Tab 1

(SAR) ADC WITH CAPACITOR CHARGE DISTRIBUTION SELECTOR



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DECLARATION

It is declared hereby that this thesis paper or any part of it has not been submitted to anywhere else for the award of any degree.

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CERTIFICATION

This is to certify that this thesis entitled **"(SAR) ADC WITH CAPACITOR CHARGE DISTRIBUTION SELECTOR"** is done by the following students under my direct supervision.This thesis work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering, Sonargaon University(SU) in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering(EEE).

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ABSTRACT

This work presents the design and implementation of a Successive Approximation Register (SAR) Analog-to-Digital Converter (ADC) architecture featuring a capacitor charge distribution selector. The proposed system enhances the traditional SAR ADC by incorporating multiplexers (CD4052B, CD4053B) and digital shift registers (74HC595) to dynamically manage the distribution of charge across the capacitor array during the conversion process. In a series capacitor connection the voltages are divided by equal pieces . With the help of a control circuit by selecting voltage level, we can complete a binary search Algorithm. A high-speed switching mechanism utilizing MOSFETs ensures minimal latency and improved accuracy in charge redistribution, which is critical for achieving high-resolution conversion. The design employs standard TTL logic gates (74LS series) for precise control logic and clock generation. The proposed architecture offers significant advantages in scalability, noise resilience, and power efficiency, making it well-suited for high-speed, low-power applications requiring moderate to high resolution. Simulation results validate the effectiveness of the charge distribution selector in optimizing the linearity and dynamic performance of the SAR ADC.

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Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Successive Approximation Register (SAR) Analog-to-Digital Converters (ADCs) are widely used in low-power and medium-to-high resolution applications due to their excellent balance between speed, power consumption, and accuracy. A key component in SAR ADCs is the capacitive Digital-to-Analog Converter (CDAC), which performs the binary-weighted voltage division during the conversion process.

To improve the performance and flexibility of SAR ADCs, a capacitor charge distribution selector can be introduced into the architecture. This selector enables dynamic control over how charge is shared or redistributed among the capacitor array during the approximation steps. By adjusting the charge distribution path, the selector can:

- Optimize power consumption,
- Improve matching and linearity,
- Allow for calibration techniques,
- Support multiple resolution modes or input ranges.

This added flexibility makes the SAR ADC with capacitor charge distribution selector especially suitable for adaptive systems and applications where high precision and energy efficiency are critical, such as in biomedical devices, IoT sensors, and portable instrumentation.

1.2 OBJECTIVE

The objective of the "SAR ADC with Capacitor Charge Distribution Selector" is to design and implement an advanced Successive Approximation Register (SAR) analog-to-digital converter (ADC) architecture that incorporates a dynamic capacitor charge distribution mechanism. This mechanism optimizes the conversion process by selecting and distributing charge across capacitors during the successive approximation steps, enabling:

1. Improved Conversion Accuracy: By selecting capacitors with precise charge storage characteristics, the design aims to minimize errors due to capacitor mismatch, thus improving the overall accuracy of the ADC.

2. Enhanced Resolution and Precision: The capacitor charge distribution selector allows for fine-tuned control over the charge stored in each capacitor, leading to better resolution and more accurate digital representations of analog input signals.

3. Faster Conversion Speed: Dynamic selection of capacitors based on the conversion step allows for quicker processing, enabling faster conversion times while maintaining high resolution and accuracy.

4. Power Efficiency: By reducing the number of capacitors in operation at any given time and optimizing charge distribution, the design aims to reduce power consumption compared to traditional SAR ADCs, which is particularly beneficial for battery-powered or low-power systems.

5. Adaptability to Different Applications: The system’s flexible architecture allows it to be tailored for use in a variety of applications, from high-resolution instrumentation to low-power, high-speed systems.

1.3 LITERATURE REVIEW

The Successive Approximation Register Analog-to-Digital Converter (SAR ADC) has become a popular architecture for low-power and high-resolution applications due to its simple structure, scalability, and energy efficiency. The core operation of SAR ADCs relies heavily on the Digital-to-Analog Converter (DAC) implementation, which is typically realized through a capacitive charge redistribution network. As such, optimizing the capacitor switching scheme has been a focal point of research to enhance power efficiency and area utilization.

One of the seminal works in this domain by Liu et al. introduced a monotonic capacitor switching procedure, reducing DAC switching energy by over 80% compared to the traditional binary-weighted approach. This set the foundation for further innovations targeting even greater energy savings.

Later, Tong and Zhang proposed ultra-low energy switching schemes achieving up to 98.8% energy reduction, which are particularly suited for biomedical and portable applications where the energy budget is extremely limited. Similarly, Osipov and Paul developed two advanced SAR architectures achieving up to 99.37% energy savings, highlighting the potential of optimized digital control in analog front-end designs.

Capacitor-splitting techniques, such as those discussed by Xie et al. and Huang et al. , have proven effective in minimizing total capacitance, thereby reducing area and dynamic power consumption. These methods segment the capacitor array into multiple domains, activating only relevant segments during each conversion phase.

Several works also focused on asymmetric and dual capacitor arrays to enable energy reuse and charge recovery. Kim et al. and Yoon and Chang implemented schemes using floating capacitors to recycle charge, further minimizing energy loss during bit trials.

Switching algorithms have evolved from conventional binary search to more intelligent strategies such as two-step approximations, and asymmetric binary search. These

methods tailor the DAC switching path dynamically, minimizing voltage swings and improving both speed and energy efficiency.

Application-specific designs have also been explored. Mahmoud et al. presented a SAR ADC tailored for ECG detection, showcasing that simplified switching logic and a reduced bit count can meet clinical requirements with sub-microwatt power consumption.

Finally, works by Ghoshal et al. and others provided hybrid schemes combining several of these techniques—charge recovery, capacitor splitting, and smart control logic—into unified frameworks for optimized SAR ADC performance across a wide range of applications, from IoT to biomedical electronics.

These diverse approaches underscore the richness of innovation in SAR ADC design. As technology scales and application requirements grow stricter, continued refinement of capacitor switching methods and charge distribution architectures remains pivotal to achieving higher energy efficiency and better performance in mixed-signal systems.

Chapter 2

THEORY OF THE THESIS

A SAR (Successive Approximation Register) ADC converts analog signals into digital by using a binary search algorithm. It typically uses a capacitive DAC, which consists of a binary-weighted capacitor array. The input voltage is sampled onto this array, and the SAR logic determines each bit by comparing the DAC voltage to the input via a comparator.

The Capacitor Charge Distribution Selector (CCDS) enhances this structure by selecting specific capacitors during conversion steps. Instead of switching all capacitors in each step, the selector allows controlled charge distribution, leading to:

- Lower power consumption
- Reduced switching energy
- Improved speed and accuracy

This technique is especially useful in low-power and high-precision ADC applications.

Linear Search Algorithm:

Linear Search is a basic method to find an element in a list or array.
It checks each item one by one from the beginning to the end.

