A Tri-Layer Filter Structure for Individual Device Biasing of Subharmonically-Pumped Mixers Employing Antiparallel-Pair Diodes

T. H. Lee, I. Mehdi, R. J. Dengler, A. Pease, and P. H. Siegel
Jet Propulsion Laboratory, California Institute of Technology

Abstract

Antiparallel Schottky diodes, in both whisker contacted and integrated planar chip packages, have been utilized to produce millimeter-wave subharmonically-pumped (SHP) mixers for many years [1-5, e.g.]. SHP mixers have the advantage of operating with a local oscillator (LO) at one half of the signal frequency and have been shown to yield conversion loss and noise temperatures only slightly higher than conventional single-ended mixers [1,5]. However, the required LO power for these demonstrated SHP mixers is many times that of a single diode circuit. This is due to the difficulty involved in incorporating individual diode bias circuitry with the antiparallel pair and is the most limiting factor in scaling SHP mixers up to higher submillimeter-wave frequencies. In this paper the authors describe a very compact multiple layer bias circuit for an antiparallel-pair diode arrangement which can be implemented in microstrip. The concept was first proposed by the millimeter-wave development group at Rutherford Appleton Labs in the U.K., but, to our knowledge, has not yet been successfully implemented [6]. We report on the design and testing of a multiple layer transmission line bias structure which has been used with our Quartz Upside-down Integrated Device (QUID) process to produce a working SHP circuit which we have tested in a waveguide mixer block at 200 GHz. The addition of the bias circuit reduces the LO power by 50% without significant increase in the mixer conversion loss or noise temperature. The design is currently being implemented at 640 GHz for a NASA space Earth remote sensing instrument - Microwave Limb Sounder.

Extended Summary

The idea of separately biasing each diode of an antiparallel pair to reduce the turn-on voltage and, hence, the required LO power is not new and has been used in both waveguide-based and MMIC-based circuitry [7,8]. However, past implementations have required extra ports for isolating the two devices and bringing in the second bias line. This makes the implementation especially difficult in high-frequency waveguide structures where additional circuit elements are often added at a tremendous price. A very compact bias circuit arrangement was recently demonstrated in an open structure quasi-optical SHP mixer system at 180 GHz [3]. This arrangement utilizes a gap-cap configuration on one side of the two diodes and requires that there be a split in the feed lines going to the devices on this side of the circuit. Such an arrangement is not practical in a waveguide SHP circuit where there is generally not enough space to implement the feed line gap. The design presented here utilizes the vertical space within the existing filter circuitry to implement a multi-layer transmission line structure which isolates the two diodes of the antiparallel pair. It requires no additional space and has been incorporated into an existing mixer circuit design [4] and tested at 200 GHz.

The bias circuitry is formed at the same time as the diodes and IF and RF transmission line filters using the QUID process which integrates the planar diodes with the filters and then transfers everything from the GaAs host wafer to a low-loss quartz substrate [5]. The center portion of the drawing of the lower half split-block waveguide mount with the diode bias and microstrip circuitry is shown in Figure 1.

The details of the biasing scheme near the anode region are shown in Figure 2. The filter on one side of the diode pair is duplicated and overlayed with its twin using a thin layer of nitride for DC isolation. During processing, each of the metallic filter layers is coupled to a different active device, thus electrically isolating the two diodes. The strong capacitive coupling between the filter layers preserves the AC performance. Details of the fabrication process follow.

The stacked filters are formed from a metal/nitride/metal tri-layer. The metal layers are titanium/gold deposited by electron-beam evaporation and have a total thickness of 9000 Å. The intermediate nitride layer is deposited by an electron cyclotron resonance (ECR) dielectric deposition system to a thickness of 8000 Å. The nitride layer has to have low pin-hole density and good step coverage. The deposition was performed in a high-pressure (20 mTorr) environment with the use of an etch-back process. The thickness of nitride determines the coupling capacitance required for proper filter performance. For our particular circuit, 6000 Å of nitride results in approximately 1 ohm impedance at the lowest mixer IF frequency of 1.5 GHz. However, it was necessary to use a slightly thicker nitride layer (8000 Å) to improve the processing yield.

A prototype circuit using optically-formed diodes with 2 μm diameter circular anodes was fabricated for insertion into our existing mixer block design. The measured DC parameters for the diode pair are given in Table 1. A higher turn-on voltage in the second diode, causing nonsymmetry in the I-V characteristics, can be compensated through different bias voltages at the two diodes. Due to the larger than average anode area and high series resistance, we did not expect to have extremely good mixer performance in the existing waveguide blocks. Indeed, the best mixer performance results, obtained at 195 GHz, yielded a double sideband (DSB) noise temperature of 2380 K with 16 mW of LO power required when no external bias was applied. With the application of separate bias in the two devices, we were able to decrease the required LO power to 8 mW with a subsequent increase in noise temperature to 2730 K. Bias current in the two devices was 800 μA. The DSB conversion losses were 10.1 and 10.9 dB, in the former and latter cases respectively. The IF output impedance at optimum RF performance was around 80 Ω, regardless of the bias conditions. The results translate to 0.7 dB degradation in noise performance with a 3 dB LO power reduction. Figure 3 shows the noise temperature and conversion loss at several LO frequencies, with the same device with no external bias, and with a bias condition which requires 3 dB less LO power.

