Design and Simulation of a CMOS Bandgap Voltage Reference

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Abstract

A bandgap voltage reference is an essential circuit used in analog, digital, and mixed-signal ICs for providing a temperature-independent and supply-insensitive reference voltage. In this project, a CMOS-based bandgap reference circuit is designed and simulated using eSim (NgSpice) with SKY130 device models. The circuit combines the complementary-to-absolute-temperature (CTAT) and proportional-to-absolute-temperature (PTAT) voltages to achieve a stable reference of approximately 1.2 V. The performance is analyzed through DC sweep, transient analysis, and temperature variation from –40°C to +125°C. The results demonstrate that the proposed circuit achieves a stable voltage reference, making it suitable for low-power and precision applications such as ADCs, DACs, and voltage regulators.

Keywords: CMOS OTA, Folded Cascode, Low-Power Design, Analog Circuit, Operational Transconductance Amplifier, eSim Simulation, MOSFET, Gain Enhancement, Low Noise Amplifier, Integrated Circuit Design.

I. INTRODUCTION

Voltage reference circuits are critical components in modern analog and digital integrated systems. A stable reference voltage is required for data converters, voltage regulators, sensors, and communication ICs. However, conventional voltage sources are affected by temperature, supply voltage, and process variations. To overcome these limitations, the bandgap reference circuit was developed. It produces a nearly constant reference voltage (≈1.2 V) that is independent of external variations by combining voltages with opposite temperature coefficients. This makes bandgap references indispensable in precision electronic applications.

II. PURPOSE

The purpose of this project is to design and simulate a CMOS bandgap voltage reference circuit that provides a stable and temperature-independent output voltage using eSim and SKY130 PDK. Such circuits are widely used in analog and mixed-signal systems where precise reference voltages are essential for ADCs, DACs, regulators, and communication devices. The goal is to achieve a reliable reference voltage around 1.2 V that remains stable across variations in temperature, supply voltage, and process.

III. WORKING PRINCIPLE

The working principle of the CMOS bandgap voltage reference is based on combining two opposite temperature-dependent voltages to achieve temperature compensation. The base-emitter voltage (Vbe) of a bipolar transistor decreases with increasing temperature, representing a Complementary to Absolute Temperature (CTAT) behavior. On the other hand, the difference in base-emitter voltages (ΔVbe) between two transistors operating at different current densities increases proportionally with temperature, representing a Proportional to Absolute Temperature (PTAT) behavior. By scaling these two voltages with proper resistor ratios and current mirror circuits, the PTAT and CTAT components cancel out, yielding a constant and stable reference voltage. CMOS transistors are used to implement current mirrors and biasing networks, ensuring reliable operation over process, voltage, and temperature (PVT) variations.

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IV.CIRCUIT DIAGRAM

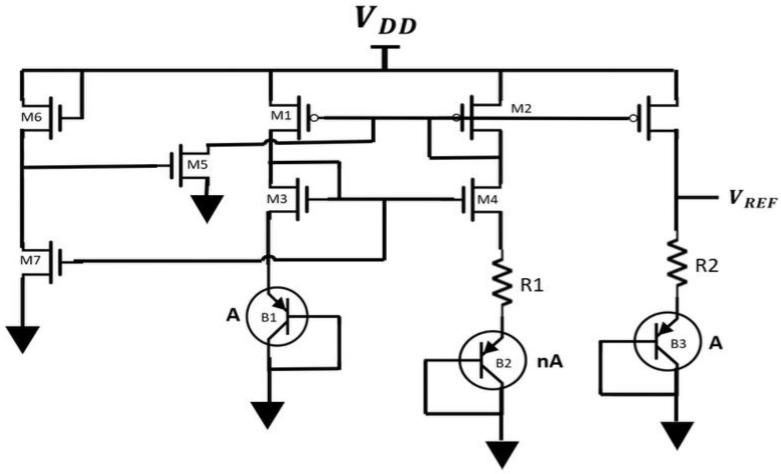

Fig. 1: Circuit Diagram.

