Balanced SIS Mixer System with Modular Design for 490 GHz

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***Abstract*—We present measurements on a balanced mixer for 490 GHz. The system consists of a central -3 dB waveguide branchline coupler, which has been fabricated in split block technique in the KOSMA workshop. It is connected to two SIS mixers and two feed horn antennas. A corrugated horn is used for the signal and a diagonal horn with the same beam parameters is used to feed the coupler with the LO signal.**

The modular design allows to characterize every component separately. In particular, various waveguide couplers have been investigated with a vector network analyzer at their respective operating frequencies at the university of Bern [1]. The SIS mixers have been tested in standard double sideband mode and show 60-80K DSB noise temperature over the RF band.

These results can be compared with simulations and with measurements of the entire balanced mixer in order to gain insight into function and interaction of the different components as well as into critical fabrication tolerances.

I. Introduction

A balanced mixer configuration has many advantages compared to a simple mixer, in particular a very efficient and stable LO coupling, cancelation of LO amplitude noise and, resulting from the latter, an improved system stability [2]. Because of these advantages, which become more and more essential with increasing frequency, it is worth to study the much more complex design of a balanced mixer in praxis, in order to gain insight into the interactions of the different components of the mixer.

As a first step towards more compact and integrated mixers we have chosen a modular design for a balanced mixer, operating at 490 GHz. The modularity allows to measure performance for each component separately.

II. Balanced Mixer System

A. Overview

The mixer consists of a central waveguide directional coupler, fabricated in split block technology. Two standard mixer blocks from the SMART receiver [3] and two horns, one for signal and one for LO feed, are mounted at the four ports of the coupler, as shown in Fig. 2. The modularity allows to measure the performance for each mixer block separately. Also the S-parameters of the coupler can be studied with a vector network analyser.

Both IF output signals of the mixer blocks are amplified and recombined outside the cryostat by a very broadband 4-stage Wilkinson power combiner, which also has been tested separately.

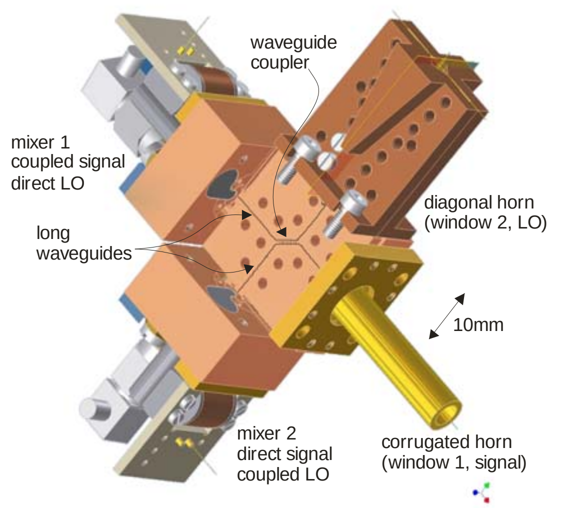

Fig. 25 3D model of the balanced mixer unit. The upper split block half is blanked out in order to allow a view to the waveguide arms and the waveguide coupler.

B. Waveguide Coupler for 490 GHz

The split block waveguide coupler for 490GHz, fabricated in the KOSMA workshop, was micromilled on a *Deckel FP 2* with a 60krpm spindle. With the machines 1µm resolution xyz stages, an absolute precision of ~10µm can be obtained. Prior to every milling process, a test slot has been milled in order to measure the actual tool dimensions. This way, an overall precision better 20µm was achieved.

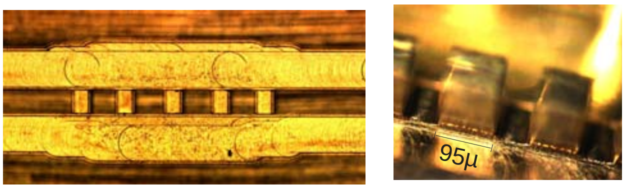

Fig.2 Split block waveguide coupler for 490GHz, fabricated in the KOSMA workshop.

Simulations and measurements with a vector network analyzer of a similar waveguide coupler for 345GHz revealed degradation of the coupler performance due to the fabrication tolerances [1]. Likewise a strong imbalance of the 490 GHz coupler could be observed in the measurements presented in this paper.

C. 4-Stage Wilkinson Power Combiner for 2-12 GHz

A 4-stage Wilkinson power combiner was used to recombine the IF signal coming from the two LNAs. The TMM10 board of the power combiner has been manufactured also in house with an LPKF surface milling machine. Ultra miniature resistors (0402) have been used in order to keep parasitics as small as possible. High isolation (-20...-15dB) between the input ports and a high symmetry in power and phase could bee obtained over a very broad band (2...12GHz).

