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14. Abstract/Notes

The fluctuation spectrum of the cosmic background radiation can potentially provide one of the best experimental inputs to constrain cosmological models. At large angular scale the dipole anisotropy in the background radiation has been measured with a signal to noise of 100, and upper limits for the quadrupole and autocorrelation function have been established, while at small scales upper limits have also been established. These limits are of order one part in 10^5 both scales. At intermediate angular scale few experiments have been carried out and the results are not fully understood. We discuss an ongoing experiment in this angular region.

15. Remarks

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SEARCH FOR FLUCTUATIONS IN THE COSMIC BACKGROUND RADIATION

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SUMMARY

The fluctuation spectrum of the cosmic background radiation can potentially provide one of the best experimental inputs to constrain cosmological models. At large angular scale the dipole anisotropy in the background radiation has been measured with a signal to noise of 100, and upper limits for the quadrupole and autocorrelation function have been established, while at small scales upper limits have also been established. These limits are of order one part in 10^5 for both scales. At intermediate angular scale few experiments have been carried out and the results are not fully understood. We discuss an ongoing experiment in this angular region.

1. INTRODUCTION

The anisotropy of the angular distribution of the cosmic background radiation (CBR) is one of the few experimental inputs we have to compare to cosmological models and plays an important role in our description and understanding of the universe (for a detailed discussion, see the recent review by Kaiser and Silk (1986)). Anisotropy at large scales measures our peculiar motion relative to the frame of the CBR, as well as giving input to discussions of large scale structure (matter distribution), and global anisotropy models. At small and intermediate scales, theories of galaxy formation have calculable and testable consequences for CBR fluctuations. In addition, there are a host of other effects and theories ranging from cosmic strings (Kaiser and Stebbins, 1984) (which should produce step discontinuities in CBR temperature) to the Sunyaev-Zel'dovitch effect (Sunyaev and Zel'dovitch, 1972), a temperature shift caused by photons interacting with localized hot plasma.

Measurements on angular scales from arc-seconds to one hundred eighty degrees have been performed with varying levels of sensitivity. On small angular scales (arc-minutes), the recent measurements of Uson and Wilkinson (1984) have placed a 95% confidence level upper limit of $\Delta T/\mathrm{T} = 2\times10^{-5}$. On angular scales of 6 degrees, Melchiorri et al (1981) quote an upper limit of 4×10^{-5}, with a possible detection at 1.1×10^{-4}. At an angular scale of 8 degrees, Davies et al. (1987), report a detection of anisotropy at the level of 3.7×10^{-5} , which they quote only as an upper limit on actual CBR fluctuations, due to galactic contribution uncertainties. The measurements of Fixsen et al. (1983) and Lubin et al. (1985) place a 95% confidence level limit of 6×10^{-5} on quadrupole anisotropy, with an autocorrelation consistent with instrument noise at the 0.01 mk^2 level. The Prognoz 9 experiment should push this quadrupole limit to 2×10^{-5} if the current sidelobe contamination problem can be resolved. At 180 degrees angular scale, the dipole due to the solar motion has been measured with a signal to noise of 100, although calibration accuracy limits the absolute error to 5%. The direction of the dipole is known to better than 2 degrees (Fixen et al. 1983, Strukov and Skulachev 1984, Lubin et al. 1985). Near full sky maps of the CBR have been made from these data sets at 12, 9, and 3mm wavelength. The CBR anisotropy measurements are summarized in Figure 1.

The measurements on scales larger than 10 degrees have been done almost exclusively from high altitude platforms, due to atmospheric emission, while the measurements at less than 1 degree have been done from the ground, since atmospheric fluctuations are smaller on small angular scales and larger antennas are required as well as very stable pointing systems.

The scale from 1 to 10 degrees has not received much attention due to the difficulties mentioned above. Because of the increased sensitivity of small (< 1 degree) and large (> 10 degrees) angular scale measurements and the intensified theoretical interest in the region of 1-10 degrees, a highly sensitive measurement is needed here. Many theories which predict fluctuation in the background radiation predict a fluctuation spectrum which decreases rapidly below 1 degree since regions of the sky separated by less than a few degrees are causally connected and hence fluctuations may be smaller. In addition, recombination effects tend to smear out the fluctuations on scales much less than one degree. For example, if the limit of Uson and Wilkinson (2.1×10^{-5}) could be applied to angular scales of the order of 1 degree instead of 4.5 arc-minutes a significant number of cosmological models would have been ruled out. The galaxy formation problem (e.g. Vittorio and Silk 1984) can be investigated more precisely once we know the CBR fluctuation spectrum between 1 degree and 10 degrees.

