230 GHz sideband-separating mixer array

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***Abstract*—Since 2001 the HEterodyne Receiver Array , HERA, is installed at IRAM's 30m telescope in Spain. It consists of two arrays with 3x3 pixels for two orthogonal polarizations. The receiver is equipped with SSB backshort mixers covering an RF frequency range from 218 to 267 GHz with an IF band of 3.5 to 4.5 GHz.**

In the near future IRAM will replace this receiver by a new dual-polarization multi-beam receiver with 7x7 pixels. The receiver will be equipped with sideband-separating mixers covering an RF frequency range from 200 to 280 GHz with an IF band from 4 to 12 GHz. The RF quadrature couplers as well as the LO couplers will be realized as branchguide couplers and be integrated with the mixer blocks into one E-plane split-block. The DSB mixers will use Nb junction technology and the IF couplers will be custom made for the use at cryogenic temperatures. This paper presents the concept of the new array as well as the designs of the DSB mixers and the different couplers.

***Index Terms*—2SB mixer array, multi-beam receiver, SIS mixer**

I. Introduction

IN 2001 IRAM installed the **HE**terodyne **R**eceiver **A**rray, HERA, at its 30m telescope in Spain [1]. In the beginning the receiver was equipped with 3x3 pixels for one polarization. In 2004 the second unit of 3x3 pixels for the second polarization followed. Since then it has been operating successfully and delivered routinely many interesting astronomical results.

The receiver is equipped with SSB mixers tuned with backshorts. They cover an RF frequency range of 218 GHz to 267 GHz with an IF band of 1 GHz [2].

Since the installation of HERA, mixer development progressed further. Nowadays, mixers delivering both sidebands with larger RF bands and instantaneous bandwidths of 8 GHz are available [3]. Furthermore, the noise performances of recently developed mixers are better than those of the HERA mixers.

Therefore IRAM started the work on a new multibeam receiver called **S**uper **HE**terodyne **R**eceiver **A**rray, SHERA, which will make use of these new developments. SHERA will be equipped with sideband-separating mixers. The mixer design covers RF frequencies from 200 to 280 GHz and the IF band of the mixers is 4 to 12 GHz. Due to the currently limited capacities of the backends, only one sideband per pixel and an IF band of only 4-8 GHz will be exploited in the beginning. But as soon as the necessary backends are available the receiver can be easily upgraded.

II. Sideband-separating mixer array

The new multibeam-receiver will be composed of respectively two 7x7 pixels units as shown in Figure 1 for each of the two orthogonal polarizations. Each range of 7 pixels is composed of a 3 and a 4 pixels unit. The 3, respectively 4 pixels have one common LO input. The flanges for the LO inputs of the 3 pixels units can be seen in Figure 1 on the right-hand side. The 4 pixels units are fed with LO power from the left. The feedhorns for the signal input are mounted on the flanges on the front of the units and the IF signals are coming out on the back.

The size of such a 7x7 mixer array is 175x175x30 mm^3, which means that one pixel (without feedhorn) fits into a cube of 25x25x30 mm^3.

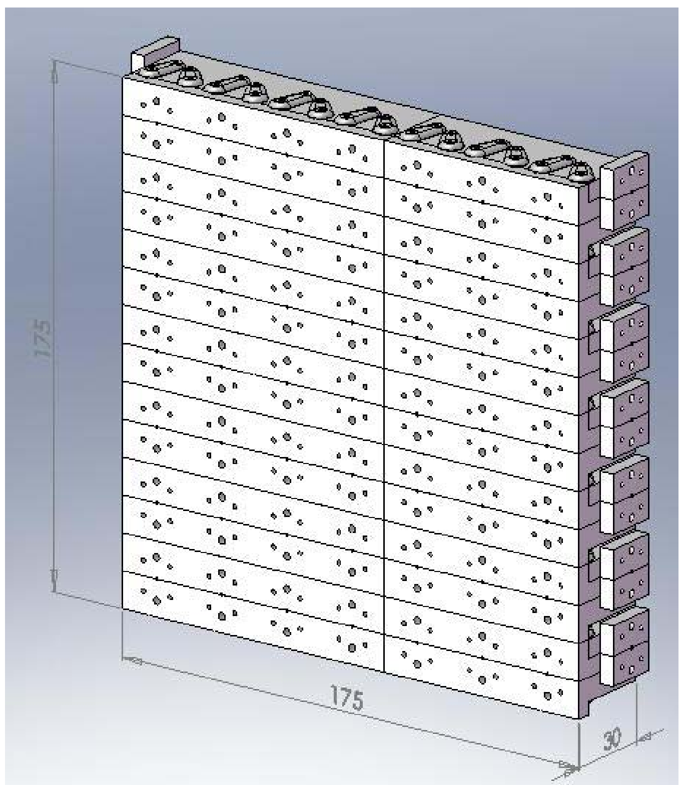

Figure 1: 7x7 pixels unit for one polarization.

