Design of Bandgap Voltage Reference Circuit

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Abstract- A Bandgap Voltage Reference (BGR) circuit is a crucial building block in modern analog and mixed-signal electronic systems. It is designed to generate a stable and precise reference voltage that remains nearly constant despite variations in temperature, supply voltage, and process conditions. This stability is essential for the proper functioning of circuits such as analog-to-digital converters, voltage regulators, and sensor interfaces.

The basic principle of a bandgap reference circuit is to combine two voltage components with opposite temperature characteristics. One component, known as the base-emitter voltage of a bipolar junction transistor (BJT), decreases with an increase in temperature (CTAT – Complementary To Absolute Temperature). The other component, derived from the difference in base-emitter voltages of two transistors operating at different current densities, increases with temperature (PTAT – Proportional To Absolute Temperature). By carefully scaling and adding these two voltages, a temperature-independent reference voltage (approximately 1.2V) is achieved.

The design of a BGR circuit involves selecting appropriate device sizes, biasing conditions, and resistor ratios to ensure accuracy and minimize power consumption. Advanced designs may also include curvature correction techniques to improve performance over a wide temperature range. The circuit is widely implemented in integrated circuits due to its reliability, low cost, and robustness. In conclusion, the bandgap voltage reference circuit plays a vital role in ensuring precision and stability in electronic systems. Its ability to provide a constant reference voltage under varying environmental conditions makes it an indispensable component in modern electronic design.

I. INTRODUCTION

A Bandgap reference circuit is a fundamental building block in analog and mixed-signal integrated circuits, designed to generate a precise and stable reference voltage that remains almost constant regardless of changes in temperature, supply voltage, and fabrication process variations, which are common challenges in semiconductor devices. The operation of the bandgap reference is based on the physical properties of semiconductor materials, particularly silicon, and the predictable temperature behavior of bipolar junction transistors (BJTs), which are often used even in CMOS technologies due to their reliable characteristics.

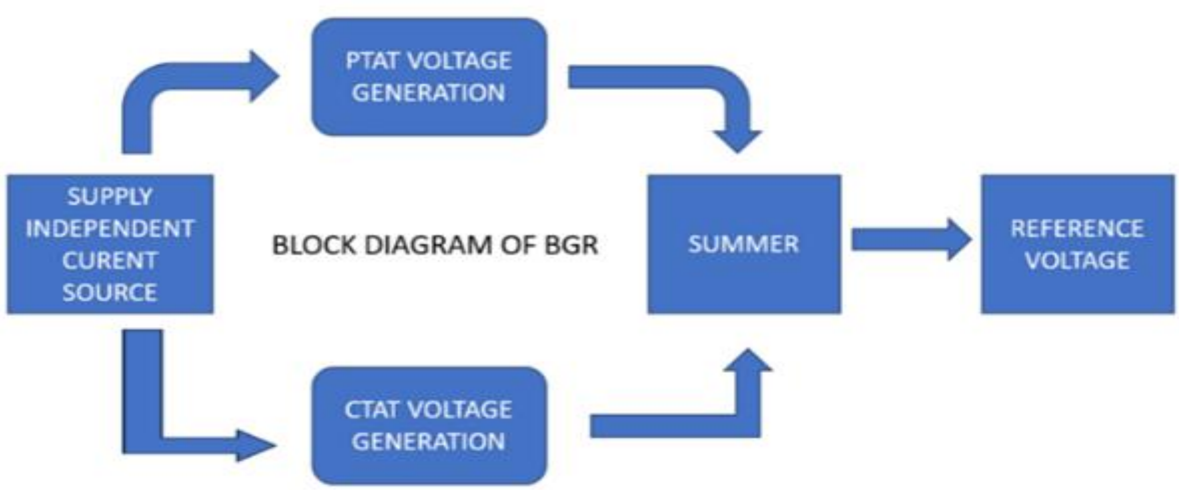

Figure 1: Block diagram of Bandgap reference circuit

The final output voltage of the bandgap reference is typically around 1.2 to 1.25 volts, which corresponds to the extrapolated bandgap energy of silicon at absolute zero temperature, and this is the reason behind the name "bandgap reference

II. METHODOLOGY

Basic Principle

The methodology of a Bandgap Voltage Reference (BGR) is based on generating a stable voltage by combining two voltages that have opposite temperature characteristics. One voltage decreases with temperature, known as CTAT, while the other increases with temperature, known as PTAT. By properly adding these two components, their temperature effects cancel each other, resulting in a nearly constant reference voltage of approximately 1.2 V.

