Low Noise 5 GHz Differential VCO Using InGaP/GaAs HBT Technology

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***Abstract*—This letter presents the first InGaP/GaAs HBT differential VCOs with low phase noise performance. One is a cross coupled differential VCO, and the other is a Colpitts differential VCO. To achieve a fully integrated VCO, collector-base junction capacitance of HBT transistor is used for frequency tuning varactor. The measured output frequency ranges of VCOs are 290 MHz and 190 MHz, and the phase noises at an offset frequency of 1 MHz are -118 dBc/Hz and -117 dBc/Hz respectively. The each VCO core dissipates 13.2 mW from a 3.5 V supply, and the output power is about -0.2 dBm. Concerned with cross coupled VCO, it shows the figure of merit of -179 dBc/Hz, which is the best result among the reported compound semiconductor FET and HBT VCOs.**

***Index Terms*—Cross coupled VCO, InGaP/GaAs HBT, low phase noise.**

I. Introduction

Recently, the increasing demand for high speed data communication drives us to 5 GHz band rather than 2.4 GHz band for wireless LAN application, because IEEE802.11a and HIPERLAN, where 5 GHz band is used, can enable the high speed data transmission of up to 54 Mbps. Most of the reported 5 GHz works are based on SiGe HBT and Si CMOS technologies [3]–[9], but there are few works using GaAs FET and HBT [1], [2]. However, considering low noise performance and high operating frequency, InGaP/GaAs HBT has many advantages over Si based devices to be used for VCO as well as LNA, power amplifier, and the other RF circuits. Therefore, a commercial HBT foundry process(Knowledge* on KON-M) is used for our VCOs, which features a InGaP/GaAs HBT with an emitter width of 2 μm and f_T of 22 GHz at 2 mA, 3 V conditions.

To achieve a fully integrated VCO, the varactor for tuning frequency must be realized using on chip devices, and so the base-collector capacitor of HBT is used as the varactor. Although its tuning range of capacitance is smaller than that of external varactor, the designed VCO using on chip varactor can cover the required frequency range of 200 MHz. The bias point of core HBT devices should be optimized and the inductors of highest Q at 4.3 GHz are chosen for low phase noise. Furthermore, the differential configuration cannot only reduce the up-converted $1/f$ noise, but also is desirable for compatibility with any other integrated tranceiver chips. To make comparison of VCOs with other topologies, Colpitts VCO as well as cross coupled VCO is implemented and measured in this work.

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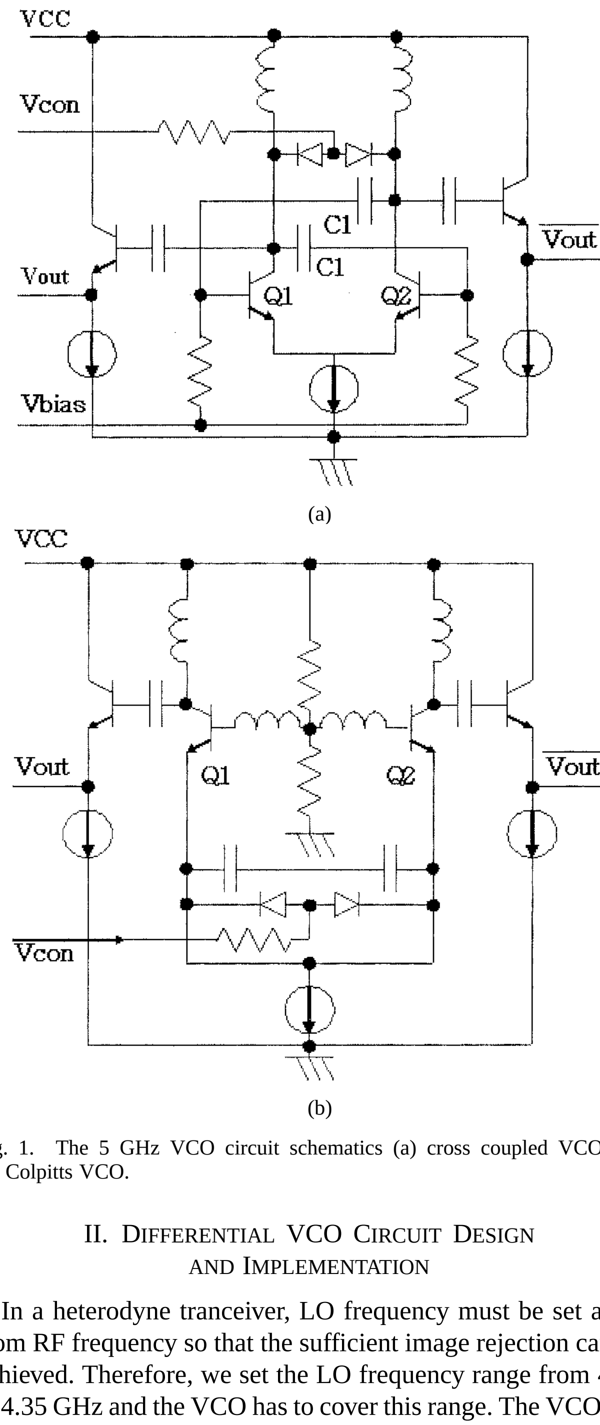

