Design of a Low Noise Integrated Sub-harmonic Mixer at 183GHz Using European Schottky Diode Technology

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Abstract
This paper describes the design of a broadband fixed-tuned 183 GHz sub-harmonically pumped mixer featuring an anti-parallel pair of planar Schottky diodes monolithically integrated on a 50 µm-thick GaAs substrate. The circuit is about 4 mm long, 0.28 mm wide and is mounted in a waveguide block that includes waveguide matching elements at the Local Oscillator (LO) and RF frequencies. The mixer is expected to work efficiently in the band 160-190 GHz using only 2 mW of LO pump power, with a Double Side Band (DSB) conversion gain greater than -5.5 dB. Best performances obtained in simulations are a minimum DSB gain of -5.1 dB at 183 GHz. The circuit will be fabricated using the standard BES process of United Monolithic Semiconductors (UMS).

Keywords: Sub-harmonic mixer, broadband mixer, planar Schottky diode.

1. INTRODUCTION

Among the spectral lines that can be observed at millimeter wavelengths with heterodyne receivers to retrieve the vertical moisture profile of planets such as the Earth or Mars, the water vapor line at 183 GHz is certainly one of the most important. For heterodyne instruments dedicated to planetary and atmospheric science, very high sensitivity is not a critical issue; the best mixing element at room temperature is still a GaAs Schottky diode due to it low noise performances, it easy usage, and well controlled fabrication process. In the frame of oncoming projects for the Centre National d'Etudes Spatiales (CNES), a Schottky diode based sub-harmonic mixer at 183 GHz has been designed and is intended to demonstrate the feasibility of millimeter and submillimeter-wave receivers based on European Schottky diodes. Future space-borne instruments of CNES or the European Space Agency (ESA) will use these components.

2. DESIGN OF THE 183 GHZ MMIC MIXER

2.1 Planar Schottky Diodes Chip

Our design is based on a preliminary study of the technology of UMS diodes [1]. Fig.1 shows a three-dimensional (3D) view of a Schottky diode from UMS with a single anode. The diode is connected to the rest of the monolithic microstrip circuit with two side pads. The anode is connected to one of the pads with a surface finger tapered from the anode pad to the anode. The anti-parallel design configuration has been optimized for best SHP mixing performances including the anode size, as seen in Fig.2. The resulting electrical characteristics for each is an ideality factor η=1.2 , a saturation current I_{SAT}=4.10^{-15} A, and an estimated series resistance R_s=10 Ω. A zero bias junction capacitance C_{jo}=2 fF is calculated based on the anode size and the epitaxial layer doping. The configuration is shown in Fig.2.

2.2 Circuit Optimization

First, an ideal mixer circuit featuring an anti-parallel pair of diodes and ideal matching elements loads is built as described in [2]. The non linear simulation results give an optimum LO power of 1.5 mW for the pair of diodes, with the embedding impedances Z_{RF}=82+j.45 Ω at f_{RF}=183 GHz and Z_{LO}=197.5+j.182 Ω at f_{LO}=89.5 GHz. The IF load impedance is set to 100 Ω. Second, the RF and LO matching circuits are optimized in a set of linear simulations (Agilent ADS software [3]) to present an embedding impedance as close as possible to the values found previously, using a similar method as the one defined in [4]. Each individual section of the three-dimensional (3D) electromagnetic (EM) mixer circuit is solved using a finite element method (Ansoft HFSS software [5]) and imported as S-parameter files in the circuit simulator before optimizing the circuit. Finally, a non-linear analysis of the entire mixer circuit, including the S-parameters data of the mixer EM structure, is performed to compute the mixer noise temperature and conversion losses. Results of the simulations are presented in section 3.

