Simple K-Band MMIC VCO Utilizing a Miniaturized Hairpin Resonator and a Three-Terminal p-HEMT Varactor With Low Phase Noise and High Output Power Properties

Cheol-Gyu Hwang, Jeong-Seon Lee, Jeong-Hoon Kim, Noh-Hoon Myung, *Member, IEEE*, and Jong-In Song, *Senior Member, IEEE*

***Abstract*—This letter presents a fully monolithic K-band MMIC voltage-controlled oscillator (VCO) implemented by using a 0.25 μm AlGaAs/InGaAs pseudomorphic HEMT (p-HEMT) technology. The use of a half-wavelength miniaturized hairpin-shaped resonator and a three-terminal p-HEMT varactor was effective in reducing the chip size and simplifying fabrication processes of the microwave MMIC VCO without impairing the performance of the circuit. The VCO provides a typical output power of 11.5 dBm at 20.8 GHz and a free-running phase noise of −82 dBc/Hz at 100 kHz offset and −95 dBc/Hz at 1 MHz offset. It also shows a tuning range of 70 MHz with little reduction in output power and high yield properties. The chip size of the MMIC VCO is 1.5×2.0 mm^2.**

***Index Terms*—Hairpin resonator, MMIC VCO, oscillator, three-terminal varactor.**

I. INTRODUCTION

THE fast growing commercial wireless communications market of recent years has significantly increased the demand for low-cost and low phase noise MMIC implementation of voltage-controlled oscillators (VCOs) [1]. In order to implement fully monolithic oscillators, on-chip resonators composed of planar microstrip lines are widely used because of their easier fabrication and higher yield properties. However, their inherent low quality factor and larger size have been the technological bottleneck to the application of low-noise and small-sized MMIC VCOs. V. Gungerich *et al.* recently reported that a coupled resonator structure had a higher Q factor than that of a single microstrip lined counterpart [2]. A hybrid-type miniaturized hairpin-shaped resonator filter showed the possibility of even smaller and simple MMIC VCO application at K-band or above frequency bands [3].

Manuscript received September 6, 2002; revised December 12, 2002. This work was supported, in part, by ITRC-CHOAN, ERC-UFON, and BK21 programs. The majority of this work was done at the Kwangju Institute of Science and Technology (K-JIST). The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

C.-G. Hwang and N.-H. Myung are with the Department of Electrical Engineering and Computer Science, Korea Advanced Institute of Science and Technology (KAIST), Daejon, Korea 305-701.

J.-S. Lee, J.-H. Kim, and J.-I. Song are with the Department of Information and Communications, Kwangju Institute of Science and Technology (K-JIST), Kwangju, Korea 500-712 (e-mail: jisong@kjist.ac.kr).

Digital Object Identifier 10.1109/LMWC.2003.814595

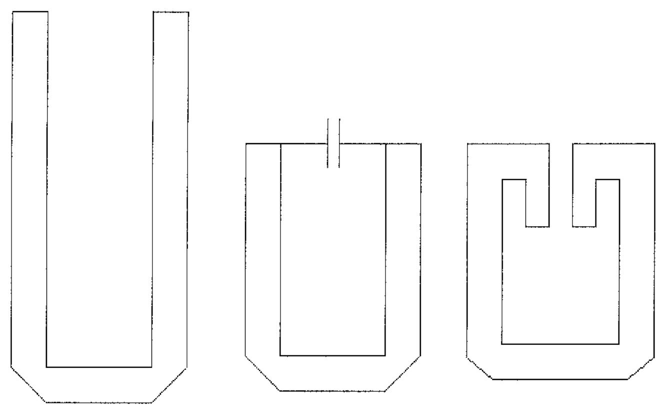

Fig. 1. Structural evolution of hairpin resonators: (a) conventional structure, (b) structure having a lumped element capacitance, and (c) miniaturized structure having coupled lines.

