A Wideband CMOS LC-VCO Using Variable Inductor

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***Abstract*— This paper proposes a wide-range tunable CMOS voltage controlled oscillator (VCO). VCO uses an on-chip variable inductor and switched capacitors as variable elements. The VCO was fabricated using a standard 0.18μm CMOS process with five metal layers. The oscillation frequency can be tuned from 1.28 GHz to 2.75 GHz with tuning range of 72 %.**

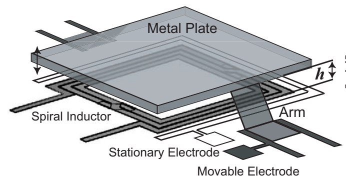
I. INTRODUCTION

Many kinds of wireless communication standards are used in these days, and they use several frequency bands. Handheld terminals have been obtaining more multi-band/mode function, smaller size, and lower power operation [1]. Multi-band/mode wireless communication circuit covering multi standards has been investigated. The software defined radio (SDR) has been studied [2]. This technique requires multi-band RF front-end. One of promising technologies to achieve multi-band RF front-end is the *reconfigurable RF circuit design* [3]. This technology can reconstruct analog RF circuits by controlling bias of RF circuits and variable passive devices. In this paper, a wide-range CMOS LC-VCO is presented, which is one of key circuits for the *reconfigurable RF circuit* [4], [5]. In general, LC-VCO using switched capacitors is proposed to achieve wider frequency-tuning range [6], [7]. Although it exhibits wide tuning range, the switch resistance degrades phase noise characteristics. The LC-VCO using variable inductor as an additional variable element has been proposed by authors' group [4]. It achieves the wide-range tuning, low phase noise and low power consumption. In this paper, a novel wide-range tunable CMOS LC-VCO is proposed. The proposed VCO uses variable inductor and switched capacitors, resulting in more wide-band tuning range [8].

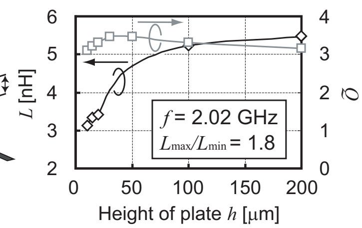
II. VARIABLE INDUCTOR

Figure 1(a) shows a structure of a variable inductor, proposed by authors' group [9]. The variable inductor consists of a conventional planar spiral inductor, a shielding metal plate and a MEMS actuator. In Fig. 1(a), h is the distance between the spiral inductor and metal plate. In this case, the metal plate can be moved vertically using a MEMS parallel-plate actuator. The variable inductor changes inductance by moving the shielding metal plate above the spiral inductor. When the magnetic flux of spiral inductor penetrates the shielding metal plate, an eddy current flows in the plate. The eddy current induces a counteractive magnetic field according to Lenz's law. Therefore, the shielding metal plate decreases the magnetic flux that penetrates the spiral inductor, resulting in the variation of inductance. Inductance varies according to the shielding metal plate height h.

A symmetrical spiral inductor was fabricated using a 0.18 μm standard CMOS process with five aluminum metal layers. Vector network analyzer (Agilent E8364B) was used for measurement of variable inductor. In this measurement, the metal plate was moved manually using the micromanipulator instead of the MEMS actuator. Figure 1(b) shows measured inductance and quality factor as a function of height of the metal plate h at 2.0 GHz. Before inserting the metal plate, inductance is 5.5nH. As the height of metal plate h decreases, the inductance decreases continuously because of increase in the amount of shielded magnetic flux. The inductor has exhibited variable ratio ($L_{\max}/L_{\min}$) of 1.8, between 10 μm and 200 μm of the metal plate height h. The metal plate decreases not only inductance but also substrate loss because of decreasing the eddy current in Si substrate, so the quality factor is not degraded by the metal plate so much as shown in Fig. 1(b). The parasitic capacitance caused by the metal plate also has small influence. The variable inductor realizes inductance variation without the degradation of quality factor, which is an ideal characteristic for a tunable LC-VCO.



(a) Structure of variable inductor



(b) Inductance and quality factor

Fig. 1. Variable inductor consists of a conventional spiral inductor, a metal plate and a MEMS actuator. Inductance varies by moving the metal plate vertically above the spiral inductor.

III. WIDE-BAND TUNABLE VCO DESIGN

Figure 2 shows a schematic of a proposed LC-VCO. The LC-VCO consist of the cross-coupled N- and P-MOSFETs, the on-chip variable inductor explained in section II, the varactor, and three switched capacitors. The LC resonance frequency becomes oscillation frequency of LC-VCO. In the conventional LC-VCO, oscillation frequency is tuned by only the varactor. Oscillation frequency of the proposed VCO can be tuned by the variable inductor and switched capacitors as well. Therefore, the proposed VCO can achieve wider tuning range. Figure 3 shows a chip micrograph of fabricated VCO. VCO core area is 400 μm $\times$ 600 μm. Signal Source Analyzer (Agilent E5052A) was used for measurement.