Steps of Linear Search:

1. Start from the first element.
2. Compare it with the target value.
3. If they match → Target found.
4. If not, go to the next element.
5. Repeat steps 2–4 until:

Time Complexity:

- Best case: O(1) → if the item is at the beginning.
- Worst case: O(n) → if the item is at the end or not in the list.

Binary Search Algorithm: Binary search is an efficient algorithm for finding a target value within a sorted array. It works by repeatedly dividing the search interval in half.

Steps of Binary Search:

1. Start with the whole sorted array.

2. Find the middle element.

3. Compare the middle element with the target:

- If it matches, the search is complete.
- If the target is less than the middle element, search in the left half.
- If the target is greater than the middle element, search in the right half.

Repeat the process on the new sub-array until the element is found or the sub-array has no elements left.

Time Complexity:

- Best Case (O(1)): Occurs when the target element is at the middle of the array during the first comparison.
- Average and Worst Case (O(log n)): In both cases, binary search halves the search space with each iteration, leading to a logarithmic time complexity.

Non-Polarized Capacitor

- A non-polarized capacitor (like ceramic or film capacitors) doesn't have positive or negative leads.
- It can be connected in any direction, unlike polarized capacitors (e.g., electrolytic), which must follow polarity.
- All standard capacitor formulas still apply for non-polarized capacitors.

Behavior in series:

- Total capacitance decreases.
- All capacitors carry the same charge (Q).
- Voltage divides across them.

Component Description

2.1 COMPONENT LIST:

1. IC 7493 (4-bit binary ripple counter)
2. IC 7402 (Quad 2-Input NOR Gate)
3. IC 7408(Quad 2-Input AND Gate integrated circuit)
4. IC 74595(8-bit Serial-in, Parallel-out Shift Register)
5. IC CD4053(Triple 2-Channel Analog Multiplexer/Demultiplexer)
6. IC CD4052(Dual 4-Channel Analog Multiplexer/Demultiplexer)
7. IC 74HC595(8-bit serial-in, parallel-out shift register with a storage register and 3-state outputs)
8. PMOS(P-channel Metal-Oxide-Semiconductor transistor)
9. NMOS(N-channel Metal-Oxide-Semiconductor transistor)
10. LED(Light Emitting Diode)
11. Resistor
12. Diode
13. Comparator
14. Potentiometer

2.2 IC 7493 (4-bit binary ripple counter): The IC 7493 is a 4-bit binary ripple counter, commonly used in digital electronics to count pulses. Here's a breakdown of how it works and what it includes.



Figure 1: IC 7493

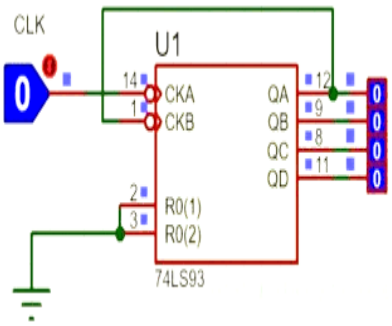


Figure 2: IC 7493 Pin Diagram

Basic Features of IC 7493:

- Type: 4-bit binary ripple counter (mod-16 counter).
- Configuration: Divide-by-2 and divide-by-8 sections.

Inputs:

- Two clock inputs: CP0 (pin 14) and CP1 (pin 1)
- Two reset inputs: R0(1) (pin 2) and R0(2) (pin 3) — both must be HIGH to reset the counter.

Outputs:

- Four outputs: Q0 (pin 12), Q1 (pin 9), Q2 (pin 8), Q3 (pin 11) — representing the 4-bit binary count.

Operation:

- Internally, IC 7493 is divided into:

Reset Function:

- Applying HIGH to both reset pins (pin 2 and 3) instantly resets the count to 0000.

2.3 IC 7402 (Quad 2-Input NOR Gate): The Quad 2-Input NOR Gate is a logic IC that contains four independent NOR gates, each with two inputs. The most common IC for this is the IC 7402.



Figure 1: IC 7402

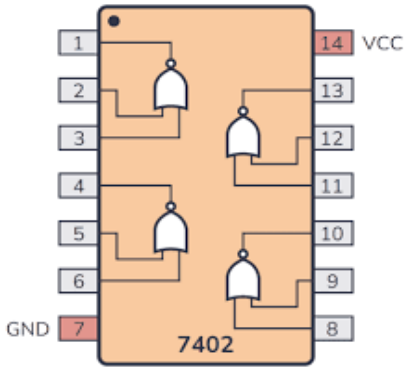


Figure 2: IC 7402 Pin Diagram

Key Features:

- Contains 4 separate NOR gates
- Each gate has:
- 2 inputs
- 1 output

Logic Function:

- Y= $\overline{A + B}$

Common Applications:

- Digital logic design
- Timing and control circuits
- Logic function construction (e.g., NOT, AND from NOR)

2.4 IC 7408(Quad 2-Input AND Gate integrated circuit): IC 7408 is a digital logic integrated circuit that contains four independent 2-input AND gates. Each gate gives a HIGH output only when both inputs are HIGH, performing the logical AND operation.



Figure 1: IC 7408

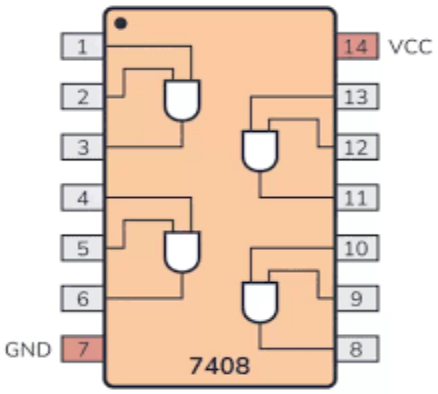


Figure 2: IC 7408 Pin Diagram

Key Features:

- 4 independent AND gates
- Each gate has 2 inputs and 1 output
- Operates on TTL logic (Transistor-Transistor Logic)
- Power supply voltage: usually 5V

Logic Function:

- $Y=A \cdot B$

2.5 IC CD4053 (Triple 2-Channel Analog Multiplexer/Demultiplexer): The CD4053 is an IC (Integrated Circuit) that functions as a Triple 2-Channel Analog Multiplexer/Demultiplexer. It contains three independent single-pole double-throw (SPDT) analog switches. Each switch has two inputs/outputs and one common input/output.

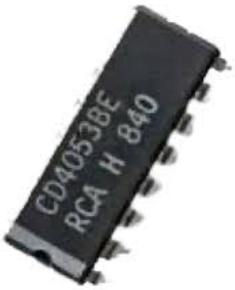


Figure 1: IC CD4053

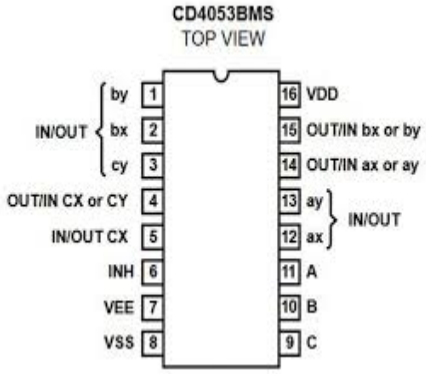


Figure 2: IC CD4053 Pin Diagram

Features:

- 3 independent analog switches (A, B, C)
- Each switch can connect one of two inputs to a common terminal
- Can pass analog or digital signals
- Operates with wide supply voltage: 3V to 20V
- Low ON resistance (~125 ohms typical at VDD = 10V)
- Low power consumption

Application Examples:

- Signal routing
- Data multiplexing
- Analog signal control in instrumentation

2.6 IC CD4052(Dual 4-Channel Analog Multiplexer/Demultiplexer): The CD4052 is an Analog Multiplexer/Demultiplexer IC that provides dual 4-channel switching capability. It's commonly used for routing analog or digital signals from multiple sources to a single destination, or vice versa.



