Two 320 GHz Signal Sources Based on SiGe HBT Technology

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***Abstract*—Two 320 GHz signal sources, a push-push oscillator and an integrated oscillator-doubler, based on a 130 nm SiGe HBT technology are reported. Both signal sources adopt a common-base cross-coupled topology as an oscillator core. The doubler employs a G_m-boosting technique for improved conversion loss. The push-push oscillator exhibits an output power of -6.3 dBm and a phase noise of -96.6 dBc/Hz at 10 MHz offset. The output power and the phase noise of the integrated oscillator-doubler are 1.6 dBm and -94.7 dBc/Hz at 10 MHz offset, respectively. They dissipate dc power of 101.2 mW and 197.4 mW, leading to DC-to-RF efficiency of 0.2 % and 0.7 %, respectively.**

***Index Terms*—Heterojunction bipolar transistors (HBTs), multiplying circuits, oscillators, signal generators, silicon germanium.**

I. Introduction

The growing interests towards the THz band (0.3–3 THz) reflect its great potential for numerous applications including imaging and broadband communication. Among various approaches for THz system implementation, semiconductor-based on-chip THz systems would be highly favored for their practical advantages such as small volume, low cost, and compatibility with other electronic parts, especially when they are based on Si technologies. One major challenge in implementing THz systems is the development of high-power signal sources. When employed for transmitters, they will enable sufficient signal-to-noise ratio required at the receiving blocks. They will also be favored for local oscillators of heterodyne receivers as well as for frequency synthesizers, which will benefit from their high power as well. There have been recent reports on Si-based THz sources [1]–[4] from several groups, which adopt various techniques to achieve high output power at the high frequency band. The available output power may differ for different techniques, while their correlation is not clear at this moment. This work introduces two THz signal sources operating around 320 GHz based on a 130 nm SiGe HBT technology, a push-push oscillator and an integrated oscillator-doubler, the performances of which are characterized and compared.

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II. Circuit Design

The schematics of the signal sources proposed in this work are shown in Fig. 1: the push-push oscillator (a) and the integrated oscillator-doubler (b). The push-push oscillator employs a pair of common-base (CB) amplifiers for the core, which are cross-coupled through the collector and emitter. Compared to the conventional cross-coupled core based on the common-emitter (CE) amplifier, it is expected to provide oscillation at higher frequencies [5]. The oscillation frequency of the push-push oscillator is determined by the feedback components, $L_{F1,2}$ and $C_{F1,2}$, together with $L_{3,4}$ and the parasitic components of transistors $Q_{1,2}$. $L_{1,2}$ provide dc paths to the ground, not significantly affecting the operating frequency. To extract the second harmonic signal, the output of the push-push oscillator is taken at the common node of the oscillator core, where a bypass stub combined with microstrip lines $(L_5 - L_7)$ suppress the fundamental signal. It is noted that the high operation frequency enables a small size bypass stub that can be easily integrated on-chip. The design rules of the technology used in this work, however, does not allow a curved pattern, leading to a triangle-shaped bypass stub as opposed to the round radial stubs widely adopted for hybrid circuits. Simulation showed no significant difference in performance between these two different shaped stubs.

The integrated oscillator-doubler is composed of a 160 GHz fundamental-mode CB cross-coupled oscillator with a stacked output buffer and a 320 GHz doubler. To obtain high output power from an integrated oscillator-doubler, two conditions need to be satisfied: high output power from the oscillator and low loss from the doubler. One common approach to extract high power from the oscillator is to place a power amplifier after the oscillator, but it typically requires a large area and dc power dissipation. In this work, instead, a simple output buffer based on the CB topology was employed in a stacked manner. The CB topology is expected to provide high gain owing to its higher MAG (maximum available gain) compared to the CE topology, efficiently boosting the signal power streaming out of the oscillator. To achieve low loss from the doubler, a G_m-boosting topology, which employs the base-emitter cross-coupling in the core differential pair, was adopted [6]. The doubler output is taken at the collector common node of the pair, the fundamental component being suppressed by a bypass stub and microstrip lines $(L_{17} - L_{19})$ as was the case for the push-push oscillator. Additional microstrip lines

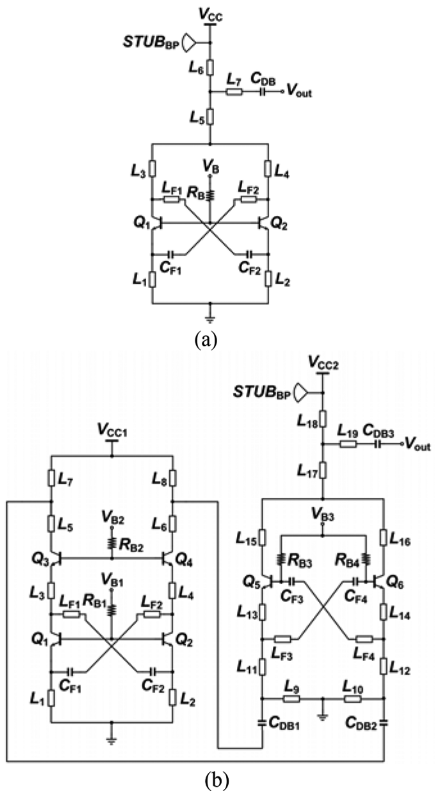


Fig. 1. Schematic of (a) 320 GHz push-push oscillator and (b) 320 GHz integrated oscillator-doubler, which is composed of a 160 GHz fundamental oscillator and a 320 GHz doubler.

