HEB Waveguide Mixers for the upGREAT 4.7 THz Heterodyne Receiver Array

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***Abstract*— We report on integration and testing of HEB waveguide mixers for the upcoming upGREAT 7-pixel 4.7 THz high frequency array (HFA). upGREAT is the array extension of the modular GREAT (German Receiver for Astronomy at Terahertz frequencies) heterodyne receiver platform.The mixers are based on similar technology to the mixer of the single pixel 4.7 THz receiver in operation on SOFIA and use waveguide feedhorn coupling. Forthe array application the mixers are optimized tolowerlocal oscillator powerby reduction of the thickness of the NbN superconducting microbridge layer. Preliminary laboratory measurement results indicate performance comparable to the single pixel mixers.**

INTRODUCTION

Above 1 THz superconducting hot electron bolometer (HEB) mixers are employed in the lowest noise heterodyne receivers([1]-[4]). TheHEB mixers for the GREAT (German Receiver for Astronomy at Terahertz frequencies)single-pixel receivers operated on SOFIA have been continuously improved in performance (Trec, intermediate frequency bandwidth), reliability and higher operation frequency, ultimately leading to the 4.7 THz mixerin operation since 2014 ([5]-[7]).

All mixers are based on waveguide membrane devices and use a feedhorn antenna coupling. The main motivationof this approach is that the center axis of the feedhorn defines a precise locationand orientation of the optical axis with respect to a mechanical reference on the mixer unit. Forfocal plane array applications, i.e. receiver front-endswith several mixer units (pixels),this should favor aregularly spaced and well-defined beam pattern on sky, and therewith an optimum in mapping efficiency of the instrument.

The mixers we report on here are being developed for the upGREAT high frequency array (HFA) receiver, which is the focal plane array extension of GREAT. After successful commissioning of the 14-pixel low frequency array (LFA) receiver in 2015 ([8], [9]), with frequency range centered on the 1900 GHz [CII] fine structure transition,we are now focusing on integration of the second upGREAT receiver, the 7-pixel HFA, which solely targets the [OI] fine structure transition at 4745 GHz (63 μm) ([10], [11]).

MIXER DESIGN

The 4.7 THz HEB mixer design and hardware for the HFA is similar to the 4.7 THz operated in the single-pixel receiver, for full details see [7]. In the following we will only give a brief summary.

Device Fabrication

Each HFA mixer is based on a 3–4 nm thick by 200 nm long and 4000 nm wide NbN microbridge embedded into an on-chip matching circuit and integrated probe antenna, precisely aligned to a 24 μm x 48 μm waveguide. Beamleads are used for DC and RF contacting of the device and they also serve as mounting points. The 2 μm thick Si membrane substrateis fabricated by means of backside processing of a thick SOI wafer after the front side circuit definition has been performed. All critical circuit layers (HEB microbridge and contacts, RF circuit elements) are defined by e-beam lithography.

Waveguide Fabrication

The operation frequency leads to the technically very challenging fabrication of 48 μm x 24 μm sized waveguides. The waveguide backshort and device channel features are fabricated by direct-machining into a Cu-Te block by means of a sophisticated mix of precision stamping and milling techniques in our in-house workshop. For the HFA the mixer blocks have a reduced footprint of 16 mm x 16 mm that is compatible with the array optics. The footprint currently is determined by the use of a standard Huber-Suhner SMA flange type female connector that we kept due to its long heritage in operation and because the SiGe LNA units have SMA input connectors [12].

Feedhorn

The feedhorns are designed and fabricated at Radiometer Physics GmbH using a mandrel / electroforming process, see [13] for details. We press-fit each feedhorn into a T6061 Al clamp that is mounted to the top of the mixer block. The waveguide output is put into direct contact to the device. For the HFA we dropped to usage of M1 dowel pins for alignment to the receiver optics and for improved accuracy now use machined reference stops on the sides. Our machine shop readily achieves the +/- 10 µm specification on the horn center position.

MIXER QUALIFICATION

The main challenge for array mixer development is to make all mixers sufficiently similar in performance. For the HFA a single local oscillator (LO) sourcewill be used [14] and for interchangeability of the array mixers an even split for the LO power by means of a Fourier grating mirror is chosen [15]. Therefore the mixers need to be sufficiently similar in LO power consumption for optimum array sensitivity. For the HFA we selected devices from a batch that that haveapprox. 1/3of the LO power requirement of the older single-pixel devices. For upGREAT this will ensurea safeLO power margin whilst permitting maximum signal couplingthrough the diplexer.

DC Qualification

We pre-characterize the RT and IV curves each device on diced wafer pieces with up 18 devices each using a liquid Helium dipstick setup. TheIV and RT curve characteristicsare used for selection of the devices to be mounted into a waveguide mixer block after the final backside (membrane) fabrication process. The typical device yield at DC testing is 90%.

RF Qualification

For the RF heterodyne characterization of the HFA mixers we have developed a new setup that includes a completely evacuated signal path that ensures measurements independent from atmospheric influences in particular near the rest frequency of [OI]. It has a selectable signal path to hot (RT) and cold (LN2) loads as well as agas cell. This methanol gas cell is used for in-line frequency determination of the LO. For simplifying the procedures with have opted to keep the cryostat on its separate vacuum using a Parylene coated Si dewar window with 92% transmission procured from Tydex.

The LO is based on a quantum-cascade laser (QCL) from the ETH Zürich and is an in-house developed prototype for the HFA. We have the option to select from two different QCLs in-situ, one emitting at 4785 GHz and the other close to 4745 GHz. Signal/LO diplexing is achieved with a 5 µm thick Mylar beamsplitter and we remotely attenuate the LO with a rotatable wire grid. Our new setup features 0–5 GHz intermediate frequency (IF) processing with two 2.5 GHz digital FTS spectrometers kindly on loan from the MPIfR. We combine the spectra for single-shot spectrometer measurements over the full IFrange [16].

Due to the QCL's intrinsic tunability limitation we can only measure a very small frequency range of the mixer RF bandpass in heterodyne mode. In order to measure the broadband response we therefore use a commercial FIR FTS from Bruker and operate the HEB mixer as a direct detector. The FTS measurements are important as they can feedback observed changes in the RF bandpass to our 3D-EM circuit modeler (CST Microwave Studio™), and e.g. allow more precise modeling of the on-chip THz circuit.

CONCLUSIONS

We are in the integration and testing phase for the upGREAT HFA 4.7 THz array scheduled for commissioning on SOFIA in late 2016. We are measuring the HFA flight mixers and preliminary Trec(IF) results are similar to our initial results for the single-pixel receiver mixers (Fig. 1). Optimization is still ongoing and based on our experience with the LFA arrays we will need to carefully select HEB mixers not only based on best Trec(IF) but also on LO power consumption and uniformity.

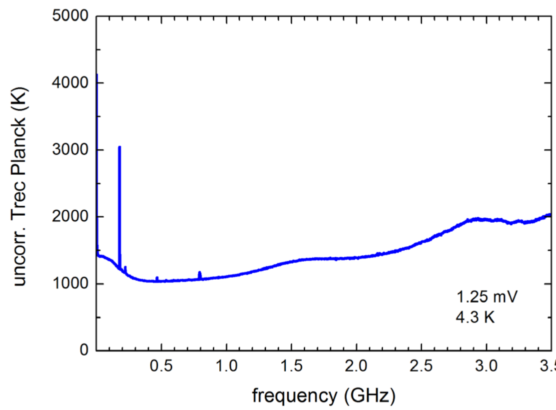

Fig. 1Uncorrected DSB Trec(IF) (Planck) for a HFA flight mixer candidate at a LO frequency of 4785 GHz. A 5 µm thick Mylar beamsplitter in vertical polarization was used as diplexer with a fully evacuated signal path. No corrections for signal path losses were applied (beamsplitter T=70%, dewar window T=92%) were applied. The spurs at low IForiginate from the QCL local oscillator.

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