

Coupling between CPW and slotline modes in finite ground CPW  
with unequal ground plane widths

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# Coupling between CPW and slotline modes in finite ground CPW with unequal ground plane widths

G. E. Ponchak, J. Papapolymerou, and E. M. Tentzeris

The coupling between the desired CPW mode and the unwanted, slotline, mode is presented for finite ground coplanar waveguides with unequal ground plane widths.. Measurements, quasi-static conformal mapping, and Method of Moment analysis are performed to determine the dependence of the slotline mode excitation on the physical dimensions of the FGC line and on the frequency range of operation.

*Introduction:* Finite ground coplanar waveguide (FGC) is often used in low cost Monolithic Microwave Integrated Circuits (MMICs) because of its many advantages over microstrip and conventional coplanar waveguide (CPW). It is uniplanar, which facilitates easy connection of series and shunt elements without via holes, supports a low loss, quasi-TEM mode over a wide frequency band, and since the ground planes are electrically and physically narrow, typically less than  $\lambda/5$  wide where  $\lambda$  is the guided wavelength, they reduce the circuit size and the influence of higher order modes. However, they still support the parasitic slotline mode that plagues all CPW transmission lines.

FGC was developed and is typically modeled as a symmetric transmission line with slot widths and ground planes of equal values. However, in practice, especially in Wilkinson power dividers, rat race dividers, switched line phase shifters, and meander lines, this symmetry is often sacrificed to ease circuit layout. For example, in a Wilkinson power divider, the ground planes between the two  $\lambda/4$  sections are often combined while the outer ground planes are finite. In this letter, the effect of this asymmetry is presented.

*Characterization Methods:* The FGC line with unequal ground planes is shown schematically in Figure 1. Determining or measuring the slotline and CPW modes is difficult and involves measuring the current on each ground plane and then separating it into even and odd modes. Alternatively, the ratio of slotline mode to CPW mode can be found by  $|(C_1 - C_2)/(C_1 + C_2)|$  where  $C_1$  and  $C_2$  are the capacitances between the center conductor and ground planes of width  $B_1$  and  $B_2$  respectively. A first order, static solution is obtained by determining the capacitances through conformal mapping [2]. While approximate, conformal mapping yields quick solutions over the entire parameter space. A 2.5-D Method of Moments (MoM) analysis based on Sonnet software is used to determine frequency dependent characteristics. For the MoM simulations, a CPW mode is excited at the input port and the output port is defined to measure the slotline mode as shown in Figure 1. The line geometry and length for the MoM simulations is the same as for the experimental measurements, 12000  $\mu\text{m}$ .

Measured results are obtained from circuits fabricated on a high resistivity silicon substrate. A Thru-Reflect-Line (TRL) calibration with Ground-Signal-Ground (GSG) probes at both ends of the line is performed using standards fabricated on wafer to de-embed the measurement system and probe pads. At the input port, an airbridge is placed immediately after the probe pads to connect the two ground planes and short out any slotline mode excited by the probes. Circuits are fabricated with  $S$ ,  $W$ , and  $B_1$  of 15, 10, and 45  $\mu\text{m}$  respectively (Case 1) and 50, 28, and 150  $\mu\text{m}$  respectively (Case 2), or  $k = S/(S+2W)$  is 0.43 and 0.47 respectively. For RF characterization, GSG probes are used to excite the CPW mode at the input port and SG probes are used at the output ports to measure the slotline mode as shown in Figure 1. To guarantee the accuracy of the

measurements, SG probes require balanced currents, which do not occur for the CPW excited lines.. Thus, the measurements shall be considered approximate. Lastly, because the output port does not have a probe on the center conductor for the measurements and for the MoM analysis, the CPW mode is terminated in an open circuit, which results in a very high CPW mode reflection coefficient at the input port.

