Izvori referentnog napona

Osnovne ideje

Cilj: izvor napona koji ne zavisi od temperature.

Ideja: koristiti dva naponska izvora sa temperaturskim koeficijentima suprotnog znaka.

$$v_R = v_1 + v_2$$

$$\frac{\partial v_R}{\partial T} = \frac{\partial v_1}{\partial T} + \frac{\partial v_2}{\partial T}$$

$$\frac{\partial v_R}{\partial T} = 0$$

$$\frac{\partial v_1}{\partial T} = -\frac{\partial v_2}{\partial T}$$

Koji nam naponi stoje na raspolaganju?

$$v_{BE} = V_T \ln \frac{i_C}{I_S}$$

$$\frac{\partial v_{BE}}{\partial T} = -2 \frac{\text{mV}}{^\circ\text{C}}$$

$$V_T = \frac{kT}{q}$$

$$\frac{\partial V_T}{\partial T} = \frac{k}{q} = 0.083 \frac{\text{mV}}{^\circ\text{C}}$$

A sada da ih iskombinujemo:

$$V_{REF} = V_{BE} + a\, V_T$$

$$\frac{\partial V_{REF}}{\partial T} = 0$$

$$-2 \frac{\text{mV}}{^\circ\text{C}} + a\, 0.083 \frac{\text{mV}}{^\circ\text{C}} = 0$$

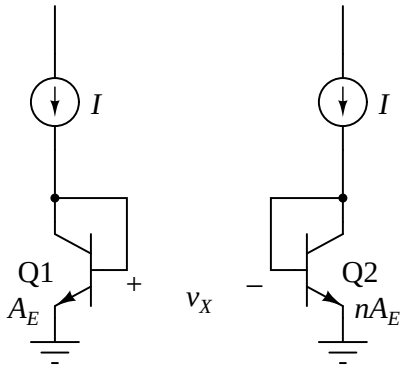
$$a = 24$$

$$V_{REF} = 0.6 \text{ V} + 24 \times 25 \text{ mV}$$

$$V_{REF} = 1.2 \text{ V}$$

Kako se meri apsolutna temperatura?

Ili: kako se generiše V_T?



Slika 1: Generisanje napona proporcionalnog apsolutnoj temperaturi.

$$v_X = v_{BE1} - v_{BE2}$$

$$v_X = V_T \left(\ln \frac{I_{C1}}{I_{S1}} - \ln \frac{I_{C2}}{I_{S2}} \right)$$

$$v_X = V_T \ln \left(\frac{I_{C1}}{I_{C2}} \frac{I_{S2}}{I_{S1}} \right)$$

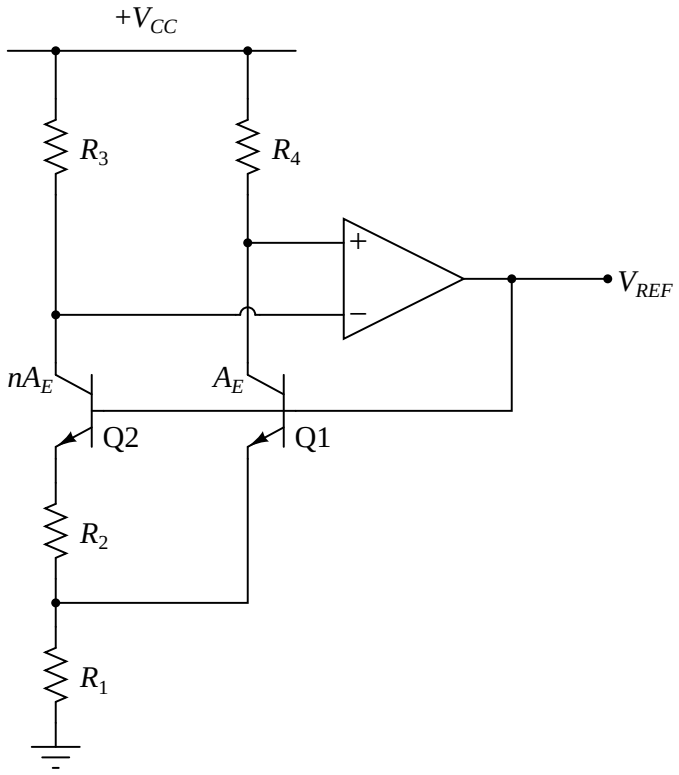
$$I_{C1} = I_{C2} = I$$

$$v_X = V_T \ln \frac{I_{S2}}{I_{S1}} = V_T \ln \frac{nA_E}{A_E}$$

$$\boxed{v_X = V_T \ln n = \left(\frac{k}{q} \ln n \right) T}$$

Ovo kolo se zove PTAT (Proportional To Absolute Temperature) Circuit.

