SUBMILLIMETER RECEIVER DEVELOPMENT AT THE UNIVERSITY OF COLOGNE

J.Hernichel, F.Lewen, K.Matthes, M.Klumb
T.Rose, G.Winnewisser, P.Zimmermann

I. Physikalisches Institut
Universität zu Köln
Zülpicher Straße 77
D-5000 Köln 41
Germany

Abstract

A 345 GHz radio-astronomy receiver was developed at the I. Physik. Institut of the university of Cologne and optimized for observations of the CO 3→2 line. The GaAs Schottky mixer and HEMT-amplifier are cooled to 20 K. The DSB noise temperature measured at the telescope is in the range of 350-380 K. A quasi-optical mirror arrangement focuses the sky and local oscillator radiation through a Potter horn into the mixer. For diplexing we use a folded Fabry-Perot. In order to optimize the observing mode, the stability was analyzed through the Allan variance method adopted in Cologne for this purpose using a 1 GHz bandwidth acousto-optical spectrometer (AOS) built in Cologne. The results of the Allan plots showed that the complete system could be operated in total power mode with integration times up to 100 seconds per duty cycle. Baseline ripples were analyzed in detail by simulated spectra with the AOS and were reduced by insertion of tilted vacuum windows and installing a phase shifter in the signal path.

A 460 GHz "bread board" receiver was tested in the lab. The final receiver should be finished in fall 1991 so that the first observing run will be in winter 1991/92.

Introduction

Astronomical observations at wavelengths below 1 mm require accurately figured telescopes located on very dry sites. These requirements are well satisfied by the Cologne radio telescope located on the Gornergrat near Zermatt, Switzerland (KOSMA, <u>K</u>ölner <u>O</u>bservatorium für <u>S</u>ub<u>m</u>illimeter <u>A</u>stronomie). The site has excellent weather conditions in winter time: in the period mid-November to mid-March the precipitable water vapor is below 1 mm for about 20% of the time. The 3 m telescope is a Cassegrain antenna with an altitude-azimuth mount and a surface accuracy on manufacture of 30 μm rms. Since December 1988 the telescope has been equipped with a GaAs Schottky mixer receiver operating around 345.8 GHz. With a spatial resolution of about 80" it is ideally suited for mapping large areas of molecular clouds. The submillimeter Schottky receivers presently developed are steps of a large program aiming at a Schottky receiver at 650 GHz with solid-state LO source for future airborne and space applications.

The 345 GHz Receiver

As a first step into the submillimeter range we have developed a 345 GHz Schottky-Receiver [1]. Based on the experiences of two winter sessions at the observatory we modified the optics and designed a new system for the winter 1990/91 observing period. We use a foldet Fabry-Perot resonator (FPR) instead of a Martin-Puplett Interferometer (MPI). Measurements have shown that the transmission at the band-pass edge (±300 MHz) is 90% for the MPI compared to 98% for the FPR. This will give a better signal-to-noise ratio at the band edge. Transmission loss through the diplexer is 0.5 dB. A block diagram of the receiver is shown in figure 1. The quasi optical design incorporates elliptical of-axis mirrors. The mirror diameters are three times the 1/e beam radius, resulting in power loss of less than 20 dB. The new mirrors are corrected for phase errors [5] and were produced on the NC-milling machine in our institute. The power loss through the optics is in the range of 0.9–1.1 dB. For calibration purposes the signal input port can be switched to a cold load (40 K) and a hot load (300 K) by a load-select mirror. For decoupling the mixer block from vibrations of the cold-head, we located the mixer on a fiberglass support at the dewar bottom. To cool down the mixer we connect it via flexible copper cable with the 18 K-stage. Local oscillator power is provided by a 115 GHz Gunn oscillator (PLL stabilized) followed by a varactor tripler which was developed at the University of Cologne. The Gunn oscillator is a GaAs type with 40 mW output power. The multiplier uses a University of Virginia Schottky diode of type 6P4. The multiplier produces an output power of 3.2 mW (8% efficiency) [8]. The mixer uses a single diode, is fundamentally pumped and the IF section is coaxial. The 2I1-150 diode (Univ. of Virginia) has C_0=4.5 fF, R_s=13.5 Ω and U_{br}=8.0 V. The bandwidth of the HEMT-amplifier is 800 MHz at 1.4 GHz midfrequency; its noise temperature is ≃10 K [3]. The system noise temperature measured at the telescope is 350-380 K (DSB) compared to 500-550 K with the "old" version optics.