Figure 1: IC CD4052

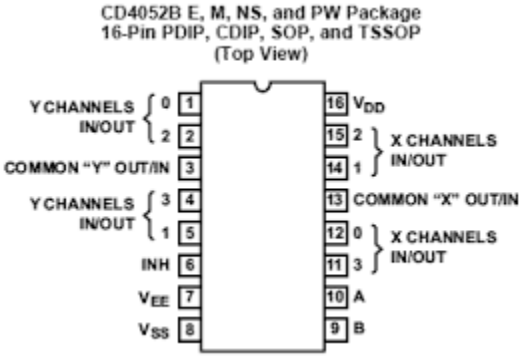


Figure 2: IC CD4052 Pin Diagram

Features:

- Dual 4-channel multiplexer/demultiplexer
- Analog and digital signal compatibility
- Wide supply voltage: 3V to 20V
- Low ON resistance (~125 ohms at 10V)
- Low crosstalk and low power dissipation

How It Works:

- Two independent multiplexers (X and Y)
- Each multiplexer selects 1 of 4 inputs to connect to a common terminal
- Controlled by two select lines: A and B
- One INH (Inhibit) pin disables both multiplexers when HIGH
- Can pass signals in either direction

2.7 IC 74HC595(8-bit serial-in, parallel-out shift register): The 74HC595 is a popular 8-bit serial-in, parallel-out shift register IC. It allows you to expand the number of digital output pins using just 3 pins from a microcontroller like Arduino, ESP32, Raspberry Pi, etc.



Figure 1: IC 74HC595

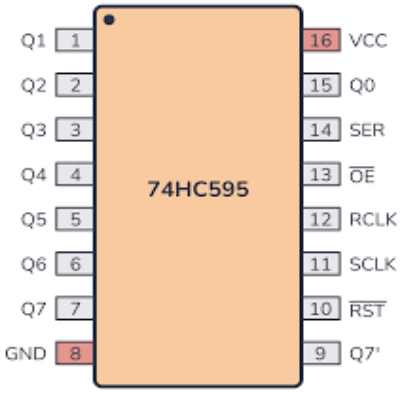


Figure 2: IC 74HC595 Pin Diagram

Key Features:

- 8-bit shift register + 8-bit storage register
- Serial input, parallel output
- 3-state outputs (can be set to high-impedance)
- Operates at 2V to 6V
- High-speed CMOS (HC = High-speed CMOS logic)
- Allows daisy chaining to connect multiple ICs for more outputs

2.8 PMOS(P-channel Metal-Oxide-Semiconductor transistor): A PMOS (P-channel Metal-Oxide-Semiconductor) transistor is a type of MOSFET(Metal-Oxide-Semiconductor Field-Effect Transistor) that uses holes (positive charge carriers) as the main current carriers. It is commonly used in analog and digital circuits,especially in CMOS (Complementary MOS) technology along with NMOS.

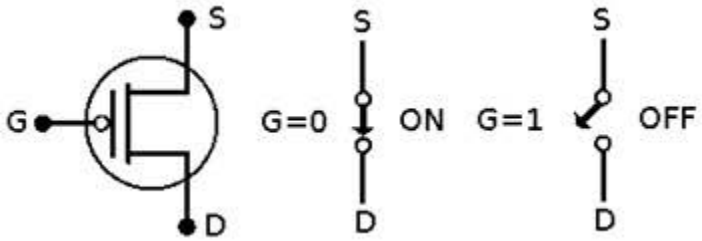


Figure 1: PMOS

Basic Structure and Terminals:

A PMOS transistor has three main terminals:

1. Source (S) – connected to a higher voltage
2. Drain (D) – connected to the output or load
3. Gate (G) – controls the current flow between source and drain
4. (Body or substrate is usually internally connected to the source)

- PMOS turns ON when the gate is LOW (lower than the source).
- PMOS turns OFF when the gate is HIGH (equal to the source).

2.9 NMOS(N-channel Metal-Oxide-Semiconductor transistor): An NMOS (N-channel Metal-Oxide-Semiconductor) transistor is a type of MOSFET that uses electrons (negative charge carriers) to conduct current. It's widely used in both analog and digital electronics, often paired with PMOS in CMOS logic.

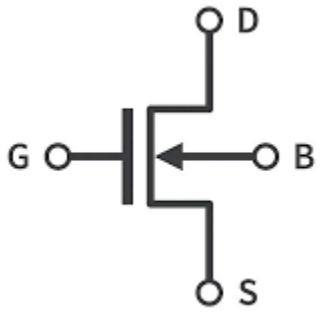


Figure 1: NMOS

Basic Structure and Terminals:

NMOS transistors have three main terminals:

1. Source (S) – typically connected to ground
2. Drain (D) – connected to the load
3. Gate (G) – controls the current flow between source and drain
4. (The body is usually connected to the source internally)
5. NMOS turns OFF when the gate is LOW

This is opposite of PMOS, which turns on with a LOW gate voltage.

NMOS Characteristics:

- Faster switching than PMOS (due to higher electron mobility)
- Lower ON resistance than PMOS
- Often used for low-side switching

2.10 LED(Light Emitting Diode): An LED (Light Emitting Diode) is a type of diode that emits light when an electric current passes through it. It is one of the most common and energy-efficient light sources used in electronics.

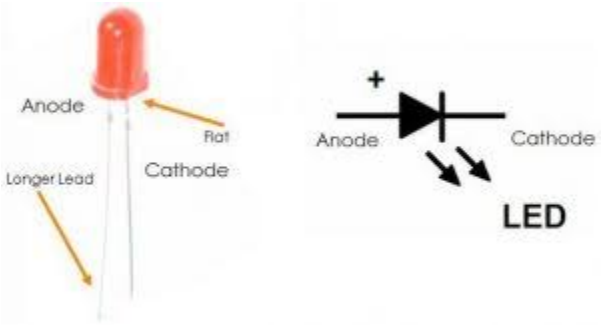


Figure 1: LED

How It Works:

- When forward biased (positive to anode, negative to cathode), electrons and holes recombine in the LED's semiconductor material.
- This recombination releases energy in the form of photons (light) — a process called electroluminescence.