We propose to perform an experiment to measure anisotropies in the angular scale between 0.5 degree and 10 degrees and we expect to make measurements at a level that will have a significant impact on theoretical models. It is clearly important, however, to make measurements at a variety of angular scales to determine not only the nature of the fluctuation spectrum but also disentangle any systematic effects. It will also be a crucial check of the suggestive results of Melchiorri et al (1981) and Davies et al (1987).

2. BACKGROUNDS

Emission from our galaxy is a serious problem in large scale anisotropy measurements. Although the galaxy is generally not as serious a problem for scales less than 10 degrees, the possibility of patchy dust emission at high galactic latitudes did prevent Melchiorri et al. (1981) from claiming an actual measurement of anisotropy at 1.1×10^{-4}. We will observe at 3.3 mm wavelength (90 GHz) where the galactic emission is near minimum. Our 3.3 mm large scale anisotropy measurements confirm the small amount of galactic emission at 3.3 mm with a cosec b (b: galactic latitude) fit giving a galactic pole value of $44 \pm 11\ \mu K$ (Lubin et al. 1985). These data also imply that this is an upper limit and that the actual emission at high galactic latitudes may be significantly less.

Atmospheric fluctuations are a considerable problem for ground based anisotropy measurements. Atmospheric emission is reduced to 5 mK at 3.3 mm wavelength by going to a balloon altitude of 30 km, about 4 orders of magnitude lower than sea level emission. Calculated emission as a function of frequency is shown in Figure 2 for a flight altitude of 30 km. We also know from our experience in large scale anisotropy measurements at 3.3 mm, with a beam opening angle of 90 degrees, that atmospheric emission is not a serious problem for a coherent detection system at this altitude. Since we will be making measurements at smaller angular scales, 1 to 10 degrees, it should be even less of a problem. One of the principal advantages of using a narrow band coherent technique, as in this experiment, is that atmospheric effects are greatly reduced when compared to a broad band measurement, a result of the line structure of atmospheric emissions.

3. EXPERIMENTAL APPARATUS

To make the measurement most effective a pointing system is required which can point to a fraction of the beam size of which the smallest will be about 0.25 degrees. For this measurement we require a system capable of stabilizing at about the 15 arc-minute level (rms) at least, in order that the smearing due to pointing errors not significantly degrade our sensitivity.

3.1. GONDOLA

The gondola frame and stabilization concept are shown in Figures 3 and 4. The platform is a reaction wheel stabilized system with a gyro and accelerometer-based inertial guidance system and magnetometers as sensors. The system uses a D.C. torque-motor driven reaction wheel to stabilize in azimuth, and a separate servo to stabilize in elevation. The servo also does real time tracking, as will be necessary for our long (1 hour) integration times. The motor driven bearing assembly at the top of the gondola is incorporated into the servo to decouple the gondola from balloon rotation and also to dump excess angular momentum accumulated in the reaction flywheel.

The system is currently operational in the lab, with short term rms stability of about 2 arc minutes with gyro reference, and about 20 arcminutes with magnetometer reference. The 20 arc minute limit is due to magnetometer noise. The inflight environment should be quieter, although the present limit is sufficient for the larger beams. As a way of checking and correcting either or both sensor systems, we have mounted a CCD camera with a 75 mm diameter lens on the gondola, co-aligned with the telescope beam, to act as a star camera. The video image will be telemetered to the ground and the positions of fiducial stars checked against their expected positions. This information will be used in real time to offset drifts in the gyro or to do in-flight magnetic field calibration. This star camera has been tested with the tracking system and has already been used in measurements of gyro

Additional bolometric detectors are also being prepared for flights in collaboration with other groups.

