A SUBMILLIMETER-WAVE PLANAR LOW NOISE SCHOTTKY RECEIVER

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ABSTRACT

A planar quasi-optical Schottky receiver based on the quasi-integrated horn antenna has been developed and tested over the 230-280GHz bandwidth. The receiver consists of a planar GaAs Schottky diode placed at the feed of a dipole-probe suspended on a thin dielectric membrane in an etched-pyramidal horn cavity. The antenna-mixer results in a measured DSB conversion loss and noise temperature at 258GHz of 7.2dB±0.5dB and 1310K±70K, respectively, at room temperature. The low cost of fabrication and simplicity of the design makes it ideal for submillimeter-wave receivers requiring a 10% bandwidth.

INTRODUCTION

Fundamental waveguide mixers using whisker-contacted Schottky diodes are currently used in room temperature submillimeter-wave receivers. The waveguide mixer and associated corrugated-horn antenna are very expensive to machine for frequencies above 200GHz. Integrated receivers consisting of a planar antenna and a planar diode are easier to manufacture, smaller, and much less expensive than waveguide mixers when produced in large quantities.

In this work, we present a 260GHz and 330GHz receivers based on the quasi- integrated horn antenna [1,2]. The quasi-integrated antenna has a directivity of 20dB, a high Gaussian coupling efficiency and a wide bandwidth (20%). The dipole-probe suspended on the membrane inside the horn is designed so that its impedance offers a close conjugate match to the diode impedance, eliminating the need for an RF matching network. This results in a wideband mixer circuit that forms an integral part of the antenna structure.

MIXER DESIGN

The quasi-integrated receiver consists of an integrated section (Fig. 1), and a machined section which is attached to the front of the integrated horn antenna and is not shown in the figure. The receiver structure consists of low and high resistivity silicon wafers etched anisotropically and stacked together to form a pyramidal cavity with a 70° flare angle [2]. Wall A is not coated with gold and the height of the V-shaped groove in wall B is 140μm which is seven times larger than the separation between the two strips forming the CPS line. The cavity is small enough so that no higher-order modes are present at 250GHz. The absence of gold on wall A results in a 1.2-1.3dB loss measured using a microwave model at 2.5GHz.

In the 250GHz mixer design (fig. 2), the length of the feed-dipole and its position inside the integrated horn antenna are chosen to result in a diode impedance that is a conjugate match to the RF diode impedance [3]. The planar diode is therefore epoxied right at the dipole apex without any additional RF matching network . The separation between the two strips on the membrane is 40μm and is reduced to 20μm on the silicon wafer. The CPS line impedace is 240Ω on the membrane and 85Ω on the silicon substrate. The capacitor integrated on the membrane is 53fF approximately and the one integrated on silicon is 64fF. This results in a LPF with a -3dB corner frequency of 70GHz and a rejection of -26dB at 250GHz. A microstrip quarter-wave transformer is fabricated on a Duroid 5870 substrate [4] and used to match the 1.4GHz IF diode output impedance to 50Ω. The IF matching network is specifically not integrated on the high resistivity silicon substrate to facilitate the use of different IF matching networks.

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The mixer diode is the UVA SC1T4-S20 planar Schottky diode with 1.2μm anode diameter, a 2-3fF zero-bias junction capacitance, a 5-6fF parasitic capacitance, an ideality factor of 1.12 and a 9-11Ω DC series resistance. The 5-6fF parasitic capacitance is reduced by chemically thinning the diode before mounting it from a thickness of 50μm to a thickness of 20μm. The reflection algorithm developed by Kerr et al. [5] predicts a diode impedance of 65-j30Ω at 250GHz. By using a 1.35GHz microwave model of the receiver structure shown in Fig. 1 and modeling the thinned diode using a stycast block on the dipole feeds, we obtain a close conjugate match to the diode RF impedance with a 0.4λ-long dipole positioned 0.38λ from the apex. The measured input impedance on the scale model is 60+j25Ω at the design frequency including the effect of the uncoated sidewall (wall A), the V-shaped groove (wall B), and the stycast block. The quasi-integrated antenna is simply a scaled version of the 90GHz design [1,6] and therefore, the measured patterns (Fig. 3) at 237GHz and 258GHz show low sidelobe levels and a 10dB beamwidth of approximately 34°.

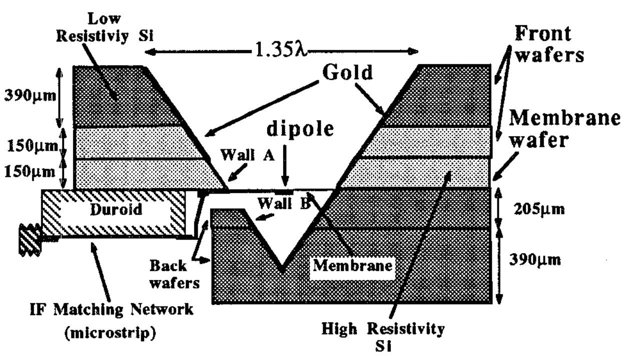

Figure 1 The integrated horn antenna receiver structure.

