Design of RF waveguide structure for 2SB SIS receiver for Millimetron 211-275 GHz VLBI channel

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Abstract—**The waveguide structure of a Sideband-separating (2SB) receiver based on superconductor-insulator-superconductor (SIS) mixers strongly influences the Sideband Rejection Ratio (SRR), one of the key parameters of the receiver. During development of a RF waveguide structure for a 211-275 GHz 2SB SIS receiver it was found that SRR degrades from 26 dB to about 18-20 dB due to reflections from SIS mixers and from RF loads. Additionally, the imbalance of an LO signal is found and described. This imbalance can cause up to 0.5 dB difference in pumping level of SIS junctions and additional phase shift up to 5 degrees. This effect strongly depends on LO frequency. As result, the SRR can degrade further down by 1..2 dB.**

Keywords—SIS receivers, sideband separation, sideband rejection ratio

I. INTRODUCTION

The 1.3mm band corresponding to ALMA Band 6 is the prime observational range for the current and for the future Event Horizon Telescope activities. The VLBI instrument for Millimetron space project includes a 211-275 GHz receiver, which is planned to be based on superconductor-insulator-superconductor (SIS) mixers. For the best possible sensitivity of the Space-Earth interferometer the onboard receiver should have the same sideband configuration as the receivers installed in the ground telescopes, i.e. it should be sideband separating (2SB) one. Using a DSB mixer on board of Millimetron would cause degradation of the interferometer sensitivity by a factor of square root of 2.

II. DESIGN

In our development of 2SB SIS receiver for the frequencies 211-275 GHz we have designed a waveguide block comprising of RF hybrid, 3dB LO splitter and LO couplers, see Fig.1. The design has modular approach same as in [1] and the elements structures are similar to [2]. The RF hybrid was designed with a gain balance within 1 dB and with a phase imbalance not exceeding 0.3 degrees (see fig.2). The corresponding Sideband Rejection Ratio (SRR) is better than -26dB in the entire frequency band. The prime focus in the design of the waveguide structures was dedicated to the reduction of reflections, which are strongly distorting the sideband rejection ration (SRR) [3].

Using 3D-simulator and we have analyzed the entire waveguide structure of the RF block and estimated the SRR efficiency for different levels of reflection form RF loads and from the SIS mixers.

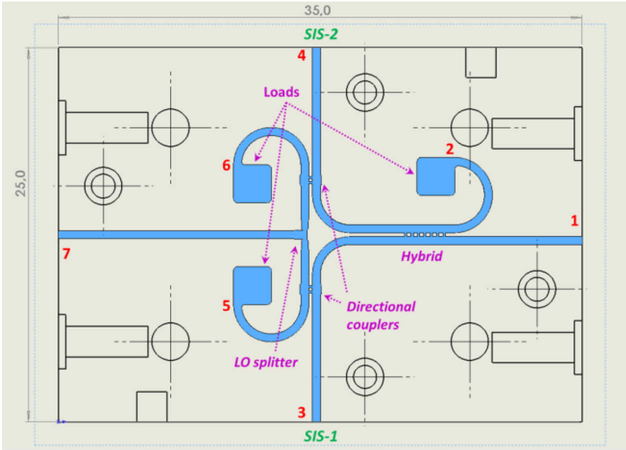

Fig.1 Drawing of the hybrid block showing the RF waveguide structure. Ports 1 and 7 show the inputs for the LO and RF signals correspondingly. Ports 3 and 4 are associated with signs ``SIS-1" and ``SIS-2", which indicate the location of the SIS junctions after the backpieces are installed. Ports 2, 6, 5 indicates the loads: 2 - RF load to suppress parasitic reflections, 6 and 5 - LO loads dump the unused LO power. The waveguide block size is 25\,mm x 35\,mm.

III. RESULTS

The influence of the reflections form SIS mixers and from the RF load is demonstrated in Fig.2 and Fig.3. The reflection level for SIS mixers is varying here from -3.4dB to -9.2dB, at the same time reflection from RF load is fixed at -20dB. A strong degradation of amplitude and phase balance leads to deterioration of the SRR level, as example for SIS reflection of about -7dB it reaches 19 dB in the worst point, while for the pure RF hybrid it was not higher than -26 dB.

Additionally, the imbalance of an LO signal is found (see Fig. 3). It takes place also due to reflections from the SIS mixers and the RF load. This imbalance is periodic and the period is determined by the distance between the mixers and the RF load. For the given above levels of reflection, the LO amplitude unbalance can be up to 0.5 dB, causing different

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pumping level and, as result, different gain of the mixers. Meanwhile, more critical is the phase shift, which can reach the level of 5 degrees. This effect strongly depends on LO frequency.

