Single-Chip 135-160 GHz Doubler with more than 150 mW Output Power based on Discrete Schottky Diodes

D. Moro-Melgar[1*], O. Cojocari[1], I. Oprea[1], M. Rickes[1] and H. Hoefle[1]
[1]ACST GmbH, Hanau, 63457, Germany. (http://www.acst.de/)
*Contact: diego.moro-melgar@acst.de

***Abstract*— Single chip doubler based on novel diamond-based discrete Schottky diodes is presented here. CVD Diamond technology has been integrated by ACST GmbH in the discrete diode structure to implement in high power multipliers development. A single chip 135-160 GHz doubler able to handle up to 400 mW input power and provide more than 150 mW output power is reported. Conversion efficiency higher than 30 % is performed in band and up to 40% at some frequencies point.**

I. Introduction

Schottky diode technology has demonstrated during last decades to be a good option to achieve THz frequencies. This technology is particularly interesting because of the performance provided at room temperature. Schottky modules do not require any cryogenic systems to work and it makes them very compact and robust. These properties have encouraged the use of Schottky diodes in space-born applications like MIRO [1], HERSEL [2] and more recently in JUICE-SWI [3]. The THz modules proposed in the submillimeter wave instrument for JUICE is completely based on Schottky multipliers and mixers to cover the frequency range from 540-640 GHz and 1080-1280 GHz [4]. However, the power handling capabilities of Schottky technology at THz frequencies is the main limiting factor to provide higher power. The local oscillator power requirements of the 1.2 THz mixer in JUICE-SWI was address using power combining techniques at 135-160 GHz and 270-320 GHz multiplication stages [4]. There parallelization of multipliers [5] or/and chips [6] are the typical approaches proposed for power-combining applications. However, power-combining techniques increase both the complexity and the amount of resources implemented in every Schottky multiplier. Additionally, power combining usually requires the implementation of power splitters that increase the complexity of the design and fabrication costs. The interest of the JUICE-SWI frequency range and the demand of more powerful Schottky multipliers has motivated the work reported in this paper. ACST GmbH [7] has developed a new kind of Schottky diodes to address power handling capabilities of Schottky multipliers. The new Schottky diodes developed at ACST integrate CVD diamond in the structure. A 135-160 GHz doubler based on these novel diodes has been developed to handle at least twice the input power reported by other authors at similar frequencies [8], [9] while avoiding power combining techniques. We report in this paper a Schottky doubler able to provide even more power than the reported in [5] and [10] using power combining, and also a state-of-the-art efficiency comparable to MMIC-based doublers [10].

II. Doubler Design

An illustrative image of the diamond-based Schottky diode developed at ACST is presented in Fig. 1 (left side). The Schottky diode structure integrates a CVD diamond substrate. The diamond substrate is physically connected to the anodes to more efficiently distribute the heat to the contact pads used to place the diode on the chip. Two discrete diodes with three anodes each have been used in the 135-160 GHz doubler design. The design of the chip is based on the doublers used in SWI [4] and [11]. However, the MMIC design has been modified in this case to place two discrete diodes in antiparallel balance configuration. The chip architecture has been defined in AlN substrate to further improve thermal distribution of the heat generated in the diodes.

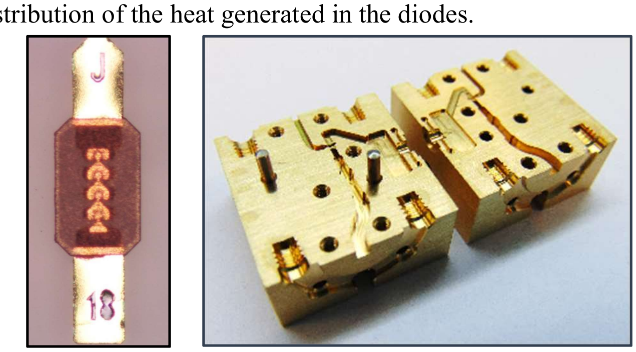

Fig. 1. Representative structure of diamond-based Schottky diodes developed by ACST (left). Mechanical part of the single chip 135-160 GHz doubler (right).

The mechanical design is shown in Fig. 1 right, and it is possible to notice a single waveguide module with WR12 input waveguide flange and WR6.5 output flange. The ACSTs varactor Schottky diamond-diodes used in this doubler have a breakdown voltage between -13.5 V and 14 V per anode. The doubler has been designed to optimally handle up to 400 mW (26 dBm) input power. The bias is provided via an SMA connector and the chip does not require more than -15 V bias.

III. Results

A. *Experimental Setup*

The experimental setup is shown in Fig. 2 and it consists of a signal generator used to provide an 8.125-10 GHz input signal to an 8x active multiplication chain (AMC). Then the 65-80 GHz signal provided by the AMC is used to pump the 135-160 GHz doubler. The output power of the doubler is measured using a VDI PM4 through the corresponding WR6.5 to WR10 waveguide transition taper. An E-band isolator is placed after the AMC to reduce the presence of standing waves and a standard E-band directional coupler is placed between the 135-160 GHz doubler and the isolator. A E8486A Keysight power sensor head is placed in the third port of the directional coupler to monitor the input power in the 135-160 GHz doubler.

