A Frequency Synthesizer
Using Low Voltage Active Inductor VCO with a Feedback Resistor

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Abstract: - This paper presents a frequency synthesizer using low voltage active inductor VCO (Voltage Controlled Oscillator). The low voltage active inductor VCO with feedback resistor increases the quality-factor (Q) and its equivalent inductance. Under certain conditions, the low voltage active inductor with feedback resistor generates a negative resistance at the input. In this paper, the conditions for negative resistance are obtained by small signal analysis. The designed low voltage active inductor VCO has a measured tuning range from 1059MHz to 1223MHz. The measured phase noise at 1.178GHz is -81.8dBc/Hz at 1MHz offset.

Key-Words: - Active inductor, Frequency synthesizer, VCO

1 Introduction
Frequency synthesizers are widely used in modern communication systems. A frequency synthesizer generally employs a PLL (Phase Locked Loop) based structure. In a PLL, the VCO is an essential building block as it determines the key performances: phase noise, harmonics, and power consumption. An LC-VCO using a spiral inductor is often used for frequency synthesizer because of good phase noise performance. However the LC-VCO suffers from a relatively narrow tuning range, a large area, and low Q-factor values[1]. Due to its high Q-factor, a bond wire is used as an inductor in some VCO designs. However the bond wire inductance differs up to ±20% from the desired inductance[2]. This means that VCO must have a very large tuning range. So, the switched capacitor tuning technique is needed to cover the desired frequency range. Ring oscillator is tunable over wide frequency range in a small chip area. However, poor noise performance and large power consumption, proportional to the stage count, limit their applications[3]. In order to overcome these limitations, an active inductor was proposed[4].

The advantage of using active inductors is higher Q-factor and wider tuning range compared to the conventional spiral inductors. However, an active inductor VCO has poor phase noise performance, due to the relatively smaller output voltage swing and more active components used.

In this paper, a low voltage active inductor VCO with a feedback resistor is applied to the design of a frequency synthesizer. Useful design equations for VCO are obtained by small signal analysis and are verified through simulation and measurement. A dual-compensated CP (Charge Pump) decreases the current mismatch. A second order passive off-chip LF (Loop Filter) is employed in the frequency synthesizer.

2 Circuit Design
The basic frequency synthesizer consists of a PFD (Phase Frequency Detector), a CP, an LF, a VCO, and divider in the feedback path. Its block diagram is shown in Fig. 1. The feedback operation in the loop causes the output frequency to be N times the reference frequency.

Fig. 1. The block diagram of frequency synthesizer.

2.1 Voltage controlled oscillator
The most common active inductor topology is the grounded active inductor, which is based on the gyrator theory. This topology makes it possible to obtain several nH of inductance at a few GHz. Fig. 2 (a) shows the low voltage active inductor with a feedback resistor[4]. The feedback resistor increases the effective inductance and the quality factor. The
The equivalent gyrator model is shown in Fig. 2(b). The effective inductance and capacitance can be expressed as in (1) through small-signal analysis. C1, C2, and C3 are the capacitances at node ①, ②, and ③, respectively.

\[
L_{\text{eff}} = \left( \frac{C_1 + C_2 + \frac{R_g C_1}{R_c}}{S_{a1} S_{a2}} \right), \quad C_{\text{eff}} = C_3 = C_{g1} + C_{g2}
\]  

The low voltage active inductor VCO with the feedback resistor generates a negative resistance under certain conditions. Equation (2) is the condition for satisfying \(\text{Re}(Z_{\text{in}}) < 0\).

\[
0 < f < \frac{1}{2\pi} \sqrt{\frac{S_{a2}}{R_f C_{g1} C_{g2}}}
\]

Fig. 3 shows the simulation results for the real part of the input impedance. (\(R_f = 3\, \Omega\))

2.2 Phase frequency detector
The PFD senses the phase and frequency error between the reference and the VCO output after being scaled by the divider. The tri-state PFD is implemented as shown in Fig. 4.

2.3 Charge pump
The dual-compensated CP decreases the current mismatch and the current variation using a dual compensation method. Fig. 5 shows the dual-compensated CP. In the first feedback loop, VR1 is controlled to track VCP by the compensation method. So the pump-up current (IUP) is equal to the bias current (IB). In the second feedback loop, VR2 is controlled to track VCP. So, the pump-down current (IDN) is equal to the pump-up current (IUP).

Fig. 6 shows the simulation results of the dual-compensated CP. The maximum mismatch was 0.15% and the maximum current deviation was 1.42% over the output voltage from 0.25 to 1.45V.
2.4 Loop filter and divider
The loop filter has been optimized with a simulator for a phase margin of 60 degree and a loop bandwidth of \( f_{\text{ref}}/20 \). In this work, a second-order loop filter is realized by off-chip circuit. The divider is implemented by pulse swallow method.

3 Chip Test

3.1 Voltage controlled oscillator
The designed low voltage active inductor VCO with feedback resistor has a frequency tuning range 1049 ~ 1239 MHz. The measured active inductor VCO has a frequency tuning range 1059 ~ 1223 MHz. Fig. 7 shows the operation of the active inductor VCO and Fig. 8 shows the difference between simulation and measurement.

3.2 Frequency synthesizer
The measured VCO has a frequency tuning range 1059 ~ 1223 MHz. However frequency synthesizer using the VCO has a limited frequency range of 1098 ~ 1190 MHz because of the reverse current of charge pump. The current of charge pump using source switch type flows in reverse direction when the control voltage is very high or very low. The measured phase noise of the VCO is -77.77 dBc/Hz at 300 KHz offset and -81.8 dBc/Hz at 1MHz offset as shown in Fig. 9. The size of implemented frequency synthesizer is 0.9mm × 0.9mm. Fig. 10 shows the microphotograph of frequency synthesizer.

4 Conclusion
This paper presents a frequency synthesizer using low voltage active inductor VCO. The low voltage active inductor VCO with a feedback resistor generates a negative resistance and has a tuning range from 1059 MHz to 1223 MHz. The measured phase noise of the VCO is -77.77 dBc/Hz at 300 KHz offset and -81.8 dBc/Hz at 1MHz offset. The frequency synthesizer was fabricated using a 0.18\( \mu \)m CMOS process.

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References:


