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A 200 GHz Planar Diode Subharmonically Pumped Waveguide Mixer with State-of-the-Art Performance

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Abstract

This paper presents recent performance data for a 200 GHz subharmonically pumped waveguide mixer using an antiparallel pair of planar air bridge type GaAs Schottky barrier diodes. The measured mixer noise and conversion loss are below that of the best reported whisker contacted or planar diode mixers using the subharmonic pump configuration. In addition, the required local oscillator power is as low as 3 mW for the unbiased diode pair and significant LO noise suppression was observed. The waveguide design is a prototype for 640 GHz and uses split-block rectangular waveguide with a 2:1 width to height ratio throughout.

Introduction

Recent advances in the production of high quality, low capacitance, planar integrated GaAs Schottky barrier diodes [1,2] make it possible to implement many high frequency mixer designs which were considered mechanically impractical using traditional whisker contacted arrangements. As a prototype for a 640 GHz space qualified waveguide Schottky diode system we have designed, fabricated and tested a 200 GHz subharmonically pumped mixer [3,4] using planar air bridge Schottky diodes in a number of substrate configurations. The antiparallel diode pair arrangement has the advantages of pumping at one half the signal frequency and inherent local oscillator noise suppression [5], both useful for submillimeter wave operation, where sources are difficult to come by.

Mixer Mount Configuration

The mixer mount uses a crossed-guide configuration with the local oscillator waveguide perpendicular to the signal guide and electrically coupled with a shielded quartz microstrip line (Fig. 1). The microstrip contains the planar diodes and provides LO, signal and intermediate frequency (IF) isolation through low pass hammerhead filters [6,7]. The filters and coupling probes are fabricated lithographically using standard chrome gold lift-off techniques with subsequent build up of electroplated gold to improve solderability. In an added step, the back side of the quartz is metallized under the microstrip filters (gaps are left under the LO and signal waveguide coupling probes). This has the advantage of allowing the microstrip to be soldered, rather than glued, into the machined channel and reduces the effects of surface roughness. A DC return for the diodes is provided by a separate shorting wire on the LO side of the microstrip filter. The LO waveguide is formed in one piece by wire electro-discharge machining (an electroformed insert or split block structure could also be used) and the remaining waveguides are produced with carbide slitting saws in the two halves of the mixer block. All waveguide is full height (2:1 aspect ratio) and the microstrip cavity is sized to prevent waveguide mode propagation in the LO and signal filter stopbands. The diode pair is suspended across the center of the broad wall of the signal waveguide with the plane of the filter metallization along the direction of propagation. Tapered probes couple both signal and LO power to the diodes. The IF pass and signal block hammerhead filters are designed so as to present a short at the waveguide walls for the signal and at the same time to maximize coupling of the LO into the diodes. Local oscillator power is coupled into the microstrip filter through a probe which protrudes halfway across the center of the broad wall of the LO guide. Both the signal and LO guides have contacting backshorts behind the microstrip probes and E-plane tuners. The E-plane tuner for the LO is directly opposite the E-plane coupling probe. In the case of the signal guide the E-plane tuner is approximately half of a guide wavelength in front of the diodes at the band edge of 200 GHz, and tapers out across the mixer block at an angle of 10 degrees to avoid cutting across the LO guide. IF removal is performed through a K-connector whose center pin is ribbon bonded to the end of the microstrip filter. The signal and LO mixer mount characteristics were optimized at 8.5 GHz on a 25X frequency scaled model using coaxial probes and capacitively scaled antiparallel pair diodes obtained from Microwave Associates.

The planar diodes are GaAs Schottky air bridge type devices similar to those described in [1,2 and 8]. To facilitate assembly, the diodes are indium bump bonded to the host microstrip. All the measured diodes were formed as integrated antiparallel pairs. Various diode package sizes and substrate configurations were tested (Table I). As the diodes have a common contact pad on each end, separate DC biasing, to lower the LO power consumption, was not possible. The common DC return was used during RF measurements to slightly misbalance the diode pair and optimize the LO coupling by peaking the current flow through a single device.

