

Progress Report FP6 – RadioNet – AMSTAR

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From: SRON and TU Delft
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W.P 2.1.3. Wide IF-band 0.5 mm Mixers

This work package concerns the development of a wide band IF SIS mixer for the frequency range 600-720 GHz.

At SRON

A new junction layout for waveguide mixers in the 600-720 GHz range has been developed. The activity included:

- 3-D electro-magnetic simulation of waveguide structures to calculate the probe impedance;
- tolerance analysis of these structures to assess the feasibility of producing the waveguides in a mechanical workshop;
- calculation of integrated superconducting tuning structures and optimizing SIS junction performance.

The design calls for several novel technological steps which are to be tried at TU Delft, e.g. NbTiN wiring and e-beam junction definition for submicron sized junctions.

The mask drawings were delivered to TU Delft and performance verification is ongoing.

At TU Delft

In the course of optimizing the SIS mixers for the ALMA Band 9 receiver, we have fabricated and tested three device batches. All of them are based on a design mask set (labeled SIS17) which contains various microwave circuits. The purpose is to compare the performance of devices with different material combinations for the embedding circuit.

In these devices also the top wire (as part of the embedding circuit) is defined using e-beam lithography, improving uniformity and accuracy in pattern transfer. The use of e-beam lithography has greatly improved the uniformity and the yield of the devices.

- Batches 17-01 and 17-02: Standard Nb / AlO_x / Nb junctions and Nb topwire. Devices have been delivered to SRON-Groningen, rf evaluation to be carried out in the near future.
- Batch 17-03: Standard Nb / AlO_x / Nb junctions and a NbTiN top wire. Using a higher gap superconductor, T_c (NbTiN) ~14 K, should move the cut-off frequency of

the tuning circuit well above 720 GHz (upper end of ALMA Band 9). DC evaluation reveals a suppressed gap voltage by about 0.1 mV. This is explained by the gap discontinuity between Nb top electrode and NbTiN top wire.

A new PhD student, C.J. Lodewijk (starting 15/05/2004), has been hired at Delft. He will take part in the device development at Delft and the RF evaluation at SRON for WP 2.1.3 and 2.2.2.

W.P 2.2.2. 600-720 GHz 2-SB Mixer

Work is carried out towards the design of a sideband separation (2SB) mixer in the 600-720 GHz band. The development of this mixer will allow a significant improvement of the system noise temperature at ground based telescopes due to the suppression of the relatively high atmospheric noise in the 650 GHz image sideband.

At SRON

Several design concepts for a 2SB mixer have been worked out and numerically evaluated. Due to the high RF frequency, the mechanical tolerances become a key issue for fabricating a waveguide based 2SB receiver. We look into a baseline design of various components, i.e. directional coupler, 90-degree hybrid, 180-degree hybrid, with the goal to relax the tolerances and optimize it for larger physical dimensions. As a first step, simplified CAD models of various waveguide components have been made and verified with 3D EM simulator (HFSS). This allows building the model of a whole mixer and evaluating its robustness with respect to parameter variations.

Additional effort went into the analysis of waveguides with tilted walls. The classical waveguides with vertical walls are difficult to fabricate with dimensions less than 100 micron. Many of the manufacturing technologies that are going to be tried will naturally result in a wall tilt of the waveguides up to 20 degrees from nominal. This effect was studied numerically by means of 3D EM simulations.

A new post-doc, Dr P. Mena, who did his PhD at the University of Groningen, is hired 50% for the 2SB work at SRON and starts from the middle of Aug 2004.

W.P 2.3.1. Phonon cooled HEB mixers

To meet the requirements of heterodyne instrumentation for ground- (South Pole) and space-based radiation detection at frequencies above 1 THz, we develop hot electron bolometer (HEB) mixers. The HEB mixers are equipped with a twin slot antenna and have a small bridge size; the first is for the requirement of polarization and beam pattern and the second is to keep the required LO power low. We designed twin slot antennas at central frequencies of 1.6 and 1.8 THz, using the following geometry: $L=0.3\lambda_0$, $S=0.17\lambda_0$, $W=0.07L$, where L , S , W , and λ_0 are the slot length, the separation between two slots, the width of a slot, and the wavelength, respectively. This antenna design allows easy impedance matching to a HEB and provides a symmetric beam.

At TU Delft

Two new batches were produced. The size of the (DC and RF) characterized HEB mixers range from $2 \times 0.2 \mu\text{m}^2$ to $1 \times 0.1 \mu\text{m}^2$. The smallest HEB mixers of $0.5 \times 0.1 \mu\text{m}^2$ have not been evaluated in a RF setup yet. The DC characteristics of the devices indicate a very high production yield. Measurements are supported by models of a HEB mixer in which we calculate the (un)-pumped current-voltage characteristics, including the electron temperature profile inside the bridge. The new approach in this modeling is the introduction of a local resistivity, which depends on the temperature, and to introduce a boundary condition for solving heat balance equations with a realistic interface transparency. At present, the measured (pumped) IV curves still show differences from the calculated ones in the low bias range, which require further work.

At SRON

The sensitivity of HEB mixers with a size of $1 \times 0.1 \mu\text{m}^2$ was evaluated at 1.6 and 1.9 THz; for several (7) devices noise temperatures ranged from 910 K to 1030 K, showing the best performance of such type of HEB mixers (small size) in combination with a high reproducibility. The required LO power is, following the isothermal technique, as low as 30 nW. The actual LO power at the mixer lens (in front of the lens) is, of course, higher and is about 170 nW. This power need is lower than the output power of recently developed solid state LO source by JPL (US) for HIFI-Herschel, thus allowing for space applications of these particular HEB mixers.

A new post-doc, Dr Yang, who did his PhD at Leiden University in the Netherlands, is hired for HEB work at SRON and started in June 2004.

W.P 2.4.2. Detectors for bolometer array

In this work package we will develop superconducting Kinetic Inductance Detectors (KIDs), which have, potentially, a high sensitivity and offer the possibility to produce large-format arrays. We have identified to start with superconducting Ta (4 K) or Nb (9K), in contrast to Al (1 K) used in California Institute of Technology (US). We will start with a Coplanar Waveguide Transmission (CPW) resonator because of its simplicity and the possibility to produce high-Q (up to 10^6) resonators.

At TU Delft

A test setup for KID evaluation is being developed. This includes wiring of a ^3He cooler (a test cryostat allowing low temperatures down to 300 mK) allowing to feed DC and microwave signals to a detector. Further, we bought a network analyzer for the frequency range 0 - 20 GHz. The first Nb KID structure, and the measurement of their Q-factor, is expected soon.

At SRON

For first tests in which we plan to detect short wavelength photons, a planar antenna is not optimal. Instead, we consider the absorption of a superconducting absorber; our calculations show that a satisfactory high absorption efficiency can be achieved with

(multilayer) anti-reflection coatings. This opens a route towards short-wavelength (single) photon detection using a KID in combination with a superconducting absorber structure. Dr Jochem Baselmans will move from SRON-Groningen to SRON-Utrecht in October of this year to start the experimental work.

A new PhD student, R. Barends, has been selected to take part in WP 2.3.1 and 2.4.2 at Delft (starting 15/11/2004).

Publications:

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- M. Hajenius, J.J.A. Baselmans, J.R. Gao, T.M. Klapwijk, P.A.J. de Korte, B. Voronov, and G. Gol'tsman "Low noise NbN superconducting hot electron bolometer mixers at 1.9 and 2.5 THz", *Supercond. Sci. Technol.* 17 (2004) S224–S228.
- M. Hajenius, J.J.A. Baselmans, J.R. Gao, T.M. Klapwijk, P.A.J. de Korte, B. Voronov and G. Gol'tsman, "Increased bandwidth of NbN phonon cooled hot electron bolometer mixers", *Proc. of Fifteenth International Symposium on Space Terahertz Technology*, Northampton, Massachusetts, USA, April, 2004. (in press)
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- J.R. Gao, M. Hajenius, J.J.A. Baselmans, T.M. Klapwijk, P.A.J. de Korte, B. Voronov and G. Gol'tsman, NbN Hot Electron Bolometer Mixers with Superior Performance for Space Applications, in *Proceedings of International Workshop on Low Temperature Electronics - WOLTE 6 on 23-25 June 2004*, Noordwijk, The Netherlands, page 11 (invited paper)
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- Jochem Baselmans, MerlijnHajenius, Jianrong Gao, Piet de Korte, Teun Klapwijk, Boris Voronov, and Gregory Gol'tsman, "Doubling of sensitivity and bandwidth in phonon cooled hot electron bolometer mixers", SPIE Astronomical Telescopes and Instrumentation , 21–25 June 2004, Glasgow, Scotland United Kingdom.