Design of Band- gap Reference

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Band-Gap Reference Circuit

- A bandgap reference is a circuit widely used in analog and mixed-signal integrated circuits to generate a stable voltage that is largely independent of temperature, power supply variations, and manufacturing process changes.
- The concept is based on combining two voltages with opposite temperature coefficients.
- It is a vital analog building block used in many applications like Low Dropout voltage regulators, Analog to digital converter, Digital to analog converter, Buck converters etc. Compared to a voltage regulator, reference circuit lack current driving capability.
- As per industry standards, range of variation in temperature is considered as from -40 ^{0}C to 125 ^{0}C. Range of supply variation depends on applications, typically 10% to 20% from the typical value of voltage supply.
- Basically 2 important variations are discussed in this report
  i) Supply variations
  ii) Temperature variations

Effect of Temperature

- All electronic devices are sensitive to temperature variations.
- If voltage across a device increases with the increase in temperature, then such devices are called PTAT [Proportional to Absolute Temperature].
- If voltage decreases with the increase in temperature, then such devices are called CTAT [Complementary to Absolute Temperature]

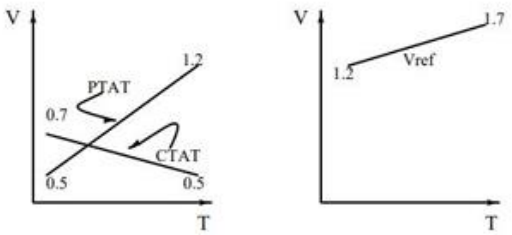


Fig. 1: (a) PTAT and CTAT responses (b) Response of voltage reference

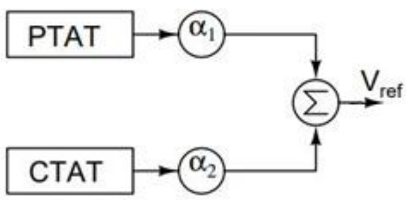


Fig. 2: Generation of V_{ref} voltage

CTAT and PTAT Design

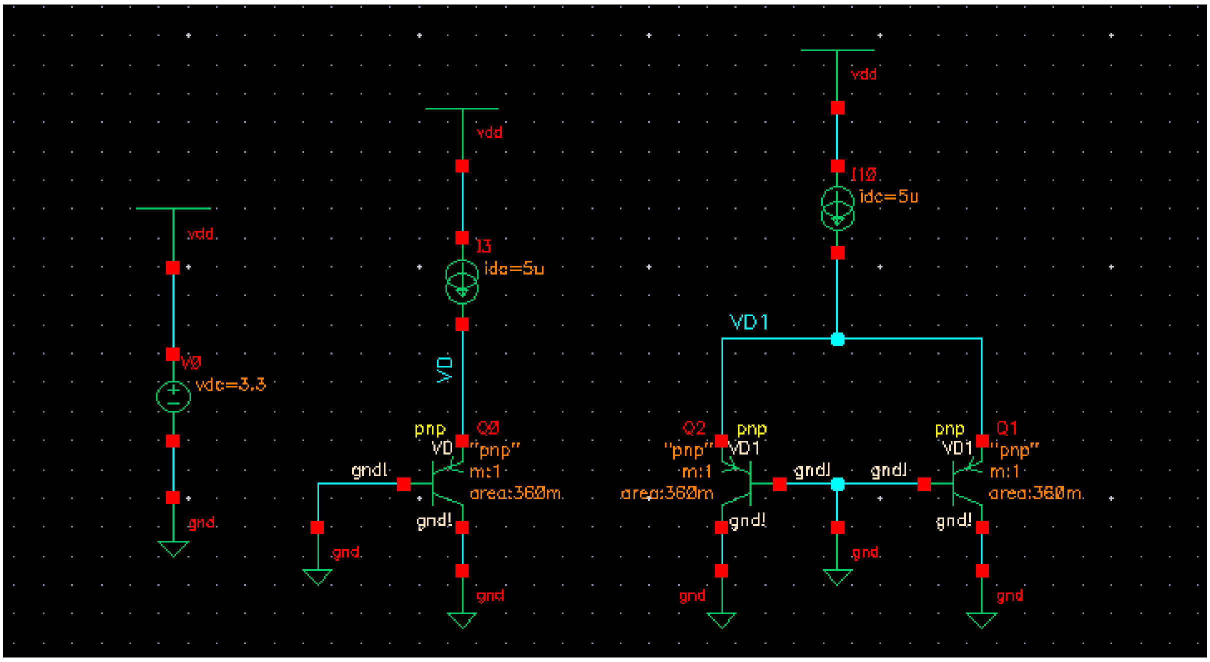


Fig3: Schematic of CTAT and PTAT design

Final Circuit

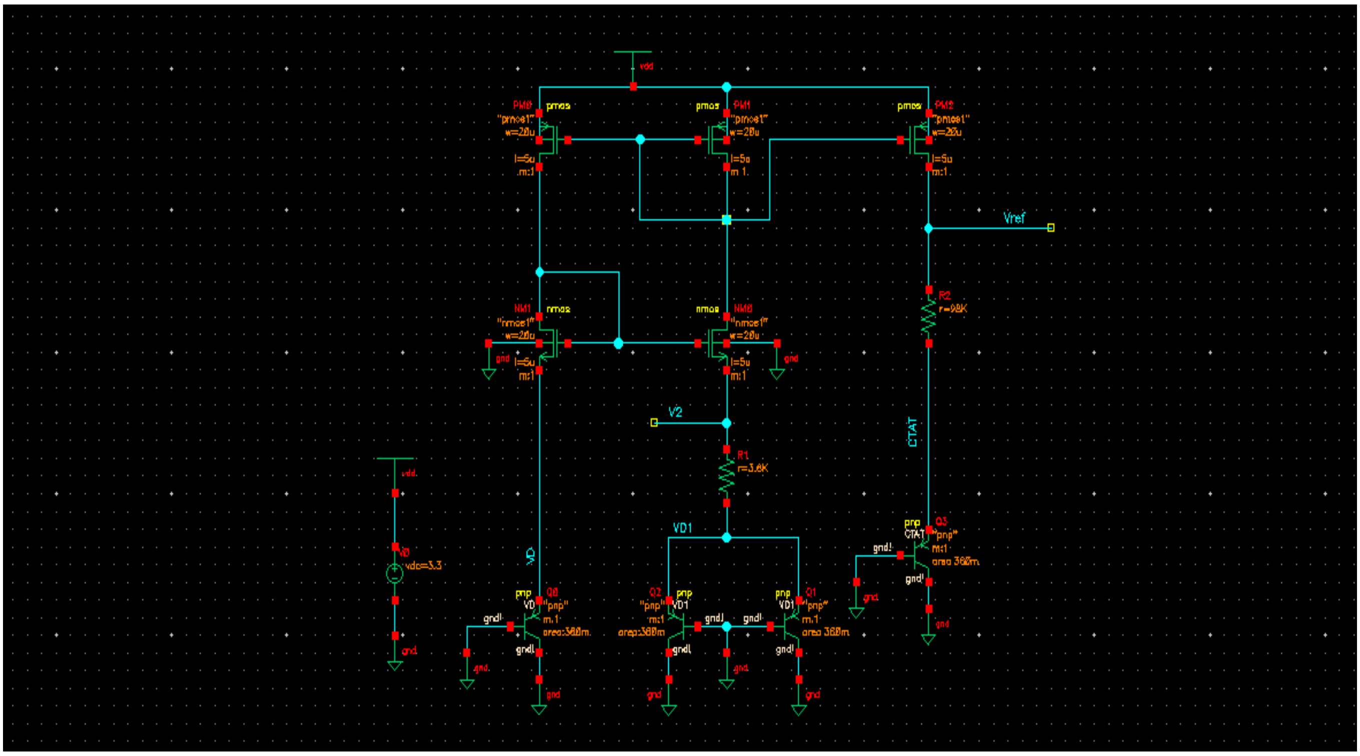


Fig 4: Schematic of the final circuit implementation

Results:

