SUBHARMONICALLY INJECTION LOCKED 94 GHz MMIC HEMT OSCILLATOR USING COPLANAR TECHNOLOGY

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ABSTRACT

A coplanar subharmonically injection locked VCO for 94 GHz with a tuning range of 4.5 GHz was developed, using 0.15 μm AlGaAs/InGaAs/GaAs PM-HEMTs. A phase noise of -71 dBc/Hz at 1 MHz offset from the carrier was measured for the unlocked VCO. Using 3rd subharmonic injection locking, a phase noise of -106 dBc/Hz at 1 MHz offset (-91 dBc/Hz at 100 KHz offset) for the locked VCO with a locking range of 1 GHz was achieved.

I. INTRODUCTION

The use of MMICs for millimeter-wave applications offers a great potential for low cost fabrication of high performance subsystems. Radar front-ends in coplanar technology using PM-HEMTs were recently presented [1]. For complete submodules, the integration of the millimeter-wave signal source is a key issue. Especially when using PM-HEMTs, the performance of free running oscillators [2] is strongly limited by the 1/f-noise. It is thus necessary to stabilize the signal source. Different concepts were realized in the past. In addition to phase locking [3] and frequency multiplying techniques [4], injection locking is an interesting alternative [5], even for W-band applications. No additional components such as frequency dividers and phase comparators for a PLL or RF filters and amplifiers for the multiplier are needed. Subharmonically injection locked oscillator MMICs have been reported up to V-band in the past [6-8]. In this work we report results covering the 94 GHz W-band range. Linear and non-linear simulations using HP-MDS were performed using our in-house models for passive structures [9] and active devices [10]. The presented voltage controlled oscillator (VCO) was realized in coplanar technology using a 0.15 μm T-gate PM-HEMT process and can therefore be easily integrated in our existing radar subsystems.

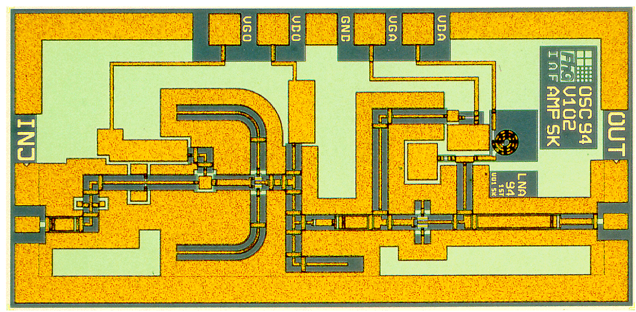

Fig. 1: Chip photo of the oscillator with buffer amplifier (chip size: 1×2 mm^2).

II. OSCILLATOR CIRCUIT

The oscillator MMIC, shown in Fig. 1, comprises the oscillator circuit and a one stage buffer amplifier to ensure isolation of the output port of the chip to the oscillator circuit. The schematic diagram of the oscillator circuit is depicted in Fig. 2. The active element of the

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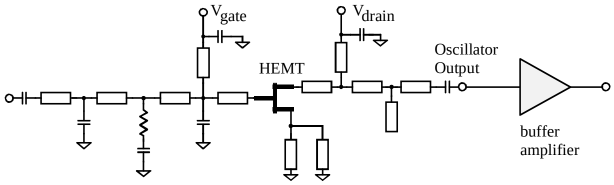

Fig. 2: Schematic of the MMIC VCO

VCO is a 0.15 µm PM-HEMT with a gate width of 2×20 µm in common source configuration. To obtain a negative resistance at the gate, series feedback in the source path of the transistor is used. Therefore, the source is grounded via a 70 Ω transmission line of 420 µm length.

The resonance circuit is formed by a 50 Ω transmission line at the gate, the intrinsic capacitances C_{gs} and C_{gd} of the transistor and the transmission lines at the source of the transistor. The transmission line at the gate is RF-shorted via an MIM capacitor of 350 fF, which is used to supply the gate bias and to inject the subharmonic locking signal into the resonator loop.

To obtain broadband matching at the injection port (see Fig. 3) for the 3^{rd} to the 5^{th} subharmonic frequency, it was necessary to design a lossy filter structure which introduces some attenuation for the injection signal. As an alternative, a low loss narrow band matching network at only one subharmonic frequency may be used.

