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TIQ Based Flash ADC

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Abstract: This project presents the design and analysis of a Threshold Inverter Quantization (TIQ)-based Flash Analog-to-Digital Converter (ADC), aiming to address the limitations of conventional flash ADCs in terms of power consumption and chip area. Traditional flash ADCs, while offering high-speed conversion due to their parallel architecture, suffer from exponential growth in the number of comparators with increasing resolution, resulting in high power usage and large die size. The proposed TIQ Flash ADC replaces conventional comparators with cascaded CMOS inverters, leveraging transistor sizing to set internal reference voltages. This approach eliminates the need for a resistor ladder and reduces power consumption and complexity. The design also applies techniques such as gain boosting for sharper voltage thresholds and efficient encoding of the thermometer code to binary format. Simulation and analysis demonstrate that the TIQ-based ADC achieves comparable speed and resolution.

Keywords: VLSI, TIQ, ADC, Cadence Virtuoso.

I. INTRODUCTION

A digital comparator or magnitude comparator is a hardware electronic device that takes two numbers as input in binary form and determines whether one number is greater than, less than or equal to the other number.

A TIQ (Threshold Inverter Quantizer) comparator is a circuit that uses two cascaded CMOS inverters to compare an input voltage to a series of internal reference voltages. It's often used in flash ADCs (Analog-to-Digital Converters) as a way to replace traditional resistive voltage dividers and comparators.

An analog-to-digital converter is a system that converts an analog signal, such as a sound picked up by a microphone or light entering a digital camera, into a digital signal. A flash ADC (also known as a direct-conversion ADC) is a type of analog-to-digital converter that uses a linear voltage ladder with a comparator at each "rung" of the ladder to compare the input voltage to successive reference voltages.

II. OBJECTIVES

The objective of the project is:
To design a Flash ADC using Threshold Inverter Quantizer Comparators (TIQ).

III. BLOCK DIAGRAM

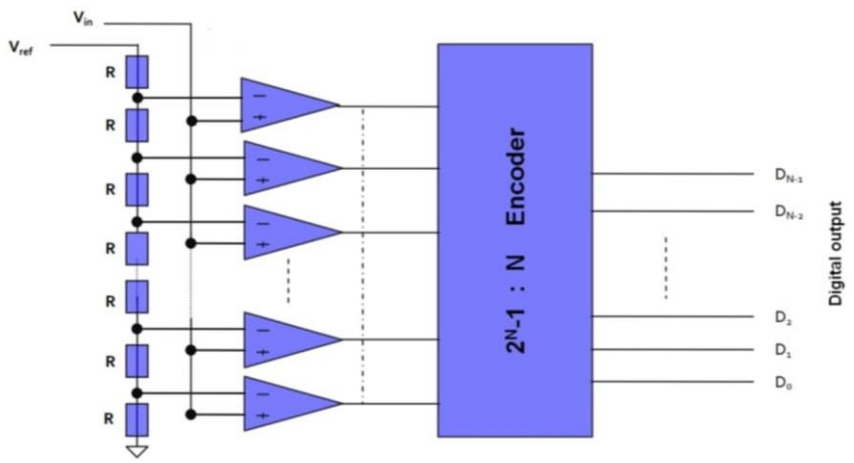

Figure 1. Block Diagram

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This figure shows an analog-to-digital converter is a system that converts an analog signal, such as a sound picked up by a microphone or light entering a digital camera, into a digital signal. A flash ADC (also known as a direct-conversion ADC) is a type of analog-to-digital converter that uses a linear voltage ladder with a comparator at each "rung" of the ladder to compare the input voltage to successive reference voltages.

IV. CIRCUIT IMPLEMENTATION

1. ADC Architecture:
TIQ based ADC chip, which is comprised of three basic blocks. These blocks are TIQ comparator, gain booster, and thermometer to binary encoder. The architecture of the ADC chip is shown in figure along with pins assignments. The architecture and schematics of three blocks are discussed in the following subsections.

