PROGRESS IN INTEGRATED-CIRCUIT HORN ANTENNAS FOR RECEIVER APPLICATIONS

Part II: A 90 GHz Quasi-Integrated Horn Antenna Receiver

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ABSTRACT

A receiver belonging to the family of integrated planar receivers has been developed at 90 GHz. It consists of a planar Schottky-diode placed at the feed of a dipole-probe suspended inside an integrated horn antenna. The measured planar mixer single-sideband conversion loss at 91.2 GHz (LO) with a 200 MHz IF frequency is 8.3dB±0.3dB. The low cost of fabrication and simplicity of this design makes it ideal for millimeter and submillimeter-wave receivers.

INTRODUCTION

Fundamental mixers are currently the front-ends components for all millimeter-wave receivers above 100 GHz. The mixers use a Schottky-diode suspended in a machined waveguide with an appropriate RF matching network. These components are expensive to manufacture especially above 200 GHz where waveguide tolerances become severe. A low noise planar receiver consisting of a planar Schottky diode integrated with an efficient planar antenna is a needed alternative at millimeter-wave frequencies. Recent advances in planar Schottky diodes resulted in excellence performance at 94 GHz with measured diode temperatures competitive with whisker-contacted diodes [1]. In this work, a planar diode is combined with an integrated horn antenna [2,3] to yield a 90 GHz receiver. The antenna feed-dipole impedance can be designed to conjugate match the RF diode impedance [4]. This eliminates the need for an RF matching network and thereby simplifies the mixer design. A machined section is attached to the front of the integrated horn antenna to yield a multi-mode horn [5]. The planar configuration results in an inexpensive quasi-monolithic receiver with an expected performance as good as the best waveguide receiver at 100 GHz.

MIXER DESIGN AND THEORETICAL PERFORMANCE

The length of the feed-dipole and its position inside the integrated horn antenna are designed so that its impedance conjugate matches the RF diode impedance [4]. As a result, the planar diode is epoxied right at the dipole apex. An RF choke is obtained by using two integrated lumped capacitors on a coplanar stripline. The first capacitor is $\lambda_o/4$ away from the dipole feed and the second capacitor is $\lambda_d/2$ away from the first one. These capacitors introduce an RF open circuit at the dipole feed and let the IF signal pass through the coplanar stripline (Fig.1). The circuit is integrated on highly resistive Silicon in order to minimize any losses of the IF signal on the surrounding dielectric substrate. A microstrip quarter-wave transformer over a Duroid 5870 substrate [7] is used to match the 1.4 GHz IF diode output impedance to 50Ω. Fig.2 shows the structure of the integrated horn antenna receiver. The machined section, not shown in this figure, is attached to the front aperture of the horn antenna. Gold is evaporated on all the horn walls except on the membrane wafer walls, in order not to short-out the feed lines. The diode of choice to be used in this design is the UVa SC2R4 planar Schottky diode with 2.5μm anode diameter, a 5-6fF zero-bias junction capacitance, a 12-13fF parasitic capacitance and a 5-6Ω series resistance. A microwave model of the horn receiver structure shown in Fig.2 was built at 2.55 GHz in order to find the right feed-dipole impedance to conjugate match the UVa diode RF impedance. A feed-dipole, which is 0.392λ long and positioned 0.38λ from the apex of the horn, has an input impedance of 75+j55 Ω with the membrane walls uncoated and with no diode chip modeled at the dipole feeds. The input impedance dropped to 70+j10 Ω due to the capacitive effect of the diode block when it was modeled. A 1.1dB-1.3dB power loss was found in the microwave model by measuring the difference in powers detected by the feed- dipole for the case of coated and uncoated membrane walls respectively. Table I shows the mixer theoretical performance for the UVa diode at 91.2GHz(LO) and 91.4GHz(RF) for a bias of 0.65V and an available LO power of 2dBm. The analysis was done using the reflection algorithm [6]. the variation in conversion loss over 10% bandwidth is due to the variation in the feed dipole impedance.