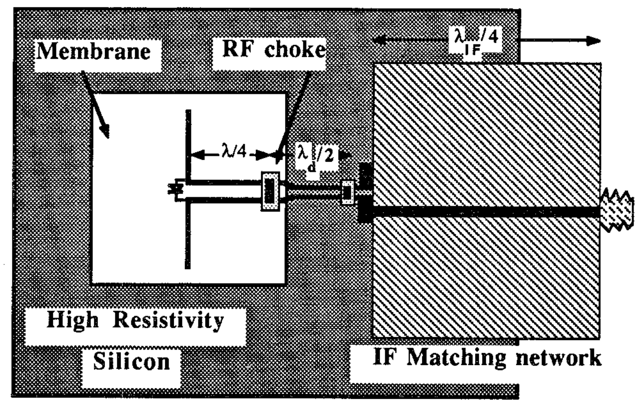

Figure 2 The mixer design.

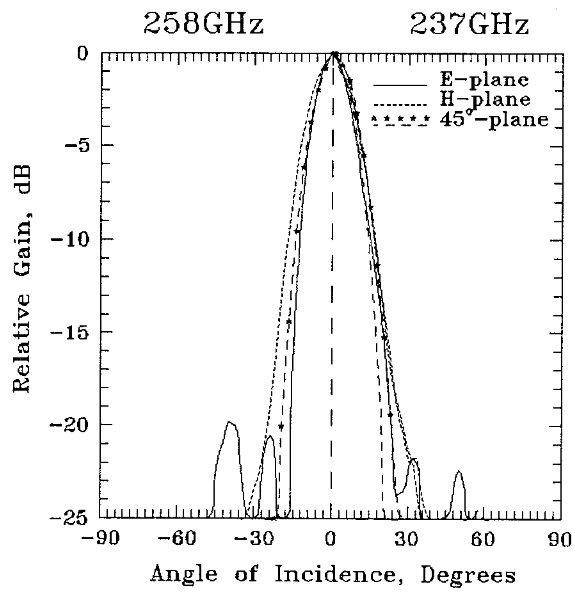

Figure 3 The measured E-, H-, 45°-plane patterns of the quasi- integrated horn antenna at 237GHz and 258GHz.

The measured conversion loss differs by about 4dB from the predicted conversion loss using the reflection algorithm [5]. Part of this 4dB discrepancy is the 1.2dB loss in the uncoated side wall A. The remaining discrepancy is expected from the non-zero impedance of the higher order harmonics and the increase in the series resistance of the diode at higher frequencies. The measured DSB conversion loss and noise temperature between 248-265GHz are about 3dB higher than the best room temperature waveguide mixers in this frequency range [8,9]. This marks the first time a planar integrated submillimeter-wave mixer with a planar diode has been designed and tested successfully at these frequencies. Currently, it is easy and inexpensive to array four of these receivers on a single chip. Together, the four planar receivers have a bandwidth of 10% and a sensitivity similar to that of one of the best tuned waveguide mixers.

330GHz RECEIVER

The receiver performance can be improved by etching via-holes type trenches in the high resistivity silicon membrane wafer around the side walls in order to eliminate any RF power loss through the uncoated wall. Figure 5 shows the mixer design for a 330GHz quasi-integrated horn antenna receiver with trenches etched in silicon around the membrane. Also, the quasi-integrated horn antenna to be used in the 330GHz receiver has a directivity of 23dB. This receiver is currently being built at the University of Michigan and its design and performance will be presented at the conference.

RECEIVER MEASUREMENTS

A quasi-integrated horn antenna receiver was built at 250GHz. Video detection measurements were done from 230GHz to 280GHz (see [1] for more detail). The peak video responsivity is 450±50 mV/mW at a bias current of 3μA over the 230-280GHz range and is competitive with whisker-contacted diodes.

The double-sideband conversion loss and noise temperature of the mixer are measured using a hot/cold load method over the 230-280GHz range. A Mach-Zender interferometer is used to combine the RF signal and the LO signal from a 230- 280GHz tripler. At each frequency, the optimum LO power is found to be approximately 2mW available at the quasi-integrated antenna aperture, and the optimum dc bias current around 1.4mA. During measurements, the loss due to the non-zero IF reflection coefficient at the mixer output port was 0.5dB. The RF loss in the f/0.85, 2.5" teflon lens in front of the receiver is estimated to be 0.3dB due to reflection loss and 0.3-0.4dB due to dielectric loss (obtained from [7]). The RF diplexer loss is estimated to be 0.1-0.2dB. The IF and RF path losses are removed from the receiver measurements [1], and the double sideband conversion loss and noise temperature are shown in Fig. 4. The conversion loss includes the antenna Gaussian coupling loss, any power loss in the antenna structure, the RF mismatch between the feed-dipole and diode impedances, and the diode intrinsic conversion loss. A minimum antenna-mixer DSB conversion loss of 7.2dB±0.5dB and noise temperature of 1310K±70K are obtained at 258GHz.

