AN AIRCRAFT RADIOMETER FRONT END

Report No. TR080
Final Report Addendum
JPL Contract No. 954492

Prepared for:

JET PROPULSION LABORATORY
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ABSTRACT

This report gives a detailed description of a completely quasi-optical aircraft radiometer for use at frequencies of 150 GHz and above. The radiometer calibration and beam switching is described as well as a reflection isolator utilizing a reciprocating mirror and a quasi-optical local oscillator injection system. Receiver applications and performance levels are also given.

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1.0 INTRODUCTION

The following report describes an aircraft radiometer constructed for airborne atmospheric limb sounding programs at JPL. The receiver has been in operation since 1976 with numerous flights on the NASA CV-990 and C-141 aircraft where it was used to study rotational spectra in airborne radio astronomy and the measurement of atmospheric constituents. This report treats the portion of the receiving system in front of the first I.F. amplifier stage. This portion of the system was designed and constructed by J.J. Gustincic under contract to JPL. The system has primarily been used with klystron local oscillators and waveguide type Schottky Barrier mixers provided by A.H. Kerr (GISS). Some high frequency measurements were made with this system above 240 GHz by replacing the klystron with a carcinotron local oscillator system provided by T.H. de Graauw (ESTEC) and quasi-optical Schottky mixers developed at JPL.

Rotational spectra of interest are generally at frequencies in the range between 150 and 1000 GHz and the receiver was designed to be quasi-optical so as to provide the maximum flexibility for use at these high frequencies.

At frequencies above about 150 GHz, it becomes difficult to construct receiving systems with the waveguide technology so well developed at the lower frequencies. High ohmic loss per unit length and close physical tolerance requirements produce real practical limitations on the fabrication of waveguide devices, which have dimensions that are necessarily fractions of a wavelength. At these higher frequencies it has been demonstrated that most microwave network functions can be accomplished quasi-optically. The quasi-optical techniques basically involve operations with diffraction limited beams a few tons of wavelengths in diameter. Since the energy in such beams does not interact with any guiding structure, transmission losses are non-existant. Furthermore, the effect of imperfections in quasi-optical devices such as beam splitters, lenses, etc., tend to be averaged over the large beam area yielding reduced local tolerance requirements. Generally speaking, quasi-optical devices tend to be simpler to construct since their dimensions are large compared to the operating wavelength. The receiver described in the following sections represents a typical application of the quasi-optical design philosophy.

2.0 GENERAL RECEIVER DESCRIPTION

A schematic diagram of the quasi-optical receiver is shown in Fig. 1. Basically the receiver receives energy in a 5°, 3 db beamwidth from either a horizontal signal beam or a sky beam at 30° elevation depending on the position of the switching mirror. In operation the switching mirror nutates at a 4 Hz rate and synchronous detection is used to compare the signal and sky beam energies. A moveable mirror is provided to switch all or a portion of the sky beam over to a liquid nitrogen cold load for balance and calibration purposes. A 50°C heated load is also provided for low level calibrations. In this case an ambient load is lowered over the signal beam and the switching mirror nutates between the ambient load and hot load to yield a 27°K calibration signal. The moveable ambient load and heated load can be seen above and below the signal beam opening in Fig. 2.

After leaving the switching mirror the energy to be received by the radiometer travels to the signal mixer via reflections from a reciprocating mirror and a local oscillator injection resonator. The energy is focused into the mixer by means of a teflon lens one inch in diameter. The reciprocating mirror is a flat surface which vibrates back and forth and serves the function of averaging the effects of energy which leaves the mixer and returns via an unwanted reflection from the switching optics or aircraft window. The standing wave from such reflections can exhibit itself as spurious spectral features in the radiometer baseline.

