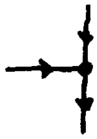
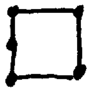
CHAPTER 0

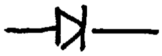
Revision of Electronics 1

A : Leis de Kirchhoff

$\sum I = 0$  cargas não desaparecem

$\sum V = 0$  voltar ao início : mesma tensão

B :

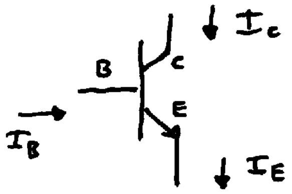


diodo

aberto : $\Delta V \sim 0.7$, $I > 100\ \mu A$

fechado : $I \sim 10^{-14}\ A$ (~ 0)

C : (junction) transistor is current amplifier



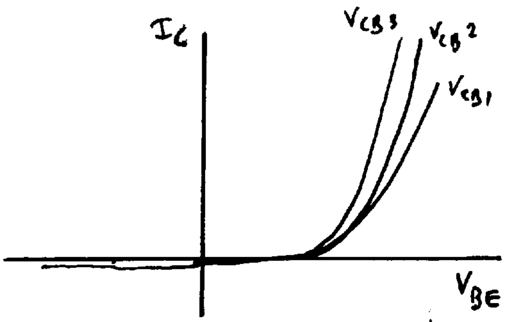
$$\left.\begin{aligned} I_E &= (\beta+1)\, I_B \\ I_c &= \beta\, I_B \\ I_c &= \alpha\, I_E \end{aligned}\right\} \quad \left(\text{Kirchhoff} \quad I_c + I_B = I_E\right)$$

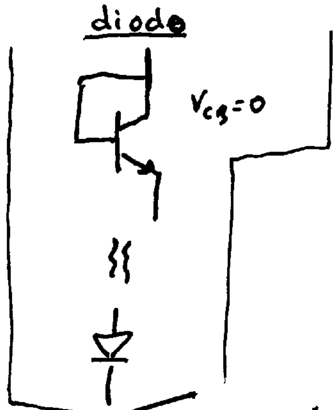
$$\alpha = \frac{\beta}{\beta+1} \approx 1$$

typical : $\beta = 100$, $\alpha = 0.99$

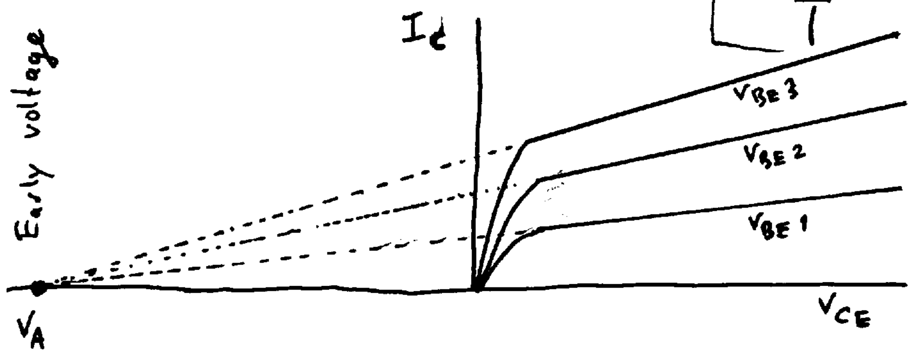
D : Ebers - Moll :

$$I_c = \underbrace{I_0\left[\exp\left(\tfrac{q}{kT} V_{BE}\right) - 1\right]}_{\text{diodo}} + \underbrace{I_1\left[\exp\left(\tfrac{q}{kT} V_{CB}\right) - 1\right]}_{\text{perturb.}}$$





causa não saturação V_A, etc.



E : simplificação

$$I_E = I_0 \left[\exp\left(\frac{q}{KT} V_{BE} \right) - 1 \right]$$

$I_0 \sim 10^{-14}$ A   reverse-bias-leakage current
($V_{BE} = -\infty$, $I_E = -I_0$)

$$I_E \sim I_0 \exp\left(\frac{q}{KT} V_{BE} \right) = I_0 \exp\left(V_{BE}/V_T \right) \qquad V_T \equiv \frac{KT}{q}$$

corrente típica : 1 mA , $T = 300K$ ($V_T = 26$ mV)

$V_{BE} = V_T \ln\left(I_E/I_0 \right)$:

0.60 V ⟷ 100 μA
0.66 V ⟷ 1 mA
0.72 V ⟷ 10 mA
0.78 V ⟷ 100 mA

$$\boxed{\text{Transístor aberto} \longleftrightarrow V_{BE} = 0.7 \text{ V}}$$

F : Resistência de entrada

$$\boxed{r_i \equiv 1 \Big/ \frac{\partial I_i}{\partial V_i}}$$

dinâmico

example : $V_i = V_{BE}$
$I_i = I_B = \frac{1}{(\beta+1)} I_E$

$$\frac{\partial I_i}{\partial V_i} = \frac{1}{(\beta+1)} \frac{\partial I_E}{\partial V_{BE}} = \frac{I_0}{(\beta+1) V_T} \exp\left(\frac{V_{BE}}{V_T} \right) = \frac{I_E}{(\beta+1) V_T}$$

$$r_i = (\beta+1) \frac{V_T}{I_E} = (\beta+1) r_e = r_\pi$$

2.6 kΩ

$$\boxed{R_i \equiv 1 \Big/ \frac{I_i}{V_i}}$$

estático

example : $R_i = 1 \Big/ \frac{I_E}{(\beta+1) V_{BE}}$

70 kΩ

example com $\beta = 100$, $V_{BE} = 0.7$, $1 mA = I_E$

note : $g_m \equiv \frac{\partial I_{out}}{\partial V_i} = \frac{\beta \, \partial I_i}{\partial V_i} = \frac{\beta}{\beta+1} \cdot \frac{1}{r_e}$

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r_e is a <u>parameter</u> that describes the <u>dynamic</u> response to a signal input (δV_i). It is not a real resistance !

$v_i = \delta V_i$

$$r_e \equiv V_T / I_E$$

(depends on bias I_E and temperature)

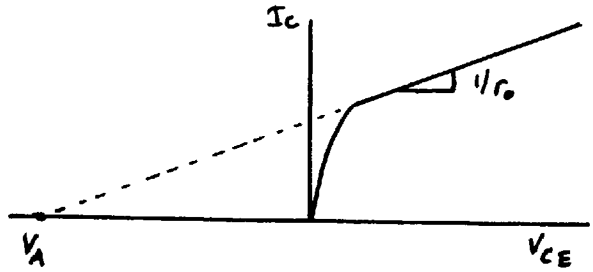
G : Resistência de saida

$$\boxed{r_o \equiv 1 \Big/ \frac{\partial I_o}{\partial V_o}}$$

exemplo : transistor

$I_o = I_c$

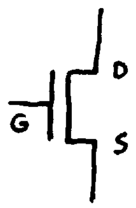
$V_o = V_c = V_{CE}$



$$\frac{\partial I_o}{\partial V_o} = \frac{\partial I_c}{\partial V_{CE}} = \frac{I_c}{V_{CE} + V_A}$$

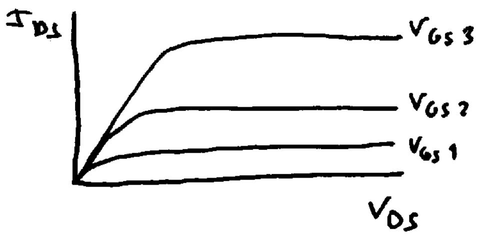
$$r_o \sim \frac{V_A}{I_c} \quad , \quad ex \quad \frac{200\ V}{1\, mA} = 200\ k\Omega$$

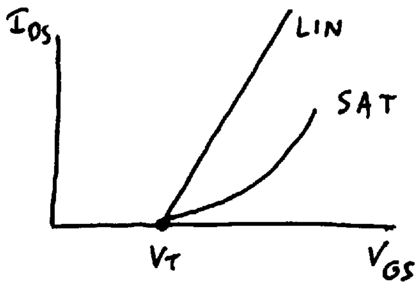
H : Field - Effect Transistor



LIN : $I_{ds} = C_{ox}\, \mu \frac{W}{L} \left(V_{GS} - V_T \right) V_{DS}$

SAT : $I_{ds} = \frac{1}{2} C_{ox}\, \mu \frac{W}{L} \left(V_{GS} - V_T \right)^2$

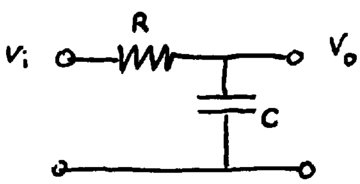




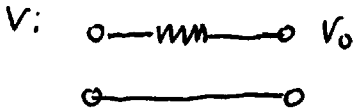
$$r_o = 1 \Big/ \frac{\partial I_{DS}}{\partial V_{DS}} = \infty \qquad r_i = 1 \Big/ \frac{\partial I_G}{\partial V_{GS}} = \infty \quad (I_{GS} = 0)$$

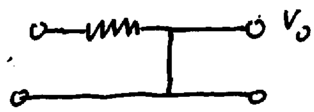
I : Filtros

"em altas frequências um C é um curto-circuito"
"em baixas frequências um C é um circuito-aberto"



LPF (low- pass filter)



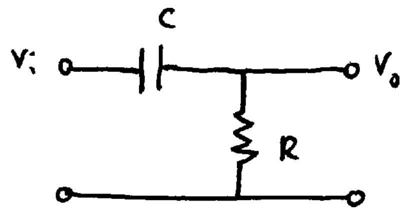


baixas - freq. $\longleftrightarrow$ altas - freq.