There also have been efforts to reduce the cost of MMIC VCO by replacing the monolithic on-chip varactors with three-terminal devices including MESFETs and HEMTs [4]. Application of three-terminal devices for both as an active component in amplifier stage and as a tuning varactor of resonator stage was very effective in simplifying the whole fabrication steps of MMIC VCO. In this paper, we introduce a fully monolithic, simple, high-power, low-noise VCO, incorporating a miniaturized hairpin resonator coupled to microstrip line and a three-terminal p-HEMT varactor.

II. OSCILLATOR DESIGN

Fig. 1 shows the historical evolution of hairpin-shaped half-wavelength resonators. The conventional hairpin resonator is miniaturized by introducing the parallel-coupled lines with an open-circuited end as shown in the figure. The resonator was designed according to the resonance condition equation derived in [5] considering the effective permittivity and the dispersion effect of the microstrip line on a GaAs substrate. The electrical frequency tuning of the resonator was done by changing the capacitance of the p-HEMT varactor coupled to the upper line in the resonator section. The capacitance change was done using the dependency of C_{gs} (gate-source capacitance) on V_{gs} (gate-source voltage) with source and drain of the p-HEMT connected together to the ground. The use of a three-terminal de-

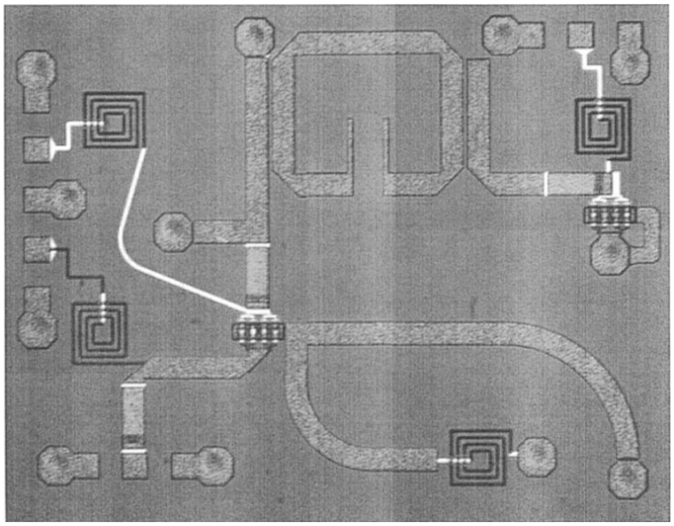

Fig. 2. Photograph of the fabricated MMIC VCO.

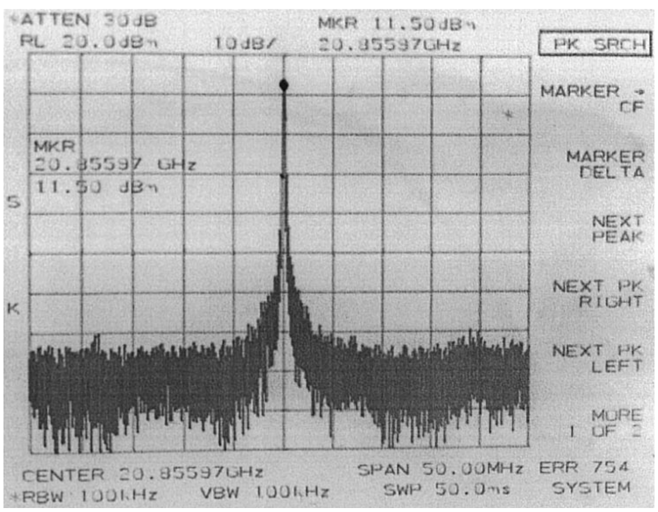

Fig. 3. Output spectrum of the fabricated VCO: $\mathrm{Vds(drain - source\ voltage)} = 2.2$ V, $\mathrm{Vgs(gate - source\ voltage)} = -0.45$ V, $\mathrm{Ids(DC\ current\ in\ drain\ port)} = 58$ mA, and $\mathrm{Vdiode(tuning\ voltage)} = 0$ V.

