5∼6 GHz-Band GaAs MESFET-Based Cross-Coupled Differential Oscillator MMICs With Low Phase-Noise Performance

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***Abstract*—LC-tank oscillators in the 5∼6 GHz frequency range have been designed and implemented in a commercial 0.6 μm GaAs MESFET technology. One is a voltage-controlled oscillator (VCO), and the other is an oscillator without a controlling element. The output frequency range of the VCO is from 5.44 to 6.14 GHz, and the measured phase-noise is −101.67 dBc/Hz at an offset frequency of 600 KHz from the 5.44 GHz carrier. The phase-noise of the 6.44 GHz oscillator is −108 dBc/Hz at an offset frequency of 600 KHz, and the phase-noise curve, in the offset frequency range between 100 KHz and 1 MHz, shows a −20 dB/decade slope. These phase-noise characteristics are comparable to, or better than, those of the reported 5∼6 GHz-band CMOS oscillators. To our knowledge, this is the first GaAs MESFET-based oscillator which has a cross-coupled differential topology and a capacitive coupling feedback to suppress the up-conversion of $1/f$ noise. Also, it is first reported that the GaAs MESFET-based oscillator shows $1/f^2$ phase-noise behavior across the offset frequency range from 100 KHz to 1 MHz.**

***Index Terms*—$1/f$ noise up-conversion, capacitive coupling feedback, cross-coupled differential topology, GaAs MESFET, phase-noise, voltage-controlled oscillator (VCO).**

I. Introduction

In recent years, the 5∼6 GHz-band mobile communication market has been growing rapidly. The GaAs MESFET-based MMIC approach has traditionally been used to implement microwave components at these frequencies. However, in case of VCO, the critical building block in all wireless communication transceivers, GaAs MESFETs are not considered as suitable candidates for the low phase-noise VCO application. Even though a GaAs process provides high-Q inductors due to its semi-insulating substrate, which is required to make the low phase-noise performance, the relatively high $1/f$ noise characteristic of GaAs MESFETs makes the phase-noise worse than VCOs in Si processes. Hence, there have been few papers reporting GaAs MESTFET-based VCOs in the 5∼6 GHz-band in terms of the low phase-noise performance.

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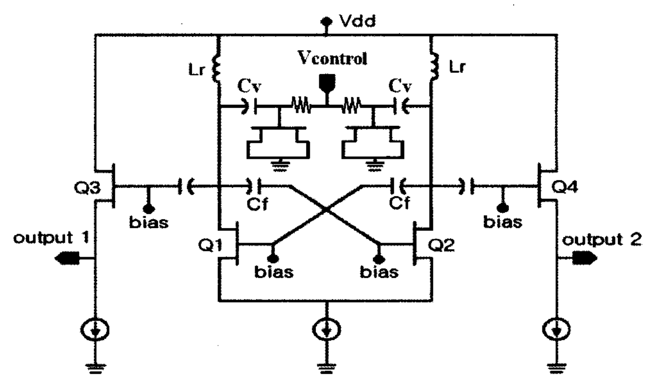

Fig. 1. Schematic of the VCO circuit.

It has been well known that $1/f$ noise in the active device is up-converted to the phase-noise, resulting in a $1/f^3$ region around the oscillation frequency in the phase-noise spectrum. Recently, it is reported that the $1/f^3$ region can be reduced by the differential configuration [1] and the capacitive feedback [2]. This is due to the suppression of $1/f$ noise up-conversion. In this paper, GaAs MESFET-based oscillators are implemented using both schemes so as to reduce the $1/f^3$ region in the phase-noise spectrum. Owing to the reduction of $1/f$ noise up-conversion and the high-Q inductors, the phase-noise performance of oscillators in this paper is comparable to, or even better than, the best reported results of 5∼6 GHz-band oscillators implemented in a CMOS technology [3]–[6].

II. Circuit Design and Implementation

A commercial 0.6 μm MESFET GaAs foundry process (TRIQUINT TQTRX) was used for the design and implementation. Three metal layers are used in this process. Active devices show a cutoff frequency (f_T) of 19 GHz, a maximum oscillation frequency $(f_{\max})$ of 60 GHz, and a threshold voltage of −2.2 V. Inductors are implemented stacking two metal layers. Varactors are 480 μm FETs with the drain and the source connected together. The number of finger and the width are carefully designed to maximize the quality factor of varactors. Capacitors are implemented as a high-Q MIM type, and show a capacitance of 1.2 fF/μm^2.

