Sideband Separating SIS Mixer with On-Substrate LO-Injection Circuitry

V. Vassilev, R. Monje, A. Pavolotsky, I. Lapkin, C. Risacher and V. Belitsky
Group for Advanced Receiver Development (GARD)
Onsala Space Observatory, Chalmers University of Technology

***Abstract*—We present results of the development and characterization of a second generation sideband separating (2SB) SIS mixer for 85-115 GHz band.**

In the mixer design the LO power is injected into the RF signal path through a -15 dB microstrip directional coupler which requires a matched termination. We use a "dot" termination, which is made of a resistive normal-metal film and is designed such that it occupies a minimum area on the substrate providing a good return loss over the whole LO band. The required sheet resistance of the film forming the dot is obtained by sputtering Ti in atmosphere containing N_2.

Preliminary mixer tests show minimum SSB noise temperature of 50 K and below 65 K in the band 86-115 GHz with sideband rejection around 10 dB.

***Index Terms*— SIS mixer, sideband separating mixer, double probe transition, sideband suppression ratio**

I. Introduction

THE advance of two big international projects ALMA and APEX prompted the development of sideband separating (2SB) mixer technology for mm-wavelengths [1]-[7]. The motivation for using 2SB mixers for radio astronomical applications at mm-wavelengths is that the noise performance of a double-side band (DSB) heterodyne receiver is often limited by the atmospheric noise fed into the system via the image band [8]. Thus, to further increase the system sensitivity, 2SB or single sideband (SSB) operation is preferred where the image band is either filtered out reactively or dissipated on a low temperature load.

2SB mixers are based on a quadrature scheme where the RF and LO signals are divided and introduced to two identical DSB mixers. The IF components of both DSB mixers are combined in an IF hybrid where the sideband cancellation takes place. The quadrature scheme requires 90^0 phase delay for either RF or LO signals in one of the mixer channels.

A common feature of 2SB mixers is that they require power division for the RF/LO signals. On-substrate power dividers such as branch line coupler require matched terminations at the fourth port, usually a lumped resistor, which is inconvenient to produce at mm-wavelengths using thin-film technology. The same issue concerns if the LO power is coupled to the RF through microstrip coupled lines. Therefore most of the 2SB mixer designs demonstrated at mm-wavelengths avoid using microstrip couplers and instead use waveguide components to divide RF/LO power and to provide LO coupling to the RF [4], [5], [6], [7]. In this case waveguide terminations are easily realized using absorbers built in the waveguide cavity [9]. This type of designs allows two DSB mixer blocks to be pre-selected and connected to a block containing all waveguide components, but increases the overall size and mechanical complexity of the 2SB mixer unit.

In this paper we suggest a more compact design where all mixer components are placed on a single substrate containing both mixers with their tuning circuitry together with the LO injection circuitry. The design requires only two microstrip terminations, which are realized using a circular area of resistive material connected to the line – "a dot termination" [10], [11].

II. Mixer Design

A. Mixer Description

Figure 1 shows a block diagram of the suggested 2SB mixer and Figure 2 illustrates the mixer substrate coupled to the LO/RF waveguides.

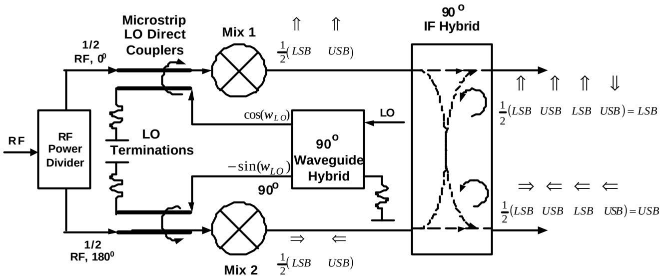

Figure 1 Block diagram of the 2SB mixer. Sideband separation is achieved by using a quadrature scheme where two identical mixer junctions are pumped by a local oscillator (LO) with 90° phase difference. To illustrate the sideband cancellation, the relative phases of the sideband signals are shown at different points of the mixer. USB and LSB stand for Upper and Lower Side Band respectively. A waveguide hybrid is used to divide the LO power with the required 90^0 phase delay and coupled to the RF through microstrip coupled lines. The RF power divider is a 3-port structure, which does not contain resistive terminations.

