Design of a Sideband Separation Receiver for 500 GHz

Raquel Monje, Christophe Risacher, Vessen Vassilev and Victor Belitsky

Group for Advanced Receiver Development (GARD), Department of Radio and Space Science with Onsala Space Observatory, Chalmers University of Technology, MC2, S 412 96, Gothenburg, Sweden

Abstract — **We describe design of a sideband-separating superconductor-insulator-superconductor (SIS) mixer for the APEX telescope Band 3, 385 – 500 GHz. The mixer design combines waveguide components and on-chip local oscillator (LO) injection. The receiver used quadrature scheme where the RF signal is divided equally with a 90°-phase shift by a waveguide 3 dB hybrid with novel design using several microstrip probes. The LO is divided using an in-phase or 180-degree waveguide E-plane Y-junction. The output waveguides of the hybrid are coupled to the mixer SIS junctions through an E-probe based on waveguide-to-microstrip transition with integrated bias-T. A directional coupler for the LO and RF signals, the SIS junction, the tuning circuitry lines and the bias-T are integrated on a single mixer chip. We use a novel component, an ellipse termination to provide easy and high-performance on-chip LO injection.**

Index Terms — **SIS mixer, sideband separating receiver, waveguide-to-microstrip transition.**

I. Introduction

The Atacama Pathfinder Experiment (APEX) will have a suite of heterodyne receivers for spectroscopy and bolometer arrays for continuum observations across the range from 200 GHz - 1.5 THz divided in different bands. For band 3 (385 - 500 GHz), sideband separation (2SB) SIS mixer is chosen. This technology provides better sensitivity for spectral line observation than double sideband (DSB) [1]. Besides, DSB observations may lead to spectral line-confusion or degrade the system noise temperature and the receiver sensitivity with strong absorption bands falling into the image band. This is a driving reason to choose this technology considering that some of the important molecules for this band are very close to telluric absorption line, as in the case of deuterated water, HDO, with its fundamental transition frequency at 465 GHz.

In the proposed design, sideband separation is achieved using a quadrature scheme. The configuration used in the presented work is shown schematically in Figure 1. The RF signal is divided equally with 90° phase difference, and the local oscillator (LO) is symmetrically split and applied to 2 identical DSB mixers 180 degree phase difference. The mixers outputs at intermediate frequency (IF) are connected to IF cryogenic amplifiers followed by a quadrature 3 dB hybrid. Since one of the sidebands is combined in phase and the other out of phase, sideband cancellation occurs and both sidebands appear separated. Alternative scheme considers the hybrid inputs take the mixer IF signals directly while the outputs of it is connected to cryogenic IF Low Noise Amplifiers (LNA).

The mixer chip design is based on the previous development of a 2SB mixer for 85-115 GHz using a combination of waveguide components and on-chip LO injection [2], whose results confirm the capability of such integrated structure.

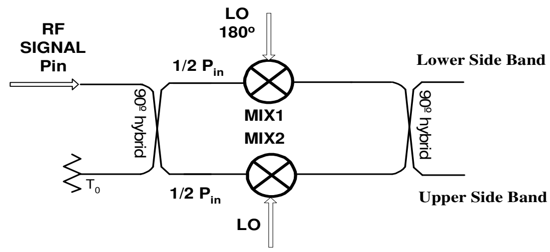

Fig. 1. Sideband-separation mixer configuration for Band 3.

II. Waveguide Quadrature Hybrid

The quadrature hybrid is used to divide equally the RF signal with a 90° phase difference. At these frequencies the branch dimensions become very small, and thus conventional waveguide 3 dB branch line coupler is extremely difficult to machine. We designed a waveguide hybrid using several microstrip probes inspired by the design with broad-wall coupling [3]. Our design provides 3 dB coupling using 6 E - field probes in each waveguide combined with short microstrip line optimized to obtain a maximum RF bandwidth. The probes are placed on quartz ($\varepsilon_r = 4.34$) with substrate dimensions of about 310 μm x 120 μm x 50 μm. The distance between the two probes is a quarter of wavelength in order to provide 90° phase difference between port 3 and port 4.

This kind of hybrid will be built into the mixer block using a split-block technique. The back-piece part of the mixer block will accommodate the microstrip probes oriented parallel to the electric field and the termination of the idle port of the hybrid.

Figure 2 shows the HFSS simulated parameters of this structure, the magnitude imbalance is of ± 0.5 dB around -3 dB in the band of interest (385-500 GHz). Whereas, the return losses and isolation are better than -15 dB. Our study of the tolerances reveals that the displacement of the branch-line substrate along the y-axis allows a deviation of ± 10µm without changing the coupler performance any noticeable.

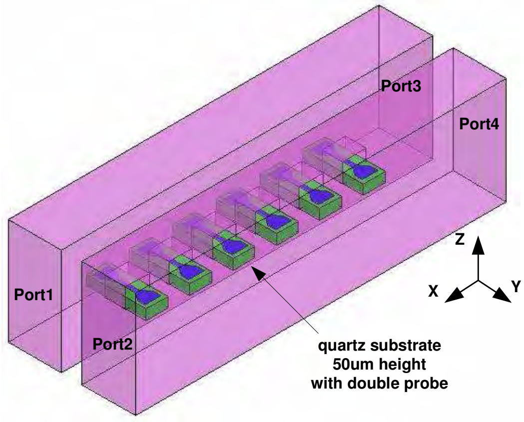

Fig. 2. 3 dB Quadrature hybrid with 6 microstrip branches sections using broadband probes.

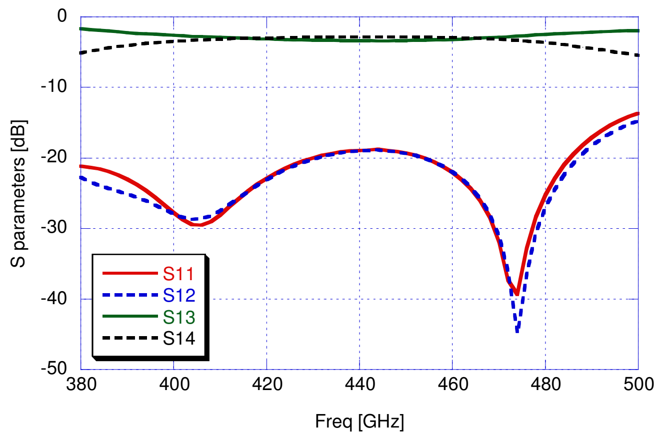

Fig. 3. S-parameters from the simulation, coupled signals (port 3 and 4) are about -3 dB and the return loss and isolation (port 1 and 2) better than -15 dB.

III. Waveguide-to-Microstrip Transition

The proposed waveguide-to-microstrip transition is made of a full-height waveguide, a fixed waveguide backshort, an E - probe with an integrated bias-T [4] using choke filters. With the aim of adding an isolated port for DC and IF signals, we connect the E-probe wide side via a (2n+1)λ/4 long line to the choke filter at the other side of the waveguide (Fig. 4). This provides isolation of the port and minimize its influence on the performance of the waveguide-to-microstrip transition because the lane has length of an odd number of quarter wavelengths and at the waveguide wall plane, the line ends on a choke structure, providing RF ground for the high impedance line and port for DC and IF signals. The quartz substrate used for this design will have a thickness of 50 µm and width of 150 µm. The RF probe is shaped in order to achieve a broadband matching between the waveguide and the probe output and to obtain as low impedance as possible at the microstrip port. According to our simulations the impedance observed at the microstrip is approximately 30 Ω see insert Figure 4, the 30 Ohm normalized Smith Chart, we can observe the "tear drop" shaped frequency dependent input impedance of the microstrip.

The probe structure is oriented perpendicular to the Pointing vector in the waveguide with an airgap underneath the substrate (see Figure 4). This airgap increases the cutoff frequency of the dielectric channel and therefore, it allows us to increasing the substrate width. The dimensions of the airgap are 10 µm x 120 µm, deeper gap will produce the excitation of higher modes. The simulated results shown in Figure 5 predict an insertion loss less than -0.05 dB and a return loss better than -15 dB at the entire band.

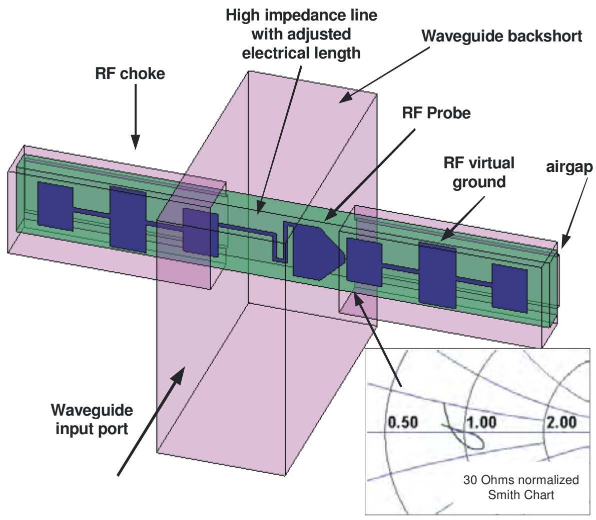

Fig. 4. Schematic drawing of the waveguide-to-microstrip transition and the 30 Ohm normalized Smith Chart showing the frequency dependent impedance at the output of the probe.

