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A performance comparison of single ended and differential ring oscillator in 0.18 µm CMOS process

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Abstract— **In this work, a performance comparison of extended single-ended and differential CMOS ring oscillators is presented. The proposal is characterized by compared these two types of oscillators with the same center frequency (fc = 5.28 GHz) and the same number of stage (N = 3).**

We simulated specific characteristics for differential and single-ended ring oscillator using 0.18µm technology in order to made a comparison in terms of frequency stability with temperature and power supply variations, oscillation frequency, power consumption and phase noise.

Keywords— **Ring oscillators, single-ended, differential, phase noise, supply sensitivity.**

I. INTRODUCTION

The remarkable growth of modern wireless communication systems calls for higher frequencies, low power consumptions, low cost and more integrated wireless transreceiver.

The Voltage controlled oscillator (VCO) is a critical and essential component in the many wireless communication systems and have wide applications in phase-locked loops (PLLs), clock recovery circuits and analog-to-digital converters(ADC), etc.

The size, the cost requirements and higher levels for integration make a voltage controlled ring oscillator, a good choice [1, 2].

CMOS ring oscillator have advantages in terms of relative high spectral purity (compared to relaxation oscillator), small chip area as they do not need on chip inductors as compared to LC tank oscillator, large tuning range and low power consumptions.

ring oscillator is composed of delay stages along with feedback from output to input stage. Their output frequency is a function of a control input. An ideal oscillator is a circuit whose output frequency is a linear function of its control input (voltage or current) [3].

VCO can be implemented by single-ended or differential architecture of delay cell [4].

Each of thesetopologies presentsboth advantages anddisadvantages, and none would be moreidealthan another.For the designers of a VCO,ring oscillators must satisfy some specifications to obtain a suitable performance for VCO such as low phase noise, low power dissipation, low voltage operation, high speed oscillation, supply sensitivity reduction, small layout area and wide tuning range.

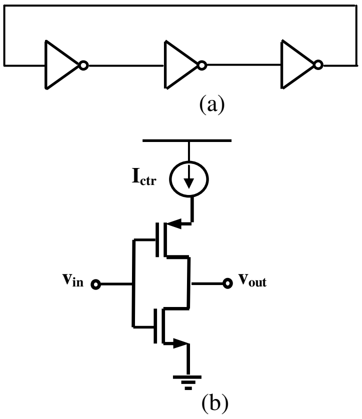
This paper describes the effect of supply and temperature on the performance of single-ended and differential ring oscillators, giving information's that prove useful in the design of other types of oscillators as well. Section II summarizes the oscillators studied in this work. Simulation results of tuning frequency range, sensitivity supply voltage and temperature are discussed in section III and IV. The comparison of different topologies regarding phase noise is presented in section V. Section VI presents the conclusion.

II. RING OSCILLATORS DESIGN

A CMOS ring oscillator is composed entirely of active devices that generate by itself a periodic signal at frequency ω_0. It is implemented by N stages in a close loop.

In this paper, we investigate both single-ended ring oscillators and differential ring oscillators.

The latter are much more important in digital circuit applications, since single ended oscillators are less complex to design when compared to a differential and requires less space, the circuit topologies are shown in Fig. 1 for the single ended and in Fig. 2 for the differential ring oscillators.


(a)

(b)

Fig. 1 Single-ended ring oscillator: (a) block diagram and (b) implementation of one stage.

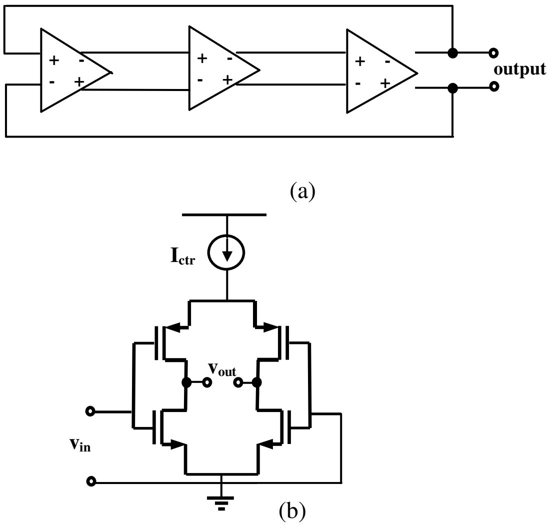


Fig. 2 Differential ring oscillator: (a) block diagram and (b) implementation of one stage.

