SWITCHED CAPACITORS

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Contents

1 Abstract:

Switched capacitor circuits are integral to modern analog and mixed-signal integrated circuits, offering high efficiency in applications such as filtering, analog-to-digital conversion, and signal processing. This report explores the design and implementation of switched capacitor circuits using MOSFETs as switches, providing a comprehensive analysis. The study begins with an introduction to the fundamental principles of switched capacitor circuits, followed by a detailed discussion of their applications, design requirements, and state-of-the-art advancements. The report outlines the software implementation using LTspice And Cadence for simulation, highlighting the transient analysis and waveform generation to understand the circuit's behavior.

2 Introduction:

Switched capacitor circuits are an essential part of modern electronics, especially in ana- log and mixed-signal systems. These circuits use capacitors and switches to perform important tasks such as filtering signals, converting analog signals to digital, and pro- casing data. The key idea is to move charge between capacitors by turning switches on and off, which allows these circuits to handle signals with high precision and efficiency. MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) are often used as the switches in these circuits. MOSFETs can control the flow of current in both directions and switch very quickly. By turning a MOSFET on or off, we can control how charge moves through the circuit, which allows us to process signals accurately without using too much power. The design and implementation of switched capacitor circuits involve several critical considerations, including voltage levels, switching speed, capacitor size, and power consumption. These factors must be carefully balanced to ensure optimal performance and efficiency. Additionally, the integration of these circuits into larger systems requires a thorough understanding of both theoretical principles and practical constraints.

3 Applications:

Switched capacitor circuits are widely used in various fields of electronics.

- Analog Filters: Switched capacitor circuits are used to create analog filters that can process signals by allowing certain frequencies to pass while blocking others.They offer precise control over filter characteristics and can be easily adjusted by changing the switching frequency. Used in audio processing, communication systems, and instrumentation.

- Analog-to-Digital Converters (ADCs): These circuits are integral in ADCs, which convert analog signals into digital data. They provide high accuracy and can be integrated into compact designs. Typically found in data acquisition systems, digital signal processing, and consumer electronics such as smartphones and cameras.

- Signal Processing: These circuits are used for various signal processing tasks such as amplification, modulation, and demodulation. They offer high precision and can handle complex signal manipulations efficiently. They are used in telecommunicator, radar systems, and medical imaging.

- Sensor Interfaces: Switched capacitor circuits interface with sensors to process and condition the sensor signals. They provide accurate signal conditioning and can be tailored to specific sensor requirements. Used in environmental monitoring, indus- trial automation, and wearable devices.

- Clock Generation and Timing: Switched capacitor circuits are used to generate pre- cise clock signals and manage timing in electronic systems. They provide stable and accurate timing signals that are essential for synchronous operations. Used in mi- coprocessors, communication systems, and digital clocks.

4 State of the Art:

state-of-the-art in Switched-Capacitor (SC) circuits

Category	Key Advancements	Performance Metrics	Applications	Challenges
Energy Efficiency & Power Delivery	Reconfigurable SC DC-DC converters, resonant SC (soft-charging), hybrid inductor-capacitor converters	>90% efficiency, dynamic load handling	Multi-core CPUs, AI accelerators, IoT devices	Switch losses at advanced nodes (<7nm)
High-Speed Data Converters (ADCs/DACs)	Noise-shaping SAR ADCs, time-interleaved SC pipelines, hybrid charge-redistribution DACs	>100dB SNDR, >1GS/s sampling rates	5G/wireless, radar, high-speed sensors	Capacitor mismatch, clock jitter
Advanced CMOS Compatibility	FinFET/3nm SC designs, deep trench capacitors, FD-SOI switch optimization	Capacitance density >10fF/μm², leakage mitigation	FinFET/3nm analog-mixed-signal ICs	Reduced voltage headroom, parasitics
Machine Learning & In-Memory Computing	SC-based analog MAC units, time-domain weight encoding, charge-domain processing	40TOPS/W (energy efficiency)	Edge AI, neural network accelerators	Non-idealities in analog compute
Emerging Applications	Cryogenic SC circuits (quantum control), SC-based energy harvesters (piezo/RF)	4K operation, μW-power management	Quantum computing, self-powered IoT	Cryogenic modeling, low-noise design
Future Directions	3D-integrated SC power delivery, AI-optimized capacitor sizing, cryogenic interfaces	Higher integration density, automated optimization	Next-gen computing, quantum systems	Thermal management, yield in 3D ICs

