Optimized Impedance Standard Substrate Designs for Dual and Differential Applications

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Abstract -- **Optimized dual signal Impedance Standard Substrate (ISS) designs are demonstrated. The optimal designs had loop-under grounds, were selected for minimum deviation from lumped element behavior and used mode dampening structures. A comparison of existing design approaches is given and the quality of the designs is illustrated to 50GHz.**

I. INTRODUCTION

Historically, most wafer probe measurements use two single transmission line probes opposing each other. The most popular probe configuration is ground-signal-ground (GSG), due to it's well behaved launch from the probe tips to the substrate [1]. Undesired modes that can occur at the launch are microstrip mode (sometimes referred to as parallel plate mode, to the DUT ground plane [2]) or slotline mode between the two grounds [3]. Both probe calibration structure and DUT transitions need to be well designed to minimize mode conversion by virtue of their symmetry and small size relative to a wavelength.

To characterize planar differential/mixed-mode or multiport devices, more transmission lines are required in each probe head. One common configuration is a ground-signal-ground-signal-ground (GSGSG) but the additional conductors and the increased size of the standards increases the likelihood of mode conversion. This paper details the optimization of short, open, load and thru calibration structures for GSGSG probe configurations in the pitch range of 100 to 250 microns. The calibration structures make use of a number of features to dampen the mode conversions that are inherent in the larger structures necessary for dual signal probes. These include loop-under grounds, opens on the substrate, microwave absorber and the use of thin-film resistor elements.

II. LOOP-UNDER GROUNDS

A coplanar waveguide (CPW) structure will have an imbalance of energy if the length of one slot is longer than another as in [3] and the grounds are not tied together. This imbalance will lead to mode conversion, and if the line is long enough or if the frequency is high enough resonant behavior may be observed. A 50 micron signal and 25 micron gap CPW on alumina has a 130 micron per picosecond propagation velocity [4], or approximately 7.2 microns per degree at 50GHz. A number of effects, including probe asymmetry, slot lengths and widths and probe placement can add up to result in a significant phase difference in the slots and undesired mode conversion.

The mode conversion problem is compounded with dual signal probes and structures since the outside grounds are that much farther away for a given pitch. As well, the probe grounds are longer on the outside than in the center as shown in the photograph in figure 1 below. Regardless of how the probe is manufactured, the length of the gaps or the probe fingers will never be perfectly matched.
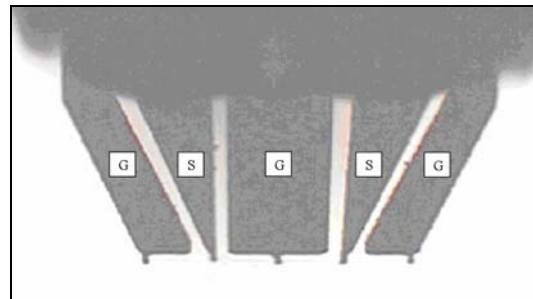

Fig. 1 – Photograph of the tip of a 250 micron pitch ground-signal-ground-signal-ground   (GSGSG)

probe to illustrate the difference in ground and gap lengths.

It is also difficult to insure perfect angular alignment to what is being probed. Tying the grounds together under the probe adds an additional capacitance to the signal but the benefit of the short path from one ground to the other is enormous. Figure 2 illustrates the effect for calibrated probes, probing tied and untied CPW transmission lines.
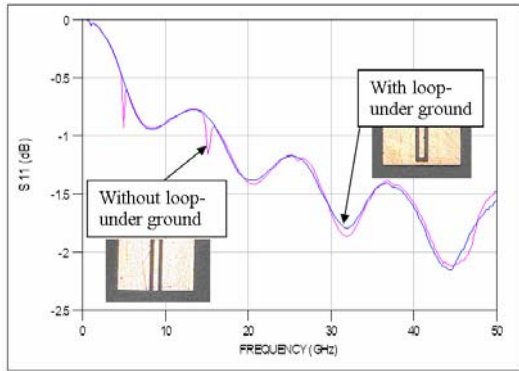

Fig. 2 – Illustration of the effect that loop-under grounds have on undesired modes. The measurements were of otherwise identical 40ps CPW lines – one with loop-under grounds and one without.

