Research Migration Project

A PROJECT REPORT ON

Design and implementation of 4-bit binary weighted current steering DAC

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ABSTRACT

This project focuses on the design and simulation of a 4-bit current steering Digital-to-Analog Converter (DAC) using eSim. The proposed circuit converts digital input signals into corresponding analog current outputs by employing MOSFET-based current sources and switching networks. Binary input signals are applied using pulse voltage sources, and the resulting analog output is observed across a load resistor. The simulation is carried out using Ngspice, and the output waveform verifies the correct functioning of the DAC. The results demonstrate that the output current varies proportionally with the digital input, confirming accurate digital-to-analog conversion. This design highlights the advantages of current steering DACs in terms of speed and efficiency, making them suitable for high-speed applications.

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1. INTRODUCTION

In modern electronic systems, the interaction between digital and analog domains is essential for efficient signal processing and communication. While most processing units operate using digital signals, real-world signals such as sound, temperature, and light are inherently analog in nature. This necessitates the use of Digital-to-Analog Converters (DACs), which play a crucial role in converting discrete digital data into continuous analog signals.

Among various DAC architectures, the current steering DAC is widely preferred for high-speed and high-performance applications due to its simplicity, accuracy, and fast switching capability. It operates by steering binary-weighted currents through a network of switches, typically implemented using MOSFETs, to generate the desired analog output.

In this project, a 4-bit current steering DAC is designed and simulated using eSim, an open-source electronic design automation tool that integrates schematic capture with Ngspice simulation. The circuit employs MOSFET-based current sources and pulse voltage inputs to represent digital signals. The performance of the DAC is analysed through transient simulation, and the output waveform is studied to verify correct digital-to-analog conversion.

This project provides a practical understanding of DAC design principles, CMOS switching behaviour, and simulation techniques, making it relevant for applications in communication systems, signal processing, and embedded electronics.

2. OBJECTIVE

The main objective of this project is to design and simulate a 4-bit current steering Digital-to-Analog Converter (DAC) using eSim. The project aims to convert digital input signals into corresponding analog outputs using MOSFET-based current sources and switching techniques. It also focuses on analysing the output waveform through simulation and verifying the proper functioning of the DAC. Additionally, the project helps in understanding the principles of DAC operation, CMOS circuit design, and the use of simulation tools like eSim and Ngspice.

3. THEORY

3.1 Digital to Analog Converter (DAC)

A Digital-to-Analog Converter (DAC) is an electronic device that converts discrete digital signals into continuous analog signals. In most real-world applications, signals such as audio, temperature, and pressure exist in analog form, whereas processing systems like microcontrollers and processors operate in digital form. Therefore, DACs act as an essential interface between digital systems and the analog world.

A DAC takes a binary input (for example, a 4-bit digital signal) and produces a proportional analog output in the form of voltage or current. The resolution of a DAC depends on the number of bits used; higher resolution results in more precise output levels. DACs are widely used in applications such as audio systems, communication systems, instrumentation, and control systems.

3.2 Current Steering DAC

A Current Steering DAC is a type of DAC that generates an analog output by steering currents through different branches of a circuit. Instead of using resistors, it employs current sources and switches (usually MOSFETs) to control the flow of current based on digital input signals.

In this architecture:

- Each bit controls a switch
- Binary-weighted current sources are used
- The output is obtained by summing selected currents

Current steering DACs are preferred in high-speed applications because:

- They have fast switching capability
- They offer better performance at high frequencies
- They reduce delay compared to resistor-based DACs

Due to these advantages, current steering DACs are commonly used in communication systems, video processing, and high-speed data converters.

3.3 Working Principle

The working principle of a current steering DAC is based on controlling current flow using digital inputs. Each bit of the digital input corresponds to a switch that either allows or blocks a specific amount of current.