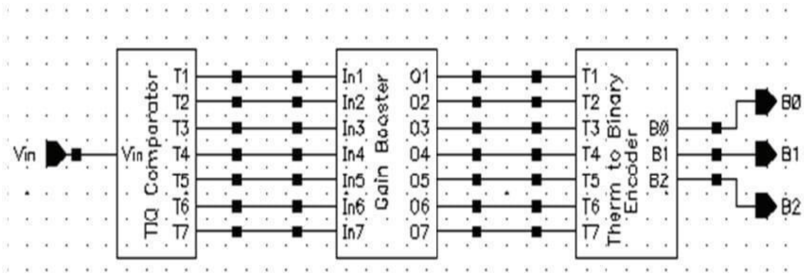

Figure 2 ADC Architecture

A. Threshold Inverter Quantization (TIQ):
Schematic of comparator, which is composed of two cascaded inverters. If the input voltage to the first inverter exceeds its switching voltage, its output switches from logic 1 to logic zero which in turn switches the second inverter from logic 0 to logic 1. Second inverter increases the gain and achieve the desired low to high transition for input voltage higher than threshold level. TIQ converter uses inverter's internal swathing voltage as reference voltage. So, the voltage references used in TIQ comparators are obtained internally. Figure 4 shows the symbol of comparator.

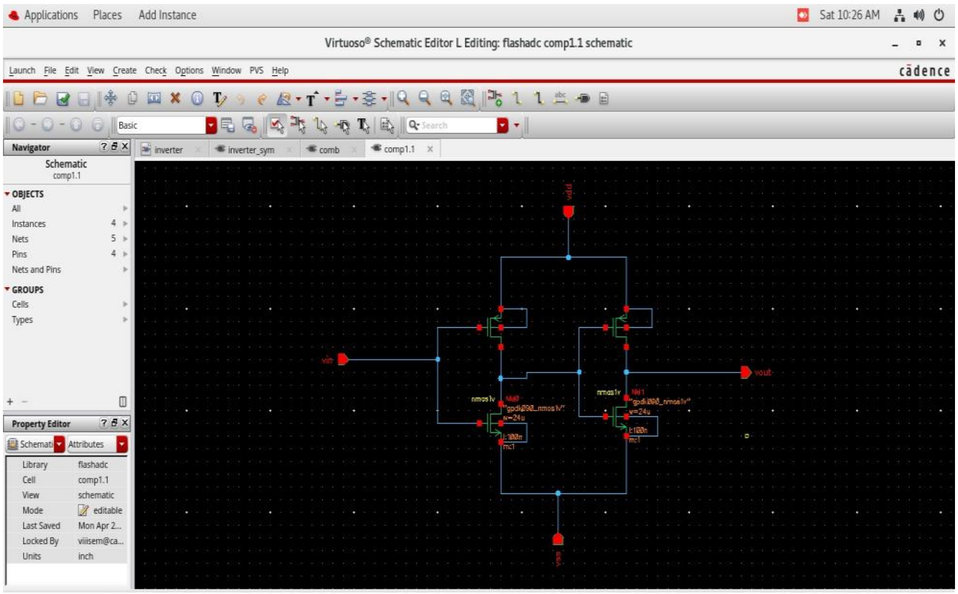

Figure 3 Schematic of Comparator

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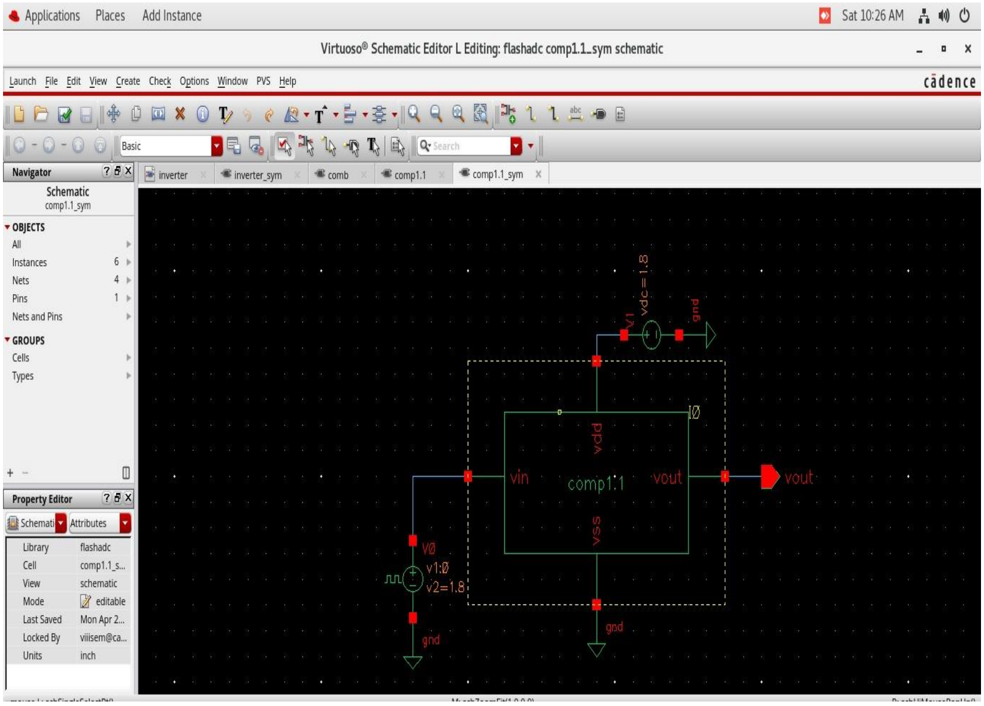

