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6-Bit Fully Differential Current Steering DAC

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1 Introduction

This project presents the design and analysis of a 6-bit fully differential current-steering Digital-to-Analog Converter (DAC) fabricated in a 180 nm CMOS process. The DAC is engineered to deliver precise analog outputs with a full-scale voltage of 1.6 V and an input range of 0–1.6 V, operating on a 1.8 V analog supply. It achieves a maximum static power consumption of less than 1 mW while maintaining stringent linearity specifications: integral nonlinearity (INL) and differential nonlinearity (DNL) both within 0.5 Least Significant Bit (LSB).

The design process is executed in two phases. The first phase involves the conceptualization of the DAC using ideal current sources, followed by plotting the transfer characteristic to verify its theoretical performance. In the second phase, the DAC is implemented with PMOS current sources and a row-column decoder. The impact of device mismatches on the DAC's performance is analyzed by introducing random variations in transistor widths, with maximum deviations set at 0.1

This work offers valuable insights into the challenges of current-steering DAC design, emphasizing the effects of device mismatches and power efficiency. It establishes a framework for achieving high precision in advanced mixed-signal applications.

2 Circuit Diagram

2.1 DAC Using Ideal Current Sources

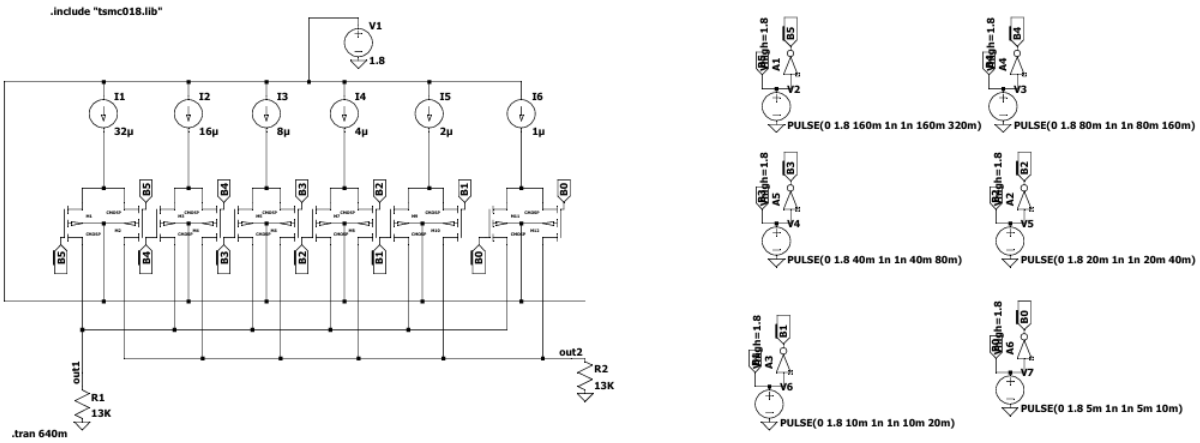

Figure 1: Circuit Diagram of DAC with Ideal Current Sources

This circuit is a 6-bit fully differential current-steering Digital-to-Analog Converter (DAC) designed using ideal current sources with binary-weighted scaling. It operates on a 1.8 V supply and uses six current sources configured to produce currents in binary proportions: 1 µA, 2 µA, 4 µA, 8 µA, 16 µA, and 32 µA.

Digital control signals (labeled B0 to B5) manage the PMOS transistors, directing the current from these sources based on the 6-bit digital input. These currents are then combined and converted into a differential voltage using precisely matched resistors, each with a resistance of 13 kΩ. The total power dissipation is 113.4 µW. This setup ensures accurate conversion of digital signals into their corresponding analog outputs.

