Design and Comparative Analysis of Conventional and Current Mirror Based Ring Oscillators in CMOS Technology

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***Abstract*—In this paper, the design and comparison between conventional ring oscillator made of CMOS inverters and ring oscillator designed by the use of current mirrors (or current starved) is presented. Both designs have been designed on a 5-stage inverter chain in CMOS circuit and simulated using Cadence Virtuoso. In addition to that, the proposed current mirror method helps in controlling the bias current and thus minimizing the power dissipation. The results of simulation indicate that the conventional ring oscillator runs at around 1.51 GHz and consumes a power of 897 µW, while the power consumed by the current mirror ring oscillator was reduced to 680 µW.**

***Index Terms*—Ring Oscillator, Current Mirror, Current-Starved, CMOS, Low Power, Delay, Frequency.**

I. INTRODUCTION

Ring Oscillator is a basic but frequently utilized structure in IC Design used for applications like clock generation, timing circuits, and Built-In Self-Test functions. It contains an odd number of inverter circuits linked together in a loop fashion wherein oscillations happen owing to propagation delay in each stage. Traditional ring oscillators are simple to design and widely adopted but possess high dynamic power losses because of constant switching. Current mirror or current-starved ring oscillators are developed to overcome the drawback of traditional ring oscillators. In a current mirror ring oscillator, the current through each stage is regulated using current mirrors, reducing the switching losses, thus lowering power loss. Although this is an effective method of lowering power losses, it comes with certain drawbacks like higher propagation delay and lower voltage swings. In this study, a comparative analysis between traditional and modern mirror ring oscillators is conducted. The comparative analysis will be done considering some important characteristics, including oscillation frequency, propagation delay, power dissipation, voltage swing, and efficiency. The aim of this analysis is to determine whether the design can be used in low-power circuits without compromising its performance.

II. LITERATURE SURVEY

Ring Oscillators have become increasingly popular among integrated circuit designs owing to their simplicity and ease of implementation in clock/timing generation circuits. A typical Ring Oscillator is designed in CMOS Technology using an odd number of inverters in the feedback path. Oscillation in this case arises out of the sum total of propagation delays of the individual stages. The frequency of oscillation thus depends inversely on both the propagation delay and number of stages, meaning that the higher the propagation delay, the lower the frequency.

The downside of a typical Ring Oscillator, however, is the high dynamic power dissipation arising from the switching operations. To overcome this problem, Current-starved ring oscillators are employed whereby the flow of current in each of the stages is controlled using a current mirror. The technique helps reduce the power dissipation in a manner that controls the charging and discharging currents in the inverter nodes. Temperature is another factor that influences the performance of an oscillator. Rising temperatures in the device result in reduced carrier mobility in the MOS transistors. This increases the propagation delay leading to a reduction in oscillation frequencies.

III. Methodology

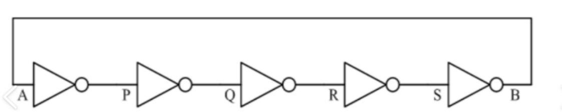


Figure 1 Block Diagram Ring Oscillator

The new system comprises designing and comparing two different kinds of ring oscillators: the CMOS ring oscillator and the current starved ring oscillator (based on the current mirror). This design utilizes the 5-stage inverter chain for oscillations.

Circuit design simulation is done by Cadence Virtuoso with a 1.8 volt supply voltage. Performance analysis will be done for both circuits on the basis of frequency, propagation delay, power consumption, and variations in temperature.

