J. Astron. Space Sci. 11(2), 232–249 (1994)

# A CRYOGENIC TWO MILLIMETER RECEIVER SYSTEM

**Chang Hoon Lee, Seog Tae Han, and Yong Sun Park**
Korea Astronomy Observatory
36-1 Whaam-dong, Yuseong, Taejeon 304-348, Korea
email: chlee@apissa.issa.re.kr

*(Recieved November 26, 1994; Accepted December 2, 1994)*

## ABSTRACT

Since we finished the purchase of the cooled Schottky diode mixer receiver made by Radiometer Physics Co. for the 120–170GHz range in October 1991, we have not prepared the PLL hardware and software for this receiver and the ellipsoidal mirror for beam guiding. After these problems were solved, this receiver was installed at the 14m telescope in late December 1993, and used for the confirmation of a spectral line detection and the measurement of the beam efficiency. The beam efficiency is about 36% at 146 GHz.

## 1. INTRODUCTION

The two millimeter wavelength band is a very under-explored region of the millimeter spectral region, which appears to have many valuable spectral lines for researches of molecular cloud structure, tracing the morphology of outflows related for young stars, and probing chemical pathways in the dense interstellar medium.

The Daeduk Radio Astronomy Observatory's(DRAO) two millimeter receiver covers the frequency range 120–170GHz(Lee *et al.* 1994). This spectral window is naturally defined by the atmospheric absorption of $O_2$ at 118.8 GHz and of $H_2O$ at 183 GHz. The frontend of this system consists of the GaAs Schottky diode mixer and HEMT IF-amplifier inside the dewar, the local oscillator system based on the GUNN oscillator on top of the dewar, the quasi-optical coupling devices in front of dewar, and the phase-lock system on side-plate of the dewar, which are mounted inside and outside the vacuum dewar (Lee 1991).

We started the measurements of performance tests at the laboratory in 1991. At that time, we got the double sideband receiver noise temperature of $\sim$160K at the total frequency range.

We designed quasi-optic system in order to install the 2mm, 3mm, and 7mm receiver on the receiver plate simultaneously and tested its quasi-optic performance after these receivers were actually installed on the receiver plate (Cho *et al.* 1990). The results were that the quasi-optic performance of 2mm and 3mm receiver was less sufficient than we expected. We therefore redesigned the quasi-optics system for only 2mm receiver which was used 3mm receiver quasi-optics except ellpisoidal mirror. And the PLL system controlled by the computer was made.

Finally we did the test observation for 2mm receiver in the beginning of January 1994. The results of the test were that the antenna aperture efficiency was 35% at 146 GHz (Park *et al.* 1993). And the line intensity from radiated Orion, $H_2CO$(140 GHz) spectral line, was detected more 1.3K than 5.8K line intensity which was observed the same source at FCRAO in 1986.

This system can be easily installed by only replacing the ellipsoidal mirror for 2mm receiver instead of ellipsoidal mirror for 3mm receiver on the receiver plate.

This receiver will be used for performing the research for spectral line in this frequency range according to observing proposal at the end of this year.

## 2. DESCRIPTION OF THE TWO MILLIMETER RECEIVER

The 2mm receiver system consists of the frontend system as shown in Figure 1, and the power supplies and control units.

### 2.1 The frontend system

The frontend system consists of the following sub-units, which are mounted inside and outside the vacuum dewar; the inside units are the Schottky diode mixer and IF HEMT amplifier on 20K stage of CTI 350-CP refrigerator, and the outside units are the local oscillator system on top of the dewar, the quasioptical coupling devices in front of dewar, and the phase-locked system on side of the dewar.

- The Mixer and the IF amplifier

The mixer is mounted on a fiberglas structure which is attached to the inner front-wall of the dewar. It is cooled to 20K by copper straps which lead to a model 350 CTI refrigerator. Input power at signal and local oscillator frequencies feed to a corrugated feed horn. The output signal at 1.4GHz is transferred by a semi-rigid coaxial cable to the cooled HEMT amplifier of 20dB gain, directly mounted on the 20K stage. The output from this amplifier is connected by a stainless steel coaxial cable and a vacuum feedthrough and that goes to the outside.

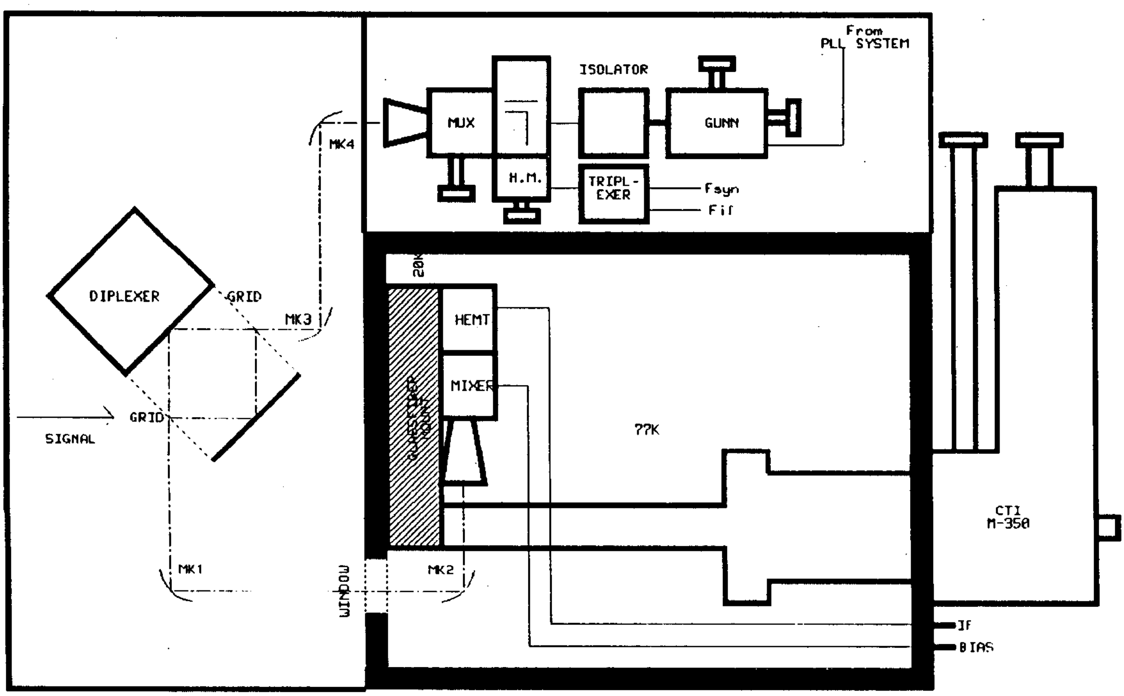



Figure 1. Schematic diagram of DRAO cooled 2mm Schottky mixer receiver.

