Design and Simulation of 3-Bit Digital to Analog Converter using Current Mirror and Binary to Thermometer Code Converter

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Abstract : In Biomedical Applications, as the signals have to be distributed to various circuit elements, the current mirrors are used in biomedical devices. The current mirror is capable of controlling the current in one active device of the circuit by copying the current through another active device and keeps the output current constant regardless of loads. The condition here is to have high output impedance and high gain with a little trade-off between them to drive a large load. For evaluating the performance of the current mirrors, the 3-bit Digital to Analog Converter is used along with current steering thermometer code converter. The designs are verified in PSPICE Tool by using SPICE Coding. From the results, it is proved that the folded cascade current mirror provides better gain and basic current mirror provides better fan-out.

***Index Terms*–Basic Current Mirror, Cascode Current Mirror, Folded Cascode Current Mirror, DAC, Thermometer code Converter.**

I. INTRODUCTION

Generally current mirrors are made up of active devices. These are widely used as biasing elements in analog circuits. The basic principle of current mirror is, the MOS-transistors are said to identical only when gate-source are equal, then the same current flows through the drain terminals. It is the basic building block in current domain signal processing circuits. In current mirrors the NMOS acts as current sinks and PMOS acts as current sources [1]. There are different types of current mirrors are their Cascode current mirror, Regulated cascode current mirror CMOS voltage divider current mirror and Wilson current mirror [2].

II. BASIC CURRENT MIRROR

The basic current mirror can be formed by using two transistors. The input is taken as current source in one transistor and the output generates the required gate-source voltage with diode connection by using the second transistor. The limitations of two transistors current mirrors are: one is there will be variation in current as the output voltage changes and other is transistor should be of same circuit then only matching of current is obtained. In basic current mirror the channel length modulation can be neglected and poor gain [3]. In the Figure 1, M1 is always in saturation region and it is diode connected.

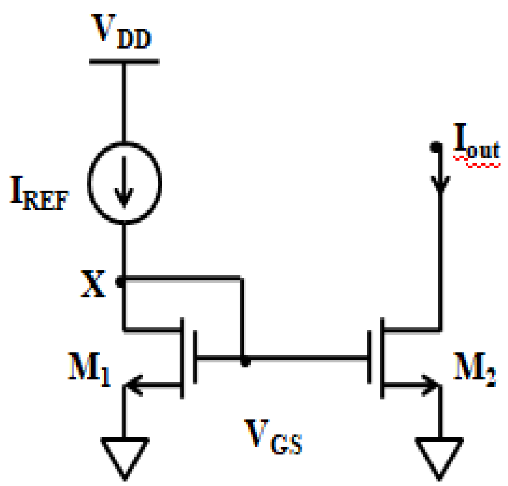

Figure 1. Basic Current mirror

Figure 1, represents Basic Current Mirror circuit. If V_{DS} changes, I_D also changes this causes channel length modulation effect. From this I_{out} is not equal to I_{REF} and V_{DS1} is not equal to V_{DS2}.

The channel length modulation can be reduced by equalling I_{out} to I_{REF}. This condition can be generated with this expression $V_{DS1} = V_{DS2}$. The transistor M3 is added to simple current mirror and applied an input voltage as V_b is shown in Figure 2. Here M2 and M3 are cascode pair. V_b is applied so that V_{DS} of M1 and M2 will be equal, it is indicated as V_y=V_x.

$$V_b = V_{GS3} + V_y \quad \textbf{(1)}$$

It has high output resistance which helps in maintaining output current as constant irrespective of load conditions and also low input resistance which helps the current mirror to have constant current irrespective of its drive conditions. In large circuits, the current mirrors are used for distribution of bias currents [4] [5].

