H2020 Grant Agreement No. 730562 – RadioNet

PROJECT TITLE:	Advanced Radio Astronomy in Europe
STARTING DATE	01/01/2017
DURATION:	48 months
CALL IDENTIFIER:	H2020-INFRAIA-2016-1
TOPIC:	INFRAIA-01-2016-2017 Integrating Activities for Advanced Communities

Deliverable 5.7

Multipixel demonstrator of FPA of HEB mixer receivers

Due date of deliverable:	2020-12-31
Actual submission date:	2020-01-26
Leading Partner:	OBSERVATOIRE DE PARIS (OBSPARIS)

Document information

Document name:	Multipixel demonstrator of FPA of HEB mixer receivers
Type	Demonstrator
WP	WP5 – AETHRA
Version date:	2020-01-26
Authors (Institutes)	Yan Delorme (LERMA) Jean-Michel Krieg (LERMA) Martina C. Wiedner (LERMA)

Dissemination Level

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of contents

RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562

COVID-19 affects the Deliverable D5.7, to which the Art.51 applies as follows:

COVID slowed any fabrication and testing down, not allowing us to iterate our design. Nevertheless the results we achieved were good. The tests were carried out at LERMA, but the final test at SRON could not take place because of the COVID travel restrictions. Unfortunately, our waveguide beam divider was lost by DHL during delivery partly because the Observatory was not always staffed because of COVID restrictions. We could therefore not test this waveguide divider in the laboratory, but can only report a successful visual verification carried out before the piece was sent.

1 Executive Summary

Heterodyne receivers are ideally suited to obtain high-resolution spectra of the sky. Usually, they have a single pixel, i.e. they observe only one point in the sky. Focal plane arrays (FPA) of heterodyne receiver allow the observation of several places in the sky simultaneously, thus increasing the observing efficiency significantly. During the AETHRA study LERMA-Obs Paris has built a 2x2 hot electron bolometer (HEB) focal plane array demonstrator with a quasi-optical coupling scheme. One of the technical challenges for a HEB array above 1 THz is how to split the single LO into multiple beams for the array. We have explored and validated two different concepts and fabrication methods for THz beam dividers. We have developed a high efficiency (≥60%) phase grating beam dividers and in addition, a THz waveguide beam divider with the aim of taking advantage of recent cleanroom microfabrication technologies, in particular the 3D-laser microfabrication on glass and deep reactive ion etching on silicon for the manufacturing of beam dividers at very high frequencies. Both of these beam dividers are good choices for future heterodyne focal plane arrays.

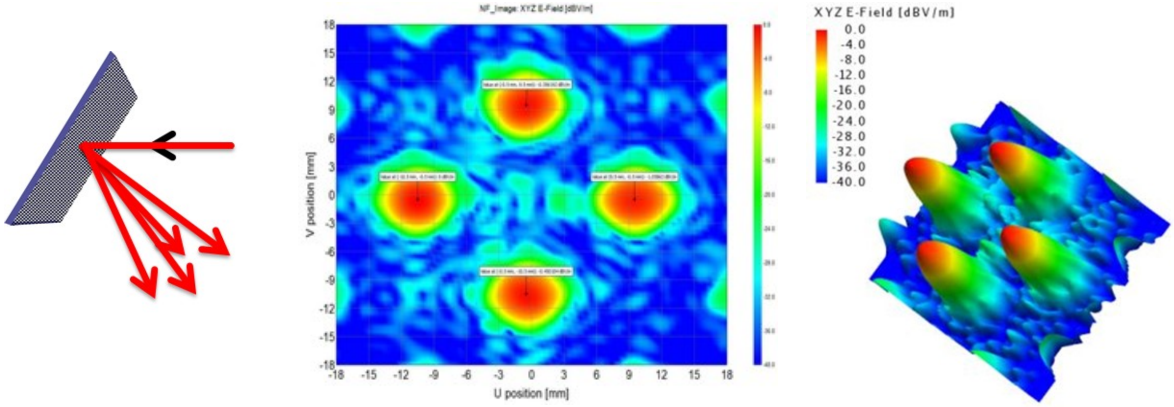
2 Beam Dividers

2.1 Phase Grating Beam Dividers

At LERMA we developed a new algorithm to calculate a phase grating beam divider. This is a new concept of the phase grating design with no constraints about the grating's element geometry or the output beam shape.

