VNA-Calibration and S-Parameter Characterization of Submillimeter Wave Integrated Membrane Circuits

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***Abstract*—A TRL-calibration kit enabling S-parameter characterization of membrane circuits has been developed for the WR-03 band. The TRL-design features 3 μm thick GaAs membrane circuits packaged in E-plane split waveguide blocks. Membrane filters have been characterized after the calibration.**

I. Introduction And Background

There is a strong need for development of compact receivers operating in the submillimeter wave band for earth observation instruments, space science missions as well as THz imaging systems. However, as circuit operating frequency increases, the difficulty of assembly increases as chip dimensions and alignment tolerances shrink. Furthermore, the high frequency circuits are usually limited by the thickness of the support substrate. To overcome these drawbacks, membrane supported monolithic integrated circuits (MICs) have been proposed and show promising results. However, little has been reported about the S-parameter characterization of membrane circuits. Although this is significant for circuit modeling and design verification.

We have developed membrane *thru-reflect-line* (TRL) calibration standards to characterize membrane circuits in the WR-03 waveguide band (220-325 GHz) [1,2]. In this paper, we have improved the design of the contacting surfaces to the beam lead and to improve ground connection and alignment tolerance. TRL calibration is performed based on an optimized design of the TRL standards. S-parameter of passive circuits are presented.

II. Design and Method

We designed the membrane TRL standards and circuits using a three-dimensional electromagnetic simulator (Ansoft HFSS) and a linear circuit simulator (Agilent ADS). The design principle of the TRL standards is described in [3]. In our design, all standards have the same waveguide to planar interface in each end, as shown in Fig.1 (a). The *thru* and *line* standards have a length of 600 μm and 850 μm respectively, with a same nominal characteristic impedance of close to 100 Ω and a phase difference of 90 degrees at 300 GHz. An *open* standard was chosen as it has a very good response characteristic and should be less sensitive and more reliable than a *short*, which has a stronger dependence on mounting tolerances and perfect ground contact. To minimize the number of different mechanical blocks, the same mechanics as for the *line* standard were used for both the *open* and all the DUTs. The epitaxial structure and the membrane circuit fabrication are described in [2].

The design of E-plane block is shown in Fig.1 (b). A 26 mm long reference waveguide (waveguide thru) was designed for evaluation of the waveguide loss. A modified block with decreased contact surface was designed to improve the contact to the beam lead.

Fig.2 shows schematic pictures of planar view and cross section view of the membrane circuits in blocks. The beam leads provide electrical contact as well as mechanical support, making the membrane circuits suspend in the air. The membrane circuits were designed to have a self aligning structure with a tolerance of maximum 20 μm movement in the split-plane. After the first achievement of this work, we found this tolerance can be decreased to 10 μm.

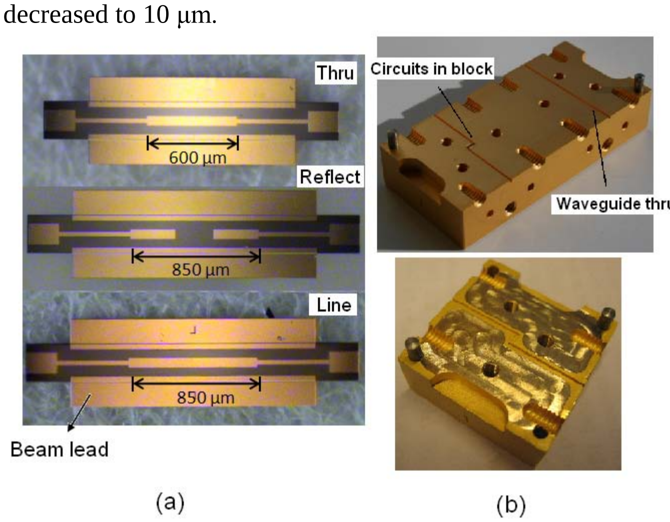

Fig.1. Microscope pictures of the membrane calibration standards (a) Photos of the blocks (b).