Table I

f_{IF}(GHz)	0.2
f_{RF}(GHz)	91.4
$Z_{dipole,RF}(\Omega)$	70+j10
$Z_{dipole,2RF}(\Omega)$	14+j10
$Z^{in}_{diode,RF}(\Omega)$	62-j19
$Z^{in}_{diode,LO}(\Omega)$	55-j49
$Z^{out}_{diode,IF}(\Omega)$	86
Diode SC2R4 SSB Conversion loss(dB)	5.7
Diode SSB Conversion loss(dB) over 10% BW	5.7-6.2

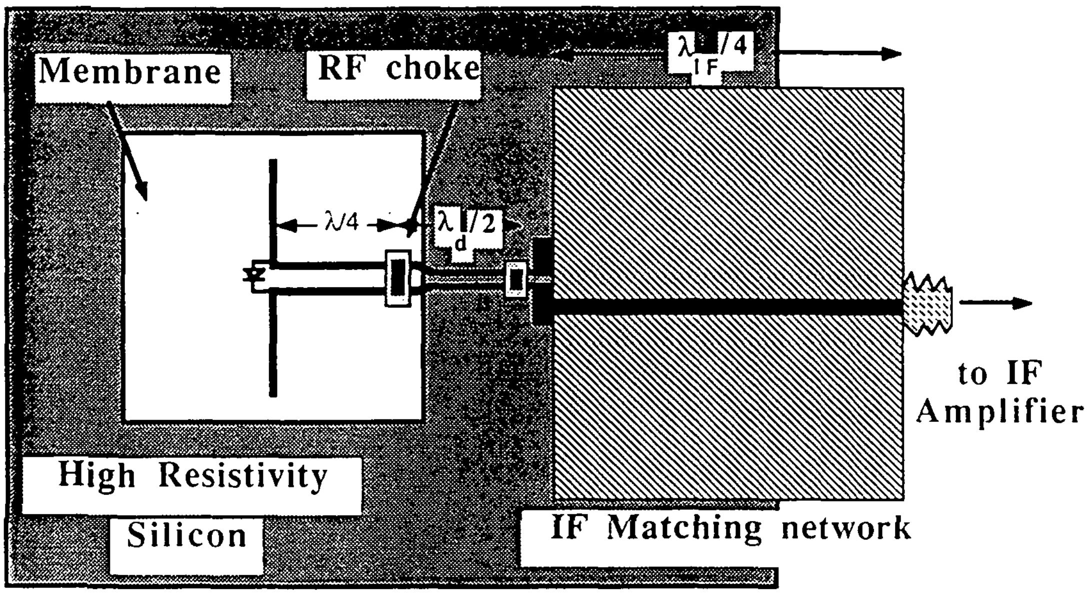

Figure 1: The mixer design consisting of the diode epoxied at the dipole feeds, the two lumped capacitors forming the RF choke, and the microstrip line IF matching network.

