A Low-Noise Fixed-Tuned 300–360-GHz Sub-Harmonic Mixer Using Planar Schottky Diodes

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***Abstract*—This letter presents the design and fabrication of a low-noise fixed-tuned 300–360-GHz sub-harmonic mixer, featuring an anti-parallel pair of planar Schottky diodes fabricated by the University of Virginia and flip-chipped onto a suspended quartz-based microstrip circuit. The mixer exhibits a double side band (DSB) equivalent noise temperature lower than 900 K over 18% of bandwidth (300–360-GHz), with 2 to 4.5 mW of local oscillator (LO) power. At room temperature, a minimum DSB mixer noise temperature of 700 K and conversion losses of 6.3 dB are measured at 330 GHz.**

***Index Terms*—Hot electron noise, Schottky-diode receiver, subharmonic mixer, submillimeter-wave, wide band mixer.**

I. Introduction

WIDE band fixed-tuned sub-harmonically pumped (SHP) mixers using planar Schottky diodes are key components for space-borne broadband submillimeter-wave heterodyne instruments dedicated to planetary and atmospheric science since they provide high spectral resolution and good sensitivity at room temperature. Future Earth observing missions (Stratospheric-Tropospheric Exchange Atmospheric Monitor project) and Mars exploration programs (Mars Atmosphere Microwave Brightness Observer project) [1], [2] will use such components.

Thanks to the improvement of electromagnetic (EM)-solvers and nonlinear circuit simulators, tuner-less mixers featuring discrete or integrated planar Schottky diodes have already demonstrated better sensitivity, operating bandwidth and robustness than traditional mixers using mechanically tunable backshorts [3]. Up to about 600 GHz, discrete planar devices can be used for low-noise fixed-tuned mixers while providing significant cost reduction [4].

Manuscript received May 27, 2005; revised September 9, 2005. This work was supported by the Centre National d'Etudes Spatiales (CNES), the Centre National de la Recherche Scientifique (CNRS), and the Instrumental Group, Observatoire de Paris. The review of this letter was arranged by Associate Editor F. Ellinger.

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Digital Object Identifier 10.1109/LMWC.2005.859992

This letter will present the design and performance of a novel low-noise fixed-tuned sub-harmonically pumped mixer operating in the 300–360 GHz band that uses a discrete pair of planar Schottky diodes fabricated by the University of Virginia (UVa).

II. Design

While a number of concepts defined in [5] are utilized for the optimization of the current mixer, a number of significant points have been introduced and must be discussed.

Schottky Diode Model: Among the devices fabricated at UVa, we used a SD1T7-D20 planar chip featuring an anti-parallel pair of Schottky diodes for its low parasitic capacitances and small contact areas (0.8 μm^2 per anode). Each anode has a series resistance of 11 to 15 Ω, depending on the device, a zero voltage junction capacitance of 1.3 fF, an ideality factor of 1.3, a saturation current of 2.10^{-16} A, and a built-in potential of 0.73 V (data provided by UVa). The non linear behavior of the diodes was computed using the standard diode model provided by the Advanced Design System (ADS) suite of Agilent [6]. Thermal and shot noises are also included in the diode model of ADS. However, as shown in [7], the hot electron noise is expected to play a significant role in the mixer performance since the currents through the junctions have a high density. Owing to cyclostationary properties, the hot electron noise cannot be rigorously modeled with ADS; a custom harmonic balance code has to be used. Nevertheless, considering that the main components of the current through the diodes are the first three harmonic currents of the LO, and neglecting the correlation between these currents, an upper limit of the contribution of the hot electron noise can be calculated with ADS [8]. This method was used to calculate the performance of an ideal anti-parallel pair of Schottky diodes as well as the performance of the real mixer (see Fig. 1).

Circuit Optimization: Non linear simulations give an optimum LO power of 1.5 mW for the ideal pair of diodes, with no consideration of circuit loss (see Fig. 1). The same simulations give $Z_{\mathrm{RF}} = 83 + \mathrm{j}53\ \Omega$ and $Z_{\mathrm{LO}} = 147 + \mathrm{j}207\ \Omega$ as the optimum embedding impedances of the ideal pair of diodes, respectively, at an RF frequency of 330 GHz and at an LO frequency of 166 GHz. The impedance at the intermediate frequency (IF) is set to 100 Ω, which is a compromise between the expected IF impedance of the pair of diodes ($\approx$150 Ω) and the input impedance of the IF low noise amplifier (LNA), expectedly 50 Ω. The RF and LO matching circuits are then synthesized using a method similar to the one defined in [5].