We did baseline ripple measurements by using a phase shifter. The idea is to shift standing waves periodically by $\lambda/2$ so that the averaged baseline ripple disappears. In our case the phaseshifter consists of a 0.21 mm half teflon disk, rotating with 20 Hz. Figure 2 shows that the power amplitude reduction is on the order of factor 2–3. In order to optimize the observing mode we had to get information about the system stability. With the knowledge of the statistical behavior of the complete sytem, (source , front end and back end) we could decide if the RMS noise decreases like white noise with longer integration time, in relation to the radiometer formula. This was analysed through the Allan variance method [6] adopted in Cologne, using a 1 GHz bandwidth acoustooptical spectrometer (AOS) built in Cologne. The program allows to show the collected data of two AOS–channels as the normalized count difference (NCD) between them. It indicates the noise evaluation versus time (figure 3). The result of the Allan plots (figure 4) shows that the complete sytem stability allows to operate in total power mode with an integration times up to 100 seconds per duty cycle [2]. Baseline ripples were analyzed in detail by simulated spectra with the AOS and were reduced by insertion of tilted vacuum windows and location of the cold load at the Brewster angle, to avoid standing waves in the optical path.

Beam pattern measurements have been made for the mixer (modified Potter horn, figure 5), the whole system, and the receiver integrated at the telescope. We measured a 1/e opening angle of the Potter horn Θ_{0m}=10.5° compared to the calculated value Θ_{0c}=10.3°. The measured receiver beam has Θ_{0m}=8.0°-8.6° compared to the calculated value Θ_{0c}=8.2°.

The 460 GHz Receiver

The next step to higher frequencies is the 460 GHz receiver. First heterodyne measurements were made in the lab. A block diagram of this receiver is shown in figure 6. The signal path is P1,E1,P2, diplexer, P3, E4 into the mixer. The LO-path is E2, diplexer, P3, E4, mixer ("E" stands for elliptical, and "P" for plane mirror). The hot load and a flat mirror for the cold load (E3) are motor driven. The LO is a InPh Gunn oscillator; 45 mW at 114.7 GHz, followed by a varactor quadrupler using a Univ. of Virginia Schottky diode 2T2; R_s=12Ω, C_j=5 fF. The multiplier output power is 800 μW (efficiency=1.8%). The mixer is a Schottky waveguide mixer with a 1T6 diode (R_s=20 Ω, C_{j0}=0.35 fF). The uncooled mixer conversion loss and noise temperature were measured [4]: T_m=1700 K L_m=6.8 dB. The overall uncooled system temperature is T_s=3500 K (DSB). One of the next steps will be to optimize the mixer IF-matching. The final cooled receiver should be ready for a CO 4→3 observing run in fall 1991.

Conclusion

We have designed and built a cryogenically cooled 345 GHz receiver which has been installed on the 3 m KOSMA telescope to observe CO 3→2 in the interstellar medium. The cooled mixer is a GaAs Schottky diode mounted in a waveguide structure. Local oscillator injection is by quasi-optical Fabry-Perot ring resonator. The noise temperature measured at the telescope is 350-380 K (DSB). We have designed and built a 460 GHz test system. The uncooled noise temperature is 3500 K (DSB). The final receiver (cooled version) will be installed in the telescope in the winter of 1991/92.

