A 245 GHz Transmitter in SiGe Technology

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***Abstract* — A 245 GHz transmitter for sensing applications has been realized, which consists of a push-push VCO with 1/64 frequency divider, a transformer- coupled one-stage power amplifier, and a frequency doubler. It is fabricated in 0.13µm SiGe:C BiCMOS technology with f_T/f_{max} of 300GHz/500GHz. The peak output power of the transmitter is 2 dBm. The 3-dB bandwidth reaches from 229 GHz to 251 GHz. The output power is 1 dBm at 245 GHz. The transmitter dissipates 0.29 W. Additionally, a test-circuit with an integrated two-stage power amplifier and a frequency doubler is presented, which reaches 1.4 dBm at 245 GHz and dissipates 0.19 W.**

***Index Terms* — SiGe , mm-wave circuits, 120 GHz, 245 GHz, VCO, power amplifier, frequency doubler, transmitter.**

I. Introduction

Silicon technology has made progress towards ever higher device cut-off frequencies, enabling the development of circuits in SiGe or even in CMOS for mm-wave applications beyond 100 GHz. SiGe BiCMOS technologies have become very attractive, as they allow high integration, low cost and combination with digital CMOS control circuits. The European project DOTFIVE developed novel process modules to push SiGe BiCMOS towards 500 GHz f_{max} [1]. This allows us to deploy SiGe BiCMOS technology for circuits operating in the frequency range above 200 GHz. Key circuits have been developed and demonstrated, e.g. [2].

An ISM frequency band at 245 GHz with 2 GHz bandwidth is available in Europe and US, which will be mainly used for industrial, scientific, and medical applications, including low-cost radar systems for consumer applications, imaging radar for security applications and bio-medical sensors. Recently, a sensor system for gas spectroscopy in the 210-270 GHz region has been reported, which uses frequency synthesis techniques in the region around 10 GHz, with frequency multiplication to 210–270 GHz [3]. Simpler and cheaper spectroscopic sensors, e.g. for environmental monitoring, which are based on integrated transmitters and receivers are now feasible in SiGe technology.

Implementing transmitters and receivers for applications in the 245 GHz range in SiGe BiCMOS requires an innovative architecture to fulfill all requirements concerning performance, low power dissipation, and low cost. The usage of transformers at mm-wave frequencies gives advantage to reduce the chip area far beyond what has been accomplished with transmission lines, see [4]. For the transmitter architecture, advantage can be obtained by applying frequency doubling techniques, as push-push oscillators, and frequency doublers, to improve the performance and to reduce the power dissipation.

This paper presents an integrated 245 GHz transmitter in 0.13µm BiCMOS SiGe technology with measured 1 dBm output power at 245 GHz, which includes 120 GHz internal voltage controlled push-push oscillator with 1/64 frequency divider, a transformer-coupled differential power amplifier, and a differential frequency doubler. The transmitter reveals 2 dBm peak output power within 3-dB bandwidth region of 229-251 GHz.

II. Technology

The circuits were fabricated in a new generation of IHPs 0.13µm SiGe BiCMOS technology which is currently under development [5]. The new high-speed HBT module was first described in [1]. It features f_T/ f_{max} values of 300 GHz/500 GHz, BV_{CEO} of 1.6 V, a current gain of 700, and CML ring oscillator gate delays of 2.0 ps. The back-end-of-line provides five fine-structured aluminum layers, two thick aluminum layers (2 µm and 3 µm thick), and MIM capacitors with 1.5 fF/µm^2.

III. Circuit Design

The transmitter consists of a 120 GHz push-push voltage controlled oscillator (VCO), 120 GHz differential one-stage power amplifier, and the differential frequency doubler, as shown in Fig. 1.

The oscillator core of the VCO consists of two sub-oscillators in common-collector topology. In the line to the supply voltage a transformer is placed, which transfers the 120 GHz signal to the differential cascode buffer with transformer-coupled single-ended output, which was used for characterization of a stand-alone VCO chip. This chip includes also a 1/64 frequency divider for the fundamental tone of the oscillator at 60 GHz for phase noise measurements. This 60 GHz signal is coupled to the 1/64 frequency divider via a second transformer.