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III. 3 AND 4 PIXELS UNITS

The whole 7x7 pixels array is subdivided into 3 and 4 pixels units. A picture of a 3 pixels unit is shown in Figure 2.

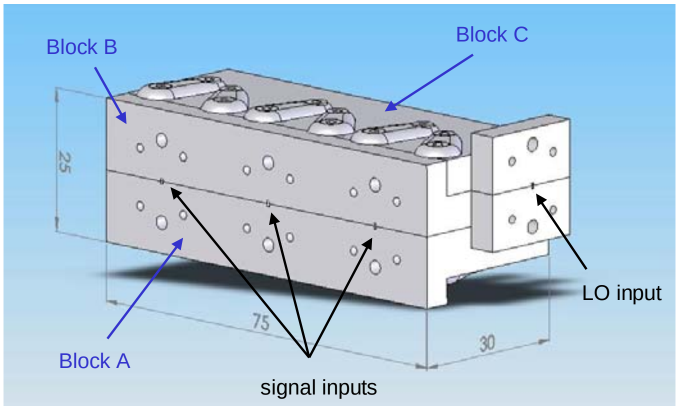

Figure 2: 3 pixels unit consisting of three E-plane split blocks.

The sub-units consist of three E-plane split blocks, called A, B, and C. Blocks A and B form the 2SB mixers with RF input and IF output. Figure 3 shows a top view of block A. The signals are coming in from the top of the figure and are going to the 2SB mixers. The IF outputs of the mixers are connected to the SSMA connectors situated at the back of the block.

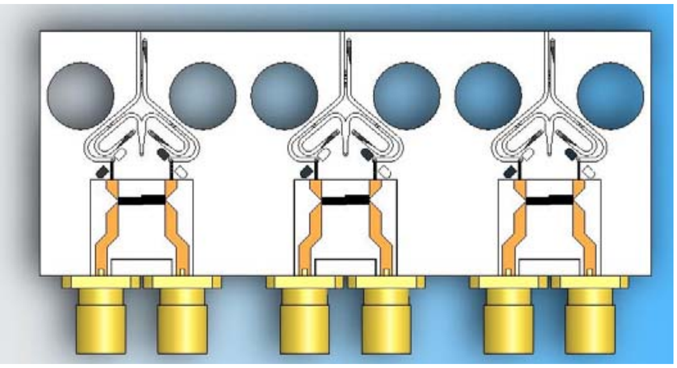

Figure 3: Top view of block A of a 3 pixels unit.

The LO input is situated in the plane between blocks B and C (see Figure 4). Branchguide couplers are used to couple a fraction of the signal to each of the first pixels. The last pixel receives the residual LO power. The couplers are designed in such a way that each pixel receives the same amount of LO power taking into account the losses in the waveguides between the pixels. The LO signals then go through block B and are coupled to the 2SB mixers.

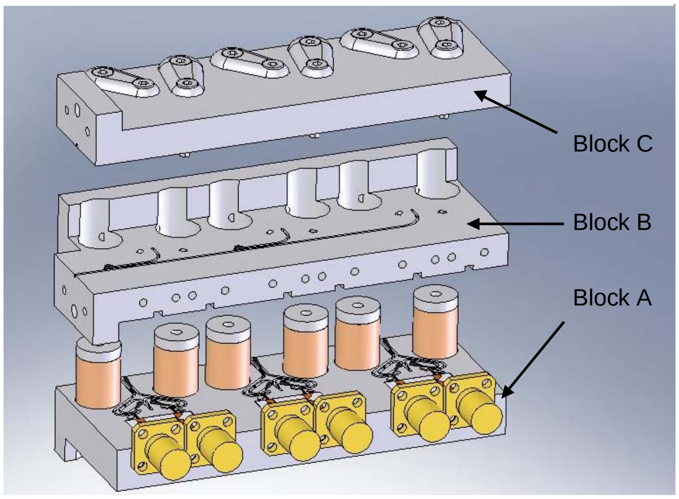

Figure 4: One three pixels unit is composed of three E-plane split blocks.