A VDI Amplifier-Multiplier Chain (AMC) provides the input signal. We have first established the 3D model of the AMC horn and simulated its radiation pattern which was used as input signal with an incidence angle of 22.5° for the 4 beams phase grating divider. The calculations are carried out with the MatLab code developed in the laboratory to generate the mirror's surface geometry required for creating the four output beams. This surface geometry is then imported into FEKO, a 3D electromagnetic simulation software, which calculates the distribution of the electromagnetic field in the space around the mirror to obtain the radiation pattern at the output of the mirror. Figure 2.1-1 shows the operation of the designed mirror, which divides an input beam into 4 beams, and the simulated radiation pattern of the 4 output beams.

RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562



(a) (b) (c)

Fig. 2.1-1 Schematics of the geometry of input and output beams at the phase grating mirror (a), simulated electric field distribution at the output of the mirror (b) & (c)

Several optimization iterations between the MatLab calculation and the simulation on FEKO were carried out in order to optimize the characteristics of the output beams. The obtained beams are well separated with an inter-beam amplitude below -25 dB and the waist of the input beam has been preserved.

The divider design has also been optimized to ease fabrication efficiency. A mechanical manufacturing company has manufactured the divider and has delivered it in December 2020. The structure measures approximately 2 x 2 cm and has pattern heights varying between 0 and 120 µm (Fig. 2.1-2).

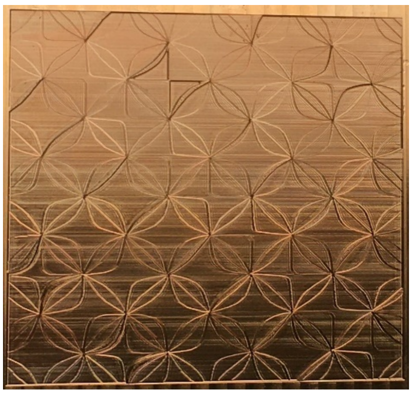


Fig. 2.1-2 Manufactured 4-beam phase grating divider

In order to test the mirror we have built a new computerized beam pattern test bench for two dimensional far-field pattern measurements in the THz range (Fig. 2.1-3). The measurement of the manufactured divider has been performed using the VDI AMC as the input beam and a QMC pyroelectric detector.

RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562

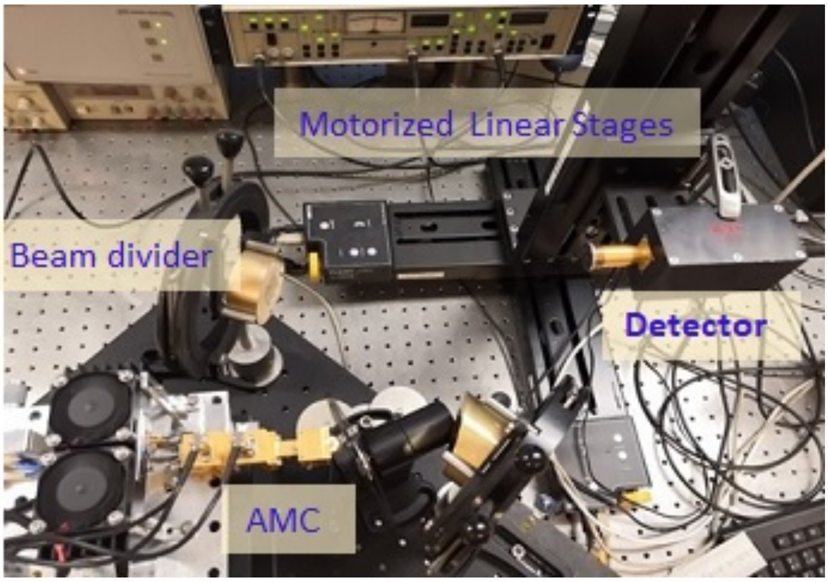


Fig. 2.1-3 Test setup for the measurements of the beam divider

The AMC's frequency was set to 1.3 THz and the results are presented in Fig.2.1-4. The single beam provided by the AMC chain (Fig. 2.1-4a) has been divided into 4 beams (Fig. 2.1-4b) as expected. The measurement is in a good agreement with the design. It has a good efficiency of 60 - 70%.

