A Straight forward method of characterizing the Intrinsic Loss Characteristics of Symmetrical Two Port Networks

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Abstract: **A method for characterizing the intrinsic loss characteristics of a symmetrical two port network using a two tier calibration procedure is presented. A first tier calibration to device fixturing ports results in symmetry. The second tier calibration uses a single through line. The resulting characterization is equivalent to the transmission factor of the network with ideal input and output matching networks. This has the effect of putting two ideal matching networks at the input and output of the network. A microstrip bandpass filter measurement and characterization using this technique is presented. The results are compared with deembedded characterization obtained using the TRL calibration procedure.**

1. INTRODUCTION

In the evaluation of new microwave technologies it is desirable to obtain the intrinsic loss of devices, or as it will be referred to here, the DUT. The intrinsic loss of a two-port DUT is defined here as the insertion loss of the DUT with ideal lossless matching networks at each of the ports of the DUT. Thus all of the power delivered to Port 1 of the combined network either is delivered to the external Port 2 or it is dissipated in the DUT. This represents the lowest insertion loss of the device. Most importantly it enables technologies to be evaluated and their ultimate system impact to be determined prior to full subsystem design involving matching network realization. In this paper we present a procedure for determining the intrinsic loss of a symmetrical DUT. The procedure, termed Intrinsic Loss Extraction (ILE) calibration, is a two tier calibration scheme and relies on symmetrical fixturing so that the fixtures plus the symmetrical device is also a symmetrical network. The first tier of calibration, using standard SOLT calibration for example, calibrates the system to the planes of the fixtures. The second tier utilizes a through connection of the fixtures only. The measurement of the DUT plus fixtures directly leads to the intrinsic loss. The intrinsic loss is also compared here to the S parameters of the device referred to the characteristic impedance of the line standard used in a full TRL calibration. The characteristic impedance of this line standard, particularly in new technologies cannot be estimated but this too is a measure of the fundamental characteristics of the device.

The evaluation of characteristic impedance is not feasible in certain cases due to insufficient knowledge of the material parameters or lack of analytic formula for a given structure. This is especially true in the case of a BST (Barium Strontium Titanate) device where the permittivity of the thin film depends on the deposition temperature, pressure and also the annealing conditions. It has been mentioned in the literature that BST (Barium Strontium Titanate) thin film microwave device needs to be well characterized [5, 6]. A TRL based algorithm has been used in one of the papers [5]. It has also been pointed out in the past by Hoer [2] that the TRL technique could be used to measure non-50 Ω devices in a 50 Ω environment. Using a more generalized mathematical theory it was shown in [3] that TRL inherently accounts for any differences in the characteristic impedance between the measurement system and the device under test.

In this work we modify the standard TRL technique [1], [4] to mathematically obtain the true transmission characteristics of the device using only one line standard. The only requirement is that the characteristic impedance of the line standard being used should be the same as the device to be characterized. This can be done even without knowing the characteristic impedance of the device under test and hence can be very useful for BST thin film based devices and other new technologies.

2. THEORY

The procedure for doing this is as follows:

A first tier calibration using standard SOLT technique or any other calibration method is done. (In our case a 3.5mm SOLT was done).

With reference to Figure 1, the thru line standard is measured

$$[R_t]=[R_a][R_{Ta}][R_b][R_{Tb}] \quad (1)$$

$$[R_t]=[R_{Na}][R_{Nb}] \quad (2)$$

Here [R] is the transfer matrix of the two port and the subscripts a, Ta, b, Tb refers to the transfer matrices of the error box and the impedance matching matrices at port 1 and 2 respectively. The transfer matrices with subscripts Na and Nb refer to the cascading of the error box and the impedance matching matrices at each port. The transfer matrix with subscript t corresponds to that measured for the thru line.