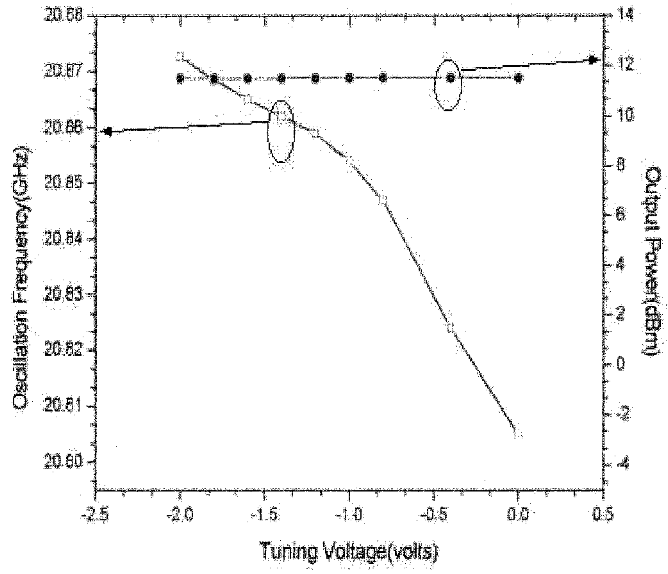

Fig. 4. Measured frequency and output power as a function of the varactor tuning voltage.

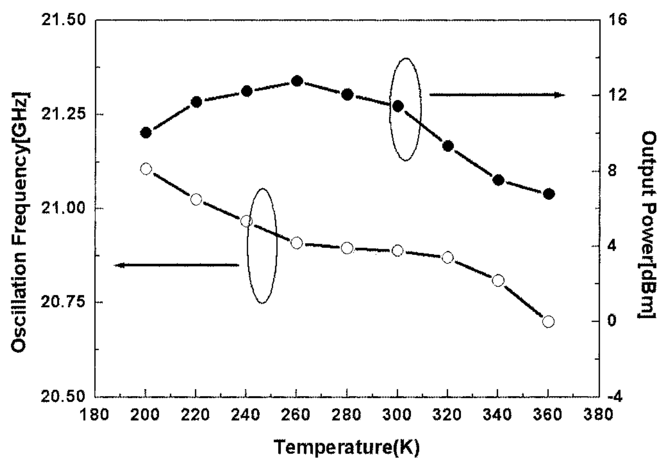

Fig. 5. Measured oscillation frequency drift and output power variation over temperature: $\mathrm{Vds(drain - source\ voltage)} = 2.2$ V, $\mathrm{Vgs(gate - source\ voltage)} = -0.45$ V, $\mathrm{Ids(DC\ current\ in\ drain\ port)} = 58$ mA, and $\mathrm{Vdiode(tuning\ voltage)} = 0$ V.

vice as a varactor was originally suggested by J. Lin and T. Itoh in 1992 [6]. For a negative gate source voltage, the capacitances C_{gs} and C_{gd} are approximately equal in size and the capacitance C_{ds} is negligibly small. When the gate voltage is changed, the capacitance C_{gs} and C_{gd} vary while the capacitance C_{ds} does not. By employing this phenomenon to the varactor of VCO circuit, simplification in MMIC processing steps can be achieved [7].

In the negative resistance generation part of the VCO, stub lines attached in source terminal are used to reduce parasitic component and to achieve easier fabrication. The active device used was a low-noise AlGaAs/InGaAs p-HEMT having 8 fingers of 0.25×50 μm^2 gate. The simulation of the VCO was performed using an Agilent ADS (S-parameter, momentum and harmonic balance simulators). The lengths of feedback stub lines in the source port of the transistor were optimized in order to generate an enough negative resistance to compensate for the loss of the resonator. A linear small signal device model was used to ensure the start-up of oscillation at the frequency of 21 GHz. And a table-based nonlinear model (root model) of the transistor was used in harmonic balance simulation to more accurately predict output power and to optimize the phase noise characteristics of the VCO. The output power of the oscillation signal was also optimized by changing the bias point of the transistor and matching circuitry while keeping harmonic components suppressed.

