Scaled Model Measurement of the Embedding Impedance of a 660-GHz Waveguide SIS Mixer With a 3-Standard Deembedding Method

W. Zhang, C.-Y. Edward Tong, *Member, IEEE*, and S. C. Shi, *Member, IEEE*

***Abstract*—In this paper, the embedding impedance of a 660-GHz superconductor-insulator-superconductor (SIS) mixer is investigated using a 100-times scaled-model with a new 3-standard deembedding technique. The mixer embedding impedance is extracted from the reflection coefficients measured at the waveguide port of the mixer for three different terminations at the SIS junction's feed point. The three standards chosen are open-circuit, short-circuit and resistive load. Measured results are compared with those simulated by high-frequency structure simulator (HFSS).**

***Index Terms*—Deembedding method, embedding impedance, scaled model, SIS mixer, time domain gating.**

I. Introduction

For the design of fixed-tuned waveguide superconductor-insulator-superconductor (SIS) mixers in the submillimeter regime, it is necessary to have a precise knowledge of the mixer embedding impedance (i.e., the impedance seen at the junction's feed point). Embedding impedances have been determined using scaled-model measurement [1]–[3] or numerical methods [4]–[6]. The conventional scaled-model method measures the embedding impedance directly via a miniature coaxial connected to the junction's feed point. The accuracy of this method is limited by the accuracy of the model of the coaxial probe's tip. Numerical methods that derive impedances from the pumped I–V curves of SIS junctions [4], [5] depend largely upon junction parameters. Full-wave electromagnetic solvers, like the high-frequency structure simulator (HFSS), have been used to model a few submillimeter mixers [6]. However, it is important to have experimental confirmation of simulated data.

In this paper, we propose a new scaled-model measurement method, which incorporates a 3-standard deembedding technique [7]. This technique extracts the scattering parameters of an entire two-port network from the reflection coefficients measured at one port when the second port is terminated with three different impedance standards. Using this new method, we have determined the embedding impedance of a 600–720 GHz fixed-tuned waveguide SIS mixer mount [8], [9] with a 100-times scaled model. The measured impedances are then compared with those simulated by HFSS.

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W. Zhang and S. C. Shi are with the Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008, China.

C.-Y. E. Tong is with the Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138 USA.

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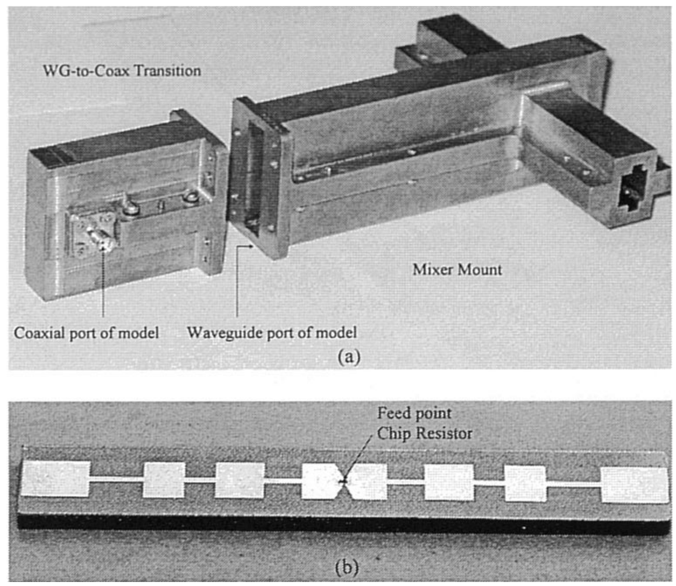

Fig. 1. The 100-times scaled model for a 660-GHz waveguide SIS mixer mount. (a) Overall view of the model including the waveguide-to-coaxial transition. The measurement with the vector network analyzer is taken at the coaxial port of the transition. The transition is first deembedded from the measurement data so that reflection coefficients Γ_i at the waveguide port of the model can be derived. (b) Photograph of the dielectric slab used inside the model to simulate the crystalline quartz substrate, which carries the SIS device. The feed point of the mixer is located in the center of the substrate.

II. Measurement Method

Fig. 1 shows the fabricated scaled model. Its operating frequency was 6.0–7.2 GHz scaled down from 600–720 GHz, as the scaling factor was chosen to be 100. In this model, the crystalline quartz substrate ($\varepsilon_r \sim 4.5$) was replaced by a dielectric slab of dielectric constant of 3.5 and exactly scaled thickness of 4 mm. The junction's feed point was scaled to a gap of 0.2 mm with a width of 1 mm. In our measurement, the feed point was connected to 3 different calibration standards: open-circuit, short-circuit and resistive load given by chip resistors (0.5 mm wide and 1 mm long). A waveguide-to-coaxial transition was included to interface to a microwave network analyzer (HP8720ET).

