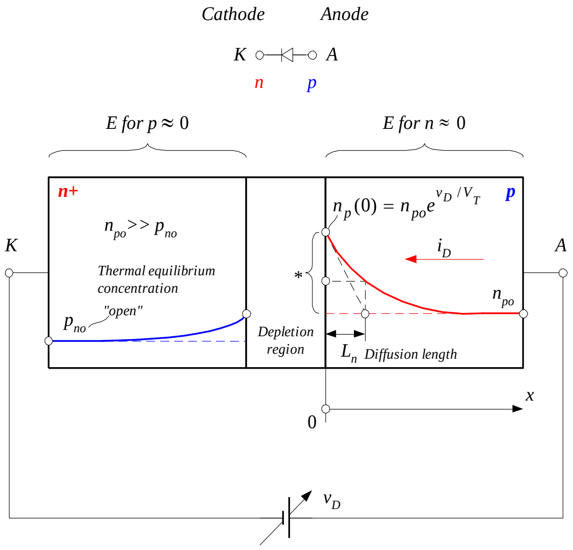
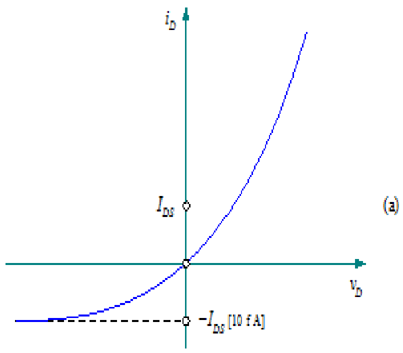
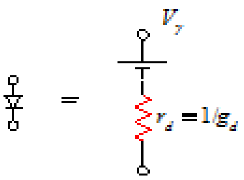
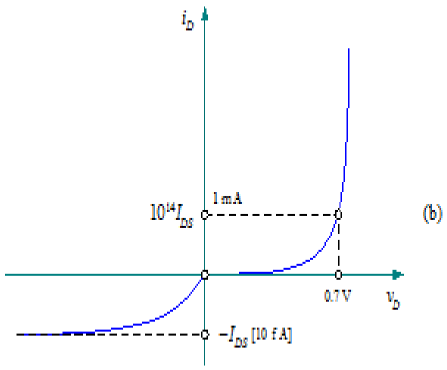
**Formula sheet – Introduction to analog electronic circuits**

## Diode




$$|i_D| = j_D A = D_n |q| \frac{\overbrace{n_p(0) - n_{po}}^{*}}{L_n} A$$

(1) $$= D_n q \frac{\overbrace{n_{po} e^{v_D/V_T} - n_{po}}^{*}}{L_n} A$$

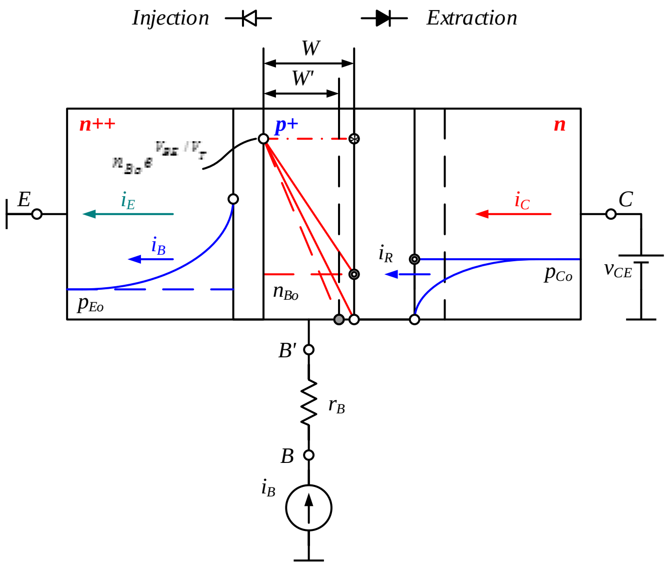
(3) $$g_d \equiv \frac{i_d}{v_d} \equiv \left.\frac{\mathrm{d}i_D}{\mathrm{d}v_D}\right|_Q$$

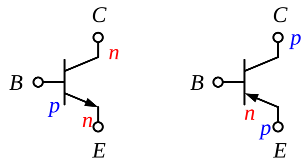
$$\underbrace{\frac{A D_n q n_{po}}{L_n}}_{\equiv I_{DS}} (e^{v_D/V_T} - 1) = I_{DS}(e^{v_D/V_T} - 1)$$