III. LUMPED ELEMENT BEHAVIOR OPTIMIZATION

The SOLT calibration method that is used on most network analyzers [e.g., 5] requires known characteristics of the open, short and load standards. The quality of the calibration is determined by how well the standards used fit the models in the vector network analyzer (VNA).

The state-of-the-art for multi-port calibrations is to accomplish the required number of calibrations single-ended and to terminate the unused ports in the VNA. This configuration was emulated while testing the candidate structures for each of the one-port standards. Two GSGSG probes of the appropriate pitch were used with the top two of four possible probe signal paths connected to port one and two of the VNA and the bottom two probe signal paths terminated with broadband loads.

Each new candidate structure was measured and the set of one-port standards that best fit the lumped element models was empirically determined with the following sequence of steps:

1. LRRM [6] calibration with new set of structures
2. Re-measure Short, Open and Load,
3. Fit each of these to a lumped model,
4. Determine the deviation of the measurements from the lumped models,
5. Use lumped model values of these structures for Short, Open and Load calibration coefficients,
6. Perform calibration with SOLT and newly generated coefficients,
7. Use this calibration as well as previous LRRM calibration to compare the measurements of a verification structure without moving the probes. Typically this was a 40ps CPW line probed from only one end (open stub).

Software like WinCal* and Nucleus* can simplify the data collection but for each calibration structure, all the others available in the SOLT set of structures were used to find the combination that produced the best calibration. The number of calculations grows quickly but decision making is reduced to comparing three values per set of one port standards.

LRRM was used in the first step because the calibration method does not rely on completely known behavior in the calibration math. SOLT requires perfect knowledge of the standards behavior. This means that if SOLT were used on an imperfect standard, measuring that standard again would result in a near perfect response that
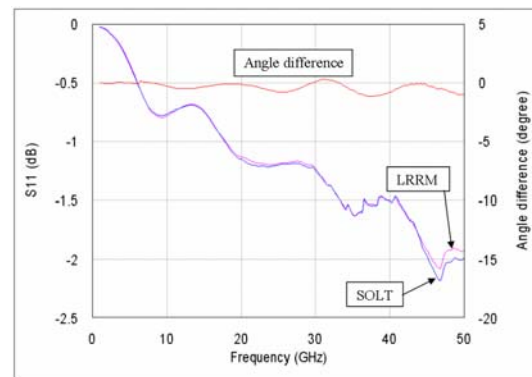

Fig. 3 – Measurement of a CPW, 40ps line with both the LRRM and SOLT techniques to illustrate the agreement between the two methods.

is limited only by the repeatability of the measurement system and probe placement. In figure 3 above, the 40ps open stub of the 100 to 125 micron pitch, GSGSG configuration ISS is measured with both the LRRM and SOLT techniques.

The open has typically been measured by raising the probes into the air 200 microns or more above the wafer. This results in an extremely repeatable measurement since probe placement is not an issue. However, with loop-under grounds on all the other standards, the difference in the first pass qualification with LRRM as mentioned in step 4 above determined that the open pads with loop-under grounds provides superior results.

