Monolithic Ka-band VCO with wide tuning range

Seonghan Ryu, Huijung Kim, Joonyoul Lim, Jounghyun Yim, Woosung Kwon, and Bumman Kim

Kyounghoon Im* , Youngwoong Kim*, Seogtae Han**

Department of Electronic and Electrical Engineering and Microwave Application Research Center
Pohang University of Science and Technology, Pohang, Korea
* Future Communications IC, Sungnam, Korea
** Taeduk Radio Observatory, Taejeon, Korea

***Abstract** This paper reports on the design procedure and mesurement results of a Ka-band MMIC VCO utilizing a 0.15 um T-gate GaAs P-HEMT technology. A balanced buffer amplifier is also developed for assurance of output power higher than 10 dBm. The VCO with center frequency of 35 GHz exhibits a tuning range of up to 3 GHz and typical output power of 10 dBm at 35 GHz without the amplifier. The best measured phase noise at 1MHz offset is –106 dBc/Hz. The buffer amplifier exhibits a typical gain of 5.9 dB with 15dBm output power. A lange coupler is used for a good matching between the VCO and amplifier.*

INTRODUCTION

As the demand for higher frequency applications such as high speed optical communication networks and automotive radars is increased, millimeter wave component technology becomes very important. Tunable low phase noise oscillators are a key component for the low cost millimeter wave systems. Several oscillators operating at millimeter wave frequencies using P-HEMTs or InP based HBTs have been reported [1]-[4]. Although HBTs based VCO demonstrate a good power performance and low phase noise, the process is not compatible with P-HEMT process which is the most favored mm-wave circuit technology. For the integration of monolithic VCOs with other MMIC components using the mature GaAs P-HEMT process, VCO's based on P-HEMT are highly desired for a high level integration at a low cost.

The motivation of this work is to develop monolithic Ka-band VCOs with a low phase noise, good power performance and wide tuning range utilizing conventional GaAs P-HEMT technology. The P-HEMT based Ka-band VCO we have developed delivers a typical output power of 10 dBm at 35GHz without buffer amplifier. This VCO exhibits a tuning range of up to 3 GHz. Best measured phase noise at 1 MHz offset is –106 dBc/Hz.

CIRCUIT DESIGN

A commercial 0.15 um T-gate GaAs P-HEMT foundry process of TRW is used for the design. Active devices show a unity current gain cutoff frequency (f_T) of 81.1 GHz, maximum frequency of oscillation (f_{max}) of 110 GHz and a pinch off voltage of –0.9 V. Capacitances are implemented as a MIM type and show a capacitance of 320 pF/mm^2. in series with the main inductor. A four finger 120 um P-HEMT device is used for output power consideration. The biases of Vds = 3V and Ids = 20 mA are chosen for efficiency consideration. The VCO design procedure follows the design example in [7]. The summation of reactances looking in and out from the gate terminal of Q1 transistor is set to zero at the oscillation frequency of 35 GHz and the negative resistance looking into the gate terminal of Q1 is designed to be about three times larger than the resistance looking into the resonator circuit to achieve a good output power performance.

