High-Power Submicron InP D-HBT Push-Push Oscillators operating up to 215 GHz

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***Abstract* — High-performance and compact push-push oscillators operating up to 215 GHz were realized in a 0.5 µm emitter double-heterojunction InGaAs/InP HBT (D-HBT) technology with maximum oscillation frequency f_{max} of 220 GHz and Vbceo>5V. Two different push-push topologies, each based on a differential Collpitt oscillators topology, were investigated. Taking the push-push output from the virtual ground at the base-resonator resulted in -8 dBm output power at 184 GHz while about -15...-10 dBm was obtained at 215 GHz by reducing the electrical length of the base resonator. A high-power second harmonic signal of more then 0 dBm was obtained at 184 GHz by directly combining the differential output signal at the collector nodes of the Colpitts oscillator. These oscillators are to our knowledge the highest frequency three-terminal device based sources reported in literature.**

I. Introduction

Voltage controlled oscillators (VCO's) with low phase-noise are essential building blocks for next-generation mm-wave telecommunication and high-resolution radar and imaging systems. The push-push oscillator topology, in which the outputs of two oscillators coupled in anti-phase are combined to yield a strong 2^{nd} harmonic output signal is often used at the highest frequencies [1] as it allows to extend the useful frequency range of high Q-resonators and of available transistor technologies even beyond their maximum oscillation frequency. It also allows locking the oscillator in a PLL loop using static or dynamic divider operating at the fundamental frequency instead of at the second harmonic.

The advantages of push-push oscillators in terms of providing high mm-wave output power and low phase noise were demonstrated using different compound semiconductor technologies: 0.13µm GaAs PHEMT oscillators were reported up to 140 GHz [2], InP HBT oscillators up to 150 GHz [3-5] and SiGe HBT oscillators up to 150 GHz [6]. Recently, even a 114 GHz push-push oscillator was reported in 0.13 µm CMOS technology [7].

In this paper, we report 0.5 µm InP D-HBT push-push oscillators operating up to 215 GHz. We compare two different push-push topologies: one taking the output from the collector node of the bipolar transistors forming the differential oscillator core resulting in the highest available power and one taking the output at the base node enabling simultaneous fundamental output.

II. Circuit Design

The schematic diagrams of the two push-push topologies investigated in this paper are shown in Fig.1. The core of each oscillator is similar to the fixed frequency Colpitts oscillator we reported in [6], with two resonators at both base and emitter (LB and LE) for maximum performance [8] and with a bypassing capacitor CB to reduce phase-noise. For this configuration, the second harmonic push-push output can be obtained at the virtual differential ground, which in fact is only ground for odd harmonics. The push-push output can be taken at either the base, emitter or collector terminals of the HBT's. In the first topology we investigated, shown in Fig 1a , the push-push output is taken from the base node [3]. For this circuit a fundamental frequency output can still be taken from the collector, allowing simultaneous fundamental and second harmonic output. The second topology investigated is shown in Fig 1b. The differential output at the collector is directly shorted, enabling to increase the available second harmonic output power, similar to the drain-connected HEMT push-push oscillators proposed by S. Kudszus [2]. The collector current is provided through a shorted bias-T on the waveguide probe. One additional advantage of directly shorting the fundamental output at collector is that the large-signal swing at this node is now significantly reduced enabling more robust operation in terms of base-collector breakdown. As a drawback, there is no easy way to obtain a simultaneous fundamental output without disturbing the oscillator core.

