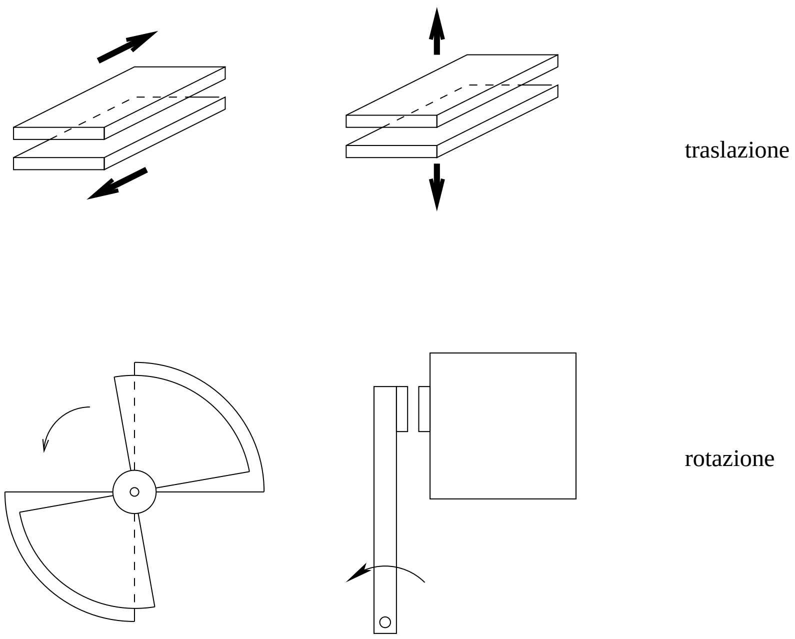
Sensori e trasduttori - figure e formule matematiche.

$$C = \varepsilon \frac{A}{d} \tag{1}$$



variazione di A variazione di d

Figura 3.1

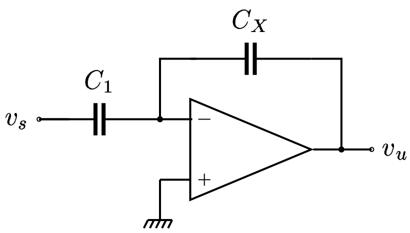


Figura 3.2

$$v_u = -\frac{Z_X}{Z_1} v_s = -\frac{C_1}{C_X} v_s \tag{2}$$

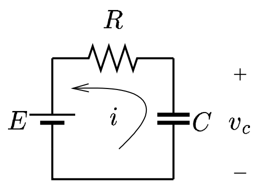


Figura 3.3

$$q = C v_C = \varepsilon \frac{A}{x} v_C \tag{3}$$

$$q \simeq q_0 + \left.\frac{\delta q}{\delta x}\right|_{x_0, v_{C0}} \Delta x + \left.\frac{\delta q}{\delta v_C}\right|_{x_0, v_{C0}} \Delta v_C \tag{4}$$

con

$$q_0 = \varepsilon \frac{A}{x_0} E, \qquad \left.\frac{\delta q}{\delta x}\right|_{x_0, v_{C0}} = -\varepsilon \frac{A}{x_0^2} E \quad \text{e} \quad \left.\frac{\delta q}{\delta v_C}\right|_{x_0, v_{C0}} = \varepsilon \frac{A}{x_0}. \tag{4'}$$

$$q \simeq \varepsilon \frac{A}{x_0} E + \varepsilon \frac{A}{x_0} \left(\Delta v_C - \frac{E}{x_0} x \right) \tag{5}$$

$$i = \frac{\mathrm{d}q}{\mathrm{d}t} = \varepsilon \frac{A}{x_0} \left(\frac{\mathrm{d}v_C}{\mathrm{d}t} - \frac{E}{x_0} \cdot \frac{\mathrm{d}x}{\mathrm{d}t} \right). \tag{6}$$