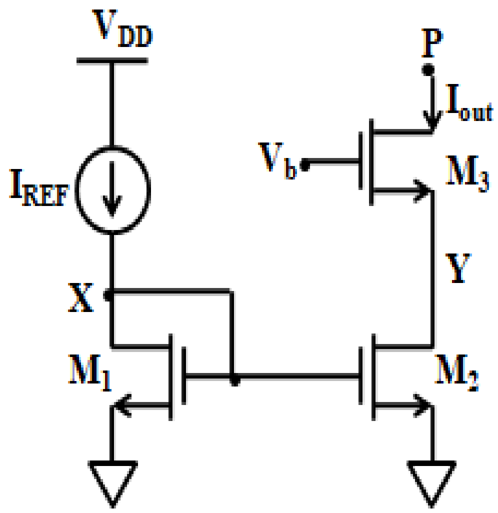

Figure 2. Current mirror Circuit

By eliminating Channel length Modulation,

$$I_{REF} = m_n C_{ox}(V_{GS} - V_{TH})^2 \quad \textbf{(2)}$$

$$I_{out} = m_n C_{ox}(V_{GS} - V_{TH})^2 \quad \textbf{(3)}$$

$$I_{out} = I_{REF} \quad \textbf{(4)}$$

From the Figure 2, the I_{out} is directly related to I_{REF}. The drain current is a function of gate-source voltage and drain-gate voltage.

III. CASCODE CURRENT MIRROR

To overcome one of the limitation of current mirror is channel length modulation which can be suppress by using cascode current sources are used. Significance error is caused due to transistor with minimum-length which are used for minimizing width of output capacitance.

When Vds1=Vds2 then the cascode current mirror eliminates the channel length modulation. In the Figure 3, describes the Cascode current mirror circuit. Here M1 and M3 are always in saturation mode. For the operation of the circuit M2 and M4 have to be in saturation mode then only the circuit can perform the current mirror operation. The M3 transistor output drives into the M2 drain terminal. Due to this the output resistance is high at the transistor M3. At node N the V_b voltage is applied [6].

$$V_{GS0}+V_X = V_{GS3}+V_Y \quad \textbf{(5)}$$

If $V_{GS0}=V_{GS3}$, then the condition $V_X=V_Y$ is satisfied. Conditions for V_{DS2} and V_{DS4} are

$$V_{DS2} > V_{GS} - V_t$$
$$V_{DS4} > V_{GS} - V_t$$

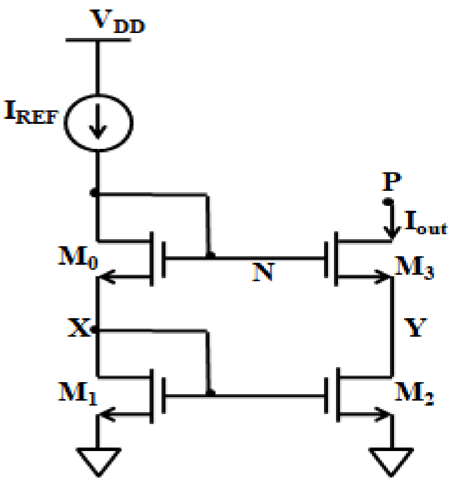

Figure 3. Cascode Current Mirror

In the Figure 3, describes the cascode current mirror. It does not require any external voltage bias. The Output resistance is increased in this circuit. The bias voltage is obtained from the reference side which is used for both the transistors at the output side of the mirror. So, the output swings as the range of the voltage is reduces. It also have advantages like high gain, bandwidth, slew rate and good stability. These current mirrors has great accuracy when compared with other current mirror circuits. The drawback of this circuit is it requires large load to increase the gain and output current is effected due to presence of body effect [7].

3.1 Folded Cascode Current Mirror

Folded Cascode Current Mirror is mostly used in the telescopic structure. It has larger output swing and high output resistance. The current feedback is between the gate and source with drain constant, has both n and p type MOSFET. Here currents are having both amplification and mirroring effect. In the Figure 4, the circuit reduces the supply voltage [8]. It is easy to stable and works slowly. The circuit minimize areas of drains and sources. The drawback of this circuit is it can be only used in voltage overhead issues.

