# LO power division circuits for the CCAT-prime Heterodyne Array Instrument (CHAI)

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

*Abstract*—**We present power dividers to be used in the local oscillator distribution network in CHAI. The power divider is based on superconducting 90° CPW hybrid with waveguide antennas on a thin Silicon substrate. We present preliminary experimental results and comparison with simulations to gain insight about the feasibility of the selected power dividing scheme.**

***Keywords—Heterodyne mixer, superconductive circuits, 90° hybrids, power division.***

## I. Introduction

The scientific goal of CHAI is to map the narrow spectral lines of [CI], 3P1-3P0 and 3P2-3P1 as well as the medium/high excitations of CO.

In order to accomplish this task, CHAI is conceived as a dual colour heterodyne receiver intended for simultaneous observations of 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 8x8 pixels in a superconductor –insulator-superconductor (SIS) balanced mixer configuration. For each band the cryogenic (4K) 64-pixel array consist of 2x8 vertically stacked 1x4 pixel waveguide blocks. These blocks are fabricated in CuTe split block technology with 460 $\mu$m x 230 $\mu$m (480 GHz) and 240 $\mu$m x 140 $\mu$m (800 GHz) rectangular waveguides connecting the 3 LO power dividers and 4 mixers in one block.

## II. Low frequency array and block

The LFA is shown in Fig.1 with the three main components depicted plus the bottom half of a 1x4 pixel block with the RF and IF components therein. This block receives the local oscillator (LO) power at his back and then distributes it to the 4 mixers by a cascade of 3 dB power dividers (white circles). Mixers and couplers are made in the same superconducting technology, consisting of Niobium coplanar waveguide transmission lines on 9 $\mu$m thick Silicon substrates, contacted by Gold beamleads. The balanced mixer design is based on the design by Westig et al [2] (**Fig. 4 top**). The LO power divider is a 3 dB 90° CPW branch line coupler with the isolated port terminated with a thin film Titanium Nitride load of 13x20 $\mu m^2$, with a DC resistance of 43 Ohm, equal to the CPW line impedance (**Fig. 2.b**). For test purposes, 2 other terminations, a resonant termination and a short circuit have been fabricated as well (**Fig. 2.c-d**). To test the LO power divider we use a simpler 2-pixel block which represents the half of the 4-pixel block with one power divider and 2 mixers (**Fig. 2.a**). Two 2-pixel blocks were fabricated in out in-house workshop, the difference between them being that one of the blocks has 5 $\mu$m deep pockets in the top half that fit just over the beam lead ends (**Fig. 3**).

