Planar Diode Solid-State Receiver for 557 GHz with State-of-the-Art Performance

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***Abstract*—The design and performance of a subharmonically pumped (SHP) 557-GHz mixer driven by a solid-state local oscillator (LO) are reported. Whisker contacts are not required as both the mixer and LO utilize planar Schottky devices. A measured mixer noise temperature of 2100-K double sideband (DSB) with a conversion loss of 8.9 dB has been achieved at room temperature. The mixer exhibits broad intermediate frequency (IF) bandwidth with measured DSB noise temperatures below 3400 K in the band from 1.5 to 17 GHz. An external 6–18-GHz amplifier has been added to the output of the mixer, and measured receiver noise temperatures below 7300 K have been measured across the IF band. The results are believed to represent state-of-the-art performance for a room-temperature broad-band solid-state receiver at this frequency.**

***Index Terms*—Planar, receiver, Schottky diode, subharmonic mixer.**

I. Introduction

THE submillimeter-wave spectrum around 550 GHz continues to be of much interest for the exploration of our solar system. We report on a subharmonic mixer with a broad intermediate frequency (IF) bandwidth that has been developed for the Microwave Instrument for the Rosetta Orbiter (MIRO) to study water transition lines occurring near 557 GHz. A number of technologies could be used to accomplish this task. Whisker contacted harmonic mixers were used for the Submillimeter Wave Astronomical Satellite (SWAS) at 490 and 555 GHz with very impressive noise sensitivity [1]; however, these mixers have inherently limited IF bandwidth. More recently, planar Schottky diodes in a fundamental mixer have been reported with performance which is very close to the best ever whisker contacted diodes in the 585–690-GHz range [2]; however, such mixers require a very high frequency source or a laser for the local oscillator (LO) in addition to a carefully designed and aligned diplexer. In the approach presented here, a planar diode subharmonic mixer based on the results of work done at 200 and 600 GHz [3]–[6] is used in conjunction with a planar Schottky diode LO circuit.

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II. LO

The mixer is pumped by an LO at a frequency of 282 GHz which is generated by a 141-GHz Gunn followed by a doubler as described in [7]. The doubler is mechanically fixed-tuned and utilizes a balanced planar Schottky 4-diode varactor chip produced at the University of Virginia's Semiconductor Device Laboratory [8], [9]. The Gunn has a measured output power of about 40 mW at the design frequency, and the doubler exhibits a 15–18% conversion efficiency delivering 6–7 mW of power at 282 GHz as measured with a calorimeter [10].

III. Mixer

The mixer uses an antiparallel planar Schottky diode pair fabricated using the QUID (Quartz-substrate Up-side-down Integrated Device) process as described in [3] and [4]. This process allows for the implantation of the Schottky GaAs diode pair on a low-loss quartz substrate with the complete removal of all the semiconductor material everywhere except in the immediate vicinity of the diodes. The diodes themselves are distinguished by the "T"-shaped architecture of the anodes.

The total capacitance of the structure is about 12–13 fF, of which 8–9 fF are a result of parasitic capacitances caused by the distributed nature of the filter structure in addition to the pad-to-pad and finger-to-pad capacitances. This parasitic capacitance can be reduced by about 20%–25% by etching away the epoxy in the region of the diode fingers as suggested in [11], which results in markedly improved LO coupling as well as mixing performance. The final total capacitance of the structure is about 10–12 fF.

As part of the QUID process, the signal separating microstrip filters and the waveguide-to-microstrip probes for both the LO and radio frequency (RF) frequencies are formed. The designs for the two filters present in the circuit are based on low-frequency models and numerical simulations using the finite-difference time-domain method [12].