First, we measured the complex reflection coefficients at the coaxial port of the waveguide-to-coaxial transition, while its waveguide port was shorted. Let Γ_m ($m = 1, 2, 3$) be

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the measured reflection coefficients corresponding to three different short circuit planes, and $[S^t]$ the scattering matrix of the transition. The relation between Γ_m and $[S^t]$ is

$$\Gamma_m = S_{11}^t + \frac{S_{12}^t S_{21}^t R_m}{1 - S_{22}^t R_m} \tag{1}$$

where R_m is the complex reflection coefficient of the waveguide short circuit m at the waveguide port. $[S^t]$ can be easily solved using (1) [7].

Next, we connected the transition to the scaled waveguide mixer block and the complex reflection coefficients were measured again at the coaxial port of the transition while the device feed point was terminated by the three calibration standards. Let Γ_i be the measured complex reflection coefficient when the junction's feed point was terminated by calibration standard i, where $i = o$ (open), s (short) or r (resistive). Let Γ_i' be the corresponding reflection coefficient at the mixer's waveguide port when the port was terminated by a matched load instead of the transition. The relation between Γ_i' and Γ_i is

$$\Gamma_i' = \frac{(\Gamma_i - S_{11}^t)}{S_{12}^t S_{21}^t + (\Gamma_i - S_{11}^t) S_{22}^t}. \tag{2}$$

The embedding impedance Z_{emb} at the device feed point can be solved in terms of Γ_i'

$$Z_{emb} = Z_r \frac{\Gamma_o' - \Gamma_r'}{\Gamma_r' - \Gamma_s'} \tag{3}$$

where Z_r is the impedance of the chip resistor at the measured frequency.

Equation (3) shows that the derived embedding impedance is directly proportional to Z_r. It is therefore very important to know the accurate value of this impedance. We have measured the actual impedances of these chip resistors in a separate experiment setup.

III. Measurement Results

The impedances of three chip resistors, whose nominal resistances are 24, 51, and 100 Ω, were measured with a fixture built using a 0.5-mm thick substrate ($\varepsilon_r = 2.65$). The circuit employed a 50-Ω microstrip line (1.2-mm wide) with a 1-mm gap at its center where the chip resistor was to be soldered. Time-domain gating technique was employed to remove the discontinuity effect due to the SMA connectors to the microstrip line [10]. The loss and phase shift of the 50-Ω microstrip line were also compensated. The measured impedances for the three chip resistors are plotted in Fig. 2. Obviously, the chip resistors have resistances close to their nominal values, but all have a considerably large positive reactance in the frequency range of 6–14 GHz. The larger the nominal resistance is, the smaller the measured reactance becomes. In addition, the measured reactance is proportional to frequency, suggesting that there is a series parasitic inductance.

The waveguide-to-coaxial transition had been designed with the aid of HFSS by optimizing its power transmission coefficient, $|S_{12}^t|$, in the frequency range of 6.0–7.2 GHz. Using the procedure described above, we have measured the scattering parameters of the transition. It has been found that the measured S_{12}^t values (both magnitude and phase) are in rather good agreement with the simulated ones.

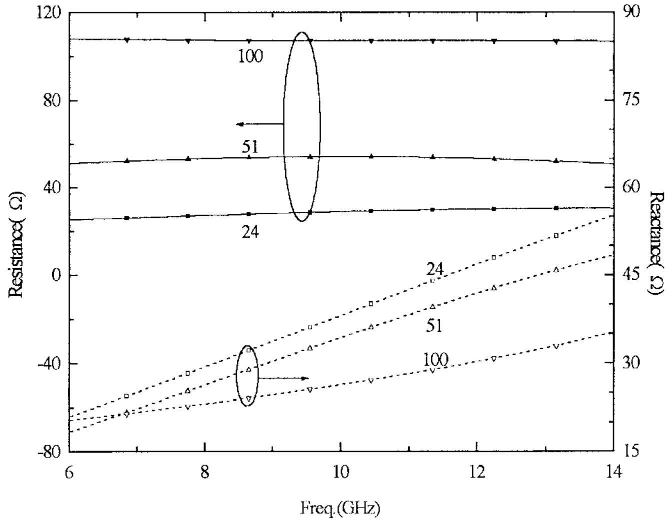

Fig. 2. Measured impedances of three chip resistors for 6–14 GHz, whose nominal resistances are 24, 51, and 100 Ω, respectively.

