330 GHz and 600 GHz Schottky Heterodyne Systems for QPSK Terahertz Telecommunication

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***Abstract*— Above 300 GHz, Schottky-based room-temperature heterodyne systems allow to detect THz radiation to the order of <0.1 K of physical temperature variations in optical blackbodies with unequaled spectral resolution. In this paper we examine some of the parameters of these low-noise and high-resolution detection systems in order to enhance their future use in the generation/detection of free space THz-carrier modulated signals. We propose and demonstrate a novel way to generate QPSK modulated signals through the bias voltage of the last multiplier element of the emitter chain that yet could reach > mW of emitted power and a signal bandwidth of several tenth of gigahertz.**

Keywords—Solid-state electronics, Terahertz, Heterodyne systems, Schottky, Terahertz Telecommunication, QPSK.

I. Introduction

The Terahertz and sub-terahertz frequency systems offer an increasingly attractive potential for ultra-large bandwidth and fast data rates wireless links as high as 100 Gbits/s [1]. However, working at these frequencies is a challenging task since the dedicated electronics must operate within bandwidths of several tenth of gigahertz. Moreover, the THz telecommunication systems shall be smartly defined within specific environmental parameters (atmospheric attenuation in the THz region, scintillation) but also take into account technological specificities related to every aspect of the THz telecommunication chain: THz signal generation, THz signal detection and THz signal modulation/demodulation schemes. A first successful approach in generating a fast modulation on a high frequency carrier is to convert beat frequencies from visible/near IR lasers. As an example, uni traveling-carrier photodiode (UTC-PD) has emerged as a viable high-bandwidth technology for the optical generation of THz signals. Their use is limited by the available emitted power and rely on the use of broad-band high electron-mobility transistor HEMT amplifiers. Another and drastically more powerful solution comes from non-linear systems based on solid-state schottky multipliers and mixers. This technology offers the possibility to generate free-space THz-modulated signal with much larger amount of power and receive very faint free-space signals over a large modulation bandwidth. These systems require more investigation in their signal modulation/demodulation processing schemes. In a first part we discuss some of the parameters of the THz heterodyne systems developed at Observatory of Paris in a goal to enhance their future use a free space carrier-modulated signals. In a second part we propose a novel way to modulate QPSK signals on a THz frequency carrier in a goal to reach a signal bandwidth of several tenth of Gigahertz. We present a first measurement bench using this method with a 334 GHz carrier frequency signal and discuss about how the efforts shall be pursued in order to reach a more mature and operative THz telecommunication system.

II. System Perfromances Consideration

THz mixers, multipliers components and heterodyne systems are developed at LERMA-Observatory of Paris for planetary and atmospheric science applications such as the Submillimeter-Wave instrument SWI in Jupiter JUICE-L1 ESA mission [2], [3]. The strong demand of astronomers to detect ultra-low noise signals is challenging the design and optimization efforts in order to push the system's sensitivity to its best. This sensitivity is theoretically defined by the minimum detectable noise temperature being proportional to the mixer noise temperature and inversely proportional to the square of the first mixer element instantaneous intermediate frequency bandwidth (IF). Low noise and wide instantaneous IF bandwidth mixers development continuously helps to either speed up the detection rate of large scale mapping systems using single pixel scanners or offers the flexibility to define a trade-off between total power radiometer sensitivity reduction or large-scale mapping [4]. Making use of these systems for fast data rate telecommunication application requires considering the system parameter from a different perspective, in order to enhance long range and high data rate transmission.

A. Detection rate bandwidth versus emitted signal power and detector sensitivity.

In [2] and [3] we propose state-of-the-art highly optimized sub-harmonic 600 GHz and up to 1200 GHz Schottky mixers and their dedicated technology process developed at C2N-CNRS. These room-temperature mixers are specially designed to detect variation of THz radiation related to the physical temperature of optical blackbodies, at a magnitude below 0.1 Kelvin, with a spectral resolution up to 10^6. Firstly, we consider how the data-rate bandwidth will relate to both the power of the free-space THz-modulated emitted signal and the responsivity of the mixer used for its detection. As illustrated in Fig. 1, for a system with a SNR = 10, a mixer with a responsivity of 100 V/W could detect a 10 mW signal with 50 GHz bandwidth. THz telecommunication system benefiting from state-of-the-art Schottky mixer will thus enhance their telecommunication range. Their limitation will come from the environmental parameters, the system IF bandwidth and the phase system stability discussed in the next paragraphs.