- When a bit is **1**, the corresponding switch turns ON, allowing current to flow
- When a bit is **0**, the switch remains OFF, blocking the current

The currents are weighted in binary form (for example: I, 2I, 4I, 8I for a 4-bit DAC). These currents are combined to produce the final output.

The total output current is proportional to the digital input and can be expressed as:

$$I_{out} = I(b_0 + 2b_1 + 4b_2 + 8b_3)$$

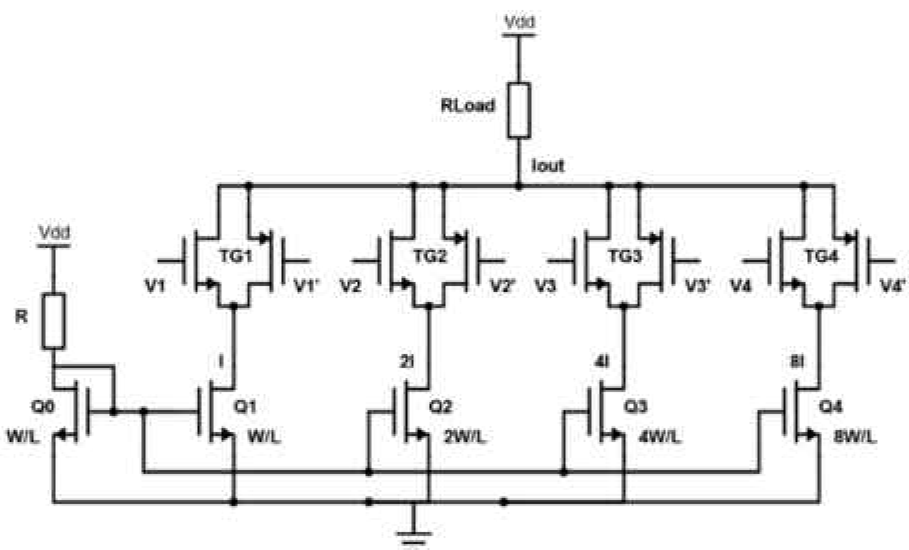
where:

- b_0, b_1, b_2, b_3 are binary inputs (0 or 1)
- I is the unit current

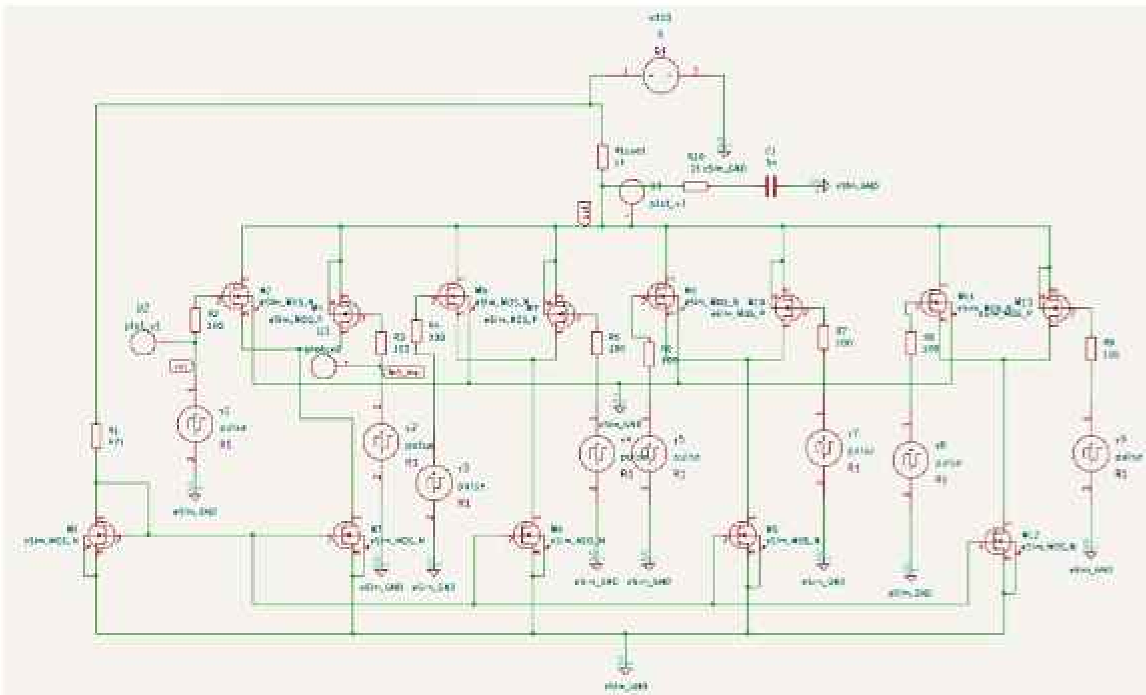
4. COMPONENTS USED

- MOSFETs (NMOS and PMOS)
- DC Voltage Source (VDD)
- Pulse Voltage Sources (Digital Inputs)
- Resistors (Load Resistor)
- Capacitor (for filtering, if used)
- Measurement Probes / Node Labels
- eSim Software
- Ngspice Simulator

5. CIRCUIT DIAGRAM



Schematic Diagram



6. DESIGN EXPLANATION

The 4-bit current steering DAC is designed using MOSFETs as switching elements and binary-weighted current sources. Each bit of the digital input controls a MOSFET switch, which determines whether a specific current branch is active or inactive. When the input is high (logic 1), the corresponding MOSFET turns ON and allows current to flow, while for logic 0, the MOSFET remains OFF and blocks the current.

The circuit consists of four branches with currents weighted in the ratio I, 2I, 4I, and 8I, corresponding to each bit of the input. These currents are directed towards a common output node where they are summed together to form the total output current. A load resistor is connected at the output to convert this current into a proportional voltage.

Pulse voltage sources are used to simulate digital input signals, enabling the observation of different input combinations. As the input changes, the output current varies in discrete steps, producing a staircase waveform. This behaviour confirms the correct operation of the DAC and its ability to convert digital signals into analog form.

7. SIMULATION SETUP

7.1 eSim Environment

The simulation of the 4-bit current steering DAC is carried out using eSim, which integrates KiCad for schematic design and Ngspice for circuit simulation. After designing the circuit, the netlist is generated and converted into Ngspice format for analysis.

A transient analysis is performed to observe the time-varying behaviour of the circuit. Pulse voltage sources are used as digital inputs, each configured with appropriate time delay, pulse width, and period to represent different binary combinations.

The power supply (VDD) is set to a constant DC voltage to properly bias the MOSFETs. A load resistor is connected at the output node to convert the output current into voltage for easier observation.

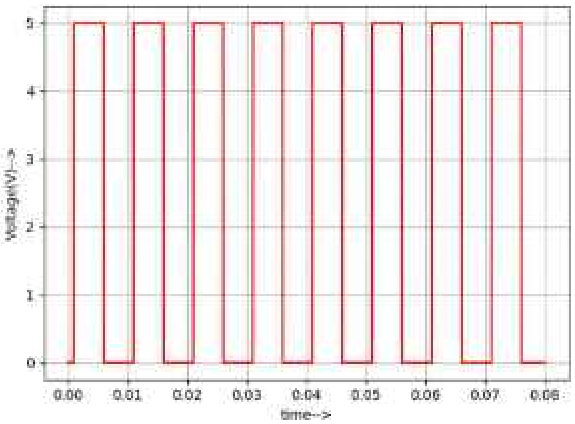
7.2 Simulation Parameters

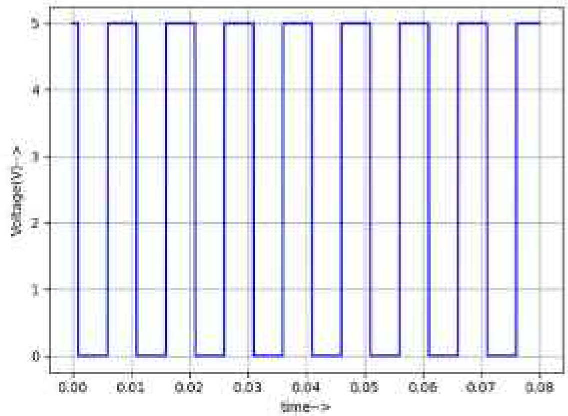
The simulation command used is:

