A Low Phase Noise X-Band MMIC GaAs MESFET VCO

C.-H. Lee, S. Han, B. Matinpour, and J. Laskar

***Abstract*—We present a fully monolithic X-band VCO MMIC implemented in a commercial GaAs MESFET process. Measurement results demonstrate a single sideband phase noise of −91 dBc/Hz at a 100 KHz offset. This VCO achieves a maximum output power of 11.5 dBm with 12 dB of output power control and a 550 MHz of frequency tuning range. Second harmonic suppression of 20 dB or more is measured across the entire power and frequency range. These results are comparable to, or better than, the best reported results of VCO's implemented in high electron mobility transistor (HEMT) and heterojunction bipolar transistor (HBT) processes.**

I. Introduction

THE RAPID growth in X- to Ku-band satellite communication technologies has created a great demand for compact and cost effective VCO MMIC's with low phase noise performance. Current state of the art microwave VCO's either use the low 1/f characteristics of the heterojunction bipolar transistors (HBT's) or take advantage of the lower noise up-conversion factor of the high electron mobility transistors (HEMT's), to achieve low phase noise performance [1], [2]. However, a penalty in cost and availability must be endured when using such specialized processes. In this work, a commercial GaAs MESFET process is used to implement a fully monolithic low phase noise VCO that provides a good tradeoff between cost and performance. This design utilizes a negative resistance common-gate inductive feedback topology to facilitate varactor tuning and implementation. Due to the series resistance of the varactor diode, the phase noise of a varactor-tuned oscillator is relatively higher than that of a fixed frequency oscillator. However, the phase noise can be reduced by using an active device with low noise figure (NF) and a resonator with high loaded Q. In this design, the device size is optimized for lower NF in this frequency range, and the load impedance is carefully designed to increase the Q-factor of the oscillator. To improve the phase noise performance, the varactor diode is placed in the source path rather than in the gate path. Low phase noise performance at high drain bias condition is demonstrated and analyzed using the reflection coefficient line analysis. This VCO's overall performance is comparable to, or better than, those achieved with monolithic HBT or HEMT VCO's [3]–[8].

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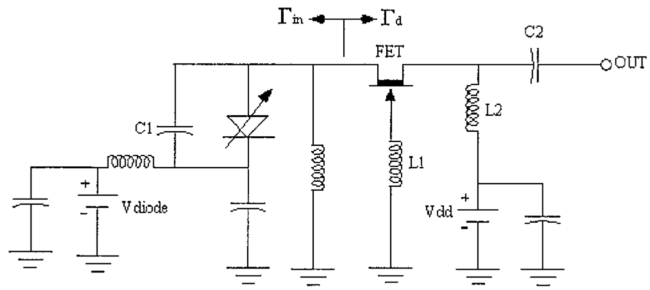

Fig. 1. Schematic of the VCO circuit.

II. Circuit Design

A common gate configuration is used to generate strong negative resistance by inductive feedback. As shown in Fig. 1, the resonator of the VCO consists of a spiral inductor, MIM capacitors, and a varactor diode, which is used for frequency tuning. Although a much wider tuning bandwidth can be obtained by placing the varactor on the gate path, the varactor is incorporated in the resonator on the source path to reduce its noise contribution to the VCO [3]. In addition, an MIM capacitor is placed in parallel with a small size varactor to reduce its loading effects on the resonator Q. To eliminate undesirable low frequency oscillations, an LC network is also incorporated as a high pass filter on the output path. Reflection coefficient line analysis is used to optimize the resonator load impedance for frequency stability and noise performance. The gate load is critical in determining the conditions of oscillation. Fig. 2 shows the reflection coefficient lines of the resonator and the device at various drain bias conditions. The cross over point implies the operating frequency of the oscillator and the angle between two lines indicates the Q-factor [9]. As the drain voltage increases, the angle approaches 90° where the Q is at a maximum. Increasing the drain voltage also reduces the phase noise by extending the depletion region in the channel to the drain side and consequently reducing the sensitivity of the oscillator to the gate-source voltage [10]. The noise parameters of the device are measured to determine the optimum matching point for a resonator. To further improve phase noise performance, the load impedance of the resonator is carefully designed to provide a perpendicular bisector for the reflection coefficient lines and to match near the Γ_{opt} point. High Q spiral inductors are implemented using 6-μm thick triple stacked metal. For an accurate inductor model, a commercial method of moments (MoM) simulator is used and transmission line effects in the layout are considered. This MMIC also includes pads for on-wafer testing

