A Novel Biased Anti-Parallel Schottky Diode Structure for Subharmonic Mixing

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Abstract—**Subharmonically pumped mixers using zero-biased anti-parallel Schottky diode pairs produce good results, but require a larger LO power than biased Schottky diodes. Presented here is a novel planar-diode anti-parallel pair that allows independent biasing of the two diodes. This diode pair is integrated into a quasi-optical wideband receiver and the RF measurements on a 1.2-μm anode diameter pair show a reduced LO power requirement at 180 GHz by a factor of 2 to 3 with a similar DSB conversion loss and noise temperature (9.7 dB and 1850°K) to an unbiased Schottky diode pair. This structure has potential for applications at submillimeter-wave frequencies where a large amount of LO power is not easily available.**

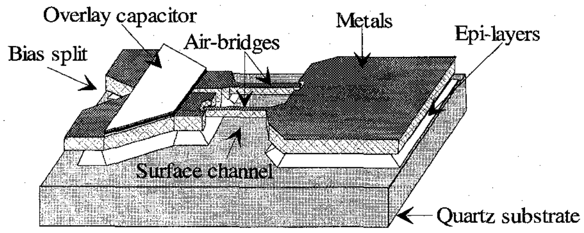

Fig. 1. The novel anti-parallel diode structure with a biasing split and overlay capacitor before mounting on a log-periodic antenna. The GaAs substrate has been removed completely and replaced with a 3-mil quartz substrate.

I. Introduction

SPACE-BORNE receivers operating in the submillimeter region of the electromagnetic spectrum employ subharmonically pumped (SHP) mixers because of the lack of adequate local oscillator (LO) power at fundamental frequencies. Such mixers utilize local oscillators at one half the signal frequency where more LO power is usually available [1], [2]. Recently, SHP mixers that were realized by a pair of anti-parallel Schottky diodes using planar-diode technology have produced excellent results at 200 GHz [3], [5]. However, most of these diodes are zero-biased and require a comparably large LO power. The use of an individually biased diode pair has the advantages of lowering the turn-on voltage in the RF equivalent circuits and effectively reducing the LO power requirement. This scheme can be easily realized using a novel anti-parallel planar diode pair on a planar antenna with a biasing split as introduced in this paper.

II. Device and Antenna Design

The anti-parallel diode pairs contain two identical GaAs Schottky diodes with opposite polarities. The anodes are formed by evaporating Ti/Pt/Au (500/500/1000 Å) on a 3×10^{17} cm^{-3} n^- epitaxial layer. The initially fabricated diodes are 4, 2, and 1.2 μm in diameter, resulting from an optical exposure system. The devices were fabricated using planar-diode technology proposed in [4], modified to include a biasing structure. The device layout is illustrated in Fig. 1. This includes a surface channel, air-bridges, bias arms, and an overlay capacitor for RF coupling. The two bias arms are DC isolated by a 2.5-μm-deep etched trench, but are RF shorted by the overlay capacitor. The overlay capacitor is a sputtered SiO_2/metal/SiO_2 tri-layer fabricated via a lift-off process after the trench is formed. The sandwiched metal layer is 6000 Å thick, enough to provide two skin depths at 90 GHz. The underlying GaAs device substrate is completely removed and replaced with a 3-mil quartz support, which is then diced into single devices. Additional fabrication details are given in [5].

The chip dimensions of a diced device on the quartz carrier are 300 μm long by 120 μm wide by 75 μm high. The quartz carrier, which has a lower dielectric constant than GaAs, reduces the pad-to-pad parasitic capacitance. The flip-chip mounting technique is used to epoxy single devices down to a log-periodic antenna.

The log-periodic antenna for the separately biased Schottky didoes is modified from the design described in [6]. This log-periodic antenna covers 35 to 350 GHz with σ=0.707 and τ=0.5. The angles of the metal teeth (α) and the trunk (β) are 30° and 60°, respectively. The antenna input impedance is independent of frequency and is 74 Ω on a silicon substrate (ε_r=11.7). The layout is given in Fig. 2(a). This includes one arm of the antenna without a split connecting to a quarter-wavelength transmission line at the IF (1.4 GHz) and an RF choke to provide a DC ground as IF ground. The other arm has a 20-μm split for biasing considerations, covered by a sputtered SiO_2/metal/SiO_2 tri-layer fabricated by a lift-off process to provide RF coupling to the antenna. This tri-layer is 1200/6000/500 Å in thickness, similar to the overlay capacitor used in the AC short in the device contact pad.

