BJT Review & PNP

- What did I just do?
- NPN modes of op. w/ silicon pix
- ~~NPN small signal~~
- PNP modes of op. w/ silicon pix
- PNP small sig. & NPN small sig

(1)

BJT Fancy Large signal

- Reverse active
- Breakdown
- β variation reminder
- Full Ebers-Moll (just mention)

(4)

common bias circuits

- i_b control is key in FAR
- Naive i_b
- divider & base loading

(2)

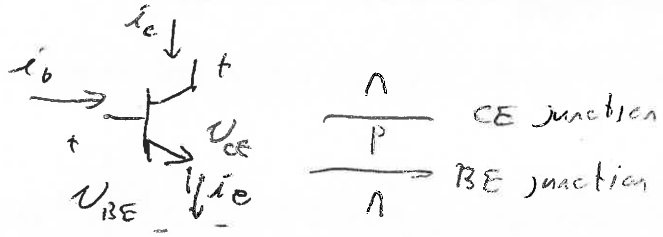
Mid-band

- How do we get signals in?
  ↳ AC couple!
  ↳ can build DC coupled ckt.
- limited f performance

- can mid-band out parts (small sig review)

(3)

— Let's review NPN BJT Large signal models



Always: $i_e = i_c + i_b$

3 States

(1) cutoff — BE junction off & CE junction off

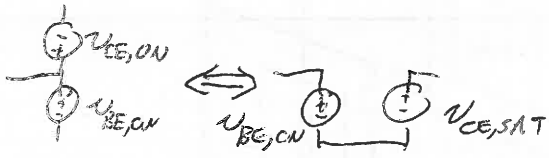
~~saturation BE junction on & CE junction o~~

i.e.: $v_{BE} < v_{BE,ON}$ & $v_{BE} - v_{CE} < v_{CE,ON}$

Naive diode model ~  — works here

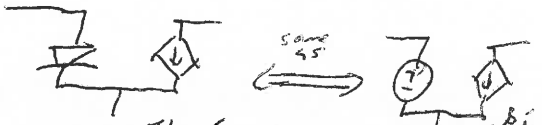
(2) saturation

- BE junction on & CE junction ON
- i.e.: v_{BE} really high
- i.e.: $v_{BE} > v_{BE,ON}$ & $v_{BE} - v_{CE} > v_{CE,ON}$

Naive diode model 

(3) fwd. active region (FAR)

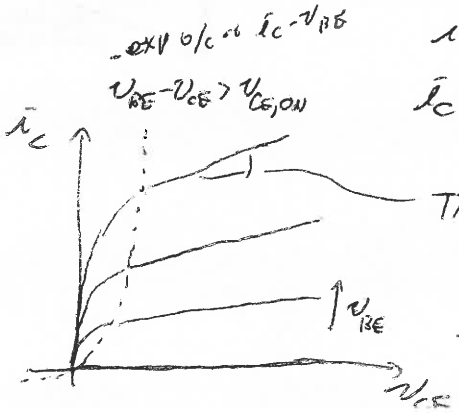
- BE junction on & CE junction off
- i.e.: $v_{BE} > v_{BE,ON}$ & $v_{BE} - v_{CE} < v_{CE,ON}$
- Naive diode model fails b/c narrow p region → current gain



$i_B = I_{ES}\left(e^{v_{BE}/\phi_T} - 1\right)$

$i_C = \beta i_B$

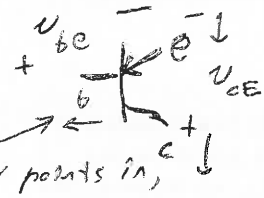
common way to draw



This slope "new" to our model

- v_{CE} affects size of base
- Quantify w/ V_A

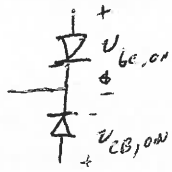
- Need to introduce PNP



Arrow points in, hint @ use

(Note:  rare but also legit!)