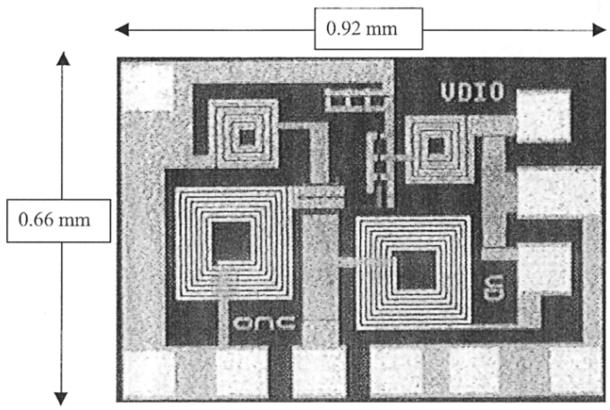

Fig. 3. Photograph of the fabricated VCO MMIC.

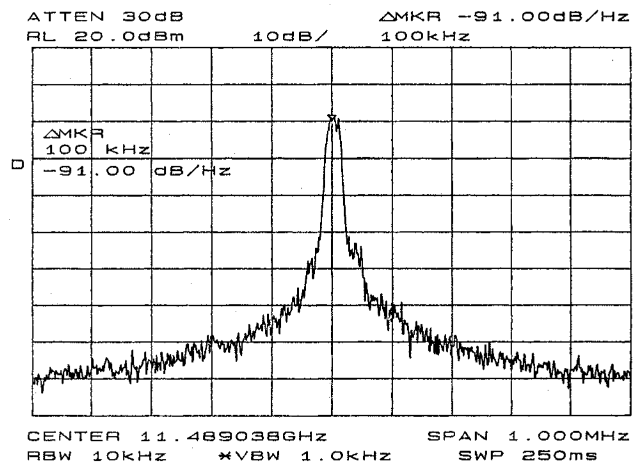

Fig. 4. Output frequency spectrum of the VCO over a 1 MHz span. (Phase noise: −91 dBc/Hz @ 100 KHz offset)

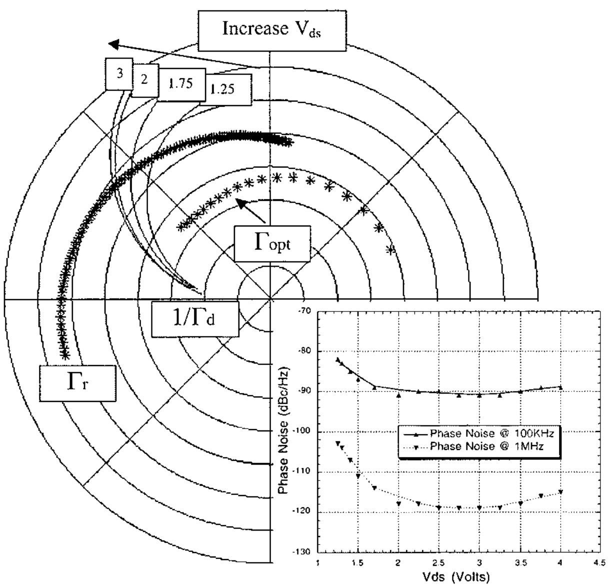

Fig. 2. Reflection coefficient lines and phase noise performance as a function of drain bias.