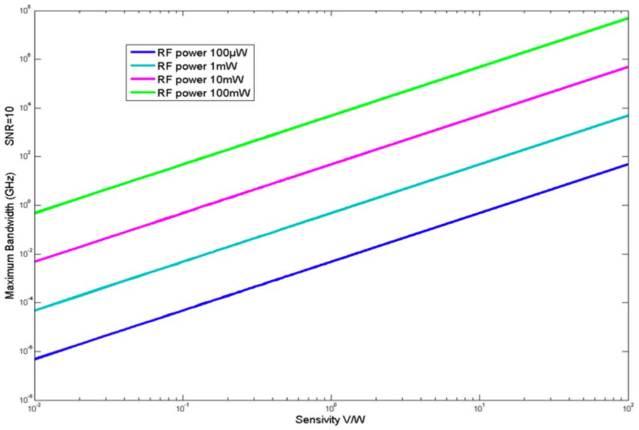


Fig. 1. Bandwidth increase with RF power versus Mixer Responsivity in V/W for a SNR =10.

B. Mixer IF bandwidth versus sensitivity.

The fast evolution of back-end processors with multiple FTS units used in interferometer systems provides today up to 64 GHz of instantaneous bandwidth [5]. In [6] a 600 GHz fundamental mixer was optimized to perform with 36 GHz instantaneous IF bandwidth that can be used to enhance either system sensitivity or fast data rate in THz telecommunication systems.

C. System spectral resolution

In the 530-625 GHz heterodyne system developed at LERMA for planetary science application such as the Submillimeter-Wave instrument SWI in Jupiter JUICE-L1 ESA mission, the system requirement and spectral purity in the local oscillator (LO) are defined to reach spectrometer resolution below 1 MHz. The immediate consequence of such high spectral resolution specification is the requirement for low phase noise and highly limited spurious signals in the LO [7]. An experiment was conducted at LERMA in order to determine the specifications of the JUICE-SWI synthesizer in K-band used for the 600 GHz detection chain. The experiment includes a 600GHz HEB superconducting mixer with two frequency multiplication chains and two Agilent E8257D and Schwarz SMF100A synthesizers at Ku-band. A phase noise specification at X-band of 1.35 x 10^{-4} rad^2 is defined in order to reach a spectrometer resolution as fine as 100kHz.

III. First QPSK-modulated telecommunication at 330 GHz

Schottky-based multipliers and mixers offer the possibility to transmit the THz signal with a much larger amount of power and receive very faint free-space signals over a large modulation bandwidth. Making use of these advantages in the design of high data rate THz telecommunication systems requires to invest in the different possibilities of implementing efficient modulation/demodulation schemes.

A. Modulation of the signal

Because a frequency multiplier degrades the phase noise of the fundamental signal by a factor of 20 log (n), n being the multiplication factor, the modulated signal will not be introduced at the input of the multiplier chain. A possible modulation scheme is introduced in [8] where the mixer IF port is used to modulate a 150 GHz LO signal, resulting in a free-space telecommunication signal on a 300 GHz frequency carrier which is radiating through the mixer RF port. Unfortunately, this methodology doesn't allow to generate strong THz signals, and in the case of [8] no more than 50 µW of power is radiated at the antenna output. In order to bypass this issue, we propose to use the multiplier element as a main contributing actor in the modulation scheme. The multiplier is designed to operate at its optimum power efficiency by defining the diodes DC operating-point close to an ideal varactor mode operation. In reality varistor mode operation are offen also excited. In order to relate the multiplication operation of the doubler we have measured in Fig.2 the doubler output power (mW) at 334 GHz and its rectified current (mA) as a function of its DC bias voltage. The two main varactor and varistor multiplication modes are clearly seen before and after the -5.5 V DC voltage value; the varactor mode being defined by a quasi-null rectified current. In a phase modulated communication system, we consider two central voltages around which a n-level voltage can be applied in order to generate the QPSK modulation: "PM central voltage 1" and "2". The "PM central voltage 1" of -3.5 V corresponds to a 6-7 mW maximum output power, however the doubler's rectified current is positive and indicates a hybrid varactor-varistor operation. The "PM central voltage 2" of -5 V corresponds to a zone where the MMIC doubler works on a pure varactor operation but its amplitude vary significantly with DC voltage ("linear AM zone").

