NUMERICAL AND SCALE MODELLING OF A BROADBAND WAVEGUIDE-TO-MICROSTRIP COUPLING STRUCTURE FOR A 100 GHZ SIS MIXER

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ABSTRACT

Recently, interest has arisen in the development of fixed-tuned SIS mixers with a full waveguide-band bandwidth. There are many reasons for developing a broadband structure with a performance comparable to that of mechanically tuned ones, the main ones being the need to eliminate the risk of a mechanical failure (*e.g.* space-borne applications) and reducing the numbers of parameters to set when changing operating frequency (*e.g.* array receivers).

Nowadays, with the availability of powerful software tools such as the Hewlett-Packard HP85180A High-Frequency Structure Simulator (HFSS) package [1], it is possible to quite accurately model the coupling structure on a computer. But, in order to do this, we have to know to what extent we can rely on the simulations.

In this paper we report a comparison between scale model measurements of a broad band waveguide-to-microstrip coupler and the predictions given by a numerical model using the HFSS package.

We find that the computer modelling, though slow, gives results that are in good agreement with the measured performance of the scale model structure. Moreover, the simulations allow us to modify some parameters that otherwise would be difficult to change, such as the properties of the dielectrics and metals. This enables us to model the behaviour of more realistic mixer coupling structures, *e.g.* losses, cooled dielectrics, *etc.*

The relative advantages of each modelling method are reviewed and a broadband waveguide-to-microstrip coupler design is presented in this paper.

INTRODUCTION

There is no doubt that present coherent broadband millimeter and submillimeter wave detection is lead by the SIS mixer in terms of receiver noise temperature. There are also many groups around the world working on the improvement of this technology to guarantee that this dominance will continue, at least for the coming years [2, 3].

So far, most of the mixer designs have relied on experience gained with Schottky diode mixers that were the workhorse for sensitive receivers during the last decades. However, the matching of an SIS structure imposes different conditions on the coupling structure to those imposed by Schottky diodes. Two approaches have been taken to couple the radiation to the SIS detector: quasioptical techniques and waveguide coupling structures.

Quasioptical techniques couple the radiation directly to the SIS detector via lenses or planar antennas, and have advantages in terms of reduced size, easy planar integration and series fabrication, but they still lack the efficiency that waveguide coupling structures have and this is a crucial factor in the design of sensitive detectors for radio astronomy.

For the mixers being built as part of the development of an imaging receiver we decided on a waveguide coupling to the SIS structure, thus we concentrate our work on the design of a transition between waveguide and microstrip and, as such, this transition should fulfil the following requirements [4]:

- Low return loss
- Low insertion loss
- Full waveguide-band bandwidth
- Easy integration to the microstrip
- Straightforward mechanical reproduction

The first step in solving the coupling problem is the necessity of matching the highly reactive component inherent to SIS junctions, so earlier designs were all based on the use of at least one (often two) backshorts. It became clear later that there were cleverer approaches to solve this problem, and the idea of embedding the tuning elements on the same substrate as the junction proved to be useful [5]. Now it remained to find the appropriate geometry of the mixer cavity and the coupling structure to have a mixer with no tuning elements.

Several different techniques have been presented elsewhere [6, 7], but they do not necessarily match what we consider to be important for our design needs. On the other hand there has been no report about a systematic design procedure based on tools available to everyone in the community.

GEOMETRY OF THE STRUCTURE

The geometry of the waveguide cavity we have investigated is shown in Figure 1. The probe can be seen with its main plane sitting parallel to the polarization direction of the incoming radiation.

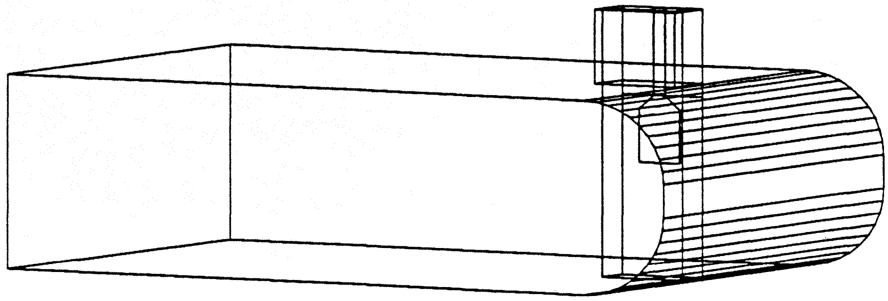

Figure 1. Geometry of the problem studied.

