

## A Planar Wideband Subharmonic Millimeter-Wave Receiver

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### ABSTRACT

A wideband planar subharmonic mixer has been designed for millimeter-wave operation. The receiver consists of a back-to-back Schottky-diode pair integrated at the base of a wideband log-periodic antenna. The antenna is backed by a hyperhemispherical lens and tested at 178.5 GHz (and 140 GHz) with a 90 GHz (and 70 GHz) local oscillator. The results indicate a single-sideband conversion-loss of -12.8 dB without any RF or IF matching networks. The subharmonic monolithic approach results in an inexpensive wideband receiver and the design can be easily extended to receiver arrays.

### I. INTRODUCTION

Millimeter-wave subharmonic mixers use an anti-parallel diode pair to generate a non-linear conductance waveform at twice the frequency of the applied LO signal [1,2]. Therefore, the required LO frequency is half that of the RF signal, and this offers unique advantages over fundamental single-ended mixers. Millimeter-wave subharmonic mixers require simpler filter-circuits designs and eliminate the use of potentially lossy quasi-optical diplexers. However, subharmonic mixing requires a well matched back-to-back diode pair for optimal performance. This is difficult to achieve at millimeter-wave frequencies with discrete devices, especially if the diodes are of the whisker-contacted type.

We have solved this problem and considerably simplified the receiver design by "integrating" a planar back-to-back GaAs Schottky-diodes at the apex of a wideband log-periodic antenna [3]. The log-periodic antenna catches both the RF and LO signals, and the LO signal

is injected quasi-optically using a simple dichroic filter (Fig. 1). The anti-parallel diodes are fabricated at the University of Virginia, and exhibit very low parasitic capacitances [4]. An optional matching network can be integrated at the antenna apex for better RF power transfer into the diode pair. The design results in an inexpensive monolithic receiver with potentially the same conversion-loss as single-ended waveguide mixers.

## II. ANTENNA DESIGN AND MEASUREMENTS

The antenna is a wideband self-complementary log-periodic antenna with  $\sigma = 0.5$  and  $\tau = \sqrt{2}$  designed to cover the 30 GHz to 240 GHz band. The log-periodic antenna is placed on the back of a hyper-hemispherical lens to eliminate substrate modes and to yield a unidirectional pattern [5]. A polystyrene quarter-wave matching layer is used at the silicon-air interface to eliminate any reflected power from the lens. The antenna input impedance is  $75\Omega$  and is independent of frequency. Pattern measurement results show excellent E and H-plane patterns with a co-polarized directivity of 24.6 dB at 180 GHz (Fig. 2). It is important to note that the pattern enhancement is a result of the "Buettgenbach effect" which dictates that the antenna should be placed farther than the hyper-hemispherical focal point [6]. In our case, a position of 0.9mm behind the hyper-hemispherical focal point resulted in acceptable patterns at the LO frequency (90 GHz) and excellent patterns at the RF frequency (180 GHz)

## III. DIODE DESIGN AND MEASUREMENTS

The anti-parallel diode chip was developed and fabricated at the University of Virginia for use in a 183 GHz waveguide receiver [4]. The chip is  $250\mu\text{m}$  long,  $125\mu\text{m}$  wide and approximately  $50\mu\text{m}$  thick and was soldered on the antenna using a low-temperature process. A surface channel technology has been used to eliminate the conducting path between the anode and cathode pads. The parasitic capacitance can be further minimized by removing the semi-insulating GaAs substrate and replacing it with quartz. Furthermore, the quartz substrate can be easily removed after the chip is soldered in place by simply dissolving its adhesive [7]. The diode used in this research has a measured series resistance of  $11\Omega$  and a zero-bias capacitance of roughly 4 fF. The total parasitic capacitance for the quartz-diode is estimated at 3 fF, thereby yielding a figure-of-merit cutoff frequency of approximately 2 THz. The measured I-V curve for the diode pair after being mounted at the antenna terminals is shown in Fig. 3. The anodes are virtually identical with an ideality factor  $n = 1.2$  and a turn on voltage of 0.7V at  $1\mu\text{A}$ .

