HIGH SENSITIVITY SUBMILLIMETER HETERODYNE RECEIVER*

H. R. Fetterman, P. E. Tannenwald, B. J. Clifton, C. D. Parker, W. D. Fitzgerald
Lincoln Laboratory, Massachusetts Institute of Technology
Lexington, Massachusetts 02173

N. R. Erickson
Department of Physics, University of California
Berkeley, California 94720

ABSTRACT

Radiometric sensitivity measurements have been made on a quasi-optical receiver in the spectral range 170 μm to 1 mm. Using GaAs Schottky mixer diodes in a corner reflector configuration, a total system noise temperature of 9,700 K (DSB) has been obtained at 447 μm. This same quasi-optical mixer has also been used for harmonic generation of tunable radiation suitable for spectroscopic applications.

Introduction

Recent developments in plasma physics, radio astronomy, frequency standards and in satellite-based mapping have created a need for fast, sensitive far infrared detectors. Several groups have been studying the use of GaAs Schottky diode heterodyne receivers using either conventional waveguide[1] or quasi-optical approaches.[2] The actual performance levels that have been achieved at frequencies above 300 GHz have not been comparable with those obtained at millimeter frequencies. We report here the results of radiometric determinations of noise equivalent powers of a new system in the wavelength range of 1 mm to 170 μm. At a frequency of 670 GHz the highest sensitivity (1.4×10^{-19} W/Hz DSB) to date has been obtained. The quasi-optical Schottky diode mixer that was used in the heterodyne receiver was also used as a high-order harmonic generator of tunable submillimeter radiation. Application of this tunable source to spectroscopic problems was demonstrated. These measurements open up new possibilities for far infrared and submillimeter experiments which require extremely high sensitivities.

Experimental System

The experimental system used in these measurements is essentially a Dicke type radiometer which mixes a laser local oscillator (LO) with a black body whose radiated power is solely a function of its temperature. Illustrated in Fig. 1, the system consists primarily of the following components: 1) corner-reflector diode mount, 2) ellipsoidal coupling mirror, 3) a quasi-optical diplexer, 4) laser local oscillator and 5) low temperature absorber. The GaAs Schottky diode mounted in the corner reflector was developed especially for high frequency applications and has been discussed elsewhere.[3] The diodes are typically 1 μm in diameter, have 1.5×10^{-15} F capacitance and a series resistance of 45 Ω.

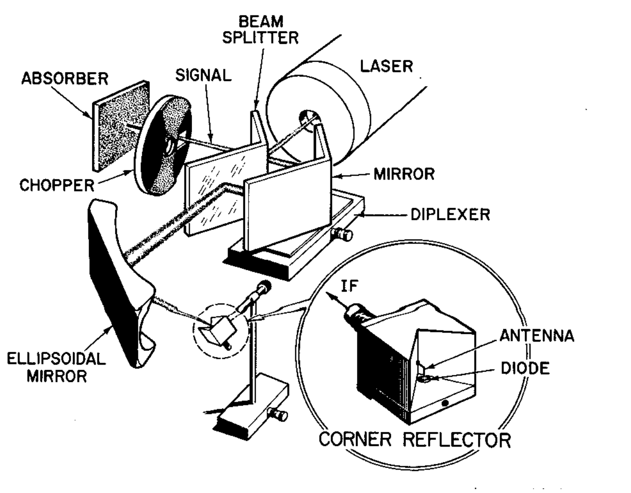

Figure 1: Quasi-optical radiometer operating between 170 μm and 1 mm. Inset shows details of corner-reflector mixer.

A quasi-optical approach for the mixer was adopted because of the physical difficulties of embedding a diode in a fundamental waveguide at these frequencies. The approach taken, first proposed for the submillimeter by Sauter and Schultz,[4] uses a long--typically four wavelengths--traveling wave-line source set in a corner reflector. The line source is an extended "whisker" point-contacted to the Schottky diode. Impedance and radiation characteristics are determined by the length of the line source, the corner angle, and the separation between line source and corner. Kräutle, et al.[5] calculated theoretically and demonstrated experimentally the relative magnitude of the gain of a traveling wave antenna with corner reflector vs antenna alone to be 12 dB. However, in their experimental setup at the time the overall conversion loss was relatively high (29.5 dB).

