ANALYSIS AND MEASUREMENTS OF COPLANAR WAVEGUIDE DISCONTINUITIES

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Abstract - **A technique for characterizing the field distribution and modeling discontinuities in coplanar waveguide discontinuities will be presented. Several passive devices with discontinuities and parasitics have been fabricated on GaAs substrates, analyzed, and the models verified using network analysis and a unique optical sampling technique.**

Parasitic reactances around discontinuities in coplanar waveguide structures are a complicated problem at millimeter wave frequencies for analysis and scaling. Rigorous characterization of these parasitics requires a full-wave analysis. However, generally the line dimensions are such that the local field distribution is dominated by static fields. A characterization technique based on these local static fields, as well as a discretized transmission line equation that recovers the dynamics, will be presented. Several passive devices with discontinuities and parasitics have been fabricated on GaAs substrates, analyzed, and the models verified using network analysis and a unique optical sampling technique [1].

In the quasi-static approximation, the 2-D potential distribution $V(\mathbf{r})$ is related to the charge distribution $\sigma(\mathbf{r})$ by

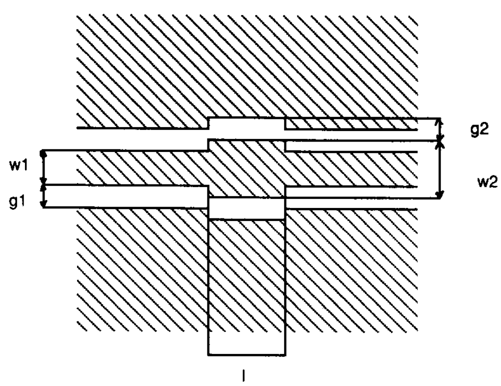

Figure 1: A CPW test structure, where $g_1 = 56\,\mu$m, $w_1 = 80\,\mu$m, $g_2 = 86\,\mu$m, $w_2 = 124\,\mu$m and $l = 335\,\mu$m and all transmission line sections have the same impedance (50 Ω on GaAs substrate).

$$V(\mathbf{r}) = \int_S G(\mathbf{r},\mathbf{r}')\sigma(\mathbf{r}')d^2\mathbf{r}', \qquad (1)$$

where $G(\mathbf{r},\mathbf{r}')$ is the static Green's function for the potential due to a charge on the surface S of a semi-infinite dielectric with relative dielectric constant ϵ_s [2]

$$G(\mathbf{r},\mathbf{r}') = \frac{1}{4\pi\epsilon_0\epsilon_{eff}} \frac{1}{\mid \mathbf{r}-\mathbf{r}' \mid}, \qquad (2)$$

where $\epsilon_{eff} = \frac{1}{2}(1+\epsilon_s)$. In the theoretical analysis of coplanar waveguide structures, we assumed that the voltage is 1 V on the center conductor and 0 V on the ground planes.

The charge distribution is extracted using the moment method:

$$\sigma = G^{-1}V. \qquad (3)$$

Using the "quasi-TEM" approximation for the charge distribution, we can define a new orthogonal coordinate system, where the transverse coordinate is given by the static field distribution. From the transmission line dimensions in this new coordinate system, where z is the longitudinal coordinate, we can find a local TEM impedance:

$$Z(z) = \frac{V}{v_{ph}\int \sigma(y,z)dy}, \qquad (4)$$

where the phase velocity is given by

$$v_{ph} = \frac{c}{\sqrt{\epsilon_{eff}}}. \qquad (5)$$

By solving the transmission line equation with this continuously varying impedance, the coefficients of reflection and transmission along the longitudinal coordinate can be found as

$$R_{i+1} = \frac{r_{i+1} + R_i e^{j2\beta\Delta}}{1 + r_{i+1}R_i e^{j2\beta\Delta}}, \qquad (6)$$

$$T_{i+1} = \frac{t_i T_i e^{j\beta\Delta}}{1 + r_{i+1}R_i e^{j2\beta\Delta}}, \qquad (7)$$

where

$$r_i = \frac{Z_{i-1} - Z_i}{Z_{i-1} + Z_i}, \qquad (8)$$

$$t_i = \frac{2\sqrt{Z_{i-1}Z_i}}{Z_{i-1} + Z_i}, \qquad (9)$$

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Δ is the length of the step and

$$\beta = k\sqrt{\epsilon_{eff}}. \quad (10)$$

Region 0 is connected to a matched load and therefore the initial values are $R(0) = 0$ and $T(0) = 1$. The values for the resulting reflection and transmission coefficients determine the S_{11} and S_{21}, respectively. Similarly, starting the integration from the other port we can obtain S_{22} and S_{12}.

This technique is expected to be valid for frequencies for which we can neglect dispersion in the connecting lines. Also, it is computationally efficient. We have to solve only one 2-D problem to get the charge distribution. Then for each frequency point, equations (6) and (7) have to be solved in order to get S-parameters. Most of the computing time is used for inverting the Green's function matrix, while the time needed to calculate the S-parameters for each additional frequency is negligible.

This general technique, together with the optical sampling technique, allows for the characterization of MMICs. By using the same algorithm, we can generate an equivalent surface charge distribution from the measured 2-D surface potentials. In previous optical sampling measurements, standing wave patterns were measured along relatively long sections of line. However, in MMICs, long sections of line are rarely found. Our electrooptic sampling technique overcomes this difficulty and any discontinuity can be characterized as a local TEM transmission line as discussed above. Also, it does not require knowledge of the metal thickness, because we can use the "surface" Green's function to calculate the equivalent surface charges.

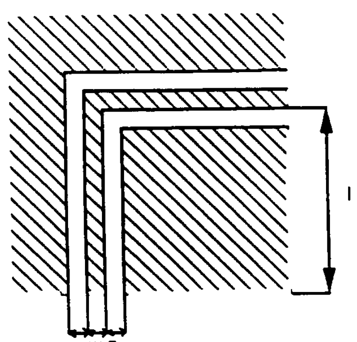

Figure 2: A CPW 56 Ω test structure on GaAs, where $g = 80\,\mu$m, $w = 80\,\mu$m and $l = 160\,\mu$m.

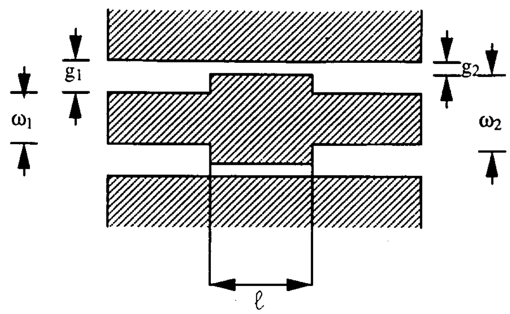

Figure 3: A CPW test structure on GaAs, with $g_1 = 86\,\mu$m, $w_1 = 120\,\mu$m, $g_2 = 46\,\mu$m, $w_2 = 200\,\mu$m and $l = 500\,\mu$m. The middle section has an impedance of 37 Ω and the other two sections of 50 Ω.

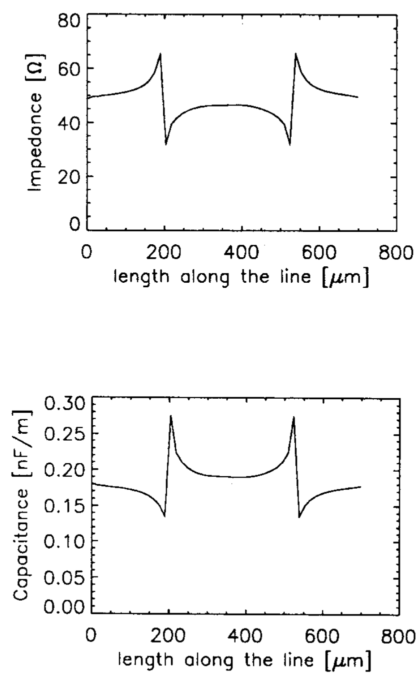

Figure 4: The capacitance and impedance as a function of the propagating coordinate for the test structure shown in Figure 1.

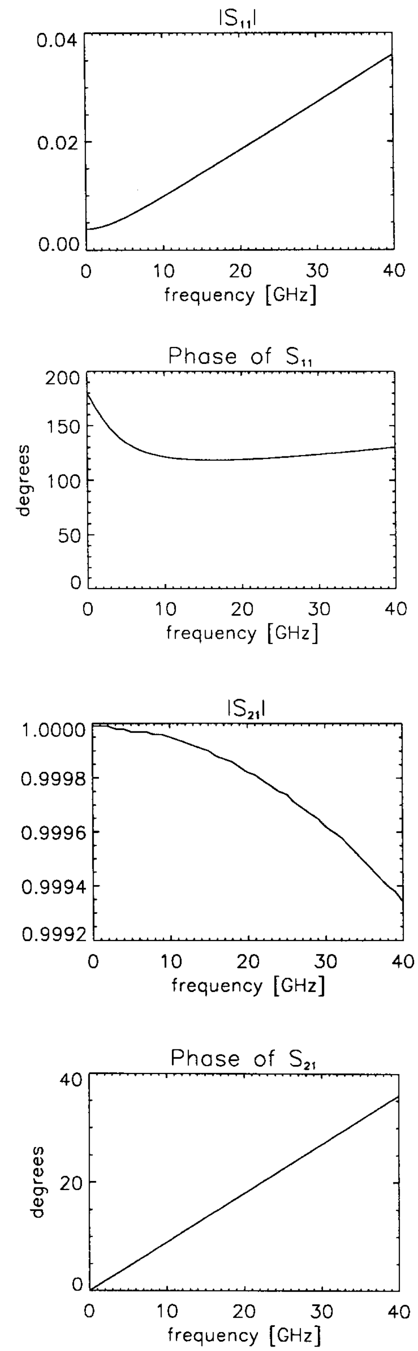

Figure 5: The calculated S-parameters for the 56 Ω CPW bend on GaAs, from Figure 2.

Test structures that we have analyzed include: a CPW structure with several sections of the same impedance, but different geometry, Figure 1; a CPW bend, Figure 2; and a double step-in-impedance in CPW, Figure 3. The impedances of these structures were found from quasi-static formulae given in [3].

For each of these structures, the potential and charge distributions, capacitance, impedance, reflection and transmission coefficients along the propagating direction and S-parameters were found. Examples of these results are shown in Figures 4,5,6 and 7. Figure 4 shows the capacitance and impedance as a function of the propagating coordinate for the test structure shown in Figure 1. Figure 5 shows the calculated S-parameters for the 56 Ω bend from Figure 2. Figures 5 and 6 show the measured 2-D potential distribution and the measured and calculated charge distribution for one cross-section for the structure from Figure 3.

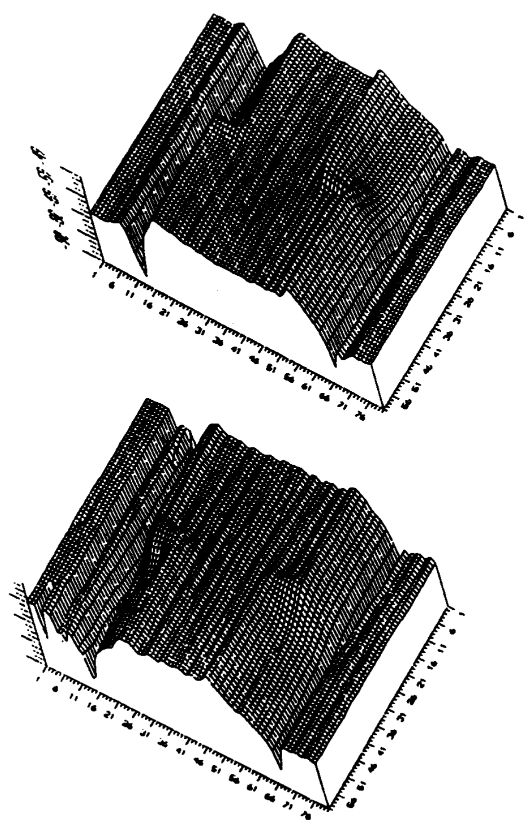

Figure 6: The measured 2-D potential distribution for the structure from Figure 3.

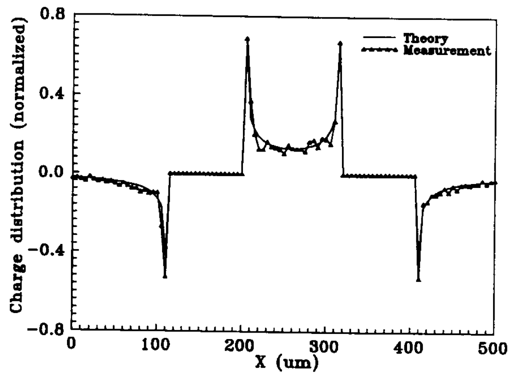

Figure 7: The measured and calculated charge distribution for one cross-section for the structure from Figure 3.

References

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