4. CONCLUSIONS

Since the discovery of the background radiation no intrinsic structure has been convincingly measured. The only well known anisotropy is the dipole, of extrinsic origin, and presumably due to our motion through the radiation. One can derive, using the standard of rest provided by the cosmic background radiation, the motions of our galaxy and the Virgo cluster, which can be used to investigate deviations from universal expansion for instance. The dipole has become a background to be subtracted to get measurements of intrinsic anisotropies.

The proposed experiment which we are building will make measurements in an angular region that is not well investigated and where the theoretical predictions can be tested. The instrument will not be limited by the atmosphere and significant detector improvements are expected and will be flown as they are available. The measurement is in a region which is complementary to other experiments and where the predicted fluctuations are expected to be near maximum.

drift rates and absolute pointing accuracy. The entire servo system and data acquisition system is controlled by a flight computer, which we interact with in real time via a ground station computer on a 4800 baud full duplex telemetry link at 400 MHz.

The system was designed to be light weight and we are now estimating a science payload weight of 380 kg with 450 kg as an upper limit.

3.2. INSTRUMENTATION

Our design uses a single horn and a nutating secondary mirror to chop the beam. The liquid helium cooled receiver uses lead-indium-gold alloy SIS (superconductor-insulator-superconductor) junctions being supplied as part of a collaboration with Bell Laboratories. At 115 GHz receivers using these junctions have demonstrated a total system noise figure of 24 K double side band over a 500 MHz bandwidth limited by the GaAs Fet IF. A 90 GHz unit has been built using a new HEMT (High Electron Mobility Transistor) amplifier which has significantly better noise figure and bandwidth than the GaAs FET amplifiers we used previously. The 90 GHz system is operational with the lead alloy junctions. Bell Laboratories is currently trying to fabricate niobium junctions which should be more robust as well as perform better since they have a higher critical temperature. For 10 hours of data we estimate a sensitivity of $\Delta T/T = 1.6\times10^{-5}$ for each of 10 fields. Figure 5 shows a block diagram of the radiometer.

The design of the antenna uses a one meter off-axis parabola, with a nutating elliptical secondary. The focus of the parabola is coincident with one focus of the ellipse, a design which has been shown to have the excellent sidelobe characteristics we need. The telescope has been fabricated using a numerically controlled mill. Several secondary mirrors have been produced, and the telescope can be adjusted for different beam sizes from 0.33 to .75 degrees, with adjustment also available to change the beam throw.

REFERENCES

1 Dall'Oglio, G. and de Bernardis, P. (1987), preprint.

2 Davies, R.D., Lasenby, A.N., Watson, R.A., Daintree, E.J., Hopkins, J., Beckman, J., Sanchez-Almeida, J. and Rebolo, R., *Nature*, **326**, 462, (1987).