Lastly the device under test is measured:

$$[R_{Dm}]=[R_a][R_{Ta}][R_D][R_b][R_{Tb}] \quad (3)$$

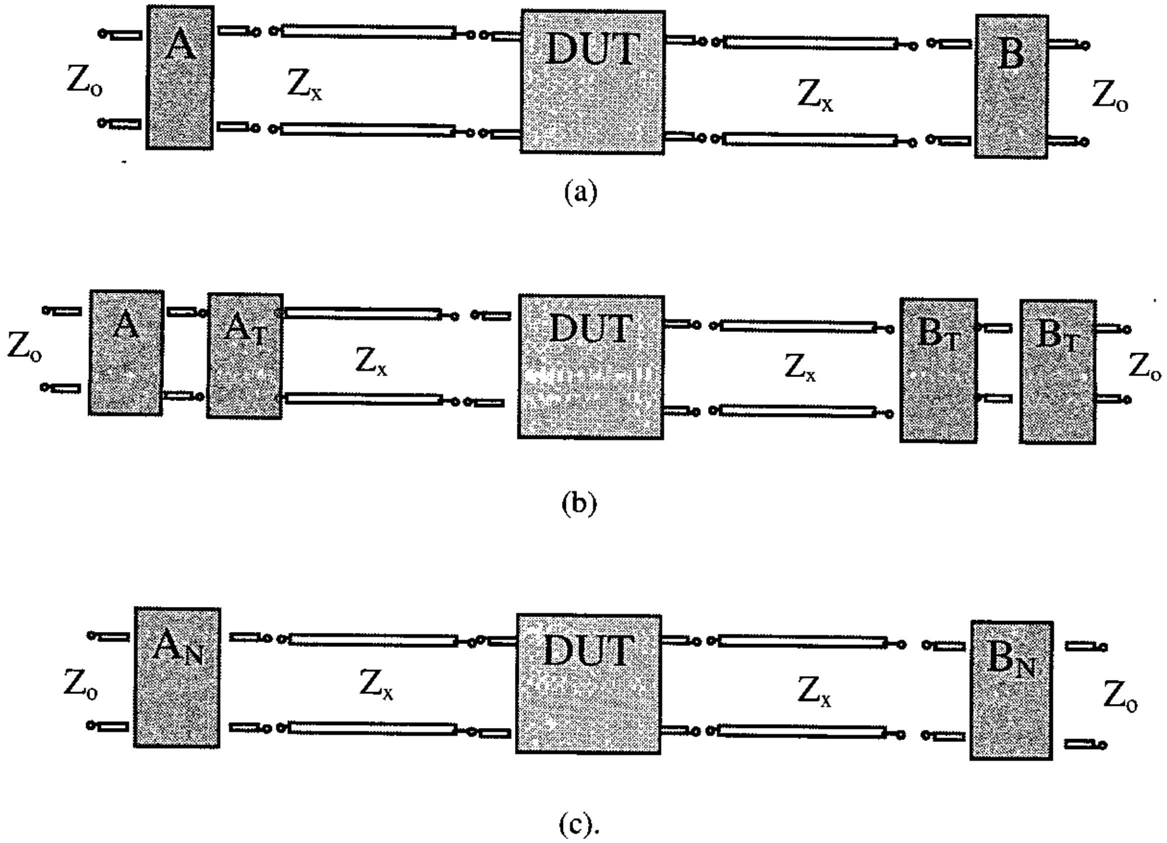
$$[R_{Dm}]=[R_{Na}][R_D][R_{Nb}] \quad (4)$$

Here the subscripts Dm and D refer to the transfer matrix of the device measured and the actual transfer matrix of the device with no reflection at its ports.

Next we assume that

$$[R_D] = \begin{pmatrix} 0 & S_{21,DUT} \\ S_{21,DUT} & 0 \end{pmatrix} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

This is mathematically equivalent to having impedance transforming networks at the input and output port of the device under test. We further assume that the device under test is symmetrical. Hereafter the solution follows the algorithm outlined in [1, 4] and yields the value of $S_{21,\,DUT}$. This is the true insertion characteristics of the device with no reflections at its ports. This procedure is outlined in Figure 1.