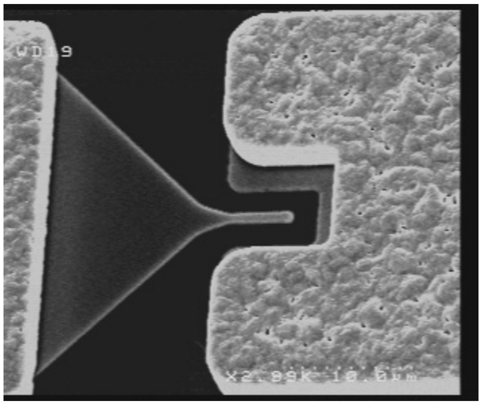

Fig. 1. View of a single anode Schottky diode from UMS

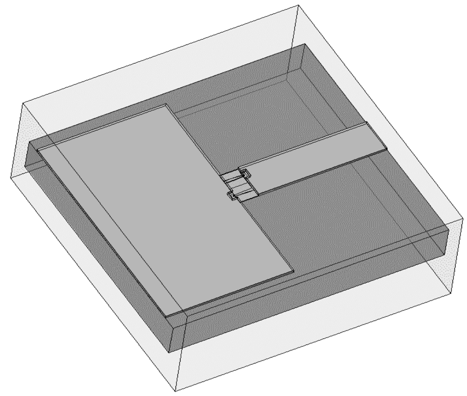

Fig. 2. The anti-parallel diodes pair configuration inside the channel.

2.3 Mixer Layout

The designed mixer block layout, similar to [6], is split in the E-plane of the RF and LO waveguides into two half blocks, resulting in a simple mixer assembly and a low cost mechanical structure. The planar diodes are integrated on a 50 µm thick GaAs circuit including the passive transmission lines matching elements. The whole circuit is flipped and suspended in an enclosed channel crossing the RF and LO waveguides. One end of the circuit is directly connected to the mechanical block providing a precise IF/DC grounding point. The other end of the circuit is reported on another microstrip quartz circuit to output the IF signal. A schematic of a mixer block is shown in Fig. 3. Wide E-probe waveguide-to-suspended stripline transitions are used to couple both the RF and LO signal into the channel. Reducing the height of both RF and LO waveguide in the vicinity of the E-probe transitions was found necessary in order to achieve broadband operation, as mentioned in [7]. Two low-pass stripline filters are used to prevent the RF signal from coupling to the LO waveguide and the LO signal to leak towards the IF connection.

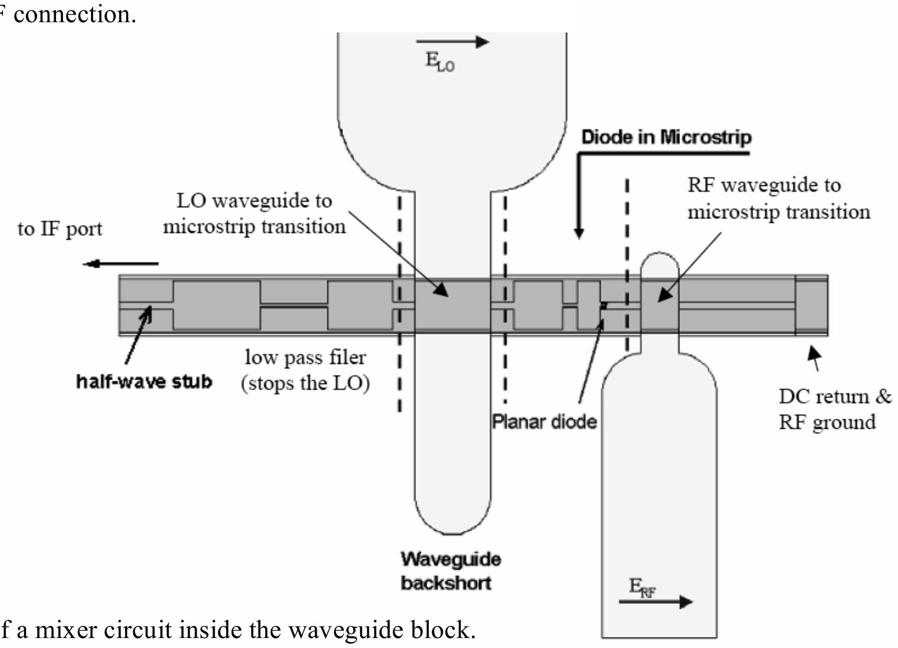

Fig. 3. Schematic of a mixer circuit inside the waveguide block.