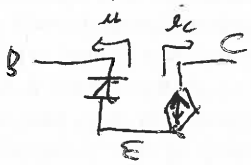
p
n
p



- same all flipped around, makes eq^n odd,
- I focus on junctions to keep my head straight
- Makes sense when you see emitter hooked to supply

e.g. FAR

→ $I_e = I_c + I_b$ always ←



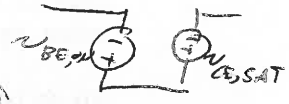
- Need v_{BE} to be on & v_{BC} to be off

so $v_{BE} < -v_{BE,ON}$ & $v_{BE} - v_{CE} > -v_{CB,ON}$

You guys write the voltage boundaries for cutoff & saturation

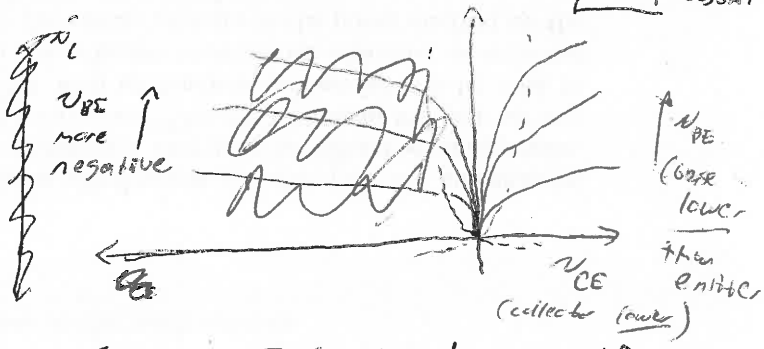
cutoff $v_{BE} > -v_{BE,ON}$ & $v_{BE} - v_{CE} > -v_{CB,ON}$

sat. $v_{BE} < -v_{BE,ON}$ & $v_{BE} - v_{CE} < -v_{CB,ON}$



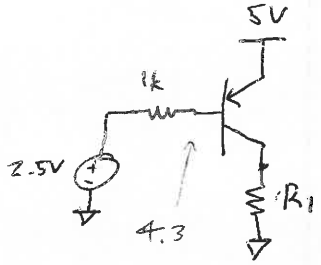
~~Recall, I find signs confusing~~

- can be plotted too



- Recall that I find this all confusing. Just think of PNP in a circuit (or as junctions)

You guys



① - Find i_c

- For PNP, if we hook emitter to supply & recall stuff turns on below supply it makes sense

$\beta = 50$

$|v_{BE,ON}| = 0.7V$

$v_R = 1.8V \rightarrow i_b = 1.8mA \rightarrow i_c = 90mA$ $(v_{CB} = 0.5V)$

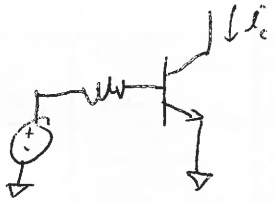
② - What is max R_1 before we enter sat.? $v_{CE,SAT} = 0.1V$

$v_{CE} = 5V - 90mA \cdot R_1$ $v_c = 90mA \cdot R_1$ must be $< 4.9V$

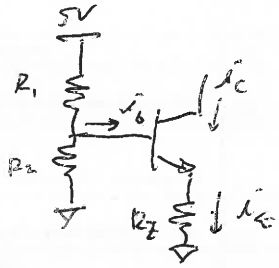
$R_1 < \sim 55\,\Omega$

Just saw an example of biasing a BJT

- depends on a precision voltage source, not practical
- But the basic idea - control i_b for the win - is good



NPN equivalent



Made w/ voltage div.

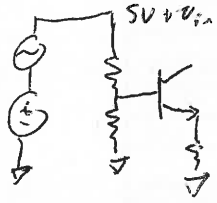
- don't forget i_b changes bias point
- large signal can pull either R_E or R_b

= pick $i_C = 1mA$ & $v_E = 2V$ → $R_E = 2k$, $i_b \approx 10\mu A$, $v_b = 2.7V$

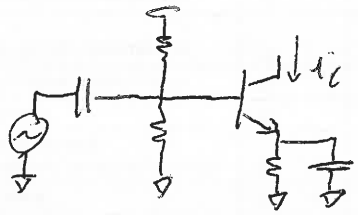
- $i_1 = \frac{2.7V}{R_2} + 10\mu A = \frac{5V - 2.7V}{R_1}$

- big β makes easy design. $R_2 \sim 1k$ ok, $R_2 \sim 10k$ is a big deal.