Acknowledgements

The receiver development presented here was funded by the Bundesminister für Forschung und Technologie (BMFT), and partly by the Deutsche Forschungsgemeinschaft (DFG) through grant SFB-301.

References

[1] Hernichel, J.: *Aufbau und Inbetriebnahme des 345 GHz Empfängers für das Kölner 3 m-Radioteleskop*, Diplom Thesis, Univ. Cologne (1989).

[2] Klumb, M.: *Untersuchung der Grenzempfindlichkeit eines radioastronomischen Empfangssystems*, Diplom Thesis, Univ. Cologne (1990).

[3] Lewen, F.: *Aufbau und Optimierung eines HEMT-ZF-Verstärkers*, Diplom Thesis, Univ. Cologne (1990).

[4] Matthes, K.: *Aufbau eines 460 GHz-Empfangssystems*, Diplom Thesis, Univ. Cologne (1990).

[5] Rose, T.: *Aufbau eines SIS-Empfangssytem mit quasioptischem Mischer*, Diplom Thesis, Univ. Cologne (1989):

[6] SCHIEDER, R.: *Characterisation and Measurement of System Stability* Proceedings of SPIE. Vol. 598, pp. 189-192 (1985).

[7] WINNEWISSER, G., ZIMMERMANN, P., HERNICHEL, J., MILLER, M., SCHIEDER, R., UNGERECHTS, H.: *CO submillimeter observations from Gornergrat*, Astron. Astophys. 230,248-251 (1990).

[8] ZIMMERMANN, P.: *490 GHz solid state source with varactor quintupler*, Proceedings of 13th International Conference on Infrared and Millimeter Waves (1988).