Mixer Performance

The performance of the subharmonically pumped mixer from 195-230 GHz is shown in Fig. 2 for the diode packages listed in Table I. Two diode package sizes and three diode substrate configurations were tested. The larger packaged devices had: an all GaAs substrate (UVa type SD1T1), a GaAs substrate chemically thinned to 5μm and then glued to a quartz carrier [2] (UVa type SR2T1), and a 5μm GaAs substrate soldered directly to the mixer filter circuitry (glue dissolved and quartz carrier lifted away [2]). The smaller packaged devices (UVa type SC1T4) had an all GaAs substrate and were tested in mixer mounts with slightly different signal E-plane tuner positions.

Discussion

Referring to Fig. 2, there is a general improvement in mixer performance with decreasing package size and overall substrate dielectric constant. The best performance so far obtained has been with the small area all GaAs diode package (T_m(SSB)=1600K, L_{dB}=8.7 at 205 GHz), and the worst performance has been with the large area all GaAs package. Scale model measurements indicate that the larger all GaAs devices have the most limited accessible RF signal matching range in this particular mixer mount. However, the difference in performance between devices may simply be due to varying diode electrical characteristics and a larger sample set is required before definite conclusions can be made.

The required LO power for optimal mixer performance is comparable for both the small all GaAs package and the thinned GaAs diodes. Twice as much power was required for the large area all GaAs device. Extra LO power was also needed for the mixer block where the signal E-plane tuner was less than $\lambda_g/2$ from the diodes. The lower than usual LO power required for these unbiased diode pairs is attributed to the E-H tuner in the LO waveguide and careful optimization of the signal coupling probe shape and first LO and IF pass filter section lengths. Table II is included to show comparisons with the better room temperature results from other groups using whisker contacted and planar diodes in fundamental, harmonic and subharmonically pumped mixer configurations near the same frequency.

As a final note, the LO source used for the measurements was a 75-110 GHz backward wave oscillator with no noise filtering. When this source was used for measurements on this same mixer block, but configured with a single planar diode used in a second harmonic mixing mode, the LO noise contributed by the oscillator added $\approx$5000 degrees at the IF. With the antiparallel diode pair the LO noise contribution was reduced to about 50K which is consistent with the reduction in LO noise reported by [5] at 60 GHz using a similar diode configuration.

Concluding Remarks

The design and performance of a 200 GHz subharmonically pumped waveguide mixer using planar integrated diodes were presented. The mixer mount design is intended for use at frequencies up to 650 GHz and utilizes full height waveguide in a split block configuration for ease of fabrication. Techniques similar to those used to form the substrateless diodes [2,8] will be used to integrate the GaAs package with the quartz microstrip structure in subsequent receivers. The performance of the planar diode package exceeds that of the best whiskered pair at 200 GHz in spite of large pad to pad capacitance [8]. In addition, considerably less LO power is required than that reported by other groups with similar mixer configurations, and excellent LO noise suppression was obtained with no external filtering.

Finally, although not discussed in this paper, computational analysis using the program developed by [9] gives reasonable agreement with measured mixer performance when the expected inductive and capacitive parasitic elements are added to the mixer embedding network. The analysis also indicates that further performance improvement is possible with careful control over these parameters.

Acknowledgments

The authors would like to thank Hardy Moham of JPL, John Oswald of MIT and Yogi Anand of Microwave Associates for help in various aspects of this research. The research described in this paper was carried out at the California Institute of Technology Jet Propulsion Laboratory, under contract with NASA.

References

[1]. W.L. Bishop, K. McKinney, R.J. Mattauch, T.W. Crowe and G. Green, "A novel whiskerless diode for millimeter and submillimeter wave applications," *1987 IEEE MTT-S Int. Mic. Sym. Digest*, pp. 607-610, June 1987.