2.2 PMOS Current Source Design

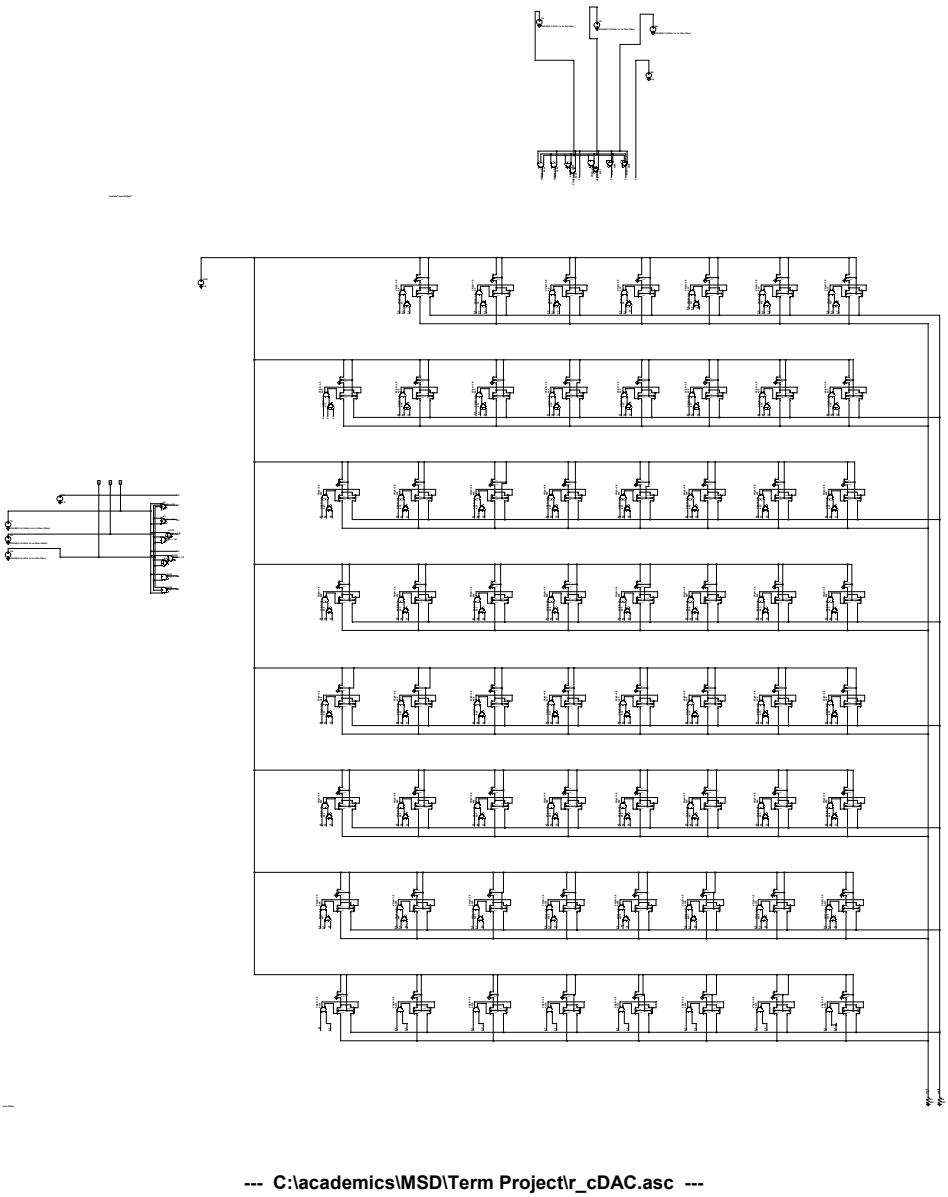

Figure 2: PMOS Current Source for Thermometer Coded DAC

This is a PMOS current source used as a basic current unit cell. We use this to implement 63 current sources in an 8x8 matrix fashion. A local decoder converts binary to thermometer code. Using the local decoder and the unit cell, a 6-bit DAC consisting of 63 current sources has been implemented.