*Results:* Figure 2 shows the ratio of the slotline mode to CPW mode determined by conformal mapping as a function of the ratio of the ground planes. It is seen that the slotline mode is large, -10 dB, when  $B_2/B_1$  is small and decreases to zero when  $B_2/B_1=1$ . Furthermore, the slotline mode is stronger for smaller values of  $k$ . Although not shown, the slotline mode excitation is inversely dependent on the ground plane width  $B_1$  and decreases approximately 4 dB as  $B_1$  is increased from 2S to 5S. . Figure 3 shows the measured ratio of slotline mode to CPW mode as a function of frequency. Although the MoM simulation do not predict a frequency dependence, the measured slotline mode increases with frequency, but this may be an artifact of the unbalanced currents at the SG probes. The maximum slotline mode is  $-18$  dB across the frequency band for  $B_2/B_1 \geq 0.2$  with a degradation of 5-15 dB with respect to the equal ground-size CPW line. The low frequency ( $f < 5$  GHz) values of the measured slotline mode for both FGC lines is shown in Figure 4 along with the MoM solution for the  $S=50\text{ }\mu\text{m}$  line. It is seen that all three methods of analysis demonstrate the same dependence and a similar magnitude of the ratio of the slotline to CPW mode on  $B_2/B_1$ .

## References

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Figure Captions:

Figure 1: Schematic of finite ground coplanar waveguide with unequal ground plane widths.

Figure 2: Ratio of slotline mode to CPW mode in FGC lines with unequal ground planes as predicted by conformal mapping.

Figure 3: Measured slotline mode on FGC lines ( $S=15$ ,  $B_1=45 \mu\text{m}$ ) excited with a CPW mode as a function of frequency.

Figure 4: Measured and theoretical (MoM) slotline mode on FGC lines excited with a CPW mode as a function of ground plane width.

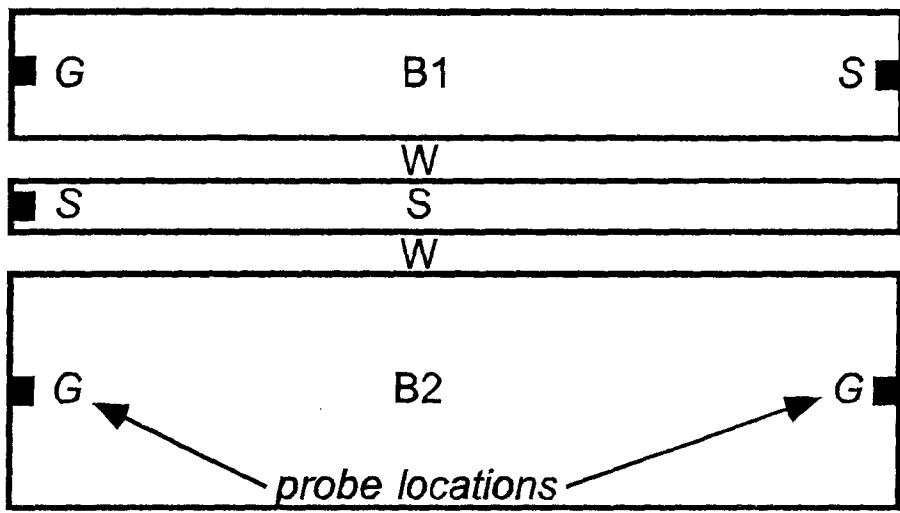


Figure 1: Schematic of finite ground coplanar waveguide with unequal ground plane widths.

