A 60 GHz InGaP/GaAs HBT Push-Push MMIC VCO

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Abstract — **A fully integrated 60 GHz push-push voltage controlled oscillator (VCO) is presented. The VCO is realized using a commercially available InGaP/GaAs hetero-junction bipolar transistor (HBT) technology with an f_T of 60 GHz and an f_{MAX} of 110 GHz. To generate negative resistance, common base inductive feedback topology is used. Push-push configuration is employed to achieve high oscillation frequency of V-band. The presented push-push VCO provides the oscillation frequency of 60 GHz. This is very close to the predicted oscillation frequency owing to the EM simulation of the microstrip line resonator and inductor. The peak output power is -4 dBm. The phase noise is -93 dBc/Hz at 1 MHz offset frequency of the push-push signal of 60 GHz and -102 dBc/Hz for the fundamental frequency of 30 GHz. The wide frequency tuning range is achieved about 1.6 GHz. The small chip of 0.90 × 0.87 mm² is also achieved with the layout consideration.**

I. INTRODUCTION

Demands of millimeter wave frequency sources have increased drastically because of explosive interests in wireless communication and mm-wave radar systems. The VCO is one of the most important circuitries in wireless communication and radar transceivers as a part of the frequency synthesizer. [1, 2] Key requirements of VCO are high output power, low phase noise and wide tuning range.

Traditionally, GaAs pseudomorphic high electron mobility transistor (pHEMT) or InP based transistors have been used in mm-wave oscillator because of their excellent frequency characteristics, while these technologies are very expensive. [3, 4] Although InGaP/GaAs HBTs have somewhat lower f_T and f_{MAX} than aforementioned transistors, their inherent low 1/f noise, reliable fabrication process and lower manufacturing cost make them very attractive to be used for mm-wave applications.

To achieve higher oscillation frequency using lower f_T, f_{MAX} device technology, push-push principle can be used especially in mm-wave source. [5, 6, 7]

This paper presents a high performance push-push VCO operating at V-band using cost effective InGaP/GaAs HBT technology.

II. CIRCUIT DESIGN

In a push-push oscillator, when anti-phased signals are combined together, the fundamental oscillation frequency is suppressed and then the second harmonic frequency is appeared at the output. The anti-phased signals can be generated using balanced topology. [8, 9]

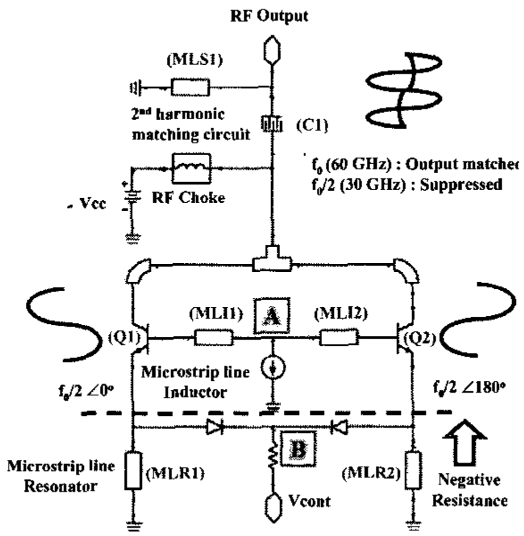

Fig. 1. 60 GHz Push-Push VCO circuit schematic

To obtain anti-phased signals in balanced topology, each VCO must oscillate in the odd mode and be quenched in the even mode. In other words, node A and node B in Fig. 1 must be a virtual ground. [6]

Negative resistance can be generated using common base inductive feedback, which allows high output power when it matched to optimum output load. [10, 11]

In the case of low frequency oscillator below X-band, common base inductive feedback topology is not owing to the additional inductor at the base or the gate node of the transistor than other topologies such as differential or balanced Colpitts type. But the lumped inductor can be replaced to a short length microstrip line inductor with

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high quality factor in the mm-wave frequency regime. [12]

Common base inductive feedback topology using micostrip line inductor is also affected less by the process variations than the capacitively feedback topology such as Colpitts oscillator because it uses less lumped elements.

