A Dual-Frequency Mixer Array for CHAMP+

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ABSTRACT

We present the design, construction and prototype measurements of two seven-mixer arrays for the new CHAMP+ instrument, which is being built by MPIfR-Bonn.

CHAMP+ is a dual-frequency multipixel heterodyne receiver to be mounted on the APEX telescope (Atacama Pathfinder Experiment) recently installed at 5000 meters altitude in the Atacama Desert in northern Chile. The two observing bands are centred at 650 GHz and 860 GHz, and the arrays will consist of seven pixels each, in a hexagonal configuration. The mixer arrays are developed at NOVA/SRON in close collaboration with MPIfR.

Because of the required small spacing between the pixels, a very tight and compact design was called for, which could lead to undesired consequences in the form of cross-talk between the Josephson-suppression magnets and deflux heaters of neighbouring mixers. Another requirement was that the mixers should be individually replaceable without disassembling large parts of the instrument. For these reasons, a two-mixer prototype was built and tested, with very promising results. Subsequently, the design of the full seven-pixel arrays commenced, and production is underway at the moment of writing.

Apart from being a contribution to a valuable instrument in its own right, the production of a series of matched mixers can also be seen as a pilot project for the future series production of large numbers of mixers for the ALMA project.

THE TELESCOPE

The APEX (Atacama Pathfinder Experiment) telescope is a modified ALMA antenna, produced by Vertex Antennentechnik. Main differences with the ALMA antennas are the addition of two observing cabins at the Nasmyth foci and an improved surface accuracy.

Some specifications:

Diameter	12 m
f/D	8
Surface accuracy	18 microns
Pointing accuracy	2 arcseconds
Total mass	125 tons

THE CHAMP+ INSTRUMENT

The CHAMP+ receiver (Fig. 1) is a dual band heterodyne array, to be mounted in one of the Nasmyth foci of the telescope. It consists of two times seven mixers, each cluster in a hexagonal layout. By orienting the mixer array (by way of the telescope's K-mirror) at a certain angle with respect to the scan direction, seven equidistant traces can be mapped on the fly.

These are the ranges for the two observing bands:

Low band	600-710 GHz
High band	790-950 GHz

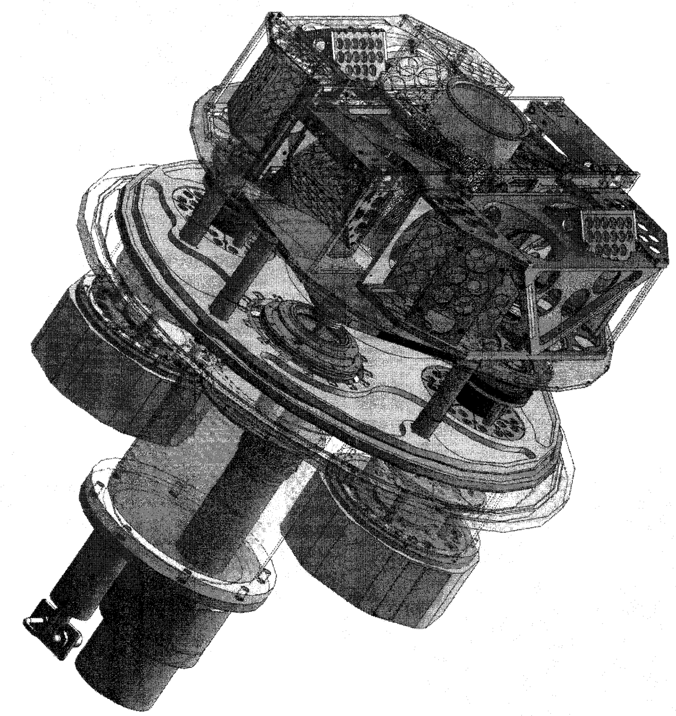

Fig. 1 The CHAMP+ instrument

Note that these bands correspond approximately with ALMA bands 9 and 10, respectively. The IF band of the system ranges from 4 to 8 GHz.