Izvor referentnog napona sa operacionim pojačavačem



Slika 2: Izvor referentnog napona sa operacionim pojačavačem, $n > 1$.

Neka je

$$R_3 = R_4$$

tada je

$$i_{C1} = i_{C2} = i_C$$

$$V_{REF} = v_{BE1} + R_1 \left(i_{C1} + i_{C2}\right)$$

$$V_{REF} = v_{BE1} + 2\, R_1\, i_C$$

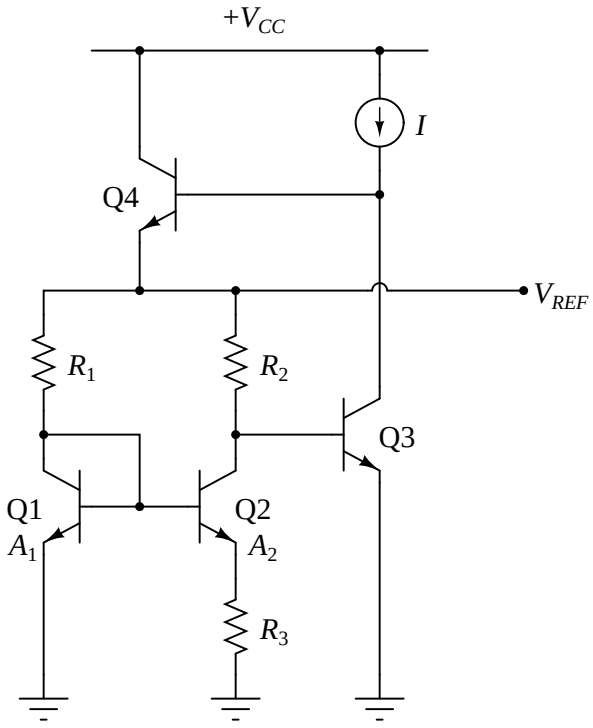
$$v_{BE1} = v_{BE2} + R_2\, i_C$$

$$R_2 i_C = v_{BE1} - v_{BE2} = V_T \ln\left(\frac{i_C}{I_{S1}}\frac{I_{S2}}{i_C}\right) = V_T \ln\frac{nA_E}{A_E} = V_T \ln n$$

$$i_C = \frac{V_T}{R_2} \ln n$$

$$\boxed{V_{REF} = V_{BE1} + 2\,\frac{R_1}{R_2}\, V_T \ln n}$$

Izvor referentnog napona sa bipolarnim tranzistorima



Slika 3: Izvor referentnog napona sa bipolarnim tranzistorima.

Malo neuobičajeno rešavanje kola . . .

$$V_{REF} = V_{BE3} + R_2\, i_{C2}$$

Koliko je i_{C2}?

$$v_{BE1} = v_{BE2} + R_3\, i_{C2}$$

$$v_{BE1} - v_{BE2} = R_3\, i_{C2} = V_T\, \ln\left(\frac{i_{C1}}{i_{C2}}\frac{I_{S2}}{I_{S1}}\right)$$

$$\frac{I_{S2}}{I_{S1}} = \frac{A_2}{A_1}$$

$$V_{BE1} \approx V_{BE3}$$

pa je

$$R_1\, i_{C1} = R_2\, i_{C2}$$

odakle je

$$\frac{i_{C1}}{i_{C2}} = \frac{R_2}{R_1}$$

Zamenom u izraz po $v_{BE1} - v_{BE2}$ dobija se i_{C2}

$$i_{C2} = \frac{v_{BE1} - v_{BE2}}{R_3} = \frac{V_T}{R_3}\, \ln\left(\frac{i_{C1}}{i_{C2}}\frac{I_{S2}}{I_{S1}}\right)$$

$$i_{C2} = \frac{V_T}{R_3}\, \ln\left(\frac{R_2}{R_1}\frac{A_2}{A_1}\right)$$

Na kraju je, zamenom u polaznu jednačinu,

$$\boxed{V_{REF} = V_{BE} + V_T \frac{R_2}{R_3} \ln\left(\frac{R_2}{R_1}\frac{A_2}{A_1}\right)}$$

Kako je jednačina oblika

$$V_{REF} = V_{BE} + a\, V_T$$

i kako zbog temperaturske stabilnosti treba da bude $a = 24$, tipične vrednosti elemenata su $A_2/A_1 = 10$, $R_2 = 10\ \mathrm{k\Omega}$, $R_1 = 1\ \mathrm{k\Omega}$ i $R_3 = 1.8\ \mathrm{k\Omega}$.