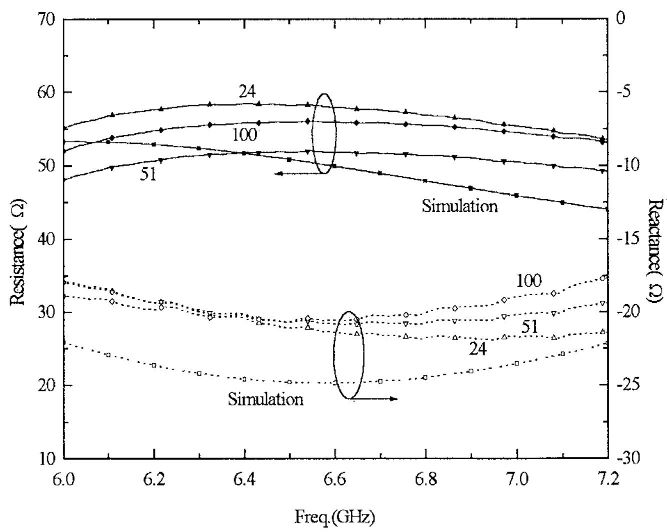

Fig. 3. Measured embedding impedance of the 100-times scaled model as a function of frequency for three instances corresponding to different chip resistors (i.e., 24, 51, and 100 Ω). Simulated embedding impedance is also given for comparison.

Equations (2) and (3) were then used to determine the embedding impedance of the scaled 660-GHz SIS mixer. Three sets of data were available, one from each of three chip resistors (i.e., 24, 51, and 100 Ω). The results are plotted in Fig. 3. The embedding impedances, both real and imaginary parts, are in good agreement for the three instances. The dispersion of the three data sets is less than 7 Ω, averaged across 6.0–7.2 GHz. The embedding impedance simulated for the same structure by HFSS is also displayed in Fig. 3. Clearly, the simulated resistance differs slightly from the measured one and the simulated reactance shows better agreement with the measured one.

To understand the effect of the substrate dielectric constant on the mixer's embedding impedance, we also simulated this mixer structure for different dielectric constants (i.e., 4.0, 4.5, and 5.0). As shown in Fig. 4, the mixer's embedding impedance

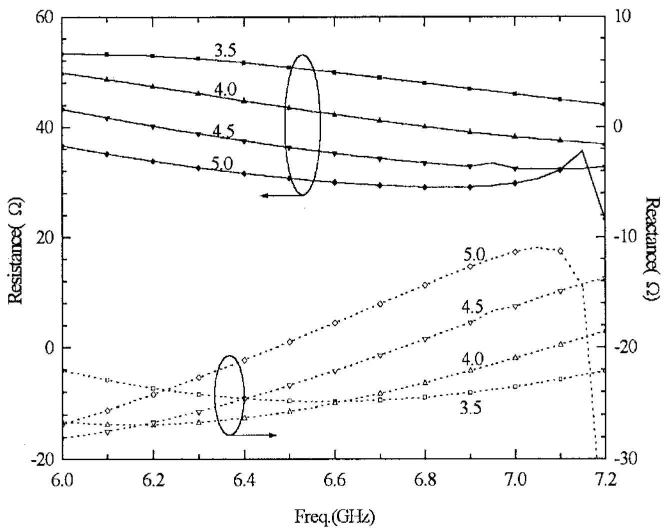

Fig. 4. Simulated embedding impedance of the 100-times scaled model as a function of frequency for different substrate dielectric constant (i.e., 3.5, 4.0, 4.5, and 5.0). For the case of $\varepsilon_r = 5.0$, there is a sharp change around 7.1 GHz, which is possibly due to higher-order modes in the suspended microstrip line.

is strongly dependent upon the substrate dielectric constant. For the case of $\varepsilon_r = 5.0$, we see a sharp change around 7.1 GHz, which is possibly due to higher-modes in the suspended microstrip line.

IV. Summary

A new scaled-model measurement method incorporating with the 3-standard deembedding technique has been employed to characterize the embedding impedance of a 660-GHz waveguide SIS mixer. The impedances of the chip resistors used in our scaled-model measurement were accurately measured using the time-domain gating technique. By comparing the data dispersion between embedding impedances derived from different calibration standards, we infer that the measured impedances are accurate to within 7 Ω. These measured embedding impedances also agree with the numerically simulated ones. The new scaled-model method is very useful for the characterization of submillimeter mixer mounts.

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