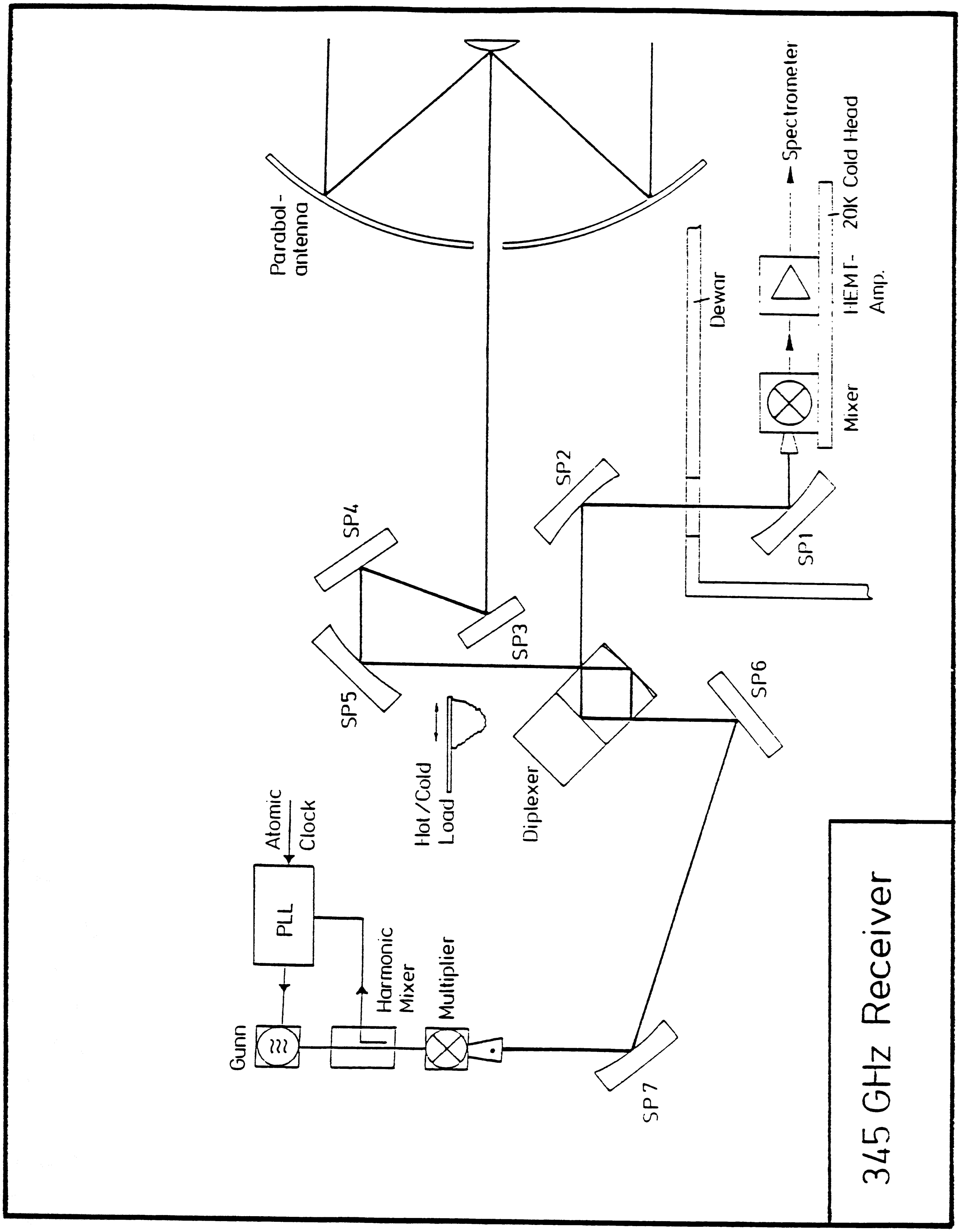
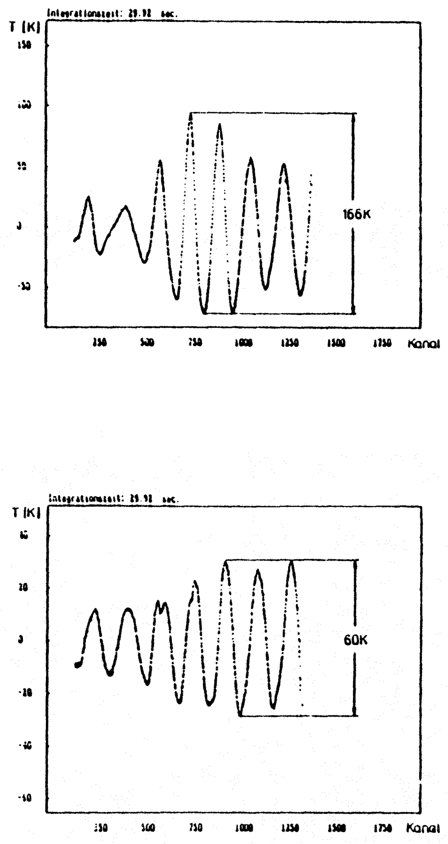
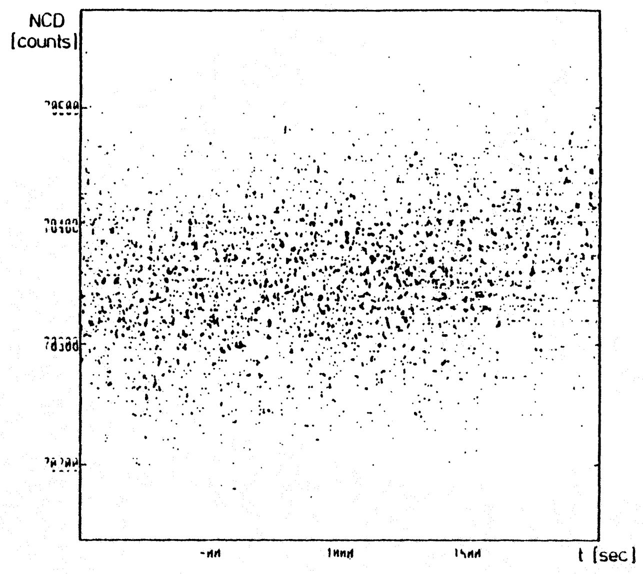