Essendo, per le variazioni, $Ri = -v_c$,

$$i = \varepsilon \frac{A}{x_0} \left(-R \frac{\mathrm{d}i}{\mathrm{d}t} - \frac{E}{x_0} \cdot \frac{\mathrm{d}x}{\mathrm{d}t} \right) \tag{6'}$$

$$I(s) \left(1 + R\varepsilon \frac{A}{x_0} s \right) = -\varepsilon \frac{A}{x_0^2} E s X(s) \tag{7}$$

$$W(s) = R \frac{I(s)}{X(s)} = -\frac{\varepsilon \frac{A}{x_0^2} E s}{1 + R\varepsilon \frac{A}{x_0} s} = -\frac{ks}{1 + \tau s} \tag{8}$$

con

$$k = \varepsilon \frac{A}{x_0^2} E, \quad \tau = R\varepsilon \frac{A}{x_0} \quad \left(f_p = \frac{1}{2\pi\tau} \right).$$

$$W(s) \simeq -ks \tag{8'}$$

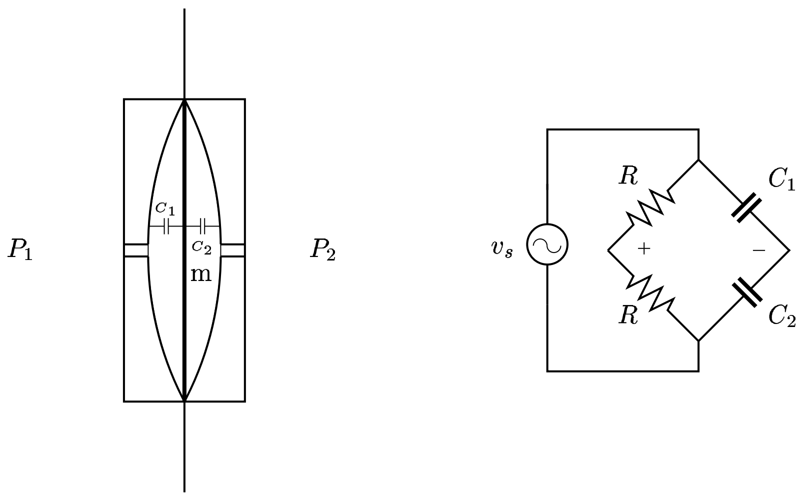


Figura 3.4

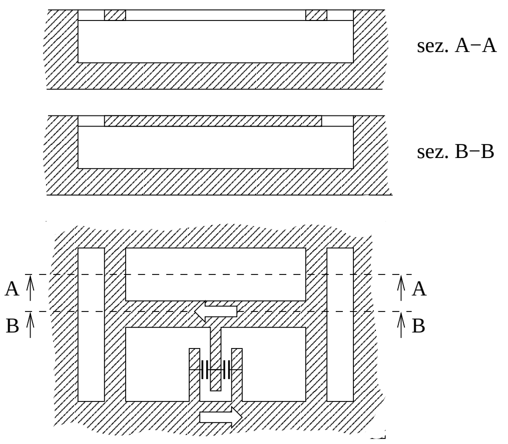