Basic Characteristics:

Parameter	**Typical Value / Note**
Current Rating	Usually 5–20 mA (max around 30 mA)
Forward Voltage	~1.8V to 3.3V (depends on color)
Polarity Sensitive	Only works when connected correctly (forward bias)
Lifespan	Very long (50,000+ hours with proper use)
Power Efficiency	High (low heat, low power)

2.11 RESISTOR: A resistor is a basic electronic component used to limit or control the flow of electric current in a circuit. It is essential in almost every electronic device.

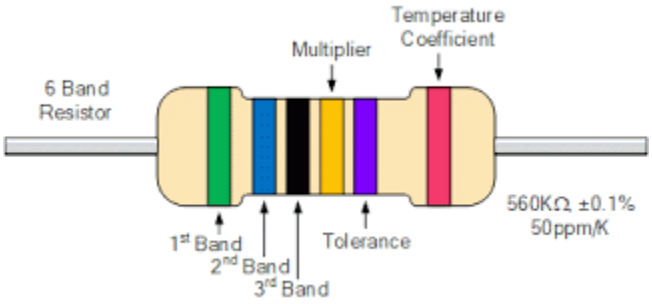


Figure 1: Resistor

Main Functions:

- Limits current (e.g., protects LEDs)
- Divides voltage (in voltage dividers)
- Pull-up/down in logic circuits
- Sets timing with capacitors (RC circuits)

Types of Resistors:

Type	Description
Fixed	Standard resistors (most common)
Variable	Adjustable (e.g., potentiometer)
SMD	Surface Mount, used in PCBs
Wirewound	For high power applications

2.12 DIODE: Diode is a two-terminal semiconductor device that allows current to flow in only one direction, blocking reverse current. It is one of the fundamental components in electronics.

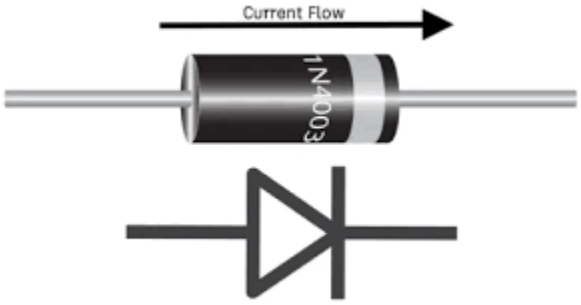


Figure 1: Diode

Basic Structure:

A diode consists of a PN junction made from two types of semiconductor materials:

- P-type (positive) semiconductor, which has an excess of holes (positive charge carriers).
- N-type (negative) semiconductor, which has an excess of electrons (negative charge carriers).

When these two materials are joined, a PN junction is formed, allowing current to flow in one direction and blocking it in the opposite direction.

Working Principle:

- Forward Bias: Current flows from the anode (positive) to the cathode (negative) when the anode is at a higher voltage than the cathode.
- Reverse Bias: The diode blocks current flow when the anode is at a lower voltage than the cathode.

Diode Characteristics:

Parameter	Description
Forward Voltage	Typically 0.7V for silicon diodes, 0.3V for germanium diodes
Reverse Breakdown Voltage	The voltage at which the diode begins to conduct in reverse
Forward Current	The maximum current the diode can conduct in the forward direction without damage
Reverse Leakage Current	Small current that flows when the diode is reverse biased, ideally zero

Types of Diodes:

1. Standard Diode: Basic diode used for rectification.
2. Zener Diode: Allows current to flow in both directions, but regulates voltage in the reverse breakdown region.
3. Light Emitting Diode (LED): Emits light when forward biased.
4. Schottky Diode: Fast switching, low forward voltage drop.
5. Photodiode: Generates current when exposed to light.
6. Varactor Diode: Used in tuning circuits (e.g., radio tuners).
7. Tunnel Diode: Has a very high-speed response, used in microwave frequencies.

2.13 COMPARATOR: A comparator is an electronic device or circuit that compares two input voltages and outputs a digital signal to indicate which input is higher.

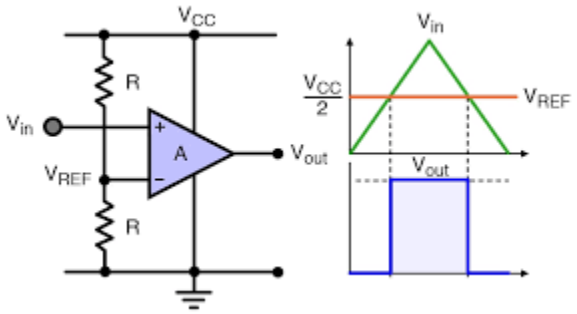


Figure 1: Comparator

Basic Function:

It has two inputs:

- Non-inverting input (+)
- Inverting input (−)

It outputs:

- High (1) if V+ > V−
- Low (0) if V+ < V−

Key Characteristics:

Parameter	Description
Open-Collector Output	Often used for flexibility with external pull-up
Fast Response	Responds quickly to input changes
No Feedback	Unlike op-amps, no negative feedback is used
Binary Output	Only two states: HIGH or LOW

Common Comparator IC's:

- LM339 – Quad comparator
- LM393 – Dual comparator
- LM311 – Single comparator with open-collector output

Applications of Comparators:

- Zero-crossing detector
- Over-voltage/under-voltage protection
- Level detection
- Analog-to-Digital Converters (ADC)
- Pulse-width modulation (PWM)
- Temperature threshold alarms

2.14 POTENTIOMETER: A potentiometer is a 3-terminal variable resistor used to adjust voltage or current in a circuit. It acts as a manual voltage divider.



Figure 1: Potentiometer

Structure:

- It consists of a resistive track and a wiper (sliding contact).
- The wiper moves along the resistive path to vary resistance between the terminals.

Terminals:

- Terminal 1 (End A)
- Terminal 2 (Wiper)
- Terminal 3 (End B)

Working:

- Connect across terminals 1 and 3 → full resistance.
- Output voltage taken between wiper (2) and one end (1 or 3) → variable voltage.

Types of Potentiometers:

Type	**Use**
Rotary	Round knob for adjusting (e.g., volume)
Slider (Linear)	Slide to adjust (e.g., audio mixers)