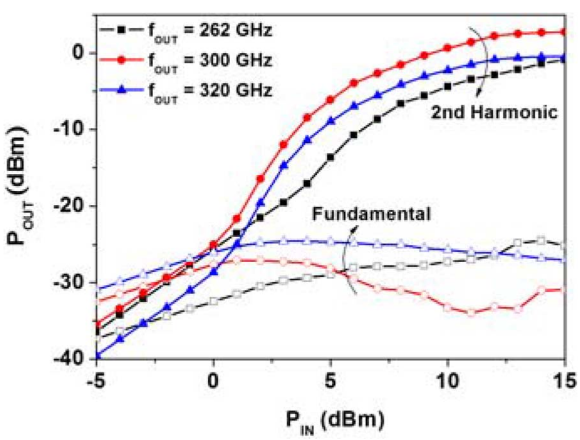


Fig. 2. Simulated output power of the 320 GHz G_m-boosted doubler, shown for both desired second harmonic and fundamental signals.

$(L_9 - L_{12}, L_{15} - L_{16})$ also serve for the input and output impedance matching. Simulated performance of the doubler is presented in Fig. 2, which exhibits a high output power level of around 0 dBm, with excellent fundamental-mode suppression and reasonable bandwidth when sufficient input power is available.

III. Measurement and Discussion

The push-push oscillator and the integrated oscillator- doubler were fabricated in IHP's 130 nm SG13G2 SiGe HBT technology that features peak $f_T/f_{\max}$ of 300/500 GHz. The die photos of the two signal sources are shown in Fig. 3(a) and (b). The output spectrum of the push-push oscillator is shown in Fig. 4(a), which was measured with an Agilent 4407B spectrum analyzer together with a Virginia Diodes WR 3.4 (220–325 GHz) external subharmonic mixer for down conversion. It is noted that an attenuator was inserted at the input of the mixer to keep the input power lower than its suggested limit. The oscillation frequency is measured to be 323.8 GHz. Shown as an inset of Fig. 4(a), is the uncalibrated output power measured through an Erickson PM4 power meter, which reads as 0.052 mW. With a measured total loss of 6.5 dB from the WR 3.4 probe and connecting waveguides, it converts to a calibrated output power of -6.3 dBm. The measured phase noise of the oscillator is shown in Fig. 4(b), indicating a value of -96.6 dBc/Hz at 10 MHz offset. For the integrated oscillator-doubler, the measured spectrum and phase noise are presented in Fig. 5(a) and (b), respectively. The measured output frequency is 321.6 GHz, and the phase noise is -94.7 dBc/Hz at 10 MHz. The uncalibrated output power, shown as the inset of Fig. 5(a), is 0.327 mW, which corresponds to a calibrated power of 1.6 dBm after loss compensation.

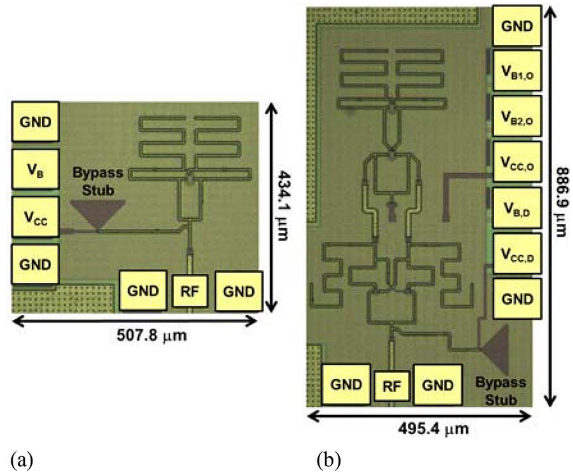
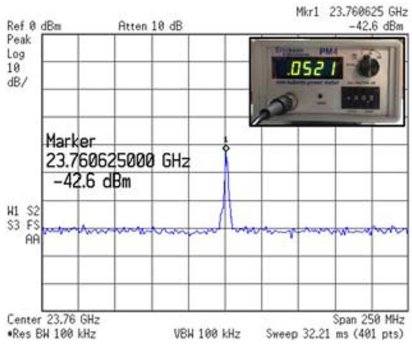
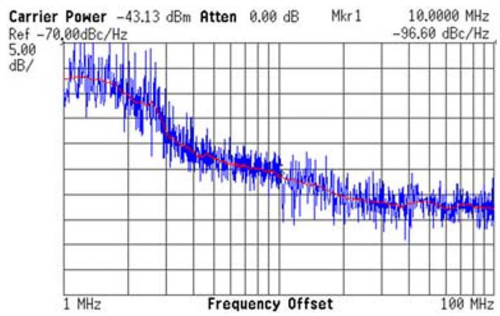


Fig. 3. Die photo of the fabricated circuits: (a) 320 GHz push-push oscillator (b) 320 GHz integrated oscillator-doubler. $V_{\rm CC} = 2.3$ V, $V_{\rm CC,O} = 4.3$ V, $V_{\rm CC,D} = 1.4$ V.

