Ch. 4 Transistor amplifiers

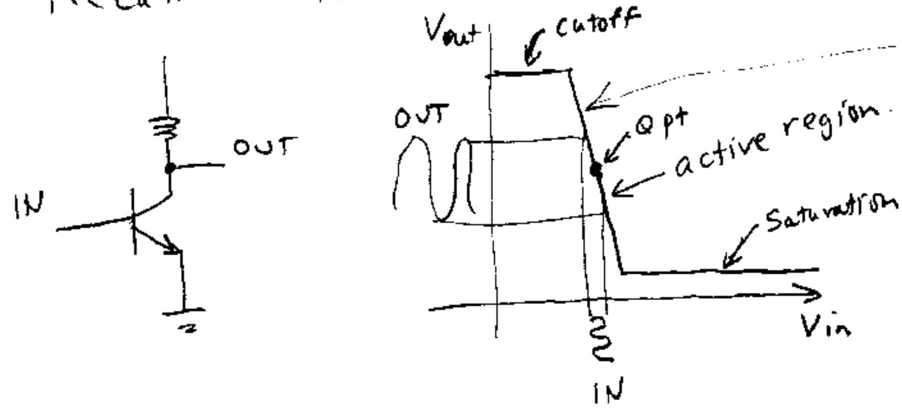
4.2 Basics.

Small signal analysis...

To analyze the signal properties of an amplifier–

Make a "small signal model"
approximating the behavior at the operating point.

Recall -- transfer characteristic is:

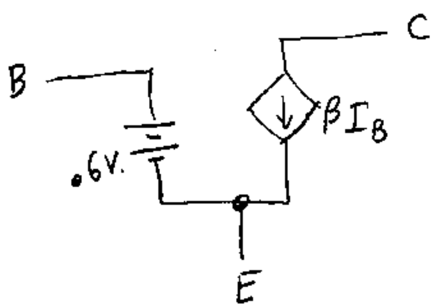


Approximate this as a straight line.

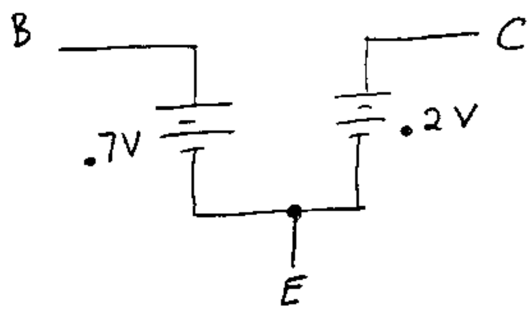
It isn't really.

Large signal models:

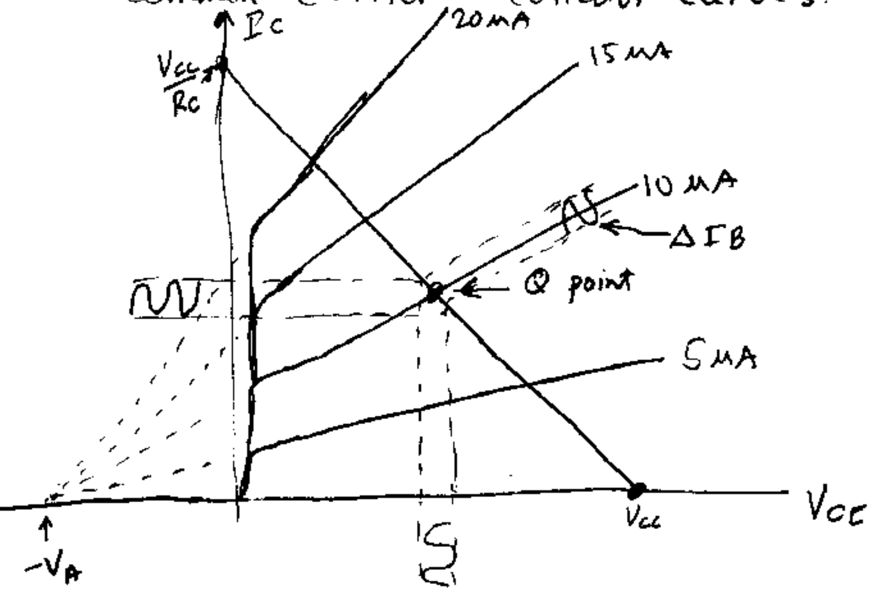
Active region



Saturation region



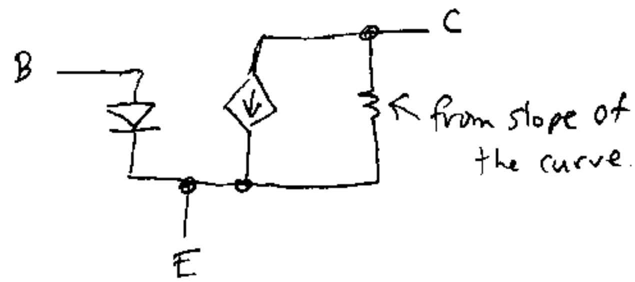
Common-emitter collector curves.



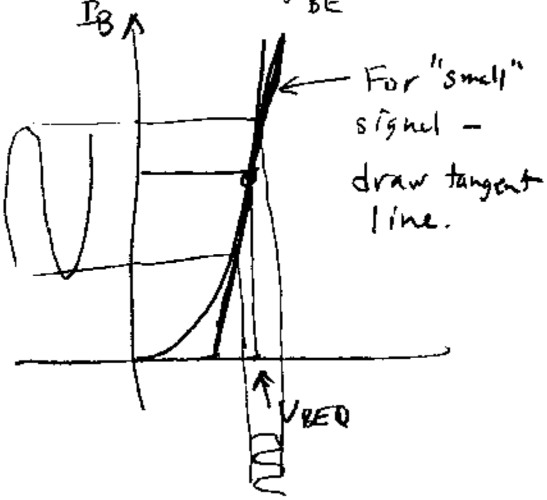
Move the base current a little –
Collector current changes (Y axis)
Reflect on load line to see that voltage changes

Treat it as linear.

Large signal model:



Base current vs. V_{BE}



p. 168 shows equations — Read it.

The essence is --

$$i_B = \frac{I_S}{1+\beta_F} e^{\frac{V_{BE}}{V_T}}$$

For AC, we care only about $\frac{\Delta i_B}{\Delta V_{BE}}$

or $\frac{d i_B}{d V_{BE}}$ = derivative of curve.

Substitute the admittance —
make believe it is linear.

Notation:

Capital letters = LARGE signal or DC

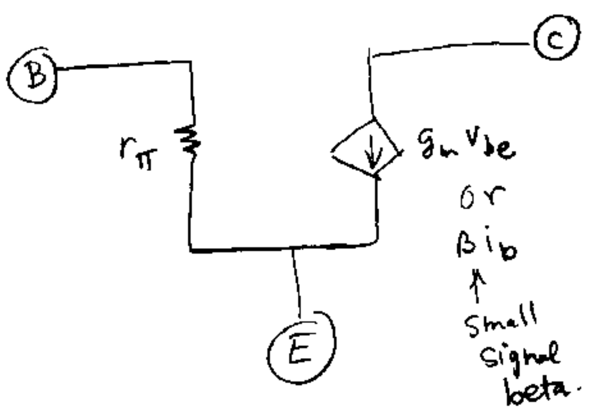
small letters = small signal or AC

so... I_B is DC base current

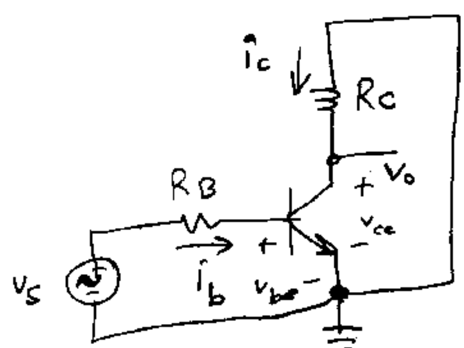
i_b is AC signal current

etc.