Chapter 3

DESIGN & METHODOLOGY

3.1 BLOCK DIAGRAM

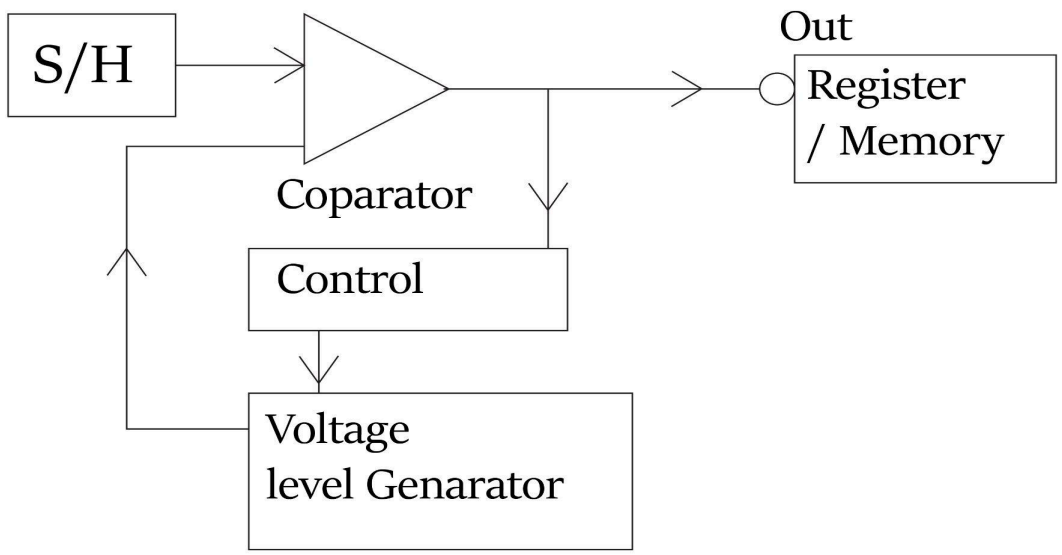


Fig: 3.1: Block diagram of SAR proposed circuit

3.2 CIRCUIT DIAGRAM

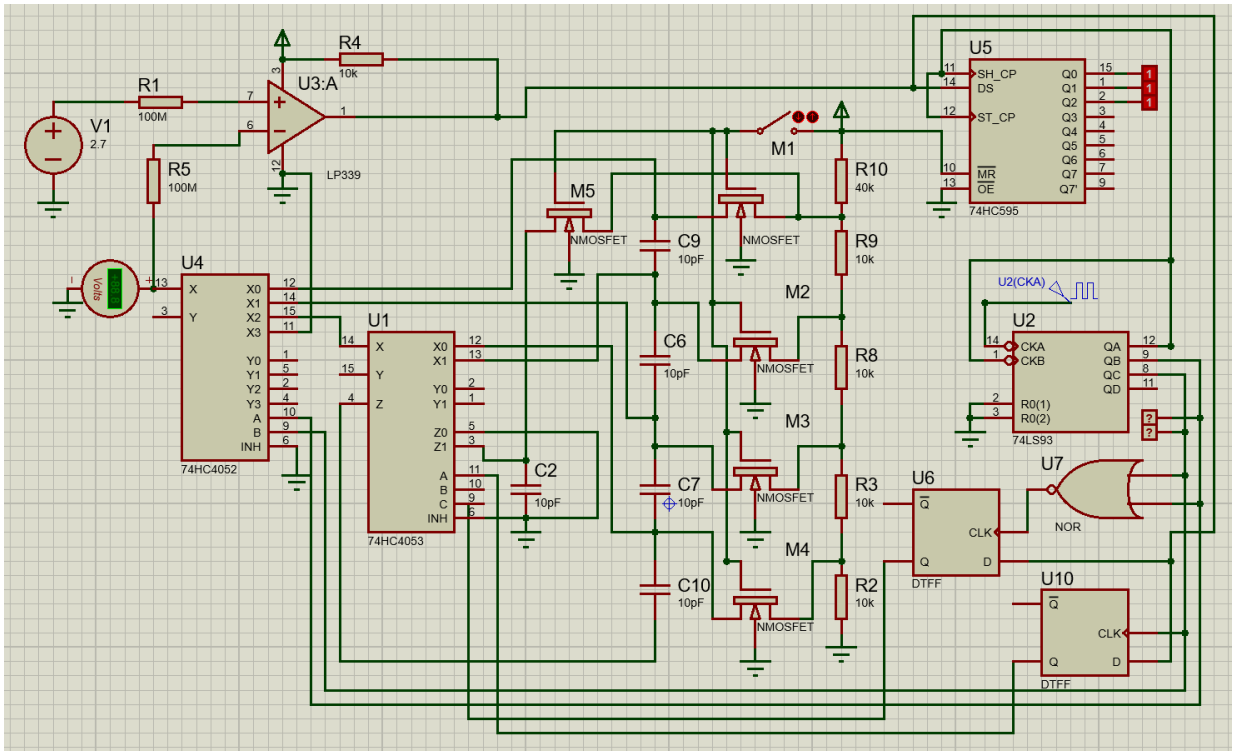


Fig 3.2: Proposed schematic circuit diagram of SAR

3.3 SAMPLE AND HOLD CIRCUIT

Working:

- Uses a switch (usually a MOSFET) and a capacitor.
- When the switch is closed (sampling mode), the capacitor charges to the input voltage.
- When the switch opens (hold mode), the capacitor retains the voltage.
- Often used in ADFunction: Captures (samples) an analog voltage at a specific moment in time and holds it constant for a period.

3.4 OP-AMP (OPERATIONAL AMPLIFIER)

Function: Amplifies the voltage difference between two input terminals.

Working:

- High input impedance and low output impedance.
- Operates in configurations like inverting, non-inverting, integrator, and differentiator.
- Often used in filtering, amplification, signal conditioning, and active analog circuits.

3.5 BUFFER CIRCUIT

Function: Isolates different stages of a circuit to prevent loading and ensures signal integrity.

Working:

- Analog buffer: Often uses an op-amp in a voltage follower configuration (gain = 1).
- Digital buffer: Strengthens digital signals and can provide logic level shifting.
- Does not alter the signal but provides high input and low output impedance.

3.6 COMPARATOR

Function: Compares two input voltages and outputs a digital signal based on which is higher.

Working:

- Uses an op-amp-like structure but without feedback.
- If V+ > V− → output is HIGH (logic 1).
- If V+ < V− → output is LOW (logic 0).
- Used in zero-crossing detectors, ADCs, and threshold detection.