Figure 4 Symbol of Comparator

Equation 1 shows the dependence of inverter switching voltage upon widths of nMOS and pMOS in CMOS technology. By adjusting the ratio of widths (Wp/Wn), inverter's switching voltage can be set to desired voltage. This equation shows, Vm increases if the width ratio, Wp/Wn is increased. Table 1 shows the transistor sizes along with the corresponding TIQs' switching voltages. The table also includes the width ratios (pMOS to nMOS) in the rightmost column. As the width ratio increases, the swathing voltage also increases which is analogous to the estimate made from equation 1.

$$V_m = \frac{\sqrt{\frac{\mu_p W_p}{\mu_n W_n}}\left(V_{DD} - |V_{Tp}|\right) + V_{Tn}}{1 + \sqrt{\frac{\mu_p W_p}{\mu_n W_n}}} \qquad \ldots\ldots\ (1)$$

The input analog voltage is connected to the inputs of all the TIQ comparators. The thermometer codes are generated at the comparators outputs. Figure 4.5 shows the combining of comparators.

Table 1 Transistor Sizes along with switching voltages

TIQs	Switching Voltage, V_s (V)	nMOS width, Wn (µm)	pMOS width, Wp (µm)	Width ratio (Wp/Wn)
T1	1.00	24	2.4	0.1
T2	1.45	15.15	5.25	0.347
T3	1.90	9	7.2	0.8
T4	2.35	6	9.45	1.575
T5	2.80	4.5	14.25	3.167
T6	3.25	3	21.15	7.05
T7	3.70	1.5	31.65	21.1

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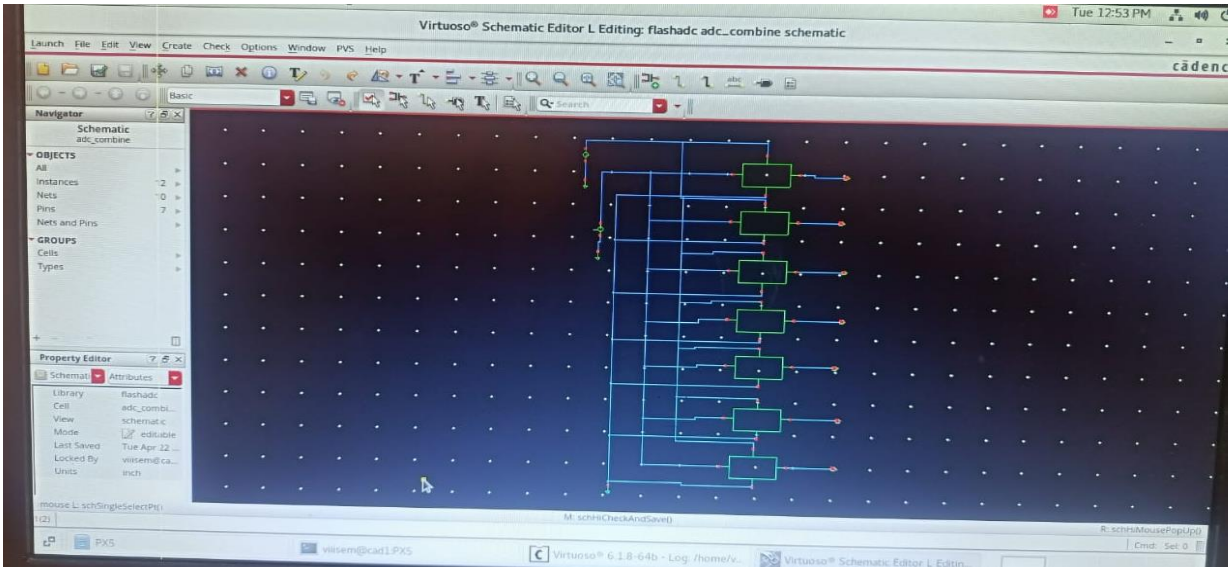

Figure 5 Combining of Comparators

B. Gain Booster:

Each of the gain booster consists of two cascaded inverters as shown in Figure 4.6 Size of the transistors are same for all the inverters. Gain boosters increase the voltage gain of output of the TIQ comparators. Adding of the gain boosters block makes the voltage transition sharper as shown later in figure of Simulation Results section. Figure 7 shows the symbol of inverter.