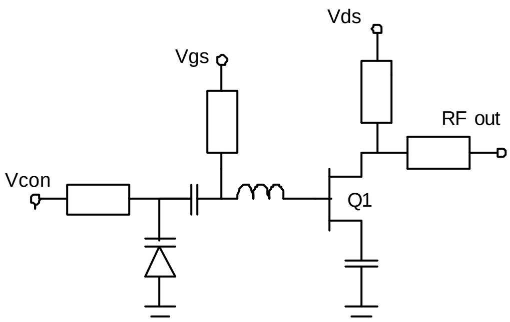

Figure 1: Circuit schematic diagram

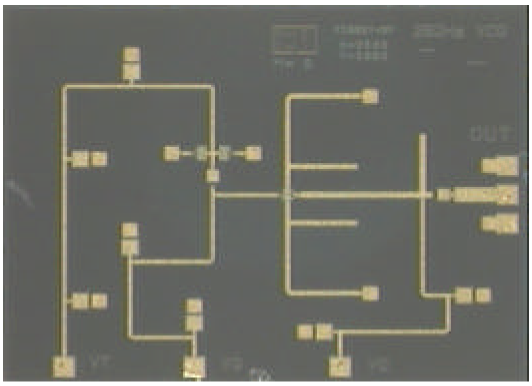

Figure 2: Photograph of the Ka-band monolithic VCO

The negative resistance is generated by connecting an open microstrip stub at the source terminal of Q1. After that, the optimum load impedance for maximum output power is chosen using nonlinear harmonic balance simulation. Two four finger 90 um varactors are connected in parallel and are added to the circuit for a voltage controlled operation with a wide tuning range. All the microstrip line structures are modified utilizing an EM simulation to compensate the uncertainty of quasi – static models at millimeter wave band. Fig. 2 shows photograph of the 35 GHz MMIC VCO. The VCO chip size is 2×2.5 mm^2 , and this size can be reduced further. The buffer amplifier is also designed for assurance of output power higher than 10 dBm. The balanced type configuration utilizing a lange coupler is used to minimize the perturbation from load variation. Fig. 3 and Fig. 4 show the schematic diagram and photograph of the buffer amplifier. The chip size is 2×2.5 mm^2 and bias point of the buffer amplifier is the same as that of the VCO.

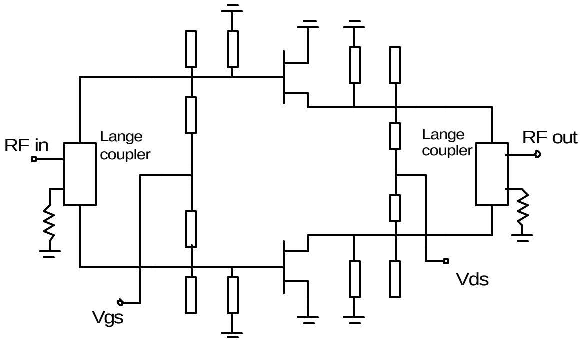

Figure 3: Amplifier schematic diagram

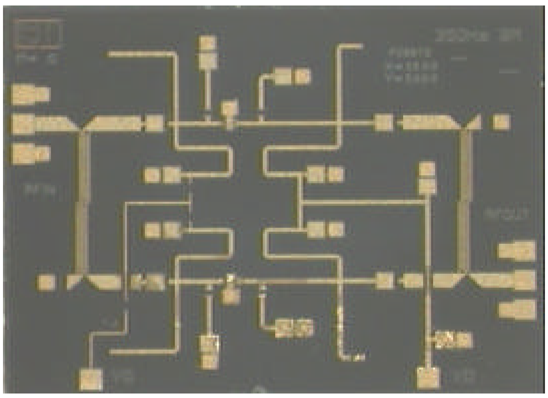

Figure 4: Photograph of the buffer amplifier

MEASUREMENT RESULTS

The 35GHz VCO is measured via on–wafer probing. Fig. 5 plots the oscillation frequency and output power of the VCO connected with the buffer amplifier. Output power higher than 15dBm is obtained within a tuning range from 33.3 to 36.3 GHz with only a slight change in output power. The gain of the buffer amplifier is around 5.9dB across the band, and the VCO generates 10 dBm output. The best measured phase noise of the VCO at 1MHz offset is –106 dBc/Hz. Fig. 6 shows a typical output spectrum of the VCO at 35 GHz. These performances are compared with the recently published results in Table? . The phase noise is comparable to the HBT based VCOs.

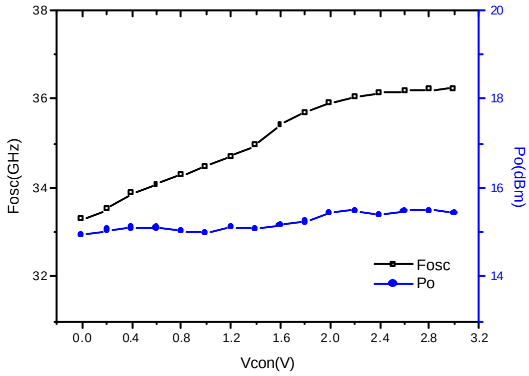

Figure 5: Oscillation frequency and output power responses of the 35 GHz GaAs P-HEMT VCO with buffer amplifier