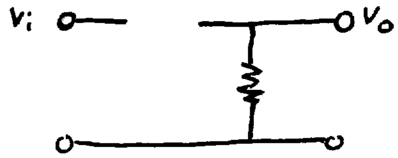
$V_o = V_i \qquad f_c \qquad V_o = 0$

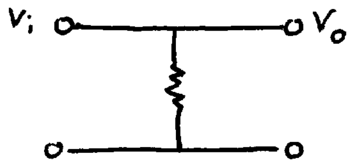
ponto de comutação : $f_c = \dfrac{1}{2\pi RC}$

(p 902 Sedra)



(HPF) (high-pass filter)



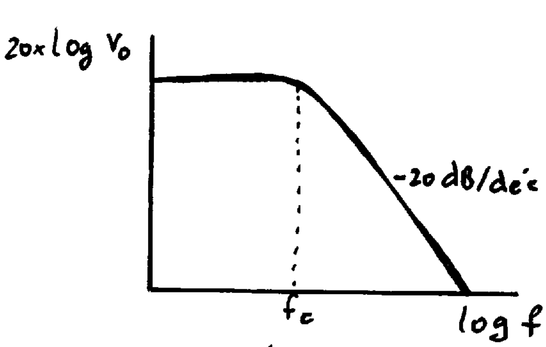


baixas - freq. ⟷ altas - freq

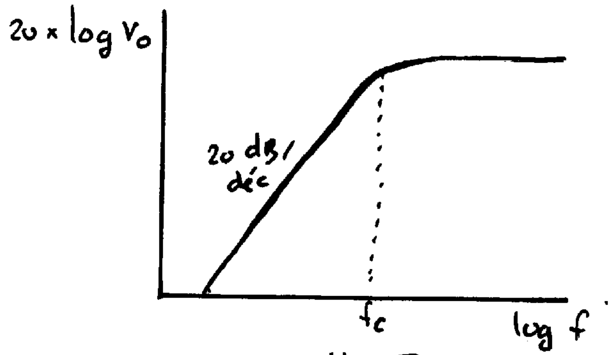
$V_o = 0$ f_c $V_o = V_i$

ponto de comutação $f_c = \frac{1}{2\pi RC}$

J: Bode plots ($20 \times \log V_o$ - $\log f$)



LPF

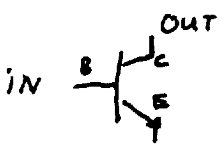


HPF

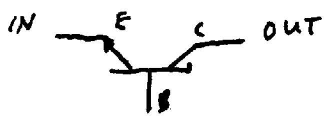
em f_c: $V_o = \frac{1}{\sqrt{2}} V_o^{max}$ $\left(P_o = \frac{1}{2} P_o^{max} \right)$

$\log V_o = -3\,dB$ $\left(20 \times {}^{10}\log \frac{1}{\sqrt{2}} = -3\,dB \right)$

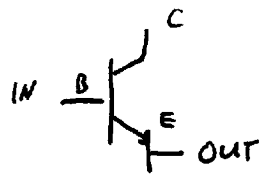
M: SIMPLE CIRCUITS



COMMON EMITTOR



COMMON BASE



COMMON COLLECTOR

Small - signal amplifiers are named after the terminal that has neither input nor output

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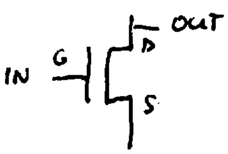
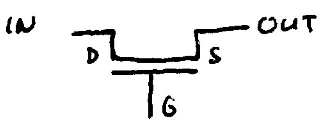
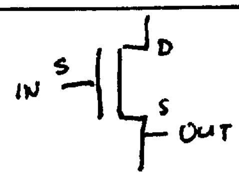