- **Analysis Type:** Transient Analysis
- **Simulation Command:** .tran 0.01m 80m
- **Time Step:** 0.1ms
- **Total Simulation Time:** 80ms
- **Power Supply (VDD):** 5V DC
- **Input Signals:** Pulse voltage sources (representing digital inputs)
- **Pulse Parameters:**
    - Initial Value: 0V
    - Peak Value: 5V
    - Pulse Width: Varies for each bit
    - Time Delay: Different for each input to generate combinations
    - Period: Set appropriately for repeating signals
- **Load Resistance:** Typically 1kΩ (or as per design)
- **Output Measurement:**
    - Voltage across load resistor OR
    - Current through load

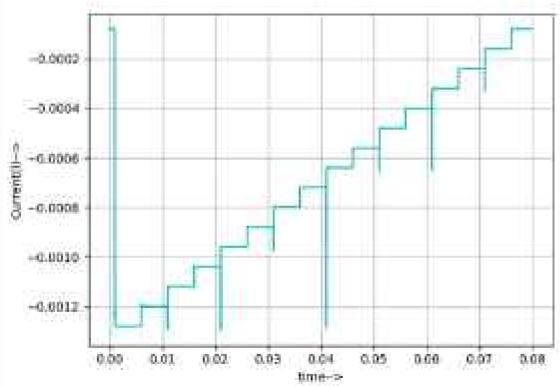
8. RESULT & ANALYSIS

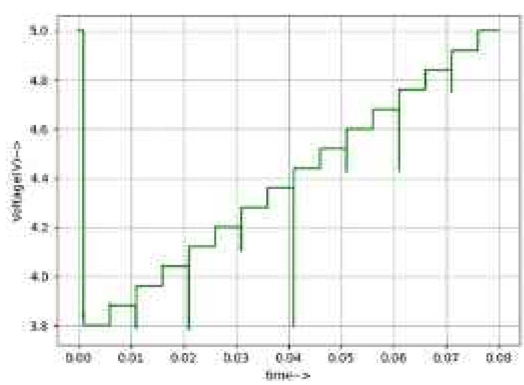
8.1 Input and Output waveforms

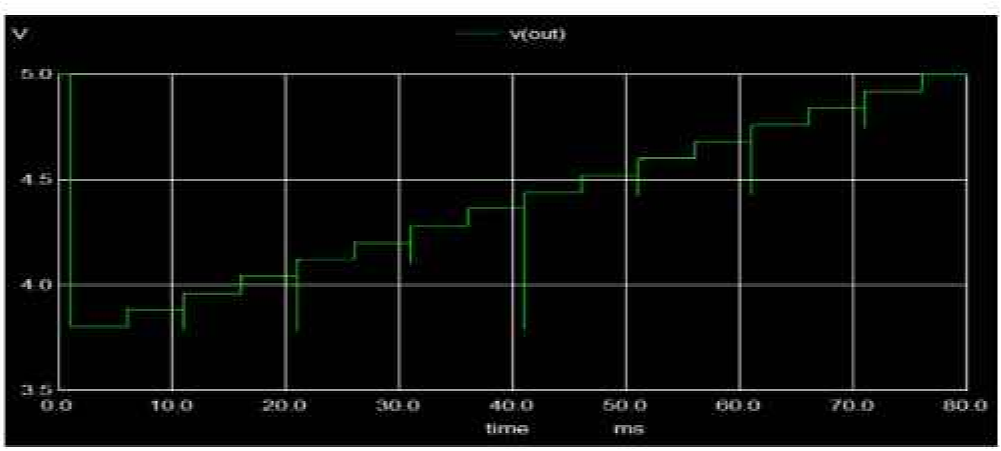




Note: Similar pulse waveforms are applied for V2–V2′, V3–V3′, and V4–V4′, with their periods scaled accordingly (each having twice the period of the previous signal) to ensure proper binary-weighted switching.







9. OBSERVATIONS

- The output waveform exhibits a **staircase (step-like) pattern**, confirming digital-to-analog conversion.
- As the digital input increases, the **output current/voltage increases proportionally**.
- Each step in the output corresponds to a **change in binary input combination**.
- The **MSB contributes the largest change**, while the LSB contributes the smallest change.
- The output levels follow a **binary-weighted progression** (I, 2I, 4I, 8I).
- Proper switching of MOSFETs is observed based on input signals (ON for 1, OFF for 0).
- The output is stable for each input combination, indicating **correct circuit operation**.
- No major distortion is observed in the waveform under ideal conditions.
- The simulation verifies that the DAC produces an **accurate analog representation of digital input**.
- Minor variations (if any) may occur due to **device characteristics or simulation parameters**.

10. ADVANTAGES

- High-speed operation due to current switching mechanism
- Suitable for high-frequency applications
- Simple architecture using MOSFET switches
- Better performance compared to resistor-based DACs
- Low output impedance
- Faster settling time
- Easily scalable to higher bit resolutions
- Compatible with CMOS technology