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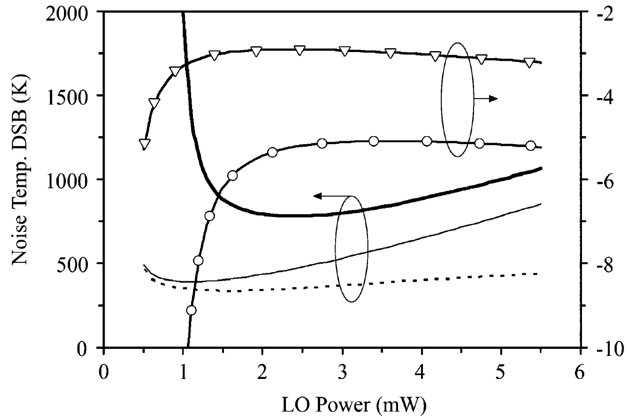


Fig. 1. Simulated performance versus LO power of an SHP mixer using SD1T7-D20 diodes from UVa operating at 330 GHz with an IF frequency of 1.5 GHz. The top two curves with open markers show the DSB conversion gain of an ideal pair of diodes (small triangles) and of the real mixer (small circles). The middle plain curves with no markers show the DSB noise temperature of the real mixer (thick plain curve) and of an ideal pair of diodes (light plain curve). The bottom dashed curve shows the DSB noise temperature of an ideal pair of diodes considering only thermal and shot noises.

The electromagnetic fields inside the mixer are solved using the finite element method of Ansoft HFSS [9], taking into account ohmic losses. Fig. 1 shows the calculated performance of the real mixer considering additional estimated losses introduced by the feed-horn (0.7 dB) and the mismatch between the mixer and the IF LNA (1 dB).

III. Mixer Architecture

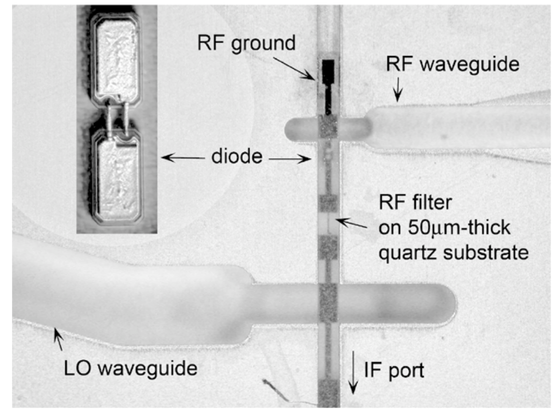
An internal view of the fixed-tuned mixer is presented in Fig. 2(a) and (b). The design is based on a traditional E-plane split-block waveguide architecture [10] with fixed LO and RF backshorts.

The planar diodes are flipped-chip mounted on a suspended 50-μm-thick quartz-based microstrip circuit [see Fig. 2(b)]. They are located inside the chip-channel, close to the RF waveguide. The circuit is inverted and connected at one end to the IF circuit. At the other end, the circuit is directly silver-epoxy glued to the bottom half of the block to ensure a very precise RF grounding and avoid the use of gold ribbons or bonding wires. The LO and RF waveguide-to-microstrip transitions are optimized for broadband operations by reducing the height of the waveguide and by using wide E-probes. To reduce the losses at RF, the waveguide block has a built-in 330 GHz Picket–Potter feed horn [11] with a -3 dB half angle of 13°.

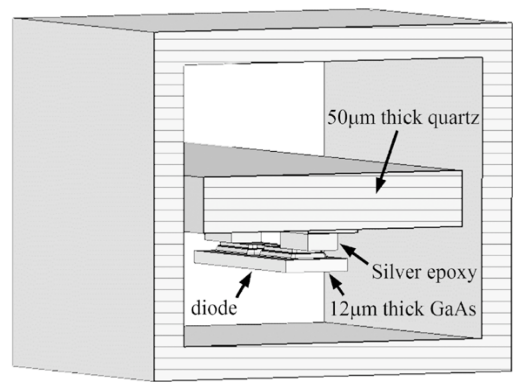
IV. Measurements

The LO signal was provided by a mechanically tunable Gunn oscillator followed by a commercial frequency doubler from radiometer physics GmbH that could provide about 10 mW in the 150–180 GHz band. A D-band waveguide isolator was inserted between the frequency doubler and the mixer. The calibration of the LO power was performed using an Erickson power meter [12].

The IF output of the mixer was connected to a LNA in the band 1–4 GHz or 4–8 GHz, depending on the experiment, followed by a wide-band amplifier in the range 0.1–12 GHz. The



(a)



(b)

Fig. 2. (a) Photograph of the bottom block of the 330-GHz SHP mixer; picture of UVa diode (top left corner) featuring two anodes in an anti-parallel configuration. (b) 3-D view of the UVa diode as flip-chip mounted onto the suspended microstrip circuit.

total noise figure of the IF stage was 1.0 dB (measured separately with an HP 8970B Noise Figure Meter.) The equivalent noise temperature of the receiver was measured by presenting alternatively a room temperature and a liquid nitrogen-cooled black-body in front of the mixer feed-horn. The classic Y-factor method was used to calculate the DSB noise temperature of the receiver [13]. In order to retrieve the DSB conversion losses and the DSB noise temperature of the mixer, a calibrated 3-dB attenuator was inserted between the mixer output SMA connector and the IF LNA; a new Y-factor was measured and a system of two classic linear equations was solved [13].

