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V. Ossenkopf-Okada, R. Schaaf, I. Breloy, J. Stutzki (eds.)

SUPERCONDUCTIVE DEVICES FOR THE CCAT-PRIME HETERODYNE ARRAY RECEIVER INSTRUMENT (CHAI)

I. Barrueto[1], U.U. Graf[1], C.E. Honingh[1], K. Jacobs[1], M. Justen[1], M. Schultz[1], S. Wulff[1] and J. Stutzki[1]

Abstract. The CHAI instrument is a heterodyne array receiver simultaneously observing 460-500 GHz and 780-800 GHz frequency bands. Current efforts are focused on the LO frequency Array (LFA) with the design and characterization of the Local Oscillator (LO) power divider network. The Mixer measurements performed show similar characteristics between the mixers tested, albeit experimental results are not in complete agreement with EM simulation. LO power divider experiments shows a range of no power coupled to the mixers. This phenomenon is probably located in the power divider networks and it prevents the proper operation of the mixers between 470-480 GHz. Noise temperature by the Y-factor yields a value around 100-150 K at the IF between 4-8 GHz with some noise spikes, mostly due mismatches in the IF circuitry. Finally, regarding the 780-820 GHz array, the preparation of the design of a balanced mixer are under way.

1 Introduction

CHAI is a instrument predominantly to map the narrow spectral lines of [CI] in the $^3P_1{-}^3P_0$ and $^3P_2{-}^3P_1$ transitions as well as the medium/high excitations of CO (see Graf et al., p 339). These transitions play a role of cooling in star formation clouds so they act as tracers for the physical process in the ISM. In order to accomplish this task, CHAI is a dual colour heterodyne receiver for simultaneous observations with the Lower Frequency Array 460-500 GHz (LFA) and the Higher Frequency Array 780-820 GHz (HFA). Each band consists of a square array of 8 × 8 pixels in a superconductor–insulator-superconductor(SIS) balanced mixer configuration. For each band the cryogenic (4K) 64 pixels consist of 2 × 8 vertically stacked 1 × 4 pixel waveguide blocks. These blocks are fabricated in CuTe split block technology with $460 \times 230\ \mu$m (480 GHz) and $240 \times 140\ \mu$m (800 GHz) rectangular waveguides connecting the 3 LO power dividers an 4 mixers in one block.

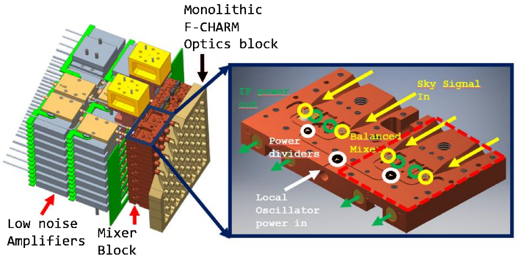

Figure 1: 3D CAD of the focal plane unit array and a detailed image of a half 4-pixel block with its core components. The dotted red line marks the which part of the 4-pixel block which is being tested with the debugging 2-pixel block.

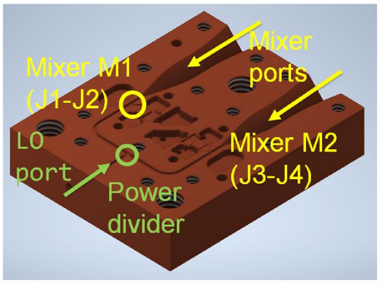

Figure 2: Half block of the 2-pixel block with the position of the main components therein.

2 Low Frequency Array (LFA) 460-500 GHz Components

The LFA is shown in Fig. 1 with the lower half piece of a 4-pixel block enlarged. This block receives the LO power at its back and then distributes it to the 4 mixers by a cascade of 3 dB power dividers. Mixers

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[1] I. Physikalisches Institut der Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany,
e-mail: `barrueto@ph1.uni-koeln.de` & `honingh@ph1.uni-koeln.de`

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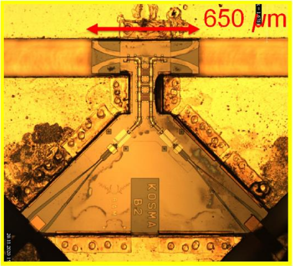

Figure 3: Fabricated and assembled mixer in the 2-pixel block

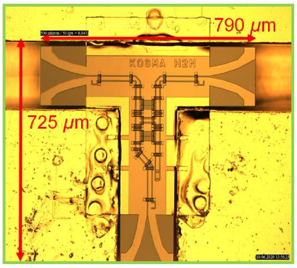

Figure 4: Fabricated and assembled power divider in the 2-pixel block.

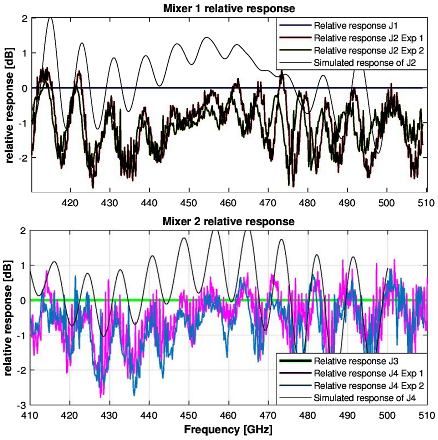

Figure 5: Measured response of the mixers in two experiments (Exp.1 & 2) compared with simulation. One of the junctions is used as reference junction for normalization