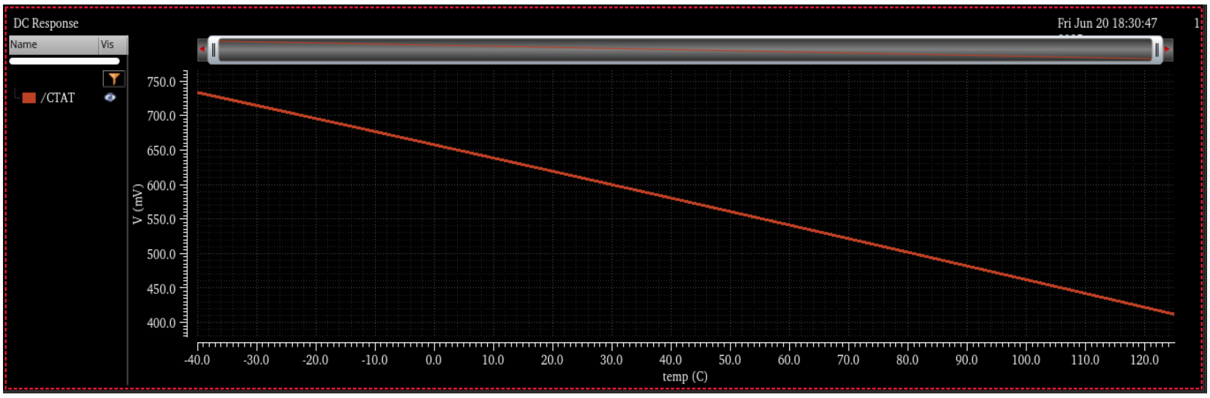


Fig5: CTAT graph

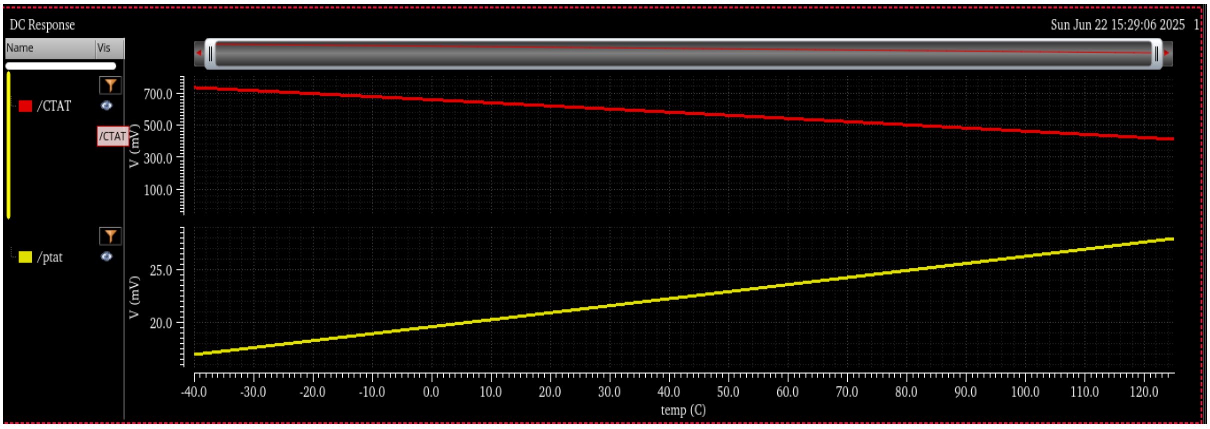


Fig5: CTAT and PTAT graph

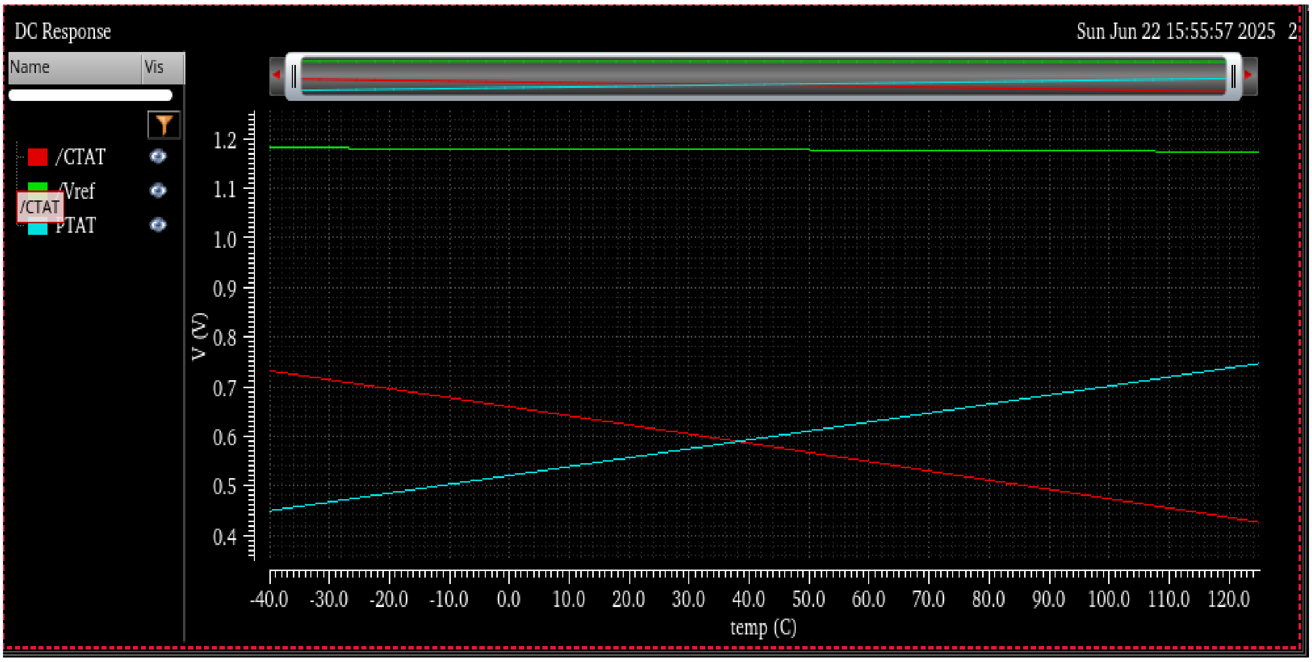