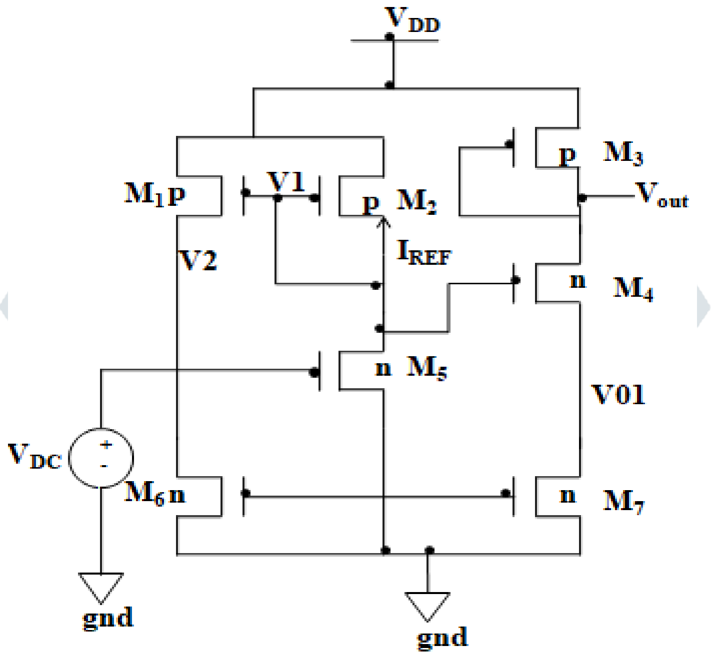

Figure 4. Folded Cascode Current Mirror

IV. Differential Cascode Current Mirror – Active Load

In this both the active loads and differential pairs are Cascode. It also reduces Miller effect. The process signals in the current mirrors are operate as "active" elements. If $V_{in1} << V_{in2}$, then the transistor M1 is OFF and M2 and M5 carries the zero current and the transistors are in deep triode region. Figure 5, describes Differential Cascode Current Mirror with Active Load [9].

When V_{in1} approaches to V_{in2}, then the transistors M2 and M4 are in saturated condition then the high gain is obtained. When V_{in1} is more positive than V_{in2}, then the current I_{D2} decreases and the remaining drain currents increases and then the transistor M4 will be in triode region. If $V_{in1} >> V_{in2}$, then the M2 is OFF condition and M4 will be in zero current with deep triode region. Hence, $V_{out}=V_{DD}$. It is a 5 transistor "Operational Transconductance Amplifier" (OTA). Here the output is single-ended. So, the circuit is used to convert the differential signals to single-ended output.

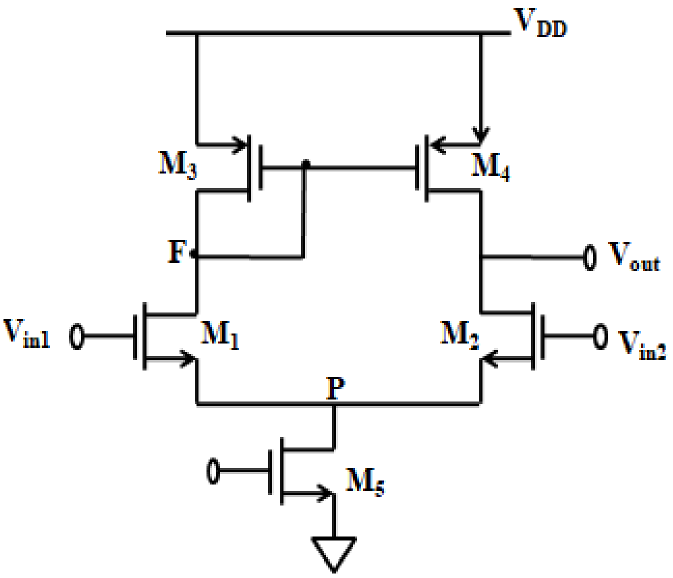

Figure 5. Differential Cascode Current Mirror with Active Load.

V. Digital-to-analog Converter (DAC)

This converter is generally used in the digital world. In this device conversion is done from digital to analog signals. One of the best example of this device is used in computers, MP3 and CD players. These audio and videos are basically in digital form are converted into analog signals for the purpose of hearing and displaying them. Here Figure 6, describes the Current Steering DAC.

In current steering, the current is used throughout the conversion. This architecture needs precision current sources which should be summed in different designs. In the Figure describes the Current steering network. Current steering and resistor ladders are well-known architectures in DACs. The parameters like area, speed and power consumption are better in these architectures [10].

