100 GHz sideband separating mixer with wide IF band

D. Maier, D. Billon-Pierron, J. Reverdy, and M. Schicke

***Abstract*—A sideband separating SIS mixer with a 4–12 GHz IF band and covering the RF frequency range of 80 to 116 GHz has been developed. First junctions have been fabricated and tested as DSB mixers resulting in good and flat noise temperatures over RF and IF bands.**

***Index Terms*—sideband separating mixer, SIS mixer, wide IF band**

I. Introduction

A sideband separating mixer for 100 GHz based on single-ended DSB mixers and an RF waveguide quadrature coupler has been developed. A schematic view of the mixer is shown in Figure 1. The two DSB mixer units are connected at their inputs and outputs to quadrature hybrids. The LO signal is split and applied in-phase to the two mixers through –23dB injection couplers. Since upper and lower sideband signals undergo different phase shifts, they appear separately at the two outputs of the IF quadrature hybrid [1].

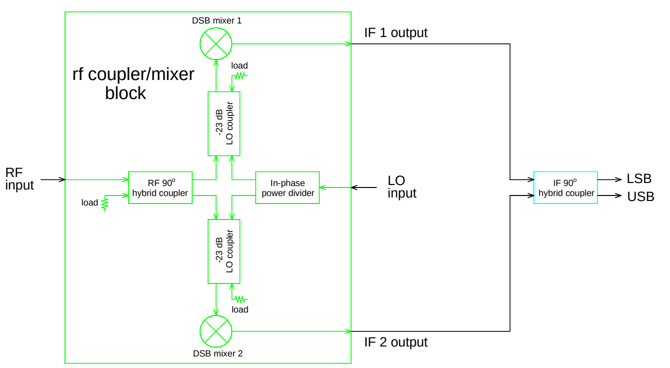

Figure 1. Schematic view of the sideband separating mixer.

II. 2SB mixer assembly

The RF 90° hybrid coupler, the two –23 dB LO couplers and the in-phase power divider as well as the two mixer blocks have been integrated into one E-plane split-block as shown in Figure 2. So, the 2SB mixer assembly consists of this combined RF coupler/mixer block and a commercially available IF 90° hybrid coupler. The IF outputs of the mixers are connected via semirigid cables to the inputs of the IF quadrature coupler.

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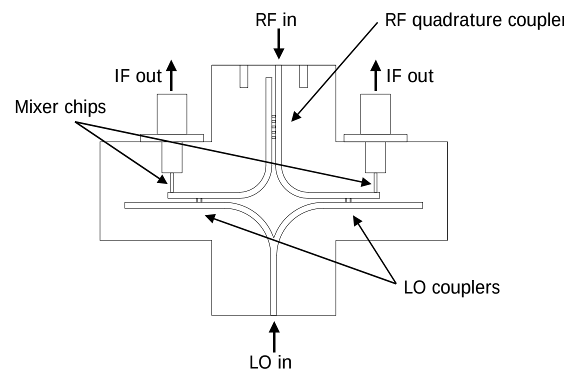

Figure 2. RF coupler/mixer block realized as E-plane splitblock.

A. RF quadrature coupler

The RF quadrature coupler has been realized as branchline coupler [2]. The dimensions of the slots have been optimized using CST Microwave Studio [3]. The results of the simulations are shown in Figure 3.

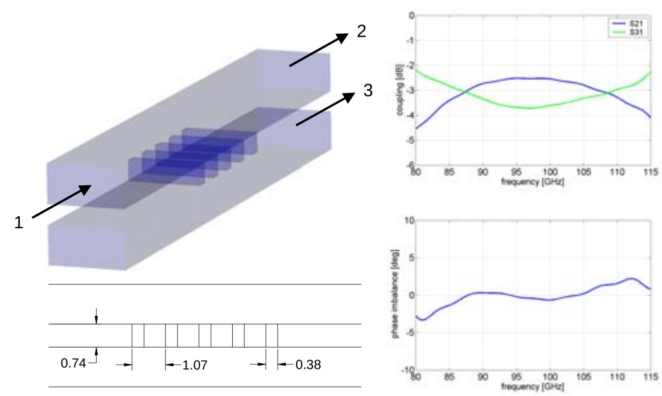

Figure 3. RF quadrature coupler.