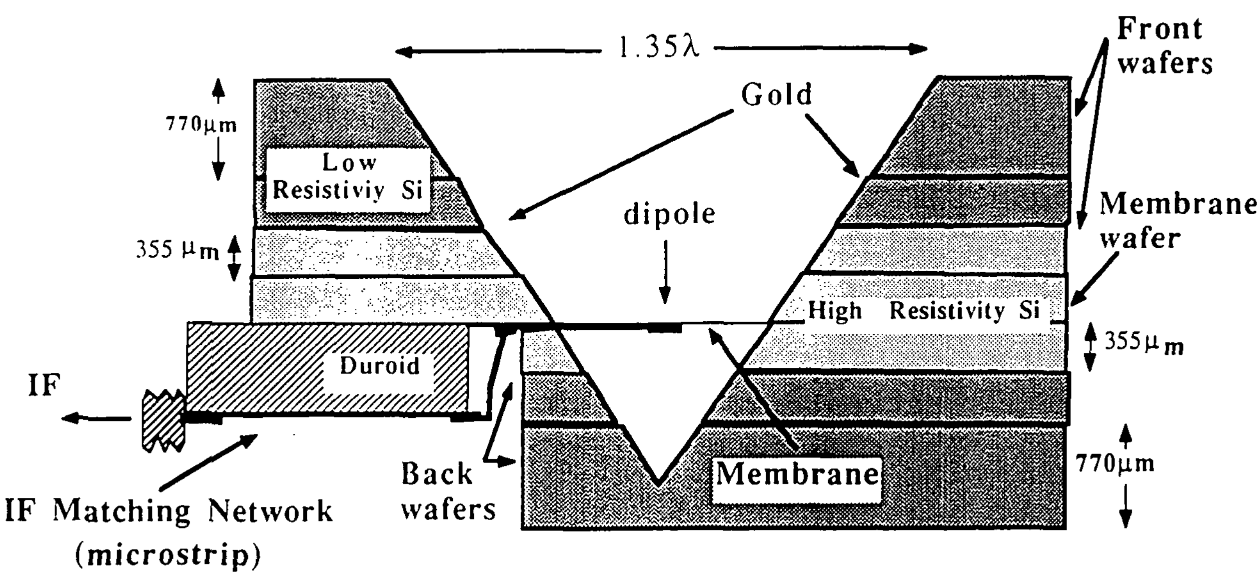

Figure 2: The integrated horn antenna receiver structure. The horn walls of the membrane wafer are not coated with gold.

RECEIVER MEASUREMENTS

A quasi-integrated horn antenna receiver was built at 91.4 GHz with a UVa SC2R4 diode epoxied at the dipole feeds. Video detection measurements were done at 91.4 GHz by shining a known plane wave power density onto the multi-mode antenna and measuring the output detected diode voltage using a lock-in amplifier. The diode theoretical video responsivity vs. bias current is fitted to the measured data by using the parameters shown in table II to model the receiver.

Table II

$\epsilon_{aperture}$	$\epsilon_{lossinwalls}$	Z_{dipole}	R_s	C_j	ϕ_{bi}	C_p	η
-2.0dB	-1.2dB	70+j10 Ω	6Ω	5.5 fF	0.88 V	12.5 fF	1.14

In fig.3, the measured video responsivity is equal to the ratio of the detected voltage across the diode over the plane wave power incident on the aperture of the quasi-integrated horn antenna. The diode parameters used in the model are those provided by University of Virginia. Although the receiver was designed for a 1.4 GHz IF frequency, we found that epoxy and solder at the junction between the duroid and the silicon substrate have added a parasitic IF capacitance. The measurements were therefore done at 200 MHz where this capacitance has negligeable effect. For the SSB conversion loss measurement, a calibrated 91.4 GHz RF plane wave and a 91.2 GHz LO were combined using a thin Mylar sheet and shined on the receiver. Figure 4 shows the measured planar mixer SSB conversion loss, defined as the received IF power divided by the RF power absorbed by the horn aperture (plane wave power density × horn area × horn aperture efficiency). The SSB conversion loss includes the 1.2dB loss in the uncoated membrane walls. An 8.3dB SSB conversion loss is measured at 91.4 GHz with 3.5dBm estimated LO power available at the feed-dipole terminals. The coupling efficiency of the horn aperture to a plane wave is normalized out of the measurement because in a receiver system the horn has a gaussian coupling efficiency of 97%. Also, the measured result can be directly compared to waveguide mixers performance which have no antennas attached. The 8.3 dB SSB conversion loss compares favorably with the best waveguide mixers performance (5.3±0.5dB) using the same diode [1].