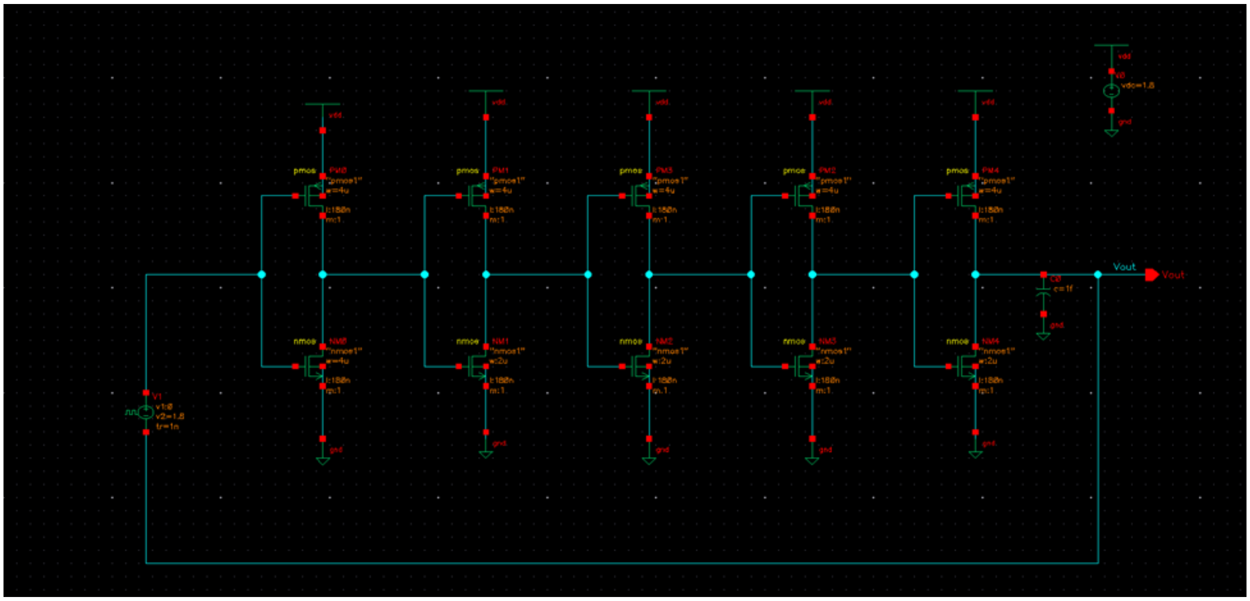


Figure 2 Normal Ring Oscillator

The above circuit constitutes a conventional ring oscillator which is made up of an odd number of inverter gates arranged in a feedback loop. These inverter gates are constituted by PMOS and NMOS transistors and are supplied by a DC voltage source (VDD = 1.8V).

The output from the last gate is fed into the first one to make the circuit oscillate. At the output there is a load capacitor that ensures smooth oscillation. The oscillation frequency depends on the propagation delay time of each gate and the total number of gates.