B. LO coupler

In order to decrease the noise contribution of the LO system, we decided to use a -23 dB LO coupler. With such a coupler we expect a noise contribution of 1.5 K compared to 6 K of a normally used –17 dB coupler. Just like the RF quadrature coupler the LO coupler has been realized as branchline coupler, but only with two slots.

III. DSB MIXER

A. RF design

The essential part of the mixer is a series array of superconductor-insulator-superconductor (SIS) tunnel junctions, which is deposited together with a supercon-ducting circuit onto a quartz substrate. This circuit comprises the antenna providing a full-height waveguide to suspended microstrip transition, the RF choke and the actual tuning circuit whose role is to compensate the junction capacitance and matching to the antenna impedance. Figure 4 shows the layout of one individual mixer chip with a size of 0.6 × 4.5 × 0.08 mm^3. These devices are fabricated by IRAM's SIS group [4].

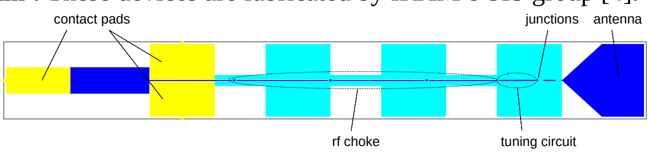

Figure 4. Layout of the mixer chip.

The mixer chip is placed in a channel perpendicular to the waveguide axis and stretches only partly across the waveguide as can be seen in Figure 5. The full-height waveguide to microstrip transition is provided by an antenna structure that has been optimized using CST Microwave Studio [3]. The resulting antenna impedance is slightly capacitive, but its real part is almost constant over the operating frequency range (see Figure 6).

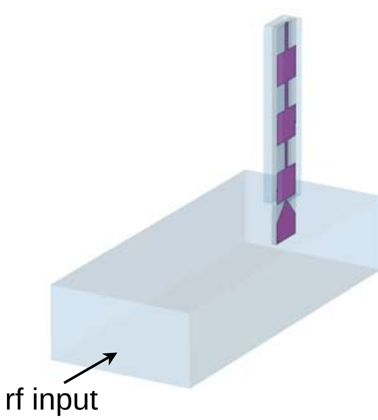

Figure 5. Full-height waveguide to microstrip transition.

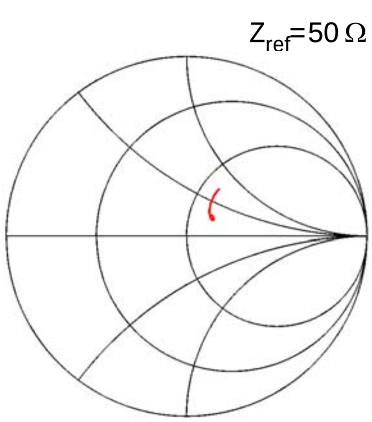

Figure 6. Antenna driving point impedances for frequencies between 80 and 116 GHz. Smith chart is normalized to 50 Ω.

A superconducting tuning circuit has been developed and optimized using Sonnet [5] and ADS [6]. Figure 7 shows a picture of the tuning structure. The equivalent circuit is shown in Figure 8.

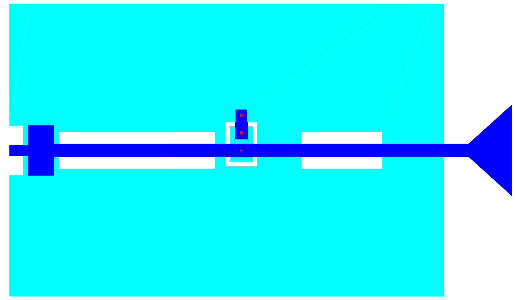

Figure 7. Tuning circuit of baseline design.

The design employs three junctions of size 1.5×1.5 mm^2 in series of which two are placed on an island structure. Although this adds a small series inductance to the junction array, the whole structure remains capacitive. This capacitance is compensated by a parallel inductance consisting of a coplanar waveguide followed by a capacitance providing the virtual ground to RF. Matching to the antenna impedance is achieved with a structure that can be viewed either as a CLCPW λ/4-transformer or as a discrete L-C transformer.