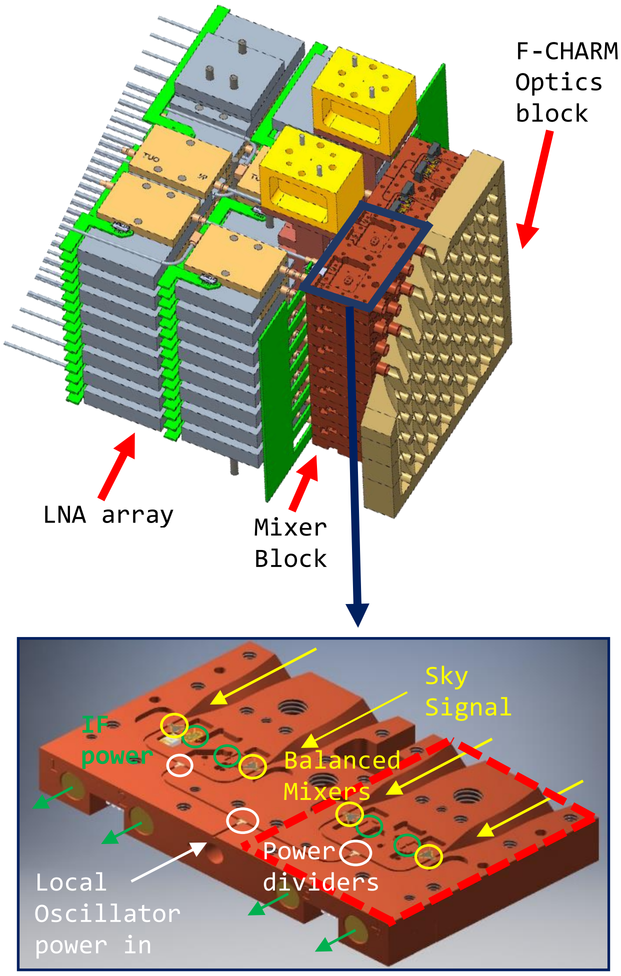


**Figure 1:** 3D CAD of the Focal plane unit array (Courtesy of U.U. Graf) with its main components labelled (**Top**) and a detailed image of a half 4-pixel block with its core components (**Bottom**). The dotted red line marks the which part of the 4-pixel block which is being tested with the debugging 2-pixel block

## III. Methods & results

To measure the LO coupling to the mixer, we use the SIS junctions as a power detector. We record the current on the first photon step below the gap voltage induced by the

[1]I. Physikalisches Institut, Universität zu Köln, Köln, 50937, Germany.

NOTES:

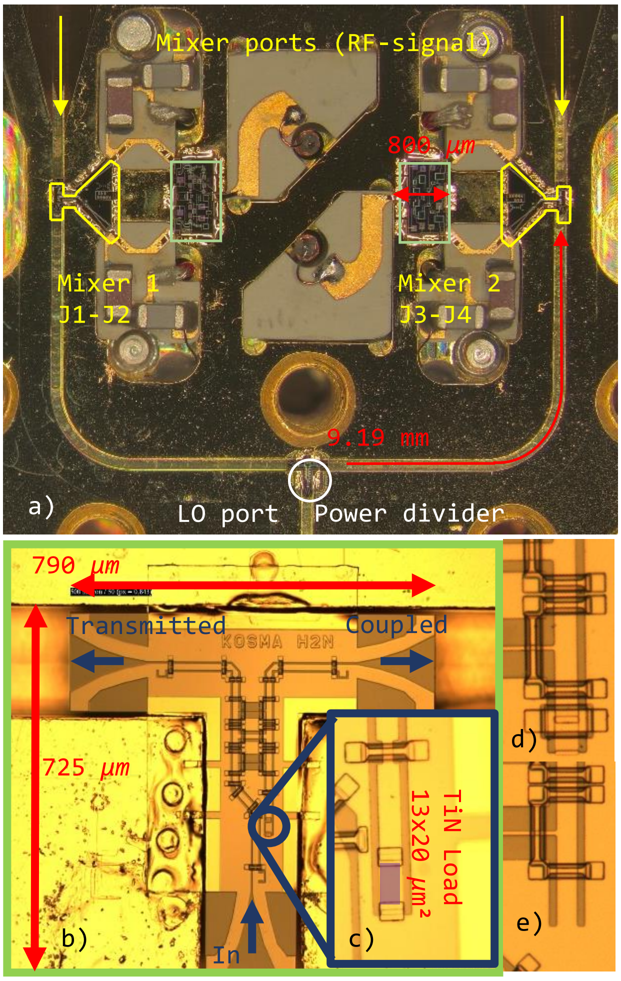


**Figure 2: a)** Half block of the 2-pixel block with the position of the main components therein. **b)** Image of the fabricated power divider with the lumped element TiN Load marked in violet. **c)** Lumped element load **d)** Lossy resonator load. e) Short circuit termination.