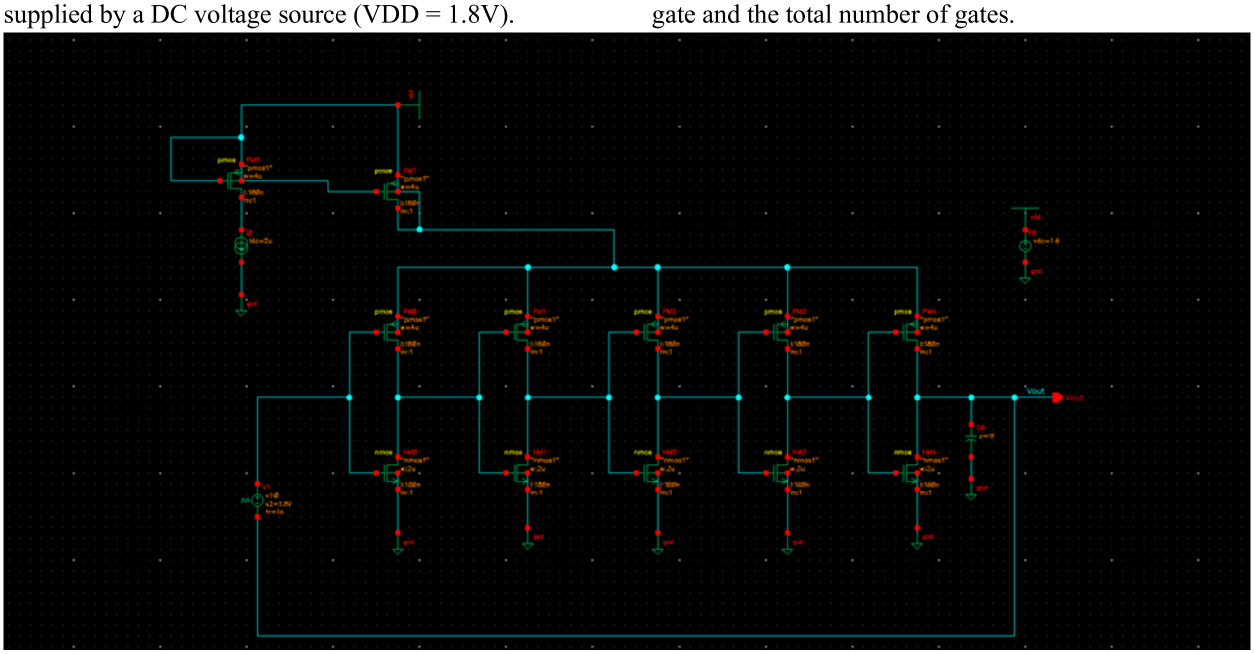


Figure 3 Ring Oscillator With Current Mirror

The above diagram shows an example of current mirror oscillator, which uses five CMOS inverter stages connected in a feedback path. Besides the usual inverter configuration, transistors for implementing the current mirror are also employed in order to regulate the current flow within each of the stages The loading current that charges and discharges the capacitance in each stage will be limited, which decreases power consumption. The output signal from the last stage is applied as an input to the first stage in order to make the circuit oscillate

Working Principle
The oscillation frequency in the case of the ring oscillator can be written as follows:

$$f = 1 / (2N \times td)$$

where N represents the number of stages while td is the time taken to propagate through one of those stages.

Parameters
Both designs are analyzed using the following criteria:

- Frequency of Oscillation
- Propagation Delay Time
- Power Dissipation
- Output Voltage Swing
- Change in Temperature

IV. RESULTS AND DISCUSSION

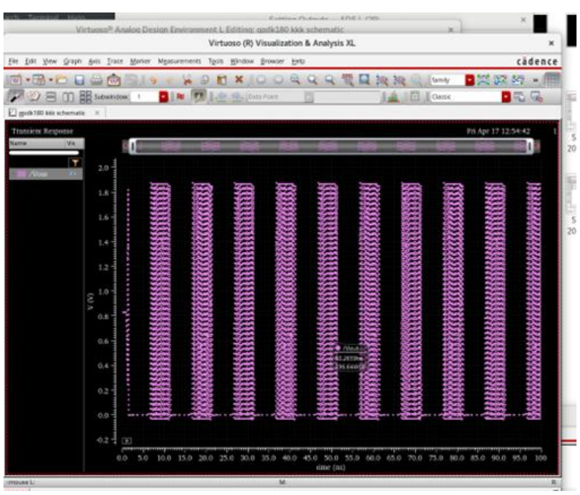


Figure 4 Transient Analysis of Ring Oscillator

The waveform shows continuous oscillations between 0 V and 1.8 V, indicating that the circuit is operating efficiently. The periodic nature of the waveform confirms stable and consistent oscillation of the ring oscillator. This demonstrates that the feedback mechanism is functioning properly and sustaining the oscillations. However, the waveform exhibits a slightly higher delay compared to the conventional ring oscillator design. This increase in delay is mainly due to the limited current flow in the current mirror configuration. As a result, the charging and discharging of capacitances take more time, leading to reduced oscillation speed and lower frequency.