Generation of CTAT Voltage

The CTAT voltage is obtained from the base-emitter voltage (V_BE) of a bipolar junction transistor. As temperature increases, the V_BE decreases due to changes in carrier concentration within the semiconductor. This negative temperature coefficient makes V_BE an ideal CTAT component in the BGR design, forming the base of the reference voltage.

Generation of PTAT Voltage

The PTAT voltage is generated by using two transistors operating at different current densities or emitter areas. The difference between their base-emitter voltages (ΔV_BE) is directly proportional to absolute temperature

Scaling and Summation

The PTAT voltage or current is scaled using resistor ratios and then added to the CTAT voltage. Proper selection of resistor values ensures that the increasing PTAT component exactly compensates for the decreasing CTAT component.

PARAMETER	VALUE
Reference Voltage	1.2 V
Technology	180 nm
Temperature Range	−40°C to 125°C
Power Supply (VDD)	3.3 V

Table: Specification and System Architecture Table

Output Voltage Generation

After combining the CTAT and scaled PTAT components, the final output voltage (V_REF) is obtained. This voltage is typically around 1.2 V, which corresponds to the bandgap voltage of silicon extrapolated to absolute zero. The output remains stable despite variations in temperature and supply voltage.

III. IMPLEMENTED DESIGN

Bandgap Voltage Reference is based on generating a stable output voltage by combining two temperature-dependent signals with opposite characteristics. In a practical circuit, two matched bipolar junction transistors are biased at different current densities to produce a voltage difference, known as ΔV_BE, which is proportional to absolute temperature (PTAT). At the same time, the base-emitter voltage of a transistor provides a complementary-to-absolute-temperature (CTAT) component, as it decreases with increasing temperature. By carefully selecting the resistor ratios, the increasing PTAT component compensates for the decreasing CTAT component, resulting in a nearly constant reference voltage of about 1.2 V.

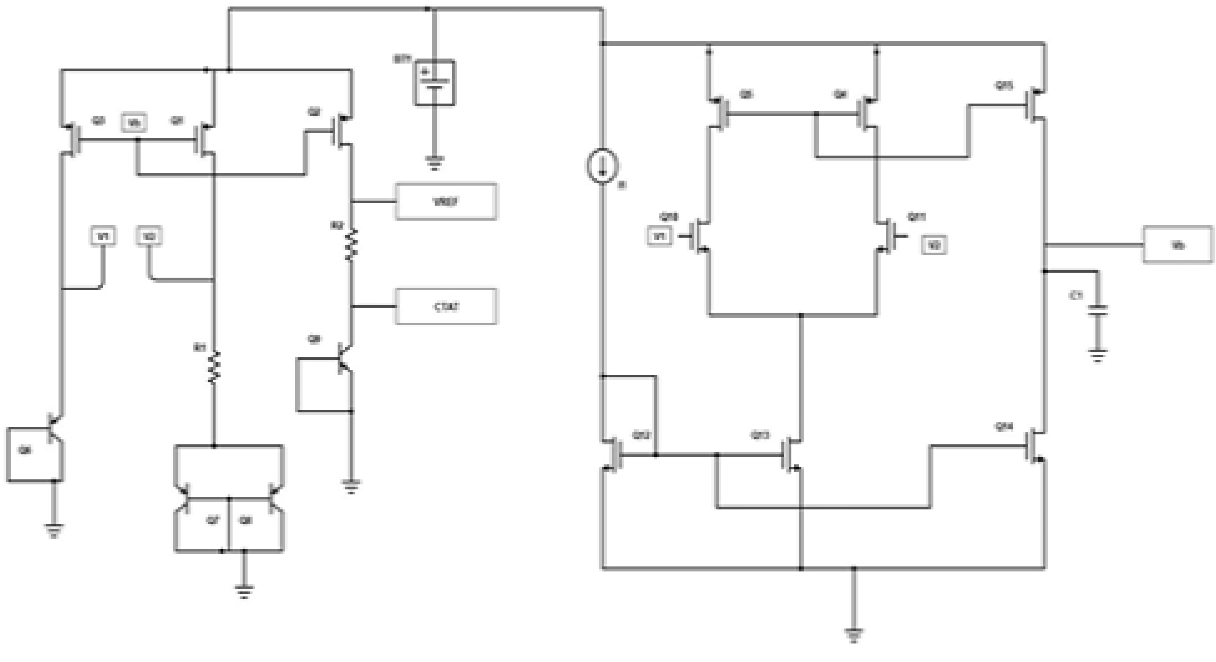

Figure 2: Bandgap Reference Circuit

IV. RESULTS AND DISCUSSION

CTAT Circuit Results

The CTAT block uses a diode-connected PNP BJT biased by a constant current to operate in the active region. Its base emitter voltage (VBE) decreases with temperature, exhibiting CTAT behaviour.