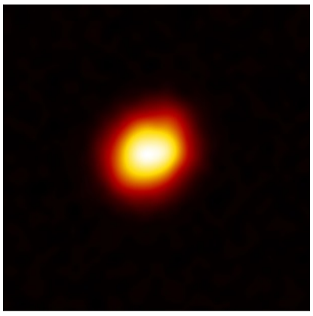


Fig. 2.1- 4a Measured input beam provided by AMC

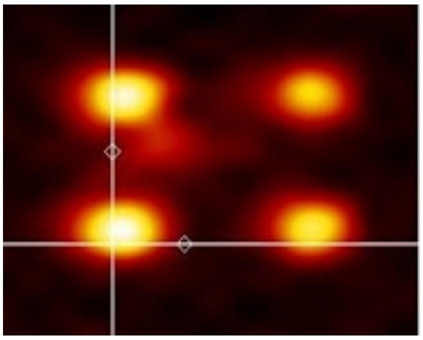


Fig. 2.1- 4b Measured output of the beam divider: the 4 generated beams are well separated and at the nominal spacing.

2.2 Waveguide beam divider

In parallel with the development of the phase grating divider, a post-doc, Haotian Zhu, has been hired during 2019-2020 to work on a waveguide divider for 1.37 THz. The LO signal is captured by a horn, transferred to the waveguide and then split by T-junctions first into two signals and then into four signals which exit through a circular horn array into free space. The concept is illustrated in Fig. 2.2-1 [1,2].

RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562

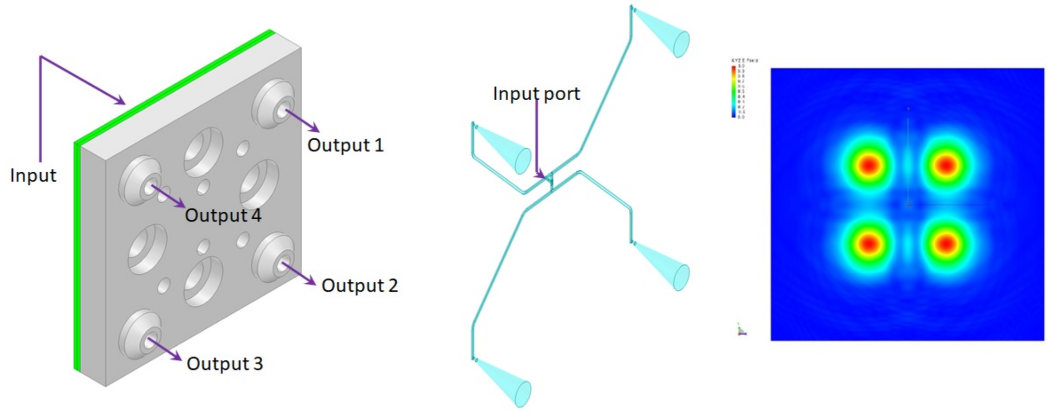


Fig.2.2-1 Waveguide divider concept. Configuration of the divider (left), waveguide T-junctions are used to split the input beam (middle) and simulated E-field distribution of the output signals (right)

The cross-sectional size of the WR0.65 waveguide is only 164 µm X 82 µm and it is challenging to fabricate. For the manufacturing of the E-plane junction and two H-plane junctions, two new microfabrication technologies have been explored: on glass or fused silica by femtosecond laser assisted wet etching (or 3D-laser microfabrication) and on silicon by inductively coupled plasma-deep reactive ion etching (ICP-DRIE). The SEM pictures of the fabricated feeding networks by the two technologies are shown in Fig. 2.2-2 The total thickness of the feeding network is 400 µm, and the designed waveguide channel depth is 82 µm. The estimated waveguide insertion losses of the feeding networks manufactured by these two technologies are between 0.31-0.35 dB/mm. A part of the waveguide divider realized with glass and coated with gold is also shown in the Fig. 2.2-2. The circular horn array has been fabricated by mechanical machining. Visual inspections of the manufactured pieces indicate a successful fabrication.