Fig 6: Final V reference voltage variation with Temperature

Variation with supply voltage:

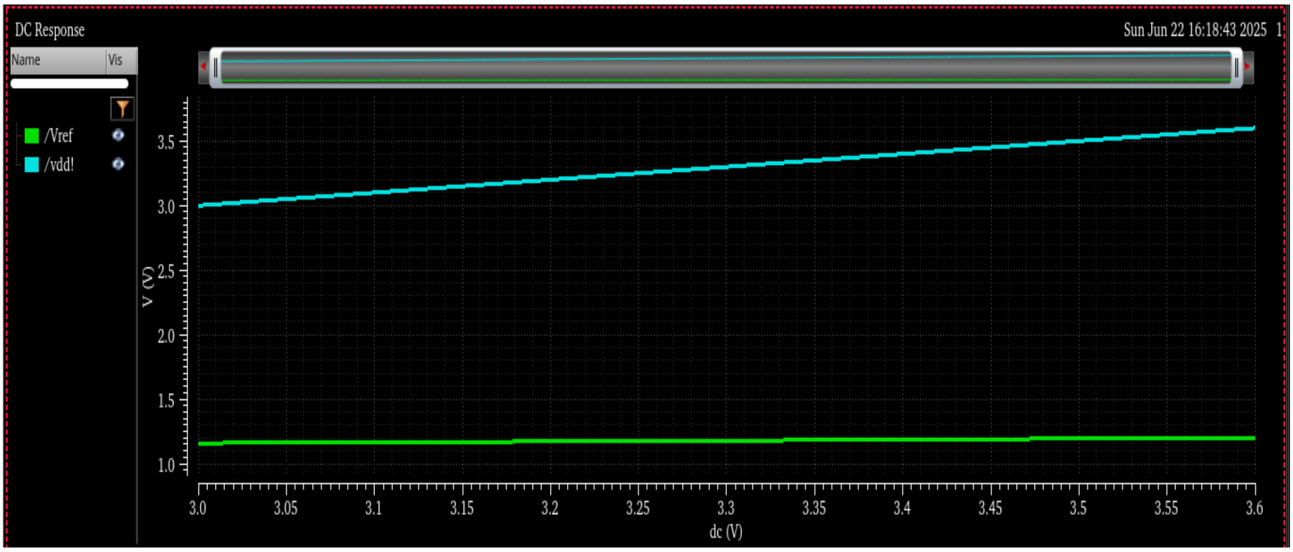
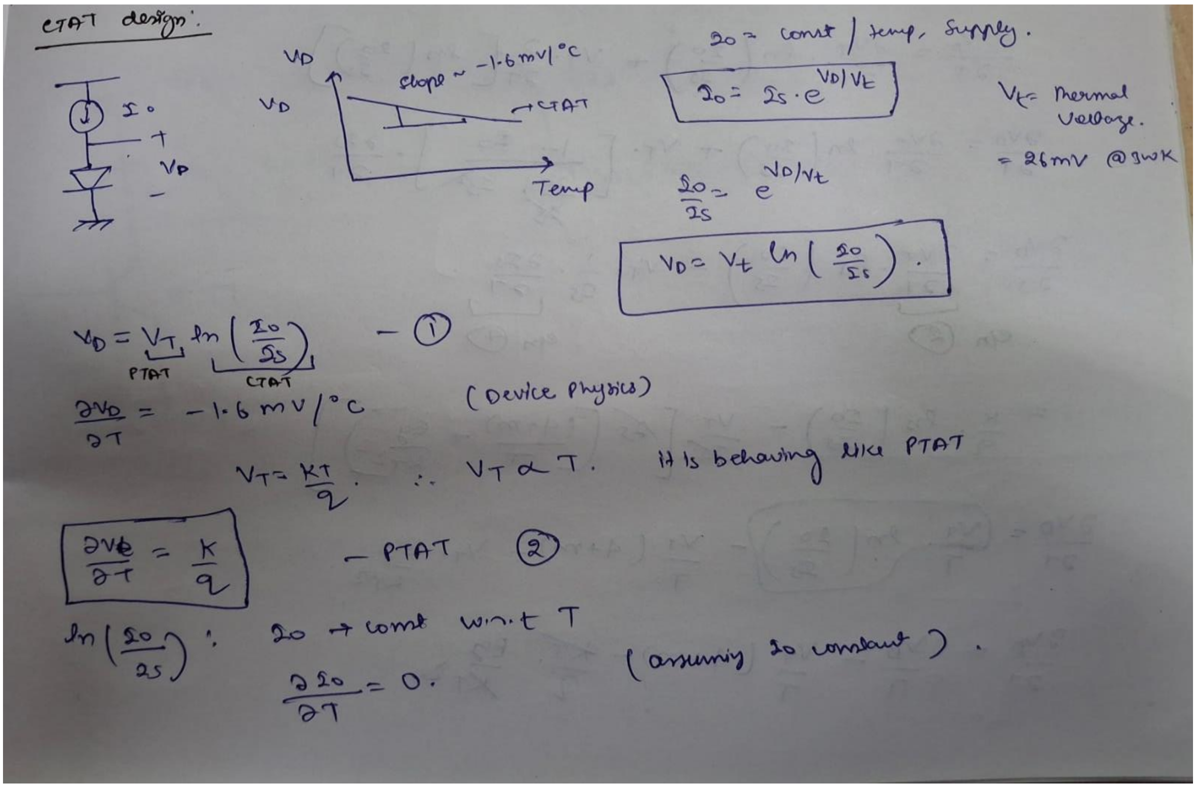