III. TUNING FREQUENCY FOR CCO's

The ring oscillator based CCO (current controlled oscillator) uses variable bias currents to control its oscillation frequency.

Each oscillator was designed using electrical parameters from advanced design system(ADS) 0.18um CMOS technology. In order to verify its performance, these oscillators were tested at the same center frequency, these CCO's exhibits a measured center frequency (fc) at 5.28 GHz which can operate linearly for a tuning current range from 2 to 10mA for single ended ring oscillator and from 2 to 4 mA for differential ring oscillator.

Fig.3 shows the tuning characteristics of these VCOs.

IV. TEMPERATURE AND SUPPLY SENSITIVITY

Our interest in this study to evaluate the sensitivity of the frequency oscillation to ward the supply voltage and temperature.

A. *Frequency temperature drift*

In case of ring oscillators, the delay stages or cells are connected back to back. If we assume that each stage provides a delay of td, the frequency of the N delay stages is given by the following equation [5]:

$$f_{osc} = \frac{1}{2\,N\,t_d} \qquad (1)$$

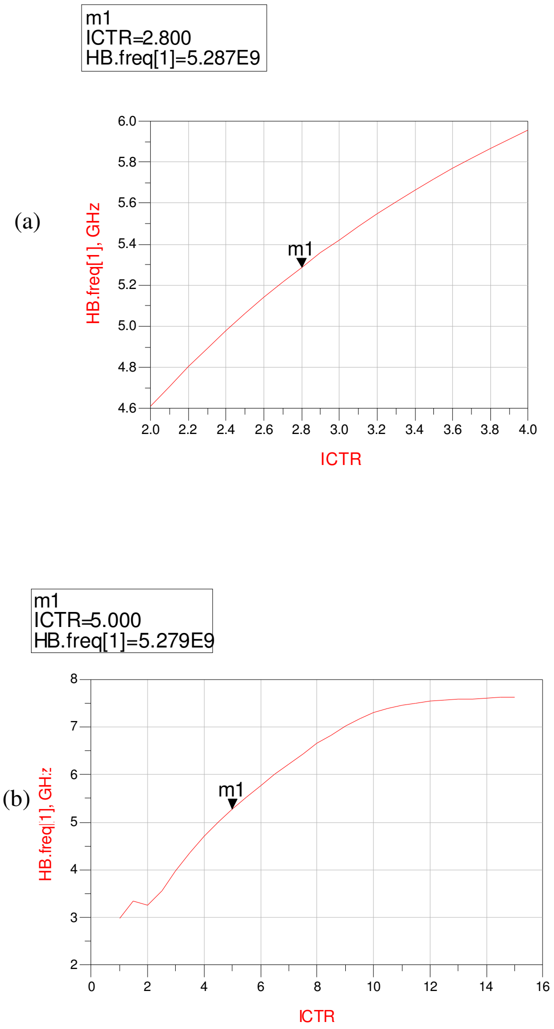


Fig.3. Frequency tunig : (a) differentiel and (b) single ended ring oscillators

Using Fig.2, the delay of each inverter stage will be given by :

$$V_{osc} = \int \frac{I_{ctr}}{C_L}\,dt \qquad (2)$$

$$t_d = \frac{V_{osc} C_L}{I_{ctr}} \qquad (3)$$

where V_{osc} is the oscillation amplitude, CL is the output load capacitance. Substituting (3) into (1) will give :

$$f_{osc} = \frac{I_{ctr}}{2\,N\,V_{osc} C_L} \qquad (4)$$

Here the oscillation frequency is determined by the current I_{ctr} of the PMOS transistors, the number of stages N, the amplitude V_{osc} and the parasitic capacitance C_L.

However the behaviour of this type of transistor varies depending to the temperature.

According to the model of constant mobility, the mobility of electrons and holes varies in temperature [6].

In saturate mode of operation [7], the current of the PMOS transistor can be approximate to:

$$\mathrm{I_{ctr}} = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_{gs} - V_T)^2 \qquad (5)$$

Where V_{gs} is the gate-source voltage, L is the channel length, W is the width of the channel, μ_p is the hole mobility and C_{ox} is the gate oxide capacitor.

As shown in equation (5), $\mathrm{I_{ctr}}$ depends on both the mobility and the threshold voltage which varies with temperature.

