7-pixels prototype for a 230 GHz multi-beam receiver

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Abstract— **IRAM is currently working on a 230 GHz multi-beam receiver to replace the Heterodyne Receiver Array installed at its 30 m telescope at Pico Veleta, Spain. The new instrument features more pixels and an increased RFobserving bandwidth. It will employ state-of-the-art sideband-separating mixers with wide IF band. The receiver design is based on 7 adjacent modules of seven pixels. A fully integrated prototype module featuring seven pixels and complete LO distribution has been designed and evaluated. A feasibility study of the unit has been carried out, in particular considering the needs of fabrication reproducibility, resulting in a less integrated, but also less risky design.**

INTRODUCTION

The HEterodyne Receiver Array (HERA) installed at the IRAM 30 m telescope in Spain is a key instrument for large-scale mapping in the 230 GHz (1 mm) atmospheric window[1]. It will be replaced in the near future by a new multi-beam receiver, which will not only provide a larger RF observing range, but will also increase the instantaneous bandwidth by a factor of 16 by employing state-of-the-art wide IF band sideband-separating (2SB) SIS mixers, similar to those currently deployed in the EMIR or NOEMA receivers[2], [3]. In addition, the number of pixels will be increased from 3x3 to 7x7, each pixel delivering two polarizations.

SINGLE-PIXEL DESIGN

In a first step a 230 GHz 2SB SIS mixer suitable to serve as the base unit for a multi-pixel mixer array has been designed. Apart from requirements concerning the RF and IF operating ranges of 200 to 280 GHz and 4 to 12 GHz, respectively, the mixer had therefore to comply with several mechanical constraints. First of all the size of the mixer block had to be kept reasonably small to achieve a suitable distance between the individual pixels. Additionally, in order that the mixer could be stacked horizontally and vertically, RF input and IF outputs had to be placed at the front and the rear of the block, respectively. And finally, the mixer should achieve state-of-the-art performances regarding noise temperatures and image rejections.

In order to obtain a very small footprint for the 2SB SIS mixer prototype for the 7 pixels array, it has been designed by integrating all components of the 2SB mixer, i.e. the RF hybrid coupler, two DSB mixer blocks, the LO splitter, two LO couplers and the IF coupler, into one E-plane splitblock[4]. In view of the size constraints for the multi-pixel receiver the Josephson effects are suppressed by employing permanent micromagnets. A photo of one half of this splitblock with mounted mixer chips, IF coupler chip, micromagnets, and waveguide loads is shown in Fig. 1.

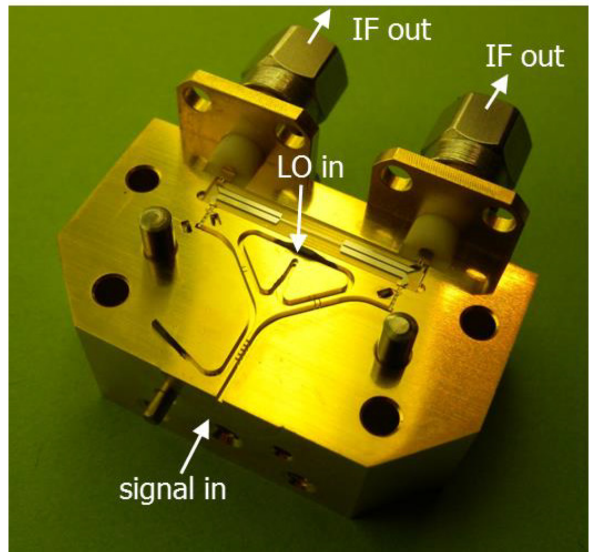

Fig. 1: One half of the E-plane splitblock of the fully integrated 230 GHz 2SB mixer.

