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A 5GHzVCO with Series VaractorBank to Compensate Large Kvco

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Abstract

This paper presents the design of a voltage controlled oscillator (VCO) with small VCO gain (K_{vco}) variation. To compensate large K_{vco} variation, a series varactor bank has been added to the conventional LC-tank with parallel capacitor bank array. Implemented in a 0.13μm CMOS RF technology, the proposed VCO can be tuned from 4.6GH to 5.5GHz with the K_{vco} variation of less than 9.6%. While consuming 3.1mA from a 1.2V supply, the VCO has -120dBc/Hz phase noise at 1MHz offset from the carrier.

Keywords:*CMOS(Complementary Metal Oxide Semiconductor), VCO(Voltage controlled oscillator), AMOS(Accumulation MOS)varactor, Series varactor bank*

1. Introduction

Among The VCO gain (Kvco) of conventional structure is variable across the entire tuning range, which increases the phase noise but is useful for widening the tuning range of the VCOs, and this essentially nonlinear characteristic will deteriorate the phase noise performance of VCO and phase locked loop[1,2].To cover such a widebandfrequency range, switching capacitor array is usually usedin LC voltage-controlled-oscillator (VCO) to extend thetuning range with low VCO tuning gain (K_{vco}), whichavoids degrading the phase noise performance. For low phase noise, it is desirable to have as small aK_{vco} as possible, but smallK_{vco} means narrow frequencylocking range. To extend the frequency locking range with smallK_{vco}, the LC-tank VCO may employ a switchable capacitorbank [3–6]. The oscillation frequency of theLC-tank VCO is given as

$$f_{osc} = \frac{1}{2\pi\sqrt{L(C_v + C_{Cap.bank})}} \qquad (1)$$

Where C_v and $C_{Cap.bank}$are the capacitance of the varactorand switchable capacitor bank, respectively. The oscillation frequencyf_{osc} coarsely controlled by$C_{Cap.bank}$and finelytuned by$C_v$whose value is determined byV_{tune}. The VCOgain,K_{vco}, can be derived as given by Eq. (2)

$$K_{VCO} = \frac{\partial f_{osc}}{\partial V_{tune}} = -\frac{1}{4\pi\sqrt{L}(C_v + C_{Cap.bank})^{1.5}} \cdot \frac{\partial C_v}{\partial V_{tune}} \quad (2)$$

From the above equation, it can be easily shown thatK_{vco} isa strong function of the capacitance$C_{Cap.bank}$of the switchedcapacitor bank. Therefore, the loop characteristics of the PLLemploying the LC-tank VCO will change according to the valueof$C_{Cap.bank}$, which is a function of the operation frequency of the PLL. Then, the loop characteristics of the PLL cannot beoptimized for the whole operation frequency range due to thevariation ofK_{vco}. This problem becomes more severe whenthe frequency tuning range is required to be wide. For widefrequency tuning range, the difference between the minimumand maximum values of$C_{Cap.bank}$would be large, meaningthelarge variation ofK_{vco}. Therefore,

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there must be a trade-offbetween the frequency tuning range and VCO gain variation.This paper proposes a series-varactor, parallel capacitor bank structurewhich minimizes the VCO gain variation. Section 2describesAMOS varactor and the proposed VCO circuit. Results of theVCO implementedin a 0.13μm CMOS technology are given in Section 3. The conclusion follows in Section 4.

2.1 AMOS (Accumulation MOS) Varactor

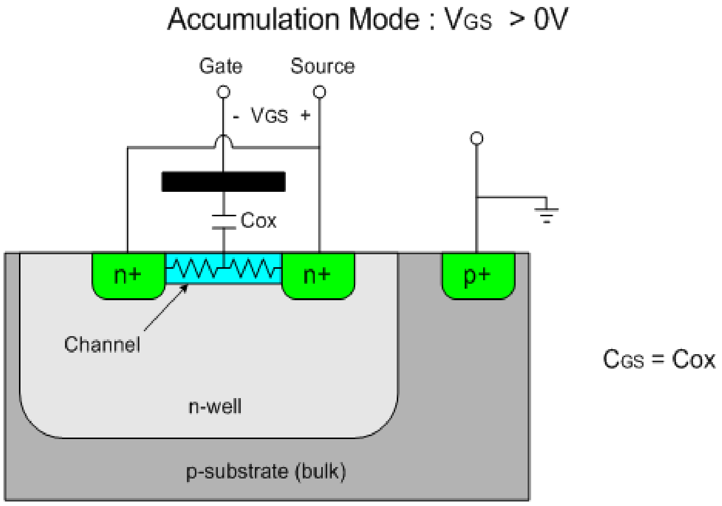

Figure 1. AMOS Varactor Structure and Operation

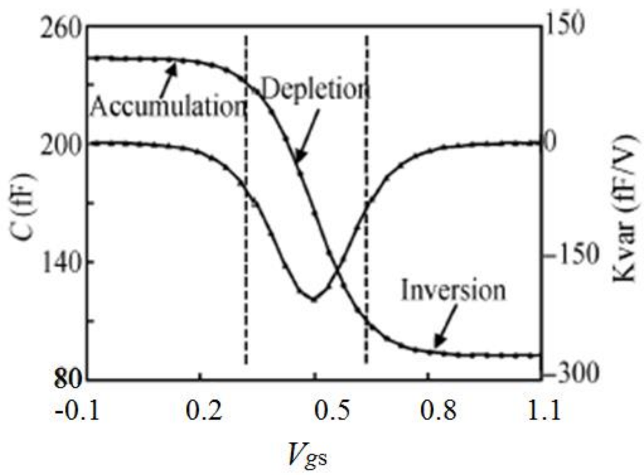

Figure 2. AMOS VaractorC-V Characteristic

The accumulation MOS (AMOS) varactor has been a popularchoice for VCO varactor, and has been employed in manyVCO circuits.[7-13] The AMOS varactor has three modes of operation:accumulation, depletion, and inversion, and the capacitanceof this device depend on the mode of operation.AnMOS based varactor with drain, source and bulk (S = D= B) configuration is utilized in the proposed VCO design.The dc tuning voltage (Vtune) is applied at the gate of nMOSvaractor and variable capacitance is achieved. The required capacitance of nMOSvaractorcan be achieved using Eq. (3).

$$C_v = C_{ox} \times W.L.nf \quad (3)$$

Where Cox is the oxidation capacitance, W is the width, L isthe length of the active device and nfstands for the numberof the fingers [14].

The structure and operation of the AMOS capacitor isshown in Figure 1, and the C–V characteristic is shown in Figure 2. When the gate electrode is biased at the positive end, theAMOS is operated in the accumulation mode, the Cv representsCmax. As the gate electrode becomes negative, a depletionregion is formed, and the Cv represents Cmin.The AMOS varactor has a wider tuning range and lowerparasitic resistance, and the VCOs adopting the AMOS varactorsdemonstrate low power dissipation and low phasenoise. The C–V characteristic of the AMOS varactor exhibitsa good adjusting ratio (Cmax=Cmin). However, the C–Vcurve has a highly nonlinear characteristic, which means Kvaris not constant across the tuning range, and the more the curvedeparts from linearity, the more it converts low frequency noiseinto phase noise [10].

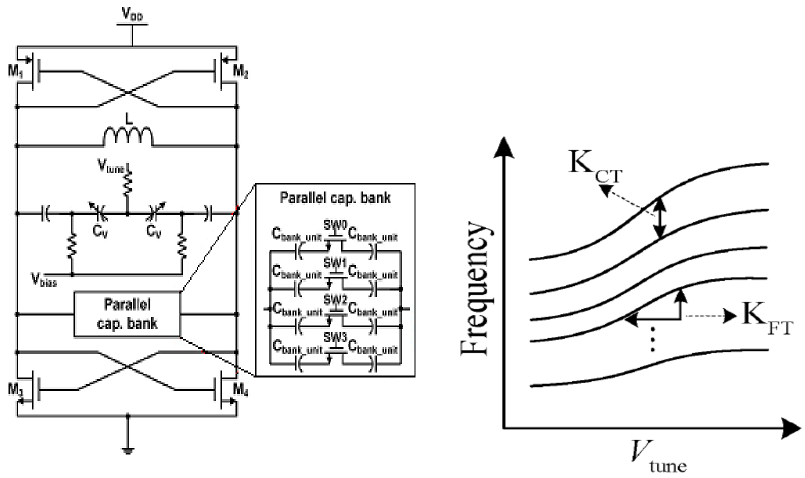

Figure 3. Conventional LC-tank VCO with Parallal Capacitor Bank

2.2. Voltage-controlled Oscillator with Small VCO Gain Variation

The conventional LC-tank VCO shown in Figure 3 employs as witchable capacitor bank that is connected to the varactor inparallel. According to Eq. (2), as$C_{Cap.bank}$ getslarger, $|K_{vco}|$ decrasesand thus for higher oscillation frequency, $|K_{vco}|$ becomes larger. To cover a wideband frequency rangewith low KVCO, switching capacitor array is usuallyadopted, which is shown in Figure 3. Varactor Cvis tunedby the control voltage to change the output frequencycontinuously, while a binary weighted capacitor array iscontrolled digitally to shift the output frequency banddiscretely, where 4bit is used for example. The typical schematic and tuning characteristic of conventionalfully-integrated cross-coupled CMOS LC-VCO is shown in Figure 3. Coarse and fine tuning is realized by settinga proper digital code to the switched capacitor bank and applyingan analog voltage to thevaractor respectively, and thedigital and analog tuning sensitivities are defined as KCTandKFT respectively. To achieve linear tuning characteristic, weshould reduce the variation of fine and coarse tuning sensitivity.

Although the switching capacitor topology is useful toextend the output frequency range while maintaining alower KVCO, it has two disadvantages. Firstly, equalcapacitor is switched in or out of the bank whenever alower or higher band is required. Due to the nonlinearityof frequency to capacitance, KVCO will change by a factorof 8 when the output frequency doubles by reducing thetank capacitance to a quarter.

If the capacitor bank is connected to the varactor in series asshown in Figure4, the oscillation frequency is given as

$$f_{osc} = \frac{1}{2\pi} \cdot \sqrt{\frac{C_v + C_{ser.Var}}{L(C_v C_{ser.Var})}} \quad (4)$$

and the VCO gain K_{VCO} is

$$K_{VCO} = \frac{1}{4\pi C_v^2} \cdot \sqrt{\frac{C_v C_{ser.Var}}{L(C_v + C_{ser.Var})}} \cdot \frac{\partial C_v}{\partial V_{tune}}$$
$$= -\frac{1}{8\pi^2 C_v^2 L} \cdot \frac{1}{f_{osc}} \cdot \frac{\partial C_v}{\partial V_{tune}} \quad (5)$$

Therefore, for higher oscillation frequency, K_{vco} decreases with a series-connected varactor bank while it increases with a parallel-connected capacitor bank. So, if we combine the series-connected varactor bank and parallel-connected capacitor bank as shown in Figure 5, the VCO gain variation can be minimized.To minimize the variations of boththe analog tuninggain K_{VCO} and band step for wideband applications, aproposed architecture is shown in Figure 3. The idea is tomake both the size of capacitors and varactors changeable.Instead of using one fixed analog varactor and a binaryweighted capacitor array, a number of capacitors andvaractors with different values are adopted. At lowerfrequency band the gain K_{VCO} is low, so a majority ofvaractor units are connected to the analog control voltage,and other varactor units are connected to the power supplyor ground to get minimum fixed capacitance. On thecontrary, at higher frequency band only a minority ofvaractor units are switched in. On the other hand, toobtain equal frequency band step, the fixed capacitors arealso made changeable.

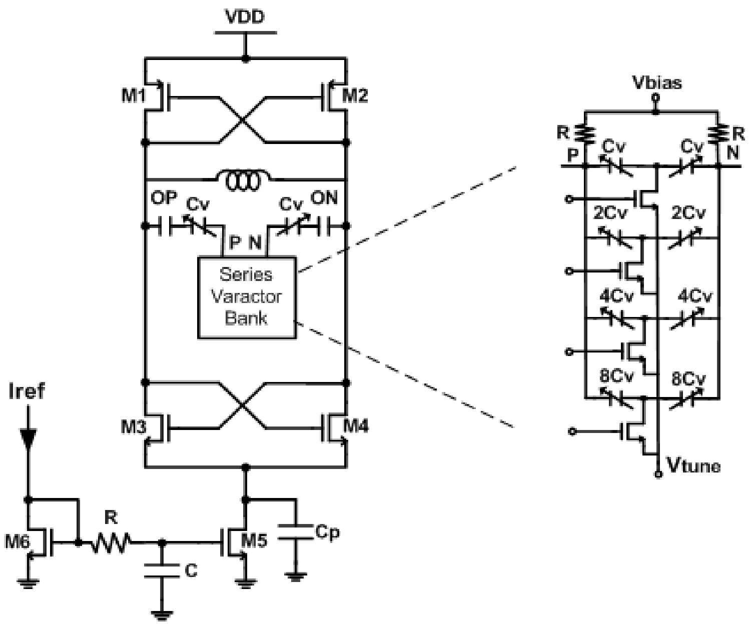

Figure 4. Conventional LC-tank VCO with Series Varactor Bank

The oscillation frequency of the proposed VCO shown in Figure5 is given as

$$f_{osc} = \frac{1}{2\pi\sqrt{L(C_v \| C_{ser.Var} + C_{par.Cap})}} \quad (6)$$

and the VCO gainK_{vco} is Eq. (7), shown below,where$\alpha = C_{ser.Var}/C_{par.Cap}$.We can find the design parameters such as α and $C_{ser.Var}$(Series varactor bank) which minimize the variationofK_{vco}. To obtain right above parameters, $C_{par.Cap(}$(Parallel capacitor bank)$_{)}$, V_{tune} are actually fixed in this simulation.

$$K_{VCO} = -\frac{(C_{ser.Var}/C_{par.Cap})^2 \cdot C_{ser.Var}}{4\pi\sqrt{L(C_v + (C_{ser.Var}/C_{par.Cap})\cdot C_{ser.Var})}\left\{C_v(1+C_{ser.Var}/C_{par.Cap})+C_{ser.Var}\right\}^{1.5}} \cdot \frac{\partial C_v}{\partial V_{tune}} \quad (7)$$

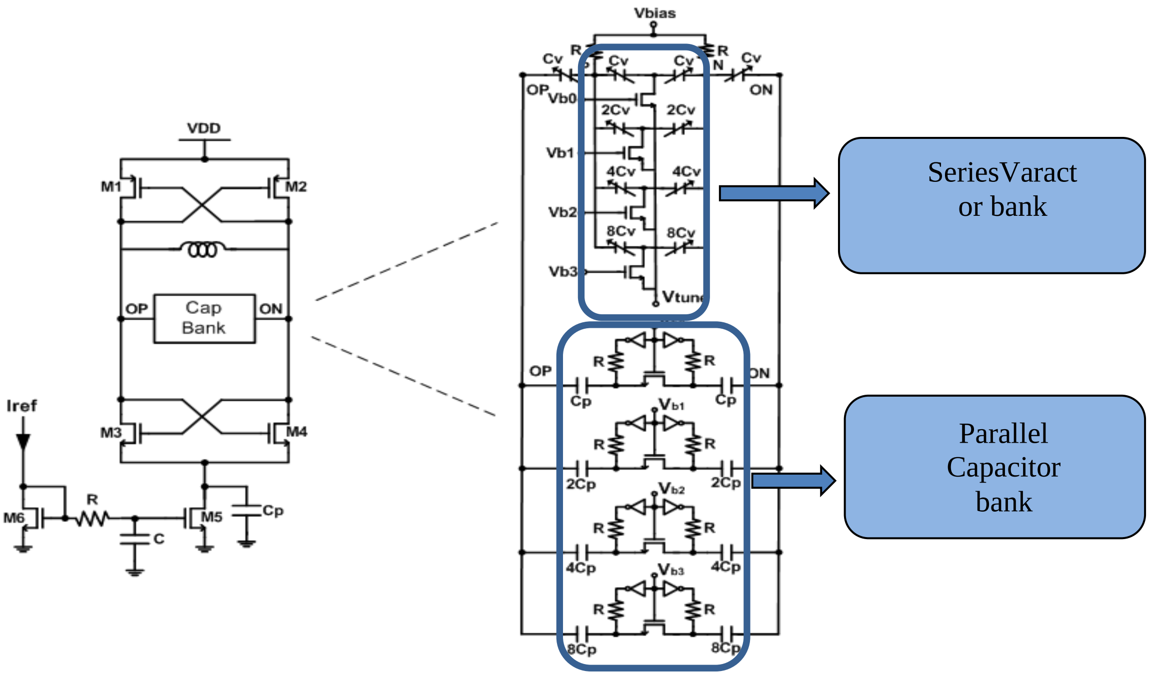

Figure 5. Proposed LC-tank VCO with Series Varactor Bank

3. Measurement Result

The wide bandVCOwith smallK_{vco} variation has been implementedin a 0.13μm 1-poly, 6-metal CMOS RF technology. Figure 6 shows the microphotograph of the fabricated chip.

As shown been in Figure 6,microphotograph of the proposed VCOoccupies less than 0.24mm^2. The output frequency of the proposedVCO can be tuned from 4.6 GHz 5.5 GHz as shownin Figure 7. Thephase noise of the output is measured to be -120dBc/Hz at1 MHz offset from the carrier frequency of 5.5GHz as shown in Figure 8.The VCO gain,K_{vco}, and phase noise of the proposedVCO aremeasured as a function of the control code ofthe switchable capacitor bank while the analog varactor controlvoltage$V_{tune}$is fixed at 0.6 V and the result is shown Figure 9.The variation of VCO gainis less than 9.6% whilethe previously reported LC-tank VCOs show larger than 25.3%variation in the VCO gain as summarized in Table I [15–18]. The VCO consumes 3.1 mA from a 1.2 V supply voltage.To compare the performance of the proposed VCO with that of some prior works, the well known figure-of-merit (FoM) of the VCO defined as Eq. (8) is used.

$$FoM = 10\log\left(\left(\frac{\omega_0}{\Delta\omega}\right)^2 \cdot \frac{1}{L\{\Delta\omega\}P}\right) \quad (8)$$

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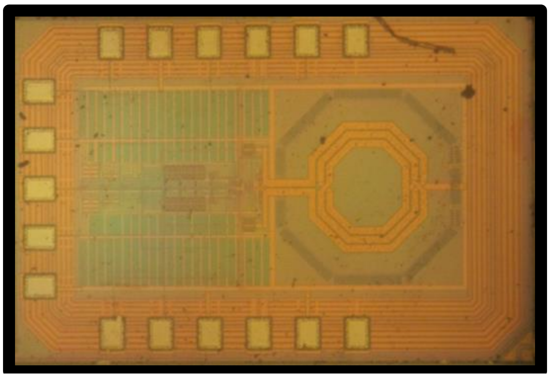

Figure 6. Chip Microphotograph of Proposed VCO

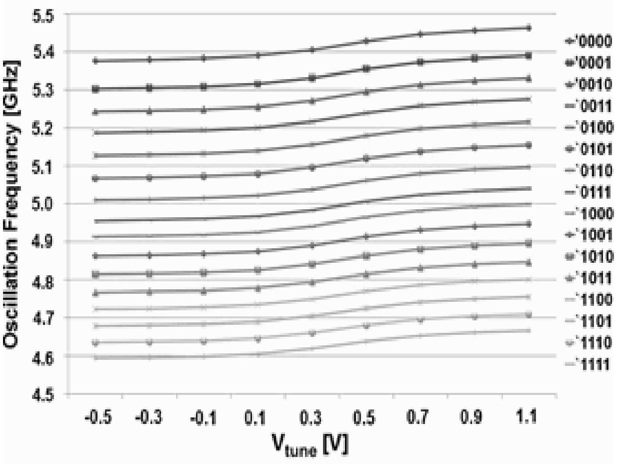

Figure 7. Frequency Tuning Range of the Proposed LC-tank VCO with Series Varactor Bank

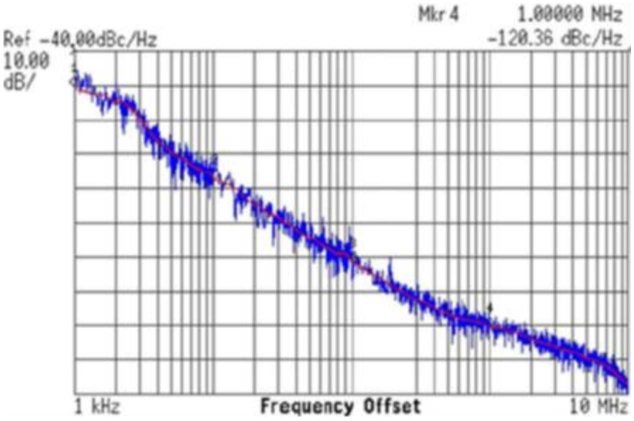

Figure 8. Measured Phase Noise of the Proposed 5.5 GHz VCO

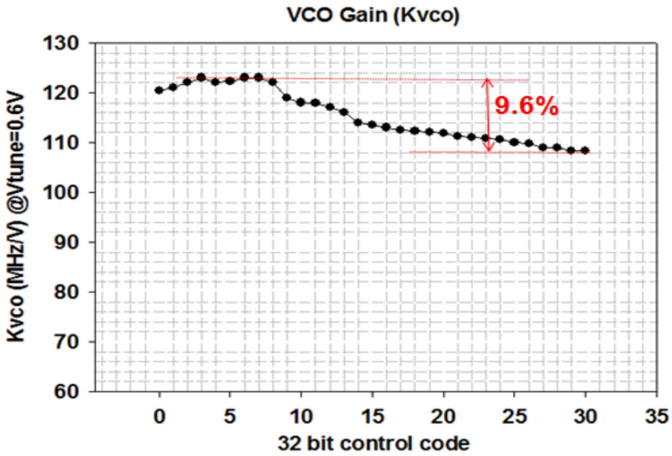

Figure 9. VCO Gain as a Function of Varactor and Cap Bank

Table 1. Comparison of the Performance of Other VCOs

Ref.	fosc [GHz]	ΔKVCO [%]	Tuning Range [%]	Phase Noise [dBc/Hz]	Power [mW]	FoM [dBc]	Tech [μm]
[15]	6.0	57.5	5.1	-115.2@1M	12.5	179.8	0.13
[16]	1.7	69.5	63.1	-128.0@1M	14.0	179.2	0.18
[17]	1.8	27.2	66.7	-130.0@1M	41.4	175.7	0.18
[18]	2	25.3	52	-124.0@1M	18	176	0.18
This Work	**5.5**	**9.6**	**18.5**	**-120@1M**	**3.72**	**180**	**0.13**

4. Conclusion

For small variation of VCO gain, series varactor banks and parallel capacitorbanks are used together in a wide band LC-tank voltagecontrolled oscillator (VCO). Implemented in a 0.13μm CMOSRF technology, the proposed VCO shows less than 9.6% variationin the VCO gain while the frequency tuning range is from4.6 GHz to 5.5 GHz. TheVCOconsumes 3.1mAfrom a 1.2Vsupply and the phase noise is 120dBc/Hz at 1 MHz offsetfrom the carrier.

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References

[1] J. Kim, J. Shin, S. Kim, et al., “A wide-band CMOS LC VCO with linerized coarse tuning characteristics,” in IEEE Trans Circuits Syst, **(2008)**, pp.399-403.

[2] M. A. L. Mostafa, S. Tuncer, and G. Luff, “Low power low phase noise3.9 GHz SiGe VCO whit data modulation correction loop”, IEEERFIC Symp., **(2004)**, pp. 273–276.

[3] A. Kral, F. Behbahani, and A. A. Abidi, “RF-CMOS oscillators withs witched tuning”, Proc. IEEE Custom Integr. Circuits Conf., **(1998)**, pp. 555–558.

[4] N. H. W. Fong, J. O. Plouchart, N. Zamdmer, and D. Liu, “A 1-V3.8–5.7 GHz wide-band VCOwith differentially tuned accumulationMOS varactors for common-mode noise rejection in CMOS SOItechnology”, IEEE Trans. Microw. Theory Tech., vol. 51, no. 8, **(2003)**, pp.1952–1959.

[5] P. Vaananen, N. Mikkola, and P. Helio, “VCO design with on-chipcalibration system,” IEEE Trans.

Circuit Syst. I, vol. 53, no. 10, **(2006)**, pp.2157–2166.
[6] C. H. Lee, A. Ali, and S. Lioyd, "A 0.18- μmSiGeBiCMOS UHFVCO with auto tuning for DCT AMPS and CDMA application", Proc. IEEE RFIC Symp., **(2004)**, pp. 471–474.
[7] A. D. Berny, A. M. Niknejad and R. G. Meyer, "A 1.8-GHz LC VCO with1.3-GHz tuning range and digital amplitude calibration", IEEE JSolid-State Circuits, vol. 40, no. 4, **(2005)**, p. 909.
[8] M. Oh Se, C. W. Kim and S. G. Lee, "A 74%, 1.56–2.71 GHz, widetunableLC-tuned VCO in 0.35-_μm CMOS technology", Microwa Opt Technol Lett, vol. 37,no. 2, **(2003)**, p. 98.
[9] K. Manetakis, D. Jessie and C. Narathong "A CMOS VCO with 48% tuning range for modern broadband systems", IEEE Custom Integrated Circuits Conference, **(2004)**, p. 265.
[10] N. H. W. Fong, P. Jean-Olivier and Z. Noah, "Design of wide-bandCMOS VCO for multiband wireless LAN applications", IEEE J Solid-State Circuits, **(2003)**, vol. 38, no.8, p. 1333.
[11] J. Kim, J. Shin, S. Kim, et al., "A wide-band CMOS LC VCO withlinearized coarse tuning characteristics", IEEE Trans Circuits Syst, **(2008)**, vol. 55, no. 5, p. 399.
[12] S. S. Broussev, T. A. Lehtonen, N. T. Tchamov, "A wide-band lowphase-noise LC-VCO with programmable Kvco", IEEE MicrowWireless Compon Lett, **(2007)**, vol. 17, no. 4, p. 274.
[13] H. Kwon and B. Kang "Linear frequency modulation of voltagecontrolledoscillator using delay-line feedback", IEEE Microwave Wireless Compon Lett, vol. 15, no. 6, **(2005)**, p. 431
[14] H. Ramiah and T. Z. A. Zulkifli, "Design of Low Phase Noise SIPCbased Complementary LC-QVCO for IEEE 802.11a Application", American Journal of Applied Sciences, vol. 5, no. 2, **(2008)**, pp 136-141.
[15] L. Jia, Y. B. Choi, and W. G. Yeoh, "A 5.8-GHz VCO with precisiongain control", IEEE RFIC Symp. Dig., **(2007)**, pp. 701–704.
[16] E. Y. Sung, K. S. Lee, D. H. Baek, Y. J. Kim, and B. H. Park, "Awideband 0.18- μm CMOS _fractional-N frequency synthesizerwith a single VCO for DVB-T", IEEE Asian Solid-State CircuitsConf. Dig., **(2005)**, pp. 193–196.
[17] J. W. Shin, J. S. Kim, S. S. Kim, and J. K. Choi, "A wideband fractional-N frequency synthesizer with linearized coarse-tuned VCO forUHF/VHF Mobile Broadcasting Tuners", IEEE Asian Solid-StateCircuits Conf. Dig, **(2007)**, pp. 440–443.
[18] L. Lu, Y. Lu, M. Hao and T. Zhangwen, "A fully integrated 1.175-to-2GHz frequency synthesizer with constant bandwidth for DVB-T applications", IEEE RFIC Symp., **(2008)**, pp. 303–306.

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