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. A machined section attached to the front of the etched horn increases the gain to 20dB and results in Gaussian coupling efficiency of 97%. 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 to yield a 90 GHz receiver. Integrated horn antennas consist of a dipole probe suspended in an etched pyramidal cavity. They are easy to fabricate, free of dielectric and surface wave losses, and suitable for millimeter and submillimeter-wave applications [2,3,4]. The feed-dipole impedance can be designed to conjugate match the RF diode impedance. This eliminates the need for an RF matching network and thereby simplifies the mixer design [5]. A machined section is attached to the front of the integrated horn antenna to yield a multi-mode horn. The planar configuration results in an inexpensive quasi-monolithic receiver with an expected performance as good as the best waveguide receiver at 100 GHz.

ANTENNA DESIGN

Integrated horn antennas have a maximum aperture of 1.5λ, a gain of 11-13dB and a 75-80% Gaussian coupling efficiency [5]. This is due to the large horn flare angle of 70° which is inherent in the anisotropic etching of Silicon. To overcome this limitation, a flared machined section is attached to the front of the integrated horn antenna (Fig. 1). The modes triggered from the flare discontinuity are properly phased inside this section to result in a multi-mode horn(TE_{10}, TE_{12}+TM_{12}). The antenna shown below, designed by G.V. Eleftheriades at UM [6], has symmetrical patterns with high gain (20dB) and 97% Gaussian coupling efficiency (Fig. 2). The smallest dimension in the machined section is 1.35λ, and therefore this antenna can be easily fabricated up to terahertz frequencies.

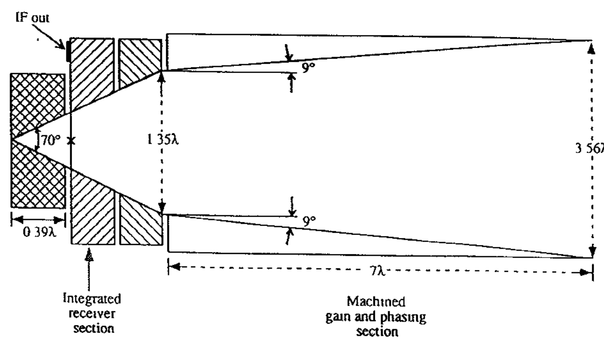

Figure 1: The 20dB quasi-integrated horn antenna.

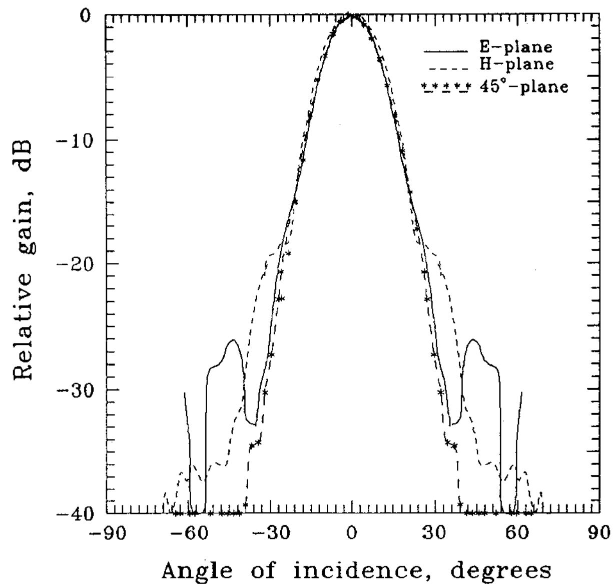

Figure 2: The measured E-, H-, and 45°-plane patterns of the quasi-integrated horn antenna at 91 GHz.

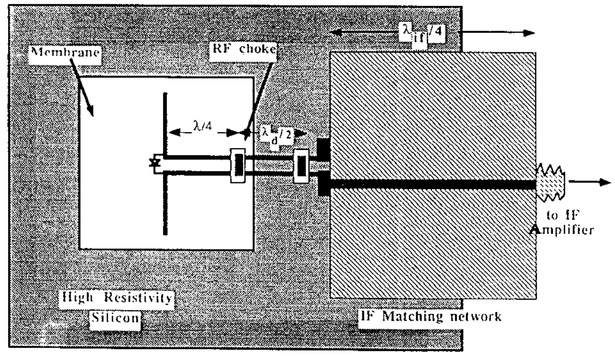

Figure 3: The mixer design consisting of the diode epoxied at the dipole feeds, the two lumped capacitors forming the RF choke, and the microstrip line IF matching network.

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 [5]. 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. 3). 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 [10] is used to match the 1.4 GHz IF diode output impedance to 50Ω. Fig. 4 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. The effect of the uncoated walls will be seen later in the measurements section.

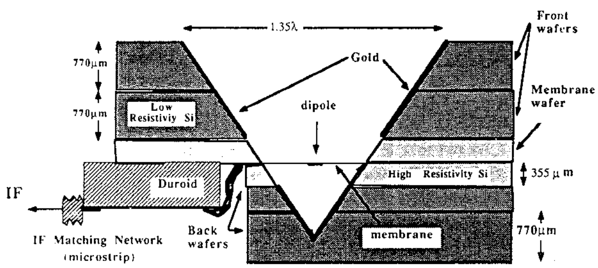

Figure 4: The integrated horn antenna receiver structure. The horn walls of the membrane wafer are not coated with gold.