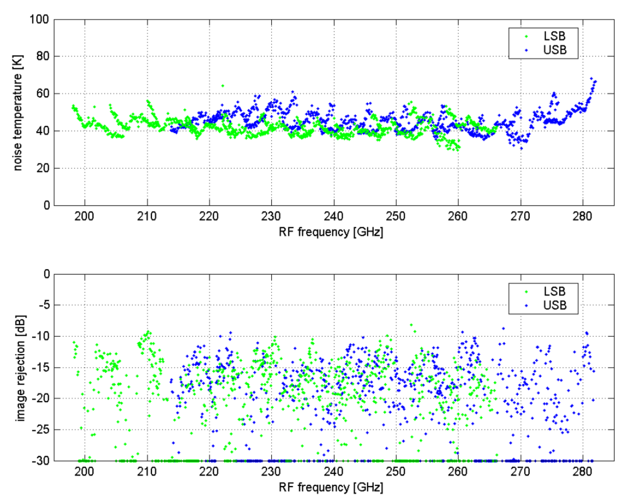

Fig. 2: Performances of the 2SB mixer: noise temperatures (upper plot) and image rejections (lower plot). Lsb measurements are plotted in green, usb measurements are shown in blue.

The measured performances of this mixer are shown in Fig. 2. The achieved noise temperatures lie between 35 K and 55 K and the image rejections lie well under 10 dB.

Due to its mechanical design this prototype 2SB mixer can easily be stacked in horizontal and vertical directions and is therefore suitable to serve as the base mixer unit for forming a multi-pixel mixer array.

MULTI-PIXEL DESIGN

For the overall design of the 7-pixels prototype the distance of the pixels in horizontal as well as vertical direction has been fixed in view of the sky coverage of the pixels to 25 mm. So each component had to fulfil the requirement of not exceeding a footprint of 25 mm x 25 mm per pixel in the horizontal and the vertical directions, respectively. The dimension in the z-direction was not subjected to any constraint. The signal had to be input from the front side of the prototype and to be output on its rear side, in order to allow a stacking of the 7-pixels prototypes to build a multi-beam receiver. Therefore, the LO signal is fed in from one side.

MIXERS AND LO DISTRIBUTION

In a first approach the 7-pixels mixer array has been designed as one unit consisting of three parts as shown inFig. 3. The 2SB SIS mixer base unit has been replicated 7 times horizontally and integrated into one E-plane splitblock which is represented by the two lower parts of the unit shown inFig. 3.

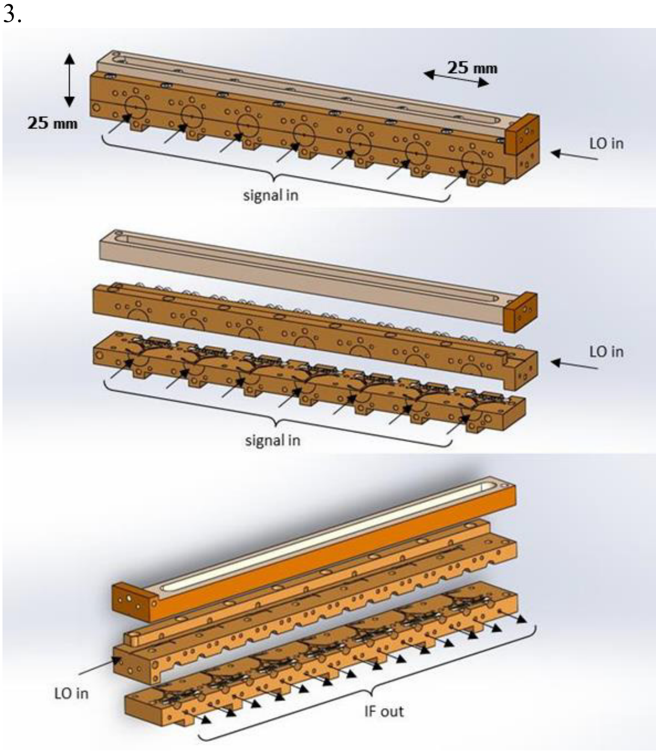

Fig. 3: Initial design of the mixer array and the LO distribution.

The LO signal distribution has been added in the plane between the upper and the middle parts. The LO injection is effected through the flange on the side of the unit into the continuous waveguide formed by the upper and the middle parts. Seven couplers then distribute the signal into seven branches. The couplers have been designed with different coupling factors taking into account the losses between the different pixels such that every branch receives the same LO power percentage. Each branch descends through the middle part and injects the LO signal from the top into each mixer, respectively.

