Lumped-Element Impedance Standards

Dylan F. Williams and David K. Walker
National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303
Ph: [+1] (303)497-3138 Fax: [+1] (303)497-3122 E-mail: dylan@boulder.nist.gov

Abstract- **We measure the electrical parameters of commercial lumped-element impedance standards manufactured for the calibration of on-wafer probing systems. The standard's impedance depends not only on the standard itself, but also on probe placement, probe construction, and the reference calibration.**

INTRODUCTION

We present electrical measurements of lumped elements fabricated on a commercial impedance standard substrate. The measurements show that the impedances of these lumped elements, which are intended for use as calibration artifacts, depend on probe placement, probe construction, and the calibration selected as a reference for the measurements.

References [1], [2], and [3] document some of the differences between on-wafer thru-reflect-line (TRL) calibrations [4] in different lines. In essence, calibrations developed for a particular substrate, set of contact pads, and transmission line do not measure scattering parameters accurately on another substrate or pad configuration without some adjustment of the calibration.

In 1990, Lautzenhiser et al. [5] and Davidson et al. [6] showed that the reactance of lumped resistors is a function of probe placement.

There is also nothing new in the notion that the impedance of a lumped-element calibration standard depends not only on the standard itself, but on the probe construction. In fact, one probe manufacturer includes a table on the inside of the probe package listing appropriate values of open, short, and resistor parasitics for different probe types, and has patented calibration software [7] to generate these values automatically when used with the manufacturer's calibration substrate.

However, the studies of [5], [6], and [7] investigated measurements of the electrical parameters of lumped elements corrected by calibrations based on those same lumped elements, or corrected by calibrations based on impedance standards whose contact geometries differed significantly from each other. This made the results difficult to interpret, since the calibrations were designed to map the standards into their definitions, and the calibrations did not account for differences between contacts.

This work employs a different and straightforward approach for investigating lumped standards. We first calibrate a number of probes of different pitches and constructions with a single well-understood broadband TRL calibration [4] with reference impedance correction [8]: this calibration accurately measures the impedances of devices embedded in the transmission lines on which the TRL calibration was based. Then we measure the impedances of commercial lumped-element calibration standards with this standard reference calibration, and investigate the differences due to probe type and placement.

TRL REFERENCE CALIBRATION

Our TRL reference calibrations were performed with the multiline algorithm of [4] and a 550 μm long coplanar waveguide (CPW) thru line, five longer lines of length 2.685 mm, 3.75 mm, 7.115 mm, 20.245 mm, and 40.55 mm, and two shorts offset 225 μm from the beginning of the line, all fabricated on a semi-insulating gallium arsenide (GaAs) substrate. The CPW had a center conductor width of 64 μm separated from two 261.5 μm wide ground planes by two 42 μm gaps. We moved the reference plane of the calibration to 25 μm in front of the physical beginning of the lines and set the reference impedance to 50 Ω using the procedure of [8]. While these choices are arbitrary, the resulting

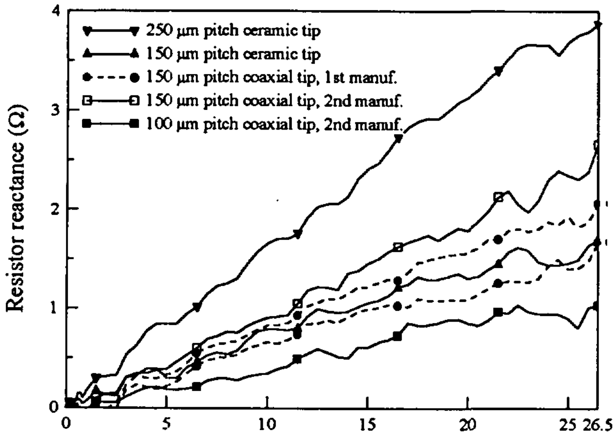

Fig. 1. The reactance of a lumped resistor measured with respect to the TRL reference calibration.

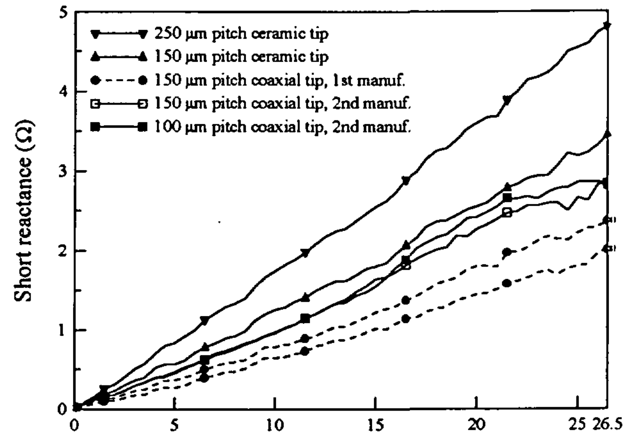

Fig. 2.The reactance of a lumped short measured with respect to the TRL reference calibration.

calibration corresponds to the accepted definition of a "probe-tip" calibration.