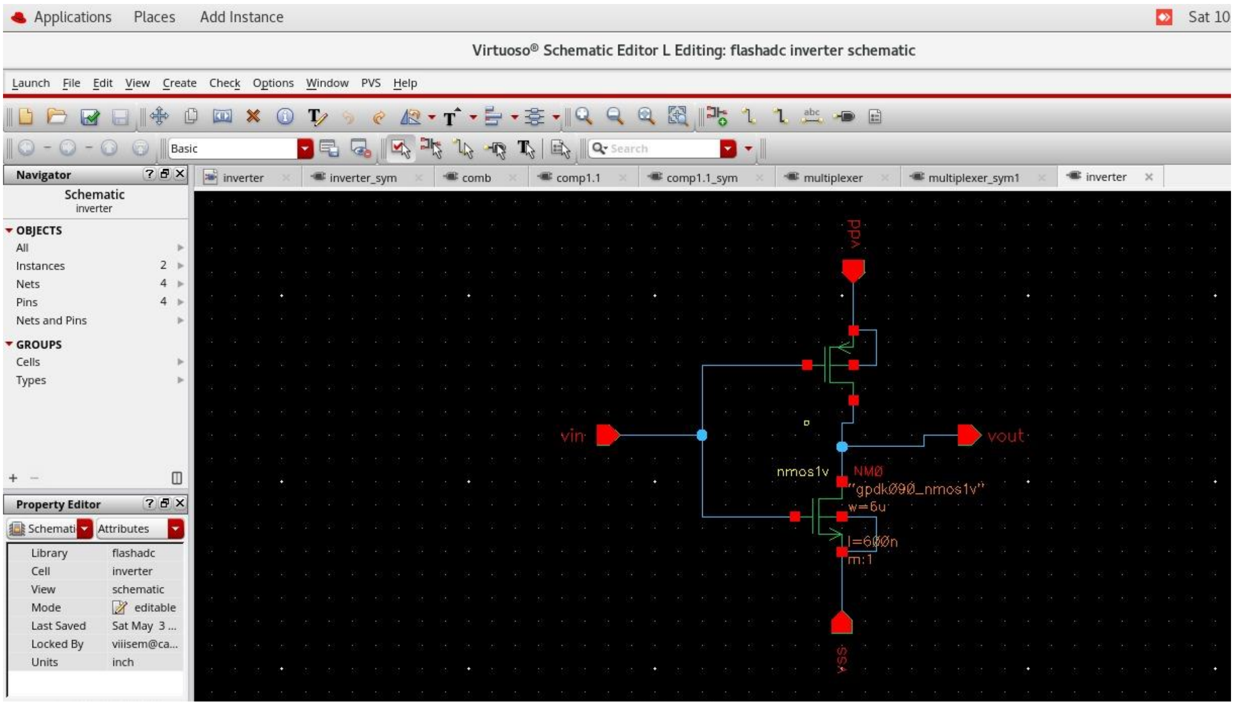

Figure 6 Schematic of Inverter

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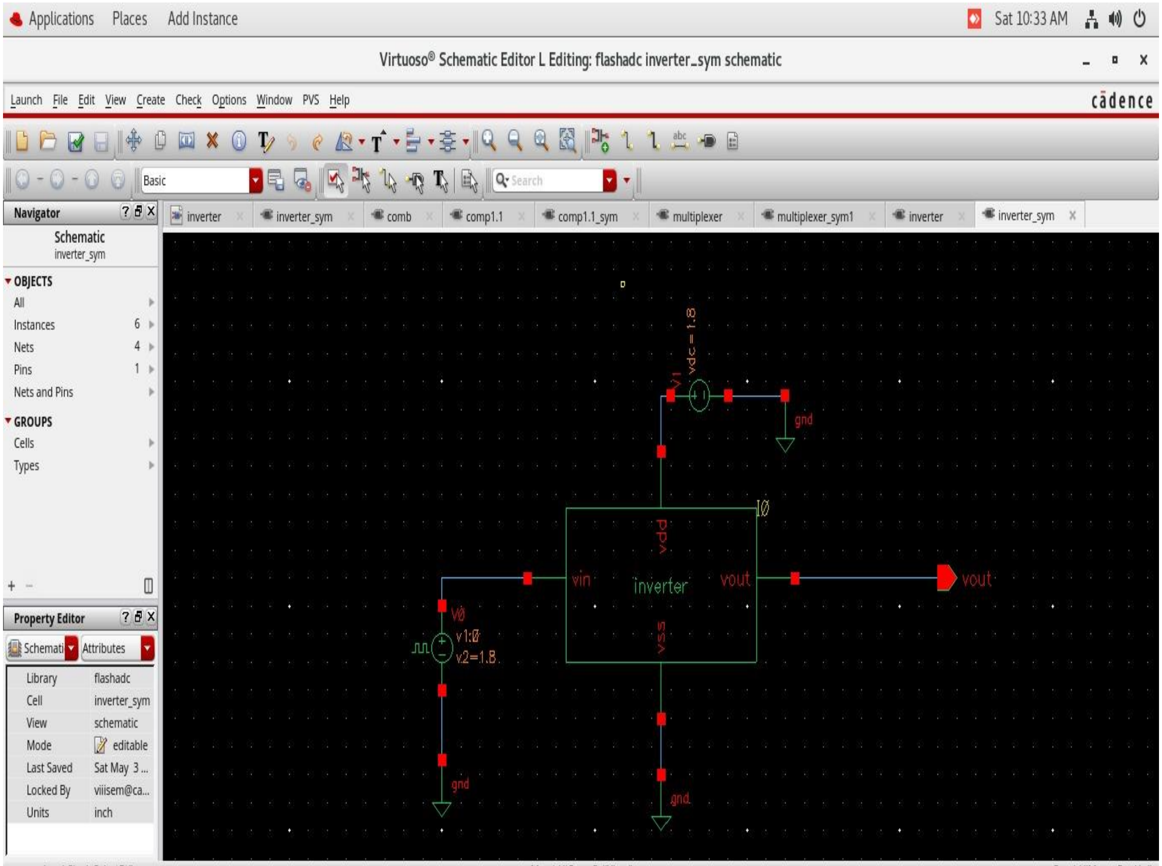

Figure 7 Symbol of Inverter

C. Thermometer to Binary Encoder:

Thermometer to binary code (TM2B) encoder is a very important part of any ADC. Output of the comparator or gain booster block is thermometer code. This thermometer code needs to be converted into binary code which is the output of ADC. For example, if the thermometer code generated by comparator is 0000111, the final output of a 3-bit ADC should be 011. Table 2 shows the thermometer to binary code conversion chart. Thermometer-to-binary encoders are essential in applications like flash ADCs, where high-speed and precise analog-to-digital conversion is required.

Table 2 Thermometer Code to Binary Code Conversion

Thermometer Code							Binary Code		
T7	T6	T5	T4	T3	T2	T1	B2	B1	B0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	1
0	0	0	0	0	1	1	0	1	0
0	0	0	0	1	1	1	0	1	1
0	0	0	1	1	1	1	1	0	0
0	0	1	1	1	1	1	1	0	1
0	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1

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There are various methods of implementing TM2B encoder, such as ROM encoding, Wallace tree, and 2:1 MUX based encoder etc. In this work, multiplexer based encoding system has been utilized. Figure shows the schematic of the thermometer to 3-bit binary encoder. The encoder is comprised of four 2:1 MUXs and two inverters. The 2:1 MUX has been implemented by transmission gates as it has less transistors count, highly efficient response with less power consumption. Figure shows the schematic of the 2-input MUX used in thermometer to binary encoder. The 2-input MUX requires select (S) input and its complement (S_bar). An inverter has been used to get this complementary select signal. Figure 8 and 9 shows the schematic and symbol of multiplexer.