To divide the input RF signal and to couple it to the substrate we designed a special structure, a waveguide to microstrip double probe transition [12]. This structure has a simple geometry and does not require any termination load; in this case the amount of microstrip terminations is minimized to two.

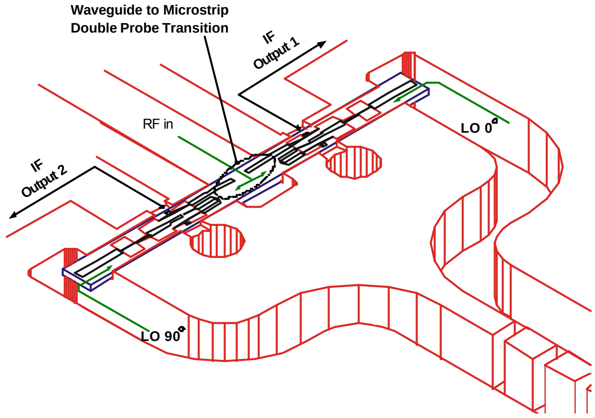

Figure 2 The mixer substrate penetrates 3 waveguides in the mixer block. The divided LO power is introduced at the ends of the substrate while the RF power is coupled to the substrate in the middle and divided between the two mixer junctions by the waveguide to microstrip double probe transition. The mixer substrate is a Z cut crystal quartz with dimensions 0.7 / 8.74 / 0.15mm (W/L/H). The substrate size is chosen such that it does not allow waveguide modes inside the substrate channel.

B. *The First Generation 2SB Mixer*

The divided LO power is coupled at the ends of the substrate via an E-probe and fed to the 15 dB LO-directional coupler through a microstrip circuit. The RF and LO signals are then fed to each of the mixer junctions with its tuning circuitry.

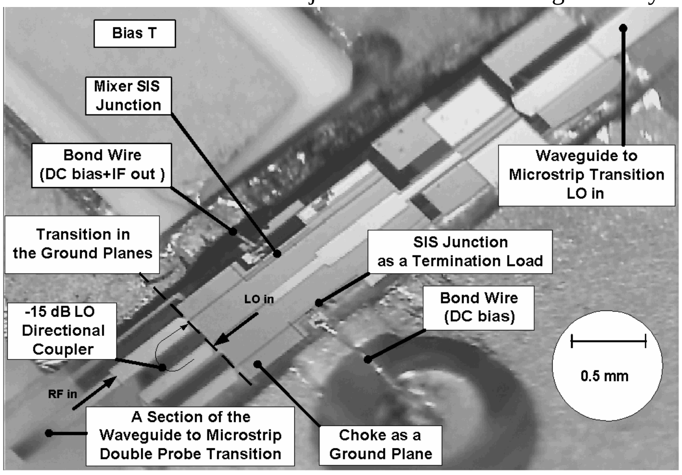

Figure 3 A closer view of the mixer components. The LO is injected to the RF line through a -15dB directional coupler. A second SIS junction and its tuning circuitry provides real impedance to terminate the rest of the LO at the idle port of the LO coupler. To avoid critically small spacing between the lines, the LO coupler uses the 0.15 mm thick crystal quartz substrate as a dielectric and substrate backside metallization as a ground plane. The choke serves as a ground plane for the rest of the circuitry.

In the first 2SB mixer generation [13], [14] the fourth ports of the directional couplers are terminated by an additional pair of SIS junctions which requires in total four SIS junctions per 2SB mixer.

C. *The Second Generation 2SB Mixer*

To reduce the complexity and to facilitate the mixer tuning, in the current design we use a "dot" termination which is made of a resistive normal-metal film [10], [11]. The dot is designed such that it occupies a minimum area on the substrate and provides return loss S11<-12 dB over the whole LO band [15]. The required sheet resistance of the film forming the dot is obtained by sputtering Ti in atmosphere containing N_2, resulting in a Ti/N_2 mixture.