SCALE MODEL MEASUREMENTS

The scale model measurement was done with a standard WR-229 (IEC-R40) waveguide with 3.5 GHz and 4.8 GHz band limits that translate to 84.6 GHz and 116 GHz, respectively, with a scaling factor of 24.167.

The probe was etched on a 0.72 mm Duroid ® substrate, $\varepsilon_r = 2.34$, with a 7.2 mm superstrate of Stycast ®, $\varepsilon_r \approx 4.0$. This in order to simulate a fused quartz substrate for the final probe-mixer structure. With these dielectric constants and dimensions it was possible to calculate the 50 Ω strip line geometry [8]. This strip line terminated at an SMA connector to have access to the probe with the network analyser.

On one side of the probe cavity the non-contacting backshort structure was connected, and at the other side a commercial waveguide-to-SMA adapter was placed (Sivers Lab, type 7606/3).

We used an HP 8720B network analyser and the results of such measurements can be seen in Figures 2 and 3 for the backshort at the *$3\lambda/4$* position and in Figures 4 and 5 for the backshort at the *$\lambda/4$* position. This position is measured from the symmetry axis of the probe to the surface of the backshort.

NUMERICAL SIMULATIONS

The results of the simulation of the two cases measured on the scale model can be seen in Figures 2 to 5 together with the measured values.

For the backshort at *$3\lambda/4$* (Figures 2 and 3) we see that HFSS predicted within 0.5 dB over the band the value of the response for $|S_{12}|^2$ and predicted quite accurately the shape of it. For $|S_{11}|^2$ the predicted values are not in such a good agreement, but the general shape is predicted. On this particular case it is quite clear that the prediction works very well, since the bandpass characteristics of the *$3\lambda/4$* backshort position matching is clearly defined on the simulation.

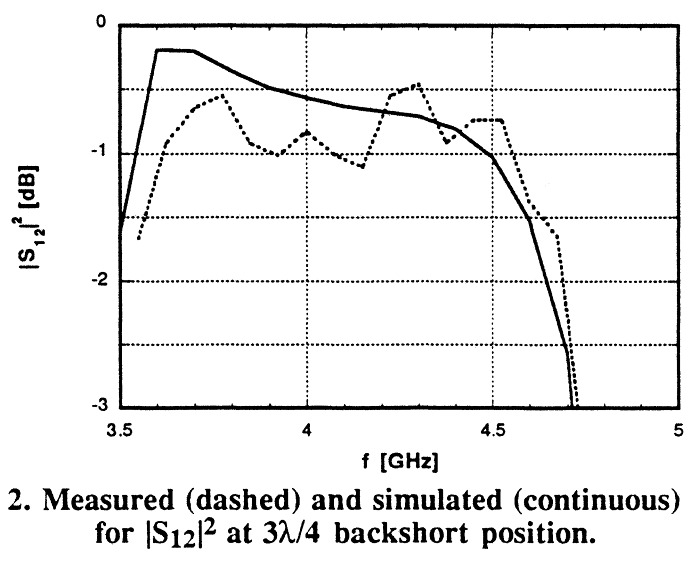

Figure 2. Measured (dashed) and simulated (continuous) results for $|S_{12}|^2$ at $3\lambda/4$ backshort position.

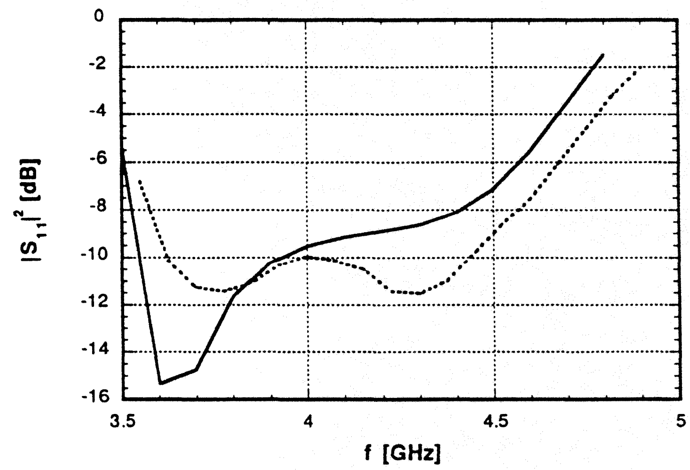

Figure 3. Measured (dashed) and simulated (continuous) results for $|S_{11}|^2$ at $3\lambda/4$ backshort position.

