THE IRAM 230 GHz MULTIBEAM SIS RECEIVER

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Abstract:
We present the optical, electrical and cryogenic design of the SIS 230GHz heterodyne array receiver for the IRAM 30m telescope. This telescope receiver combination will offer unique possibilities for high resolution mapping at mm wavelengths. The design of the multibeam receiver includes compact low loss optics including a possibility for field derotation. The size of the dewar window and therefore the heat load on the closed cycle refrigerator can be kept small and independent of the number of mixer elements The receiver will use SIS mixers in waveguide technology including a waveguide LO coupling scheme. The SIS mixers will have single variable backshorts which allow for SSB tuning. We discuss theoretical and experimental results of the receiver optics, which characterise the image quality and coupling efficiency.

Introduction:
The interest in array receivers for mm-radio telescopes originates from the idea that such receivers should allow for an increase in mapping speed over single-beam receivers. As the noise temperatures of existing receivers have constantly decreased over the last years, more and more attention is drawn to the possibility of mapping with high efficiency even during suboptimal weather conditions where the system temperature may be more influenced by the sky emission. Array receivers are the obvious solution to this demand. The considerable effort in the development of such receivers should pay off with a clear improvement in mapping speed (factor 5-10).
Increased mapping speed is however not the only advantage of array receivers. Array receivers also allow for various self-calibration schemes, which can reduce sky noise and improve relative calibration. Furthermore, with chopping between different elements of the array a maximum point source sensitivity can be achieved.
In practice there are currently two possible ways to achieve a real improvement in mapping speed. On one side it is possible develop an array with a very large number of elements with simple electrical and mechanical construction but probably mediocre performance in terms of noise temperature and optical coupling. On the other hand one can think of a moderate sized array with an optimised element performance very close to that of a single or dual channel receiver.
For the IRAM 30m telescope a moderate sized high performance array is more attractive than a very large array with mediocre single element performance because the number of beams is

limited anyway by the Nasmyth apertures. Such a solution is also better adapted to the still very limited availability of suitable wideband backends. IRAM decided to develop a medium sized array receiver (with 9 then 18, with possible future extension to maximal 32 elements) with high efficiency single elements reaching the performance of state of the art single channel receivers and the following specifications:

- Close Spacing of Beams (2 FWHM)
- Possible Field Derotation
- $T_{DSB} < 50$ K
- RF Bandwidth 206-275 GHz
- IF Bandwidth 1 GHz
- SSB Operation Option.

Optics:

The optics of a suitable array receiver should have very low loss and allow for field derotation. The constraints to be considered in any design are given by the telescope apertures, the maximum heat load on the dewar, the tolerable aberrations and last but not least the very limited space in the receiver cabin.

We chose a combination of a modified Gaussian telescope and a truncated lens array (Fig. 1). The external warm part of the optics is purely reflective. A combination of two off axis elliptical mirrors forming the Gaussian telescope with a moderate demagnification factor of 1.4 turned out to be useful for several reasons.
The external ambient temperature mirror focuses the beams onto a relatively small dewar window (∅ 9 cm). The primary aperture field is reimaged as a topheat function onto the dewar window. Therefore all energy coming from the telescope passes through a well-defined diameter at the dewar entrance.
By placing the warm elliptical mirror as the top mirror in a K-mirror derotator combination the incidence angles (and therefore the aberrations) as well as the spatial dimensions of the K-mirror can be kept small.
The cold part of the optics consists of the second elliptical mirror and flat which folds the beams onto a crossed wire grid. This grid separates out the different polarisation of the beams, which are finally coupled over truncated lens arrays into the individual corrugated feed horns.
The performance of the optics was investigated with the software packages ASAP and ZEMAX. We used ZEMAX to minimise aberrations occurring from the combination of two off axis ellipsoids with varying relative orientation due to the derotator movement. The optimisation resulted in a configuration where the mirrors had unchanged effective focal lengths but considerably lower conical constants. In other words we could improve the imaging performance of the system for different K-mirror positions by making the mirrors more spherical.