A comparison clearly shows that the output power achieved from the integrated oscillator-doubler is significantly higher than that from the push-push oscillator, by a factor of around 6 (or 7.8 dB). The push-push oscillator may be favored from its compact size (0.22 mm^2 versus 0.44 mm^2 of the oscillator-doubler) and lower dc power dissipation (101.2 mW versus 197.4 mW), but the DC-to-RF efficiency of the integrated oscillator-doubler is higher, which is 0.2 % and 0.7 % for the two circuits, respectively. The observed superior performance of the integrated oscillator-doubler compared to the stand-alone oscillator is consistent with the result obtained from [6], although generalization would need more accumulated data. Fig. 6 compares the signal sources developed in this work with other recently reported sources (without power combining) operating beyond 200 GHz in terms of output power. To the author's knowledge, the integrated oscillator-doubler source developed

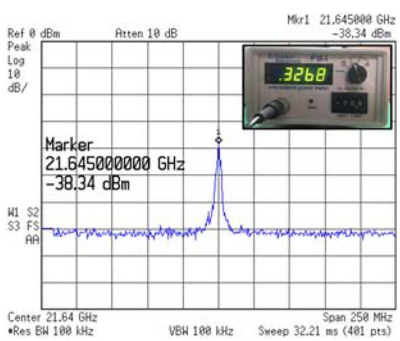


(a)

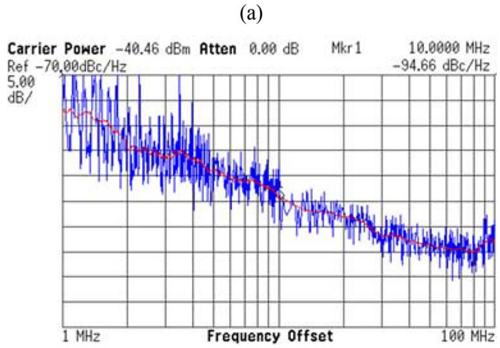


(b)

Fig. 4. Measured characteristics of the 320 GHz push-push oscillator: (a) Output spectrum, (b) Phase noise. Inset of (a) is the measured $P_{\rm OUT}$ (before calibration).



(a)



(b)

Fig. 5. Measured characteristics of the 320 GHz integrated oscillator-doubler: (a) Output spectrum, (b) Phase noise. Inset of (a) is the measured $P_{\rm OUT}$ (before calibration).

in this work exhibits the highest output power among Si-based single sources above 200 GHz. Some of these Si-based sources are listed in Table I for comparison.

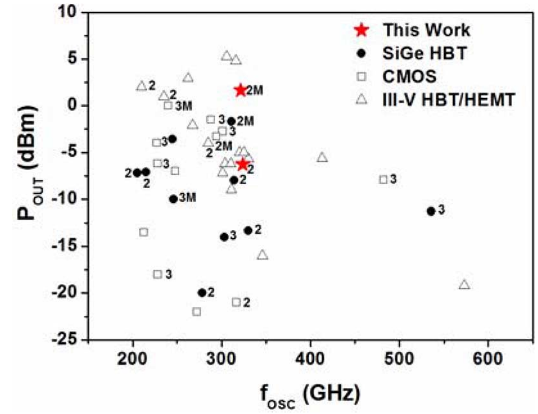


Fig. 6. Comparison of $P_{\rm OUT}$ of single sources operating above 200 GHz (power combining circuits excluded). The numbers next to symbols indicate the harmonic number and the letter "M" specifies multiplier integration.

TABLE I
COMPARISON WITH SELECTED SIGNAL SOURCES BASED ON SI TECHNOLOGIES

Ref	Tech.	Freq. (GHz)	Peak $P_{\rm OUT}$ (dBm)	Eff. (%)	P.N. @10 MHz (dBc/Hz)
[1]	65 nm CMOS	284-301	-2.7	2.8	-93
[2]	65 nm CMOS	482	-7.9	0.27	-76*
[3]	120 nm SiGe HBT	288-311 309-330	-1.7 -13.3	0.4 0.07	-101.6 -78
[4]	130 nm SiGe HBT	519-536	-11.3	0.05	-
This	130 nm SiGe HBT	321.6	1.6	0.7	-94.7
This	130 nm SiGe HBT	323.8	-6.3	0.2	-96.6

*Phase noise at 1 MHz offset

IV. CONCLUSION

Two signal sources operating near 320 GHz, a push-push oscillator and a fundamental oscillator integrated with a G_m-boosted doubler, have been demonstrated based on SiGe HBT technology. Output power of -6.3 and 1.6 dBm and phase noise of -96.6 and -94.7 dBc/Hz at 10 MHz offset were, respectively, obtained from the two fabricated sources. The developed circuits are expected to be well suited for various THz applications as high power signal sources.

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