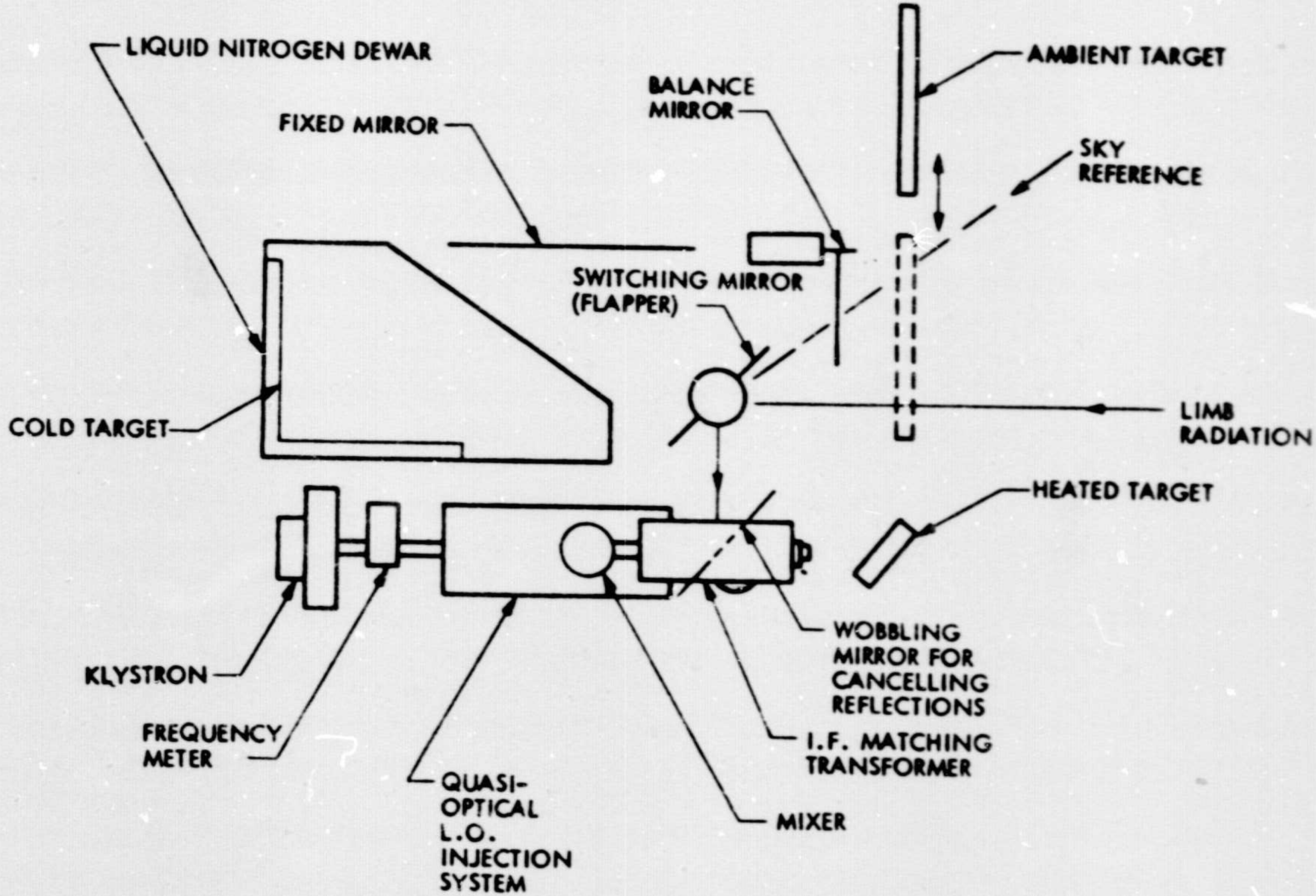

Figure 1-A. Arrangement of the receiver components.

