A K-Band InGaP/GaAs HBT Balanced MMIC VCO

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***Abstract*—A fully integrated K-band balanced voltage controlled oscillator (VCO) is presented. The VCO is realized using a commercially available InGaP/GaAs hetero-junction bipolar transistor (HBT) technology with the f_T of 60 GHz and the f_{MAX} of 110 GHz. To generate negative resistance at mm-wave frequency, common base inductive feedback topology is used. The VCO provides the oscillation frequency from 21.90 GHz to 22.33 GHz. The frequency tuning range is about 430 MHz. The peak output power is −0.3 dBm. The phase noise is −108.2 dBc/Hz at 1 MHz offset at the operating frequency of 22.33 GHz. The chip area is $0.84 \times 1.00\ mm^2$.**

***Index Terms*—Balanced topology, common base inductive feedback, InGaP/GaAs HBT, VCO.**

I. Introduction

RECENTLY, the demands of K-band frequency sources are growing because of explosive interests in mm-wave communication and sensor systems. VCO is one of the most important circuitries in wireless transceivers as a part of frequency synthesizers. [1]–[2] Traditionally, GaAs pseudomorphic high electron mobility transistor (pHEMT) or InP based transistors have been used in mm-wave oscillators because of their excellent frequency performance, while these technologies are very expensive. [3]–[4] However, InGaP/GaAs HBT technology has inherent low 1/f noise performance, reliable fabrication process and low manufacturing cost. It makes InGaP/GaAs HBT techonlogy is very attractive to be used for mm-wave oscillators.

In order to implement a balanced topology such as a balanced mixer, a balanced multiplier, and so on, the signal source which can generate anti-phase signals is needed. In the case of single-ended oscillator, a balun is needed to generate anti-phase signals. However, a passive balun is bulky and an active balun is very noisy. It is also difficult to achieve exactly balanced signals in mm-wave frequencies. Therefore, it is very beneficial if an oscillator by itself can provide anti-phase outputs. [5] Also, it is known that the balanced topology in oscillators suppresses phase noise. [6] In most balanced VCOs, Colpitts or capacitive feedback topologies are used to generate negative resistance. [5]–[6] However, it is not adequate in mm-wave frequencies because the small capacitance which is very difficult to be implemented is needed. Instead, common base inductive feedback can

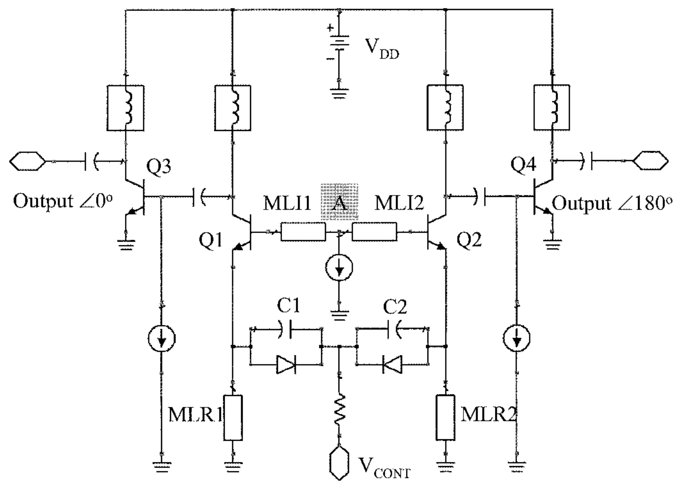

Fig. 1. K-band balanced VCO circuit schematic.

be used to provide negative resistance. In the case of low frequency oscillator below X-band, common base inductive feedback topology is seldom used. This is owing to the additional inductor at the base or the gate, which is bulky and results in poor phase noise performance. However, in mm-wave frequencies, these feedback inductors can be implemented with a short length microstrip line. Since the microstrip line inductors have higher quality factor and self-resonant frequencies than lumped inductors in mm-wave frequencies, low-phase noise performance can be achieved. Also, microstrip line inductor is less affected by process variations than MIM capacitor because its inductance is determined only by the designed layout. [7]

In this paper, a balanced VCO with common base inductive feedback operating at K-band is presented using low cost InGaP/GaAs HBT technology.

