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A low phase noise multi-band LC VCO using a switched differential inductor

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Abstract: This paper presents a low phase noise multi-band LC VCO using a switched differential inductor in a standard 0.18 µm CMOS technology. In the proposed LC VCO, it is achieved multi-bands of 0.9, 1.8, 2.4, and 4.5 GHz, and the phase noises of −133, −135, −125, and −127 dBc/Hz at 1 MHz offset, respectively. The chip size is $1.0 \times 1.1\,\text{mm}^2$ including pads. The DC power consumption is 16.2 mW at 1.8 V supply voltage.

Keywords: LC VCO, multi-band, switched differential inductor, low phase noise
Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

Multi-band wireless transceivers have recently become attractive to support multiple standards and application in the IoT application system, such as BLE, Zigbee, and Wifi [1, 2]. Therefore, the multi-band signal sources of 0.9–1.8 GHz and 2.4–5 GHz are required for IoT application system. Various topologies, especially the frequency tuning range of the LC VCO with switched inductor and capacitors, have been introduced [3, 4, 5, 6]. However, since the operation frequency of the VCO is usually controlled by varying the inductance and capacitance, it is difficult to achieve the multi-octave bandwidth, which covers the frequency band of IoT application system, compact size, and low phase noise [3, 6, 7]. In this paper, a multi-band LC VCO using a switched differential inductor from 0.9 to 5 GHz for IoT application system is presented using a standard 0.18 µm CMOS technology.

2 Design of multi-band LC VCO

Fig. 1 shows the circuit schematic of proposed multi-band LC VCO. The proposed multi-band LC VCO consists of complementary cross-coupled pairs, a switched capacitor bank, and a switched differential inductor ($L_{Diff.}$) to achieve multi-band operation.

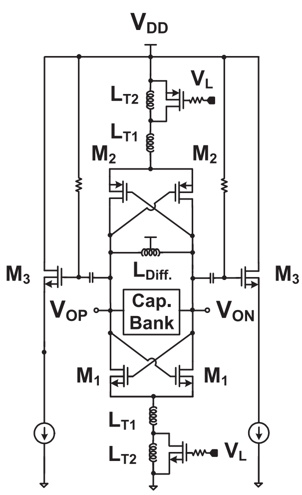

Fig. 1. Circuit schematic of the proposed multi-band LC VCO.

Typically, the complementary cross-coupled pairs generate negative transconductance. The switched capacitor bank consists of switched MIM capacitors and varactor diodes as shown in Fig. 2(a). Fig. 2(b) shows the equivalent circuit

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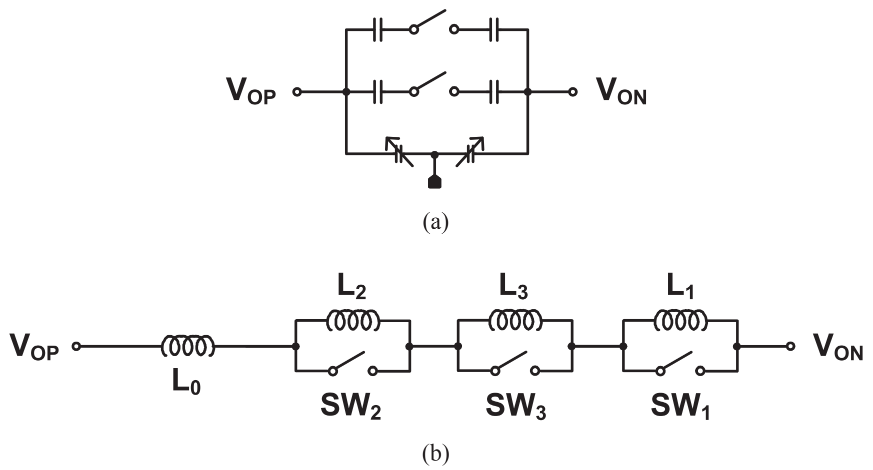

Fig. 2. (a) Circuit schematic of the switched capacitor bank, and (b) the equivalent circuit schematic of a switched differential inductor ($L_{Diff.}$).