IV. 2SB MIXER

Figure 5 shows one pixel of the mixer array. The signal comes in on the left-hand side and is split by the 90º hybrid coupler in two. The LO signal comes in from above. It is split in two and coupled to the signal by the LO couplers which is then coupled to the mixer chip. On the right-hand-side the IF output of the mixers is connected to an in-plane 90º IF coupler. Magnetic coils are placed in the holes indicated in Figure 5 and pole pieces are placed in the vicinity of the mixer chips, in order to suppress the Josephson currents in the junctions.

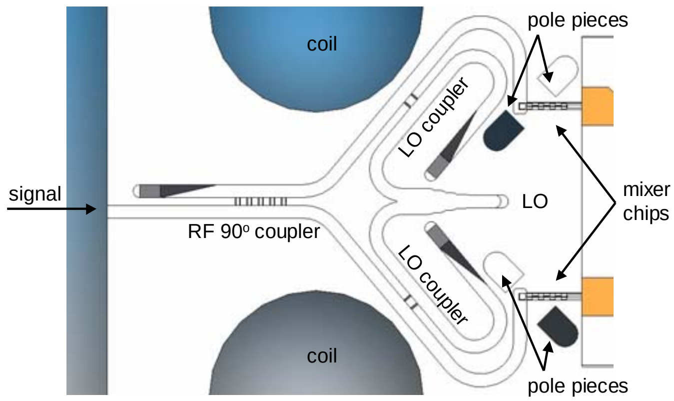

Figure 5: View of the sideband-separating mixer (for details see text).

A. LO input

Since the LO input is located in a plane parallel to the 2SB mixers, we need not only a splitter, but also two H-plane bends in order to feed the LO signal to the two DSB mixers of each pixel. Both components have been designed as described in [4] and optimized using CST Microwave Studio [5]. Design and simulated performances are shown in Figure 6 and Figure 7.

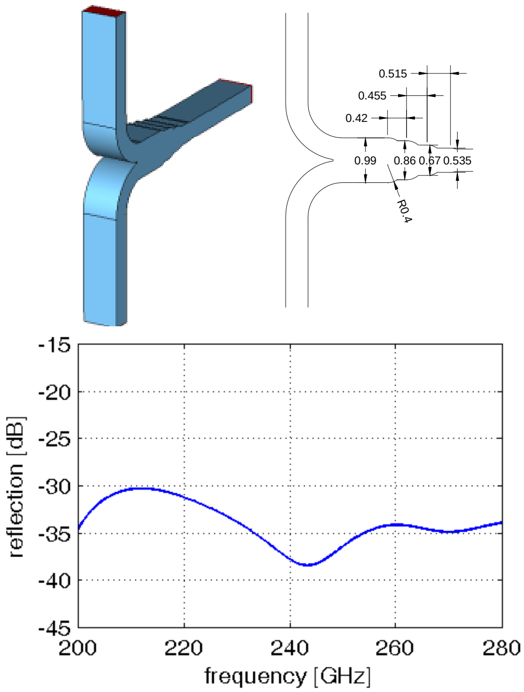

Figure 6: Design and simulated performance of the Y-splitter.

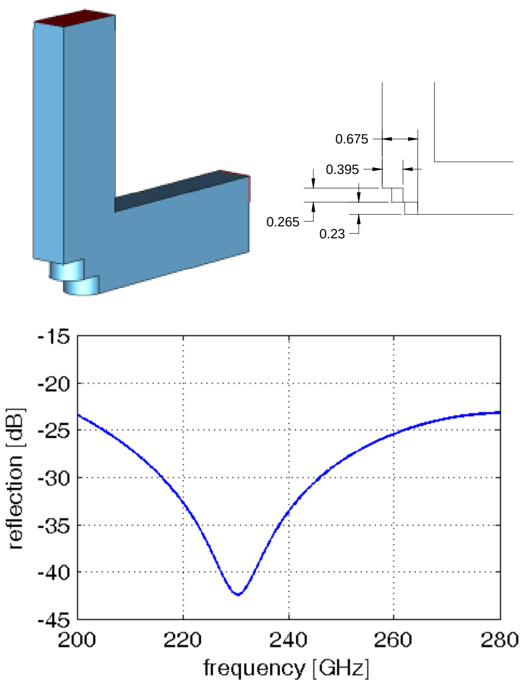

Figure 7: Design and simulated performance of the H-plane bend.