III. Measurements

A. Asymmetry in LO Power and Sensitivity

Heterodyne measurements revealed a strong imbalance in the RF waveguide system. The pump level (DC current at the optimum bias voltage) (Fig. 3) of the mixer shows an imbalance depending on LO frequency and depending on which port (horn) has been used for LO injection. In contrast, in the separate measurement, the optimum pump level of the mixers was very similar and at approximately the same LO input power (measured with a Golay).

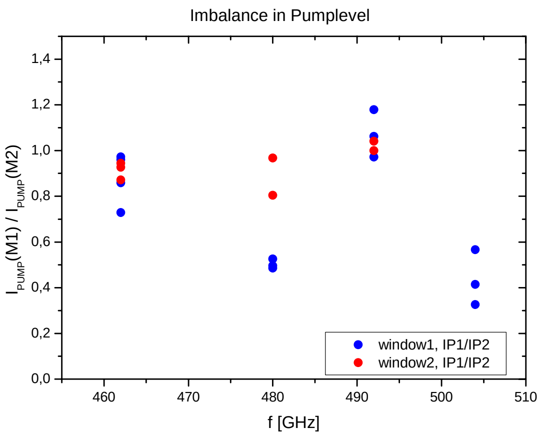

Fig. 3 Variations in the pump level ratio $I_{PUMP}(M1)$ / $I_{PUMP}(M2)$ in dependence of frequency and LO injection port (window 1 and window 2). The variations are probably due to asymmetry of the coupler and due to standing waves in the RF system.

The coupled signal is observed to be stronger than the signal in the direct path at some LO frequencies.

Also the noise temperature, measured separately for each mixer in the balanced configuration, shows a comparable imbalance, even if the LO power is adjusted for each mixer to its optimum level. For instance, the noise temperature, measured with mixer 1, is lower when the signal is injected via window 1 (Fig. 4), compared to the noise temperature via window 2, which is the direct path (compare Fig. 1). This unexpected coupling factors are in contrast to the measurements on the 345GHz waveguide coupler with the NWA.

In addition strong standing waves in the RF system could be observed over the whole frequency range.

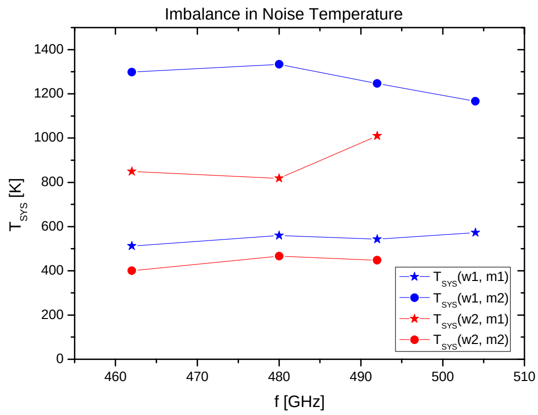

Fig. 4 Noise temperatures of each mixer have been recorded in dependence of LO frequency and signal injection (via window 1 or window 2). The noise temperatures should be doubled in comparison to a single mixer configuration, because only about 50% of the signal is coupled in one mixer block. The further increase of noise temperature is due to absorption of the signal in (the long waveguide arms of) the split block coupler. Furthermore the performance of the SIS mixers is reduced by a somewhat higher bath temperature, resulting in higher noise levels (compare Fig. 5).

Fig. 5 shows pumped and unpumped I(V)- and P(V)-curves of mixer 1, on one hand measured separately in a standard DSB measurement setup and on the other hand measured while being use as part of the balanced mixer (bold lines). The reduced gap voltage in the balanced mixer configuration indicates a higher temperature of the mixer chip due to an increased thermal resistance via the split block coupler.

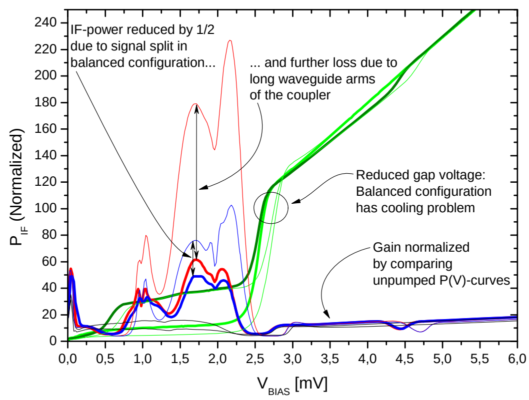

Fig. 5 Pumped and unpumped I(V)-curves (green) and P(V)-curves (red and blue) of mixer 1, measured separately in a standard DSB measurement setup (thin lines) and measured while being used as part of the balanced mixer (bold lines). The IF output power at the hot load is strongly reduced compared to the measurements without waveguide coupler in simple DSB mode. This is attributed to the attenuation of the long waveguide arms in the coupler.