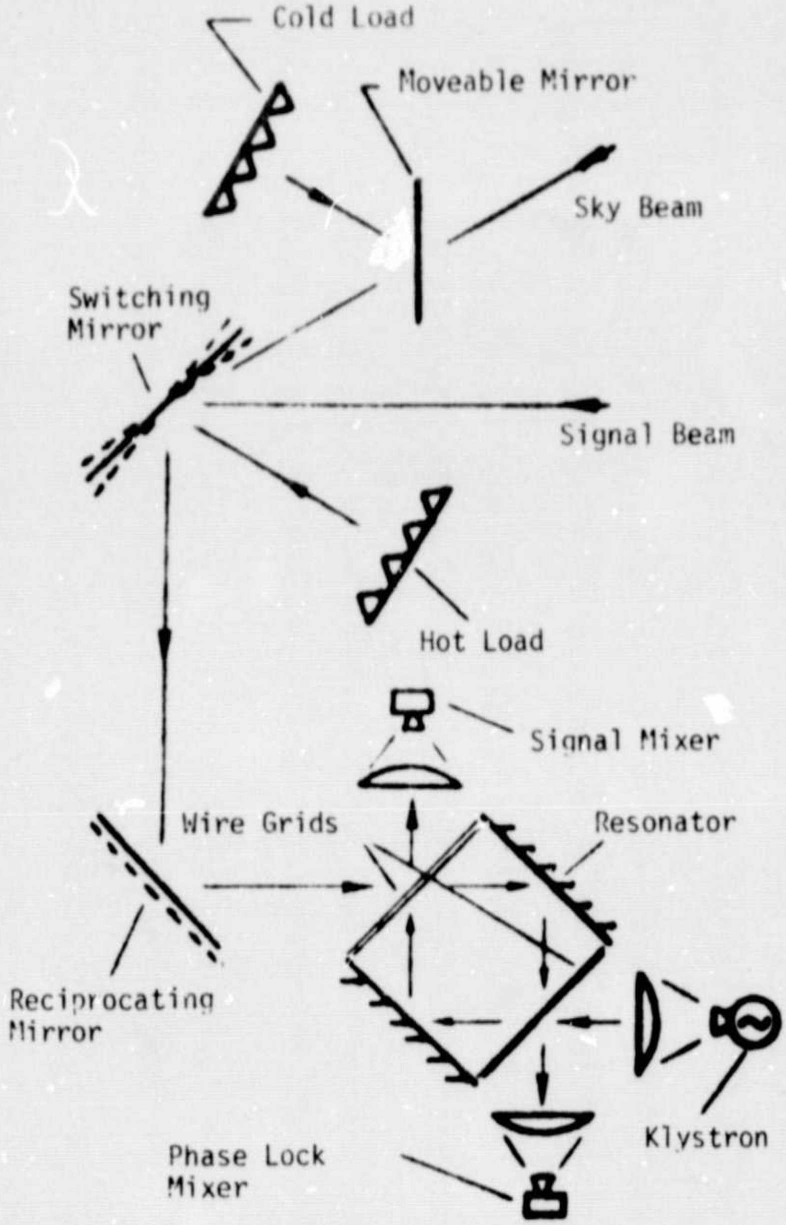

FIGURE 1-B

Schematic diagram of the receiver operation.

