First results of a 1.2 THz MMIC sub-harmonic mixer based GaAs Schottky diodes for planetary atmospheric remote sensing

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Abstract- **We present here the first measurement results of a 1200 GHz heterodyne receiver front-end prototype based on this Schottky GaAs membrane technology. The 1200 GHz sub-harmonic mixer design, previously reported, uses a suspended MMIC GaAs membrane that feature a balanced pair of planar Schottky diodes and an on-chip MIM capacitor for DC forward biasing capabilities. The possibility to bias the sub-harmonic mixer is very important in order to release constraints on the amount of LO power required at 600 GHz. Measurement results show a DSB mixer noise temperature better than 6000 K and DSB mixer conversion losses better than 15 dB are achieved in the RF range 1130 GHz to 1220 GHz. The estimated LO input power available is between 1 mW and 1.5 mW. For this relatively low LO power levels, the optimum bias voltage is approx. 0.85 V with a rectifying current of 170 uA. These performance values are in agreement with predictions, but it is believed that the performance can be improved by selecting devices with better electrical characteristics and increasing the amount of LO power available.**

I. INTRODUCTION

A Submillimetre Wave Instrument (SWI) has been proposed as a potential payload instrument for the JUICE mission (JUpiter ICy moon Explorer, the formerly joint ESA/NASA mission called EJSM) [1]. The primary scientific objectives are to investigate the exchange mechanisms in the middle atmosphere of Jupiter by the remote sensing of key molecular species such as the water line at 557 GHz and the methane line at 1256 GHz. As a secondary objective, it would also investigate the exosphere/ionosphere dynamics and thermo-physical surface properties of Jupiter's moons. The proposed radiometric and spectroscopic instrument features two heterodyne channels, one centered around 560 GHz close to the water line, and another one centered around 1200 GHz close to the methane line.

Significant effort has already been done in order to demonstrate high sensitivity and broad bandwidths at frequencies around 560 GHz, using MMIC GaAs membrane Schottky diode based sub-harmonic mixer. Moreover, previous developments of local oscillators for the HIFI instruments onboard HERSCHEL satellite using similar JPL Schottky technology enabled few mW of output power to be available from 540 to 640 GHz [2]. Building on these achievement, the successful demonstration of an all-solid-state, semiconductor based heterodyne receiver channel front-end operating at room temperature or compatible with passive cooling temperatures in space (approx. 100 K) with high enough sensitivity and covering the 1100 to 1300 GHz range is now possible.

The 1200 GHz channel is under development at JPL. The receiver architecture is directly inherited from the HIFI project for the LO generation at 600 GHz. Using identical MMIC GaAs membrane process, a novel 1200 GHz MMIC sub-harmonic mixer has been designed, and is presented here.

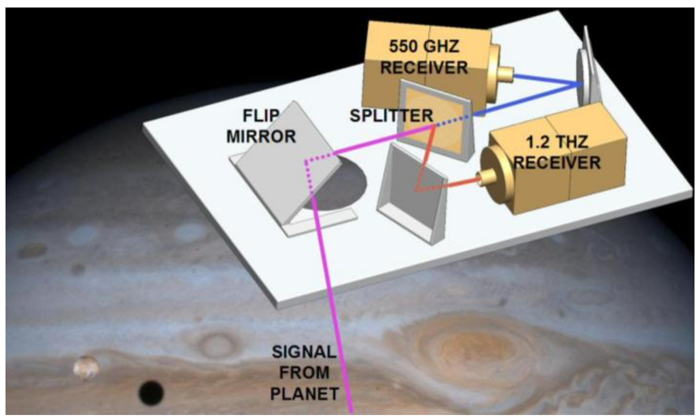


Fig.1: artistic representation of the SWI Front-End dual-channels receiver baseplate with a 557 GHz receiver channel, and a 1.2 THz receiver channel.

II. 1.2 THZ MIXER DESIGN

The 1200 GHz sub-harmonic mixer design has been previously described for a scaled version at 874 GHz [3]. The design methodology and prediction tools are described in [4]. It's a balanced design with the diodes placed along the cross-section of the channel. It creates an open loop at the second harmonic of the Local Oscillator signal, whose propagation is cut-off by the channel cross-section dimensions, as for a balanced tripler. This topology allows for a good phase balance between both diodes at RF and LO frequencies, without the need to use very short fingers as for an anti-parallel configuration, therefore relaxing some constraints on the diode fabrication process at these high frequencies.