## IV. MIXER MODELING AND MEASUREMENTS

A non-linear mixing program was written at the University of Michigan for the analysis of subharmonic mixers [8]. The program takes into account the asymmetrical I-V curve

of the back-to-back diodes. The higher-order terminating impedances are assumed to be resistive and equal to  $75\Omega$  in parallel with the parasitic capacitance of the diode. The analysis indicate that a conversion loss of 9.9dB is attainable at 180 GHz without an RF matching network. The corresponding RF and IF impedances are  $26 - j30\Omega$  and  $60\Omega$ , respectively. It is possible to increase the conversion loss by 2 dB with an RF matching network at the expense of a narrowband design.

The single-sideband mixer performance was measured at 178.5 GHz (and 140 GHz) using a local oscillator at 90 GHz (and 70 GHz, respectively). The antenna directivity and substrate-lens dielectric losses (estimated at 0.5 dB) have been normalized out of the measurements. The directivity is measured by a full two- dimensional co- and cross-polarized scans of the antenna pattern. The conversion loss presented below (Fig. 4) is defined as the power measured at the IF port divided by the 178.5 GHz RF power available at the antenna terminals. It includes the RF and IF mismatch losses and the intrinsic conversion loss of the subharmonic mixer. A minimum conversion loss of  $12.8 \pm 0.5$  dB was measured at 178.5 GHz with an estimated local oscillator power of 4.5 mW available at the antenna terminals. The minimum conversion loss at 140 GHz was  $11.2 \pm 0.5$  dB with an estimated available LO power of 6 mW. The conversion loss could be further reduced by 2 dB with the addition of an RF matching network between the antenna and the mixer diodes. This will result in a double-sideband conversion loss of 6-7 dB at 140 GHz or 180 GHz, which is competitive with the best available waveguide mixers.

#### ACKNOWLEDGEMENTS

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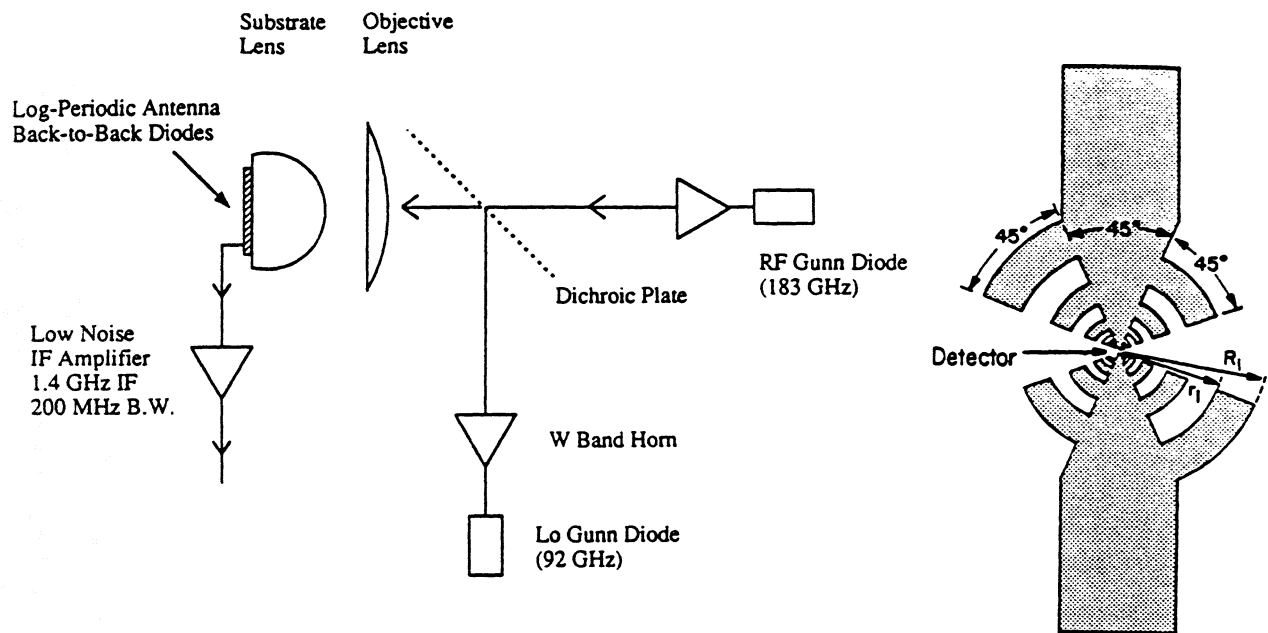