B. RF couplers

The RF couplers of the sideband-separating mixers are realized as branchguide couplers [6]. The 90º hybrid coupler uses five slots, whereas the LO couplers are made with only 2 slots. The designs have been optimized with CST Microwave Studio. Dimensions and theoretical performances of the couplers are shown in Figure 8 and Figure 9.

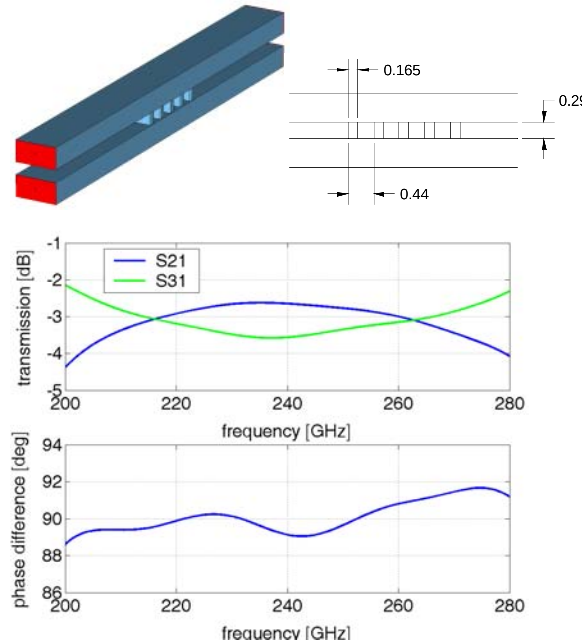

Figure 8: Design and simulated performance of the 90º hybrid coupler.

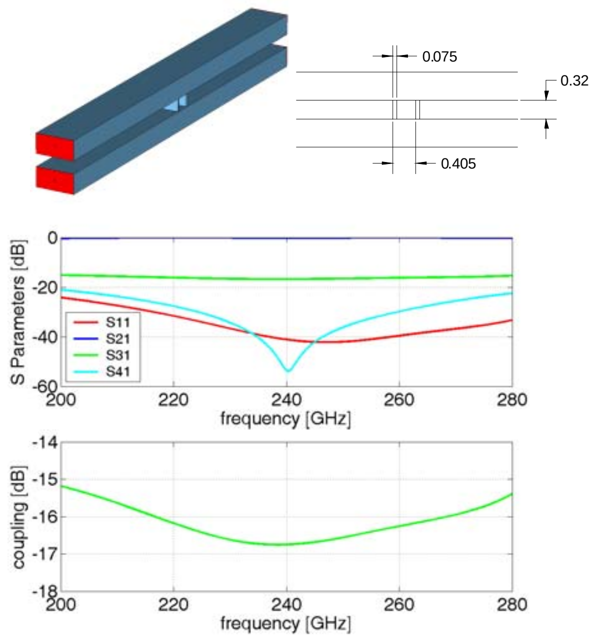

Figure 9: Design and simulated performance of the LO coupler.

C. DSB mixer

The design of the DSB mixer is quite similar to our previous designs [7]–[9]. The mixing element is a superconductor-insulator-superconductor (SIS) tunnel junction, which is deposited together with a superconducting circuit onto a quartz substrate. This circuit comprises the waveguide-probe providing a full-height waveguide to suspended microstrip transition, the RF choke and the actual tuning circuit, whose role is the compensation of the junction's capacitance and matching to the antenna impedance. Figure 10 shows the layout of one individual mixer chip with a size of 0.26 x 2.4 x 0.08 mm^3. These devices are fabricated by IRAM's SIS group. The Nb-Al/ALO_x-Nb tunnel junction has an area of 1 μm^2 and is made by e-beam lithography [10], [11].