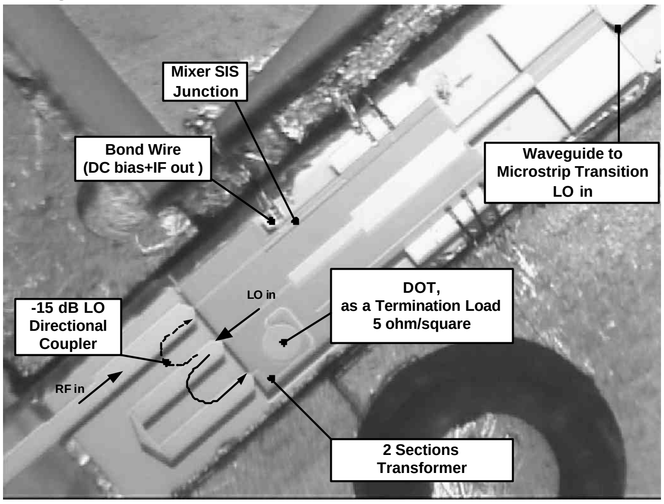

Figure 4 The LO-injection circuitry in the second 2SB mixer. The SIS-load junction is replaced by a dot termination made of Ti/N2 mixture having sheet resistance of 5 Ohm/square resulting in dot input impedance of about 5 Ohm. The dot impedance is transformed to a high impedance value of 70 Ohm required to terminate the LO directional coupler.

We find the "dot" termination particularly convenient for use in 2SB mixers at mm-wave frequencies. It has number of advantages compared to a lumped resistor load.

- It does not require connection to ground.
- Important limitation of the lump resistor termination is that in order to realize large resistor values with good accuracy one needs couple of squares long resistors, leading to increased inductance which affects the impedance of the resistor.
- The "dot" is tolerant to variation in the resistance per square resulting in only a minor change of the return-loss of the structure (dot plus transformer lines).
- The dot does not require very thin films. The required value of the sheet resistance is controlled not only by the film thickness but also by the content of N_2 atoms in the film. For example to obtain resistance of 5 Ohm/square we use a 200 nm Ti film sputtered in atmosphere containing 1% of N_2.
- Films with high sheet resistance can be fabricated using the technology suggested above. Film with resistance of 50 Ohm/square was obtained on a 40 nm thick Ti film.

III. RESULTS

The 2SB mixer is measured with IF hybrid following the amplifiers, as shown in Figure 5.

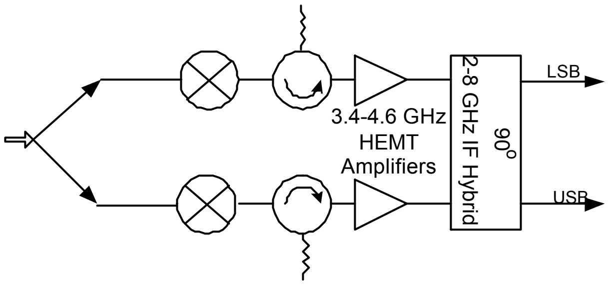

Figure 5 The configuration of the 2SB mixer used in the measurements.

The 2SB mixer is characterized at 5 LO frequencies by Y-factor and sideband-separation measurements. For each LO point a CW test signal is injected at number of frequencies at both RF sidebands and the response of the mixer is measured at the IF outputs by a spectrum analyzer. The difference between the CW amplitude at the signal and the image band is a measure for the sideband separation ratio. An example of the mixer operating in 2SB mode is illustrated in Figure 6.