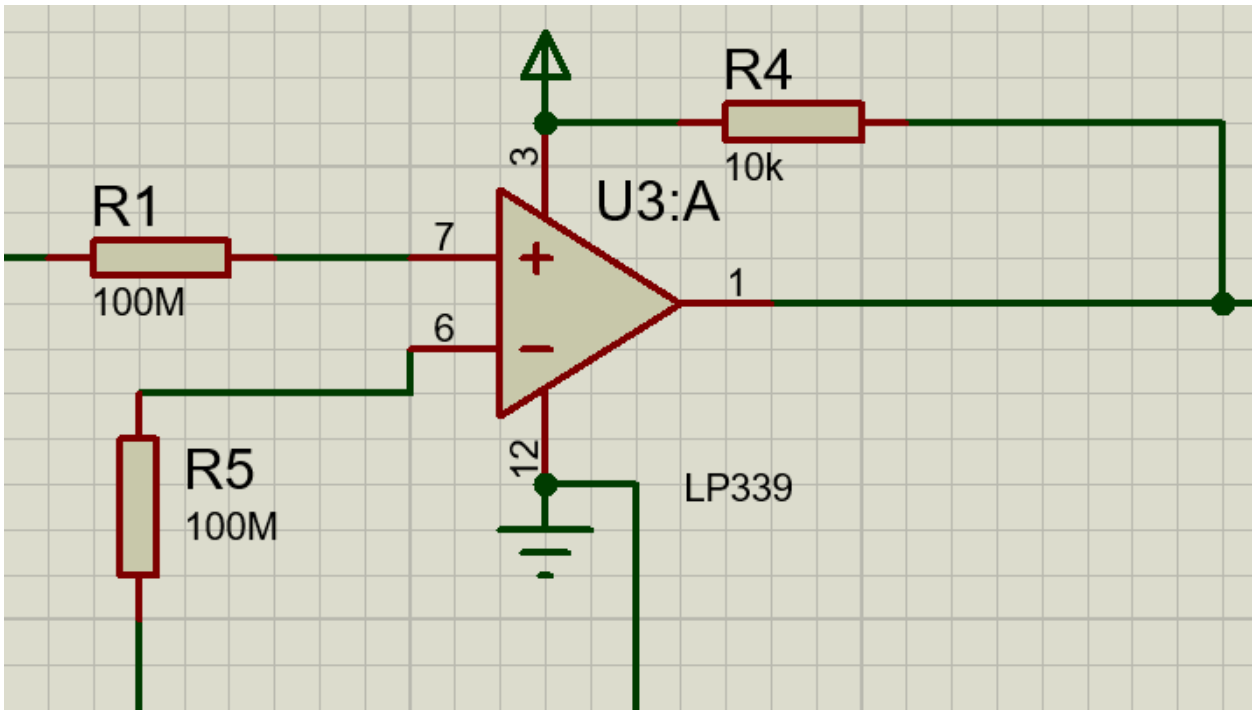


Fig 3.3: comparator

3.7 REGISTER (WITH FLIP-FLOPS)

Function: Temporarily stores binary data; essential for memory, counters, and processors.

Working:

- Made of multiple D flip-flops, each storing 1 bit.
- All flip-flops are clocked simultaneously (parallel loading).
- Data is stored on the rising or falling edge of the clock.
- Used in microprocessors, I/O data handling, etc.

3.8 ENCODER

Function: Converts one of many input signals into a binary code (opposite of decoder).

Working:

- E.g., a 4-to-2 encoder takes 4 inputs and gives a 2-bit binary output.
- Only one input should be HIGH at a time.
- Priority encoders resolve situations with multiple active inputs.
- Used in keyboard circuits, data compression, and communication systems.

3.9 CAPACITOR BANK

Function: Stores electrical energy and provides voltage stability, filtering, or power support.

Working:

- A set of capacitors connected in parallel or series.
- In parallel: increases total capacitance.
- In series: increases voltage rating.
- Common in power supplies, ADCs (for reference stability), and energy storage.

3.10 CHARGE DISTRIBUTION CIRCUIT

In an electric circuit, the distribution of charge across capacitors depends on how they are connected. When capacitors are connected in parallel, the voltage across each capacitor remains the same, and the total charge gets divided among the capacitors based on their capacitances. The larger the capacitance, the more charge it stores, following the relation Q=C×V. In this case, the total capacitance is the sum of individual capacitances. On the other hand, when capacitors are connected in series, the same charge appears on each capacitor, but the voltage across each one differs depending on its capacitance. A smaller capacitance will have a larger voltage drop. The total capacitance in series is less than any individual capacitance and is calculated using the reciprocal formula. Understanding charge distribution is important for designing circuits that either store more energy (using parallel connections) or withstand higher voltages (using series connections).

3.11 ANALOG MULTIPLEXER AND SELECTOR MODE

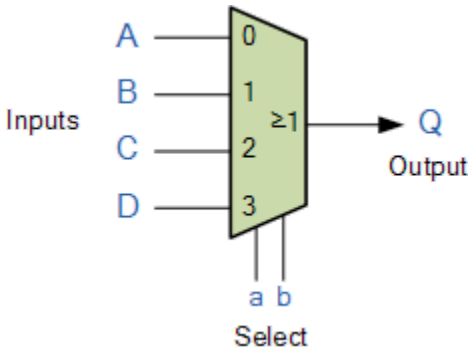


Fig 3.4: Analog Multiplexer

An analog multiplexer (MUX) is a device that can select one signal from many input signals and forward it to a single output line. It works like an electronic switch that chooses one input at a time, based on control signals. In selector mode, the multiplexer uses select lines (binary control inputs) to determine which one of the multiple inputs is

connected to the output. For example, in a 4-to-1 analog multiplexer, two select lines are used to choose among four inputs. Unlike digital multiplexers that handle only '0' and '1', an analog multiplexer can pass a full range of analog voltage or current values. Analog multiplexers are widely used in data acquisition systems, sensor signal routing, and communication devices where multiple signals need to be managed efficiently.

3.12 DIGITAL CONTROL CIRCUIT

A digital control circuit is an electronic system that uses digital signals (0s and 1s) to control the operation of devices or processes. Instead of handling continuous signals like in analog circuits, digital control circuits process information in discrete steps. These circuits are built using logic gates, flip-flops, microcontrollers, or digital ICs. They take digital inputs (such as switches, sensors, or coded signals), process them based on programmed logic, and generate digital outputs to control things like motors, lights, displays, or other machines. Digital control circuits are more accurate, reliable, and easier to design compared to analog control systems, and they are widely used in computers, automation, robotics, and communication systems.

Chapter 4

RESULTS & DISCUSSION

4.1 RESULTS

This circuit performs well in simulation but in hardware simulation there was some inaccuracy showing. We sampled by microcontroller with 1kHz frequency and tested both simulation and hardware tests, in hardware tests some inaccuracies are visible. We noticed that the physical device is giving 40% accuracy. The common problem with our proposed methodology is faulty capacitors and reliable switching. All the results are manually checked. Manually checked because microcontrollers have some input lag.

4.2 CLOCK SEQUENCE

Clock	Comparing Voltage	Binary
00	2.5	MSB
10	1.25, 3.75	2nd bit
01	0.62, 1.875, 3.125, 4.375	LSB
11	0	RESET

