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X-band CMOS VCO for 5 GHz Wireless LAN

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Abstract

The implementation of a low phase noise voltage controlled oscillator (VCO) is important for the signal integrity of wireless communication terminal. A low phase noise wideband VCO for a wireless local area network (WLAN) application is presented in this paper. A 6-bit coarse tune capacitor bank (capbank) and a fine tune varactor are used in the VCO to cover the target band. The simulated oscillation frequency tuning range is from 8.6 to 11.6 GHz. The proposed VCO is desgned using 65 nm CMOS technology with a high quality (Q) factor bondwire inductor. The VCO is biased with 1.8 V VDD and shows 9.7 mA current consumption. The VCO exhibits a phase noise of –122.77 and -111.14 dBc/Hz at 1 MHz offset from 8.6 and 11.6 GHz carrier frequency, respectively. The calculated figure of merit(FOM) is -189 dBC/Hz at 1 MHz offset from 8.6 GHz carrier. The simulated results show that the proposed VCO performance satisfies the required specification of WLAN standard.

Keywords: *Voltage Controlled Oscillator, X-band, CMOS, Wideband, Bondwire Inductor, Phase Noise*

1. Introduction

A broadband communication technology which has a vast data processing ability and a fast data transmission speed is developing rapidly these days. The very wide operating frequency range of the RF transceiver is required to meet the needs of 4G/5G communication service, which has very high data rates. CMOS is the potent candidate technology meeting these demands since continuous scaling down of CMOS technology make it possible to increase complexity and operating speed of silicon integrated circuits. Among the efforts for highly integrated wireless CMOS transceivers, the implementation of a low phase noise VCO is crucial for the signal integrity of RF transceiver and communication terminal such as smart phone. The spectral purity of a VCO actually limits the maximum number of users and channels of the communication system. Fortunately, the theory and analysis for the physical processes of the phase noise in VCOs have significantly progressed these days and the techniques to lower the phase noise have been advanced by understanding of these phase

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noise mechanism[1~3].

In this paper, We propose circuit design issues and procedures to acquire a fully integrated CMOS VCO with bond-wire inductor satisfying all requirements for WLAN standard.

2. VCO design procedures

The mobile integrated system for WLAN requires the VCO having a wide tuning range and low phase noise characteristics. For the local oscillator (LO) signal generation, complex carrier generation structures using a harmonic mixer have various non-ideal effects including harmonics coupling, therefore a simple frequency planning based on only divide-by-two pre-scaler is favored these days. In the simple pre-scaler only LO chain, even though carrier frequency doubling is needed to generate quadrature I/Q signal, side effects of other structures such as self-mixing, DC-offset and frequency pushing/pulling can be minimized. Table. 1 depicts a frequency planning for the carrier signal generation of a WLAN standard..

Table 1. VCO frequency plan

Standard	LO Frequency	VCO Frequency(LO)
802.11a low band	5.1-5.3	10.2-10.6(/2)
802.11a high band	5.7-5.8	11.4-11.6(/2)
802.11b/g	2.4-2.48	9.6-9.92(/4)
Buletooth	2.4-2.5	9.6-10(/4)

The VCO with a frequency tuning range of about 2 GHz is needed for prescaler-only scheme. For the design of a VCO with enough operating frequency margin, the proposed VCO is designed with 3 GHz tuning range from 8.6 ~ 11.6 GHz. To design a wide tuning range VCO with good phase noise performance, an NMOS-only structure are adopted. The well-known phase noise model for an oscillator is Leeson's proportionality[3].

$$L\{\Delta\omega\} \propto \frac{1}{V_o^2} \cdot \frac{kT}{C} \cdot \left(\frac{\omega_o}{Q}\right)^2 \cdot \frac{1}{\omega_m^2} \tag{1}$$

In equation (1), L is the phase noise of bandwidth $\Delta\omega_o$ in dBC/Hz, V_O is the output signal amplitude in volts, kT/C is the thermal noise in volts, ω_o is the oscillation frequency in Hz, Q is the quality factor of LC tank, and ω_m is the offset frequency in Hz. This expression reveals the dependency of the phase noise upon the signal amplitude V_O. The proposed VCO schematic diagram is shown in Figure 1.

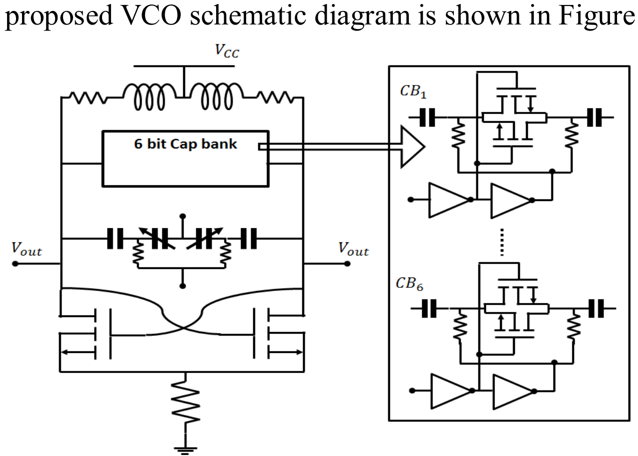

Figure 1. Schematic diagram of the proposed VCO

For the NMOS only type VCO, higher voltage swing above VDD limit is possible and a wider tuning range can also be attained due to minimized parasitic capacitances of active devices. For the Inductor, planar spiral and bondwire structures are compared and simulated by 3D EM simulator. These inductors are designed to have an inductance of around 0.5 nH. A planar inductor shows a Q factor of about 15 and a bondwire inductor shows a Q factor of about 30, therefore the bondwire structure is used for the LC tank of the proposed VCO. The inductance of the bondwire structure is linearly increased with the bondwire length and can be modified by changing the distance between the two bondpads and bondwire height. In the design of a resonator for WLAN, it is difficult to satisfy a wide tuning range and low phase noise requirement as well. In addition to attaining a high Q inductor, a switched capacitor bank and a varactor should be properly designed to avoid phase noise degradation and to acquire a reasonable vco gain, KVCO for stable phase locked loop(PLL) operation. Two accumulation-type MOS varactors are used for fine tuning and a binary-weighted 6-bit switched capacitor bank with enough frequency margin is used for coarse tuning to overcome frequency shift due to PVT variations. Though large off parasitic capacitance results from the 6bit coarse tuning capbank, it is possible to minimize these parasitics by increasing the reverse bias of the drain and source junctions with inverters in each capacitor bank unit when the MOS switch is off.

3. Simulation results

A fully integrated wideband VCO circuit for WLAN standard is designed and simulated in 65 nm CMOS technology with the proposed circuit techniques and procedures. The layout of the designed VCO and a buffer amplifier is shown in Figure 2.

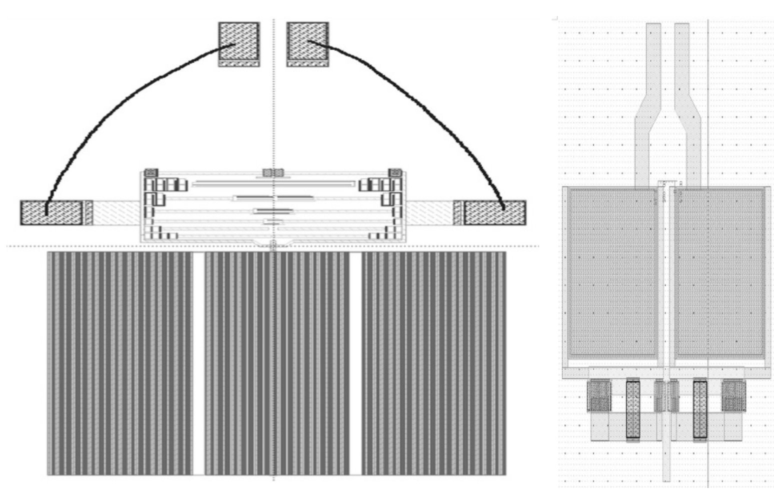

Figure 2. Layout of the proposed VCO and buffer amplifier

The VCO is tunable between 8.6 and 11.6 GHz and the VCO gain is from 85 to 177 MHz/V. The resulting range is 29.7 % of the mid frequency. The VCO operates from 1.8 V supply and biases at 9.7 mA. The measured frequency tuning range and phase noise performances satisfy all requirements for WLAN standard. A normalized figure of merit(FOM) has been defined to compare the VCO performance with other VCOs[4].

$$FOM = L\{f_{offset}\} - 20\log\left(\frac{f_o}{f_{offset}}\right) + 10\log\left(\frac{P_{DC}}{1mW}\right) \quad (2)$$

In equation (4), $L\{f_{offset}\}$ is the measured phase noise in dBC/Hz at offset frequency f_{offset} from the carrier frequency f_o. P_{DC} is the power consumption of the VCO in milliwatts. Figure 3 plots the simulated phase noise for the VCO.

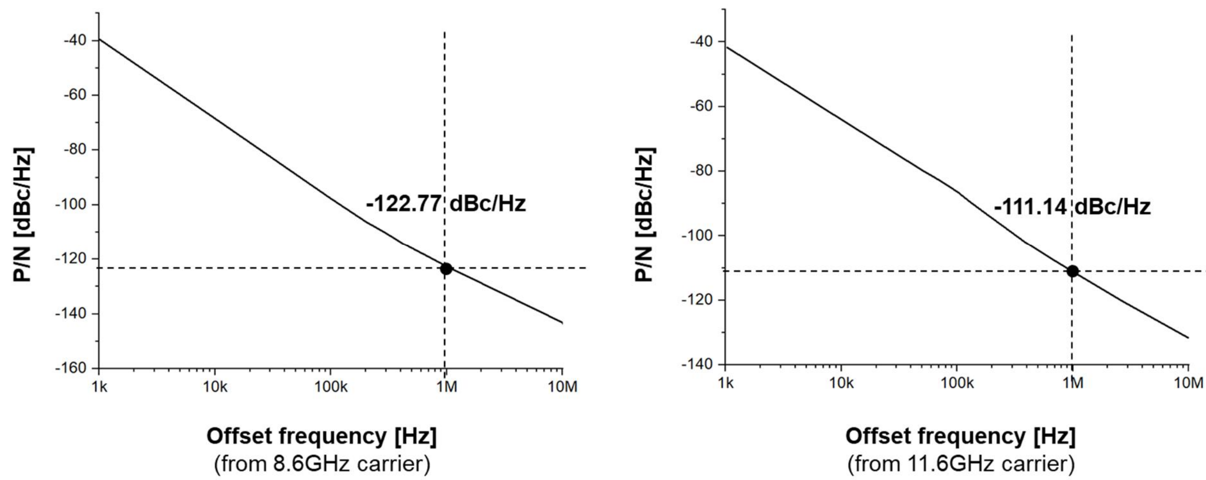

Figure 3. Simulated phase noise of the VCO

The VCO achieves -122.77 dBc/Hz and -111.14 dBc/Hz at 1 MHz offset from the carrier frequency of 8.6 and 11.6 GHz, respectively. The simulated FOMs for the VCO are -189 dBc/Hz at 8.6 GHz carrier frequency. Table 2 shows the summary of the simulation results compared to those of other low phase noise VCOs.

Table 2. VCO performance summary and comparison

VCO	Tech [nm]	Freq [GHz]	Power [mW]	P/N@1MHz [dBC/Hz]	FOM [dBc/Hz]
VCO1	180	11.22	6.84	-109.4	-182
VCO2	130	11.6	3.72	-113	-183
VCO3	180	12	8.1	-110.8	-183
VCO4	180	8	24	-117	-181.3
This work	65	11.6	17.5	-122.7	-189

VCO1 shows a FOM of -182 dBC/Hz[5]. VCO 2 shows a FOM of -183 dBC/Hz[6]. VCO 3 shows a FOM of -183 dBC/Hz[7]. VCO 4 show a FOM of -181.3 dBC/Hz[8]. Considering the wide tuning range of about 30 %, FOM of the proposed VCO is quite comparable to the previously published results.

4. Conclusions

In this work, a low phase noise, wideband CMOS VCO for a WLAN chip transceiver has been presented. Circuit design procedures and techniques for achieving a good phase noise and a wide tuning performances are proposed. An NMOS-only structure and high Q bond wire inductor are adopted for enough phase noise margin, wide frequency tunability. The design and simulation results have been achieved with 65 nm CMOS process technology. The simulation results show that the tuning range is from 8.6 to 11.6GHz. The phase noise performances of the VCO are -122.77 and -111.14 dBc/Hz at 1 MHz offset from 8.6 and 11.6 GHz carrier frequency, respectively. The calculated figure of merit(FOM) is -189 dBC/Hz at 1MHz offset from 8.6 GHz carrier, which confirms that the good phase noise and wide frequency tuning performances are simultaneously achieved. The simulated results show that the proposed VCO performance satisfies the required specification of WLAN standard

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