The radiation field of a point source was calculated at the position of the horn aperture with ASAP. From there a coupling to the horn can be derived by means of overlap integrals. In this calculations we assumed a linear relation between the point source position and the position of the horn e.g. we assumed an undistorted field of view. Figure 2 shows the calculated coupling for different positions across a diagonal of the image plane. A good coupling can be achieved for a field of 4x4 beams. The decrease in coupling with increasing diagonal offsets is a combination of beam distortion and deviations from the assumption of undistorted field

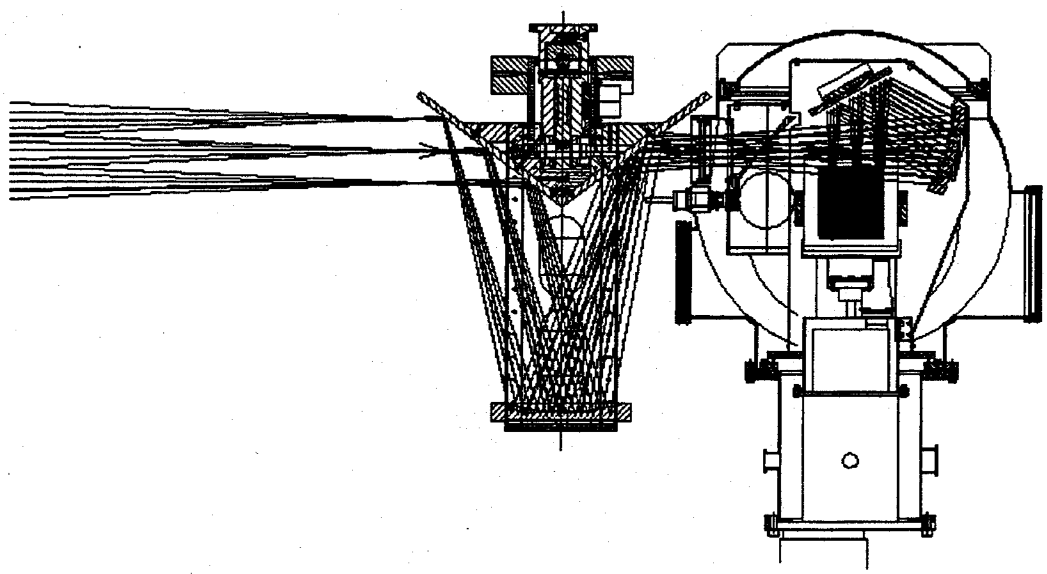

Fig. 1 : Layout of the 230 Hz SIS multibeam receiver. Although only nine beams are indicated the occupied field of view corresponds to a 4x4 field covered with beams separated by 2 FWHM . The horns of the mixers are orientated perpendicular to the plane of view.

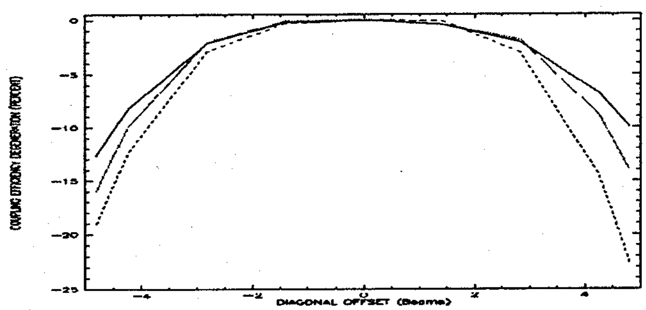

Fig 2.: Coupling efficiency across the field of view. The maximum coupling at the centre corresponds to the theoretical limit of 85 %.

To experimentally verify the optical layout all optical components including the cutted lens array and the aperture of the dewar window was mounted on a breadboard. The characteristics of the optics was measured by using the foreseen corrugated mixer horn as an emitter (200-260 GHz) while the resulting pattern was measured in a plane in front of the optics close to the location of the telescopes secondary focal plane.

