PP-6

A SUBMILLIMETER-WAVE PLANAR DIODE MIXER - DESIGN AND EVALUATION *

Tom Newman† and Kwong T. Ng‡

† Dept. of Elec. Engr., Univ. of Virginia
Applied Electrophysics Laboratory
Charlottesville, VA 22901

‡ Dept. of Elec. and Computer Engr.
New Mexico State University
Las Cruces, New Mexico 88003

ABSTRACT

A novel 345 GHz mixer employing a planar GaAs Schottky diode has been designed and tested at the University of Virginia. The design process used nonlinear and linear numerical mixer analysis as well as scale model impedance measurements. Using a planar diode eliminates the disadvantages of mechanical instability and labor-intensive assembly associated with the whisker in conventional whisker-contacted diodes. To the best of our knowledge, this represents the first attempt at using a planar diode in a submillimeter-wave mixer, and test results indicate performance on the same level as the best whisker-contacted room temperature mixers for submillimeter wavelengths.

I. INTRODUCTION

Whisker-contacted Schottky barrier diodes have been the preferred non-linear elements for submillimeter-wave mixers for the last two decades. Planar versions of these diodes are more rugged and reliable, and can be more easily integrated into a circuit than their whisker-contacted counterparts. Planar diodes from the University of Virginia (UVa) have an air-channel which substantially reduces parasitic capacitance associated with planar diodes. The fabrication [1] and testing at 100 GHz [2] of UVa diodes have been described previously.

A novel submillimeter-wave mixer has been designed for these diodes and tested at the University of Virginia. Scale models were used in conjunction with various numerical techniques for the design. The design goal was to present an optimum impedance to the intrinsic diode terminals which gives as low a noise temperature and conversion loss as possible, while keeping the machining requirements minimal for the small dimensions required for submillimeter-wave applications.

* This work is supported in part by the U.S. Air Force, Rome Air Development Center, under Contract F19628-88-K0019.

II. MIXER BLOCK DESIGN

The mixer block design, as shown in Figure 1, uses an air-channel planar diode as the nonlinear mixing element. The diode is mounted face down on a quartz substrate, as shown in Figure 2, which is placed in a microstrip enclosure. The externally combined local oscillator and RF signal is coupled into a circular waveguide through a dual-mode feedhorn, and then onto a microstrip by a waveguide probe tuned with a non-contacting, adjustable short circuit. A non-contacting short circuit provides a more repeatable short circuit than a contacting one at submillimeter wavelengths. A quarter-wavelength bond-wire functions as a DC return allowing DC biasing of the diode. A series of alternate high and low impedance quarter-wavelength microstrip sections between the diode and the IF port allow DC

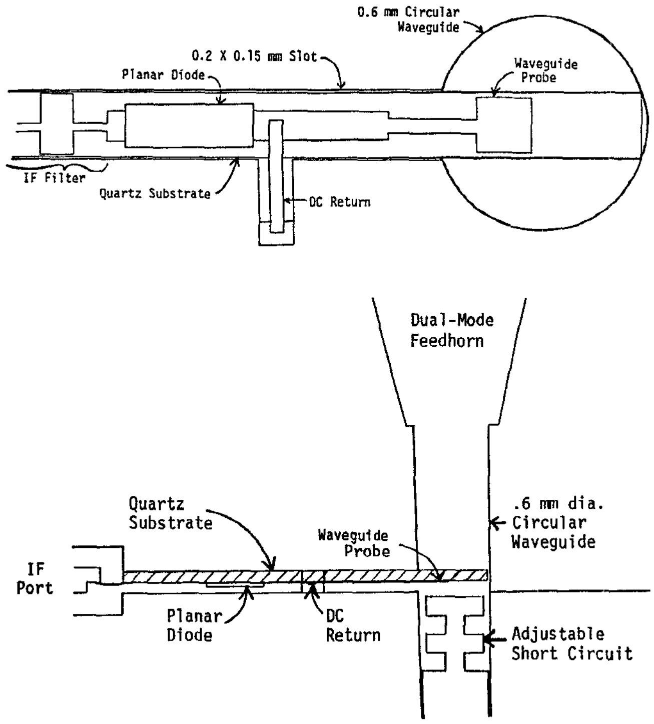


Fig. 1. Two cross sectional views of the submillimeter-wave planar diode mixer.

