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High Power Discrete Schottky Diodes Based 275-305 GHz Transceiver for FMCW-Radar

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***Abstract*— A heterodyne 275-305 GHz transceiver intended for frequency modulated continuous wave radar applications is presented here. A commercial E-band active multiplication chain is used to provide the required power and frequency band of the transceiver. All modules beyond E-band are solid-state discrete Schottky diodes based developed by ACST GmbH. The transceiver consists of a 135-160 GHz and a 270-320 GHz doublers to increase the frequency up to Y-band for the transmitter part. The receiver part consists of a 270-320 GHz sub-harmonic mixer pumped by the 135-160 GHz doubler. A D-band directional coupler distributes the power at 137.5 GHz to 152.5 GHz between the transmitter and receiver part. The transmitted power is higher than 20 mW in band and 8.5 dB average doubler side band noise figure is performed by the receiver.**

I. Introduction

Nowadays the market volumes for submm-wave sources and receivers are very limited. Moreover, specification requirements may vary from one particular application to another. Under these conditions, the use of discrete diode structures for frequency multipliers and mixers is of significant advantages in comparison to monolithically-integrated diode circuits, concerning flexibility and price. However, the implementation of discrete diodes approach becomes difficult beyond W band due to the size reduction as the frequency increases. Dedicated high frequency diodes structures and substrates are required to go up in frequency and provide the maximum performance of the chip. Discrete diodes approach has been successfully demonstrated up to 200 GHz using doublers in [1], [2] with equivalent performance provided by MMIC like in [3]. A 270-320 GHz discrete diodes based doubler and mixer are demonstrated by ACST in this work as part of the presented 275-305 GHz transceiver. These modules are combined together to define the transmitter and receiver part. The aim of this work is to provide as much power as possible from the transmitter part using discrete diodes approach and single chip modules. Additionally, it is of high interest to obtain as low noise as possible from the receiver. The maximization of the transmitted power and the minimization of the receiver noise improves the radar range equation of the transceiver [4]. A new type of diodes has been developed by ACST for high power applications. These diodes integrate a CVD diamond substrate to improve heat dissipation and have been implemented in the doublers of the transmitter part. Standard ACST mixer diodes of type 2MAF1.5 have been used in the mixer development. These discrete diodes are fabricated using ACSTs Film-Diode process in a similar way described in [5]. The discrete diodes approach allows both flexibility in the design and the assembly of diodes. On one hand, the same diodes properties can be used in different designs with different frequency range. On the other hand, different diodes properties can be used in the same design to enhance the performance at different frequencies. The use of proper discrete diodes structures and substrate chips have allowed to demonstrate a transceiver with more than 10 mW transmitted power and less than 9 dB average double side band (DBS) noise figure (NF) of the receiver between 275-305 GHz.

II. Transceiver Architecture

An image of the transceiver is shown in Fig. 1. The transceiver consists of an initial active multiplication chain (AMC) and a high power amplifier (HPA) commercially available. This AMC is able to multiply six times the initial signal and provide more than 250 mW output power from 68.7 GHz to 76.3 GHz. The transmitter part consists of a 135-160 GHz (D150) and a 270-320 GHz (D300) doublers completely developed by ACST [6]. The receiver part consists of a 270-320 GHz subharmonic mixer (SHM300) developed at ACST and a commercial 46 dB gain low noise amplifier (LNA).

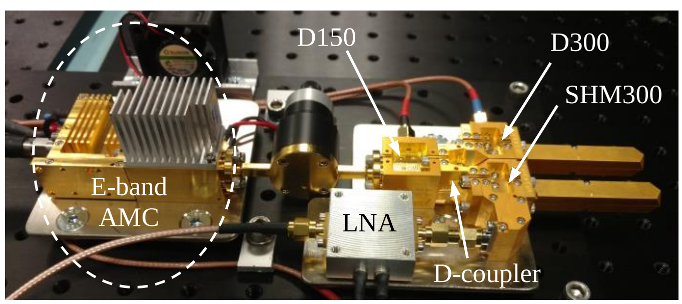

Fig. 1. Discrete Schottky diodes based 275-305 GHz transceiver developed by ACST.