Figure 1: A quasi-optical subharmonic receiver with a dichroic plate for LO injection.

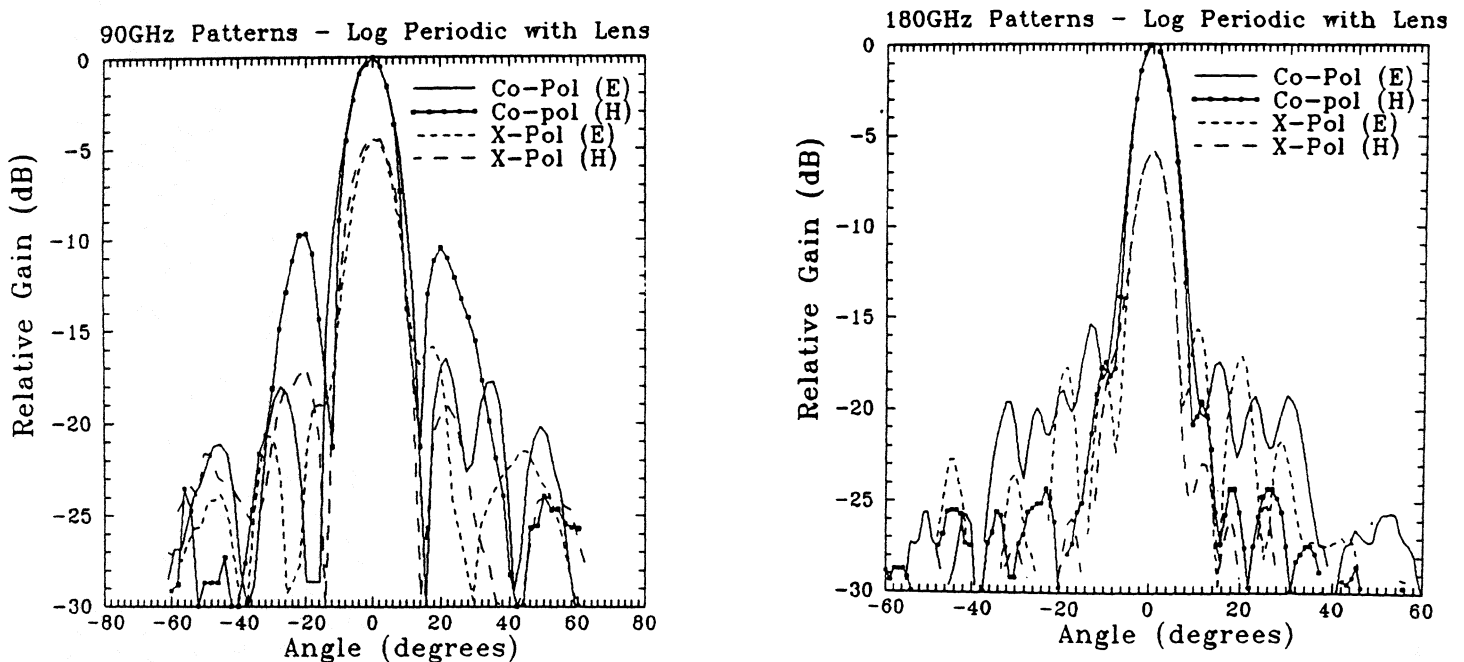
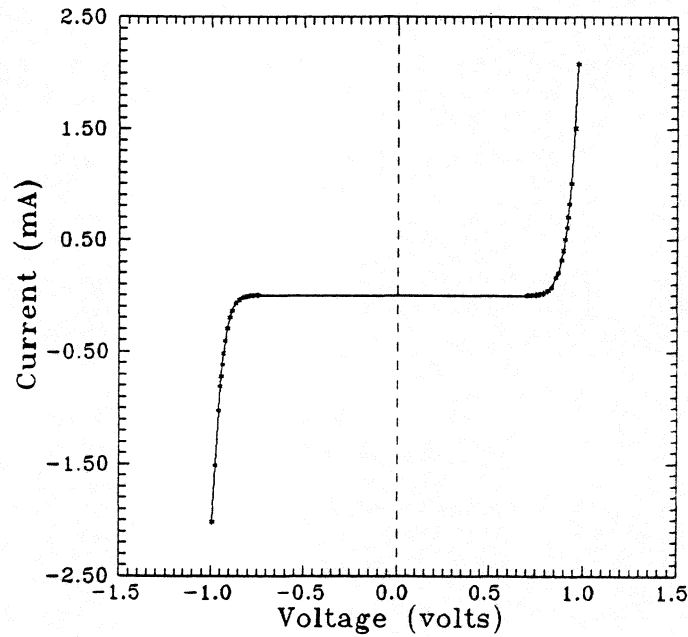
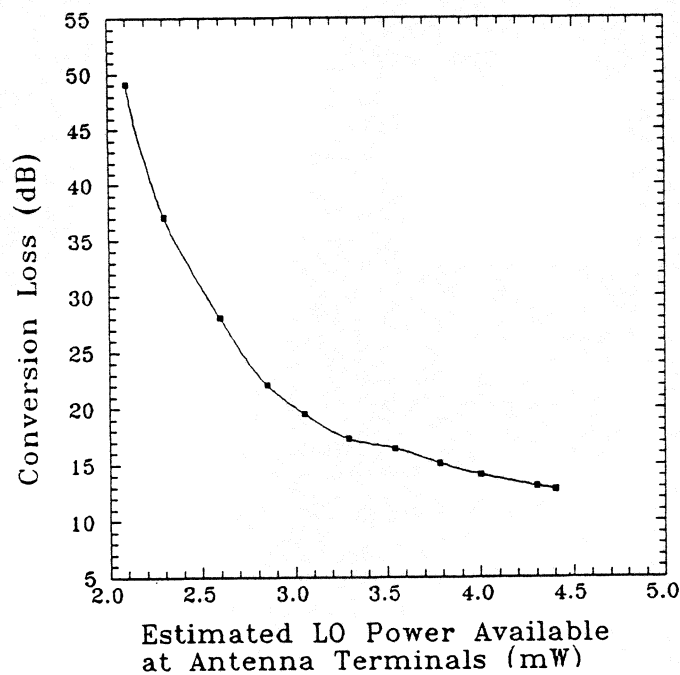


Figure 2: Measured antenna patterns at 90 GHz (left) and 180 GHz (right). The high cross-polarization component should not affect the coupling efficiency for radiometric applications but will reduce the quasi-optical local oscillator coupling by 1.5dB.



**Figure 3:** The measured dc I-V curve of the back-to-back Schottky diodes. The diode parameters are determined by least-square fitting of the equation  $I = I_s \exp(V/nV_T - IR_s)$ . The fitted parameters are  $I_s = 7 \times 10^{-17}$ ,  $n = 1.2$  and  $R_s = 11 \Omega$ .



**Figure 4:** Measured subharmonic single-sideband conversion loss at 178.5 GHz with the antenna gain normalized out. The measured conversion loss is  $12.8 \pm 0.5$  dB and can be reduced by 1-2 dB with a higher LO power.