PP

CH2870-4/91/0000-1293$01.00 © 1991 IEEE

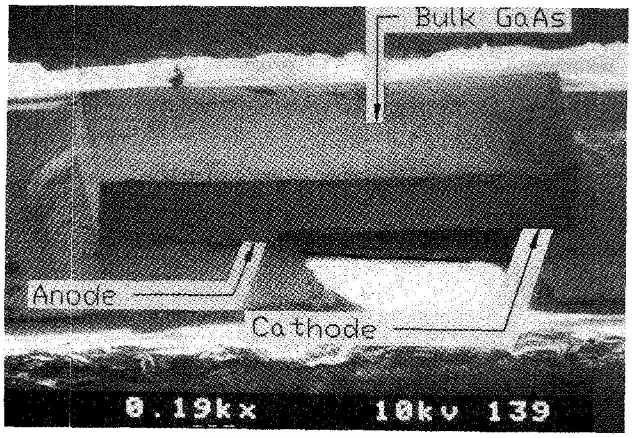


Fig. 2. Scanning electron microscope photo of a planar diode which has been mounted face down on a quartz substrate and chemically thinned.

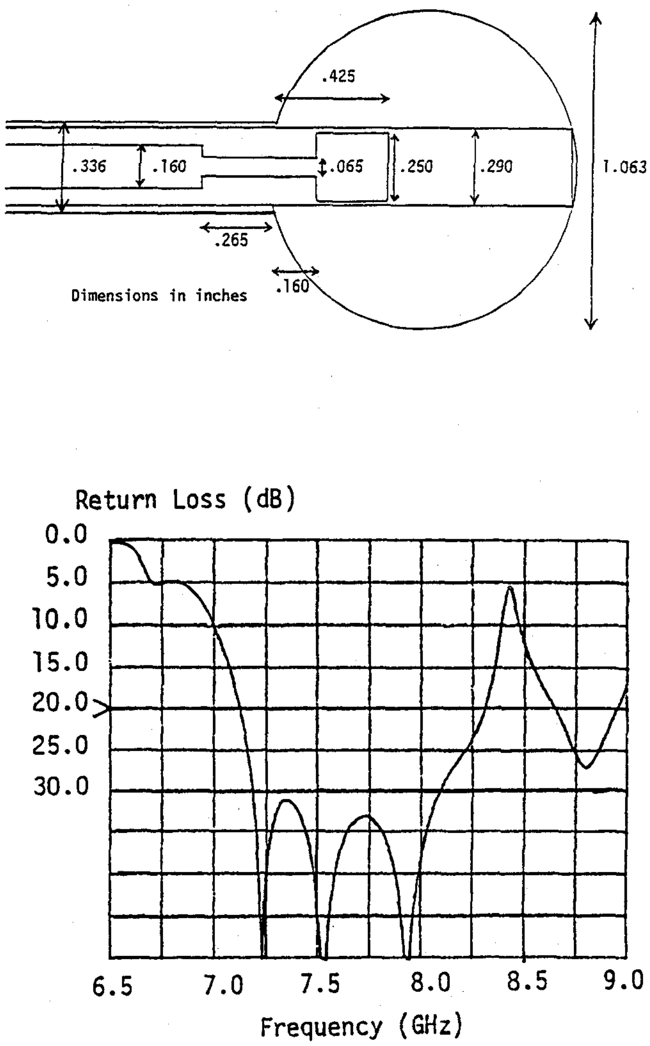


Fig. 3. 45 X scale model of the circular waveguide to microstrip probe shown in Fig. 1. (a) Probe design, (b) Return loss.

and IF power to pass through, but present nearly a short circuit in series with the diode at RF. Eliminating the use of rectangular waveguide and scalar feedhorn allows the mixer block to be machinable for submillimeter wavelengths but does restrict the bandwidth to ≤ 20%.