Table 1: State of the Art in Switched Capacitor Circuits

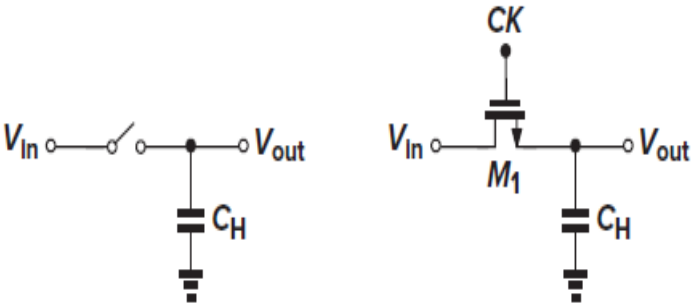
5 Design Requirements:

design requirements for a switched capacitor circuit:

- NMOS Transistor: A circuit consists of a switch and a capacitor A MOS transistor can serve as a switch.
- Capacitor: The capacitor (C1) must be appropriately sized to store and transfer the required charge. The capacitor value should be chosen based on the desired time constant and charge transfer efficiency.
- Voltage Levels Input Voltage (Vin): The circuit must handle input voltages as defined by the pulse signals (e.g., 0V to 1.8V). Clock Voltage (V1): The clock signal must operate within the specified voltage range (e.g., 0V to 1.8V). Output Voltage (Vout): The output must stabilize to the desired voltage level after charge transfer.

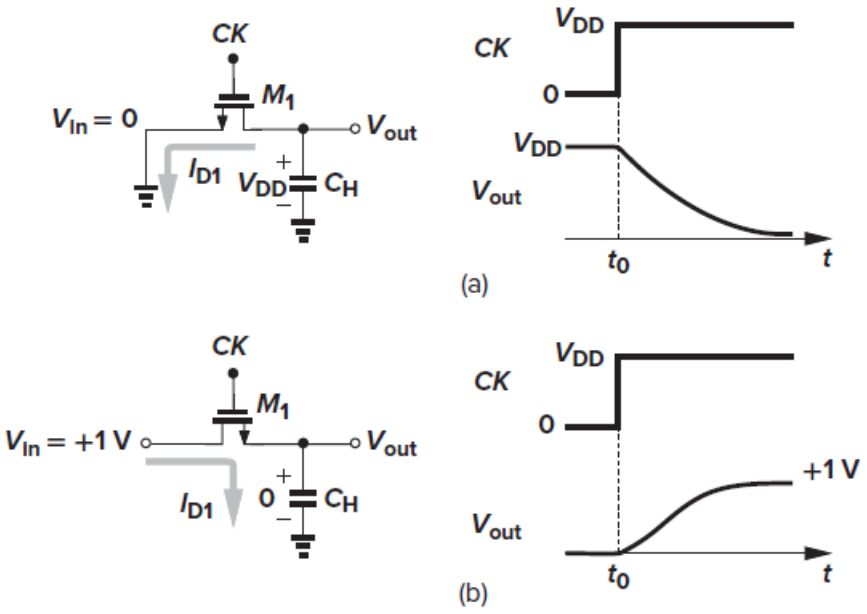
6 Working Principle:

- A switched capacitor circuit consists of capacitors and switches (usually MOS- FETs). Switches are controlled by a clock signal, which alternates between the ON and OFF states. When the switch is ON, the charge is transferred between capaci- tors or from the input to the capacitor. When the switch is OFF, the charge is stored in the capacitor, and the output voltage is kept constant.



- MOSFET as a Switch:

  Conduct current in both directions (bidirectional). Switch ON and OFF quickly with minimal power loss. Operate at low voltages, making them suitable for CMOS technology. When the MOSFET is ON, it acts as a low-resistance path for charge transfer. When the MOSFET is OFF, it isolates the capacitor, preventing charge leakage.



- Advantages of Switched Capacitor Circuits:

1. Compact Size

- Switched capacitor circuits can be implemented using small capacitors and switches, making them highly area-efficient compared to traditional resistor-based circuits. This is especially beneficial in integrated circuits (ICs) where space is limited.