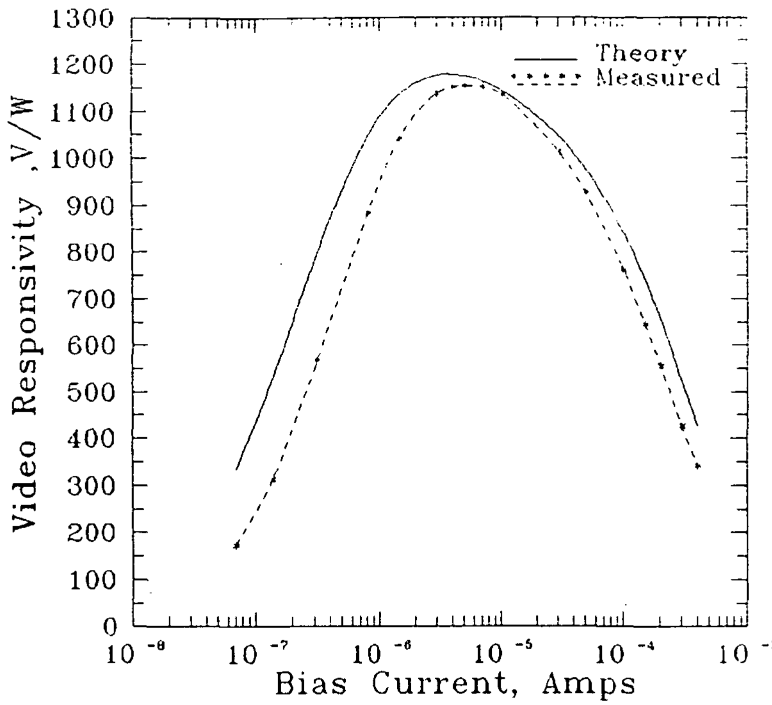

Figure 3: Measured and theoretical video responsivity at 91.4GHz.

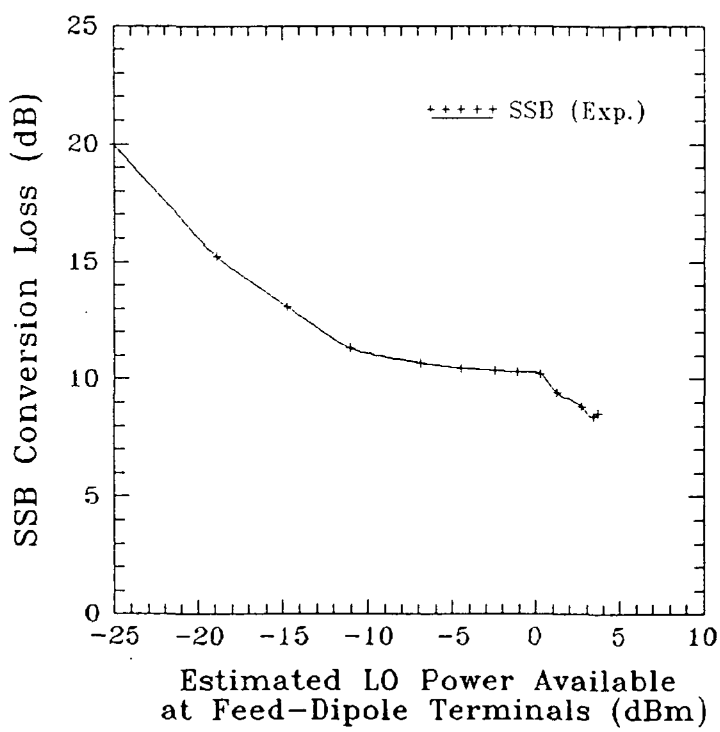

Figure 4: Measured planar mixer SSB conversion loss for the SC2R4 diode at 91.2 GHz (LO). The measured values include a 1.2dB loss attributed to power loss in the horn walls.

CONCLUSION

A 90GHz quasi-integrated horn antenna receiver has been designed and tested. The measurements show that this new receiver is a very good candidate for millimeter-wave applications. DSB measurements are being done on a new improved receiver design and using the UVa SC2T3 diode which has lower parasitic capacitance and series resistance than the UVa SC2R4 diode.

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