A differential radiometer for mm wavelengths

L.Piccirillo, M. Calabresi, M. Zucchetti

Istituto Superiore PT - viale Europa 190 - 0144 Rome, Italy

Abstract

The performances of an antenna system operating at mm wavelengths are discussed. Results from several measurements under different test conditions are presented. The antenna was used to make observations from Antarctica of the diffuse sky emission at 94 GHz.

1. Introduction

In the mm/sub-mm wavelength region of the spectrum, the atmosphere contains few windows where the transparency is high enough to allow ground-based astronomy. The attenuation is related to the presence of several atmospheric constituents which contraint the quality of the measurements.

The water vapour is the main source of attenuation and it is quantified by the Precipitable Water Vapour (PWV), i.e. the tickness of a layer of water obtained by condensing on the ground all the vapour contained in a column of unit area. A good observing site is represented by a PWV content of few millimiters. In fig. 1 the vertical attenuation is plotted for some values of the PWV.

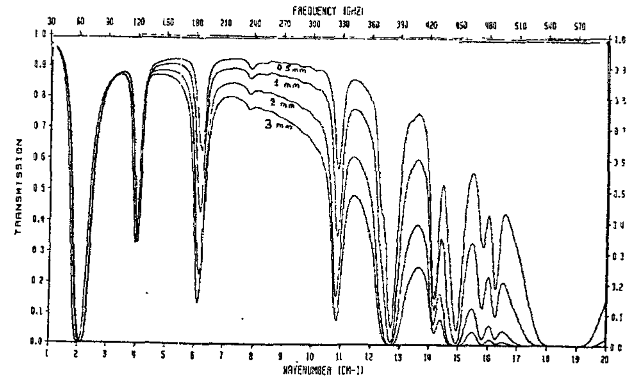

fig. 1

Antarctica offers a very good observing site thanks to its very cold and dry atmosphere also during the summer. At the Italian Base (Terra Nova Bay), where we performed most of our measurements, the average PWV is between 2 and 3 mm during the summer season. We expect that these values are strongly reduced (less than 1 mm) during the antarctic winter season.

Special care must be put in the design and the realization of an antenna system dedicated to work in Antarctica mainly because of the strong adverse environmental conditions. Even during the summer season we had days with wind larger than 80 knots and temperature lower than -15 C. In order to operate in such a strong adverse environment, we decided to make extensive use of titanium, stainless steel and carbon fibers both for the optics and for the structure. The rapidly changing weather conditions forced us to design a system easy to transport and disassemble.

KK

2. The optics

A full description of the optics is given elsewhere {1} Here we give only a brief description.

The antenna system is a combination of an off-axis parabolic primary mirror with an off-axis hyperbolic secondary mirror. The optics is designed to have a Field of View (FOV) of 50 arcmin with a focal ratio of 3. The primary mirror oscillates at a frequency of 10 Hz performing a beam-switching in the sky. The beam separation in the sky can be set in the range 0 - 2 degrees. The elevation axis coincides with the optical axes so as to keep fixed the position of the focus when the beam direction change from the horizon up to the zenith. With this optics, the detector does not inclinate during the tracking. This feature is particularly useful when using cryogenic detectors.

The primary and the secondary mirrors can be dismounted in few seconds without using any tool. This feature was demonstrated very useful during all the rapidly changing weather conditions avoiding any damages to the optics.

Special care was put in the choice of the technology used in the construction of the mirrors. An silver-coated aluminium layer is glued on a carbon fiber structure. The glue used constitues an elastic substrate on which the alluminum layer can move slightly with respect to the structure. This techniques avoid deformations of the mirrors under temperature variations. The tickness of the aluminium layer is 500 μm while the silver coated tickness is respectively 40 μm for the primary mirror and 350 μm for the secondary mirror. This tickness allows us to easily remove oxide regions and small scratches by polishing.

The surface roughness of both mirrors is 0.2/0.4 μm r.m.s. and the maximum deviation between the theoretical profile of the mirrors and the measured profile is less than 250 μm along the maximum diameters.

A ray-tracing simulation shows a small coma aberration produced only in the maximum tilted position of the primary mirror resulting in a power loss less than 0.1 dB. A measured beam-profile of a distant IMPATT source agreed substantially with the ray-tracing results.

