Characterization of the Embedding Impedance for a 660-GHz Waveguide SIS Mixer

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Abstract – With the help of an electromagnetic field simulator (i.e., HFSS), the embedding impedance of a 660-GHz waveguide SIS mixer is thoroughly investigated using a lumped-gap-source and de-embedding method. The effects of the junction's feed-point displacement and chip thickness are examined.

Key words – embedding impedance, SIS mixer, sub-millimeter, lumped gap source, and de-embedding

1. Introduction

It is quite common that developed SIS (superconductor-insulator-superconductor) mixers of the fixed-tuned type, which are very beneficial to practical applications (e.g., radio astronomical interferometers), cannot measure a performance as good as theoretically predicted, especially at submillimeter wavelengths. Inaccurate embedding impedance of the mixer (i.e., the mixer impedance seen by the SIS junction) might be accounted for one major reason for this difference. Hence it is necessary to have a reliable method in characterizing the embedding impedance of SIS mixers. In addition, it is important to understand how the embedding impedance of SIS mixers is influenced by the mixer's structural parameters as a fabricated SIS mixer (including its mixer mount and SIS junction chip) often differs slightly with its designed model. With the help of an electromagnetic field simulator (i.e., HFSS) [1], here we thoroughly investigate the embedding impedance of a 660-GHz waveguide SIS mixer (i.e., the impedance seen at the junction's feed point,

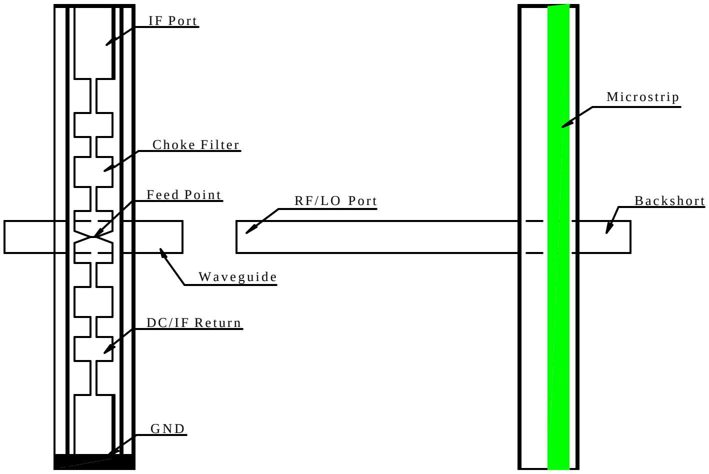

Fig. 1 Geometry of the 600-720GHz SIS mixer mount.

refer to Figs. 1-2), which is being developed jointly with the receiver group of ASIAA in Taiwan for the SMA (Submillimeter Array) project [2]. A lumped-gap-source port method was adopted for simulation. The result was then compared with that by a de-embedding method, which just imitates an experimental method. It is well known that for submillimeter waveguide SIS mixers, it is difficult to align the feed point of the SIS junction chip precisely in waveguide and the thickness of a lapped SIS junction chip might differ with the designed one. It is therefore of particular interest to study the effects of the junction's feed-point displacement and chip thickness on the mixer's embedding impedance.

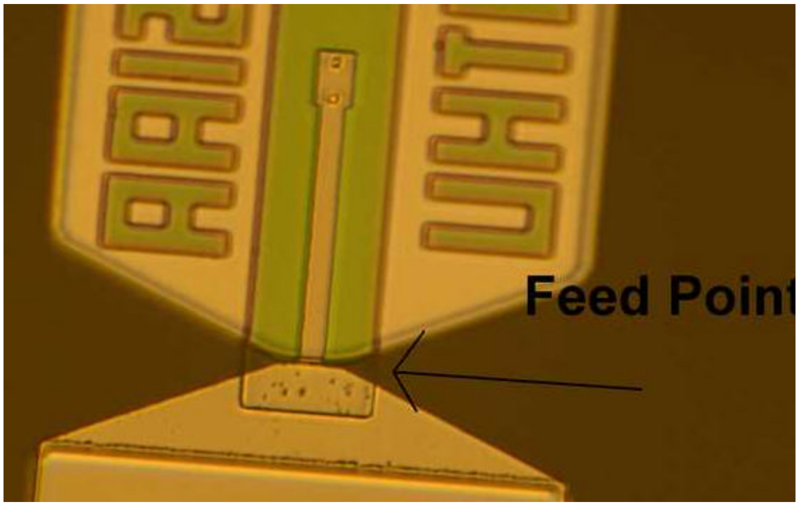

Fig. 2 Photograph of an actual SIS junction chip (part) for the 600-720GHz SIS mixer.