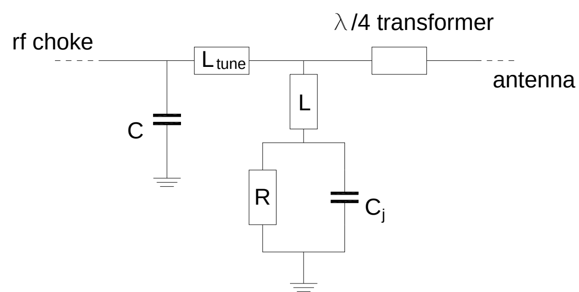

Figure 8. Equivalent circuit of the tuning structure.

IRAM's standard fabrication process for SIS junctions includes anodization for better isolation [4]. Since in this design two junctions are placed on an isolated island, they cannot be anodized and so the standard process cannot be used. In order to limit the risk of the development of a process without anodization, a second design based on the standard process has been made. In this design the array consists only of two junctions of size 1.2×1.2 mm^2. The short to ground has been realized with a large area junction. The order of the different layers is inverted compared to the baseline design. A small line connects the large junction to mass, so that both junctions can be anodized. The characteristics of the two junction array in the backup design have been chosen to equal those of the three junctions array in the baseline design so that tuning and matching to the antenna impedance are almost the same for the two designs.

The achieved matching to the junction is quite homogenous over the whole frequency range for both designs as can be seen by the junction's embedding impedances plotted in the Smith chart in Figure 9. The red line in the Smith chart delimits the region of impedances for which we expect unconditionally stable behaviour. The power coupled to the junction lies above 96% (see Figure 10).

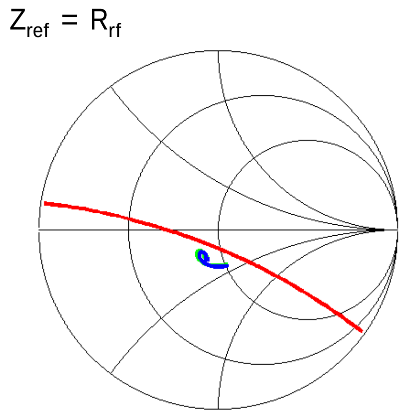

Figure 9. Embedding impedances of the junctions for baseline (green) and backup (blue) design. The red line delimits the region of unconditionally stable behaviour. Smith chart is normalized to the junction's RF impedance.

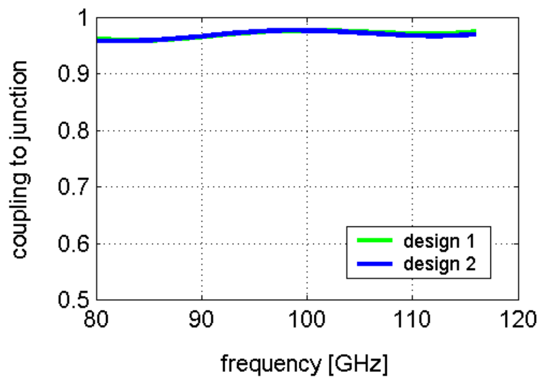

Figure 10. Fraction of power coupled to the junctions for both designs.

B. Noise measurements

First wafers have been fabricated having a very low yield and bad homogeneity of chips of design 1. No chips of design 2 could be fabricated so far. Figure 11 shows a photograph of the 3 junctions array of a design 1 mixer chip, which has been tested as DSB mixer.

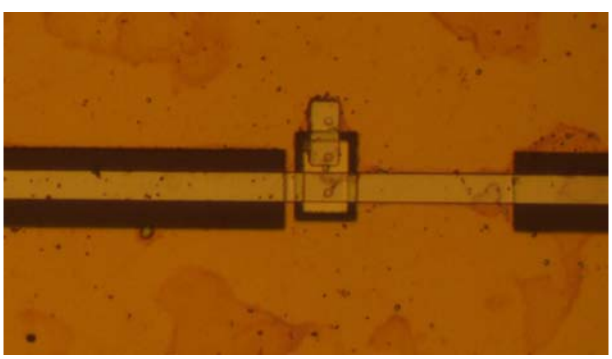

Figure 11. Photograph of the 3 junctions array of design 1.

Although in the final design the junctions are directly mounted into the integrated coupler/mixer block without prior testing, mixer blocks have been fabricated to be able to validate the mixer design by DSB mixer tests. Figure 12 shows a mixer chip mounted in the DSB mixer block for testing. On the right-hand side the IF output of the mixer is connected via bond wires to a 50Ω line.