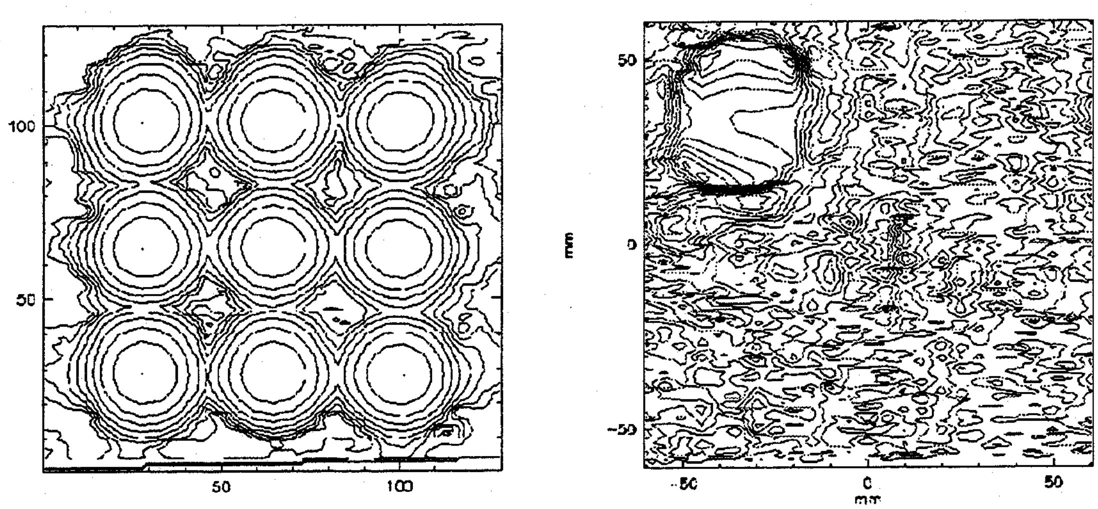

Fig 3. : Left: Measured amplitude pattern of the assembled receiver optics in 5 dB steps.
Right. : Measured phase pattern of a single beam, contours in 10 degrees steps.

The planar measurement was done with a waveguide probe mounted on a remote controlled XY table. Phase and amplitude were recorded with the set-up described in [1]. Fig 3 shows the amplitude pattern of the array. The beams are very clean and sidelobe levels are lower than 25 dB. The individual beams are arranged in a perfect 3x3 pattern with displacements smaller than 0.2mm corresponding to a deviation from the ideal pattern of less than 0.15 arcsec on the sky.

The correct position of the beams is however not the only necessary condition, a proper and common illumination of the subreflector by all pixels is equally important. To verify such an operation we performed a two-dimensional fit of a fundamental gaussian mode to the measured amplitude and phase distribution of each pixel (see Table 1). The maximum angular deviation of the beams is about 0.004 radians corresponding to a misalignment of about 8 cm at the 2 meter wide secondary. The results therefore show that all beams are illuminating the secondary mirror of the telescope equally well for a common focus.

As the derotator is very critical to align we developed a high precision mechanics which allows a compact motor drive under the rooftop mirrors of the K-mirror. By laser alignment we found that the beams move less than 0.5 mm in the focal plane which corresponds to a movement of 0.36" on the sky. Such a beam displacement is tolerable without changing the pointing model of the telescope.

Pixel	w0 [mm]	z0 [mm]	αx [rad]	αy [rad]	η
1	11.2	-16	0.001	0.002	0.99
2	10.9	-16	0.002	0.001	0.98
3	11.2	-12	-0.003	0.001	0.99
4	10.2	-37	0.001	-0.001	0.98
5	11.5	-36	0.001	-0.001	0.99
6	11.3	-80	0.002	-0.002	0.98
7	11.1	-60	0.0	0.0	0.98
8	11.2	-70	-0.001	0.001	0.99
9	11.1	-11	-0.002	0.0	0.98

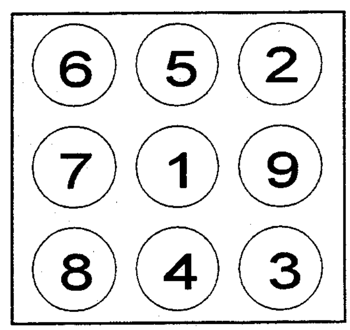

Table 1: Result of two-dimensional fits to nine pixels in the focal plane in front of the receiver optics. w0 designs the waist radius and z0 the position of the waist in direction of the beam propagation. αx and αy are the angle of the best fit gaussian beams in respect to the normal vector as defined by the measurement plane. Because η is not the final beam efficiency it should best be considered as a quality parameter of the fit.