Table 1. Test data of the tunable GUNN oscillator.

| Frequency [GHz] | Micrometer Setting TOP | Micrometer Setting BACK | POWER [mW] |
|---|---|---|---|
| 61.5 | 2.32 | 1.70 | 12 |
| 62.5 | 2.16 | 1.70 | 18 |
| 63.5 | 1.96 | 2.10 | 22 |
| 64.5 | 1.80 | 2.17 | 24 |
| 65.5 | 1.65 | 2.20 | 24 |
| 66.5 | 1.51 | 1.90 | 29 |
| 67.5 | 1.37 | 2.20 | 28 |
| 68.5 | 1.27 | 2.00 | 29 |
| 69.5 | 1.15 | 1.90 | 31 |
| 70.5 | 1.06 | 1.80 | 29 |
| 71.5 | 0.97 | 1.50 | 28 |
| 72.5 | 0.88 | 1.40 | 24 |
| 73.5 | 0.82 | 1.15 | 21 |
| 74.5 | 0.75 | 0.80 | 18 |
| 75.0 | 0.71 | 0.80 | 18 |
| 75.5 | 0.68 | 0.30 | 20 |
| 77.0 | 0.59 | 1.95 | 16 |
| 78.0 | 0.54 | 1.60 | 16 |
| 79.0 | 0.48 | 1.45 | 15 |
| 80.0 | 0.44 | 1.30 | 12 |
| 81.0 | 0.40 | 1.20 | 12 |
| 82.0 | 0.36 | 1.05 | 10 |
| 83.0 | 0.33 | 0.90 | 10 |
| 84.0 | 0.30 | 0.85 | 9 |
| 85.0 | 0.27 | 0.75 | 10 |
| 85.9 | 0.25 | 0.63 | 8 |

- The Local Oscillator System

The local oscillator section comprises of a GUNN oscillator, multiplier(×2), directional coupler and harmonic mixer. The GUNN oscillator is mechanical tunable and provides power in the 63–85GHz as shown in Table 1. The multiplier doubles into the 126–170GHz range. And the output signal which is transmitted by a conical feed horn, goes to the mixer through the several mirrors and the FABRY-PEROT diplexer in front of the dewar.

- The Quasi-optical Coupling Device

These devices comprise of several ellipsoidal mirrors and the FABRY-PEROT diplexer. The input signal has a beam waist of 9.29mm which is located at a distance 37mm from the diplexer grid. The diplexer operates in reflection with a free spectral range of 2GHz. The signal beam is reflected from the diplexer to an ellipsoidal mirror in front of the entrance window of the dewar. In order to feed the signals to the corrugated feed horn at the mixer input, there is another ellipsoidal mirror inside the dewar.

### 2.2 The Controller for power supplies and control of the frontend

The two control boxes contain the power supplies and control units for the frontend. The control box I delivers power for the GUNN oscillator, the HEMT amplifier, the PLL module, and the FABRY-PEROT diplexer. The digital meters indicate the GUNN oscillator voltage/current to the PLL module. Two other digital meters indicate a value of vacuum and temperature in the dewar. The control box II delivers power for the mixer, the multiplier, and the harmonic mixer. There are digital meters to indicate the mixer voltage/current, the multiplier voltage/current, and the harmonic mixer voltage/current for the receiver tuning. Another meter indicates the setting of the diplexer movable mirror. And the controller I and II are connected to the frontend by a set of connecting cables.

## 3. THE PERFORMANCE TEST AND INSTALLATION

### 3.1 Performance Test

We started the measurements of performance tests at the laboratory in the summer season of 1991 and 1992. At that time, we got the double sideband(DSB)

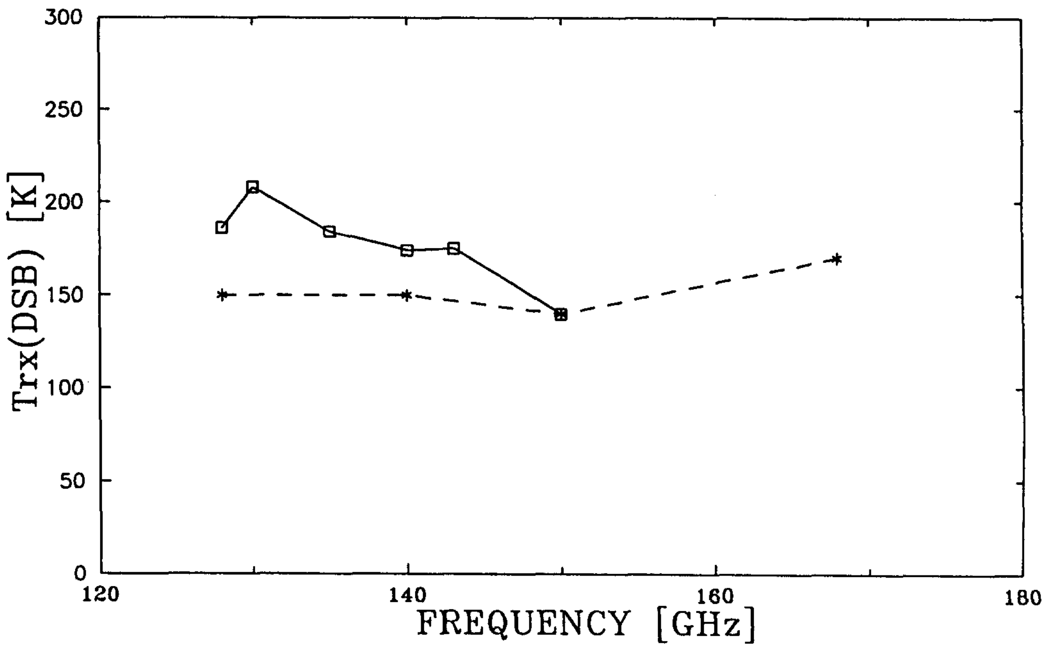



Figure 2. Noise temperature as function of frequency for 2mm receiver. Solid line : FCRAO(1986), Dotted line : DRAO(1991)

receiver noise temperature of ~160K at the total frequency range as shown in Figure 2. From Figure 2, this results are comparable to those obtained with GaAs Schottky mixers operating in frequency range 127–150GHz at the FCRAO (Irvine 1986).

