NOVEL COPLANAR STRIPLINE: DESIGN, CHARACTERIZATION AND APPLICATIONS

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ABSTRACT

Up to this point, Coplanar Waveguide (CPW) has been the coplanar transmission line of choice for microwave probes and coplanar GaAs interconnect, while Coplanar Stripline (CPS) has found very limited use. The reason for this is that the traditional CPS is not nearly as well behaved as CPW. The CPS would find wide use, due to the significant real estate savings, if it would perform adequately.

This paper presents a novel approach to CPS design that produces CPS which performs nearly as well as CPW and requires only 65% as much real estate. The measured complex characteristic impedance of this novel CPS will be given as a function of frequency. Also, its performance as a Line-Reflect-Line calibration element will be demonstrated.

INTRODUCTION

In the world of on-wafer measurements, coplanar transmission lines are a necessity. Microwave probes are a coaxial to coplanar transmission line adapter. The on-wafer launch is always coplanar; even if the on-wafer transmission line type is microstrip. Coplanar transmission lines are also used as Line-Reflect-Line (LRL) calibration elements, both on Sapphire and GaAs, as well as interconnect elements for coplanar GaAs MMIC's.

Up to this point Coplanar Waveguide (CPW) has been the dominant coplanar structure for both microwave probes and coplanar GaAs interconnect. The coplanar GaAs MMIC's, usually on a 20-25 mil thick wafer, use CPW almost exclusively. Coplanar Stripline (CPS), See Figure 1, has found very limited use. Even the two-conductor probes (Signal-Ground or Ground-Signal) use CPW until just before the tip, where they convert to CPS. These GS/SG probes are used almost esclusively for 4 mil thick GaAs wafers which transition immediately to microstrip after the coplanar on-wafer probe launch.

The reason for the dominance of CPW is that the traditional CPS is not nearly as well behaved as CPW. However, if the CPS would perform properly, it would find wide use due to the significant real estate savings.

This paper presents a novel approach to CPS design that produces CPS which performs nearly as well as CPW and requires only 65% as much real estate. The measured complex characteristic impedance (Zo) of this novel CPS will be given as a function of frequency. Also, its performance as a Line-Reflect-Line calibration element will be demonstrated.

DESIGN and GEOMETRY

The geometry of the asymmetrical CPS is shown in Figure 1. For a given signal conductor width, W1, a ground conductor width, W2, that is wider than W1 allows the gap width, g, to be larger for a given impedance. This increases manufacturability and decreases the sensitivity to variations in conductor thickness.

The structure shown in Figure 1 has significant advantages over simple symmetrical CPS, but the really novel part of this design, what really makes this structure perform, is a layer of nichrome on the backside of the substrate [6] -- as shown in Figure 2. Note that the substrate should be placed on a quartz spacer for maximum parasitic mode suppression [3].

To show the improvement that the back-side nichrome (BSNC) makes, two different CPS structures were built. Both CPS structures have the pattern shown in Figure 1 on the front side of a 20 mil Sapphire substrate. However, one CPS structure has BSNC and the other does not. Both CPS structures are 4.825 mm long. The effect of the quartz spacer is also demonstrated.

PERFORMANCE TESTS on CPS

A SG probe was calibrated at the probe tip using Open-Short-Load (OSL) calibration elements. Then the two different CPS structures, one with BSNC and the other without, were probed on one end; thus, an Open Stub was measured. Both CPS structures were measured with and without a quartz spacer between the Sapphire and the metal wafer chuck. Figures 3 and 4 show the results of these measurements.

Note that a very small scale, 0.2 dB/div, was used for the Figure 3 and Figure 4 plots. You can see from Figure 4b that the CPS with back-side nichrome, on a quartz spacer, is far superior to the CPS without the BSNC (either with or without a quartz spacer). Note that the quartz spacer definitely improves the performance of the CPS structure, but most of the improvement is due to

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the BSNC. The BSNC is suppressing parasitic microstrip and dielectric modes. It can be shown mathematically that much of the field that was coupling with the metal wafer chuck is now terminating in the nichrome layer.

The performance of an Open Stub is a good indication of how the CPS will perform as an interconnect element. In general, modes are more easily excited when the line is terminated in a high impedance than when it is terminated in 50 ohms.

CHARACTERIZATION of CPS with BSNC on a QUARTZ SPACER

Using different lengths of CPS as LRL calibration elements, in conjunction with the NIST multiline LRL software (DEEMBED) [1,3], we can quantitatively determine the complex effective permittivity (Eeff) vs frequency. Then we can use a 50 ohm termination, at a low frequency, to find the electrostatic capacitance/meter, C, of the CPS. The complex characteristic impedance, as a function of frequency, can then be calculated using Equation 1 below [2,3].