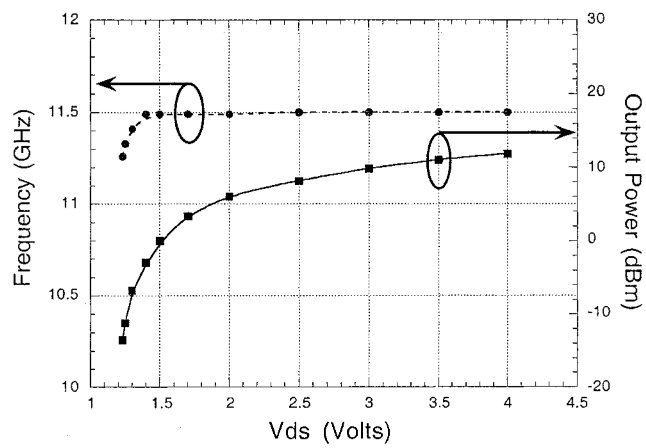

Fig. 5. Measured frequency and output power as a function of drain bias.

and shunt capacitors on the bias pads to minimize parasitic effects of the dc probes. The VCO is implemented in a commercial 0.6-μm TriQuint GaAs MESFET process using a depletion mode FET. The circuit occupies a 0.66×0.92 mm^2 die area, as shown in Fig. 3.

III. Experimental Results

On-wafer measurements of oscillation frequency, output power, and phase noise were performed using an Agilent8563E spectrum analyzer. The Agilent8563E spectrum analyzer has low enough noise floors (i.e., <-102 dBm with a resolution bandwidth of 10 KHz) to measure the phase noise of many commercial local oscillators and it has the ability to correct the measured power spectrum automatically and display the resulting phase noise [11]. Single-side-band phase noise was measured as the relative spectral density of the noise sidebands for a given offset frequency from the carrier. Fig. 2 plots the VCO phase noise at 100 KHz and 1 MHz offset as a function of drain bias. Phase noise improvement of 9 dB at 100 KHz offset was achieved as the drain voltage increases up to 3.25 V. Fig. 4 shows the signal spectrum of the VCO over a 1 MHz span showing a phase noise of −91 dBc/Hz at a 100 kHz offset. Second harmonic suppression of 20 dB or more was observed across the entire power and frequency range, and no parasitic oscillations were detected. Fig. 5 shows the dependence of oscillation frequency and output power level on the drain voltage. A maximum output power of 11.5 dBm was measured and a power control level of 12 dB was obtained by varying the drain voltage from 1.5 to 4 V. The frequency pulling occurs at the drain voltage less than 1.5 V and can be reduced by using a buffer amplifier. Fig. 6 shows the measured frequency and output power level as a function of the varactor voltage. A frequency tuning range of 550 MHz, ranging from 11.25 to 11.8 GHz, with uniform phase noise performance was achieved over a tuning voltage range of −1 – 3 V. These characteristics have been achieved without any buffer amplifiers.

IV. Conclusion

We have presented an X-band GaAs MESFET VCO MMIC with a phase noise of −91 dBc/Hz at a 100 kHz offset frequency.

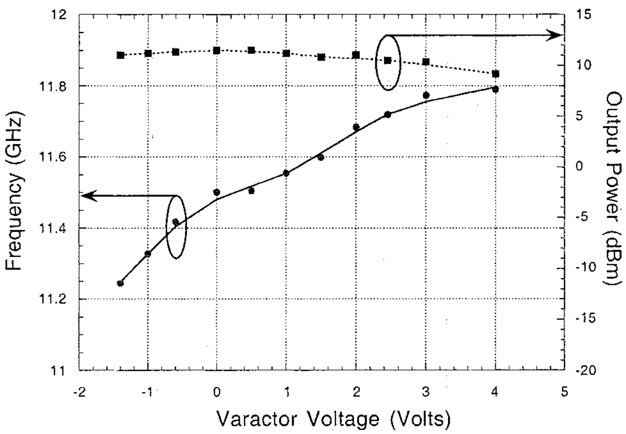

Fig. 6. Measured frequency and output power as a function of varactor control voltage.

Reflection coefficient line analysis and layout optimization have been used to maximize resonator load-Q for low phase noise performance. The VCO has a center frequency of 11.5 GHz with a 550 MHz of frequency tunability and an output power of 11.5 dBm. The output power can be controlled over 12 dB while maintaining excellent phase noise and low second harmonics. These are the best monolithic GaAs MESFET VCO results reported to date.

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