A SIMPLE QUASI-OPTICAL MIXER FOR 100-120 GHz

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Abstract

An open-structure quasi-optical mixer for 100-120 GHz is described. The mixer uses a GaAs diode coupled to a cavity-backed two-slot radiator. The design should be usable to sub-millimeter wavelengths with appropriate frequency scaling, and should be suitable for cryogenic operation.

Introduction

At frequencies above 100 GHz construction of mixers using the established diode-across-waveguide configuration [1,2] becomes increasingly difficult because of the very small dimensions involved. New construction techniques have recently been reported [3,4] which result in high performance mixers up to ∿230 GHz, but these still require the fabrication of extremely precise waveguide structures.

Millimeter-wave mixers are frequently used as receivers on reflector antennas, and are located as close as possible to the focus of the antenna; coupling between the antenna and mixer is by a feed-horn and waveguide. The question arises of whether it is necessary to couple the energy from the antenna into a waveguide mode via a horn, and then from the waveguide into the mixer diode via the diode contact whisker across the waveguide, or whether the antenna-to-diode coupling can be accomplished more easily without the intermediate horn and waveguide. This *quasi-optical* approach to mixer design is the subject of the present paper, and the construction and performance of one such mixer is described.

Theory

At frequencies below a few GHz twin-dipoles above a ground-plane have long been used to feed paraboloidal reflectors. This configuration meets two important requirements: (i) it efficiently illuminates, in both E- and H-planes, a paraboloid with $f/d \simeq 0.4$, and (ii) the size of the ground-plane, provided it is larger than some small number of wavelengths across, has little effect on the radiation pattern of the feed. In principle the twin-dipole feed could be used at millimeter and submillimeter wavelengths with the mixer stage of the receiver integrated into the dipole structure. Practical considerations make it difficult to achieve this integration without inadvertently introducing additional radiating elements which severely perturb the desirable radiation pattern of the simple dipole-pair. The problem of this unwanted radiation from the mixer structure is overcome by using a slot radiator in a ground-plane--the mixer can then be constructed in microstrip above the ground plane.

A single slot in a ground-plane has two limitations when used as a feed for a paraboloid or lens: (i) its radiation patterns in the E- and H-planes differ widely [5] making efficient illumination of a circular aperture impossible, and (ii) its radiation pattern is strongly affected by the ground-plane size [5]. Both of these problems are overcome by using a two-slot radiator with the slots driven in-phase, as shown in Fig. 1. The E- and H-plane patterns can be well matched over ∿15% bandwidth by the choice of slot length and spacing. For spacings close to a half-wavelength the ground-plane currents beyond a few wavelengths from the slots are small, so the ground-plane size has little effect on the radiation pattern. Radiation from the rear of the ground-plane is prevented by a tuned cavity.

Coupling between the slots and the mixer diode is simply achieved using microstrip lines as shown in Fig. 2. Impedance matching between the diode and the slots can be controlled by three parameters, none of which has any appreciable effect on the radiation pattern. These are: the slot width, the cavity tuning, and the characteristic impedance of the $\sim\lambda/4$ transformers formed by the microstrip between the slots and the diode.

Construction

Details of the quasi-optical mixer are shown in Fig. 3. The ground-plane is gold on fused quartz, 0.007-in. thick. The slots are etched using standard photolithographic techniques, and the microstrip structure is likewise fabricated on 0.003-in. fused quartz. Microstrip A is glued to the ground-plane using epoxy adhesive, and the GaAs chip is soldered to its end. Microstrip B bearing the diode contact spring is then advanced towards the chip until contact is made. The process is monitored using a microscope, I-V curve tracer, and a capacitance bridge as described in Ref. 3. When contact is made with a diode, microstrip B is advanced an additional ∿2 microns to provide sufficient spring pressure, and then glued in place.* The whole structure is finally attached to the backing cavity using aluminum foil and conductive epoxy, and a coaxial IF and dc connection is made to the end of microstrip B.

The GaAs Schottky diodes used in this work were 2.5-microns in diameter, with $R_S \simeq 10$ ohms, $C_{j_o} \simeq 7.0$ fF, and ideality factor $\eta = 1.11$.

*Eastman 910 adhesive is used on microstrip B.