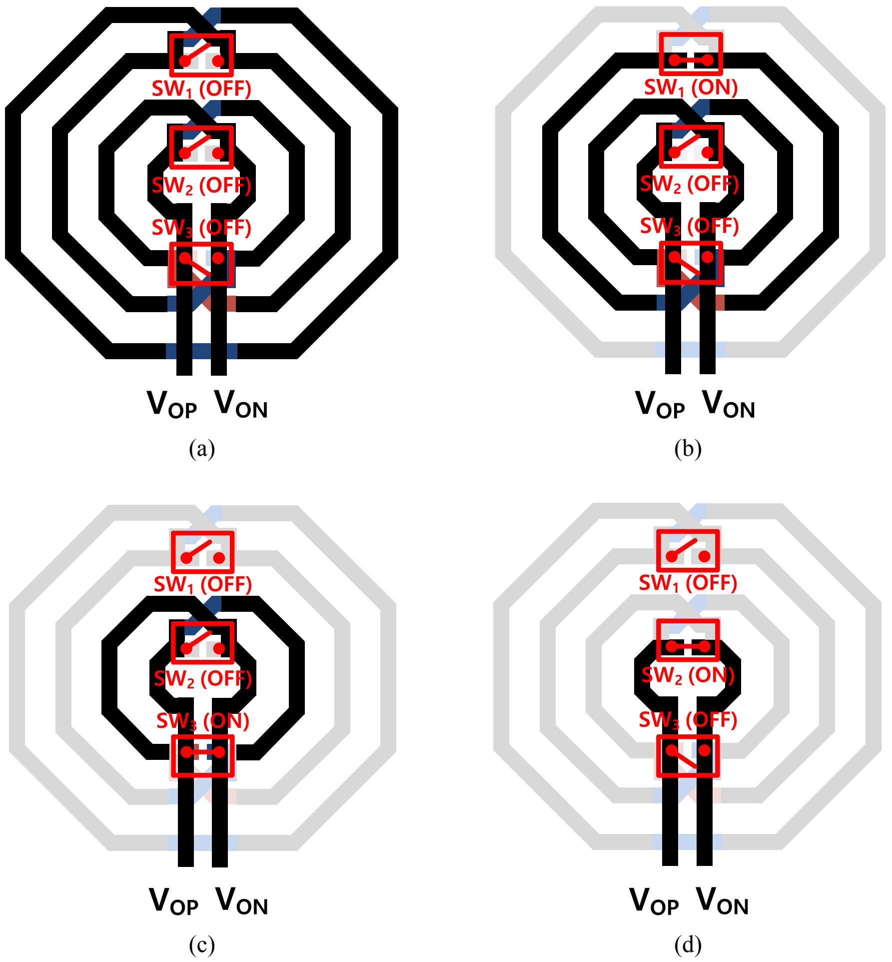

Fig. 3. Configurations of a switched differential inductor for (a) 0.9 GHz, (b) 1.8 GHz, (c) 2.4 GHz, and (d) 5 GHz frequency bands operation.

schematic for the switched differential inductor, and each inductor is selected by switch operation. Fig. 3 shows the four different configurations of a switched differential inductor depending on operating frequency. The transistors are used in

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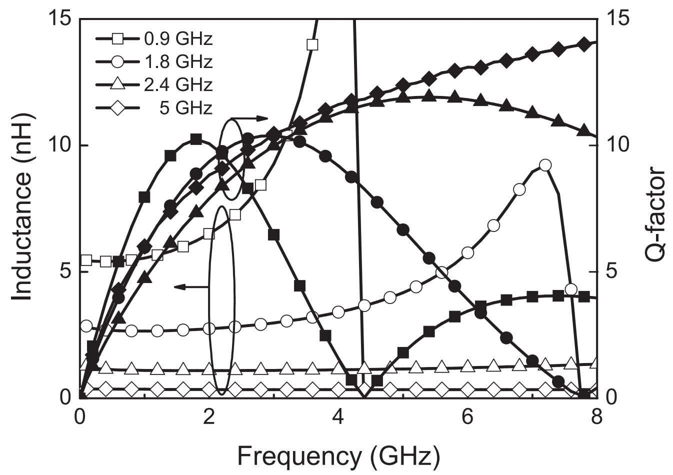

Fig. 4. Q-factor simulation results for four frequency bands.

