

A Performance Comparison of Current Starved VCO and Source Coupled VCO for PLL in 0.18 μ m CMOS Process

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Abstract— This paper describes a performance comparison of two Voltage Controlled Oscillator for Phase Locked Loop. Current Starved VCO and Source Coupled VCO for PLLs in a 0.18 μ m digital CMOS process are designed and their performances are compared based on the measurement results. The design is implemented in Tanner environment with high oscillation frequency, low power consumption, and low area. Design procedures and simulation results are illustrated. Measured performances shows that area and power consumption in Current Starved VCO is reduced as compared to Source Coupled VCO with wide frequency range. These designs are suitable for PLL as a frequency multiplier.

Index Terms— Current starved VCO, low area, low power, ring oscillators, Tanner.

I. INTRODUCTION

A CMOS Voltage controlled oscillator (VCO) is a critical building block in PLL which decides the power consumed by the PLL and area occupied by the PLL. VCO constitute a critical component in many RF transceivers and are commonly associated with signal processing tasks like frequency selection and signal generation. RF transceivers of today require programmable carrier frequencies and rely on phase locked loops (PLL) to accomplish the same. These PLLs embed a less accurate RF oscillator in a feedback loop, whose frequency can be controlled with a control signal. Transceivers for wireless communication system contain low-noise amplifiers, power amplifiers, mixers, digital signal-processing chips, filters, and phase-locked loops.

Voltage controlled oscillators play a critical role in communication systems, providing periodic signals required for timing in digital circuits and frequency translation in radio frequency Circuits. Their output frequency is a function of a control input usually a voltage. An ideal voltage-controlled voltage oscillator is a circuit whose output frequency is a linear function of its control voltage. Most application required that oscillator be tunable, i.e. their output frequency be a function of a control input, usually a voltage.

There are two different types of voltage controlled oscillators used in PLL, Current starved VCO and Source

coupled VCO [1]. In recent years LC tank oscillators have shown good phase-noise performance with low power consumption. However, there are some disadvantages. First, the tuning range of an LC-oscillator (around 10 - 20%) is relatively low when compared to ring oscillators (>50%). So the output frequency may fall out of the desired range in the presence of process variation. Second, the phase-noise performance of the oscillators highly depends on the quality factor of on-chip spiral inductors. For most digital CMOS processes, it is difficult to obtain a quality factor of the inductor larger than three. Therefore, some extra processing steps may be required. Finally, on-chip spiral inductors occupy a lot of chip area, typically around 200 * 200-300 * 300 m^2 , which is undesirable for cost and yield consideration [2].

The ring oscillators, however, do not have the complication of the on-chip inductors required for the LC oscillators. Thus the chip area is reduced. In addition to a wide tuning range; ring oscillators with even number of delay cells can produce quadrature-phase outputs [3]. The phase noise performance of ring oscillators is much poorer in general [3], [4]. Also, at high oscillation frequencies, the power consumption of the ring oscillators may not be low which is a key requirement for battery operated devices [5]. To overcome these problems, we work on five stages current starved Oscillator and single stage source coupled oscillator without an LC tank. Finally their performances are compared based on their results.

II. CIRCUIT DESCRIPTION

A. Current Starved VCO

The operation of current starved VCO is similar to the ring oscillator. Fig 1. Shows a five stage Current-Starved VCO [6]. Middle PMOSM1 and NMOSM2 operate as inverter, while upper PMOSM13 and lower NMOSM14 operate as current sources. The current sources limit the current available to the inverter. In other words, the inverter is starved for current. The current in the first NMOS and PMOS are mirrored in each inverter/current source stage. PMOSM11 and NMOSM11 drain currents are the same and are set by the input control voltage [6]. Fig 2 shows the inverter schematic [2].