Figure 4 shows measured VCO tuning characteristics. The fabricated VCO in this paper can be tuned from 1.28 GHz to 2.75 GHz. The tuning range is found to be 72 %. Figure 5 shows the measured phase noise at 1.28 GHz, 2.02 GHz, and 2.75 GHz. The phase noise is below −127 dBc/Hz at

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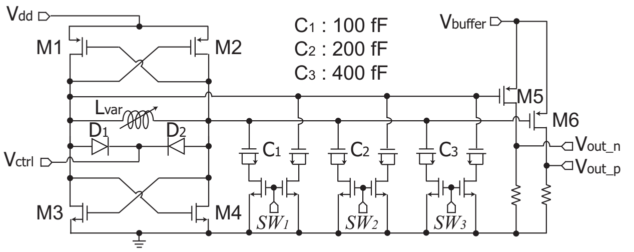

Fig. 2. LC-VCO consists of the variable inductor and switched capacitor.

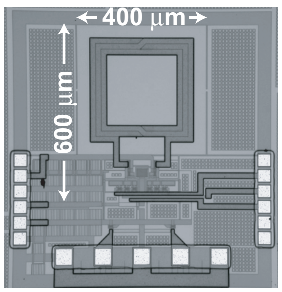

Fig. 3. Chip micrograph of fabricated LC-VCO. VCO core area is 400 μm x 600 μm.

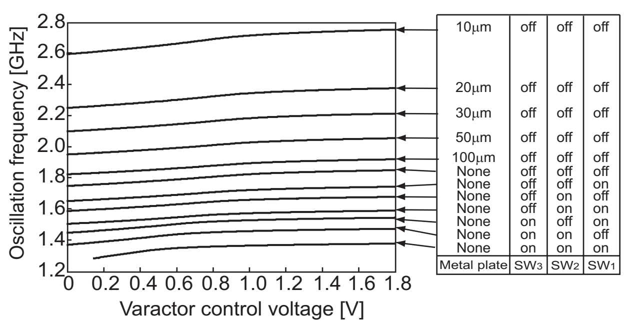

Fig. 4. VCO can totally be turned from 1.28 GHz to 2.75 GHz, which corresponds to tuning range of 72 %.

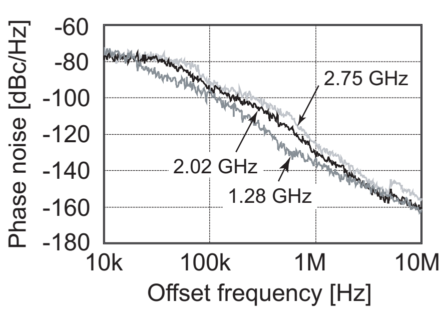

Fig. 5. Phase noise at 1.28 GHz, 2.02 GHz and 2.75 GHz

each offset frequency of 1 MHz. Figure 6 shows measured phase noises characteristics at 1 MHz offset as a function of oscillation frequency. Here, there are several choices to achieve the same oscillation frequency in proposed VCO. However, the switched capacitor degrades the phase noise. On the other hand, the variable inductor can achieve wider tuning range without the phase noise degradation. Table I summaries the measured result.

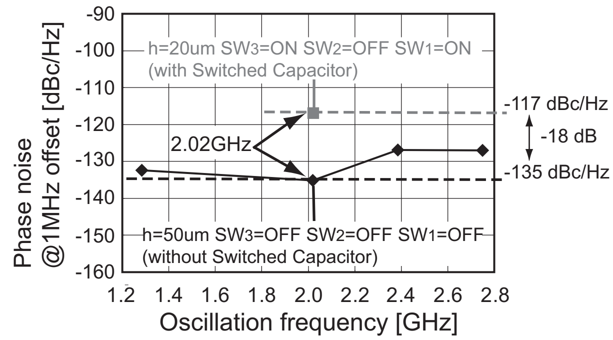

Fig. 6. Measured phase noise characteristics at 1 MHz offset as a function of oscillation frequency.

TABLE I

VCO PERFORMANCE SUMMARY.

Technology	0.18 μm standard CMOS process
Supply voltage V_{DD}	1.8 V
VCO core current	9.81∼ 13.1 mA
Power consumption	17.7∼ 23.6 mW
Center frequency	2.02 GHz
Tuning range	1.28 GHz ∼ 2.75 GHz 72 %
Phase noise at 1 MHz offset	−135 dBc/Hz@2.02 GHz
FoM	−189 dBc/Hz@2.02 GHz

IV. Conclusion

This paper presents a wide-band tunable CMOS voltage controlled oscillator (VCO), which uses an on-chip variable inductor and switched capacitors as variable elements. The fabricated LC-VCO can be tuned from 1.28 GHz to 2.75 GHz (tuning range of 72 %) with appropriate phase noise.

Acknowledgement

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