CONDOR - AN ASTRONOMICAL HETERODYNE RECEIVER AT 1.25 - 1.5 THZ

M.C. Wiedner[1], S. Bedorf[1], F. Bielau[1], M. Emprechtinger[1], U. Graf[1], C. E. Honingh[1], K. Jacobs[1], P. Muñoz[1], M. Olbrich[1], D. Paulußen[1], K. Rettenbacher[1], G. Schmidt[1], O. Siebertz[1], J. Stutzki[1], N. Volgenau[1]

[1] *Universität zu Köln, I. Physikalisches Institut, Zülpicher Str. 77, 50937 Köln, Germany*
wiedner, bedorf, bielau, emprecht, graf, honingh, jacobs, espacio, olbrich, paulussen, rettenba, gschmidt, siebertz, stutzki, volgenau@ph1.uni-koeln.de

ABSTRACT

The CO N^+ Deuterium Observations Receiver (CONDOR) is a modular heterodyne receiver for 1.25 to 1.5 THz frequencies. It will be used on the Atacama Pathfinder EXperiment (APEX), a 12 m telescope in Chile, and the Stratospheric Observatory For Infrared Astronomy (SOFIA), a 2.7 m telescope mounted in a high-altitude aircraft, as a low frequency extension of the German REceiver At THz frequencies (GREAT).

CONDOR is basically designed like a standard heterodyne receiver, but features customized optics, Local Oscillator (LO), mixer and cooling system. Because LO power is scarce at THz frequencies, a Martin-Puplett interferometer is used to overlay the sky and the LO signal efficiently (3% loss in our case). We have two alternative LOs: a Gunn oscillator followed by a multiplier chain produced by Radiometer Physics GmbH, and also a YIG followed by amplifiers and multipliers manufactured by Virginia Diodes. LO and sky signal are mixed by a phonon cooled Hot Electron Bolometer (HEB) mounted in a waveguide mixer block with a corrugated feed horn. HEBs are particularly sensitive to temperature variations and modulations of the LO power caused by mechanical vibrations and are hence usually cooled in a wet Dewar. We will use a standard wet Dewar on SOFIA, but we will use a Pulse Tube cooler at APEX, where liquid helium is not readily available. This decision was supported by previous tests with an 810GHz HEB and SIS mixer placed side-by-side in a closed-cycle cooling system. Both types of mixers have comparable spectral Allan variances of several 10s of seconds and detected astronomical objects. We have now built CONDOR and have recently conducted first tests in the laboratory in a wet Dewar, where we measured uncorrected receiver noise temperatures well below 200K over 800 MHz IF bandwidth. Allan variances using the Allan baseline variance method resulted in minimum times of 20 s. The test confirm that CONDOR is fit for astronomical observations.

To take advantage of the spectral lines that will be revealed by CONDOR, we are concentrating our efforts on three astronomically important areas of research. High rotational transitions of CO (at 1267 GHz, 1382 GHz and 1496 GHz) will reveal physical and kinematic conditions deep inside high mass star forming regions. The ground transition of H_2D^+ (1370 GHz) is observable with CONDOR; H_2D^+ is not only a key ion in the formation of deuterated molecules, but also the last kinematic tracer to freeze out in cold molecular clouds. The N^+ transition at 1461 GHz is the third strongest line COBE detected in our Galaxy. It traces the warm ionized medium, which is thought to be ionized by supernovae explosions. N^+ is particularly prominent in starburst galaxies.

1 INTRODUCTION

The CO N^+ Deuterium Observations Receiver (CONDOR) is a heterodyne receiver that operates at THz frequencies. Its primary goal is to observe star-forming regions in CO, N^+, and H_2D^+ emission. CONDOR is a modular receiver that we anticipate deploying at several telescopes, including the Atacama Path Finder EXperiment (APEX), a 12 m telescope in Chile, and the Stratospheric Observatory For Infrared Astronomy (SOFIA), a 2.7 m telescope mounted in a high-altitude aircraft.

