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High Efficiency and Powerful 260–340 GHz Frequency Doublers based on Schottky Diodes

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Abstract

Terahertz (THz) high-resolution observations for astronomy can only be accomplished with the heterodyne receivers, in which the important local oscillator (LO) is necessary. Found in various THz instruments, GaAs Schottky diodes based frequency multipliers continue to be one of the most useful LOs. This paper briefly reviews two 300 GHz wideband doublers based on the LERMA-C2N Schottky process, as a single chip doubler with high efficiency and a power-combined dual-chip doubler with high power handling capacity. The single chip doubler featuring six diodes will be used as the LO for the 600 GHz sub-harmonic Schottky mixer, and the other dual-chip one would be served to pump a 600 GHz doubler of Submillimeter Wave Instrument on JUpiter ICy Moons Explorer (JUICE-SWI), which is planning to explore the Jupiter and its icy moon atmospheres.

1 Introduction

Terahertz (THz) high-resolution heterodyne receivers and spectrograph have provided abundant technical observations for astronomy, such as stellar origins and evolution, galactic structure as well as molecular clouds in the region of 0.1~10 THz. A lot of large THz exploration programs based on such heterodyne receivers have been implemented for better astronomical observations, including ALMA, Herschel, SOFIA and Antarctic Observatory. All solid-state frequency multipliers based on GaAs Schottky diodes have also been employed as a part of the key local oscillators (LOs) in these systems. Besides, the Schottky multipliers, which have advantages of wideband, high efficiency, continuous wave and spectrally pure signal, continue to be the preferred workable solution for LOs in submillimeter wave and THz band [1].

The current space program of Jupiter Icy Moons Explorer (JUICE) [2] led by the European Space Agency (ESA) will investigate the chemistry, meteorology and structure of Jupiter's stratosphere and troposphere, as well as the exospheres and surfaces of the icy moons. The onboard Submillimeter Wave Instrument (SWI) is the heterodyne receiver working on two bands of 530-625 GHz and 1080-1275 GHz to achieve science goals. The front-end of SWI will be developed and composed through 600 GHz and 1200 GHz sub-harmonic Schottky mixers pumped by two frequency multiplier chains at 300 GHz and 600 GHz.

In this paper, two 300 GHz frequency doublers developed at LERMA are momently reviewed, focusing mainly on the results and performance comparison. Both doublers based on LERMA-C2N Schottky process feature wideband, high efficiency and robust output power, which can be served as the prototypes for the last stage multiplier to pump 530-625 GHz mixer and the driving stage multiplier to input the 600 GHz doubler for pumping the 1080-1275 GHz mixer of JUICE-SWI, respectively.

2 Doublers Development

2.1 Single-Chip Doubler

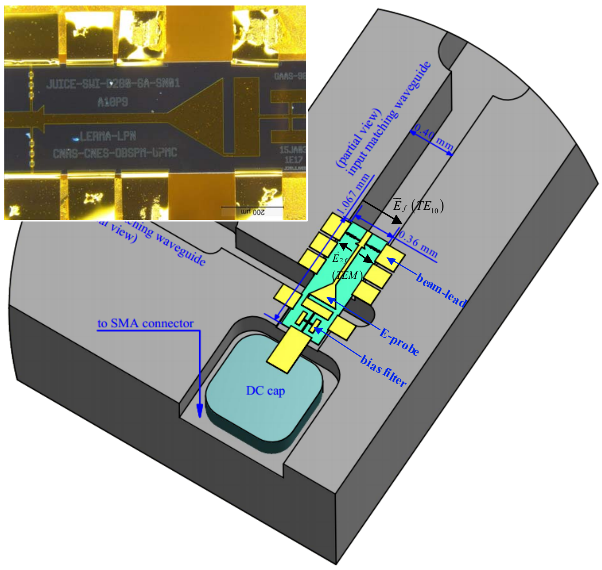

Figure 1. 3D view of the developed single-chip doubler, cited from [3].

Fig. 1 gives the compact 300 GHz frequency doubler, which has been successfully developed by the LERMA-C2N Schottky process [3]. This symmetrical chip features 6-anode, an *E*-plane triangular probe and an excellent RF choke filter integrated on a 5-μm-thick membrane. Six Schottky diodes can enhance the power handling quality of the single chip. This novel pseudo-lowpass filter can both improve the RF performance and reduce the chip size, hence, improving the global fabrication yield. Therefore, this chip with volume of 1.067 mm×0.36 mm×0.005 mm has a well moderate aspect ratio.