The mixers formed between the middle and the lower parts receive the RF signal by their flanges on the front side of the unit. As seen above, the LO signal enters from the top. And the IF signals leave the unit by its rear side.

FEASIBILITY STUDY

All couplers in the LO distribution path as well as the RF and LO couplers in the mixers are designed as branchguide couplers with very small dimensions and requiring a high precision of a few tenths of microns. The slots of these couplers are usually defined by spark erosion. Although this is a regularly used technique for the fabrication of a single-mixer unit, the fabrication of this 7-pixels mixer unit presents a big challenge not only because of the large number of slots to be realized, but the requirements for the positioning of the individual pixels over a total length of about 17 cm, so that the half slots of two opposing parts fit within a few microns to each other.

In order to evaluate the fabrication feasibility of such a unit, a simplified workpiece has been defined (seeFig. 4). This workpiece consists of two halves of an E-plane splitblock and features seven simplified coupler structures spaced respectively 25 mm apart from each other. The couplers are represented each by two slots of 0.1 mm width with a distance of 0.9 mm. No real waveguides, but only two cavities on each side of the slots have been realized. After the fabrication of the pieces one of the cavities of each coupler structure has been milled away, in order to allow a view on the matching of the coupler slots when both parts are mounted together.

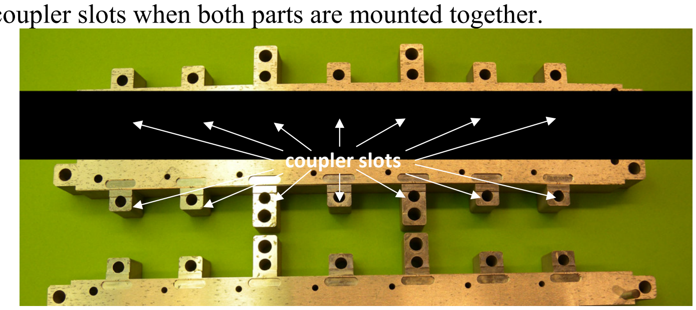

Fig. 4: Simplified workpiece for the fabrication feasibility study.

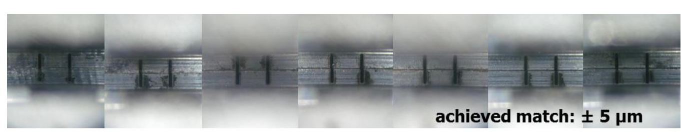

Fig. 5: Cross-sectional view of the seven coupler structures.

Fig. 5shows a cross-sectional view of the seven coupler structures. The achieved match between the coupler halves lies approximately within ± 5 µm, which corresponds to the usually achieved precision for the fabrication of a single mixer unit. Based on these results we decided to keep the LO coupler design.

The overall design of the 7 pixels unit however, we judged not suitable for a mechanical fabrication. Especially, the middle part of our design featuring coupler slots on both of its sides seemed to risky. Therefore we decided to modify our design.

ITERATED DESIGN

The iterated design is shown inFig. 6. It now consists of an LO signal distribution coupler and seven individual mixer units. The overall height of the unit is the same as for the initial design, so that the distance of the pixels did not change. Apart from relaxing the requirements for the mechanical fabrication, this solution offers the possibility to test each mixer individually prior to integration which facilitates the fabrication of the unit.

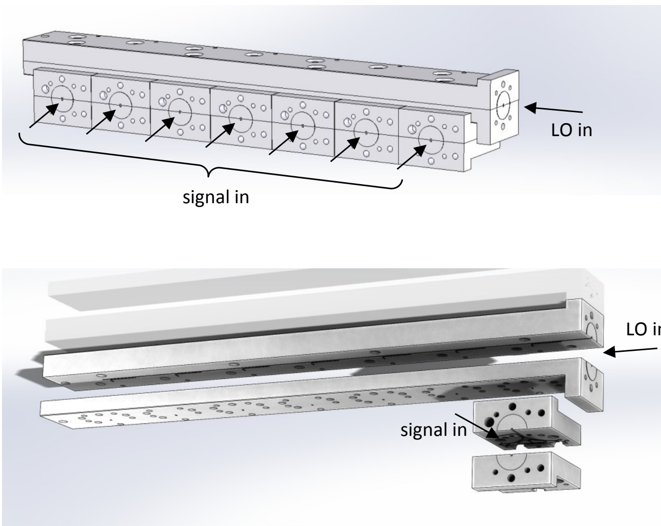

Fig. 6: Iterated design of the mixer array and the LO distribution.