COMMON SOURCE



COMMON GATE



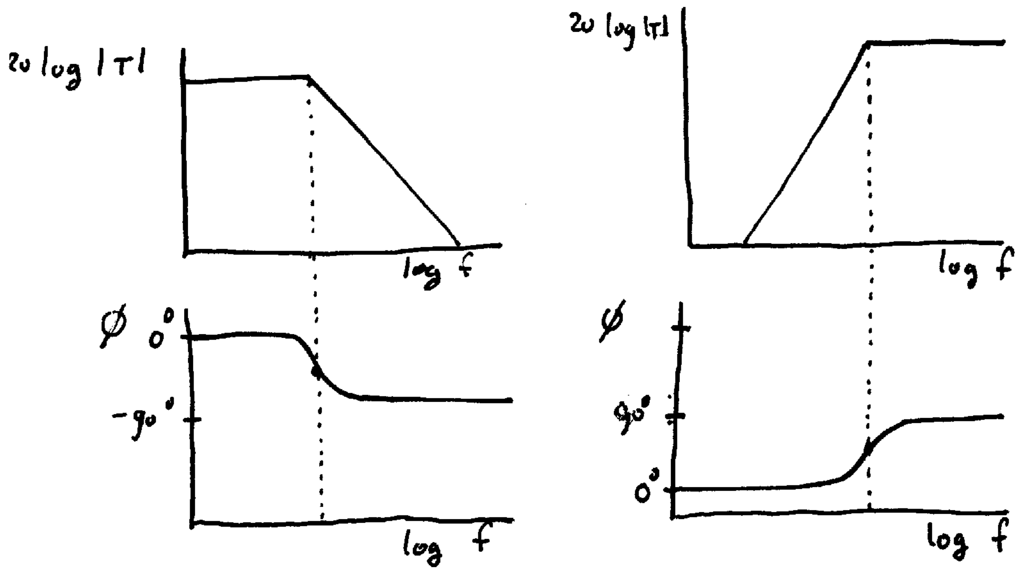
COMMON DRAIN

K: Transfer functions

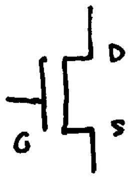
$$T(f) \equiv V_o(f)/V_i(f) \quad \text{or} \quad T(s) = V_o/V_i, \quad s = j\omega$$

	LPF	HPF	
$T(s)$	$\dfrac{1}{1 + s/\omega_o}$	$\dfrac{s}{s + \omega_o}$	
$T(\omega)$	$\dfrac{1}{1 + j\omega/\omega_o}$	$\dfrac{1}{1 - j\,\omega_o/\omega}$	
$\lvert T(\omega)\rvert$	$\dfrac{1}{\sqrt{1 + (\omega/\omega_o)^2}}$	$\dfrac{1}{\sqrt{1 + (\omega_o/\omega)^2}}$	
$\omega = 0$	1	0	
$\omega = \infty$	0	1	
$\omega = \omega_o$	$\lvert T\rvert = \frac{1}{\sqrt{2}}, \ \phi = -45^\circ$	$\lvert T\rvert = \frac{1}{\sqrt{2}}, \ \phi = +45^\circ$	$(-3\,dB)$
$\omega \ll \omega_o$	1	$\sim \omega$ (20 dB/dec)	
$\omega \gg \omega_o$	$\sim 1/\omega$ (-20 dB/dec)	1	
$\omega_o =$	$\dfrac{1}{RC}$	$\dfrac{1}{RC}$	

Bode Plots

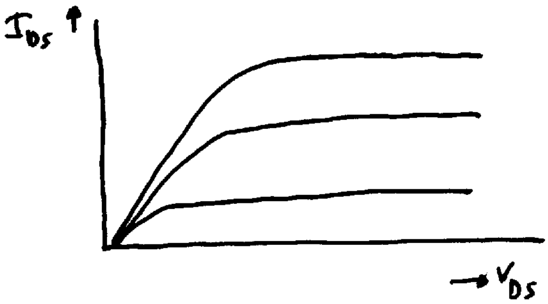


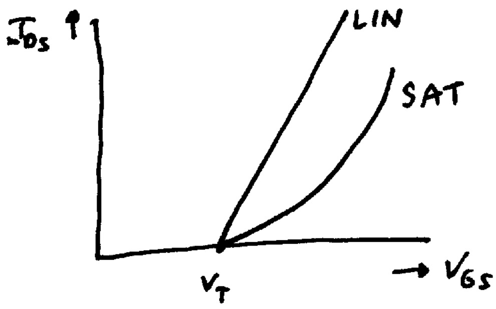
H: Field - Effect Transistor



$$\text{LIN}: \quad I_{ds} = C_{ox}\,\mu \frac{W}{L}\,(V_{GS} - V_T)\,V_{DS} = \lambda\,(V_{GS} - V_T)\,V_{DS}$$

$$\text{SAT}: \quad I_{ds} = \tfrac{1}{2}\,C_{ox}\,\mu \frac{W}{L}\,(V_{GS} - V_T)^2 = \tfrac{1}{2}\,\lambda\,(V_{GS} - V_T)^2$$





$$r_o = 1 \Big/ \left.\frac{\partial I_{DS}}{\partial V_{DS}}\right|_{V_{GS}=\text{const}} = \infty \,, \qquad r_i = 1 \Big/ \left.\frac{\partial I_G}{\partial V_{GS}}\right|_{V_{DS}=\text{const}} = \infty \quad (I_{GS} = 0)$$

(no leakage current or polarization current !)

