The APEX 345GHz/460GHz 7-pixel heterodyne array

S. Heyminck, R. Güsten, C. Kasemann, J. Stutzki, K. Jacobs, C.E. Honingh and U.U. Graf

Abstract—**Since August 2005 the Atacama Pathfinder EXperiment (APEX), a novel 12m submillimeter telescope is in science operation. As a powerful mapping tool for the 345 GHz and the 460 GHz atmospheric windows we launched the development of a dual-color 7-pixel heterodyne array receiver. The beam pattern is planed to be hexagonal while both colors will be observed simultaneously in orthogonal polarizations. We present the opto-mechanical layout including numerical optics simulations.**

Index heterodyne arrays, submillimeter wave receivers, submillimeter wave spectroscopy

I. Introduction

APEX[1] [1] offers outstanding observing conditions (see also Fig. 1) in the submillimeter wavelength regime (from 1mm to 200 μm). Currently, as first-generation instruments, a single-pixel 345 GHz facility receiver [2] and FLASH [3], a dual-channel 460 GHz/810 GHz MPIfR PI-instrument, are available for heterodyne observations.

To make best use of the telescope time for spectroscopic mapping projects heterodyne arrays are widely used (e.g., SMART [4], HERA [5] or CHAMP [6]). With the new CHAMP$^+$-array [7] a powerful heterodyne-mapper for the 660 GHz and the 810 GHz atmospheric windows will go into commissioning at APEX in August 2006, but still a comparable array for the 345 and the 460 GHz atmospheric windows is missing. In collaboration with the Universität zu Köln, providing the SIS-mixer units for both frequency bands we launched the development for such a "low-frequency" array in February this year. This paper briefly describes the design and the receiver layout including first simulations of the optical layout.

II. The Receiver

The new array will be located in the Nasmyth B-cabin (right cabin) of the telescope where also the CHAMP$^+$ array is mounted. This implies strong design boundaries due to the limited space available and also because parts of the existing CHAMP$^+$ optics haves to be shared.

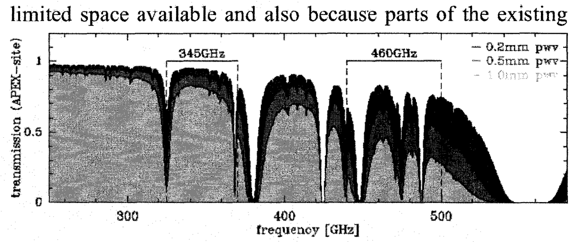

Fig. 1. The zenith transmission of the atmosphere above the APEX site for 1 mm, 0.5 mm and 0.2 mm precipitable water vapor (pwv) is shown. The baseline tuning ranges for both colors are also given in the plot.

The performance goal for each channel of an array receiver always should be to be as good as a single pixel receiver. This is primarily an optics concern since all other parts follow more or less the same design as for a single pixel receiver.

To improve sensitivities single-sideband (SSB) filters are foreseen for both sub-arrays. To avoid losses due to a coupling foil a Martin-Puplett interferometer as diplexer is chosen.

For the beam spacing we decided for 2 FWHM for both sub-arrays (see Fig. 2), which is a good compromise between the losses at the individual beam apertures, when separated before the mixer horn-antennas, and the filling factor of the field-of-view). A K-mirror design with a resulting image rotation-angle of more than 360° acts as image de-rotator for the array.

The high machining accuracy of modern CNC-milling machines allows designing the filter-unit including the SSB-

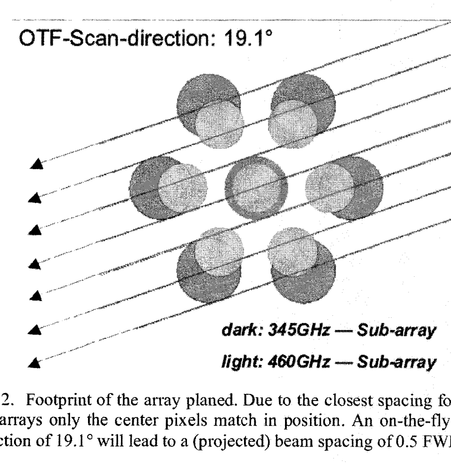

Fig. 2. Footprint of the array planed. Due to the closest spacing for both sub-arrays only the center pixels match in position. An on-the-fly scan-direction of 19.1° will lead to a (projected) beam spacing of 0.5 FWHM.

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[1] APEX is a collaboration between the Max-Planck-Institut für Radioastronomie, the European Southern Observatory, and the Onsala Space Observatory

filters, the diplexers, and the calibration unit as one monolithic block (without the need of adjustment possibilities).