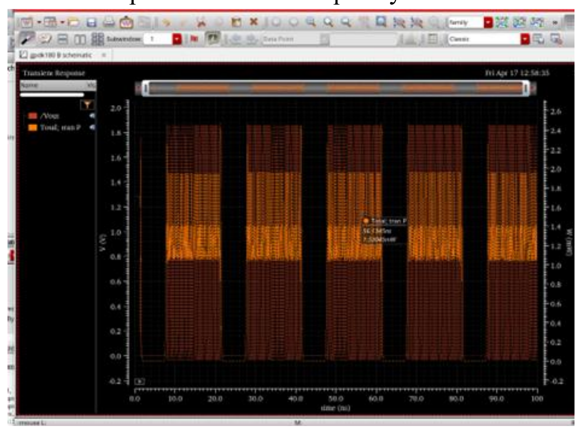
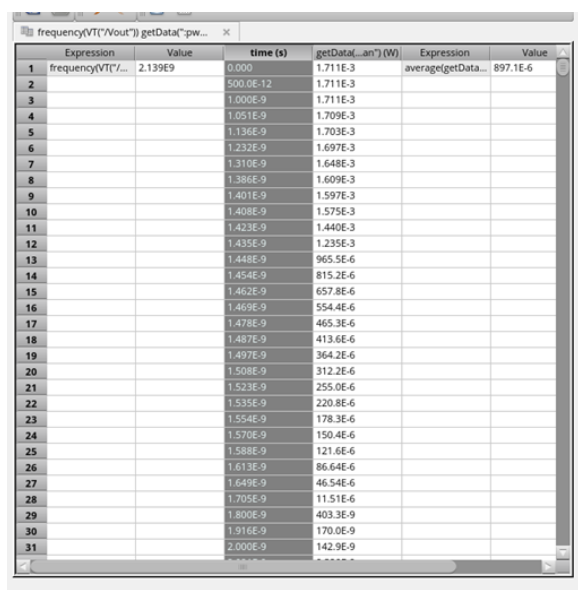


Figure 5 Power Analysis of Ring Oscillator

Both the output voltage and power fluctuations can be seen in the waveform. There is an increase in power usage when switching takes place and there is a decrease in power usage when there is a state of stability.

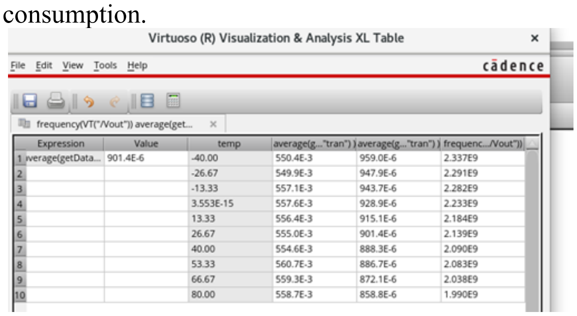


frequency(VT("/Vout")) getData(":pw...

	Expression	Value	time (s)	getData(...an") (W)	Expression	Value
1	frequency(VT("/...	2.139E9	0.000	1.711E-3	average(getData...	897.1E-6
2			500.0E-12	1.711E-3		
3			1.000E-9	1.711E-3		
4			1.051E-9	1.709E-3		
5			1.136E-9	1.703E-3		
6			1.232E-9	1.697E-3		
7			1.310E-9	1.648E-3		
8			1.386E-9	1.609E-3		
9			1.401E-9	1.597E-3		
10			1.408E-9	1.575E-3		
11			1.423E-9	1.440E-3		
12			1.435E-9	1.235E-3		
13			1.448E-9	965.5E-6		
14			1.454E-9	815.2E-6		
15			1.462E-9	657.8E-6		
16			1.469E-9	554.4E-6		
17			1.478E-9	465.3E-6		
18			1.487E-9	413.6E-6		
19			1.497E-9	364.2E-6		
20			1.508E-9	312.2E-6		
21			1.523E-9	255.0E-6		
22			1.535E-9	220.8E-6		
23			1.554E-9	178.3E-6		
24			1.570E-9	150.4E-6		
25			1.588E-9	121.6E-6		
26			1.613E-9	86.64E-6		
27			1.649E-9	46.54E-6		
28			1.705E-9	11.51E-6		
29			1.800E-9	403.3E-9		
30			1.916E-9	170.0E-9		
31			2.000E-9	142.9E-9		