The transmitter and receiver parts are integrated together using a dedicated D-band coupler (D-coupler) developed by ACST. The D-band coupler distributes the power provided by the 135-160 GHz doubler between the 270-320 GHz doubler and mixer. An E-band tuneable attenuator is placed between the 135-160 GHz doubler and the E-band AMC to calibrate the ensemble of the transceiver in the required frequency band. The transmitter and the receiver use a diagonal antenna each. A dedicated power supply unit (PSU) is included in the system to bias the different modules.

III. Diodes Technology & Modules

A. *Diodes Technology*

An illustrative image of ACSTs diamond-based varactor and film varistor Schottky diodes is shown in Fig. 1. The Schottky diode structure integrates a CVD diamond substrate (Fig. 1 left). The diamond substrate is physically connected to the anodes to more efficiently distribute the heat to the contact pads, used later to place the diode on the chip. The film diodes (Fig. 1. right) feature a film substrate as part of the fabrication process. Both diode structures are based on a quasi-vertical fabrication process [7].

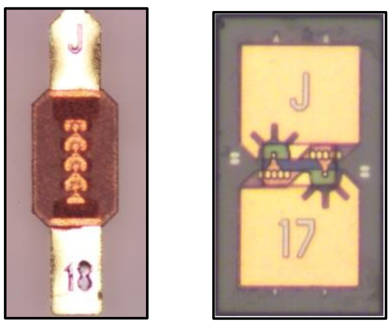

Fig. 2. Representative structures of diamond-based varactor (left) and film varistor (right) Schottky diodes developed by ACST.

B. *135-160 GHz Doubler*

Two discrete diamond diodes are placed in the chip in anti-series balanced configuration. The discrete diode features three Schottky anodes with -13.5 to -14 V breakdown voltage each. The bias is applied using a SMA connector with no more than -16 V required. A single chip is used in this multiplier based on the same architecture proposed in [8]. The mechanical design of the module features a WR12 and WR6.5 input and output waveguide flange, respectively.

C. *270-320 GHz Doubler*

Two discrete diamond diodes are placed in the chip in anti-series balanced configuration. The discrete diode features two Schottky anodes with -10 to -10.5 V breakdown voltage each. The bias is applied using a SMA connector with no more than -9 V required. A single chip is used in this multiplier based on the same architecture used in the D150. The mechanical design of the module features a WR6.5 and WR3.4 input and output waveguide flange, respectively.

D. *270-320 GHz Mixer*

A single discrete film diode is placed in the chip featuring two Schottky anodes in anti-parallel configuration, like in [9]. No bias is required for this mixer. A WR6.5 and WR3.4 input waveguides lead the local oscillator (LO) and the radiofrequency (RF) signals to the chip. The chip is also defined on film-substrate technology [5] and the architecture is based on [10]. The output intermediate frequency (IF) signal is extracted through a 50 Ohm SMA connector featuring an 18 GHz frequency band. The DSB noise figure of this mixer is lower than 6 dB and it requires only 2.1 mW LO input power along the frequency band to correctly work.

E. *D-band Coupler*

The D-band coupler is specially design to work in the frequency range of the developed transceiver. The mechanical design features a WR6.5 waveguide input and two WR6.5 outputs in parallel configuration. The internal waveguide lengths are defined to have similar electrical path of the D-band signal to the D300 and SHM300 modules. A -15 dB to -16 dB coupling factor between the input of the coupler and the output for the SHM300 is defined. Less than 0.5 dB transmission loss factor between the input of the coupler and the output for the D300 is defined.

IV. Results

A. *Transmitted Power*

The experimental setup is described in Fig. 1. A signal generator is used to provide the initial signal at 11.45-12.71 GHz. The signal is multiplied and amplified up to E-band and the high power multipliers developed in this work increase the signal up to Y-band. The antenna of the transmitter is replaced by a power meter PM4 in this case. The bias required by the AMC, multipliers and LNA is provided by a dedicated PSU. It is important to note that the bias of multipliers is fixed along the frequency band. The experimental transmitted power between 275-305 GHz is plotted in Fig. 3. The receiver part was working during the measurement of transmitted power.