3. SIMULATION RESULTS OF THE MIXER PERFORMANCES

The performances of the whole mixer structure are computed with a harmonic balance code over the frequency range 160-200 GHz. The results are presented in Fig.4 for different values of LO input power. The expected DSB conversion losses are higher than -4 dB between 160 GHz and 196 GHz using 2 mW of LO power, with a best value of -3.1 dB at 183 GHz. Considering additional losses of about 2 dB due to the total conductor and dielectric loss of the horn and waveguide, as well as possible mismatches between the IF output of the mixer and the first IF low noise amplifier, the DSB mixer conversion loss is expected to be approximately 5.1 dB at 183 GHz. The DSB noise temperature of a receiver using this mixer and connected to a low noise preamplifier (estimated noise figure NF=1 dB at 1.5 GHz) is estimated around 500 K at 183 GHz, as shown in Fig.5.

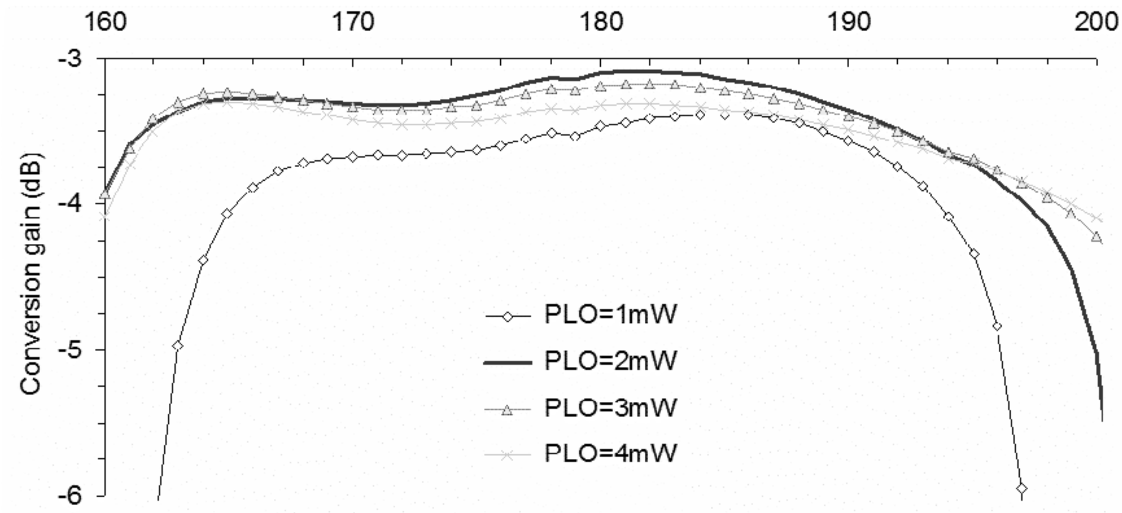

Fig. 4. Simulated performance of the mixer DSB conversion loss at 183 GHz with different LO power. Optimum mixer conversion losses are obtained for a LO power of 2 mW. The IF frequency is set to F_{IF}=4 GHz.