A different optical test was performed placing a small stainless sphere in the focus of the antenna system. A laser beam was directed on the sphere and reflected on the secondary and then on the primary mirror. We used the property of a laser beam to be Gaussian. We shaped properly the curvature of the sphere placed in the focus so as to fully illuminate the secondary and (then) the primary mirror. The resulting beam has a size equal to the diameter of the primary mirror.

With this techniques we checked the geometry, the combined surface roughness and we were able to set with great accuracy the beam separation produced by the wobbling primary mirror.

3. Structure and tracking system.

The entire optics is placed on a rotating platform producing the azimuth motion. Two different speed can be selected: high speed to find the object in the sky and low speed to perform the tracking. The azimuth motion is realized with a toothed wheel (360 teeth of 1 mm) and a pinion coupled to a brushless motor.The secondary mirror can run on a semi-circular guide by means of a special gear coupled to the second brushless motor.

Both the azimuth and the elevation motors are equipped with an encoder controlling, in closed loop, the speed. Both the axis are also equipped with an additional (dual) encoder dedicated to the measurements of the angular position.

The primary mirror is mounted on a cradle running on 8 pre-loaded bearings. The oscillation amplitude is obtained by means of a connecting rod attached to an electrically driven wheel. We worked at a frequency of about 9 Hz and with a peak-to-peak sky modulation of 2 degrees. All masses are well balanced and the system is (at the first order) virtually free of vibration.

We measured the vibrations induced in the structure by the modulating primary mirror for two different position of the elevation (+0 degrees looking at the zenith and +90 degree looking at the horizon). A set of three accelerometers was put along three different axes on the detector. The results of the measurements are shown in fig. 2.

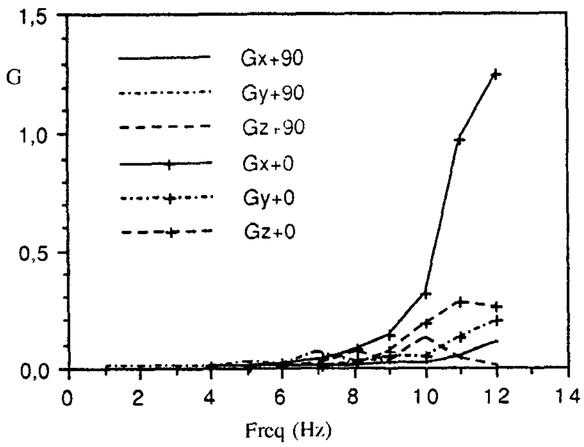

fig. 2

We decided to work at 9 Hz where a clear minimum in the rms acceleration is visible.

4. Detectors

Two different kind of detectors were used during the Antarctica expeditions. The first detector is a super-heterodyne mixer pumpedat 94.1 GHz by means of a phase-locked Gunn oscillator. The IF output is first filtered, via a microstrip bandpass filter with 400 MHz bandwidth and 1.5 GHz central frequency, and then sent to an IF amplifier.. The amplified signal is followed by a variable attenuator and then applied to a detector diode. The video signal from the diode togheter with the reference signal coming from the modulation system is applied to a lock-in amplifier that produces a voltage proportional to the differences between the radiation coming from the two positions of the beam in the sky.

The second detector is a He-3 bolometer equipped with a bandpass filter centered at 2.2 mm wavelengths. The sensitivity of this second detector was higher than the previous by a factor of 20.

We used the first detector to measure the long term atmospheric stability and, on very long integration time, the 94 GHz emission of the galactic plane and the Magellanic Clouds. The second detector was used to measure the CBR anisotropy at intermediate angular scale (1.1 degrees).

5. Results and conclusions

The instrument was used with the 94 GHz detector during the 1989/90 Italian Antarctica Expedition. We observed the emission from both the Small and the Large Magellanic Clouds indicating the presence of a very cold dust component (15 K) co-existing with the warm dust detected by the IRAS satellite {2}. A different run of measurements was dedicated to the emission of the galactic plane. Again a strong emission was detected indicating the presence of a similar cold dust component.

A typical measurements of the mm emission of the galactic plane is shown in fig. 3. The vertical axes (mK Antenna temperature) is proportional to the signals coming from different galactic latitudes and longitudes. The latitude profile obtained from several scans is roughly consistent with a cosec law.