3 Fixen, D.J., Cheng, E.S. and Wilkinson, D.T., *Phys. Rev. Lett.*, **50**, 620, (1983).

4 Kaiser, N. and Silk, J., Nature, **324**, 529, (1986).

5 Kaiser, N. and Stebbins, A., Nature, **310**, 391, (1984).

6 Lubin, P., Villela, T., Epstein, G. and Smoot, G., *Ap. J.*, **298**, L1, (1985).

7 Melchiorri, F., Melchiorri, B., Cecarelli, C. and Petranera, L., *Ap. J. Lett.*, **250**, L1, (1981).

8 Strukov, I.A. and Skulachev, D.P., *Sov. Astron. Lett.*, **10**, 1, (1984).

9 Sunyaev, and Zel'dovich, *Com. App. Sp. Sci.*, **4**, 173, (1972).

10 Uson, J. and Wilkinson, D.T., *Nature*, **312**, 427, (1984).

11 Vittorio, N. and Silk, J., *Ap. J. Lett.*, **285**, L39, (1984).

FIGURE CAPTIONS

1. Anisotropy limits of the cosmic background radiation.

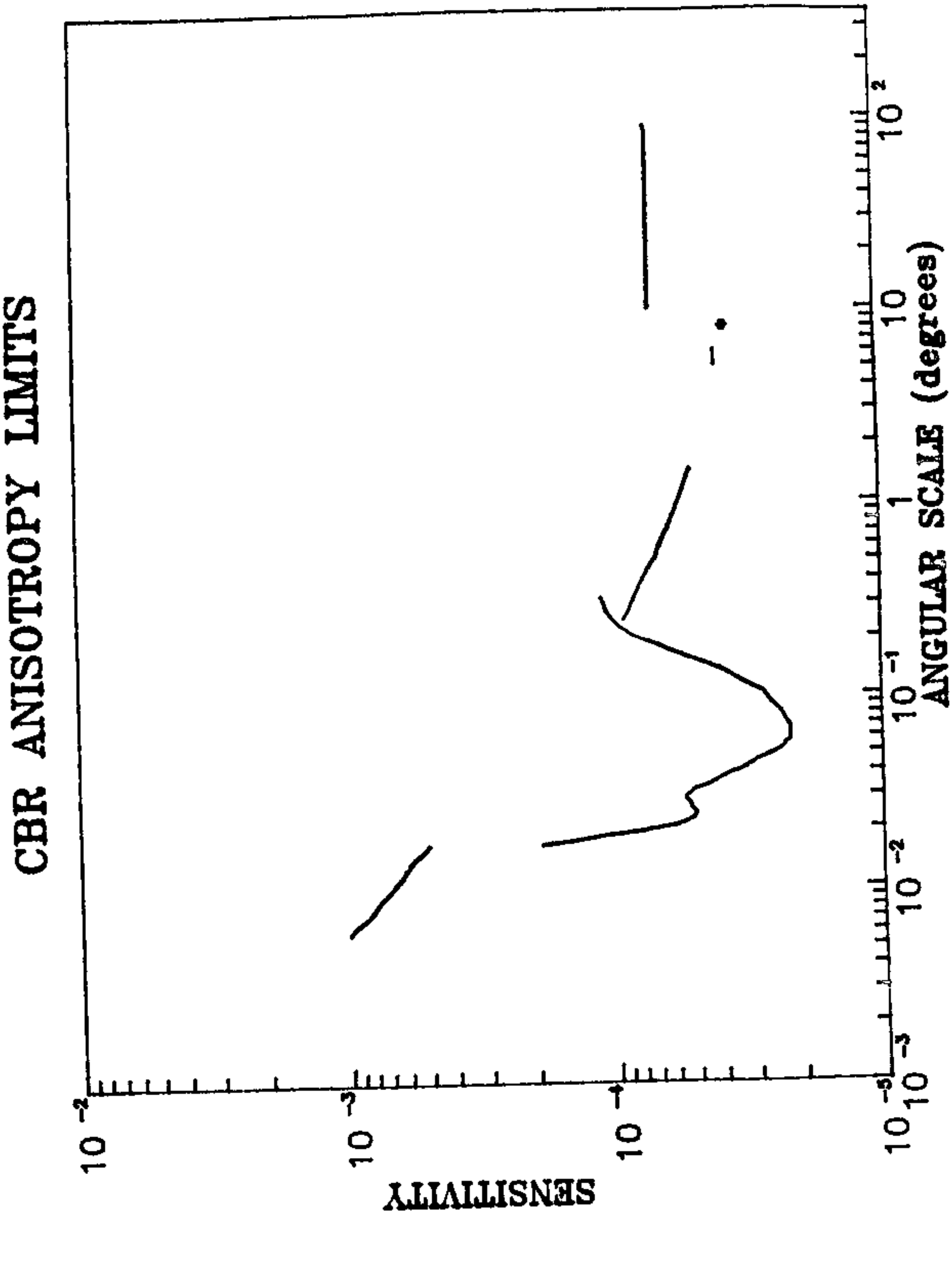
2. Atmospheric emission at different altitudes. From top to bottom: emission at sea level (0 km), on a high altitude mountain top (3.6 km), and at typical balloon altitude (30 km).

3. Gondola flight configuration.

4. Block diagram of stabilization system.

5. Block Diagram of the 3.3 mm radiometer.

FIGURE 1.