Key Observations are: As temperature increases, the increase in intrinsic carrier concentration causes the saturation current to increase exponentially. This results in a logarithmic decrease in the base-emitter voltage V_{BE}, which is clearly depicted in the DC response. The CTAT output is hence useful for cancelling the positive temperature coefficient of the PTAT component.

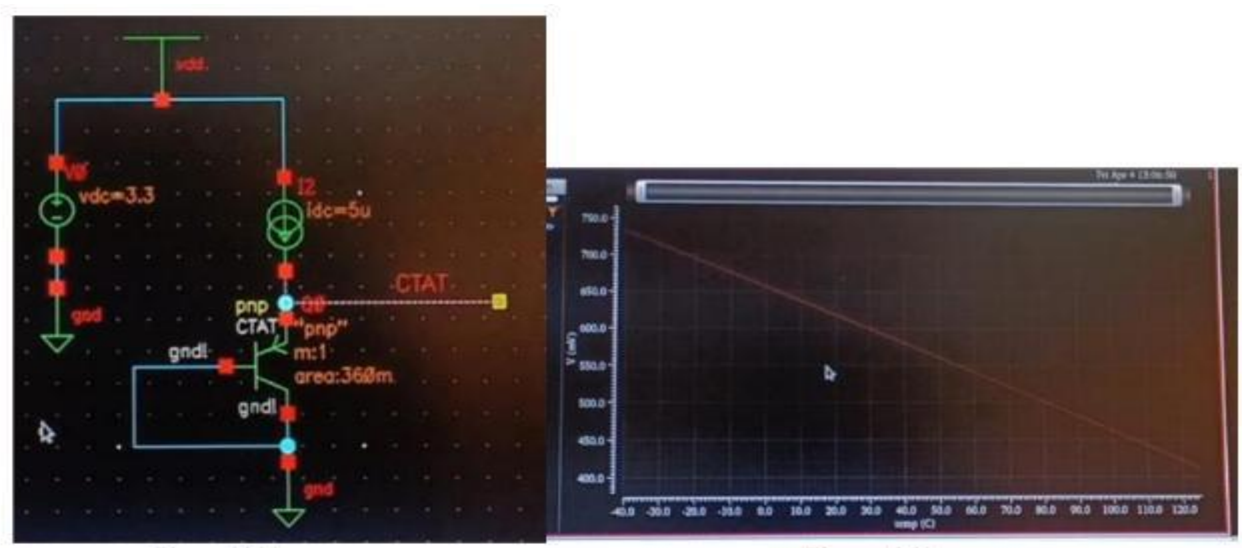

Figure 3: Schematic of the CTAT circuit and the DC response of the CTAT circuit.

PTAT Circuit Results

The PTAT (Proportional to Absolute Temperature) circuit produces a current that increases linearly with temperature using the ΔV_{BE} between two BJTs. This voltage is applied across a resistor to generate a PTAT current, which is mirrored for biasing. The positive temperature coefficient helps offset CTAT behaviour, ensuring temperature stability