the switched differential inductor to select four frequency bands, and its size of 400 µm is to reduce R_{ON}. In order to operate the proposed VCO at 0.9 GHz, all transistor switches (SW_1, SW_2, SW_3) in the differential inductor are turned OFF as shown in Fig. 3(a). For 1.8 GHz frequency band operation, the SW_1 is turned ON as shown in Fig. 3(b). The SW_3 at 2.4 GHz and the SW_2 at 5 GHz are turned ON as shown in Fig. 3(c) and Fig. 3(d), respectively. The phase noise for $1/f^2$ and $1/f^3$ regions can be relatively reduced as using harmonic tuning. The series inductors (LT_1, LT_2) at the common source nodes are used for low phase noise by noise filtering [8]. Fig. 4 shows the simulated inductance and Q-factor results for four frequency bands. With the switched differential inductor ($L_{Diff.}$), the switched MIM capacitors, and the varactor diodes, the four oscillation frequency bands (0.9, 1.8, 2.4, and 5 GHz) can be given as below:

$$f_{o(Multi\text{-}band)} = \frac{1}{2\pi\sqrt{L_{Diff.}(C_M + C_{VAR})}}$$

where C_M is the capacitance given by switched MIM capacitors, and C_{VAR} is the capacitance of varactor diodes. All the inductors, the interconnection lines, and the GSSG pads are simulated with electromagnetic (EM) simulator.

3 Measurement results

Fig. 5 shows the microphotograph of fabricated multi-band LC VCO in a commercial 1-poly 6-metal 0.18 µm CMOS technology. The chip size is $1.0 \times 1.1\,mm^2$ including pads. The DC power consumption is 16.2 mW at 1.8 V supply voltage. The output frequencies and phase noise performances are measured by Keysight E5052B signal source analyzer. Fig. 6 shows the measured spectrums and oscillation powers for four frequency bands. The oscillation powers are achieved −2.4 dBm (0.9 GHz), −5.2 dBm (1.8 GHz), −8 dBm (2.4 GHz), −10.7 dBm (4.5 GHz). Fig. 7 shows the measured oscillation frequencies versus the varactor voltage of multi-band LC VCO, and it is covered from 0.9 to 5 GHz frequency bands. Fig. 8 shows the measured phase noise of multi-band LC VCO, and the phase noises are achieved −133 (0.9 GHz), −135 (1.8 GHz), −125 (2.4 GHz), −127

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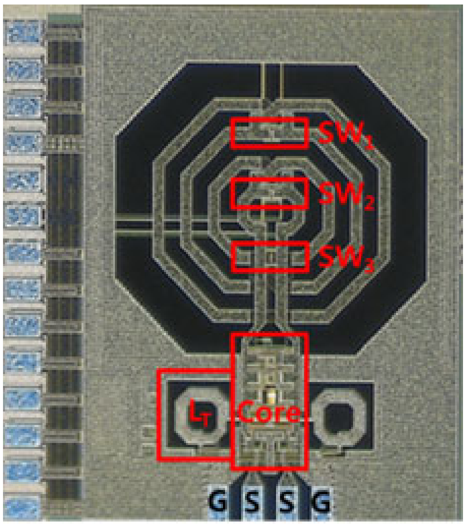
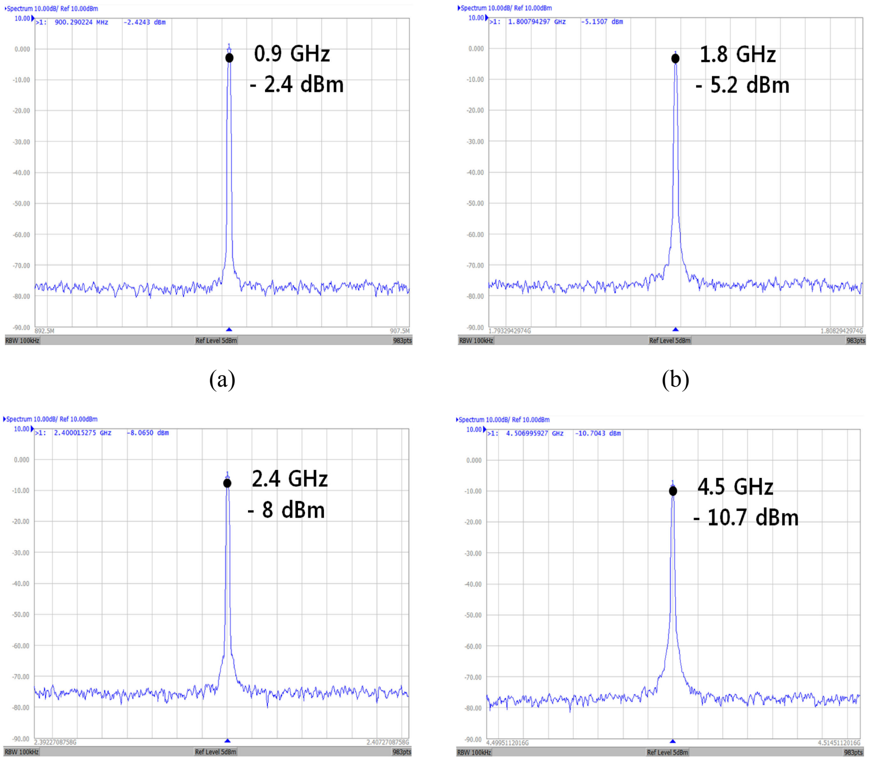


Fig. 5. Microphotograph of the multi-band LC VCO.