$$g_m = \left.\frac{\partial I_{DS}}{\partial V_{GS}}\right|_{V_{DS}=\text{const.}} = \lambda\,V_{DS} \quad (\text{LIN})$$

$$= \lambda\,V_{GS} \quad (\text{SAT})$$

L: components analyzed

$V = I.R$

→ A resistance is a linear element that translates current to voltage

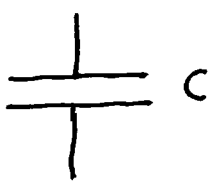
$I \rightarrow V$

→ A resistance defines a current

$V \rightarrow I$

$$\partial V = R \cdot \partial I$$

$$(V = R \cdot i)$$



$C = Q/V$

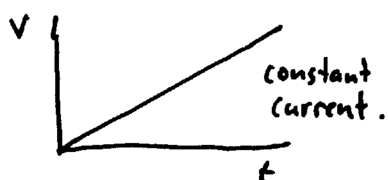
→ A capacitor is a charge storage "how much charge stored per volt"

$V \rightarrow Q$

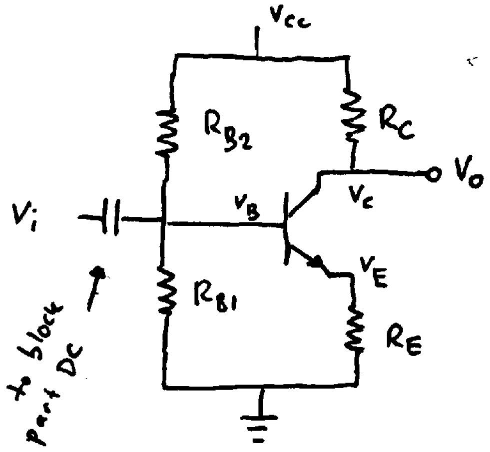
→ is "integrator"

$Q \rightarrow V$

$\int I dt \rightarrow V$



Example common-emittor amplifier PART 1B



$\beta = 100$

$R_{B1} = R_{B2} = 10\ k\Omega$

$R_E = 3.3\ k\Omega$

$R_C = 3.3\ k\Omega$

$V_{CC} = +10\ V$

POLARIZATION / BIAS

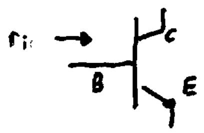
1) V_B ?

Assumption r_i at transistor $\gg 10\ K$

why ?

$r_i = r_\pi + R_E$? No!

$r_i = r_\pi + \underline{(\beta+1)}\, R_E$!



remember : $r_i \equiv 1 \Big/ \dfrac{\partial I_B}{\partial V_B}$

$$\frac{\partial I_B}{\partial V_B} = \frac{\frac{1}{\beta+1}\,\partial I_E}{\partial\,(V_E + 0.7\,V)} = \frac{1}{\beta+1}\,\frac{\partial I_E}{\partial V_E} = \frac{1}{(\beta+1)\,R_E}$$

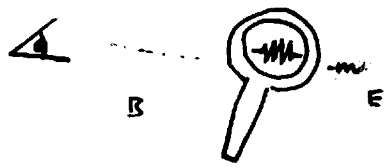
implies $r_\pi = 0$

$r_i = (\beta+1)\, R_E$

total (including r_π) : $r_i = r_\pi + (\beta+1)\, R_E$

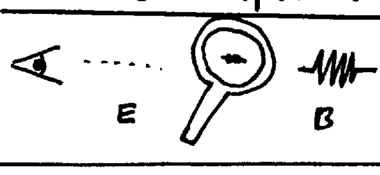
order $1\ k\Omega$ — order $100\ k\Omega$

O transistor funcione como uma lente. Vista da base, as resistências (e outros componentes) aperecem ampliadas.



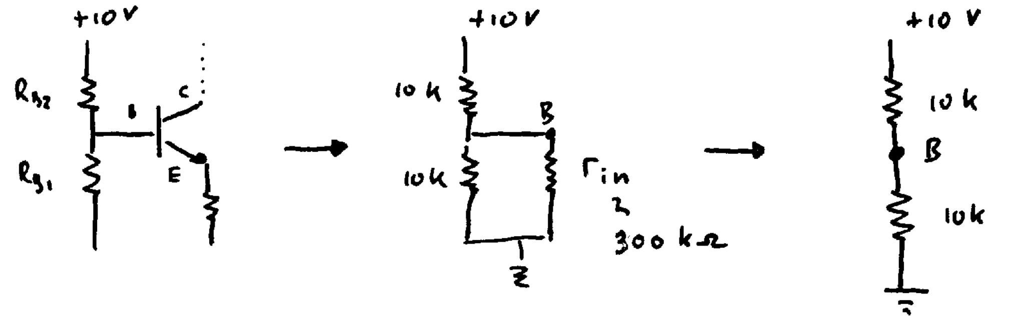
$(\beta+1) R_E \longleftarrow R_E$

Vista do emisor, os componentes na base aperecem reduzidos



$R_B \longrightarrow \dfrac{R_B}{\beta+1}$

$r_{in} >> R_B$:



→ $V_B = +5$ V

$$V_B = \frac{R_{B1}}{R_{B1} + R_{B2}} \cdot V_{CC} = \frac{10\ k\Omega}{10\ k\Omega + 10\ k\Omega} \cdot 10\ V = 5\ V$$

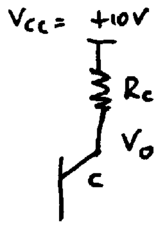
$V_E = V_B - 0.7$ V (in case transistor open. check at end!)