An analysis was performed with transverse resonance and spectral domain techniques [3] to find a single mode microstrip enclosure with the largest possible dimensions. The limiting factor is the thickness of the GaAs planar diode, which can be reduced to about .02 mm by chemically etching after mounting on the quartz substrate (although even more of the GaAs can be removed using more complex techniques [4]). A mounted and chemically thinned planar diode is shown in Figure 2. A quartz substrate of thickness .075 mm topped with a .02 mm GaAs layer in a .15 mm X .20 mm enclosure with a .075 mm wide metal strip will support only a single mode for frequencies up to 400 GHz.

III. SCALE MODEL DESIGN OF COMPONENTS

45X scale models were used to design the different components. For example a network analyzer has been used to obtain return loss information on various designs of the transition from circular waveguide to 50 Ω shielded microstrip, as described more thoroughly in [5]. The design shown in Figure 3a yielded, for an optimum location of the waveguide short circuit, a return loss that is greater than 20 dB over a 15% bandwidth, as the measured data show in Figure 3b.

IV. DIODE EMBEDDING CIRCUIT

Of primary importance in mixer design is the matching at RF of the impedance seen from the intrinsic diode terminals, Z_{RF} , to a calculable optimum impedance. The analysis method described in [6,7] was employed for calculating mixer noise temperature and conversion loss as a function of Z_{RF}. For design purpose, at LO harmonics above the fundamental frequency the diode was assumed to be terminated with short circuits, and the IF impedance was assumed to be perfectly matched to the IF port. Figure 4 shows calculated contours of constant mixer noise temperature (double side-band) and conversion loss (single side-band) plotted on Smith charts for all possible values of Z_{RF} at a frequency of 345 GHz. The calculations were made using the following diode parameters measured on a UVa planar diode with an anode diameter of 1.5 μm: DC series resistance of 14 Ω and zero-bias junction capacitance of 2.3 fF at 1 MHz. An additional series resistance of 4 Ω was added to account for the skin effect in the GaAs chip.