In the instrument, as shown in Fig. 2, the telescope beam is distributed over the two mixer arrays by a cross grid, implying that the two frequency bands have orthogonal polarizations on the sky. After the cross grid, each channel passes a Martin-Puplett SSB filter and a diplexer for LO injection. Before the diplexer, the LO beam is split into seven sub-beams be a holographic diffraction grating.

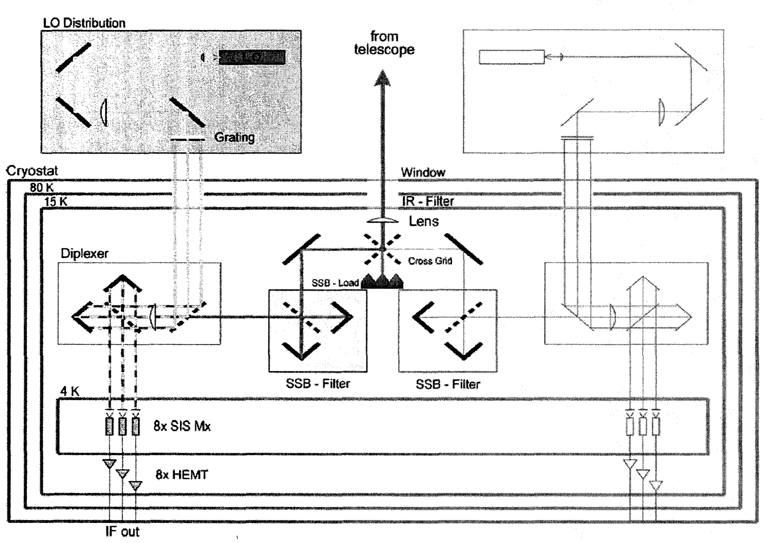

Fig. 2 CHAMP+ system design

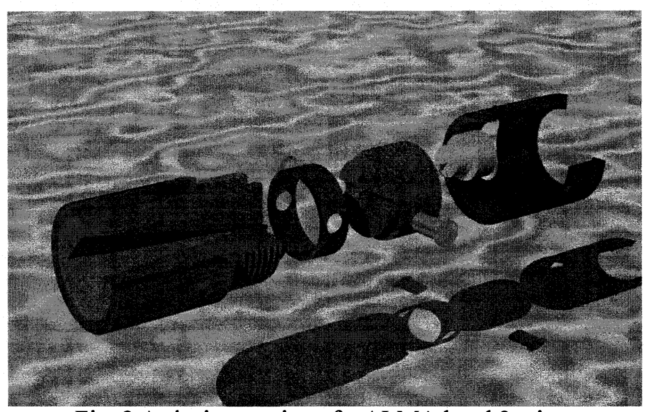

Fig. 3 Artist impression of a ALMA band 9 mixer

The following are the goals for the mixer noise temperatures:

Low band	150 K (80% of the band)	200 K (full band)
High band	300 K (80% of the band)	400 K (full band)

