Design of 129-174 GHz SSB SIS mixer for Band 2 of New Generation Receiver of IRAM PdB Interferometer

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Abstract

We present the design of a Single Side Band (SSB) SIS mixer covering the band 129-174GHz. A reactive termination is used to reject the image sideband. We discuss the problems posed by the requirements of SSB operation, stability, wide IF band (3.85-7.85 GHz), and the design solutions that were adopted.

Introduction. A stability criterion for an SSB SIS mixer with distinct signal and image termination impedances under typical operating conditions has been derived for the band 129-174 GHz using the standard quantum theory of mixing. One of the most significant design issues is to achieve SSB operation over a wide tuning range, while ensuring stable operation in all cases according with the derived criterion. A series array of N=2 SIS junctions has been preferred to a single junction design to increase the saturation power of the mixer, which scales approximately as N^2.

Waveguide and transition to Suspended Substrate Microstripline (SSL). We use a WR6 full-height waveguide (1.651×0.825 mm^2), which is easier to fabricate and has lower loss than a reduced-height waveguide. The wideband transition to SSL (quartz thickness and width 160 μm and 500 μm, respectively) is similar to the one adopted in a previous work [1], properly rescaled and further optimized using a numerical EM simulator. This is based on a probe (and quartz substrate) stretching only part way inside the waveguide with the substrate perpendicular to the waveguide axis (see Figs.(1) -(2)).

A choke type noncontacting backshort with rectangular cross-section can be displaced inside the waveguide. It has been optimized to provide a large amplitude of reflection coefficient (above –0.03 dB) over the 129-174 GHz band taking into account of mechanical tolerances. For a given position, it provides a good match to a ~75 Ω impedance at the single-ended probe driving point. Image rejection is achieved by adjusting the backshort so that, simultaneously, an optimum match is achieved at the signal frequency, while a reactive termination is presented to the junctions at the image frequency. With a central IF frequency of 5.85 GHz, the required backshort distance from the antenna plane necessary to fulfill such condition is of the order of $l_{BS} \approx 5$ mm. The mixer can also be operated in DSB with a fixed backshort position close to the antenna plane at a distance of $\approx\lambda_g/4\approx0.5$ mm.

RF and IF Matching Circuits. Each of the two Nb/Al-AlO$_x$/Nb junctions has an area of 1.6×1.6 μm^2, a critical current density of ≈4 kA/cm^2 ($C_s\approx58$ fF/μm^2), and a normal state resistance of $R_n=25\Omega$ ($\omega R_nC\approx3.5$). The top contacts of the tunnel barriers are located inside a short section of an electrically isolated rectangular pad on a Niobium layer 430 nm thick. RF currents from the antenna gets to the junctions flowing from a bottom Niobium strip (120 nm thick) connected to the pad (see bottom of Fig.(2)). The short length (18 μm) of the isolated rectangular pad allows to minimize the series inductance of the array (≈6 pH) so that its total RF reactance is still dominated by the total intrinsic capacitance of the junction series C≈75 fF. A parallel tuning inductor (9 pH), realized as a short section of coplanar waveguide (CPW) terminated into a short circuit through a 16×16 μm^2 junction via, allows to tune out the reactive part of the series combination of the SIS array with a capacitive stub. Such a stub provides a ground for the RF and a path for the IF output and junction bias through a two sections RF choke connected to it. Each section of the choke is realized as CPW followed by a microstrip capacitor, and is designed to present a high RF impedance to the junction array. The resulting impedance of the tuned SIS series array is matched to the 75 Ω antenna using a two section impedance transformer consisting of a short inductive CPW section (≈λ/20) followed by a short capacitive microstrip section (≈λ/40).

To achieve the required 4 GHz IF band, the intrinsic capacitances and inductances of the chip have been kept to a minimum value. An IF matching circuit external to the chip has been designed to present a real part of the load impedance as seen at the junction port in the range 50-80 Ω over the 3.85-7.85 GHz IF band.

The mixer has been optimized using various electromagnetic simulators.

Mixer block construction. The main mixer block ($25\times25\times20$ mm^3) is split in two parts which will be made of brass to allow easy machining (see Fig.(3)). The rear mixer block houses the mixer chip and the copper-beryllium backshort. The rectangular waveguides will be realized by spark erosion technique, while the other parts require standard micromachining process.

Predicted performances. The final result of simulation for the impedance seen by the junctions when the mixer is operated in SSB mode (ex. LSB 149 GHz, backshort at 5.6 mm from the antenna plane) is shown in Fig.(4). At intervals of $2\times\nu_{IF}=11.70$ GHz, the junction sees alternately an approximate match and a reactive termination which is confined in the derived stability region. The quantum theory of mixing is used to compute the mixer and receiver noise temperatures. The results are shown in Fig.(5) (we have assumed a noise temperature of the IF amplifier of 6 K; input losses are not taken into account). A receiver noise below 15 K (quasi-SSB, image gain less than –14 dB) is estimated over the operating band of the mixer.