(a) (b) (c) (d)

Fig. 6. Measured spectrums and oscillation powers for (a) 0.9 GHz, (b) 1.8 GHz, (c) 2.4 GHz, and (d) 5 GHz frequency bands operation.

(4.5 GHz) dBc/Hz at 1 MHz offset, respectively. Table I shows the performance comparison of multi-band VCOs [9, 10, 11].

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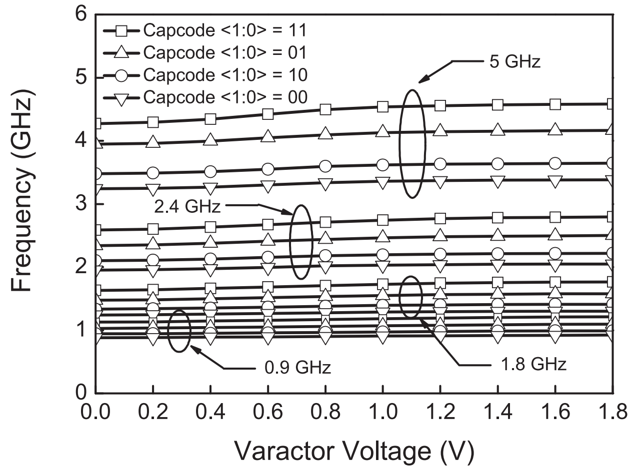

Fig. 7. Measured oscillation frequencies of the multi-band LC VCO.

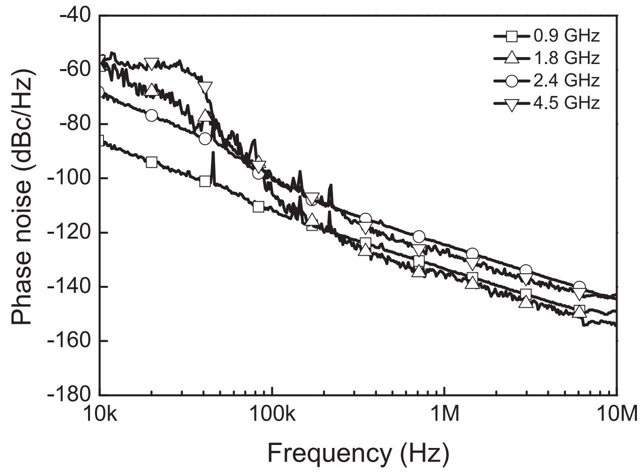

Fig. 8. Measured phase noises of the multi-band LC VCO.

Table I. Performance comparison of multi-band VCO.

	[9]	[10]	[11]	This work	
Technology	0.18 μm CMOS	0.18 μm CMOS	0.13 μm CMOS	0.18 μm CMOS	
Frequency (GHz)	0.9 1.8	2.4 4.5	3 5.3	0.9 1.8	2.4 4.5
Phase noise (dBc/Hz)	−125 −123 @ 0.6 MHz	−120 −121 @ 1 MHz	−112.6 −104.3 @ 1 MHz	−133 −135 @ 1 MHz	−125 −127 @ 1 MHz
FOM* (dBc/Hz)	−176 −181	−179 −185	−176 −172	−180 −188	−181 −188
DC consump. (mW)	16	-	5.4	16.2	
Size (mm^2)	0.9	1.06	0.74	1.1	

*FOM = Phase noise $(f_{offset}) - 20\log(f_o/f_{offset}) + 10\log(P[1\,mW])$

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4 Conclusion

This paper presents a low phase noise multi-band LC VCO using a switched differential inductor in a standard 0.18 μm CMOS technology. The proposed LC VCO is achieved to operate 0.9, 1.8, 2.4, 4.5 GHz. The measured phase noises of all bands are achieved less than −125 dBc/Hz at 1 MHz offset. The chip size is $1.0 \times 1.1\,mm^2$ including pads. The DC power consumption is 16.2 mW at 1.8 V supply voltage. Since the proposed LC VCO using a single switched differential inductor, which covers from 0.9 to 4.5 GHz, with low phase noise, it can be applied to multi-standard IoT application with compact size and low cost.

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