A LOW-NOISE 86-90 GHz UNIPLANAR SCHOTTKY-RECEIVER

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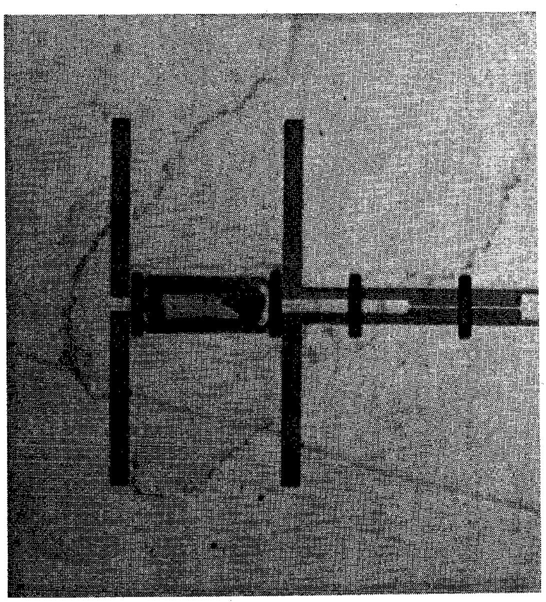
ABSTRACT

A millimeter-wave Schottky-receiver based on a coplanar-waveguide (CPW) fed double-slot antenna is described. The double-slot antenna is backed by an extended hemispherical silicon substrate lens. The design is uniplanar and requires no via holes or a backing ground-plane. The receiver results in a 6.9 dB measured double sideband (DSB) conversion loss at 86-90 GHz and a DSB noise temperature of 1200K. The DSB conversion loss drops to 5.7 dB when the residual matching-cap reflection loss (0.9 dB) and IF reflection loss (0.3 dB) are calibrated out of the measurements. The CPW-fed double-slot antenna results in a low-cost millimeter-wave uniplanar receiver with a performance that is within 3 dB of the best waveguide mixers at millimeter-wave frequencies.

I. INTRODUCTION

Integrated-circuit receivers consisting of a planar antenna integrated with a matching network and a planar Schottky-diode offer an attractive advantage over the waveguide-based receivers at millimeter-wave frequencies. They are easier and less expensive to build and can be easily arrayed for millimeter-wave imaging applications. In recent years, there has been a tremendous advance in integrated antenna technology and many integrated receivers based on the integrated horn antenna, log-periodic and spiral antennas have been developed. Another candidate for a potential of excellent millimeter-wave performance is the double-slot antenna. In this design, the length of the slot controls the E-plane pattern and the separation between the slot antennas controls the H-plane pattern.



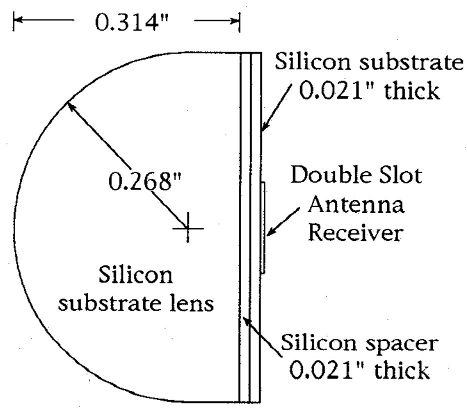


Figure 1: Photograph of the CPW-fed double-slot antenna receiver (left) and the extended hemispherical lens design (right).

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This antenna was proposed by Kerr et al. in 1978 [1] and recently used in conjunction with a hyperhemispherical quartz substrate lens in a liquid-helium cooled SIS receiver at 492 GHz [2]. However, in both designs, the slot antennas are fed by a microstrip line which is integrated over the slot ground plane and exhibits high room-temperature losses at 100 GHz. We have improved the design by: 1) using a CPW transmission-line between the slot antennas and 2) placing the slot antenna on an extended hemispherical substrate lens to result in higher gain patterns and therefore easier coupling to large f-number receiver systems. The current design is uniplanar and compatible with monolithic integration for low-cost millimeter-wave applications.

II. RECEIVER DESIGN

The CPW-fed double-antenna receiver is shown in Figure 1. The slot antennas are $0.28\lambda_a$-long with a separation of $0.14\lambda_a$. This results in a symmetrical pattern inside the silicon dielectric lens. The Schottky-diode is integrated in series between the slot antennas to achieve a sum-mode pattern. The CPW line dimensions are $s = 50\mu$m and $w = 25\mu$m at the slot-antenna inputs resulting in a line impedance of 50Ω. The potentials of the CPW ground-planes are equalized using air-bridges near the feed-points of the slot-antennas. The CPW is widened in the middle to accommodate a planar (hybrid) Schottky-diode. The CPW line is short-circuited to the ground-plane on the left slot antenna to provide a DC return for biasing the diode. On the right slot-antenna, the CPW line is connected to a low-pass IF filter and an IF impedance transformer. The IF filter presents a short-circuit at the RF frequency to result in proper feeding of the slot antenna by the CPW line. The measured input impedance at the diode terminals using a microwave model is around $60+j5\Omega$ which is compatible with Schottky-diode mixers.

