KOSMA's 490/810 GHz Array Receiver

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ABSTRACT

We describe the frontend design of KOSMA's new multi frequency SIS array receiver, which is currently being built to be used at our submillimeter telescope. The receiver consists of two 2×4 mixer arrays. One array operates at a frequency of 490 GHz, the other one at 810 GHz. We can thus simultaneously observe eight spatial positions in two frequencies.

After passing through a K–mirror type image rotator, the two frequencies are separated by polarization and individually combined with their local oscillators (LOs), using Martin–Puplett diplexers. Splitting of the LOs is performed with a new type of phase grating, the collimating Fourier grating.

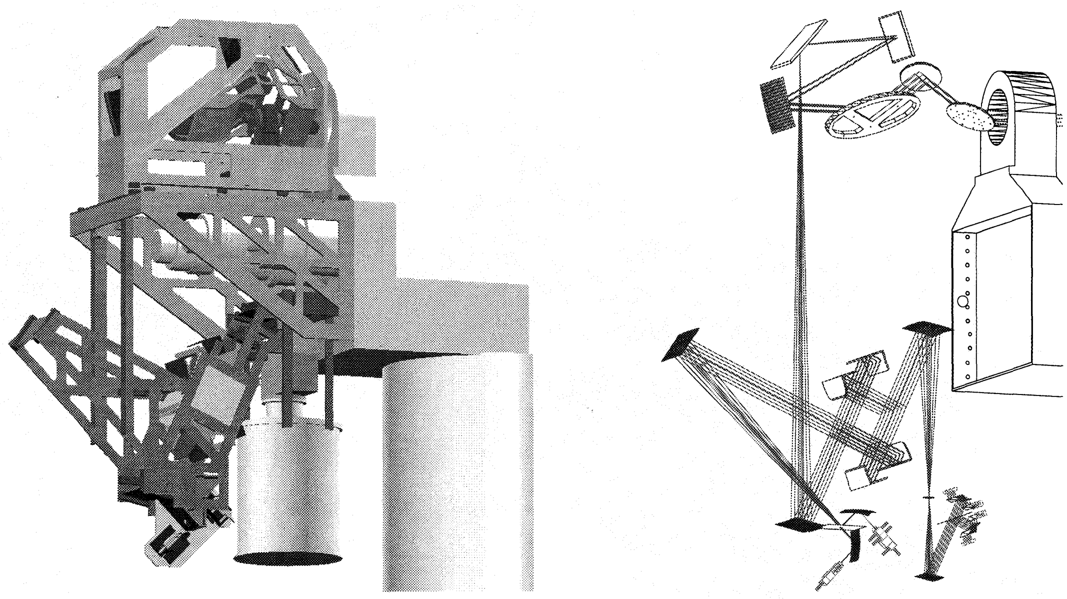
Because of space and weight restrictions at the 3m KOSMA telescope, most of the optics is outside the dewar. The dewar window is located at an image plane of the telescope pupil to reduce the window size. Inside the dewar the two polarizations are split and the individual beams are focused into the feed horns with a faceted mirror. The opto–mechanical design makes extensive use of our CNC machining capabilities. As far as possible we machine complete sub–units from monolithic blocks, in order to reduce the need for optical alignment.

We describe the optical design of the instrument and present the first test results obtained in early 2001.

GENERAL FEATURES

The receiver will be installed at the KOSMA 3m telescope[1] at Gornergrat near Zermatt/Switzerland later this year. It will be capable of observing two frequency bands simultaneously extending from approximately 450 to 500 GHz and from 800 to 880 GHz, respectively. The two frequencies are split by polarization.

Each frequency is equipped with a 2×4 pixel array of waveguide SIS mixers. The two subarrays are superimposed on the sky with a spacing between the array pixels of 100″, which corresponds to twice the FWHM of a single beam at 490 GHz. We use a K–mirror type image rotator to compensate for the image rotation introduced when tracking an astronomical source with an Alt–Az–mounted telescope.



(a) Receiver geometry

(b) Beam path

Figure 1. Drawings of the receiver layout and the beam path as it will be mounted at the telescope.