2.Low Power Consumption

- Switched capacitor circuits often consume less power compared to traditional analog circuits, especially in low-frequency applications. This is because they rely on charge transfer rather than continuous current flow.

3. Compatibility with CMOS Technology

- Switched capacitor circuits are well-suited for implementation in CMOS (Complementary Metal-Oxide-Semiconductor) technology, which is the dominant technology for ICs. They leverage the strengths of CMOS, such as low power and high integration density.

4. Noise and Interference Rejection

- Switched capacitor circuits can be designed to reject certain types of noise and interference, such as DC offsets and low-frequency noise, by using techniques like correlated double sampling (CDS).

7 Software Implementations:

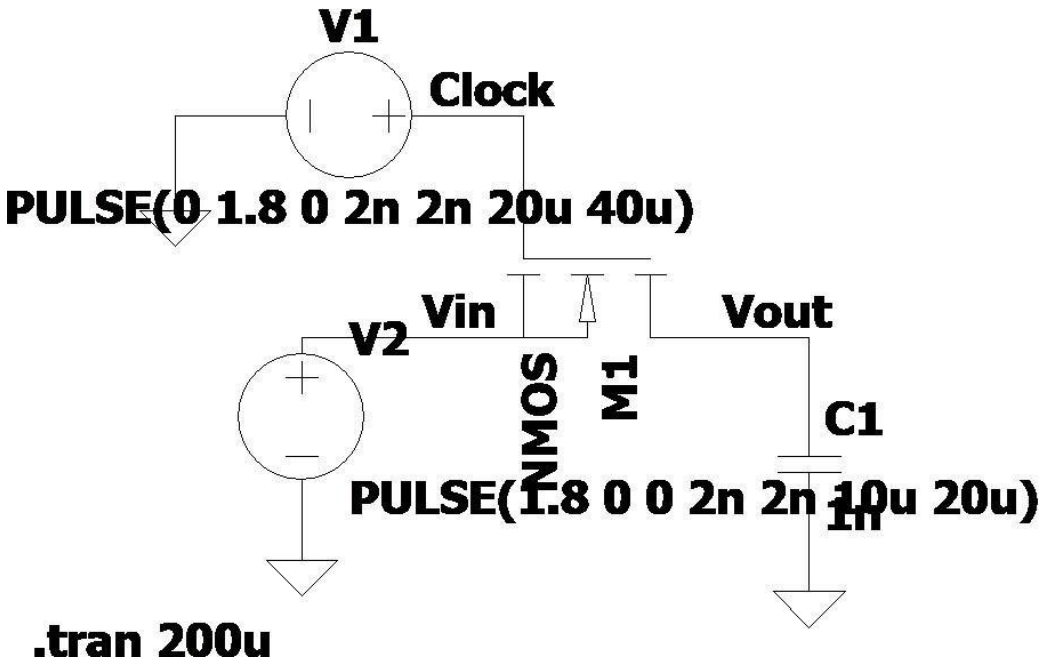


Figure 1: LTSpice implementation

8 Transient analysis:

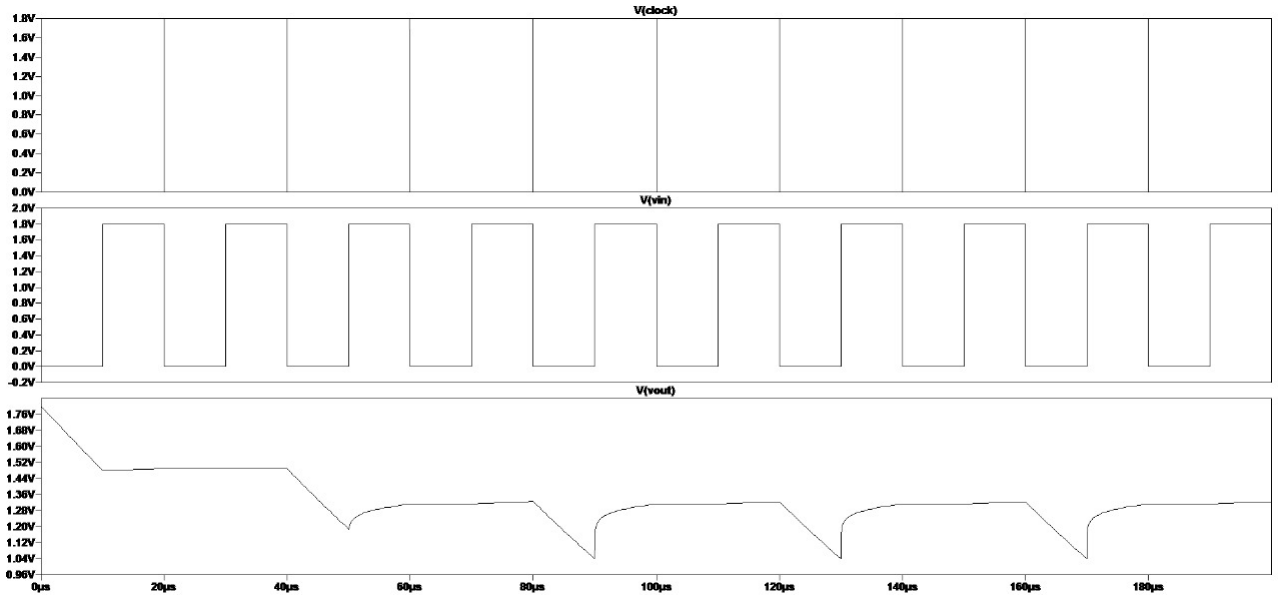


image Figure 2: Transient analysis

9 Transient analysis in mm:

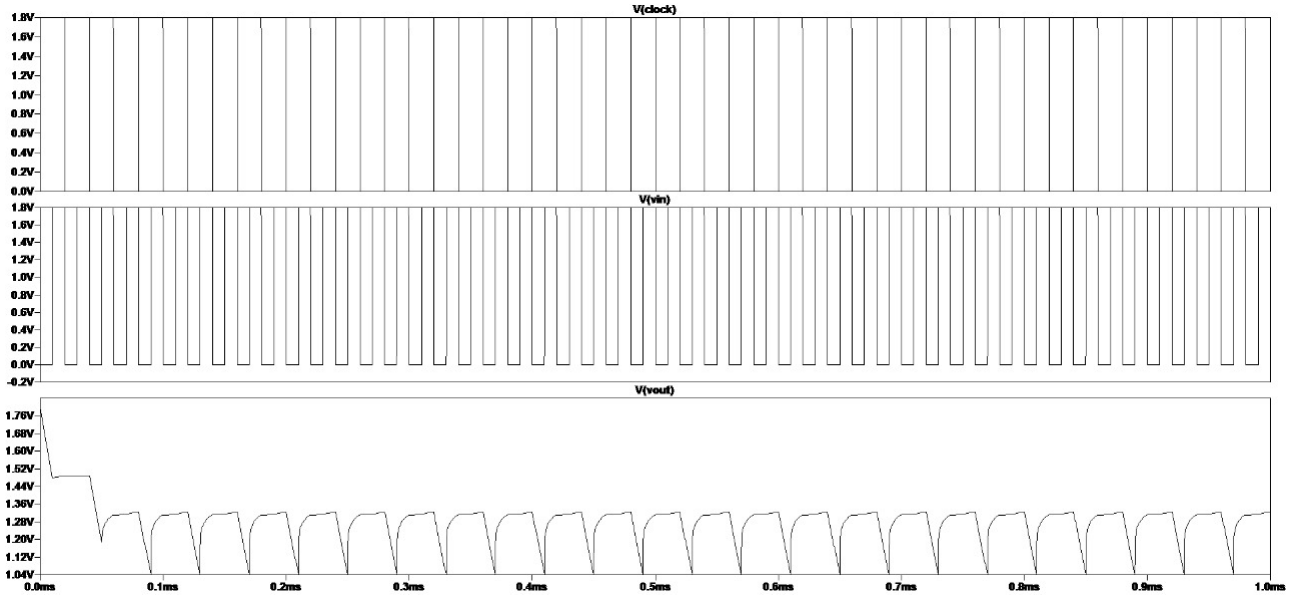


image Figure 3: Transient analysis

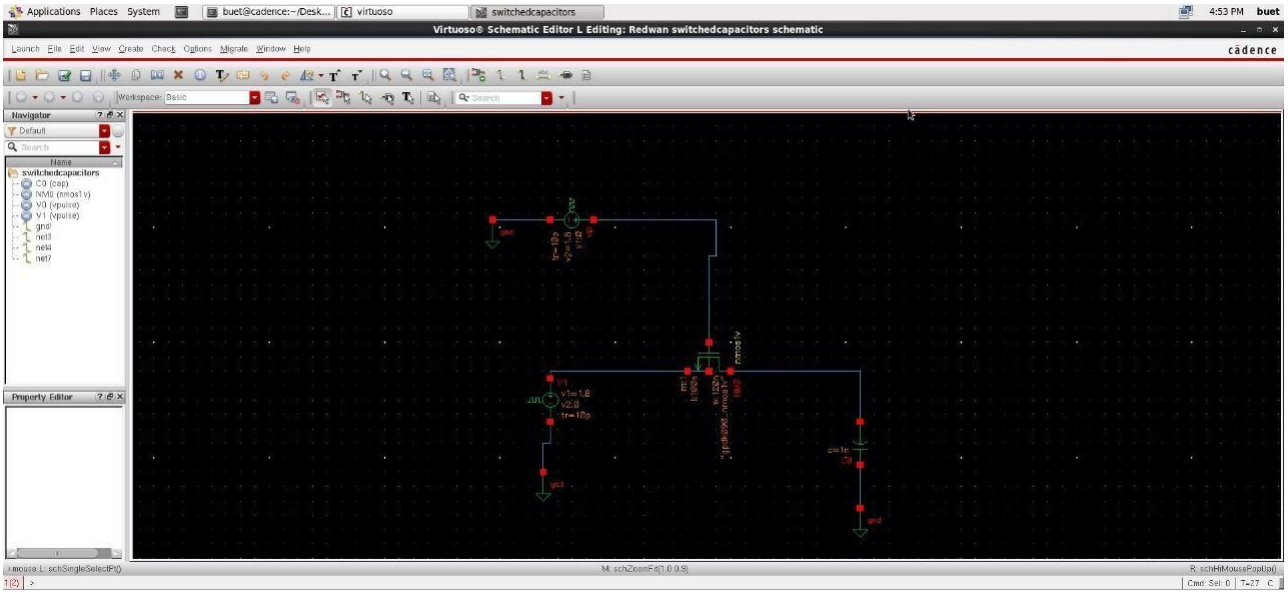


Figure 4: Cadence implementation

