A SIMPLIFIED CALIBRATION PROCEDURE FOR CRYOGENIC MICROWAVE MEASUREMENTS

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Abstract: *A single standard co-axial two-port calibration procedure which uses only one short-circuit as a calibration standard, is presented. The technique uses time-domain reflectometry to model the embedding networks as two lossy transmission lines. It has particular significance for cryogenic measurements where cooling cycles can take up to several hours.*

Introduction

Two-port calibration techniques currently used for microwave network analyzer measurements include thru-match-open-short (TMOS), thru-short-delay (TSD) [1], thru-reflect-line (TRL) [2] and line-reflect-line LRL [3] techniques. All of these require the use of at least three standards. This requirement becomes a problem when microwave measurements of cryogenically cooled devices have to be made. A typical cryogenic measurement requires firstly the creation of a vacuum and then cooling of the device, followed by the inverse procedure. One complete cooling-heating cycle can take up to 1.5 hours on some coolers, bringing the time for one calibration to 4.5 hours.

In spite of the long calibration times, the TRL technique is currently the most popular one for use in cryogenic measurements [4,5,6]. All of the authors do however note the inaccuracies incurred due to drift in the network analyzer parameters over such extended times. As a result, some authors perform calibrations only at room temperature, followed by a measurement of the cooled device [7]. This will be seen to introduce quite substantial errors, especially in the phase measurements.

This paper introduces a calibration procedure which makes use of only one known short-circuit calibration standard, thereby saving a significant amount of time. Although simple, to this author's knowledge this technique has not been used to reduce calibration times for cryogenic measurements before. The technique is valid for co-axial measurements, provided that the cables used can accurately be modelled by a lossy transmission line model.

Basic Technique

A general cryogenic measurement setup is shown in figure 1. The aim of the suggested procedure is to calculate the scattering parameters of the cables inside the cryostat leading to the DUT. A room temperature calibration procedure is carried out at the planes of the cooler. Following, the cables inside the cryostat are terminated with known short-circuits. The setup is then cooled and reflection measurements are performed. The measurements are converted to the time-domain with the Inverse Discrete Fourier Transform. From the time-domain information, the complex impedances, attenuation- and phase constants of each cable are calculated. These parameters are used to calculate the scattering parameters of each cable, which in turn are used to de-embed the

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scattering parameters of the DUT from measurements performed at the planes of the cooler.

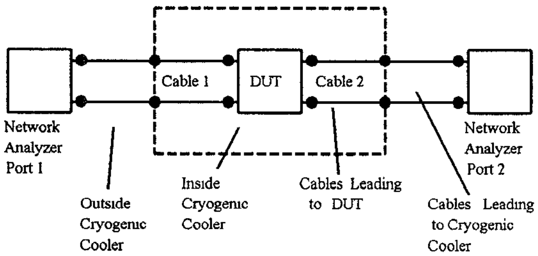

Figure 1: Cryogenic Measurement Setup

Calculating the S- Parameters of the Cables

Time-domain-reflectometry (TDR) measurements are obtained by launching an impulse into the DUT and observing the response. Using a network analyzer, the frequency data must be mathematically transformed to the time domain. For a transmission line terminated by a perfect short-circuit, the time domain measurement of the reflection coefficient is shown in figure 2.

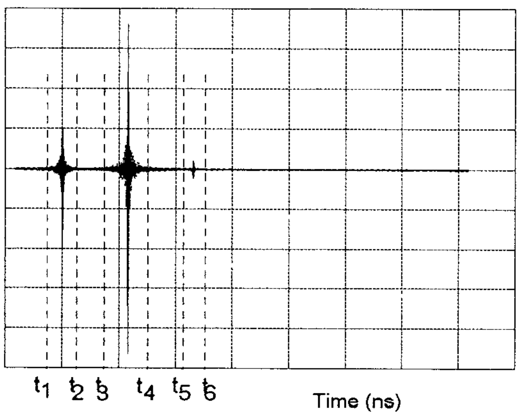

Figure 2: Reflected Impulse

Time-gating the first impulse between t_1 and t_2, produces a measurement equivalent to that of the reflection coeffficient of an infinitely long transmission line connected to the measurement system. The impedance of this line is calculated from the Discrete Fourier Transform of this gated impulse, S_{11C}, as in equation (1).

$$Z_1 = Z_0 \frac{1+S_{11C}}{1-S_{11C}} \tag{1}$$

Assuming no dispersion, the phase velocity, v_p, is a constant over frequency. As shown in [8, p 224], the phase contribution of the line, $\beta_1 l_1$, can be expressed as in equation (2) with t_{trav} twice the time at the peak of the pulse t_3-t_4.

$$\begin{aligned} \beta_1 \ell_1 &= \frac{2\pi}{\lambda} \ell_1 \\ &= 2\pi \frac{\ell_1 f}{v_p} \\ &= 2\pi \, t_{trav} f \end{aligned} \tag{2}$$

The attenuation, α, is determined by equation (3), with S_{11D} calculated from the time-gated pulse t_3-t_4.

$$\alpha_1 \ell_1 = -\ln\left(\frac{|S_{11D}|}{1-|S_{11C}|^2}\right) \tag{3}$$

The transmission line's scattering parameters can now be calculated from these values. With the scattering parameters of the transmission lines available, the scattering parameters of a device embedded between these two lines can be calculated by de-embedding the device.

Results

To evaluate the method, two sets of measurements were made, one at room temperature and one at cryogenic temperatures, in this case 77K. For the sake of brevity, the proposed calibration technique is referred to as the SSS-technique (single standard short).