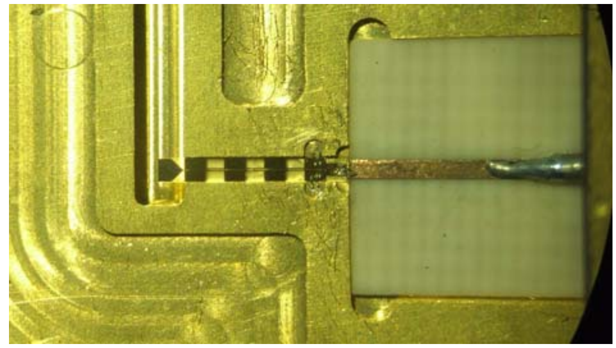

Figure 12. Photograph of mixer chip mounted in the DSB mixer block.

An example of a DSB noise measurement for f_{LO} = 100 GHz and an IF band of 4 to 12 GHz is shown in Figure 13. It can be seen that the three junctions in series behave like one single junction.

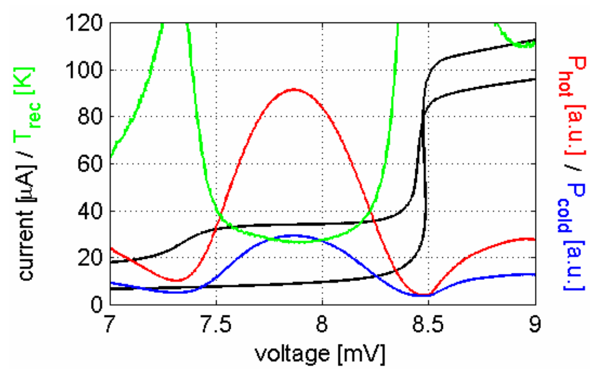

Figure 13. Example of noise measurement for f_{LO} = 100 GHz and f_{IF} = 4-12 GHz.

Noise measurements have been carried out first for an IF band of 4 to 8 GHz. The result is shown in Figure 14 represented by the blue curve. When changing the IF chain to 4–12 GHz, the noise increases by ~6 K due to the higher noise of the HEMT amplifier [7] (green curve in Figure 14). Since these measurements have been made with a –17 dB LO coupler these results will improve by around 4.5 K when changing to the initially foreseen LO coupler with –23 dB coupling.

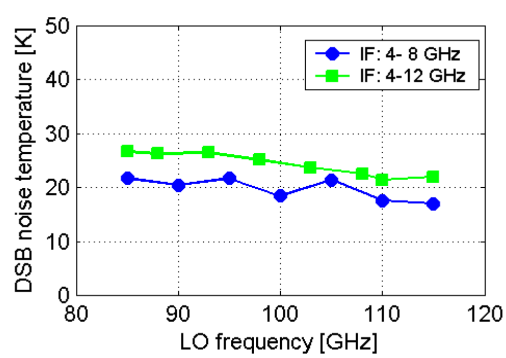

Figure 14. DSB noise measurements integrated over 4 to 8 GHz and 4 to 12 GHz IF band.

Noise temperatures as a function of the IF frequency are shown in Figure 15. Apart from the point at 4 GHz where the cryogenic isolator is not working correctly noise curves are flat over the IF band.

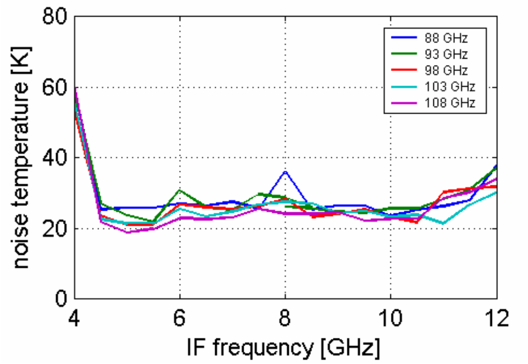

Figure 15. Noise temperatures as a function of the IF frequency.

IV. CONCLUSIONS

A sideband separating mixer for the RF frequency range of 80 to 116 GHz has been designed. First junctions have been characterized as DSB mixers for LO frequencies from 85 to 115 GHz and an IF band of 4 to 12 GHz achieving integrated noise temperatures between 22 and 27 K. The DSB mixer design could thus be validated for signal frequencies between 77 and 123 GHz. The design also covers the IF band of 4 to 12 GHz as can be seen by the flat noise curves as function of IF frequency.

ACKNOWLEDGEMENTS

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