### 3.2 Installation

The complete installation of the two millimeter receiver required the construction of a 1.4GHz IF-strip unit, quasi-optic mirrors, a computer control system for the PLL as well as software upgrade for the receiver. These additional parts were made completely in the summer of 1993, and we installed the system on the telescope to illustrate its performance in December 1993.

- IF-strip unit

This unit consists of the isolators, the 30dB and 40dB amplifiers, and the band-pass filter as shown in Figure 3.

- Quasi-optic system

Quasi-optics system, which can be installed at the 2mm, 3mm, and 7mm receiver on the only one receiver plate simultaneoulsy, was designed in the middle of 1991 as shown in Figure 4. To guide the beam for 2mm receiver, the designed beam parameters are shown in Figure 5 (Goldsmith 1982). The specifications of ellipsoidal mirrors M1 and M2 are shown in Table 2. These mirrors were made by machine shop of KIM(Korea Institute of Machine).

Table 2. Specification of ellipsoidal mirror M1 and M2.

| Frequency[GHz] | Parameter | M1 mirror [mm] | M2 mirror [mm] |
|---|---|---|---|
| 120 | W | 70.16 | 69.97 |
| | RI | 537.62 | 140136.30 |
| | RO | -71306.40 | -808.24 |
| | B | 130.40 | 130.00 |
| 150 | W | 56.25 | 56.00 |
| | RI | 539.88 | 89785.60 |
| | RO | -45827.90 | -810.85 |
| | B | 104.54 | 104.09 |
| 180 | W | 46.99 | 46.70 |
| | RI | 542.65 | 62433.40 |
| | RO | -31988.02 | -814.07 |
| | B | 87.30 | 86.79 |

W : Beam radius at lens, RI : input radius of curvature
RO : output radius of curvature, B : 30dB beam radius

After the 2mm receiver with the quasi optics system was intalled completely in 14m telescope, we observed the spectral lines as shown in Figure 5 and 6 in October 1991. However, we found out several problems such as the repeatability problem of the beam switching mirror, the reliability of manufacture and difficulty of beam alignment for long distance between the Cassegrain focus and the 2mm receiver.

And so the only 2mm receiver was installed at optimum position instead of the 3mm receiver using the original quasi-optics for the 3mm receiver. We observed the

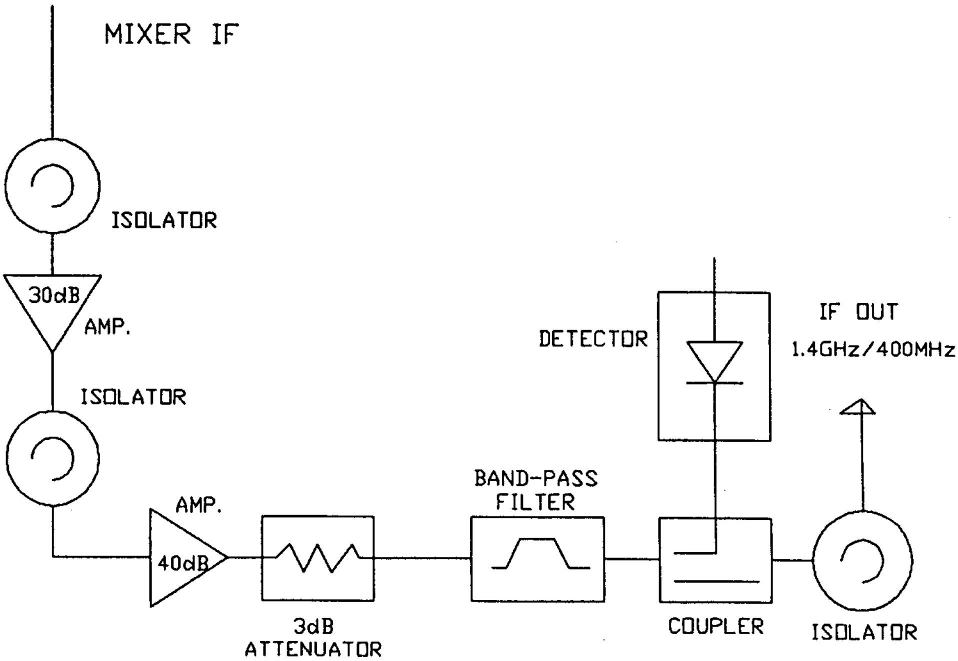



Figure 3. Block diagram of IF-strip for 2mm receiver.

spectral lines as shown in Figure 8 and 9. From these results, we recognized that 2mm receiver could be used for observations if we design only the ellipsoidal mirror for 2mm receiver, even though there is some inconvenience that 3mm receiver replaces 2mm receiver. After several tests were performed, we designed and made the ellipsoidal mirror for 2mm receiver at ADD(Agency for Defense Development) as shown in Figure 10 and Table 3.

