38 GHz Push-Push GaAs-HBT MMIC Oscillator

M. Schott, H. Kuhnert, F. Lenk, J. Hilsenbeck, J. Würfl, and W. Heinrich

Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH), D-12489 Berlin, Germany

Abstract **— Two differential coplanar MMIC HBT oscillators are presented, a fixed frequency and a VCO version. They provide single-ended output at the second harmonic at 38 GHz as well as differential output at 19 GHz. The oscillators show excellent phase noise performance, the fixed-frequency type reaches –95 dBc/Hz at the fundamental frequency and -89 dBc/Hz at the second harmonic, at 100 kHz offset.**

I. Introduction

The increasing demand for cost-efficient mm-wave systems for wireless communications and sensors has fueled the need for fully monolithic oscillators. Since on-chip resonator elements provide only low Q factors, transistors with low 1/f-noise and special concepts have to be applied in order to meet the requirements. Beyond this, many applications need a differential output in order to drive a mixer or a divider.

One of the methods to reach this goal is the push-push principle, a well-known concept for harmonic oscillator design [1,2,3,4]. In this type of oscillators, the first harmonic is cancelled out by combining two single-ended oscillators anti-phase, while the second harmonic, which is inherently apparent in any oscillator, is coupled out. This approach is particularly useful, if the frequency is such high that a fundamental oscillator is beyond the capabilities of the given MMIC process.

In this presentation, the push-push principle is applied not only for second-harmonic generation, but also to provide a differential output at the first harmonic frequency. While previous work dealt with non-monolithic concepts [2,3] or HEMT-based circuits [4], we apply the push-push strategy to coplanar MMICs with InGaP/GaAs-HBTs, which are known to combine low 1/f noise with mm-wave capabilities (e.g. [5]).

II. The Push-Push Principle

In a push- push oscillator, the two active devices of a symmetrical topology are operating in antiphase at the fundamental frequency. After adding the two signals at a certain point the fundamental cancels out while the first harmonic interferes constructively. Thus, separation of the two harmonics is accomplished using symmetry, which avoids space-consuming filter elements.

A push-push design has several advantages over single-ended versions. First of all, the usable frequency range of the transistors can be extended. This is because each device is running at one half of the desired output frequency. This can be exploited, for instance, to use transistors with larger size that, in general, exhibit lower 1/f noise due to the reduced current density [6]. Another important benefit of this downscaling in frequency is the increased loaded Q due to the higher available transistor gain.

Usually, a design concept is chosen that allows to separate the coupling network providing the 180° antiphase between the active devices from the combiner network, which performs the addition of the two output signals. For the combiner network, a Wilkinson coupler at the second harmonic is often preferred. Then, for the fundamental frequency, a suitable reflection coefficient must be realized by an additional phasing network in order to enforce stable oscillation.. The coupling network is usually of transmission-line type ensuring odd-mode oscillation only.

Our push-push oscillator is designed to operate at both the fundamental and the second harmonic frequency. Instead of an output combiner, the 50 Ω output is placed directly at the virtual ground of the phasing network. Fig. 1 presents the circuit schematics of the fixed-frequency version.

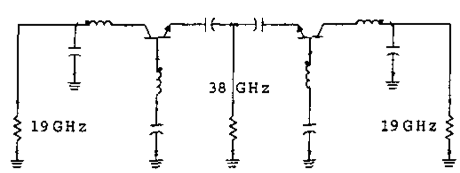

Fig. 1 Circuit schematics of the fixed-frequency HBT oscillator.

III. Technology

The MMICs are fabricated on the 4-inch InGaP/GaAs-HBT process line at the FBH (see [5]). The epitaxial HBT design consists of a 55 nm n-InGaAs graded emitter-contact layer, a 100 nm thick n-GaAs layer, a 30 nm n-InGaP emitter, and a 100 nm uniformly doped p-GaAs base layer (4×10^{19} cm^{-3}). The HBT structure is completed with a 1000 nm thick n-GaAs collector, a 20 nm n-GaInP etch stop layer and a 700 nm thick n^+-GaAs subcollector.

The process follows a double-mesa approach. He^+-implantation is employed to achieve isolation between devices. To suppress recombination at the surface of the GaAs base-layer a fully depleted GaInP legde technology is applied. The circuits are realized as coplanar MMICs, thus backside processing is not required. From S-parameter measurements, f_T and f_{max} were determined to be 38 and 109 GHz, respectively.

III. DESIGN APPROACH

Two push-push oscillators were designed according to the same principle, one in a fixed-frequency version (OSC), the other as voltage-controlled oscillator (VCO). This allows a comparison of the behaviour between both types. A further objective is to evaluate the phase-noise characteristics at the fundamental and second harmonic output ports. It is interesting to note in this context that the phase-noise simulations performed predict identical values for both frequencies.