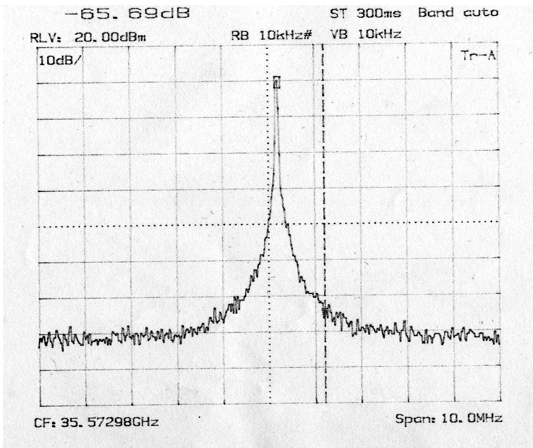

Figure 6: Output spectrum of the 35GHz VCO

CONCLUSION

Monolithic VCO at Ka-band have been developed utilizing 0.15um T-gate GaAs P-HEMT process. Tuning range of up to 3GHz and output power higher than 10dBm have been achieved. Best measured phase noise at 1MHz offset is –106 dBc/Hz. When it is amplified by the buffer amplifier, the power level is increased to 15 dBm. These measurement results are obtained without any tuning on the matching structures. The low phase noise performance, wide tuning range and good output power performance of the VCO enable the possibility for higher level integration for cost effective multi-functional MMIC chips at millimeter wave frequencies for various applications such as single chip transceiver in wireless communication systems or automotive radar systems.

ACKNOWLEDGEMENT

This work was supported by the Agency for Defense Development and Brain Korea 21 projects of the ministry of education in Korea.

REFERENCES

(1) A. Kurdoghlian, et al., "*40 GHz fully integrated and differential monolithic VCO with wide tuning range in AlInAs/InGaAs HBT*," in 23th Ann. IEEE GaAs IC symp. Dig., Oct. 2001, pp. 129-131.
(2) Y. Kwon, et al., " *Large signal analysis and experimental characteristics of monolithic InP-base W-band HEMT oscillators*," in 21th Europen Microwave Conf. Tech Dig., Stuttgart, Germany Sept. 1991.
(3) H. Wang, et al., "*Monolithic W-band VCO's using pseudomorphic AlGaAs/InGaAs/GaAs HEMT's*," in 14th Ann. IEEE GaAs IC Symp. Dig., Philadelphia, PA. Oct. 1994, pp. 30-33.
(4) K Riepe, et al., "*35-40 GHz Monolithic VCO's utilizing high speed GaInP/GaAs HBT's*," in IEEE Microwave and Guided Wave Letters. Vol.4. NO.8. August 1994, pp274-276.
(5) H. Wang, et al., "*An ultra low noise monolithic three stage amplifier using 0.1 um InGaAs/GaAs pseudomorphic HEMT technology*," 1992 IEEE MTT-S International Microwave symposium Digest, vol. 2, pp. 803-806, New Mexico, June, 1992.
(6) K. W. Chang, et al., " *A W-band monolithic down converter*," IEEE Trans on Microwave Theory and Tech., vol. MTT-39, No. 12, pp. 1972-1979, Dec., 1991.
(7) G. Gonzales, '*Microwave Transistor Amplifier Analysis and Design'*, Chapter 5, Prentice-Hall, Englewood Cliffs, NJ, 1998.

Table 1
Comparison of performances of previously published oscillators at the millimeter wave band

	Process	Oscillation Frequency (GHz)	Output power (dBm)	Phase noise at 1MHz offset (dBc/Hz)	Tuning range (GHz)
This work	**P-HEMT**	**35**	**10**	**-106**	**3**
Kurdoghlian [1]	AlGaAs/InGaAs HBT	39	2	-95	3.5
Wang [3]	P-HEMT	90.5	8.8	-68.2	0.6
Riepe [4]	GaInP/GaAs HBT	35	< 3.5	-107	1