A. Mixer Performance versus Bandwidth

All the measurements were done at room temperature. Receiver and mixer noise performance as a function of the frequency are presented in Fig. 3. A DSB receiver noise temperature below 1270 K was measured between 300 and 360 GHz with a minimum of 1050 K at 330 GHz. A DSB mixer noise temperature below 930 K was measured over 18% of bandwidth with a minimum of 700 K at 330 GHz. A minimum DSB mixer conversion loss of 5.7 dB was measured at 350 GHz. The conversion losses were below 7 dB from 305 GHz to 360 GHz with an average of 6.5 dB.

The IF circuit consists of a quartz-based 50-Ω microstrip line connected to an SMA connector. The transition from the SMA

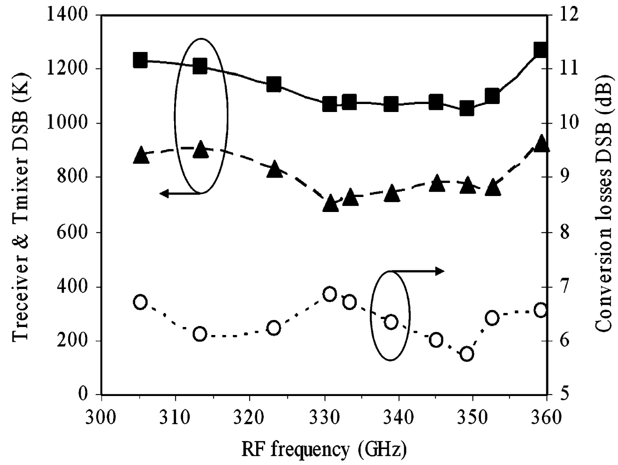


Fig. 3. Measured performance versus RF frequency. The top plain curve with filled squares shows the DSB receiver noise temperature, the middle dashed curve with filled triangles shows the mixer DSB noise temperature and the bottom dotted curve with open circles shows the DSB mixer conversion losses. The IF frequency is centered at 1.5 GHz.

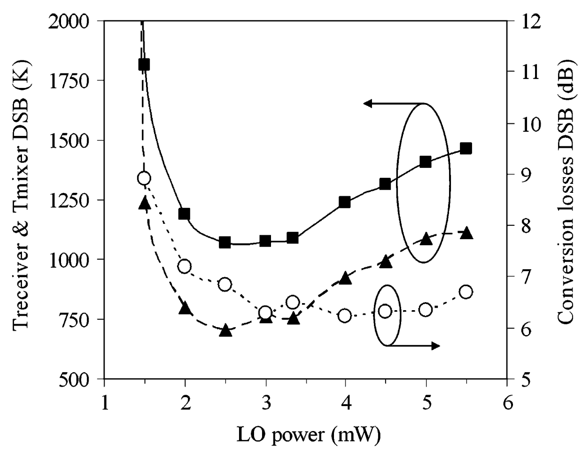


Fig. 4. Measured performance versus LO pump power, at 330 GHz. The top plain curve with filled squares shows the DSB receiver noise temperature, the middle dashed curve with filled triangles shows the mixer DSB noise temperature and the bottom dotted curve with open circles shows the DSB mixer conversion losses. The IF frequency is centered at 1.5 GHz.

connector to the microstrip line was optimized for IF frequencies below 10 GHz. Up to an IF frequency of about 6 GHz, no change in the mixer performance was noticed.

B. Noise Performance versus LO Power

The LO power was swept from 1 to 5.5 mW by tuning or detuning the local oscillator chain. Fig. 4 shows the receiver and mixer performance versus LO power at 330 GHz.

The optimum LO power in terms of mixer noise performance is 2.5 mW. The stiff increase in the mixer noise temperature observed when the LO power rises over 3 mW is attributed to the hot electron noise contribution, as suggested by the simulations performed during this study (see Fig. 1.) The amount of LO power necessary for optimum performance ranges from 2 to 4.5 mW for RF frequency between 300 GHz and 360 GHz. These values, as well as the measured values of the mixer DSB noise temperature, are in close agreement with simulations but the measured DSB conversion losses of the mixer are significantly higher than those predicted by the simulations described in Section II (around 1 to 1.5 dB of discrepancy typically). This could be explained in part by additional ohmic losses at the RF frequency and/or a worse than expected match between the mixer and the IF LNA.

V. Conclusion

A robust fixed-tuned sub-harmonically pumped mixer working in the frequency range 300–360 GHz has been designed and tested. To the authors' knowledge, it exhibits state-of-the-art performance in terms of DSB mixer noise temperature at room temperature. As only 2.5 mW of LO power suffice to optimally pump the mixer, it is believed that this design is suited to create a linear array of heterodyne detectors pumped by a single solid state LO source.

Acknowledgment

The authors wish to thank Dr. T. Crowe and Dr. A. Räisänen for their help and support.

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