The 120 GHz VCO, the 120 GHz PA, and the frequency doubler were designed and tested as stand-alone components with their on-chip baluns, as well as, in the

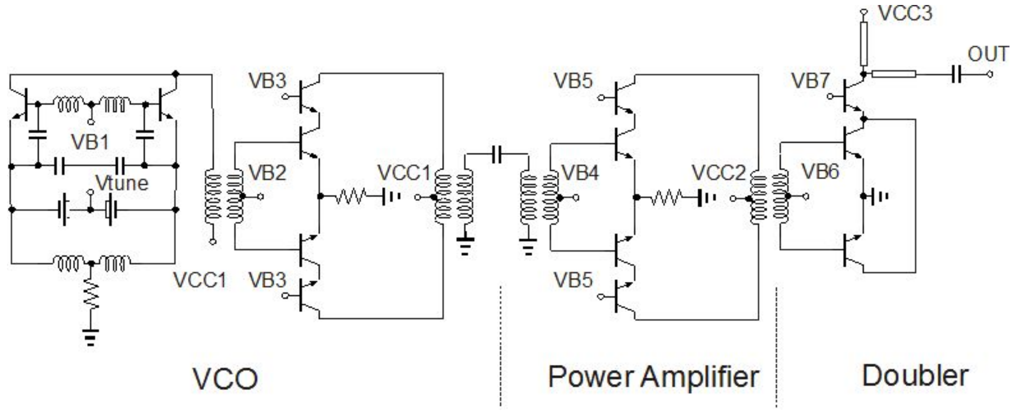

Fig. 1. Schematic of the 245 GHz transmitter including the 120 GHz VCO, the one-stage 120 GHz power amplifier, and the frequency doubler.

combinations VCO + PA, PA + doubler, and VCO + PA + doubler as fully integrated 245 GHz transmitter.

The power amplifer (PA) uses one stage, see Fig. 1, or two stages, see Fig. 2, with a differential-cascode, transformer-coupled topology [4]. The one-stage PA (PA1) draws 33 mA at 4 V supply voltage as well as the second stage of the two-stage PA (PA2). The transistors of the first stage of PA2 are scaled by factor 0.5, and the first stage draws correspondingly 20 mA at 4 V supply voltage.

The single-ended input of the PA is due to the measurements of stand-alone power amplifier chips.

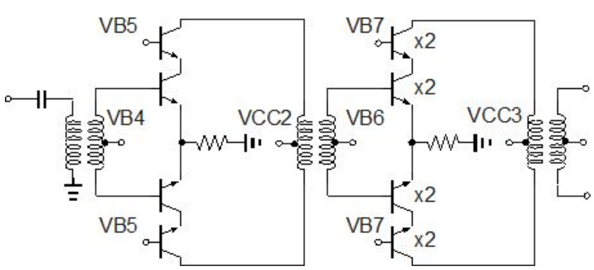

Fig. 2. Schematic of the two-stage power amplifier.

The differential 245 GHz frequency doubler consists of a differential transistor pair with a common collector connected to a cascode transistor as shown in Fig.1, [6].

We used the GoldenGate® RF integrated circuit simulator to design and optimize the transmitter. The subcircuits of the transmitter were designed using GoldenGate and ADS from Agilent. The transmission lines and transformers were simulated with a 2.5D planar EM-simulator (Momentum). For the transformers we applied S-parameter based models.

IV. Results and Discussion

Fig. 3 shows the micrograph of the fabricated transmitter chip. The die area is 0.71x0.45mm^2.

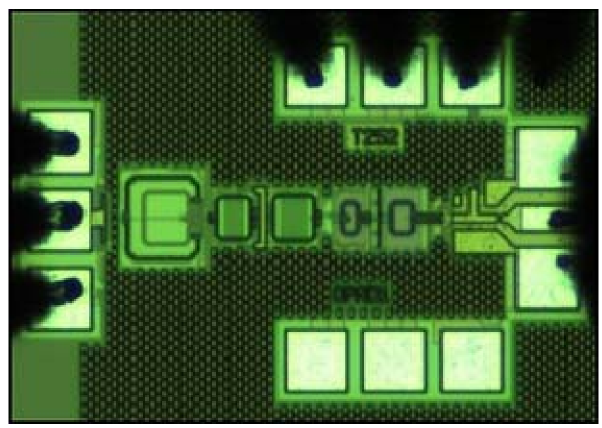

Fig. 3. 245 GHz transmitter chip micrograph.

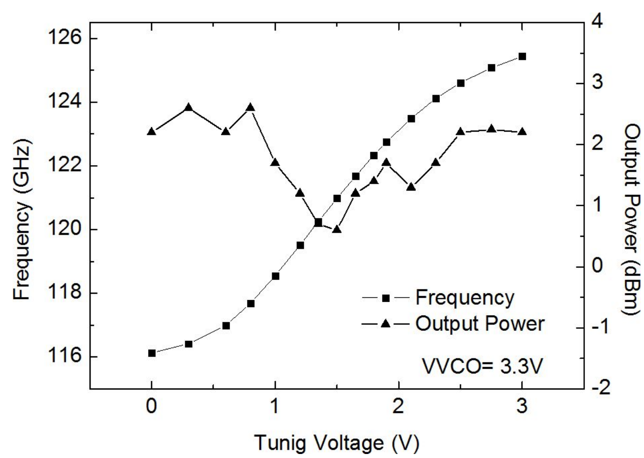

Fig. 4. 120 GHz VCO Frequency and output power versus tuning voltage.