Performance

Initial measurements have been made using the quasi-optical coupling scheme shown in Fig. 4. The polarizing grid transmits half of the LO power to the mixer, and reflects half of the signal power to the mixer. The results below have been corrected for this factor of two loss, and give the figures which would be obtained with a good quasi-optical LO/signal diplexer such as a Michaelson interferometer [6]. Measurements were made using liquid nitrogen and room temperature RF loads, with the 1.4 GHz IF radiometer/reflectometer system described in Ref. 7. Single-sideband conversion loss and noise temperatures are given in Table I. The noise temperatures have been corrected for klystron noise in the upper and lower sidebands as the measuring system had no LO filter.

Conclusion

A simply fabricated quasi-optical mixer for the 100-120 GHz band has been described. Initial measurements indicate a conversion loss ∿3 dB worse than the best reported waveguide mixers at this frequency [2]. The basic design should be usable at sub-millimeter wavelengths with appropriate frequency scaling. Because a single structural material (quartz) is used, the design is expected to be suitable for cryogenic operation.

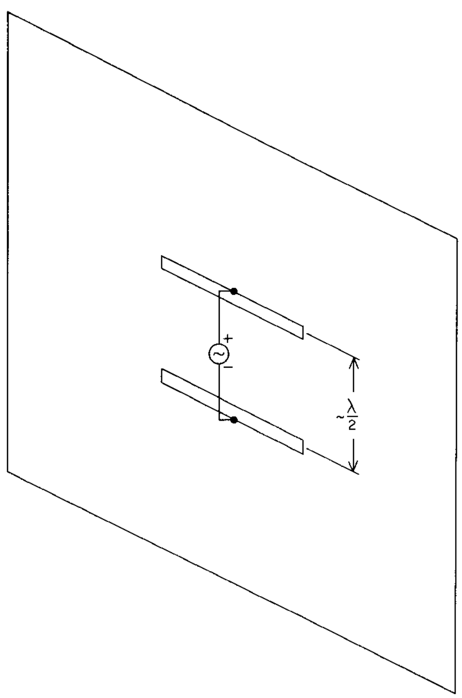

Fig. 1. Two slots driven in-phase. The ground-plane size does not affect the radiation pattern, which is determined by the slot length and spacing.

References

1. W.M. Sharpless, "Wafer-Type Millimeter-Wave Rectifiers," Bell Syst. Tech. J., vol. 35, pp. 1385-1402, Nov. 1956.

2. A.R. Kerr, "Low-Noise Room Temperature and Cryogenic Mixers for 80-120 GHz," IEEE Trans. Microwave Theory Tech., vol. MTT-23, no. 10, pp. 781-7, Oct. 1975.

3. A.R. Kerr, R.J. Mattauch and J.A. Grange, "A New Mixer Design for 140-220 GHz," to be published in IEEE Trans. Microwave Theory Tech., May 1977.

4. M.V. Schneider and W.W. Snell, "Harmonically Pumped Stripline Down-Converter," IEEE Trans. Microwave Theory Tech., vol. MTT-23, no. 3, pp. 271-5, March 1975.

5. J. Blass, "Slot Antennas," a chapter in "Antenna Engineering Handbook," H. Jasik editor, New York: McGraw-Hill, 1961.

6. D.H. Martin and E. Puplett, "Polarized Interferometric Spectrometry for the Millimeter and Sumbillimeter Spectrum," Infrared Physics, vol. 10, pp. 105-109, 1969.

7. S. Weinreb and A.R. Kerr, "Cryogenic Cooling of Mixers for Millimeter and Centimeter Wavelengths," IEEE J. Solid State Circuits, vol. SC-8, no. 1, pp. 58-63, Feb. 1973.

Table I

FREQUENCY	L dB SSB	T_M °K SSB**
90 GHz	10.8 dB	2400°K
100 GHz	9.8 dB	2200°K
112 GHz	8.6 dB	1000°K
114 GHz	8.6 dB	1300°K

**Figures for T_M are ± 500° because of the approximate correction for klystron noise. T_M does not include the IF amplifier contribution.

