A 270 GHz Push-Push Oscillator in InP-DHBT-on-BiCMOS Technology

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Abstract — A 270-GHz reflection-type push-push oscillator is presented, realized using 0.8μm emitter InP-DHBTs. The InP DHBT-on-BiCMOS offers both InP HBT and BiCMOS technologies but in this case only the InP part is used. The transistors exhibit a maximum oscillation frequency f_{max} of 300 GHz. The oscillator delivers -9.5 dBm output power. DC consumption is only 31 mW from a 1.8 volts power supply, which corresponds to 0.4 % overall DC-to-RF efficiency.

Index Terms — InP double heterojunction bipolar transistor (DHBT), monolithic microwave integrated circuit (MMIC) oscillators, reflection oscillator, sub-terahertz (THz), transferred-substrate.

I. INTRODUCTION

Next-generation commercial and defense applications sub-terahertz and mm-wave integrated circuits are subject of intensive research [1]. The frequency range between 100 GHz and 1 THz offers large bandwidth for high-speed communications as well as improved performance of radar sensors and imaging applications due to the short wavelength. Frequency sources are key building blocks for these systems. Low phase noise, low power consumption and good DC-to-RF efficiency are important parameters in the design of such a signal generator or frequency source. Particularly, reducing the power consumption of RF blocks is a key challenge in many applications. The transmitter path is one of the most critical ones in terms of DC consumption. This is true not only for the power amplifier stage, but also for the signal source.

In the recent years, significant progress has been made in pushing oscillators to the sub-terahertz frequency range, using various semiconductor technologies. Mostly, these oscillators have been realized in push-push configuration [2], [3]. Few of them are fundamental frequency sources [5], [6], but they are relatively power-hungry and deliver less output power.

The major challenge in signal generation at such frequencies is that the active devices have to be operated close to their limits in terms of frequency and breakdown voltage. Additionally, the quality factor of the passive components degrades compared with lower frequencies. Recently, SiGe and CMOS circuits have been demonstrated operating at frequencies beyond 250 GHz [7], [8]. Nevertheless, due to the more relaxed geometrical dimension of compound semiconductors such as InP, the latter offer better power capabilities.

In this paper, a push-push oscillator using an InP TS-DHBT MMIC process is presented, which delivers -9.5 dBm output power at 270 GHz.

The paper is organized as follows: Sec. II briefly describes the technology and Sec. III explains push-push topology and circuit design. Section IV then presents the realized circuit and the measurement results, followed by a discussion, while Sec. V contains the Conclusions.

II. TECHNOLOGY

Fig. 1 shows the layer stack of the InP-DHBT-on-BiCMOS technology. In this figure, the available different metallization layers are shown and how the transmission lines and the inter connection is formed using these layers. The InP substrate is bonded on a fully processed SiGe BiCMOS wafer in a wafer-level process. After this, the InP substrate is etched away until only the epitaxial layers of the active circuit elements remain. This approach substantially reduces device parasitics, which increases the operating frequency without transistor downscaling, and enables improved heat-sinking through vias to the Silicon transfer-substrate. These two characteristics of the transferred substrate technology make it ideally suited for high-frequency power applications.
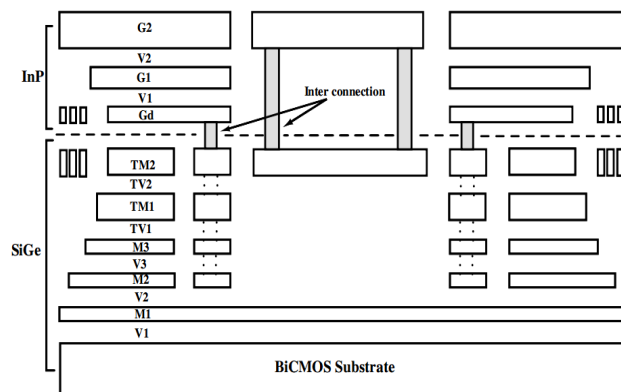

Fig.1 Layer stack of the of the InP TS-DHBT-on-BiCMOS environment.

The InP part offers three gold metal layers with 2μm, 1.5μm and 4.5μm thickness, respectively. It also includes MIM capacitors (dielectric material: SiNx). For further details of the MMIC process see [9].

III. PUSH-PUSH TOPOLOGY AND CIRCUIT DESIGN

The basic principle of push-push approach is to employ a symmetric topology with the spectral components at the fundamental frequency f_0 (and all odd harmonics) operated differentially, i.e., 180 degrees out-of-phase. These signals are combined so that the fundamental signal and the odd harmonics cancel, while the second harmonic $2f_0$ and even harmonics add constructively (see Fig. 2). The advantages of push-push oscillators are that they can provide relatively high mm-wave output power, exhibit low phase noise and allow to extend the output frequency close to the maximum oscillation frequency of the transistors or even beyond. It can also be used for locking the oscillator with a PLL loop operating at the fundamental frequency instead of the second harmonic [2], thus saving one divide-by-two stage.
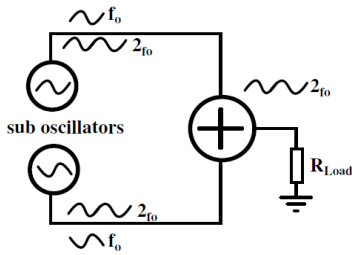

Fig. 2. The push-push principle.