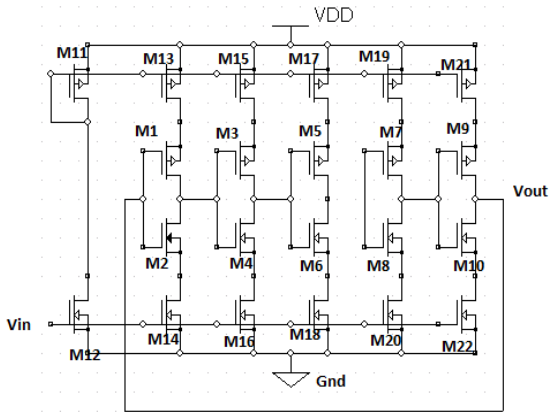


Fig. 1. Five Stages Current-Starved VCO

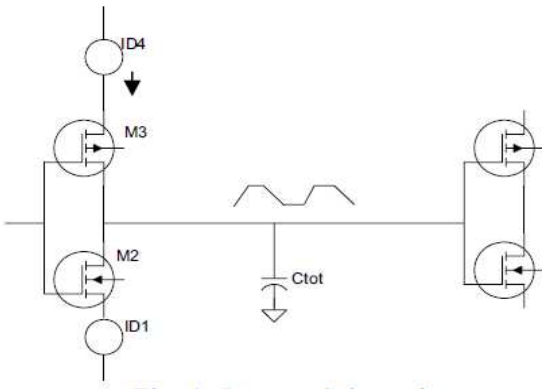


Fig.2. Inverter Schematic

The Designed five stages current-starved VCO is shown in Fig 3. The VCO is composed of 5 cascaded inverters. The inverter schematic is given in Fig 3. The inverter sizes PMOS1 and NMOS1, of Fig,2, are calculated [7].

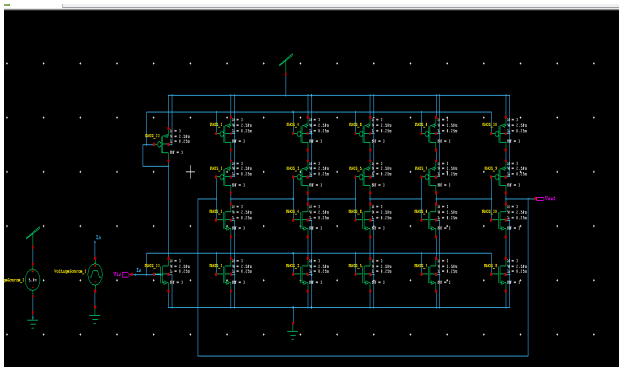


Fig. 3. Designed Current Starved VCO

The total capacitance Ctot is given by,

$$C_{tot} = \frac{5 * C_{ox}(W_p L_p + W_n L_n)}{2} \quad (1)$$

Where Cox is the oxide capacitance.

The number of stages of the oscillator is selected; there are 5 stages. The centre drain current is calculated as:

$$I_{D_{centre}} = N * V_{DD} * C_{tot} * F_{cen} \quad (2)$$

Where N is the number of stages of inverter. The sizes of PMOS11 and NMOS12 are determined as:

$$I_{D_{centre}} = \frac{\beta(V_{gs} - V_{thn})^2}{2} \quad (3)$$

Where, $\beta = \frac{k_p * W}{L}$ it can be shown that the oscillation frequency is:

$$F_{osc} = \frac{1}{N * T_d} = \frac{I_D}{N * C_{tot} * V_{DD}} = F_{cen} @ V_{inVCO} \quad (4)$$

Where Td is the time delay above equation gives the centre frequency of the VCO when ID=IDcentre. The VCO stops oscillating, neglecting sub threshold currents, When, VinVCO<Vthn. Thus, Vmin=Vthn and Fmin=0. The max VCO oscillation frequency Fmax is determined by Finding ID when VinVCO=VDD. At the max frequency then, Vmax=VDD. (5)