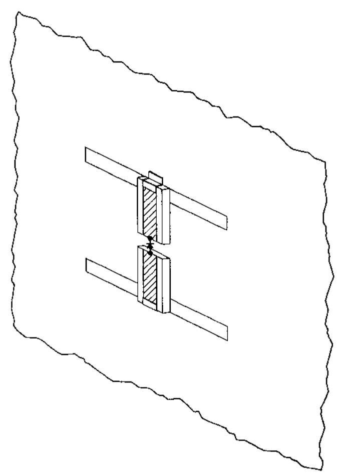

Fig. 2. Two slots coupled to the mixer diode by microstrip lines. The microstrip lines act as quarter-wave transformers between the slots and the diode. DC and IF circuitry not shown.

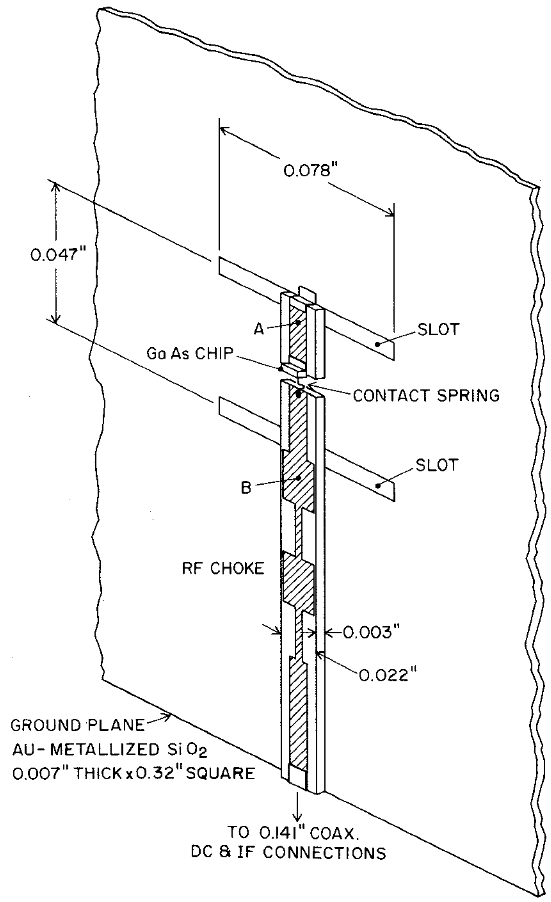

Fig. 3. The complete quasi-optical mixer.

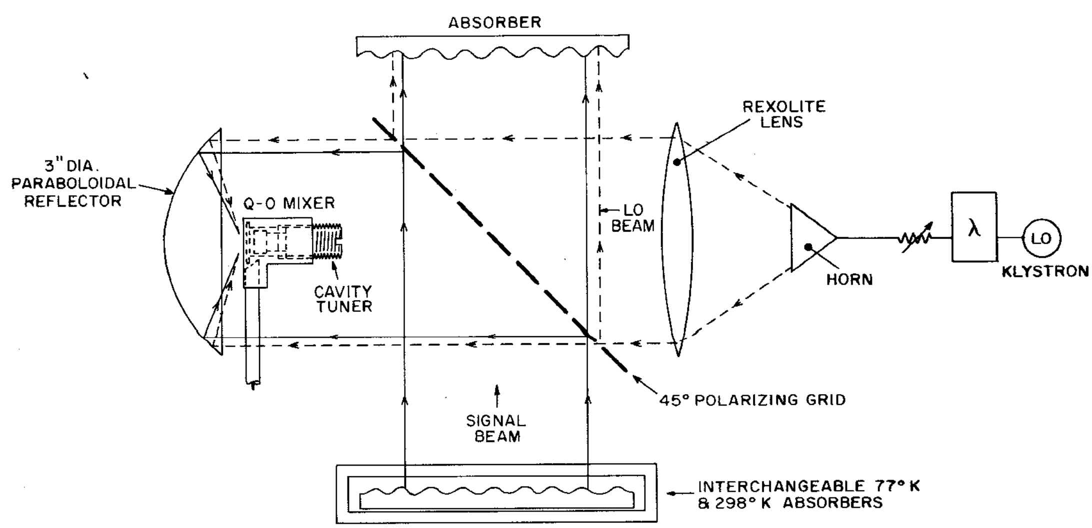

Fig. 4. The simple mixer test system, using a polarizing grid as a 3-dB beam-splitter.