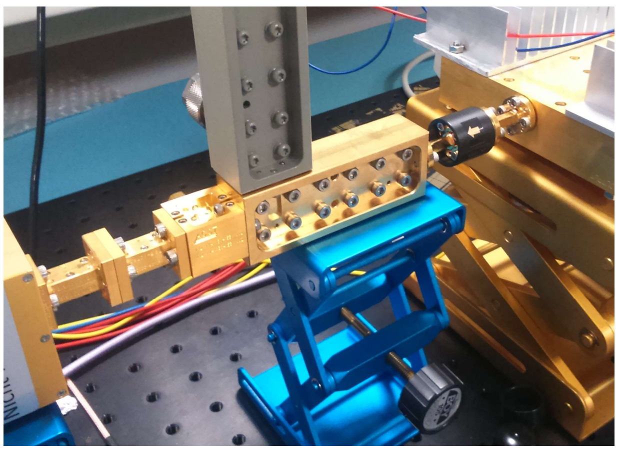

Fig. 2. Experimental setup to characterized the 135-160 GHz doubler developed at ACST.

B. *Experimental Results*

The experimental output power and efficiency in the 130-160 GHz frequency range are plotted in Fig. 3. The doubler has been characterized from 65-79.5 GHz with 24 dBm and 26 dBm fixed input power. The bias of the doubler has been optimized for every frequency in accordance with the input power. An output power between 19 dBm and 20 dBm is typically performed by this doubler with 24 dBm input power. More than 21 dBm is provided in band with 26 dBm input power and a peak value of 154 mW is achieved by this particular unit at 157 GHz. The efficiency at every frequency point shows a very flat performance of the doubler along the frequency band and also at different input power levels. More than 30 % efficiency is provided by the doubler in the specified frequency range and more than 35 % is achieved at certain frequencies. A peak efficiency of 38 % is performed by this unit at 140 GHz and 157 GHz with 24 dBm and 26 dBm input power, respectively.

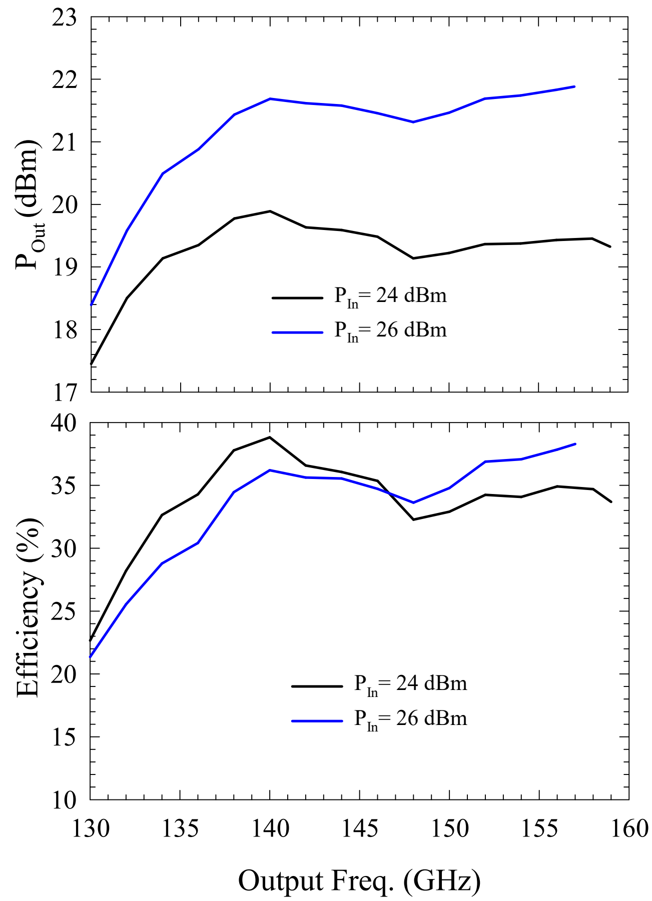

Fig. 3. Experimental output power (a) and efficiency (b) of the doubler from 130 to 160 GHz. The results are obtained with 24 dBm (black line) and 26 dBm (blue line) fixed input power.

The results obtained by the reported discrete-diode-based doubler are in agreement with the state-of-the-art efficiency achieved even by MMIC based doublers [8]. However, it is able to efficiently handle twice more power than other reported doublers at similar frequencies [8], [9]. Similar power handling capabilities with 25 % conversion efficiency have been previously reported by Dr. J. V. Siles at 170-200 GHz using Schottky MMIC chips [12]. These results indicate a state-of-the-art discrete-diode-based doubler in both power handling capabilities per chip and conversion efficiency.

Conclusions

A 135-160 GHz doubler based on a novel discrete Schottky diamond diodes is reported in this paper. The new type of diode developed at ACST GmbH has been implemented in the development of a single chip doubler able to efficiently handle up to 400 mW input power and provide more than 150 mW output power. The conversion efficiency is higher than 30 % in band and achieve up to 38 % in some frequency points. These are state-of-the-art results stablished by MMIC devices but using discrete diode technology.

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