The measured mixer performance is not nearly as good as that obtained with other devices in the same blocks. We believe this is largely the result of the anode size which is not optimum for this circuit at this frequency. However, these early results do demonstrate the feasibility of the multi-layer bias concept and encourage our ongoing efforts of making smaller diodes for higher operating frequencies using this configuration.

References

[1] M. V. Schneider and W. W. Snell, "Harmonically Pumped Stripline Down-Converter," *IEEE Trans. Microwave Theory Tech.*, vol. 23, no. 5, pp. 271-275, Mar. 1975.

[2] M. Cohn, J. E. Degenford, and B. A. Newman, "Harmonical Mixing with an Antiparallel Diode Pair," *IEEE Trans. Microwave Theory Tech.*, vol. 23, no. 8, pp. 667-673, Aug. 1975.

[3] T. H. Lee, J. R. East, C. Y. Chi, G. M. Rebeiz, and G. I. Haddad, "A Novel Biased Anti-Parallel Schottky Diode Structure for Subharmonic Mixing," *IEEE Microwave and Guided Wave Letters*, vol. 4, no. 10, pp. 341-343, October, 1994.

[4] P. H. Siegel, R. Dengler, I. Mehdi, J. Oswald, W. Bishop, T. Crowe, and R. Mattauch, "Measurements on a 215 GHz Subharmonically Pumped Waveguide Mixer Using Planar Back-to-Back Air-Bridge Schottky Diodes," *IEEE Trans. Microwave Theory Tech.*, vol. 41, no. 11, pp. 1913-1921, Nov. 1993.

[5] I. Mehdi, M. Mazed, R. Dengler, A. Pease, M. Natzic, and P. Siegel, "Planar GaAs Schottky Diodes Integrated with Quartz Substrate Circuitry for Waveguide Subharmonic Mixers at 215 GHz," *IEEE MTT-S Int. Microwave Symp. Digest*, pp. 779-782, 1994.

[6] B. Ellison, B. Maddison, and D. Matheson, private communication.

[7] J. W. Archer, R. A. Batchelor, and C. J. Smith, " Low-Parasitic, Planar Schottky Diodes for Millimeter-Wave Integrated Circuits," *IEEE Trans. Microwave Theory Tech.*, vol. 38, no. 1, pp. 15-22, Jan. 1990.

[8] P. H. Siegel, S. Weinreb, S. Duncan, W. Berk, A. Eskandarian, and D.-W. Tu, "Design and Measurement of a 210 GHz Subharmonically Pumped GaAs MMIC Mixer," *IEEE MTT-S Int. Microwave Symp. Digest*, pp. 603-606, 1992.

Figures and Tables

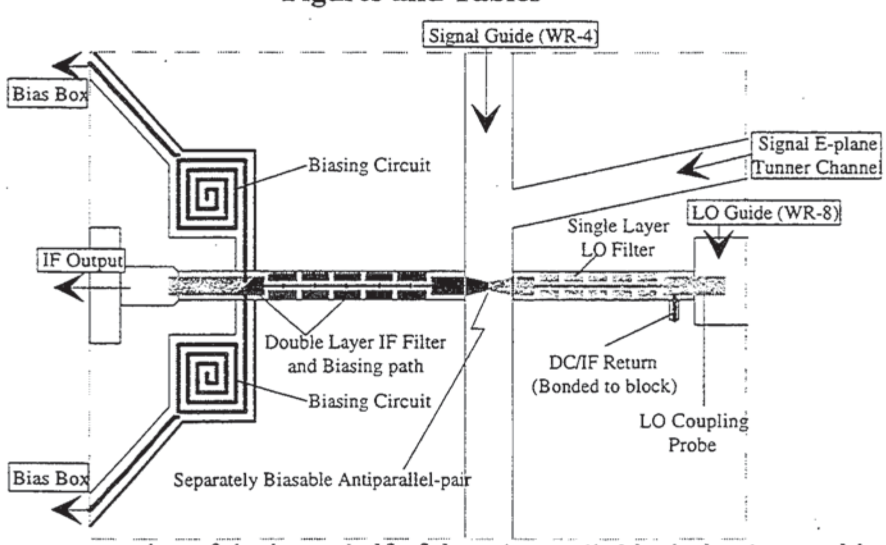

Figure 1. The center portion of the lower half of the mixer split-block that houses biasable diodes and microstrip circuits.