[2]. W.L. Bishop, E. Meilburg, R.J. Mattauch, T.W. Crowe and L. Poli, "A micron-thickness, planar Schottky diode chip for terahertz applications with theoretical minimum parasitic capacitance," *1990 IEEE MTT-S Int. Mic. Sym. Digest*, pp. 1305-1308, May 1990.

[3]. M.V. Schneider and W.W. Snell, Jr., "Harmonically pumped stripline-downconverter," *IEEE Trans. MTT*, vol. MTT-23, pp. 271-75, Mar. 1975.

[4]. M. Cohn, J.E. Degenford and B.A. Newman, "Harmonic mixing with an antiparallel diode pair," *IEEE Trans. MTT*, vol. MTT-23, pp. 667-73, Aug. 1975.

[5]. P.S. Henry, B.S. Glance and M.V. Schneider, "Local-oscillator noise cancellation in the subharmonically pumped down-converter, " *IEEE Trans. MTT*, vol. MTT-24, pp. 254-7, May 1976.

[6]. E.R. Carlson and M.V. Schneider, "Subharmonically pumped millimeter-wave receivers," *4th Int. Conf. on IR&MM Waves*, pp. 82-83, Dec. 10-15, 1979.

[7]. P.H. Siegel, J.E. Oswald, R.J. Dengler, D.M. Sheen and S.M. Ali, "Measured and computed performance of a microstrip filter composed of semi-insulating GaAs on a fuzed quartz substrate," *IEEE MGWL*, vol. 1, pp. 78-81, Apr. 1991.

[8]. P.H. Ostdiek, T.W. Crowe and I. Galin, "Integration of an anti-parallel pair of Schottky barrier diodes in millimeter wave mixers," *15th Int. Conf. IR&MM Waves*, pp. 401-3, Dec. 10-14, 1990

[9]. A.R. Kerr, "Noise and loss in balanced and subharmonically pumped mixers: Part I-Theory", and "Part II-Experiment," *IEEE Trans. MTT*, v. MTT-27, pp.938-50, Dec. 1979.

Table I. Diodes Used for the Measurements Shown in Fig. 2

Designation diode mixer filter	Description	C_{j0} fF	Φ_b V	η	R_s Ω	I_{sat} 10^{-16}	Anode Diam.	Finger lgth.	Bond Pad wxl (μm)
SD1T1/A9 200B3 2A	Large area all GaAs 120wx260lx80t (μm)	3.0 3.0	1.09 1.08	1.28 1.25	10.7 12.0	2.5 1.2	1.4 μm	50 μm	120x100
SR2T1/H4 200B4 2A	Thinned GaAs/Quartz 130wx240lx100t (μm)	3.0 3.0	1.08 1.06	1.26 1.22	6.8 7.7	2.2 1.3	1.2 μm	50 μm	130x50
SR2T1/G5 200B4 2A	Large area thinned GaAs no substrate	3.0 3.0	1.09 1.07	1.25 1.22	8.1 7.3	1.5 0.9	1.2 μm	50 μm	130x50
SC1T4/A4 200B4 1A	Small area all GaAs 80wx200lx50t (μm)	3.0 3.0	1.09 1.07	1.28 1.25	11.9 12.6	2.5 1.4	1.4 μm	20 μm	30x50
SC1T4/B5 200A2 1A	Small area all GaAs in mod. mxr. block	3.0 3.0	1.07 1.05	1.25 1.18	11.4 12.8	1.6 1.2	1.4 μm	20 μm	30x50

All diodes were fabricated at the Univ. of Virginia Semiconductor Device Laboratory (see Ref. [8] for details).
Diode parameters (except C_{j0}) are derived from the measured DC IV curves after mounting. Parameters for both diodes are given.
Values of C_{j0} and anode diameter are the nominal for the processed diode wafer.
Filters 2A and 1A differ in having diode bonding pads of 100 and 30 μm wide and gaps of 100 and 40 μm respectively.
Mixer 200A2 has the signal E-plane tuner $1/2\lambda_g$ behind the diodes at band center (215GHz) rather than at band edge (200 GHz).