Table 3. Parameters of final ellipsoidal mirror.

| | | | | | |
|---|---|---|---|---|---|
| Focal length | : | 272mm | Eccentricity(e) | : | 0.4279 |
| RI | : | 450.6mm at 150GHz | Major radius(a) | : | 568.5mm |
| RO | : | 686.3mm at 150GHz | Minor radius(b) | : | 513.8mm |
| Incidence angle | : | 22.5 degree | | | |

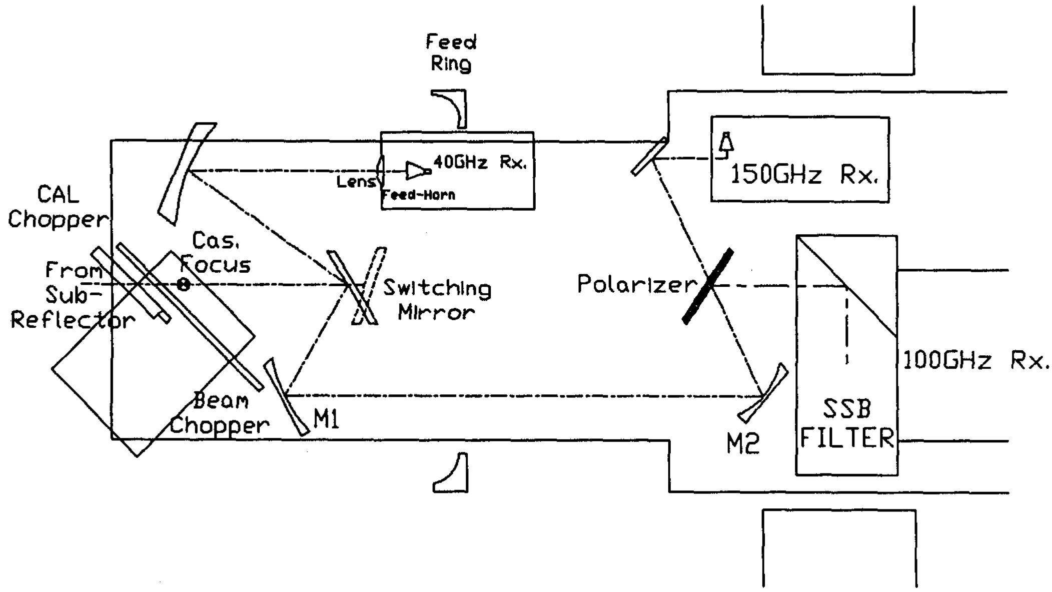



Figure 4. Schematic diagram of quasi-optic system in order to install 2mm, 3mm, and 7mm receiver simultanuously.

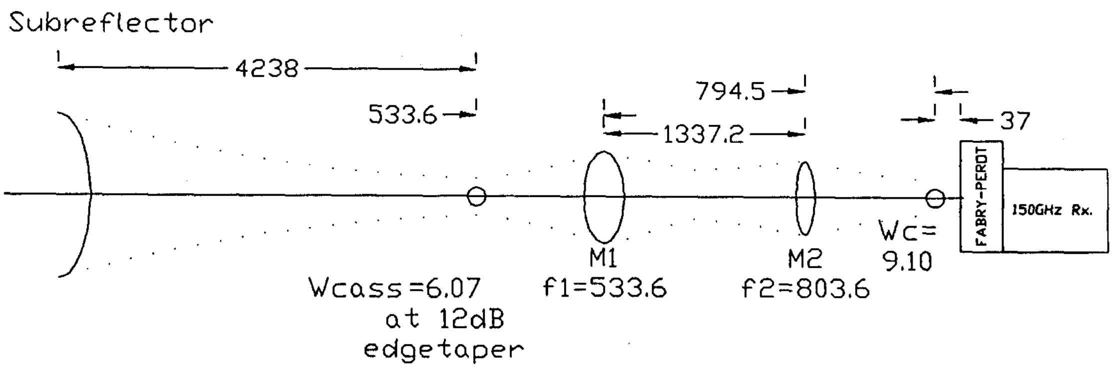
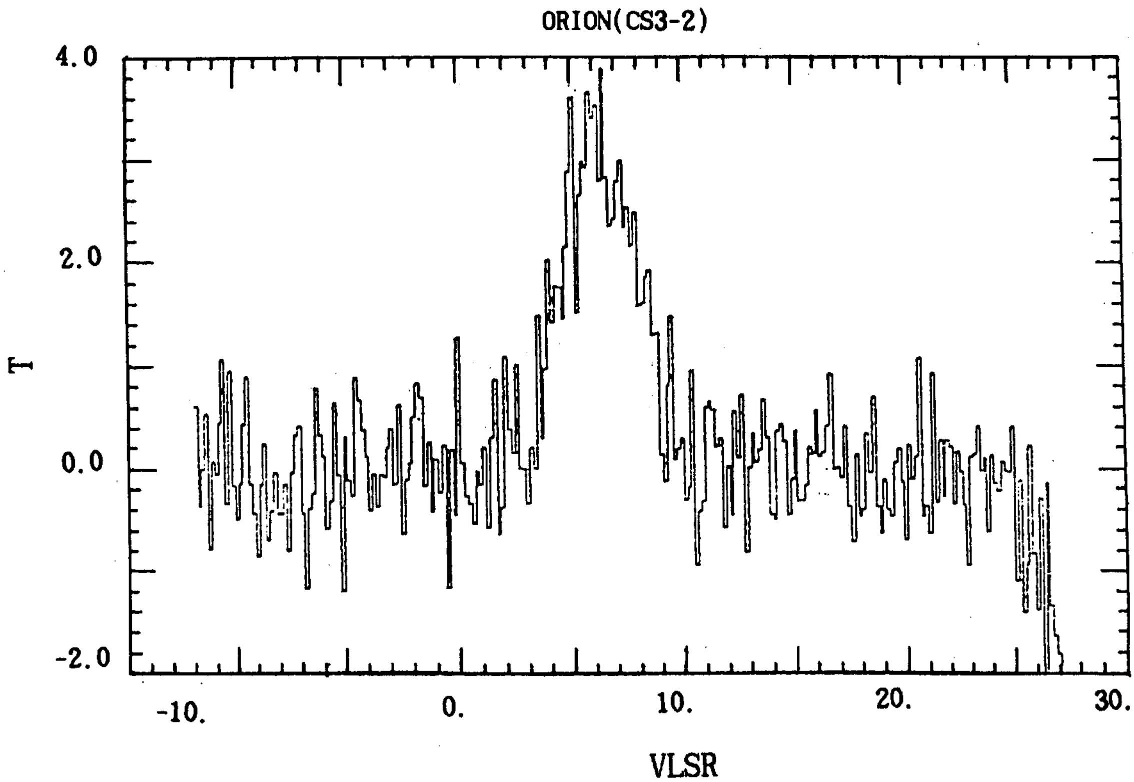
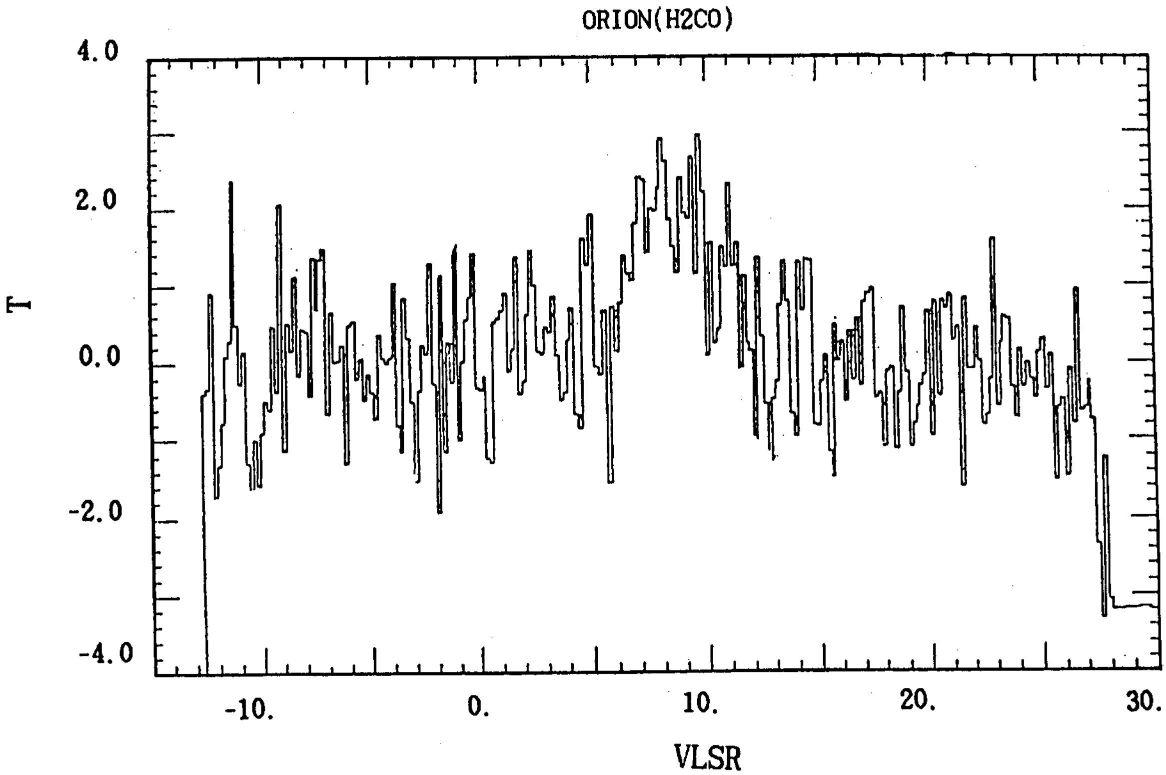