To compare the two types of the ring oscillator, we calculate the sensitivity frequency to ward temperature for a center frequency fc by using this equation:

$$\mathrm{S_T}(\mathrm{ppm°C^{-1}}) = \frac{1}{\mathrm{f_c}}\frac{\partial \mathrm{f_c}}{\partial \mathrm{T}} \qquad (6)$$

Fig. 4 shows the effect of temperature on the frequency of oscillation of single ended and differential ring oscillator to a center frequency 5.28 GHz, and the results are summarizing in table 1.

TABLE 1: TEMPERATURE COEFFICIENT OF CCOs

Structure	Single ended	differential
$\mathrm{S_T}(\mathrm{ppm°C^{-1}})$	-571.97	-986.71

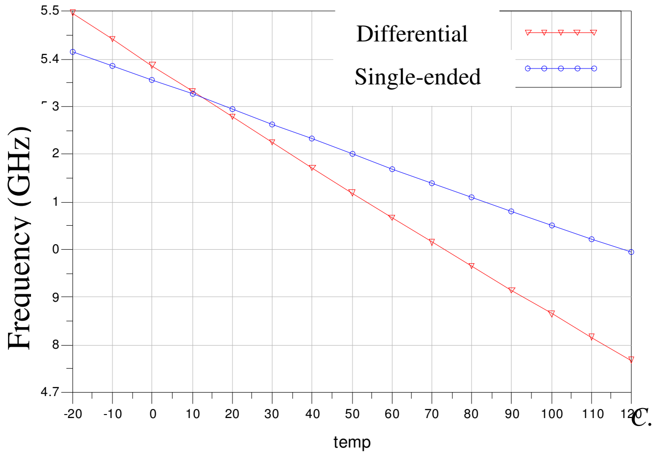


Fig.4 Drift frequency with temperature.

The variations of the frequency along with the drift of temperature are perfectly linear.

The structure of single ended presents the lowest temperature coefficient. The operating frequency has a temperature coefficient of -571.97 ppm/°C in the -20 to 120°C range.

B. Frequency stability with the supply voltage variation

The supply voltage is varying along the time; which results in an undesirable variation in the frequency oscillation. Thus the study of the sensitivity of oscillation frequency is necessary. For a given control current and the varying supply voltage from 1.5 to 2.1 ranges for CCO1 and CCO2, we evaluate the supply sensitivity of VCOs which expression is :

$$\mathrm{S_v}(\%) = \frac{\mathrm{f_{max}} - \mathrm{f_{min}}}{\mathrm{f_c}} \times 100 \qquad (7)$$

Fig. 5 shows the drift of frequency by varying the supply voltage.

The results obtained show that the differential structure causes a linear variation in frequency in function to the supply voltage variation with a sensitivity quite low relative to the other structure (Table 2).

TABLE 2 : SUPPLY COEFFICIENT OF CCOs

Structure	Single ended	differential
$\mathrm{S_v}$ (%)	8.25	2.25

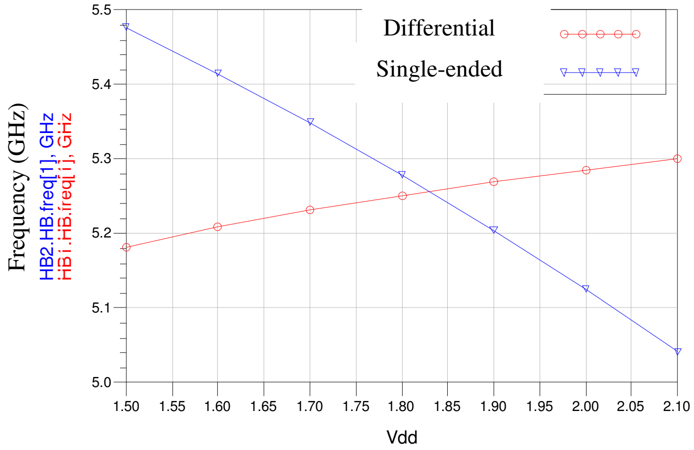


Fig.5. Drift frequency with supply voltage

V. JITTER AND PHASE NOISE

In general, ring oscillators are sensitive both temperature and power supply variations, as well as, the noise and interferences sources affecting the frequency stability of the ring oscillator.

Noise sources can be categorized into two types, Thermal, shot and flicker noise are examples of the first type, while substrate and supply noise are in the second type.

Because of these effects, the spread delay, td, is variable [8], [9]. This deviation is result in change of the rising and falling pulse edges, is known as jitter and can be seen in Fig.6.