On the $\lambda/4$ case, seen in Figure 4 and 5, the value predicted for $|S_{12}|^2$ is again within 0.5 dB of the measured value, predicting the general shape. For $|S_{11}|^2$ again we see that the predicted values vary more against the measured ones, but the shape of the response agrees very well with the measurements.

It is important to remark here that the HFSS program has a built in CAD user interface that is far from being a final version: it is not very user friendly and suffers from lack of flexibility. The simulation itself takes about half an hour for each point of the frequency scan, thus, for a complete simulation between 3.5 and 4.8 GHz with a resolution of 100 MHz it needs 7 hours.

It was found also that HFSS cannot predict the behaviour of superconducting metals since it cannot handle complex conductivity. This did not allow us to model the structure at its operating frequency.

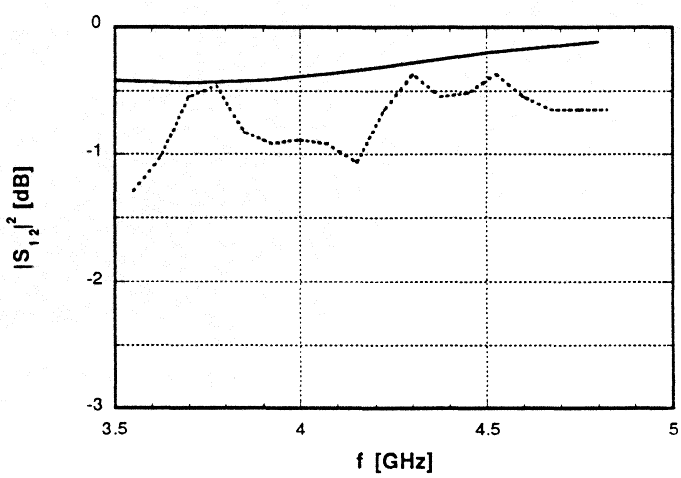

Figure 4. Measured (dashed) and simulated (continuous) results for $|S_{12}|^2$ at $\lambda/4$ backshort position.

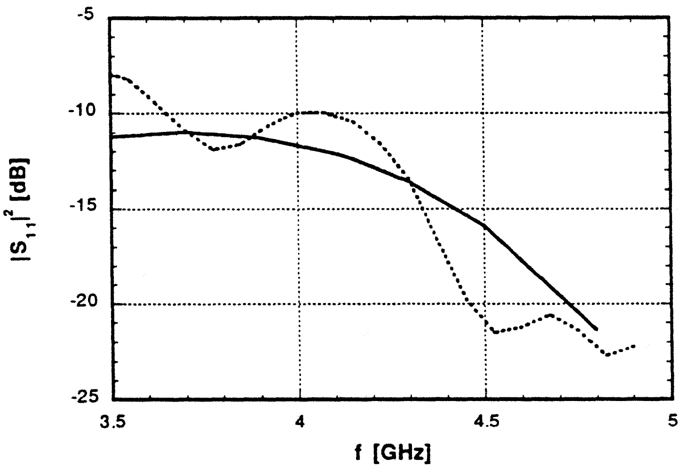

Figure 5. Measured (dashed) and simulated (continuous) results for $|S_{11}|^2$ at $\lambda/4$ backshort position.

DISCUSSION AND CONCLUSIONS

As to the results we get a working coupling structure that allows us a full waveguide-bandwidth coupling with losses less than 1 dB over a 32 GHz band. This structure is planar, thus allowing immediate integration of it to the SIS junction substrate, allowing the creation of a mixer with coupling probe, tuning structures, mixer junction, and IF matching structures, all on one piece of substrate.

The HFSS was successfully contrasted against real measurements. We can see, from a direct comparison of the results shown in Figures 2 and 3, that the simulation results are in quite good agreement with the measured ones.

The fact that the CAD phase on HFSS is cumbersome does not weigh as much when compared with the time consuming process of etching a probe (that includes the drawing and photolithography of it) or mechanically modify the mixer cavity geometry. Still it is much faster to modify anything in the geometry of the structure on the computer than on the real scale model.

It is clear that the availability of this powerful computational tool is a major step towards an easy and fast microwave design in the millimeter wave region.

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