This is a review paper. The material presented below has been submitted for publication in IEEE Microwave and Guided Wave Letters.

A Wideband 760GHz Planar Integrated Schottky Receiver

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ABSTRACT

A wideband planar integrated heterodyne receiver has been developed for use at submillimeter-wave to far-infrared frequencies. The receiver consists of a log-periodic antenna integrated with a planar 0.8μm GaAs Schottky diode. The monolithic receiver is placed on a silicon lens and has a measured room temperature double sideband conversion loss and noise temperature of 14.9±1.0dB and 8900±500K respectively, at 761GHz. These are the best results to date for room temperature integrated receivers at this frequency.

INTRODUCTION

Open structure mixers with whisker contacted Schottky diodes are the current favorite for far-infrared receivers [1]. Problems with the open structure mixers include low coupling to gaussian beams [2], structural instability, and the lack of an RF matching network. These mixer mounts have an input impedance of approximately 150Ω which does not supply a good conjugate match for a Schottky diode. Additionally, open structure mixer mounts are expensive to array for imaging applications.

Many of these problems can be overcome with the use of a planar integrated receiver. A planar log-periodic antenna with a silicon lens can be designed to couple more than 80% of its pattern to a fundamental Gaussian mode [3,5]. Many receivers can be fabricated at once to form a two-dimensional array, and an RF matching network can be integrated at the antenna apex to conjugately match the Schottky diode impedance. Although the receiver is tested at 761GHz, with the wideband performance of the log-periodic antenna and the absence of a narrowband RF matching network, the receiver is expected to have nearly identical performance over the 500GHz to 1THz frequency range. Planar integrated receivers show great promise to replace open structure mixers for radio astronomy applications.

RECEIVER DESIGN

A planar self-complimentary log-periodic antenna with $\sigma = 0.707$ and $\tau = 0.5$ [4] is chosen for the receiver due to its wideband input impedance and radiation patterns. A self-complimentary antenna has a frequency-independent input impedance of

$$Z_{\text{ant}} = 189\Omega/\sqrt{\frac{\epsilon_r+1}{2}} = 74\Omega$$

The log-periodic antenna is linearly polarized and has a cross-polarization level of -5 to -15dB which varies periodically with frequency [5]. The antenna is designed to cover the frequency range of 100GHz to 2.4THz and allows the diode performance to be measured over a wide frequency range. The antenna and GaAs substrate are mounted on an extended hemispherical silicon lens to eliminate power loss to substrate modes. Filipovic [3] has theoretically and experimentally found the lens extension length that results in good Gaussian patterns for a double-slot antenna feed, and Kormanyos has experimentally verified that these results are also applicable for the planar log-periodic antenna [5]. At 761GHz, the log-periodic antenna is placed 1000μm behind a 6mm diameter high resistivity silicon hemispherical lens using GaAs spacer wafers.

A planar UVa GaAs Schottky diode with a 0.8μm anode diameter is integrated at the apex of the antenna. The diode consists of a 900Å n^--layer with a doping of $2\text{x}10^{17}\text{cm}^{-3}$ and a 5μm n^+-layer doped at $5\text{x}10^{18}\text{cm}^{-3}$. A finger length of 7$\mu$m separates the antenna leads. A surface channel etch is used to etch all of the n^+ material under the finger and around the log-periodic antenna (Figure 2). The diodes have a measured DC series resistance of 25Ω, a junction capacitance of 1-1.5fF, a parasitic capacitance of approximately 2fF, an ideality factor of 1.25, and a built-in potential of 0.77V.

RECEIVER MEASUREMENTS

Antenna patterns and video responsivities were measured at 184GHz and 761GHz. A Gunn diode with a multiplier is used as a source at 184GHz, and a far-infrared laser is used at 761GHz (393μm). Using measured E-, H-, and D-plane patterns, a co-pol directivity of 24±0.5dB with a 12mm diameter silicon lens and 30±1dB with a 6mm lens is calculated at 180 and 761GHz, respectively. The measured cross- polarization levels are -8dB at 184GHz and less than -16dB at 761GHz. The video responsivity measurements were performed by illuminating the receiver with a known plane wave power density and measuring the low- frequency (100Hz) diode video voltage in a 100kΩ load. With respect to the plane wave power incident upon the silicon lens, the measured video responsivity is 370V/W at 184GHz and 160V/W at 761GHz. Compensating for a reflection loss of 1.5dB at 761GHz (0.9dB at 184GHz - a matching layer is used) at the silicon-air interface, an estimated absorption loss of 0.3dB in the silicon, and the measured co-polarized effective aperture of the antenna, the peak video responsivity from a 74Ω source (the antenna terminals) is 810V/W at 184GHz and 380V/W at 761GHz. This is the highest video responsivity ever measured for a planar diode at 761GHz.