The mixer device substrate is housed in a split waveguide mount that uses a crossed-channel approach similar to the one reported in [3] and successfully demonstrated at other frequencies [6] (see Fig. 1). The RF input feed horn is a Picket–Potter design [13] drilled directly into the split-block such that it is integral to the mixer. The circular guide of the horn is butted up against a square waveguide which immediately transitions to the rectangular RF waveguide using a variation of the transformer described in [14]. Tuning of the LO and RF coupling is accomplished by a single contacting BeCu spring finger backshort [15] in each guide. We have

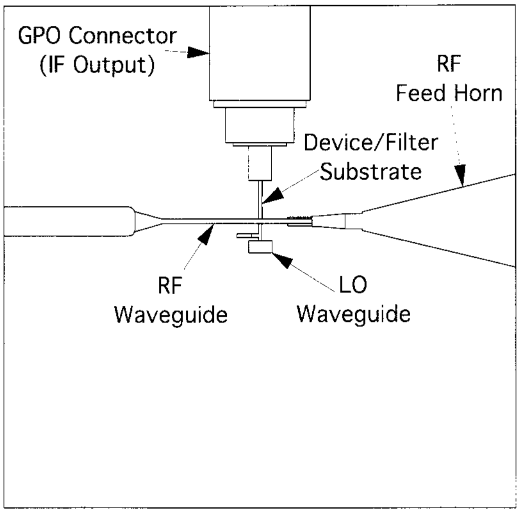

Fig. 1. Drawing looking down on bottom half of split-block waveguide mixer. The mixer block measures about 0.75 in × 0.75 in and is about 0.575 in thick.

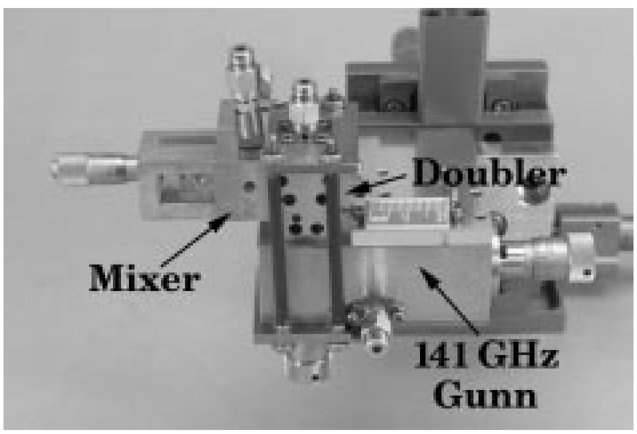

Fig. 2. Mixer and LO source (141-GHz Gunn + doubler).

found that filling the gap between the springy fingers of the backshorts with indium keeps the fingers spread, ensuring contact, and results in significant improvement in performance. The IF mixer product is coupled out of the microstrip into a compact GPO connector which then transitions to SMA.

IV. Mixer/Receiver Measurements

In order to couple the maximum amount of the available LO power from the solid-state source into the mixer, the mixer block was clamped directly to the output flange of the doubler with all extraneous waveguide removed as seen in Fig. 2. The mixer noise temperature was measured by switching between hot (room temperature) and cold (liquid nitrogen) loads at the RF input to the mixer with the data collected and processed with a computer-controlled calibrated IF test system which removes the IF mismatch at the output of the mixer [16]. Fig. 3 shows the noise temperature and conversion loss of the best mixer device to date from 1.5- to 17-GHz IF. The tuning for this measurement was optimized at an IF frequency of 11 GHz to flatten the broad-band response with noise temperatures ranging from 2200 to 3350 K DSB and conversion losses from

