New High Performance and Wide Range Tunable Two-Stage 3GHz CMOS RF Hetero-Linked Oscillators

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Abstract

New CMOS High performance and wide range tunable two-stage oscillators applicable to the places requiring in- and quadrature-phase components such as RF and data retiming applications are presented. We present two-stage CMOS ring oscillators using phase-look-ahead technique and two kinds of ***hetero-linked oscillators****, the LCRO and the LCXRO. Two-stage ring oscillator is fabricated using 0.8-μm CMOS technology. The maximum oscillation frequency is 914-MHz at 2-V supply. Its phase noise is -87-dBc/Hz at 600-kHz offset. The LCRO and the LCXRO show maximum oscillation frequency of 2.85-GHz and 3-GHz with 3-V power supply. The measured tuning range of the LCRO and the LCXRO are 500-MHz and 100-MHz, respectively, without varactor diodes. Their phase noises are -109-dBc/Hz and –97-dBc/Hz at 600-kHz offset.*

1. Introduction

High performance voltage-controlled oscillators are critical components in RF communication systems. Considering the RF radio local oscillator applications and the clock recovery circuit based on quadricorrelator, in- and quadrature-phase outputs are required to reject the image signals and obtain correct data retiming. Design challenges of controlled oscillators lie in low noise, low power, wide tuning range with completely integrated in on-chip.

In general, the ring oscillators [1-2] are widely used in monolithic form. They are much simpler than any other oscillators and easily reach the highest possible frequency of operation for a given process. They also provide wide range of the oscillation frequency, which is easily tunable with electrical method. Their phase noise, however, tends to be high because they lack passive resonant elements.

The L-C oscillators [3-4] using inductors in spiral show better phase noise characteristic than that of the ring oscillators as much as ~20dB. In general, sufficient tuning range is required to account for process variations, circuit aging and temperature variations. For the L-C oscillators, the reverse-biased varactor diodes are generally used to tune the oscillation frequency. Unfortunately, their tuning range is narrow and typically about 100-MHz with varactor diodes.

In this paper, the authors present new CMOS two-stage ring oscillators operating in gigahertz region at low supply voltage and hetero-linked oscillators providing high speed operation, low phase noise and wide tuning range without varactor diodes.

2. Two-Stage Ring Oscillation

Minimum choice of stages in the ring type oscillator which generates in- and quadrature phase outputs must be two. However, it is usually difficult to ensure reliable oscillation if the number of stages are less than three because the total phase shift around the loop is not sufficient to allow complete switching in each stage.

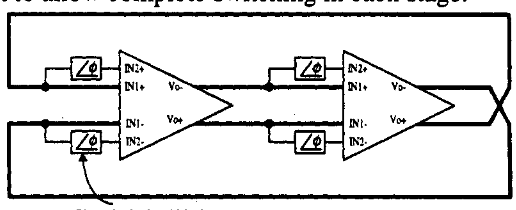
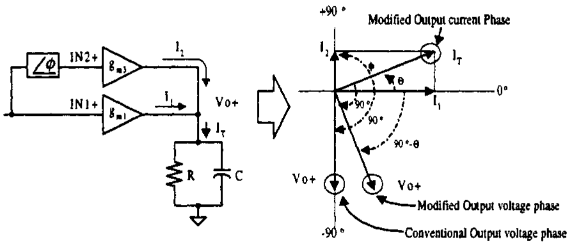


Fig. 1. Proposed 2-stage Ring Oscillator using PLA.