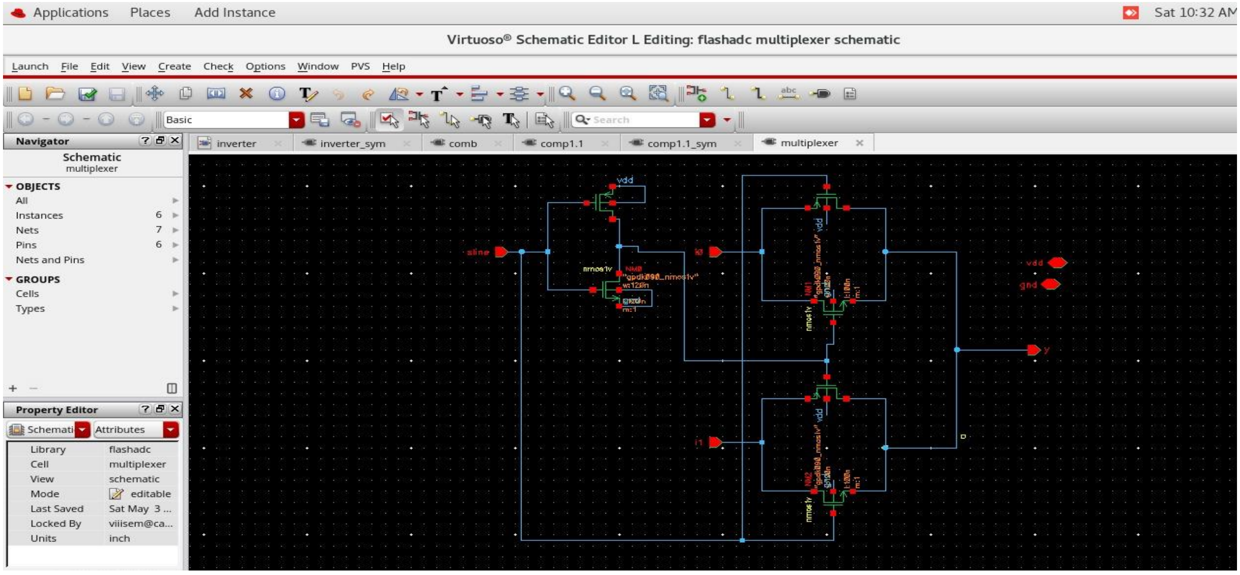

Figure 8 Schematic of Multiplexer

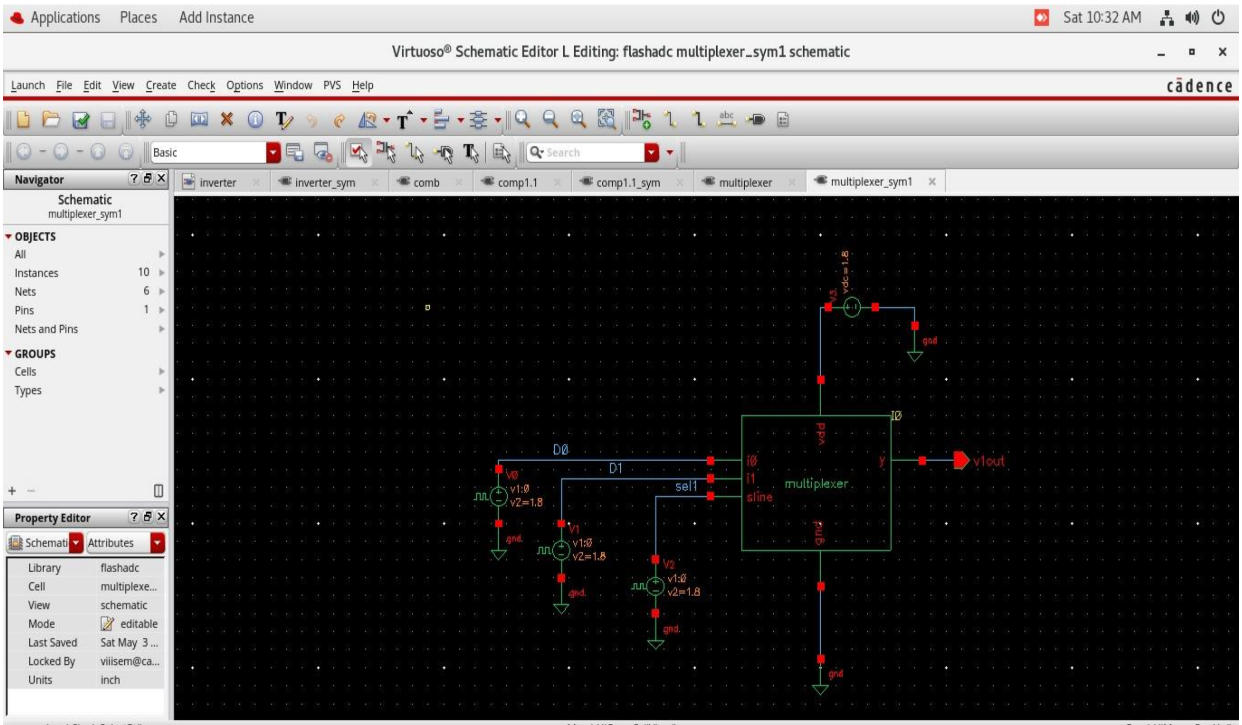

Figure 9 Symbol of Multiplexer

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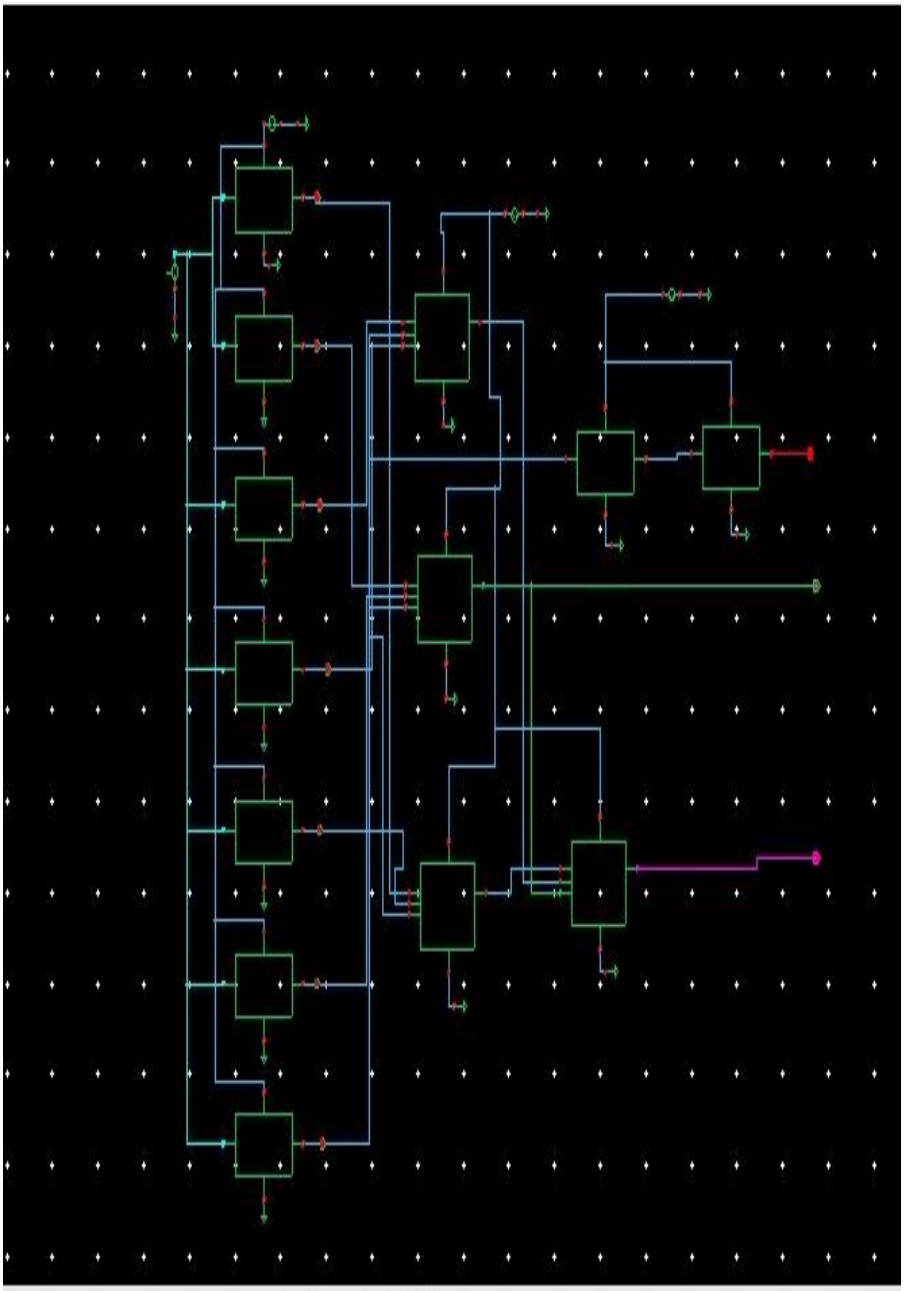

Figure 10 TIQ based Flash ADC

V. SIMULATION RESULT

Table 3 Transistor Sizes along with switching voltages

TIQ	nMOS width	pMOS width	Width Ratio	Switching voltage	Threshold voltage
T1	24	2.4	0.1	1.00	0.40
T2	15.15	5.25	0.347	1.45	0.52
T3	9	7.2	0.8	1.90	0.67
T4	6	9.45	1.575	2.35	0.8
T5	4.5	14.25	3.167	2.80	0.98
T6	3	21.15	7.05	3.25	1.12
T7	1.5	31.65	21.1	3.70	1.27