The detectors are fixed tuned SIS waveguide mixers.[2] The IF signals are analyzed with four 4–channel array–acousto–optical spectrometers.[3] In order to speed up the tuning cycle of the instrument, we implemented a computer controlled automatic mixer tuning algorithm, which sets the mixer bias voltages and the magnet currents to suppress the Josephson effect. The software also advises the observer to increase or decrease the local oscillator (LO) power level for optimum mixer performance.

Since the telescope and the observatory are relatively small, we had to make an effort to keep the instrument as compact as possible. We therefore placed most of the optics elements at ambient temperature to reduce the dewar size, although this will increase the receiver noise temperature to some extent.

The two frequencies each use one LO chain which is multiplexed between the 8 mixers using a new variant of the recently developed Fourier grating[4,5], a reflective phase grating.

The optical alignment of the instrument is simplified by the usage of pre-aligned optical building blocks, which are quasi–monolithically machined on a CNC milling machine.

We use a closed cycle Gifford–McMahon refrigerator* to cool the detectors to approximately 4 K.

Fig. 1 shows the receiver mounted to the telescope. In order to keep a compact arrangement, the receiver optics wraps around the telescope structure and the elevation drive motors sticking out of it. The instrument consists of three main parts: the image rotator unit, which is mounted above the triangular receiver mounting brackets, the main optics part, which contains the LO–unit and the diplexer unit, and the dewar.

OPTICAL LAYOUT

The instrument uses one of the Nasmyth ports of the KOSMA telescope (Fig. 1). The first optical element is the image rotator, which consists of three plane mirrors mounted in a K–arrangement on a rotating unit. The subsequent optics contains two Gaussian telescopes. The first Gaussian telescope reimages the focal plane to the center of the diplexer unit. Within the diplexer unit, the signal is split by a polarizer grid to distribute the two input frequencies to two independent Martin–Puplett interferometric diplexers. The same polarizer grid is used to couple the LO signals into the diplexers. The output ports of the diplexers are combined again using a second polarizer grid.

The second Gaussian telescope reimages the diplexer waists to the mixer units inside the dewar. The dewar window is located between the two mirrors forming this Gaussian telescope. To minimize the window size, we put it at an image of the telescope aperture, where the beam cross section is minimal.

The space underneath the diplexer unit is taken up by the LO–unit, creating and distributing the LO signals. This unit is described in detail in the paper by Heyminck and Graf.[5]

The mixer units inside the dewar collimate and combine the beams of the individual mixers before injecting them into the common optics. In contrast to other array receiver designs[6,7,8], we avoided lenses and use only reflective optics in the design of the mixer units.

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*Sumitomo, SRDK–415

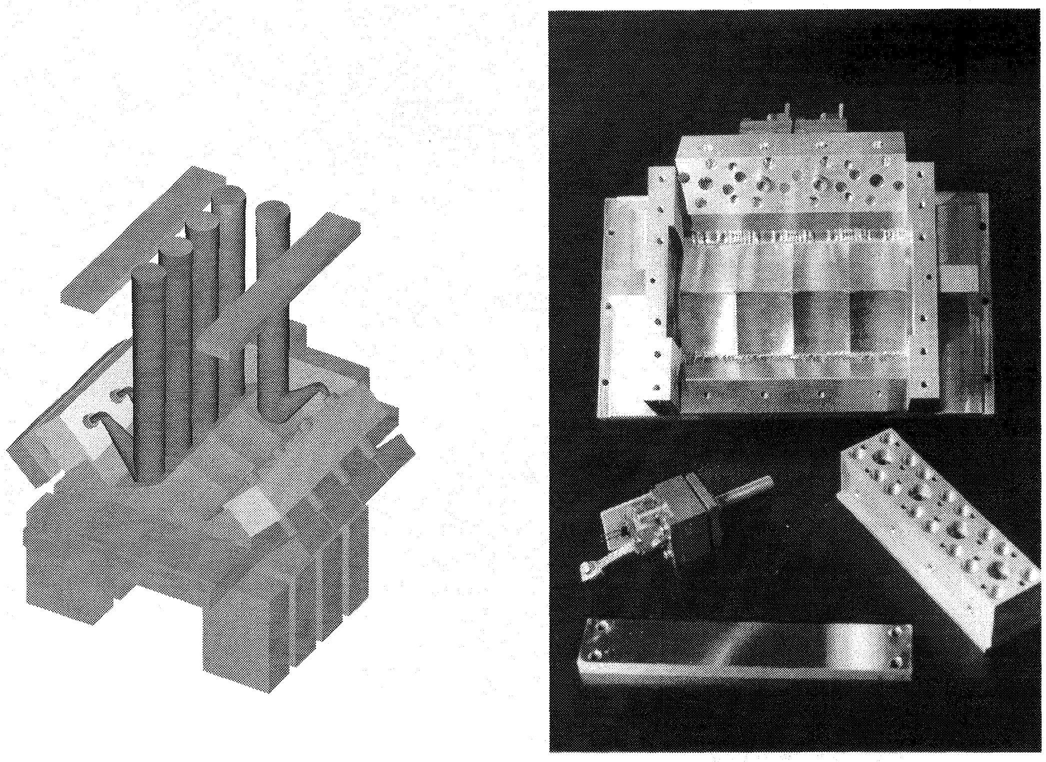
(a) (b)