To meet its scientific goals, CONDOR will cover a frequency range of 1250 to 1500 GHz. For Galactic observations, an intermediate frequency (IF) bandwidth of 0.8 GHz (170 km/s) will be sufficient; for extragalactic observations, we anticipate upgrading the IF to up to 4 GHz. The greatest technical challenges are achieving a low receiver temperature and maintaining good system stability. It is particularly important to meet these challenges for ground-based observations, as both poor atmospheric transmission (see Fig. 1) and imperfections in the dish surface lead to high system temperatures.

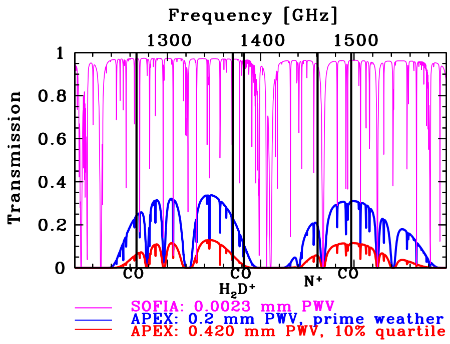

Figure 1: Earth atmospheric transmission at APEX and from SOFIA

2 DESIGN

The design follows that of a standard heterodyne receiver (see Fig. 2). The sky and local oscillator (LO) signals are combined and directed to the mixer, where the difference between the signals is produced. The IF signal is subsequently amplified and sent to the telescope's spectrometer.

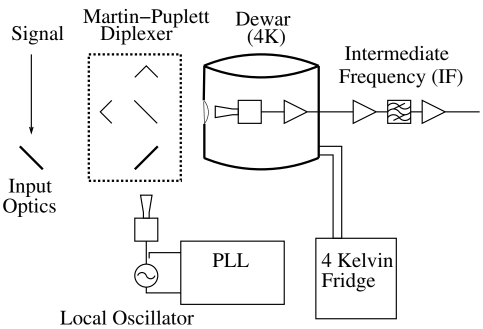

Figure 2: Schematic of CONDOR

2.1 Optics

Fig. 3 shows the optics for APEX. The design was driven by the desire to keep the number of mirrors to a minimum. However, a Martin-Puplett interferometer is required to efficiently overlay the LO and sky signals (3% loss in our case). The mirrors are mounted on an optical table that can be transported to the telescope as one unit. The first two mirrors will be aligned to the telescope beam using a laser, then fine-tuned at THz frequencies.

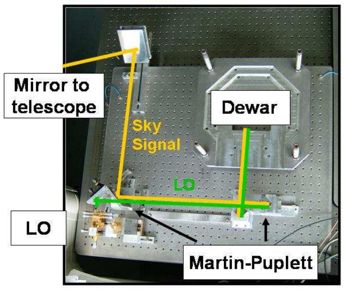

Figure 3: CONDOR optics for APEX

2.2 Local Oscillator

Powerful, stable monochromatic oscillators are rare at THz frequencies. We obtained a Gunn oscillator followed by a tripler and a quadrupler from Radiometer Physics GmbH, which has a power output of ~1 μW over the 1250 - 1500 GHz range. Because of the good coupling with the Martin-Puplett, this power is sufficient to pump the mixer. The Gunn was locked with a 60 dB carrier-to-noise (c/n) ratio, which is calculated to give a 19 dB c/n ratio of the LO at 1 MHz bandwidth. This ratio is sufficient for astronomical observations.

2.3 Cryostat

The mixer and the first amplifier of CONDOR need to be cooled to about 4 K. For APEX, where liquid helium is not readily available, a closed-cycle system with a pulse tube cooler is used. Fig. 4 shows a the cold plate of the cryostat built for APEX. On board SOFIA, the components are cooled in a wet helium Dewar.