New model



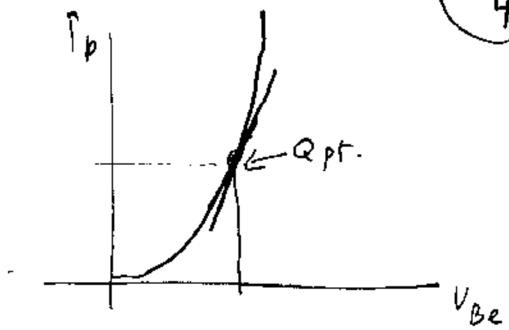
The old circuit, new labels



For AC small signal, power supply is just like ground.

Finding the values:

$$\frac{1}{r_\pi} = \left.\frac{\partial i_B}{\partial v_{BE}}\right|_{Q\,pt}$$



$\frac{1}{\text{Slope}}$ at Q pt

recall: Scale current

$$I_B = \frac{I_S}{1+\beta} e^{\frac{V_{BE}}{V_T}}$$

← This could also be stated as $I_{S_{B}} e^{\frac{V_{BE}}{V_T}}$ — I_{S_B}: saturation current of Base emitter diode.

Be careful which I_S You use!!!

Note how they are related. Ask which one you have if you are not sure.

so:

$$\frac{1}{r_\pi} = \left.\frac{\partial}{\partial V_{BE}} \frac{I_S}{1+\beta} e^{\frac{V_{BE}}{V_T}}\right|_{Q\,pt.}$$

$$= \left.\frac{1}{V_T}\left[\frac{I_S}{1+\beta} e^{\frac{V_{BE}}{V_T}}\right]\right|_{Q\,pt}$$

but since $I_{BQ} = \frac{I_S}{1+\beta} e^{\frac{V_{BE}}{V_T}}$

$$\frac{1}{r_\pi} = \frac{I_{BQ}}{V_T} \qquad \text{so} \quad r_\pi = \frac{V_T}{I_{BQ}} \approx \frac{.026}{I_{BQ}}$$

r_π is "diffusion resistance"

it is the incremental resistance of the BE diode

For small signal, we just say: $\frac{1}{r_\pi} = \frac{i_b}{v_{be}}$ ← small signal AC values

Transconductance:

$$g_m = \frac{\partial i_C}{\partial v_{BE}}$$

(by definition)

small signal notation –

$$g_m = \frac{i_c}{v_{be}}$$

note...

$$\beta_F = \frac{I_C}{I_B}$$

for small signal...

$$\beta = \frac{\partial I_C}{\partial I_B} \quad \text{or} \quad \frac{i_c}{i_b}$$

Notation: β_F = DC beta
β = AC beta

Relation to β ---

$$g_m = \frac{\partial i_C}{\partial v_{BE}}, \quad \beta = \frac{\partial i_C}{\partial i_B}, \quad \frac{1}{r_\pi} = \frac{\partial i_B}{\partial v_{BE}}$$

so...

$$\frac{\partial i_C}{\partial v_{BE}} = \frac{\partial i_C}{\partial i_B} \frac{\partial i_B}{\partial v_{BE}}$$

$$g_m = \frac{\beta}{r_\pi} \qquad \text{or} \qquad \beta = g_m r_\pi$$

It might be specified either way –
You need to convert.

More conversions ---

For DC --- $\beta = \frac{I_C}{I_B}$, $g_m = \frac{\beta_F}{r_\pi}$, $r_\pi = \frac{V_T}{I_B}$

Substituting .. $g_m = \dfrac{\frac{I_C}{I_B}}{\frac{V_T}{I_B}} = \dfrac{I_C}{V_T}$