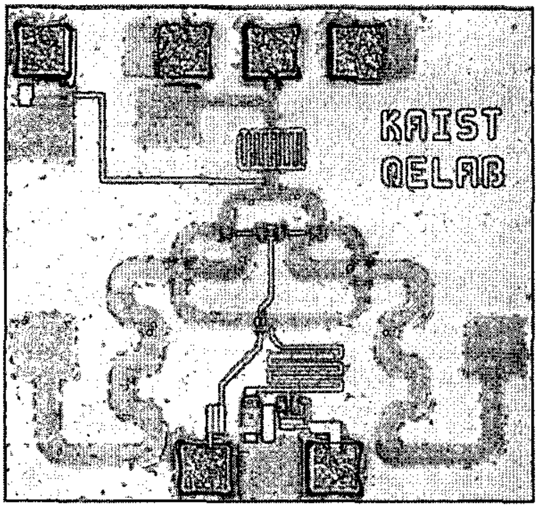


Fig. 2. The photograph of 60 GHz push-push VCO
(Chip size : 0.90 x 0.87 mm^2)

Fig. 1 shows the schematic of the push-push VCO circuit. It consists of microstrip line resonators (MLR1, MLR2) and a pair of common base inductive feedback negative resistance cells (Q1, Q2). The oscillation frequency is determined by $\lambda/4$ microstrip line resonators (MLR1, MLR2) and the oscillation frequency is tuned by the varactor. Negative resistance which compensates the loss of resonators is generated by the microstrip line feedback inductors (MLI1, MLI2). Those mictrostrip line elements are bended to reduce the chip size. The microstrip line components are simulated using HP Momentum 2.5D EM simulator to predict the oscillation frequency well. In addition, since the microstrip line resonators have higher quality factor than on-chip lumped inductors in mm-wave bands, low-phase noise performance can be achieved. The core current is controlled by current mirror. The core current is also optimized for the low phase noise performance. To increase the output power of the 2nd harmonic frequency, the output is matched at 2nd harmonic frequency of 60 GHz using microstrip interdigital capacitor (C1) and microstrip line short stub (MLS1). The base-collector junction capacitance of HBT is used as a varactor for the frequency tuning.

III. DEVICE TECHNOLOGY

The VCO was fabricated using 6-inch InGaP/GaAs HBT process at Knowledge*on foundry. The large signal model of the transistor was performed using VBIC (Vertical Bipolar Inter-Company) model. 1 finger 2 × 10 μm^2 HBTs were used in the core circuit. This device shows a cut-off frequency (f_T) of 60 GHz and a maximum oscillation frequency (f_{MAX}) of 110' GHz. A turn-on voltage of HBT is 1.21 V. The technology provides a SiNx MIM capacitor with 600 pF/mm^2, a 50 Ω/□ NiCr resistor and two metal layers, of which thickness are 1.3 μm and 4 μm, respectively. All circuits are passivated by polyimide. The wafer is thinned to 95 μm with backside via. The properties of a 1 finger 2 × 10 μm^2 HBT are summarized in Table I. Fig. 2 shows the photograph of the fabricated 60 GHz push-push VCO. The chip size is 0.9 × 0.87 mm^2. The chip size is small compared to the reported VCO in V-band.

Table I.
InGaP/GaAs HBT Device Characteristics

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

IV. MEASUREMENT RESULTS

The output spectrums and the phase noise performance of the fundamental oscillation frequency of 30 GHz were

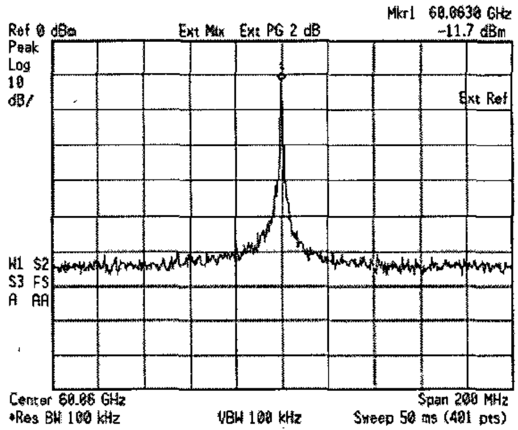


Fig. 3. Measured 60 GHz output spectrum

obtained from HP8764E spectrum analyzer. The output spectrum of 60 GHz was measured using HP E4407B with HP 11974V (50~75GHz) harmonic mixer. The fabricated VCO was tested using GSG probes on Cascade probe station.

Fig. 3 shows the push-push output spectrum of the fabricated VCO, which shows clear spectral purity without any spurious signal. The losses of the microprobe and the cable and the connectors are about 5 dB at 30 GHz, and the losses of probe tip and waveguide components in V-band measurement setup are about 3.4 dB at 60 GHz. The bias condition of VCO is that the collector voltage is 3.5 V and the total current is 45 mA. A free running oscillation frequency of 59.4 GHz is achieved with V_{CONT} of 0 V. It provides the peak output power of -4 dBm.

