Efficiency of the Image Band Suppression in Sideband Separating SIS Receivers for Radio Astronomy

Andrey Khudchenko
Astro Space Center
P.N. Lebedev Physical Institute RAS
and Kotel'nikov Institute of Radio
Egineering and Electronics RAS
Moscow, Russia
khudchenko@asc.rssi.ru

Andrey Baryshev
Kapteyn Astronomical Institute
University of Groningen
Groningen, The Netherlands,
A.Baryshev@astro.rug.nl

Ronald Hesper
Kapteyn Astronomical Institute
University of Groningen
Groningen, The Netherlands,
r.hesper@astro.rug.nl

Ludmila Filipenko
Laboratory of superconducting devices
for signal detection and processing
Kotel'nikov Institute of Radio
Engineering and Electronics RAS
Moscow, Russia,
lyudmila@hitech.cplire.ru

Kirill Rudakov
Kapteyn Astronomical Institute
University of Groningen
Groningen, The Netherlands,
rudakov@astro.rug.nl

Valery Koshelets
Laboratory of superconducting devices
for signal detection and processing
Kotel'nikov Institute of Radio
Engineering and Electronics RAS
Moscow, Russia,
valery@hitech.cplire.ru

Abstract*— The sideband separating SIS receivers are known as the most sensitive instruments for millimeter and submillimeter ground based radio astronomy. Sideband Ratio or Sideband Rejection Ration (SRR), is one of the key parameters of heterodyne receivers, because it is strongly influencing the system sensitivity. This effect takes place due to sufficient signal losses in the atmosphere or in the instrument optics, which is reducing the signal to noise ratio. To develop high performance receiver SIS sideband separating receiver with have performed a comprehensive analysis of the signal transformation in both high frequency (RF) and low frequency (IF) parts of the receiver. As result, the entire IRR pattern was simulated. It was found that SRR performance is very much restricted by reflections in RF and IF parts of the receiver. Minimization of these reflections is curtail for achieving SRR levels of 15 dB or higher. This knowledge is used in development of sideband separating SIS receiver for ground based telescope APEX and for Millimetron space mission.

Keywords*— *radio astronomy, super-VLBI, SIS receivers, quantum-limited mixers.

A sideband separating (2SB) receivers based on superconductor-insulator-superconductor (SIS) mixers are widely used in ground-based astronomy, for example in observatories like ALMA, NOEMA and SMA. The main reason to split the sidebands is to reduce the atmospheric noise by rejecting the image band contribution. A Sideband Rejection Ratio (SRR) as high as 20 dB is desirable for better sensitivity of a receiver end to reduce line confusion effect. Typically, SRR specification is only 10 dB [1], which is driven by technical reasons, and it should be noted that many groups developing receivers for ALMA had difficulties to fit this spec. They were mainly trying to optimize the balance of individual receiver components: RF and IF hybrids and mixers gain, and the imbalance of each part was reduced to a level below 0.5 dB. Still, a total imbalance of 1.5 dB would give IRR better than 20 dB in the entire band, but in reality it was only 10 dB in the worst points [2], [3]. In our work we focused on study of the SRR pattern of the 2SB receiver by analysis of the entire receiver RF and IF structures.

This development is directed to facilitate "Millimetron" space observatory and the ground-based THz telescopes with a state-of-the-art 2SB SIS receivers. "Millimetron" is a 10-meter space telescope designed to study various objects in the Universe at millimeter and infrared wavelengths. Black holes are extremely compact, so very high angular resolution is required to observe their immediate vicinity. Such resolution is provided by the space-Earth interferometry based on "Millimetron" and ground telescopes. The "Millimetron" orbit configuration; the observatory will be located near the Lagrange point L2, at 1.5 million kilometers from Earth. The relevance of this direction was confirmed recently, when all the media published the first ever "image" of a supermassive black hole in the center of the galaxy M 87. For the best interferometric efficiency the receiver at the space telescope should have the same configuration as the one at the ground, this is the key motivation to develop 2SB receiver for the "Millimetron".

By simulating of the RF chain of the 2SB receiver it was found that imbalance in the RF part is dominated by reflections from SIS mixers, by RF hybrid isolation level, by reflections from RF load and only afterwards by the RF hybrid balance. Fig. 1 demonstrates schematically an example of waveguide structure of the 2SB mixer. Basically, this is the core of the RF part, which is connecting in one unit several components: RF horn, both SIS mixers, and the LO injection.

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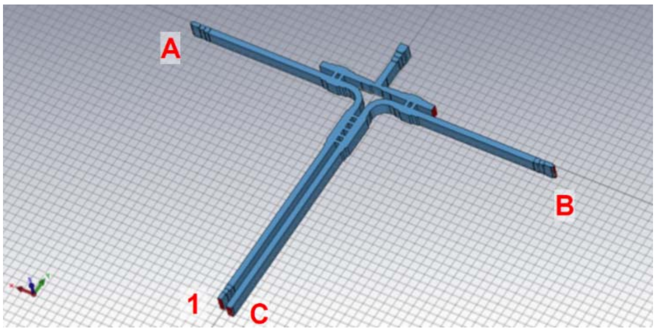

Fig. 1 Schematic representation of the RF waveguide part of the 2SB receiver. "A" and "B" show the location of the SIS mixers, "C" represents the RF input, which is connected later to the input horn, "1" marks the RF load location. The input signal arriving to the port "C" is split in the RF hybrid and directed to the SIS mixers. There are LO couplers between the hybrid and the mixers, which are injecting LO signal to the mixers. The LO signal is split between the couplers by a T-split.