Figure 5. Beam parameters of 2mm quasi-optic system.



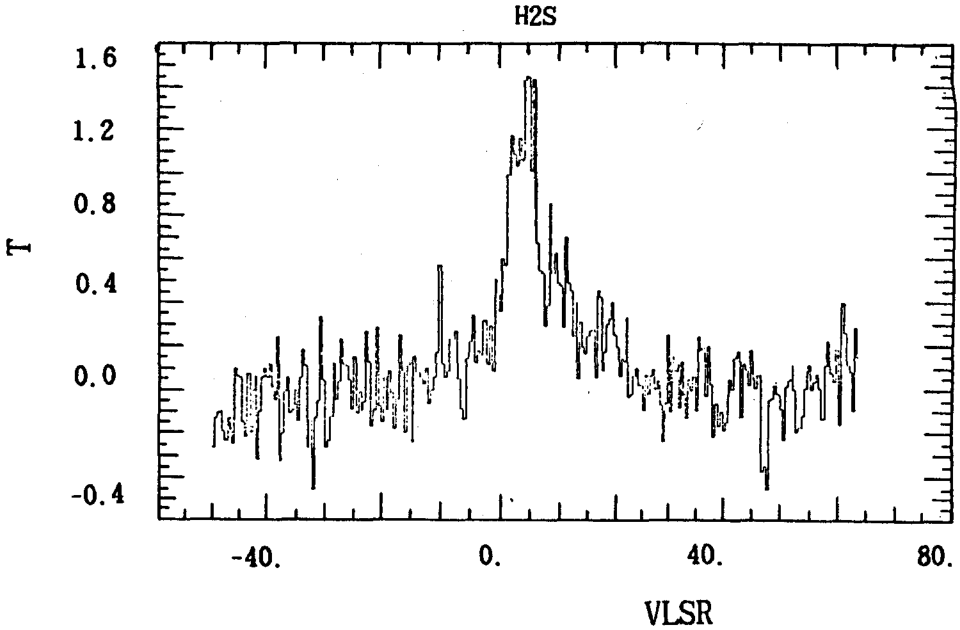

```
20068 ORION          146.9550GHz  RA =  5:32:47.0  L=208.99  DALP= 0.0
  6/10/91  LST=  7: 6  4903.SEC  DEC=- 5:24:23.0  B=-19.38  DDEC= 0.0
   24552 ORION          3944  43.3410      6.4     3.888    11.94    0.475
```

Figure 6. CS(3–2) spectrum toward Orion taken with 2mm receiver using old quasi-optic system(1991).




20081 ORION 140.8260GHz RA = 5:32:47.0 L=208.99 DALP= 0.0
6/10/91 LST= 8:43 3612.SEC DEC=- 5:24:23.0 B=-19.38 DDEC= 0.0
20081 ORION 5276 29.5934 8.0 2.903 5.93 0.829

Figure 7. $H_2CO$ spectrum toward Orion taken with 2mm receiver using old Quasi-optic system(1991).




| SCAN | YMAX | X(YMAX) | FWHP | YINT | XMEAN | SIG-X |
|---|---|---|---|---|---|---|
| 24536 | 1.45 | 5.001 | 9.51 | 13.78 | 5.309 | 6.61 |