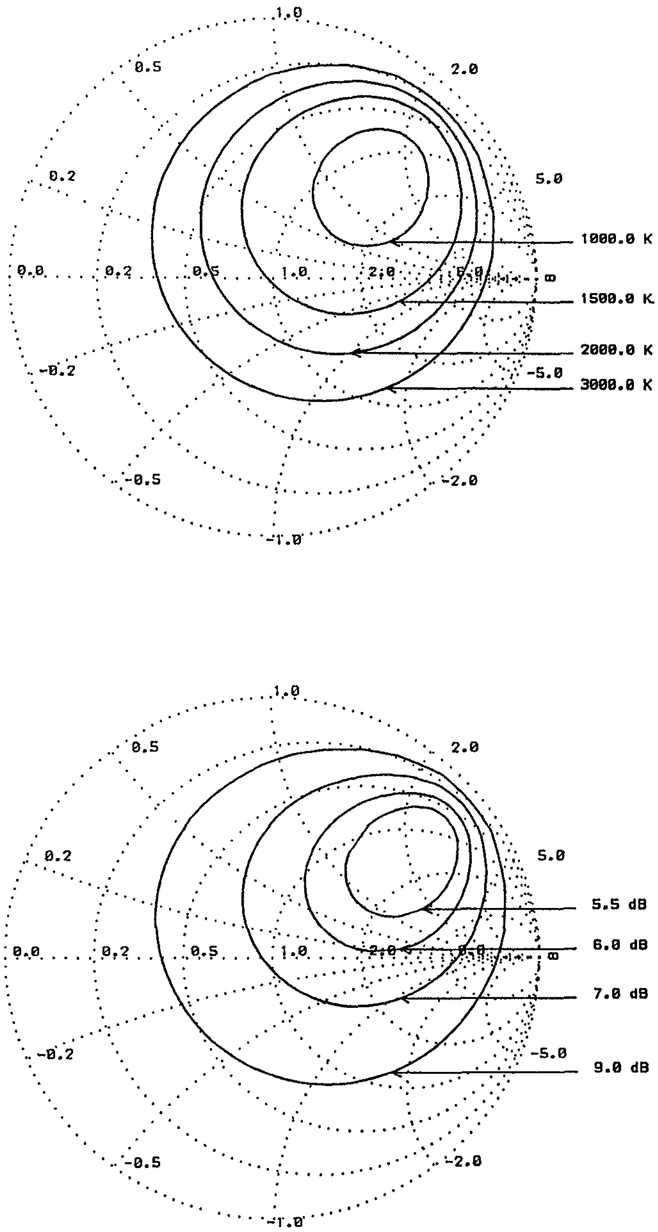


Fig. 4. Contours of constant mixer noise temperature (DSB) and conversion loss (SSB) plotted on charts of possible impedances seen from the diode terminals for a diode anode diameter of 1.5 microns.

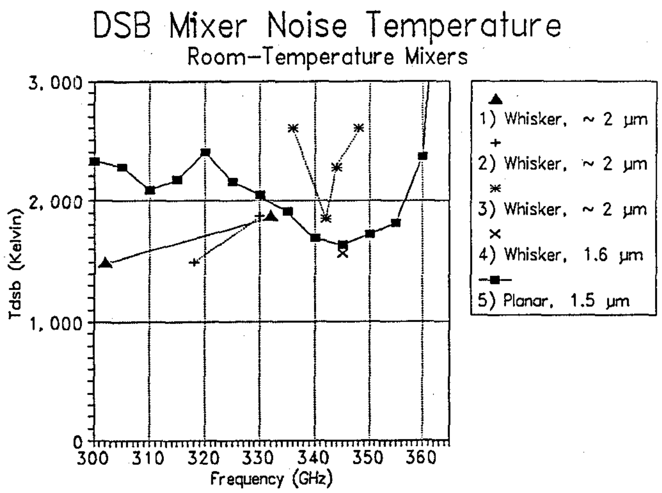
A 45X scale model was used to measure the impedance seen from the diode terminals. The model included scaled versions of the waveguide to microstrip transition, the DC return, the IF filter, and a wafer of material with the same dielectric constant of the planar diode. A miniature coaxial cable was installed which ran into the model as the DC return line and then along the microstrip to the gap between the diode bonding pads. The outer conductor of the cable was soldered to the microstrip up to one bonding pad and its inner conductor was soldered to the other bonding pad. A network analyzer was then connected to the coaxial cable, and measurements were made of Z_{RF}. Adjustments were then made to the model (predominantly the length of the first section of the IF filter) to bring Z_{RF} to a value that will give the optimum noise temperature and conversion loss from the calculated contours. Impedances at the second and third harmonic frequencies have also been measured and used in a nonlinear mixer analysis [7] to show a 1.0 dB increase in noise temperature and conversion loss due to these harmonics.

V. MIXER PERFORMANCE

Figure 5 shows the noise temperature and conversion loss of the mixer measured at room temperature. A carcinotron was used as the LO which was combined quasi-optically using a Martin-Puplett diplexer with signals from a room temperature and a liquid nitrogen temperature black body source. The noise temperature and conversion loss measurements were made similarly to those in [2] using a 50 ohm IF test set. With an IF frequency of 1.4 GHz, the mixer response in both sidebands were assumed equal. An external bias-tee is used and no IF impedance transformer. The results have been referred to the mixer feedhorn through a 1.0 dB signal path loss, due predominantly to a mismatch between the lens and feedhorn. At 345 GHz the mixer exhibits an equivalent input noise temperature 1,640 K DSB and a conversion loss of 7.2 dB SSB. The mixer shows a useful tunable range of over 20 %. It exhibits a 2.1 dB higher noise temperature and conversion loss than the theoretical optimum values shown in Figure 4. At least half this increase is due to the noise contribution of the higher order harmonics and the remainder is due to losses unaccounted for elsewhere. Also shown in Figure 5 are some of the best room-temperature mixer results reported for this frequency range [8,9]. These previous results were obtained with the standard whisker-contacted diode technology. The results in Figure 5 show that the performance of the planar diode mixer is equal to that of the best room temperature whisker-contacted diode mixers.

