MMIC Cascode VCO with Low Phase Noise in InGaP/GaAs HBT Process for Ku-Band Application

Bhanu Shrestha[1] · Jae-Young Lee[1] · Jeiyoung Lee[1] · Sang-Hoon Cheon[2] · Nam-Young Kim[1]

Abstract

The MMIC cascode VCO is designed, fabricated, and measured for Ku-band Low Noise Blcok(LNB) system using InGaP/GaAs HBT technology. The phase noise of − 116.4 dBc/Hz at 1 MHz offset with output power of 1.3 dBm is obtained at 11.526 GHz by applying 3 V and 11 mA, which is comparatively better characteristics than compared with the different configuration VCOs fabricated with other technologies. The simulated results of oscillation frequency and second harmonic suppression agree with the measured results. The phase noise is improved due to the use of the smallest value of inductor in frequency determining network and the InGaP ledge function of the technology. The chip size of $830 \times 781\ \mu m^2$ is also achieved.

Key words : HBT VCO, MMIC VCO, LC VCO, InGaP/GaAs VCO, LC Oscillator, Low Phase Noise VCO.

Ⅰ. Introduction

A wireless communication system has been developed rapidly in different fields of Radio Frequency (RF) system such as wireless local area networks (WLANs), Direct Broadcast Satellite(DBS), Global Positioning System(GPS), Radio Frequency Identification (RFID) and so on. Moreover, a satellite communication system is making the world narrower and narrower due to the state-of-the-art technology by providing various services with much more informations[1]. The DBS technology is becoming a major part in TV broadcasting around the world. The DBS tuner is the first section of the satellite receiver system that receives the signal from the antenna. The X-band VCO is an important building block that translates satellite frequency by combining with mixer. Therefore, the MMIC cascode VCO is designed for Ku-band. In satellite communication receiver system, the LNB provides gain for the broadband signal from 12.2 to 12.7 GHz and it translates the signal to the lower frequency ranges from 950 to 1,450 MHz as an Intermediate Frequency(IF) in the indoor unit where the signal amplifies and passes to the tracking filter that selects desired channel. The selected channel is lowered again into the Intermediate Frequency(IF), usually 70 MHz[2].

The frequency used for the VCO design is based on the LNB system, especially used in Japan/Asia/Australia for Convergence Sub-layer(CS), Digital Broadcast Satellite system(DBS). In this system the assigned LO frequency is 11.3 GHz.

During the design of X-band MMIC cascode VCO process, the negative circuit is built by using capacitive feedback with common base configuration followed by common collector configuration in order to increase the power and tuning range. The frequency selective network is designed as a LC tank, and the voltage tuning part is designed for frequency tuning using varactors and, thus whole circuit is fabricated on 6-inch industry process line using InGaP/GaAs HBT technology through Knowledge*on Inc. foundry service.

The cascode configuration is good for reducing external interference even though frequency amplification ratio is lower as compared to cascade configuration and has a high reverse isolation. It can be used for high frequency application with fairly good frequency stability. These are the main causes of selection of this configuration.

Ⅱ. InGaP/GaAs HBT Technology

In HBT technology for microwave application, the base is highly doped and thin base thickness can be

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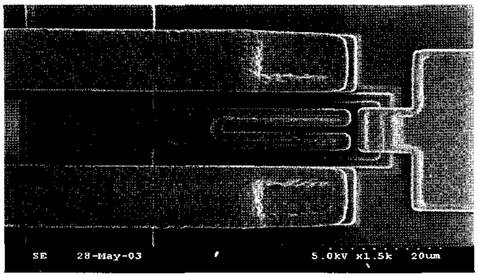

Fig. 1. Photograph of SEM 2 fingers HBT device.

obtained by the epitaxial growth technology. It results relatively thick emitter base depletion layer inside the lightly doped emitter layer for making low emitter base junction capacitance. Due to use of InP ledge, the intrinsic $1/f$ noise can be reduced to improve the phase noise characteristics of MMIC VCO. The merits of the technology are higher speed of relaxed lithographic dimensions, lower output conductance, effectively no parasitic substrate capacitance, and greater radiation hardness. The output conductance is better than that of Si-HBT technology[3].

High emitter injection efficiency and high current gain can be obtained due to the heterostructure emitter base junction with a band gap difference in HBT. The doping concentration in emitter can be lower than that of base of the transistor. There are higher mobilities and saturation velocities in GaAs or InP Ⅲ-V compound semiconductors and it generally makes efficient optical devices due to their direct band gap nature.