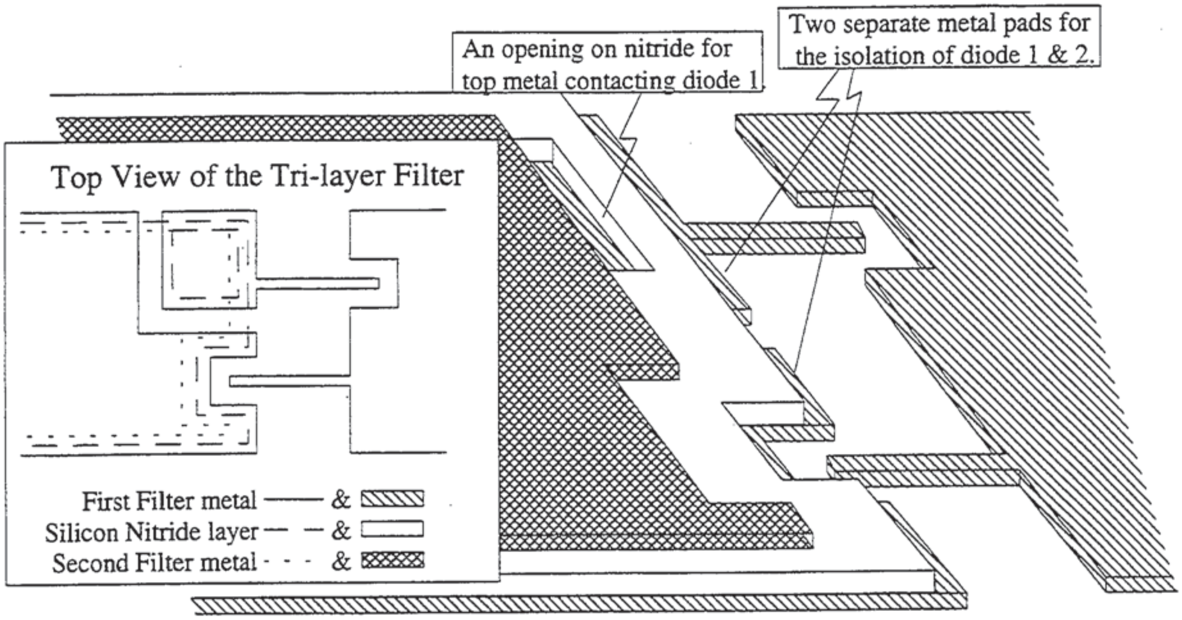

Figure 2. A tri-layer IF filter and a single layer LO filter near the anode region. The vertical structure on the IF side provides a compact way of biasing individual diodes.

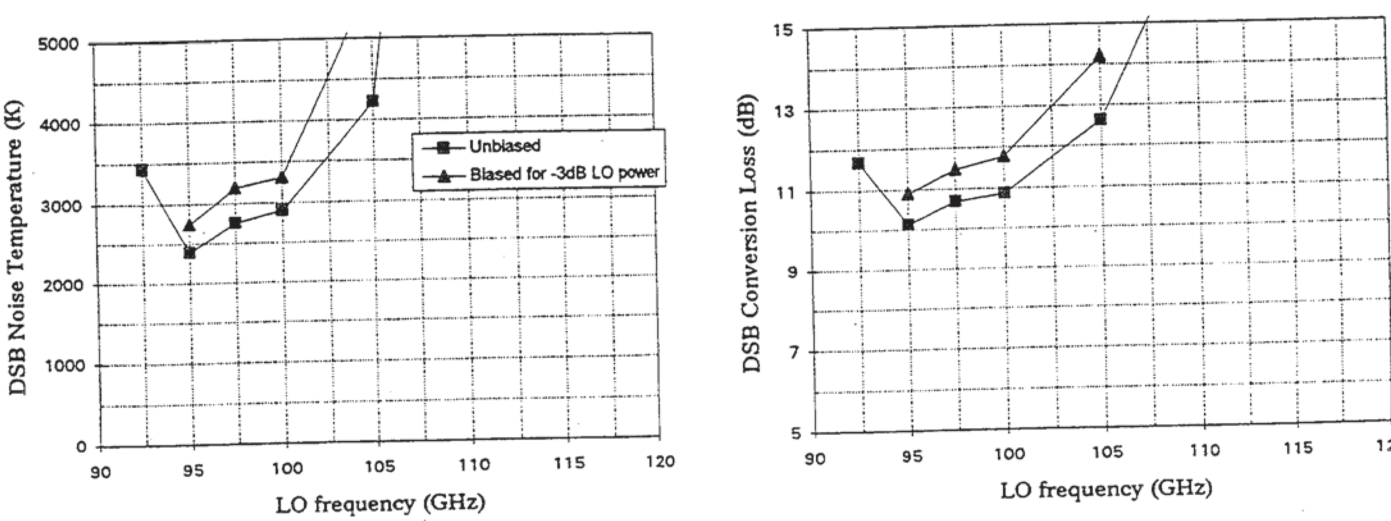

Figure 3. DSB noise temperature and conversion loss vs. LO frequency for the device with no external bias and for the same device biased to require only one-half of the LO power.

Parameters	R_s (Ω)	η	I_s (A)	$\Phi_{barrier}$ (V)
Diode 1	8	1.23	$1.2\mathrm{x}10^{-13}$	0.735
Diode 2	13	1.25	$1.4\mathrm{x}10^{-13}$	0.730

Table 1. Diode DC parameters measured from the separately biasable Schottky diode pair.