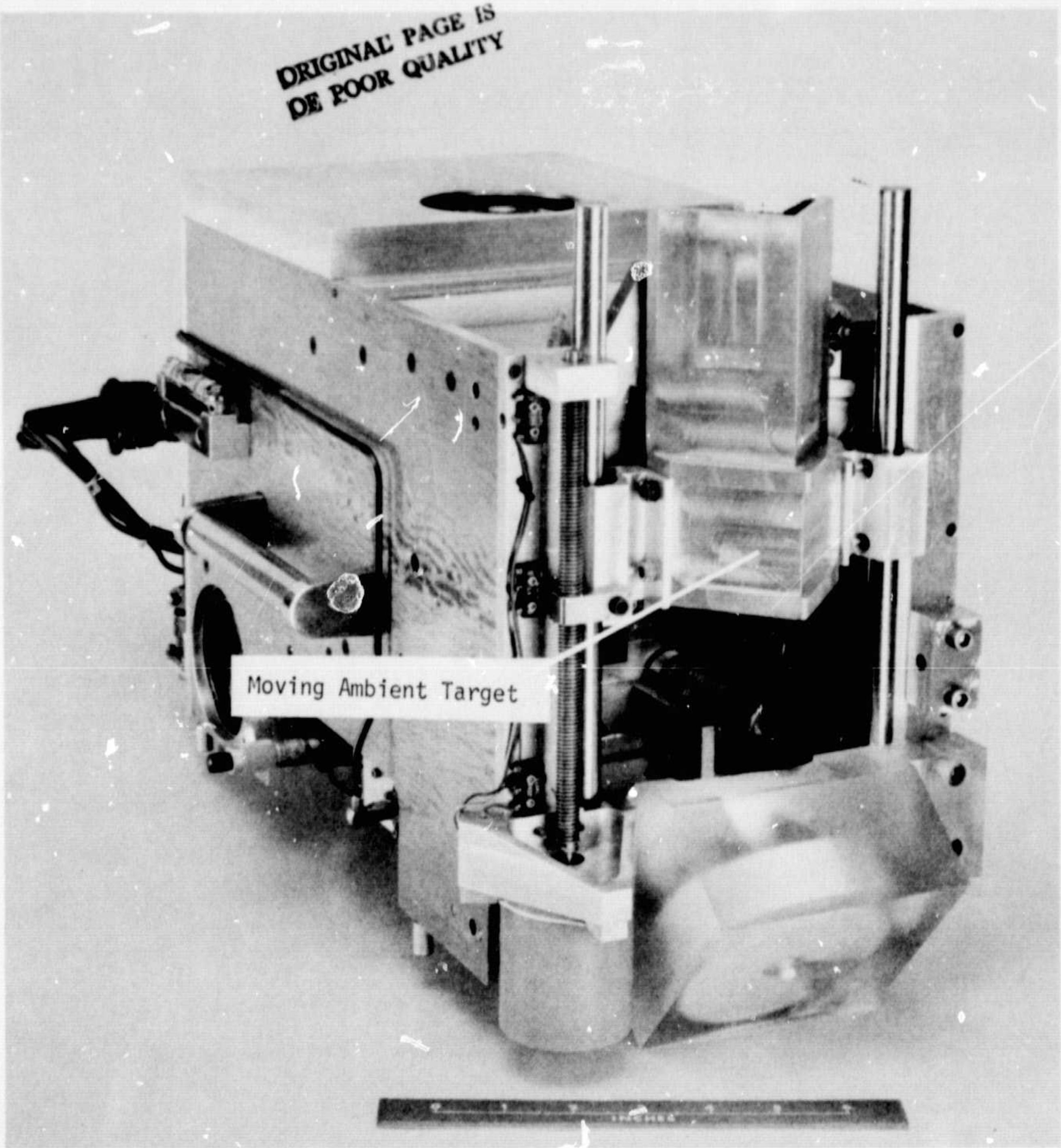

Figure 2. Front view of the aircraft receiver.