The active HBT device with two emitter fingers, emitter width of 2 μm, and emitter length of 20 μm (HL_F2×2×20) is used in the designed. The values of β, f_T, and f_{max} are 118, 50, and 80 GHz respectively. In the case of large signal, VBIC model having improved early effect and temperature modelling characteristics is used which is based on Gummel-Poon model. The InGaP/GaAs HBT photograph is shown in Fig. 1[4].

Ⅲ. Design of GaAs/InGaP HBT Cascode VCO

The MMIC VCO is designed and fabricated using high linearity GaAs/InGaP HBT, HL_F2×2×20. The HBT device has a unit gain current frequency(f_T) of 50 GHz and maximum oscillation frequency(f_{max}) of 80 GHz. The maximum current density of the collector metal is 3 mA/um(practical value). The NiCr thin film resistor of this process has a sheet resistance of 50 $\Omega/\square$.

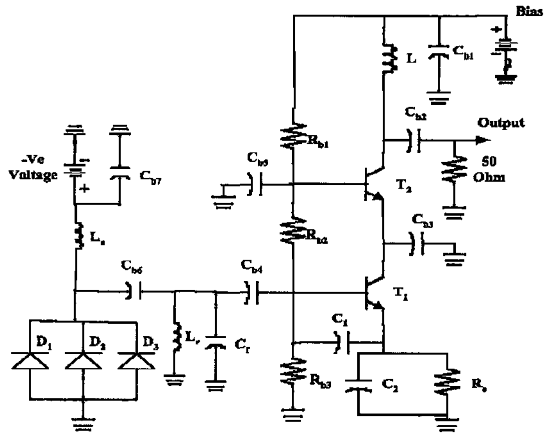

Fig. 2. A complete circuit of MMIC cascode VCO.

In the process of designing, the MMIC cascode VCO is composed of mainly three parts as shown in Fig. 2: the resonator of the VCO is designed by MIM capacitor, C_r and spiral inductor, L_r in parallel combination.

The Q value of inductor plays an important role for lowering the phase noise of the VCO. So, the smallest value of inductor provided by the foundry service is used. The HBT devices are connected in cascode configuration such that the common collector stage is connected to the common base stage to make improve in output power and tuning range. This circuit is good for reducing external interference even though there is low frequency amplification ratio. The two capacitors C_1 and C_2 are connected in series combination as capacitive voltage divider to increase the negative resistance of the circuit. The resistors R_{b1} R_{b2} and R_{b3} are used for biasing. The R_e is used for stabilizing the DC supply due to the temperature variation. So, in the Fig. 2, the lower part, T_1 of the circuit acts as a Colpitts type in common emitter configuration and the upper part, T_2 acts as a buffer amplifier in reducing external interference and in amplification of the oscillation frequency. The output is taken from the collector of the T_2 through the coupling capacitor C_{b2} and capacitors C_{b4} and C_{b5} act as the DC block. The remaining capacitors function as bypass capacitor.

The voltage controlled part is composed of diodes D_1, D_2, and D_3 provided by Knowledge*on Inc. and used as a varactor. Diode capacitance variation is 0.5 pF and its breakdown voltage is 21.7 volts. When reversed bias is applied to it, the oscillation frequency can be varied. The fabricated chip and its size is 830

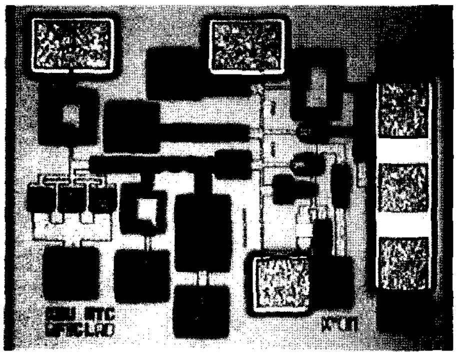

Fig. 3. Microphotograph of fabricated MMIC cascode VCO with the size of 830×781 μm^2.

$\times781$ μm^2 which is shown in Fig. 3.