Figura 3.5

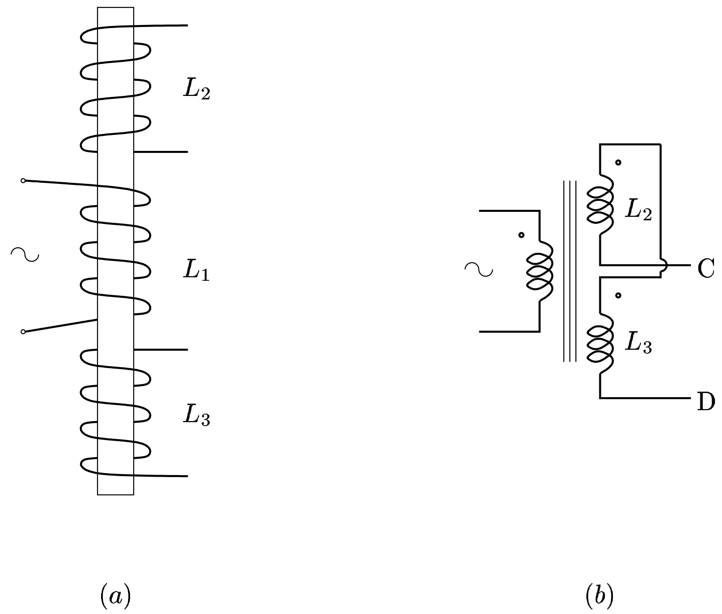


Figura 3.6

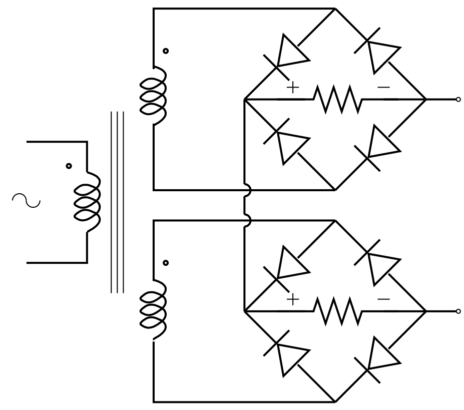


Figura 3.7

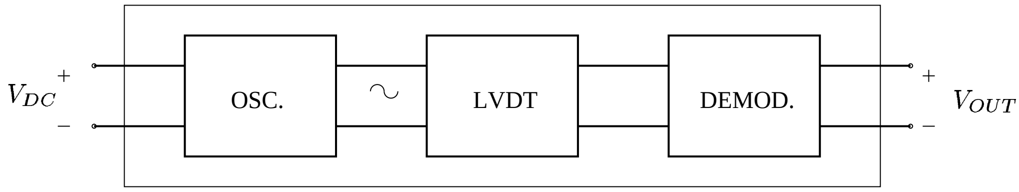


Figura 3.8

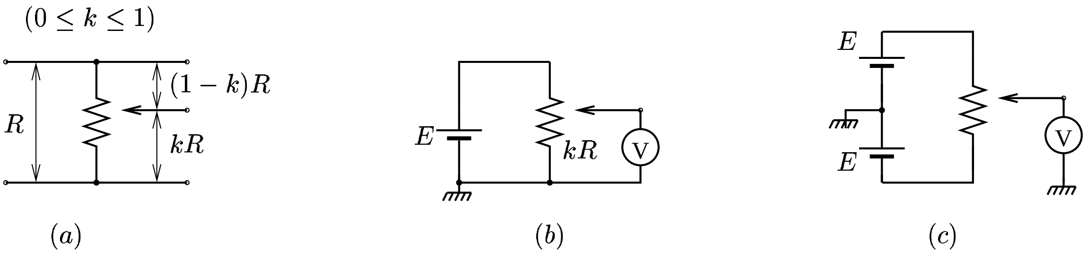


Figura 3.20

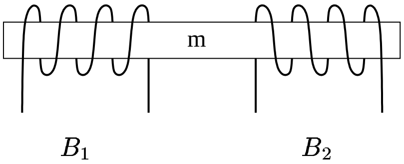


Figura 3.21

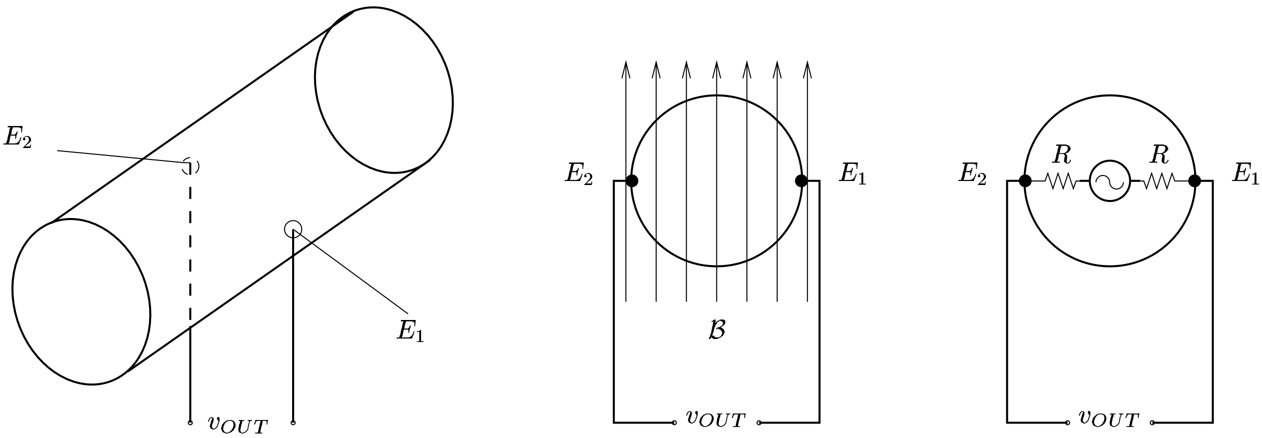


Figura 3.22

$$R = \rho \frac{l}{S} \tag{9}$$

$$V = lS = \pi l \frac{d^2}{4} \tag{10}$$

$$\Delta V = \frac{\pi}{4}(d^2 \Delta l + 2ld\Delta d) = 0 \tag{11}$$

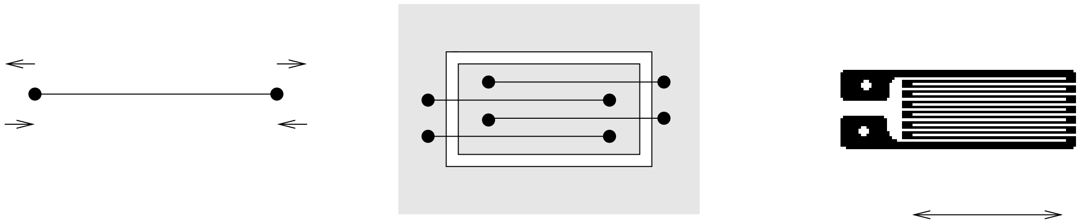
$$\frac{\Delta l}{l} = -2\frac{\Delta d}{d} \tag{12}$$

$$R = \frac{4\rho}{\pi}\frac{l}{d^2} \tag{13}$$