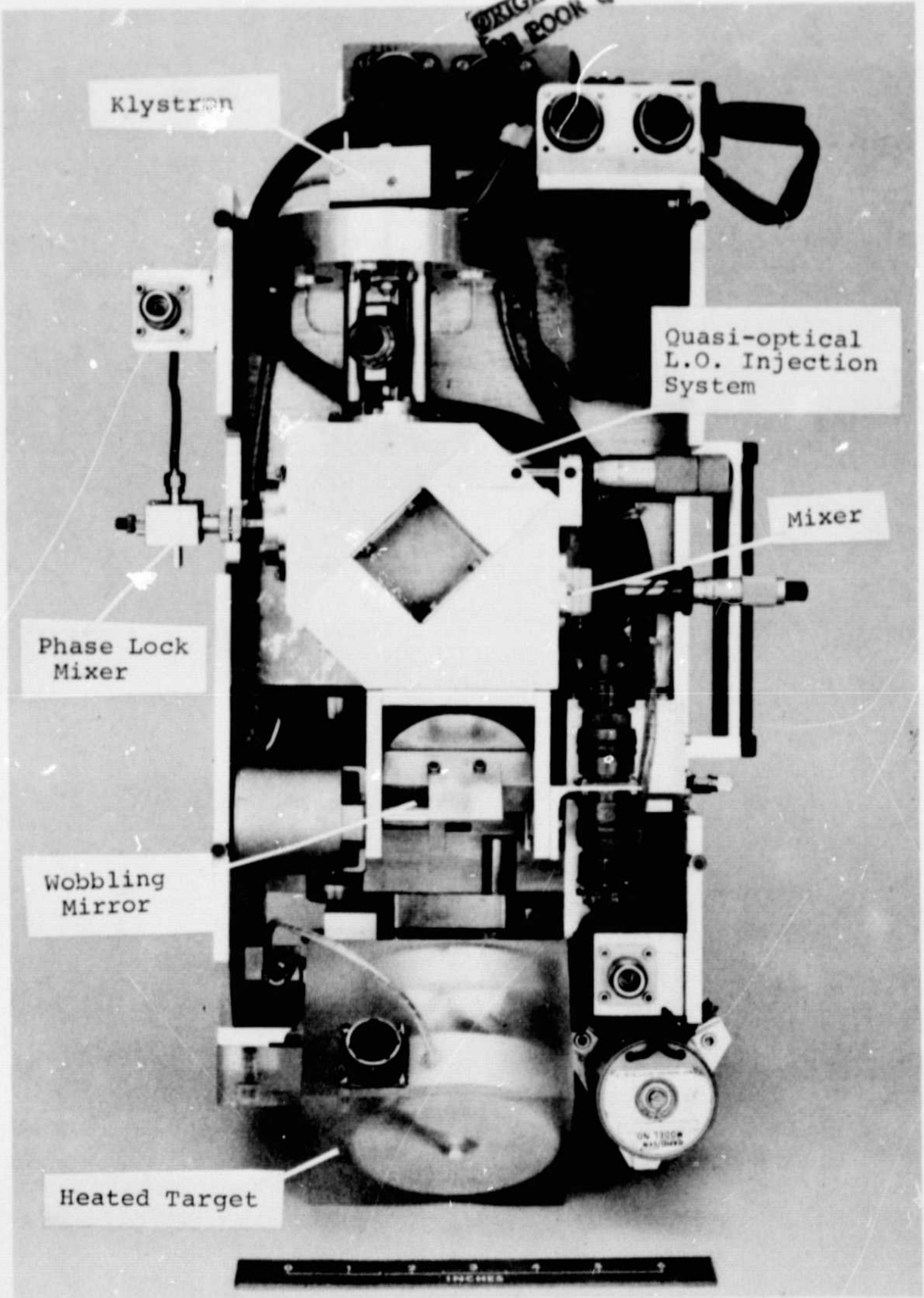

Figure 3. Bottom view of the aircraft receiver.

The local oscillator injection system is a folded Fabry-Perot resonator. This device is a quasi-optical analog of the waveguide ring coupler commonly used for local oscillator injection at the lower frequencies. It serves the purpose of filtering the noise from the klystron and diplexing the local oscillator and signal energies into the Schottky mixer.

Energy is leaked from the klystron to a hormonic mixer used for phase locking by means of a quasi-optical variable power divider. The klystron horn is rotated through an appropriate angle to generate cross-polarized energy which is reflected from a wire grid into the phase lock mixer. Fig. 3 shows the arrangement of these components at the bottom of the receiver.

3.0 DESCRIPTION OF RECEIVER COMPONENTS

The various components of the receiving system are described in the following sections.

3.1 THE FLAPPING MIRROR

Beam switching in the radiometer is accomplished by means of the flapping mirror. The mirror is a 4" x 2.5" polished aluminum plate mounted directly to the shaft of a stepper motor. The motor was 15° steps so that the mirror can be made to switch back and forth between two positions with a 15° angular displacement. This produces beam switching with a 30° angular displacement, which is sufficient to generate the required physical separation of the beam positions. In operation the mirror is switched between adjacent positions at a 10 Hz rate. Acceleration and braking pulses are applied to the stepping motor to produce a fast switching time. It is estimated that less than 10% of the switching cycle is spent in moving between the two switch positions. The flapping mirror provides an extremely compact means of switching the 2" diameter beam without introducing the knife edge diffraction and large physical size requirements of a chopper wheel system.

3.2 THE RECIPROCATING MIRROR

The wobbling or reciprocating mirror provides quasi-optical isolation of the radiometer from reflections. The mirror is a 2" diameter polished aluminum disc driven back and forth by a motor with an eccentric crank. The operation of the mirror can be described by considering the voltage at the mixer diode to be of the form

$$v_d = V_o \left[1 + R\ e^{-j(2kL-\phi)} \right] \tag{1}$$

where V_o is the diode voltage amplitude and $R\ e^{j\phi}$ is the undesireable reflection coefficient from the aircraft window. L is the additional one-way path length introduced by moving the reciprocating mirror from its center position. The mirror is constructed so that this path length varies sinusoidally with time, i.e.,

$$L = \frac{d}{\sqrt{2}} \quad \sin wt \tag{2}$$

where d is the peak-to-peak excursion of the mirror and the 45° mirror incidence angle has been taken into account. The power received by the radiometer is then proportional to

$$|v_d|^2 \cong |v_o|^2 \left[1 + 2R \cos(2kL-\phi) \right] \tag{3}$$

The time average power, averaging over many cycles of the reciprocating mirror is then

$$|\overline{V_d}|^2 = |\overline{V_o}|^2 \left[1 + 2RJ_o\left(\sqrt{2}kd\right) \cos\phi\right] \qquad (4)$$

Now by choosing the mirror displacement d so as to make the Bessel function in Eq. (4) vanish, the received power can be made independent of the frequency sensitive phase ϕ thereby stabilizing the radiometer baseline. Measured improvements of at least a factor of four in baseline power fluctuations have been observed with the reciprocating mirror.

3.3 THE BALANCE MIRROR

The balance mirror is a 3" long diamond shaped polished aluminum plate which is mounted directly on the shaft of a small D-C gearhead motor. By energizing the D-C motor the balance mirror can be driven down to occlude all or part of the sky reference beam. Micro-switch stops are provided at the two ends of the mirror travel to turn off the motor and generate reference beam "open" and "closed" indicator light signals. In operation the D-C motor can be energized by a jog switch which allows the mirror to be manually placed so that the signal and reference beams have the same average temperature. An automatic balance mode is also implemented in which the D-C motor is energized from a servo loop, which is set to minimize the average temperature between the signal and reference beam.