(2) $$V_T = \left.\frac{kT}{q}\right|_{T=300^\circ K} \approx 26\,\mathrm{mV}$$

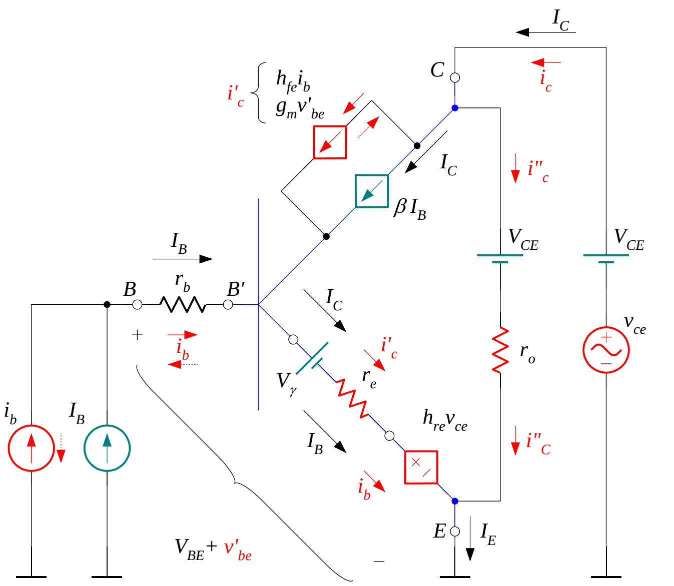
(4) $$r_d \equiv \frac{1}{g_d}$$

**BJT**




Large-signal equivalent circuit (model):




(1) $$|i_C| = D_n|q|\frac{n_{Bo}e^{v_{BE}/V_T}}{w}A_{BE} + i_R \Big|$$

(4) $$\beta_F \equiv \frac{i_C}{i_B} = \frac{D_n|q|\frac{n_{Bo}}{w}A_{BE}\,e^{v_{BE}/V_T}}{\frac{D_p|q|A_{BE}\,p_{Eo}}{L_{pE}}\,e^{v_{BE}/V_T}}$$

(2) $$|i_B| = \underbrace{\frac{D_p|q|A_{BE}\,p_{Eo}}{L_{pE}}}_{i_{BS}}(e^{v_{BE}/V_T} - 1)\Big|_{i_B >> i_{BS}}$$

(5) $$\alpha_F \equiv \frac{i_C}{i_E}$$

(3) $|i_E| = i_C + i_B = I_{CS}\, e^{v_{BE}/V_T} + I_{BS}\, e^{v_{BE}/V_T}$

(6) $h_{fe} \equiv \left.\frac{i_c}{i_b}\right|_{Q,\, v_{ce}=0} = \beta_F$

(7) $\alpha_f \equiv \left.\frac{i_c}{i_e}\right|_{Q,\, v_{ce}=0}$

(10) $\frac{1}{h_{ie}} \equiv \left.\frac{i_b}{v_{be}}\right|_{v_{ce}=0}$

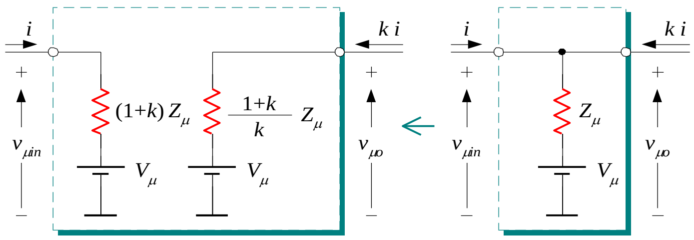
(8) $\frac{1}{r_e} \equiv \left.\frac{i_e}{v_{be}}\right|_{v_{ce}=0}$

(11) $h_{oe} \equiv \frac{1}{r_{oe}} \equiv \left.\frac{i_c}{v_{ce}}\right|_{Q,\, i_b=0}$

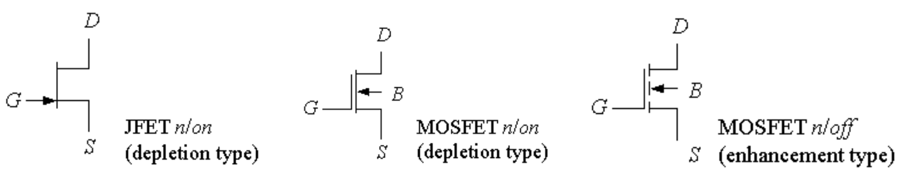
(9) $g_m \equiv \left.\frac{i_c}{v_{be}}\right|_{Q,\, v_{ce}=0}$