$$\Delta R = 4\frac{\rho}{\pi}\left(\frac{\Delta l}{d^2} - \frac{2dl\Delta d}{d^4}\right) \tag{14}$$

$$\Delta R = 4\frac{\rho}{\pi d^2}\left(\Delta l - \frac{2l\Delta d}{d}\right) = 2\frac{R}{l}\Delta l \quad \Rightarrow \frac{\Delta R}{R} = 2\frac{\Delta l}{l} = 2\varepsilon \tag{15}$$

$$\frac{\Delta R}{R} = F\varepsilon \tag{16}$$



(a) (b) (c)

Figura 3.23

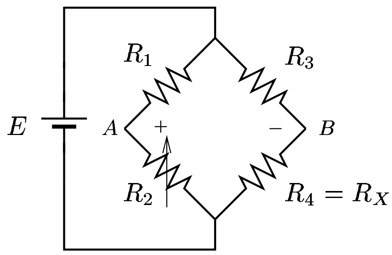


Figura 3.24

$$V_{AB} = E\left(\frac{R_X}{R_3 + R_X} - \frac{R_2}{R_1 + R_2}\right) = 0 \tag{31}$$

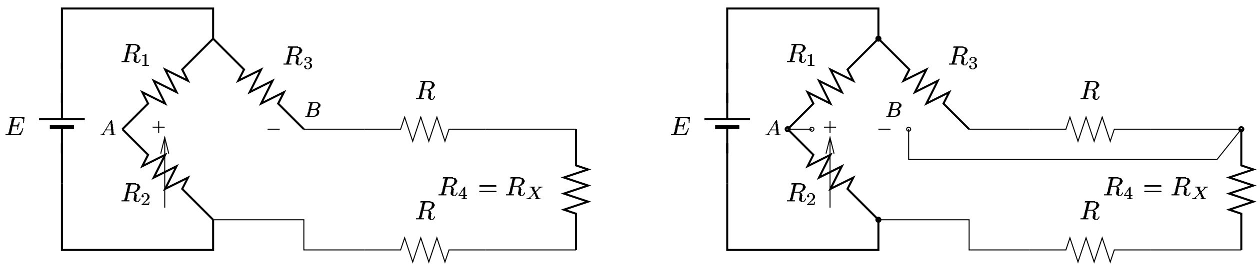
$$\frac{R_X}{R_3 + R_X} = \frac{R_2}{R_1 + R_2} \tag{32}$$

$$V_{AB} = E\left(\frac{R_X + \Delta R_X}{R_X + \Delta R_X + R_3} - \frac{R_2}{R_1 + R_2}\right) \tag{33}$$