III. Optics

For a dual-frequency receiver one of the prime optical requirements beside optimum performance, is to match both frequencies simultaneously to the telescope. Also the LO power must be supplied efficiently to the individual mixer. In the following the optics setup developed so far is explained. The overall layout is fixed, but optimizations are still ongoing.

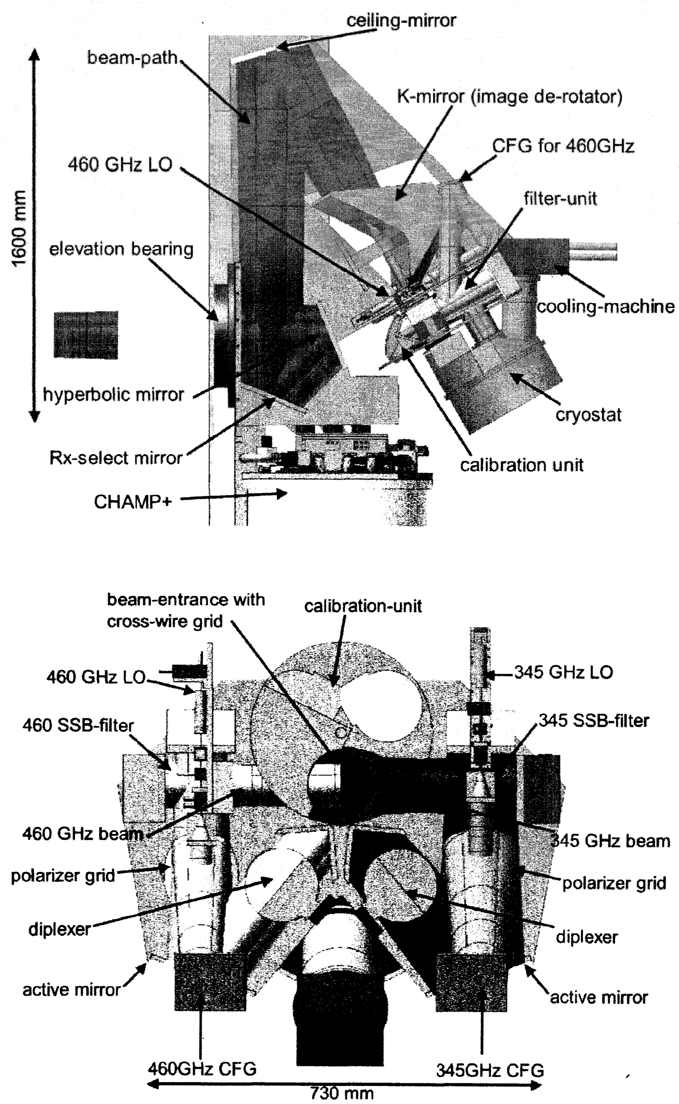

Fig. 3. Schematics of the array-receiver as planed so far. The upper figure shows the optics layout within the APEX Nasmyth-B cabin. The figure below visualizes the optics of the filter-unit.

A. Signal path

For frequency independent re-imaging of the telescope signal we use two Gaussian telescope setups [8]. The first of the two re-images the telescope signal trough the narrow elevation bearing of the telescope (this setup is also used by the CHAMP+-array and therefore a given design-constrain). The second one gains additional optical path-length to implement the image de-rotator, the SSB-filter and the diplexer. In addition, it collimates the signals and therefore decreases the size of the cryostat-window down to ≈100 mm.

The optics layout is explained in Fig. 3: seen from the telescope, the signal is re-directed towards the Nasmyth B-cabin by the first mirror of the first Gaussian telescope (not shown in the figure). This mirror is mounted on a movable arm inside the Cassegrain cabin, selecting between the two Nasmyth ports. The second mirror of the Gaussian telescope, a concave hyperbolic mirror is located inside the Nasmyth-B cabin and reflects the signal towards a flat mirror that selects between the two arrays in the cabin.

For the new array the signal is reflected upwards to the first mirror of the second Gaussian telescope, which is mounted directly under the cabin ceiling. The image de-rotator follows before the signal enters the filter-unit. Here it first passes the calibration unit, is then split by a cross-wire grid into two orthogonal polarizations. Beneath this grid the cryostat-window for the SSB-filter image side-band termination is located. The image side-band is terminated on an absorber-cone attached to the 4 K-stage.

Calibration will be performed with an internal calibration setup. For a cold load measurement the cross-wire grid is replaced by a flat mirror reflecting the image and the signal-band of one of the two sub-arrays into the cryostat onto the image side-band absorber. To calibrate both sub-arrays a second measurement reflecting this one onto the cold absorber must be taken. For measuring a hot-load an ambient temperature absorber will be placed into the beam-path.