Fig. 1. The 5 GHz VCO circuit schematics (a) cross coupled VCO and (b) Colpitts VCO.

II. Differential VCO Circuit Design and Implementation

In a heterodyne tranceiver, LO frequency must be set apart from RF frequency so that the sufficient image rejection can be achieved. Therefore, we set the LO frequency range from 4.15 to 4.35 GHz and the VCO has to cover this range. The VCO circuit schematics used here are shown in Fig. 1(a) and (b). One is a cross coupled differential VCO, and the other is a differential Colpitts VCO. The used HBT model is VBIC model, which includes improved modeling of early effect and thermal behavior.

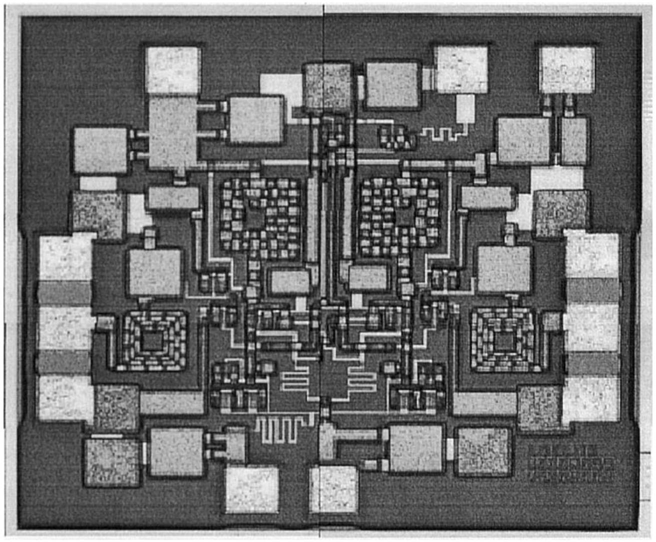

Fig. 2. Microphotograph of the 5 GHz differential cross coupled VCO (1.2 mm × 1.1 mm).

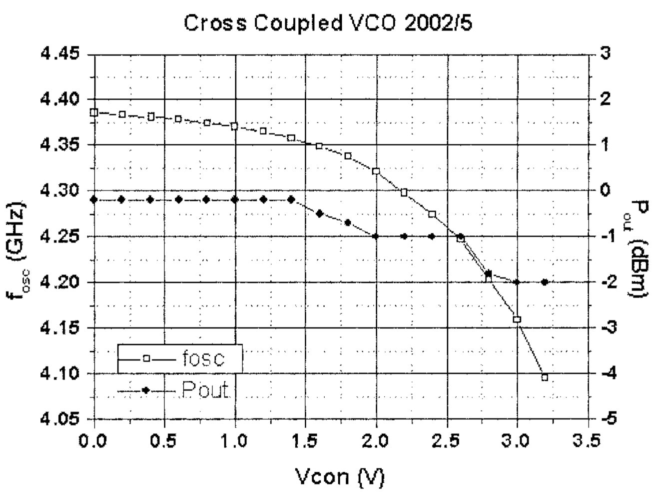

Fig. 3. Oscillation frequency and output power as a function of varactor control voltage.

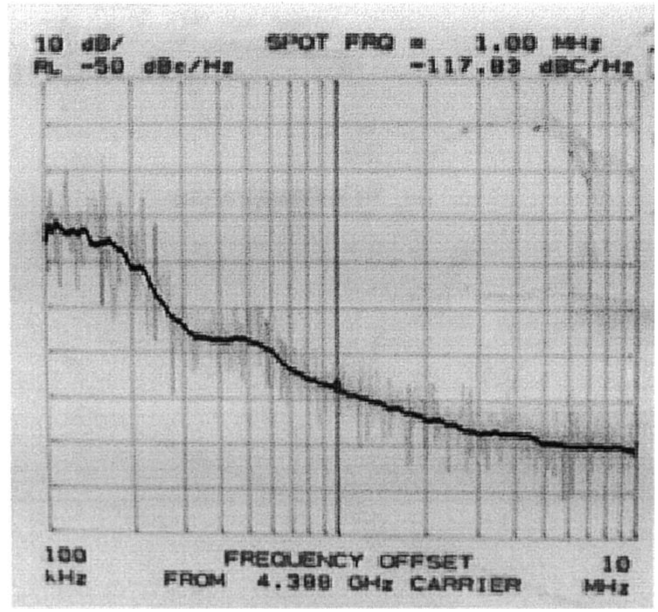

Fig. 4. Measured phase noise of the cross coupled VCO between 100 kHz and 10 MHz offset.