Figure 2. Drawing (a) and photograph (b) of the 490 GHz mixer unit. The beam from the mixer feed horn is reflected by a plane mirror onto one of eight paraboloidal mirror facets, which collimates the beam for injection into the array optics.

MIXER UNIT

The relative spacing of the array pixels on the sky is determined by the ratio of the beam spacing to the beam waist at the point where the beams enter the common receiver optics. In order to reduce the beam spacing on the sky it is therefore necessary to increase the individual beam waists before injecting them into a common optics. This is most easily done with a collimating optical element directly in front of each mixer. Fig. 2 shows the arrangement we have chosen, to achieve the collimation with purely reflective optics.

The divergent beam from the mixer feed horn is reflected back by a plane mirror (lifted up in Fig. 2(a) to expose the underlying features) onto a paraboloidal collimating mirror. 8 paraboloids for the 8 mixers are combined to create a facetted mirror block. These mirror facets together with the mounting surfaces for the plane mirrors and for the blocks holding four mixers each, are machined in one machining cycle on a numerically controlled milling machine. This means that from the first to the last cut neither the workpiece nor the tool have been removed from the machine, making sure that all the machining is done in the same machine reference frame. Through this technique the accuracy of the finished workpiece does not depend on the skills of the machinist anymore, but exclusively on the positioning accuracy of the machine. The latter, we estimate is on the order of a few microns for the relative positioning of all the relevant surfaces of the block.

To avoid alignment errors introduced by the mounting of the mixers, we decided not to fix the mixer blocks in place, but rather to hold the feed horns in their exact positions. In this way we exclude alignment errors from the fact that feed horns may not always be perfectly aligned perpendicular to the mixer body. Accurate positioning of the feed horns is achieved by inserting them into tight fit reamed holes in CNC–precision machined blocks, which in turn are mounted to the CNC–machined mounting surfaces on the mixer units.

Fig. 2(b) shows a photograph of the finished parts of the mixer unit for 490 GHz, with two mixer blocks mounted and a third one ready to be mounted. Fig. 3 is a side view of the fully assembled unit, showing four mounted mixer blocks and the HEMT–amplifiers connected to them.

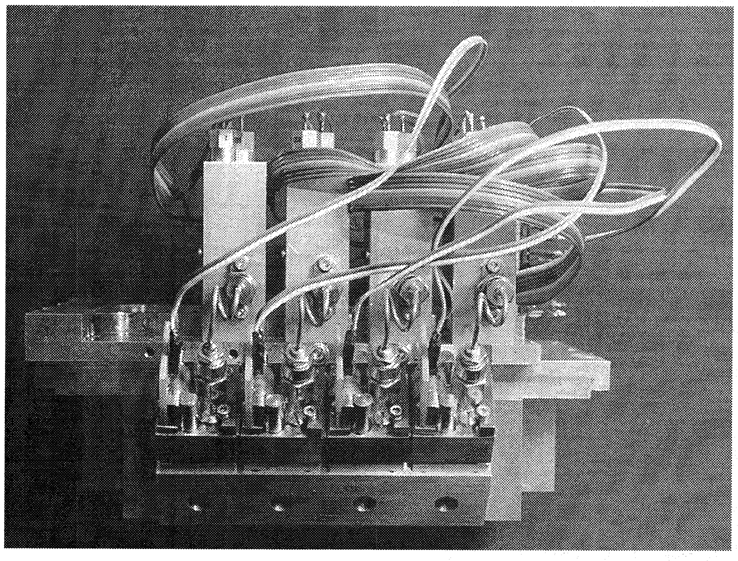

Figure 3. Side view of the assembled 490 GHz mixer unit showing four mixers and their HEMT amplifiers.