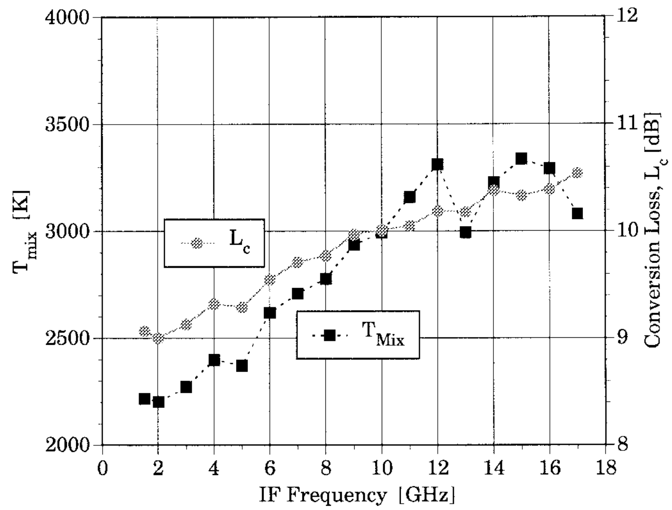

Fig. 3. Measured 557-GHz mixer noise temperature and conversion loss as a function of IF frequency. The available LO power at the input flange of the mixer is about 6 mW. Measured output impedance of the pumped mixer indicated that this LO power level is probably slightly less than what is required for optimal mixing.

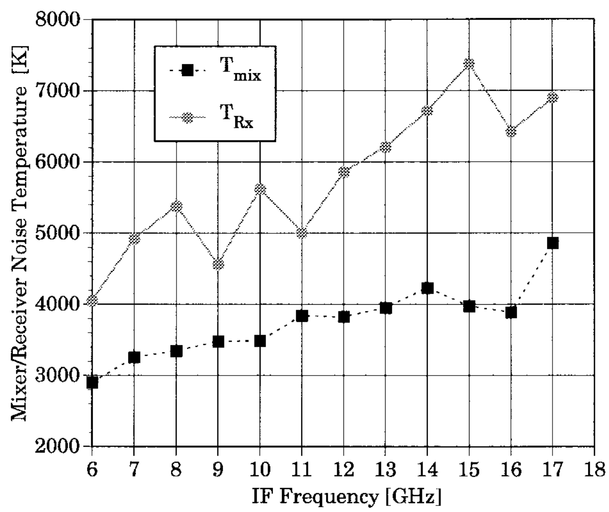

Fig. 4. Measured receiver noise temperature as a function of IF frequency. Note that the mixer device used here was different from that shown in Fig. 3, and its performance is also plotted in this figure. The apparent standing wave in the receiver measurement is likely caused by the mismatch between the mixer and the amplifier.

9 to 10.5 dB. Tuning the mixer at 1.5-GHz IF resulted in a best single point measurement of about 2100-K DSB with 8.9 dB of conversion loss.

To measure the mixer as a receiver, an external connectorized low-noise Miteq 6–18-GHz amplifier was added directly to the IF port of the mixer. The measurement was computer controlled and used a Tektronix 2792 spectrum analyzer with a programmable 3-MHz bandwidth over the 6–17-GHz IF and an HP437B power meter used as a detector on the IF output of the analyzer. Again, hot and cold loads were alternately shown to the RF input of the mixer. Fig. 4 shows the measured mixer noise temperature and receiver noise temperature. Note that the mixer device used here was different from the one used in Fig. 3 and that its performance is not as good. Nevertheless, a very good broad-band measurement was achieved. The standing wave in the receiver noise versus IF frequency curve is most likely a result of mismatch between the mixer and the amplifier.

V. Conclusion

A DSB best mixer noise temperature of 2100 K at 1.5-GHz IF has been realized with a planar Schottky diode subharmonic 557-GHz mixer pumped with a solid-state 282-GHz LO. The mixer exhibits broad IF bandwidth with measured noise temperatures in the range of 2200–3350-K DSB from 1.5- to 17-GHz IF. When coupled with a Miteq amplifier (and a different and, unfortunately, poorer performing mixer device), the measured receiver noise temperatures range 4000–7300-K DSB in the 6–17-GHz IF band. Both the mixer and the doubler use planar Schottky devices, eliminating all whisker contacts. The result is a very compact state-of-the-art front-end receiver intended for use on MIRO, a volume- and power-limited space-borne instrument.

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