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Low-Phase Noise QVCO for WLAN in 0.13-μm RF CMOS Process Technology

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Abstract

In this paper, a Quadrature Voltage Controlled Oscillator of a wireless transceiver operating in the 5GHz UNII band of the wireless LAN 802.11a standard was proposed. In addition, a new structure of low-noise, low-power Quadrature Coupled VCO was proposed using the quadrature phase output as an input to the switching current source. If this structure is applied to other circuits such as a structure in which the current source is separated or a common use of a current source, a phase noise characteristic of 17 dB better than the existing VCO can be obtained. In particular, it is designed to operate with low power in a simple structure compared to the existing in-phase QVCO. The circuit was designed to operate with a supply voltage of 1.2V by the TSMC 0.13μm RF CMOS process. The measured VCO has a large tuning range of 20% operating at frequencies of 4.5 - 5.6 GHz, and phase noise of -117 dBc/Hz or less was obtained at the 1 MHz offset. The output phase error of the proposed QVCO was less than 0.5 degrees, and the total power consumption was able to obtain 5.3 mW at 1.2V.

Keywords: *Quadrature-coupled VCO, Low phase noise, RF CMOS, I/Q signal*

1. Introduction

Today's advanced modulation methods of radio transceivers require LO (Local Oscillator) signals of I/Q (In-phase, Quadrature-phase) for both transmission and reception paths. Widely used methods to create LO signals with I/Q signals include poly-phase filters, VCO(Voltage-Controlled Oscillator)+ frequency divider (I/Q clock generator), and QVCO (Quadrature-coupled VCO) [1]-[4]. These methods have their respective advantages and disadvantages, such as power consumption, integration, and noise, and their features will be described in this paper. The method using a poly-phase filter generates an I/Q phase signal using the phase change of the RC network as shown in Figure 1. However, since the multi-stage RC network must be connected in series to make the output amplitude constant, a loss due to resistance occurs. The resulting decrease in LO voltage swing causes an increase in noise of the mixer, so a buffer stage that consumes a large current is required at

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the output en

d to compensate for this, which has the disadvantage of consuming a large amount of power.

The method using a VCO+ frequency divider generates an I/Q signal using the output of the frequency divider configured by the master-slave flip-flop in Figure 2. This structure uses a frequency divider, and for the desired frequency, the VCO must operate at twice the frequency. Therefore, it has a great advantage in terms of integration because a smaller inductor is used and the area of the frequency divider is very small, and LO pulling can be avoided by using twice the frequency. However, this method also requires a buffer at the output stage, which increases the total power consumption.

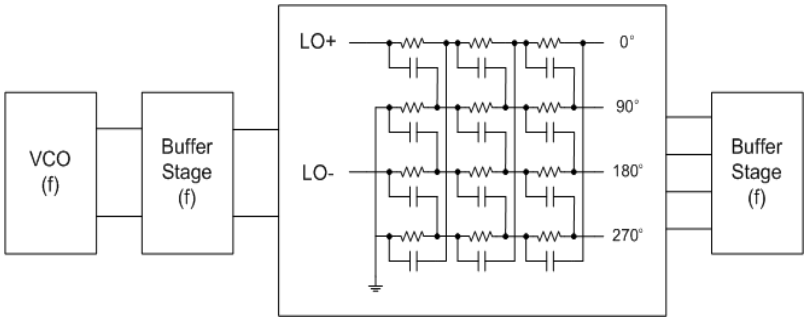


Fig. 1. Block Diagram of Poly-Phase Topology

Finally, quadrature coupled VCO is a method of generating a separate I/Q signal that operates at the same frequency by using the same two VCOs as shown in Figure 3 with direct connection and cross connection using a coupling transistor. This method occupies a large area due to the increase in inductors due to the use of two VCOs, and has the disadvantage of increasing phase noise due to the increase in the transistor, which is the source of noise of the VCO, but it uses less current compared to the two methods described above because no additional buffer is required.

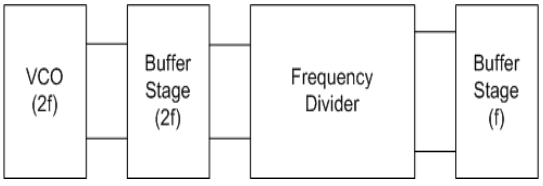


Fig. 2. Block Diagram of VCO+Frequency Divider

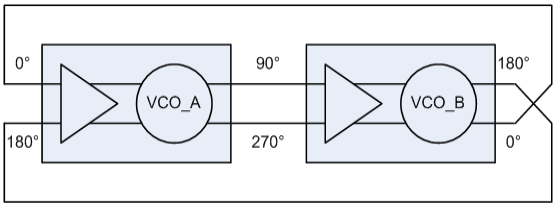


Fig. 3. Block Circuit and Sgnal Phase of QVCO

2. QVCO proposed by Rofougaran

The most widely known QVCO is a structure using the parallel coupling transistor in Figure 4 proposed by Rofougaran[4]. It has a structure in which two VCOs are coupled by transistors connected in parallel to the switch transistor. This structure has the characteristics that phase noise and phase error are reversed depending on the size of the two transistors. By improving this, Andreani proposed a structure that improves the phase noise of 10 dB regardless of phase error by connecting coupling transistors in series as shown in the circuit in Figure 5[4]-[6]. In addition, many studies have been published that have improved the characteristics of QVCO such as phase noise and phase error.

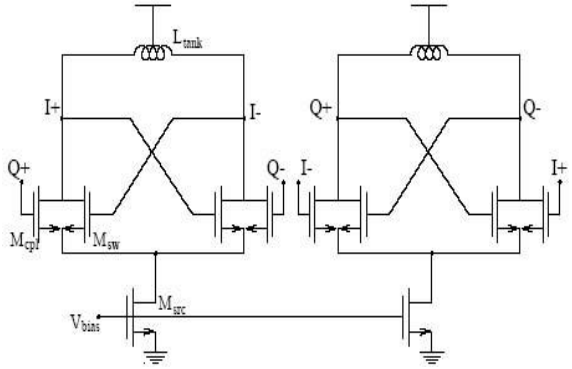


Fig. 4. QVCO of using Parallel Coupling Transistor

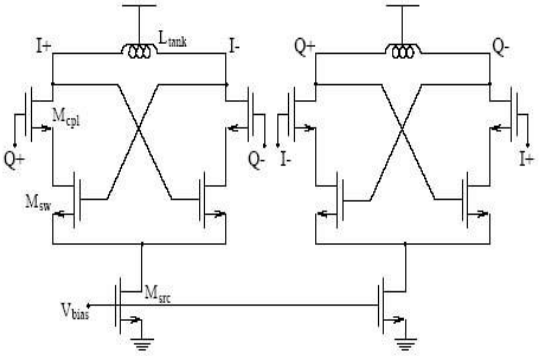


Fig. 5. QVCO of using Series Coupling Transistor

3. Proposed Low Noise Quadrature VCO Design

In this study, based on Rofougaran's QVCO, a QVCO with improved phase noise was proposed. The structure of VCO is designed to oscillate at low power using a small current using the quadrature coupling structure of nMOS and pMOS.

The QVCO in Figure 6 used transistors in parallel only for nMOS to couple the quadrature phase, and was designed based on the current source using the switching transistor [6] proposed by Boon instead of a specially fixed bias current source.

Switching of the current source is possible by using a large output amplitude as the gate input of the switching transistor. This switching transistor reduces flicker noise (1/f noise) because it has the power to release electrons trapped in the gate oxide of the MOS[7]-[13]. It has a more improved phase noise than VCO without a fixed current source or current source as compared in [6]. Based on this structure, the structure proposed in this study uses the output of the VCO having a quadrature-phase as the input of the current source, not the output of the VCO having an in-phase as the input of the current source as shown in Figure 7. For example, QP and QN were used as the gate input of the current source of the VCO with QP and QN outputs, and QP and QN were used as the gate input of the current source of the VCO with IP and IN outputs, on the contrary. This structure reduces phase noise by increasing the output swing limited by the current source by matching the phase of the common drain node of the current source with the swing of the output voltage.

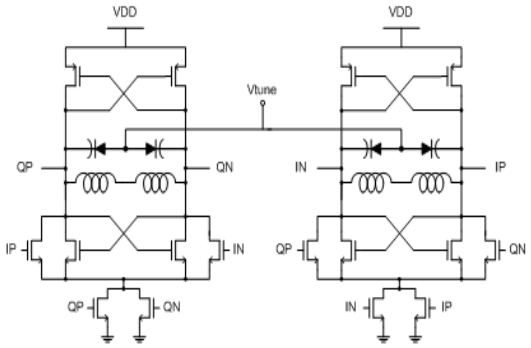


Fig. 6. Quadrature VCO of Switching Current Source using Inphase Output

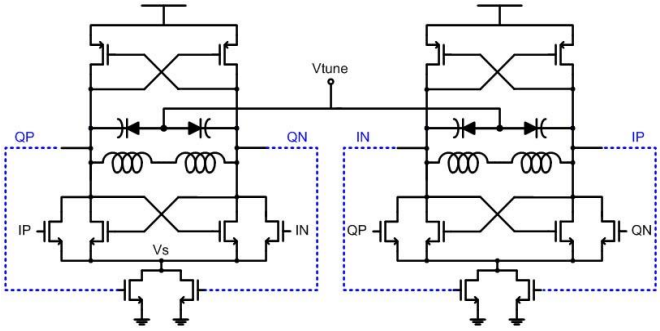


Fig. 7. Quadrature VCO of Switching Current Source using Quadrature Phase Output

In the VCO with a fixed bias and the current source in Figure 6, the output phase waveform and the waveform of the common drain node of the current source do not match as shown in Figure 8(a) due to the resistance of the triode region transistor and the time delay caused by the capacitance of the common drain node of the current source. However, by using the proposed structure, the two phase waveforms are matched as shown in Figure 8(b) to have a larger output amplitude. Since the phase noise of the VCO is proportional to the magnitude of the output amplitude, it has a more improved phase noise [14]-[16].

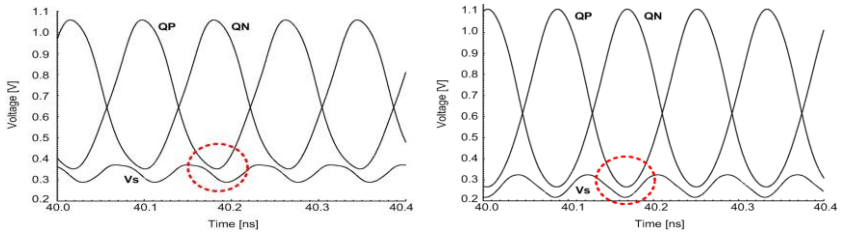


Fig. 8. Voltage Waveform of VCO Output and Common Drain node of Current Source
(a) Fixed Bias Current Source
(b)Switching Current Source using Quadrature Phase Output

Figure 9 is the result of simulating the phase noise characteristics of the proposed structure using the same-phase output and the quadrature phase output as the current source input compared to the case of using a fixed bias. It can be seen that 17 dB is improved compared to the case of using a fixed bias. By releasing the trapped electrons with switched tail current sources, the phase noise is reduced by 7dB and the remaining 10dB improvement is due to the optimum alignment by switching the separated current source with the coupling inputs.

Figure 7 is the most basic circuit, and if it is applied to other circuits such as a structure in which a current source is separated or a common use of a current source, more improved phase noise characteristics can be obtained.

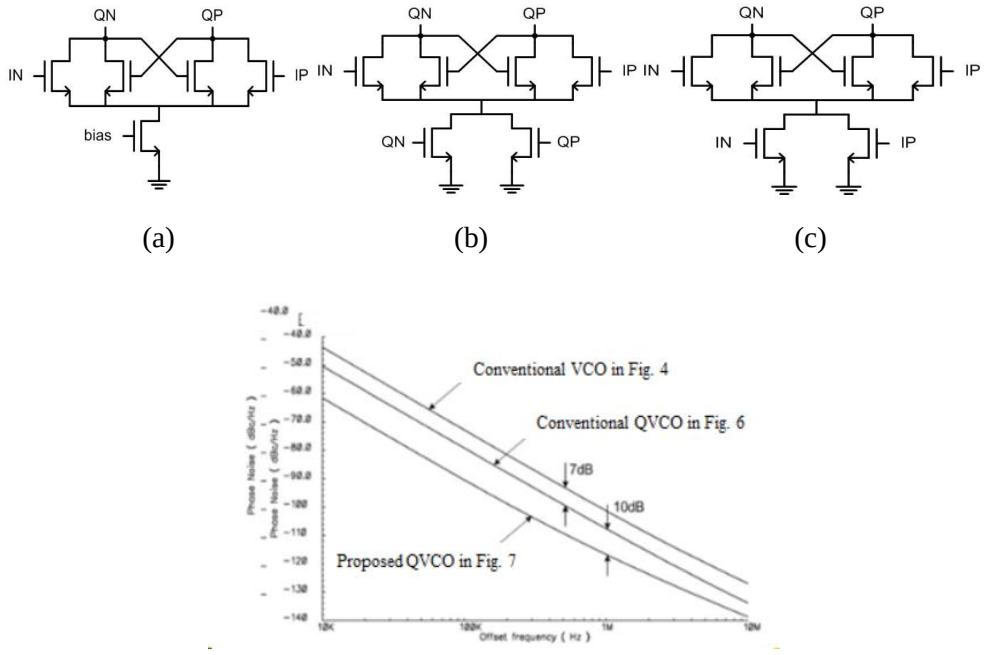
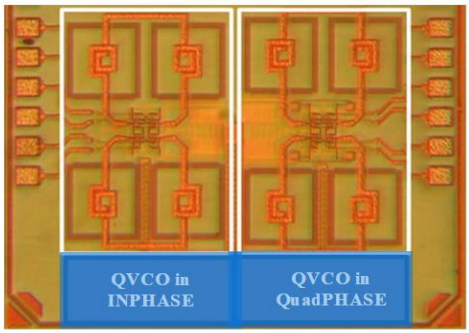


Fig. 9. QVCO with Tail Current Source
(a) Fixed Bias Current Source (b) Switching Current Source using Inphase Output (c)Switching Current Source using Quadrature Phase Output (d) Simulated Phase Noise of the Conventional QVCO (Fig. 5), the QVCO with the Tail Current Source Switched by its Own Output (Fig. 6), and the QVCO with the Tail Current Source Switched by the Coupling Input (Fig. 7).

Figure 10 is a picture of the microchip of CMOS QVCO. It shows the chip photographs of the in-phase QVCO and quadrature QVCO chips in the actual process on the same circuit. Figure 11 is the output waveform of QVCO during quadrature phase switching, and a high output waveform of -8.085dBm could be obtained. Figure 12 shows that as the control voltage changes at 0V to 1.2V, the resonance frequency changes at constant frequency intervals from 5.5 GHz to 4.5 GHz. The range of relatively inconsistent frequency intervals is a phenomenon caused by the characteristics of the p+n diode varactor used for the LC-tank, and a phenomenon in which a voltage hanging as a reverse between two terminals of the varactor is hung as a forward.



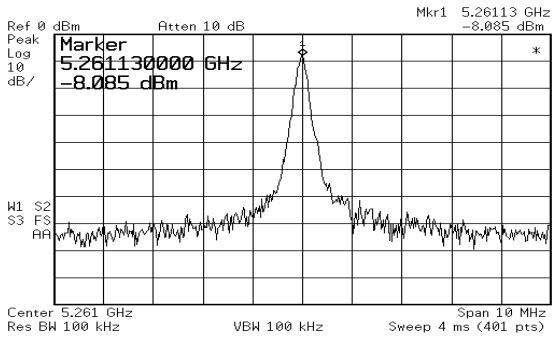
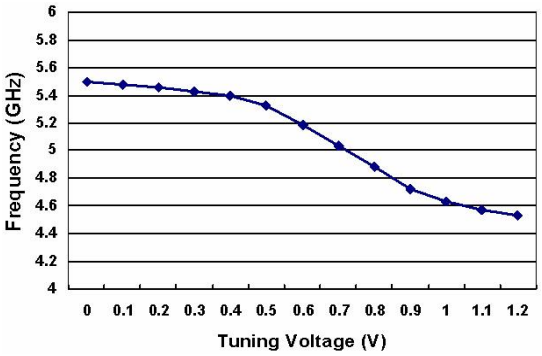


Fig. 10. Microphotograph of the Fabricated QVCOs **Fig. 11. Output Spectrum of QVCO at 5.26GHz**



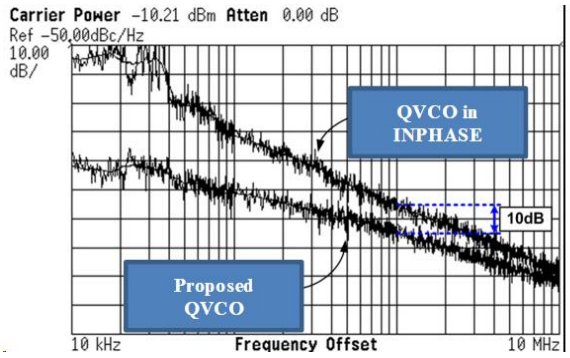


Fig. 12. The Characteristic of Measured Frequency Tuning Conventional

Fig. 13. Measured Phase Noise Performance of and Proposed QVCO

Figure 13 shows a comparison between the basic concept of QVCO and the phase noise waveform of QVCO proposed in this paper. In the case of QVCO with orthogonal phase switching, it shows that the phase noise obtained -117 dBc/ Hz@1 MHz at the EEE 802.11a WLAN target frequency of 5.5 GHz.

Table 1. Comparison of the Performance with Some Prior Works

CMOS QVCO	Tech. [um]	fc [GHz]	Power [mW]	Phase Noise [dBc/Hz]	FoM [dBc]
[5]	0.25	5	21.2	-113@2M	167.7
[6]	0.18	5	22	-124@1M	184.6
[12]	0.35	6.5	18	-98.4@1M	162
[16]	0.18	6	6.8	-106@1M	173.2
This Work	0.13	5.5	5.28	-117@1M	184.6

In this paper, compared to the basic concept of QVCO, QVCO with quadrature phase switching was proposed to increase the LO voltage swing, and a method of obtaining a swing of the same size was used even when low power was used. Table 1 shows the comparison with other papers [5]- [6] to [12],[16]. As in the well-known

equation (1) representing the performance of VCO, the FOM (Figure Of Merit) can be written as follows. As shown in Table 1, the QVCO presented in this paper shows that the FOM is the highest at 184.6 compared to other papers operating in the 5-6 GHz band among CMOS QVCO.

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

4. Current Reference (Iref) circuit for PVT variation

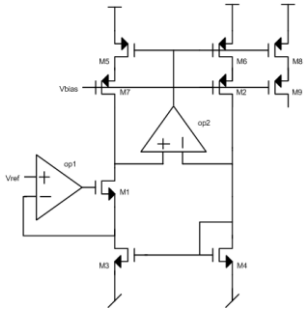


Fig. 14 Conventional current reference circuit

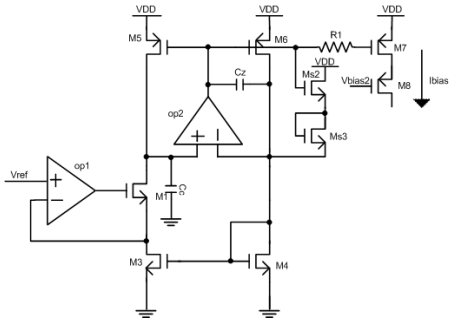


Fig. 15 Proposed safe current reference circuit

The bias circuit insensitive to P.V.T. variation in analog IC's has become an essential circuit for accurate, stable and safe operation. A representative example of a bias circuit insensitive to P.V.T variation is a current reference circuit, which generates a current independent of P.V.T. For safe and stable operation of a circuit, the current flowing in the circuit must be insensitive to P.V.T variation, which requires an additional circuit to obtain a current insensitive to P.V.T variation. For reference, the process variation of the poly resistor in the TSMC process is ±25%. Fig. 14 is a circuit that makes a current reference independent of the existing P.V.T. However, the existing current reference is a cascode structure, so it is an unfavorable structure for low voltage. The current reference circuit proposed in this paper removed the common gate more safely for use at a low voltage of 1.2V, as shown in Fig. 15. The important thing in this structure is the phase marin of loop. First of all, if you look at the loop phase marin of op1, op1 is implemented in 2 stages, so in the end, loop consists of 3 stages. To compensate for PM, Cz, which forms zero, and Cc, which pulls the random pole, were added. When Cc is added together, it is more advantageous in size. Since the path through Cz and the path through M5 are input as the + input of op2 in the same phase, Cz has LHP zero. Ms1 and Ms2 were connected in series to reliably turn off even in the rotor as a start-up.

4. Conclusions

This paper proposed a multi-voltage regulator oscillator for a wireless transceiver operating on the 5GHz UNII band based on the wireless LAN 802.11a standard. In addition, a new structure of low-noise, low-power Quadrature Coupled VCO was proposed using the quadrature phase output as the input of the switching current source. If this structure is applied to other circuits, such as a structure in which a current source is separated or a common use of a current source, more improved phase noise characteristics can be obtained. In particular, it was possible to obtain 17dB of phase noise compared to the existing in-phase QVCO and was designed to operate with low power with a simple structure. The circuit was designed with a supply voltage of 1.2V as a

TSMC 0.13μm RF CMOS process. The measured VCO operates at a frequency of 4.5-5.6 GHz and has obtained phase noise of -117 dBc/Hz or less at the 1 MHz offset. The proposed QVCO output phase error has less than 0.5 degrees, and the total power consumption is 5.3 mW at 1.2V.

5. Futurework

In this work, VCO for WLAN operating at a frequency of 4.5-5.6 GHz has developed. The challangess for the design of QVCO MIMO(Multiple Input Output)technologies continue to evolve, this trend will present a number of a component of the QVCO, this would be designed for dual-band 802.11a/b/g applications covering world-bands of 2.4GHz to 5.5GHz.This study designed a QVCO with superior performance to those in other studies. The QVCO proposed in this study was designed to achieve a smaller chip area and lower phase noise, and will be available for use in IEEE 802.11a/b/g chips for 2.4GHz–5.5 GHz Wireless-LAN in the future.

Acknowledgement

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