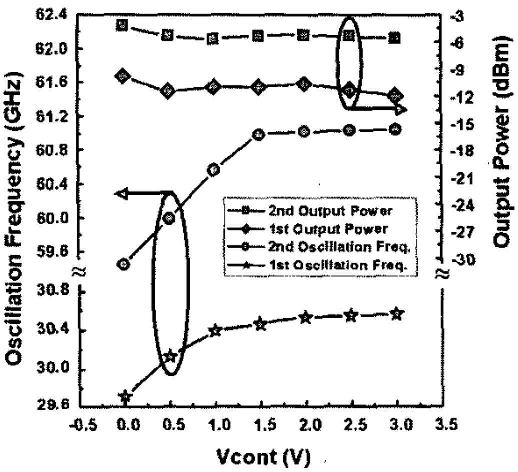
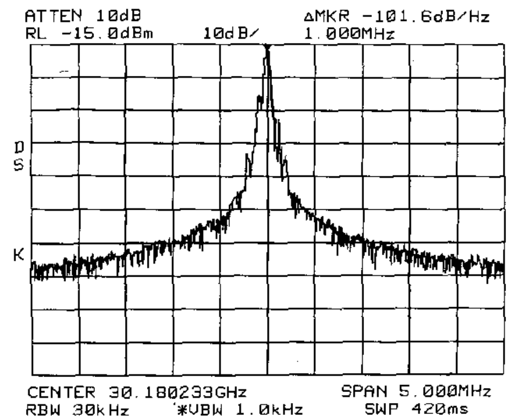
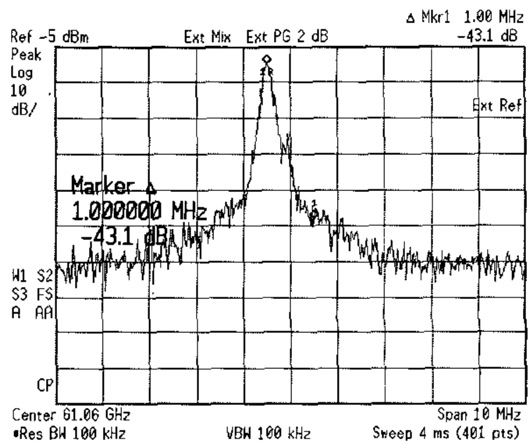


Fig. 4. The oscillation frequency and the output power of the VCO as varying the varactor control bias.

Fig. 4 illustrates the oscillation frequency and the output power characteristics as varying the varactor control bias from 0 V to 3 V. The output power at the fundamental frequency is suppressed about –5 dB lower than that of the push-push output. The output power variation is less than 1.5 dBm in the tuning range. Wide frequency tuning range is achieved to 1.6 GHz from 59.4 to 61 GHz. The measured phase noise is shown in Fig. 5. The phase noise is –101.6 dBc/Hz at 1 MHz offset frequency at the fundamental frequency of 30 GHz and –93 dBc/Hz at 2[nd] harmonic frequency of 60 GHz. The measurement results of the designed VCO are summarized in Table II.



(a)



(b)

Fig. 5. Measured phase noise of the VCO
(a) –101.6 dBc/Hz @ 1 MHz offset for 1[st] frequency
(b) –93.1 dBc/Hz @ 1 MHz offset for 2[nd] frequency

Table II.
Summary of the designed VCO

Oscillation Frequency	59.4 GHz ~ 61 GHz
Output Power	-4 dBm
Phase Noise	-93 dBc/Hz @ 1MHz
Tuning Range	1.6 GHz
DC Bias Supply	3.5V (I_C = 45 mA)

VI. CONCLUSION

We have presented a 60 GHz push-push VCO using commercially available InGaP/GaAs HBT technology. The balanced topology with common base inductive feedback is used to realize the push-push operation. To achieve high 2nd harmonic output power, the output load is matched at 2nd harmonic frequency. For low phase noise performance, $\lambda/4$ microstrip lines are used as a resonator instead of lumped passive resonator. The oscillation frequency is predicted well with an aid of EM simulation for microstrip line resonator and inductor. The presented VCO shows the wide tuning range and the small chip area. It has also comparable performances to other device technologies.

Table III.
Summary of the properties
for the V-band oscillators

Device Technology	Fosc (GHz)	Pout (dBm)	Tuning BW (GHz)	Circuit Size (mm^2)	Phase Noise @ 1MHz offset
InGaP/InGaAs HEMT [13]	60	6.7	0.2	1.4 × 0.92	-87
InP HBT [14]	62	4	0.3	2 × 1.5	-105
AlGaAs/InGaAs HEMT [15]	56	11	X	1.3 × 1.4	-103
SiGe HBT [16]	58	1	X	7.85 × 5	-108
SiGe HBT [17]	58	-8	0.5	10 × 6	-105
This Work	**60**	**-4**	**1.6**	**0.9 × 0.87**	**-93**

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