incident LO power at a fixed bias voltage of about 2 mV. We use a VDI signal generator extender module SGX 494 WR 6.5, with a range from 110 to 170 GHz plus a frequency Tripler that allows it to reach the 330-510 GHz band. In order to characterize the mixers in the present setup we inject the CW signal through the Mixer ports (**Fig. 2.a** yellow arrow) and record the induced current in the junction. The experimental results and simulations are presented as relative response, meaning one of the junctions in the mixer (**Fig. 4 Top**) is selected as reference and it is used to normalize the response of the second one. This format allows for a reduction of external influences, such as variations in the available signal power, making the evaluation of the performance of the mixer easier. Three facts jump out immediately. First, is that the measured mixer seems to be shifted down in frequency by about 20 GHz compared to simulation results. Second, the expected standing wave behaviour is similar to the measured one, However, this similarity ends about 470 GHz. Third, there is a

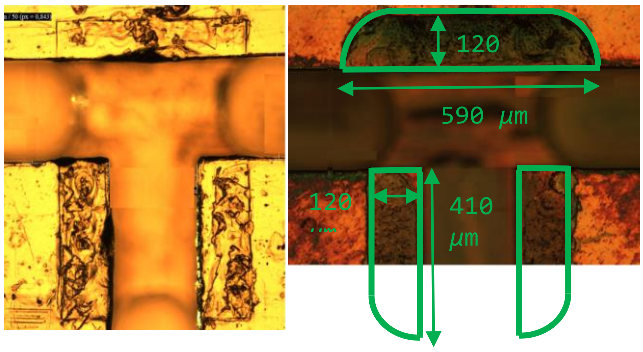


**Figure 3:** Top half of the fabricated test blocks. **Left:** Block with no beamlead pockets milled. The effects of pressing the beamleads is visible after the removal of the device. **Right:** This block has 5 $\mu$m deep pockets in the top half that fit over the beamleads of the device. The purpose of these pockets is to decrease mechanical strain on the beamlead ends when the block is closed, facilitating the mounting and demounting of devices in the block, preventing damage in the remaining devices.

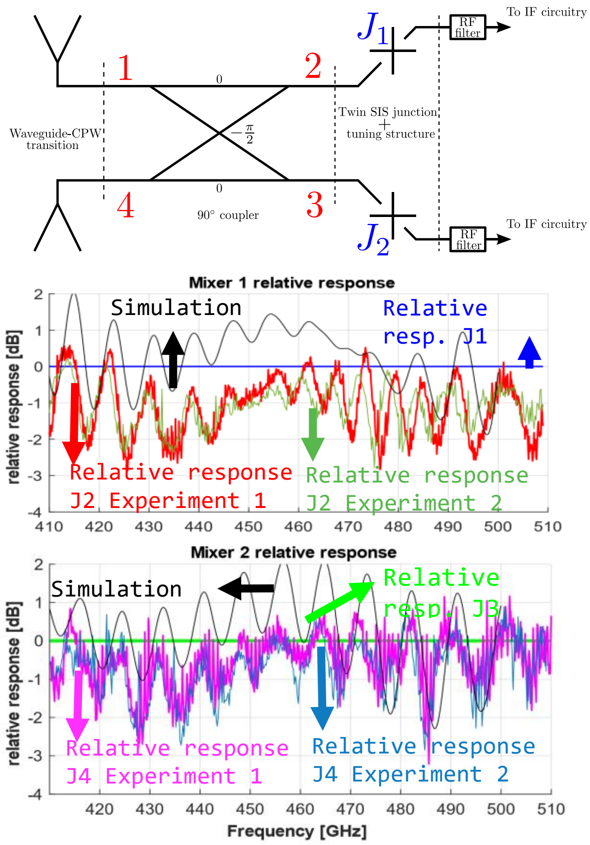


**Figure 4:** Schematics and mixer response for both mixers. Given the mirrored placement of mixers M1 and M2 in the 2-pixel block M1 receives the CW signal from the port 1, meanwhile, M2 receives it from port 4. For M2 the port junction correspondence is J3- Port 3, J4- Port 2. The experiment is repeated with different LO power dividers, a lumped element load and a resonant respectively, without significant differences. A 20 GHz downshift is present in both mixers, when comparing to simulations **Top:** Simulated and measured relative response of mixer 1. **Bottom:** Simulated and measured relative response of the mixer 2.