B. Source Coupled VCO

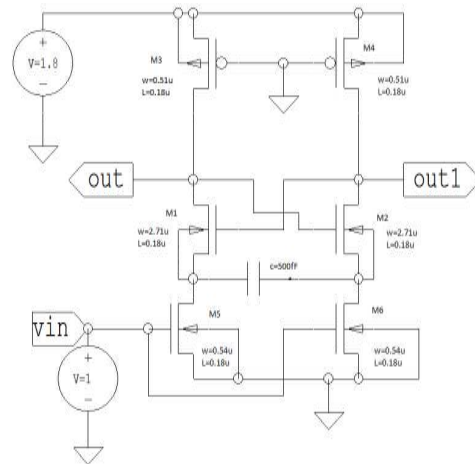


Fig. 4. Single Stage Source Coupled VCO

These circuits can be designed to dissipate less power than the ring oscillator and current-starved voltage controlled oscillator. The operation of the CMOS source coupled VCO in fig 4 is, load MOSFETs M3 and M4 pull the output [8]. The MOSFETs M5 and M6 behave as constant-current source sinking a current Id. MOSFETs M1 and M2 act as switches. MOSFET M1 is off and M2 is on, because the voltage of terminal out1 is larger than voltage of terminal out. Therefore current through MOSFET M2 is 2 Id and the capacitor will be charged by current Id, because constant current source M6 sinking current Id. When the voltage of X and Y capacitor terminal is same then capacitor is fully charged. The current Id through C, cause point X to discharge down towards ground. When point X gets down, M1 turn on and M2 turns

off [7], [8]. Fig 5 shows the designed single stage Source Coupled VCO.

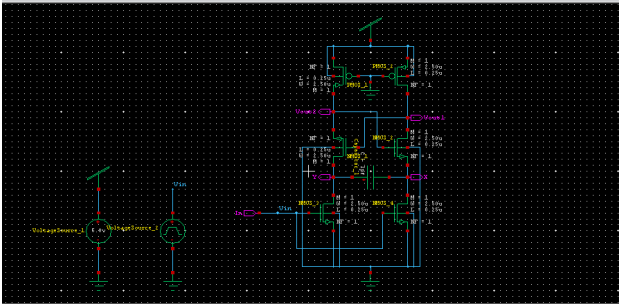


Fig. 5. Designed Source Coupled VCO

The voltage of point X changed before switching took place the time it takes point X to change $2V_{thn}$ is given by

$$\Delta t = C \cdot 2 \cdot V_{thn} / I_d \quad (6)$$

Since the circuit is symmetrical two of these discharge time are needed for each cycle of oscillator the frequency of oscillation is given by

$$f_{osc} = 1 / (2 \cdot \Delta t) = I_d / (4 \cdot C \cdot V_{thn}) \quad (7)$$

III. SIMULATION RESULTS

A. Output Waveforms

Fig 6. shows the output waveforms of current starved VCO. Thus it is noted that at a constant control voltage of 1.8V the output frequency of current starved VCO is 222.53 MHz. Simulation results reported that the power consumption is 58.47uA @ 1.8 VDD.

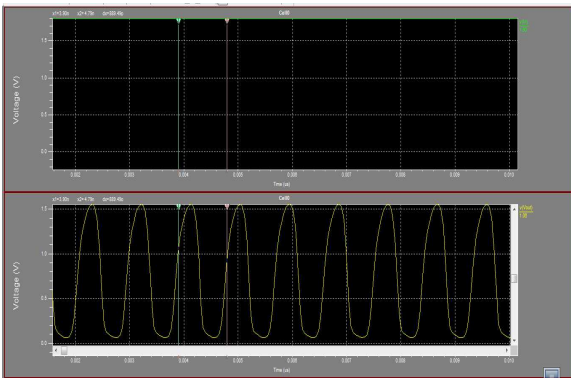


Fig.6. Output Waveforms of Current Starved VCO

When the control voltage is varied from 0V to 1.8V, the Oscillation frequency of the designed current starved VCO ranges from 25.70 MHz to 222.53 MHz Table I. gives the characteristics of the current starved VCO i.e. control voltage (V) Vs frequency (MHz). The graph shown in Fig.7 shows that the relationship between frequency (MHz) Vs control voltage (V) is linear. Fig 8. shows the output waveforms of source coupled VCO. The following waveform shows that differential output out1 and out2 is having Phase difference of

1800. Thus it is noted that at a constant control voltage of 1.9V the output frequency of current starved VCO is 427.35 MHz Simulation results reported that the power consumption is 3.62mA @ 1.9 VDD.