LO Distribution :

The LO distribution is entirely made in WG technology which allows a very compact optical design. The LO power is generated separately for each polarisation of the array by a gunn-tripler combination. This power is then split up by an optimised 3 way power splitter

a) b)

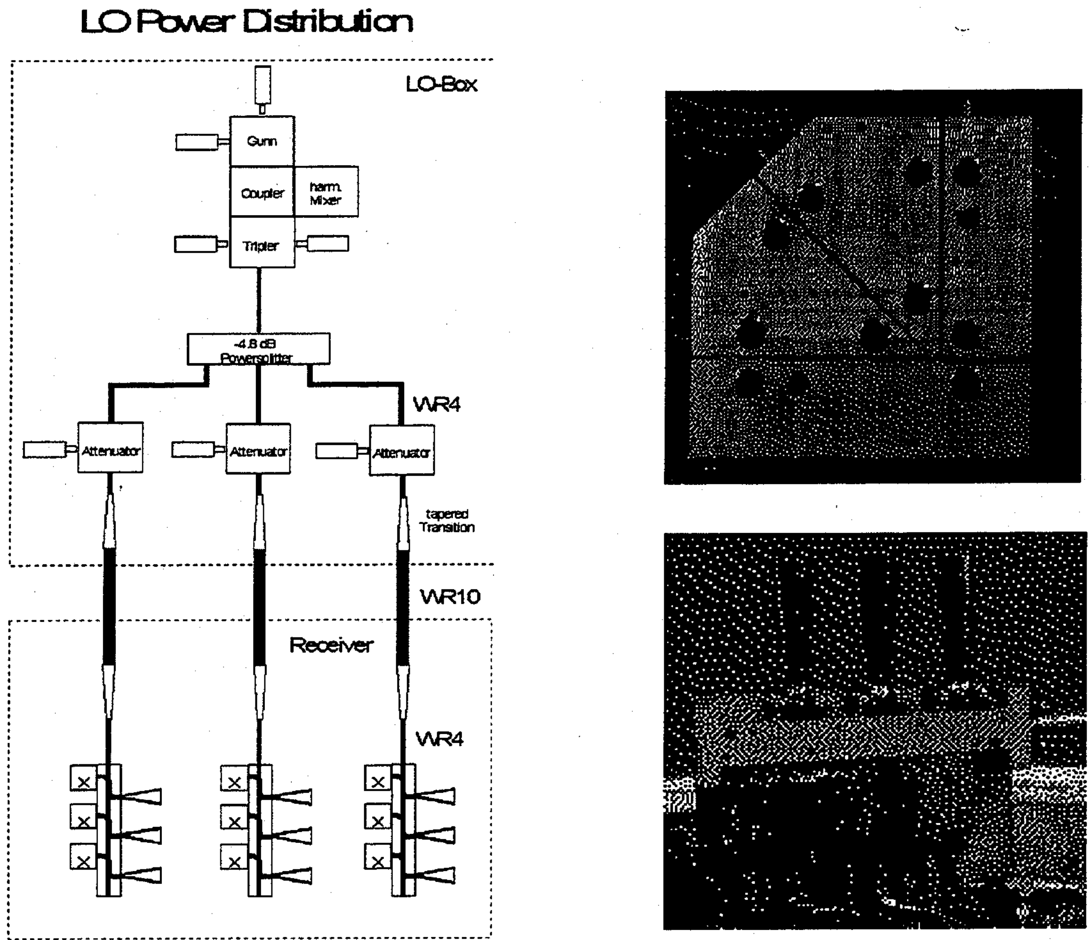

Fig. 3: a) LO power distribution scheme for one polarisation. Waveguide power splitter (upper photo) and triple mixer waveguide coupler unit (lower photo).

(see Fig. 3) followed by an attenuator in each branch. Three mixers are provided with LO power by a serial triple coupler built as a sidewall hole coupler (coupling 15 dB). This arrangement emerges from a compromise between available LO power and the necessary flexibility to adjust the LO power for different mixers of the array (see below). The connection between the external LO box and the couplers on the 4 K stage of the receiver is done by overmoded waveguides in order to reduce losses. First results of the triple mixer unit indicate a possible operation of the mixers within the defined specifications.

[1] M. Carter, S. Halleguen, B. Fouilleux , Proceedings of the 5th International Workshop on Terahertz Elektronics, Sep. 1997, Grenoble, France.