Design of VCO for 2.4GHz Wireless Applications Using Transmission Line Resonators

R. K. Pokharel, A. Imada, S. Sasaki, H. Kanaya, and K. Yoshida

Graduate School of Information Science and Electrical Engineering

Kyushu University

744 Motooka, Nishi-ku, Fukuoka, 819-0395 Japan
Email: pokharel@ed.kyushu-u.ac.jp

***Abstract*—A voltage-controlled oscillator (VCO) employing on-chip coplanar waveguide (CPW) resonator is proposed for 2.4GHz wireless applications and comparative study between the proposed VCO and a conventional VCO which is composed of LC-tank resonator (LC-VCO), is carried out. By comparing the measured results on the fabricated chip on TSMC 0.35μm BiCMOS technology, it has noted that the VCO employing on-chip CPW resonator is smaller in size by about 30% and frequency-tuning range is higher than LC-VCO. Phase noise is comparable but power consumption is deteriorated.**

Index terms: VCO, CPW resonator, LC-tank resonator, chip size, frequency-tuning range.

I. INTRODUCTION

As evidence from the recent and rapid growth of wireless communication systems such as 3G cellular phones, wireless LAN, RFID tags, ETC (ETC: Electronic-Toll Collection) systems and so on, there are ever increasing demands of low cost, high performance, small size, and high speed microwave devices, circuits, components to meet the existing and future demands of wireless systems [1]-[5]. Therefore, the design of high frequency analog circuits (RFIC components) has become important in LSI technology. Although the performance of the CMOS chip has a limitation in the high frequency and high-speed applications, it has become a better option due to its low cost compared to GaAs device [4], [5].

Spiral inductors are indispensable in designing RFIC components such as amplifiers, mixers, voltage-controlled oscillators (VCO), or impedance-matching circuits that results in the miniaturization of RFIC components a difficult task. Distributed elements made of transmission lines to replace spiral inductors are particularly effective when their size becomes smaller, as the frequency in use increases. Among the transmission lines, coplanar waveguide (CPW) is easy to fabricate by the LSI technology compared to its counter part such as microstrip or strip lines because the signal line and ground plane exist on the same plane [6] so that there is no need of via holes.

The applications of the distributed elements made of transmission lines were reported in the CMOS or BiCMOS LSI chip [7]-[9]. The CPW was exploited as an inductor and used to design a conventional-type matching circuit for an LNA [7] in microwave frequency band. However, the application of CPW as an inductor takes larger space than a conventional spiral inductor [7]. Some of the present authors have also implemented CPW as a resonator to realize on-chip matching circuits for LSI chip using quarter-wave length resonator and impedance inverters [8], [9].

Furthermore, CPW has also been employed to design VCO at various frequency bands where CPW acts as an inductor [10] and as a resonator [11]. They are particularity effective and popular in millimeter-wave frequency band and above [11]. The on-chip CPW resonator for VCO design in microwave frequency band has not been reported yet to our knowledge. It may be due to its difficulty to accommodate the frequency-dependent resonator's length for on-chip fabrication.

In this paper, we implemented on-chip CPW quarter wavelength resonator to design a VCO for 2.4GHz-band wireless applications on TSMC 0.35 μm BiCMOS technology. The CPW resonators are designed in meander line structure so that it can easily exploit the vacant space of the chip. One of the advantages of the proposed VCO using on-chip CPW resonator compared to a LC-VCO is the chip area which is reduced by about 30%, and higher frequency-tuning range (FTR).

1-4244-0749-4/07/$20.00 @2007 IEEE.

II. DESIGN OF ON-CHIP CPW RESONATOR

On-chip CPW resonator is designed and fabricated. To adjust it inside chip, CPW resonator is designed in meander line structure. Therefore, its losses are discussed in this section at first. Fig. 1(a) shows the cross-section of CPW lines and Fig. 1(b) shows the fabricated on-chip CPW line in meander structure. In order to avoid the loss in the Si-substrate, we covered the lowest metal (metal-1) in all area of the CPW structure, namely conductor backed CPW. The conductance of the metal is $4.1x10^7$ S/m. The signal width and the interval between the slots of the CPW transmission line are 5 μm and 15 μm, respectively.