$$\begin{aligned} \frac{V_{AB}}{E} &= \left(\frac{R_X + \Delta R_X}{R_X + \Delta R_X + R_3} - \frac{R_X}{R_3 + R_X}\right) = \left(\frac{1 + \Delta R_X/R_X}{1 + \Delta R_X/R_X + R_3/R_G} - \frac{1}{1 + R_3/R_X}\right) \\ &= \frac{\frac{\Delta R_X}{R_X}\frac{R_3}{R_X}}{\left(1 + \frac{R_3}{R_X}\right)\left(1 + \frac{\Delta R_X}{R_X} + \frac{R_3}{R_X}\right)} \end{aligned} \tag{34}$$

$$
\begin{aligned}
\frac{V_{AB}}{E} &\simeq \frac{\dfrac{\Delta R_X}{R_X}}{2\left(2+\dfrac{\Delta R_X}{R_X}\right)} = \frac{\dfrac{\Delta R_X}{R_X}}{4\left(1+\dfrac{\Delta R_X}{2R_X}\right)} = \frac{\dfrac{\Delta R_X}{R_X}}{4\left(1+\dfrac{F\varepsilon}{2}\right)} \\
&\simeq \frac{F\varepsilon}{4\left(1+\dfrac{F\varepsilon}{2}\right)} \simeq \frac{F\varepsilon}{4} \quad \text{se} \quad F\varepsilon/2 \ll 1 \quad \left(\frac{\Delta R_X}{2R_X} \ll 1\right)
\end{aligned}
\tag{35}
$$

$$
\frac{V_{AB}}{E} = \left(\frac{R_X+\Delta R_X}{2R_X} - \frac{1}{2}\right) = \frac{\Delta R_X}{2R_X} = \frac{F\varepsilon}{2} \tag{36}
$$



(a) (b)

Figura 3.25

$$
R(T) = R_0 \left\{1 + \alpha\left[T + \delta\left(1 - \frac{T}{100}\right)\frac{T}{100} + \beta\left(1 - \frac{T}{100}\right)\left(\frac{T}{100}\right)^3\right]\right\} \tag{41}
$$

con

$$
\begin{aligned}
\alpha &= 0.00385\ ^\circ\mathrm{C}^{-1} \\
\beta &: \text{costante di Van Dusen} \qquad \begin{array}{ll} \beta = 0 & T > 0 \\ \beta \neq 0 & T < 0 \end{array} \\
\delta &= 1.491 \\
R_0 &= R(0\ ^\circ\mathrm{C})
\end{aligned}
$$

$$
R(T) = R_0(1 + \alpha T) \tag{42}
$$

$$
\ln(R) = a_0 + \frac{a_1}{T} + \frac{a_2}{T^2} + \frac{a_3}{T^3} \tag{43}
$$

$$
\ln(R) = a_0 + \frac{a_1}{T} \tag{44}
$$

$$
R(T) = R_0\ \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right] \tag{45}
$$