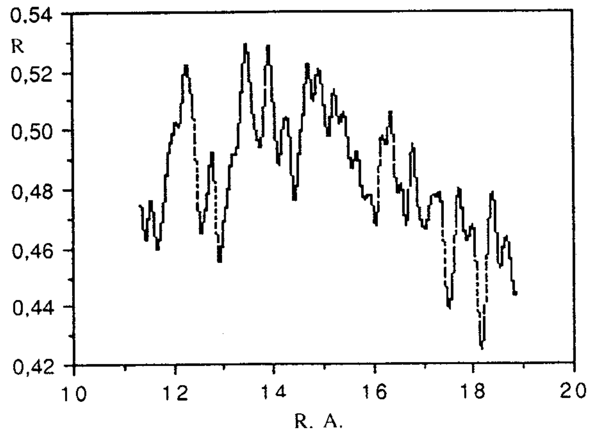

fig. 3

The good performances demonstrated by the entire system allow us to plan an improved experiment to be performed in Antarctica during thenext expedition (1992/93). The stiffness and reliability of the system described are suitable for using it on a permanent remote observatory placed at the Italian Base. Several problems are to be analyzed in all the aspects including, for example, a long duration cryostat and a reliable dome for the telescope.

The sensitivity obtained with the He-3 system seems to be adequate for continuum measurements but an SIS receiver must be used for spectral observations. Some views of the entire system are shown in fig. 4 and 5.

6. Aknowledgments

This work was supported by Istituto Superiore P.T. and by the ENEA Progetto Antartide. The Istituto Superiore P.T. developped all the relevant technologies and system studies in the mm region of the e.m. spectrum for telecom services in the future. The ENEA Progetto Antartide provided us with an excellent logistics during all the experiments.

Special thanks to Paolo G. Calisse for helping one of us (LP) during the measurements in Antarctica.

7. References

{1} L. Piccirillo, Rev. Sci. Instr., **62**, 5, (1991).

{2} Andreani et al., Ap. J., **348**, 467 (1990)

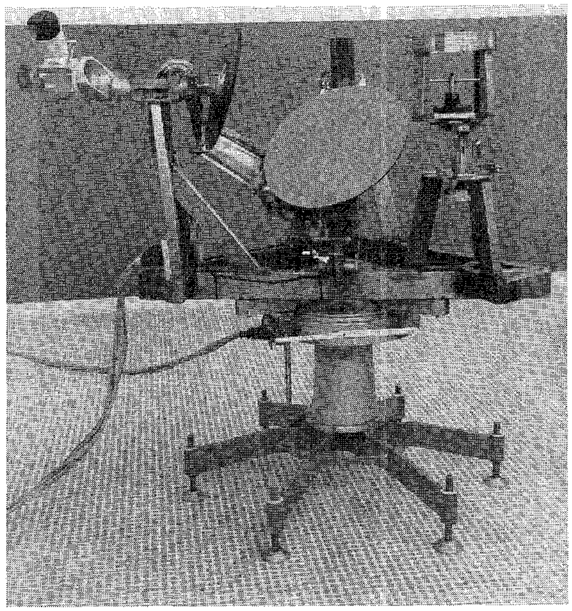

fig. 4

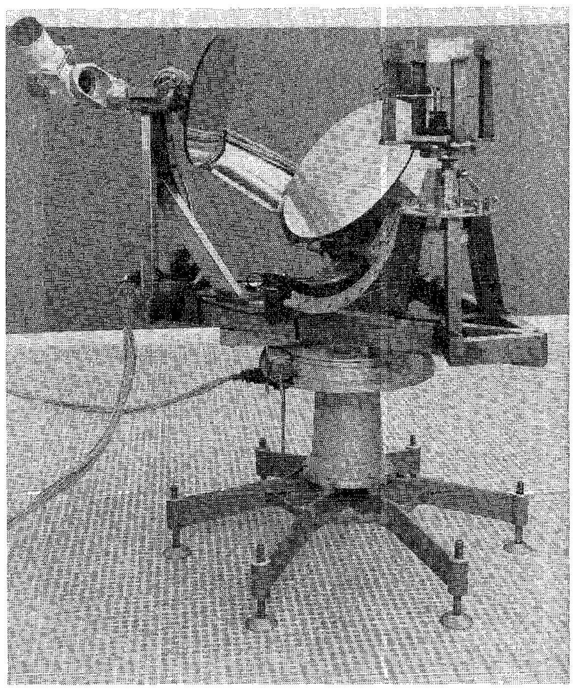

fig. 5