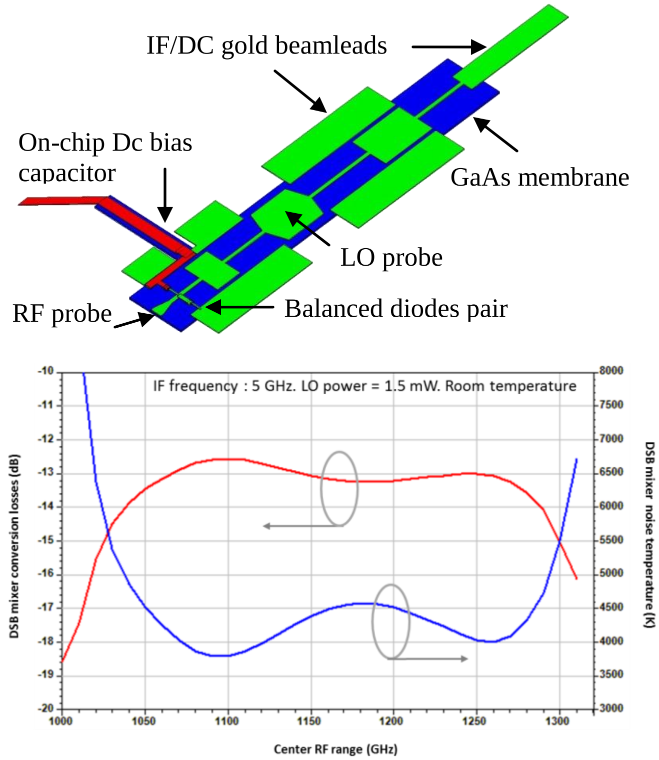


Fig.1. Top: 3D view of the MMIC 1200 GHz sub-harmonic mixer based on MMIC GaAs membrane Schottky diodes, including the on-chip DC bias capacitor (in red). Bottom: Predicted performance of the MMIC 1200 GHz sub-harmonic mixer at room temperature. IF is fixed to 5 GHz, LO bias is set to 1.5 mW and mixer is DC forward bias to 0.5V per anode.

Moreover, the RF and LO grounding of the diodes is done with the beamleads which are located on each side of the circuit, allowing for a very short distance between the ground and the diodes, therefore increasing the RF, LO and IF bandwidth significantly. In this topology, the diodes are also very close to the RF waveguide which contributes to reduce the suspended stripline transmission losses between the diodes and the RF waveguide.

The optimization and simulation of the mixer is done using a combination of 3D-EM simulations using HFSS (Ansys) [5] and ADS (Agilent) [6]. As shown in Fig. 1, the predicted DSB mixer noise temperature of the mixer is between 4000 and 4500 K at room temperature in the frequency range 1050 to 1280 GHz, corresponding to DSB conversion losses between 12.5 dB and 14 dB approximately. With an available input LO power increasing to 4-6 mW, simulation results show that it is possible to improve the mixer conversion losses by 1 or 2 dB, and the DSB mixer noise temperature by up to 1000 K.

III. 1.2 THz Mixer Fabrication

The 1.2 THz sub-harmonic mixer relies on the MMIC GaAs and gold beamleads “Momed“ circuit fabrication process developed by JPL in the framework of previous space instruments such as EOS-MLS and Herschel-HIFI [7]. An MIM on-chip capacitor allows to bias the diodes in-series. The MMIC, shown in Fig. 2, is suspended along the cross-waveguides channel by clamping the ground beamleads when closing both halves of the split waveguide block.
The block shown in Fig. 3 has been machined at JPL, and includes an SMA connector for DC biasing, a K-connector for IF output, and an integral diagonal feed horn for RF testing. The LO connection is done by a precision UG387 waveguide flange.

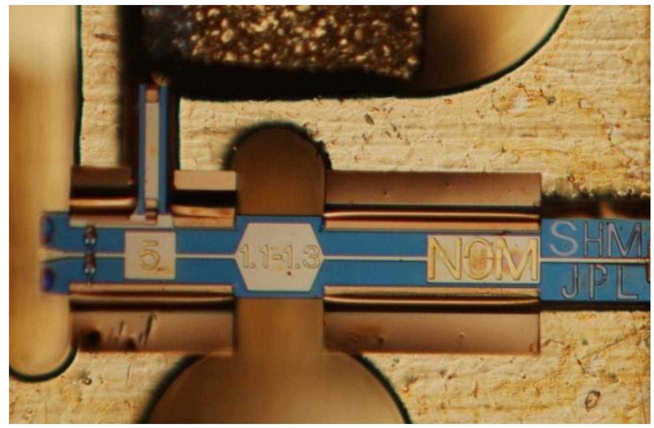


Fig.2. View of the 1.2 THz MMIC membrane sub-harmonic mixer mounted inside the lower half of the split-waveguide block.

IV. 1.2 THz Receiver Channel Test Results

The complete 1200 GHz receiver channel includes a 600 GHz LO source based on MMIC membrane 200 GHz doubler and 600 GHz tripler inherited from the HIFI Local Oscillator developments [2][8], and a 1100-1300 GHz MMIC membrane biasable sub-harmonic mixer. The Local Oscillator can output between 1.5 mW and 2 mW of power at room temperature, in the frequency range 550-605 GHz.