After separating both colors the SSB-filters follow. The second mirror of the Gaussian-telescope is placed between the SSB-filter and the diplexer.

Now the signal enters the cryostat where all individual signals are re-imaged to match the mixer beam to the telescope.

Several numerical simulations of the optics have been done to predict the behavior especially of the off-center pixels. We inserted a Gaussian fundamental mode with the width expected by the horn antenna of the given frequency and then calculated the overlap-integral with the nominal Gaussian fundamental mode at the telescope focal plane. As a brief summary, for all calculations performed so far, the Gaussicity at the telescope focal plane is above 96% for all pixels under all conditions. As an example the resulting field-distribution (phase and amplitude) of the center-pixel of the 345GHz sub-array and the less efficiently coupling off-axis pixel for 90° elevation and no image-rotation are displayed in Fig. 4. The simulations show no strong elevation dependency of the optics setup (change in Gaussicity is in the order of 0.6%, see also Fig. 6).

B. LO-path

The LO-signal required for the heterodyne mixing process is provided by two commercial LO-chains. Collimating Fourier gratings (CFGs)[9][10] provide the signal splitting into the seven beams required. A CFG is a combination of a diffraction grating designed to match the required beam-pattern and a parabolic mirror to collimate the resulting diffraction orders. The CFG allows to match the LO directly to the signal path without additional optics. Fig. 5 shows the grating structure and the resulting diffraction pattern as a simulation. The usable bandwidth of the grating is about 15% (±7.5%).

IV. MIXERS

The Universität zu Köln develops the overall mixer design (junction, tuning structures and mixer block) and also fabricates the devices. The mixers will follow the standard DSB fixed backshort waveguide design of the KOSMA-group, like for example used for HIFI Band 2, scaled back to 345 GHz and 460 GHz. Integrated are also internal tuning structures and superconductive magnets to suppress the AC-Josephson effect. In Fig. 7 the CAD-model of such a standard mixer-block is shown.

The IF-band is specified to be 4-8 GHz while the goal for

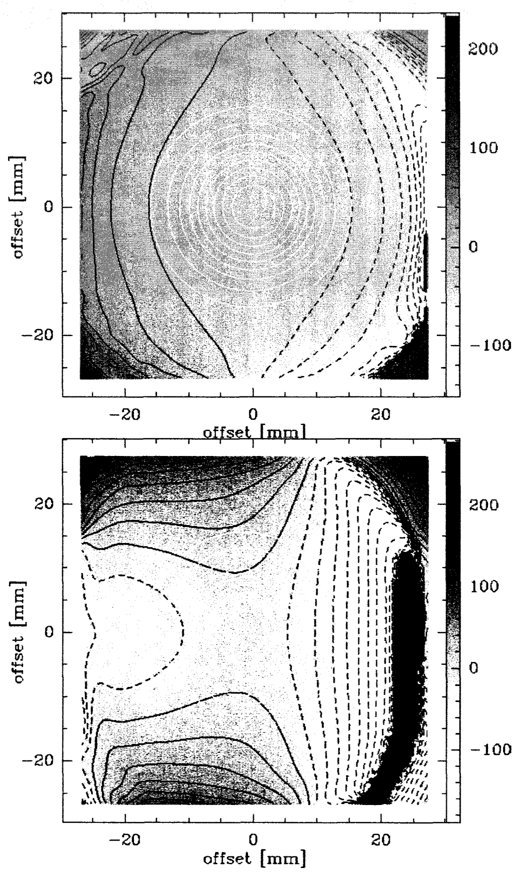

Fig. 4. Results of the optics simulations: the figures (upper figure for the center pixel at 345 GHz; lower figure for the less performing off-axis pixel of the same frequency) show the phase-distribution in grayscale, with black contours in steps of 15°. The white contours display the field-amplitude in steps of 10% of the maximum amplitude. The overlap-integral gives 99.8% Gaussicity for the center and 96.8% for the off-axis pixel.