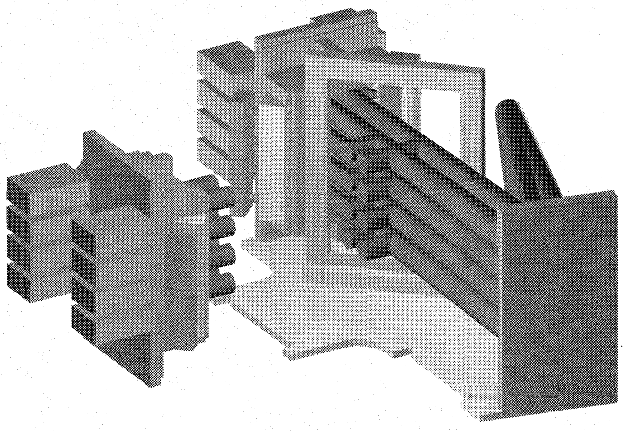

Figure 4. Drawing of the 4K assembly. Two mixer units, the polarizer grid and the first common mirror of the array optics are sandwiched between two identical, CNC–machined plates (top plate not shown here).

THE 4K ASSEMBLY

Two mixer units are mounted together with a polarizer grid and the first common mirror to form the 4K assembly of the receiver (Fig. 4). Again we simplified the alignment by precision machining all the components. The optical elements are sandwiched between two identical plates. The outer contour of these plates has been cut in one machining cycle on the CNC milling machine, thereby creating the mounting surfaces for all the optical elements and a number of stiffening plates with very high accuracy.

There are no adjustable parts in the 4K assembly. When all the pieces are bolted together, it forms a single optical element, which only has to be aligned to the rest of the receiver optics as a whole. In this way the 16 pixel array receiver does not require more optical adjustments than a single pixel receiver.

Mounted inside the dewar, the 4K assembly is hanging down from the dewar top plate by a number of epoxy straps. All the electrical feed throughs as well as the cold head flange are located in the top plate of the vacuum vessel. This design improves the serviceability of the system, since all the components can be accessed easily after removal of the dewar cylinder and the radiation shield.

The refrigerator cold head is connected to the mixer units with flexible copper straps to reduce the mechanical coupling and to provide a thermal low pass to dampen temperature fluctuations.

CLOSED CYCLE REFRIGERATOR

We use a Sumitomo SRDK 415 closed cycle refrigerator to cool the instrument to 4 K. The high cooling capacity of the refrigerator (approximately 1.5 W at 4 K) is very convenient. However, the cold head temperature fluctuates significantly. Fig. 5 shows the temperature fluctuations measured at different places during a 3 second time interval. Directly at the cold head, the peak to peak temperature change is almost 150 mK. This variation is dampened to some extent on the way to the mixer unit, where we measure a peak to peak variation of somewhat less than 20 mK. It is not clear, how much of this variation is seen by the SIS junction, because some of it may also be dampened by the thermal coupling to the mixer block. If further measurements indicate that the temperature change at the junctions is significant, we will either have to compensate it with a regulated heater or dampen it more by adding a passive volume of liquid helium.[9]