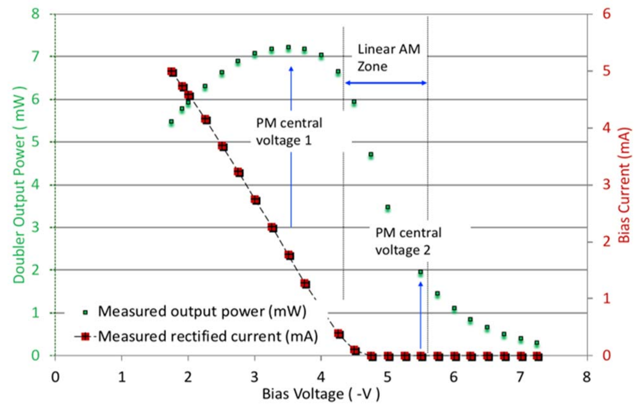


Fig 2. Doubler measured output power in mW at 334 GHz and its rectified current in mA as a function of DC bias voltage. Two central voltage for QPSK modulation are considered and used in the simulations.

In order to illustrate the multiplier operation in a QPSK constellation of the modulated / demodulated signal, the 334 GHz doubled signal and the received 334 GHz signal are simulated in ADS using the electrical model for both the doubler [9] and mixer [10] elements. In Fig. 3 (Top) the central DC voltage is -5V and the constellation features four different states corresponding to four added voltage levels of -3, -1, +1 and +3 V. In this example we see how the different spreading of the phase are related to each multiplication mode. A similar analysis can be conducted at mixer level, which is functioning on a varistor mode only. For a terahertz telecommunication application, a dedicated modulator would feature a maximum output power (flat AM zone) and a pure varactor mode. This type of dedicated design will enhance predictability of the modulation rather than optimum output power. Such a trade-off will not affect the telecommunication range if used together with mixers performing as in [2] and [3].

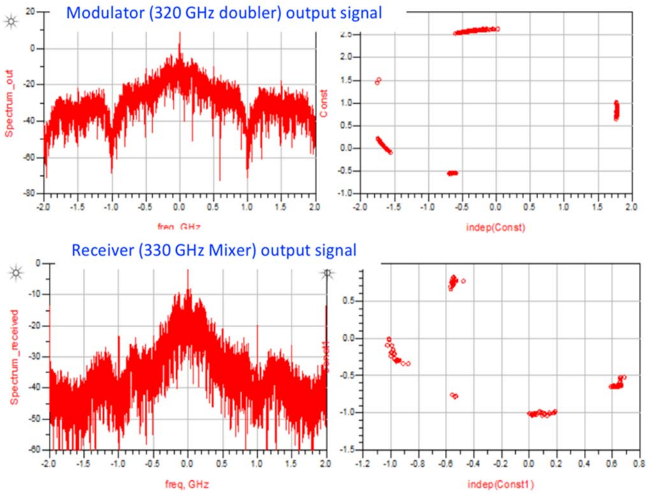
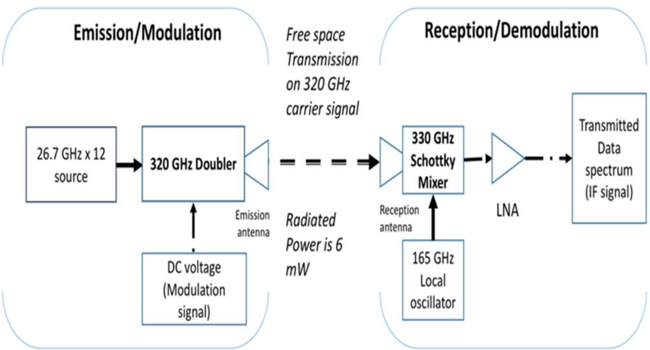


Fig 3. Example of simulated signal spectrum and constellation diagram with DC voltage of -5 V and 4 voltage states. Top: Emitted signal with the model defined in the doubler element [9]. Bottom: Simulated received signal with the model defined in the mixer element [10].

B. *Experimental Bench*

A preliminary emitter/receiver experimental bench is presented in order to demonstrate the modulation of the bias voltage of the last multiplier element. As illustrated in Fig. 2, the emitter chain features a commercial RPG Tx 160-180 GHz sextupler fed by a 27.8 GHz synthetized signal. The 167 GHz signal is amplified and multiplied at 334 GHz by a MMIC doubler designed at LERMA and fabricated at C2N-CNRS [9]. A n-level voltage with an optimum value of Vmod 3V is generated by a Tektronix AWG7122B signal generator and introduced through the doubler DC bias port. The free-space 334 GHz telecommunication signal is radiated through a directional feed horn with a power of 5-6 mW. The signal is then detected with a 334 GHz subharmonic mixer design at LERMA with discrete VDI diodes [10] and transposed to the mixer IF port. A two-symbol frequency signal transmission at 500MHz and 3000 MHz was performed with a bandwidth of respectively 1 and 3 GHz. Further investigation will be pursued in order to characterize the telecommunication range, but also the phase stability of the system without external synchronization and compare it with the simulations. The stability of the system will be related to the one of its DC modulated voltage and low frequency oscillator driver.