CBR ANISOTROPY LIMITS
SENSITIVITY
10^{-2}
10^{-3}
10^{-4}
10^{-5}
ANGULAR SCALE (degrees)
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}

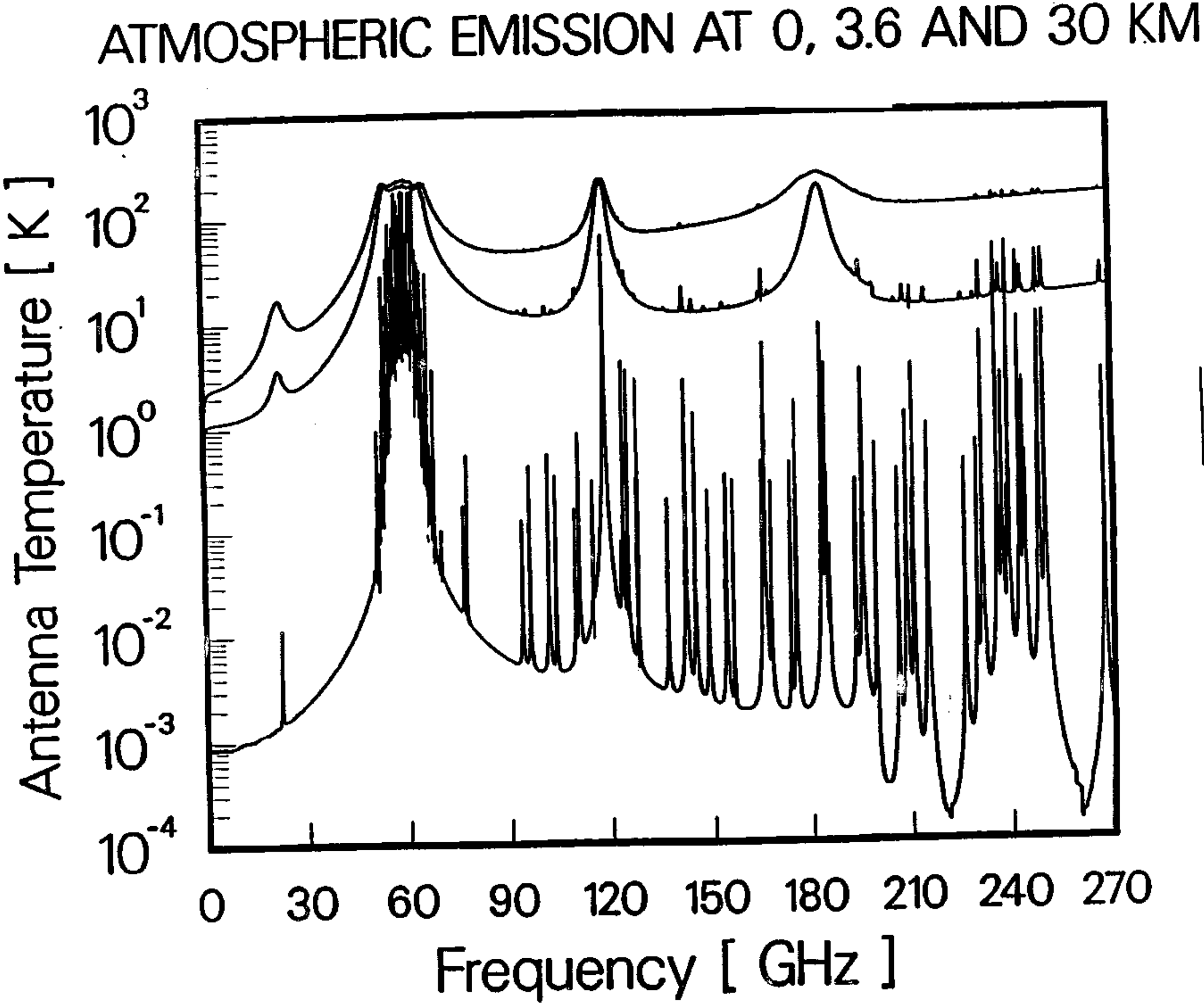

ATMOSPHERIC EMISSION AT 0, 3.6 AND 30 KM
Antenna Temperature [K]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
30
60
90
120
150
180
210
240
270
Frequency [GHz]

FIGURE 2.

FIGURE 3.

