80 GHz MMIC HEMT VCO

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***Abstract*—In this letter, a monolithic voltage-controlled oscillator (VCO) operating in the 77.5–83.5 GHz range is presented. InP HEMTs are used for both the active device and varactor. The VCO demonstrated a tuning range of 6 GHz and an output power better than 12.5 dBm in the entire tuning range.**

***Index Terms*—MMIC oscillators, MODFETs.**

I. INTRODUCTION

OSCILLATORS are important components in microwave systems. Increasingly, these systems operate at millimeter range wavelengths where there are few available commercial sources. For example, automotive radar systems operate in 76–77 GHz range, next generation high-speed fiber optics systems will operate up to 80 Gb/s, and imaging systems are being developed at 94 GHz.

Oscillators utilizing bipolar or HBT transistors have exceptionally low phase noise and good DC-RF efficiency, but have had limited applications above 70 GHz [1], [2]. Push–push configuration will double the frequency range, but at the price of more complex system [3].

Alternatively, FET or HEMT oscillators can operate at much higher frequencies and are typically used in 70–200 GHz range [4], [5]. A HEMT voltage-controlled oscillator (VCO) for automotive applications has been reported [4]. It demonstrated tuning range of 2 GHz and an output power of 7 dBm. At 100 GHz, a cascode HEMT oscillator has been demonstrated with 2 dBm of output power [5].

In this letter, we report an 80 GHz VCO with 6 GHz tuning range and minimum output power of 12.5 dBm. This design utilizes HRL Laboratories' AlInAs/GaInAs/InP HEMT with maximum oscillation frequency ($f_{\max}$) of 600 GHz. The transmission lines are realized using grounded coplanar waveguide (GCPW) technology. The GCPW design was chosen for its advantages over microstrip in terms of improved gain characteristics obtained by eliminating source via holes and related parasitics.

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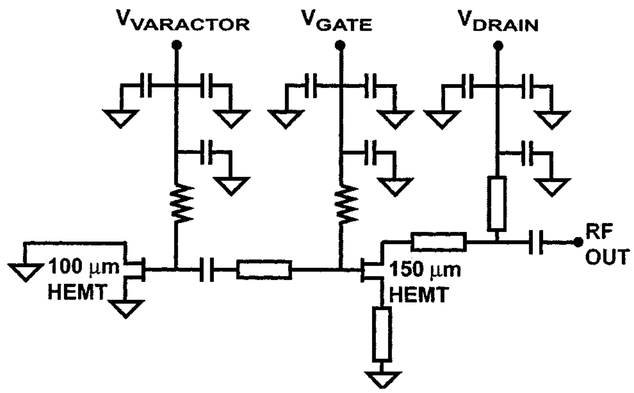

Fig. 1. Circuit diagram of MMIC VCO.

II. DEVICE MODELING

The oscillator is designed using AlInAs/GaInAs/InP HEMT devices grown by MBE. The HEMTs are fabricated using a planar process with boron ion implantation for device isolation. AuGe/Ni/Au alloy is used for the source and drain ohmic contacts. Ti/Pt/Au metallization is used to form 0.1 μm long T-gates. The devices are passivated with a 500 Å layer of Si_3N_4. The device exhibits a dc transconductance of 1050 mS/mm, breakdown voltage of 4 V, and extrinsic cutoff frequency (f_τ) of at least 180 GHz.

Large signal analysis is used to analyze the oscillator, therefore a large signal HEMT model is needed. The Curtice quadratic model was chosen due to its simplicity. The device S-parameters were measured on wafer from 1–50 GHz using a TRL calibration. From these measurements the parasitic elements and intrinsic capacitances were determined.

III. VCO DESIGN

The oscillator circuit topology is shown in Fig. 1. It consists of a 4×37 μm gate periphery HEMT device in a common source configuration. The series feedback element is a CPW transmission line at the source. The varactor element is a gate-source capacitance of a 4×25 μm gate periphery HEMT. Larger gate periphery device is used at the output in order to increase the output power. The varactor capacitance is varied by changing the gate supply voltage of the 4×25 μm HEMT. In this circuit configuration the varactor and the circuit are strongly coupled. This, as it will be seen from the measured results, increases varactor effect on the circuit and therefore gives wide tuning range, but it also increases the phase noise, as well as pulling effect.

The bias point of the oscillator is chosen to maximize the output power. Therefore, the 150 μm HEMT is biased for Class

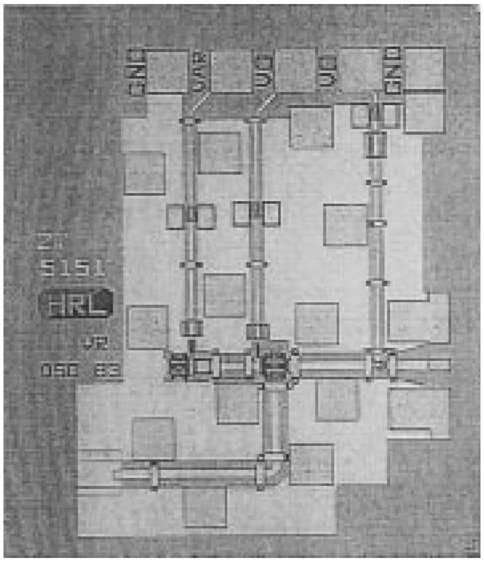

Fig. 2. Photograph of the fabricated MMIC VCO. The die size is 1.6 mm^2.