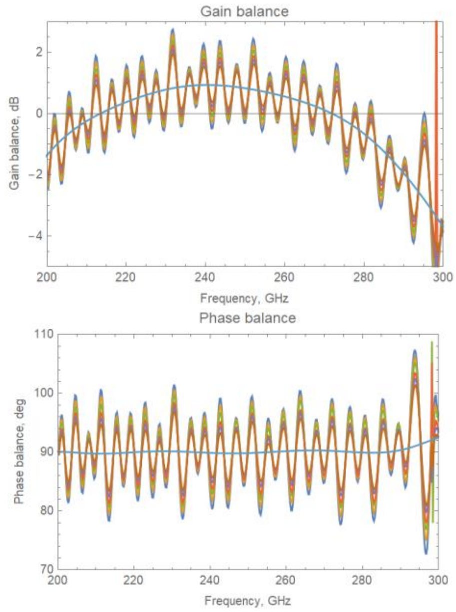

Fig.2 The top plot shows the simulated amplitude balance between two SIS mixers then reflections are added – oscillating curves; the smooth blue line represents gain balance of the single hybrid. The bottom plot similarly shows the simulated phase balance with reflections are added – oscillating curves; the smooth blue line is a phase balance for the single hybrid.

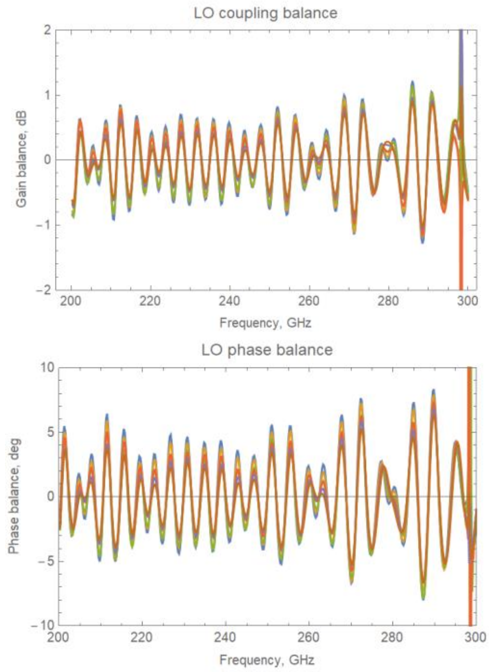

Fig.3 The top plot shows the simulated LO coupling balance between two SIS mixers then reflections are added; the bottom plot similarly shows the simulated phase error between LO signals arriving to the SIS mixers.

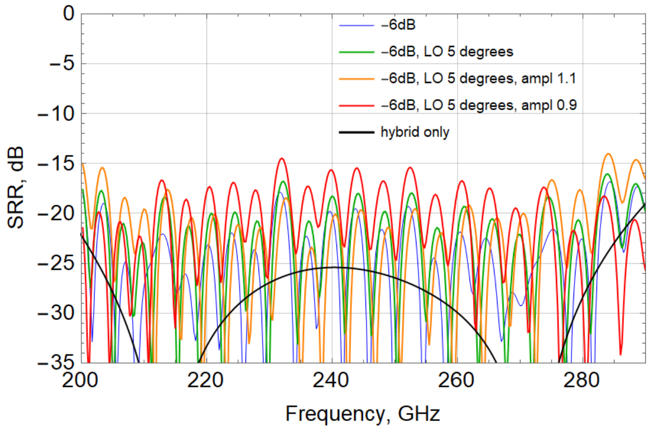

Fig.4 SRR vs frequency.

As seen from Fig.4 SRR degrades from 26 dB (black curve) to about 18..20 dB (blue curve) due to reflections from SIS mixers and from RF loads. Here SIS reflection is -6.7 dB, RF Load reflection -20 dB. For this design the hybrid isolation is 26…30 dB.

Taking into account the LO phase imbalance reduces the SRR level further by about 2 dB in the worst points (green curve vs blue one). The mixer gain imbalance caused by difference of mixers and by various LO pumping level could be estimated as 10% in amplitude or 0.8dB in power. This imbalance can be in-phase or contra-phase to amplitude imbalance causing degradation or improving of SRR, as shown by red and by orange curves in Fig.4. This give motivation to try swapping SIS mixer in 2SB block for better performance.

As conclusion, the influence of reflections on SRR level shows necessity to improve RF load, hybrid isolation and to pay attention to SIS mixer reflections for better performance of the entire 2SB receiver.

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