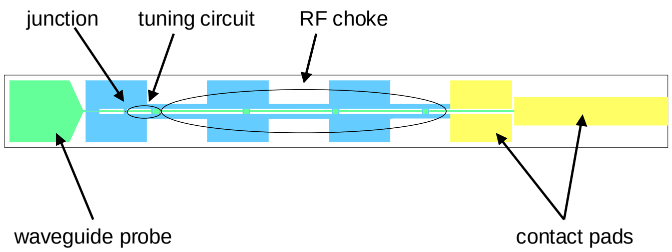

Figure 10: Layout of the mixer chip.

The mixer chip is placed in a channel perpendicular to the waveguide axis and stretches only partly across the waveguide as can be seen in Figure 11. The full-height waveguide to microstrip transition is provided by an antenna structure that has been optimized using CST Microwave Studio [5].

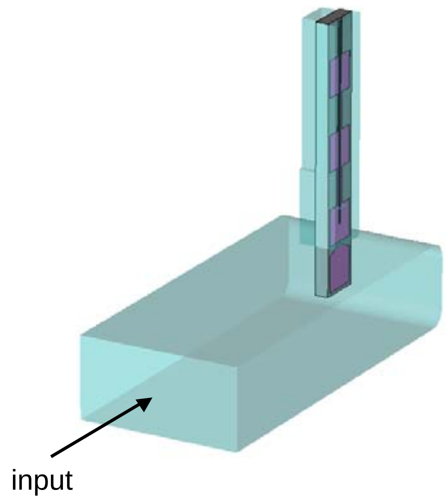

Figure 11: Full-height waveguide to microstrip transition.

The resulting antenna impedance is shown in Figure 12 for frequencies between 200 and 280 GHz. It is slightly capacitive, but its real part is quite constant over the whole frequency range.

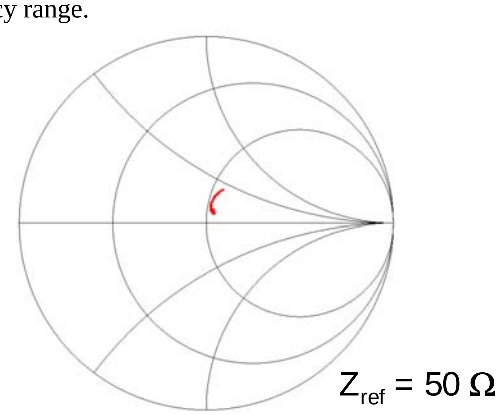

Figure 12: Antenna impedances for frequencies between 200 and 280 GHz.

In order to tune out the junction's capacitance, a superconducting tuning circuit has been developed and optimized using Sonnet [12] and ADS [13]. Figure 13 shows a picture of this circuit. Its equivalent circuit is shown in Figure 14.

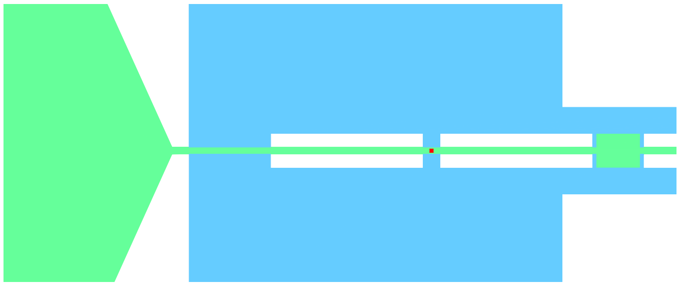
Figure 13: Picture of the tuning circuit.

The compensation of the junction's capacitance is achieved with a coplanar waveguide followed by a capacitance serving as a parallel inductance connected to a virtual ground. The whole structure is then matched to the antenna impedance with the help of a λ/4 transformer realized as a series of microstrips and coplanar waveguide.

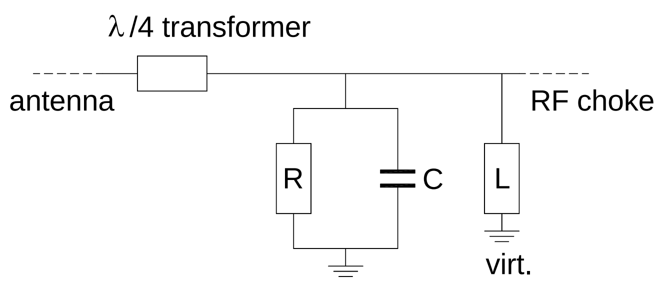

Figure 14: Equivalent circuit of the tuning structure.