Conclusions. A new type of SSB SIS mixer has been designed for the 129-174 GHz frequency band of the new generation receiver of IRAM PdBI. The mixer chip includes a series array of two junctions and has been designed with low output capacitance and inductance to cover an IF band of 4 GHz. The mixer can achieve low noise and image band rejection while maintaining stable operation over the whole RF band.

References

[1] Navarrini, A., Lazareff, B., Billon-Pierron, D., and Peron, I., "Design and characterization of a 225-370 GHz DSB and a 250-360 GHz SSB full height waveguide

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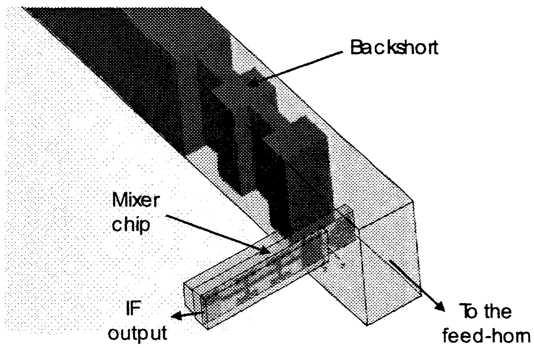
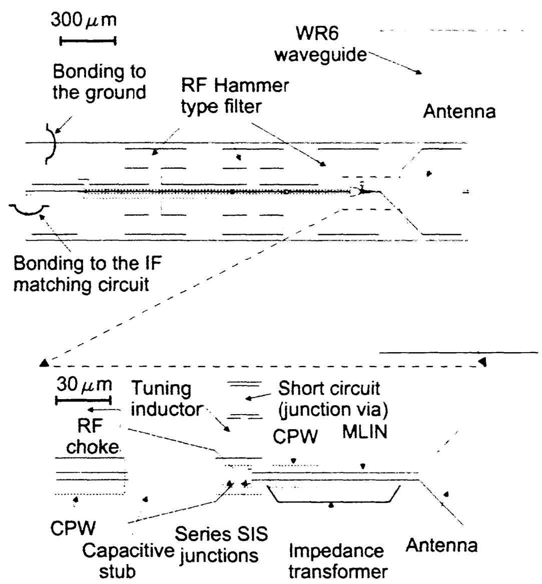
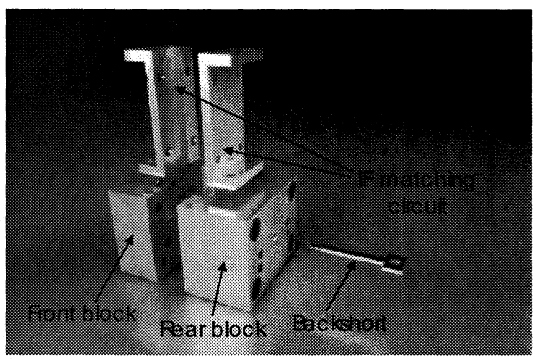


Fig.(1): Inner structure of the SSB mixer.





Fig(3): Overview of the mechanical assembly of the mixer.

Fig.(2) *Top):* View of the mixer chip showing the antenna, the RF Hammer type filter and the bonding wires to the external ground and IF matching circuit. *Bottom):* Central part of the chip including the array series of two SIS junctions with its RF tuning structure. The mixer chip has dimensions 0.16×0.5×2.37 mm^3.

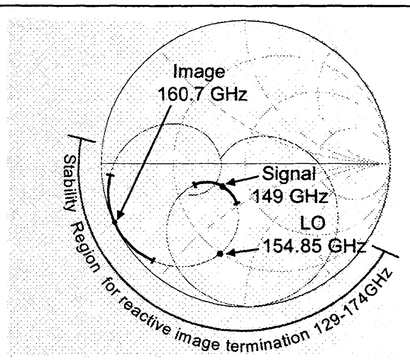


Fig.(4): Embedding impedance seen by the junction, over the design operation band for a SSB tuning in LSB at 149 GHz. The Smith chart is normalized to the small signal RF resistance of the series array $R_{RF}(150GHz) \approx 24\ \Omega$.

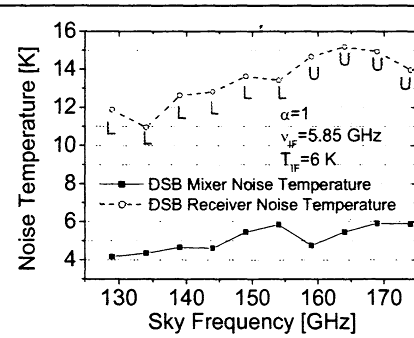


Fig.(5): Predicted DSB mixer and receiver noise temperature of the SSB mixer referred at its input. The letters *L* and *U* over each point indicate whether the corresponding value is obtained in, respectively LSB or USB.