$= 4.3$ V

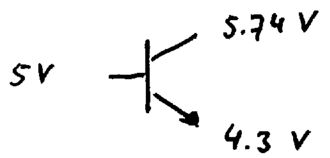
$I_E = V_E / R_E = 1.30$ mA

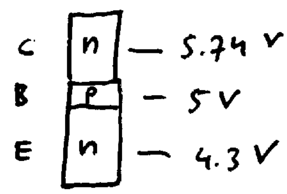
$I_B = I_E/(\beta+1) = 12.9\ \mu A$

$I_C = \alpha I_E = 1.29$ mA



$V_o = V_{CC} - R_C \cdot I_C = 10 - 3.3\ k\Omega \times 1.29$ mA $= 5.74$ V





A properly working transistor has the C-B biased reverse and the B-E junction in forward. Forward bias : n = negative, p = positive. Thus, the above transistor is working correct.

$$r_e = \frac{V_T}{I_E} = \frac{26\ mV}{1.30\ mA} = 20\ \Omega$$

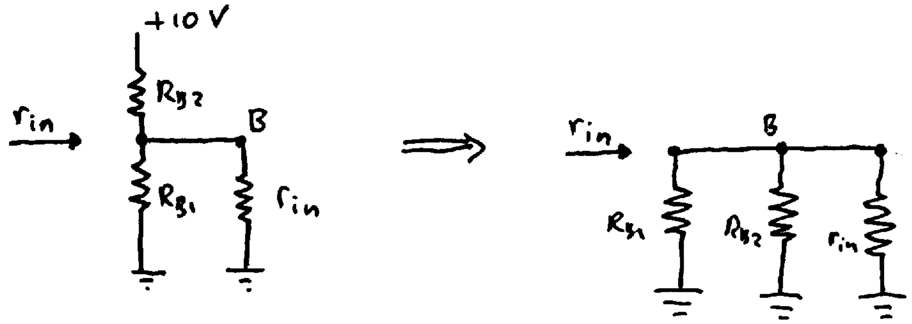
$r_\pi = (\beta+1)\, r_e = (100+1)\, 20\Omega = 2\ k\Omega$

$r_{in} = r_\pi + (\beta+1) R_E = 335\ k\Omega$

Total dynamic input resistance of amplifier:

> For AC signals : any DC power supply point is equal to ⏚ (and current source = open)

(because v $(= \delta v) \equiv 0$!



$$r_{in} = R_{B1} // R_{B2} // r_{in}$$
$$= 10\,k\Omega // 10\,k\Omega // 335\,k\Omega$$
$$\sim 5\,k\Omega$$

AC signal amplification:

$$r_i = r_\pi + (\beta+1) R_E$$

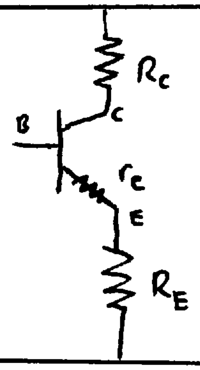
$$r_i \equiv 1 \Big/ \frac{\partial I_B}{\partial V_B} \Rightarrow \partial I_B = \frac{\partial V_B}{r_i} = \frac{\partial V_B}{r_\pi + (\beta+1) R_E}$$

$$I_c = \beta I_B \Rightarrow \partial I_c = \beta\, \partial I_B = \frac{\beta\, \partial V_B}{r_\pi + (\beta+1) R_E}$$

$$V_o = V_{cc} - R_c I_c \Rightarrow$$
$$\partial V_o = -R_c \cdot \partial I_c = -\frac{\beta R_c}{r_\pi + (\beta+1) R_E} \cdot \partial V_B$$

minúsculas   maiúsculas

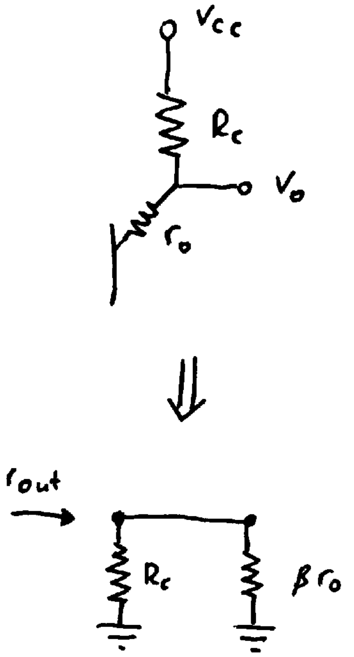
$$A = \frac{v_o}{v_B} = \frac{\partial V_o}{\partial V_B} = -\frac{R_c}{r_e + R_E} \qquad (r_\pi = (\beta+1) r_e \,, \quad \beta \approx (\beta+1))$$