Fig. 1 shows the block diagram of the proposed two-stage ring oscillator with phase-look-ahead (PLA) block. To configure fully differential two-stage oscillator, two new delay cells having double input differential amplifiers are needed comparing with general single input differential delay cells. In the new delay cell, IN1+ and IN1- are used for configuring conventional two-stage oscillator, while IN2+ and IN2- are reserved for phase look-ahead. Fig. 2(a) shows the simple half circuit small signal model of a new delay cell which is composed of two transconductance amplifiers having one PLA block at one input and R-C load. Assuming the PLA block provides a phase leading of ϕ degree, the phase relationships are illustrated in Fig. 2(b) where I_1, I_2 and Vo are the output currents of the two transconductance amplifiers and the output voltage across the R-C load, respectively. The load current I_T is the vector summation of I_1 and I_2, and the resultant phase of I_T yields θ degree leading than that of I_1. In the two-stage ring, a delay cell should have to satisfy 90 degrees phase shift from its input to output, in other words, the load current and load voltage should have 90 degree phase difference for two-stage oscillation. On the other hand, the phase shift condition to oscillate with two-stage is reduced to $90°-\theta$ in the new delay cell because the load current leads θ degree with the help of PLA block. PLA scheme can simply be implemented using the internal nodes of the oscillator. In the case of the two-stage oscillator, each output generates 90 degrees phase shift when the oscillator works continually and two-stage oscillator can be configured as Fig. 3. With this configuration, ϕ is set to 90^o and θ can be represented as $\tan^{-1}(g_{m3}/g_{m1})$. Applying load characteristic and its phase relation, the oscillation frequency ω_o can be obtained as

$$\omega_o = \frac{1}{RC}\tan(90°-\theta) = \frac{1}{RC}\frac{g_{m1}}{g_{m3}}. \qquad (1)$$


(a) Half Circuit of a Delay Cell

(b) Phase domain representation of input currents and output voltage

Fig. 2. Phase Domain Representations.

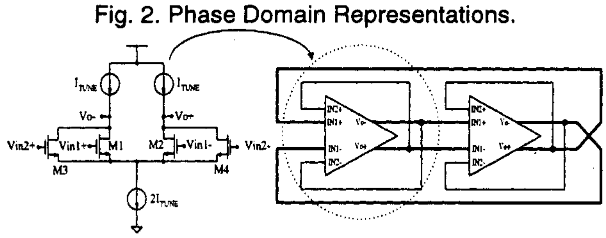


Fig. 3. 2-Stage Ring Oscillator with 90^o PLA.

3. Hetero-Linked Oscillator

The various kinds of oscillators have their own advantages as if the ring oscillators have a wide tuning range. On the other hand, the L-C oscillators using inductors in spiral show better phase noise characteristic than that of the ring oscillators. It goes without saying that oscillator satisfying both of these two merits is our design target. If we properly merge the ring oscillator with L-C oscillator, a new oscillator could be obtained showing wide tuning range as the ring oscillator and good phase noise as the L-C oscillator. The combinatory architectures of oscillators are named "**Hetero-Linked Oscillator (HLO)**".

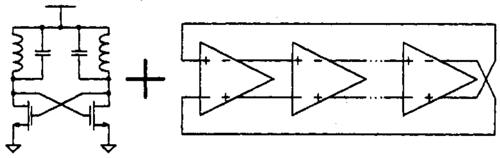

L-C oscillator Ring oscillator

Fig. 4. Combination of L-C and Ring Oscillator.

3.1. LC-Ring Oscillator (LCRO)

The HLO considered firstly is implemented by combining the L-C resonator with the two-stage ring oscillator as in Fig. 4. This oscillator is named "**L-C Ring Oscillator (LCRO)**" and a two stage case is shown in Fig. 5. Applying Barkhausen's oscillation condition, the oscillation frequency, ω_o, and the required gain, A_R, for oscillation can be obtained as

$$\omega_o = \frac{\alpha}{2RC} + \sqrt{\left(\frac{\alpha}{2RC}\right)^2 + \frac{1}{LC}}, \qquad (2)$$

$$A_R = g_{m3}R = -1, \qquad (3)$$

where $\alpha(=g_{m1}/g_{m3})$ is the transconductance ratio of M1 and M3. The oscillation frequency of the LCRO has the following relationship:

LCRO oscillation frequency <
Ring osc. frequency + L-C osc. frequency

It is similar to that the oscillation frequency of the two-stage ring oscillator is modulated with that of the L-C oscillator. As shown in (2), the tuning of oscillation frequency is accomplishable by varying the load resistance, the capacitance and the transconductance ratio of α. Consequently, an LCRO tuning range must be wide as the two-stage ring oscillator.