VI. CONCLUSIONS

For the first time a submillimeter-wave planar diode mixer has been designed and tested, and very promising results have been achieved. Numerical techniques and scale models have been combined effectively to yield a useful, rugged mixer for 300 - 360 GHz.



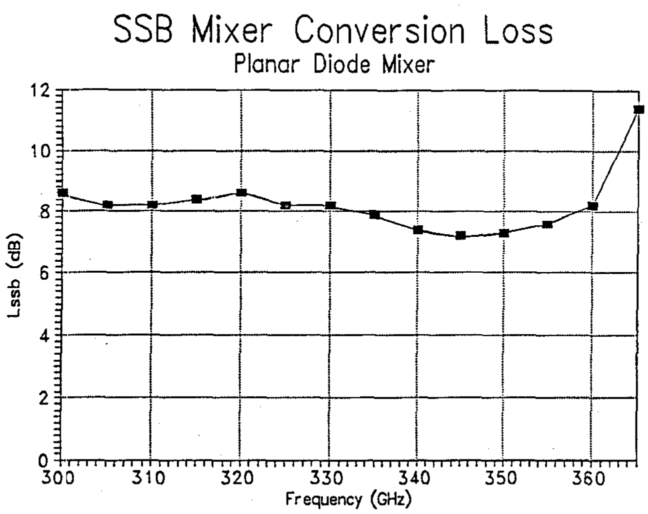


Fig. 5. Double side-band mixer noise temperature and single side-band conversion loss for the planar diode mixer. Also shown are mixer noise temperatures for other room-temperature Schottky barrier diode mixers: 1)-3) three mixers using diodes with ~ 2 micron anodes [8], and 4) a mixer using a diode with a 1.6 micron anode [9].

REFERENCES

[1] W.L. Bishop, K. McKinney, R.J. Mattauch, T.W. Crowe, and G. Green, "A Novel Whiskerless Schottky Diode for Millimeter and Submillimeter Wave Application," in *IEEE 1987 MTT-S Int. Microwave Symp. Dig.*, pp. 607-610, Las Vegas, NV, June 1987.

[2] D.G. Garfield, R.J. Mattauch, and S. Weinreb, "RF Performance of a Novel Planar Millimeter-Wave Diode Incorporating an Etched Surface Channel," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-39, pp. 1-5, Jan. 1991.

[3] T. Itoh, Ed., Planar Transmission Line Structures. New York, NY: IEEE Press, 1987.

[4] W.L. Bishop, E.R. Meiburg, R.J. Mattauch, T.W. Crowe, and L. Poli, "A Micron-Thickness, Planar Schottky Diode Chip for Terahertz Applications with Theoretical Minimum Parasitic Capacitance," in *IEEE 1990 MTT-S Int. Microwave Symp. Dig.*, pp. 1305-1308, Dallas, TX, May 1990.

[5] T. Newman and K.T. Ng, "Design of a Circular Waveguide-to-Microstrip Coupling Probe for Submillimeter-Wave Applications," in *Proc. IEEE 1990 AP-S Int. Antennas and Propagat. Symp. Dig.*, pp. 1910-1913, Dallas, TX, May 1990.

[6] D.N. Held and A.R. Kerr, "Conversion Loss and Noise of Microwave and Millimeter-Wave Mixers: Part 1 - Theory," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-26, pp. 49-55, Feb. 1978.

[7] P.H. Siegel, A.R. Kerr, and W. Hwang, Topics in the Optimization of Millimeter-Wave Mixers, NASA Technical Paper # 2287, Mar. 1984.

[8] N.R. Erickson, "A 200-350 GHz Heterodyne Receiver," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-29, pp. 557-561, June 1981.

ACKNOWLEDGEMENTS

The authors would like to thank W.L. Bishop for the fabrication of the planar diodes, type SC2T1, used for this project.