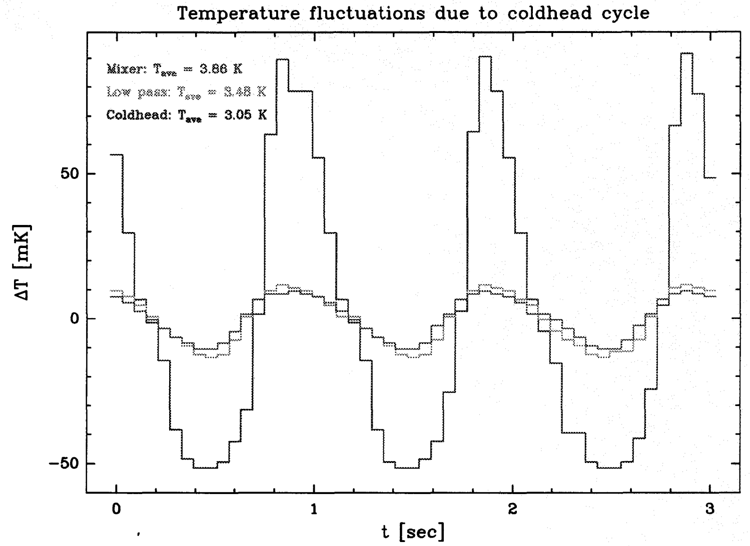

Figure 5. Temperature fluctuation measured at different places.

In addition to the temperature fluctuations, the cold head introduces vibrations to the system. Measurements with an accelerometer indicate that at some places in the receiver these vibrations reach an amplitude of several tens of microns. We are currently developing a vibration damping system to reduce these oscillations.

FIRST RESULTS

Shortly before the Symposium, we obtained our first results with a preliminary setup of only two active mixers inside the dewar. The main purpose of these measurement was to find out whether the optical concept of the receiver is reasonable. We used a chopped cold load mounted on an XY–translation stage to scan the intensity distribution in the receiver beams near the location of the telescope focus. Fig. 6 shows the beam maps measured.

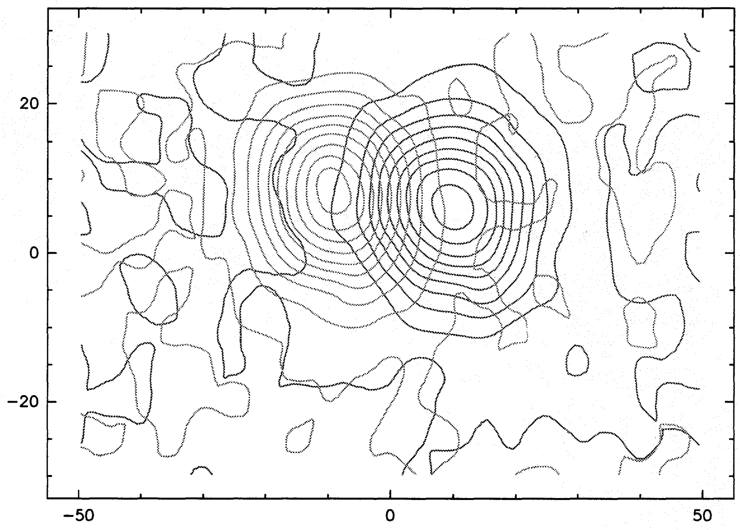

Figure 6. Beam map measured simultaneously with two mixers at 490 GHz.

Both beams are round and have the same size, which coincides with their nominal size to within 5%. Also the spacing between the two beams agrees well with the design value. Although this result is very preliminary, and more beam maps will have to be measured with a complete array, it indicates that the optical setup performs as designed.

Receiver noise temperatures have not been measured yet, because the polarizer grids required in the diplexer unit have not been delivered, due to a severe delay in the manufacturing. Thus, the measurements described above were made with Mylar beam splitters as substitutes for the polarizer grids in the Martin–Puplett diplexer, which results in a high loss in the diplexer and greatly increased receiver temperature.

CONCLUSION

We have built a dual–frequency 490/810 GHz, 16 pixel array receiver system, which is scheduled to be operational at the KOSMA telescope by fall 2001.

The frontend optics design of the receiver makes massive use of our CNC–machining capability. Wherever possible, we precision machine optics building blocks containing several optical elements in one prealigned unit. Through this technique we reduce the alignment effort for the array receiver to a level typical for a single pixel receiver.

We have obtained the first preliminary measurements of the receiver's antenna patterns, indicating that the optical setup works as designed. Further measurements will be made during the testing phase which has just started. Also, we will have to investigate the extent of instabilities introduced by the closed cycle refrigerator and possibly find ways to eliminate them.

ACKNOWLEDGMENTS

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