- Reduced propagation delay
- Efficient for integrated circuit implementation

11. LIMITATIONS

- Requires precise matching of current sources
- Sensitive to variations in MOSFET parameters
- Mismatch can lead to accuracy errors
- Power consumption may increase with higher resolution
- Circuit complexity increases as the number of bits increases
- Susceptible to noise and switching glitches
- Layout design is critical for proper performanc

12.APPLICATIONS

- Audio signal processing systems
- Communication systems (modulators, transmitters)
- Video and image processing
- Digital signal processing (DSP) systems
- Data acquisition systems
- Embedded systems and microcontrollers
- Instrumentation and control systems

13.CONCLUSION

The 4-bit current steering DAC was successfully designed and simulated using eSim. The circuit effectively converts digital input signals into a corresponding analog output using MOSFET-based switching and binary-weighted current sources. The simulation results show a step-like waveform, confirming correct DAC operation. The project demonstrates the advantages of current steering DACs in terms of speed and efficiency. Overall, the design validates the concept of digital-to-analog conversion and provides practical understanding of DAC implementation using CMOS technology.

14.REFERENCES

https://spie.org/samples/TT97.pdf

file:///C:/Users/Bharath%20Kumar/Downloads/22576-44990-1-PB.pdf

https://www.seas.ucla.edu/brweb/papers/Journals/BRWinter18DAC.pdf

S. Sarkar and S. Banerjee, "*A 10-bit 500 MSPS Segmented DAC with Optimized Current Sources to Avoid Mismatch Effect*," IEEE Computer Society Annual Symposium on VLSI, Montpellier, pp. 172-177, 2015.

D. Przyborowski and M. Idzik, "*A 10-bit low-power small-area high-swing CMOS DAC,*" IEEE Transactions on Nuclear Science, vol. 57, pp. 292–299, 2010.

G. Park and M. Song, "*A CMOS current-steering D/A converter with full-swing output voltage and a quaternary driver,*" IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 62, pp. 441–445, 2014.

N. Pal, P. Nandi, R. Biswas and A. G. Katakwar, "*Placement-based nonlinearity reduction technique for differential current-steering DAC*," IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 24, no. 1, pp. 233–242, 2015.