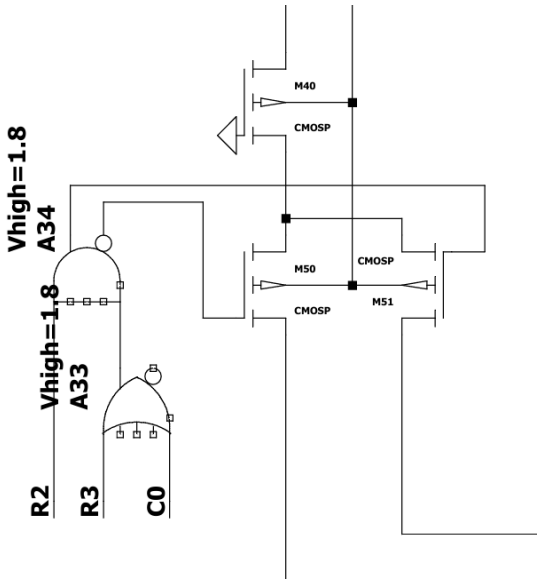

Figure 3: UNIT CURRENT CELL WITH LOCAL DECODER

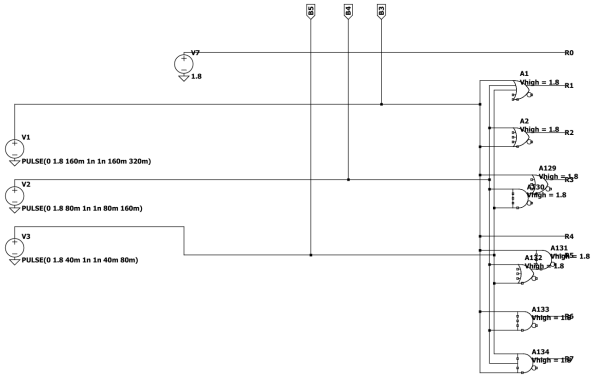

Figure 4: 3 TO 8 THERMOMETER

3 Results and Simulations

3.1 DAC Using Ideal Current Sources

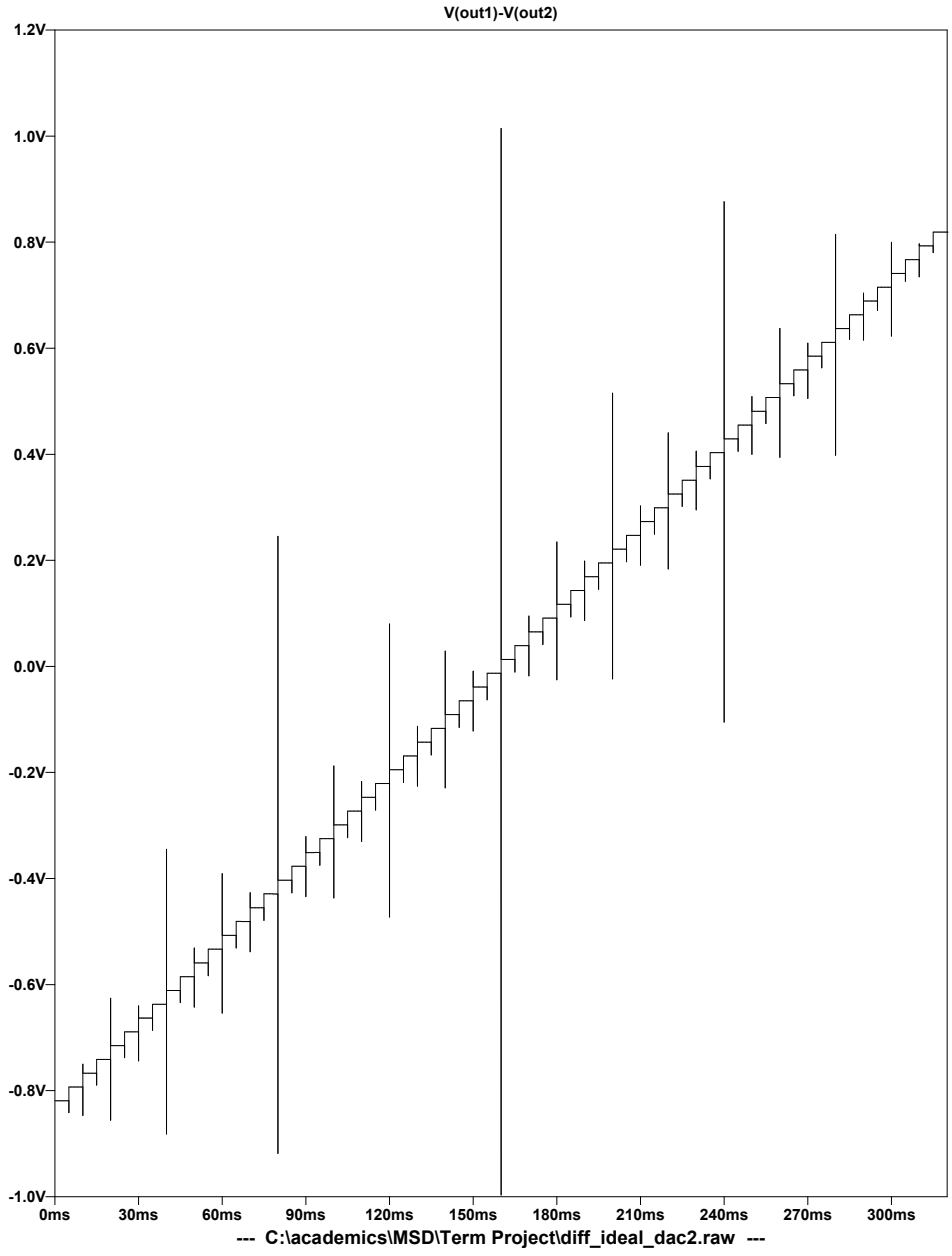

Figure 5: Transient Response of Ideal Current Source DAC (IN V)