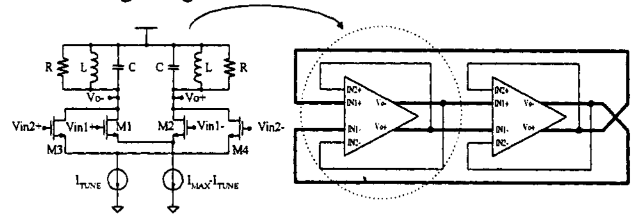


Fig. 5. 2-Stage L-C Ring Oscillator (LCRO).

To analyze the phase noise of output voltage, *Vo*, the LCRO is treated as a feedback system and current noise source, *In*, is applied to the oscillator output. From the loop gain, the noise spectral density shape at the frequency of $\omega_o+\Delta\omega$ is obtained as

$$\left|\frac{Vo}{In}[j(\omega_o+\Delta\omega)]\right|^2 = \frac{1}{Q_o^2}\cdot\left[\frac{1}{2(1+\Omega_o^2)}\right]^2\cdot|Zout(\omega_o+\Delta\omega)|^2\cdot\left(\frac{\omega_o}{\Delta\omega}\right)^2 . \qquad (4)$$

where Q_o is the quality factor of the inductor, Ω_o is the ratio between the LCRO oscillation frequency and the L-C resonance frequency and $|Zout(\omega_o+\Delta\omega)|$ is the magnitude of the RLC load impedance at the frequency of $\omega_o+\Delta\omega$. Carefully observing (4), the phase noise shape is composed of four terms as follow:

***Phase Noise Shape* = Function of**
Q of the inductor
information of 2-stage ring oscillator
RLC load characteristic
frequency information.

Actually, good phase noise characteristic of an L-C oscillator is owing to the quality factor of the inductor because the high quality factor introduces low noise generation and suppression of the surrounding noise at the oscillation frequency. Fortunately, the LCRO is also affected by the quality factor of the inductor. Consequently, the LCRO has tuning ability like a two-stage ring oscillator and the phase noise characteristic as an L-C oscillator.

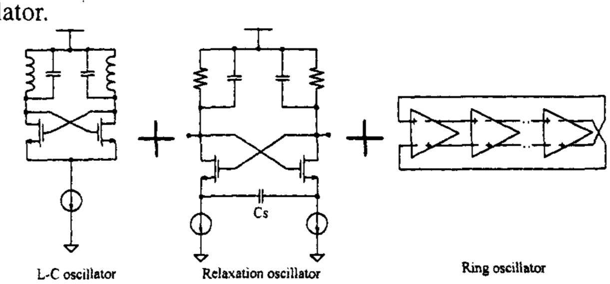


Fig. 6. Combination of L-C, Relaxation and Ring Oscillator.

3.2. L-C Relaxation Ring Oscillator (LCXRO)

The architecture considered finally is the **L-C** relaxation **r**ing oscillator (**LCXRO**) which is composed of L-C, relaxation and ring oscillator as shown in Fig. 6. In Fig. 7, two-stage LCXRO is depicted. The estimated characteristics of the LCXRO are similar to those of LCRO. However, owing to the source coupled capacitor coming from the relaxation architecture, the LCXRO oscillates faster than the LCRO. To increase the oscillation frequency, MOS transistors should be selected as small as possible to reduce the burden of parasitic capacitance. Small size design, however, limits lowering the power supply voltage. In the LCXRO, Cs plays a role to enhance the oscillation speed. Cs prevents M3 and M4 from falling into deep non-saturation region because the voltage drop applied across Cs forces to decrease the gate-to-source voltage of cross-coupled pairs. Furthermore, the pre-charged Cs helps fast alternating of Vo1+ and Vo1- around the duration of their voltage-crossing. Consequently, the upper limit of the oscillation frequency can be extended without re-sizing the devices.