Zo = sqrt(Eeff) / (3E+8 * C)   Equation 1

Figure 5 shows the complex Zo of CPW on 20 mil Sapphire. From 5 to 40 GHz, the imaginary part of Zo, IM(Zo), has a mean of -0.48 ohms and a standard deviation of 0.12 ohms. Looking at the Re(Zo), from 5 to 40 GHz, the mean is 48.70 ohms and the standard deviation is just 0.12 ohms.

Figure 6 shows the complex Zo of CPS with BSNC. From 5 to 28 GHz, the imaginary part of Zo has a mean of -0.91 ohms and the standard deviation is 0.21 ohms. Looking at the Re(Zo), from 5 to 28 GHz, the mean is 45.59 ohms and the standard deviation is just 0.14 ohms. Note that the mean value of the Re(Zo) was increased on the next run by increasing the gap width in Figure 1.

Comparisons of the complex Zo of CPS with BSNC and CPW show that the CPW still outperforms the CPS, but for most practical applications the difference will be negligible. In fact, the next section presents a practical application, LRL Calibration Elements, where the CPS could replace the CPW in most situations.

LINE-REFLECT-LINE APPLICATION for CPS with BSNC

Figure 6 indicates that this CPS structure makes a good LRL calibration element. It is in this capacity that it has already proven its practicality and usefulness in an important application: characterization of Short-Open-Load-Thru (SOLT) and Line-Reflect-Match (LRM) calibration elements. The SOLT/LRM calibration elements, which we characterized, have the same launch as the CPS LRL calibration elements; they are called CPS-type calibration elements [5]. This allows the SOLT/LRM calibration elements to be accurately characterized after an LRL calibration. Then simple models can be made for the SOLT/LRM elements, to be used during SOLT/LRM calibration, or the characterization data itself can be used during the SOLT/LRM calibration [4,5].

The traditional Open element, for on-wafer calibration, is simply the probe lifted "in Air" above the wafer. The variation from an ideal Open (S11 = +1) is modeled with a lossless and linear capacitor, Co. Figure 7 shows the "In Air" Open vs the CPS-type Open [4,5], measured after an LRL calibration. The CPS-type Open, right half of Figure 7, is clearly more ideal, and easier to model, than the "In Air" Open, left half of Figure 7. This quantitative comparison is made possible because of the novel CPS structure. This method of characterizing SOLT/LRM calibration elements is far superior to the traditional method of assuming a perfect Short and then changing the Co, of the Open model, until the Open Stub response is fit [4,5].

CONCLUSIONS

1) This novel CPS structure is a major improvement over traditional CPS, with its performance approaching that of CPW.

2) This CPS structure has been shown to be an excellent LRL calibration structure, proving itself in an important application: characterization of SOLT/LRM calibration elements.

3) This CPS structure has potential for use on coplanar GaAs MMIC wafers because of its 35% reduction in real estate (compared to the current CPW interconnect).

4) This structure has great potential for use with microwave probes, including multi-contact microwave probes, where the reduction in size, compared to CPW, will be important.

FUTURE WORK

Future work will be directed at characterizing the CPS with BSNC to higher frequencies, as well as optimizing the BSNC parameters.

REFERENCES

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[3] "NIST/Industrial Consortium Software Manuals and Related Papers", Publication of the National Institute of Standards and Technology.

[4] Williams, Frank and Mattern, James, "Calibrating Microwave Probes", Tektronix Application Note #60W-8057.

[5] Williams, Frank, "Characterization of Thin-Film Calibration Elements", 38th ARFTG Conference Digest, Fall 1991.

[6] Patent pending.

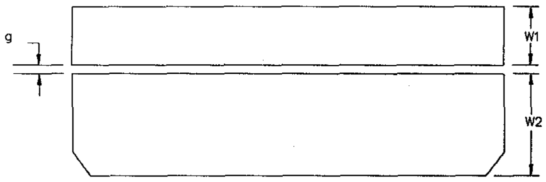


Figure 1: Geometry of Coplanar Stripline (Front-side)