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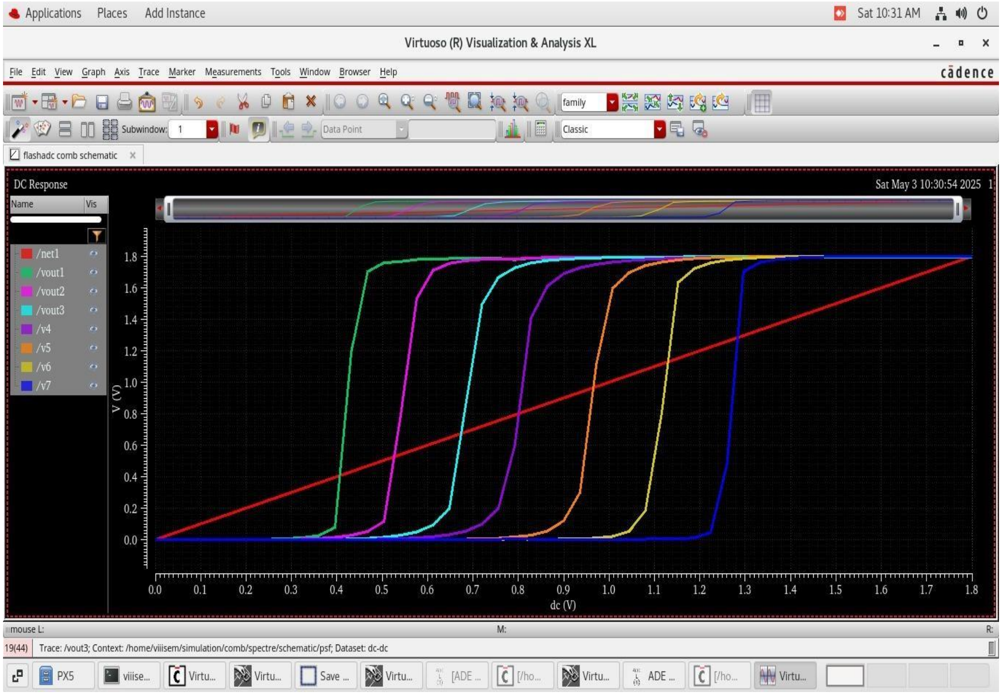

Figure 11 Shifting of switching position for varying transistor's width ratio

The result demonstrates how the switching position (input voltage at which the inverter output switches) changes as the transistor width ratio in the TIQ comparator is varied. In the graph, each colored curve represents the voltage transfer characteristic of a TIQ inverter with a different width ratio. As we move from left to right on the X-axis (input voltage), the point where each curve sharply transitions from high to low (or vice versa) represents the switching threshold (Vth) of that inverter. By changing the transistor width ratio, the switching threshold of each inverter shifts. The switching thresholds are evenly spaced, which is ideal for ADC operation this allows for consistent quantization levels. The lowest switching voltage observed is 0.4V and the highest is 1.5V, covering a wide input range. The spacing between switching voltages (e.g., ~450 mV) confirms that the TIQ comparators are effectively tuned to respond at different voltage levels. This uniform spacing ensures accurate and efficient analog-to-digital conversion in a Flash ADC, as each comparator fires at a distinct, predictable input level based on its design.

Figure 12 TIQ Flash ADC's Output

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The result illustrates the output behavior of a TIQ-based Flash ADC as the input voltage increases gradually from 0V to 1.8V.On the left side of the figure, the transient response is shown for three output bits (B2, B1, B0). These waveforms indicate how the digital outputs change over time in response to the varying analog input.On the right side, the DC response plots each output bit against the analog input voltage. These curves show the precise transition points where each output bit flips between logic levels (0 and 1).

The comparators in the TIQ ADC trigger at different threshold voltages depending on their transistor sizing.Each output bit (B0, B1, B2) transitions sharply at a specific input voltage range, corresponding to the thresholds set by the TIQ design.These transitions are clean, sharp, and well-defined, showing that the ADC is able to accurately and reliably distinguish different input voltage levels.This confirms that the TIQ Flash ADC is functioning correctly, with clearly distinguishable digital output levels that accurately represent the range of analog input voltages. This sharpness is essential for precise digital conversion in high-speed applications.

VI. CONCLUSION

The TIQ comparator-based Flash ADC presents a compelling solution for high-speed, low- power analog-to-digital conversion, particularly in applications requiring moderate resolution (typically 4–6 bits). By leveraging resistor-divider-based TIQ comparators instead of traditional analog comparators, the design simplifies circuitry, reduces power consumption, and minimizes offset voltage errors. However, this architecture is best suited for applications where process variations can be well controlled, as TIQ comparators are sensitive to mismatch and temperature drift. Overall, it is an efficient and scalable approach for integrated high-speed ADCs in modern CMOS technologies.

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