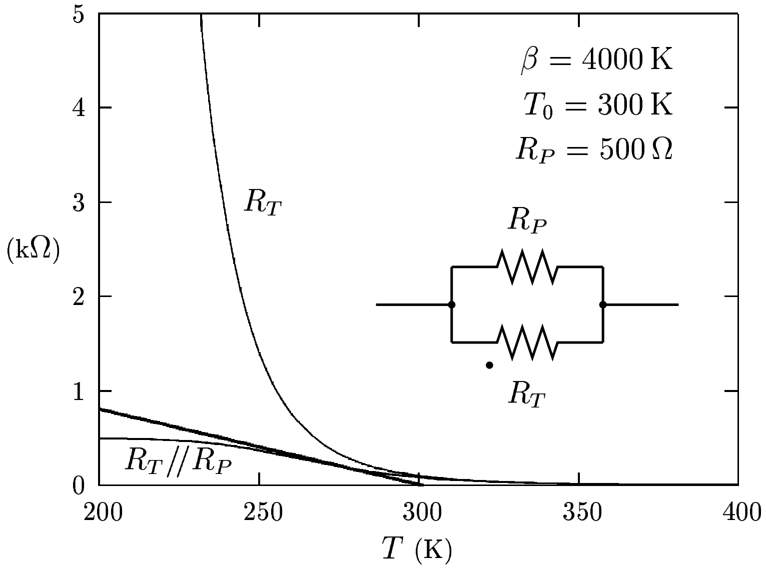


Figura 3.26

$$E^2 = A + B\sqrt{v} \quad (+Cv) \tag{46}$$

$$E = C_1(T_1 - T_2) + C_2\left(T_1^2 - T_2^2\right) \tag{47}$$

$$\alpha = \frac{dE}{dT_1} = C_1 + 2C_2T_1 \tag{48}$$

$$V_U = -R_3(I_2 - I_1) = \alpha R_3(T_1 - T_2) \tag{49}$$

$$V_U = -R_3(I_2 - I_1 + I_3) = \alpha R_3(T_1 - T_2 + T_3) \qquad \text{con} \qquad I_3 = \alpha T_3 \tag{50}$$

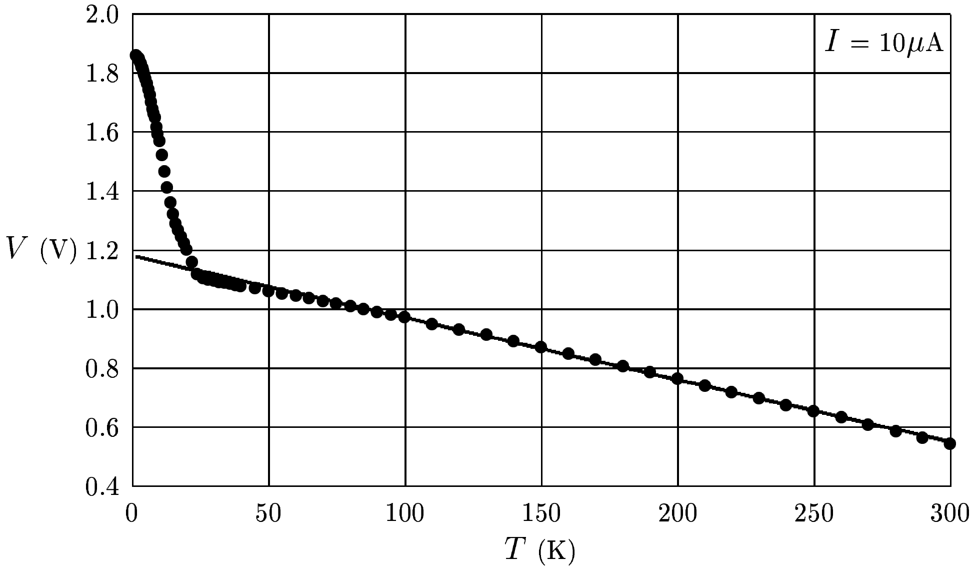
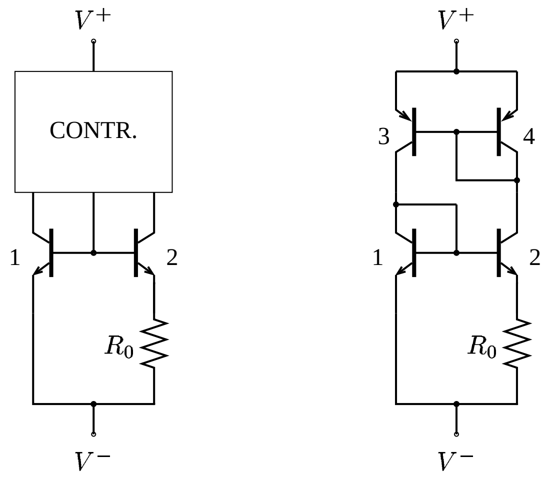


Figura 3.27



(a) (b)