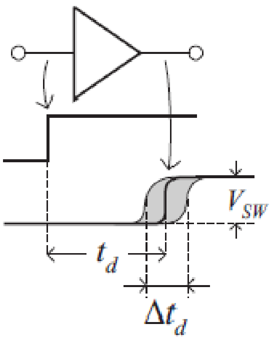


Fig.6 Jitter effect

Phase noise and jitter are two related quantities associated with a noisy oscillator, Phase noise is usually characterized in the frequency domain and jitter is usually characterized in the time domain.

Therefore, focus on phase variation will be considered. Several techniques have been proposed for estimation of phase noise in oscillators.

Hajimiri and Lee develop a general theory for phase noise calculation [10].The advantage in this model is it does not depend on any oscillator topology.

Using this model the phase noise of an oscillator in the regions of 1/f2, 1/f3 are determined by (8).

$$L(f_{off}) = N\frac{\Gamma_{rms}^2}{8\pi^2 f_{off}^2}\cdot\frac{\sum \overline{i_n^2}/\Delta f}{q_{max}^2} \qquad (8)$$

Where Γ_{rms}^2 is the rms value of the impulse sensitivity function (ISF), $\overline{i_n^2}/\Delta f$ is the power spectral density of the noise current source, f_{off} is the frequency offset from the carrier.

$q_{max} = C_L V_{max}$ is the maximum charge swing at the output node where C_L is the average capacitance at the output node of the circuit and V_{max} is the maximum swing which is given by the fig.7 for the two types ring oscillators.

N is the number of stages. In the presented three-stage ring oscillator.

For differential ring oscillator each stage composed of two identical half- stages. So the analysis is based on each half-stage ($N = 2.N_{single\ ended} = 6$)

The phase noise for these two types of ring oscillators discussed in this paper is presented in Fig. 8.

By analysing Fig. 8 we can conclude that the best performance have differential ring oscillators.

Fig. 8 shows the simulation phase noise in the single ended ring oscillator, indicate the phase noise of -88.87 dBc/Hz at a 1 MHz offset.

The phase noise of differential oscillator is –90.84 dBc/Hz at an offset frequency of 1 MHz, this is inferior to the phase noise of single ended oscillator. It is a predicted result because the lower sensitivity of differential ring oscillator to substrate and supply noise.

