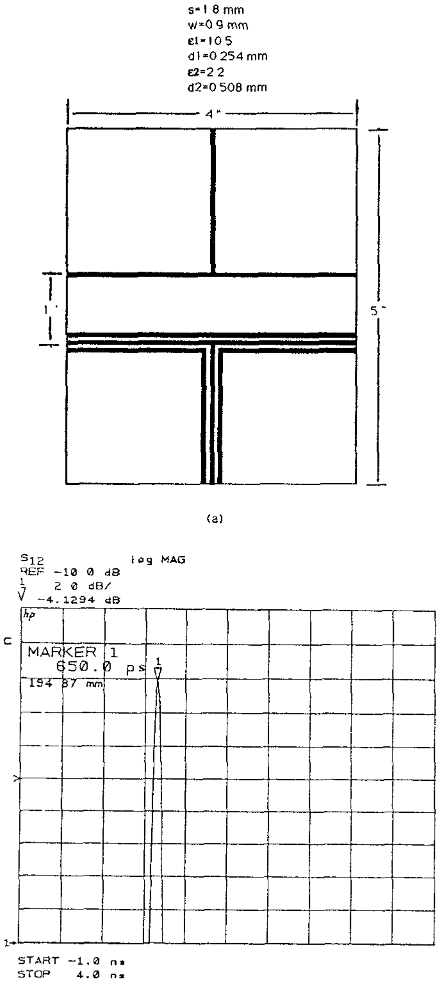

Figure. 6 a) Geometry and b) Insertion loss measurements of a T coplanar waveguide circuit

IV. Conclusion

This paper presents pulse measurements of coplanar waveguide in single and multilayer media. On a single layer of dielectric, an isolated CPW has slightly higher insertion loss than the microstrip line. However, coupled CPWs have shown less pulse loss and distortion than coupled microstrip lines. Metal-backed CPW on a single dielectric layer has shown to be unacceptable as a digital transmission media due to overmoding. However, it is possible to equalize the propagation speed of the two different modes using a multilayer structure. This structure also helps to reduce losses of the CPW. In addition, using multilayer structure resulted in reducing coupling between adjacent CPW lines. This is similar to the effects of multilayer structures on coupling and crosstalk in microstrip circuits [4]. The multilayer metal-backed CPW has shown less loss at discontinuities than a similar microstrip line, at least in the case of bends. Measurements presented in this paper show that the multilayer metal-backed CPW structure has an excellent potential in high speed digital transmission media.

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