Ⅳ. Simulation and Measurement Results

The simulated results of the HBT VCO at the frequency of 11.55 GHz exhibits the output power of 3.3 dBm and tuning range of 740 MHz. In the process of measurement, the fabricated VCO is mounted over Printed Circuit Board(PCB) and attached with chip capacitors by using epoxy. Then the DC bias and voltage controlled part are connected by wire bonding. And the measurement is performed using power supply, connecting cable, probe station, and spectrum analyzer. While measuring, the output power of 1.3 dBm with tuning range of 261 MHz are obtained. The phase noise of -116.4 dBc/Hz at 1 MHz offset in 11.526 GHz is achieved as shown in Fig. 4 and Fig. 5 shows the same phase noise characteristics at 1 MHz and 100 kHz offsets. Fig. 6 shows the oscillation frequency and output power as a function of control voltage which is not fully linear curve. Some fluctuations in the oscillation frequency and output power are caused by the effect of diodes used in voltage controlled part. The output power is also increased as the control voltage

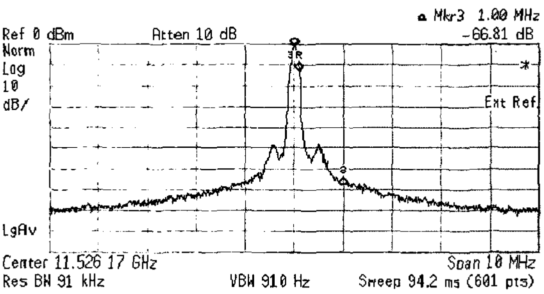

Fig. 4. Phase noise -116.4 dBc@1 MHz offset.

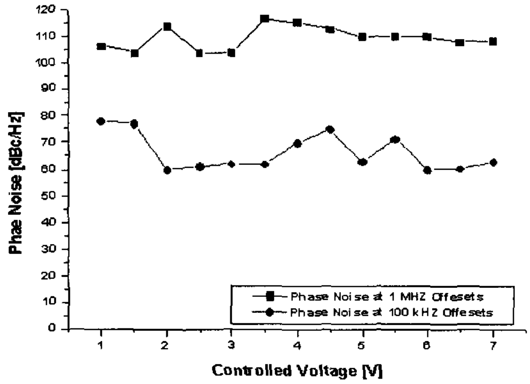

Fig. 5. Phase noise at 100 kHz and 1 MHz offsets.

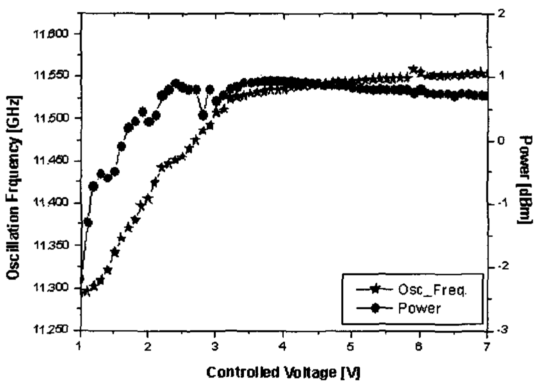

Fig. 6. Oscillation frequency and output power as the function of controlled voltage.

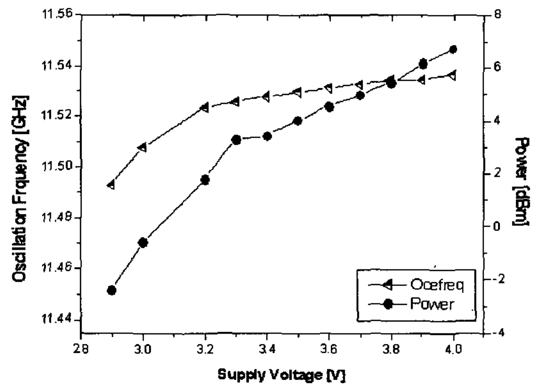

Fig. 7. Frequency pushing and power as a function of supply voltage.

increases. But its pushing figure is 41.2 MHz/V when applying 3.4 V ±0.5 V. This is shown in Fig. 7 which is better result of pushing figure or frequency pushing characteristics. The power dissipation within that frequency range is above the 0 dBm which is necessary as in the specification. The second harmonic supp-

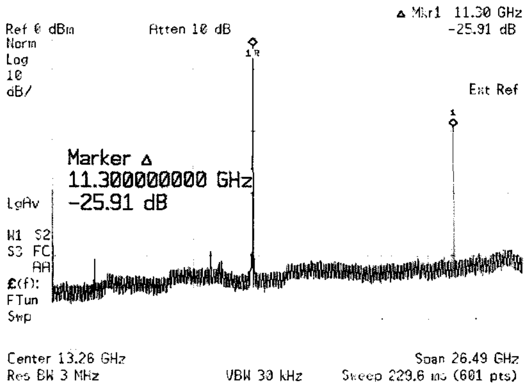

Fig. 8. Ouput spectrum over full span with 2nd harmonic suppression.

ression of 26 dBc over full span having Resolution Bandwidth(RBW) of 3 MHz and Video Bandwidth (VBW) of 30 kHz is shown in Fig. 8 which agrees with the simulated results.