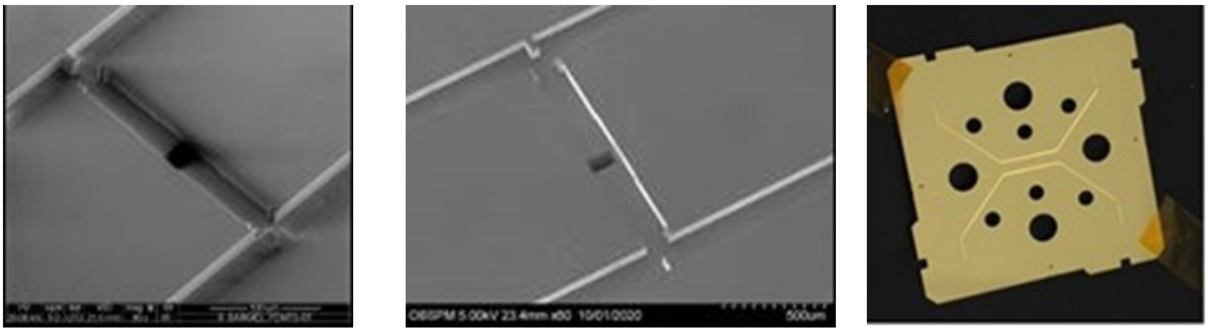


Fig. 2.2-2 SEM pictures of the T-junction of the beam divider, on glass by 3D laser assisted wet etching (left) and on silicon by ICP-DRIE (middle). Part of the waveguide divider with gold coated glass (right).

The first divider assembly with pieces from mechanical machining and 3D laser assisted fabrication took place in spring 2020. Unfortunately, a critical part of the divider has been damaged during the assembly and the new pieces processed in summer 2020 have been lost by DHL during the delivery from the laboratory where the gold deposition was made. Despite this unfortunate incident, believe that a waveguide beam divider has great potential. We have accomplished a design, developed specific fabrication process using new microfabrication technologies, have shown that the delicate waveguide parts can be structured and gold coated with satisfactory visual outcome. The remaining step is the laboratory test. We intend to build a new waveguide divider once our engineers are able to work in the clean room of C2N where currently only C2N staff members are allowed due to Covid-19 restrictions, in order to characterize the waveguide beam divider. In contrast to mechanically cut beam dividers, the clean room fabrication approach allows the fabrication of beam dividers even for very high frequencies applications.

3 HEB mixer array

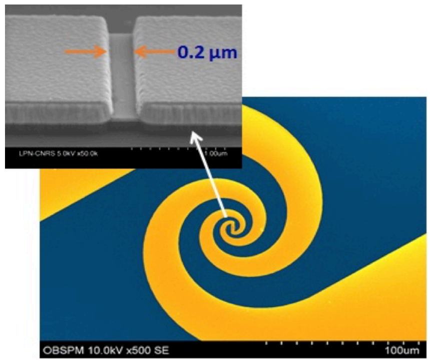


Fig.3-1 HEB device with its spiral antenna

HEB devices have been designed at LERMA and manufactured in the cleanroom of C2N-CNRS by engineers from LERMA. We developed a simple and high-yield fabrication process. A quasi-optical concept with integrated lens-antenna configuration was used for the mixer array development. The phonon-cooled HEB device consists of a 2 µm wide, 0.2 µm long and about 3.5 nm thick NbN micro-bridge connected to an on-chip gold spiral antenna on a high resistivity silicon substrate. Fig. 3-1 shows a scanning electron microscope (SEM) image of the HEB device, the inset is a close-up of the NbN bridge. The HEB device has a critical temperature Tc around 9.2 K and a critical current around 220 µA at 4.2 K, which shows that the fabrication process was successful. The normal resistance at room temperature is about 76 Ω.

The HEB devices are glued on the flat side of the hyper-hemispherical silicon lenses and then are mounted into a 4-pixel integrated lens/antenna HEB mixer block that we developed during AETHRA (fig.3.2).