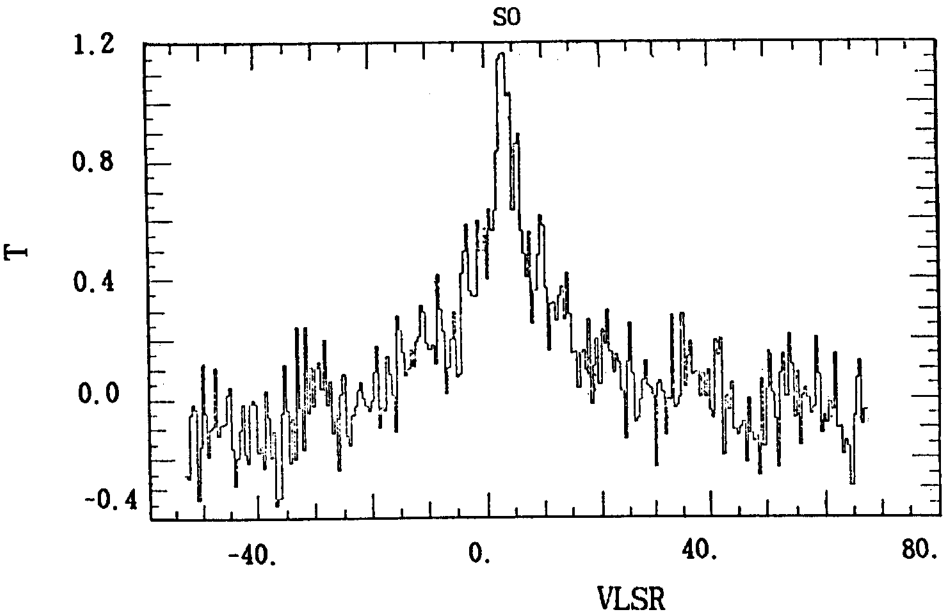
24536 ORION 168.7486GHz RA = 5:32:47.0 L=208.99 DALP= 0.0
12/14/92 LST= 4:47 848.SEC DEC=- 5:24:23.0 B=-19.38 DDEC= 0.0

| SCAN | NAME | TS(1) | TINT | YMAX | YINT | YSIGMA | UTD |
|---|---|---|---|---|---|---|---|
| 24536 | ORION | 1412 | 848. | 1.448 | 13.78 | 0.155 | 1992.952 |

Figure 8. $H_2S$ spectrum toward Orion taken with 2mm receiver using old ellipsoidal mirror(1992).

The surface accuracy of the mirror was checked by ADD and KRISS. We confirmed that the measured results were satisfactory.

In order to use the 2mm receiver for an observing research, the interfacing hardwares between the PLL controller & MODCOMP and the signal generator(HP8665A) & MODCOMP, and the software for controlling those hardwares should be prepared.




| SCAN | YMAX | X(YMAX) | FWHP | YINT | XMEAN | SIG-X |
|---|---|---|---|---|---|---|
| 24552 | 1.17 | 3.464 | 12.69 | 14.81 | 4.912 | 10.68 |

| | | | | | |
|---|---|---|---|---|---|
| 24552 ORION | 158.9584GHz | RA = | 5:32:47.0 | L=208.99 | DALP= 0.0 |
| 12/14/92 LST= 6:49 | 724.SEC | DEC=- | 5:24:23.0 | B=-19.38 | DDEC= 0.0 |

| SCAN | NAME | TS(1) | TINT | YMAX | YINT | YSIGMA | UTD |
|---|---|---|---|---|---|---|---|
| 24552 | ORION | 1025 | 724. | 1.167 | 14.81 | 0.142 | 1992.953 |

Figure 9. SO spectrum toward Orion taken with 2mm receiver using old ellipsoidal mirror(1992).

- PLL(Phase-Locked Loop) system

First, we interfaced between the PLL controller and the MODCOMP so that the observers can monitor the status of a frequency locking. If the locking singal comes from PLL controller is out, MODCOMP can not perform the data acquisition process. We made and installed the remote controller which can be switched at the position of local/remote in the observing room, so that the PLL locking is relocked by the controller if out of locking happens.

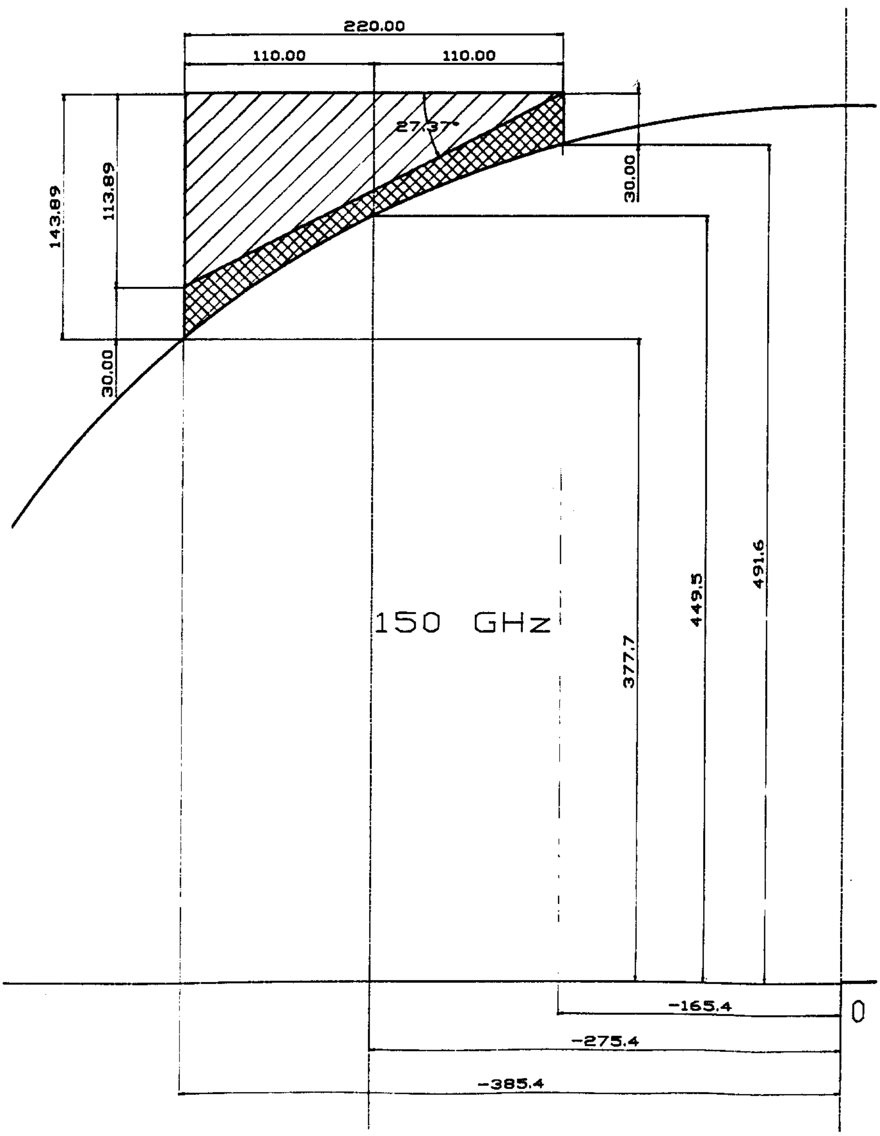



Figure 10. Drawing of ellipsoidal mirror for 2mm receiver.