V. Comparison of Measured Results of VCO with Other Technologies

Phase noise is an important parameter of VCO in wireless communication system. If the VCO's phase noise is not good, it can arise fatal problem in communication. The better the phase noise, the more pure the spectrum. The power is also another important parameter of VCOs.

Therefore, the result of phase noise and powers are compared with other VCOs to show how much this design has better phase noise and power characteristics. Even though the references given in the table has different VCO configurations with the same and different technologies, this work is focused on the comparison of phase noise characteristics at 1 MHz offsets at oscillation frequency around 11.526 GHz which are shown in Table 1. All the references included here have better tuning ranges than this work. However, this design has better phase noise characteristics when compared with even at 20 GHz oscillation frequency with output power of − 2 dBm[5]. In the same way, the designed LC cascode VCO has better phase noise characteristics than other VCOs with different technologies with lower power[6]~[8],[11].

The comparison of power consumption is also shown in the Fig. 9. Certainly, the purpose of the designed VCO given in the references may be differ with this design. However, when the results are compared with this design in terms of VCO for Ku-band application, the resulted power is better than other VCOs except for the reference [8]. But the current consumption in the references [6] and [7] have 39 mA and 17 mA respectively which are so higher than this work, and when compared with the higher frequency[8],[10], the phase noise is not bad at 1 MHz offset. All references used in this table have LC resonator as their frequency selective network. The output power of this work is better than LC-VCO[11] of BiCMOS-0.35 μm process. But the supply voltage of those LC-VCOs are less than this work.

Table 1. Comparison of phase noise at 1 MHz offsets with other technologies.

Ref. No.	Technology	Frequency [GHz]	Phase noise @ 1 MHz offsets
[5]	InP HBT	20	− 90
[6]	SiGe-BiCMOS	11	− 112.3
[7]	CMOS	10	− 115
[8]	AlGaAs/GaAs HBT	15.6	− 110
[9]	InGaP/GaAs HBT	15	− 115
This work	InGaP/GaAs HBT	11.52	− 116.4

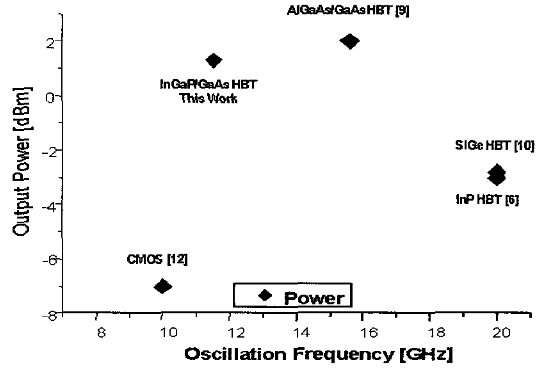

Fig. 9. Comparison of output power as a function of oscillation frequency.

VI. Conclusions

A X-band MMIC cascode VCO is fabricated using InGaP/GaAs HBT process. The oscillation frequency of 11.526 GHz is achieved exactly as in the simulated result when applying supply voltage of 3 V and 11 mA with control voltage of 1.5 V. The phase noise at the same frequency is − 116.4 dBc/Hz at 1 MHz offset with 1.3 dBm output power is achieved. The VCO shows the relatively good phase noise characteristics when compared with other technologies in different VCO configurations. The second harmonic suppression is 26 dBc which agrees with the simulated value.

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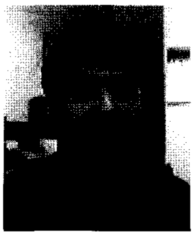

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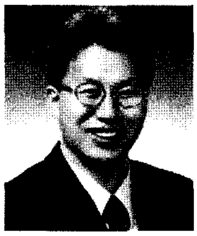

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