# A Wide-Band 760-GHz Planar Integrated Schottky Receiver

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***Abstract*—A wide-band 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 0.8-$\mu$m GaAs Schottky diode. The monolithic receiver is placed on a silicon lens and has a measured room temperature double side-band conversion loss and noise temperature of 14.9 $\pm$ 1.0 dB and 8900 $\pm$ 500 K, respectively, at 761 GHz. These results represent the best performance to date for room temperature integrated receivers at this frequency.**

## I. Introduction

OPEN structure mixers with whisker contacted Schottky diodes are currently the favored design 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 150 $\Omega$ 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 761 GHz, the wide-band performance of the log-periodic antenna and the absence of a narrow-band RF matching network ensure that the receiver will have nearly identical performance over the 500-GHz to 1-THz frequency range. Planar integrated receivers show great promise to replace open structure mixers for radio astronomy applications.

## II. 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 wide-band input impedance and radiation patterns. A self-complimentary antenna has a frequency-independent input impedance of

$$Z_{\text{ant}} = 189\,\Omega\sqrt{\frac{e_r + 1}{2}} = 74\,\Omega.$$

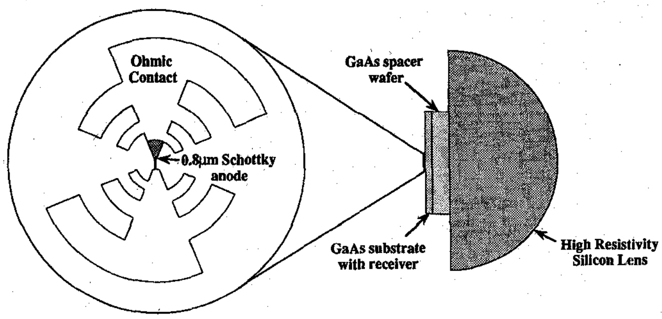


Fig. 1. Planar receiver with spacer wafers and silicon lens.

The log-periodic antenna is linearly polarized and has a cross-polarization level of -5 to -15 dB, which varies periodically with frequency [5]. The antenna is designed to cover the frequency range of 100 GHz to 2.4 THz 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 761 GHz, the log-periodic antenna is placed 1000 $\mu$m behind a 6 mm diameter high resistivity silicon hemispherical lens using GaAs spacer wafers.

A planar UVa GaAs Schottky diode with a 0.8-$\mu$m anode diameter is integrated at the apex of the antenna. The diode consists of a 900-Å $n^-$ layer with a doping of $2\times10^{17}$ cm$^{-3}$ and a 5-$\mu$m $n^+$ layer doped at 5 $\times10^{18}$ 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 (Fig. 2). The diodes have a measured dc series resistance of 25 $\Omega$, a junction capacitance of 1-1.5 fF, a parasitic capacitance of approximately 2 fF, an ideality factor of 1.25, and a built-in potential of 0.77 V.

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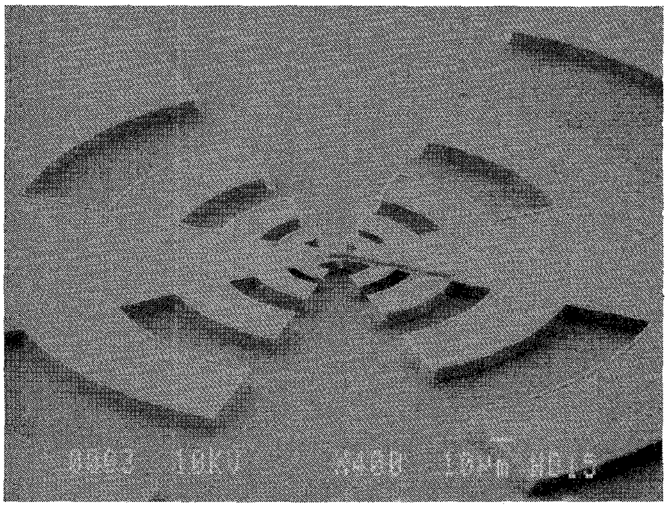

Fig. 2. The integrated receiver. Due to the surface channel etch, the log-periodic antenna appears to be a 5 $\mu$m-high plateau.

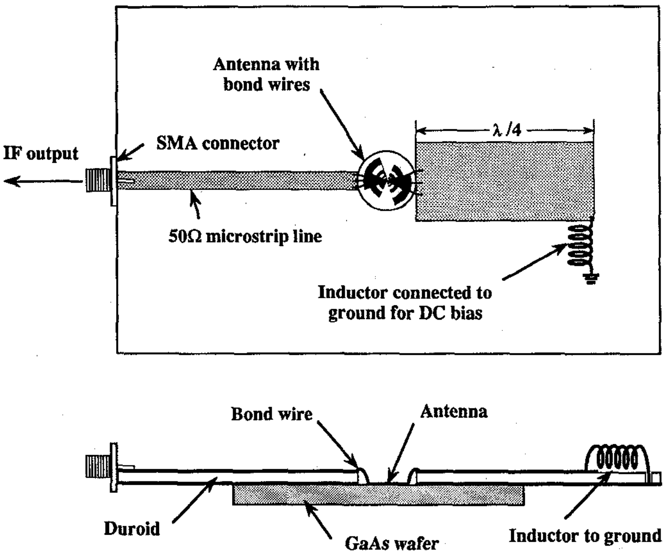


Fig. 3. The IF circuit. To reduce IF reflections, the 50 $\Omega$-line could be replaced by a quarter-wave IF matching network.