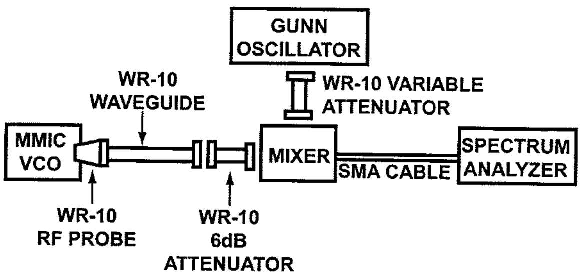

Fig. 3. Test setup for measuring frequency of oscillation.

A operation. The input and output matching are chosen to provide maximum output power and to satisfy the oscillation condition. The matching elements are realized using GCPW lines.

Fig. 2 shows a photograph of the fabricated MMIC VCO. The chip size is 1.22×1.3 mm^2. The oscillator was fabricated on a 3″ wafer, which was then thinned to 50 μm. The process also includes a wet etched backside via holes for parallel plate mode suppression. The high density of vias is necessary to suppress the undesired parallel plate mode, which can propagate energy into the substrate. Additionally, airbridges are used at each discontinuity to suppress undesired slot mode excitation. The airbridges and transmission lines use a 1.5 μm layer of gold fabricated by a lift-off process.

IV. Measured Results

Fig. 3 shows the setup used for measuring the frequency of oscillation. The VCOs output is connected to a WR-10 RF probe and then to a 6 dB WR-10 waveguide attenuator. First, frequency of oscillation is determined by down-converting the signal with a 68–97 GHz second harmonic gunn oscillator and viewing the resulting signal on 8564E spectrum analyzer. It should be noted that the oscillation frequency is simply the sum of the measured frequency at the spectrum analyzer and the frequency of the gunn oscillator. The spectrum was also viewed broadband to insure that this was the fundamental mixing product of the oscillator and gunn. No lower frequency spurious emissions were

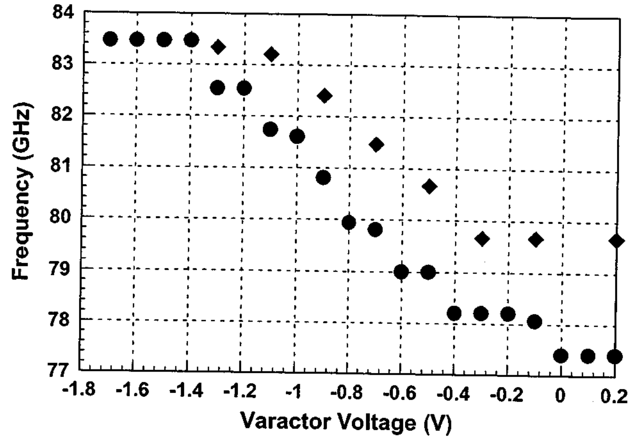

Fig. 4. Measured oscillation frequency versus varactor bias voltage.

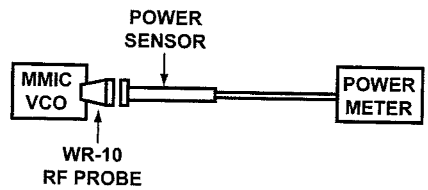

Fig. 5. Test setup for VCO output power measurement.

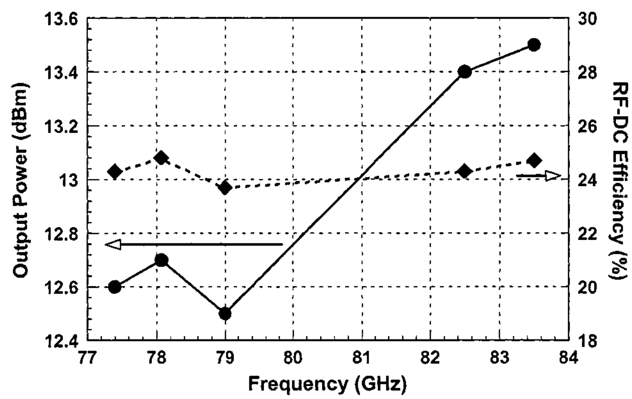

Fig. 6. Measured output power and RF to DC efficiency of the VCO.

visible, indicating that this was indeed the case. Determining whether the resulting spectrum is a high-side or low-side conversion is determined by shifting the frequency of the gunn oscillator and looking at the resulting shift of the down-converted spectrum.

Fig. 4 shows the measured oscillation frequency versus the varactor voltage. The drain bias is 2.5 V and the DC drain current is about 30 mA. The oscillation frequency tuning range is very wide from 77.5 to 83.5 GHz, which is a result of a strong coupling between the varactor and oscillating device. The oscillation frequency exhibits hysteresis, which is due to the multi-resonant oscillator load. The hysteresis happens when the locus of $Z(\omega)$ forms a loop [6]. Two stable operating points exist and which one will be selected depends on the oscillation's history. The hysteresis can be eliminated if a multi-resonant load is not used.

Fig. 5 shows the setup for measuring the VCO output power. The MMIC output is connected to a WR-10 RF probe and then to a W8486A power sensor and EPM-441A power meter. Fig. 6 shows the measured output power and RF to DC efficiency versus oscillation frequency. The minimum power of 12.5 dBm or 17.8 mW is achieved in the entire tuning band. The RF-DC efficiency is better that 23.7% in the entire frequency range. These are excellent power and efficiency results for an oscillator above 70 GHz.

V. Conclusion

In this letter, an 80 GHz MMIC VCO is presented. It uses AlInAs/GaInAs/InP HEMT devices and grounded CPW technology. The total size of this compact chip is 1.6 mm^2. In this first pass design, we have demonstrated a tuning range of 6 GHz and minimum output power of 12.5 dBm. RF to DC efficiency is better than 23.7% in the entire tuning range.

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