A microstrip coupled line filter with a passband from 2.5 to 2.8 GHz was measured with a HP 8753C Vector Network Analyzer at room temperature using both the proposed calibration technique and the standard full two port (TMOS) calibration technique. The result for S_{21} is shown in figure 5.

The measured results agree to within 1 dB in amplitude and 6 degrees in phase with each other.

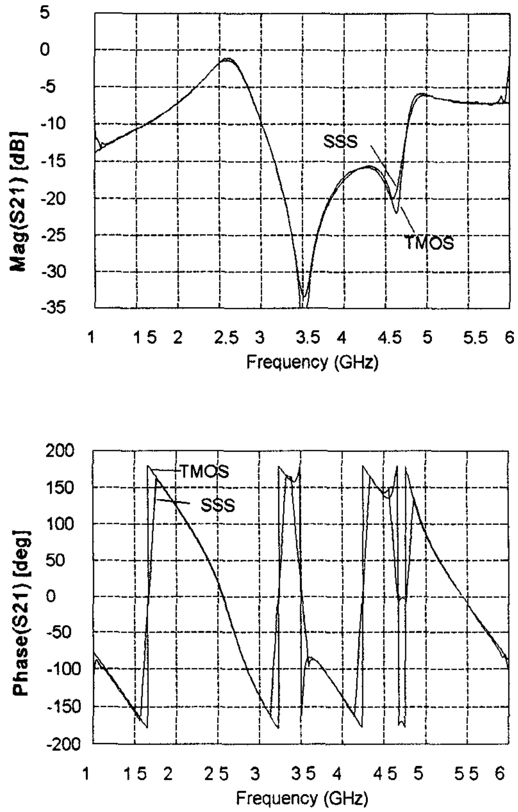

Figure 5: Comparison of magnitude and phase of S_{21} for TMOS and SSS calibration procedures.

To investigate the performance of the proposed technique in cryogenic measurements, it was applied to a DUT immersed in liquid nitrogen at 77K. For comparison, a Line-Reflect-Line (LRL) calibration was also performed, with the longer line used as DUT. The comparisons are shown in figures 6 and 7.

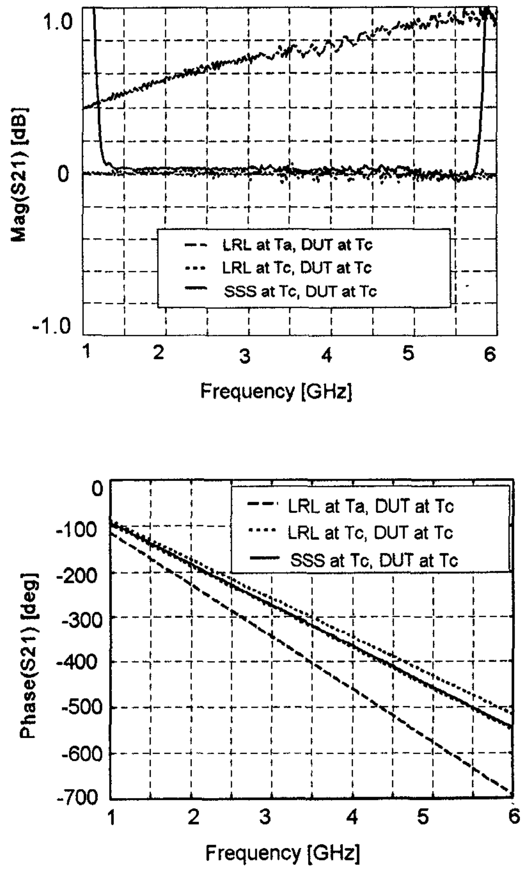

Figure 6: Comparison of magnitude and phase of S_{21} for SSS and LRL calibration for a device cooled to 77K.

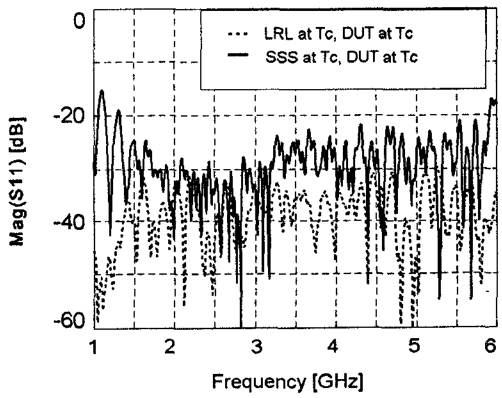

Figure 7: Comparison of magnitude of S_{11} for SSS and LRL calibration for a device cooled to 77K.

Two LRL calibrations were performed, one at room temperature (Ta) and one at 77K (Tc). Furthermore, as the phase computed from the LRL calibration is dependent on the ratio of the two lines used as standards, an error in this ratio can cause an error in the phase of S_{21}. If allowance is made for an error of 0.25mm in either of the lines, the resultant phase of S_{21} will be in the area bounded by the two dotted lines in figure 6.

From figure 6 it is clear that a calibration performed at room temperature, while not requiring any cooling cycles, does not give accurate results for cooled devices. While the magnitude of the transfer function is clearly affected, the more important errors are in the phase, where an error of nearly 150 degrees results at 6GHz. The three standard LRL calibration performed at Tc quite clearly gives the best results, at the expense of repeating the cooling cycle three times. The proposed single standard short technique represents a compromise between these two techniques. The amplitude differs by less than 0.05dB from the LRL data and the phase is completely within the region bounded by the LRL results.

Conclusion

A calibration technique is presented which makes use of only one short-circuit standard. Deviations of 0.05 dB in amplitude and 5 degrees in phase were observed when measurements were compared to those obtained by using the TMSO or LRL calibration technique. The technique offers a trade-off between calibration time and calibration accuracy.

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