# THE DEVELOPMENT OF PLANAR SCHOTTKY DIODE WAVEGUIDE MIXERS AT SUBMILLIMETER WAVELENGTHS

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## ABSTRACT

This paper reports on progress towards state-of-the-art submillimeter wavelength waveguide mixers using planar Schottky barrier diodes. A double-sideband system noise temperature of 2380 K was measured at 585 GHz with 1.2 mW of local oscillator power using a fixed tuned mixer in which the diode is mounted in a microstrip channel. A system noise temperature of 2550 K was measured with 1.1 mW of LO power using a mixer in which the diode was mounted in a waveguide in front of a tunable backshort. These represent the best planar diode mixer results in this frequency range. Simulations indicate an IF bandwidth in excess of 100% and an RF bandwidth of 40% are achievable using the fixed tuned mixer block design.

## INTRODUCTION

The heterodyne measurement of submillimeter wavelength radiation is important for such applications as molecular spectroscopy, scaled-model radar, radio astronomy, plasma diagnostics, and passive or active imaging [1]. The use of a Schottky diode for the mixer element allows operation at room-temperature, thus reducing the complexity of the overall receiver. Currently, the most sensitive submillimeter Schottky diode mixers rely on whisker-contacted diodes mounted in a waveguide mixer block [2]. One drawback of the whisker-contacted geometry is that it is difficult to make the mixer resistant to stresses or shocks. The results presented here show that planar Schottky diodes can provide similar sensitivity while allowing for a more rugged mixer design. Another benefit of the planar Schottky diode geometry is that the fabrication process lends itself to a relatively simple integration of multiple devices and to the integration of the diode with the mixer circuitry. Mixer simulations presented in this paper indicate that integration of the diode and circuit can also significantly improve the mixer bandwidth, allowing for a fixed tuned mixer which is predicted to cover a full waveguide band. For these reasons, planar Schottky diodes offer promise for the development of relatively simple and inexpensive mixers for use at submillimeter wavelengths.

## A FIXED TUNED WAVEGUIDE MIXER USING DISCRETE PLANAR SCHOTTKY DIODES

The fixed tuned mixer block, designated N1, has the planar diode mounted in an enclosed microstrip channel, as shown schematically in Fig. 1 [3]. The coupling from feedhorn to waveguide to microstrip line has been designed to operate over the full waveguide band (450 GHz to 700 GHz) with no variable tuning elements. The mixer circuit was modeled using Hewlett Packard's (HP's) High Frequency Structure Simulator and Microwave Design System (HFSS and MDS). The measured mixer performance at 585 and 690 GHz are given in Table 1. The

* NRAO is operated by Associated Universities, Inc. under cooperative agreement with the National Science Foundation.

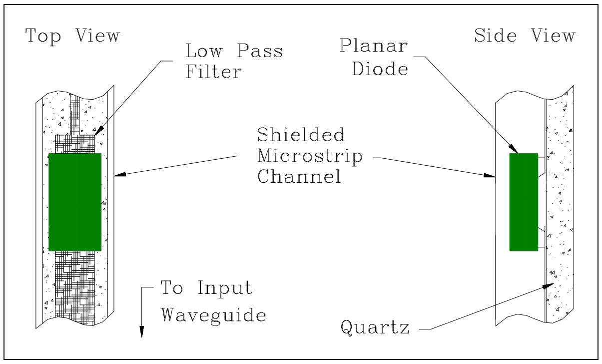


Fig. 1. Schematic of discrete planar diode mounted in the fixed-tuned mixer block N1.

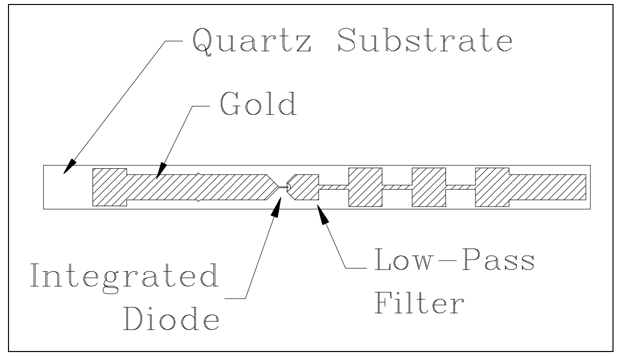


Fig. 2. Schematic of planar diode integrated with mixer circuitry.