Fig. 4 presents the output frequency of the VCO and the measured output power as function of the tune voltage. An output power of about 1.5 dBm was obtained at 122 GHz.

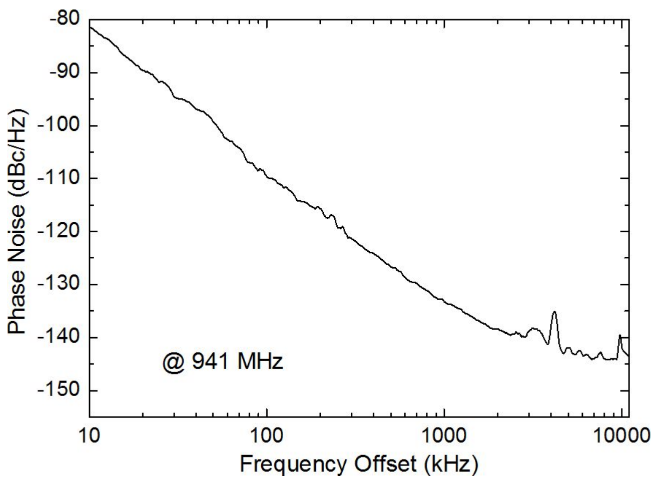

Fig. 5. Measured phase noise of the 120 GHz push-push oscillator with 1/64 frequency divider at a tune voltage 1.5 V.

Fig. 5 depicts the phase noise of the VCO with 1/64 divider as function of the offset frequency at 941 MHz revealing -133 dBc/Hz at 1 MHz offset, which allows to estimate the phase noise at 120.4 GHz better than –91 dBc/Hz at 1 MHz offset, and accordingly better than -85 dBc/Hz at the doubled frequency at the transmitter output.

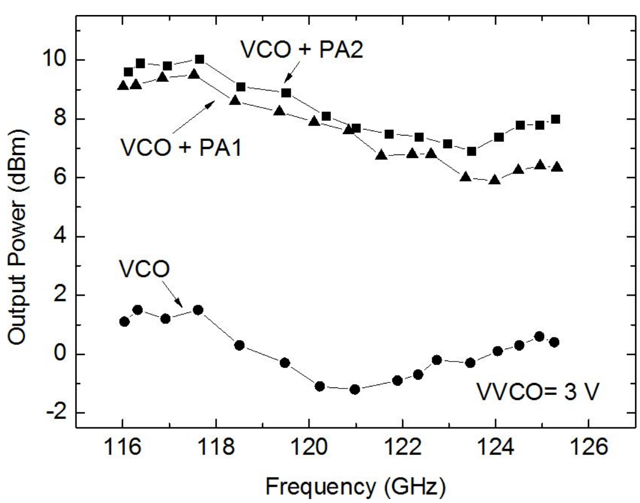

Fig. 6. Measured output power of the 120 GHz VCO, of the VCO combined with the power amplifier, 1-stage (PA1) and 2-stage (PA2), respectively.

Fig. 6 shows a frequency sweep of the output power for the 120 GHz VCO and the stand-alone chips VCO + 120 GHz PA measured with the ELVA power meter. The output power of VCO + PA reaches 8 dBm at 120 GHz for 3 V VCO supply voltage, indicating that the gain of the power amplifiers is equal or larger than 8 dB. The measured gain of the two-stage PA is 19 dB at 120 GHz. The one-stage PA on the test-chip showed stability problems at VCC= 4V during the S-parameter measurements of the stand-alone chip.

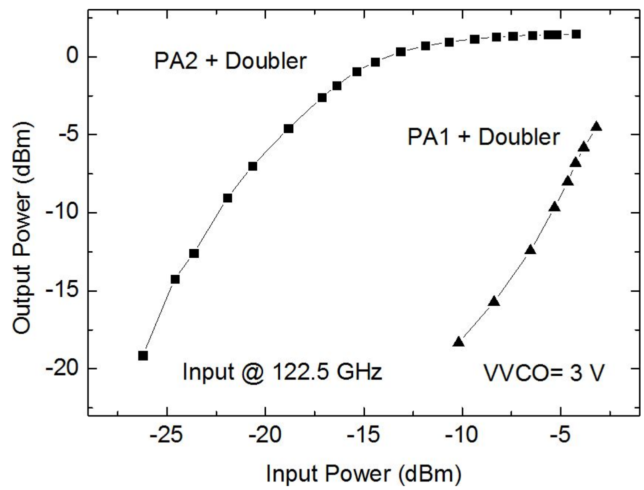

Fig. 7. Measured output power of the frequency doubler at 245 GHz with integrated 120 GHz power amplifier versus the input power at 122.5 GHz, one-stage power amplifier (PA1) and two-stage power amplifier (PA2) .

Fig. 7 depicts the output power of the frequency doubler with the 120 GHz PA as function of the input power at 122.5 GHz. The output power was measured using an Erickson calorimeter. For the two-stage PA (PA2) saturation of the output power is nearly reached at -10 dBm input power with 1 dBm at the output. The maximum output power is at 1.4 dBm. For the one-stage PA + doubler the measured curve is shifted to higher input power suggesting about 17 dB lower gain of PA1 compared to the PA2, probably due to stability problems of PA1caused by parasitic feedback.

Fig. 8 shows the output power of the transmitter, which consists of VCO + power amplifier + doubler, as function of the output frequency with VCC1 of the VCO at 3.3V, VCC2 = 4 V of the power amplifier, and VCC3 = 2.8 V of the doubler. The output power is nearly the same for both versions of the transmitter with PA1 and PA2, respectively, indicating stable conditions for both power amplifiers in combination with the VCO in correspondence with the results for the combination VCO + power amplifier, see Fig. 6. A peak output power of 2 dBm is obtained, which is to our knowledge a record value for a SiGe frequency source at the frequency range of 230-250 GHz.

TABLE I

COMPARISON OF SIGE MILLIMETER SOURCES

	SiGe f_T/f_{max} (GHz)	Bandwidth (GHz)	Circuit	Peak output power (dBm)	Power DC (W)	Chip Area (mm^2)
Öjefors [2]	250/380	215 - 240	3 stage PA+doubler	-3	0.430	1.3x0.47
		308 - 328	3 stage PA+doubler	-1	0.424	1.2x0.43
		317 - 328	x18 multiplier	-3	1.62	2.2x0.43
This work	300/500	229 - 251	VCO+ 1stage PA+doubler	2	0.29	0.71x0.45
		at 245	2 stage PA+doubler	1.4	0.19	0.53x0.41

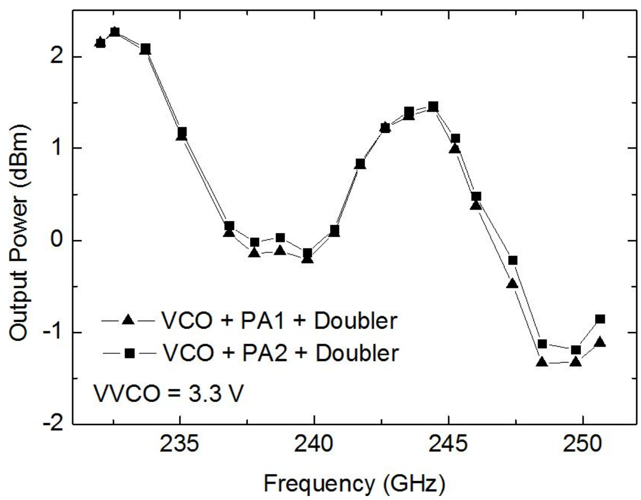

Fig. 8. Measured output power of the frequency doubler combined with the integrated 120 GHz and the power amplifier, 1-stage (PA1) and 2-stage (PA2), respectively.

Table I compares the results of this work with previous work [2]. Besides the higher output power of the presented transmitter, the DC power dissipation is essentially lower, and the chip area is smaller.

Table II summarizes the technical data of the transmitter.

V. CONCLUSION

A transmitter for imaging and sensing applications in the frequency range 229 GHz – 251 GHz has been presented consisting of a push-push VCO, power amplifier, and frequency doubler. It is fabricated in 0.13µm SiGe:C BiCMOS technology with f_T/f_{max} of 300GHz/500GHz. The transmitter reaches 2 dBm peak output power. PLL function can be implemented in this transmitter by integrating the tested 1/64 frequency divider.

TABLE II

SUMMARY OF TRANSMITTER PERFORMANCE

VCO: DC current	32 mA at 3.3 V
PA1: DC current	33 mA at 4 V
Doubler: DC current	19 mA at 2.8 V
Frequency range	229 GHz - 251 GHz
Output power	1 dBm at 245 GHz
Phase Noise	-85dBc/Hz at 1 MHz offset

ACKNOWLEDGEMENT

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