(a)

(b)

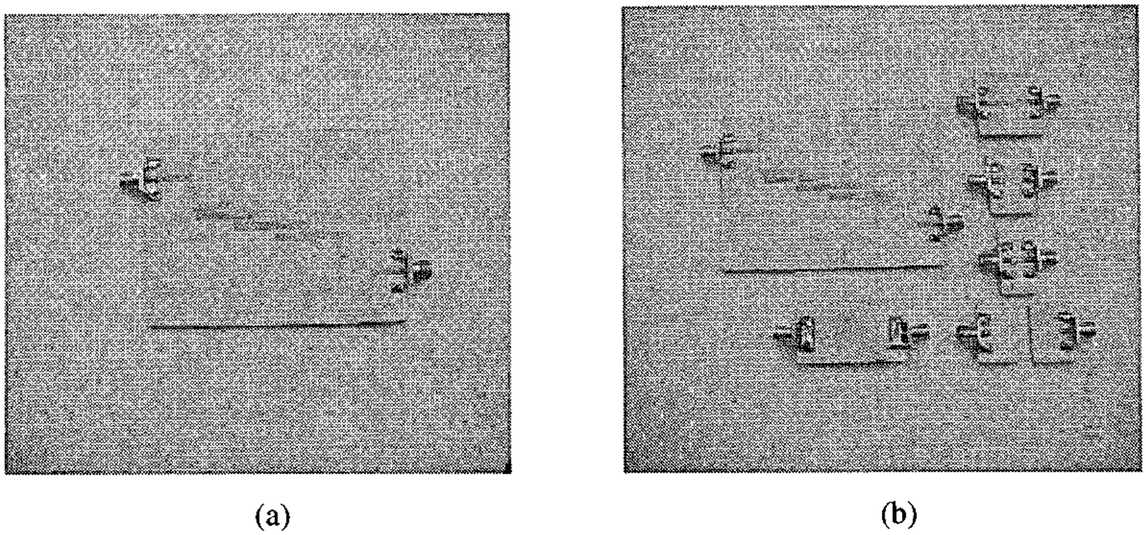
(c).

Figure 1, Through Calibration Procedure: (a) a device embedded in an unknown system; (b) introduction of matching networks to convert between Z_o and Z_x and (c) impedance networks and error boxes lumped together at the two ports.

3. IMPLEMENTATION

As a proof of concept an edge coupled microstrip bandpass filter (Fig2a) on a Gilam 2032 board with 75 Ω input and output impedance was fabricated and measured on a HP 8510 C Network

Analyzer. The filter was designed using the SFILTER synthesis tool from Eagleware and the EM simulation was done in Momentum ADS. The filter was de-embedded using the TRL algorithm. TRL standards namely a 75 Ω thru, 75 Ω line and an open were also fabricated on the same substrate (Fig 2b). The actual length of the thru was used to properly position the reference plane. The filter and the thru line were also measured after a first tier 3.5mm SOLT calibration.



(a) (b)

Figure 2, Experimental Fixtures: (a) 75 Ω bandpass filter and (b) TRL/characterization kit.

4. MEASURED RESULTS

The measured data for the filter and the thru line after a first tier calibration were processed offline using the steps outlined above to obtain the true transmission characteristics of the device. A full TRL calibration was also implemented on the HP 8510C system. The results are compared in Fig 3.