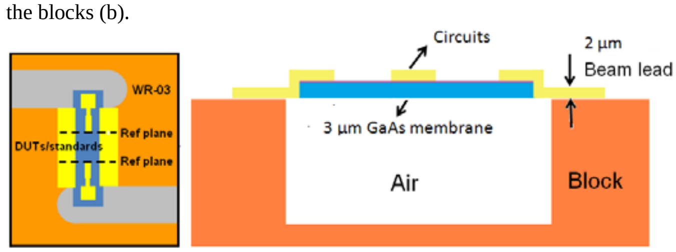

Fig.2. Schematic pictures of planar view and cross section view of the circuits in blocks.

For the WR-03 test set, Oleson Microwave Labs (OML) V03VNA2-T/R frequency extension modules with an Agilent E8361A PNA S-parameter test set are used.

III. VNA calibration

Calibration was first performed with waveguide TRL standards from OML to verify our membrane TRL standard design. Once calibrated, the reference planes were set at the flange of the two frequency extenders. First, the flange thru (flanges directly connected) and the waveguide thru were measured, as shown in Fig.3. S_{21} of the waveguide is approximately -0.7 dB. Then the membrane standards were measured. As shown in Fig.4, S_{21} of the membrane *thru* and the membrane *line* is approximately -1 dB, respectively. These results indicate that the loss in a 2 mm long membrane is less than 0.3 dB. The ripples seen in S_{11}, are most likely due to imperfect repeatability of the flange connections and inequality assembly. S_{11} of the membrane *reflect* is about -0.7 dB. S_{12} of the membrane *reflect* is below -40 dB, so that the two ports are well isolated even though only one reflect standard is used for calibration.

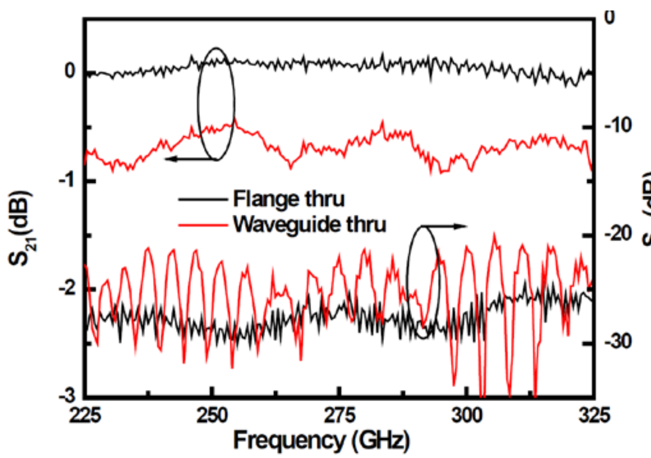

Fig.3. S_{21} and S_{11} of the flange thru and the waveguide thru.

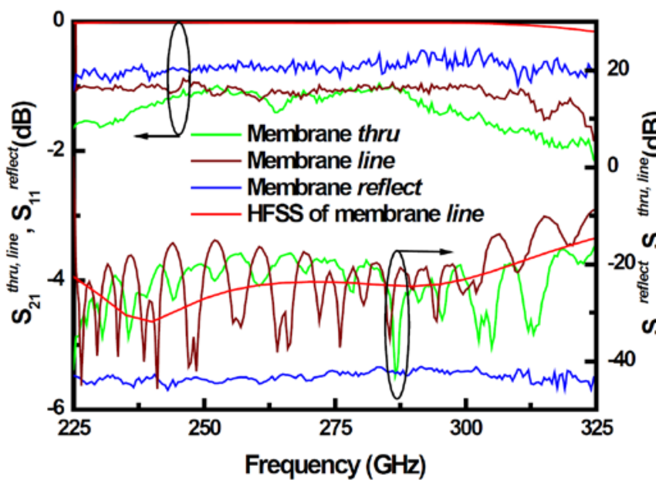

Fig.4. S_{21} and S_{11} of the membrane standards and simulation of membrane *line*.