The thus achieved embedding impedance of the junction is shown in the Smith chart of Figure 15 for frequencies between 200 and 280 GHz. It is quite close to the junction's RF impedance, so that the coupling to the junction is better than 97% as can be seen in the plot in Figure 16.

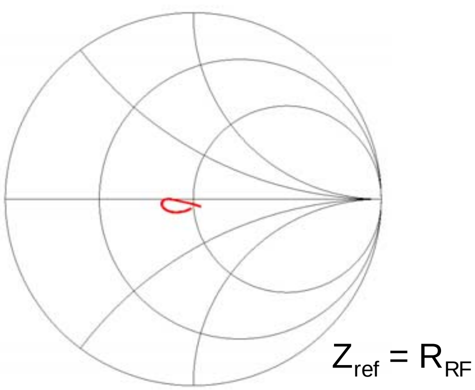

Figure 15: Embedding impedance of the junction for frequencies between 200 and 280 GHz.. The Smith chart is normalized to the junction's RF impedance.

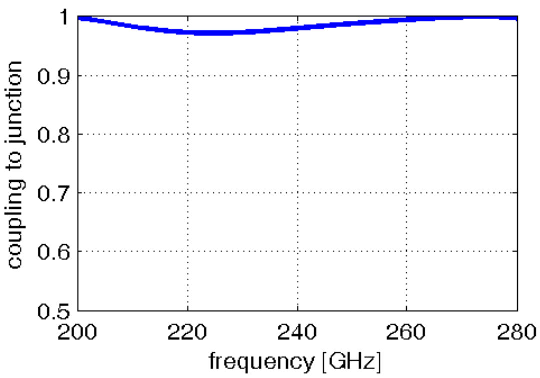

Figure 16: Fraction of power coupled to the junction.

D. IF coupler

Up to now we used commercially available IF 90º couplers for our sideband-separating mixers [7], [9]. But this is no longer possible, if we want to reduce the size of one pixel to fit into about (25 mm)^3. Therefore the IF coupler will be custom made. It will be realized as Lange coupler [14]. This allows the integration of the coupler into the combined RF coupler/mixer block. This type of coupler has already been used in 2SB mixers [15].

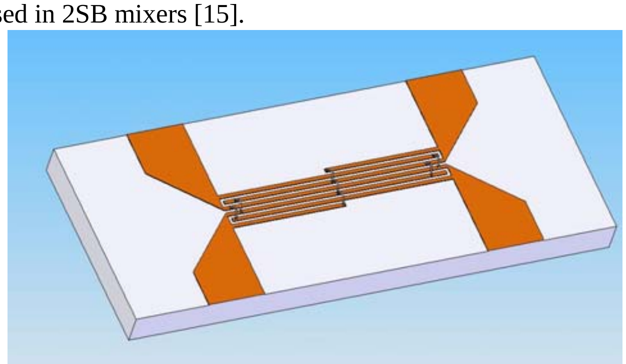

Figure 17: Lange coupler.

We intend to use a Rogers 4003 substrate with 1.524 mm dielectric thickness [16]. Figure 18 shows the simulated performance achievable with such a substrate for the 4-8 GHz band.

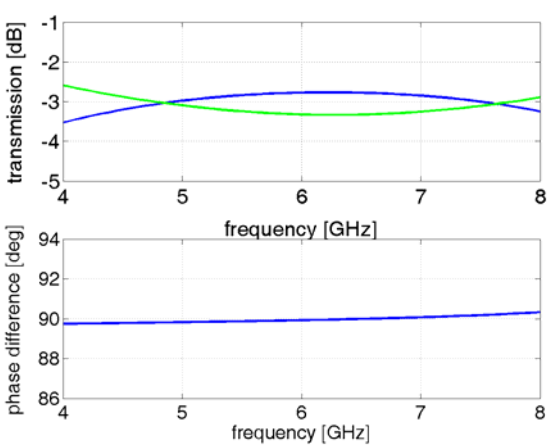

Figure 18: Simulated performance of a Lange coupler with a Rogers 4003 substrate with 1.524 mm dielectric thickness.

V. Outlook

Before realization of the new mixer array, the different components will be tested individually or in sub-units. First the mixer design will be verified by DSB mixer tests in simple DSB mixer blocks and the design of the IF coupler will be optimized. In the next step one pixel, i.e. one sideband-separating mixer, will be made and characterized. And finally, a 3 pixels unit will be made and tested.

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