A spiral inductor and an MIM capacitor were used for biasing of the transistor. G-S-G type probing pads were also used for on-wafer testing to minimize possible parasitic effects of the dc probes. Passive microstrip lines were placed as far as possible to avoid unwanted coupling effects between them. Fig. 2 shows the photograph of the fabricated MMIC VCO circuit. The chip size of the fabricated MMIC VCO was 2.0×1.5 mm^2.

III. Measurement Results

On-wafer measurements of oscillation frequency, output power, and phase noise characteristics were performed using an Agilent 8565E spectrum analyzer. Fig. 3 shows a typical output spectrum of the fabricated VCO. The oscillation frequency was 20.8 GHz and the output power was 11.5 dBm at the varactor diode tuning voltage of 0 V. Phase noise at 100 kHz and 1 MHz offset from carrier was measured to be −82 dBc/Hz and −95 dBc/Hz, respectively. This phase noise and output power characteristics of the MMIC VCO were comparable with or even better than those reported in [8]. Fig. 4 shows the measured frequency and output power level while varying the varactor voltage. A tuning rage of 80 MHz was achieved with a very little reduction in the output power. Second harmonic suppression of 17 dB or more is observed over the tuning range. The oscillation frequency drift and output power variation over temperature is shown in Fig. 5. The average temperature coefficient (TC) of oscillation frequency is −119 ppm/K for temperatures between 200 K and 360 K.

IV. Conclusions

A K-band p-HEMT MMIC VCO with a miniaturized microstrip hairpin resonator and a three-terminal p-HEMT varactor has been demonstrated. The introduction of a miniaturized hairpin resonator and a three-terminal p-HEMT varactor to the MMIC VCO application was proved to be effective in reducing the overall chip size and simplifying the processing steps without reducing oscillator performances.

Acknowledgment

The authors would like to thank ETRI and KAIST IDEC for their support in MMIC fabrication.

References

[1] Y. Takimoto and T. Ihara, "Research activities on millimeter wave indoor communication systems in Japan," in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1993, pp. 673–676.

[2] V. Gungerich, F. Zinkler, W. Anzill, and P.Peter Russer, "Noise calculation and experimental results of varactor tunable oscillators with significantly reduced phase noise," *IEEE Trans. Microwave Theory Tech.*, vol. 43, no. 2, pp. 278–285, Feb. 1995.

[3] Y. H. Yon, S. Y. Lee, J. Y. Lee, T. W. Yoo, M. S. Park, and U. S. Hong, "A design of voltage controlled hair-pin resonator oscillator for the use of clock recovery/data regeneration circuit in 10 Gbps SDH fiber optic systems," *J. Korean Inst. Commun. Sci.*, vol. 21, no. 5, pp. 1304–1316, 1996.

[4] R. Kozhuharov and H. Zirath, "A millimeter wave monolithic VCO with an integrated HEMT as a varactor," in *IEEE Frequency Control Symp. PDA Exhibition*, 2001, pp. 820–823.

[5] M. Sagawa, K. Takahashi, and M. Makimoto, "Miniaturized hairpin resonator filters and their application to receiver front-end MIC's," *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 1991–1997, Dec. 1989.

[6] J. Lin and T. Itoh, "Tunable active bandpass filters using three-terminal MESFET varactors," in *IEEE MTT-S Dig.*, 1992, pp. 921–924.

[7] K. Ohata *et al.*, "A millemeter wave monolithic VCO with integrated heterojunction FET as a varactor," in *1994 Eur. Microwave Conf. Proc.*, 1994, pp. 1667–1672.

[8] C. H. Lee, S. Han, B. Matinpur, and J. Laskar, "GaAs MESFET-based MMIC VCO with low phase noise performance," in *2000 IEEE GaAs IC Symp. Tech. Dig.*, 2000, pp. 95–98.