Double sideband noise temperature and conversion loss were measured at 761GHz using the hot/cold load technique. The RF and LO power were combined with a Martin-Puplett interferometer. The 1.4GHz IF chain consists of a bias-T, a circulator, a low-noise amplifier chain, a 100MHz filter centered at 1.4GHz, and a calibrated power meter. Additionally, a 10dB coupler was placed between the receiver output and IF chain for IF reflection measurements. A microstrip quarter-wave IF matching network is used to reduce the IF reflection from 2.4dB to 0.9dB. This means that the diode output IF impedance is 250Ω as expected for small diameter diodes. The double sideband conversion loss and noise temperature versus bias is shown in figure 4. At 761GHz, the minimum room temperature conversion loss of 14.9±1.0dB and noise temperature of 8900±500K occurs at a bias of 0.4V. This estimated optimum LO power level is 5mW and is large due to the high series resistance of the diode compared to the RF impedance of the junction. This noise temperature and conversion loss are 4-5dB higher than *cooled* whisker contacted 800GHz receivers and represents the best result to date for a planar room temperature integrated receiver in this frequency range.

At 761GHz, the diode series resistance is much higher than the measured DC value of 25Ω and is a primary reason for the high conversion loss and noise temperature. Increasing the n^- doping level from 2x10^{17}cm^{-3} to 1x10^{18}cm^{-3} should reduce the RF series resistance at 760GHz. For use at terahertz frequencies, the diode anode diameter should be decreased to 0.5μm for a minimum R_sC_{jo} product [6]. Additionaly, decreasing the thickness of the n^+ level should increase the overall RF coupling efficiency of the antenna.

ACKNOWLEGDMENTS

This work was supported by the NASA/Center for Space Terahertz Technology at the University of Michigan, Ann Arbor. We thank Perry Wood and Tim Scholz at the University of Virginia for their help with the far-infrared laser.

This work is supported by US Army DAHC-90-91-C-0030 and AASERT-DAAL03-92-G- 0057.

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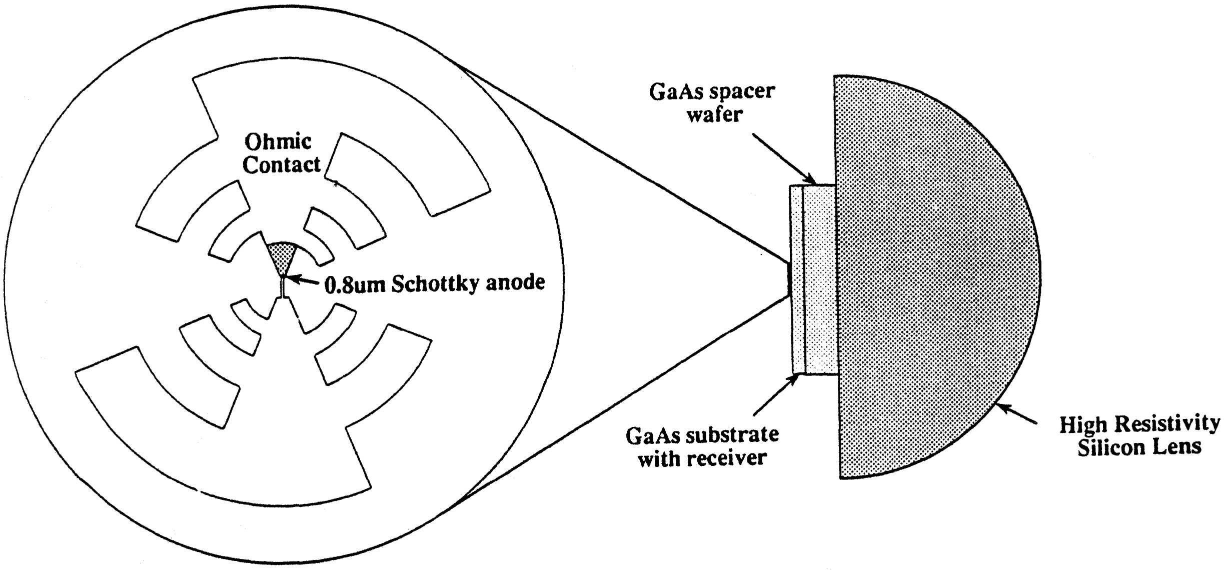
Figure 4: 761GHz DSB Conversion Loss and Noise Temperature vs. bias current.