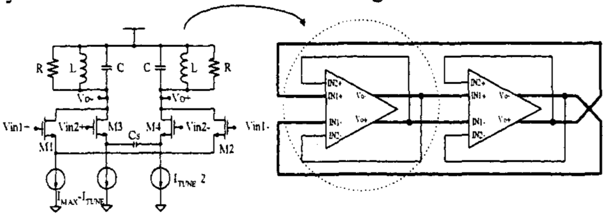


Fig. 7. 2-Stage L-C Relaxation Ring Oscillator.

4. Chip Implementation

In the two-stage ring oscillator shown in Fig. 3, M3-4 and M1-2 provide both PLA and transconductance amplifier operations. The transconductance of M1-2 have to be large enough to surmount the strength of positive feedback circuit. The oscillation frequency is controlled by adjusting the source current I_{TUNE} since the dominant pole frequency of the delay cell is changed. This two-stage ring oscillator is fabricated using 0.8-μm double-poly double-metal CMOS process and its chip photo is shown in Fig. 8. The size is 275 x 245-μm^2 except the output buffers. In this case, the sizes of MOS transistors M1-2 and M3-4 are scaled up by 240-μm and 22-μm to operate with low voltage.

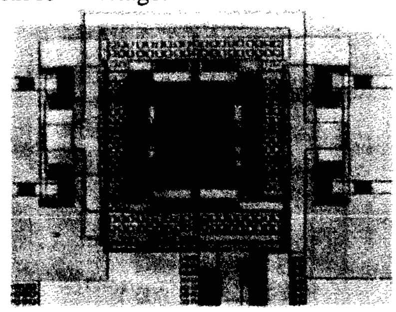


Fig. 8. Chip Photo of 2-Stage Ring Oscillator.

Another chip is for the schematic of the LCRO with two-stage as shown in Fig. 5. It is interesting to note that the oscillation frequency can be tuned by controlling the output current phase angle θ as presented in (1), which is proportional to the transconductance ratio of M1-2 and M3-4. Thus, the LCRO splits the sources of M1-2 from M3-4 sources and uses two tail current sources per a stage. I_{TUNE} is supplied to M3-4 and varied to change the oscillation frequency. To increase tuning range furthermore, I_{MAX}-I_{TUNE} is supplied to the source-coupled pairs, M1-2. The chip photo is shown in Fig. 9 and its size is 661 x 568-μm^2. The size of cross-coupled transistors, M3-4, are W/L=80-μm/0.6-μm and the size of other source-coupled pairs, M1-2, are three times larger.

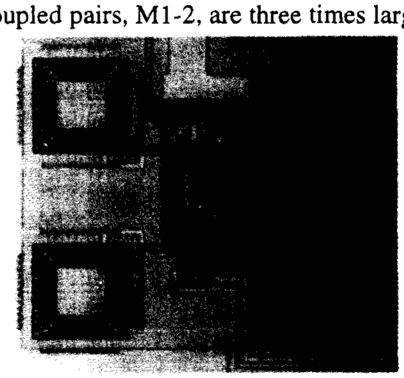


Fig. 9. Chip Photo of 2-Stage LCRO.

The sizes of the transistors configuring the LCXRO shown in Fig. 7 are exactly the same as those of the LCRO. The difference is only the source-coupled capacitor, Cs. The capacitor Cs is implemented using second and third metals. To provide the symmetrical layout and the equal parasitic effect at sources of M3-4, metal 2 and metal 3 are crossly coupled and forming the top and the bottom plates exactly the same amount. The expected capacitance is 200-fF. The chip photo is shown in Fig. 10.

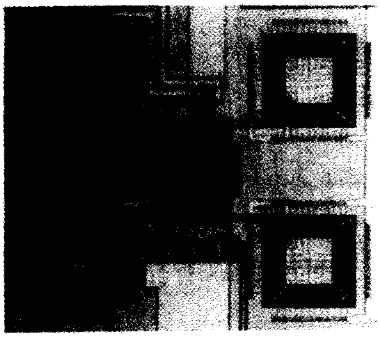


Fig. 10. Chip Photo of 2-Stage LCXRO.