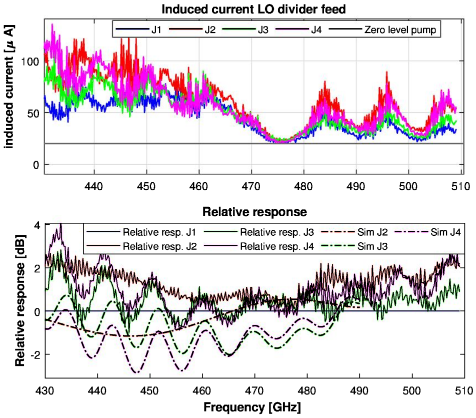

Figure 6: Normalized power coupled of all SIS devices with respect to Junction 1 and comparison to simulation. Simulations have a ≈ 25 GHz downshift in frequency.

and couplers are made by the same technology, on Nb (CPW) transmission lines on 9 μm thick Silicon membrane substrates, contacted by Au beamleads.

In order to test the components, we use a simpler 2-pixel block, shown in Fig. 2, which represents the half of the 4-pixel block with one power divider (Fig. 4) and 2 balaced mixers SIS junctions as non-linear elements (Fig. 3, Mixer 1& 2 in 5). The balanced mixer design is based on the design of Westig et al. (2011). The LO power divider is a 3 dB 90° CPW branch line coupler with a 25 Ω/square thin film Titanium Nitride termination on the isolated port. The SIS junctions on the mixer are used as power detectors by recording the induced current on the first photon step below the gap voltage. The mixer's response to the LO coupling is tested by injecting the LO from the mixer ports as this allows to record their characteristics separate from the LO power divider (Fig. 5). Results show that measured relative response of the 2 mixers is similar(Relative response of J2 and J4 in Fig. 5). Both are not completely in accordance to the simulated response of the mixers, done in a circuit model of the 2-pixel block (Fig. 5 black curve). The exact cause for this disagreement is currently under investigation. The power divider is then tested by injecting the LO power through the LO port and recording the induced current at all of the 4 junctions of mixers 1 and 2 respectively (Fig. 6). Taking the relative response (Fig. 6, bottom) to some extent eliminates the frequency dependence of the response of the mixers, improving the insight in t the LO divider performance, as shown in Fig. 5. Also here a similarity to the response expected from simulation is visible, but the correspondence is far from perfect. In addition the recorded induced current across frequency (Fig. 6, top) shows a frequency range, extending from 470 to 480 GHz, where there the junctions exhibit no induced current at all. The fact that this phenomenon is not observed when injecting the LO through the mixer ports suggests that its cause is located in the LO power divider network. This behaviour is not at all in correspondence to simulation and

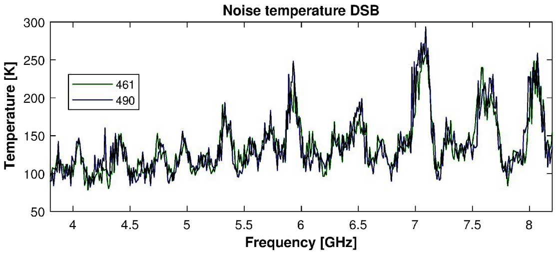

Figure 7: DSB noise temperature as a function of the IF frequency taken at 461 and 490 GHz.

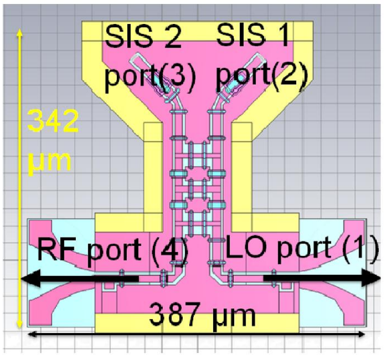

Figure 8: CST schematic of the 800 GHz hybrid

is at the moment our biggest concern for this design. The noise temperature is measured by the Y-factor method, injecting the LO in the LO port and using a hot(300K)/cold(77K) load at the mixer ports. This measurement allows us to get insight on the performance of the IF recombination circuit (Fig. 7). Aside from the peaks at higher frequency, the noise temperature is between 100 and 150 K, with the cause of the peaks believed to be due to mismatches in the IF circuitry.

3 HFA 780-820 GHz Designed Components

The superconducting components for the HFA are designed for Niobium Titanium Nitride (NbTiN) on 5 μm Silicon membranes. The change from Nb to NbTiN as superconductive material is due the fact that the gap frequency of Nb is below the operational band of the HFA. The balanced mixer design will follow a similar structure as the one presented in Westig et al. (2011), designed for an 240x137 μm waveguide interface (Fig. 8). The nonlinear detector will be Nb-AlN-NbN SIS junctions. The design must comply to the 780-820 GHz bandwidth required and a possible extension to 880 GHz is under discussion.

4 Conclusion

The mixer response over the LO power divider exhibits an unexpected zero coupled power to the junctions between 470-480 GHz. This phenomenon is not observed when the LO is couple dto the mixers directly (by the mixers ports), this suggest that the cause of this is located in the LO power division network. The mixer noise temperature is close to specifications even in a less than ideal scenario and optimization of the IF wiring is still required to eliminate peaks at IF frequencies and comply to requirements. Finally, the preparations for the development of the mixer for HFA are currently on going.

References

Westig, M. P. ; Jacobs, K. ; Stutzki, J. ; Schultz, M. ; Justen, M. ; Honingh, C. E.; 2011, Superconducting Science Technology, 24, 085012