Fig. 2 shows the comparison of the frequency responses of the designed CPW line resonator where insertion loss (S_{21}) of the EM-simulation result (Agilent Co., Momentum) is almost in agreement with that of the experimental result. However, it is noted that there is loss of about 2.5 dB at 2.4 GHz which has to be improved to achieve better performance of the designed RFIC components using these on-chip CPW lines and this is considered as one of the priorities works in near future. Fig. 3 shows the air coplanar probe system used in this paper for on-wafer measurement. The input and output microwave characteristics are measured by using air coplanar probes (GSG 150; Cascade Microtech Inc.) and computed controlled vector network analyzer (HP-8722; HP).

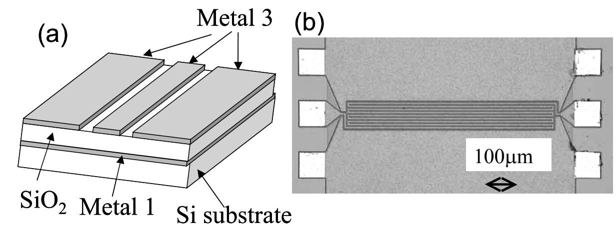


Figure 1. Cross-section of CPW (a) and chip photo of designed on-chip CPW resonator (b).

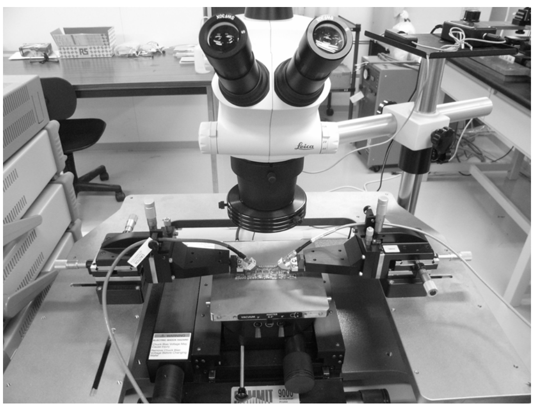


Figure 2. Air coplanar probe system (GSG 150; Cascade Microtech Inc.)

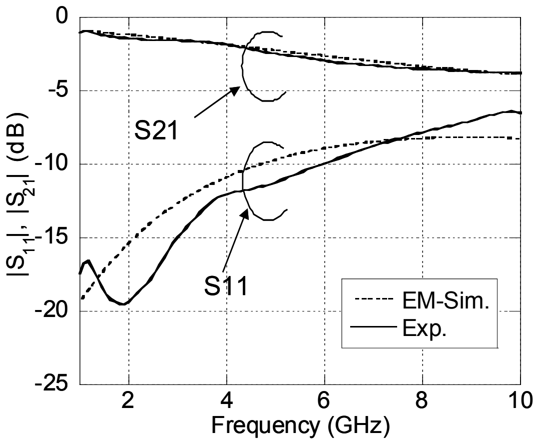


Figure 3. Frequency responses of the CPW meander line.