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. 4 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 77+j55 Ω and results in a near conjugate match to the UVa diode RF impedance (see Table I). In both cases, 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
$Z_{dipole,RF}(\Omega)$	77+j55
$Z_{dipole,2RF}(\Omega)$	14+j56
$Z^{in}_{diode,RF}(\Omega)$	70-j60
$Z^{in}_{diode,LO}(\Omega)$	51-j56
$Z^{out}_{diode,IF}(\Omega)$	100
Diode SSB Conversion loss(dB)	5.5
Diode SSB Conversion loss(dB) over 10% BW	5.5-6.8

Table I shows the mixer theoretical performance for the UVa diode at 91.2 GHz(LO) and 91.4 GHz(RF) for a bias of 0.6V and an available LO power of 2dBm. This analysis was done using the reflection algorithm [7].

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 video voltage. The diode theoretical video responsivity vs. bias current is fitted to the measured data by choosing an antenna coupling efficiency to a plane wave of 62% calculated from the theoretical analysis for the multi-mode horn, a diode parasitic capacitance of 12.5fF, and an RF feed-dipole impedance of 77+j55 Ω, and a 1.2dB loss. This 1.2dB loss is attributed to a power loss in the walls of the membrane wafer, which were kept uncoated with gold. This power is carried by the TEM mode propagating down the four parallel waveguide plates surrounding the membrane. A 1.1dB-1.3dB power loss was found in the microwave model built at 2.55 GHz by measuring the difference in powers detected by the feed-dipole for the case of coated and uncoated membrane walls respectively.

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. We therefore chose to make the measurements 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. Fig. 5 shows that the measured planar mixer SSB conversion loss and the calculated SSB conversion loss, using the receiver parameters obtained from video detection, follow each other closely. Although the predicted best conversion loss is obtained at a bias of 0.6V, we got the optimum performance at a bias of 0.85V.

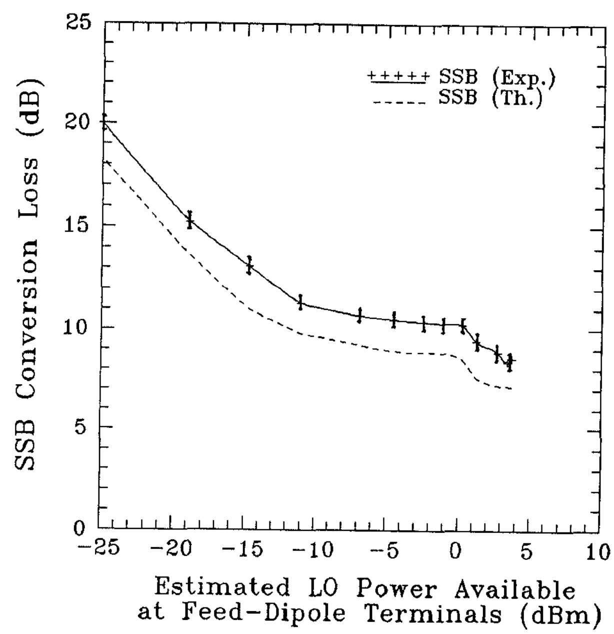

Figure 5: Measured and theoretical planar mixer SSB conversion loss for the SC2R4 diode at 91.2 GHz (LO) and a bias of 0.85V. The measured values include a 1.2dB loss attributed to power loss in the horn walls.

Defining the SSB conversion loss as the measured IF power divided by the RF power absorbed by the horn aperture (plane wave power density × horn area × horn aperture efficiency), we find an 8.3dB planar mixer SSB conversion loss was measured at 91.4 GHz with 3.5dBm estimated LO power available at the feed-dipole terminals. We normalize out the coupling efficiency of the horn aperture to a plane wave because in a receiver system the horn has a gaussian coupling efficiency of 97%. Also, we can now compare our data to waveguide mixers performance which have no antennas attached. Our 8.3 dB SSB compares favorably with the best 5.3±0.5dB waveguide mixers using the same diode [1]. DSB measurements at 1.4 GHz on an optimized receiver will be presented at the conference.

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REFERENCES

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

[2] G.M. Rebeiz, D.P. Kasilingan, P.A. Stimson, Y. Guo, and D.B. Rutledge,"Monolithic millimeter-wave two-dimensional horn imaging arrays," *IEEE Trans. Antennas Propag.*, vol. AP-28, Sept. 1990.

[3] W.Y. Ali-Ahmad, and G.M. Rebeiz,"92 GHz dual-polarized integrated horn antennas," *IEEE Trans. Antennas Propag.*, vol. AP-39, June 1991.

[4] W.Y. Ali-Ahmad, G.V. Eleftheriades, L.P. Katehi, and G.M. Rebeiz,"Millimeter-Wave Integrated Horn Antennas, Part II: Experiment," *IEEE- Trans. Antennas Propagation*, vol. AP-39, pp. 1582-1587, Nov. 1991.

[5] G.V. Eleftheriades, W.Y. Ali-Ahmad, and G.M. Rebeiz,"A 20dB Quasi- Integrated Horn Antenna," *IEEE- Microwave Guided-Wave Lett.*, vol. 2, pp. 72-75, Feb. 1992.

[6] D.N. Held and A.R. Kerr,"Conversion loss and noise of microwave and millimeter-wave receivers: Part I-Theory; Part II-Experiment," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, 1978, p.49-61.

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