EXPECTED OUTPUT:

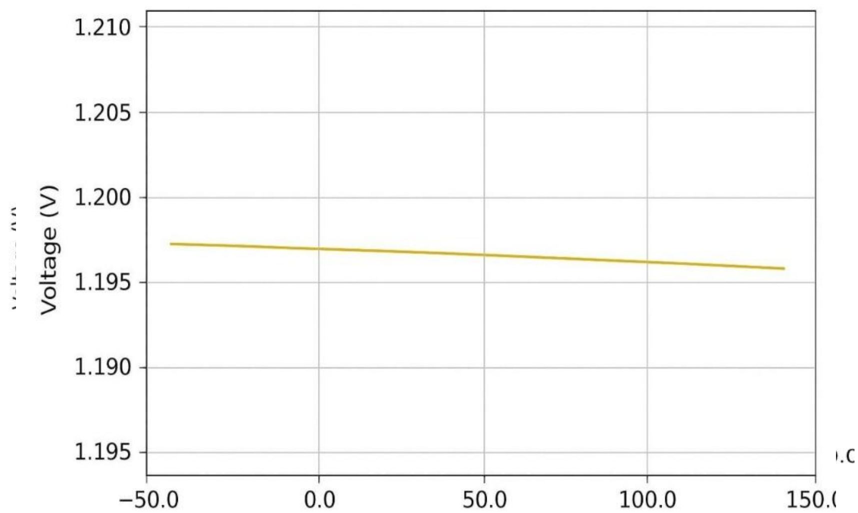

Fig. 2: Expected Output of bandgap reference circuit

The CMOS bandgap reference circuit is designed to generate a stable reference voltage of about 1.2 V. This voltage remains almost constant and is independent of supply voltage, temperature variations, and device parameters. The circuit uses CMOS transistors for current mirroring and biasing, while PNP transistors are used to generate complementary to absolute temperature (CTAT) and proportional to absolute temperature (PTAT) voltages. These voltages are combined in such a way that their temperature effects cancel each other, giving a nearly constant output. Resistors are used to set current ratios and scaling for correct operation.

V. PROPOSED SYSTEM

First, the required NMOS, PMOS, and PNP libraries are included in the netlist. A DC supply voltage, typically 1.8 V or 3.3 V, is given to the circuit. The transient analysis is performed to check the startup behavior and ensure the reference voltage settles correctly. A DC sweep analysis is also carried out to observe the behavior of the output voltage when the supply voltage is varied. In addition, a temperature sweep is performed to confirm that the output voltage remains stable across different operating conditions.