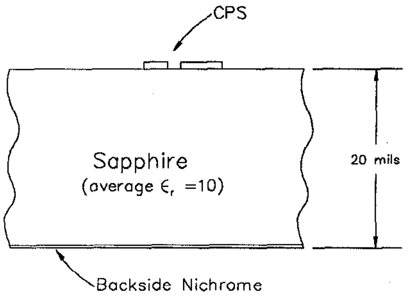
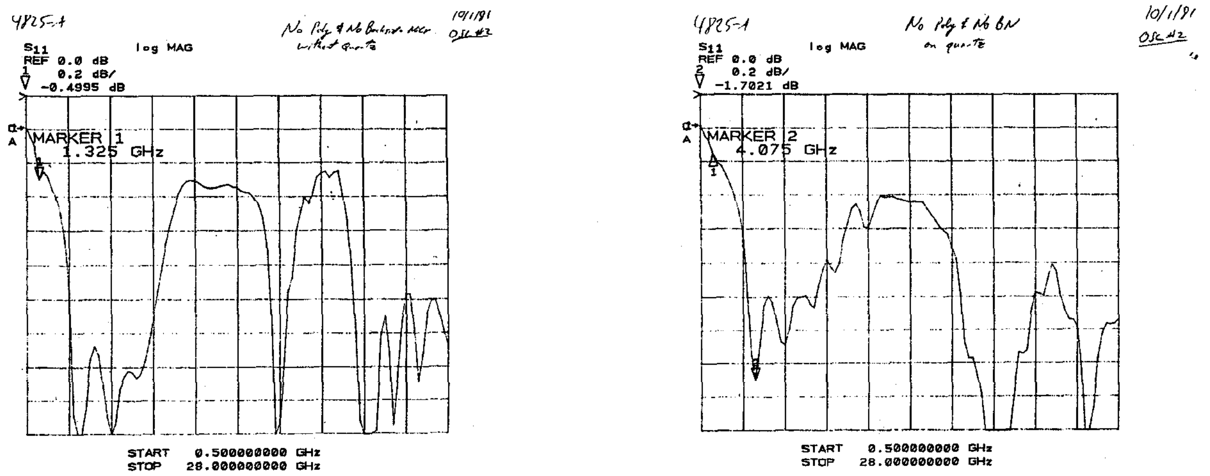


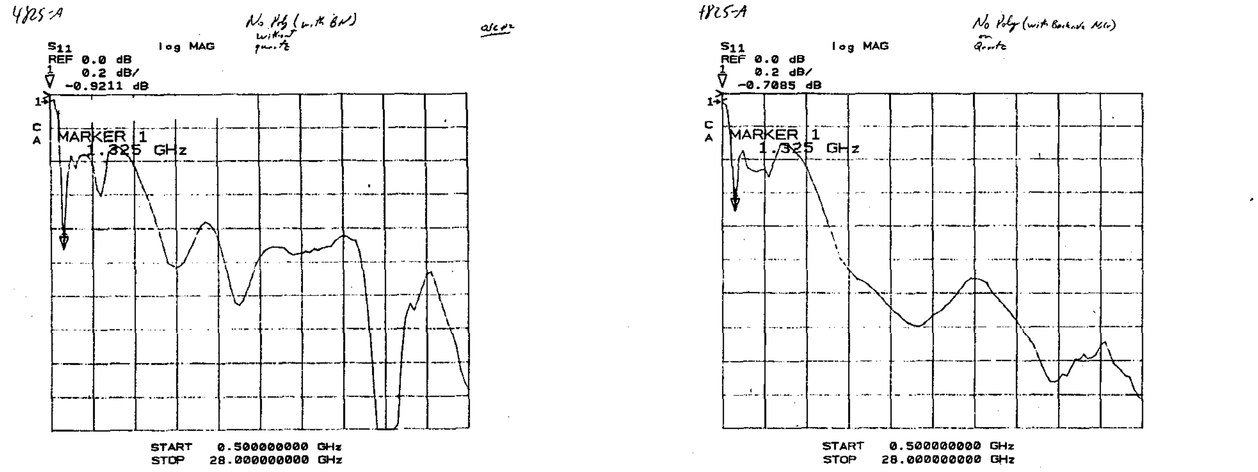
Figure 2: End view of Coplanar Stripline Structure



(a)

(b)

Figure 3: CPS *without* Back-Side Nichrome: a) without quartz spacer, b) with quartz spacer.



(a)

(b)

Figure 4: CPS *with* Back-Side Nichrome: a) without quartz spacer, b) with quartz spacer.