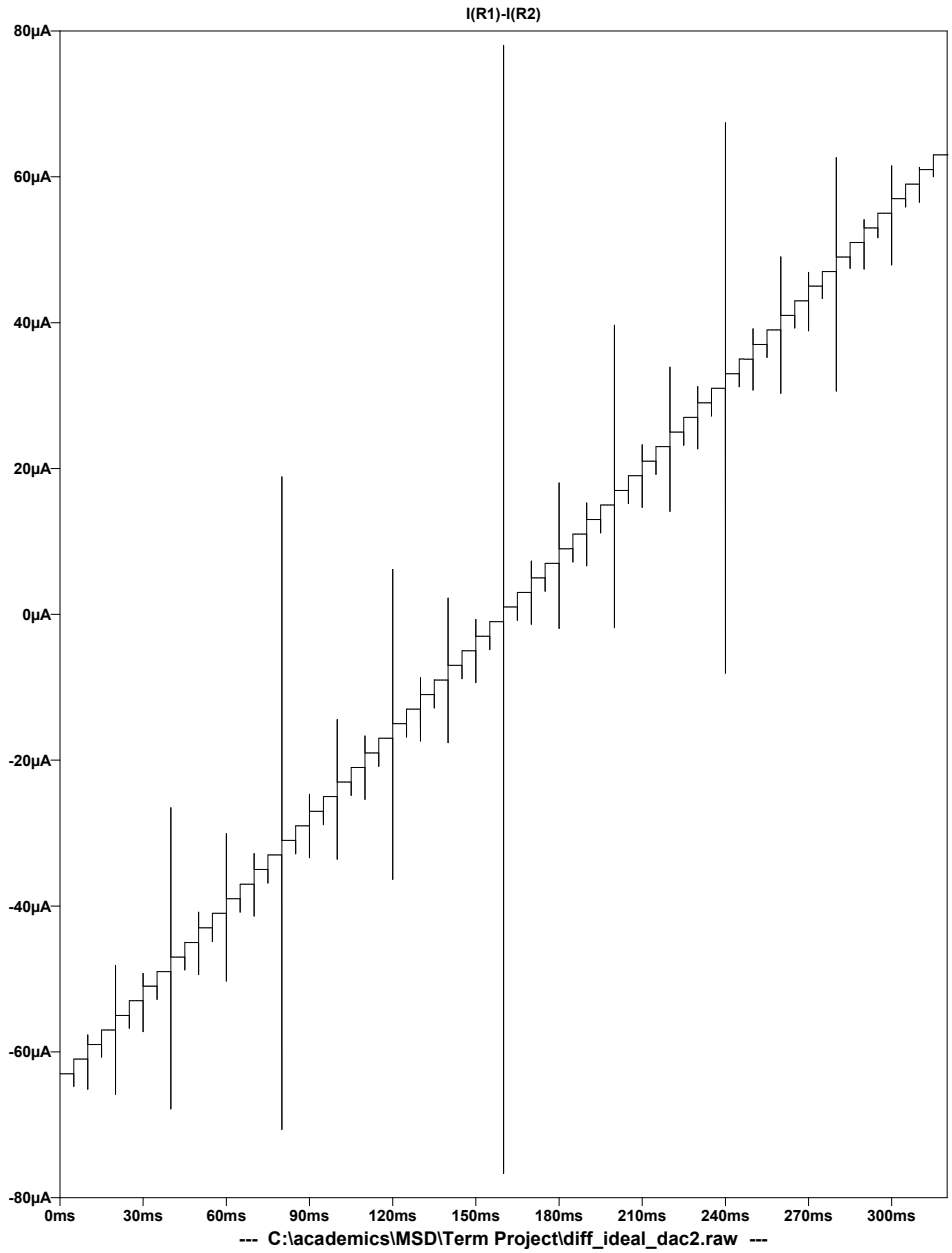

Figure 6: Transient Response of Ideal Current Source DAC (IN I)