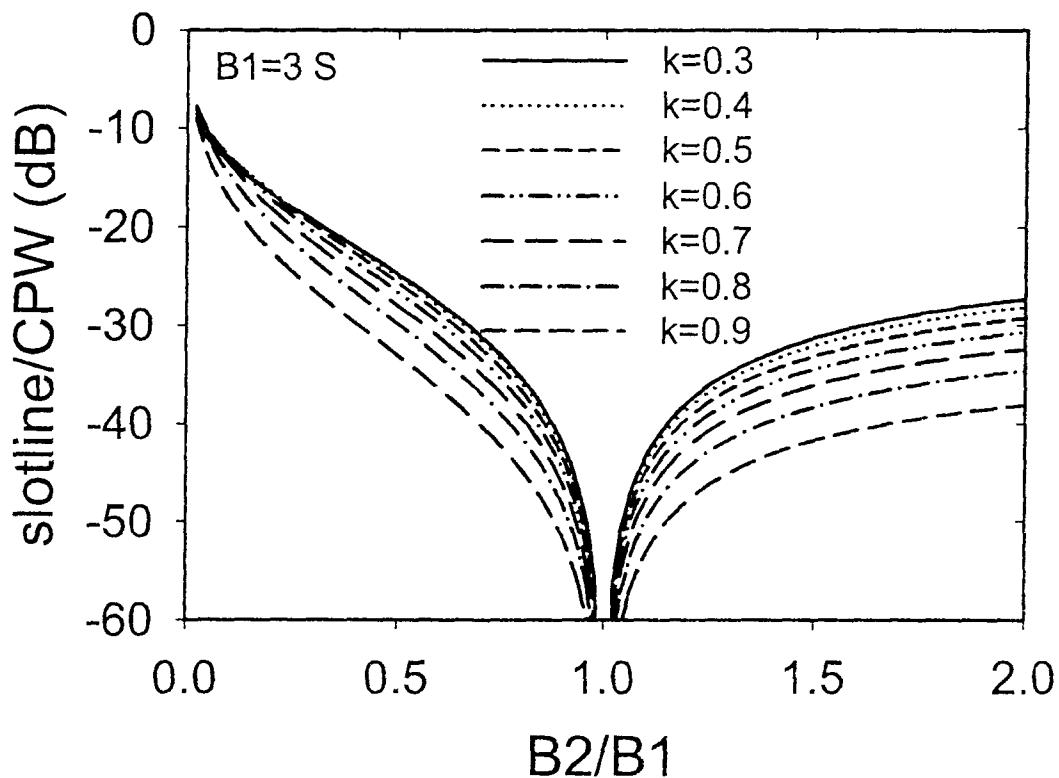


Figure 2: Ratio of slotline mode to CPW mode in FGC lines with unequal ground planes determined by conformal mapping.