Both oscillators are series-feedback circuits. A lumped series resonant circuit at the base operated above the first resonant frequency is used to make the transistor unstable. In comparison to a simple inductive element this provides a steeper slope of the phase. Simultaneously, the 50 Ω output impedance is shifted into low impedances at the collector. At the emitter, a simple capacitor fulfills the phasing requirement for oscillation. Having designed the VCO as single-ended version, one obtains the differential one by mirroring the circuit. In doing so one has to take care to prevent any even-mode oscillations for the fundamental frequency.

Electrical tuning of the VCO is done by replacing the emitter loading capacitors with reverse-biased varactors, formed by base-collector transistor junctions.

Fig. 2 presents a chip photograph of the VCO. Coplanar lines with 50 μm ground-to-ground spacing are used. The varactor is located in the center. The two HBTs are positioned as close to the varactor as possible since phase-noise simulations indicate degradation with increasing line length between HBTs and varactor. The two prober pads for the differential output can be seen in the upper part of the layout in Fig. 2.

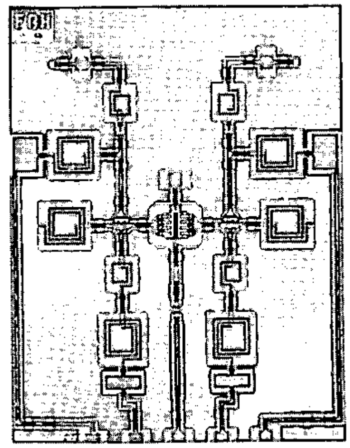

Fig. 2 Chip photo of the 19/38 GHz VCO (chip size 1.6 x 2 mm^2).

IV. MEASUREMENT RESULTS

The differential output ports are on-wafer connected to 50 Ω resistors via airbridges. For measurements at these outputs, the airbridges can be removed. Otherwise, this preloading guarantees a maximum of symmetry in the circuit.

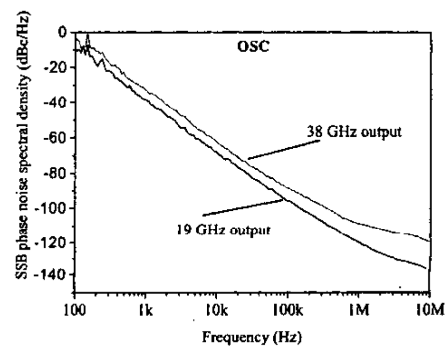

Fig. 3 Fixed-frequency oscillator (OSC): SSB phase noise against offset frequency for fundamental 19 GHz output port and 38 GHz output port, I_C=2x15mA.

In a first step, the fundamental harmonic output was measured with regard to phase noise, power, and frequency. Afterwards one airbridge was lifted, which allows investigations at the corresponding port. Fig. 3 presents the SSB phase-noise behaviour at the fundamental and second-harmonic output of the fixed-frequency type. At 100 kHz offset, -96 dBc/Hz at the 19 GHz and -89 dBc/Hz at the 38 GHz port are achieved. Output power is -5 dBm and -25 dBm, respectively. The bias point was chosen for best phase- noise performance. Note that the data at fundamental frequency refers to one of the two differential ports. This means that after suitable combining the output power should be doubled and the phase noise be reduced [1].

For the VCO version (see Fig. 4), we find slightly higher values than in the fixed-frequency case. A phase noise of -86 dBc/Hz at the fundamental and -81 dBc/Hz at the second harmonic are measured (both at 100 kHz offset). The varactor voltage was set to V_D=5V in this case.

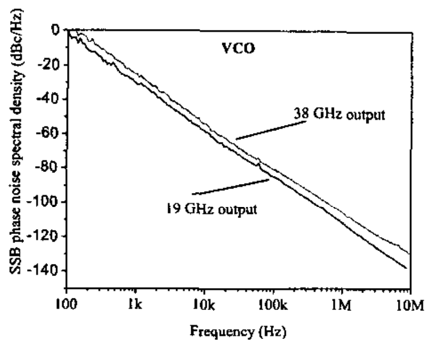

Fig. 4 VCO: SSB phase noise at fundamental 19 GHz output port and at second-harmonic 38 GHz port, I_C=2x22.5mA, V_D=5V.

In Fig. 5, the observed time signal of the differential outputs is plotted. The measurements were performed by using a two-channel sampling oscilloscope (Tektronix 11801A) and carefully calibrating both signal paths with regard to electrical length. Odd-mode oscillating behaviour is clearly to be seen.

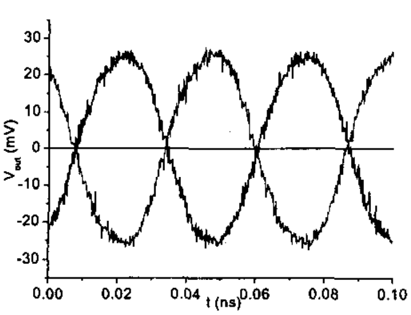

Fig. 5 VCO: Time signal at the differential ports.