Fig. 2(b) shows that the log-periodic antenna is placed on the back of a 12.7-mm-diameter hemispherical silicon dielectric lens and spacing wafers for 2400-μm extension [7]. The use of the silicon lens and extension wafers helps to eliminate

Manuscript received May 27, 1994.

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IEEE Log Number 9404759.

TABLE I
ANTI-PARALLEL SCHOTTKY DIODE DC PARAMETERS EXTRACTED FROM I-V AND LOW FREQUENCY CAPACITANCE MEASUREMENTS

Anode Diameter	R_s (Ω)	n	I_s (A)	$\phi_{barrier}$ (V)	Capacitance (fF)		
					C_j	$C_{pad\text{-}to\text{-}pad}$	$C_{finger\text{-}to\text{-}pad}$
2.0 μm	7.8	1.17	$2.0\text{x}10^{-14}$	0.716	6.3	< 4	< 3
	5.1	1.18	$5.1\text{x}10^{-14}$	0.693	6.3	<4	<3
1.2 μm	14	1.15	$6.7\text{x}10^{-15}$	0.719	2.3	< 4	< 2
	15	1.20	$1.2\text{x}10^{-14}$	0.704	2.3	<4	<2

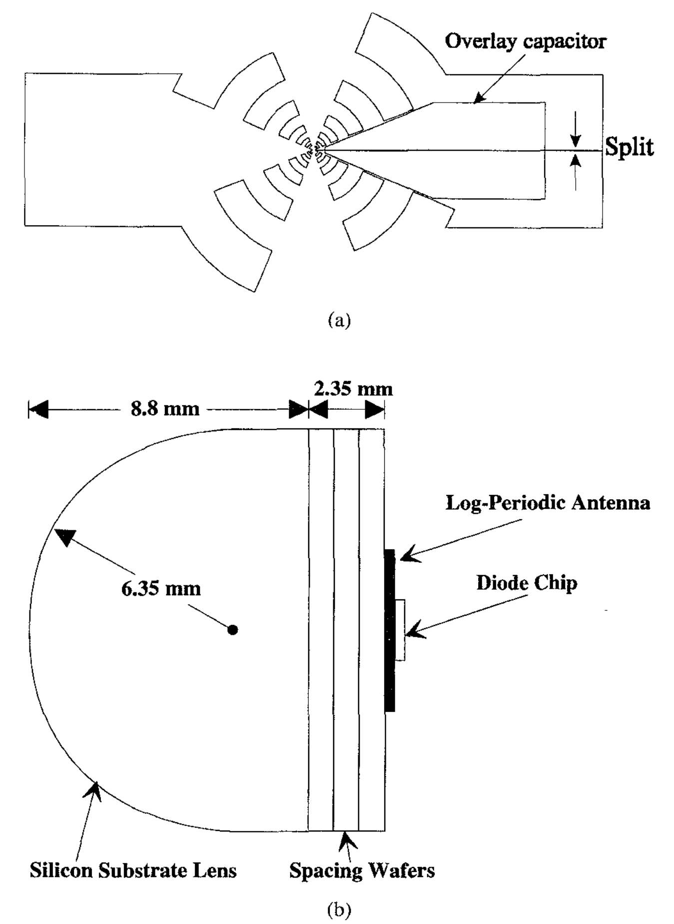

Fig. 2. (a) The layout of a log-periodic antenna with a split and an overlay capacitor. (b) The diode/antenna is placed on the back of a 12.7-mm-diameter silicon lens and spacing wafers.