> The gain of a common-emittor amplifier is <u>all resistance at collector</u> divided by <u>all resistance at emittor</u> with minus sign

$$A = -\frac{3300}{20 + 3300} \sim -1$$

output resistance of amplifier



r_o is resistance of transistor (with E connected to ground!!)

$r_o \approx 200\ k\Omega$ (p. 3)

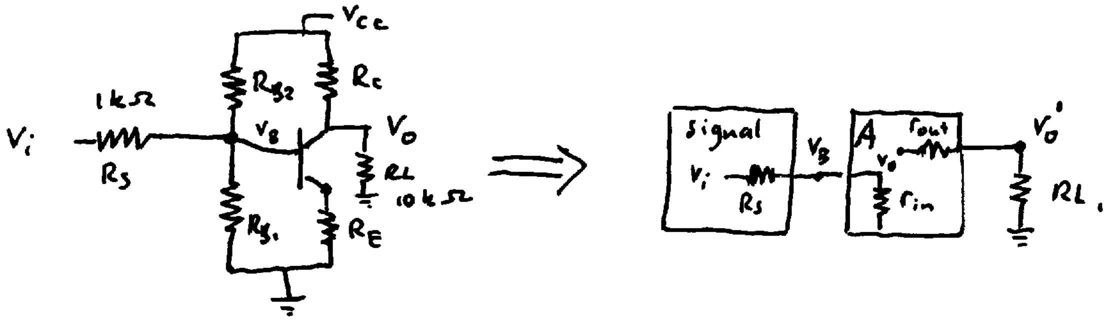
$(r_o >> R_c)$

r_{out} of transistor in Com. Em. is <u>MUCH</u> larger than r_o (something like $\beta \times r_o$) (see p.7 of ch. 1)

$r_{out} \sim R_c = 3.3\ k\Omega$

Combining amplifier stages

imagine signal source has $1\ k\Omega$ output resistance and a $10\ k\Omega$ Load resistance is at output
what will be the total gain of circuit ?



$R_S = 1\ k\Omega$, $r_{in} = 5\ k\Omega$ (p.7) , $R_L = 10\ k\Omega$

$A = -1$ (p.7) , $r_{out} = 3.3\ k\Omega$ (p.8)

$$A_{tot} = \frac{V_o'}{V_i} = \frac{V_o'}{V_o} \cdot \frac{V_o}{V_B} \cdot \frac{V_B}{V_i}$$

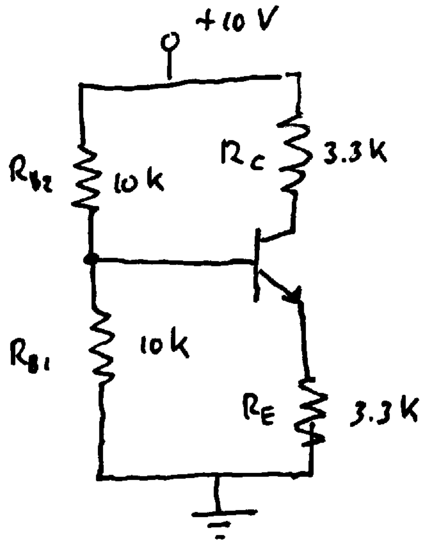
$$\frac{V_o'}{V_o} = \frac{R_L}{R_L + r_{out}} \quad , \quad \frac{V_o}{V_B} = A \quad , \quad \frac{V_B}{V_i} = \frac{r_{in}}{r_{in} + R_S}$$

$$= 0.429 \qquad\qquad = -1 \qquad\qquad = 0.833$$

$$A_{tot} = 0.429 \times -1 \times 0.833 = -0.357$$

DC power consumption of amplifier

$P = I^2R$ or V^2/R or VI



R_{B1} : $V = 5V$, $R = 10k \Rightarrow P = 2.5$ mW

R_{B2} : $V = 5V$, $R = 10k \Rightarrow P = 2.5$ mW

R_E : $V = 4.3V$, $R = 3.3k \Rightarrow P = 5.6$ mW

R_C : $V = 4.3V$, $R = 3.3k \Rightarrow P = 5.6$ mW

* trans : $V = 0.7V$, $I = 1.29mA \Rightarrow P = 0.90$ mW

total $P = 17.1$ mW

Note : there is power loss at every part where we have a voltage drop and a current simultaneously. You can also say : where there is a current and a resistance. The heat generated in the transistor is not much in this case, but other amplifiers will lose a lot of power in the transistors and have to be cooled.