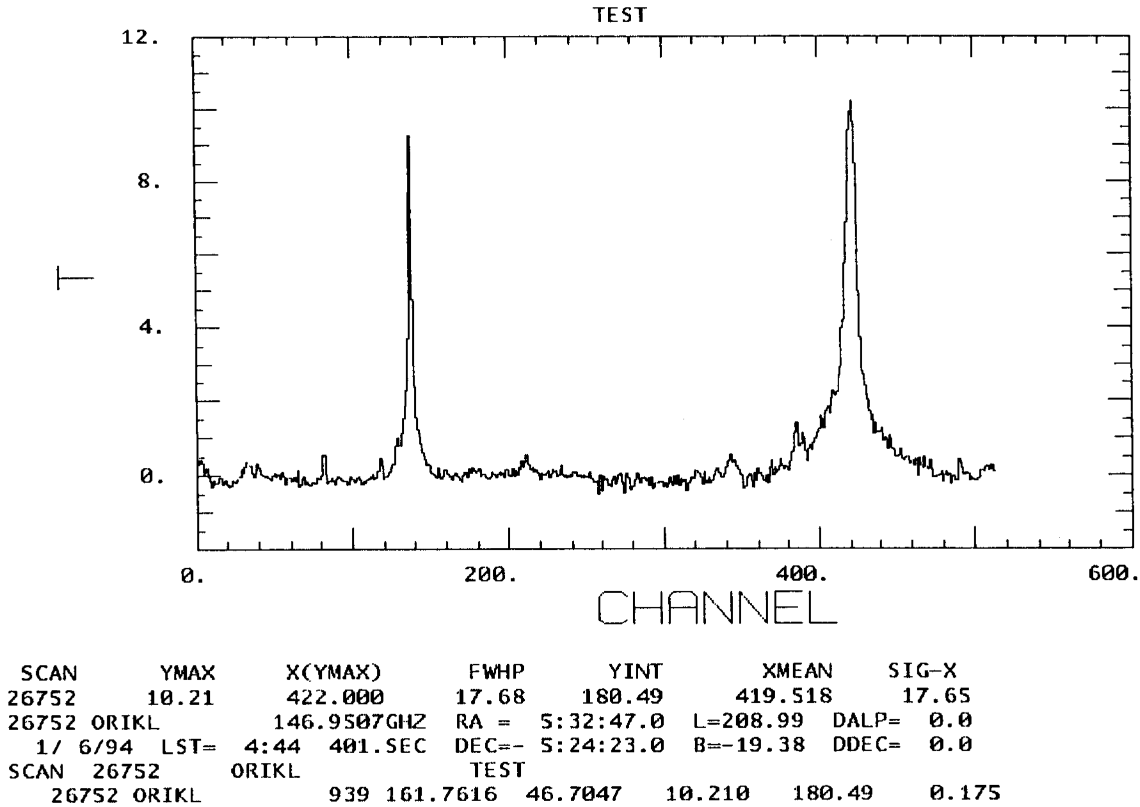
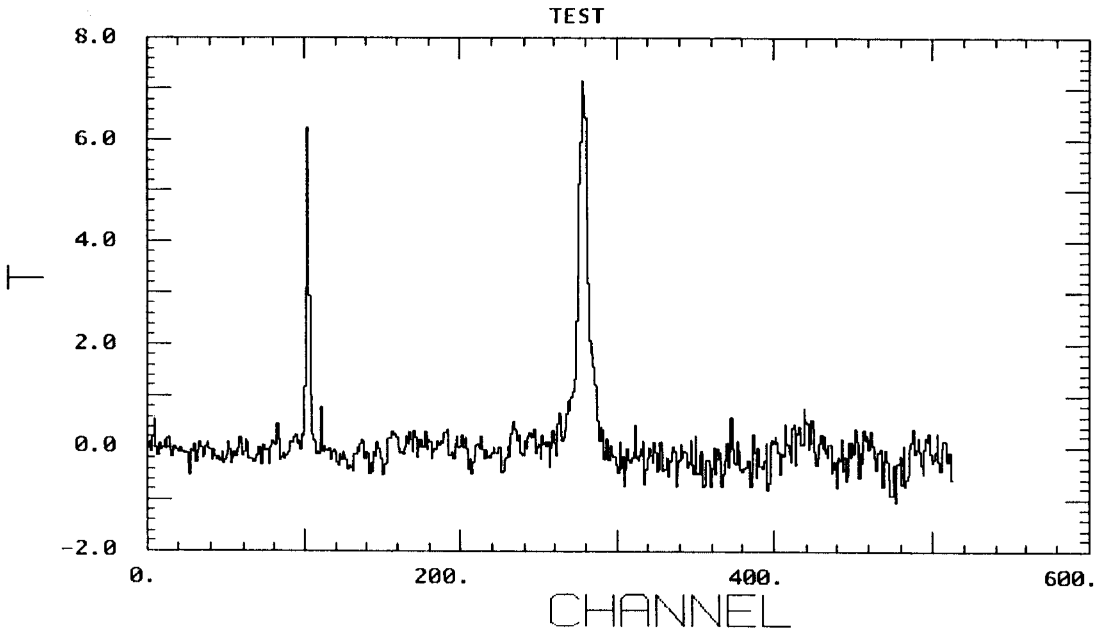



Figure 11. CS(3–2) spectrum toward Orion taken with 2mm receiver using new ellipsoidal mirror.




| SCAN | YMAX | X(YMAX) | FWHP | YINT | XMEAN | SIG-X |
|---|---|---|---|---|---|---|
| 26960 | 7.17 | 278.000 | 8.09 | 57.96 | 274.584 | 0.00 |

26960 ORIKL 140.8217GHZ RA = 5:32:47.0 L=208.99 DALP= 0.0
1/ 8/94 LST= 1:41 802.SEC DEC=- 5:24:23.0 B=-19.38 DDEC= 0.0
SCAN 26960 ORIKL TEST
26960 ORIKL 2593 114.4929 21.5120 7.167 57.96 0.282

Figure 12. $H_2CO$ spectrum toward Orion taken with 2mm receiver using new ellipsoidal mirror.