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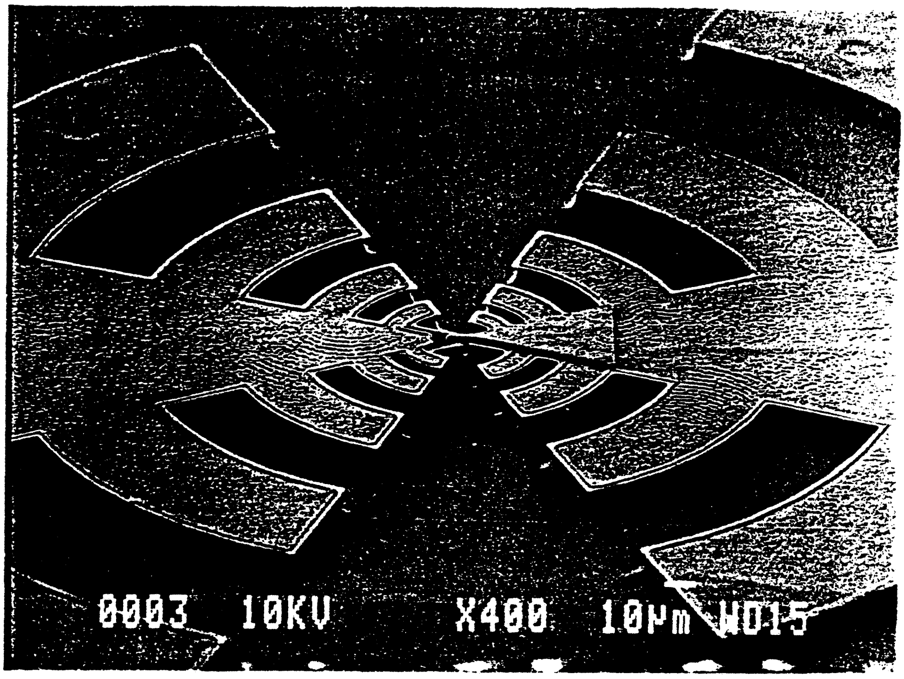

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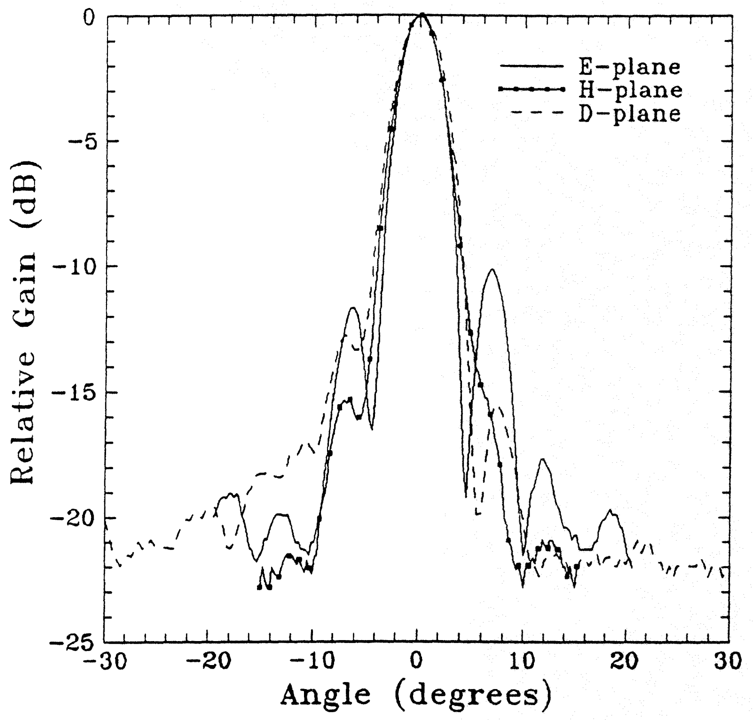

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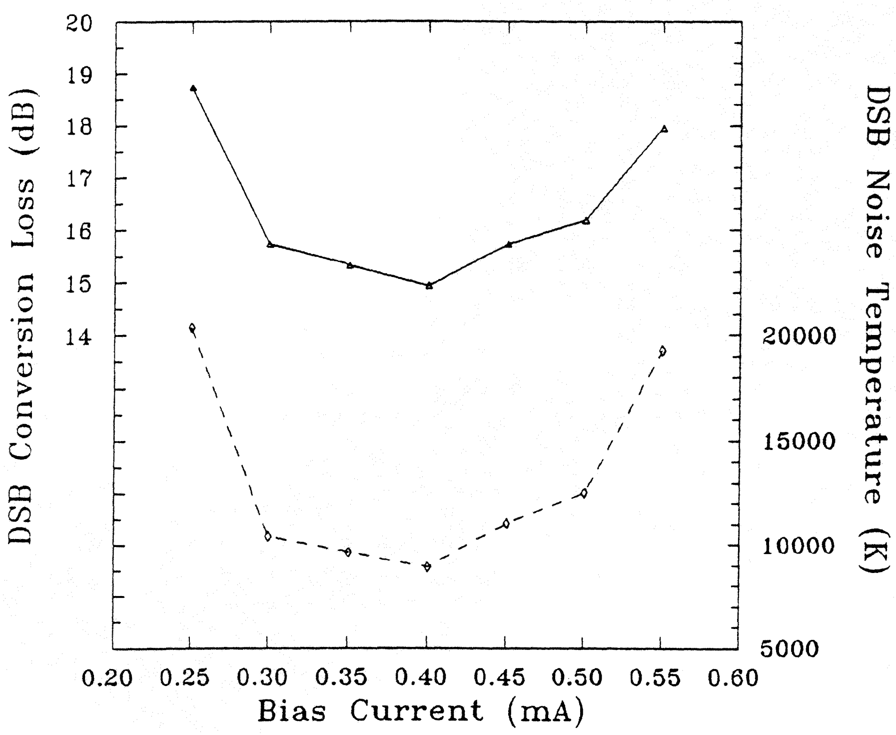

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