LUMPED-ELEMENT MEASUREMENTS

We used our TRL reference calibration to measure the impedances of a lumped resistor and a short fabricated on a commercial calibration substrate. Figures 1 and 2 compare the reactance of the lumped resistor and short measured with several ceramic and coaxial tipped probes. The two dashed curves correspond to measurements repeated with the same probe and provide an indication of our measurement resolution.

Although the noise in the measurements is large, Fig. 1 shows a clear correlation between the reactance of the lumped resistor and the probe pitch. This is not surprising, as the distance that the currents must travel through the contact bars to the resistor is proportional to the pitch of the probe. Figure 2 shows a smaller correlation between the reactance of the short and probe pitch, but also indicates that there may be a correlation between the reactance of the short and probe construction.

PROBE PLACEMENT

Only consistent probe placements are required to obtain accurate measurements with the TRL calibration. This is because the TRL calibration measures impedance or scattering parameters in the transmission line used for the calibration, not "at the probe tips."

Since our CPW contacts differ significantly from the contacts to the lumped elements, there was no way to place probes consistently on our TRL standards and the lumped element. Figure 3 shows the reactance of the lumped short as a function of three different but equally valid placements of the probe on the short. The figure shows small but easily measurable differences in short reactance at these different positions, confirming the results of [5] and [6].

CHOICE OF REFERENCE CALIBRATION

Our choice of a GaAs TRL reference calibration was arbitrary. Figure 4 compares measurements of the reactance of the lumped resistor measured with respect to a TRL calibration using CPW lines fabricated on quartz, rather than on GaAs. The figure shows clearly that the reactance of the lumped resistor also depends on which calibration the measurement is referred to. Reference [3] investigates differences between GaAs and quartz TRL calibrations in depth, showing that these differences can be attributed to differences in contact pad capacitance on the two wafers.

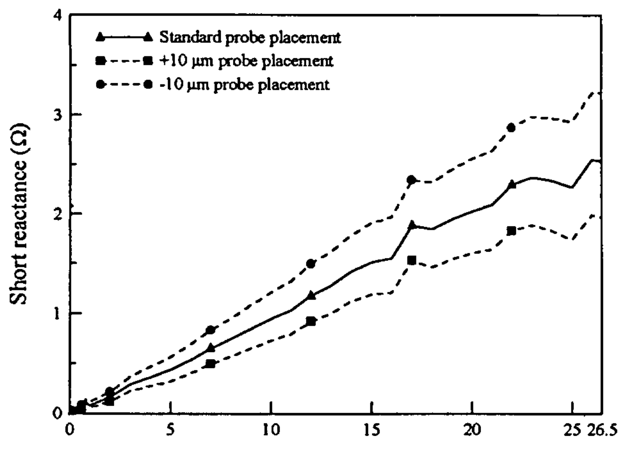

Fig. 3. The reactance of a lumped short measured with respect to the TRL reference calibration for three different, but equally valid probe positions. The curve labeled "Standard probe placement" corresponds to the placement used in all our other experiments. Here the tip of the probe contacts are approximately 10 μm from the far edge of the short bar. The two dashed curves correspond to probe placements approximately ±10 μm from our standard placement.

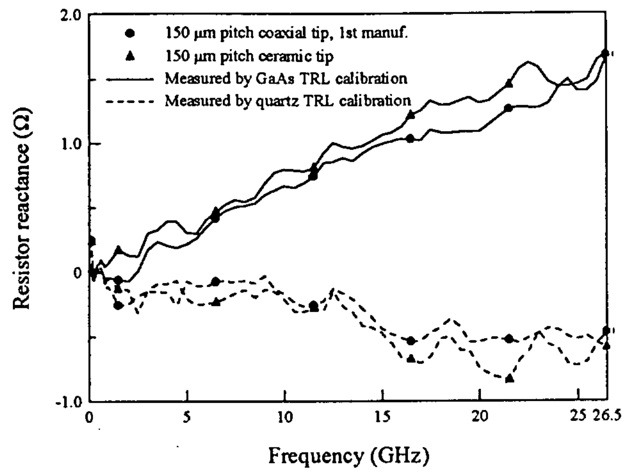

Fig. 4. The reactance of a lumped resistor measured with respect to GaAs and quartz TRL reference calibrations.

CONCLUSION

Our experiments show that the impedances of lumped electrical circuits measured by a TRL reference calibration depend on the probe type, the probe construction, and the probe placement, as well as on the reference calibration with which the measurements are corrected. This implies that it is not possible to assign a unique impedance to lumped-element calibration standards; these results are supported by [5] and [6].

Our experiments also imply that two different probes calibrated with the same lumped-element standards and procedures will measure different impedances. This contrasts with the TRL approach, in which devices are embedded in transmission lines, the reference plane is found inside those lines, and the measurements are independent of the probe type.

ACKNOWLEDGMENTS

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