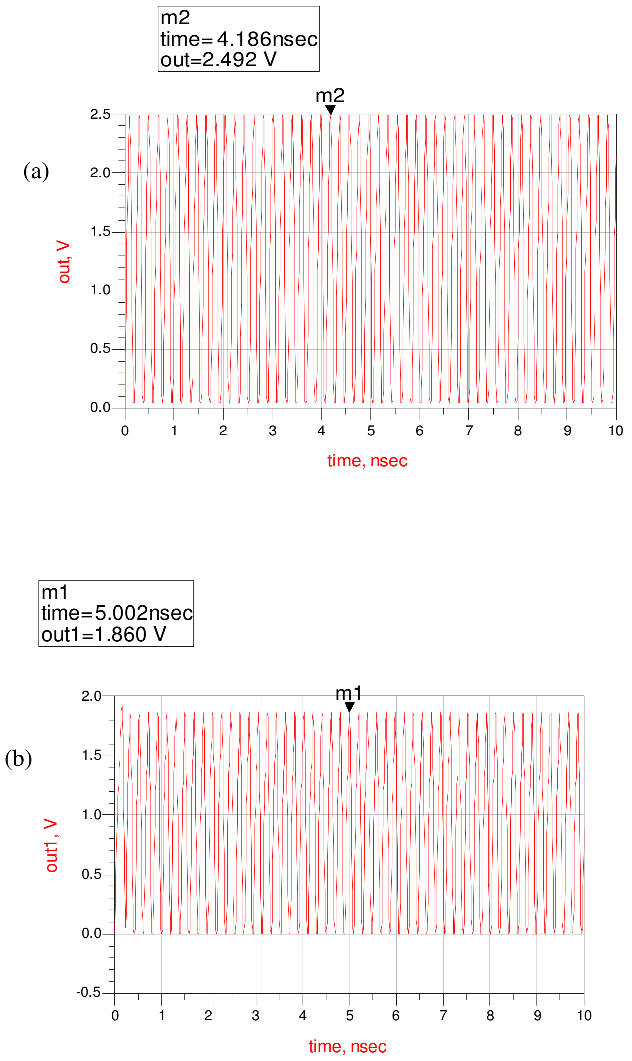


Fig.7 Output signal of: (a) differential and (b) single ended ring oscillator

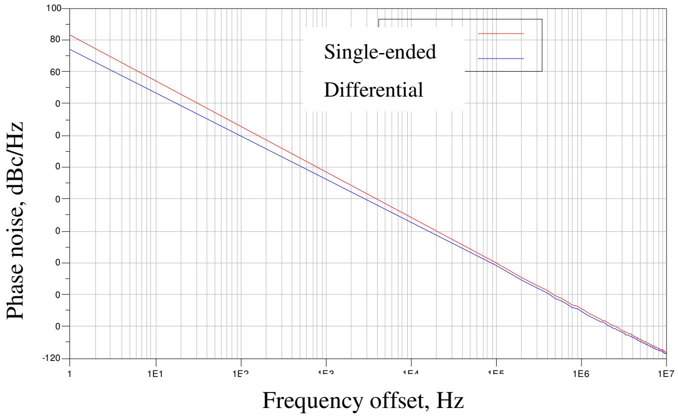


Fig.8 Simulation of the Phase noise of single ended and differential ring oscillator at 5.28 GHz.

In order to make a comparison between different VCOs which respect to power, phase noise and carrier frequency, a figure of merit (FOM) expression is used [11].

$$\mathrm{FOM} = \mathrm{P}_{\mathrm{noise}} - 20\log\frac{\mathrm{f}_{\mathrm{osc}}}{\mathrm{f}_{\mathrm{off}}} - 10\log\frac{\mathrm{P}_{\mathrm{diss}}}{1\mathrm{mw}} \qquad (9)$$

Where f_{osc} is the oscillation frequency, f_{off} is the offset frequency and P_{diss} is the power consumed by the VCO core, and P_{noise} is the phase noise simulated at an offset from the carrier.

In the Fig. 3 to 8 the simulation results of the ring oscillators are shown. The power consumption was measured at the center frequency (fc = 5.28 GHz). The phase noise of the oscillator was extracted at a 1 MHz offset from a center frequency. The results are summarized in table 3.

TABLE 3 : SUMMARIZED RESULTS

Results	Differential	Single ended
N	3	3
fc (GHz)	5.28	5.28
Tuning range (GHz)	1.34	4.09
Output voltage (V)	1.86	2.49
SV (%)	2.25	- 8.25
ST (ppm°C^{-1})	- 986.71	- 571.97
P (mW)	15	22
Phase noise @1MHz (dBc/Hz)	- 90.84	- 88.87
FOM (dBc/Hz)	- 177.04	- 176.72

For examination table 3, it is clear that the differential oscillator simultaneously generates and distributes a signal with a maximum operating frequency and output voltage of 5.958 GHz and 1.86 V, respectively. The maximum operating frequency of this oscillator is 19 % lower than the maximum frequency of the single ended ring oscillator that shows the highest operating frequency (7.34 GHz). The differential oscillator resulted with the lowest tuning range (1.348 GHz) and output voltage (1.86 V); however, it has the highest efficiency stability frequency in terms of power supply variation (2.25 %), i.e., has the lowest supply sensitivity which is one of its main advantages.

For the case of phase noise, as can be observed in Table 3, the differential's oscillator presents the best phase noise performance with a - 90.84 dBc/Hz at a 1 MHz offset frequency from a 5.28 GHz center frequency.

VI. CONCLUSIONS

Ring oscillators are the main component in complex integrated circuits. They are commonly used as clock generating circuits. Many different types of ring oscillators are presented in literature [12-14]. They differ in regard to architectural, realization of delay stages, number of stages N, etc. In this paper we have studied and compared two types of ring oscillator.

The simulation was performed using Advanced design system and library model for 0.18 µm CMOS technology. According to the obtained simulation results we can conclude:

a) that for frequency stability with temperature variations the best performance has single-ended ring oscillator

b) that for frequency stability with power supply voltage variations the best performance has differential ring oscillator

c) in regard to phase noise, differential ring oscillator have the best performance.

Both single ended and differential ring oscillator are used depending on the application, Single-ended structures are usually demanded over the differential architectures every time the simplicity is essential.

Although differential structures presents a more complex to design when compared to a single-ended and needs more space, it is often used due to its advantages as regards to phase noise and frequency stability with power supply variations.

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