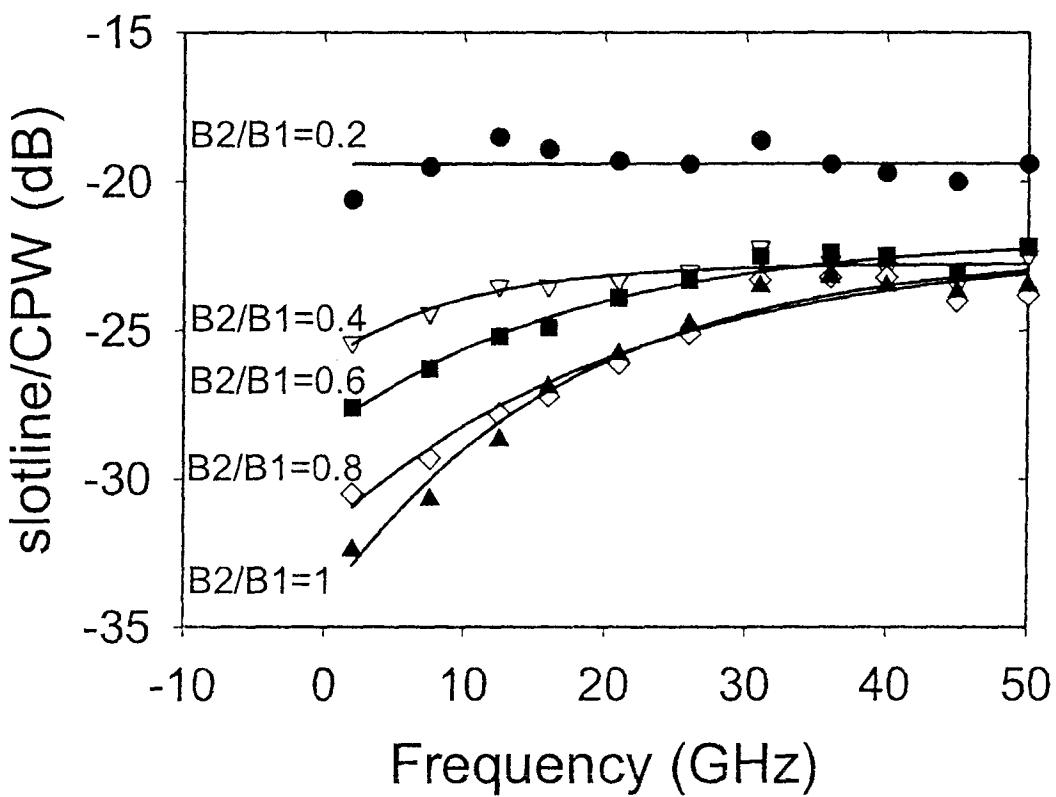


Figure 3: Measured slotline mode on FGC lines ( $S=15$ ,  $B_1=45 \mu\text{m}$ ) excited with a CPW mode.

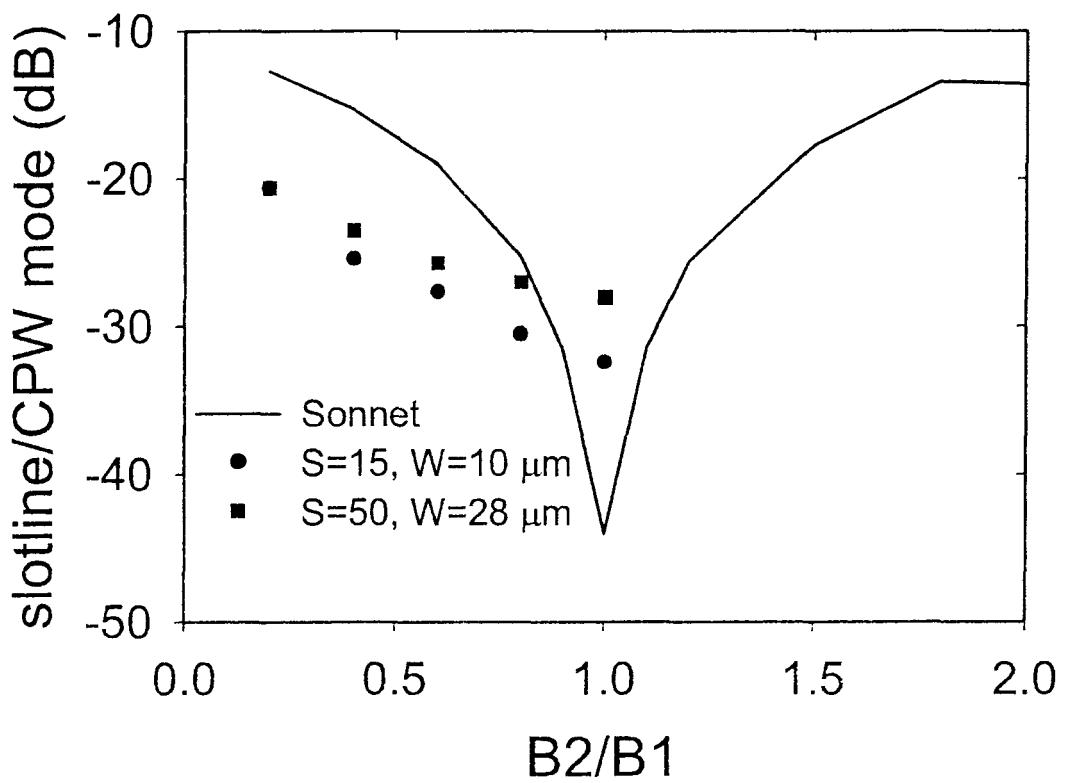


Figure 4: Measured and theoretical (MoM) slotline mode on FGC lines excited with a CPW mode as a function of ground plane width.