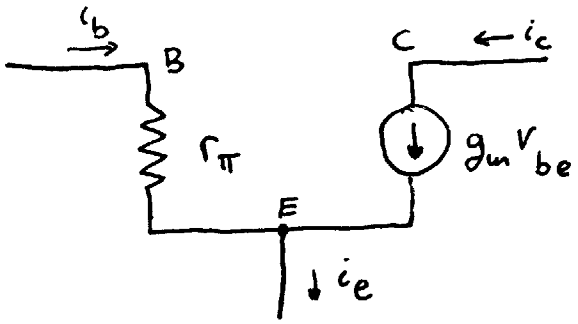
* : note that we cannot use r_e or r_π here because they are for signals (AC) only.

Alternative calculation : The +10 V power supply supplies a total current of 1.29 mA through R_c plus 0.5 mA $\left(\frac{+10V}{10k+10k}\right)$ through the base resistors. Total : 1.79 mA. $P = V \cdot I =$ 17.9 mW

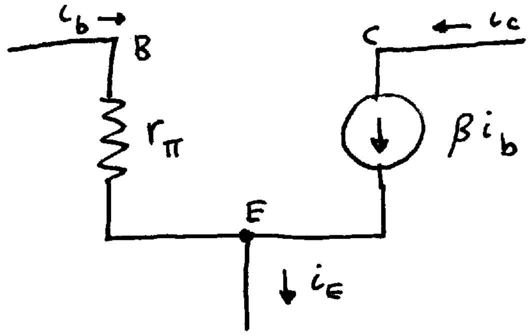
N: Small-signal models of transistors and amplifiers.

Although electronic circuits can be analyzed without the help of small-signal models, in some cases those small-signal model can help to understand things. Examples of npn BJT models

"base oriented" = HYBRID - π

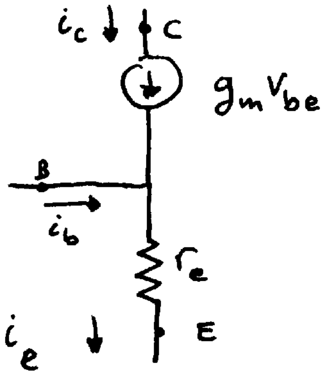


Hybrid - π model with voltage - controlled current source

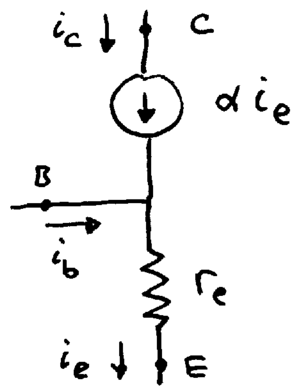


Hybrid - π model with current controlled current source

"emitter oriented" = T MODEL

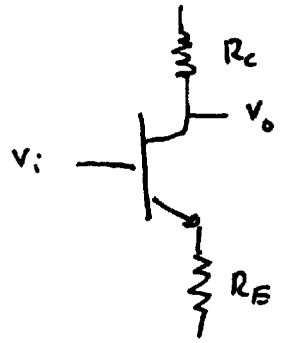


T model with voltage - controlled current source



T model with current controlled current source

0: BASIC BJT AMPLIFIERS

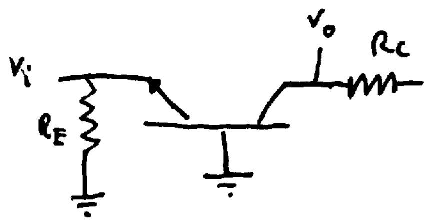


COMMON - EMITTER AMPLIFIER (CEA)

signal gain : $\frac{v_o}{v_i} = -\frac{R_c}{r_e + R_E}$

$r_{in} = (\beta+1)(r_e + R_E)$

$r_{out} = R_c$

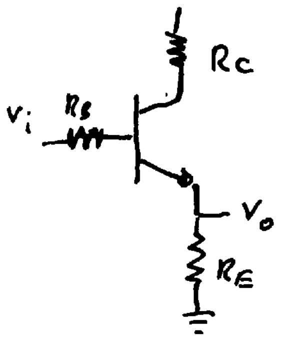


COMMON - BASE AMPLIFIER (CBA)

gain $\frac{v_o}{v_i} = +\frac{R_c}{r_e}$

$r_{in} = r_e \,//\, R_E$

$r_{out} = R_c$



COMMON - COLLECTOR AMPLIFIER (CCA)

gain $\frac{v_o}{v_i} = R_E/(r_e + R_E) \approx 1$

$r_{in} = (\beta+1)(r_e + R_E) + R_B$

$r_{out} = R_E \,//\, \left(\frac{R_B}{\beta+1} + r_e\right)$