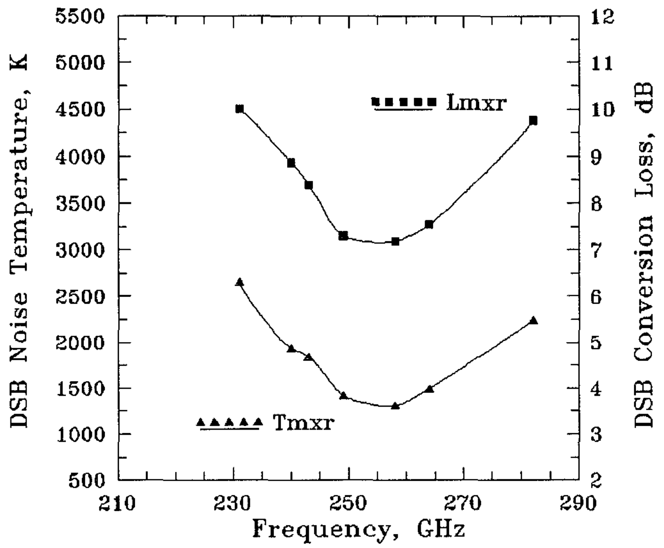

Figure 4 The measured antenna-mixer DSB conversion loss and noise temperature over the 230-280GHz range.

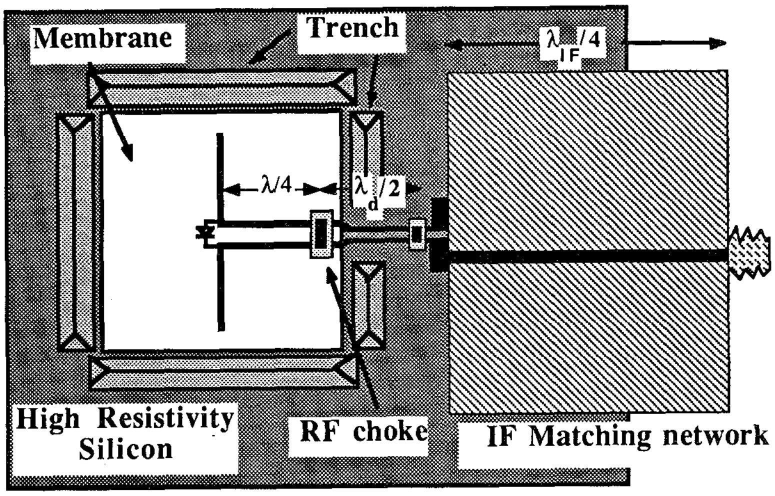

Figure 5 The mixer design for the 330GHz receiver including the trenches around the membrane.

ACKNOWLEDGMENTS

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REFERENCES

[1] W.Y. Ali-Ahmad, W.L. Bishop, T.W. Crowe, and G.M. Rebeiz, " An 86- 106GHz Quasi-Integrated Low Noise Schottky Receiver," To appear in the April 1993 issue of the *IEEE-Trans. Microwave Theory Tech.* journal.

[2] G.M.Rebeiz, D.P. Kasilingan, P.A. Stimson, Y. Guo, and D.B. Rutledge,"Monolithic millimeter-wave two- dimensional horn imaging arrays," *IEEE Trans. Antennas Propag.*, vol AP-38, pp. 1473-1482, Sept. 1990.

[3] W.Y. Ali-Ahmad, G.V. Eleftheriades, L.P. Katehi, and G.M. Rebeiz,"Millimeter-Wave Integrated Horn Antennas, Part II: Experiment," *IEEE- Trans. Antennas Propagation*, vol. AP-39, pp. 1582-1587, Nov. 1991.

[4] Duroid is a trademark of Rogers Corporation. We thank Rogers Co. for the donation of the substrate.

[5] D.N. Held and A.R. Kerr,"Conversion loss and noise of microwave and millimeter-wave receivers: Part I-Theory; Part II-Experiment," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp.49-61, Feb. 1978.

[6] G.V. Eleftheriades, and G.M. Rebeiz,"Design and Analysis of Quasi- Integrated horn antennas for Millimeter- and submillimeter-wave Applications," To appear in the May 1993 issue of the *IEEE-Trans. Microwave Theory Tech.* journal.

[7] M.N. Afsar," Dielectric Measurements of Millimeter-Wave Materials," *IEEE- Trans Microwave Theory Tech.*, vol. MTT-32, pp.1598- 1609, December 1984.

[8] J.W. Archer," All Solid-State Low Noise Receivers for 210-240 GHz," *IEEE- Trans. Microwave Theory Tech.*, vol. MTT-30, pp.1247-1252, August 1982.

[9] N.R. Erickson,"A Very Low-Noise Single-Sideband Receiver for 200-260GHz," *IEEE- Trans. Microwave Theory Tech.*, vol MTT-33, pp.1179-1188, November 1985.