3.4 THE MOVING AMBIENT TARGET

A moveable ambient target is provided which can be used to cover the sky reference beam or the sky reference beam and signal beam together. This moveable load can be seen in Fig. 2. It is driven up and down in front of the receiver openings by means of a stepping motor and worm screw drive. Three micro-switches are arranged so as to sense and indicate the three possible positions of the load. The load itself is constructed from Emerson and Cuming AN-72 absorber material cemented to the V-shaped aluminum structure seen in the Photo. The angle of the V was designed so that only multiple absorber reflections can occur yielding an extremely "black" load.

3.5 THE QUASI-OPTICAL L.O. INJECTION SYSTEM

The operation of the L.O. injection cavity can be understood by referring to Fig. 1-B. Energy from the local oscillator is collimated by the teflon lens and impinges on the resonator at a 45° angle. In a manner analogous to that of a waveguide ring coupler, the energy resonates around the four walls of the cavity and finally exists into the signal mixer via a second lens. At the signal frequency the cavity is anti-resonant and the signal energy reflects from the cavity with very little loss. The cavity is tuned by mechanically varying its diagonal dimension. The cavity was designed for I.F. center frequencies which are odd multiples of 1.4 GHz. Signal loss of less than 0.5 db, local oscillator injection loss of 3-6 db and local oscillator noise rejection of -15 db have been measured on this device at 186 GHz.

The entrance and exit walls of the cavity are made up of partially reflecting wire mesh grids. The grids are replaceable so that the receiver can easily be modified to operate over any desired frequency band. The system has been used at 380 GHz with the installation of the appropriate grids.

3.6 THE COLD TARGET

A cold target is provided in the system by means of a styrafoal Liquid Nitrogen Dewar. The Dewar was constructed by cementing 1" thick foam walls together with epoxy. The target was then formed by cementing Emerson and Cuming AN-72 load material down into the Dewar as shown in Fig. 1-A. The arrangement again provides for multiple absorber reflections to ensure high absorptivity. A fan is mounted in the receiver case in such a position so as to blow ambient air over the slanted foam face of the Dewar through which the radiation from the target must pass. The fan prevents undesireable condensation of moisture on this surface. The Dewar holds approximately two liters of Liquid Nitrogen for about four hours.

3.7 THE HEATED TARGET

A heated target is included in the receiver to provide an accurate low level calibration signal. In operation the load is heated to about 50°C by means of resistive heating elements. The temperature is sensed by means of thermistors and maintained at a constant level by means of an external temperature controller. The load was constructed by cementing Emerson and Cuming AN-72 load material to the inside of a machined aluminum cone. Again the conical load design produces multiple absorber reflections as with the other load designs in the receiver. The heating elements are cemented to the outside of the cone and the load is encapsulated in the plastic insulating mount which can be seen in Fig. 3. The remaining empty volume in the inside of the cone is filled with styrafoam to ensure the load loses heat as slowly as possible.

4.0 APPLICATIONS

The receiver was primarily designed for atmospheric limb sounding measurements from the NASA CV 990 aircraft. The photograph of Fig. 4 shows the actual mounting of the receiver at the side window of the airplane. The receiver is supported on brackets mounted to an aluminum plate which is bolted down to the top of the standard CV 990 low-boy rack. The mount is designed so that the look-angle of the receiver can be varied from 0 to 20° in elevation by tipping the entire receiver relative to the mounting brackets. A bubble level is permanently mounted to the side of the receiver to provide a horizon reference during flight. A small battery operated bias supply for the Schottky mixer can be seen mounted to the very back of the receiver. The 1.4 GHz 50°K parametric I.F. amplifier can also be seen in the temperature controlled box mounted with the receiver on the top of the low-boy rack.

In operation the receiver looks out through a 2" thick high density polyethylene window. The window has matching grooves machined into its inboard surface. The window had a measured total insertion loss of about 10% at 164 GHz and a loss of about 30% at 380 GHz.

Accurate system temperature measurements were made on the receiver unit as a whole by performing hot-cold temperature measurements looking into an absorbing load contained in a foam Liquid Nitrogen Dewar completely external to the receiver.