Table II. Reported Room Temperature Waveguide Schottky Diode Mixer Performance Around 200 GHz

Approx. Signal Frequency	Whisker Contacted Diode							Planar Diode		
	Single Diode Fund. Mixer		Single Diode Harm. Mixer		Two Diode Subharmonic Mixer			Two Diode Subharmonic Mixer		
F_{GHz}	T_m	L_{dB}	T_m	L_{dB}	T_m	L_{dB}	P_{LO}	T_m	L_{dB}	P_{LO}
180	750[1]	5.7	2600[5]	10.0	2400[6]	10.5	6.5	2750[8] $T_{Receiver}$		10
205	1250[2]	7.1	2400[5]	9.0	1800[7]	9.6	10	1590[9] 1715[9] 1990[9]	8.7 8.7 9.3	5.7 4.0 3.0
230	800[3] 800[4]	6.2 6.6			2400[7]	10.9	10			

All results are at room temperature and for an IF frequency between 1 and 2 GHz unless otherwise indicated.
T_m=single sideband mixer noise temperature in K L_{dB}=SSB conversion loss in dB P_{LO}=required LO power in mW
The authors could not find data for planar diode fundamental and harmonic mixers at these frequencies in the literature.
1. P.H. Siegel and A.R. Kerr, *IEEE Trans. MTT*, vol. MTT-32, pp. 1579-90, Dec. 1984.
2. M.A. Frerking, J.A. Hardy, W.J. Wilson and P. Zimmermann, *1983 IEEE Int. Mic. Sym. Dig.*, pp. 110-112, June 1983.
3. N.R. Erickson, *IEEE Trans. MTT*, vol. MTT-33, pp. 1179-88, Nov. 1985 (includes feedhorn losses).
4. J.W. Archer, *IEEE Trans. MTT*, vol. MTT-30, pp. 1247-52, Aug. 1982.
5. N.R. Erickson, *unpublished results*, private communication, Oct. 1991.
6. C.M. Mann, D.N. Matheson and M.R.B. Jones, *Int. J. of IR & MM Waves*, vol. 10, no. 9, pp. 1043-49, Sept. 1989.
7. E.R. Carlson and M.V. Schneider, *4th Int. Conf. on IR & MM Waves*, pp. 82-83, Dec. 1979.
8. P.H. Ostdiek, T.W. Crowe and I. Galin, *15th Int. Conf. on IR & MM Waves*, pp. 401-3, Dec. 1990.
9. P.H. Siegel, *This work*.