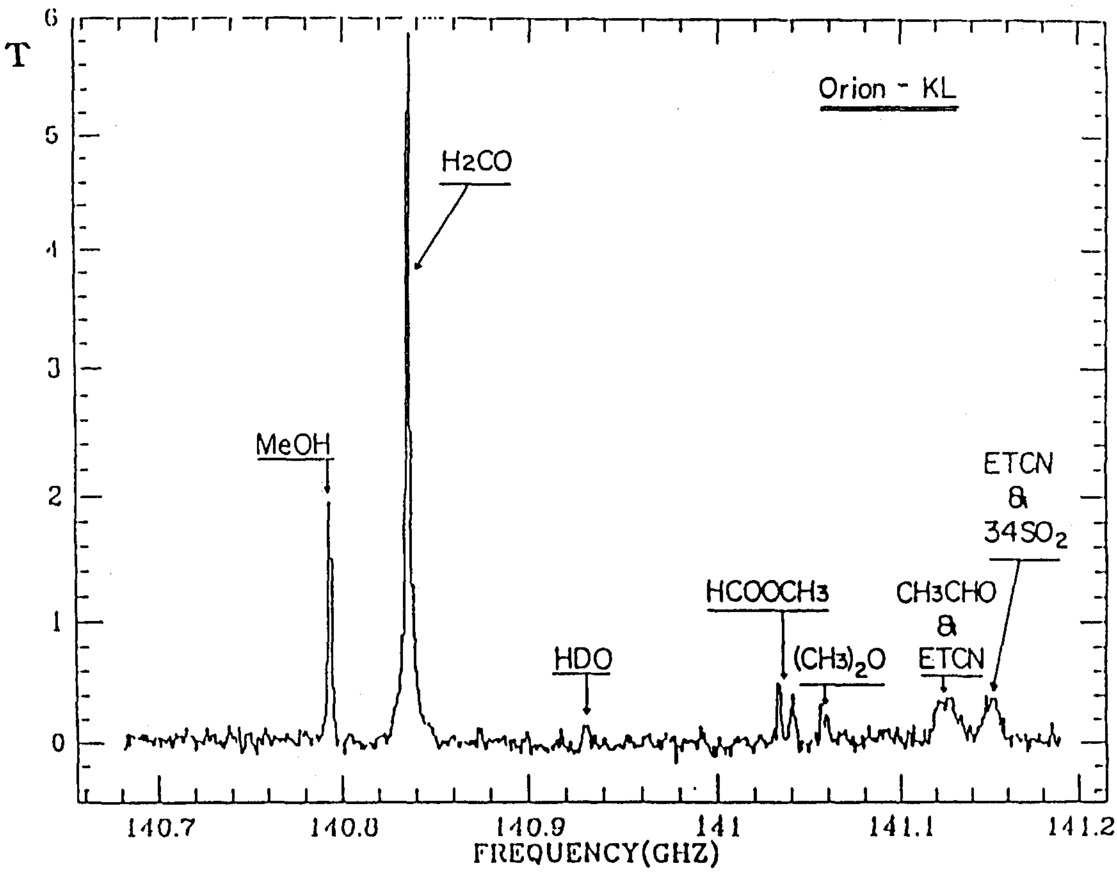



Figure 13. Spectrum toward Orion taken with FCRAO 2mm receiver.

We not only made the interface between signal generator and MODCOMP, but also prepared its control software, so that the local oscillator frequency corresponding to VLSR is controlled by MODCOMP automatically.

## 4. RESULTS AND DISCUSSION

The 2mm receiver was installed on 14m Daeduk radio telescope in the end of December 1993 through the several test steps.

First of all, in order to confirm the detecting of spectral line, we observed the line of CS(146GHz) and $H_2CO$(140GHz) toward Orion. We successfully observed the lines as shown in Figure 11 and 12.

As comparision the intensity of $H_2CO$ spectral line at FCRAO in 1987 (Figure 13) with the intensity of $H_2CO$ spectral line at DRAO, our result was stronger 1.3K than FCRAO's result.

We also performed the continuum observation toward Jupiter so as to measure the antenna aperture efficiency and the beam efficiency at 146GHz. The measured performance is extremely encouraging, with the telescope beam efficiency equal to 36% at 146GHz, including the losses from the radome. We believe that the performance of the 2mm receiver system is acceptable as considering the 34% of beam efficiency of FCRAO at 150GHz in 1987.

The beam efficiency of 45–50% could be achieved if the surface of main reflector is more accurately readjusted.

In point of view of above mentioned results, this receiver will be used for observing in the end of 1994, according to the observing proposals. We will measure the antenna aperture efficiencies regularly at several frequencies for 2–3 days during the observing time

## REFERENCES

Cho, S. H., Han, S. T., Lee, C. H., Park, Y. S. & Kim, H. G. 1990, N9017, report

Goldsmith, P. F. 1982, Infared and Millimeter Waves, 6, 272

Irvine, W. M. 1986, FCRAO Annual report

Lee, C. H. 1991, Technical manual of 120–170GHz receiver

Lee, C. H., Han, S. T., Park, Y. S., Yim, I. S., Kim, K. D., Kim, H. R., Seo, J. B. & Kim, T. S. 1994, DRAO Annual report

Park, Y. S., Lee, C. H., Han, S. T., Yim, I. S., Kim, K. D., Kim, H. R., Seo, J. B. & Kim, T. S. 1993, Efficiency Estimation and Stabilization of DRAO, DRAO report