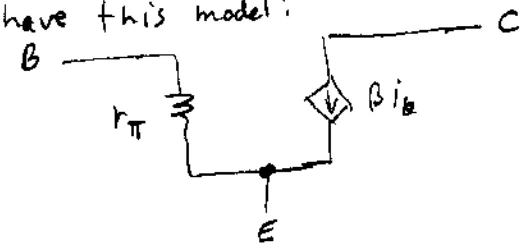
This notation can be confusing —

DC parameters vs. ac parameters

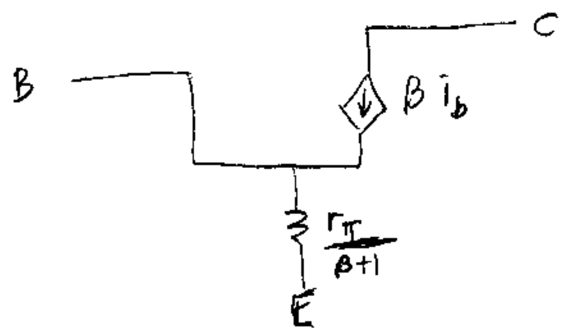
(DC ↑ large. ac ↑ small)

Alternate model:

We have this model:

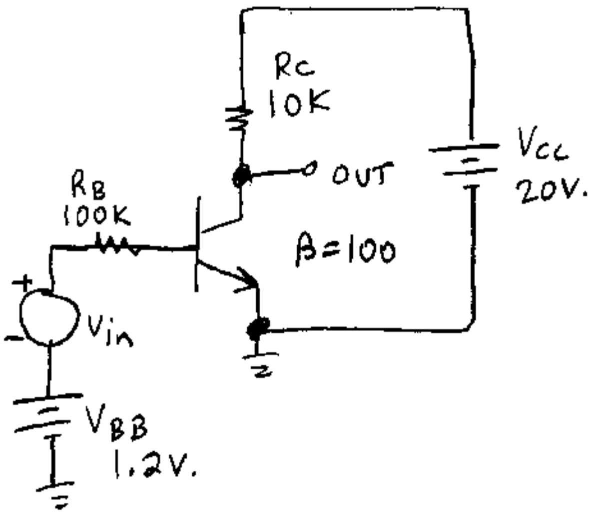


We can reflect r_π through a node:



← This circuit is equivalent, and sometimes easier to use.

Example:



What is small signal voltage gain?

First: Compute the DC operating point

$$I_{BQ} = \frac{1.2 - .6}{100K} = \frac{.6}{100K} = 6\,\mu A$$

$$I_{CQ} = \beta I_{BQ} = 600\,\mu A$$

$$V_{RC} = (600\,\mu A)(10K) = 6\,V.$$

$$V_{CE} = 20 - 6 = 14V.$$

It is in the active region.

AC solution:

$$r_\pi = \frac{.026}{I_{BQ}} = \frac{.026}{6\,\mu A} = 4333\,\Omega$$

$$\frac{i_c}{V_{be}} = g_m = \frac{I_{CQ}}{V_T} = \frac{600\,\mu A}{.026} = .023$$

By ohms law.....

$$g_m R_C = (.023)(10k) = 230.7$$

↑ if $g_m = \frac{i_c}{V_{be}}$ and $V_o = i_c R_C$

then $V_o = g_m V_{be} R_C$ so $\frac{V_o}{V_{be}} = g_m R_C$

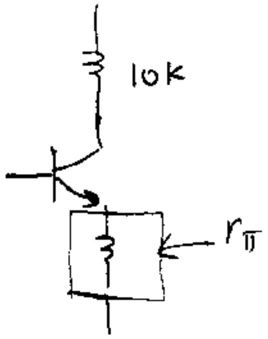
But we really need to consider the loss in R_B...

$$\frac{V_{BE}}{V_{in}} = \frac{4333}{104333} = .04$$

so, real gain is:

$$\left(\frac{V_o}{V_{be}}\right)\left(\frac{V_{be}}{V_{in}}\right) = (.04)(230) = 9.58$$

Using the alternate model:



$$\frac{r_\pi}{\beta+1} = \frac{V_T}{I_E}$$

$$= \frac{r_\pi}{\beta+1} = \frac{4333}{101} = 42.9\ \Omega$$

$$\text{Gain} = \frac{10k}{42.9} = 233.1$$

Very close to 230.7 the other way