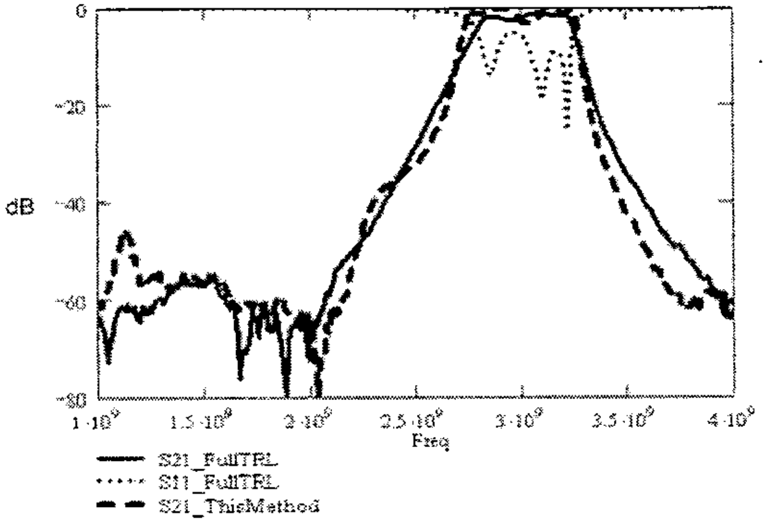


Figure 3: Comparison of symmetrical filter characteristics using a full TRL algorithm and the method outlined in this work.

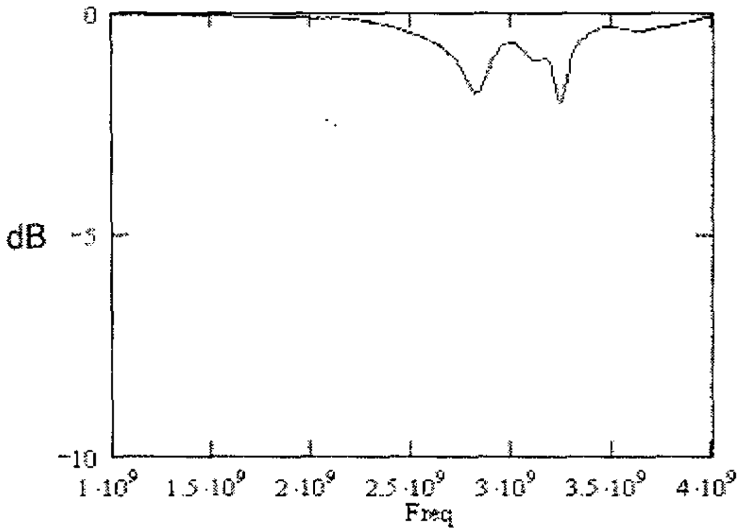


Figure 4: Plot of $|S_{11}|^2 + |S_{21}|^2$ obtained from TRL

The intrinsic loss of a device determined using the ILE procedure determines the transmission loss due solely to the device. The results can be interpreted as follows. The ideal matching networks effectively placed at Port 1 of the DUT serves to deliver all of the power inserted at the external Port 1. This power is either dissipated in the DUT or it emerges at the external Port 2. The loss plotted in Figure 3 is the loss in the DUT alone and is the best that can be achieved. This can be contrasted to an alternative measure of device loss: $|S_{11}|^2 + |S_{21}|^2$ which is shown in Figure 4. Here the S parameters are obtained using conventional TRL calibration and the device S parameters are referred to the characteristic impedance of the line standard. The impedance transforming network inherent in the TRL deembedding procedure is not a matching network. Thus power that enters the external Port 1 is delivered to the load but power reflecting from the internal Port 1 reflects from the fixture and enters the device again.

A further observation can be made about these results. The filter tested here is a 5th order filter so that there are 5 resonators with the resonant frequencies approximately uniformly spaced in the pass band of the filter. In resonance there is higher loss than at other frequencies as currents and fields peak leading to higher losses such as I^2R losses. This can clearly be seen in Figure 3 where the intrinsic loss between resonances reduces to virtually zero. The association of losses with resonance cannot be observed using the standard S parameter extraction.

5. CONCLUSION

A simple and straightforward method of characterizing the intrinsic insertion loss characteristics of a symmetrical two port network has been presented. As way of demonstration a symmetrical filter was measured and characterized using this technique. This work could also be extended to asymmetrical devices in future publications.

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