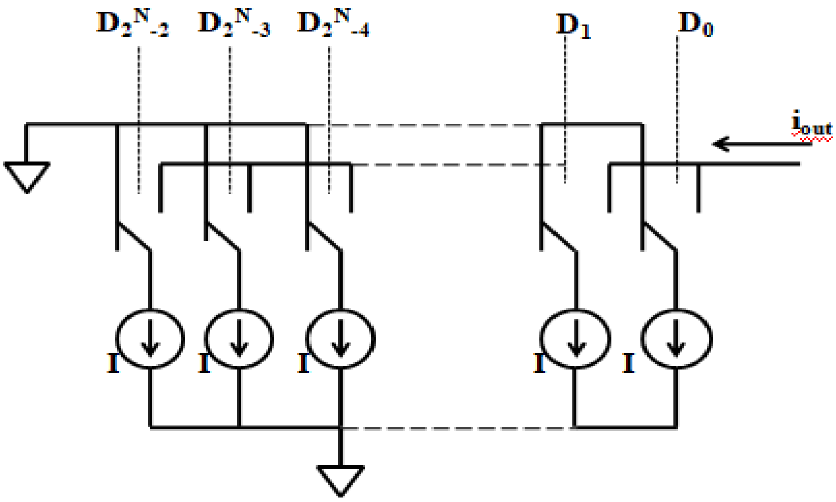

Figure 6. Current Steering DAC

5.1 Thermometer Code Converter

In this code the elements are equally weighted. If they are N binary bits, then the thermometer code has $M=2^{N-1}$. Here the decoder bits are accessed from binary to thermometer bits [11]. Figure 7, describes the N-Bit DAC using Binary to Thermometer Decoder with equivalent switches as MOSFETs. The output of the decoder is used to change all one bits to zero bits. When the data converts to digital from to analog simulates the current sources to activate on the occurrence of the higher order input bit. It has monotonicity. When the digital input is high then the analog output also increases. These are prominently used in low distortion segmented DACs and also in pipelined ADCs [12].

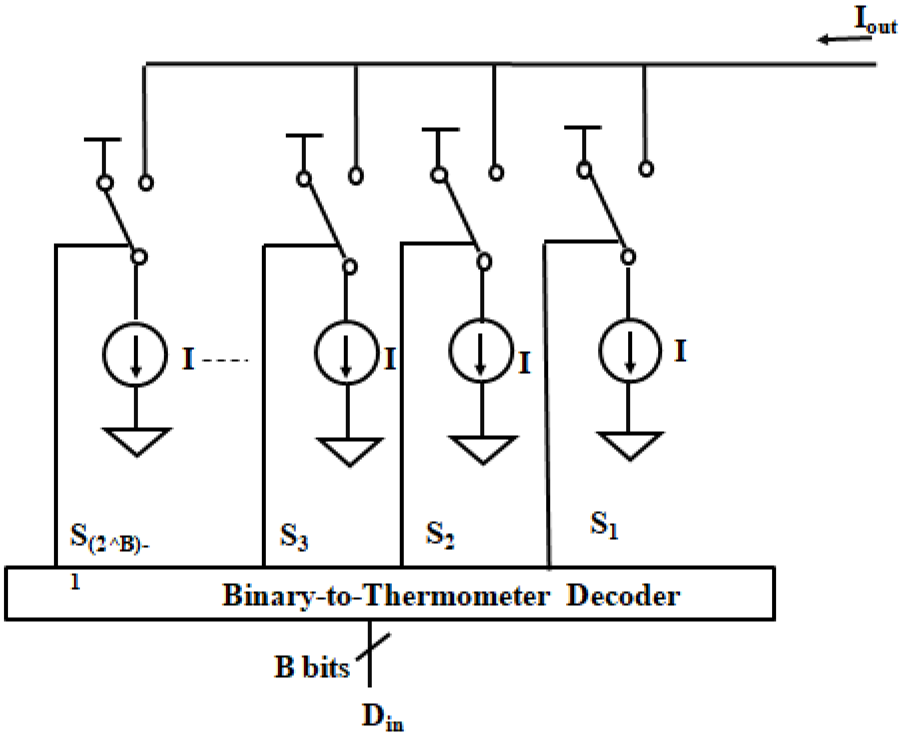

Figure 7. N-Bit DAC using Binary to Thermometer Decoder with equivalent switches as MOSFETs

In above Figure 7, we used current mirror circuit is replaced in the place of current sources.