II. Circuit Design

The schematic diagram of the proposed balanced VCO is shown in Fig. 1. It consists of two identical HBTs (Q1, Q2) whose bases are interconnected through microstrip line inductors (MLI1, MLI2). Common base inductive feedback is applied to both HBTs to generate negative resistance which compensates the loss of LC resonator. Because common base node (A) forms a virtual ground, anti-phase signals can be generated. [8] The LC resonator consists of microstrip line inductors (MLR1, MLR2), MIM capacitors (C1, C2), and varactors. To achieve low phase noise performance, microstrip line inductors were used instead of lumped inductors in the resonators which have low quality factor and self-resonant frequencies. The base-collector junction capacitance of HBT is used as a varactor to tune the oscillation frequency. The mictrostrip line elements are bended to reduce the chip area. To predict the oscillation frequency accurately, the bendings of microstrip line

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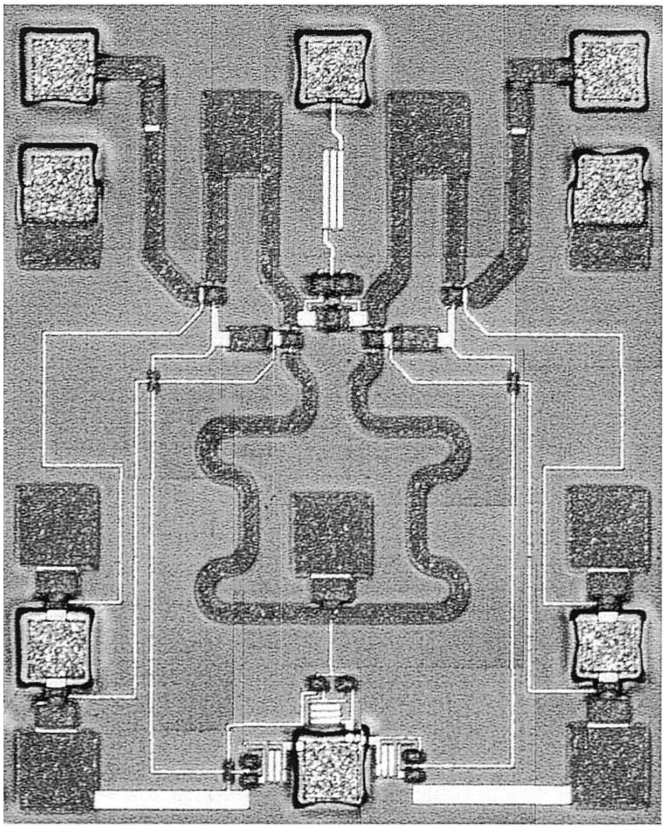

Fig. 2. Microphotograph of the fabricated VCO (chip size: $0.84 \times 1.00\ \mathrm{mm}^2$).

components were simulated with 2.5D EM simulator of HP Momentum. The VCO core current is controlled by the current mirror. The VCO core current is also optimized for the low phase noise performance. Output buffer amplifiers are used to reduce the frequency pulling effect of the output loads.

III. Device Technology

The balanced VCO was fabricated using 6-in InGaP/GaAs HBT HS process at Knowledge*on foundry. The large signal model of the transistor was performed using VBIC (Vertical Bipolar Inter-Company) model. 1 finger $2 \times 10\ \mu\mathrm{m}^2$ HBTs were used as VCO core transistors. This device shows a cut-off frequency ($\mathrm{f_T}$) of 60 GHz and a maximum oscillation frequency ($\mathrm{f_{MAX}}$) of 110 GHz. Turn-on voltage of HBT is about 1.21 V. The properties of 1 finger $2 \times 10\ \mu\mathrm{m}^2$ HBT are summarized in Table I. The technology provides a SiNx MIM capacitor with $600\ \mathrm{pF/mm}^2$, a 50 $\Omega/\square$ NiCr resistor and two interconnecting metal, of which thickness are 1.3 $\mu\mathrm{m}$ and 4 $\mu\mathrm{m}$, respectively. All circuits are passivated with polyimide. The wafer is thinned to 95 $\mu\mathrm{m}$ with backside via. Fig. 2 shows the microphotograph of the fabricated K-band balanced VCO. The chip size is $0.84 \times 1.00\ \mathrm{mm}^2$. The chip size is very small compared to the reported VCOs at K-band.