2. Simulation Method

As far as the mixer structure around the junction's feed point (refer to Fig. 2) of the 660-GHz waveguide SIS mixer is concerned, it is impossible to settle an ordinary port such as waveguide and microstrip ports there, which can be easily treated by the HFSS simulator. To calculate the mixer's embedding impedance (i.e., the impedance seen at the feed point, namely feed point impedance), we indeed treated the feed point as a lumped-gap-source port, which is rather similar to the case of quasi-optical antennas, as the width and gap distance of the feed point are both much smaller than the working wavelength. Notice that simulation results do vary with the width of the lumped-gap source port. Here the source port width was taken as the width of the thin-film impedance transformer that is directly connected to the feed point as we think most electromagnetic field is concentrated there, while the source port height as the gap distance. The structural parameters of the mixer mount simply followed its original design [3], and the dielectric constant of the junction chip substrate (quartz) was assumed to be 4.45. The complex reflection coefficient G at the feed point for a source impedance Z_0, which can be specified arbitrarily, is calculated by HFSS, thereby giving the feed point impedance as $Z_0*(1+G)/(1-G)$.

It is well known that the mixer's embedding impedance can be measured with the help of a mixer's scale model with a miniature coaxial cable put at the measured feed point. Another experimental method (i.e., de-embedding method) is to measure the reflection coefficients at the mixer's waveguide port for three different loads (i.e., open, short, and an arbitrary resistance) connected at a desired feed point, and then numerically extract the embedding impedance at the feed point in terms of those measured reflection coefficients [4]. Obviously, it is easy to imitate this experimental method with a numerical simulator like HFSS. The reflection coefficient at the mixer's waveguide port can be calculated for different feed-point loads, which can be easily modeled by HFSS. Let us assume G_s, G_o, and G_r as the simulated reflection coefficients at the mixer's waveguide port for a short-, open-, and resistive-load at the feed point, respectively. Then the embedding impedance seen at the feed point (Z_{fp}) can be formularized as $Z_{fp}=Z_0*(G_o-G_r)/(G_r-G_s)$.

3. Simulation Results

With the help of the HFSS simulator, the embedding impedance of the 660-GHz waveguide SIS mixer including its two choke filters on the IF and ground sides was calculated by assuming the feed point as a lumped-gap-source port (10.56μm x 2.0μm, «λ @ 660GHz). The waveguide and IF ports were the other two ports for simulation. To understand the dependence of the embedding impedance upon the size of the lumped-gap-source port, the embedding impedance was firstly calculated at 660GHz for different source port widths with its height fixed as 2μm. As shown in Fig. 3, the feed point impedance varies with the width of the lumped-gap-source port. Given the fact that the lumped-gap-source port has uniformly distributed field, we suggest that its width should be taken as that of the impedance transformer (3.8μm) connected between the feed point and the junction's tuning circuit.

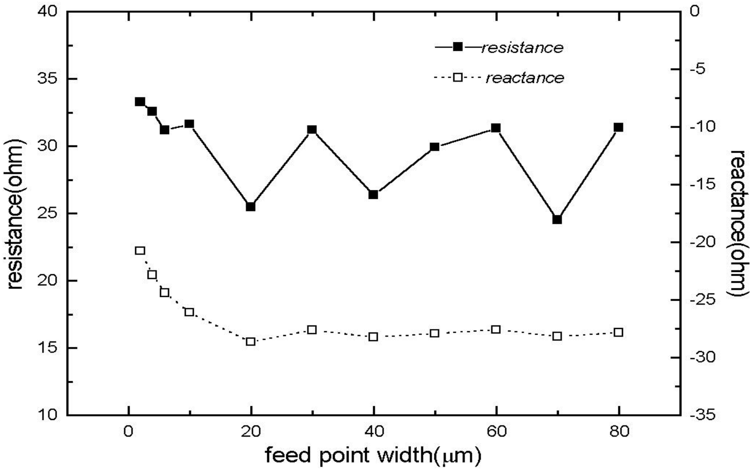

Fig. 3 Mixer's embedding impedance simulated at 660 GHz, as a function of the feed-point width.

The frequency dependence of the embedding impedance of the 660-GHz waveguide SIS mixer was then calculated for a lumped-gap-source port measuring 3.8μm x 2.0μm. As plotted in Fig. 4, the calculated resistance is well close to 35Ω, while the reactance is around –20 Ω. To compare with the results by the lumped-gap-source method, we also calculated the mixer's embedding impedance by the de-embedding method described above. It should be pointed out that while calculating the mixer's reflection coefficient at its waveguide port, we left the feed point with no any connection as the open-load case, a perfect conductor strip measuring 3.8μm x 2.0μm as the short load, and a resistive strip (=40Ω) also measuring 3.8μm x 2.0μm as the resistive load. The mixer's embedding impedance extracted from the simulated reflection coefficients for the three different loads at the feed point is also plotted in Fig. 4 for comparison. Obviously, the two results are in good agreement, although they were simulated with two different methods.