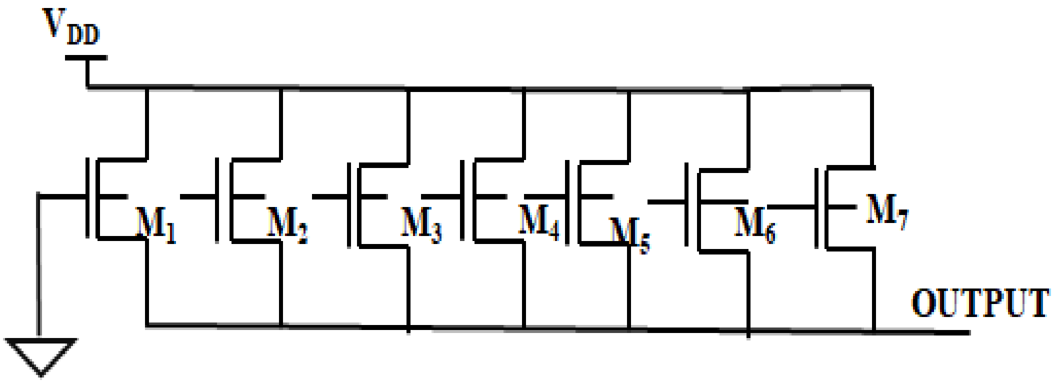

Figure 8. Thermometer Code Converter

VI. Design Aspect

There are many design aspects for Current Mirror like:

Gain: It is the ability to measure, the circuit signal by increasing their amplitude or power from input to the output by adding power supply as energy to the signal.

$$n = \frac{1+\lambda VDS2}{1+\lambda VDS1} \qquad \textbf{(6)}$$

Bandwidth: It is measure of frequency ranges while transmitting a signal within a given band.

$$\text{Bandwidth} = f_H - f_L \qquad \textbf{(7)}$$

Phase Margin: It is the difference between phase and 180°,to measure an output signal at zero dB gain.

Output Impedance: Here the current flow in resistance and reactance are in the reverse direction and the load network is connected as internal to electrical source.

Offset Error: In DAC, the offset error is defined as the analog output voltage response to an input code of all zeros.

Gain Error: It is defined as the slope of an actual transfer function must be equal to the slope of ideal transfer function. It is expressed in LSB. It can estimate out either in Hardware or software.

$$\text{Gain Error} = \text{Full scale error} - \text{Offset error} \qquad \textbf{(8)}$$

INL and DNL are used to verify the performance characteristics in Analog to Digital Converters (ADC) and Digital to Analog Converters (DAC).

Integral NonLinearity (INL): The maximum difference between the actual finite resolution characteristic and the ideal finite resolution characteristic measured vertically. INL is independent of gain and offset errors.

$$|\Delta I_k|_{max,\ INL} = I_{REF} / 2N \qquad \textbf{(9)}$$

Differential Non Linearity (DNL): In this all DAC output increment should have same size.

$$|\Delta I_k|_{max,\ INL} = I_{REF} / 2N \qquad \textbf{(10)}$$

VII. Results And Discussion

The 3-bit Digital to Analog Converter is simulated in ORCAD PSPICE Tool by using SPICE Coding. The designs are evaluated for chosen current mirrors whose outputs are evaluated in Avanwaves GUI as shown in Figures 9, 10, 11.