modeled mixer conversion loss was found to be within 1 dB of the measured value. This work has demonstrated that sensitive submillimeter wavelength planar Schottky diode mixers can be designed and built without variable tuning elements. Also, this research has shown that modern high frequency design tools can be used to reduce the mixer development time.

| Mixer Block | $\upsilon_{RF}$ (GHz) | $T_{sys}^{DSB}$ (K) | $T_{mix}^{DSB}$ (K) | $L^{DSB}$ (dB) |
|---|---|---|---|---|
| N1 | 585 | 2380 | 1800 | 7.6 |
| N1 | 690 | 2970 | 2240 | 8.8 |

Table 1. Summary of room temperature mixer performance for the N1 mixer block.

## INTEGRATION OF THE DIODE WITH THE MIXER CIRCUITRY

Fig. 2 shows a schematic of a planar diode integrated with the mixer circuit. The process by which the diode can be integrated with the circuit is the same as that used previously at UVa to replace a planar diode’s GaAs substrate with quartz [4]. In this process, an AlGaAs etch stop layer is integrated in the diode’s semi-insulating substrate. The substrate is then adhered to the very thin GaAs epitaxial layer, thereby replacing the high dielectric GaAs substrate with quartz.

Harmonic balance and embedding impedance modeling have been performed for the discrete and integrated planar diode mixers mounted in the N1 style mixer block. As shown in Fig. 3, the bandwidth for the integrated circuit is much wider that the discrete diode, and covers a full waveguide band with little degradation in performance. Thus, the integration of the diode and the mixer circuitry not only simplifies mixer construction, but it is also predicted to increase the bandwidth of the mixer. In addition, the integration of the diode and circuit should improve the repeatability of the mixer construction by eliminating the need to solder the diode onto the circuit.

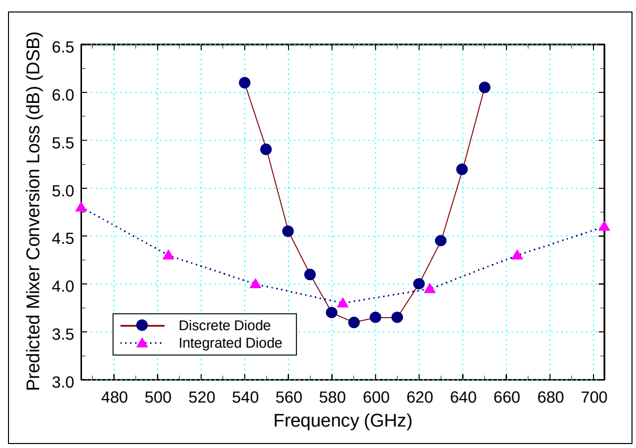


Fig. 3. Predicted mixer conversion loss versus frequency for discrete and integrated planar Schottky diodes in the N1 mixer block.

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## PREDICTED IF BANDWIDTH OF THE N1 MIXER

The diode in the N1 mixer block has an IF impedance of 150 Ω when the mixer is tuned for optimum performance. Modeling of the block was performed to determine its IF behavior. A broadband IF transformer centered at 6 GHz was designed using a simple two section impedance transformer. The first transformer section begins within the mixer block immediately after the microstrip low-pass filter. The simulations predict that an SWR of less than 2:1 can be maintained over a 115% bandwidth, as shown in Fig. 4.

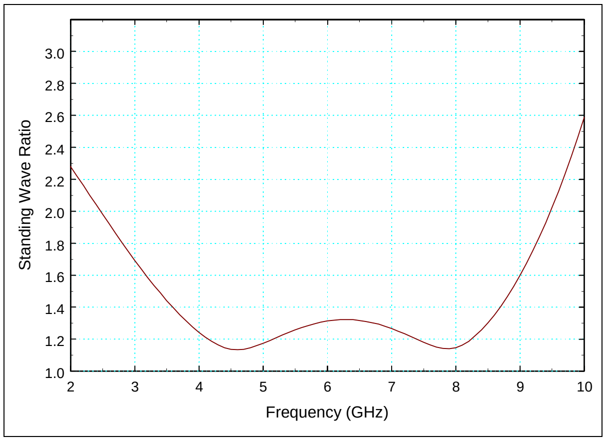


Fig. 4. Predicted IF Bandwidth for the N1 mixer block.