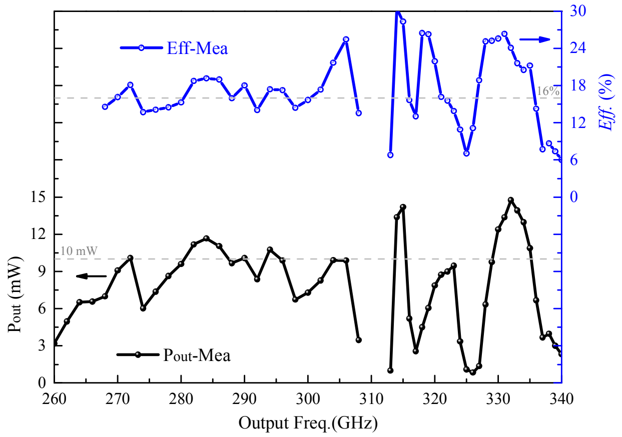

Figure 2. The measured single-chip doubler performance.

The *E*-plane split-waveguide block with only 10 mm long was manufactured by CNC-milling and then gold-plating in China. The actual performance was measured with the RPG source at Observatoire de Paris-LERMA, as shown in Fig. 2. In the low-frequency band of 266–300 GHz, the output power with ~10 mW and a stable conversion efficiency of level 16% have been achieved. While at the high frequencies of 300–340 GHz, several frequency points with very high efficiency (>20%) were delivered, which is a testament to the high breakdown voltage and the high quality for these devices. More than ~16% high efficiency across the available wideband of 266–336 GHz has been generally accomplished in this single chip doubler.

2.2 Power-Combined Doubler

In order to effectively drive the higher 600 GHz doubler for future pumping the 1200 GHz sub-harmonic mixer, it is necessary to further improve the power limit of this current single chip 300 GHz doubler. Thus a power-combined one based on *E*-plane 90°-hybrid and Y-junction was also developed, as shown in Fig. 3. A 5-branch waveguide hybrid coupler is first used to split input power with 3 dB and introduce a 90° relative phase shift. Then two symmetrical and independent single chip doublers will output two-way second harmonics with the same phase, due to the other 180° phase shift would also be introduced by two symmetric *E*-plane probes. A simple Y-junction power combiner is finally used to combine the output power through two channels in-phase.

A new block with 13 mm long based on the power-combined architecture has been fabricated and the working condition was examined too, as shown in Fig. 4. When the input power with level of 20~60 mW is pumping, the output power with about 4~9 mW and the efficiency of near 12~17% were delivered across the band of 262~312 GHz, which can indicate that this power-combined method with dual chips can work effectively. Although the results above 310 GHz is missing now, the quite high efficiency can still be expected. The efficiency from this power-combined doubler is almost agree with the single chip one pumped with a similar level of ~30 mW P_{in}. Referring to the single-chip doubler performance, this power-combined one will be speculated to deliver ~20 mW output power when driving by ~120 mW. The above discussion can demonstrate that the power combining function based on *E*-plane 90°-hybrid and Y-junction is nearly ideal with the bandwidth and efficiency as the single-chip version.

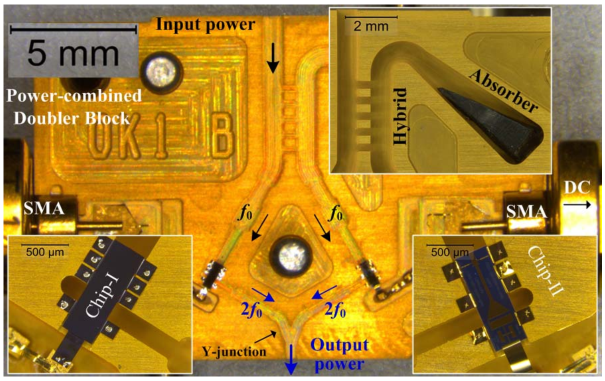

Figure 3. Images of the practical power-combined doubler split-block with completed installation, cited from [4].

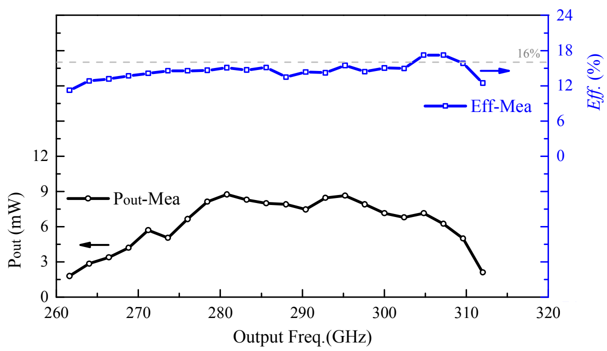

Figure 4. The initial measured results of this power-combined one.