Fig 7: Variation with supply voltage

Design methodology and discussion:

CTAT Design



$I_S = \mu K T . n_i^2$, $n_i^2 \propto T^3 \exp\left[-\frac{E_g}{KT}\right]$.

$\mu \propto \mu_0 T^m$ $m \approx -3/2$

I_S is depending on Temp.

$$I_S \propto bT . T^m . T^3 \exp\left[-\frac{E_g}{KT}\right] = I_S \propto bT^{4+m} \exp\left[-\frac{E_g}{KT}\right] \quad (3)$$

$$\therefore I_S = bT^{(4+m)} . \exp\left[-\frac{E_g}{KT}\right] \quad -(3).$$

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

$$= b . \exp\left[-\frac{E_g}{KT}\right]\left[T^{(4+m)} . \frac{E_g}{KT^2} + (4+m) . T^{3+m}\right)$$

$$\frac{\partial I_S}{\partial T} = I_S . \left[\frac{4+m}{T} + \frac{E_g}{KT^2}\right] \quad -(4)$$

we know, $V_D = V_T \ln\left(\frac{I_0}{I_S}\right)$

$$\frac{\partial V_D}{\partial T} \Rightarrow V_T, I_S, \frac{\partial V_T}{\partial T}, \frac{\partial I_S}{\partial T}$$

$$\therefore \frac{\partial V_D}{\partial T} = \frac{\partial V_T}{\partial T} . \ln\left(\frac{I_0}{I_S}\right) + V_T . \frac{\partial}{\partial T}\left[\ln\left(\frac{I_0}{I_S}\right)\right]$$