Parabol-
antenna
Dewar
Spectrometer
HEMT-
Amp.
20K Cold Head
Mixer
SP1
SP2
SP3
SP4
SP5
SP6
SP7
Diplexer
Hot/Cold
Load
Atomic
Clock
PLL
Harmonic
Mixer
Multiplier
Gunn
345 GHz Receiver

figure 1



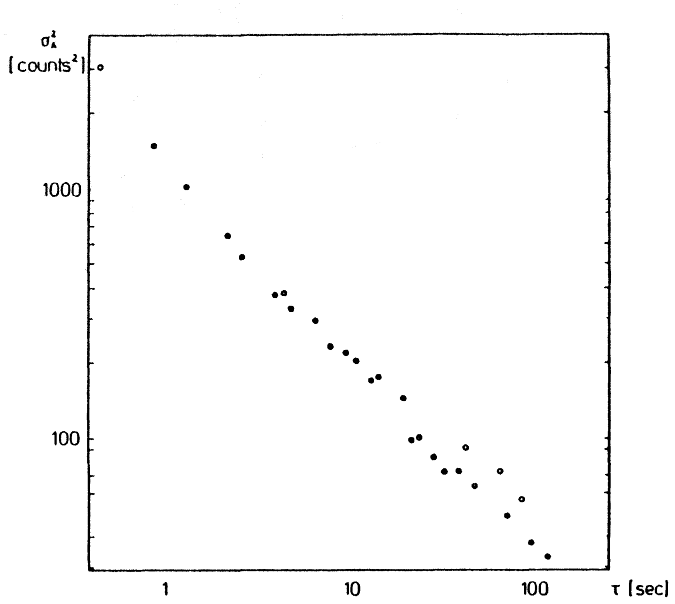
aluminium plate in front of the receiver