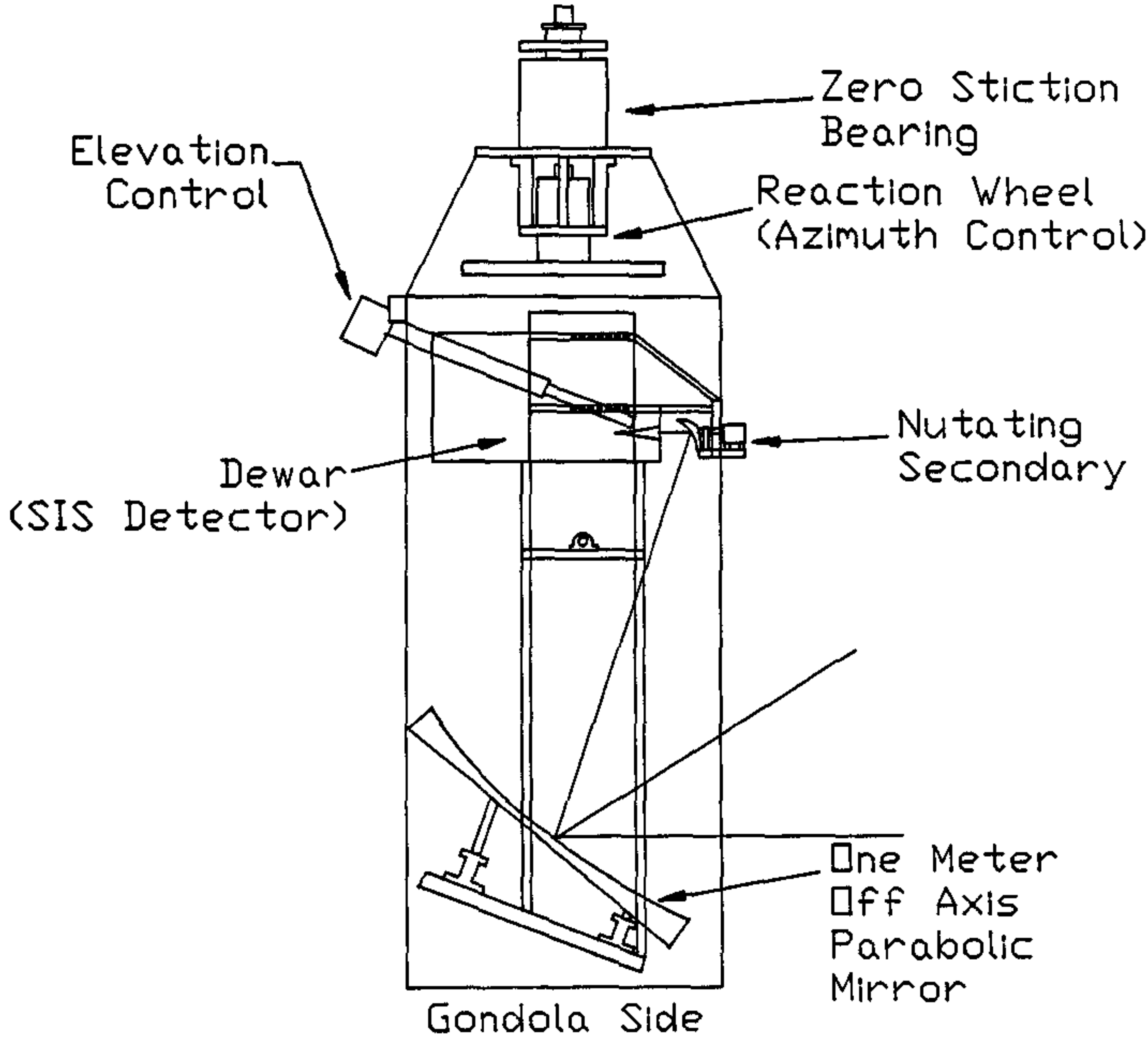

Zero Stiction
Bearing
Elevation
Control
Reaction Wheel
(Azimuth Control)
Nutating
Secondary
Dewar
(SIS Detector)
One Meter
Off Axis
Parabolic
Mirror
Gondola Side

FIGURE 4.