3.2 Thermometer Coded DAC

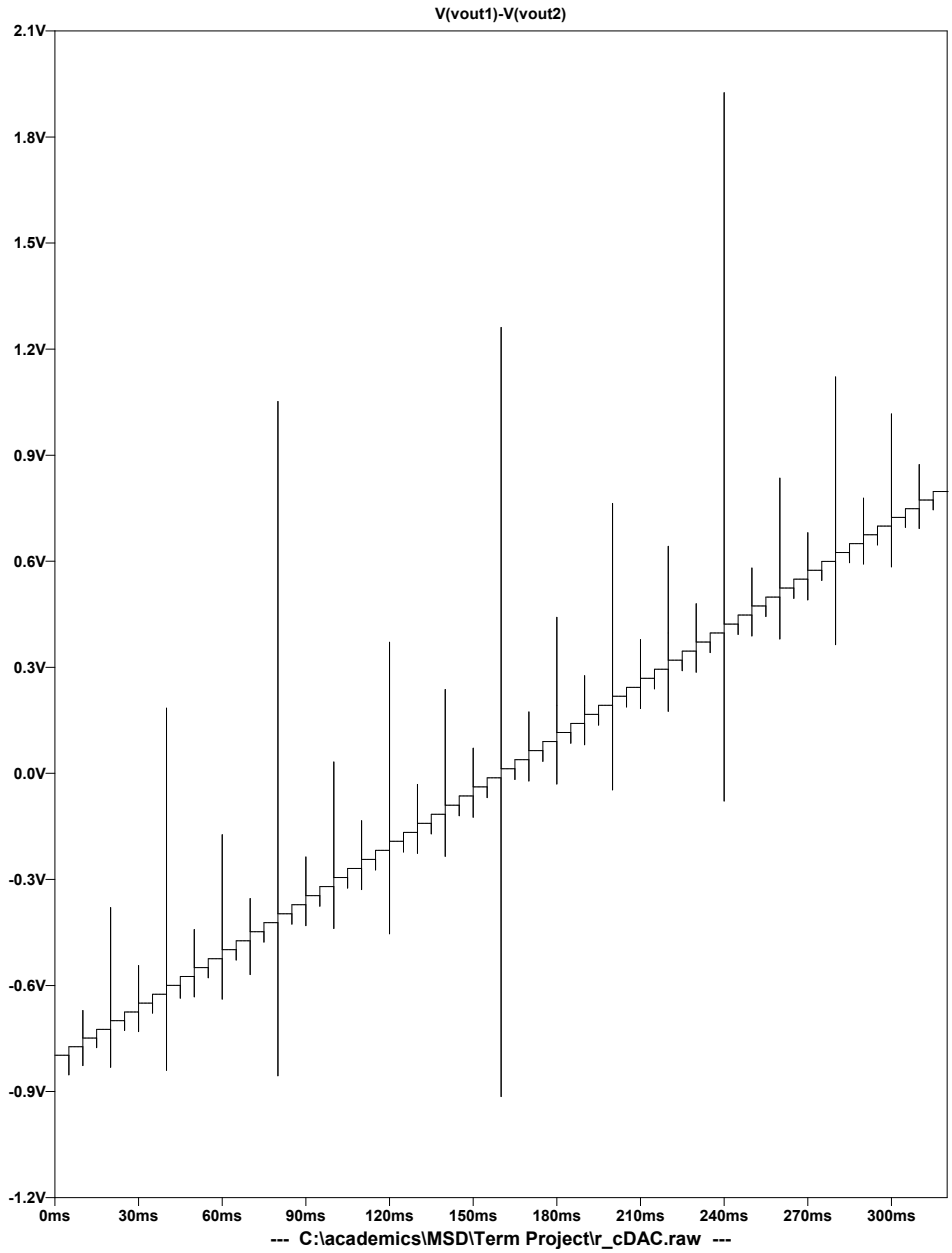

Figure 7: Transient Response of Thermometer Coded DAC (IN V)