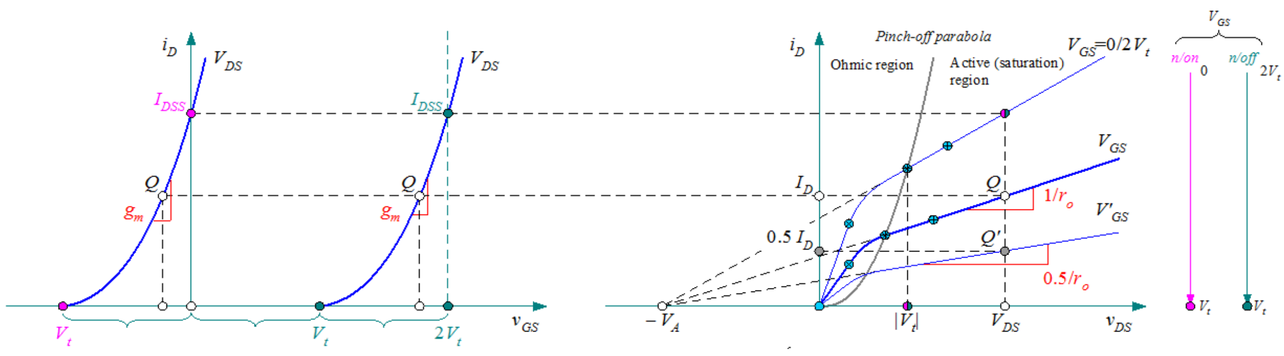
(12) $h_{re} \equiv \left.\frac{v_{be}}{v_{ce}}\right|_{Q,\, i_b=0}$

(12) Miller theorem for currents:




**FET**



$$i_D = \frac{I^*_{DSS}}{V_t^2(1+V^*_{DS}/V_A)}(v_{GS}-V_t)^2(1+v_{DS}/V_A)$$

(1) $$= \underbrace{I^*_{DSS}\frac{1+v_{DS}/V_A}{1+V^*_{DS}/V_A}}_{I_{DSS}}(1-v_{GS}/V_t)^2$$

(3) $$|g_m| \equiv \left.\frac{i_d}{v_{gs}}\right|_{Q,v_{ds}=0}$$

$$= I_{DSS}(1-v_{GS}/V_t)^2$$

(2) $V_{DS} \geq V_p = V_{GS} - V_t$ (active region)

(4) $$r_o = \left.\frac{V_A+V_{DS}}{I_D}\right|$$

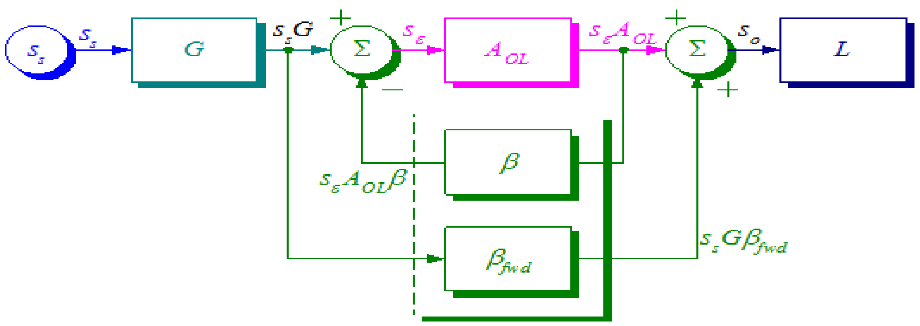
**Differential Amplifier**

(1) $v_\varepsilon = v_a - v_b$

(2) $v_{cm} = \dfrac{v_a+v_b}{2}$

(3) $CMRR = 20\log_{10}\left|\dfrac{A_{v\varepsilon}}{A_{vcm}}\right|$

**Feedback**




(1) $$A_{CL} \equiv \frac{s_o}{s_s} = G\frac{A_{OL}}{1+A_{OL}\beta} + G\beta_{fwd} =$$

(2) $G \equiv \dfrac{s'_\varepsilon}{s_s}$ (3) $\beta_{fwd} \equiv \dfrac{s'_o}{s'_\varepsilon}$ (4) $A_{OL} \equiv \dfrac{s''_o}{s_\varepsilon}$ (5) $\beta \equiv -\dfrac{s''_\varepsilon}{s''_o}$ (6) $RR \equiv A_{OL}\beta \equiv -\dfrac{s''_\varepsilon}{s_\varepsilon}$

Blackman formula:

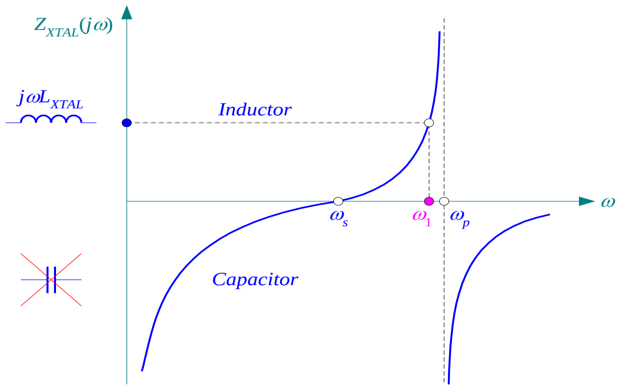
(7) $$R_x = R'_x\frac{1+RR_{SC}}{1+RR_{OC}} = R'_x\frac{DSF_{SC}}{DSF_{OC}}$$

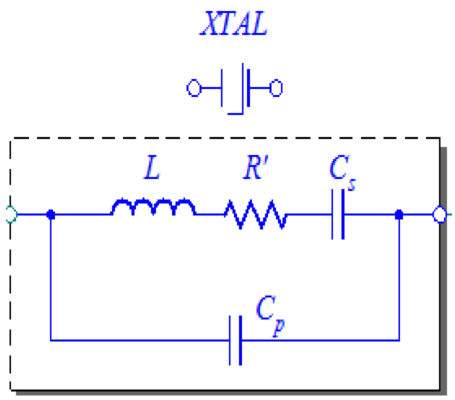
**Positive feedback oscillators**

*Barkhausen criterion*

(1) $H(s) = \dfrac{A_{OL}}{1-A_{OL}\beta(s)}$

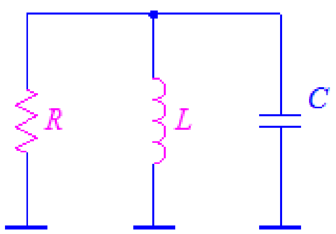
(2) $A_{OL}\beta(j\omega_1) = 1$

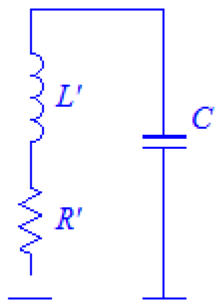



$$\varpi_s\big|_{R'=0} = \frac{1}{\sqrt{LC_s}}$$

**Parallel RLC circuit**



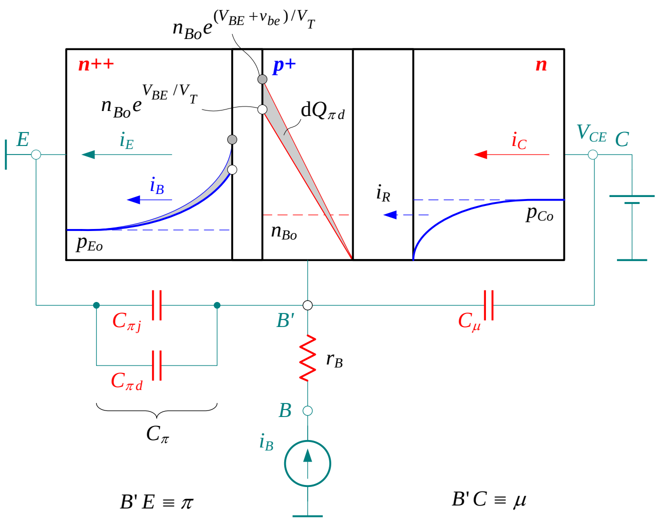




$$\omega_0 = \frac{1}{\sqrt{LC}}\ ; \quad Q = \frac{R}{\omega_0 L}; \quad \alpha = \frac{\omega_0}{2Q} = \frac{1}{2RC};$$

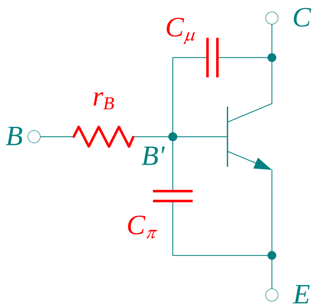
$$R = R'(1+\frac{\omega^2 L'^2}{R'^2})\Big|_{\omega_0} = R'(1+Q^2)$$

$$L = L'(1+\frac{R'^2}{\omega^2 L'^2})\Big|_{\omega_0} = L'(1+\frac{1}{Q^2})$$

*High frequency response*




$$C_{\pi j} \equiv \frac{dQ_{\pi j}}{dv_{\pi}} \qquad C_{\pi d} \equiv \frac{dQ_{\pi d}}{dv_{\pi}} \qquad C_{\mu} \equiv \frac{dQ_{\mu j}}{dv_{\mu}}$$




Miller theorem for voltage: