Broadband Measurement of Asymmetric Coupled Lines Built in a 0.25 µm CMOS Process

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This paper investigates the properties of asymmetric coupled lines built in a standard 0.25 µm CMOS technology in the frequency range of 50 MHz to 26.5 GHz. We show that the frequency dependent line parameters extracted from calibrated four-port S-parameter measurements agree well with data predicted by numerical calculations. We use the electrical model for multiconductor transmission lines and the nonlinear regression method presented in [1] for the analysis. To our knowledge these are the first complete high-frequency measurements of the line parameters for asymmetric coupled lines on silicon ever reported.

The cross section of the lines we studied is shown in Fig. 1, and the top view of the coupled line system is shown in Fig. 2. The first conductor has a width of 1 µm, and the second a width of 10 µm. The two coupled lines are separated by a gap of 1 µm. The metal thickness in layer 2 is 0.7 µm, and the metal conductivity is 27.8×10^{6} S/m. The asymmetric coupled lines are surrounded by 20 µm wide grounds that are connected to the substrate with via arrays connected through all 6 metalization layers. The lengths of the coupled line segment are 0.5 mm, 1.0 mm and 2.5 mm.

The test structures differ from the experimental setup described in [1] in several important aspects. The skin effect in the conductive substrate leads to an even more complex frequency dependent behavior. The vias between the metal layer where the measurement contact is made (metal 6) and the layer where the coupled line systems are built (metal 2) have to be taken into account. In addition the access lines that connect the vias and the coupled line segment in metal 2 are subject to the same substrate effects as the coupled line segment, and must also be accounted for.

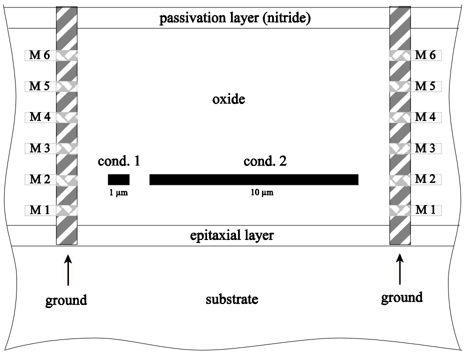

Figure 1: Cross section of test structures

The calibration procedure used for the four-port measurement is described in [2]. It eliminates the need of orthogonal calibration standards and requires only three in-line calibrations. To this end we calibrated the system “at the probe tips” using coplanar waveguide standards and the multiline TRL procedure of [3].

Since the initial reference plane position of the four-port calibration [2] is near the probe tips, we required an additional deembedding step to account for the access lines. We employed a second-tier TRL calibration in the access lines for this purpose, using the propagation constant from the TRL calibration to set the reference planes to the beginning of the coupled line segment (marked A in Fig. 2) and the calibration comparison method [4] to set the reference impedance to 50 Ω.

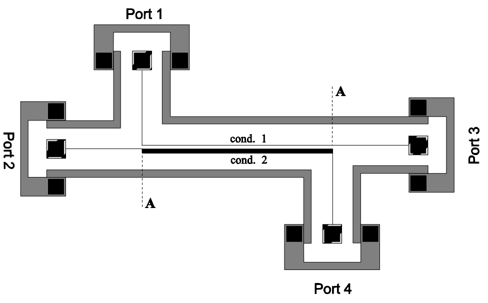

Figure 2: Top view

We determined the matrices of line parameters $\boldsymbol{R}_\mathrm{c}, \boldsymbol{L}_\mathrm{c}, \boldsymbol{G}_\mathrm{c}$, and $\boldsymbol{C}_\mathrm{c}$ in the conductor representation [1]. The voltage paths were chosen between each of the two conductors and the ground. We ignored the discontinuities between the single-mode access lines and the multi-mode coupled line segment in our analysis.

We estimated $\boldsymbol{R}_\mathrm{c}, \boldsymbol{L}_\mathrm{c}, \boldsymbol{G}_\mathrm{c}$, and $\boldsymbol{C}_\mathrm{c}$ from the four-port measurement data using ODRPACK, an implementation of the weighted orthogonal distance regression algorithm of [5] using the procedure described in [1]. This procedure solved for all of the elements of the line-parameter matrices at each frequency independently. The starting values for the lowest frequency were calculated with the method of [6], and the results of the optimization at each frequency point were used as starting values for the optimization at the next higher frequency point.

We also used ODRPACK to characterize the random error in the redundant four-port measurement data. The analysis implemented in ODRPACK determines the 95% confidence intervals for the estimated results over the entire frequency range under the assumption that the error sources in the experiment are entirely random, independent and normally distributed.

Figure 3 shows the estimated resistance per unit length of the asymmetric coupled-line system (labelled “measurement”), the lower and upper bounds for the confidence intervals (dashed lines), and the line parameters calculated from the quasi-analytical formulas given in [6] (labelled “calculation”). The agreement between measured and calculated values is good over the entire frequency band. However, some of the calculated values fall outside of the 95% confidence intervals for the estimated parameters. This is a clear indication that there is still some systematic error in either the measurements or the calculations. Possible sources of systematic error in the measurements include the proper consideration of the four-port error boxes describing the transition between access lines and coupled line segment. Errors in the calculations might be due to quasi-TEM approximations used in [6] and to uncertainties in the information from the manufacturer about the cross-sectional parameters of the six layer CMOS process.

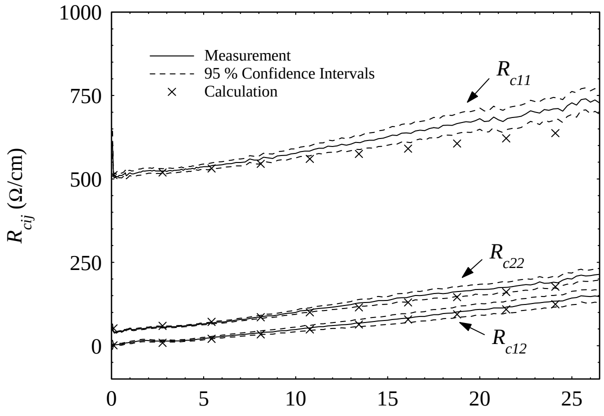

Figure 3: Resistances per unit length

ACKNOWLEDGEMENT

This work was supported in part by the Automatic Radio Frequency Techniques Group (ARFTG).

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