In this paper, the proposed push-push oscillator was synthesized based on a reflection-type oscillator topology. The first consideration was to design one sub-oscillator in both the small-signal and large-signal case. The sub-oscillator circuit uses a single emitter-finger HBT with an emitter size of $0.8 \times 5 \ \mu m^2$ and f_t/f_{max} of 280/300 GHz. In order to keep power consumption as low as possible and to achieve the maximum oscillation frequency, the sub-circuit is designed as single transistor structure, with the HBT operated in common base configuration.
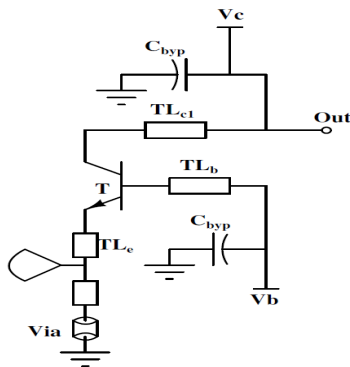

Fig. 3. Schematic of the sub-circuit

A transmission-line section TL_b is used to boost the negative impedance seen when looking into the emitter and collector of the transistor (T). (see Fig. 3) The transmission lines are all realized as thin-film microstrip geometries. The impedances formed by the lines TL_{c1} on the collector and the line TL_e on the emitter side cause the transistor (T) to become more unstable and define the steepness of the phase. To fulfill the oscillation condition, the phase of the reflection coefficient at the emitter port is set to zero by optimizing TL_{c1} and adding a resonator using a radial stub and a transmission line with a ground via. In this manner, one sub-oscillator configuration is completed.

In general, there are three possible ways to extract the second harmonic push-push output of the HBTs. It can be taken either from the base, emitter, or collector. The largest signal swing can be obtained at the collector by directly shorting the differential output, similar to the drain-connected HEMT push-push oscillators proposed by S. Kudszus [10]. A further advantage of directly shorting the fundamental output at the collector is that the large-signal swing at this node is reduced, enabling more robust operation in terms of base-collector breakdown [2].

The circuit diagram of the whole oscillator including its bias network is drawn in Fig. 4. The collector lines TL_{c2} and TL_{c3} are used for impedance matching and to maximize the output power. A harmonic balance analysis was performed to ensure the push-push oscillator functionality. The transmission lines were optimized using Agilent ADS, assisted by a 2.5D planar EM-simulator (Momentum). The circuit is designed so that it can operate without any resistive feedback or particular biasing topology, which would decrease efficiency.
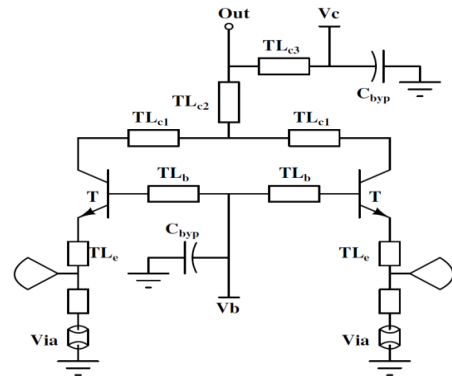

Fig. 4. Schematic of the reflection-type push-push oscillator.

IV. MEASURED SETUP AND PERFORMANCE

Fig. 5 shows a chip photograph of the realized oscillator circuit. The chip area is 0.9x0.7 mm².
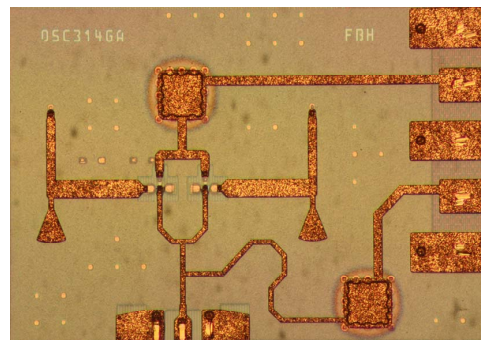

Fig. 5. Chip photo of the push-push oscillator.

The circuits were characterized on-wafer with the setup shown in Fig. 6. For RF, a ground-signal-ground (GSG) i325-S-GSG-50-BT (infinity) WR3.4 waveguide probe was used to extract the output signal and a 4-channel precision voltage source was employed for DC supply. Characterization of the signal source was performed in two major steps: First, the oscillation frequency was measured. For this purpose, a WR3.4 wave guide probe with a WR3.4 second-harmonic mixer (SHM) was connected to the output. The mixer shows 35 dB conversion loss at 280 GHz. The down-converted signal was measured using a FSUP signal source analyzer from R&S.
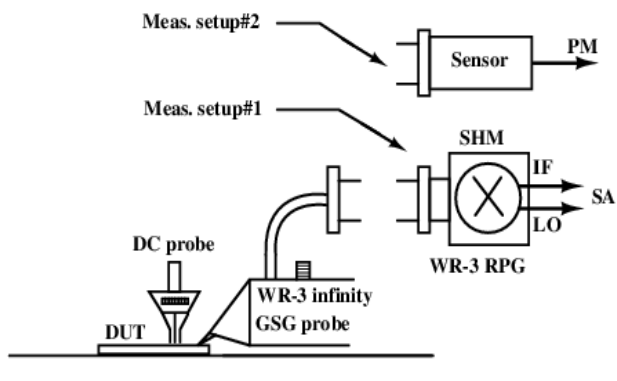

Fig. 6 Measurement setup.

Fig. 7 shows the raw data of the measured spectrum. Special care has to be taken in order to ensure that the correct spectral component is evaluated. This has been verified using the spectral position of individual harmonics and sideband signals.

Note that in Fig. 6 the spectrum power is lower than the actual power due to the losses (probe, waveguide and cable) in the test setup. These have been corrected using a known power source at the desired frequency. An accurate phase noise measurement using a spectrum analyzer at such high frequencies is very difficult, due to the impact of the down-conversion mixer and local oscillator purity. The temperature sensitivity of the signal source has not been determined.

The second step was to measure the peak power of the circuit. A WR3.4 GSG wave guide probe with a pitch of 50 μm was connected to a 90-degree WR10.1 bend, a WR3.4 taper and a WR3.4-to-WR10 taper, which connects to the input of a power sensor and an Ericson PM4 power meter. The insertion loss of the output probe is 5 dB as given by the vendor and the waveguide bend and tapers are estimated to contribute 3 dB insertion loss in the 270 GHz band. Accordingly, the measured output power values need to be corrected by +8 dB to account for the losses of probe, waveguide extension, and tapers. Thus, one arrives at an actual output power of -9.5 dBm. Here we have assumed that interface losses at the flanges etc. are negligible.
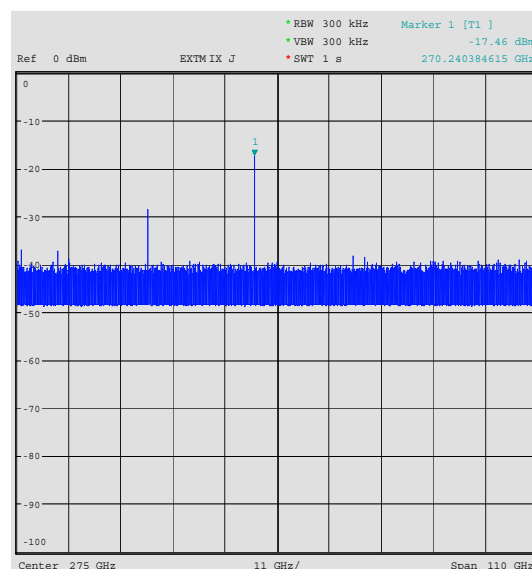

Fig. 7. Measured output power spectrum of the push-push oscillator.

Table I benchmarks the performance of our oscillator against other published push-push mm-waves sources beyond 250 GHz frequency on silicon and III-V technologies. As can be seen, our source offers good output power at low DC power consumption, though the f_T/f_{max} values are only moderate.

Also, one should note that the source presented in this paper is a reflection type push-push frequency source, which does not require any additional feedback resistors, coupling capacitors and bias network. The source tuning characteristic can be realized in a simple way employing a varactor. This will be implemented in a future design.

Further simulations indicate that by reducing resonator length and suitable devices scaling, this performance should be achievable up to THz frequencies. This proves that InP D-HBT based push-push oscillators are promising candidates for high-efficiency and high-power sources in the THz frequency range.

TABLE I.   STATE-OF-THE-ART COMPARISON OF SILICON AND III-V PUSH-PUSH SOURCES BEYOND 250 GHz

Ref./Year	[2]/2007	[3]/2007	[4]/2013	This work
Frequency [GHz]	285	278	309-330	270
Output Power [dBm]	-4	-20	-13.3	-9.5
DC Power [mW]	45	132	63	31
DC-to-RF Efficiency [%]	0.8	0.0076	0.07	0.4
Circuit Topology	Colpitts	Hartley	Colpitts	Reflection
ft/fmax [GHz]	405/335	200/275	300/400	280/300
Technology	500nm InP D-HBT	130nm SiGe	130nm SiGe	800nm InP D-HBT (on BiCMOS)

V. Conclusions

This paper presents a 270 GHz reflection-type push-push frequency source with low power consumption, based on an InP HBT MMIC process on BiCMOS technology. It delivers -9.5 dBm output power and achieves 0.4% overall DC-to-RF efficiency. This demonstrates the capabilities of the InP DHBT process, obtained with a relatively relaxed geometry node of 0.8μm.

Acknowledgment

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