Design of a Broadband Sub-Harmonic Mixer Using Planar Schottky Diodes at 330GHz

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Abstract

The design of a broadband fix-tuned 330GHz sub-harmonic mixer is presented. The possibility to model accurately the hot electron noise of Schottky diodes using Agilent ADS software suite has been investigated. The circuit uses an anti-parallel pair of Schottky diodes fabricated by the University of Virginia and flip-chipped on a suspended microstrip filter. The circuit is mounted in a split-block that includes a Pickett feedhorn. At room temperature, the mixer performances were measured in the band 300-360 GHz with conversion losses of 6.5 dB and DSB noise temperature bellow 800 K with an local oscillator power ranging from 2.5 to 4 mW. Best performances were obtained at 330 GHz with a DSB mixer noise temperature of 650 K.

1. Introduction

Sub-Harmonically Pumped (SHP) mixers use a local oscillator signal (LO) corresponding to half of the RF signal frequency. This feature makes the SHP mixers very suitable for heterodyne observations at millimeter and submillimeter wavelengths. The observation of numerous molecular lines spread in frequency, for remote sensing applications as well as planetary studies, drives the need to design sensitive mixers with large instantaneous bandwidth. The use of planar Schottky diodes enables to design robust and easy-to-fabricate devices.

For a decade, reliable commercial simulations software tools associated with increased PCs capabilities make possible the design of tuner-less mixers which performances are similar to fundamental mixers, with low local oscillator (LO) power requirements [1]. These techniques are applicable for mixers/multipliers design up to several THz [2].

In that context, we present a fix-tuned SHP mixer working in the 330 GHz band. The mixer uses an anti-parallel pair of planar Schottky diodes SD1T7-D20 from the University of Virginia. The mixer configuration is taken from a traditional Archer cell.

2. Diode noise model

The Schottky barriers were modeled using the standard diode model of Agilent ADS software suite [3]. The harmonic balance code gives the conversion losses of the mixer and calculates the contribution of the thermal and shot noise. The impedance of the diodes at the frequency of the mixing products is also retrieved.

However, the noise performances of the mixer obtained with the noise model of ADS are significantly underestimated, especially when the diodes are over-pumped by the LO. Actually, Crowe [4] and Hegazi [5] showed that, with strong current densities crossing the barriers at theses frequencies, an additional Hot Electron Noise, exhibiting cyclostationary properties, has to be added to the model. Being unable to retrieve the correlation matrix during the harmonic balance analysis, the Hot Electron Noise contribution has been approximated by assuming that the harmonic currents generated by the LO are uncorrelated. A Voltage Noise source taking into consideration the amplitudes of the currents of the first four harmonics of the LO signal, is connected in series with the Schottky diode model in ADS. This source increases the total mixer noise of an amount that depends on the LO power coupled to the diodes.

The S-parameters of the passive structure around the diode barriers are calculated with a 3D electromagnetic-field solver that uses the finite element method. In order to retrieve the embedding impedances in the plane of the diodes, micro-coaxial probes are inserted at the exact location of the Schottky contacts, as described in [6]. Then, the passive circuit, including the planar diodes structure (see Fig.1), is optimized in the circuit simulator (ADS) to match the impedances presented by the Schottky barriers when pumped optimally.

3. Mixer architecture

The SHP mixer design, illustrated in Fig.1, is based on a traditional E-plane split-block waveguide architecture. The RF and LO waveguides are milled in the same plane, reducing the number of mechanical elements to be assembled. The planar diodes chip is flipped and soldered with silver-epoxy glue on a 50 µm-thick quartz circuit. Afterwards, the quartz circuit is flipped and

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suspended inside a channel that crosses the waveguides. This topology makes possible a very precise grounding at the RF end of the mixer circuit. The other end of the circuit is soldered to an IF quartz circuit.

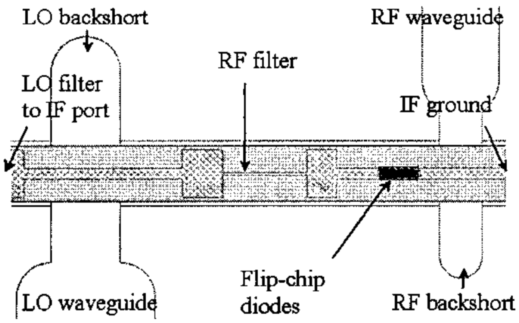

Fig. 1: Schematic view of the mixer circuit and the part of the waveguide mounting circuit.

4. Estimated and measured performances

A prototype of the SHP mixer has been built and tested. The mechanical block integrates a Pickett feedhorn connected to the RF waveguide by a rectangular-to-circular waveguide transition.

The mixer is pumped by a LO source with an available output power of approximately 10 mW covering the frequency range 150-180 GHz. The IF stage has a total noise factor of 1.1 dB and includes a low noise preamplifier in the band 1-4 GHz or 4-8 GHz, followed by a wide-band amplifier.

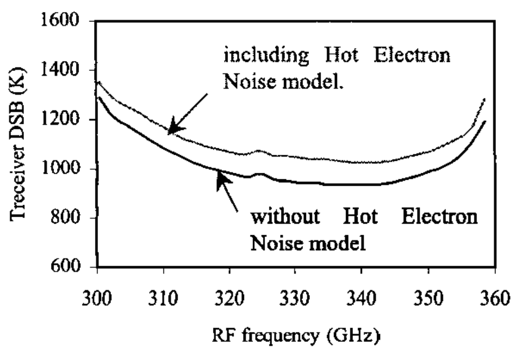

Fig. 2: simulated DSB receiver noise temperature. Parameters for SD1T7-D20 planar diodes from UVa are : Rs=15 Ω, Cjo=1.3fF, η=1.3, $Is=2*10^{-16}A$

Fig.2 shows the simulated DSB receiver noise temperature performances, at an IF frequency of 1.5 GHz. The black curve gives the predicted receiver noise temperature computed with ADS diode noise model. The gray curve gives the predicted receiver noise temperature computed with an additional noise source that takes into account the Hot Electron Noise. With this additional noise source, an average receiver noise temperature of 1100 K DSB at 340 GHz and a bandwidth of 17% are expected.

Preliminary results showed excellent agreement with the simulations. A DSB receiver noise temperature bellow 1250 K has been obtained at several frequencies in the expected frequency band. Best performance gives 1050K DSB around 330 GHz. Varying the IF Noise by inserting a 3 dB calibrated attenuator in front of the 1^{st} IF LNA, gives a DSB mixer noise temperature bellow 800 K and conversion losses around 6.5dB over the full bandwidth. Best performances were obtained at 330 GHz with a DSB mixer noise temperature of 650 K.
The required LO power has been measured with an Erickson power meter PM2 [7]. It ranges between 2 and 4.5 mW across the full band. The IF bandwidth extends until 8 GHz at least.

5. Conclusion

The design of a robust fix-tuned low-LO-power SHP mixer working in the 300-360 GHz band has been presented. A good approximation at the first order of the Hot Electron Noise has been found to better the prediction of the noise performances of the SHP mixer made by the standard ADS Schottky diode model. A fix-tuned mixer has been built and tested, with very good agreement with the simulations.

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