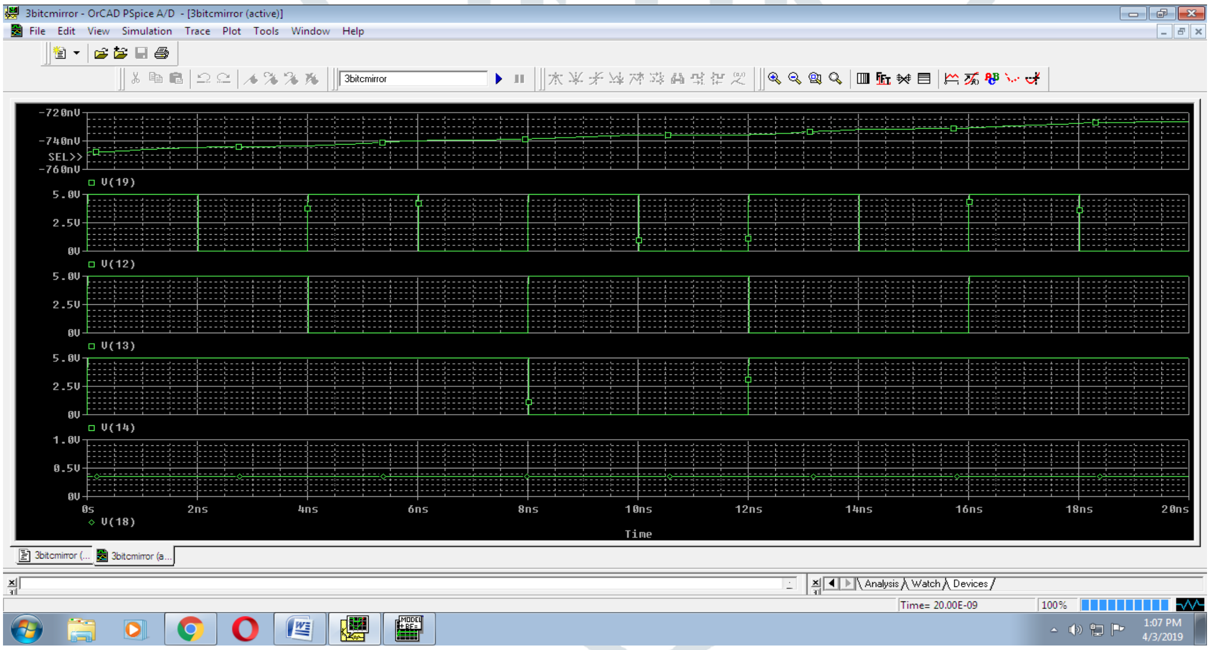

Figure 9. 3bit DAC using Basic Current Mirror

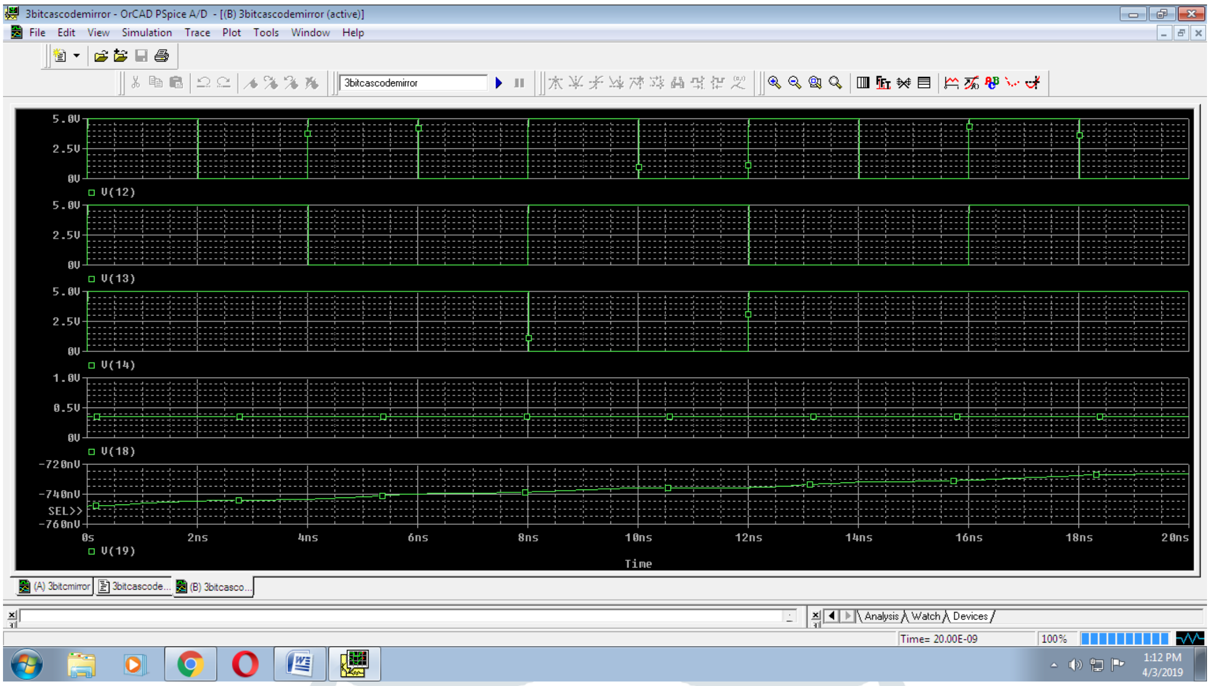

Figure10. 3bit DAC using Cascade Current Mirror

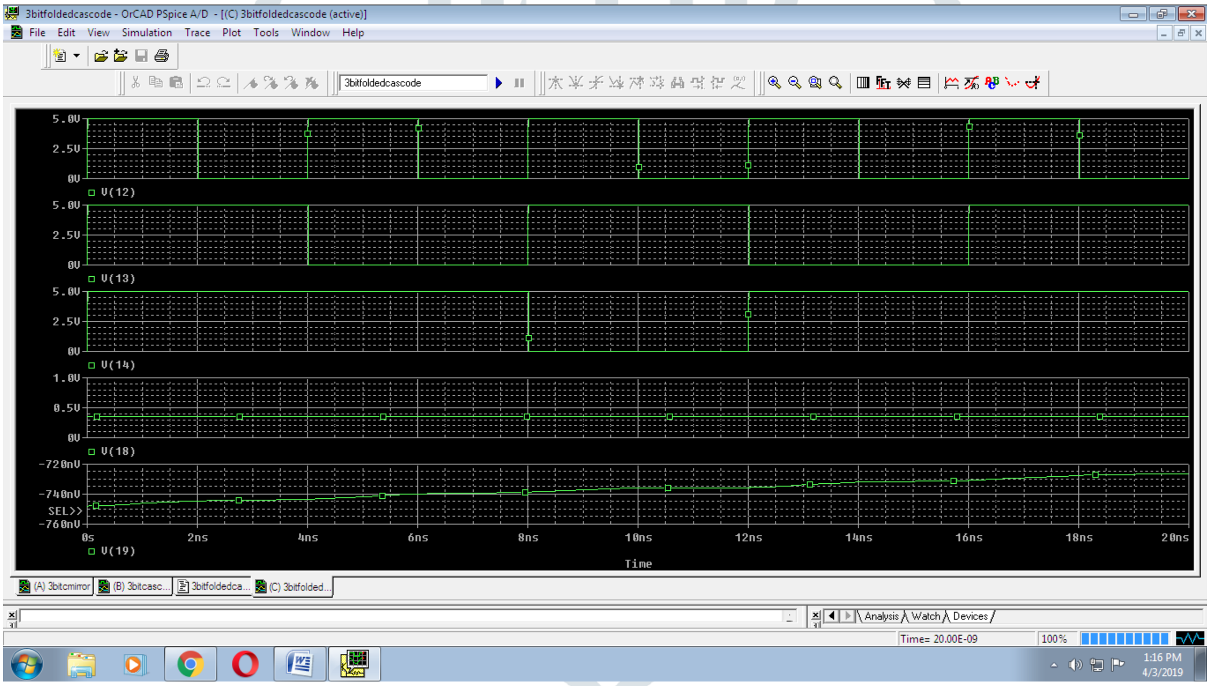

Figure 11. 3bit DAC using Folded Cascode Current Mirror

The 3-bit Digital to Analog Converters are compared and verified for parameters like gain and output impedance for the desired Fan-Out as shown in figure Table-1. Among these, the Folded Cascode Current Mirror provides the better gain of nearly 242% when compared to basic current mirror and 204.8% when compared to cascade current mirror. Also the better fan-out is provided by basic current mirror by 8.5% than cascade current mirror and 35.8% than the folded cascade current mirror

Table.1: Comparison Table of 3-Bit DACs using various current mirrors

Current Mirrors	Gain	Output Impedance
Basic Current Mirror	1.1256	85.146KΩ
Cascode Current Mirror	1.0000	1.0000MΩ
Folded Cascode Current Mirror	2.4560	163.732KΩ

VIII. Conclusion

The current mirrors are commonly used in biomedical devices to control the current in one active device of the circuit by copying the current through another active device and keeps the output current constant regardless of loads. They require high output impedance and high gain with a little trade-off between them to drive a large load. For evaluating the performance of the current mirrors, the 3-bit Digital to Analog Converter is used along with current steering thermometer code converter. The designs are verified in ORCAD PSPICE Tool by using SPICE Coding. From the results, it is proved that the folded cascade current mirror provides better gain by around 200% when compared to other current mirrors described and the basic current mirror provides better fan-out of nearly 35% when compared to other current mirrors.

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