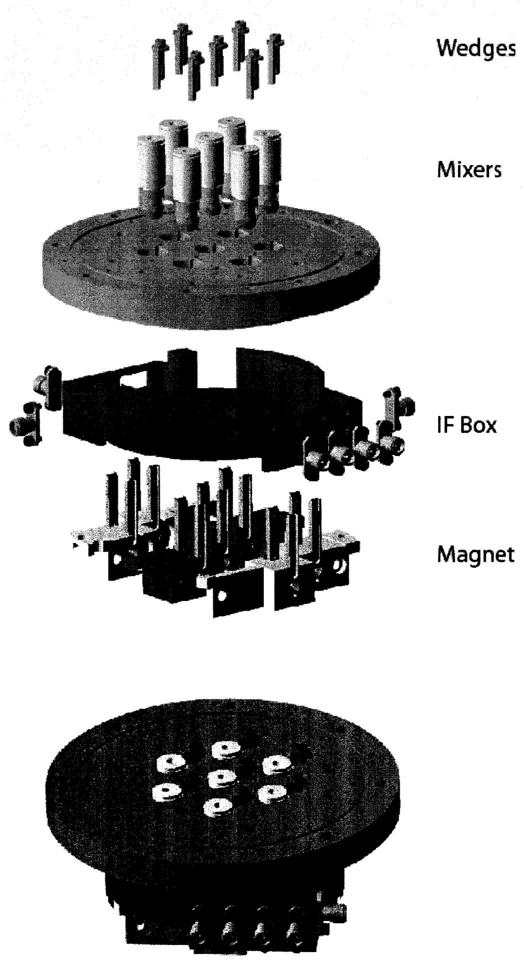

Fig. 4 Design concept of the CHAMP+ low band mixer array

THE CONCEPT: A CLUSTER OF 7 MIXERS

The CHAMP mixer arrays consist of modified ALMA band 9 mixers, as developed by NOVA/SRON. For the low band, only the horn and the outer envelope of the mixers are slightly different from the ALMA mixers. The concept is shown in Fig. 3. The mixer consists of two main parts: a corrugated feedhorn and a backpiece with a backshort cavity and the SIS device. Also in the backpiece are a miniature coaxial IF connector, a deflux heater and two magnetic poleshoes. The backpiece and the horn are aligned within a few microns with respect to each other by a centring ring. The angular alignment is provided by the poleshoes. A capnut holds the horn and the backpiece together.

In the case of the high band, the basic mixer design is the same, but the RF structures in the horn and backpiece are scaled appropriately and the ALMA SIS device is substituted by a HIFI band 3 device.

The design of the low-band mixer cluster is shown in Fig. 4. The high-band cluster will be slightly different because of the smaller spacing between the mixers. Within the array, the mixers have to be positioned with an accuracy of 20 microns with respect to each other, with a maximum angular alignment error of 0.045 degrees. Also, the mixers have to be individually replaceable without taking apart the rest of the instrument. To achieve these goals, the mixers are placed into a copper plate with accurately machined holes, honed to a diameter to fit the mixer horns closely. Each mixer is clamped into its hole by a wedge that is held in place by a screw. When the screw is loosened, the wedge is pulled out by a collar under the head of the screw, and the mixer can be extracted either by hand or by a tool fitting into a slot in the top of the horn. The longitudinal position of the mixers is determined by a stop plate below the mixer plate (not visible in the figure).

When the mixer is inserted, its IF connector blind-mates with a connector in the IF box by way of a so-called bullet or barrel. At the same time, a leaf spring contacts the deflux heater in the mixer backpiece. The magnetic field, required for suppressing the Josephson current in the mixer device, is generated by a superconducting coil below the IF box, and led upwards by two magnetic conductors. At the top of these are spring-loaded poleshoes that contact the poleshoes integrated into the mixer.

In the IF box there will be a PCB with the IF connectors mating to the mixers, micro striplines to guide the signals to SMA connectors on the sides of the IF box, and the posts with leaf-spring contacts for the heaters.