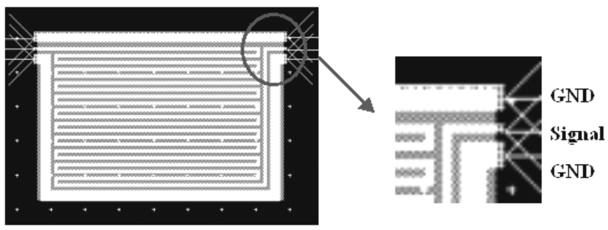


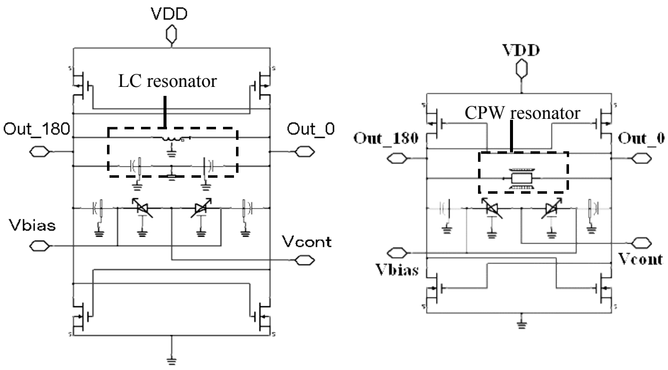
Figure 4. Layout of CPW line resonator.

III. DESIGN OF VCO USING ON-CHIP CPW RESONATOR

In this section, we design a VCO using on-chip CPW resonator instead of LC-tank resonator. Fig. 4 shows the layout of on-chip CPW resonator designed and characterized by EM simulator. The signal line and slot size is 5 μm each, respectively. Bottom metal (Metal-1) is used as ground planes covering all portion of CPW to reduce the losses. Total length of the line is 6700 μm which is supposed to be a quarter-wavelength resonator at 2.4 GHz.

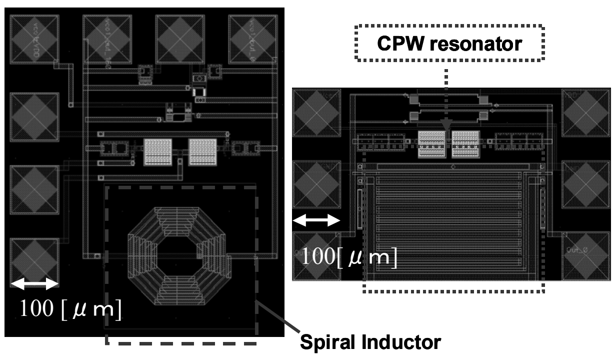
Fig. 5 shows the schematics of the designed VCO. In the design, widely used CMOS cross-coupled structure [13][14] is used. In Fig. 5(a), LC-VCO is shown and that of using the CPW resonator is shown in Fig. 5(b). Co-simulations method is used to simulate the passive components together with active elements. Layouts of both VCO are shown in Fig. 6. One of the advantages of using CPW resonators is that it takes 30% less on-chip space than that of a conventional LC-VCO in same fabrication technology.

The comparison of simulated parameters between the VCOs using CPW resonator and LC resonator is shown in Table 1. From the table, it is noted that the VCO using CPW resonator has advantages in terms of chip size and frequency-turning range (FTR). On the other hand, it has the adverse performance in terms of power consumption and phase noise.



(a) (b)

Figure 5. Schematics of VCO using LC resonator (a) and proposed CPW resonator (b).



(a) (b)

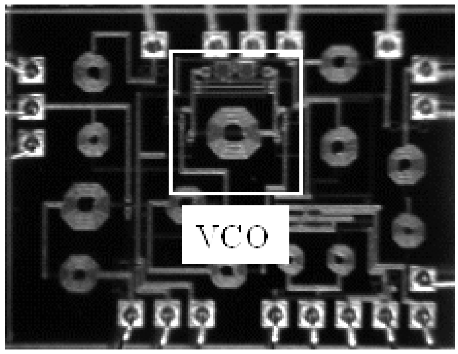
Figure 6. Layouts of the designed VCO using LC resonator (a), and CPW resonator (b).

TABLE I. COMPARISON OF SIMULATED PARAMETERS BETWEEN TWO VCO USING LC RESONATOR AND ON-CHIP CPW RESONATOR, RESPECTIVELY. [FTR=FREQUENCY-TUNING RANGE]

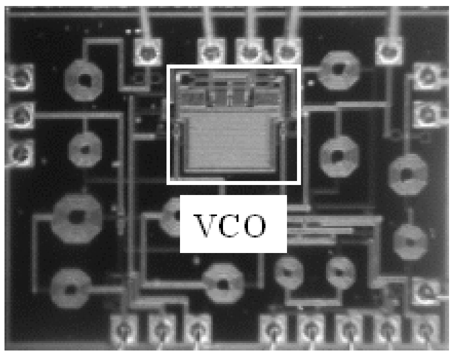
	LC resonator	CPW resonator
Center Frequency [GHz]	2.456	2.789
FTR [%]	10	24
Phase noise [dBc/Hz]	-126	-118
Area [m^2]	$2.2x10^{-7}$	$1.8x10^{-7}$

IV. FABRICATED CHIP AND EXPERIMENTAL RESULTS

Fig. 7 shows a chip photo of proposed VCOs integrated with down conversion mixer. Our purpose was to fabricate an integrated RF front-end containing LNA, mixer and VCO, therefore we fabricated here an integrated down-conversion mixers with the designed VCOs. Therefore, we could not carry out the detail study of noise performance of the fabricated VCOs, so the motivation of this research is to confirm the operation of the proposed VCO. In Fig. 7(a), chip photo of a LC-VCO is shown whereas chip photo of VCO using on-chip CPW resonator is shown in Fig. 7(b).



(a)



(b)

Figure 7. Chip photographs of an integrated down conversion mixer with fabricated VCOs using LC resonator (a) and on-chip CPW resonator (b).

The integrated chip of VCO and mixer is measured. In this paper, we present only a few of the measured results of VCO to confirm its operation while mixer is in off-state. A spectrum analyzer is used to measure the output frequency of VCO. One of the examples of the output spectrum of VCO is shown in Fig. 8. The variation of measured output frequency so-called frequency-turning range (FTR) with respect to the controlled voltage is shown in Fig. 9. The measured results also verify the designed FTR shown in Table 1. In the measured results of the VCO using the proposed on-chip CPW resonator, the center frequency is 2.63GHz which is 0.23 GHz greater than the designed value. One of the reasons of this discrepancy is the relative permittivity of Si-substrate that assumed in the design of CPW resonator which directly results in the length of CPW resonator.

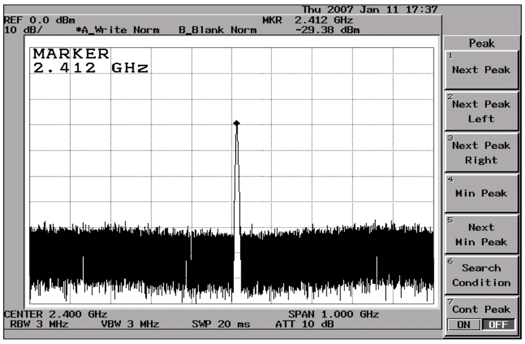


Figure 8. An example of VCO output measured by spectrum analyzer.

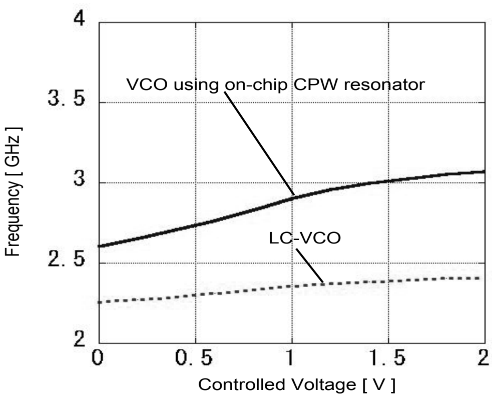


Figure 9. Measurement results of frequency-turning rage showing comparison of two fabricated VCOs.

V. CONCLUTIONS

A 2.4GHz-band VCO employing on-chip CPW resonator instead of LC-tank resonator is proposed, designed and fabricated on TSMC 0.35 μm CMOS technology. The advantages of employing CPW resonator is the larger frequency-tuning range, and it also saves about 30% of chip size. The simulated noise figure of the proposed VCO employing on-chip CPW resonator is comparable to that of using LC resonator.

ACKNOWLEDGMENT

This work was partly supported by a grant of Knowledge Cluster Initiative implemented by Ministry of Education, Culture, Sports, Science and Technology(MEXT). This work was also partly supported by VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with CADENCE Corporation and Agilent Corporation.

REFERENCES

[1] A. Matsuzawa, "RF-SoC-expectations and required conditions", IEEE. Trans. Microwave Theory Tech., vol. 50, no. 1, pp. 245-253, January 2002.

[2] M. S. J. Steyaert, G.D. Muer, P. Leroux, M. Borremans, and K. Mertens, "Lov-Voltage Low-Power CMOS-RF Transceiver Design", IEEE. Trans. Microwave Theory Tech., vol. 50, no. 1, pp. 281-287, January 2002.

[3] T. H. Lee, H. Samavati, and H. R. Rategh, "5-GHz CMOS Wireless LANs", IEEE. Trans. Microwave Theory Tech., vol. 50, no. 1, pp. 268-280, January 2002.

[4] D. L. Harame, D. C. Ahlgren, D. D. Coolbaugh, J. S. Dunn, G. G. Freeman, J. D. Gillis, R. A. Groves, G. N. Hendersen, R. A. Johnson, A. J. Joseph, S. Subbanna, A. M. Victor, K. M. Watson, C. S. Webster, and P. J. Zampardi, P.J., "Current status and future trends of SiGe BiCMOS technology," IEEE. Trans. Electron Device, vol. 48, no. 11, pp. 2575-2594, November 2001.

[5] O. Shana, I. Linscott, and L. Tyler, "Frequency-Scalable SiGe Bipolar RF Front-End Design", IEEE Journal of Solid-State Circuit, vol.36, no. 6, pp. 888-895, June 2001.

[6] I. Wolff, "Coplanar micrwave integrated circuits," pp. 514-517, Wiley Interscience, 2006.

[7] M. Ono, N. Suematsu, S. Kubo, K. Nakajima, Y. Iyama, and O. Ishida, "Si substrate resistivity design for on-chip matching circuit based on electro-magnetic simulation", IEICE Trans. Electron., vol. E84-C, no. 7, pp. 923-929 July 2001.

[8] H. Kanaya, R. K. Pokharel, F. Koga, D. Arima, S. Kim, and K. Yoshida, "Design of Coplanar Waveguide On-Chip Impedance-Matching Circuit for Wireless Receiver Front-End," 2006 IEEE Radio-Frequency Integrated Circuits (RFIC) Symposium, paper no. 1229, June 2006.

[9] H. Kanaya, R. K. Pokharel, F. Koga, and K. Yoshida, "Design and Verification of On-Chip Impedance-Matching Circuit Using Transmission-Line Theory for 2.4 GHz-Band Wireless Receiver Front-End," Trans. of IEICE on Electron., Vol. 89-C, no. 12, pp. 1888-1895, Dec. 2006.

[10] J. Lin, Y. Chen, D. Humphrey, R. A. Hamm, R. Malik, A. Tate, R. Kopf, and R. Ryan, "Ka-band monolithic InGaAs/InP HBT VCO in CPW structure," Microwave and Guided Wave Letters, vol. 5, issue 1, pp. 379-381, Nov. 1995.

[11] P. Chen, Z. Tsai, S. Lu, and H. Wang, "An ultra low phase noise W-band GaAs-based PHEMT MMIC CPW VCO," 33rd European Microwave Conference, pp. 503-506, 2003.

[12] R. E. Amaya, V. Levenets, N. G. Tarr, and C. Plett , "Copper coplanar waveguides in Si substrates for 10 GHz applications," Journal of Vacuum Science and Technology, Surfaces, and Films, vol. 22, Issue 3, pp. 847-850, May 2004.

[13] L. Dai, and R. Harjani, "Design of high-performance CMOS voltage controlled oscillators," Kluwer Academic Publishers, 2003.

[14] A. Hajimiri and T. H. Lee, "The design of low noise oscillators," Kluwer Academic Publishers, 2004.