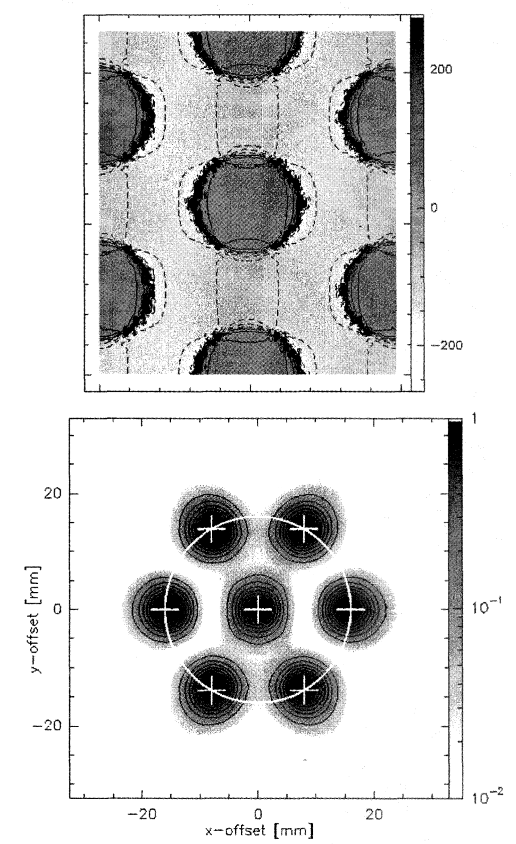

Fig. 5. Phase sensitive structure (left hand side) of the CFG for the LO-splitting. The contour-levels are in steps of 18°-phaseshift. The structure is stretched to have a side-ratio of √3 to achieve a round diffraction pattern. Below the simulated diffraction pattern is shown. White crosses mark the nominal positions of the individual mixers. The contour-levels are in steps of 10% of the maximum intensity. Approx.11% of the incident power is redirected into each of the 7 diffraction orders.

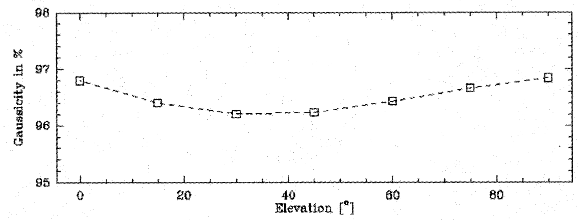

Fig. 6. Numerical simulation of the elevation dependency of one of the off-center beams at 345 GHz.

the mixer DSB noise-temperature (measured after the horn antenna) is ~40 K for the 345 GHz band and ~60 K for the 460 GHz band.

V. Electronics

The electronics can be split into two major parts: the mixer-electronics (bias, magnet current and heater) and the IF-processing.

For the bias-electronics we plan for a modular system. Each module contains the electronics for a single mixer and is controlled via computer. Stacking of several modules will easily be possible. All mixers can be set or read out nearly in parallel which makes effective auto-tuning of all mixers within the array possible for the future.

The IF-electronics can be split into two parts: First the HEMT amplifiers (developed in-house at MPIfR) sitting on the 4 K-stage followed by additional amplifiers directly after the vacuum feed through, and second the IF-processor with internal total power detectors and adjustable attenuators matching the signal to the backends. The IF-processor as well as the 32-channel MACS autocorrelator system as backend is part of the CHAMP$^+$ array, which has the capability to switch between two array receivers. The usable bandwidth is up to 2 GHz per pixel (using two 1 GHz correlator bands for each of the pixels) with a spectral resolution of 1 MHz. A high-resolution mode with a bandwidth of 2x 500 MHz and spectral resolution of 256 kHz is also available.

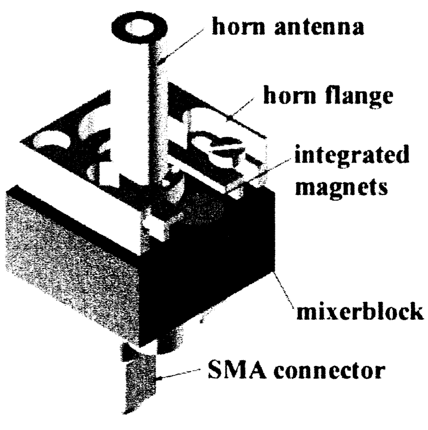

Fig. 7. CAD-drawing of the cologne standard waveguide mixer block.

TABLE I
TECHNICAL DATA OF BOTH SUB-ARRAYS.

Sub-array	ν = 345 GHz	ν = 460 GHz
Tuning range (baseline)	<325 – 370 GHz	440 – 500 GHz
IF-bandwidth	4 — 8 GHz	4 — 8 GHz
Half power beam width	17.3"	13.3"
Autocorrelator Backend		
normal resolution mode		
bandwidth	2 ×1 GHz	2 ×1 GHz
	2 ×870 km/s	2 ×650km/s
channel spacing	1 MHz	1MHz
	0.87 km/s	0.65km/s
high resolution mode		
bandwidth	2 ×500 MHz	2 ×500 MHz
	2 ×435 km/s	2 ×325km/s
channel spacing	256 kHz	256 kHz
	0.22 km/s	0.16km/s

VI. References

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