A QUASI-OPTICAL RECEIVER DESIGN

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Abstract

The design of a completely quasi-optical 1.5 mm aircraft radiometer receiver is discussed in detail. The radiometer beam switching is described as well as a reflection isolator utilizing a reciprocating mirror. A quasi-optical local oscillator injection system using a Folded Fabry-Perot resonator is described and receiver performance levels given.

Introduction

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 tens 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. Interesting design problems do exist due to diffraction of the quasi-optical beams and the difficulties encountered in focusing the beam energy down into semiconductor devices. The following paper describes the details of a 1.5 mm aircraft radiometer receiver which was designed using quasi-optical techniques exclusively. The receiver is presently being used at the Jet Propulsion Laboratory for radio astronomy and the measurement of atmospheric constituents.

Receiver Description

A schematic diagram of the quasi-optical receiver is shown in Figure 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 Figure 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.

The local oscillator injection system is a novel 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. Figure 3 shows the arrangement of these components at the bottom of the receiver.

The Folded Fabry-Perot Injection Cavity

A photograph of the local oscillator injection cavity is shown in Figure 4. Also shown are one of the teflon lenses and a quasi-optical mixer mount previously described in reference (1). This biconical mixer is presently under study for use in the receiver over the frequency range 180-270 Ghz.

The operation of the cavity can be understood by referring to Figure 1. 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 resonator is also being used successfully in a receiver development program at 671 Ghz.

The Reciprocating Mirror

The reciprocating mirror provides quasi-optical isolation of the radiometer from reflections. The operation of the mirror can be described by considering the voltage at the mixer diode to be of the form

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

where V_o is the diode voltage amplitude and $Re^{j\phi}$ 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.,

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

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

$$|V_d|^2 \cong |V_o|^2 \left[1 + 2R\cos(2kL-\phi)\right] \quad (3)$$

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

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

Now by choosing the mirror displacement d so as to make the Bessel function in (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.

The receiver has measured double sideband noise temperatures of 1000^oK at 170 Ghz. Baselines linear to within peak to peak fluctuations of 0.1^oK over a 100 Mhz bandwidth have been obtained switching between sky and signal beams while looking through a two inch thick polyethylene aircraft window.

Acknowledgments

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References

1. J.J. Gustincic, "A Quasi-optical Radiometer," Digest of the Second International Conference on Submillimeter Waves and their Applications, San Juan, Puerto Rico, December 6-10, 1976.

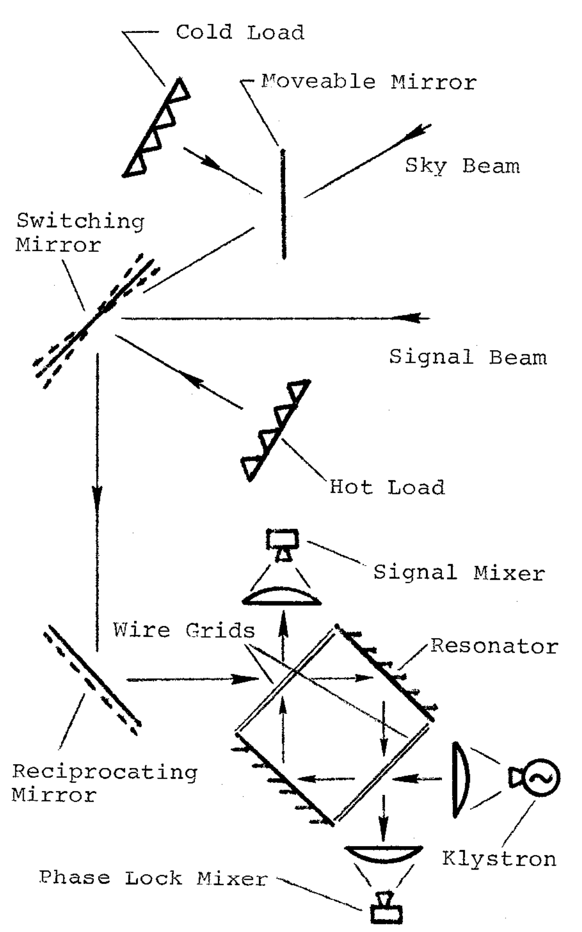

Fig. 1-A diagram of the quasi-optical receiver.

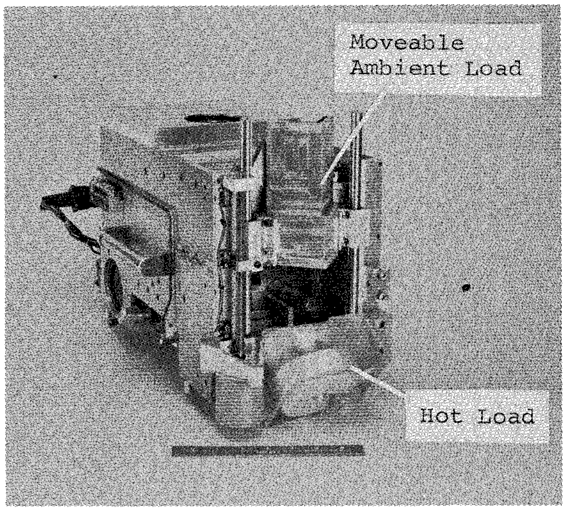

Fig. 2-Front view of the Receiver.

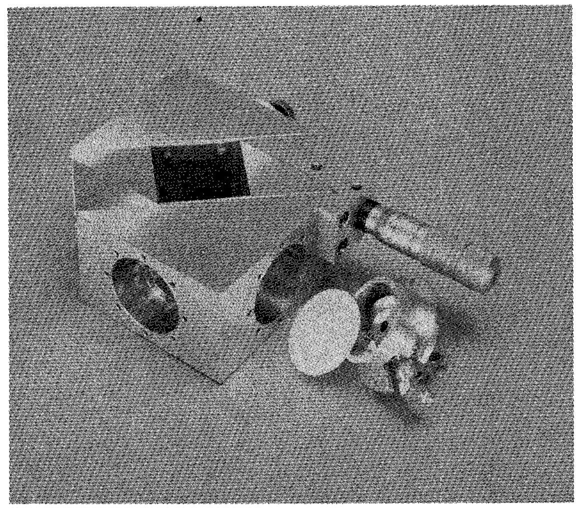

Fig. 4-The quasi-optical injection system and mixer.

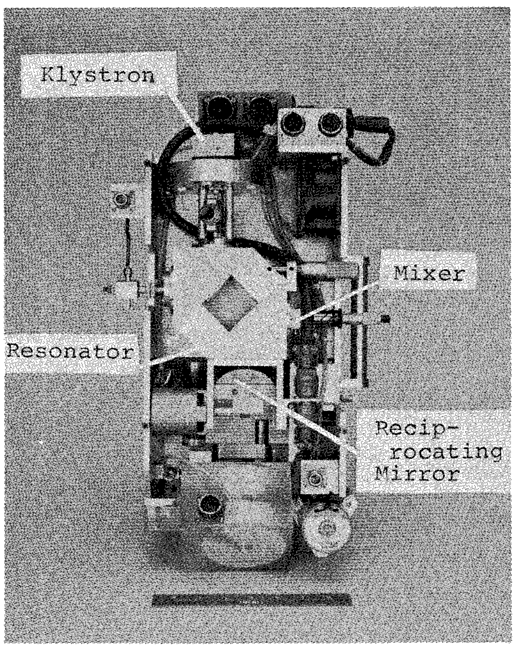

Fig. 3-Bottom view of the Receiver.