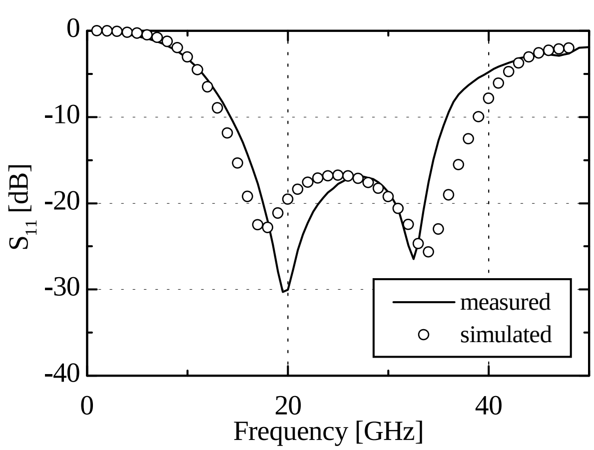

Fig. 3: Matching at the injection port.

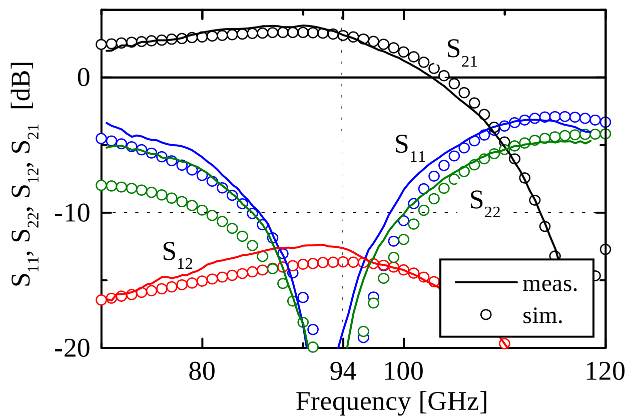

Fig. 4: Matching and gain of the buffer amplifier.

The major purpose of the buffer amplifier is to ensure proper matching of the oscillator output and isolation to the output port of the MMIC. Therefore, a small one stage reactively matched design, using a 0.15 µm PM-HEMT with a gate width of 2×30 µm, was designed. Short transmission lines at the source of the transistor are used for stability and broadband matching. An isolation of more than 12 dB and a matching at the input and output port of the amplifier better than 18 dB was achieved. The performance of the buffer amplifier is shown in Fig. 4.

III. VCO Performance

Frequency control of the oscillator is possible by sweeping the gate voltage. A tuning range of 4.5 GHz with the center frequency at 94 GHz for a voltage sweep from -0.4 V to 0.6 V was measured. A semiconductor parameter analyzer was used for the bias supply of the oscillator MMIC. A maximum output power of 2 dBm was measured using a power meter in combination with a W-band power sensor. The tuning characteristic and the spectrum of the oscillator signal was monitored on a spectrum analyzer using a harmonic mixer. A typical tuning characteristic of an oscillator MMIC is shown in Fig. 5.

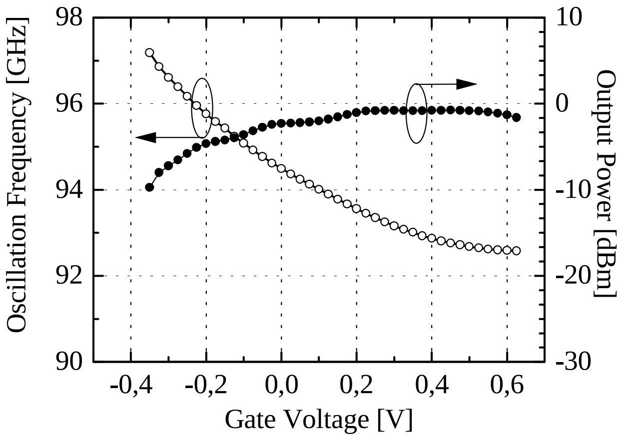

Fig. 5: Tuning characteristic of the VCO (V_{drain}=3.0 V at the oscillator).

IV. LOCKING CHARACTERISTICS

Applying an input signal at the injection port, the output spectrum can be locked by transmission-type injection locking. The locking range for the subharmonic signals is depicted in Fig. 6. A locking range of 1 GHz is achieved for the third subharmonic with 12 dBm input power. For subharmonic factors of four and five, the maximum locking range decreases to 270 MHz and 190 MHz, respectively. The spectra of the locked and the unlocked oscillator are shown in Fig. 7.

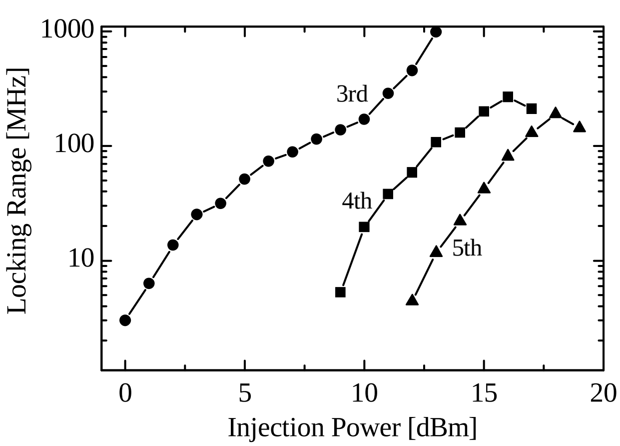

Fig. 6 : Locking range for 3rd, 4th and 5th subharmonic.