Figure 5: Analysis

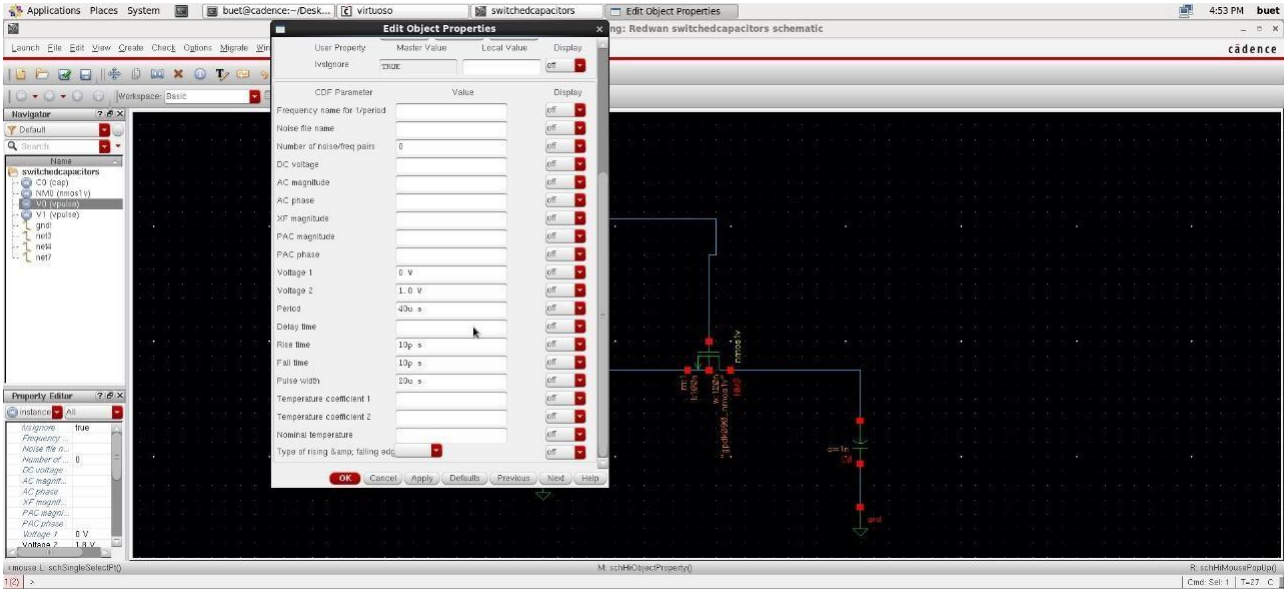


Figure 6: Parameters

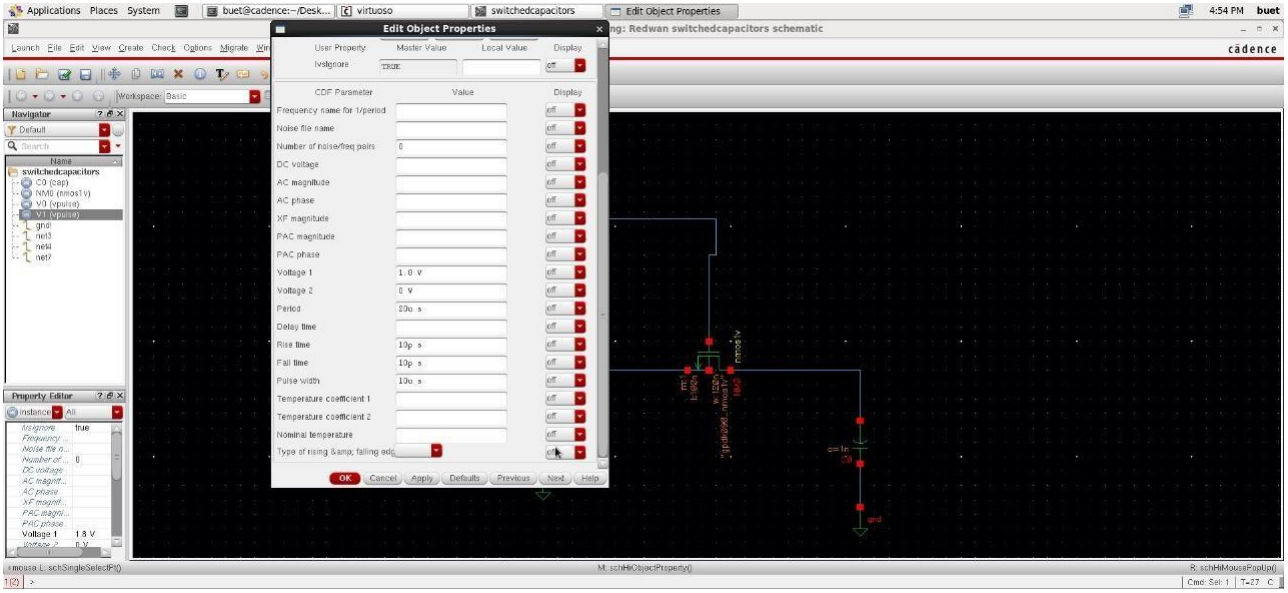


Figure 7: Parameters

10 Video Link:

Drive link:

https://drive.google.com/drive/folders/1UzLnC99QXw6OhV0RgfAP9bZKQFa8e_gZ?usp=drive_link

11 Conclusion:

Switched capacitor circuits offer high precision in charge transfer, making them suitable for applications requiring accurate signal processing. They are highly efficient, with low power consumption, which is critical for portable and battery-operated devices. These circuits can be integrated into compact designs, making them ideal for use in integrated circuits (ICs) and System-on-Chip (SoC) designs. Switched capacitor circuits are used in various applications, including audio processing, telecommunications, sensor interfaces, and power management. They can be adapted to different tasks, such as adaptive filtering and reconfigurable signal processing.

Their scalability allows them to be used in a wide range of applications, from simple filters to complex data converters.

12 References

- Design of Analog CMOS Integrated Circuits by Behzad Razavi.