Table I: Control Voltage Vs Frequency Of Current Starved Vco

Control Voltage(V)	Frequency(MHz)
0.1	25.70
0.2	44.64
0.3	57.14
0.4	101.52
0.5	129.03
0.6	147.05
0.7	161.29
0.8	178.57
0.9	188.67
1.0	192.30
1.1	198.01
1.2	203.99
1.3	208.62
1.4	212.24
1.5	212.77
1.6	216.00
1.7	216.37
1.8	222.53

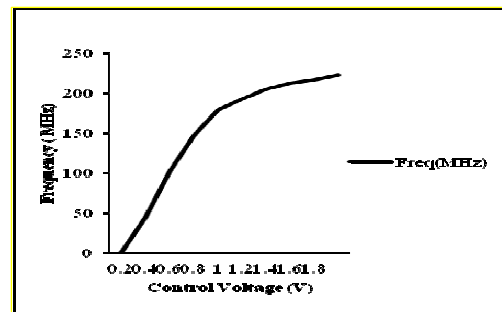


Fig.7. Frequency (MHz) Vs Control Voltage (V)

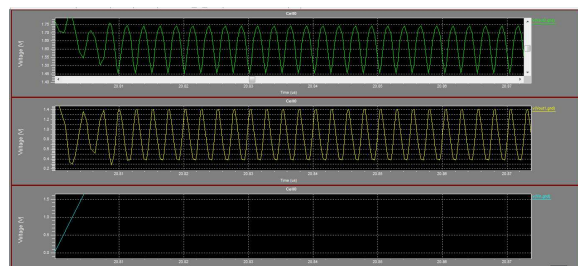


Fig. 8. Output Waveforms of Source Coupled VCO

When the control voltage is varied from 1.4V to 1.9V, the Oscillation frequency of the designed current starved VCO ranges from 307.69 MHz to 427.35 MHz Below this voltage, VCO gives oscillations, but variations are not linear. Table II. Gives the characteristics of the source coupled VCO i.e. control voltage (V) Vs frequency (MHz).

IV. CONCLUSION

This paper compares the performance of two VCO's for PLLs, a current starved VCO and source coupled VCO with the design experiment and with the qualitative evaluation. Our measurement results show that in chip area, power consumption and tuneable frequency range, a RC based Current starved VCO is superior to a Source Coupled VCO. Also the relative performance difference between ring VCO and LC VCO will be almost constant in the future. Power consumption and chip area of both PLLs will decrease proportional to the technology node. However, noise characteristics will get worse inversely proportional to the technology node. The techniques proposed in this paper can also be applied to other low voltage analog and RF circuits to improve their performance.

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Table II: Control Voltage Vs Frequency of Source Coupled Vco

Voltage(Volts)	Frequency(MHz)
1.4	307.69
1.45	311.32
1.5	318.47
1.55	324.61
1.6	330.03
1.65	341.29
1.7	347.22
1.75	370.37
1.8	425.53
1.85	427.0
1.9	427.35

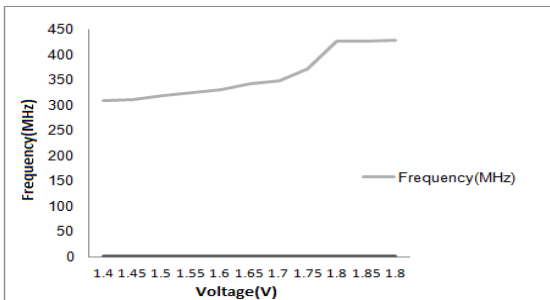


Fig. 9. Frequency (MHz) Vs Control Voltage (V)

B. Performance Comparison

In this section, we predict major performances of both VCO's such as i/p tuning range, range of oscillation frequency, and area and power consumption with a qualitative discussion by an analytical approach. Table III shows the performance comparison of both current starved VCO and source coupled VCO. We use the minimum channel length and width of the device. Thus it can be seen that through both VCO's we can achieve minimum area with wide tuning frequency range for PLL. Also the power consumption in Current Starved VCO is reduced as compared to Source Coupled VCO.

Table III: Measured Performances

Parameters	Current Starved VCO	Source Coupled VCO
Technology	0.18µm	0.18µm
I/P Tuning Range	0-1.8V	1.4-1.9V
Range of Oscillation Frequency	25.70 MHz to 222.53 MHz	307.69 MHz to 427.35 MHz
Area	9.68µm ²	75.9µm ²
Power Consumption	0.1052mW	6.69mW



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