3 Performance Comparison

Table I lists the performance comparison between such two doublers and state-of-the-art Schottky-based frequency multipliers working near 300 GHz. All the multipliers can be grossly divided into two groups to achieve the high power goal, as: (1) only using a single-chip circuit [5-9] and (2) adopting the power-combining way [10-14].

In the (1) doublers [5-7], the record-breaking efficiency with higher than 35% and high output power have been achieved mainly through sacrificing partial bandwidth. The high performance doubler provided by VDI [8] is also trade off the bandwidth and efficiency. Comparing with our previous one [9], this 6-anode doubler has obtained stronger power handling ability and much wider bandwidth, especially can work well above 300 GHz. Therefore, this single chip design with high efficiency of greater than 16% over the wideband of 24% will make the state-of-the-art 300 GHz doubler possible.

From (2) multipliers, it is clear that the power-combining solution is still the most efficient way for improving the power handling. The latest multipliers including doublers and triplers prepared by JPL have acquired record-breaking output power of 500 mW@180 GHz, 110 mW@220 GHz, 35 mW@330 GHz, 30 mW@550 GHz based on the on-chip power-combining techniques, in which the process and assembly of such a single thin membrane comprising of two or four multiplying circuits are rigorous [10]. Although the power-combined design in [14] has output high power, the fractional bandwidth (10%) is clearly compromised and the refined *E*-fields counter-rotated waveguide structure is also a limit for developing higher frequency doublers. Thus, our power-combined layout based on 90°-hybrid and Y-junction will acquire more than 20 mW with enough input power in wideband of 260~336 GHz as mentioned above, which perhaps can make the THz high power doubler possible.

4 Conclusion and Perspective

This paper has reviewed two 300 GHz frequency doubler prototypes based on LERMA-C2N Schottky process for the multiplier chain of JUICE-SWI. The single-chip doubler has delivered high efficiency with better than 16% across the wideband of 266–336 GHz (FBW of 24%) at room temperature. The reported power-combining method based on 90°-hybrid and Y-junction together makes an important step towards developing more powerful doublers at higher frequencies.

Table I

State-of-the-art frequency multipliers around 300 GHz (focusing mainly on the high output power)

	Ref.	*P_{in} (mW)*	*P_{out} (mW)*	*Efficiency*	*Band (3-dB FBW)*	*Technology*	*Comment*
Tripler (×3)	[10] by JPL	~400	10–30	6–9%	490–560 GHz (~13%)	On-chip power-combining	15-µm GaAs membrane
	[11] by JPL	50–200	~20 (26@318 GHz)	5~13%	265–330 GHz (22%)	Power-combining	5-µm GaAs membrane
Quadrupler (×2×2)	[12] by Virginia	175–325	~70 (79@160 GHz)	25% (Peak 30%)	144–172 GHz (13%)	×2×2 Quadrupler, quasi-vertical	15-µm silicon membrane
Doubler (×2)	[10] by JPL	~2 W	~400 (500@175 GHz)	20–25%	165–190 GHz (~14%)	On-chip power-combining	Four-way
	[13] by UMS	~80	~6	6–8%	177–202 GHz (12%)	Single waveguide power combining	Dual-chip
	[14] by RAL	~150	40–50	~25% (Peak 37%)	170–188 GHz (~10%)	Power-combining	Counter-rotated *E*-Fields
	[5] by ACST	80–100	20–35	20–35%	270–320 GHz (17%)	Quasi-vertical	Discrete
	[6] by FTL	200	40–90	20–45%	175–200 GHz (13%)	—	—
	[7] by Chalmers	~10	~3	20–35%	160–176 GHz (10%)	Surface channel etch	Full *E*-beam based
	[8] by VDI	20–50	—	6–8%	Full-band (40%)	Surface channel etch	Wideband
		—	—	Peak 18% @300GHz	~6%		D-series
	[9] by LERMA	~50	8–10	15–22%	274–307 GHz (10%)	Single-chip, 4 diodes	5-µm GaAs membrane
	Our works by LERMA [3, 4]	20–60	~10 (14.8@332 GHz)	~16% (Peak 30.5%)	266–336 GHz (>24%)	Single-chip, 6 diodes	5-µm GaAs membrane
		20–60	4–9	12–17%	262–312 GHz (~17%)	Power-combining (Hybrid+Y-junction)	Initial measured results
		~120	~20	~16%	260–336 GHz (~25%)		Expected results

Although the development of Schottky based multipliers has reached an unprecedented height, it is still of particular interest to pursue wider bandwidth, larger power and higher frequency to meet the future requirements of THz astronomical instruments.

5 Acknowledgements

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