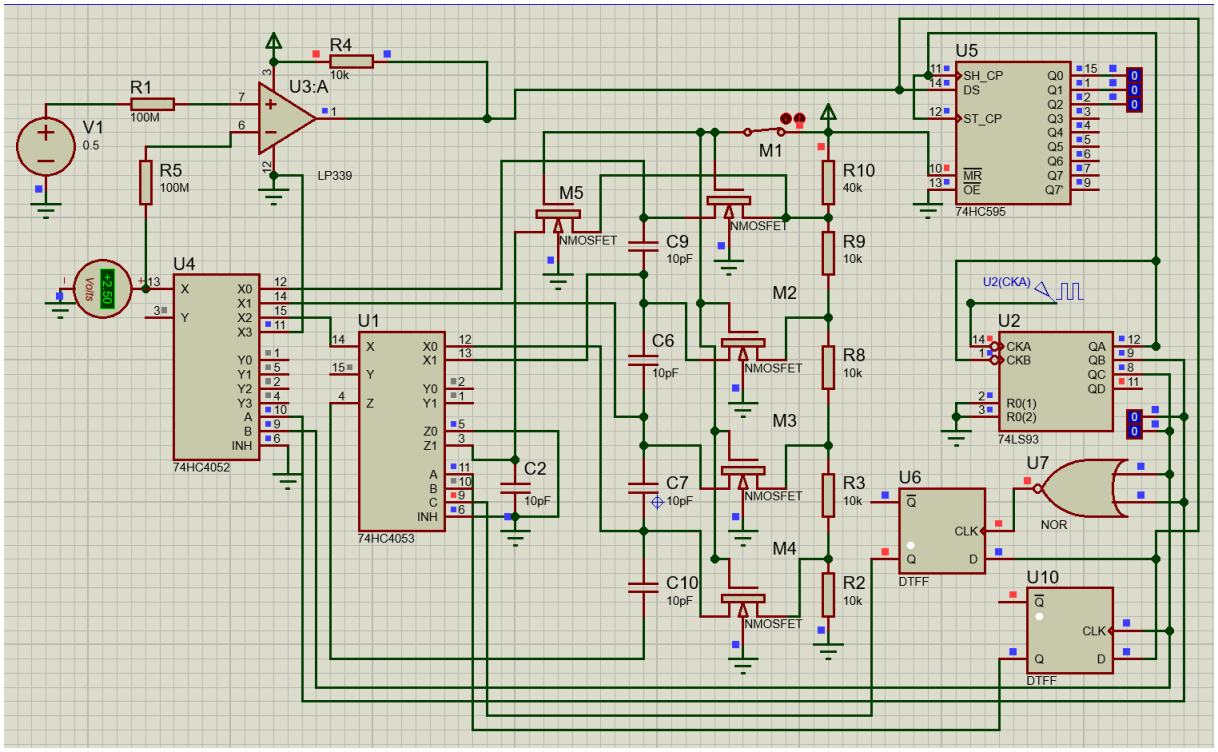


Figure 4.1: Sample at 0.5v

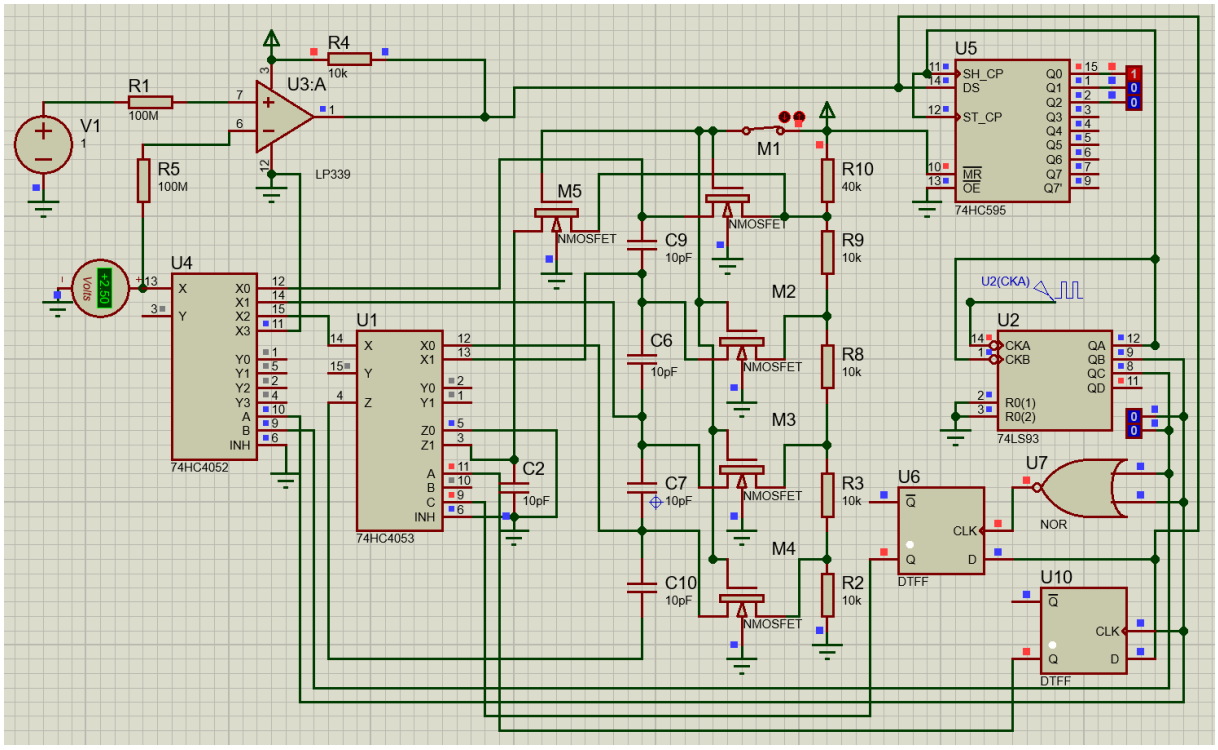


Figure 4.2: Sample at 1v

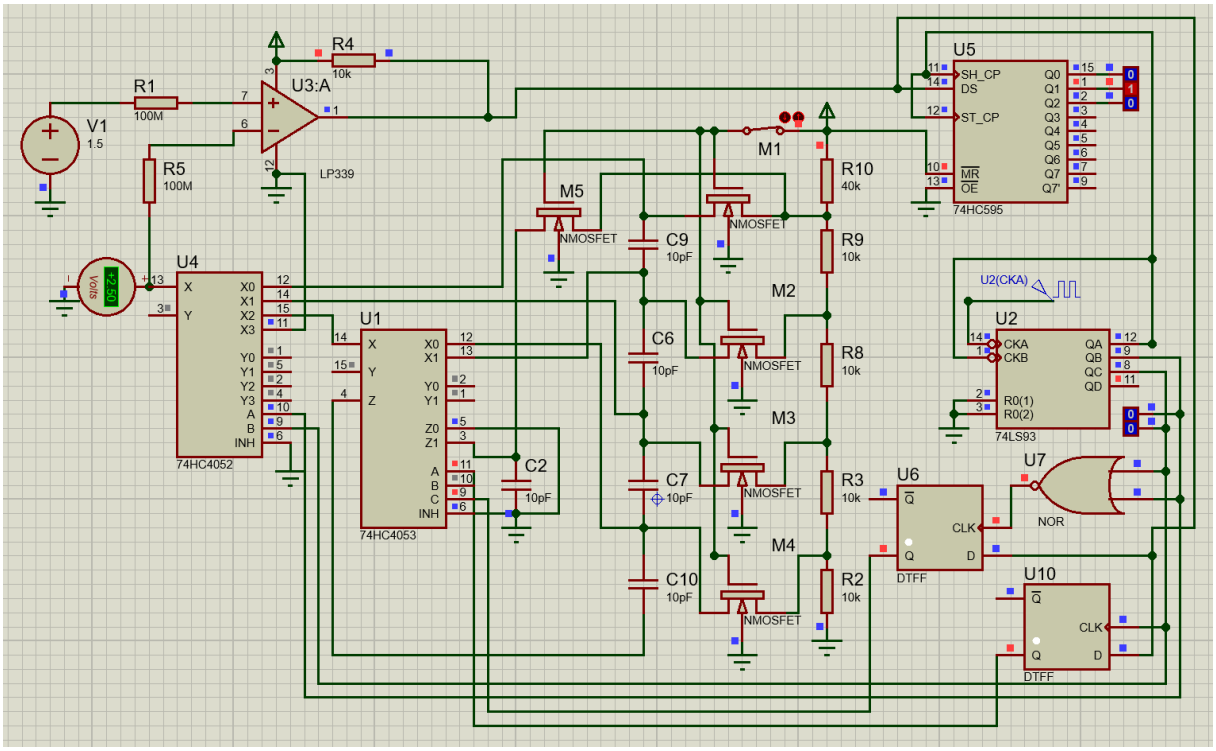


Figure 4.3: Sample at 1.5v

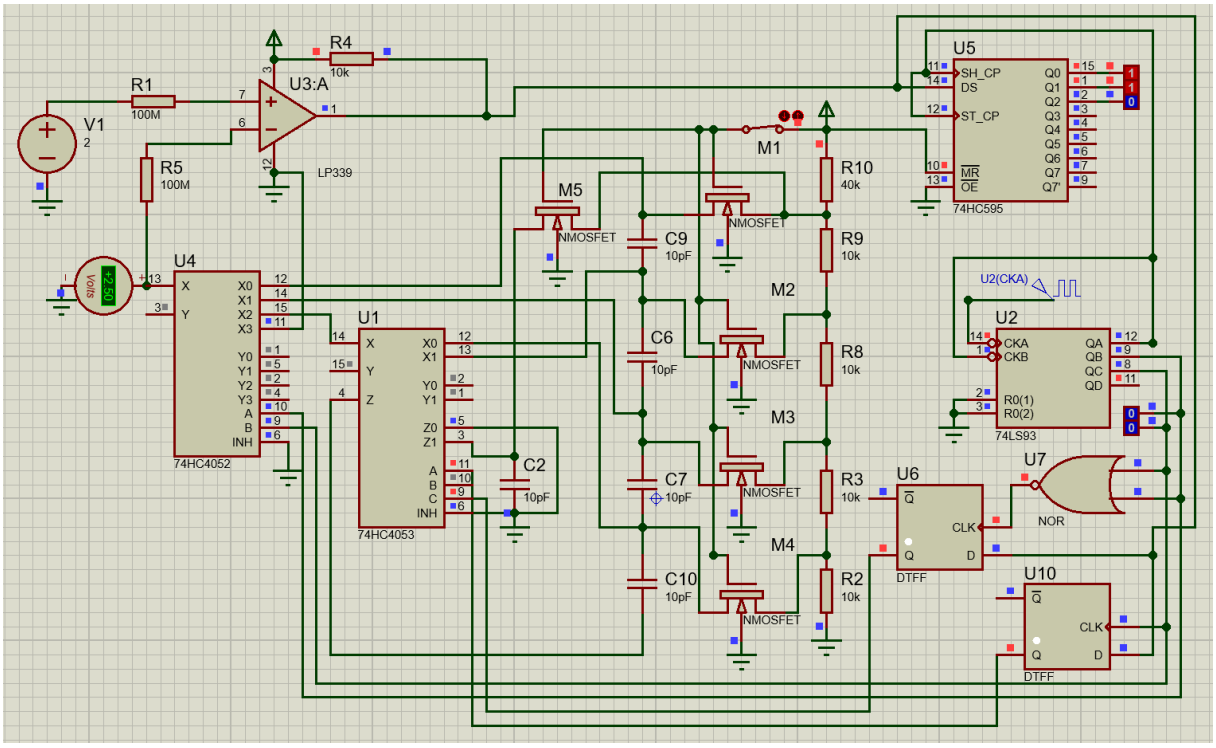


Figure 4.4: Sample at 2v

4.3 OUTPUT TABLE

Input voltage	Output binary
0.5	000
1	001
1.5	010
2	011
2.7	100
3	100
3.5	101
4	110
4.5	111
5	111

4.4 RESULTS ANALYSIS

The results are generated based on a 3 bit ADC circuit. The results were very hard to acquire as all the capacitor charges discharged very quickly. At a high speed clock the results can be collected. Plotting the overall results will not be viable for any analysis because of the poor resolution at high speed and rapid changes in transient behavior. Although there are alternative options for better simulation results.

The designed pullup capacitor is meant to pull the array voltage by *Vref/2* but the capacitor shows different unexpected behavior in the practical experiment. In ideal conditions and ideal capacitors the equation shows it is possible. However physical limitations are not negligible. To compensate for this problem, another design can be implemented where a resistor array with the capacitor array can support this overall

system and generate output at a reliable rate. Replacing the capacitors with resistors is an obvious choice for now. However, better quality switching can make this proposed circuit a more reliable and power efficient option.

4.5 DISCUSSION

The proposed method focuses on component reduction and compactness for simplicity. The proposed method can replace DAC completely and require no additional complex circuit for the register. Though in this demonstration a register is used to collect sequential data but if used with a microcontroller the data can be collected serially. In that case no additional register is required in the proposed ADC.

The capacitor array shows lower power consumption as it is not necessary to recharge them after every sample. Though parasitic capacitance is in play, it reduces the voltage over time. Thus, charging the capacitors after a certain iteration is a must in this proposed method.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