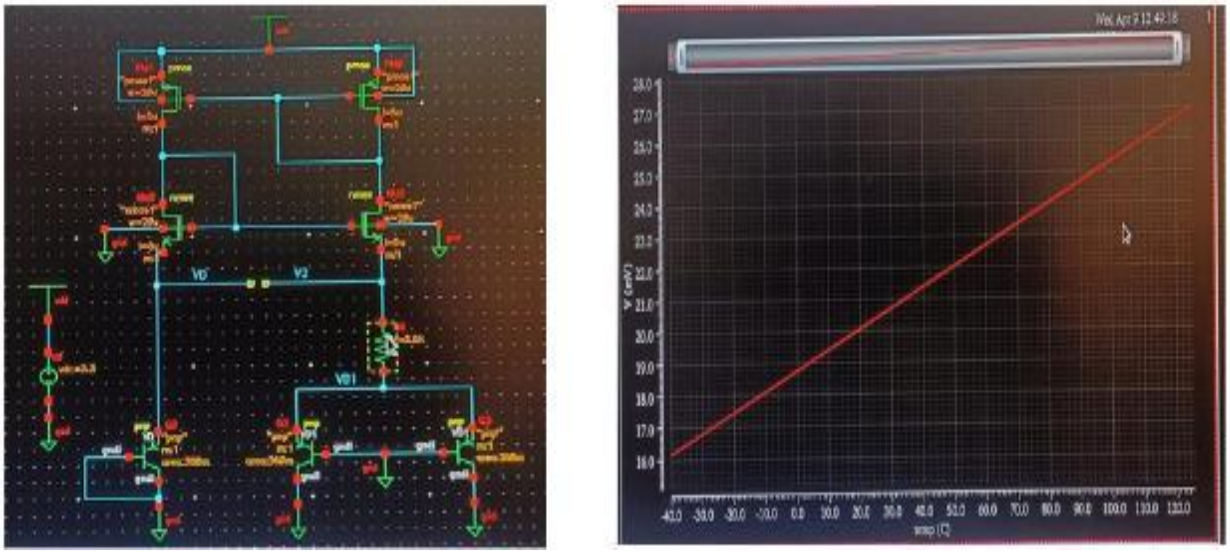

Figure 4: Schematic of the PTAT circuit and the DC response of the PTAT circuit.

Bandgap Voltage Reference Circuit Results

The final stage combines scaled PTAT and CTAT voltages to produce a stable, temperature-independent Bandgap Reference output (V_{REF}). Design Strategy: PTAT and CTAT ratios are chosen to cancel temperature effects, yielding a stable V_{REF} near 1.2V.

