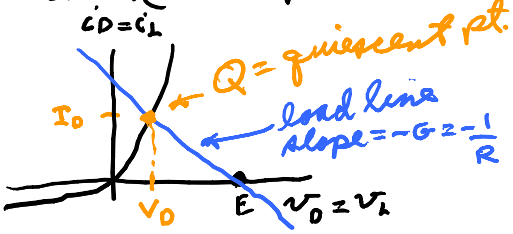
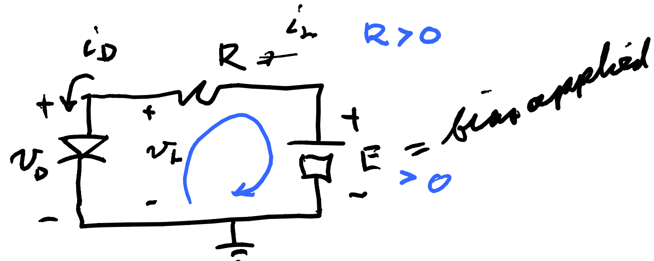
For next time: appendix B, pp. B-1 through B-7
BJT biasing, pp. 432-436
BJT hybrid $\pi$, p. 488

EE 303
02/02/10

## Load line p. 154



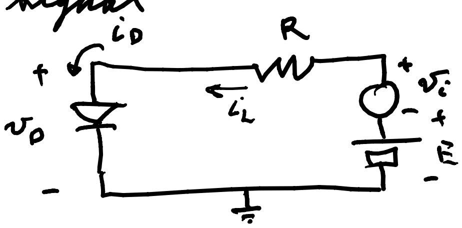



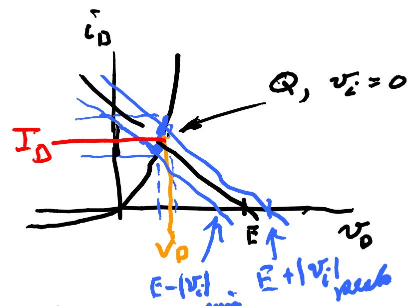

KVL: $-v_L - R i_L + E = 0 \Rightarrow i_L = \frac{E - v_L}{R}$

KVL: $v_L = v_D$

KCL: $i_D = i_L$

## Put in signal




desire to know changes in $i_D$, call this signal current, $i_d$, when $v_i$ changes
i.e. desire current due to signal.

$i_D = I_D + i_d$ ; $i_D$ = total current
$I_D$ = bias current
$i_d$ = signal current

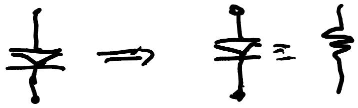
$v_D = V_D + v_d$

$i_D = f(v_D)$ make a Taylor series expansion about $V_Q = V_D$

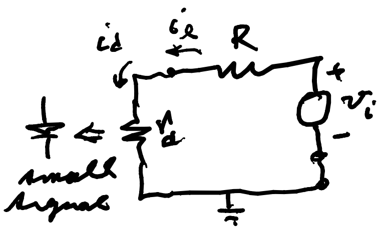
$$= f(V_D) + \left.\frac{df(v_D)}{dv_D}\right|_{v_D = V_D} (v_D - V_D) + \underbrace{\frac{1}{2!}\frac{d^2 f(v_D)}{dv_D^2}(v_D - V_D)^2 + \ldots}_{\text{ignore if small signal}}$$

$$\left.\begin{aligned} i_D - f(V_D) &= i_D - I_D = i_d \\ v_D - V_D &= v_d \end{aligned}\right\} \quad i_d = \left.\frac{df(v_D)}{dv_D}\right|_Q \cdot v_d = g_d \cdot v_d$$

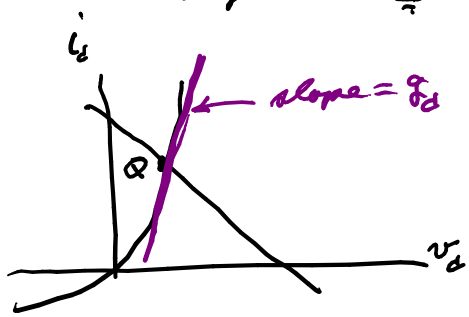
for small signal



$r_d = \frac{1}{g_d}$



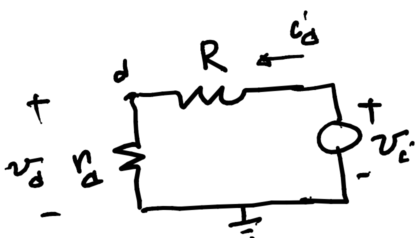

equivalent circuit for small signals




$i_L = I_L + i_R \Rightarrow i_L - I_L = i_R$

by KCL $= i_d$

can analyze for small signal behavior




$(R + r_d)\, i_d = v_i$

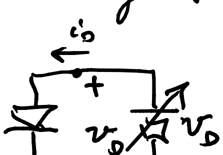
$$i_d = \frac{v_i}{R + r_d}$$

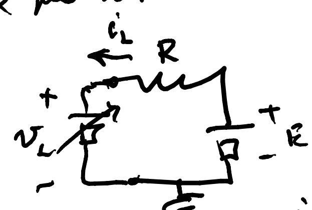
$$v_d = \frac{r_d}{R + r_d} \cdot v_i$$

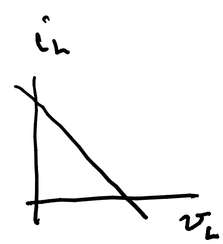
power into $v_i$:

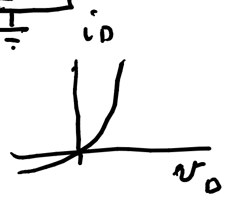
$$v_i(-i_d) = -\frac{v_i^2}{R + r_d}$$

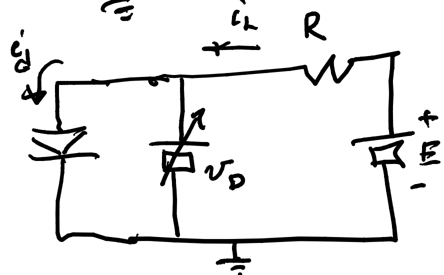
To find the Q point in Spice

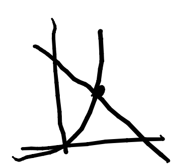


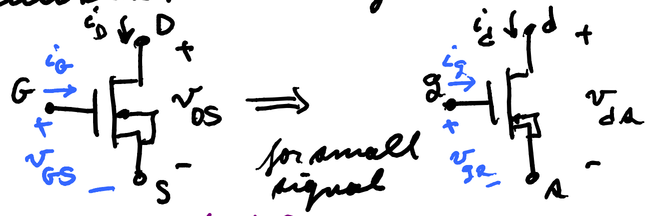



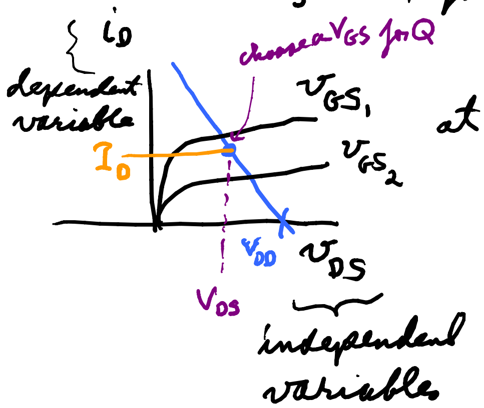



# Equivalent circuit for a transistor NMOS




at DC $\quad i_G = 0 \Rightarrow i_g = 0$ if near DC

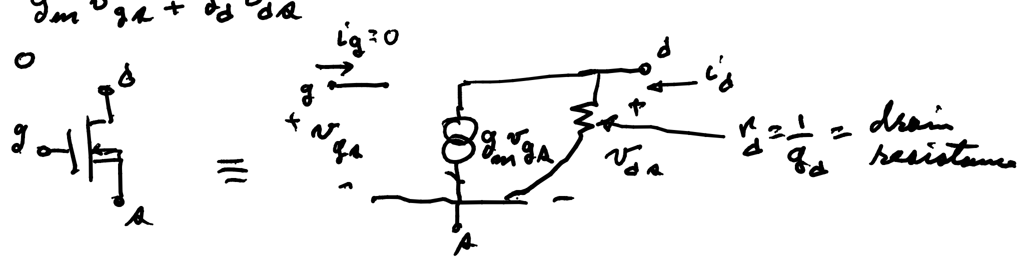
$$v_{DS} = V_{DS} + v_{ds}$$
$$i_D = I_D + i_d \qquad ; \; Q = (V_{GS}, V_{DS}) = \text{bias point of transistor}$$
$$v_{GS} = V_{GS} + v_{gs}$$

m = mutual

$$i_D = f(v_{GS}, v_{DS}) = \underbrace{f(V_{GS}, V_{DS})}_{I_D} + \underbrace{\left.\frac{\partial i_D}{\partial v_{GS}}\right|_Q}_{g_m} \underbrace{(v_{GS} - V_{GS})}_{v_{gs}}$$
$$+ \underbrace{\left.\frac{\partial i_D}{\partial v_{DS}}\right|_Q}_{g_d} \underbrace{(v_{DS} - V_{DS})}_{v_{ds}} + \frac{1}{2!}\left.\frac{\partial^2 i_D}{\partial v_{GS}^2}\right|_Q (v_{GS} - V_{GS})^2$$
$$+ \frac{1}{2!}\left.\frac{\partial^2 i_D}{\partial v_{DS}^2}\right|_Q (v_{DS} - V_{DS})^2$$
$$+ \left.\frac{\partial^2 i_D}{\partial v_{GS}\partial v_{DS}}\right|_Q (v_{GS} - V_{GS})(v_{DS} - V_{DS}) + \cdots$$

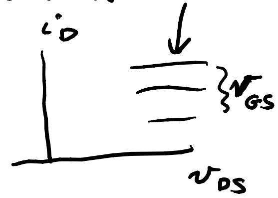
Throw away for small signals

$$i_d = g_m v_{gs} + g_d v_{ds}$$
$$i_g = 0$$




To find these parameters, $g_m$ & $g_d$, when in saturation

$$i_D = \frac{KP}{2} \cdot \frac{W}{L} (v_{GS} - VTO)^2 (1 + \lambda v_{DS})$$



for $g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{DS}=V_{DS},\, v_{GS}=V_{GS}} = 2\left(\frac{KP}{2}\frac{W}{L}\right)(v_{GS}-VTO)(1+\lambda v_{DS})\Big|_Q$

$= 2 \cdot \left.\frac{i_D}{(v_{GS}-VTO)}\right|_Q = 2 \cdot \frac{I_D}{(V_{GS}-VTO)}$

for $g_d = \left.\frac{\partial i_D}{\partial v_{DS}}\right|_Q = \frac{KP}{2}\frac{W}{L}(v_{GS}-VTO)^2 \cdot \lambda\Big|_Q \approx I_D \cdot \lambda$