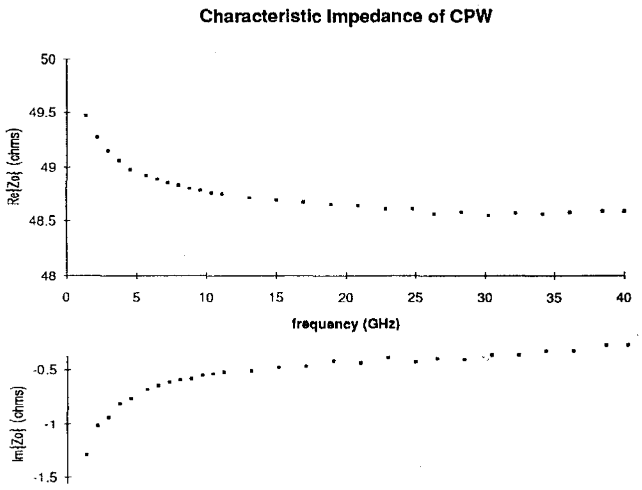


Figure 5: Complex Characteristic Impedance of CPW

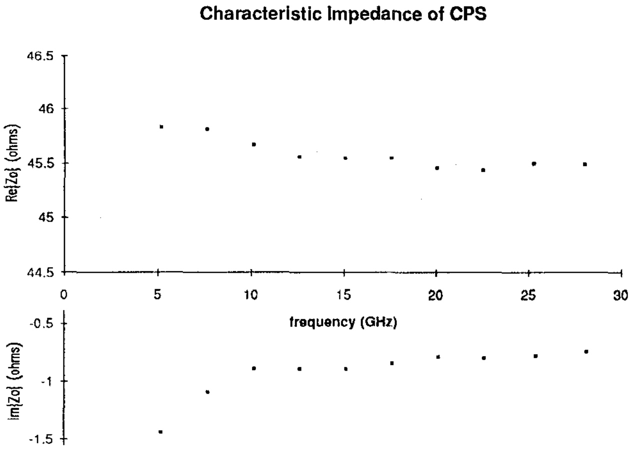


Figure 6: Complex Characteristic Impedance of CPS

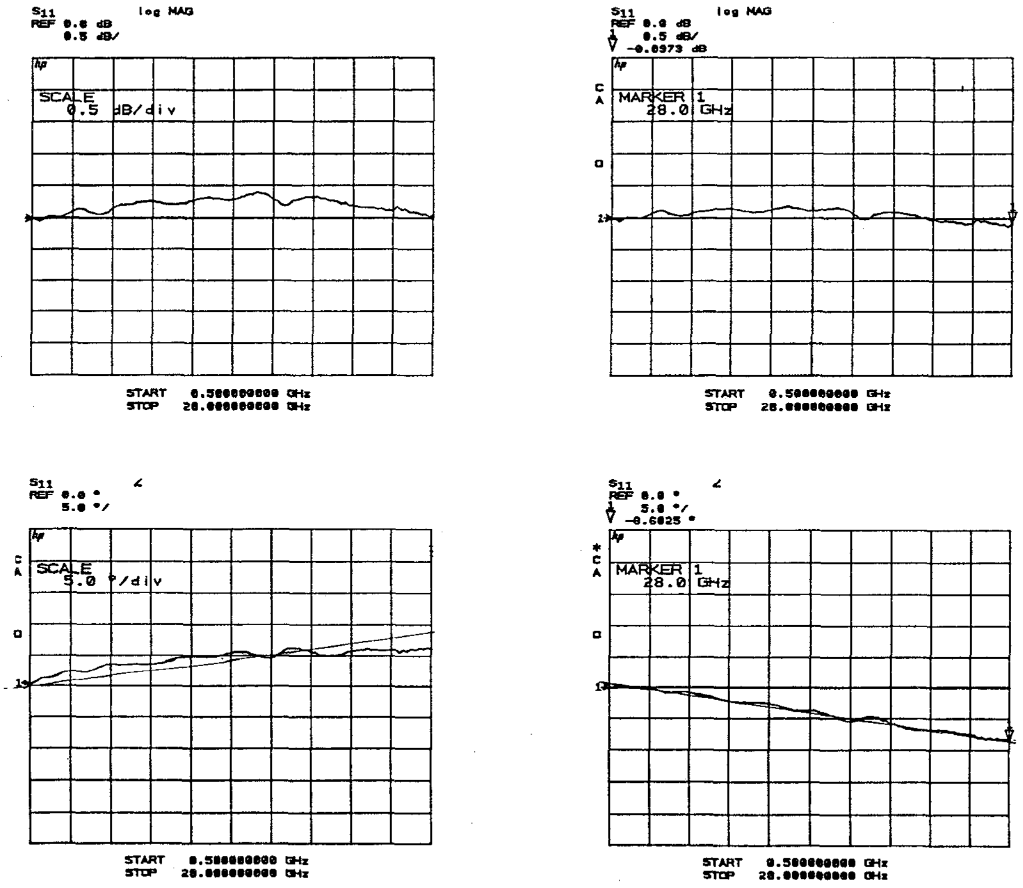


Figure 7: "In Air" Open (left) vs CPS-type Open (right) after LRL calibration with CPS.