upGREAT: Status of the 1.9 to 2.5 THz Heterodyne Array for SOFIA

Christophe Risacher[1], Nicolas Reyes[1], Rolf Güsten[1], Jürgen Stutzki[2], Heinz-Wilhelm Hübers[3], Patrick Pütz[2], Andreas Bell[1], Denis Büchel[2], Ivan Camara[1], Rafael Castenholz[1], Mose Choi[1], Urs Graf[2], Stefan Heyminck[1], Cornelia Honingh[2], Karl Jacobs[2], Matthias Justen[2], Bernd Klein[1], Thomas Klein[1], Christian Leinz[1], Heiko Richter[3], Oliver Ricken[1], Alexei Semenov[1], Achim Wunsch[1]

[1]*Max Planck Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany*

[2] *KOSMA, I. Physikalisches Institut des Universität zu Köln, Zülpicher Strasse 77, 5093 Köln, Germany*

[3] *German Aerospace Center (DLR), Institute of Planetary Research, Rutherfordstr. 2, Berlin,Germany*

Contact: crisache@mpifr-bonn.mpg.de, phone +49-228-525 338

Abstract— **The NASA-DLR airborne observatory SOFIA is now performing routine observations, having the German PI instrument (GREAT) as one of its four main instruments. The instrument currently comprises a set of single pixel heterodyne receivers observing in selected frequency windows between 1.25 and 4.7 THz. We are developing new instruments, the upGREAT receivers, which consist of mid-size heterodyne arrays based on superconducting waveguide HEB mixers. The Low Frequency Array (LFA) will cover the 1.9-2.5 THz range using dual polarization 7-pixel HEB arrays. The second receiver, the High Frequency Array (HFA), will observe the [OI] line at ~4.7 THz using a 7-pixel HEB array. We present the status of the LFA receiver, which is in the final stages of integration, testing and characterization. The installation and commissioning aboard SOFIA is planned for May 2015.**

I. Introduction

Due to the high atmospheric losses, THz astronomy observations are not possible from ground-based telescopes, except in few remote locations at very high elevation and having extreme dry conditions such as the Andes or the South Pole. Even so, only few atmospheric windows are then accessible, 1.0-1.1 THz, 1.3-1.4 THz and 1.45-1.6 THz. To observe above 1.6 THz, to access for example the [CII], [OI] atomic transitions, which are major targets as coolant reservoir in the molecular clouds, other solutions are needed. Satellite missions allow an unobstructed view, free of any atmospheric absorption. Other alternatives are high-altitude balloons, and in our case, airborne observatories, such as the Stratospheric Observatory for Infrared Astronomy SOFIA ([1]). The main advantage of such an alternative as opposed to satellites is the flexibility in placing newer developed technologies with very short turn-around times. To increase the efficiency of large-scale mapping observations with SOFIA, we are developing a new set of instruments, upGREAT. This instrument consists on two heterodyne arrays based on HEB mixers. The LFA receiver will cover the frequency range 1.9 to 2.5 THz, while the HFA receiver will observe at 4.7 THz. The main system characteristics are summarized in Table 1.

TABLE I
upGREAT specifications

	Low Frequency Array (LFA)	High Frequency Array (HFA)
RF Bandwidth	1.9-2.5 THz (goal)	~4.745 THz
IF Bandwidth	0.2-4 GHz	0.2-4 GHz
HEB technology	Waveguide-based HEB NbN on Si membrane	Waveguide-based HEB NbN on Si membrane
LO technology	Photonic mixers / solid-state chains	Quantum cascade lasers (QCL)
LO coupling	Beamsplitter (goal) or Diplexer (baseline)	Beamsplitter
Array layout	2x7 pixels dual polarization in hexagonal layout	1x7 pixels in hexagonal layout with a central pixel
T_{REC}	Goal <2000K SSB	Goal <3000K SSB
Backends	0-4 GHz with 32k channels	0-4 GHz with 32k channels

II. Description of the LFA receiver

A. LO Sources

For the commissioning flights, planned in May 2015, the chosen LO sources are solid state multiplying chains, built by VDI Inc. The frequency coverage for the chains are limited to 1.88 to 1.92 THz, centred to cover the [CII] transition. Those LO chains produce about 20 µW of output power at ambient temperature. To increase the output power, the last two passive triplers are cooled down to 80K, which gives a factor 2 improvement, hence reaching about 40 µW. The output LO beam is split into 7 equal beams by using a phase grating [3]. In order to successfully pump the two sub-arrays, two identical LO chains will be used, one per polarization.

In parallel, the MPIfR is developing photonic mixers local oscillators to cover the full RF range, from 1.9 to 2.5 THz. Pending the confirmation that they can provide sufficient LO power, they will be used with the LFA receiver in subsequent flight series.

B. HEB Mixers

The superconducting detectors are Hot Electron Bolometers (HEB) developed by the KOSMA group [2], with state of the art performance, having 2-4 times the quantum noise limit. The uncorrected receiver noise temperatures for the LFA mixers, when measured in a test cryostat with optimized LO coupling is in the range 750-800 K minimum with an IF noise bandwidth of ~3-3.5GHz.

C. IF signal processing

The IF signal in the range from 0.2-4 GHz is then amplified by a set of cryogenic low noise amplifiers (SiGe LNAs from S. Weinreb, Caltech), which have a low thermal dissipation of about 10mW.