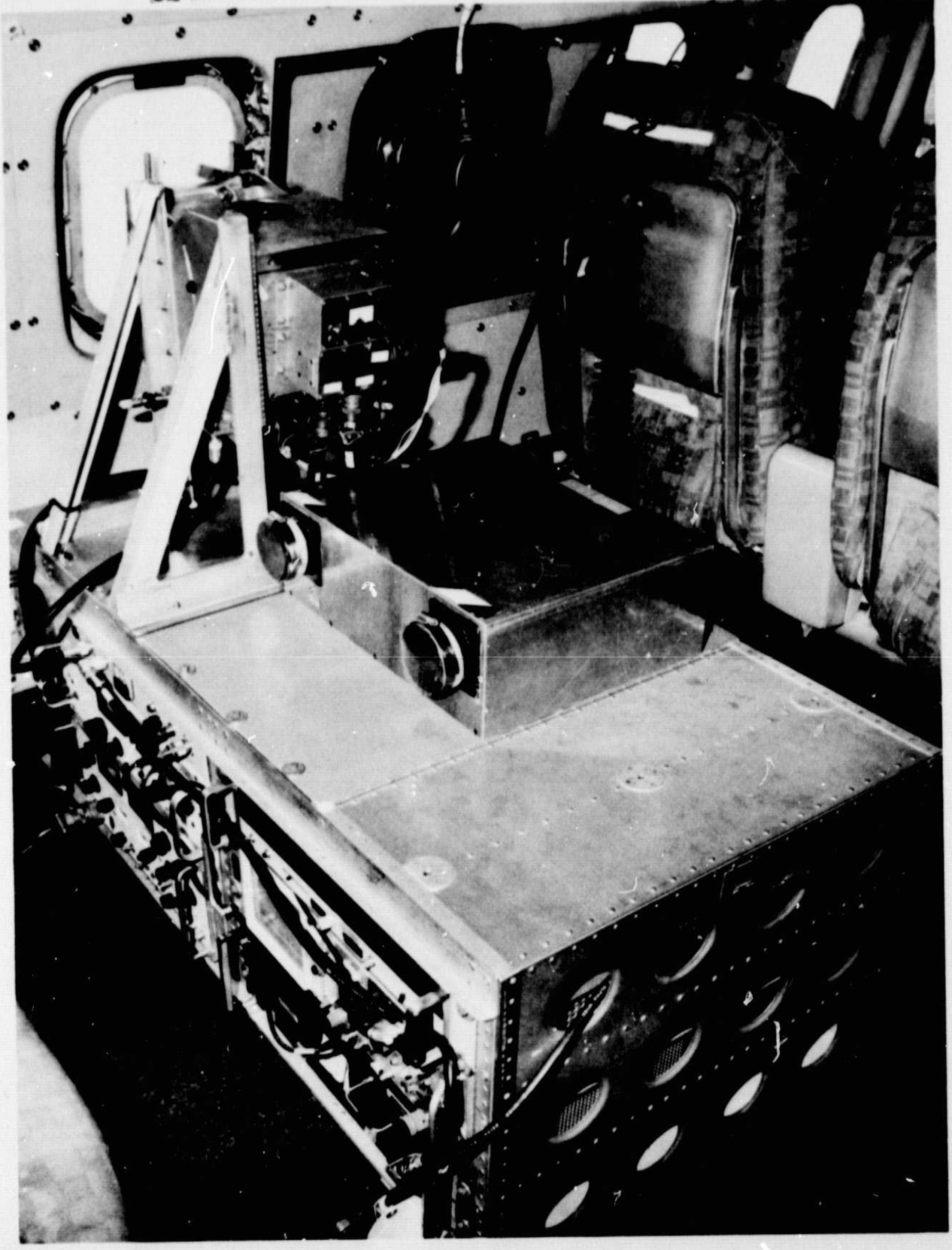

Figure 4. Installation of the receiver st the side window of the NASA CV-990 aircraft.