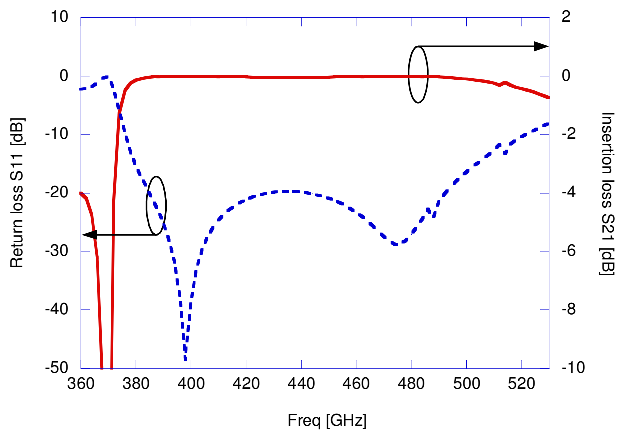

Fig. 5. Simulated results: upper curve is the insertion loss and lower curve is the return loss.

V. Mixer Block Description

The main mixer block part containing the LO in-phase power divider and the RF 3 dB coupler will be split in two parts following the split block technique, Figure 6 shows one half of the mixer chip. The mixer blocks attached laterally to this structure will house the mixer chip together with the magnetic field concentrators for the Josephson effect suppression and all IF and the DC bias circuitry.

For the LO in-phase power divider is an E-plane Y-junction with a 3-section Chebyshev transformer from a rectangular to square waveguide has been chosen [5] due to its good performance. The radius used in this structure is equal to 0.6 mm providing a very compact design.

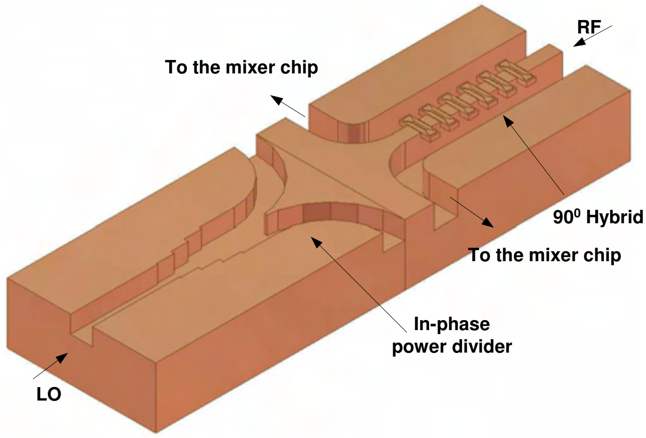

Fig. 6. Drawing of one half of the mixer block containing the LO in – phase power divider and the RF 3-dB coupler.

IV. On Chip LO Directional Coupler

The LO directional coupler, shown in Figure 7, is integrated on the mixer chip, this configuration presents a compact and alternative solution to the branch waveguide couplers that in order to provide such a weak coupling the branch waveguides should become extremely small and therefore very difficult to fabricate.

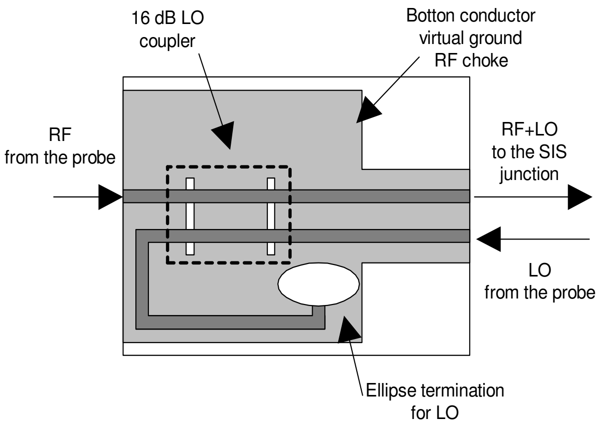

Fig. 7. Schematic drawing of the LO directional coupler with two perforations slot-holes and the ellipse termination for the idle LO port

The two in-phase LO output from the splitter will enter the mixer chip through a waveguide-to-microstrip probe at the opposite end of the RF probe, and it will be coupled to the RF path through a 16 dB directional coupler. The LO directional coupler is made with superconducting lines coupled via lumped links, the two perforations slot-holes in the ground plane on the same substrate as the SIS junction and the RF tuning circuitry. The LO idle line is terminated with an elliptical termination [5], which provides a very high and wideband performance. This termination is made of a resistive material having a sheet resistance equal to the impedance of the line [6].

VI. Conclusion

We present the design of a sideband separation mixer for 385-500 GHz. The mixer design introduces a novel 3 dB coupler, combining waveguide and microstrip components. Furthermore, the mixer include some other novel components as a waveguide probe with integrated bias-T, allowing to extract IF signals and to inject DC current as well as a high-performance ellipse termination for the LO. The first test of the receiver is planned for the beginning of 2006.

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