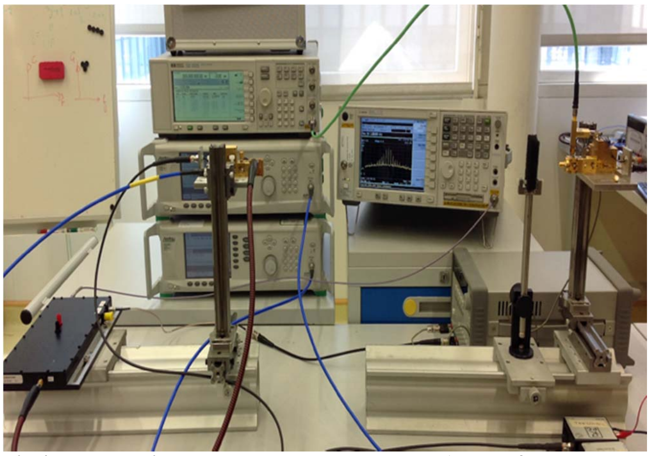


Fig 4. The experiment conducted at both LERMA and L2E.

IV. Conclusion

The terahertz and not yet allocated frequencies band above 0.275 THz is available for communication and offers several advantages over microwave and infrared systems, including low atmospheric attenuation as compared to optical waves. Above 300 GHz, heterodyne systems offer the most attractive way to characterize or detect signals with high sensitivity, large instantaneous IF bandwidth, and high spectral resolution. State-of-the-art THz mixers and multipliers components and heterodyne systems developed at LERMA-Observatory of Paris for planetary and atmospheric science application can be used and optimized in order to enhance their future use in the generation/detection of THz free space carrier-modulated signals. In this work we propose and demonstrate a novel way to generate QPSK modulated signals through the bias voltage of the last multiplier element of the emitter chain. A first experiment has been carried out to test generation/emission of a QPSK modulated signal on a 334 GHz frequency carrier with a power of several of mW, tackling the problem of power reduction along usual modulation process. Further work is expected to refine and optimize the quality of the QPSK modulation scheme: a dedicated modulator will feature a maximum output power located at its pure varactor mode. This type of dedicated design will enhance predictability of the modulation. The telecommunication rate system will be enhanced by using 600 GHz fundamental mixer performing with 36 GHz instantaneous IF bandwidth [6].

References

[1] J. Federici, and L. Moeller *Review of terahertz and subterahertz wireless communications* Journal of Applied Physics, 107, 111101, 2010

[2] J. Treuttel, L. Gatilova, A. Maestrini, et al., 520–620-GHz Schottky Receiver Front-End for Planetary Science and Remote Sensing With 1070 K–1500 K DSB Noise Temperature at Room Temperature, IEEE Transaction on Terahertz Science and Technology, Vol.6, No.1, January 2016.

[3] A. Maestrini, L. Gatilova, J. Treuttel,.The 1200GHz Receiver Frontend Of The Submillimetre Wave Instrument Of ESA JUpiter ICy Moons Explorer

[4] P. F. Goldsmith Heterodyne Receivers for CCAT – Selected Astronomical Perspectives and Cornell Caltech Atacama Telescope Feasibility/Concept Design Study,2006.

[5] K.F. Schuster, Applicable Lessons from the IRAM 30m Telescope Atacama Large-Aperture Submm/mm Telescope (AtLAST) ESO-HQ, Garching b. München, Germany January 17-19, 2018

[6] J. Treuttel, D. Gonzalez-Olvejero, C. Lee, I. Mehdi, *Enhancing heterodyne system performances using fundamental millimeter wave mixers with 36 GHz instantaneous IF Bandwidth and 35 % relative detection bandwidth,* submitted to IRMMW-THz, Japan, sept 2018.

[7] Schlecht JUICE-SWI consortium Meeting, 2010

[8] C. Jastrow, K. Munter, R. Piesiewicz, T. Kurner, M. Koch, and T. Kleine-Ostmann, "300 GHz transmission system," Electron. Lett. 44, 213 2008.

[9] J.Treuttel, L.Gatilova, F.Yang, A.Maestrini, Y. Jin, A. Cavanna T.Vacelet, F.Tamazouz, and J-M. Krieg C. Goldstein *A 330 GHz Frequency Doubler Using European MMIC Schottky Process Based on E- Beam Lithography ,* URSI GAAS China 2014

[10] B. Thomas, A. Maestrini and G. Beaudin: *A low noise fixed tuned 300-360 GHz sub-harmonic mixer using planar Schottky diodes*, IEEE Microwaves and Wireless Component Letters, p.865-867, vol.15,no.12, December 2005.

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