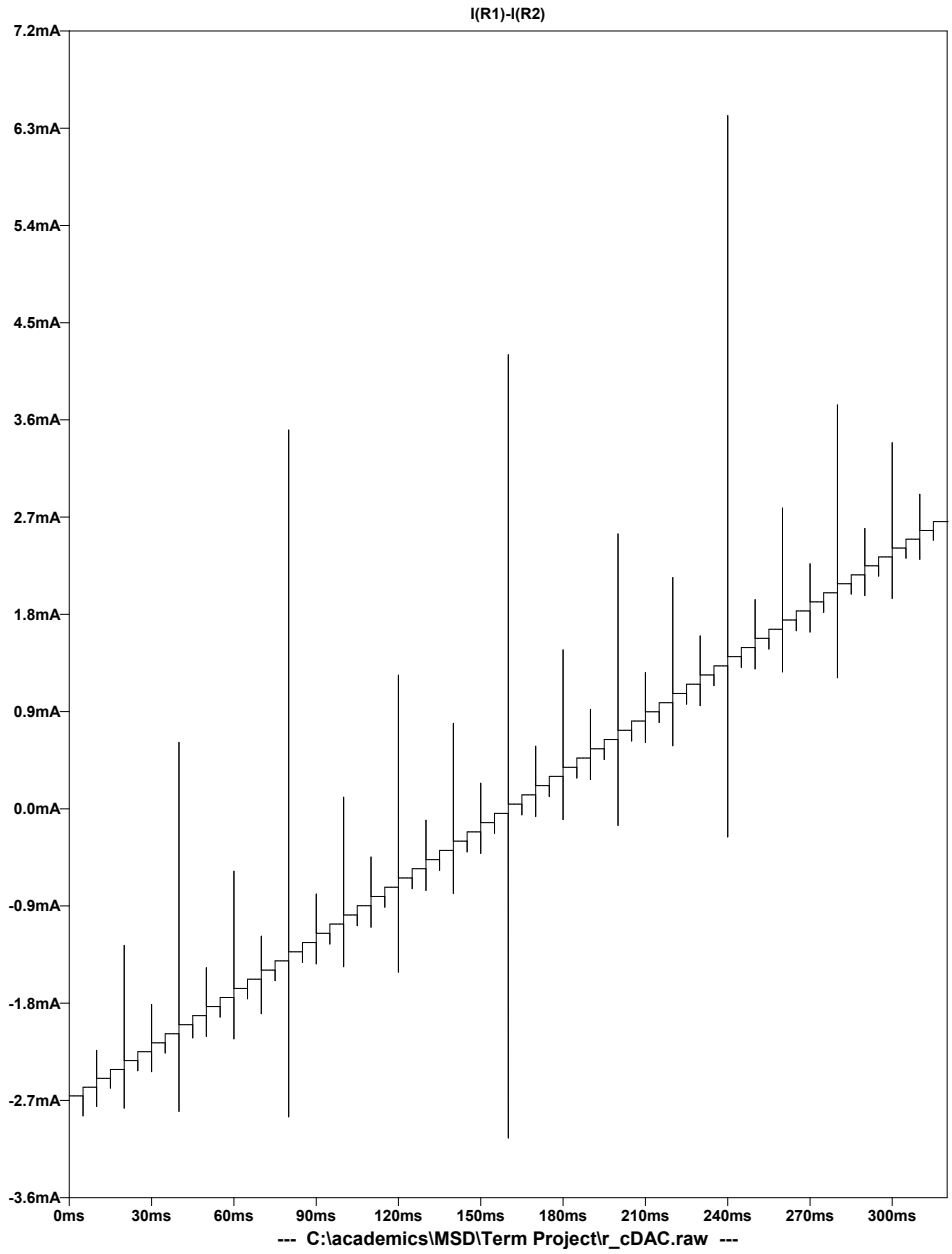

Figure 8: Transient Response of Thermometer Coded DAC (IN I)