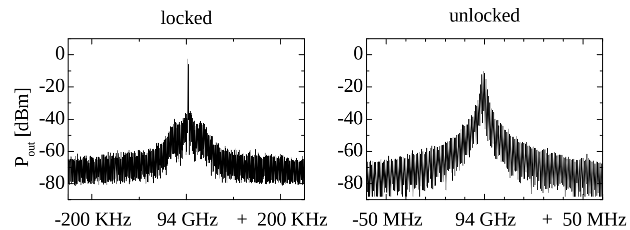

Fig. 7: Spectra of the locked and the unlocked oscillator.

The phase noise performance of the locked oscillator is strongly dependent on the purity of the injection signal and the input power level. The phase noise measurements depicted in Fig. 8 were performed using an HP 3605A synthesizer and an HP power amplifier as a locking source.

The phase noise of the free running oscillator was -71 dBc/Hz at 1 MHz offset from the carrier. The phase noise of the locked oscillator was reduced to -91 dBc/Hz at 100 KHz offset from the carrier by injection locking with the third subharmonic with the synthesizer/amplifier source.

In Fig. 9, the phase noise of the locked oscillator MMIC is shown for different power

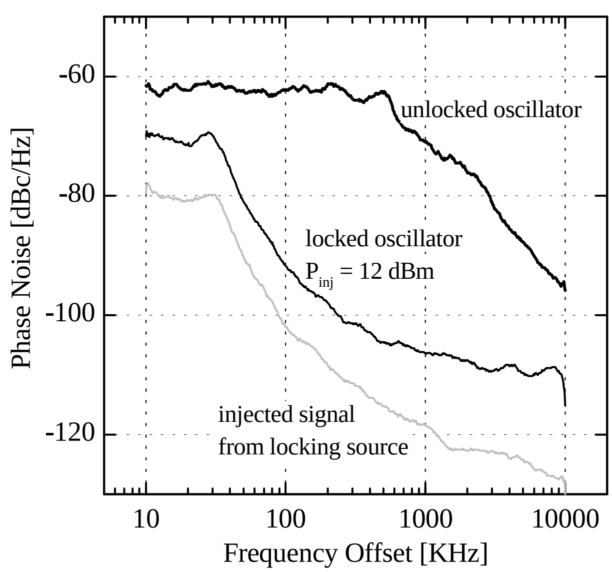

Fig. 8: Phase noise measurement of the VCO MMIC with the 3rd subharmonic as injection signal (V_{gate}=0 V, V_{drain}=3.0 V at the oscillator).

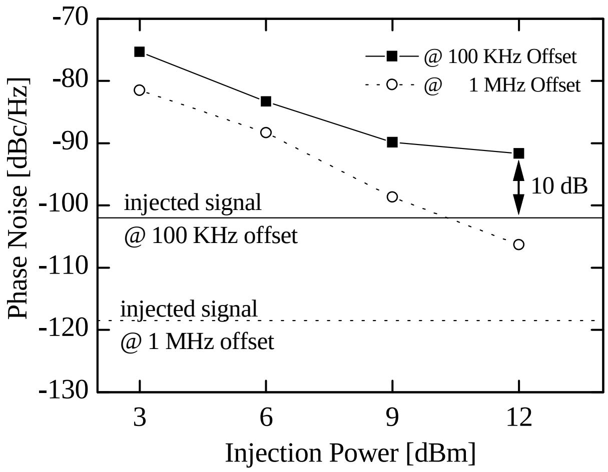

Fig. 9: Phase noise of the locked oscillator as a function of the input power at the third subharmonic.

levels of the injection signal. The difference between the phase noise of the injected signal of the locking source and the locked oscillator can be reduced with increasing injection power to 10 dB and 12.5 dB for the third and fourth subharmonic, respectively. These results correspond to the phase noise degradation versus the subharmonic factor of 20 dB/decade found for frequency multipliers and injection locked oscillators [11].

CONCLUSION

A 94 GHz W-band subharmonically injection locked oscillator MMIC based on PM-HEMT technology was designed and fabricated. The MMIC consists of a VCO with injection port and a buffer amplifier. The capability of injection locking and the wide tuning range make this oscillator highly suitable for system integration in radar applications.

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