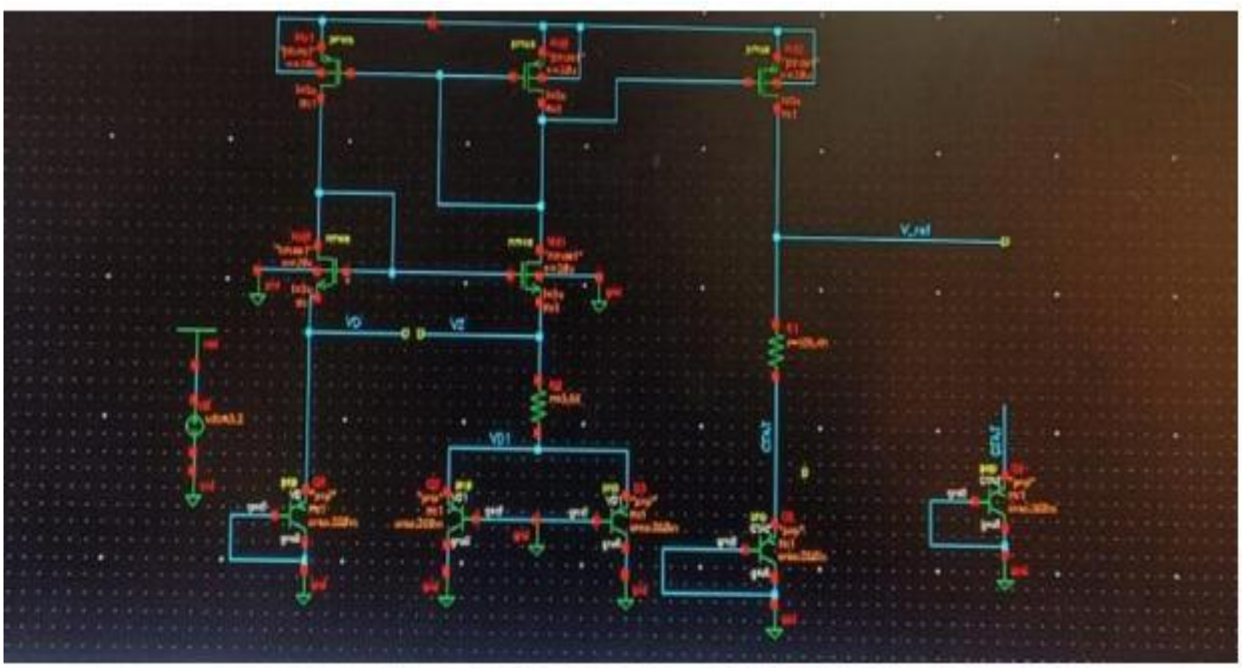

Figure 5: Schematic of the full BGR circuit

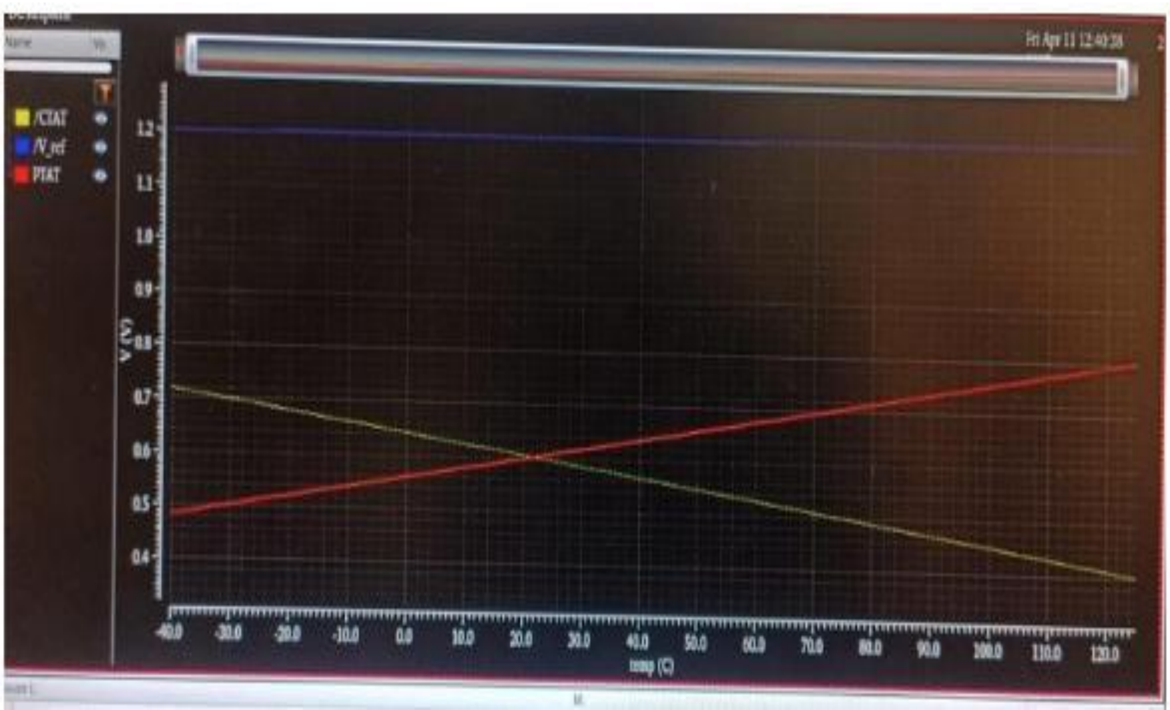

Figure 6: DC response of full BGR circuit

The key observation in the graph is that these two opposing characteristics are carefully scaled and combined within the BGR circuit. By selecting appropriate resistor ratios and current levels, the decreasing CTAT voltage and increasing PTAT voltage effectively cancel each other's temperature variations. This results in the final output voltage, Vref, which remains almost constant across the entire temperature range. Typically, this stable voltage is close to the silicon bandgap value of approximately 1.2V.

V. CONCLUSION

The Bandgap Reference (BGR) circuit is a fundamental building block in analog and mixed-signal electronics, designed to generate a stable and temperature-independent reference voltage, typically around 1.2V. It operates on the principle of combining two voltages with opposite temperature characteristics—CTAT (which decreases with temperature) and PTAT (which increases with temperature). By properly scaling and adding these components, the BGR circuit effectively cancels temperature variations, resulting in a nearly constant output voltage over a wide temperature range.

The development of BGR circuits, from early designs to modern digitally assisted versions, has significantly improved their accuracy, power efficiency, and adaptability. Today's BGR circuits can operate at low supply voltages, consume minimal power, and provide high precision, making them suitable for a wide range of applications.

Overall, the BGR circuit plays a crucial role in ensuring reliable and consistent performance in systems such as voltage regulators, ADCs, DACs, and power management ICs. Its ability to provide a stable reference under varying environmental and electrical conditions makes it an essential component in modern electronic design

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