Figure 6 Frequence and Power Calculation f Ring Oscillator

The results of the simulation for the oscillation frequency and power consumption in the ring oscillator have been presented here. The oscillation frequency is noted to be 2.139 GHz and the average power consumption is approximately 897 µW. It can be seen that it is working at a relatively high speed using medium amounts of power. The frequency in the ring oscillator will depend upon the number of inverter stages used along with their propagation delays. As the propagation delay increases, the oscillation frequency reduces. The power consumption of the oscillator is determined by the supply voltage and the amount of current being drawn for switching purposes. Switching of inverter stages occurs dynamically causing power consumption.


Virtuoso (R) Visualization & Analysis XL Table

frequency(VT("/Vout")) average(get...

	Expression	Value	temp	average(g..."tran"))	average(g..."tran"))	frequenc.../Vout"))
1	werage(getData...	901.4E-6	-40.00	550.4E-3	959.0E-6	2.337E9
2			-26.67	549.9E-3	947.9E-6	2.291E9
3			-13.33	557.1E-3	943.7E-6	2.282E9
4			3.553E-15	557.6E-3	928.9E-6	2.233E9
5			13.33	556.4E-3	915.1E-6	2.184E9
6			26.67	555.0E-3	901.4E-6	2.139E9
7			40.00	554.6E-3	888.3E-6	2.090E9
8			53.33	560.7E-3	886.7E-6	2.083E9
9			66.67	559.3E-3	872.1E-6	2.038E9
10			80.00	558.7E-3	858.8E-6	1.990E9

Figure 7 Temperature Variation Analysis

The tables represent the effect of changes in temperature on the frequency and power parameters. Frequency values decrease from around 2.33 GHz to 1.99 GHz with rising temperatures from −40°C to 80°C. The effect is attributed to delay in the propagation process. On average, there is slight reduction in power from about 959 µW to 858 µW with rise in temperature

Output voltage RMS varies negligibly depending on the temperature changes and has an average value of 910-916 mV. It can be stated that despite temperature changes, the amplitude of the input signal stays unchanged. Small changes in RMS prove the stability of the oscillator operation and its little influence on output signals power.

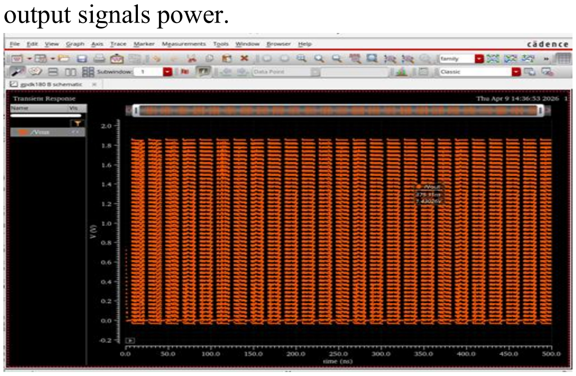
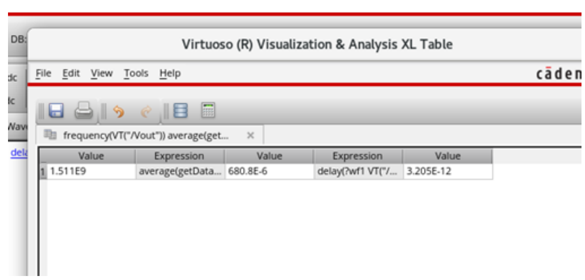


Figure 8 Output Of Current Mirror Ring Oscillator

From the graph, one can see regular oscillations ranging from 0V to 1.8V, which is a sign of correct operation of the circuit. The periodic nature of the waveform is an indication of stable and consistent oscillations, which have been achieved through the current mirror approach used in this case. This kind of arrangement manages the flow of current in the various stages of the inverters, hence making it possible to reduce the power required in the circuitry. Nevertheless, owing to the current control arrangement, it takes longer to charge and discharge the capacitors in the load, hence resulting in delayed propagation time.

