The 11th Semba (9162)

Low-Power Bandgap Reference Design

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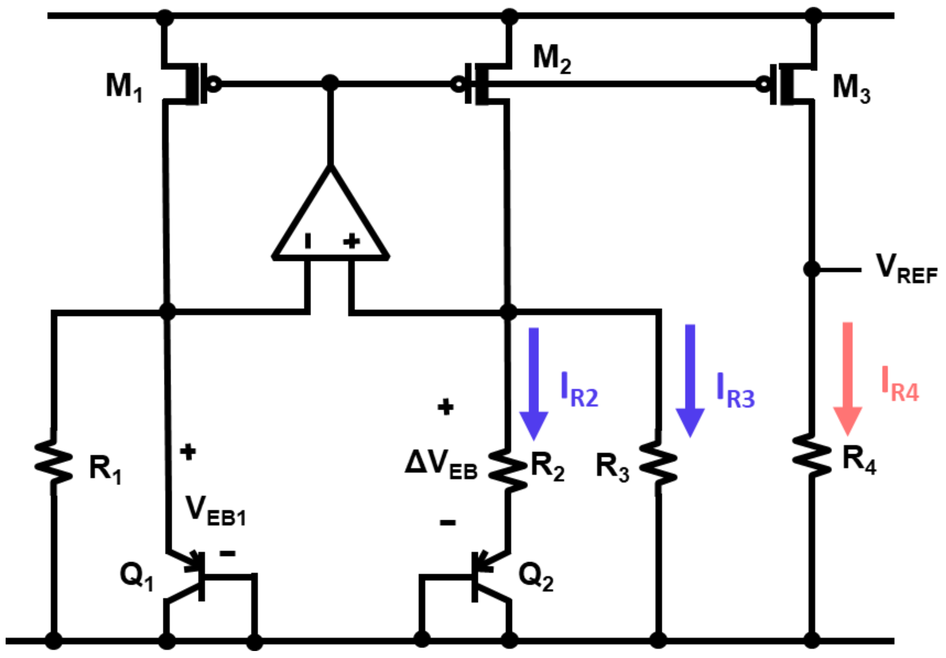
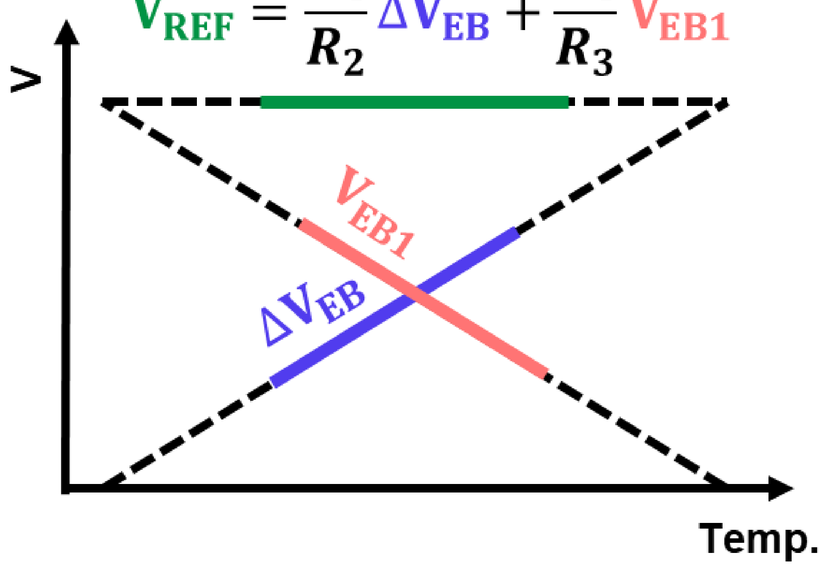
Background

- A bandgap reference (BGR) circuit produces a constant voltage regardless of power supply variations, temperature changes, or circuit loadings.
- In order to meet the demand for reduced power consumption of circuit systems in recent years, the low-power BGR has become a major challenge.
- The supply voltage is limited by V_{EB}+V_{DS}. Since $M_{1\text{-}3}$ should operate in saturation region, V_{EB} should be reduced to realize a sub-1V BGR.