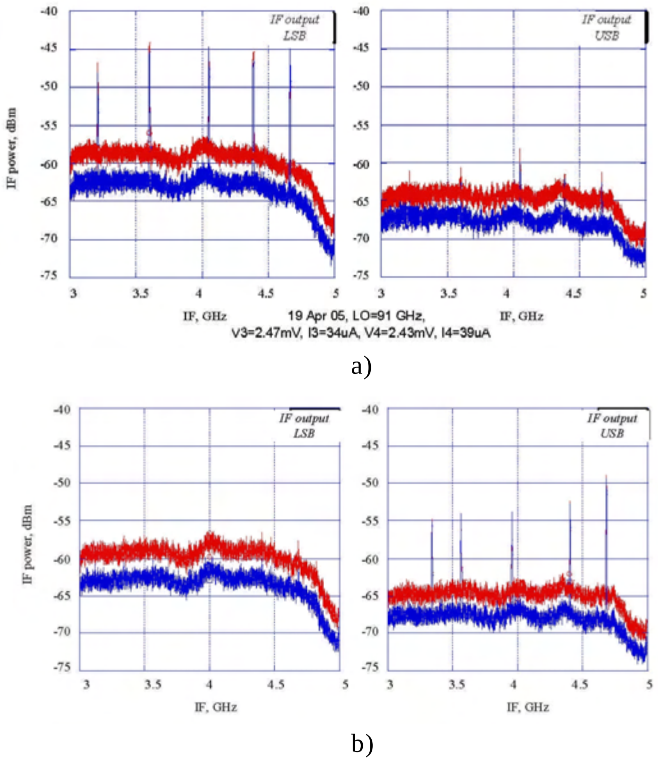

Figure 6 An illustration of the sideband separation properties of the mixer for LO=91 GHz. A CW signal is applied at number of frequencies first at the LSB a) and then at the USB b), the mixer response is shown at both IF outputs.

Both sideband separation ratios are consistent along the IF band with typical value of 13 dB. The calculated SSB mixer noise, shown in Figure 7, is based on the measured Y-factor and sideband separation ratios which account for the noise contributed by the image band.

IV. DISCUSSION

We present the design and first results on our second generation sideband separating mixer. This design differs from its predecessor in the LO-injection circuitry, where the idle ports of the microstrip directional couplers are terminated by "dots" of resistive film instead of an extra pair of SIS-junctions.

Only one mixer chip has been tested. The typical measured Y-factor is about 4.1 dB over the 3.4-4.6 GHz IF band, compared to 4.5 dB previously measured with the first mixer generation. This extra mixer noise temperature is expected since the SIS junctions' areas were measured to be 2.6 µm instead of the required 4 µm. Because of that, in order to maintain mixer stability, the mixer junctions were pumped with less LO power than the required for optimum mixer performance.

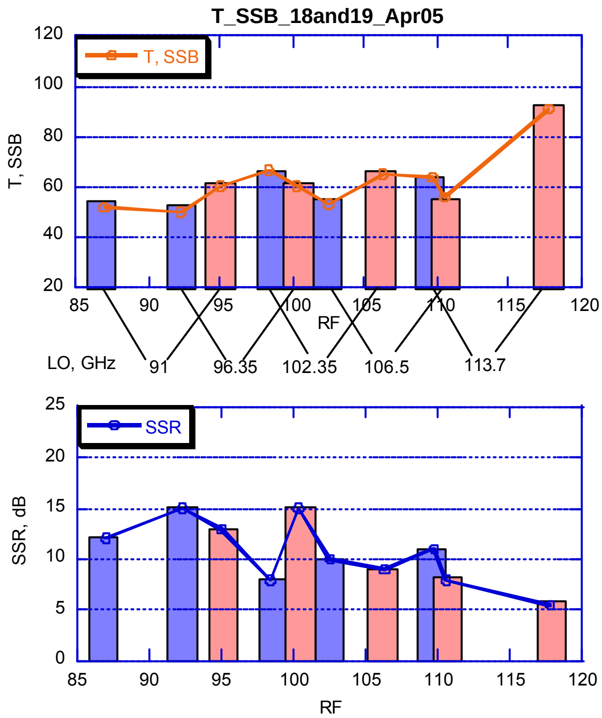

Figure 7 The calculated mixer SSB noise temperature and the measured sideband separation ratios (SSR) for 5 LO frequencies.

A second consequence of the reduced junction area is out of the IF band oscillations which were registered at 6 and 8 GHz for most of the LO frequencies. The oscillations amplitudes were comparable to the test signal peak value, which is used to measure sideband separation ratios. These oscillations were found to seriously affect the sideband rejection leading to ratios as low as 8 dB as for example at LO=102.35 GHz.

In order to achieve good sideband separation ratios when the IF amplifiers are connected between the mixers and the 90^0 IF hybrid (as shown in Figure 5) requires amplifiers with balanced phase and gains. No special care was taken to equalize the gains of the amplifiers in the measurements reported above, which additionally limits the attainable image rejection ratios. A different set of measurement was done where the IF amplifiers are placed after the hybrid resulting in typical sideband separation ratios of about 20 dB.

The mixer design presented above is a prototype used to verify the suggested technology. Parts of this mixer will be used in future 2SB mixers developed at GARD as for example APEX band 1, 2 and 3.

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