Fig. 1 shows a circuit schematic of the VCO. In order to reduce the up-conversion of $1/f$ noise, which is dominant in GaAs

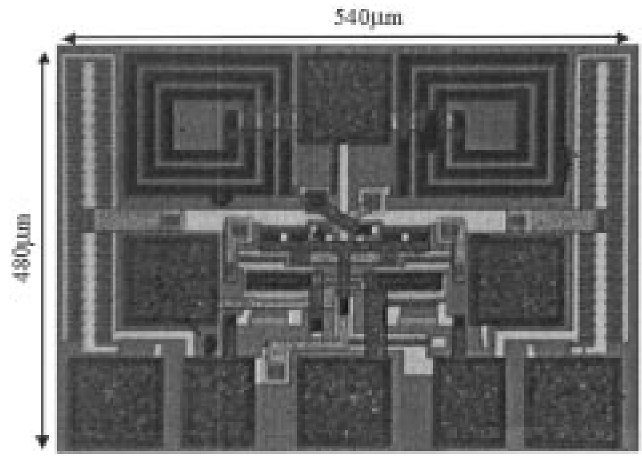

Fig. 2. Photograph of the fabricated VCO MMIC.

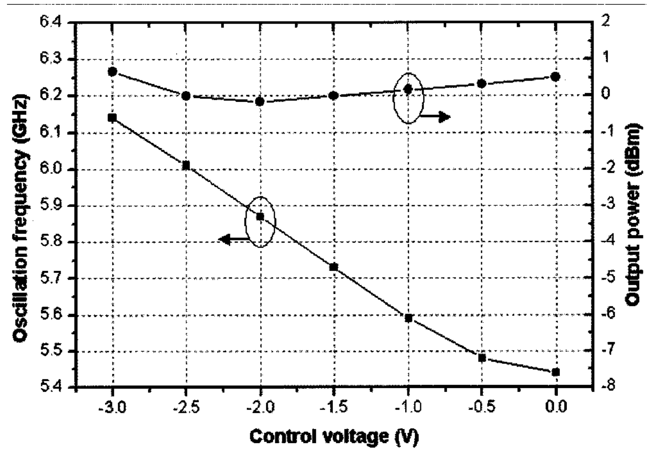

Fig. 3. Measured oscillation frequency and output power as a function of varactor control voltage.

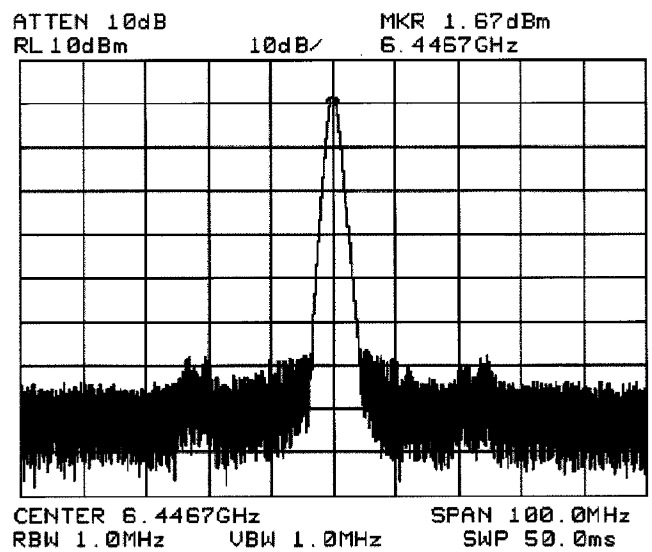

Fig. 4. Output spectrum of the 6.44 GHz oscillator.

MESFET- based VCOs, the cross-coupled differential topology with the capacitive coupling feedback was used to realize the VCO. Cross-coupled transistors (Q1 and Q2) form a positive feedback to provide a negative resistance to cancel the loss in the LC-resonators. The positive feedback is achieved through capacitors (C_f). These capacitors take roles of suppressing the $1/f$ noise up-conversion as well as dc-blocking in order to bias cross-coupled transistors. The LC-resonator at the drain consists of an inductor (L), a varactor, and a dc-blocking capacitor (C_v). The inductors in the resonator have the inductance of 1.4 nH and the quality factor of 30 at 6 GHz. The quality factor of varactors is 27 and 60 at an applied control voltage $(V_{control})$ of 0 and -3 V, respectively, at 6 GHz. The resonant frequency can be controlled with the control voltage. Q3 and Q4 form buffers capable of driving 50 Ω.All the gates of MESFETs in the design are biased with high value resistors. Fig. 2 shows a microphotograph of the MMIC VCO. The chip size measures 480 $\times$ 500 μm^2 including on-wafer probing pads. Special attention was paid to making the layout of the differential circuits as symmetrical as possible. Furthermore, in order to reduce parasitic elements, the layout was made as compact as possible. These are clearly visible in the chip photo of Fig. 2.