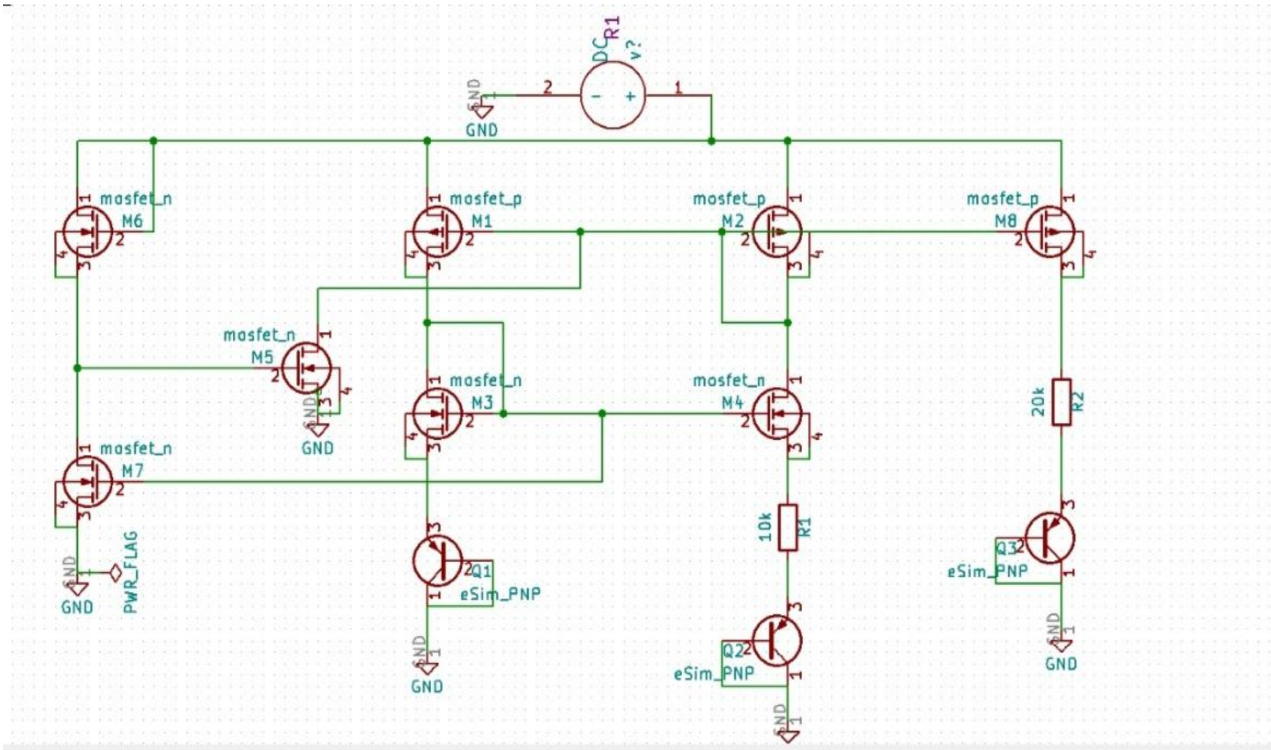

Fig. 3: CMOS-based bandgap reference circuit in eSim

OUTPUT WAVEFORM

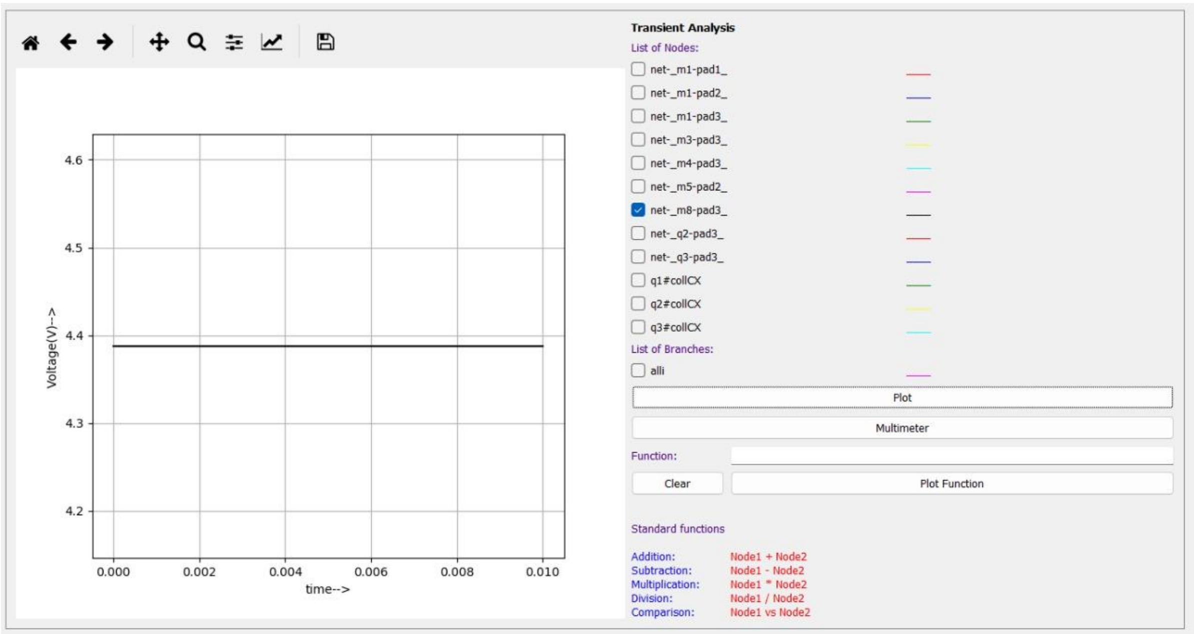

Fig. 4: Output of the bandgap reference Circuit in eSim

The expected output of the bandgap reference circuit is a stable voltage between 1.1 V and 1.3 V. From the transient analysis, the output node gradually settles to the reference voltage. In the DC sweep, the output voltage shows very little change even when the supply voltage is varied. In the temperature sweep, the output voltage remains nearly constant, confirming the temperature-independent operation of the bandgap circuit. Therefore, the bandgap reference provides a reliable and stable voltage source suitable for analog and mixed-signal applications.

VI. CONCLUSION

In this project, a CMOS bandgap voltage reference was successfully designed and simulated using eSim with SKY130 device models. The simulation confirms that the circuit produces a stable output reference voltage, independent of variations in supply voltage and temperature. The design principle relies on combining CTAT and PTAT voltages to achieve cancellation of temperature effects. Such circuits are vital for precision applications including data converters, regulators, and communication systems. Future improvements can focus on low-power design, startup circuits, and improved curvature compensation for better accuracy

VII. REFERENCE

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