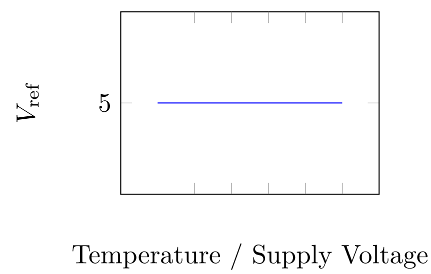
Bandgap Reference

Or Fahima

November 10, 2024

1 Introduction

A Bandgap Reference is a component that generates a constant voltage, independent of temperature or supply voltage variations. The basic concept is to combine two sources: one with a negative temperature coefficient (CTAT - Complementary to Absolute Temperature) and another with a positive temperature coefficient (PTAT - Proportional to Absolute Temperature). This combination effectively cancels out the temperature dependency, providing a stable reference voltage.



Reference voltage (V_{ref}) stability over temperature and supply voltage variations

Typical Variations:

- Temperature range: $-40°C$ to $125°C$
- Supply voltage variation: -10% to $+20\%$

Applications:

- Low Dropout Regulators (LDO)
- Analog-to-Digital Converters (ADC), Digital-to-Analog Converters (DAC)

2 CTAT (Complementary to Absolute Temperature)

A Bandgap Reference is a component that generates a constant voltage, independent of temperature or supply voltage variations. The current in the diode is given by:

$$\boxed{I_0 = I_S \exp\left(\frac{V_D}{V_t}\right)} \tag{1}$$

where V_t is the thermal voltage, approximately 26 mV at 300 K. From this, we can solve for the diode voltage:

$$\boxed{V_D = V_t \ln\left(\frac{I_0}{I_S}\right)} \tag{2}$$

We want to prove that $\frac{\partial V_D}{\partial T}$ is approximately $-1.6\,\text{mV}/^\circ\text{C}$.

- Firstly, recall that $V_t = \frac{kT}{q}$, which implies $V_t \propto T$ (PTAT !!!).
- $\frac{\partial V_t}{\partial T} = \frac{k}{q}$.

Now, let's examine the dependency of the saturation current I_S on temperature:

- $I_S \propto \mu \cdot k \cdot T \cdot n_i^2$
- $\mu \propto \mu_0 \cdot T^m$, where $m = -\frac{3}{2}$
- $n_i^2 \propto T^3 \exp\left(-\frac{E_g}{kT}\right)$

Thus, we conclude:

$$\boxed{I_S \propto b \cdot T^{4+m} \cdot \exp\left(-\frac{E_g}{kT}\right)} \tag{3}$$

,where b is a consant. Continuing from the previous section, we examine the derivative of I_S with respect to temperature:

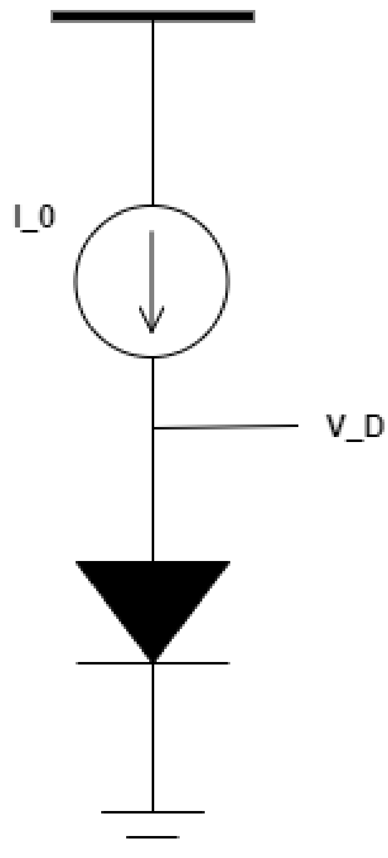


Figure 1: *
For now, we assume that I_0 is temperature-independent.

$$\frac{\partial I_S}{\partial T} = b\left[(4+m)T^{3+m}\exp\left(-\frac{E_g}{kT}\right) + T^{4+m}\cdot\frac{-E_g}{k}\cdot\frac{-1}{T^2}\exp\left(-\frac{E_g}{kT}\right)\right]$$

Simplifying further, we get:

$$\frac{\partial I_S}{\partial T} = b\exp\left(-\frac{E_g}{kT}\right)\left[(4+m)T^{3+m} + T^{4+m}\cdot\frac{E_g}{kT^2}\right] = b\exp\left(-\frac{E_g}{kT}T^{4+m}\right)\left[\frac{4+m}{T} + \frac{E_g}{kT^2}\right]$$

$$\boxed{\Rightarrow \frac{\partial I_S}{\partial T} = I_S\left[\frac{4+m}{T} + \frac{E_g}{kT^2}\right]} \tag{4}$$

Now, for $\frac{\partial V_D}{\partial T}$, we have:

$$\frac{\partial V_D}{\partial T} = \frac{\partial V_t}{\partial T}\ln\left(\frac{I_0}{I_S}\right) + V_t\frac{\partial \ln\left(\frac{I_0}{I_S}\right)}{\partial T}$$

Substituting from Equation (2), we get:

$$= \frac{k}{q} \ln\left(\frac{I_0}{I_S}\right) + V_t \cdot \frac{-I_0}{\left(\frac{I_0}{I_S}\right) I_S^2} \cdot \frac{\partial I_S}{\partial T}$$

Simplifying further:

$$= \frac{k}{q} \ln\left(\frac{I_0}{I_S}\right) - \frac{V_t}{I_S} \frac{\partial I_S}{\partial T}$$

Using Equation (4), we get:

$$\Rightarrow \frac{\partial V_D}{\partial T} = \frac{k}{q} \ln\left(\frac{I_0}{I_S}\right) - \frac{V_t}{T} \left[4 + m + \frac{E_g}{kT}\right]$$

Rearranging:

$$\boxed{\frac{\partial V_D}{\partial T} = \frac{V_D - (4+m)V_t - \frac{E_g}{q}}{T}} \tag{5}$$