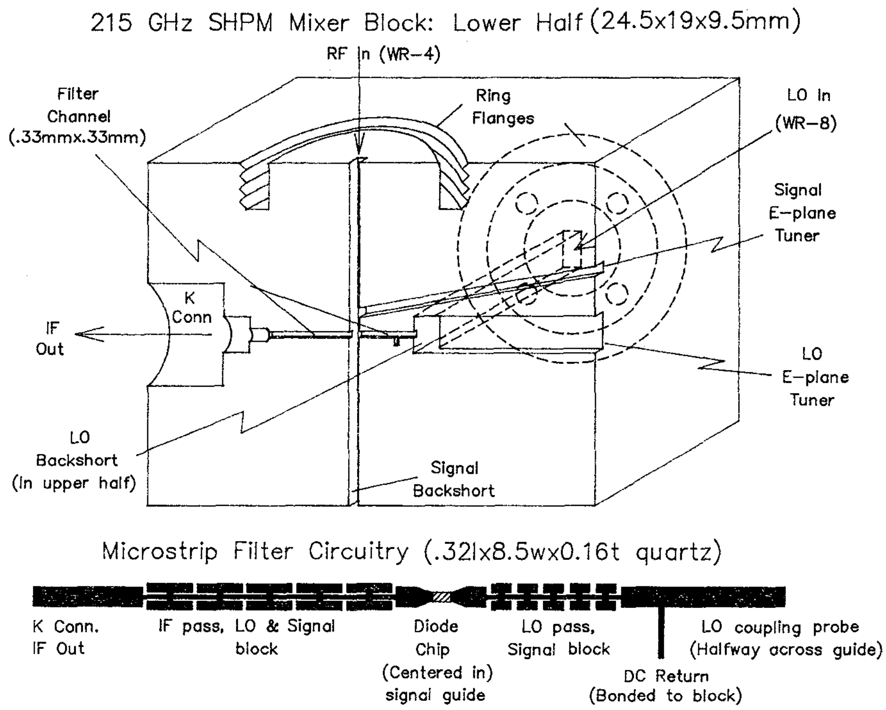

Fig. 1 Schematic drawing showing the bottom half of the 215 GHz subharmonically pumped waveguide mixer block and filter circuitry.

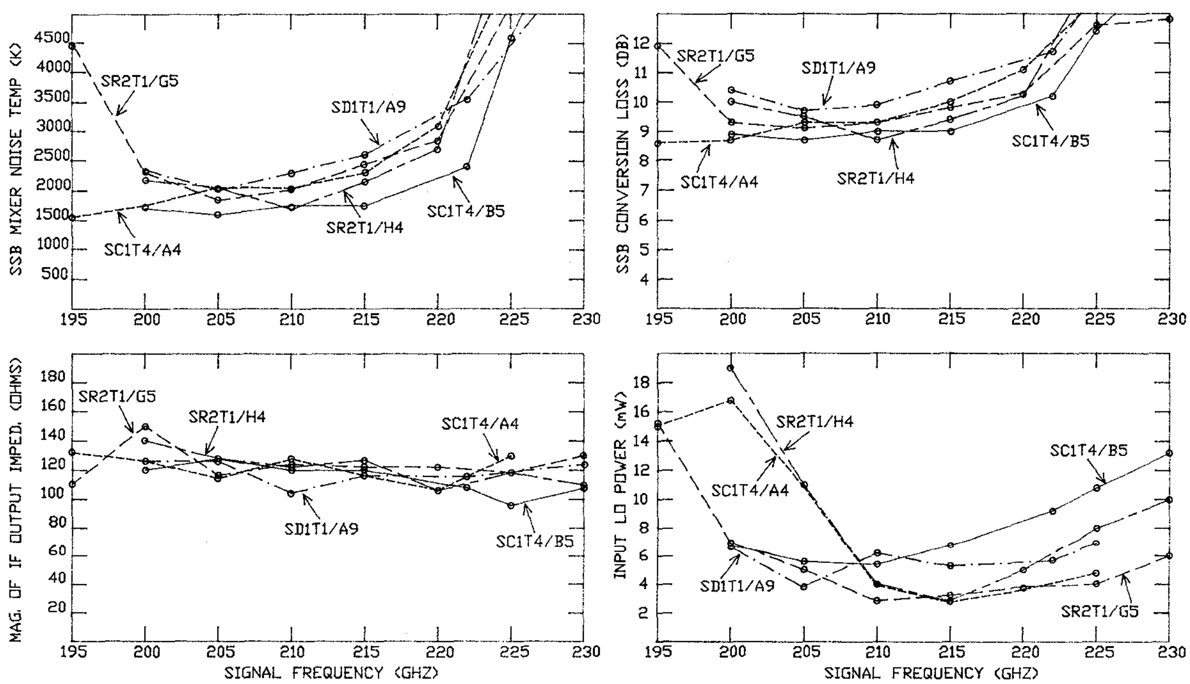

Fig. 2 Measured room temperature mixer noise, conversion loss, magnitude of the IF output impedance and required LO power between 195 and 230 GHz for the five diodes whose characteristics are given in Table I. Results are given for an IF frequency of 1.4 GHz. The mixer block was optimized for lowest noise temperature at each frequency using the two backshorts and two E-plane tuners. The noise and conversion loss are measured between the input RF signal feed horn and the IF output K-connector. LO power is referenced to the WR-8 input flange. In all cases, SSB values were obtained by doubling the measured DSB results.