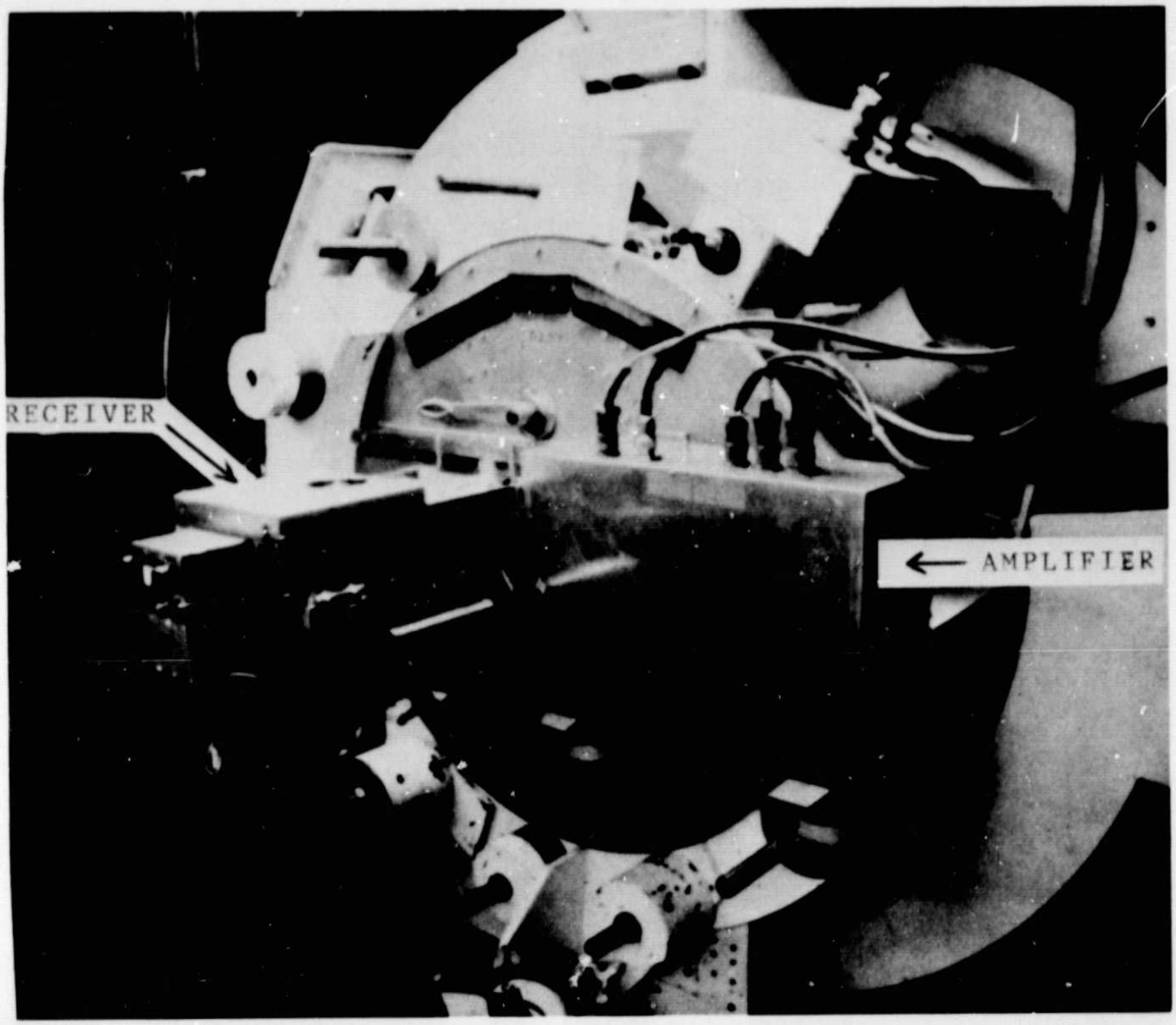

Figure 5. Installation of the receiver on the NASA C-141 KAO telescope.

Typical Single Sideband noise temperatures between 2000 and 4000°K were measured over the frequency range from 167 to 183 GHz.

The receiver was also mounted on the NASA C-141 Kuiper airborne observatory. Fig. 5 shows the installation on the 1 meter diameter aircraft telescope. The telescope optics subtend an angle of 4°, and therefore require a narrowing of the receiver beam. This was accomplished by mounting a 2.5" diameter polyethelyne lens between the receiver and the telescope. The receiver and auxiliary lens combination then received energy in a beam with a 3 db width of 1.75°, yielding an acceptable illumination of the telescope optics. The system was used extensively for observations of interstellar water vapor at 183 GHz.

5.0 CONCLUSIONS

The configuration of a versatile radiometer front end has been described. It has been demonstrated that a complete quasi-optical beam switching system can be constructed in a rugged and compact form suitable for use in aircraft experiments.

6.0 NEW TECHNOLOGY

No reportable items of new technology have been identified in the work described in this report.