A 900-MHz 1.5-V CMOS Voltage-Controlled Oscillator Using Switched Resonators With a Wide Tuning Range

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***Abstract*—A 900-MHz fully integrated VCO was fabricated in a 0.18-μm foundry CMOS process. Under 1.5 V power supply, this VCO can be tuned from 667 MHz to 1156 MHz which corresponds to a 53.6% tuning range. The VCO has nearly constant phase noise over the whole tuning frequency, credit to the switched resonators used in this VCO. The phase noise at a 600 kHz offset is −123.1 dBc/Hz at 1125 MHz center frequency and −124.2 dBc/Hz at 667 MHz center frequency.**

***Index Terms*—CMOS voltage-controlled oscillator, phase noise, switched resonators, tuning range.**

I. Introduction

A MAJOR challenge for implementing a fully integrated transceiver is integrating a VCO. The stringent phase noise requirements in a standard like 802.11a make integration of a VCO risky. A potential approach which could enable integration of in particular a CMOS VCO is use of a dual conversion receiver in which channel selection is performed by a second VCO running at a low frequency [1]. The first VCO where frequency is fixed can achieve low phase noise by using a wideband PLL [2] and a small varactor [3]. However, this architecture requires a wide tuning range for the second VCO. A 50% tuning range may be required to perform channel selection as well as to deal with process and temperature variations.

The desired wide tuning range can be achieved by using a ring oscillator, but it usually have poor phase noise [4]. On the other hand, use of an LC-VCO with a wide tuning range requires high VCO gain (MHz/V), especially at low supply voltages, which subsequently renders VCO more susceptible to the voltage noise induced phase noise [5].

In this paper, a 900 MHz CMOS VCO fabricated in a 0.18-μm foundry process with an over 53% tuning range is presented. The VCO utilizes a switched resonator concept [6], which allows a reduction in the VCO gain. At 1.5 V power supply voltage, the VCO achieves −123 dBc/Hz phase noise at a 600 kHz offset frequency over the whole tuning range. Phase noise of −79 dBc/Hz at 10 kHz offset also can be extrapolated from the data at 100 kHz offset using 30 dB/dec frequency dependence. This phase noise is adequate for 802.11a wireless LAN application.

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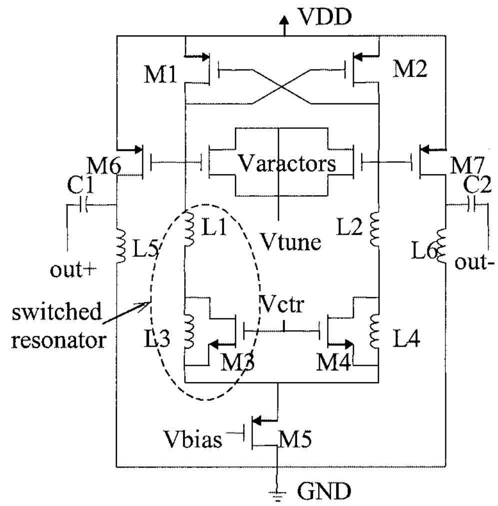

Fig. 1. VCO schematic including switchable L–C resonators.

II. Design of VCO

A. Switching Inductor Concept

A high tuning range VCO has been attempted by varying inductance [7] with very poor phase noise outcome. As mentioned, in this work, the switched resonator concept illustrated in Fig. 1 is utilized to increase the tuning range and to achieve low phase noise over the tuning range at a reasonable power consumption. The inductance seen between ports 1 and 2 are changed by turning $M3$ on and off. When the transistor is off, the inductance is approximately the sum of $L1$ and $L2$. The actual combined inductance is somehow lower due to the effects of C_{GD} in series with C_{GS}, and C_{DB} of $M1$ [6]. These capacitances also affect the capacitance seen from $L1$ side (C_{p1}). When $M3$ is on, $L2$ is shunted out and the inductance is decreased. Furthermore, when $M3$ is on, C_{p1} is reduced because the transistor capacitances and the capacitances associated with $L1$ (partially) and $L2$ are shunted to ground by the low on-resistance of $M3$, thus, leading to simultaneous decreases of inductance and capacitance. This ability to simultaneously tune L and C provides greater flexibility to tradeoff phase noise and power consumption, as well as to achieve given phase noise performance over a larger frequency range [6] compared to using only switched capacitors [8].

B. VCO Circuit Design

The VCO schematic in Fig. 1 is similar to [6] and [9]. $M1$ and $M2$ are cross-coupled and provide negative resistances for

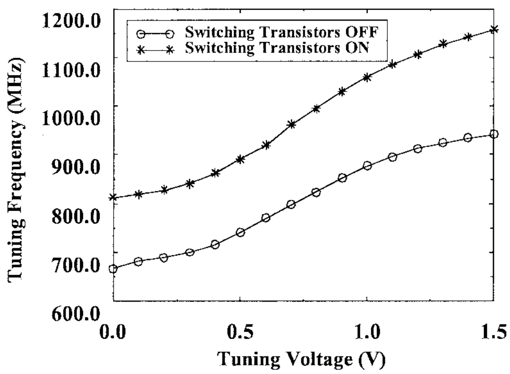

Fig. 2. VCO tuning characteristics: coarsely tuned by switching inductors and finely tuned by varactors.