IV. Measurement Results

The output spectrums and the phase noise performance were obtained from HP8764E spectrum analyzer. The fabricated VCO was tested using GS probes on Cascade probe station. Fig. 3 shows the output spectrum of the fabricated VCO, which shows clear spectral purity without any other spurious signals. The whole losses of the microprobe and the cable and the connectors are about 5 dB at K-band. Therefore, the measurement loss was compensated to calculate the output power of the VCO. A free running oscillation frequency of 21.90 GHz is achieved with 4 V supply and $\mathrm{V_{CONT}}$ of 0 V. It provides the output power of −0.8 dBm. Fig. 4 shows the oscillation frequency and the output power characteristics with respect to the varactor control bias from 0 V to 4 V. The frequency tuning range is achieved to 430 MHz from 21.90 GHz to 22.33 GHz. The peak output power is −0.3 dBm and the output power

TABLE I
InGaP/GaAs HBT Device Characteristics

1 finger $2 \times 10\ \mu\mathrm{m}^2$ (Emitter Area=20 $\mu\mathrm{m}^2$)	
β	130
$\mathrm{f_T}$	60 GHz
$\mathrm{f_{MAX}}$	110 GHz
Jc	25 kA/cm^2
$\mathrm{V_{TURN\text{-}ON}}$	1.21 V
$\mathrm{BV_{CBO}}$	18.9 V

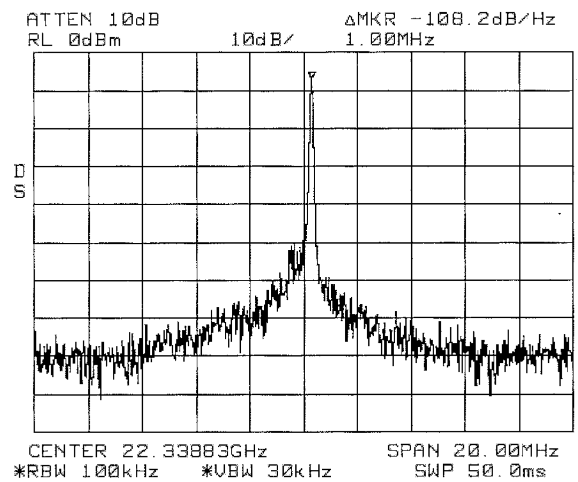

Fig. 3. Measured spectrum.

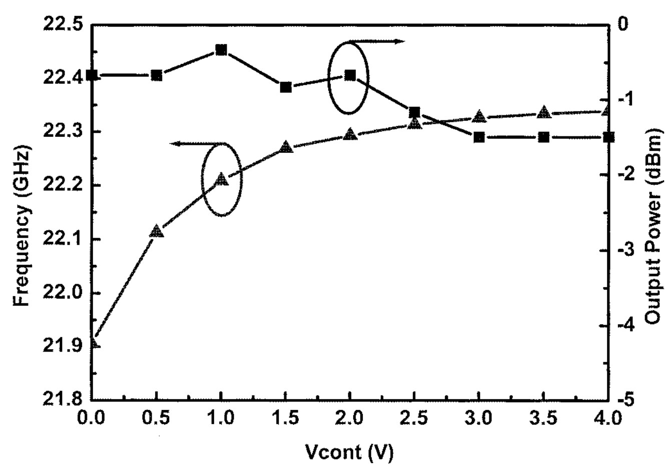

Fig. 4. The oscillation frequency and the output power of the VCO as varying the varactor control bias.

TABLE II
SUMMARY OF THE FABRICATED VCO

Oscillation Frequency	21.90 ~ 22.33 GHz
Peak Output Power	-0.3 dBm
Phase Noise	-108.2 dBc/Hz @ 1MHz
Tuning Range	430 MHz
DC Bias Supply	4 V (I_C = 35 mA)

variation is less than 1 dBm in the tuning range. The phase noise is -108.2 dBc/Hz at 1 MHz offset at the operating frequency of 22.33 GHz. This is very low phase noise performance in K-band MMIC oscillators. The measurement results of the fabricated VCO are summarized in Table II.

V. CONCLUSION

We have presented a K-band balanced VCO using commercially available InGaP/GaAs HBT technology. The balanced topology with common base inductive feedback is used. For low phase noise performance, microstrip line inductors with high quality factor are used in LC resonators, and common base feedback. The oscillation frequency was varied from 21.90 GHz to 22.33 GHz. The peak output power is -0.3 dBm. The phase noise is -108.2 dBc/Hz at 1 MHz offset frequency at the operating frequency of 22.33 GHz. The presented VCO shows low phase noise performance, and its area is as small as $0.84 \times 1.00\ \mathrm{mm}^2$. It shows comparable performances to the reported VCOs based on other device technologies.

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