In the cross coupled VCO, the collector voltage of Q1 is fed into the base of Q2 while divided by C_1 and C_π. The ratio of C_1 to C_π is important to make the oscillation properly. A mirror current source provides the constant current to VCO core as well as output buffer circuit. The output buffer can improves the VCO pulling figure, which is defined as how the frequency shifts while the load impedance is varied moving around the 10 dB return loss circle in the Smith chart. Differential topology can not only reduce the phase noise of VCO, but also can provide differential LO source to a double balanced mixer, which prohibits the LO signal from coupling into other ports.

To obtain the low phase noise performance, the optimizations of high Q resonator and core current are the most important points in VCO design. As concerned with LC resonator, since the on chip inductor, varactor, and parasitic capacitors form a resonator, therefore Q of inductor and varactor must be carefully considered. The Knowledge*on's KON-M InGaP/GaAs HBT foundry process offers various types of inductor (various width, gap, and inner diameter), so that the inductor giving maximum Q at 4.3 GHz is chosen for the resonator inductor. At 4.3 GHz, the Q factor of chosen 2.5 turn inductor is 32 and that of varactor varies from $53 \sim 66$ under control bias $0 \sim 3$ V.

The phase noise also depends on the currents passing through the core HBTs because the current gain and shot noise of HBT transistors strongly depend on collector currents. As mentioned in an earlier publication [8], the functional graph of phase noise versus current has a parabolic shape and so HBT collector current Ic can be chosen at the optimal current for low phase noise.

The photograph of fabricated cross coupled VCO is shown in Fig. 2. The total area of the VCO including pads and output buffers is 1.2 ×1.1 mm^2.

III. Experimental Results

The On wafer measurements of the oscillation frequency, phase noise, and output power are performed with an HP8563E spectrum analyzer. Fig. 3 shows the measured oscillation frequency and output power of our cross coupled VCO as functions of the varactor control voltage. It shows the tuning range of 290 MHz ($4.095 \sim 4.385$ GHz) and the output power of -2 dBm over a control voltage range of 3.2 V. The VCO core draws 4 mA from a 3.5 V supply and the output buffers 8 mA from the same supply. The measured phase noise is shown in Fig. 4. The measured phase noise is -117.8 dBc/Hz at an offset frequency of 1 MHz. In order to make a fair comparison of phase noise with other published 5 GHz VCOs [1]–[7], the figure of merit [6] is very useful while it assumes a phase noise slope of 20 dB/decade, as described by Leeson's model. Table I shows the comparison of the phase noise figure of merit among the recently published 5 GHz VCOs. In the case of Colpitts VCO, the measured phase noise at similar condition is -115.6 dBc/Hz, which is not better than that of cross coupled VCO.

TABLE I
COMPARISON OF THE PHASE NOISE FIGURE OF MERIT AMONG THE PUBLISHED 5 GHz VCOs

Reference	Frequency (GHz)	FOM (dBc/Hz)	% Tune Range
[1] GaAs MESFET	5.44	-168.6	12.9
[2] InGaP HBT	5.51	-165.3	8.0
[3] SiGe	4.82	-180.0	4
[4] CMOS	5	-176.6	18.0
[5] CMOS	4.7	-173.1	4.3
[6] SiGe	5	-180.2	12.3
[7] SiGe	5.78	-169.7	3.5
This work	4.39	-179.6	6.8

IV. CONCLUSION

The first fully integrated InGaP/GaAs HBT differential VCOs with low phase performance are designed and measured for 5 GHz applications. In order to achieve a fully integrated VCO, the base collector junction capacitors are used for varactors. To optimize the phase noise performance, the highest Q inductor is chosen for LC resonator and HBT collector current is optimized. The cross coupled differential VCO shows the 6.8% tunability and the best phase noise performance among 5 GHz compound semiconductor FET and HBT VCOs. The Colpitts topology can hardly improve the phase noise performance in the case of HBT based VCO, while it works well on FET based VCOs considerably [9].

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