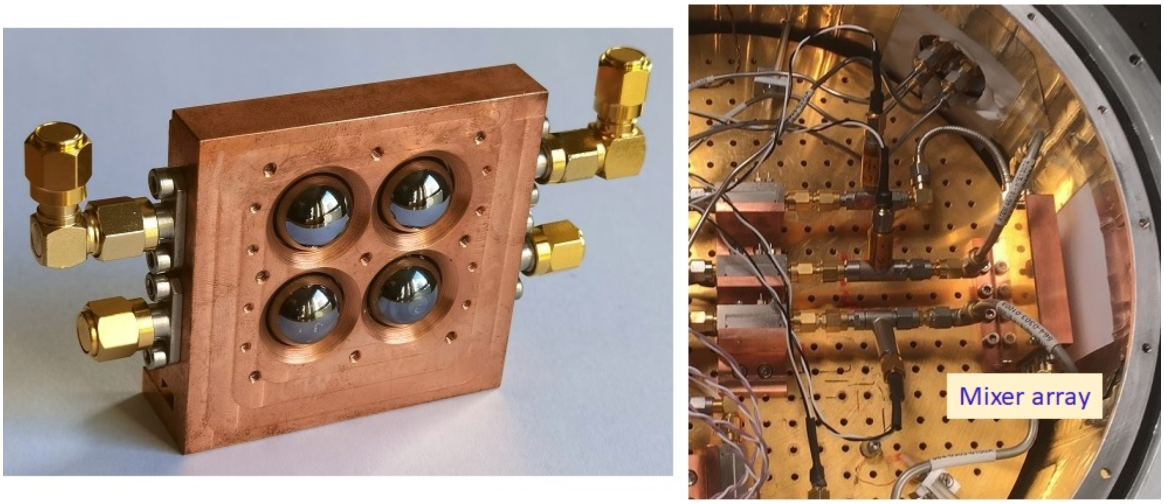


Fig.3.2 Mounted 4-pixel HEB mixer block (left) and a photo inside the 4K cryostat with the mixer block (right)

The mixer measurements have been performed at 1.3 THz with a VDI Amplifier Multiplier Chain as local oscillator. A good pumping level has been obtained as show in the fig.3.3. The double sideband (DSB) receiver noise temperature is obtained by using the Y factor method. The HEB mixer's IF output signals is connected, through a bias-T to the input of a Caltech low noise cryogenic amplifier followed by two room temperature Miteq amplifiers. A noise temperature of about 800 K has been obtained, even before any optimization.

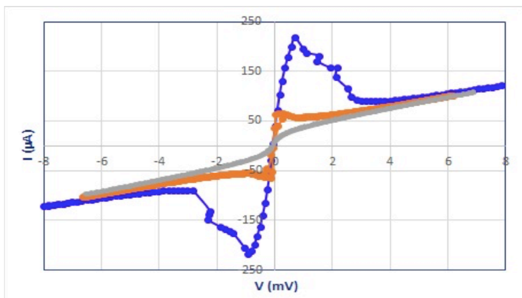


Fig.3.3 HEB's I-V curves without and with the LO

RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562

4 Conclusion and Outlook

LERMA-Observatoire de Paris has built a small 2x2 hot electron bolometer array with quasi-optical coupling. To pump the array we have developed two different beam dividers: one using phase grating mirrors, the other one exploiting the latest clean room technology to fabricate a waveguide splitter. The phase grating mirrors have been fabricated and give good beam pattern results. The waveguide splitter has also been fabricated and was very satisfactory under visual inspection. Unfortunately, it got lost in the post and could therefore not be tested in the lab. Nevertheless, the study allowed us to identify two good beam divider approaches for future heterodyne focal plane arrays and will hopefully be used on the next generation astronomical instruments.

5 References

[1] Haotian Zhu et al. “A 2 x 2 Beam Divider for an array local oscillator at 1.37 THz”, Proc. IRMMW-THz (2019)

[2] Haotian Zhu et al. “A 1.37 THz Waveguide-based 2 x 2 Beam Divider Fabricated by Two Microfabrication Technologies”, The 31st International Symposium on Space Terahertz Technology, Arizona, 2020

RadioNet has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730562