The double-slot antenna is placed on an extended hemispherical silicon lens. The dielectric lens approach eliminates the excitation of substrate modes and makes the pattern unidirectional. The directivity and forward pattern Gaussian coupling efficiency of the double-slot antenna on a 6.858mm silicon lens versus the extension length from the hemispherical center is shown in Figure 2 [3]. It is evident that the extended hemispherical lens results in high gain patterns with a slight reduction in the Gaussian coupling efficiency. In this work, the double-slot antenna is placed at an extension length of 2250μm resulting in a directivity of 22.3 dB and a Gaussian coupling efficiency of 93%. The Gaussian coupling efficiency does not include power loss to the back-side (-0.5 dB) and the reflection loss off the silicon-air interface (-1.5 dB).

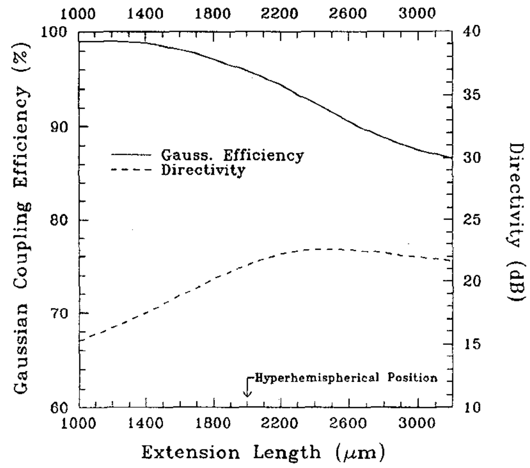

Figure 2: Calculated directivity and forward pattern Gaussian coupling efficiency at 100 GHz for a double-slot antenna on a 6.858mm-radius extended hemispherical silicon lens versus extension length.

III. MILLIMETER-WAVE MEASUREMENTS

The receiver was built using standard photolitographic techniques for 86-94 GHz operation and placed on the back of a 6.858mm-radius silicon extended hemispherical lens. The planar diode (Alpha DMK2784) is connected to the CPW line using silver epoxy. Figure 3 shows the measured patterns at 88 GHz and 94 GHz. The patterns agree well with theory and are symmetrical with low sidelobes and a high Gaussian coupling efficiency ($\geq 85\%$).

The nominal diode capacitances are $C_j = 18$fF and $C_p = 13$fF and the measured DC parameters are $R_s = 8\Omega$, $n = 1.1$, $\Phi_b = 0.78$V and $I_s = 1.6 \times 10^{-14}$A. A peak video responsivity of 800V/W is measured at 94 GHz for a bias current of 10μA. The video responsivity is defined as the measured low frequency voltage in a 120kΩ load divided by the total RF power incident on the lens aperture. The video responsivity includes the antenna aperture efficiency (estimated to be 80-85%) and the lens reflection (1.55 dB) and absorption loss (0.3 dB). The measurements show a large video responsivity due to the excellent antenna patterns and the match between the double-slot antenna and the planar diode.