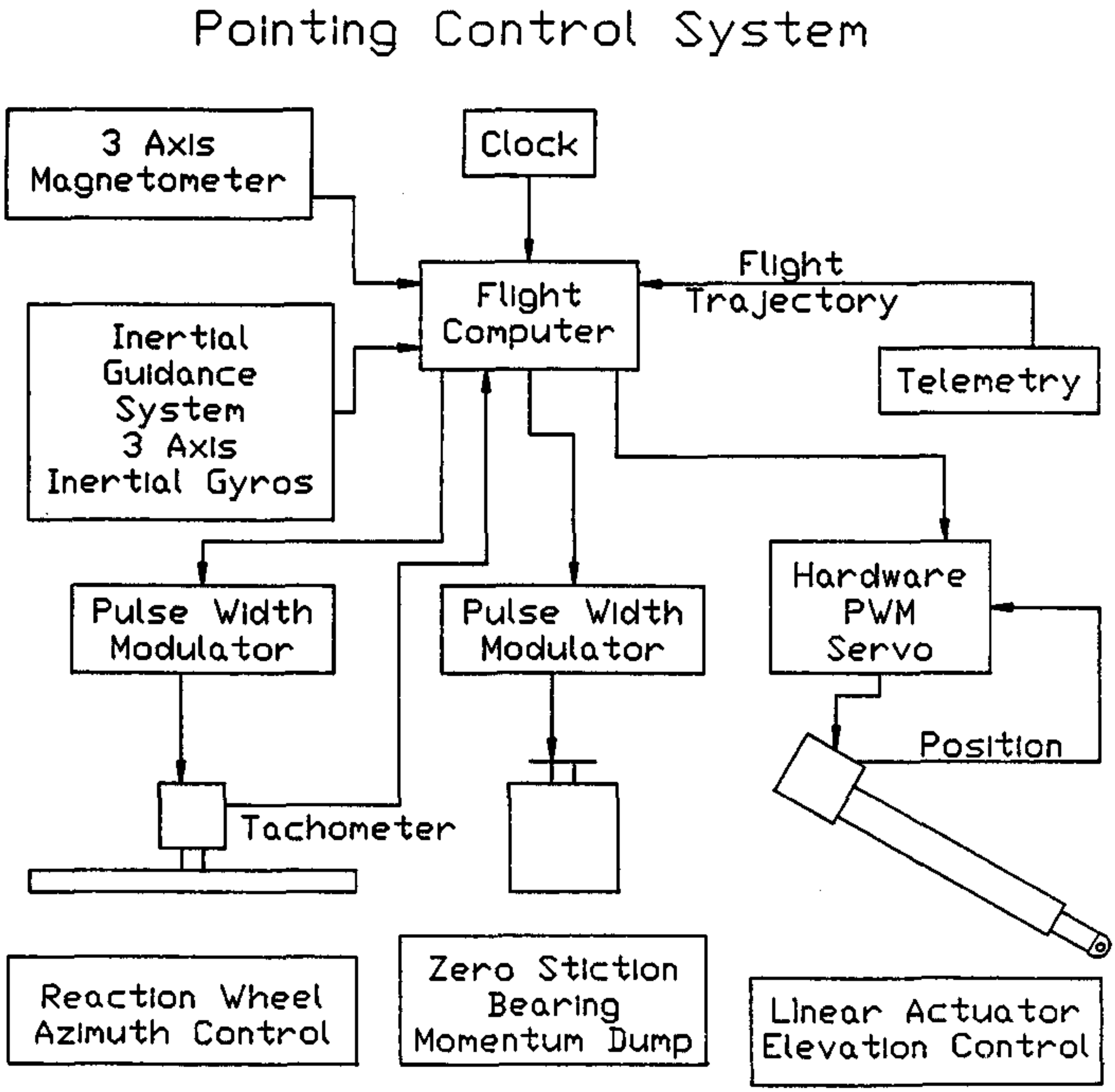
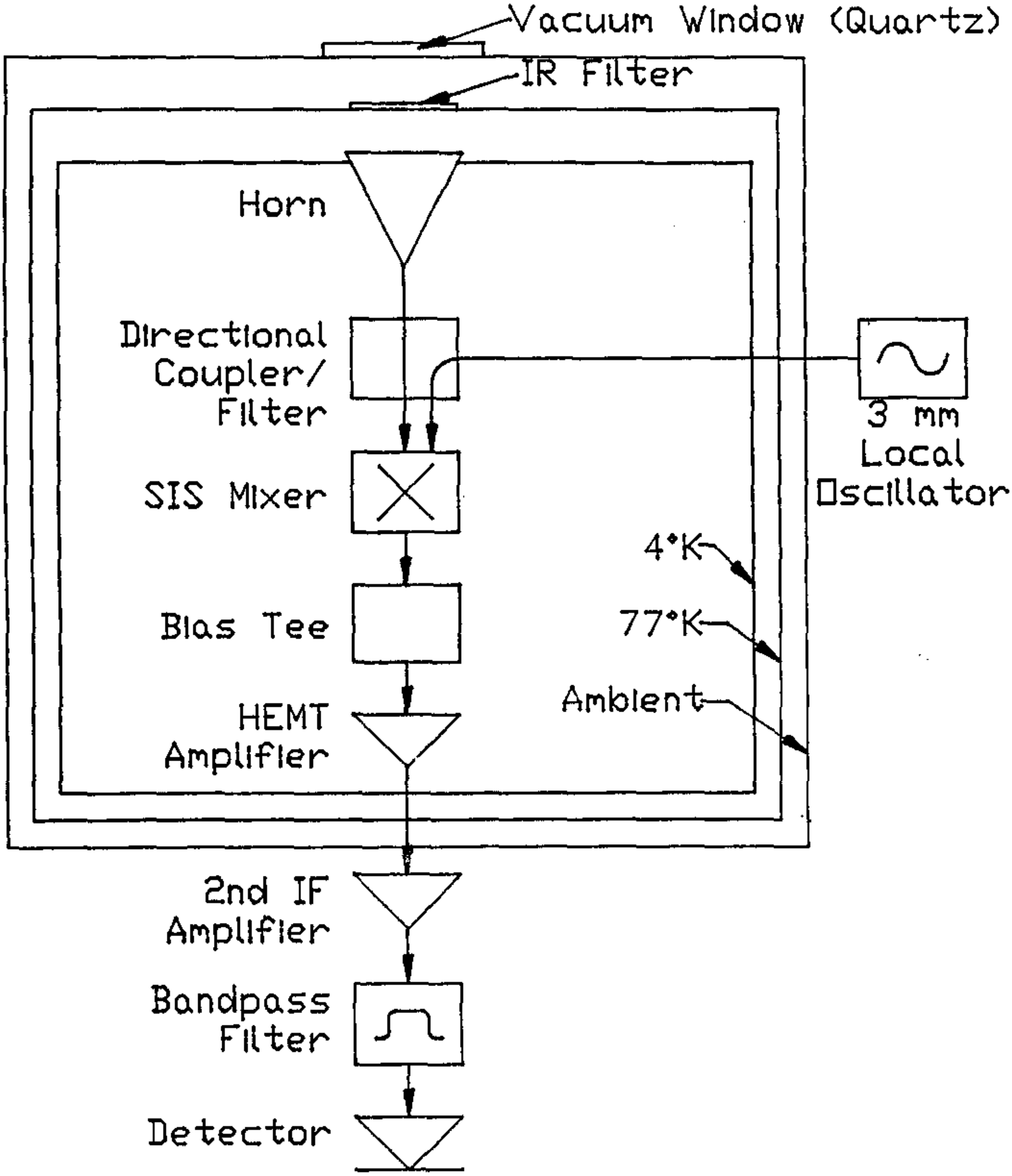

Pointing Control System
3 Axis Magnetometer
Clock
Flight Computer
Flight Trajectory
Telemetry
Inertial Guidance System 3 Axis Inertial Gyros
Pulse Width Modulator
Pulse Width Modulator
Hardware PWM Servo
Position
Tachometer
Reaction Wheel Azimuth Control
Zero Stiction Bearing Momentum Dump
Linear Actuator Elevation Control

FIGURE 5.



Vacuum Window (Quartz)
IR Filter
Horn
Directional
Coupler/
Filter
SIS Mixer
Bias Tee
HEMT
Amplifier
3 mm
Local
Oscillator
4°K
77°K
Ambient
2nd IF
Amplifier
Bandpass
Filter
Detector