A Successive Approximation Register (SAR) ADC with a Capacitor Charge Distribution Selector offers an efficient and accurate method for analog-to-digital conversion.

The SAR ADC using a Capacitor Charge Distribution Selector improves the conversion process by leveraging binary-weighted capacitors and precise charge redistribution. This architecture provides:

- Low Power Consumption — no need for continuous power like in flash ADCs
- Moderate to High Speed — ideal for medium-speed applications (e.g., sensor data)
- Compact Design — suitable for integration into SoCs and battery-operated devices

The use of the charge redistribution method reduces the number of required analog components (like op-amps), making the system more energy-efficient and cost-effective, while maintaining good resolution (commonly 8–12 bits or more).

5.2 FUTURE SCOPE

1. Error Correction Techniques: Implementing digital calibration or background calibration methods to automatically correct errors caused by parasitic capacitance and faulty capacitors, improving overall accuracy.

2. Parasitic Capacitance Compensation: Designing advanced switching techniques or compensation circuits to minimize the impact of parasitic effects and improve voltage retention over longer periods.

3. Dynamic Recharging Strategy: Developing an intelligent control system that monitors capacitor charge levels and selectively recharges only when necessary, further reducing power consumption.

4. Integration with Microcontrollers: Fully integrating the ADC design with a microcontroller platform to eliminate the need for external registers, achieving a more compact and low-power solution.

5. Scaling to Higher Resolution: Extending the design to support higher bit resolutions (e.g., 12-bit, 14-bit SAR ADCs) to meet the needs of more precision-demanding applications such as sensors and communication systems.

6. Low-Voltage Operation: Optimizing the design for ultra-low voltage operation, making it suitable for battery-powered and IoT devices where energy efficiency is critical."

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