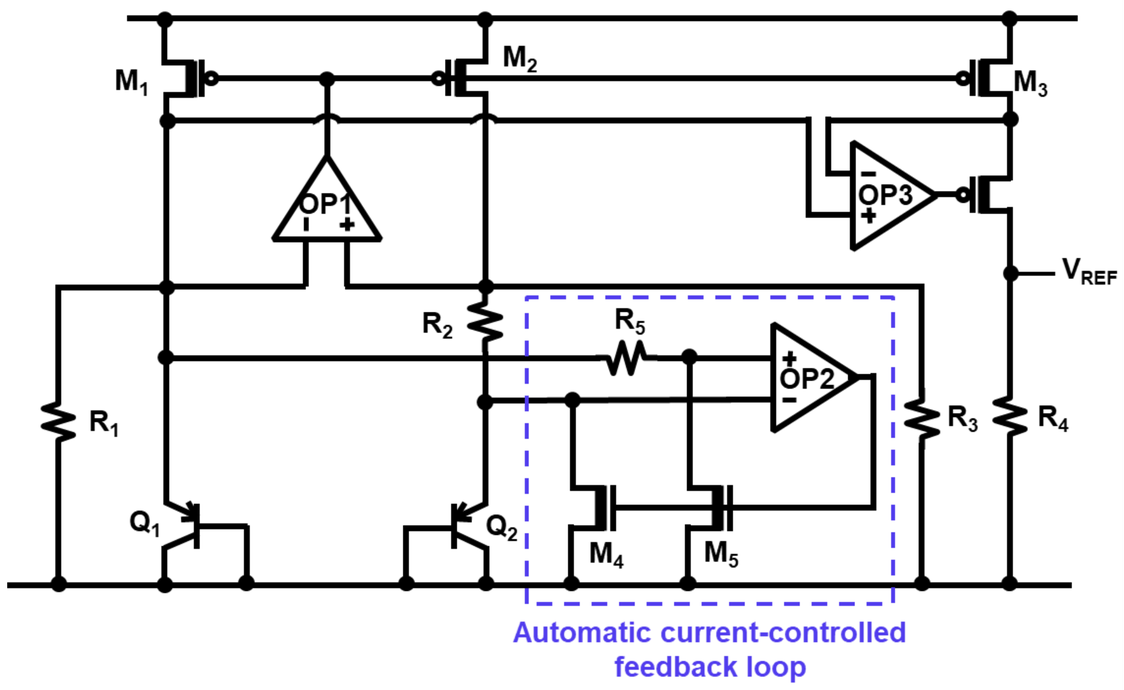


Introduction

- The traditional BGR
  - $\mathbf{I_{R2}}$ is a PTAT current. ($\mathbf{I_{R2}} = \frac{\Delta \mathbf{V_{EB}}}{\mathbf{R_2}}$)
  - $\mathbf{I_{R3}}$ is a CTAT current. ($\mathbf{I_{R3}} = \frac{\mathbf{V_{EB1}}}{\mathbf{R_3}}$)
  - $\mathbf{I_{R4}} = \mathbf{I_{R2}} + \mathbf{I_{R3}} = \frac{\Delta \mathbf{V_{EB}}}{\mathbf{R_2}} + \frac{\mathbf{V_{EB1}}}{\mathbf{R_3}}$
  - $\mathbf{V_{REF}} = \mathbf{I_{R4}} \times \mathbf{R_4} = \frac{R_4}{R_2}\Delta \mathbf{V_{EB}} + \frac{R_4}{R_3}\mathbf{V_{EB1}}$
  - $\mathbf{I_{R4}}$ and $\mathbf{V_{REF}}$ are temperature-independent.



Circuit Architecture (ISSCC 2019[1])



- The BGR is composed of a current-mode bandgap and an automatic current-controlled feedback loop.
- Decrease the current on BJTs to reduce V_{EB} by adding additional current paths (M4 and M5).
- The BJT current is controlled well by resistor ratio so as to let the BJT mismatch be fixed even for a lower bias-current range.

$$\mathbf{V_{REF}} = \mathbf{I_{R4}} \times \mathbf{R_4} = \left(\frac{\Delta \mathbf{V_{BE}}}{\mathbf{R_2}} + \frac{\mathbf{V_{EB}}}{\mathbf{R_3}}\right)\mathbf{R_4}$$

$$\frac{\mathbf{I_{R3}}}{\mathbf{I_{M5}}} = \frac{\Delta \mathbf{V_{EB}}/\mathbf{R_2}}{\Delta \mathbf{V_{EB}}/\mathbf{R_5}} = \frac{\mathbf{R_5}}{\mathbf{R_2}}$$

- However, the extra operational amplifier (OP2) may increase power consumption and area, which degrades the system performance.

Conclusion

- Sub-1V BGR circuits are necessary in many low-power applications.
- Since the supply voltage is limited mainly by V_{EB}, additional current paths are added to reduce the current on BJT, which reduce VEB at the same time.
- However, using an extra opamp results in higher power consumption and larger area.

Future Target

- We will develop new BGR architecture without using an extra opamp to reduce the current on BJTs and further decrease power consumption.
- The new BGR circuit will be applied in some low-power and low-supply-voltage applications, such as low-power energy-harvesting systems and thermal-sensors.

Reference

- [1]Y. -W. Chen, J. -J. Horng, C. -H. Chang, A. Kundu, Y. -C. Peng and M. Chen, "18.7 A 0.7V, 2.35% 3σ-Accuracy Bandgap Reference in 12nm CMOS," 2019 IEEE International Solid- State Circuits Conference - (ISSCC), pp. 306-307, 2019.
- [2]B. Yousefzadeh, S. Heidary Shalmany and K. A. A. Makinwa, "A BJT-Based Temperature-to-Digital Converter With ±60 mK (3σ) Inaccuracy From −55 °C to +125 °C in 0.16-μm CMOS," in IEEE Journal of Solid-State Circuits, pp. 1044-1052, April 2017.