Figure 9 Output & Power Of Current Mirror Ring Oscillator

Waveform analysis displays the voltage (Vout) output along with the power consumption of the ring oscillator using the current mirror structure. In this waveform, oscillation is seen for voltage in a range from 0 V to 1.8 V. In terms of power consumption, the waveform analysis depicts power consumption occurring only during transitions. Power spikes are less than those in the standard oscillator, thus demonstrating higher efficiency.


Virtuoso (R) Visualization & Analysis XL Table

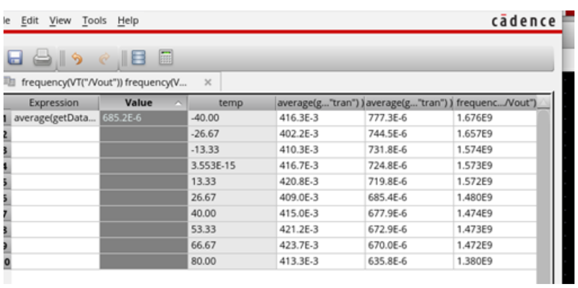
frequency(VT("/Vout")) average(get...

	Value	Expression	Value	Expression	Value
1	1.511E9	average(getData...	680.8E-6	delay(?wf1 VT("/...	3.205E-12

Figure 1 Performance Parameters Of Current Mirror Ring Oscillator

In Table I, performance parameters of the proposed current mirror based ring oscillator in the form of oscillation frequency, average power consumption, and propagation delay are listed. Oscillation frequency is found to be 1.51 GHz, which is less than that of the conventional ring oscillator due to the limitation of the current flow as a result of current mirror architecture. Average power consumption is estimated to be 680 µW, suggesting that power efficiency has been increased through controlled current flow. Power efficiency is achieved by reducing the current in each stage, which avoids wastage of current. Thus, the current mirror architecture can be used for the development of low-power applications. However, there is a drawback in the design.

Propagation delay turns out to be 3.2 ps, which is more than that of the conventional ring oscillator. Increased propagation delay causes decreased speed, which is an example of the power-efficiency/performance trade-off



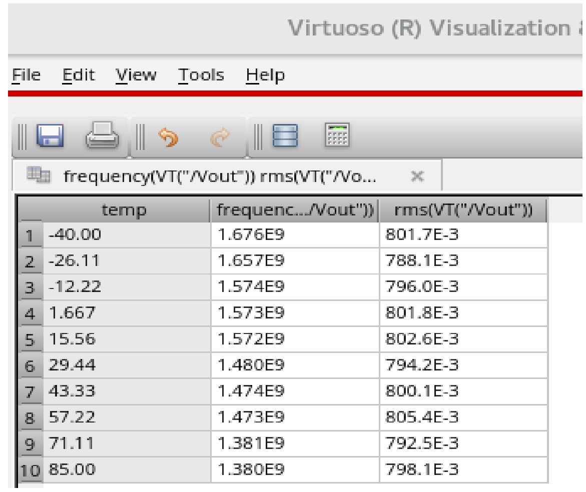
	Expression	Value	temp	average(g..."tran")	average(g..."tran")	frequenc.../Vout")
1	average(getData...	685.2E-6	-40.00	416.3E-3	777.3E-6	1.676E9
2			-26.67	402.2E-3	744.5E-6	1.657E9
3			-13.33	410.3E-3	731.8E-6	1.574E9
4			3.553E-15	416.7E-3	724.8E-6	1.573E9
5			13.33	420.8E-3	719.8E-6	1.572E9
6			26.67	409.0E-3	685.4E-6	1.480E9
7			40.00	415.0E-3	677.9E-6	1.474E9
8			53.33	421.2E-3	672.9E-6	1.473E9
9			66.67	423.7E-3	670.0E-6	1.472E9
10			80.00	413.3E-3	635.8E-6	1.380E9

Figure 11 Temperature , Frequency& Power (Current Mirror Ring Oscillator)

The table shows the variation of oscillation frequency and power consumption with temperature. As temperature increases from −40°C to 80°C, the oscillation frequency decreases from approximately 1.67 GHz to 1.38 GHz, due to increased propagation delay caused by reduced carrier mobility.