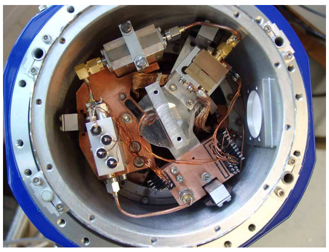

Figure 4: Cold Plate of cryostat for APEX. The window is on the right, the focusing mirror in the center and the mixer at 1 o'clock. The IF signal passes from the mixer to an isolator (top), is amplified by a HEMT (left) and passes a heat sink (bottom) before leaving the cryostat.

2.4 Mixer

CONDOR employs phonon-cooled Hot Electron Bolometers (HEBs) fabricated in-house. The NbTiN devices are mounted on 2 μm thin $Si_3N{-}4$ membranes suspended across a waveguide in the mixer block. For optimal coupling a corrugated horn was aligned with the mixer block to an accuracy of 3 mem. The mixer is placed on a sledge in order to position it accurately with respect to the mirror. The mixer is biased with a constant voltage produced by I-V electronics. These electronics also allow us to take I-V sweeps either manually or by computer.

2.5 Intermediate Frequency

Currently, CONDOR has an IF of 1 - 1.8 GHz (170 km/s at 1400 GHz), which is sufficient for Galactic observations. In order to match the backend spectrometers of APEX and SOFIA, the IF is upconverted to 5 - 5.8 GHz. A wider IF of up to 4 GHz is anticipated with the new generation of HEBs.

3 FIRST RESULTS

In the summer of 2005, tests of CONDOR and in particular of the HEB were performed in collaboration with the mixer group in a helium Dewar. Internationally competitive receiver temperatures with a minimum of ∼1500 K were obtained (see Fig. 5). These noise temperatures have been measured without chopping and have not been corected for optical coupling loss, direct detection effects etc., but are representative numbers for the receiver on the telescope. The receiver temperatures increase above 1.8 GHz due

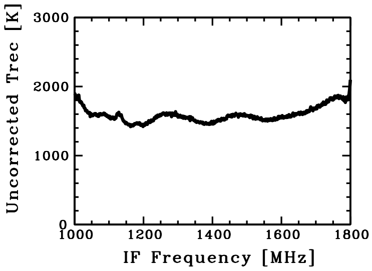

Figure 5: Receiver noise temperature measured with an AOS

to the currently used isolator cutting off at that frequency. Stability measurements suggest a minimum in the spectral Allan variance around 20 sec for the entire system using a reception bandwidth of 2.3 MHz (see Fig. 6). These Allan variances were measured using the Allan variance baseline method (Ossenkopf 2003) and are a measure for the stability when doing spectral line observations. Although further efforts will be made to improve the receiver temperature and stability the current system fulfills the requirements for astronomical observations.

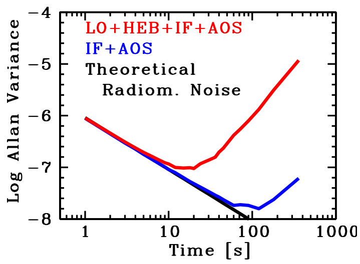

Figure 6: Allan variance using Allan baseline variance method. The upper, red curve shows the spectral Allan variance of the entire system, the lower, blue curve only that of the IF and the AOS, the black curve represents theoretical radiometric noise. The spectral Allan variance is adequate for astronomical observations and is not dominated by the IF and AOS.

4 OUTLOOK

We have built CONDOR, a 1.25 - 1.5 THz receiver, and successfully tested it in the lab. Although further tests and improvements are anticipated, the receiver is fit for astronomical observations. We are looking forward to CONDOR's "first light" on APEX in 2005/06. We expect that CONDOR will fly on SOFIA as the low-frequency extension of the 1.9 THz channel on the German REceiver for Astronomy at Terahertz (GREAT) in 2006/07.

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References: Ossenkopf, V. 2003, HIFI Technical Note