$$\frac{\partial V_D}{\partial T} = \frac{\partial V_T}{\partial T} \ln\left(\frac{I_0}{I_S}\right) + V_T . \left[\frac{1 - I_0}{\frac{I_0}{\cancel{I_S}} . I_S^{\cancel{2}}}\right] . \frac{\partial I_S}{\partial T}$$

$$\frac{\partial V_D}{\partial T} = \underbrace{\frac{\partial V_T}{\partial T}}_{eqn\ (2)} . \ln\left(\frac{I_0}{I_S}\right) - V_T . \frac{1}{I_S} . \underbrace{\frac{\partial I_S}{\partial T}}_{eqn\ (4)} .$$

$$= \frac{K}{q} . \ln\left(\frac{I_0}{I_S}\right) - \frac{V_T}{\cancel{I_S}}\left[\cancel{I_S}\left[\frac{(4+m)}{T} + \frac{E_g}{KT^2}\right)\right]$$

$$\frac{\partial V_D}{\partial T} = \frac{V_T}{T} \ln\left(\frac{I_0}{I_S}\right) - \frac{V_T}{T}(4+m) - V_T . \frac{E_g}{KT^2}$$

$$\frac{\partial V_D}{\partial T} = \frac{V_D}{T} - \frac{V_T}{T}(4+m) - \frac{\cancel{KT}}{q} . \frac{E_g}{\cancel{KT^2}}$$

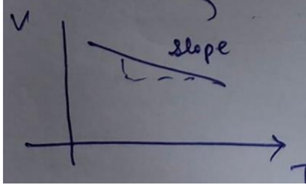
$$\therefore \frac{\partial V_D}{\partial T} = \frac{V_D}{T} - \frac{V_T}{T}(4+m) - \frac{E_g}{qT}.$$

$$\boxed{\therefore \frac{\partial V_D}{\partial T} = \frac{V_D - (4+m)V_T - E_g/q}{T}}$$

Slope of CTAT

∴ rate of change of diode voltage w.r.t. Temp^n.

$$\frac{\partial V_D}{\partial T} = \frac{0.7V - (4 - 3/2)\,26mV - 1.2}{300K}$$

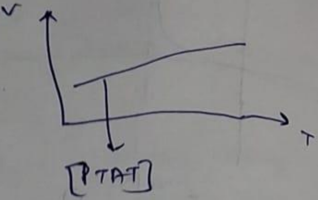


$$= -1.88\ mV$$

[In beginning we say slope $= -1.6\ mV/°K$.

PTAT DESIGN:

- Any quantity, that increases with temperature linearly is called as
  Proportional to absolute Temp^n [PTAT].



- Our aim is to try to generate some quantity, which has direct proportionality to temp^n.

$$\frac{KT}{q}\ln\left(\frac{I_1}{\cancel{I_S}} \times \frac{\cancel{I_S}}{I_2}\right)$$

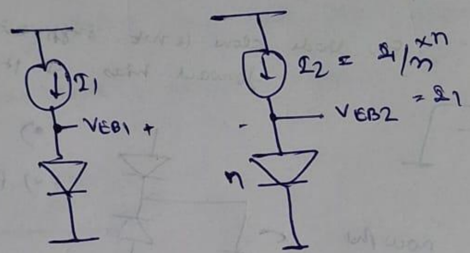
make sure it does not vary with temp^n.

] basically we want to get rid of I_S, then we get direct proportionality to Temp^n.

$$= \frac{KT}{q}\ln\left(\frac{I_1}{I_S}\right) - \frac{KT}{q}\ln\left(\frac{I_2}{I_S}\right)$$

To get this voltage we passed the current I_1 through diode.

To get this voltage, I should pass the current I_2 to diode. (Identical).



→ It's easy to make copies of current sources, so I will take n copies of I_2, so that $I_2 = \frac{I_1}{n} \times n$.

$$= \boxed{\frac{KT}{q}\ln(n)}$$

n → constant

↳ now we have the linear dependency on temp^n.

- If I have single diode voltage, that has CTAT behaviour → VEB1.

→ But VEB2 should not change, I should put n diodes in parallel to.

Then $\Delta V_{EB} = V_{EB1} - V_{EB2}$ → PTAT behaviour $= \frac{KT}{q}\ln(n)$.

- To get a constant voltage, I had to add these 2.

$$V_{out} = V_{EB1} + K_p \times (V_{EB1} - V_{EB2}) = V_{EB1} + K_p \times \frac{KT}{q}\ln(n).$$

K_p → scaling factor