Microwave Characterization of Thin-Film Multi-Chip Module Substrates and Printed Wiring Boards Accounting for Frequency-Dependent Characteristic Impedance

Michael B. Steer and Paul D. Franzon,

Picosecond Digital Systems Laboratory and the Department of Electrical and Computer Engineering, North Carolina State University, Raleigh, NC 27695-7911.

SUMMARY

Characterization of the transmission line properties of multi-chip module substrates and of printed wiring boards has generally been achieved using the through-reflect-line (TRL) calibration method [1]. TRL's major shortcoming is that the accuracy depends predominantly on the estimate of the characteristic impedance, Z_C, of the line. Error in determining Z_C leads to a systematic measurement error. If the estimated characteristic impedance of the line is in error, all deembedded impedance measurements of a DUT will be in error by the same factor.

A new measurement technique [5], the through-line (TL) method, is used here to replace the through-reflect-line (TRL) deembedding procedure and eliminates both of the problems referred to above. Otherwise TL is very similar to TRL.

TL is implemented in three steps:

Step 1 Apply open-short-load (OSL) calibration to each of the two test ports. The OSL calibration need not be precise, the only requirement is that the same reference impedances be presented to the two ports. The test ports will not be precisely calibrated but now the test ports can be modeled as shown in Fig. 1 where the error networks A and B are identical. The error networks may include fixturing parasitics when the fixtures are used with a media, or pad arrangement other than that used during OSL calibration.

Step 2. Perform through and line measurements. Because of symmetry the through measurement yields the reflection coefficient of an ideal short placed at the fixture reference plane, see section II. This removes the need for using the arbitrary reference in the TRL calibration algorithm thus removing the major source of phase ambiguity. This will be mathematically demonstrated in the full paper. We now have sufficient information to implement conventional TRL calibration if we so choose.

Step 3. Determine the frequency-dependent characteristic impedance of the line used in step 2. Several workers have presented techniques for estimating this impedance. We propose a new method for determining the characteristic impedance based on the high-frequency

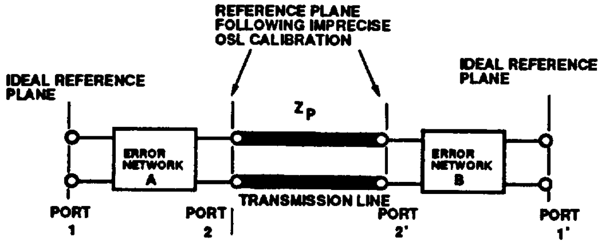

Figure 1: Error networks following approximate OSL calibration.

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asymptotic behavior of a transmission line and free-space capacitance calculation. The free-space capacitance calculation requires the conductor cross-section and free-space capacitance calculation. The free-space capacitance calculation requires the conductor cross-section.

The three steps together yield precise calibration. TL takes into account the frequency dependent characteristic impedance of the line and provides accurate in-situ calibration. Furthermore the glitches associated with TRL deembedding are largely eliminated and this is achieved by implementing steps 1 and 2 alone.

The method may be implemented using existing calibration substrates. All that is required is the free-space capacitance of the line standards. This is readily obtained once the conductor cross-section is determined. Alternatively, a characteristic impedance versus frequency characteristic could be supplied by the vendor of the calibration substrate.

II DETERMINATION OF Z_C

Recently several workers have used non-microwave measurements or additional knowledge to determine Z_C. Most recently Marks and Williams [3] calculate the capacitance, C, of the line and, by assuming that the conductance, G, of the line is negligible, determine Z_0. In a later paper [4] they present two techniques for determining C from measurements. The first of these uses extrapolated low frequency S-parameter measurements and DC resistance measurement to determine the quasi-static line capacitance. The second technique is erroneous as it neglects the difference between Z_C and the measurement reference impedance, Z_{ref}.

The aim of the work presented here is to determine the complex characteristic impedance of the transmission line standard used in TRL-type deembedding techniques. The approach taken here is to first neglect R and internal conductor inductance, L_{int}, of the conductors at the highest measured frequency so that an approximate high frequency effective relative permittivity can be determined. The frequency dependent relative permeability, $\mu_{r,\text{eff}}$, is determined and thus, combined with the calculated free-space capacitance C_0,

$$Z_C(f) = -j\frac{\gamma(f)}{\epsilon_{r,\text{eff}}\,\omega C_0} \tag{1}$$

III MEASUREMENTS

The above method was used to determine Z_C of a 4 cm. long embedded microstrip line on a thin-film substrate for use in an advanced multichip module. C_0 was found to be 54.5 pF/m using boundary element analysis and the skin depth, δ is half the microstrip thickness at 733 MHz. The dimensions of the line are shown in Fig. 2(a). From measurements of a through and the 4 in. section of line γ was determined [2] and subsequently Z_C evaluated, see Fig. 3(a). The measurements were repeated for a 4 in. long embedded microstrip line on a printed wiring board with dimensions shown in Fig. 2(b), C_0 = 31.6 pF and δ is half the microstrip thickness at 1.2 MHz. Z_C of this line is given in Fig. 3(B). Notice that in both cases the real part of Z_C falls with frequency and is asymptotic due to the internal inductance becoming less significant. Also the imaginary part is negative at very low frequencies indicating the conductor resistance is then the dominant loss mechanism. At higher frequency the dielectric loss appears to dominate however this is the assumption behind the technique used to derive the characteristic impedance.

ACKNOWLEDGEMENT

We wish to express our appreciation to Glenn Rinne and Iwona Turlik of MCNC for providing the MCM data.

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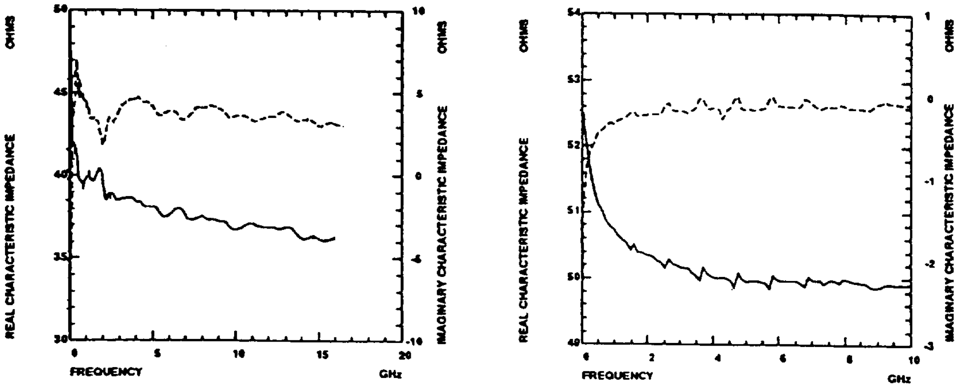
(a) (b)

Figure 2: Cross-section of microstrip transmission line (a) thin-film, (b) printed wiring board.



(a) (b)

Figure 3: Characteristic impedance versus frequency, (a) thin-film, (b) printed wiring board.