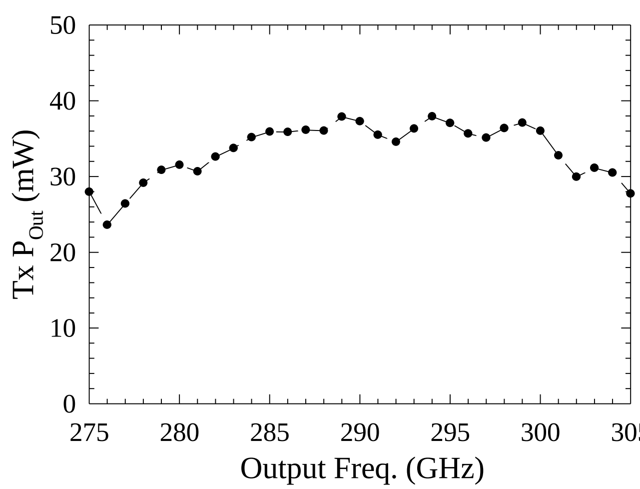

Fig. 3. Experimental transmitted power by the 275-305 GHz transceiver developed at ACST.

The transmitted power varies between 25 mW and 39 mW in the 275-305 GHz frequency range. It is important to note that this power is provided by single chip discrete diode based doublers. This power level is higher than the power provided by some authors using MMIC approach [5], [8] and the highest value reported using discrete Schottky diodes technology for doublers [6], [11]. Similar output power is obtained by JPL using MMIC Schottky technology [12]

B. Receiver Noise Figure

The experimental setup is shown in Fig. 1. The power delivered at D-band by the D150 doubler is split by the D-band coupler to properly provide the LO power to the SHM300 mixer. The calibration of the receiver part is achieved using a tunable attenuator between the E-band AMC and the D150 doubler. The D150 doubler is powerful enough to modify its output between 20-22 dBm and find the suitable output to correctly pump both the transmitter and the receiver parts. The LNA amplifies 46 dB the IF signal between 10 KHz and 200 MHz and perform ~1.9 dB noise figure. A diagonal antenna is used to receive the RF input signal. The noise figure of the receiver, while the transmitter is also transmitting, is plotted in Fig. 4. The noise figure has been obtained with the Y-factor method [13]. Liquid nitrogen has been used as cold load and a RF absorber at room temperature has been used as hot load. Each value of noise figure plotted in Fig. 4 is calculated from the Y-factor of the receiver obtained from 10 KHz to 200 MHz of the IF frequency range.

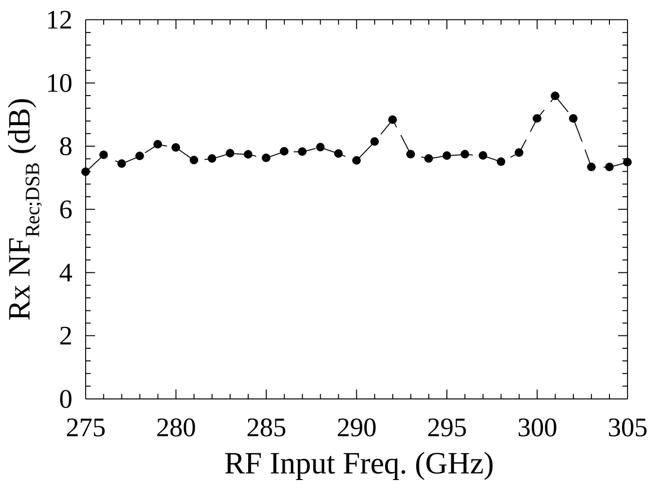

Fig. 4. Experimental double side band noise figure of the receiver part at 275-305 GHz.

The average DSB noise figure of the receiver part is ~8.5 dB in the 275-305 GHz band. The higher values at 294 GHz and 302 GHz are associated to a lack of LO power due to the standing waves between the mixer and the D-band coupler.

