Progress towards a focal plane unit for CHAI based on superconducting planar circuits

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***Abstract*— The LO distribution network is a crucial part of any heterodyne array. For the waveguide-based LO distribution for CHAI, we address problems previously found with a 3-dB quadrature planar power divider and present a new candidate for a 3-db power division based on superconducting planar circuits.**

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

I. Introduction

The CCAT Heterodyne Array Instrument (CHAI) is a 2x64 dichromatic heterodyne receiver, that is currently under development for the CCAT-prime observatory [1]. The bands intended for observation are the LFA (455-495 GHz) and the HFA (780-820 GHz), with each band consisting of a square array of 64 pixels composed of 16 sub-arrays of 1x4 pixels each. These 4-pixel blocks constitute the basic unit of the array where the LO signal is received and distributed to the four pixels. The 1-to-4 power division is achieved by a cascade network of three 3 dB power dividers.

II. Power dividers and 2-pixel block

The testing platform for the dividers is a 2-pixel block that allows for the testing of a single power divider in a simple network (Fig.1,2). This test block is fabricated in CuTe split block waveguide technology, receiving the LO power at its back through a rectangular 460x230 µm^2 waveguide interface. The power dividers are based on superconducting Nb planar circuits on a 9 µm silicon membrane. The mixers chosen to populate the test units are all based on the design presented in [2]. These mixers are used as direct power detectors by measuring the current LO-induced in the SIS junctions at a fixed voltage bias.

A first generation of power dividers based on 3 dB quadrature hybrids with on-chip loads was presented by the authors in [3], where it was observed that the power transmission to the mixers suffered from standing waves and a reduction of the LO coupling to the junctions in a limited frequency range (Fig.3a).

The reason behind the observed variation in coupling as a function of frequency was that the reflections caused by the load

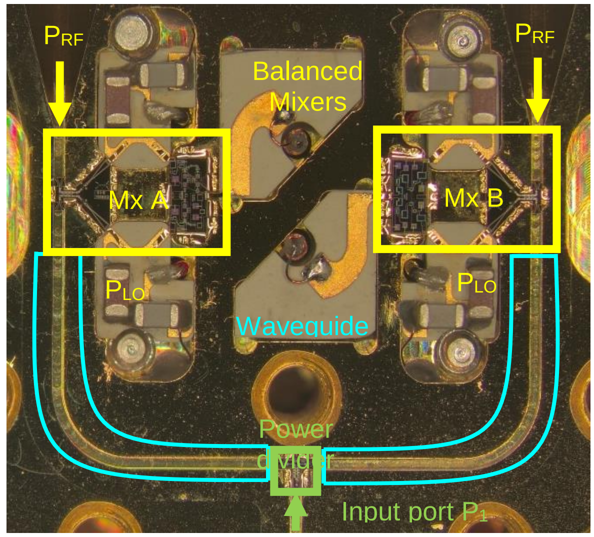

Figure 1: Microscope photo of the populated 2-pixel block's lower half.

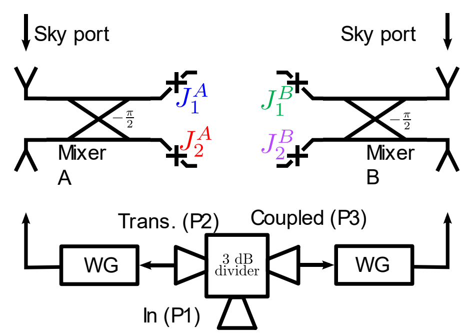

Fig. 2. Schematic of the 2-pixel block with the two mixers and power divider connected by the long waveguide.

at P_4 and the Δφ introduced by the hybrid caused standing waves cavities of different electrical lengths in the LO-paths to the mixer A and B. This results in the out-of-phase behaviour observed in the power coupled to the junctions in the mixers A and B (Fig.3a). This effect is seen clearer if the ratio in power coupled to mixers A and B is studied, where the small. imbalance of the 90° hybrid is greatly enhanced by the out-of-

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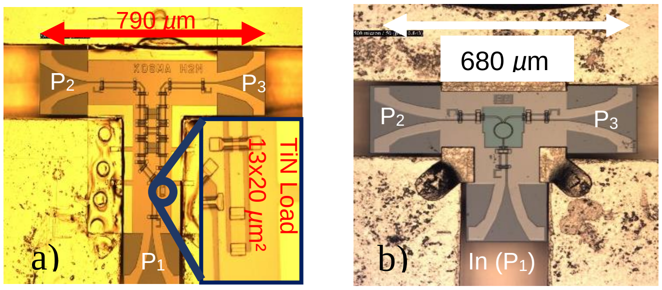

Figure 3: Microscope photos of the 2-pixel block and both power dividers. a) Bottom half of the populated w-pixel block. b) 90° three branch line CPW power divider, terminated with a resistive load c) Wilkinson power divider