3.3 DNL and INL Analysis

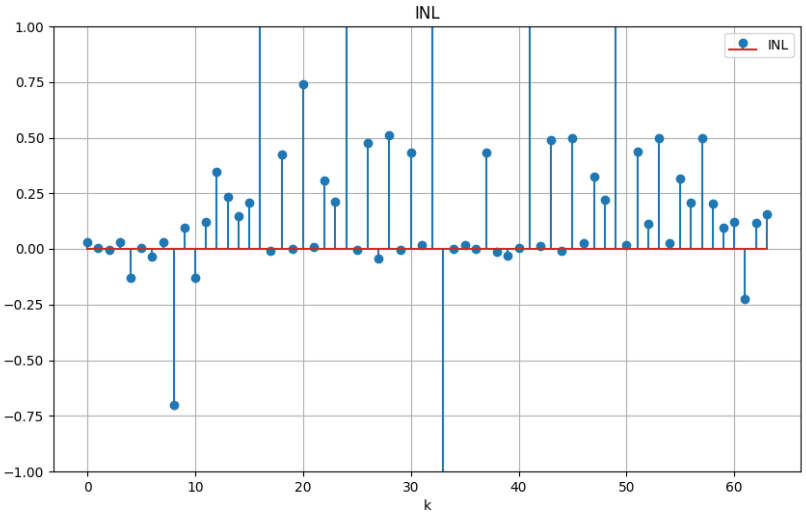

Figure 9: INL Analysis for Thermometer Coded DAC

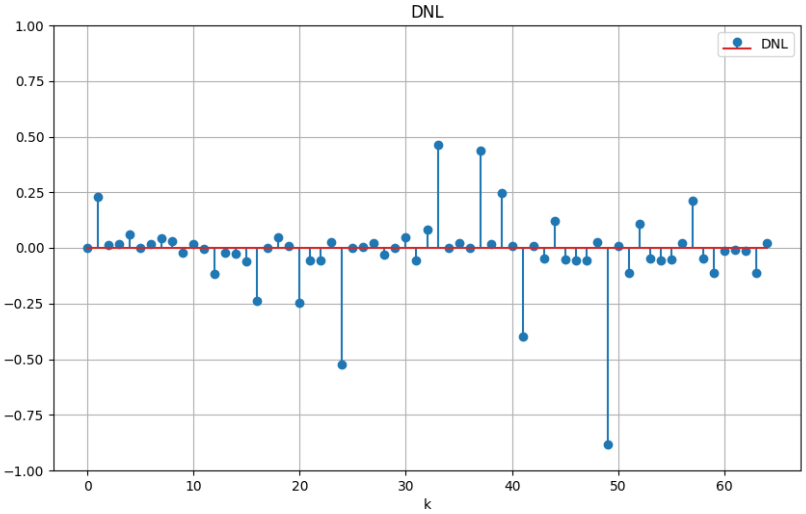

Figure 10: DNL Analysis for Thermometer Coded DAC

4 Conclusion

This project successfully demonstrates the design and analysis of a 6-bit fully differential current-steering DAC. The results show:

- **Linearity:** INL and DNL values are within acceptable limits.
- **Efficiency:** The DAC achieves power consumption under 1 mW.
- **Robustness:** The design remains functional under mismatch conditions.

Future work could focus on further reducing mismatch effects and exploring calibration techniques for improved precision.

5 References

1. Class Notes - Professor Dr. Laxminidhi T. , ECE DEPARTMENT NITK

2. Behzad Razavi, “Design of Analog CMOS Integrated Circuits”, McGraw Hill Education, 2nd edition, 2017.

3. Kenneth Martin, Chan Carusone, and David Johns, “Analog Integrated Circuit Design”, 2nd edition, Wiley, 2013.