7-PIXELS PROTOTYPE RECEIVER

A schematic view of the such defined 7-pixels prototype receiver is shown in Fig. 7. The signal is input on the front side into each horn. The horns are attached to the mixer blocks which in turn are mounted on an LO coupler feeding each mixer with the same amount of LO power. Finally, the mixers are connected at their outputs to the cold IF amplifiers.

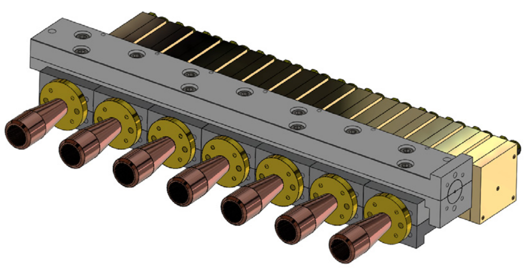

Fig. 7: 7-pixels prototype receiver.

7-PIXELS OPTICS

An optical system has been developed in order to allow testing the 7-pixelsprototype at the IRAM 30m telescope. The aim of this multi-pixels receiver optics is to transform the required angular beam spacing on the sky (~23 arc second, corresponding to a spacing of almost two half power beam widths) to the physical spacing between the feeds (25mm, given by the size of a pixel footprint). This transformation is achieved by using a pair of focusing mirrors, which form a Gaussian telescope and ensure a frequency independent illumination of the telescope. Additionally, each pixel has its own individual optics(which will be cooled to 4K). The role of this individual optics array is to maximize the coupling between each feed and the telescope by re-imaging the sub-reflector onto each of the conical corrugated feed horns. This individual optics (seeFig. 8) is fully reflective. It consists ofdouble-faced multi-mirrors: the beams are first reflected on a row of focusing mirrors, which fold them with an 80 degrees reflection angle onto a row of flat mirrors. The flat mirrors then reflect the beams towards the feeds. Such an array of individual optics is scalable to any number of pixels, wherein the side of focusing mirrors ofeach double-faced multi-mirrors serves for one row of pixels and its other side of flat mirrors serves for an adjacent row of pixels.

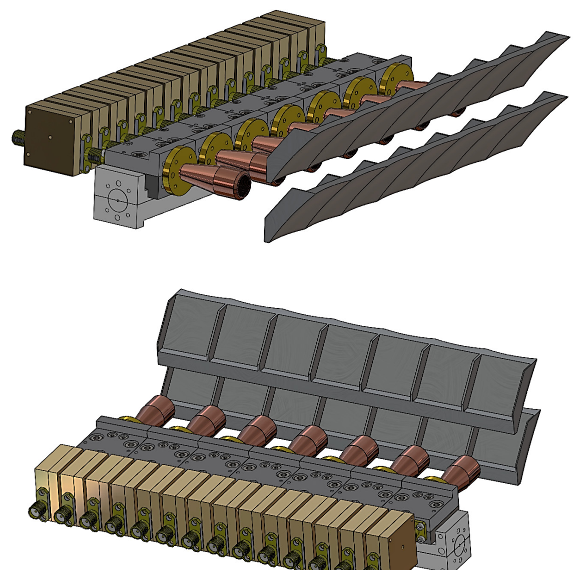

Fig. 8: Views of the 7-pixels array with its individual optics, composed of two multi-mirrors.

CONCLUSIONS

A 7-pixels prototype for an 1 mm array receiver has been developed. The array with the mixers and the LO distribution has been designed and optimized after a feasibility study with respect to its mechanical fabrication. The iterated design is currently fabricated and will be delivered in May 2016. When all subcomponents have been received, they will be integrated in a dedicated test cryostat and tests will then follow during summer 2016.

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