CONCLUSIONS

A discrete Schottky diode based 275-305 GHz transceiver for FMCW-Rada applications has been demonstrated with more than 20 mW transmitted power and 8.5 dB average DSB noise figure. A 39 mW peak value of transmitted power is provided by the transceiver system. The implementation of diamond diodes in the transmitter modules demonstrates high power handling capabilities to avoid power combining techniques. To authors knowledge, the obtained transmitted power is the highest value reported by a single chip 300 GHz source based on discrete Schottky diodes.

REFERENCES

[1] T. Waliwander. M. Fehilly and E. O'Brien. “An ultra-high efficiency high power Schottky varactor frequency doubler to 180–200 GHz”. In *Millimeter Waves (GSMM) & ESA Workshop on Millimetre-Wave Technology and Applications, 2016 Global Symposium on* (pp. 1-4). IEEE. June 2016.

[2] B. Thomas, H. Gibson, A. Walber, I. Oprea, O. Cojocari & T. Nahri. “Power-combining of 186-210 GHz frequency doublers and W-band power amplifiers with more than 100 mW peak output power”. *26th International Symposium on Space Terahertz Technology, Cambridge, MA,* 16-18 March, 2015.

[3] C. Viegas, H. Liu, J. Powell, H. Sanghera, A. Whimster, L. Donoghue, P.G. Huggard and B. Alderman. “A 180-GHz Schottky Diode Frequency Doubler With Counter-Rotated E-Fields to Provide In-Phase Power-Combining”. *IEEE Microwave and Wireless Components Letters*, 2018.

[4] S. W. Henriksen. „Radar-range equation”. *Proceedings of the IEEE, 63*, no. 5, pp.813-814. May, 1975.

[5] O. Cojocari, I. Oprea, H. Gibson and A. Walber. "Submm-wave multipliers by film-diode technology." In *Microwave Conference (EuMC), 2016 46th European*, pp. 337-340. IEEE, 2016.

[6] D. Moro-Melgar, O. Cojocari, I. Oprea. “High Power High Efficiency 270-320 GHz Source Based on Discrete Schottky Diodes”, In *Microwave Conference (EuMC), 2018 48th European*, (Submitted/Accepted). IEEE, 2018.

[7] O. Cojocari, C. Sydlo, H. L. Hartnagel, S. Biber, J. Schür, and L. P. Schmidt. "Schottky-structures for THz-applications based on quasi-vertical design-concept." In *International Symposium on Space Terahertz Technology, Göteborg, Sweden*. 2005.

[8] D. Jiangqiao, A. Maestrini, L. Gatilova, A. Cavanna, S. Shengcai and W. Wu. "High Efficiency and Wideband 300 GHz Frequency Doubler Based on Six Schottky Diodes." *Journal of Infrared, Millimeter, and Terahertz Waves* 38, no. 11, 1331-1341, 2017.

[9] I. Oprea, A. Walber, O. Cojocari, H. Gibson, R. Zimmermann and H. L. Hartnagel. "183 GHz mixer on InGaAs Schottky diodes." *Proc. ISSTT* (2010): 159-160.

[10] A. Maestrini, L. Gatilova, J. Treuttel, F. Yang, Y. Jin, A. Cavanna, D. Moro-Melgar, … & F. Dauplay. (2016, April). 1200GHz and 600GHz Schottky Receivers for JUICE-SWI. In *27th International Symposium on Space Terahertz Technology*, (April, 2016).

[11] C. Yao, M. Zhou and Y. Luo. “A High Power 320–356GHz Frequency Multipliers with Schottky Diodes”. *Chinese Journal of Electronics*, *25*(5), pp.986-990, 2016.

[12] J.V. Siles, K. B. Cooper, L. Choonsup, L. Robert, G. Chattopadhyay, & I. Mehdi. “Next Generation of Room Temperature Broadband Frequency Multiplied LO Sources with 10 times Higher Output Power in the 100 GHz-1.9 Thz Range. In *29th International Symposium on Space Terahertz Technology*, (March, 2018).

[13] A. R. Kerr. “Suggestions for revised definitions of noise quantities, including quantum effects”. *IEEE transactions on microwave theory and techniques*, vol. 47, no 3, p. 325-329, March 1999.