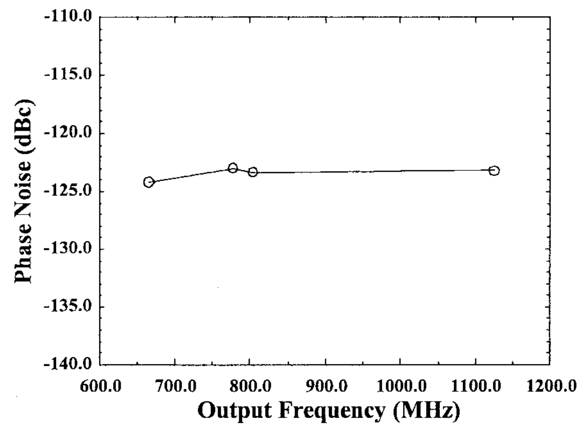

Fig. 3. VCO phase noise over output frequency range.

the VCO core. The PMOS, $M5$ is used to set the current for the VCO. The sizes are 300/0.18 μm for $M1$, $M2$ and 2000/0.18 μm for $M5$. Having this large size for $M5$ reduces $1/f$ noise in the tail transistor and, thus, the close in phase noise of the VCO.

The LC tanks include MOS varactors, inductors, and variable resonator transistors $M3$ and $M4$. $L1$ and $L2$ are 2.5-nH inductors, and $L3$ and $L4$ are 1.2-nH inductors. The inductors have patterned ground shields [10], [11] and are formed by shunting metal 4, 5, and 6 layers. When control voltage ($Vctr$) is low, i.e., the switching transistors $M3$ and $M4$ are off, the total inductance of the tanks is around $2.5+1.2 = 3.7$ nH. When $Vctr$ is high, $M3$ and $M4$ shorts out $L3$, and $L4$, then the total inductance is approximately 2.5 nH. In this case, the on-resistances of $M3$ and $M4$ are series with $L1$ and $L2$, respectively, which increases resistance thus lowering inductor Q. In order to keep this detrimental effect small, 2000/0.18 μm NMOS transistors are used for $M3$ and $M4$. Simulations show that the on-resistance is 0.4 Ω. The varactors are implemented using a MOS capacitors [12] and laid out using a differential architecture [13].

III. Experimental Results

The VCO operates between 667 MHz to 1156 MHz, which is 53.6% tuning range. As shown in Fig. 2, the VCO is coarsely tuned with switched resonators and finely tuned using MOS varactors. When the switching transistors $M3$ and $M4$ are off, i.e., when $Vctr$ is low, by changing the MOS varactor tuning voltage ($Vtune$), the output frequency is varied from 667 to 942 MHz (Band 1). When the switching transistors are on or V_{GS} of $M3$ and $M4$ is 1.5 V, the varactor tunes VCO from 813 to 1156 MHz (Band 2). There is a 130-MHz overlap between bands 1 and 2. This overlap ensures the continuity of tuning despite the process and temperature variations.

The VCO core draws about 14 mA, while the VCO buffer draws about 3 mA from a 1.5 V power supply. The output power is -1.67 dBm at the 1127 MHz center frequency. Fig. 3 shows the phase noise at a 600 kHz offset versus oscillation frequency. The phase noise is -123–-124 dBc/Hz, which is good. More importantly, the phase noise is essentially flat over the entire operating frequency range.

Table I summarizes phase noise performances for bands 1 and 2. As mentioned previously, when switching transistors $M3$ and $M4$ are on, additional series resistances arising from the transistors could increase VCO phase noise. The conditions (b) and

TABLE I
SUMMARY OF VCO CHARACTERISTICS

	(a)	(b)	(c)	(d)
Vctr (V)	2.4	2.4	0	0
Vtune (V)	1.5	0	0.8	0
Centre frequency (MHz)	1125	804	777	666
Phase Noise at 600 kHz offset (dBc/Hz)	-123.1	-123.3	-123	-124.2
Core Current (mA)	14.1	14.5	14.5	14.4

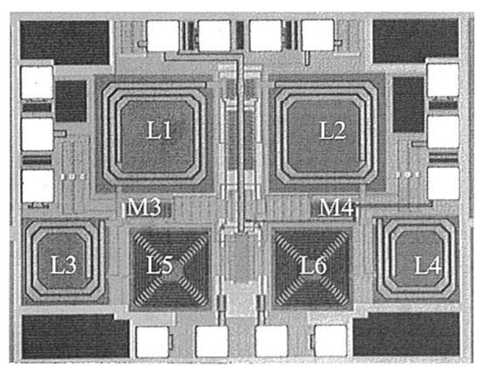

Fig. 4. VCO chip microphotograph.

(c) attempted to tune the VCO at the same frequency with the switching transistors on [case (b)] and off [case (c)]. Surprisingly, the resulting phase noise difference is less than 0.3 dB which is well within typical measurement tolerances. It appears that the on-resistances and other losses associated with the switch transistors can be made sufficiently low. This VCO has sufficient a tuning range and margins to be used for 802.11a applications with a 200-MHz band width (5.15 to 5.35 GHz). The phase noise measurements at 100 and 600 kHz offsets indicate that the VCO should be adequate for this application. Fig. 4 is a VCO chip microphotograph. It occupies 1100×860 μm^2.

IV. CONCLUSIONS

A 900-MHz monolithic VCO using switched resonators implemented in a 0.18-μm foundry CMOS process is presented. When operated under 1.5 V power supply, it achieves a 53.6% tuning range. Nearly constant phase noise of -123–-124 dBc/Hz was observed over the entire tuning range between 667 MHz to 1156 MHz. At the 100 kHz offset, phase noise is around -109 dBc/Hz. These phase noise performance should be sufficient for numerous RF applications.

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