## TUNABLE WAVEGUIDE SCHOTTKY DIODE MIXER

In addition to the research on the fixed tuned N1 mixer, research is being performed on a mixer with a tunable backshort [2]. This mixer block, designated Z1, allows the diode to be placed directly in the input waveguide, as shown schematically in Fig. 5. The diode is mounted across a gap, and the diode and circuit are then placed across the input waveguide. This design has the benefit of reduced transmission line losses, since the diode is located directly in the input waveguide. This block has achieved a performance comparable

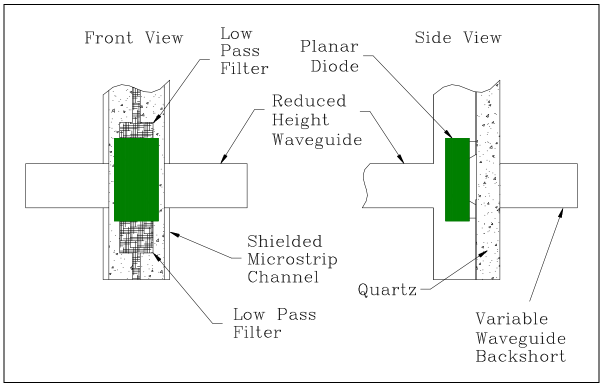


Fig. 5. Schematic of diode mounted in mixer block Z1.

to the best obtained using the N1 block, as shown in Table 2.

| Mixer Block | $\upsilon_{RF}$ (GHz) | $T_{sys}^{DSB}$ (K) | $T_{mix}^{DSB}$ (K) | $L^{DSB}$ (dB) |
|---|---|---|---|---|
| Z1 | 585 | 2550 | 1980 | 8.6 |

Table 2. Summary of room temperature mixer performance for the Z1 mixer block.

## LO POWER REQUIREMENTS FOR THE N1 AND Z1 MIXERS

Fig. 6 shows the variation of the system noise temperature as the input LO power level is varied for the two mixer blocks. While the lowest noise temperature occurs at an LO power of about 1 mW for each mixer, if a 10% increase in the system noise temperature can be tolerated, then the LO power requirement drops to about 0.4 mW for each mixer. These mixers can thus operate under conditions of low LO power with excellent sensitivity.

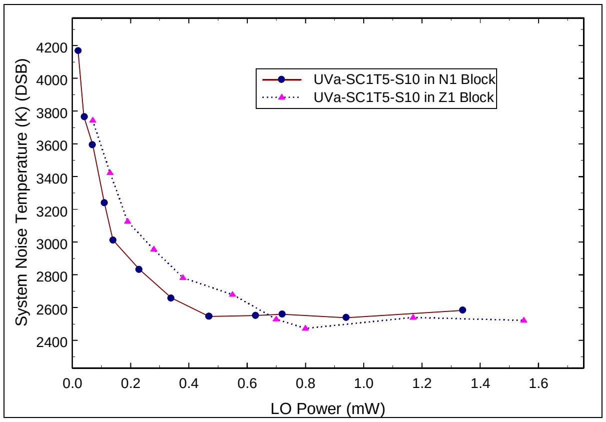


Fig. 6. System noise temperature versus LO power for the N1 and Z1 blocks.

## ALTERNATE TECHNIQUES FOR MIXER BLOCK FABRICATION

The small channels used in the N1 mixer block make conventional metal machining techniques difficult and expensive. By using new techniques for fabrication of the mixer block, including plastic molding and micro-machining, the expense of submillimeter wavelength mixers can be reduced. Research on these techniques is underway, and results will be presented at the conference.

## CONCLUSIONS

One of the main barriers to the development of inexpensive submillimeter wavelength mixers is the difficulty involved with mixer construction and assembly. The use of planar Schottky diodes as mixer elements allows the construction of rugged, room-temperature mixers. The performance of planar Schottky diode mixers is within a factor of 1.5 of the best whisker-contacted Schottky diode mixers at about 600 GHz. Integration of the planar diode with the circuit and the use of new techniques to fabricate the mixer block should reduce the expense and difficulty of building the mixer, thus allowing for more widespread use of submillimeter wavelength mixers.

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