Then we use membrane TRL standards for calibration. The reference plane is set in the middle of the *thru* after calibration. The membrane *thru* shows an insertion loss magnitude and an insertion loss phase variations within ± 0.01 dB and ±1 degree respectively without reconnection. Then, each membrane standard was reconnected and measured to check the repeatability. Small differences are observed in both magnitude and phase measurements between the two ports for all the standards.

IV. Results

Figure 5 shows S-parameter characterization of a ring resonator filter after the calibration and comparison to simulation. Measured S_{12} and S_{21} are almost identical. A 5 GHz frequency shift, between the simulation model and circuit measurements, corresponding to 1.5 % of the resonance frequency was observed.

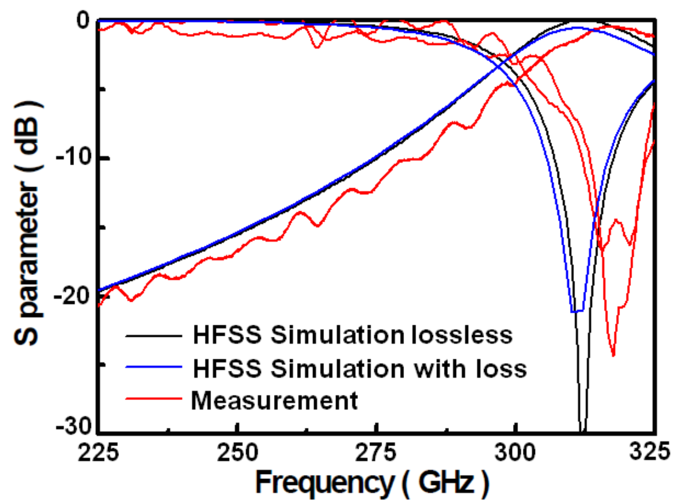

Fig.5. S-parameter characterization of a 300 GHz ring resonator filter.

Figure 6 shows S-parameter characterization of a stub filter after the calibration and comparison to simulation. Measured S_{12} and S_{21} are almost identical. A 10 GHz frequency shift, between the simulation model and circuit measurements was observed.

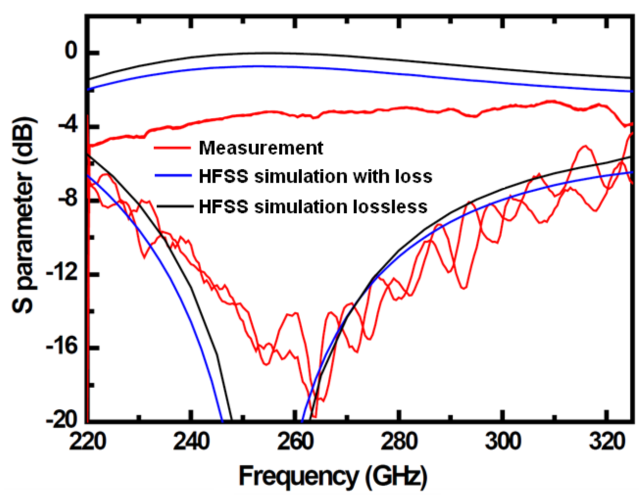

Fig.6. S-parameter characterization of a 250 GHz stub filter.

References

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[2] H. Zhao, A. Y. Tang, P. Sobis, T. Bryllert, K. Yhland, J. Stenarson, J. Stake "TRL-calibration and S-Parameter Characterization of Membrane Circuits for Submillimeter Wave Frequency", submitted to IEEE Microwave and Wireless Components Letters, 2010

[3] "Applying the 8510 TRL calibration for Non-coaxial Measurement", Agilent Application note 8510-8A.