In order to optimize a corner reflector mount we have carried out 100 times scale modeling experiments at 6 to 8 GHz. One design, similar to Kräutle, et al., which looked promising for actual submillimeter construction, is a 90° corner cube (i.e., a 90° corner reflector with a ground plane) with a 4λ antenna length spaced 1.2λ from the corner. The beam pattern obtained from the modeling is shown in Fig. 2. The principal lobe is seen to be at an angle of 25°

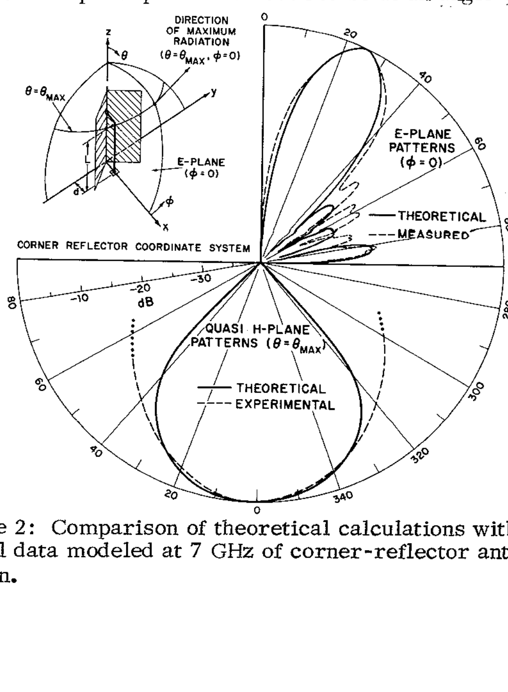

Figure 2: Comparison of theoretical calculations with experimental data modeled at 7 GHz of corner-reflector antenna pattern.

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to the antenna, and has a roughly elliptical cross-section of beam width 14° x 38° (full width at 3 dB points).

The local oscillator and a corresponding mode from the black body (Eccosorb AN-72) at liquid nitrogen temperature were coupled to the mixer utilizing a diplexer. This diplexer was essentially a folded, double interferometer, similar in principle to that used by NRAO[6] and Erickson,[7] but made specifically for the 0.4 mm wavelength region. The beam splitters are 3 mil mylar stretched over machined reflector mounts and gave roughly 50% transmission. An extremely short focal length, right angle, ellipsoidal mirror was used to match the transmitted signal and LO to the antenna pattern of the diode. With this system virtually all of the signal and better than 90% of the LO were transmitted to the detector.

The local oscillators consisted of optically pumped far infrared lasers of standard waveguide design[8] for the submillimeter, and a carcinotron for 1 mm. The laser LO was pumped by a free-running, stable CO_2 laser of about 50 W and had an output power of about 30 mw. This was found sufficient to saturate the mixer diode at all but the 170 μm line. The identity of each LO line was unambiguously determined by using the diplexer as an interferometer; tuning through approximately 10 interference maxima allowed a wavelength measurement to 0.5% accuracy.

Radiometric Measurements

The results of our first measurements are summarized in Table 1. Although the mixer was designed along with the rest of the system for approximately 400 μm, several tests were made at both longer and shorter wavelengths to estimate the potential performance. The rectified I. F. signal was read on a digital voltmeter, and the difference in voltages between the hot (room temperature absorber or chopper) and cold absorber synchronously detected. The amplifier had a measured noise temperature of 245 K (2.6 dB). A standard Y-method interpretation of the data then yielded the results shown in the table.

The conversion loss was both calculated from the expression $T_{sys} = T_{mixer} + L_c T_{IF}$ and measured directly by changing the temperature of the IF input resistor and comparing this with the signal produced by a known ΔT applied to the optical input of the radiometer. In general, the diode noise temperature was near R. T., and the LO added approximately 100 K excess noise. The diode noise temperatures were measured with an isolator inserted between the diode and the IF amplifiers to reduce the effects of changing impedances. Total system noise temperatures were measured without the isolator and are listed in the fourth column. The best values obtained are given, but variations from diode to diode and mount to mount were typically only about 1000 K.

Table 1

λ (μm)	Frequency (GHz)	Total Systems Noise Temp. (DSB) (K)	Mixer Temp. (K)	Conversion Loss (dB)
946	316.9	13,000	7,800	12.8
447.1	670.5	9,700	5,900	11.6
432.6	692.9	13,100	6,900	11.9
419.6	716.2	13,000	6,800	11.9
393.6	761.6	14,500	7,600	12.3
170.6	1757.5	370,000*	--	--

*Diplexer not working at this wavelength

Tunable Sources

Our current results suggest some immediate applications of this technology to the generation of tunable radiation. In one such experiment we have investigated the use of these diode mixers as high-order harmonic signal sources. A 37 GHz GaAs Gunn oscillator coaxially fed a mixer diode which then generated various harmonics. The 20th harmonic at 761 GHz was then detected by a second diode mixer in our standard heterodyne receiver configuration. This solid state source coupled with the rugged harmonic mixer provided a compact, stable, tunable source of about 5×10^{-11} W in the submillimeter. Because of the sensitivity of our heterodyne receiver, the observed S/N exceeded 35 dB on a spectrum analyzer having a 100 kHz bandwidth. This source-detector system is now being used for high-resolution submillimeter spectroscopic experiments.

Conclusion

We have demonstrated that sensitive detectors systems can be readily extended into the submillimeter and far infrared regime. These devices are now being introduced into specific applications in plasma diagnostics, radio astronomy and atmospheric spectroscopy.

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