The design was simulated and optimized using Agilent ADS. The design procedure can be divided in two steps. First, a small signal analysis was used to optimize the feedback and the resonator elements to find the oscillation condition at the target frequency. This condition was simulated breaking the feedback path. In the second step, a large signal analysis was performed with the harmonic balance simulator to predict the exact oscillation frequency and output power of the harmonic signals as well as the fundamental signal.

III. Experimental Results

On-wafer measurements of the oscillation frequency, the output power, and the phase-noise were performed using an Agilent 8564E spectrum analyzer. It has an ability to measure the power spectrum, to calculate the phase-noise automatically and to display the results. Fig. 3 shows the measured oscillation frequency and the output power of VCO as a function of the applied control voltage. The range of the control voltage is from 0 to -3 V. The oscillation center frequency is 5.8 GHz. The tuning range is 700 MHz, and the output power is 0.3 ± 0.5 dBm. The measured minimum phase-noise is -101.67 dBc/Hz at an offset frequency of 600 KHz from the 5.44 GHz carrier with a 3.3 V supply voltage. Fig. 4 shows the spectrum of the 6.44 GHz oscillator with the output power of 1.67 dBm. Fig. 5 shows the phase-noise plot of the oscillator. The phase-noise performance was measured across the offset frequency range from 100 KHz to 1 MHz. The phase noise curve shows a -20 dB/decade slope across the offset frequency range. The measured phase-noise is -108 dBc/Hz at an offset frequency of 600 KHz. It is commonly known that GaAs MESFET-based oscillators show the phase-noise curve with a -30 dB/decade slope due to the up-conversion of $1/f$ noise in GaAs MESFETs. In this work, using the cross-coupled differential topology with the capacitive feedback, the up-conversion of $1/f$ noise is reduced. The comparison of the phase-noise performance among 5$\sim$6 GHz-band oscillators is made in Table I.

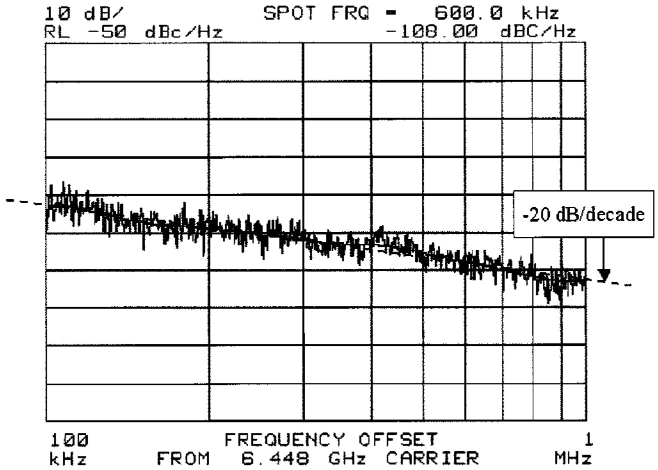

Fig. 5. Phase-noise measurement of the 6.44 GHz oscillator at an offset frequency range between 100 KHz and 1 MHz. (−108 dBc/Hz at an offset frequency of 600 KHz).

TABLE I
COMPARISON OF THE PERFORMANCE OF OSCILLATORS IN 5∼6 GHZ-BAND

	Process	Oscillation Frequency (GHz)	Phase Noise (dBc/Hz) scaled at 600KHz	Tuning Range (GHz)
This work	**MESFET**	**5.44**	**-101.67**	**0.7**
This work	**MESFET**	**6.44**	**-108**	-
[3]	CMOS	6.8	-85.6	-
[4]	CMOS	6.29	-94	1.02
[5]	CMOS	6.1	-100.7	0.37
[6]	CMOS	5.2	-86	0.32

IV. CONCLUSION

We presented fully integrated GaAs MESFET-based LC-tank oscillators in 5∼6 GHz-band. In order to suppress the up-conversion of $1/f$ noise toward the phase noise, oscillators were designed with the cross-coupled differential topology using the capacitive feedback. The VCO shows the 12% tunability and the better phase-noise performance in comparison with CMOS VCOs. The 6.44 GHz oscillator shows the phase-noise curve with a −20 dB/decade slope in the offset frequency range between 100 KHz and 1 MHz. We believe that this work is the first report of the GaAs MESFET-based cross-coupled differential oscillator showing $1/f^2$ phase-noise behavior across the offset frequency range from 100 KHz to 1 MHz.

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