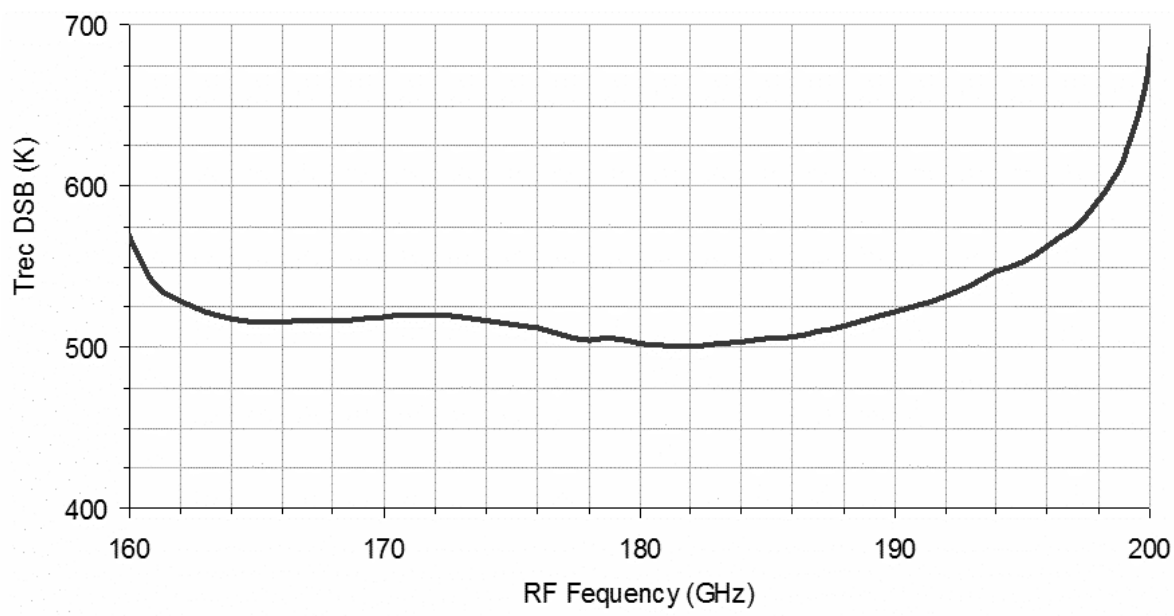

Fig. 5. Expected DSB receiver noise temperature with P_{LO}=2 mW. the IF frequency is set to F_{IF}=1.5 GHz. The noise figure of the first preamplifier is estimated to NF=1 dB. Additional losses of 2 dB are also included.

4. STATUS OF THE CIRCUIT FABRICATION

A prototype of this mixer is currently being fabricated at the University of Bath in UK, using a process that allows the air-bridging of the diodes to decreasing the parasitic capacitances. This prototype shares the same chip-layout and waveguide block as the mixer designed for UMS BES process. Simulations show that the presence of air-bridges does not change significantly the matching of the diodes; therefore the same block is expected to be optimum for both circuits allowing a direct and relevant comparison between the two processes.

5. CONCLUSION

This paper describes the design of a broadband fixed-tuned sub-harmonically pumped monolithic mixer at 183 GHz. It demonstrates the feasibility of an MMIC fixed-tuned mixer operating at 183 GHz using European Schottky diodes. The circuit should be fabricated using the standard BES process of United Monolithic Semiconductors (UMS).

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REFERENCES

[1] A. Maestrini, "Report on the Evaluation of the Capabilities of the United Monolithic Semiconductors to Produce Schottky Diodes Based Mixers in the Band 100-380GHz", *proceedings of the Round Table discussion on Schottky technology*, ESA/ESTEC, Norrdwijk, The Netherlands, March 2004.

[2] B. Thomas, "Etude et réalisation d'une tête de réception hétérodyne en ondes submillimétrique pour l'étude des atmosphères et surfaces de planètes", *PhD dissertation*, LERMA-Observatoire de Paris, France, December 2004.

[3] Advanced Design System, Version 2003A, Agilent Technologies, 395 Page Mill Road, Palo Alto, CA 94304, USA.

[4] J.L. Hesler, "Planar Schottky diodes in submillimeter-wavelength waveguide receivers", *PhD dissertation*, University of Virginia, Charlottesville, USA, Jan.1996.

[5] High Frequency Simulation Software, V9.2, Ansoft Corporation, 225 West Station Square Drive, Suite 200, Pittsburgh, PA 15219, USA.

[6] A.V. Raisanen, D. Choudhury, R.J. Dengler, J.E. Oswald, and P. Siegel, "A novel split-waveguide mount design for millimeter- and submillimeter-wave frequency multipliers and harmonic mixers," *IEEE Microwave and Guided Wave Letters*, Vol. 3, No.10, Oct.1993, pp.369-371.

[7] S.C. Shi and J. Inatani, "A Waveguide-to-Microstrip Transition with a DC/IF Return path and an Offset Probe", *IEEE Transactions on Microwave Theory and Techniques*, Vol.45, No.3, March 1997.