Comparing the unpumped P(V)-curves above the gap voltage, the gain of both measurements can be normalized. This allows the comparison of the pumped P(V)-curves in both, separate and balanced setup. It would be expected that in the balanced setup the IF output power for the hot load would be approximately 50% of that measured in the separate DSB set-up. In Fig. 5 the level in the hot P(V)-curve of the balanced setup is only about 33% of that of the P(V)-curves of the single mixers (Fig. 5). This cold loss, in the long waveguide connecting to the coupler or in the coupler itself results in an additional 50% higher noise temperature for the individual mixer in the balanced mixer setup. This effect, combined with the imbalance, results in a best noise temperature of approximately 500K for the balanced mixer (Fig. 6).

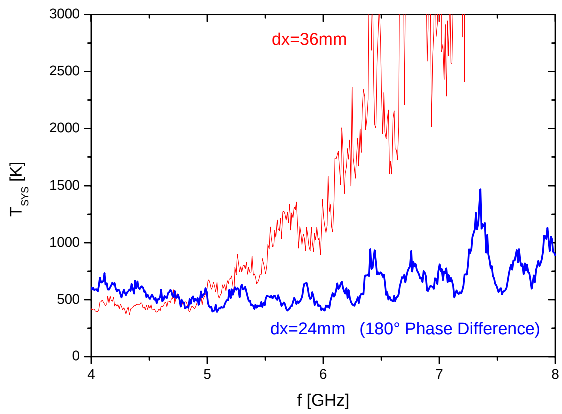

Fig. 6 Noise temperature of the balanced mixer over the IF band.. The IF signals are combined with 180° phase difference in order to obtain the balanced signal. With proper path length compensation, balance over the whole 4-8GHz IF range can be achieved.

Fig. 6 shows the noise temperature of the balanced mixer behind the Wilkinson power combiner. When the phase difference in both IF-chains is compensated by an additional 24mm SMA cable, the balanced operation is achieved over the whole IF range from 4-8GHz. The phase compensation does not depend on LO frequency and results from different IF path lengths inside the dewar.

IV. Discussion

The strong standing waves in the RF system are believed to come from the fact that the mixer blocks and the corrugated horn use half height waveguides (which improves the performance of the waveguide probe of the mixer chip) whereas the full height waveguides are used in the split block coupler in order to afford the milling process.

The strong reduction of the RF power which can be observed by comparing the P(V)-curves, can probably not only attributed to the power splitting in the coupler, but may be due to (cold) absorption in the long waveguide arms.

The observed coupler imbalance can not be explained only by the influence of standing waves in the waveguide system, but comes most likely by fabrication tolerances in the coupling slits, which are to high compared to the operating wavelength ($\Delta x/\lambda \approx 0.03$).

Conclusions

A balanced SIS-mixer at 490GHz with modular design has been investigated by heterodyne measurements.

Balanced operation could be achieved over the whole 4-8GHz IF range.

The measurements revealed a strong RF power imbalance most likely due to unacceptable tolerances of the central waveguide coupler manufactured in split block technology.

Cold attenuation due to the long waveguide arms which had to be used in a modular design, result in high noise temperatures of the balanced system, although a separate testing showed good performance of the individual mixer blocks.

Strong standing waves in the RF paths are partly the result of untapered transitions from half height to full height waveguides used in the mixer blocks and the waveguide coupler respectively.

The advantages of separate testing of a modular design are partly thwarted by the signal damping in the waveguide arms and the reflections due to waveguide transitions which could not be measured directly. Nevertheless, the measurements could show that the fabrication of the waveguide coupler on a standard milling machine, although carried out with highest elaborateness, does not give the required accuracy which is necessary to manufacture a coupler for 490GHz. A similar result has been obtained by comparing two split block couplers for 375GHz, fabricated on a *Deckel FP2* and a *Kern MMP* with a higher milling precission [1,2].

An integrated system with a more accurate fabrication, especially of the waveguide coupler, could avoid attenuation and imbalance and significantly improve the noise temperatures.

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