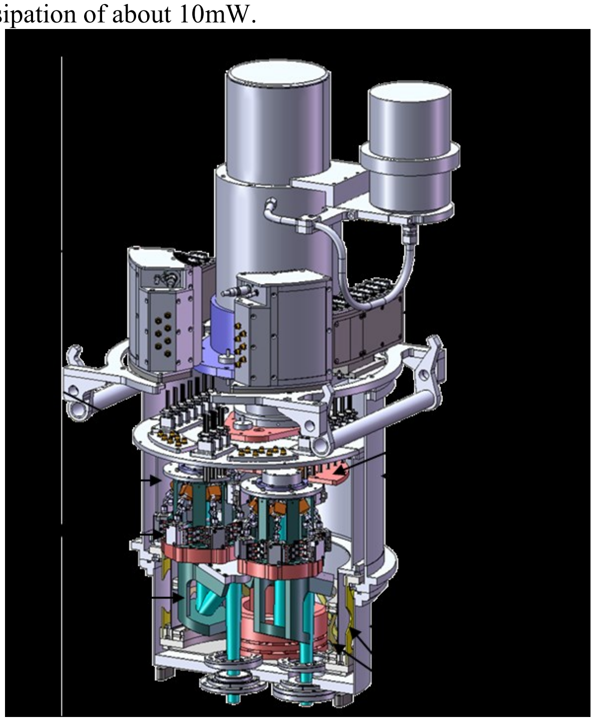

Fig. 1 : Pulse tube PTD-406C cold head. 2: Rotary valve. 3: 0.75m Flexible Helium line. 4: warm IF amplifiers. 5: Pre-amplifiers for biasing HEBs. 6: 40K stage plate. 7: 4K stage plate. 8: HEB detectors. 9: Cryogenic SiGe amplifiers.10: cold optics. 11: RF windows. 12: Vacuum Vessel upper part. 13: Seal ring. 14: Vacuum Vessel lower part. 15: Fiber glass Supports 4K-60K.

The output signal is processed by room temperature components (amplifiers, filters, equalizers, variable attenuators) in a dedicated IF processor. Finally, the signal is fed into an MPI-built Fast Fourier Transform Spectrometer (FFTS) sampling directly the 0-4 GHz range, with 32K channels obtaining an effective resolution of 144 kHz.

D. Cryostat and closed-cycle cooler

The cryostat construction is described in Fig. 1. The receiver is cooled by a closed-cycle Pulse Tube refrigerator (PT), which can operate up to large tilt angles (±45°) with only small cooling performance degradation. The PT refrigerator is the model PTD-406C from transMIT company. It provides about 0.8W cooling power at 4.2K. The cryostat was jointly designed and manufactured with CryoVac.

III. Integration and preliminary results

The LFA receiver is currently undergoing the final integrations, and is being fully characterized. The first 7 mixers were integrated in December 2014 (Fig. 2) and the full 14 pixels were integrated in January 2015.

The cryostat and cooling system were verified in the past months. The measured physical temperature for our detectors is in the range 4.0-4.5K, ideally suitable for the chosen detectors based on NbN films, which have a critical temperature of 9.5-9.8 K. Measured temperature fluctuations on the HEB mixer blocks are lower than 1mK.

Preliminary testing confirmed that the optical design of the receiver was as expected. The LO phase grating was also verified to produce equal 7 beams at 1.96 THz. Several scheme for the LO coupling are being tested, using beam splitter with a coupling of ~25-30%, which achieves uncorrected noise temperatures around 1000K DSB, and diplexer LO coupling, which is under testing and should achieve lower Trec (~700K) but in a narrower IF bandwidth (1.5-2.5 GHz).

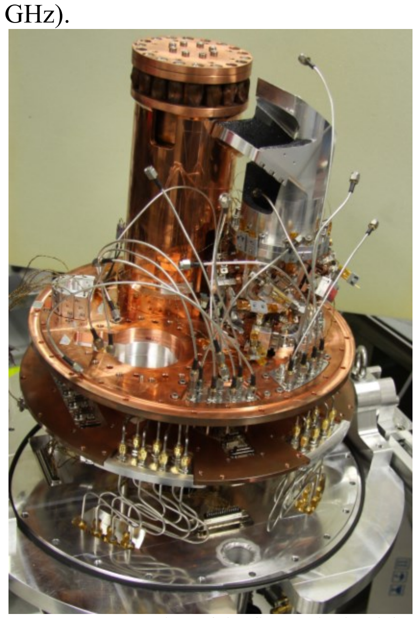

Fig. 2 Integration of the first 7 pixels of the LFA

IV. Conclusions

We are developing mid-size heterodyne arrays employing waveguide based superconducting HEB mixers for the SOFIA airborne observatory. With the successful development of many challenging components, as local oscillators at THz, waveguide-based superconducting detectors, or high resolution spectrometers, we are achieving state of the art performance. The first cryostat (LFA), containing the dual polarization 7-pixel arrays for 1.9-2.5 THz will be commissioned in spring 2015.

References

[1] E. T. Young, E. E. Becklin, P. M. Marcum et al., "Early Science with SOFIA, the Stratospheric Observatory for Infrared Astronomy", *The Astrophysical Journal Letters,* v749, L17, April, 2012.

[2] P. Pütz, this issue.J.

[3] Urs U. Graf and Stefan Heyminck, "Fourier Gratings as Submillimeter Beam Splitters", IEEE Transactions on antennas and propagation, Vol. 49, No. 4, April 2001