IV. OTHER MODE DAMPENING STRUCTURES

The loop-under grounds short the conversion of energy from coplanar to slot line mode very close to the probe tip. However, the larger a structure becomes and the higher the frequency, the more likely another mode will be excited. For this reason, the use of microwave absorber is recommended for the dual ISSs at higher frequencies. The microwave absorber used has a non-unity relative permeability at microwave frequencies. Energy that is excited in, for instance, the microstrip mode [7] which relies on a reflective, metallic back surface of the calibration substrate is at least partially absorbed. A measured difference is illustrated in figure 4.
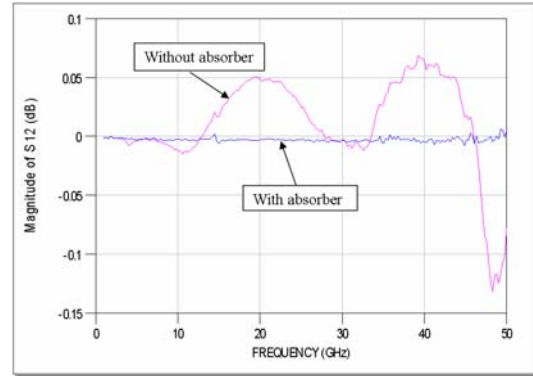

Fig. 4 – Comparison of the measurement of a two picosecond CPW thru with and without microwave absorber under the ISS.

Another mode dampening technique is to use thin film resistors on the edges of the calibration structures to terminate mode or resonant energy. As the structures get larger they resonate at lower frequencies. The GSGSG configuration at 250 micron pitch is the largest of all the ISSs developed in this work. The pitch and balanced ground widths on the double-CPW structure set the length of each calibration structure at 1400 microns and the width is set by the thru delay and loop-under grounds and is 525 microns. Figure 5 shows three of the calibration structures with the width going left to right and the length up and down for the metal structure only. This structure can be made to resonate if stimulated properly and the resonant frequency is near 33GHz. If the length were not 1400 microns but longer, the resulting line on 25 mil alumina would have a microstrip characteristic impedance of around 56 ohms. The resonance of the 1400 by 525 micron structure can be eliminated by terminating the end of the structure with a 56 ohm thin film resistor as in the illustration below. In this case, black is metal and grey is 50 ohms per square thin film resistor.
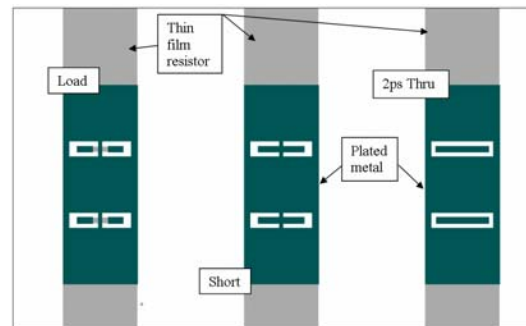
Fig. 5 – Load, short and thru calibration structures with microstrip loads on top and bottom to eliminate 33GHz resonance.

Fig. 6 – S11 response of the short with and without resistive termination of the microstrip mode.

The same could be done on the left and right sides but this resonant frequency is predicted to be of too high to be of concern in this work. In figure 6 the S_{11} response of the short with and without the resistive terminations of figure 5 are shown. We speculate that the smaller spikes that occur every 2.5GHz after 30GHz are associated with the noise floor of the network analyzer.
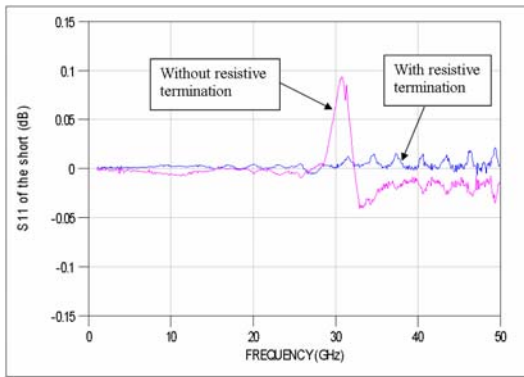

III. SUMMARY AND DISCUSSION

Optimized Impedance Standard Substrate designs have been presented along with rationale for the design choices that were made. Since the nature of the structures is mode converting, these characteristics need to be accounted for and removed wherever and however possible. Three mode removal techniques were used for these designs as well as lumped element fit optimization. The resulting structures allow excellent multi-port VNA calibration through 50GHz.

References

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