NOTES:

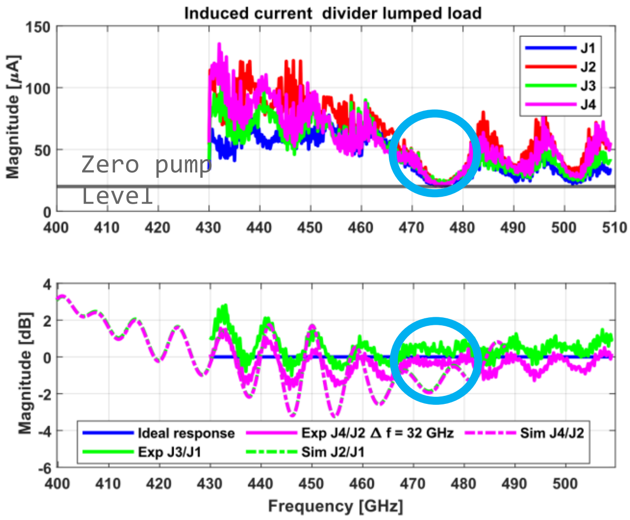


**Figure 5:** Results for a power divider with lumped element load. **Top:** Measured induced current in all junctions across frequency. Between 470 and 480 GHz there is little to no LO coupled the junctions. **Bottom:** Normalized response plus CST simulation (30 GHz downshifted). The induced current of J3 and J4 is normalized by the induced current of the corresponding mirrored junction in mixer one, that being J1 and J2 respectively.

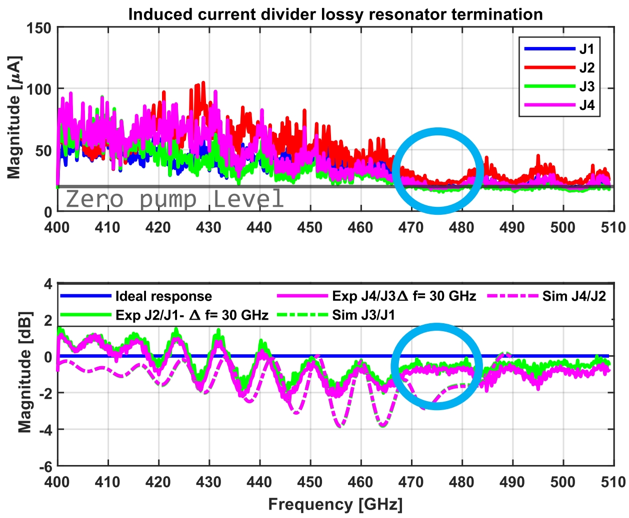


**Figure 6:** Results for a Hybrid with a resonant circuit load. **Top:** Measured induced current in all junctions across frequency. The frequency range where no power is coupled to the junctions (Blue circle) is also observed in the test of this power divider. **Bottom:** Normalized response plus CST simulation (30 GHz downshifted). The induced current of J3 and J4 is normalized by the induced current of the corresponding mirrored junction in mixer one, that being J1 and J2 respectively.

disagreement between simulation and experimental measurements with regards to the power balance between the two mixers, around 1 and 0.7 dB for mixers M1 and M2 respectively.