Figura 3.28

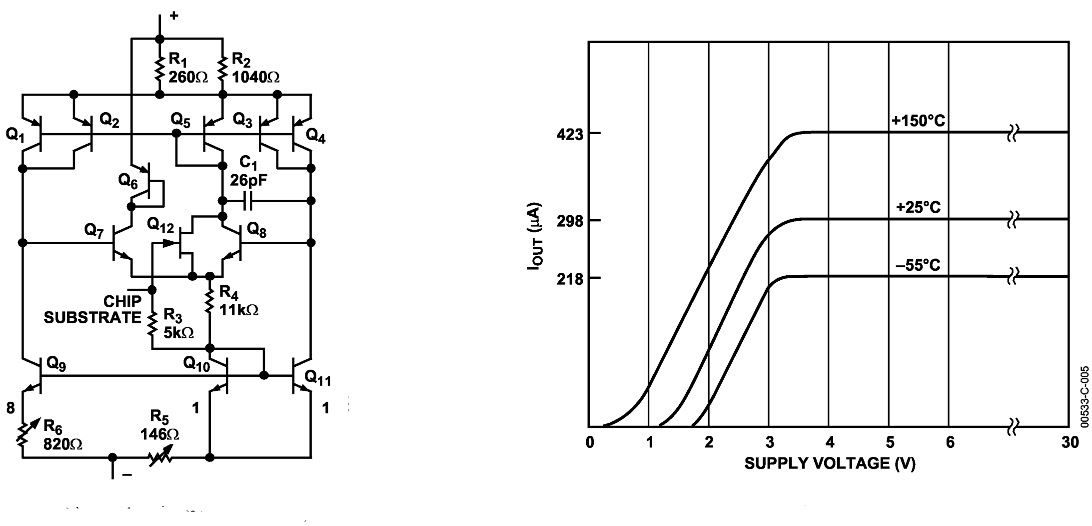
$$I_{E1} \simeq I_{C1} \simeq \alpha_{F1} I_{ES1} e^{\dfrac{V_{BE1}}{\eta V_T}} \qquad \text{e} \qquad I_{E2} \simeq I_{C2} \simeq \alpha_{F2} I_{ES2} e^{\dfrac{V_{BE2}}{\eta V_T}} \tag{51}$$

$$\frac{I_{C1}}{I_{C2}} = 1 = He^{\dfrac{V_{BE1} - V_{BE2}}{\eta V_T}} \tag{52}$$

$$\log \frac{1}{H} = \frac{V_{BE1} - V_{BE2}}{\eta V_T} \tag{53}$$

$$V_{BE1} - V_{BE2} = \eta V_T \log \frac{1}{H} = \eta \frac{kT}{q} \log \frac{1}{H} \propto T \tag{54}$$

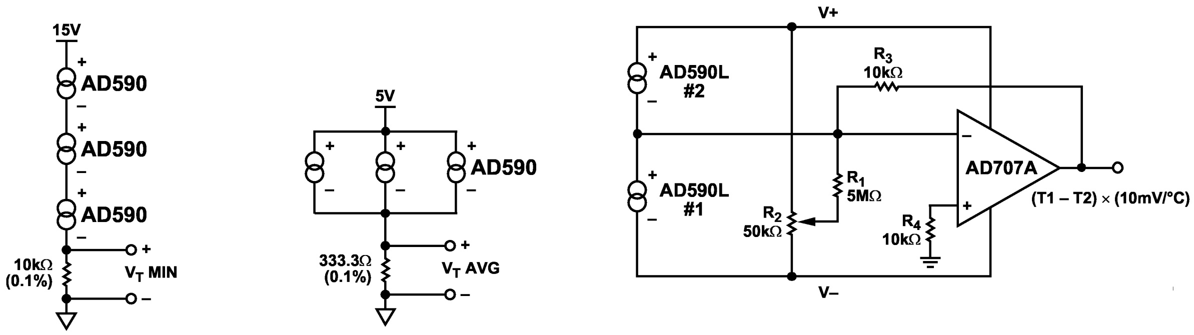
$$V_{BE1} - V_{BE2} = R_0 I_{C2} \propto T \tag{55}$$



(a) (b)

(da `www.analog.com`)

Figura 3.29



(a) (b) (c)

(da `www.analog.com`)

Figura 3.30

$$V_U = -R_3(I_2 - I_1) = -\alpha R_3(T_2 - T_1) = \alpha R_3(T_1 - T_2) \tag{56}$$

$$\begin{aligned} V_U = -R_3(I_2 - I_1 + I_3) &= -\alpha R_3(T_2 - T_1 + T_R) = \alpha R_3(T_1 - T_2 - T_R) \\ \text{con } I_R &= \alpha T_R \end{aligned} \tag{57}$$