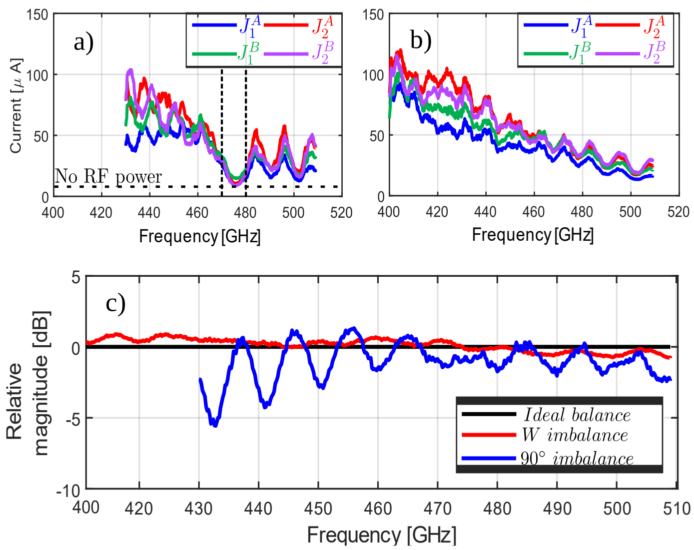

Figure 4: Measured current at constant V_{bias}=1.8 mV of the 4 SIS junctions of the 2 balanced mixers in the 2-pixel block while sweeping the local oscillator over the frequency band and deducted power division balance of the power dividers (a) 90° hybrid power divider. (b) Wilkinson power divider. (c) Balance of the power dividers, here J_1 of both mixers A and B is compared, effectively yielding the amplitude imbalance of the power divider.

phase behaviour of the standing waves (Fig.4c). In a scenario where the existence of standing waves cannot be avoided, the imbalance between mixers can be minimized by using an in-phase power divider, since with an in-phase power divider the standing waves in the LO-paths towards the two mixers are the same, resulting in a balanced power distribution, even if the total transmission is affected by standing waves. Fig.3b shows a fabricated microstrip Wilkinson power divider. It can be seen how the induced currents in the SIS junctions in the mixers A and B have the same behaviour as a function of frequency (Fig.4b) and how the imbalance is considerably better than with the CPW 90° hybrid (Fig.4c).

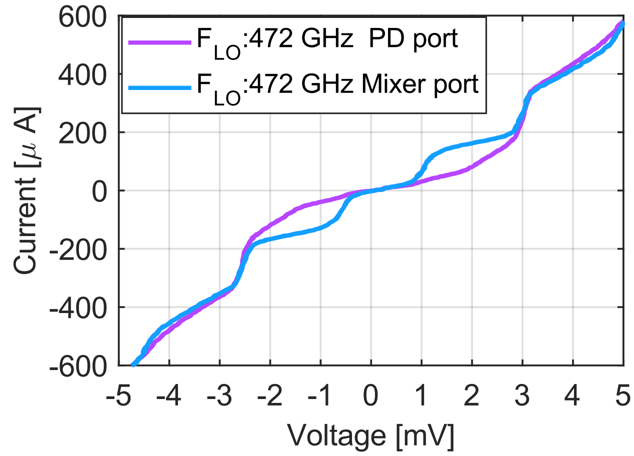

Figure 5: I-V characteristics of the SIS junctions with RF power coupled through the power divider (violet curve) and the horn (blue curve) for the same junction.

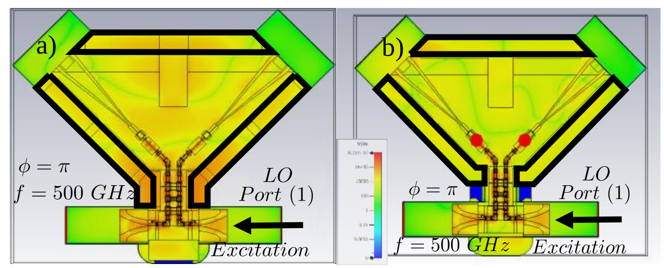

Figure 6: 3D simulation of IBAMI in its housing cavity, the beamlead pocket footprints is highlighted in the black outline. (a) Field simulation at f = 500 GHz in the original cavity. (b) Field simulation at f = 500 in the modified cavity.

The second feature observed with the CPW 90° hybrid as a LO divider was the range of low induced current between 470-480 GHz. In addition to this range of low induced current, anomalous IV curves were observed (Fig.5) when injecting the LO through the power divider. These features were only observed when the LO was coupled through the power divider and not when coupling the LO through the RF ports. The reason behind this was cavity resonances in the mixer cavity that coupled to beamlead pockets present in the mixer cavity, shown in Fig.6a delineated with the black lines. These beamlead pockets, shown in more detail in Fig.7, were included to prevent the silicon chip's mechanical degradation from several open/close cycles of the 2-pixel block. Since the addition of beamlead pockets substantially prolongs the lifetime of the mixer chips, they cannot be completely removed. Fig.6b shows a modified beamleads footprint that prevents the coupling to the resonance. This modified beamlead footprint was implemented in the Wilkinson 2-pixel block, where no range of low induced current was observed (Fig.4b).

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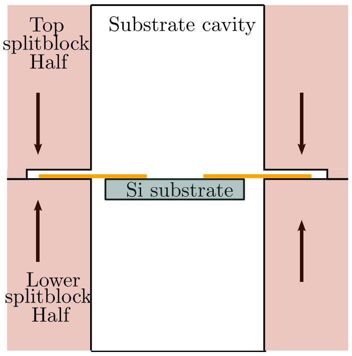

Figure 7: Cross-section of the housing cavity of the IBAMI with beamlead pockets depicted. These pockets are milled over the beamleads to prevent mechanical degradation from several open/close cycles of the block.

III. SUMMARY

The two issues initially observed in the 2-pixel block have been solved. The enhanced imbalance measured with the CPW 90° hybrid was addressed by replacing the hybrid with a microstrip Wilkinson power divider, whose phase characteristics allow for a more balanced power distribution, even in the presence of standing waves. The range of low induced current was discovered to be caused by resonances coupling to the beamlead pockets in the mixer cavity. A modified beamlead footprint avoids coupling to the cavity resonance and solves the issue.

REFERENCES

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