figure 2



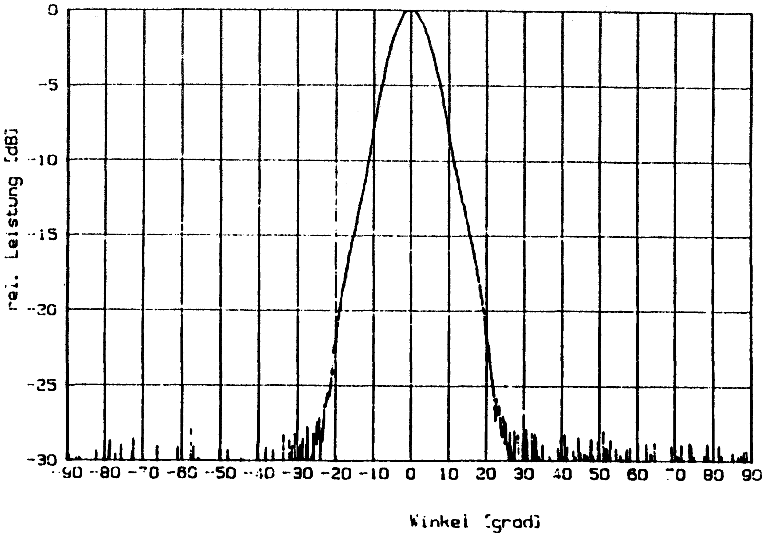
System-Noise versus time

figure 3



$\tau_{min} = 120sec$

figure 4



measured : $\Theta_0 = 10.5''$

calculated : $\Theta_0 = 10.3^o$

figure 5

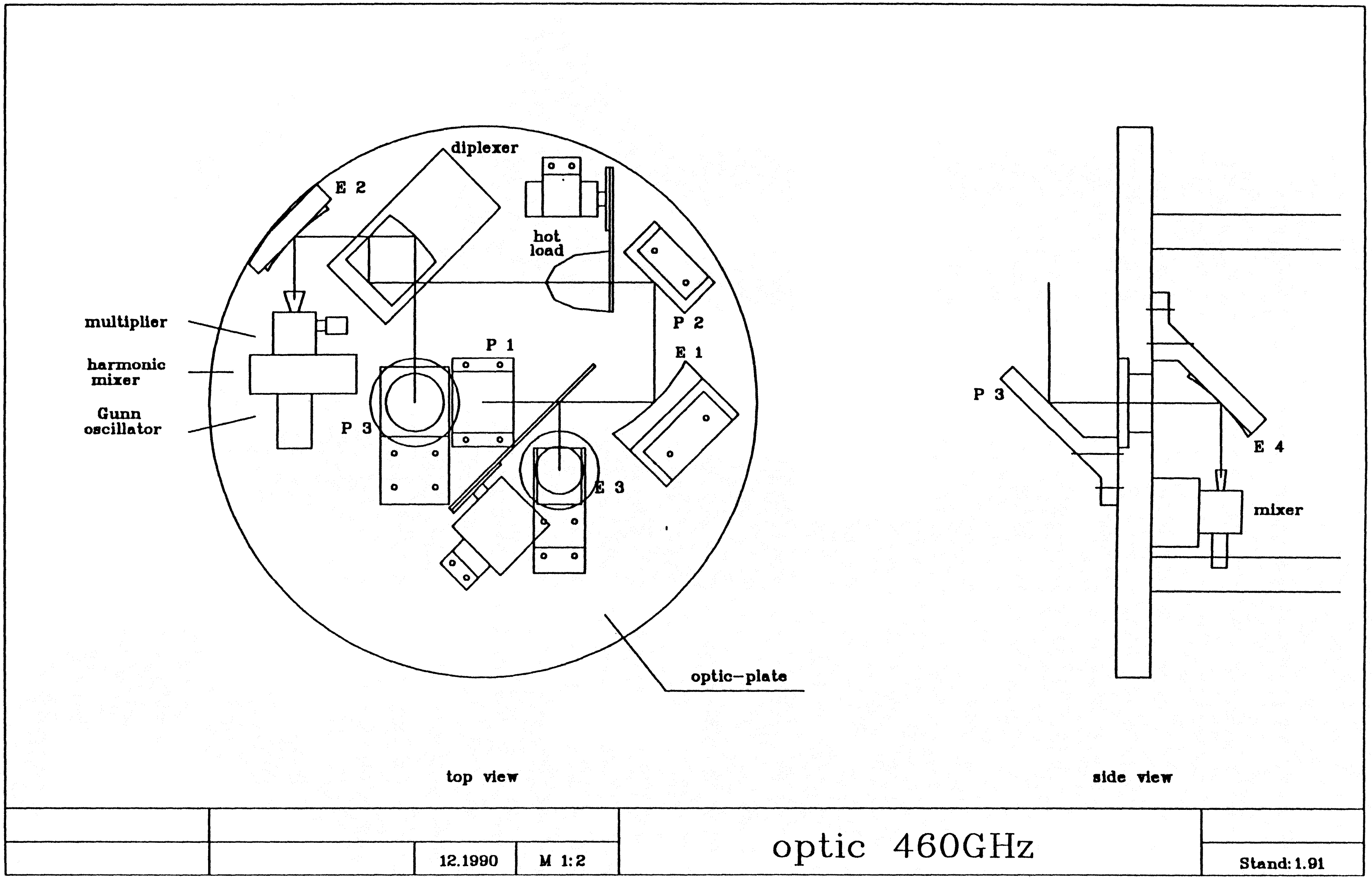

diplexer
E 2
hot
load
multiplier
harmonic
mixer
Gunn
oscillator
P 1
P 2
E 1
P 3
E 3
optic–plate
top view
P 3
E 4
mixer
side view
12.1990
M 1:2
optic 460GHz
Stand: 1.91

figure 6