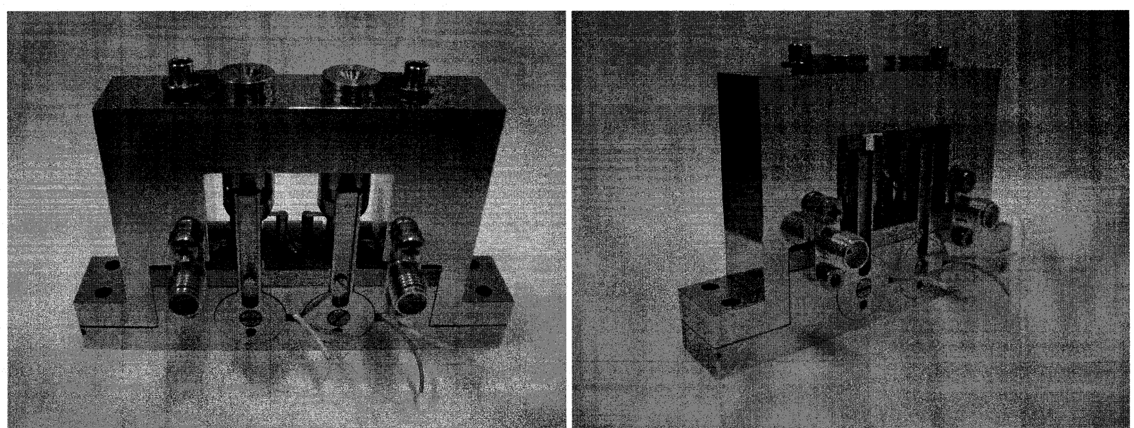

Fig. 5 Two-mixer prototype for testing the plug-in concept as well as investigating the thermal and magnetic cross-talks

THE PROTOTYPE

In order to test the plug-in concept, as well as to investigate the degree of magnetic and thermal cross-talk between the closely spaced mixers, a two-mixer prototype was constructed, as shown in Fig. 5. After several small but important modifications the mechanics of the plug-in concept turned out to work beautifully.

To test the thermal response time of a single mixer, the device was current-biased at a point halfway up the superconducting transition, after which a heat-pulse was applied by way of the deflux heater. Figure 6 shows the

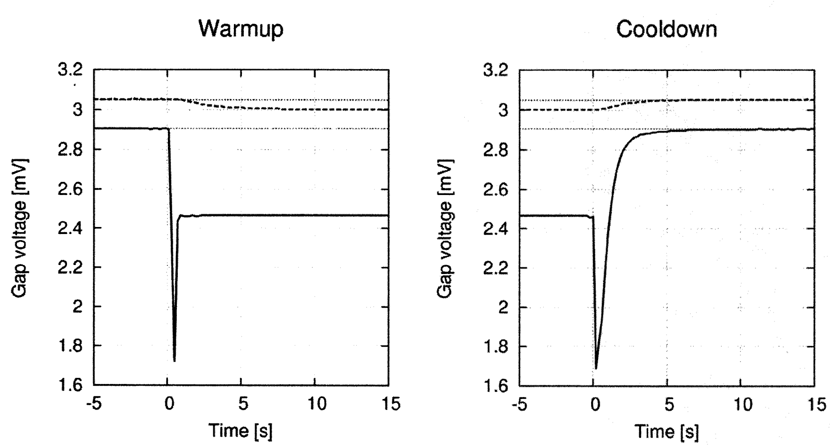

Fig. 6 Thermal relaxation and cross talk when heating mixer 1. Solid line: response of mixer 1; dashed line: response of mixer 2

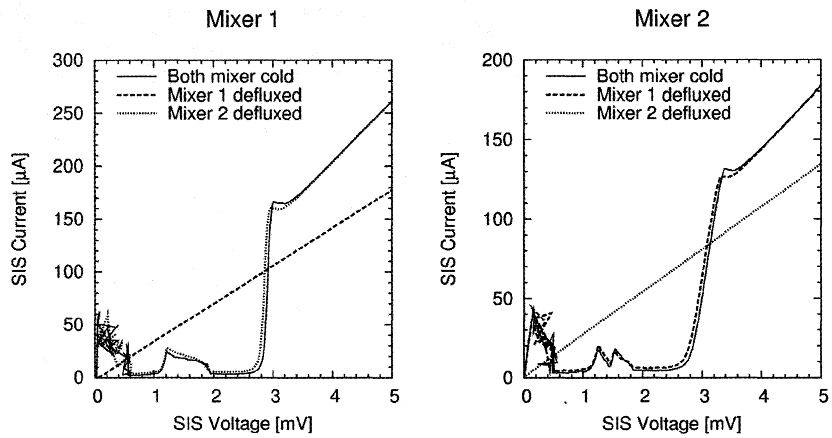

Fig. 7 I-V curves of the two mixers showing the thermal cross talk between them.

voltage over the device when at t=0 the heater current is switched on and off (left and right panel, respectively). The lower traces belong to the mixer that is being heated, the upper traces to the other mixer. Upon applying heat, first the voltage drops as the gap of the tunnel junction is suppressed, after which the voltage goes up again when the entire stripline structure of the device goes out of superconductivity. In the mixer that is not heated (upper trace), only the gap is slightly suppressed, but the entire structure remains superconducting. Also visible is that after removing the heat input, the mixer is fully recovered within, say, 10 seconds.

The full I-V curves of the mixers are shown in Fig. 7, each in the three situations: no mixers heated, mixer 1 heated and mixer 2 heated. Note that mixer 2 has a slight series resistance, which is not relevant for the present investigation. Also here is visible that the gap of the neighbouring mixer is suppressed by less than 0.1V.

Figure 8 shows the suppression of the critical current as function of the coil current. The first minimum is reached at about 10mA from the central maximum, the second minimum at about 18 mA. In the left panel, the current was swept from -40 mA to +40 mA, back to -40 mA, and forward to +40 mA once more. A clear hysteresis of about 7 mA is observed, due to the remanent field of the Vacoflux yoke material. The two forward curves almost exactly coincide. In practice, this hysteresis is usually not of great concern, since only small adjustments around the minimum are made. It is important, however, to set the field to the point of maximum critical current when defluxing the junction, to avoid freezing in extra field lines upon cooldown. Since the local flux at the junction is likely to change at this point (that is the primary goal of defluxing, after all), the operation should be repeated a few times, each time readjusting the coil current for maximum critical current.

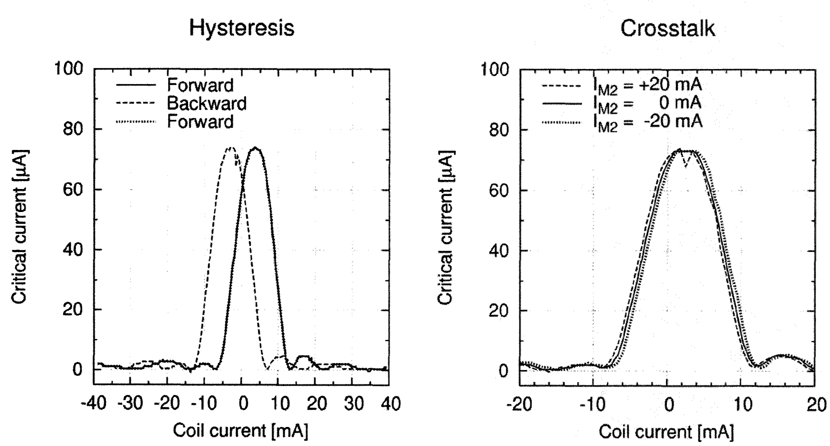

Fig. 8 Magnetic hysteresis of mixer 1 and cross-talk between mixer 1 and 2

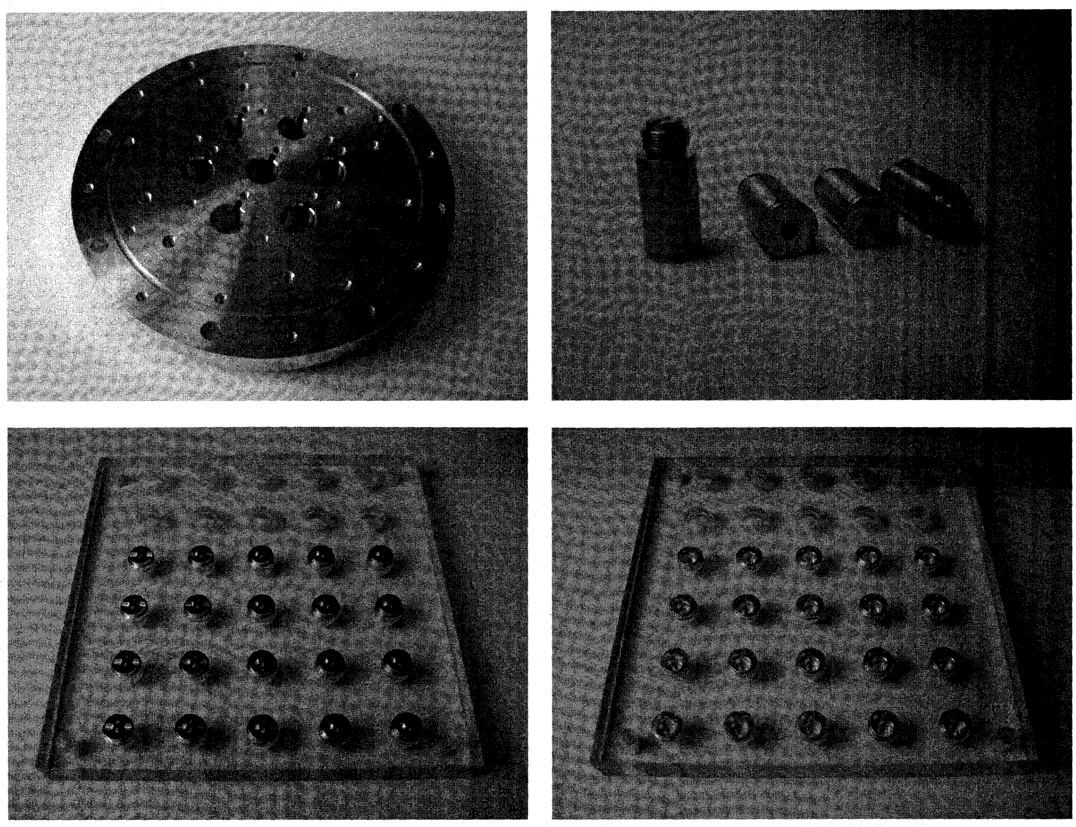

Fig. 9 Manufactured parts for the CHAMP+ low band array. Left to right, top to bottom: mixer clamp plate; corrugated horns; mixer back pieces front view and back view.

The right panel of Fig. 8 shows the effect on the suppression current of mixer 1 when the coil current of mixer 2 is changed from -20 mA to 0 mA to +20 mA. A crosstalk of about 10% is observed. Although this level of crosstalk is acceptable for operation, it probably will make it necessary to obtain optimal suppression in all seven mixers in an iterative way. In the final design we shall try to decrease the magnetic coupling, mainly by modifying the shape of the magnetic conductor components. For the high band, the coupling is likely to be much smaller, since in the high-band array, the coils are in line, contrary to the low-band array, where they are in parallel. When the coils are in line, there is much less opportunity for field lines to form closed loops through the neighbouring mixer.

THE METAL

Several actually manufactured components for the low-band mixer cluster are shown in Fig. 9. At the moment of writing more components are arriving, and assembly and testing are about to begin. The final design for the high band array is also nearing completion, and several components (backpieces and corrugated horns) arrived already.

CONCLUSIONS

A prototype two-mixer array was constructed to test the mechanics of the CHAMP+ plug-in concept and the degree of thermal and magnetic crosstalk between the mixers. Both goals were successfully met, and several design modifications were incorporated in the seven-mixer design as a result. The seven mixer cluster for the low band of the CHAMP+ instrument was designed and for the high band is being finalized. Components for both arrays are in the process of being manufactured.