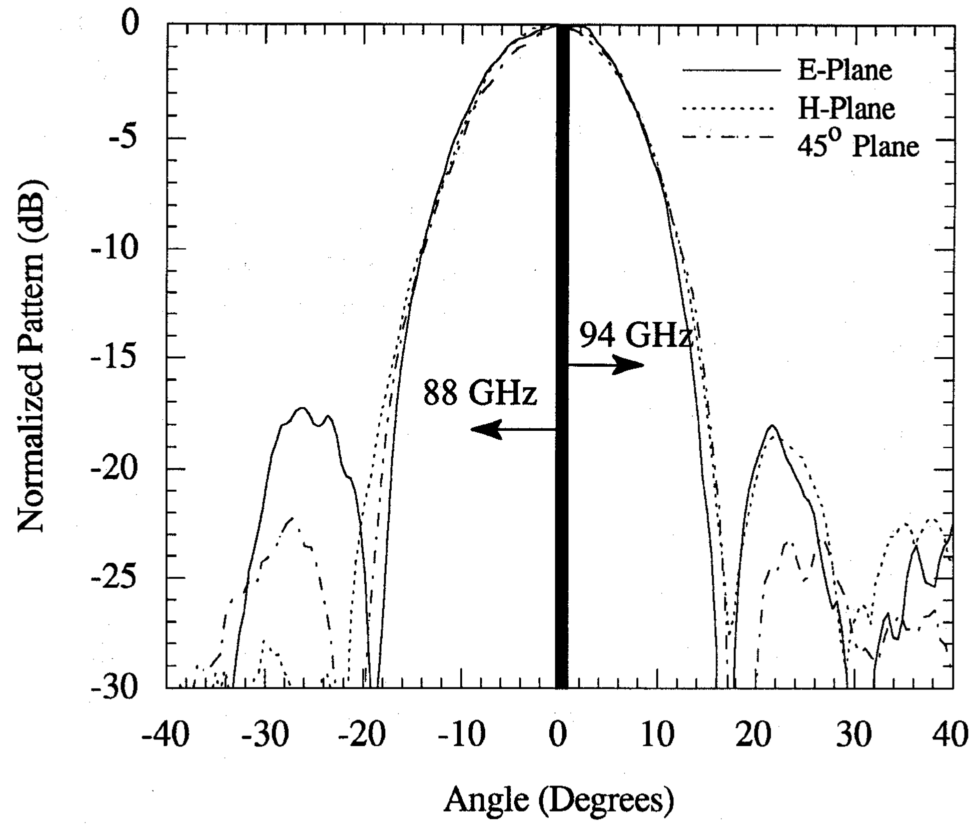

Figure 3: Measured patterns at 88 GHz (left) and at 94 GHz (right) (see text).

The measured DSB conversion loss and noise temperature are presented in Figure 4. The measurements were done using a Martin-Pupplett interferometer at an IF frequency of 1.4 GHz. A receiver DSB conversion loss and noise temperature of 6.9 dB and 1200K, respectively, are achieved over the range of 86-90 GHz. The IF reflection loss was less than 0.3 dB and is not calibrated out of the measurements. The measurements include the effect of a residual reflection loss of 0.9 dB due to the use of a non-optimal matching cap-layer at the silicon-lens/air interface and a 0.3dB residual IF reflection loss. The DSB conversion loss drops to 5.7 dB when all these effects are calibrated out of the measurements. The CPW-fed double-slot antenna results in a simple uniplanar receiver with a performance that is within 3 dB of the best waveguide mixers at millimeter-wave frequencies.

ACKNOWLEDGEMENTS

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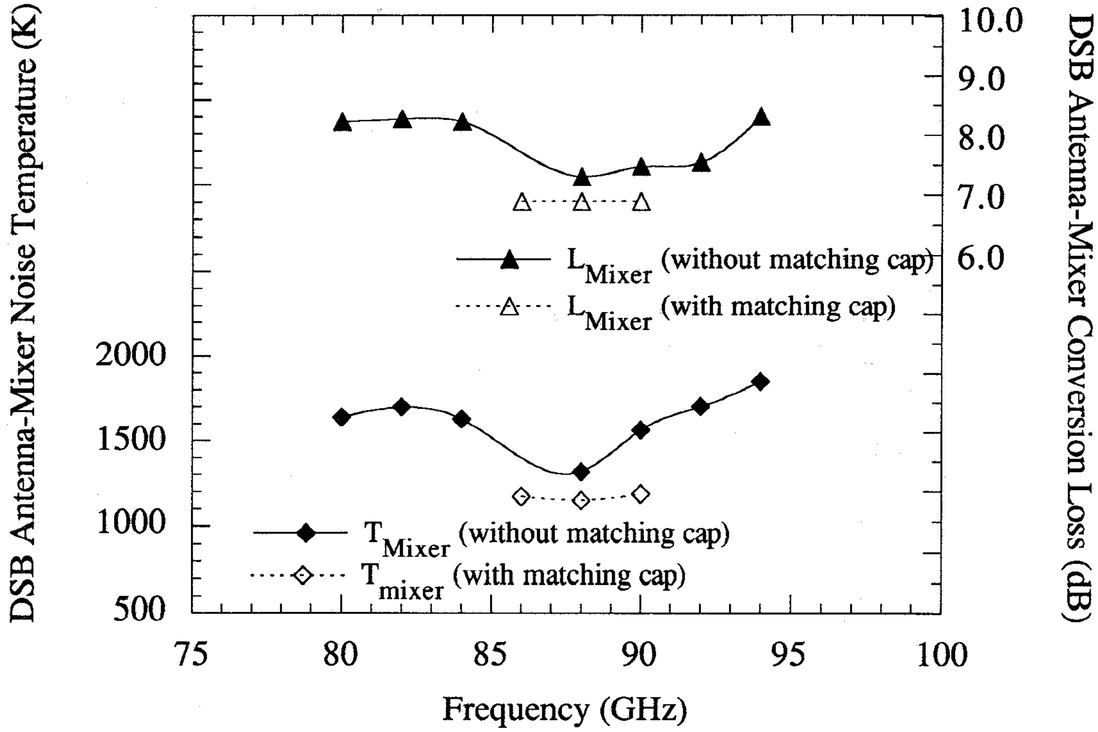

Figure 4: Measured receiver conversion loss and noise temperature from 82 GHz to 94 GHz without a matching cap layer. The 86 GHz to 90 GHz measurements were also done with a non-optimal matching cap layer.