At the same time, the average power consumption also shows a decreasing trend, from about 777 µW to 635 µW. This reduction in power is due to decreased current flow at higher temperatures.

These results highlight the temperature sensitivity of the current mirror-based ring oscillator and demonstrate the trade-off between frequency and power performance across varying thermal conditions.



	temp	frequenc.../Vout")	rms(VT("/Vout"))
1	-40.00	1.676E9	801.7E-3
2	-26.11	1.657E9	788.1E-3
3	-12.22	1.574E9	796.0E-3
4	1.667	1.573E9	801.8E-3
5	15.56	1.572E9	802.6E-3
6	29.44	1.480E9	794.2E-3
7	43.33	1.474E9	800.1E-3
8	57.22	1.473E9	805.4E-3
9	71.11	1.381E9	792.5E-3
10	85.00	1.380E9	798.1E-3

Figure 12 Rms values & Frequency Of Ring Oscillator

As depicted in the table below, there is a relationship between the oscillation frequency and the RMS voltage of the current mirror ring oscillator with respect to the change in temperature. There is a decrease in the frequency from about 1.67 GHz to 1.38 GHz as the temperature rises from −40°C to 85°C due to higher propagation delay resulting from lower carrier mobility. The RMS voltage does not show significant changes at all temperatures and maintains values ranging from 0.79V to 0.80V.

No	Parameters	Normal Ring oscillator	Current Ring oscillator
1	Frequence	2.193 GHz	1.51 GHz
2	Power	897 uW	680 uW
3	Delay	91.47 ps	110 ps

The typical ring oscillator works with a frequency of 1.51 GHz having a power dissipation of 897 µW and a delay of 91.47 ps. On the other hand, the current mirror ring oscillator lowers its power dissipation to 680 µW, which is achieved by controlling the bias current. But, in order to achieve lower power dissipation, there is a compromise on the delay value of 110 to 130 ps, which is much higher than that of the typical ring oscillator. Also, the voltage swing is lowered from the original 1.8 V to 0.8 V.

V. CONCLUSION

A comparative analysis has been carried out for the assessment of performance levels exhibited by both conventional and modern mirror-based ring oscillators. Based on the acquired outcomes, the modern mirror-based ring oscillator proves to offer substantial power saving in comparison to its conventional counterpart. This advantage is realized through the use of current mirror biasing techniques that allow controlling the current through every single inverter stage in the ring.

Nevertheless, it is crucial to acknowledge the shortcomings associated with the use of such an approach. In particular, the delay factor in the modern mirror-based ring oscillator has increased significantly as a result of lower currents involved in the charging and discharging process. Consequently, the oscillation frequency has declined in comparison to the conventional ring oscillator.

In spite of the mentioned limitations, the modern mirror-based ring oscillator has proven its suitability in cases when low power consumption plays a critical role. On the contrary, the conventional ring oscillator becomes more beneficial for use in high-speed applications.

Overall, the choice between the two ring oscillator models should be based on the requirements of the specific application.

VI. Future Scope

Comparison has been made between traditional and modern mirror-based ring oscillators to determine how well these circuits perform with regard to power, frequency, and delay. It is clear that many improvements have been made with respect to the current mirror-based ring oscillators, but there are still areas where research should be conducted to make this circuit even better.

There is always room for improvement when it comes to increasing the output voltage swing while maintaining the low power consumption seen in modern designs. One way to achieve this is through the employment of techniques such as the cascode current mirror. By doing so, better control is attained over current stability while reducing the voltage drop within each of the stages. Another area of improvement involves decreasing noise levels in order to ensure the stability of the circuit. This includes reducing phase noise and jitter since both greatly impact propagation delays and frequencies.

Lastly, the current mirror-based ring oscillator can be implemented in applications such as Phase-Locked Loops (PLLs) and frequency synthesizers.

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