5. Experimental Results

First experiment is performed using two-stage ring oscillator with supply voltage of 2-V. In Fig. 11(a), the oscillation frequency versus the tuning current, I_{TUNE}, is depicted. The result shows the wide tuning range and the maximum operating frequency exceeds 900-MHz. The phase noise measured at the oscillation frequency of 914-MHz is shown in Fig. 11(b). The measurement shows -87-dBc/Hz at 600-kHz offset frequency.

The designed LCRO and LCXRO are tested under 3-V power supply. Owing to the HLO scheme, the tuning range is incredibly wide. When I_{MAX} is set to 5.3-mA and 7.5-mA, tuning range of the LCRO is 300 and 500-MHz, respectively, without varactor diode. The LCRO shows the maximum 2.85-GHz oscillation frequency at I_{MAX}=7.5-mA and f-I curves are shown in Fig. 12(a). The measured phase noise at 2.33-GHz is depicted in 12(b). The measurement shows –109-dBc/Hz at 600-kHz offset.

In the case of the LCXRO, the f-I curves are depicted comparing with the LCRO in Fig. 13(a). This oscillator shows 3-GHz operation. By virtue of the source-couple capacitor, Cs, the oscillation frequency is increased up to the maximum of 500-MHz at the same power condition. The tuning range of the LCXRO is 100-MHz and the range can be extended by increasing the bias current, I_{MAX}. The phase noise measurements at 2.925-GHz are depicted in Fig. 13(b). The measured phase noise at the center frequency of 2.925-GHz is –97dBc/Hz at 600-kHz offset.

6. Conclusion

New two-stage ring oscillator with phase-look-ahead technique and two hetero-linked oscillators of the LCRO and the LCXRO are presented. The hetero-linked oscillator shows both wide tuning range as the ring oscillator and good phase noise as the L-C ring oscillator. These oscillators are implemented with conventional digital CMOS process and suitable for low supply voltage applications. These oscillators can generate the in- and quadrature-phases of signals with minimum stage. It can be successfully applicable to data retiming systems, e.g., ATM serial communication clock recovery circuits, serial HDTV digital video transmission systems between the HDTV video camera and the base station, VGA video signal series communication systems and RF mobile communication systems such as PCS, IMT-2000, etc.

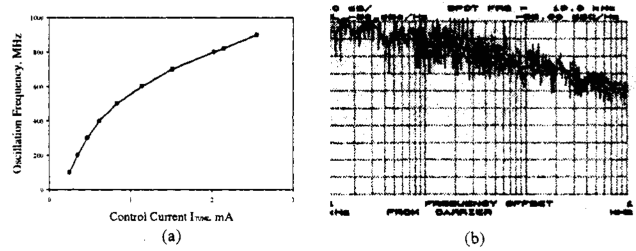


Fig. 11. Characteristics of 2-Stage Ring Oscillator.

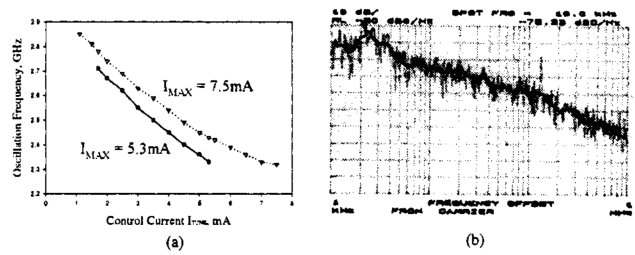


Fig. 12. Characteristics of 2-Stage LCRO.

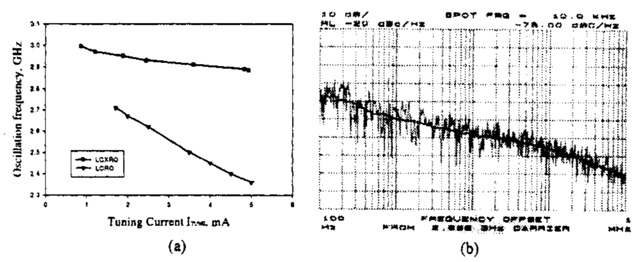


Fig. 13. Characteristics of 2-Stage LCXRO.

Acknowledgements

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