Fig.2 shows by the black curve an example of the SRR curve presented versus RF frequency as if it would be only the RF hybrid providing phase and amplitude imbalance in the entire 2SB receiver. In the current situation the receiver was designed for frequency range 600-720 GHz. The imbalance of the RF hybrid is within 0.5 dB by amplitude and below 1 degree by phase. The prediction of the SRR level by the black curve looks very promising, but has never been demonstrated in reality. The reason is in additional reflections in the system, which have very large influence, because the reflection from the SIS mixers can easily be very large, basically being in the range -4 to -10 dB. Once we make an analytical analysis of the major reflections or run simulation of the entire RF waveguide structure in the E-M simulator program, for example HFSS, the phase and amplitude balance of the signals arriving to the SIS mixers gets strongly distorted by the described reflections. The red curve in the Fig.2 presents the SRR pattern taking into account the reflections. Important to mention, that due to reflections the SRR curve is rather clearly periodic, which can be observed experimentally [4]. The periods of these kind of standing waves correspond to the electrical length between the SIS mixers through the RF hybrid and to the length between the SIS mixer and the RF load. Comparing the black and the red curves one can see a degradation of the SRR level by about 15 dB (from 30 dB to 15 dB). This clearly indicates minimization of the reflections is absolutely crucial for the design of the RF part of any 2SB receiver.

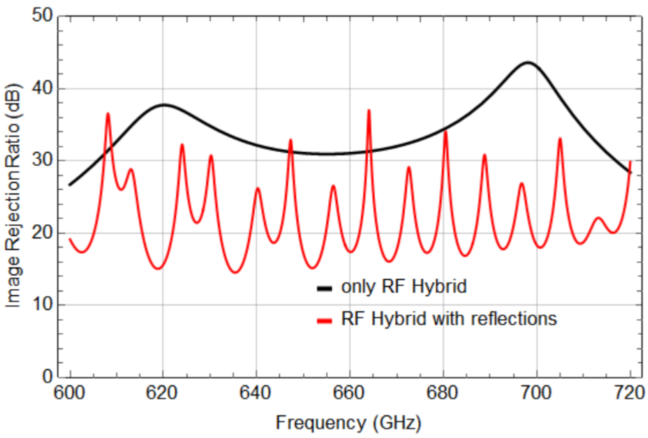

Fig. 2 Simulated sideband rejection ratio SRR determined by RF waveguide structure imbalance, the black curve corresponds to zero reflections from both SIS mixers and the RF load, while the red curve represents some realistic case then SIS reflects -6 dB, RF load -18 dB, IF hybrid isolation reaches -25 dB and the gain difference of SIS mixer is estimated as 1 dB. This simulation suggests perfect balancing in the IF chain. The red curve is calculated analytically.

Similar influence of reflections on the SRR performance is taking place it the IF chain of the 2SB receiver. It was found how reflections from the IF amplifier (or isolator, if present) and from the SIS mixers can give a periodic imbalance in the IF part. This periodic imbalance influences SRR much more than the intrinsic imbalance of the IF hybrid. The Fig.3 demonstrate the influence of IF reflections on the final SRR pattern. The red curve shows SRR pattern, which would correspond to imbalance induced only by the IF hybrid in combination with the RF imbalance. The RF imbalance is shown on the Fig. 2 and corresponds to the RF reflection levels: reflection from SIS –5 dB, reflection from RF load -18 dB, mixers gain imbalance 1 dB. And now we take into account all the reflections in IF chain. For that case: 1) SIS mixer reflection (S22) at IF frequencies is taken to be -8 dB; 2) IF amplifiers return loss is -12 dB; 3) the cable length between the SIS mixers and the IF amplifier is 350 mm. The red curve in Fig. 3 summarizes all imbalances. One can see a remarkable degradation of the SRR level from about 16 dB to 12 dB due to the IF reflections. This curve is changing very fast versus frequency with a period corresponding to the electrical length of the IF cables. For IF amplifiers with -7dB return loss the SRR level in the worst point was going down to 12 dB. The calculated curve looks very similar to experimental measurements [4].

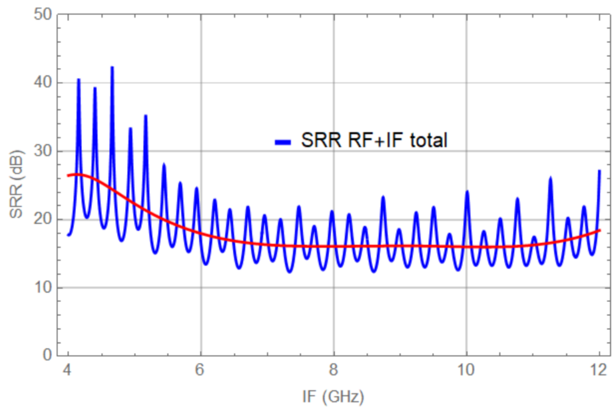

Fig. 3, Simulation of the SRR curve at the intermediate frequency then both the RF and IF reflections are taken into account (blue curve). The red curve shows the case then IF reflections are not taken into account.

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