During tuning measurements of the VCO, the collector-to-emitter voltage is kept constant while the collector current showed only a weak dependence on varactor voltage variation. In Fig. 6, the measured VCO data is shown. The fundamental 19 GHz output ports are left untouched. For varactor voltages between 4 V and 10 V, the output power behaves relatively flat within a 5 dB range, associated with good phase noise characteristics in the -80 dBc range.

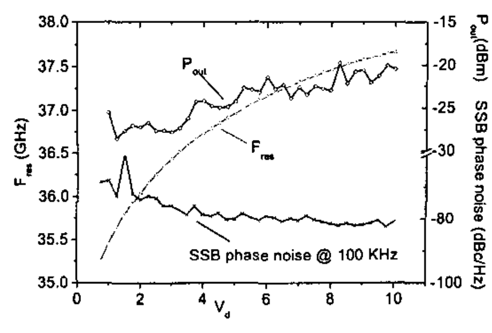

Fig. 6 VCO at 38 GHz port: Tuning characteristic, output power, and phase-noise against tuning voltage (bias point as in Fig. 4).

The same measurement is repeated for the differential output and plotted in Fig. 7. The chart shows a wide usable frequency range of more than 1 GHz for varactor voltages between 1 V and 10 V. The output power deviation from the maximum rating is well within an acceptable 2 dB range. SSB phase noise at 100 kHz tends to improve with higher voltages as expected due to increasing varactor Q.

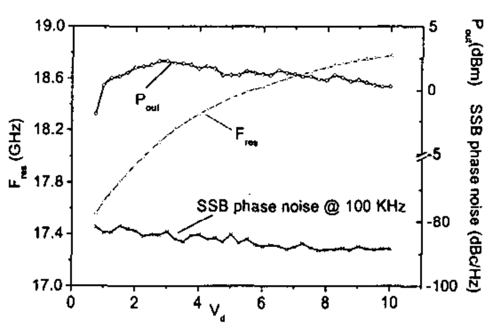

Fig. 7 Data of Fig. 6 at 19 GHz port

V. Discussion

The phase noise behavior achieved is better than that of single-ended counterparts (see [5]). This was checked additionally by comparison to single-ended oscillators on the same wafer. We expect a further improvement at the fundamental frequency when combining the two signals of the differential output properly. According to theory [1], coupling of 2 otherwise identical oscillators gives a phase-noise reduction by a factor of 2. Briefly speaking, this is due to the fact that the noise does not increase as strong as the signal, assuming uncorrelated noise sources in both oscillators.

For the second harmonic, situation is not as clear. Our commercial simulator predicts the same phase noise as for one port of the fundamental output, but this does not appear to be realistic. Measurements show a phase noise degradation of 6 dB from 19 GHz to 38 GHz for the fixed frequency type and of 5 dB for the VCO. These values are close to the 6 dB, which is the usual degradation one expects after a frequency multiplication by two.

VI. Conclusions

Differential GaAs-HBT oscillators are realized as fully monolithic coplanar integrated circuits. The fundamental output at 19 GHz is differential, which facilitates feeding of dividers in PLL applications. The 38 GHz port is single-ended. The measured phase-noise values prove the advantages of the coupled-oscillator concept. So far, output power at the second harmonic is relatively low. This is to be improved by a proper redesign reducing the output power at the fundamental and thus increasing efficiency for the second harmonic.

References

[1] H. C. Chang, X. Cao, U. K. Mishra, R. A. York, "Phase Noise in Coupled Oscillators: Theory and Experiment," *IEEE Transactions on Microwave Theory and Techniques,* vol. 45, no. 5, May 1997.

[2] F. X. Sinnesbichler, H. Geltinger, G. R. Olbrich, "A 38-GHz Push-Push Oscillator Based on 25-GHz f_T BJT's," *IEEE Microwave and Guided Wave Letters*, vol. 9, no. 4, pp. 151-153, April 1999.

[3] A. M. Pavio, M. A. Smith, "A 20-40-GHz Push-Push Dielectric Resonator Oscillator;" *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-33, no. 12, December 1985.

[4] S. Kudszus, W. H. Haydl, A. Tessmann, W. Bronner, M. Schlechtweg,"Push-Push Oscillators for 94 and 140 GHz Applications Using Standard Pseudomorphic GaAs HEMTs," *2001 IEEE MTT-S Int. Microwave Symposium Digest*, vol. 3, pp. 1571-1574, May 2001.

[5] H. Kuhnert, F. Lenk, J. Hilsenbeck, J. Würfl, and W. Heinrich, "Low Phase-Noise GaInP/GaAs-HBT MMIC Oscillators up to 36 GHz," *2001 IEEE MTT-S Int. Microwave Symposium Digest*, vol. 3, pp. 1551-1554, May 2001.

[6] P. Heymann, M. Rudolph, R. Doerner, and F. Lenk, "Modeling of low-frequency noise in GaInP/GaAs hetero-bipolar transistors," *2001 IEEE Int. Microw. Symp. Digest*, vol. 3 pp. 1967-1970.