After the mixers have been characterized, power divider devices with the three different loads are tested by injecting the CW signal through the LO port, reaching mixers M1 and

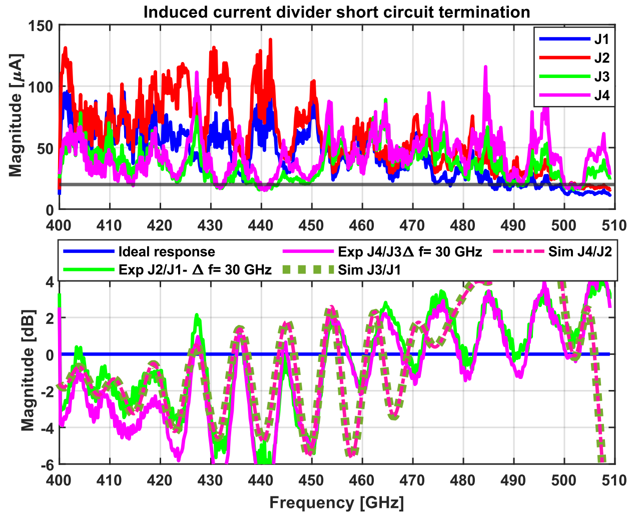


**Figure 7:** Results for a Hybrid with a short circuit load. **Top:** Measured induced current in all junctions across frequency. There is no frequency range where power is not coupled to the junctions **Bottom:** Normalized response plus CST simulation (30 GHz downshift). The induced current of J3 and J4 is normalized by the induced current of the corresponding mirrored junction in mixer one, that being J1 and J2 respectively.

M2 (**Fig.2**). Once again, junction J1 from mixer M1 is chosen as the reference junction for normalization. In addition to the normalized results, the direct measured power division results for the lumped element load, the lossy resonant load and the short circuit are displayed in **Fig.5**, **Fig.6** and **Fig. 7** respectively. A 30 GHz downshift in frequency of the measured results with respect to the simulations is observed for the three power dividers tested. This 30 GHz shift is believed to be caused by characteristics of the power divider, as it is seen in the comparison between junctions from different mixers, where the properties of the power divider come into play. In **Fig.5**, **Fig.6** and **Fig. 7** comparison between J1/J2 or J3/J4 only grants information about the mixer characteristics instead of the power divider. For the power dividers with the lumped element and resonant load, the graphs of the induced current show a frequency range between 470 and 480 GHz where there is hardly any power coupled to any junction followed by, at higher frequencies, a standing wave-like behaviour dissimilar from what is expected from simulations. Aside from this phenomenon, it can be seen that the measurements of the power divider with the lumped element load and the resonant load have similar features. This is not observed for the power divider with the short circuit load. Repeated experiments with different power dividers in the two available testing blocks (**Fig.3**) yields the insight that the phenomenon seen in **Fig.6** and **Fig.7** was only seen in power dividers tested in the block which had beamlead pockets for the power dividers (**Fig.3**). Detailed simulations of individual components did not show any indication of a behaviour similar to the observed one, suggesting that a complete 3D integrated system simulation is necessary for an accurate prediction of

NOTES:

the performance. For the power divider with a short circuit there is a good agreement between simulation and measurement up to 460 GHz, save for the 30 GHz downshift. Above 460 GHz there is a change in the period of the standing waves and the agreement is lost.

## IV. Summary & future work

In this work we have presented the status of the LO power divider devices for the Low Frequency Array of CHAI. Three power divider models were tested in two different housing blocks. Each power divider had a different load termination at the isolated port, with the termination being a lumped element load, a lossy resonator and a short circuit (For testing purposes). Experimental results of power dividers tested on a block with beam lead pockets suffered from a frequency range (470-480 GHz) where no power was coupled to the junctions, the exact cause is currently under examination.

There is a frequency downshift of around 30 GHz observed in all three power dividers results in comparison with simulation. After correcting for the frequency shift, there is a reasonable agreement between simulations and experimental results up to about 460 GHz. The power divider with a lumped element load and a resonant load have similar power division characteristics. Unfortunately, from the experimental data it is concluded that neither of the two power divider models is suitable for large array operations in the present configuration. The investigation of the present devices is currently ongoing, as well as the development of new ones.

## References

[1] http://www.ccatobservatory.org

[2] M. P. Westig, K. Jacobs, J. Stutzki, M. Justen, and C. E. Honingh, Supercond. Sci. Technol. 24, 085012 (2011).

NOTES: