Designs of CMOS Multi-band Voltage Controlled Oscillator Using Active Inductors

Ming-Jeui Wu, Yi-Yuan Huang, Yuan-Hao Lee, Yu-Min Mu, and Jenn-Tzer Yang

Abstract - In this paper, a radio frequency (RF) CMOS multiple bands voltage-controlled oscillator (VCO) using an active inductor load with a binary code band selector suitable for multi-standards wireless applications is proposed. By employing an improved high-Q active inductor including two bits binary controlled code, the multi-band VCO operating at four different frequency bands is realized. The proposed oscillator circuit is designed in TSMC 0.18-*u*m CMOS technology. Based on the simulation results, the VCO can operate at 900MHz, 1.8GHz, 1.9GHz, and 2.4GHz with phase noise of -86.92dBc/Hz, -84.49dBc/Hz, -83.77dBc/Hz, and -81.17dBc/Hz, respectively. Furthermore, the power dissipation of this VCO can retain constant at all operating frequency bands and consume around 9.43 mW from 1.8-V power supply. The occupied chip area of this VCO is about 0.3×0.3 mm^2.

Key-Words: CMOS, High-Q Active Inductor, Voltage-Controlled Oscillators (VCO), Phase Noise, Multi-Band, and Multi-Standards.

I. Introduction

In recently years, the evolution of wireless communications has motivated a strong interest toward the development of multi-standards and multi-services with operating frequencies of 900MHz/1.8GHz/1.9GHz bands for GSM and 2.4GHz band for Bluetooth. Therefore, it is desirable to combine more standard bands in one mobile unit [1]. The LC-tuned oscillator circuits can achieve lower-phase noise, but the low Q value passive inductor limits the frequency tuning-range. Various techniques have been proposed to enhance the tuning range of the LC-tank VCO by switched capacitors [2], [3] and switched inductors [4]. Though a wide frequency tuning range can be achieved, the circuits suffer from a considerable increase in the chip area and the complexity of control mechanism. To overcome the limitations imposed on the tuning range, the concept of frequency tuning by active inductors has been introduced [5], [6]. However, much effort has been invested in the design of voltage-controlled oscillator (VCO) using the integrated or the external resonators, the large power consumption is still existed. In this paper, a non-inductor RF multi-band VCO using TSMC 0.18-*u*m CMOS technology applying a high-Q active inductor with a binary code band selector for multi-standards or multi-services is presented. The VCO exhibits low constant power consumption at all operating frequency bands and can operate at 900MHz, 1.8GH, 1.9GHz, and 2.4GHz frequency bands and obtain acceptable phase noise in operating frequency bands.

The organization of this paper is described as follows. Constant power consumption with a band selectable high-Q active inductor is described in section II. In section III, the circuit of the band selector using two bits binary code is proposed. The proposed multi-band VCO using the proposed high-Q active inductor with steady power consumption and multi-band frequency selecting is introduced in section IV. Simulation results of the proposed multi-band VCO are indicated in section V. Finally, the conclusion is summarized in section VI.

Ming-Jeui Wu is with the Ming Hsin University of Science and Technology, Department of Electronics Engineering (e-mail: mrwu@must.edu.tw)
Yi-Yuan Huang is with the Ming Hsin University of Science and Technology, Department of Electronics Engineering (e-mail: c95030003@std.must.edu.tw)
Yuan-Hao Lee is with the Ming Hsin University of Science and Technology, Department of Electronics Engineering (e-mail: c95030019@std.must.edu.tw)
Yu-Min Mu is with the Ming Hsin University of Science and Technology, Department of Electronics Engineering (e-mail: c95030020@std.must.edu.tw)
Jenn-Tzer Yang is with the Ming Hsin University of Science and Technology, Department of Electronics Engineering (e-mail: yjn@must.edu.tw)

II. HIGH-Q ACTIVE INDUCTOR WITH BANDS SELECTOR

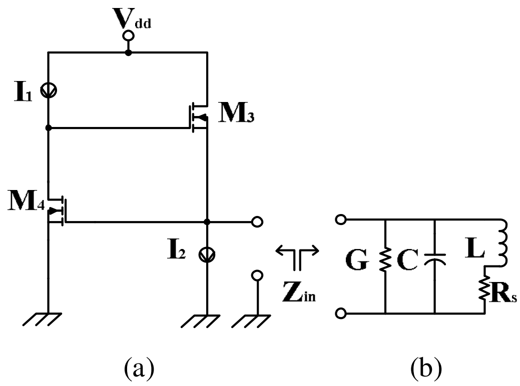

Fig. 1 Simple active inductor and equivalent circuit

Disadvantages of the spiral inductor are low Q value, large chip area, untunable, and difficult control in fabrication. Advantages of the active inductors are high Q value, electrical tunable, small chip area, and easy control in fabrication using external voltages.

The simple grounded active inductor circuit and its equivalent circuit are shown in Fig.1 (a) and (b). In order to improve the performance such as the Q value, a high-Q active inductor using a feedback resistor is proposed. The improved high-Q active inductor circuit is illustrated in Fig 2. This

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circuit is composed of common-source transistor M_4, common-drain transistor M_3, feedback resistor R_f and two biasing current sources I_1 and I_2. Feedback resistor and transistor M_4 construct a gain network. This network produces a gain factor to reduce the parallel conductance loss.

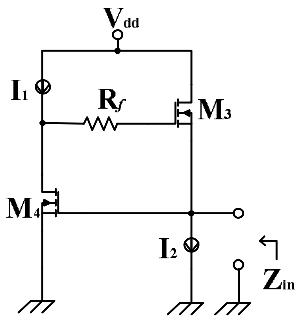

Fig. 2 High-Q active inductor

Hence, the equivalent internal loss of the inductor will be decreased, and then the Q value will be increased. Moreover, the inductance (L) is also increased due to the feedback resistor. Therefore, the performances of the active inductor containing the Q value and the inductance will be tremendously improved by applying a simple feedback resistance R_f.

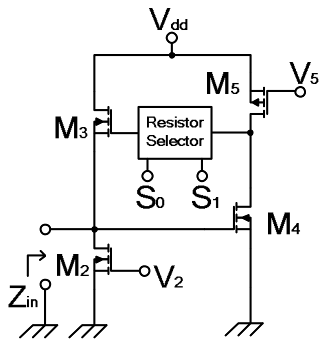

Fig. 3 High-Q active inductor circuit with band selector

In order to change the characteristics of the active inductor, the active inductor can use a simple network to control the feedback resistance. In Fig.3, the different feedback resistances can be selected by using binary code to form a band selector. The band selector can choose all kinds of resistance using different binary code, and then the inductance, the Q-value, and the resonating frequency ω0 of the inductor will be changed.

III. BANDS SELECTOR CIRCUIT

The band selector circuit is combined with four different resistors and a 4 to 1 multiplexer to process resistance selection, which uses two bits binary controlled code (S_1S_0). In Fig. 4 shows the band selecting configuration to replace the feedback resistor. The circuit of the band selector is shown in Fig. 5. It is formed by using six transmission gates and two inverters to select the resistance. As input binary code (S_1S_0) of the multiplex apply with individual 00, 01, 10, and 11, and then the feedback resistance of R_{900}, R_{1800}, R_{1900}, and R_{2400} will be selected, respectively.

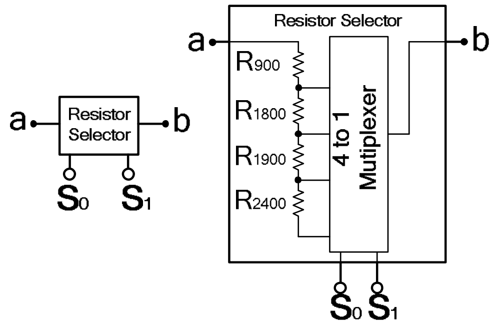

Fig. 4 Configure of bands selector

Moreover, the proposed active inductor, due to the DC bias current does not pass through the band selector. The voltage drop of the band selector is zero. Hence, the DC voltage drop of the band selector will not be affected the characters of the inductor during the feedback resistor is changed. Therefore, the power consumption of the active inductor can be retained constant.

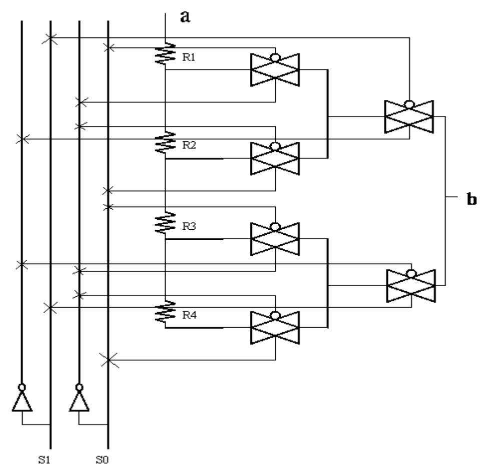

Fig. 5 Circuit of bands selector

IV. PROPOSED MULTI-BAND VCO DESIGNS

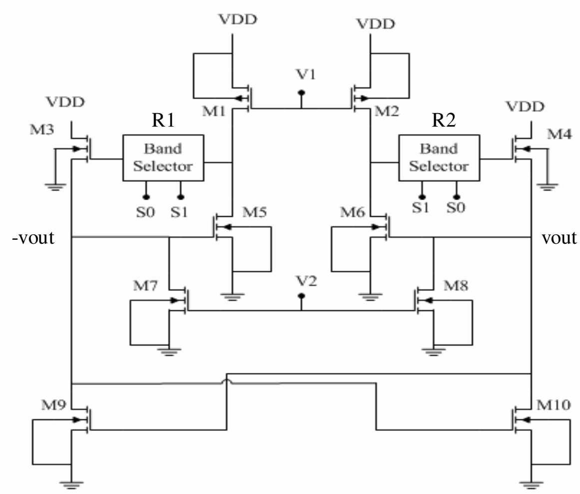

Fig. 6 Proposed multi-band VCO circuit

The main design consideration of the VCO is expected to obtain low constant power consumption, wide tuning-range and low phase noise. The circuit diagram of the proposed LC oscillator is shown in Fig. 6.

Typically, the inductance load is applied with a passive spiral inductor. However, inherently low Q-factors and occupied large chip area, the gain and the cost-performance of the amplifier designs will be significantly decreased. This design has a cross-coupled connection of NMOS transistors M_9 and M_{10}. The cross-coupled connection generates a positive feedback loop for providing negative resistance, called a negative impedance converter (NIC). The NIC configuration compensates the loss of the active inductor in the LC tank to produce lossless LC tank. The inductor of the LC tank is used to improve high-Q active inductors and is shown in Fig. 1 (a). The active inductors are composed of M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8, R_1 and R_2, which combine with the NIC to form the LC resonators. Two active inductors are acting as the equivalent inductance in the oscillator. No varactors are employed in this oscillator. The oscillator frequency modulation function can be achieved by using the resistors of the active inductor.

To provide adjustable frequency range, the feedback resistance R_f is added to tune the desired oscillator frequency. Because the equivalent inductance values are varied by the resistance R_f, the capacitance is kept unchanged. Besides, the frequency of the oscillator can tune the bias of the active inductors. Thus, the resistors R_f and the bias of the active inductor can adjust the output frequency of the oscillator.

V. SIMULATION RESULTS

Table 1 Performance of Multi-band VCO

Technology	0.18um CMOS			
VCO_bias	Analog 1.8V			
Frequency	900MHz	1.8GHz	1.9GHz	2.4GHz
Tuning Frequency	0.3~2.9 GHz	1.0~3.5 GHz	1.1~3.6 GHz	1.6~3.9 GHz
Tuning range	181.3 %	111.1 %	106.4 %	83.6 %
Phase Noise @1MHz	-86.916 dBc/Hz	-84.486 dBc/Hz	-83.774 dBc/Hz	-81.168 dBc/Hz
Power	9.43 mW			
Chip Area	0.3 × 0.3 mm²			
Core Area	0.1 × 0.1 mm²			

The proposed high-Q active inductor and the RF multi-band voltage-controlled oscillator were designed in standard TSMC 0.18-*u*m CMOS technology. The simulation tool of advanced design system (ADS) was applied in these designs. It is desirable that the frequency bands of the amplifier design can be selected by selecting the feedback resistance in band selector to obtain four different frequency bands. The bands of the frequency can be selected from 0.9GHz to 2.4GHz, which includes 0.9GHz, 1.8GHz, 1.9GHz, and 2.4GHz. To validate our analysis a VCO is integrated in a 0.18um CMOS process which performances are summary in table 1. The simulated results obtained for the designed VCO, are summary in the table 2. Compared to previous published works [7-9] and taking into account that the amplifier is fully integrated, the overall performances appear very good.

Table 2 Comparisons of VCO performance

	Unit	This work	[7]	[8]	[9]
Technology		0.18um CMOS	0.18um CMOS	0.18um CMOS	0.18um CMOS
VCO_bias	V	1.8	1.8	1.8	1.8
Tuning Frequency	GHz	0.3 ~ 3.9	0.5 ~ 2.0	0.5 ~ 3.0	0.4 ~ 1.6
Tuning range	%	83.6 ~ 181.3	120	143	120
Phase Noise @1MHz	dBc/Hz	-81.2 ~ -86.8	-78 ~ -90	-101 ~ -118	-88 ~ -95
Power	mW	9.43	13.8	6 ~ 28	26
Chip Area	mm²	0.3 × 0.3	0.3 × 0.3	0.15 × 0.3	-
Technique		Active Inductor	Active Inductor	Active Inductor	Ring Oscillator

In the Fig7-10, the selected frequency bands of 0.9GHz, 1.8GHz, 1.9GHz, and 2.4GHz, with the phase noise can achieve -86.92dBc/Hz, -84.49dBc/Hz, -83.77dBc/Hz, and -81.17dBc/Hz, respectively. The layout of performance VCO is shown in Fig. 11.

VI. CONCLUSIONS

In this study, using active inductor for an *LC*-tank, a wide turning-range VCO has been presented at radio frequency. A high-Q active inductor multi-band VCO with steady power consumption is obtained. The VCO can operate at four different frequency bands, which uses two bits binary controlled codes for GSM and Bluetooth applications. Furthermore, the constant low power consumption of 9.43 mW under 1.8V DC power supply and the small occupied core area 0.1 x 0.1 mm² are achieved.

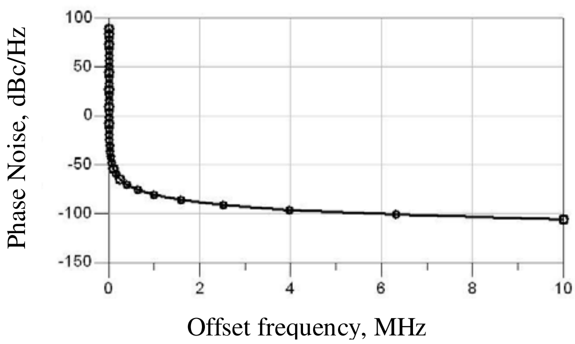

Fig. 7 Phase Noise of proposed VCO with 2.4GHz

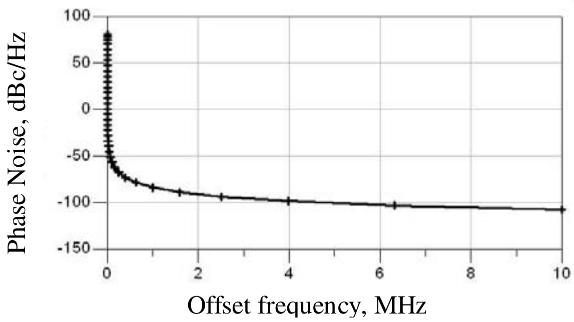

Fig. 8 Phase Noise of proposed VCO with 1.9GHz

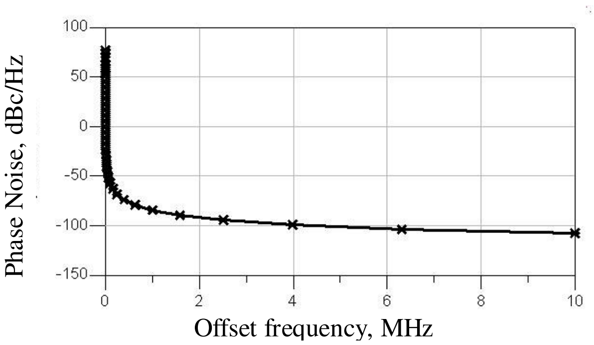

Fig. 9 Phase Noise of proposed VCO with 1.8GHz

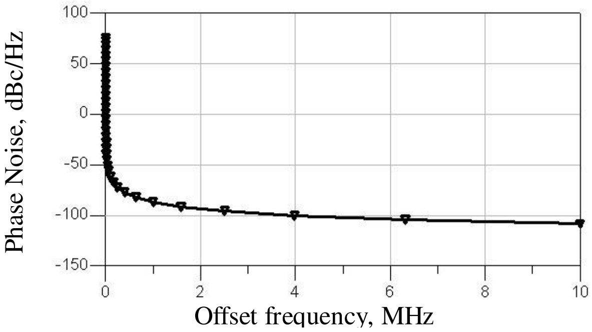

Fig. 10 Phase Noise of proposed VCO with 0.9GHz

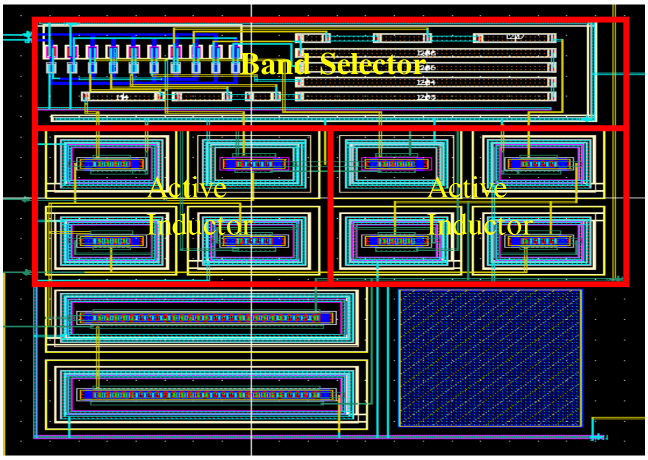

Fig. 11 Layout of proposed VCO

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