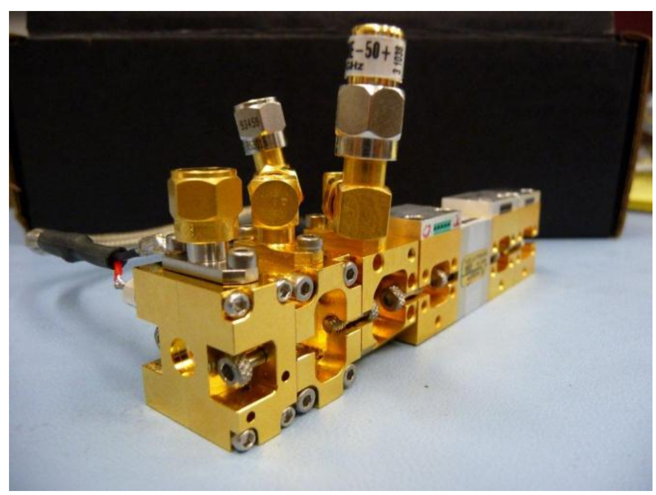
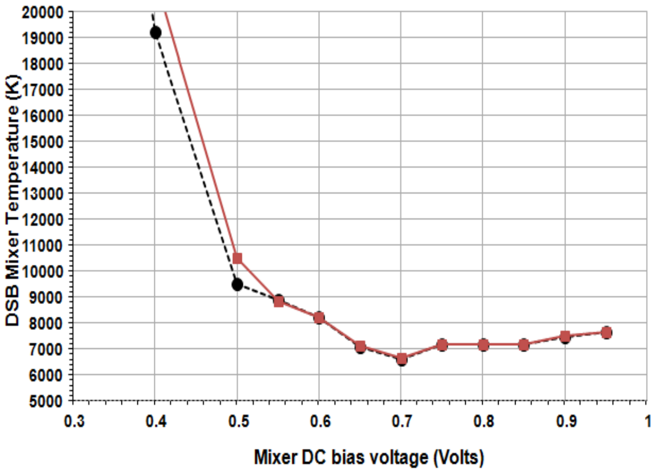


Fig.3. View of the complete 1.2 THz receiver chain, including a W-band power amplifier stage, a 200 GHz doubler, a 300 GHz tripler and a 1200 GHz sub-harmonic mixer with integrated feedhorn antenna.

The measurements are performed at room temperature in laboratory environment conditions.



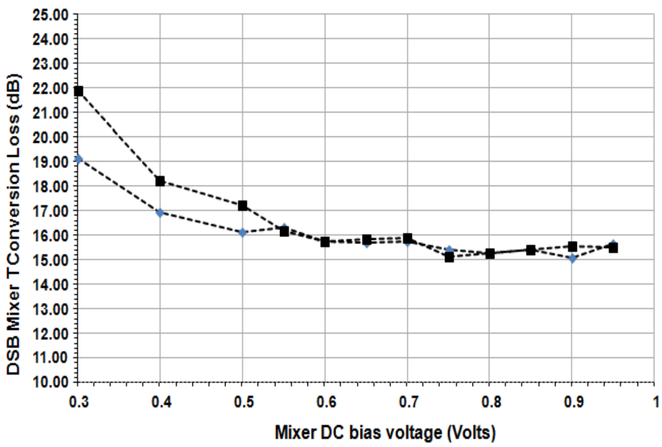


Fig.3. Preliminary measurement results of the 1200 GHz sub-harmonic mixer VS DC bias voltage of both diodes in series. Top: DSB mixer noise temperature. Bottom: DSB mixer conversion losses for two blocks under test. Available LO input power: 1-1.5 mW. Center frequency: 1193 GHz.

Preliminary results obtained at room temperature are shown in Fig. 4. For an input power available limited to 1.5 mW max., the optimum mixer DC biasing voltage is estimated at 0.7-0.85 V, corresponding to a DC bias voltage per diode of 0.35-0.45 V, in agreement with the simulations. DSB mixer noise temperature better than 5000 K and DSB conversion losses better than 15 dB have already been obtained at different frequencies within the 1100-1220 GHz band.

Further tests are on-going to characterize the mixer performances over the entire 1100-1300 GHz frequency range, in vacuum environment at the temperatures compatible with passive cooling in space.

CONCLUSION

Future sub-millimeter wave instruments for the remote sensing of planets' atmospheres such as the Earth, Mars, Jupiter and Saturn will greatly benefit from the recent advances in receiver sensitivity and integration up to 1200 GHz, as described in this paper. The development of MMIC Schottky technology and powerful Local Oscillator sources widely tunable and operating at room temperature are pivotal for THz receiver development.

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