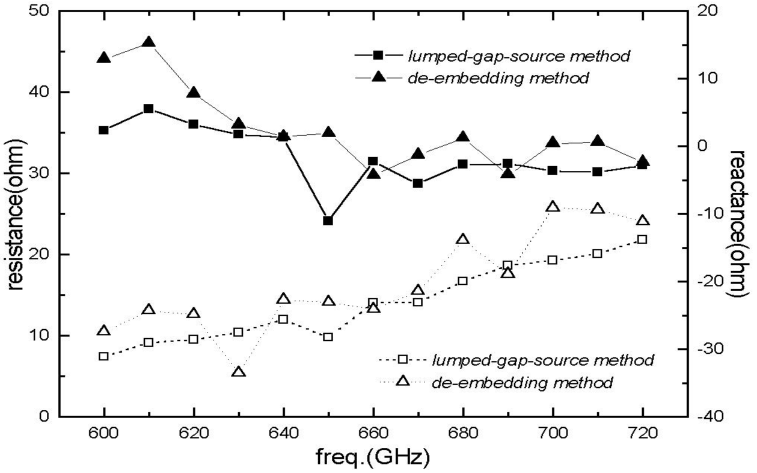

Fig. 4 Frequency dependence of the mixer's embedding impedance.

By changing the position of the feed point in waveguide in both horizontal and vertical directions, we investigated the effect of the feed-point position on the mixer's embedding impedance. Notice that the two choke filters shift correspondingly, but other structures of the mixer keep fixed. It just models the situation as if the junction chip is aligned in the mixer mount. The simulated results are demonstrated in Fig. 5 for different horizontal and vertical shifts of the feed point. It is clear that the variation of the mixer's embedding impedance is not considerable for the feed-point position displacement.

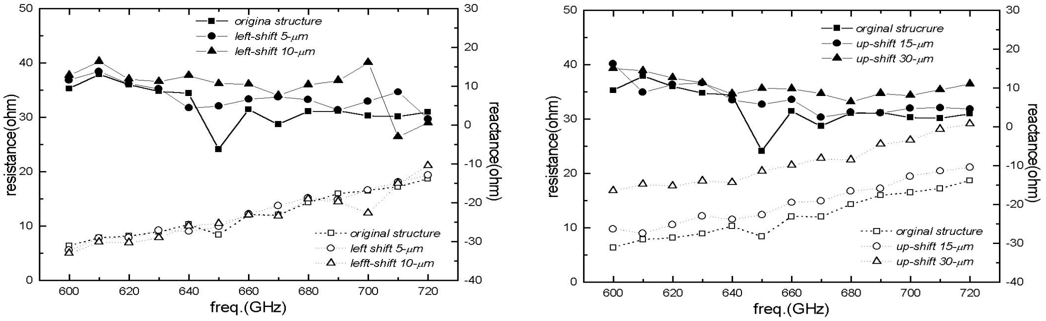

Fig. 5 Mixer's embedding impedance vs. the feed-point displacement, with (a) horizontal offset and (b) vertical offset.

We also calculated the mixer's embedding impedance for different substrate thicknesses of the junction chip. As exhibited in Fig. 6, the embedding impedance change is rather evident when the quartz-substrate thickness is reduced down to 30μm from 40μm.

4. Summary

The embedding impedance of a 660-GHz waveguide SIS mixer has been numerically studied with a lumped-gap-source and de-embedding method. A good agreement has been found between the results by the two methods. It has also been found that the mixer's embedding impedance is not affect considerably by the junction chip displacement, but by the substrate thickness of the junction chip. The results presented here are of good use for the development of waveguide SIS mixers at submillimeter wavelengths.

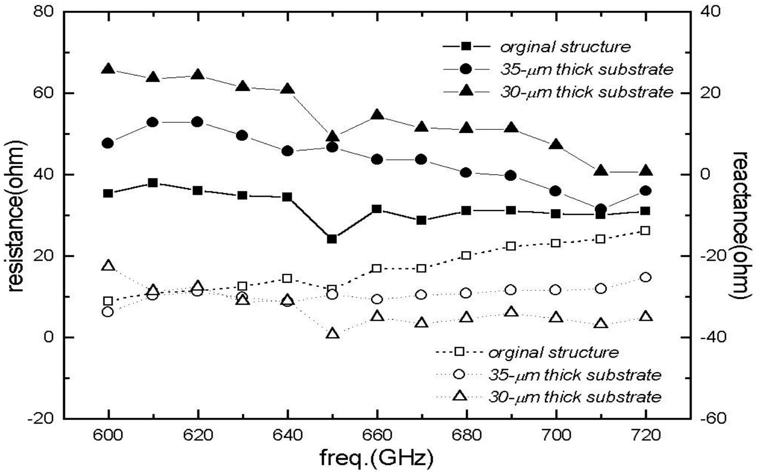

Fig. 6 Mixer's embedding impedance vs. the junction chip thickness.

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