

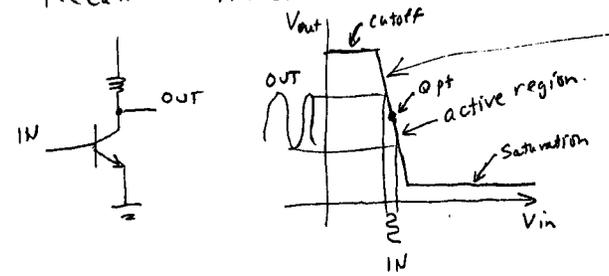
Ch. 4 Transistor amplifiers

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.

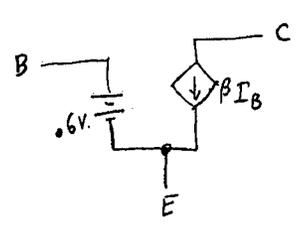
Recall -- transfer characteristic is:



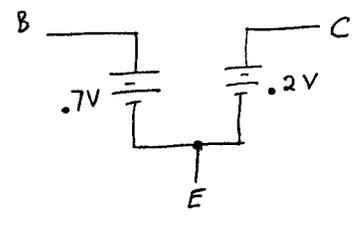
Approximate this as a straight line.
 It isn't really.

Large signal models:

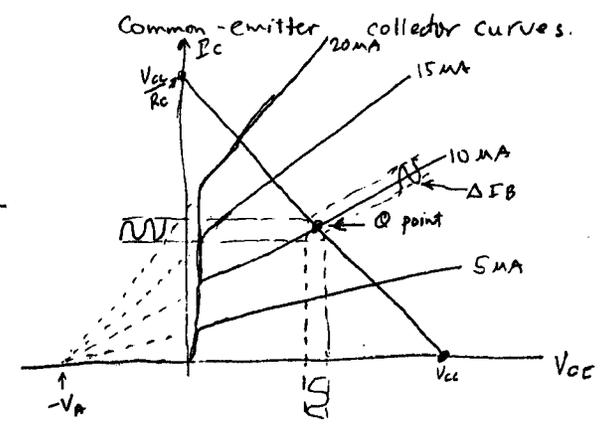
Active region



Saturation region

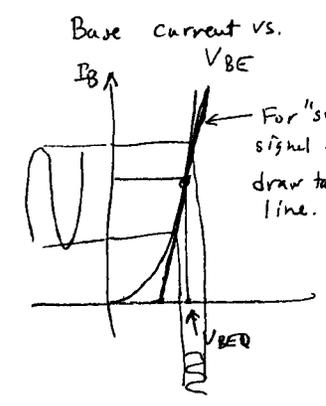
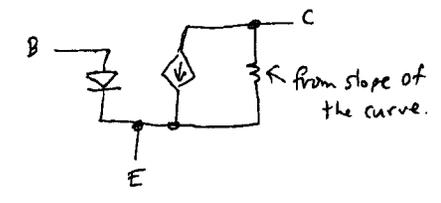


100
1



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:



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 $\frac{di_B}{dV_{BE}} = \text{derivative of curve.}$

Substitute the admittance -
 make believe it is linear.

100
2

Capital letters = LARGE signal
or DC

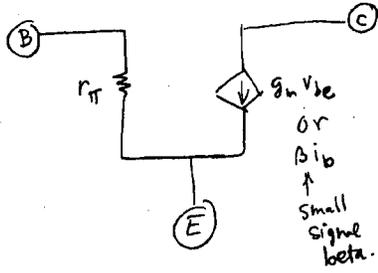
small letters = small signal or AC.

so... I_B is DC base current

i_b is AC signal current

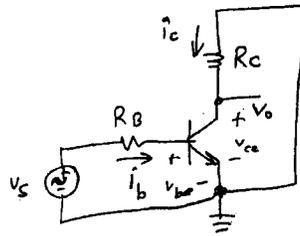
etc.

New model



$g_m v_{be}$
or βi_b
↑
Small signal beta.

The old circuit, new labels



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

Finding the values.

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

recall:

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

Scale current

so:

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

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

$$\frac{1}{r_{\pi}} = \frac{I_{BQ}}{V_T} \quad \text{so} \quad r_{\pi} = \frac{V_T}{I_{BQ}} \approx \frac{0.026}{I_{BQ}}$$

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.



1/slope at Q_pt.

This could also be stated as

$$I_{S\beta} e^{\frac{V_{BE}}{V_T}}$$

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.

Transconductance:

$$g_m = \frac{\partial i_c}{\partial V_{BE}}$$

(by definition)

Small signal notation -

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

Relation to β ---

$$g_m = \frac{\partial i_c}{\partial V_{BE}} \Rightarrow \beta = \frac{\partial i_c}{\partial i_B} \quad , \quad \frac{1}{r_{\pi}} = \frac{\partial i_B}{\partial V_{BE}}$$

so ...

$$\frac{\partial i_c}{\partial V_{BE}} = \frac{\partial i_c}{\partial i_B} \cdot \frac{\partial i_B}{\partial V_{BE}}$$

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

It might be specified either way -

You need to convert.

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: $\beta_F = \text{DC beta}$
 $\beta = \text{AC beta}$

10B
5

More conversions ---

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

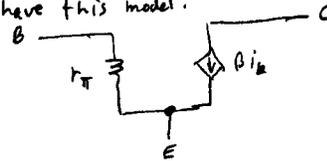
Substituting -- $g_m = \frac{\frac{I_C}{I_B}}{\frac{V_T}{I_B}} = \frac{I_C}{V_T}$

10B
6

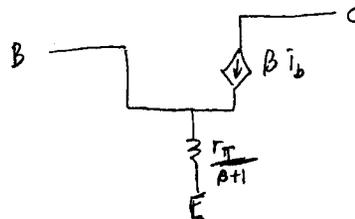
This notation can be confusing -

DC parameters vs. ac parameters
 ↑ large. ↑ small

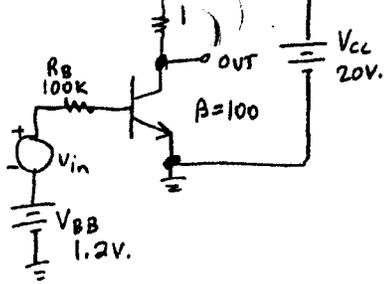
Alternate model:
 We have this model!



We can reflect r_{π} through a node!



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



Voltage gain?

First: Compute the DC operating point

$$I_{BQ} = \frac{1.2 - 0.6}{100k} = \frac{0.6}{100k} = 6 \mu A$$

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

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

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

It is in the active region.

AC solution:

$$r_{\pi} = \frac{0.026}{I_{BQ}} = \frac{0.026}{6 \mu A} = 4333 \Omega$$

$$\frac{i_c}{v_{be}} = g_m = \frac{I_{CQ}}{V_T} = \frac{600 \mu A}{0.026} = 0.023$$

By ohms law...

$$g_m R_C = (0.023)(10k) = 230.7$$

↑
if $g_m = \frac{i_c}{v_{be}}$ and $v_o = i_c R_C$

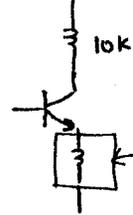
then $v_o = g_m v_{be} R_C$ so $\frac{v_o}{v_{be}} = g_m R_C$

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

$$\frac{v_{be}}{v_{in}} = \frac{4333}{104333} = 0.04$$

so, real gain is:

$$\left(\frac{v_o}{v_{be}}\right) \left(\frac{v_{be}}{v_{in}}\right) = (0.04)(230) = 9.58$$



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

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

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

Very close to 230.7 the other way