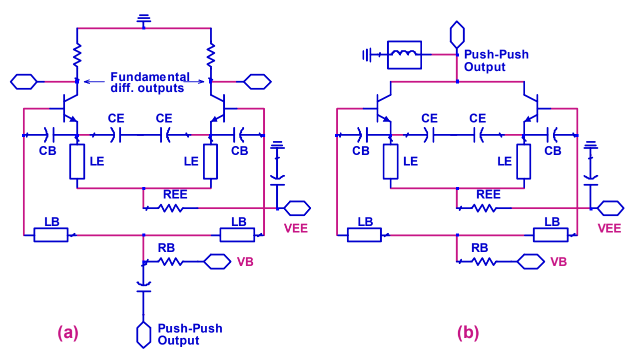

Fig.1: Simplified schematic diagram of the two push-push oscillator topologies investigated: (a) taking push-push from virtual ground at base resonator (b) directly shorting the fundamental output and collecting second harmonic at collector.

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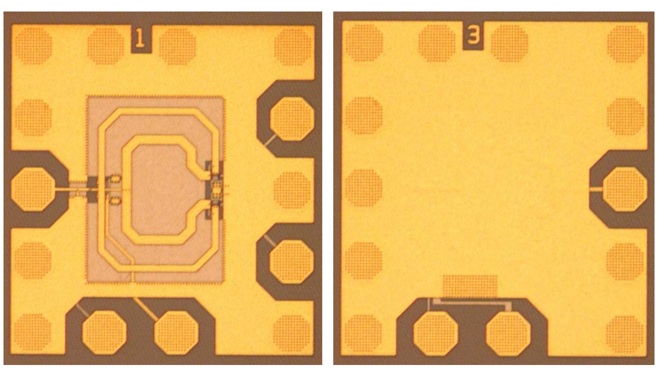
The push-push oscillators were fabricated in the all-optical lithography double-heterojunction InGaAs/InP HBT (D-HBT) process, developed at Lucent Technologies, Bell Labs [9]. For HBT's with 0.5 µm by 4 µm emitter dimensions, measured on the same wafer as the oscillators, a maximum cut-off frequency (f_T) of 320 GHz and a maximum oscillation frequency (f_{max}) of 280 GHz are obtained with a collector-to-emitter breakdown of up to 5V. However, to increase the output power and lower phase-noise, larger size emitter devices (0.5 µm by 10 µm) were used for the oscillator, resulting in a lower maximum oscillation frequency of 220 GHz due to the larger relative base resistance of long devices with elongated base layout.

Three different push-push oscillators were fabricated: two with the push-push output at base (VCO-1 & VCO-2), one with output at collector (VCO-3). Two different types of transmission lines were used: VCO-1, chip photograph shown in Fig. 2a, uses a thin-film microstrip line (TFMS) with the bottom metal as ground plane and the third metal as signal conductor, while VCO-2 and VCO-3 (Fig. 2b) use inverted microstrip line with the top metal acting as ground plane and bottom as signal conductor. Due to the lower effective dielectric constant of regular TFMS compared with its inverted variant, the electrical resonator length of VCO-1 is shorter, resulting in a slightly higher oscillation frequency.

A completely symmetric coplanar layout was adopted to reduce any parasitic fundamental output at the push-push. The total chip size is 460 by 420 µm^2.



(a) (b)

Fig. 2: Chip photograph of (a) VCO-1, 215 GHz push-push oscillator, single-ended push-push output is left, differential output at fundamental frequency right, resonator in thin-film microstrip, (b) VCO-3, high-power 184 GHz push-push oscillator, push-push output right, resonator in inverted thin-film microstrip.

III. CIRCUIT RESULTS

The downconverted output spectrum of VCO-2 measured at the single-ended push-push output using a GGB Industries WR-06 on-wafer waveguide probe and a Millitech 170-200 GHz downconversion mixer is shown in Fig. 3. This measurement is not yet corrected for the waveguide probe and mixer and cabling losses estimated to be about 14 dB in this frequency range. After correction, about –9dBm output power at 185 GHz is obtained for a total power consumption of 75 mW.

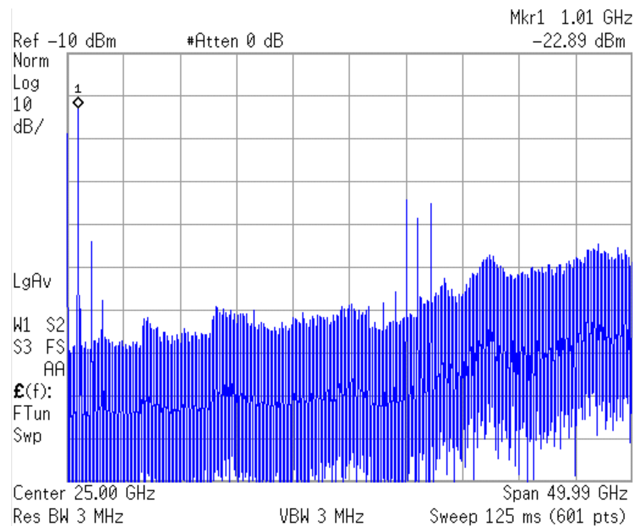


Fig. 3: Downconverted spectrum (LO=186.48 GHz) of VCO-2 at 2nd harmonic push-push output (VEE: -3V, total current: 25mA, not corrected for ~14 dB conversion loss, LSB)

A detail of the downconverted spectrum of VCO-2 biased at slightly higher supply voltage (VEE=-4V) is shown in Fig. 4. A clean output spectrum with a maximum output power of about –8 dBm is measured.

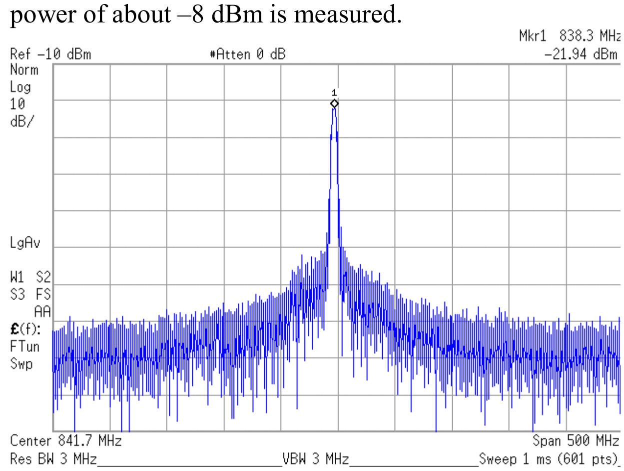


Fig. 4: Detail of downconverted spectrum (LO=186.48 GHz) of VCO-2 at 2nd harmonic push-push output (VEE: -4V, total current: 25mA, not corrected for ~14 dB conversion loss, LSB)

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Sligthly lower IF power is measured for VCO-1. As shown in Fig. 5, –31 dBm is measured at an IF frequency of 28.34 GHz. This mixing product is the upper sideband, so RF frequency is 215 GHz. The main reason for the lower output power is the frequency range of the available mixers. A mixer tuned for the 170-200 GHz range was used to perform this measurement, resulting in about 5-10 dB additional conversion loss compared with the previous measurements. Corrected output power for VCO-1 is estimated between –15 and –10 dBm.

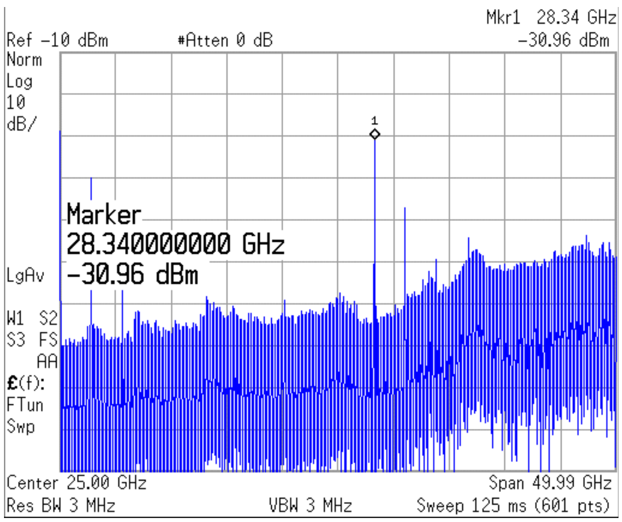

Fig. 5: Downconverted spectrum (LO=186.48 GHz) of VCO-1 at 2nd harmonic push-push output (VEE: -3V, total current: 20mA, not corrected for ~20 dB conversion loss, USB)

Finally, the down-converted spectrum of VCO-3 is shown in Fig. 6. Clearly much higher output power is obtained by taking the push-push output signal from the collector node. After correction close to 2 dBm is obtained at an RF frequency of 184 GHz.

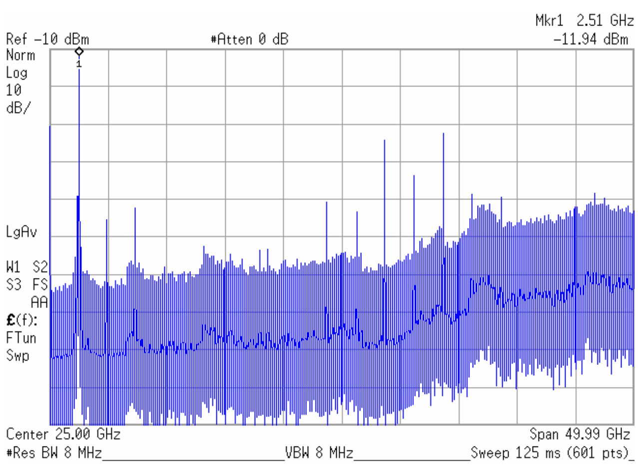

Fig. 6: Downconverted spectrum (LO=186.48 GHz) of VCO-3 at 2nd harmonic push-push output (VEE: -3V, total current: 20mA, not corrected for ~14 dB conversion loss, USB)

IV. Conclusions and Outlook

In this paper, we have reported InP D-HBT push-push oscillators operating at 185 and 215 GHz. The output power of the three oscillators is shown as a function of oscillation frequency and is compared with the best previously reported fundamental and push-push oscillators, fabricated in various semiconductor technologies. Our InP D-HBT push-push oscillators have clearly much higher output power then the fundamental InP HEMT oscillators reported in [10], the only other sources reported in this frequency range.

This performance was obtained in a scaled InP D-HBT process with 0.5x10 µm size emitters. Our simulations indicate that by moving to shorter emitter width devices, we should be able to extend this performance up to at least 300 GHz. As such, InP D-HBT based harmonic oscillators could be a prime candidate for delivering the first high-efficient sources in the submillimeterwave and even THz range.

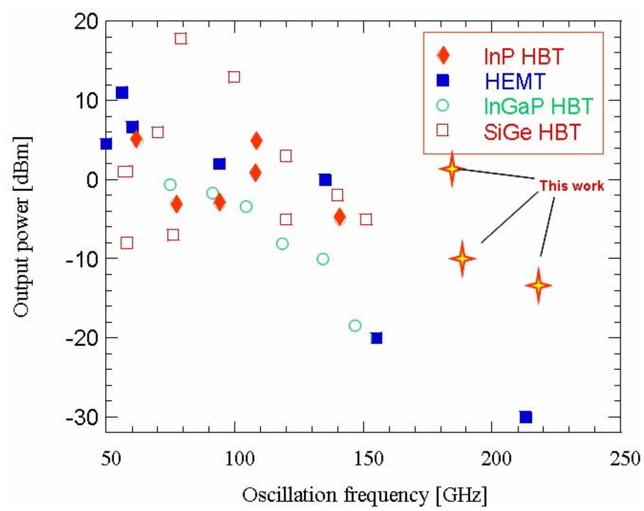

Fig 7: Output power versus frequency for published fundamental or push-push oscillators in various semiconductor technologies.

Acknowledgements

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