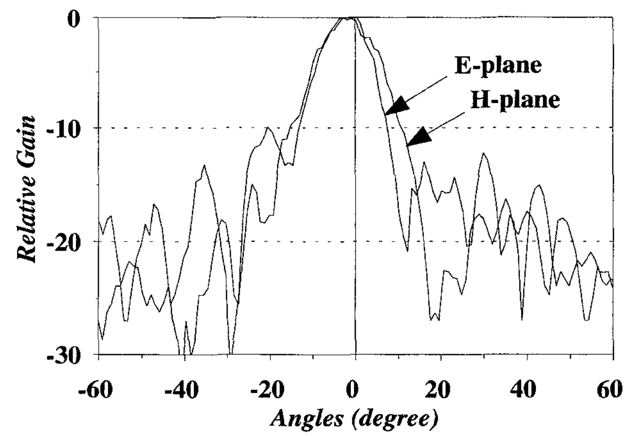

Fig. 3. Measured E- and H-plane patterns of a log-periodic antenna on 12.7-mm-diameter silicon substrate lens at 90 GHz.

substrate mode propagation and enhance gain and Gaussian coupling efficiency. The measured antenna patterns at 90 GHz are shown in Fig. 3. The log-periodic antenna is linearly polarized, but considerable cross-polarization components are found in the E- and H-planes (-5 to -10 dB). The antenna directivity calculated from full two-dimensional pattern measurements is 138 at 90 GHz.

III. DC AND 180-GHz PERFORMANCE

Listed in Table I are the extracted DC parameters from measured data for 2- and 1.2-μm diodes from a Schottky diode pair. The measured DC parameters from adjacent diodes in an anti-parallel diode pair are very similar. All parameters except capacitances are obtained from the least-squares fitting of experimental $ln(I) - V$ curves. All diodes have a barrier height close to 0.7 V, resulting from the evaporated Ti/Pt/Au Schottky metals. The diode capacitance, which consists of the zero-bias junction capacitance and pad-to-pad and finger-to-pad parasitic capacitances, was measured at 1 MHz using the high resolution mode of an HP 4275 LRC meter. The pad-to-pad capacitance was measured by removing the air-bridges. The zero-biased junction capacitance was estimated from the anode area and the depletion width of a 0.7-V barrier height, considering the effect of image force lowering. The replacement of a GaAs substrate with a quartz substrate results in a reduction of 10 ± 4 fF in parasitic capacitances.

The mixer performance of a 1.2-μm-diameter diode pair was measured at 180 GHz using the hot-and-cold load method. The setup, conversion loss, and noise temperature calculations are essentially identical to the one discussed in [6]. The IF mismatch loss is measured by the power reflection technique. The measured DSB diode performance is shown in Table II. At 180 GHz, a minimum DSB conversion loss of 9.7 dB is found at a bias current of 100 μA per diode with an estimated available LO power from a 74 Ω source at the antenna terminals of 4.5 mW. The corresponding DSB noise temperature minimum is 1850°K. It is important to note that this log-periodic antenna on an extended silicon substrate

TABLE II
MEASURED MIXER PERFORMANCE AT 180 GHz FOR DIFFERENT BIAS CONDITIONS. INCLUDED ARE CONVERSION LOSS, NOISE, TEMPERATURE, AND ESTIMATED LO POWER AT 90 GHz, ALL FROM 1.2-μm-DIAMETER ANTI-PARALLEL DIODES

Frequency	Bias Current	Minimum DSB L_m (dB)	Minimum DSB T_m (°K)	Estimated P_{LO} (mW)
90-180 GHz Subharmonic Mixer	unbiased	8.7	1800	9.0
	± 100 μA	9.7	1850	4.5
	± 400 μA	9.8	1890	4.0

lens contributes approximately 3 dB of loss in a Gaussian beam quasi-optical system (see [6] for more details). This means that the anti-parallel diode conversion loss is around 9.7 dB SSB from a 74-Ω RF source. Increasing the bias to 400 μA reduces the LO power requirement to about 4 mW, as compared to 9 mW resulting from a zero-biased diode pair using an identical setup [6]. The DSB conversion loss (9.8 dB) and noise temperature (1890°K) remain essentially the same.

IV. CONCLUSION

In this paper, we have presented a novel structure for a separately biased Schottky diode pair that shows a factor of 2–3 reduction in LO power requirement at 90 GHz. At 180 GHz a quasi-optical receiver results in a minimum DSB conversion loss of 9.7 dB and noise temperature of 1850°K at a bias current of 100 μA. The fabrication of such devices only requires an extra tri-layer lift-off process in addition to the usual planar-diode technology and is suitable for integrated receiver fabrication. This structure is well suited for higher frequency applications where LO power requirements become a limiting factor in mixer operation.

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