## III. Receiver Measurements

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

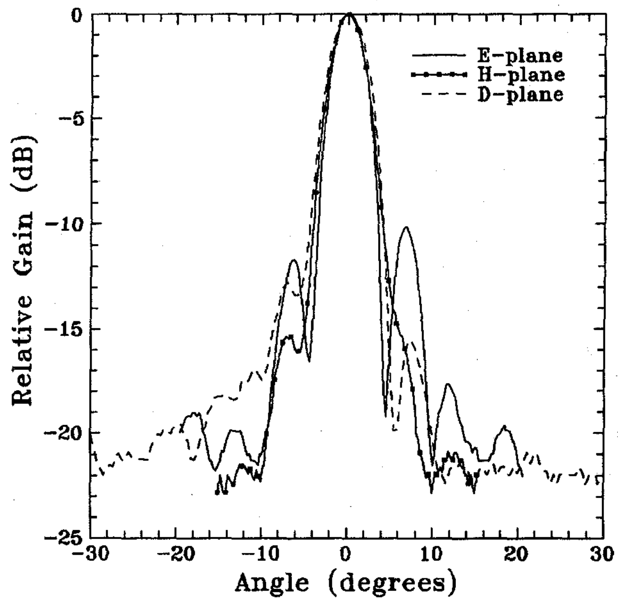


Fig. 4. 761-GHz antenna patterns. Cross-pol level is less than $-15$ dB in the E-, H-, and D-planes.

Double side-band noise temperature and conversion loss were measured at 761 GHz using the hot/cold load technique. The RF and LO power were combined with a Martin–Puplett interferometer. In order to extract the IF, the antenna leads are wire-bonded to a microstrip network fabricated on Duroid (Fig. 3). The low-impedance open-circuited quarter-wavelength line shorts one antenna lead to the ground of the microstrip at the intermediate frequency, and the inductor allows the diode to be biased through the SMA connector. The 1.4-GHz IF chain consists of a bias-T, a circulator, a low-noise amplifier chain, a 100-MHz filter centered at 1.4 GHz, and a calibrated power meter. Additionally, a 10-dB 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 due to the diode output IF impedance of 250 $\Omega$ from 2.4 dB to 0.9 dB. The double sideband conversion loss and noise temperature versus bias is shown in Fig. 5. At 761 GHz, the minimum room temperature conversion loss of 14.9 $\pm$ 1.0 dB and noise temperature of 8900 $\pm$ 500 K occurs at a bias of 0.4 V. The estimated optimum LO power level is 5 mW. This large LO power is necessary due to the high series resistance of the diode compared to the RF impedance of the junction. These noise temperature and conversion loss measurements are 4–5 dB higher than *cooled* whisker contacted 800-GHz receivers and represents the best result to date for a planar room temperature integrated receiver in this frequency range.

Future receiver work will concentrate on improving the diode characteristics and possibly including an RF matching network to better match the diode RF impedance. Due to the

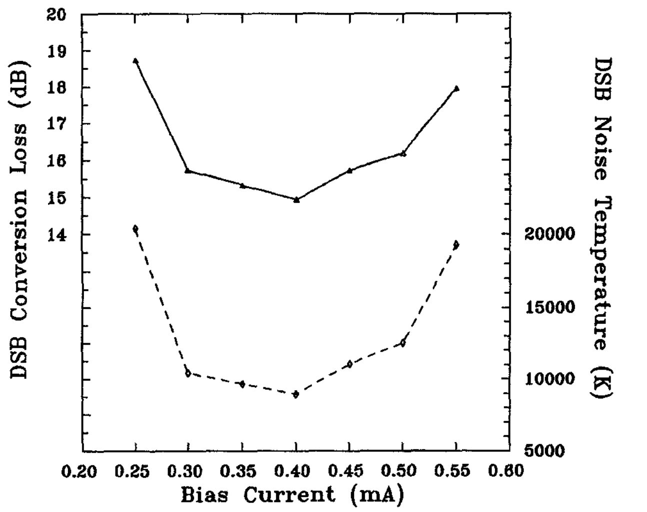


Fig. 5. 761-GHz DSB conversion loss and noise temperature vs. bias current.

skin effect, the diode series resistance is much higher at 761 GHz than the measured dc value of 25 Ω and is a primary contributor to the conversion loss and noise temperature. Increasing the $n^-$ doping level from 2 $\times 10^{17}$ $cm^{-3}$ to 1 $\times 10^{18}$ $cm^{-3}$ should reduce the RF series resistance. For use at terahertz frequencies, the diode anode diameter should be decreased to 0.5 $\mu$m for a minimum $R_s C_{jo}$ product [7]. Furthermore, the 5-$\mu$m thickness of the $n^+$ level is more than twice the skin depth of the layer at 761 GHz and may present a loss in the RF path. Decreasing the thickness of this layer to one skin depth should reduce this loss.

## ACKNOWLEDGMENT

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