How do we get signals in? (e.g.: for small signal measurements)

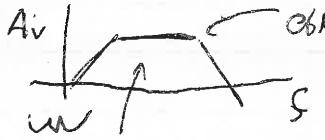


Adding supplies is hard



AC couple in

- pick C so invisible @ moderate freq.
- Amplifier works in "mid-band"



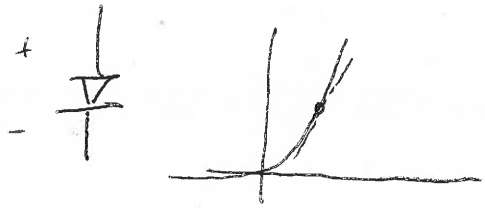
Other stuff causes high f issues.

us for now

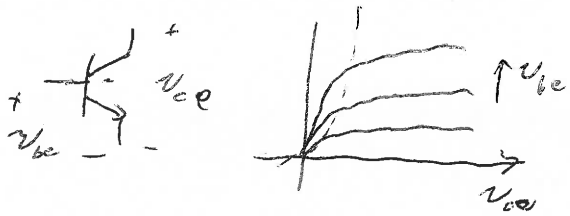
Knock out bias R in mid-band

DC is for op-amps

Let's review NPN & PNP small signal



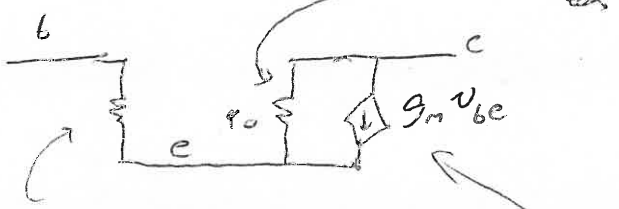
– diode is function of 1 variable
– only need to linearize i_d by v_d



– i_c varies w/ both v_{be} & v_{ce}
↳ need to linearize to both values

$$\frac{\partial i_c}{\partial v_{ce}} \approx \frac{I_c}{V_A} \quad \begin{matrix} \leftarrow \text{rise} \\ \leftarrow \text{run} \end{matrix}$$

(inverse to make resistor)



diode rdrb

$$\frac{\partial i_c}{\partial v_{be}} = \frac{\partial}{\partial v_{be}} \beta \cdot I_{ES}\left(e^{v_{be}/\phi_{th}} - 1\right)$$

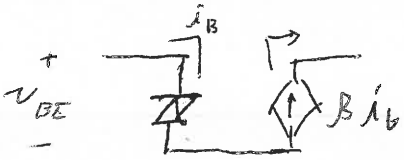
$$= \frac{1}{\phi_{th}} \cdot \beta \cdot I_{ES}\, e^{v_{be}/\phi_{th}}$$

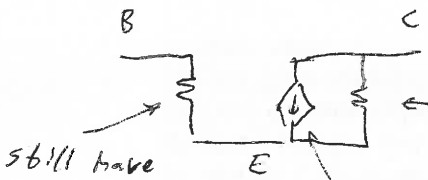
$$\approx \frac{I_c}{\phi_{th}} \equiv g_m$$

$$r_\pi = \frac{\phi_{th}}{I_b} = \frac{\beta \phi_{th}}{I_c} = \frac{\beta}{g_m}$$

→ called Hybrid-π

For PNP we have an identical model
(b/c identical graph)





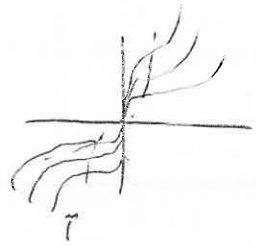
← still have V_A

$$\partial r_o = \left(\frac{I_c}{V_A}\right)^{-1}$$

still have diode & small signal doesn't care about dir.

still have

$$i_c = \beta I_{ES}\left(e^{v_{BE}/\phi_{th}} - 1\right)$$

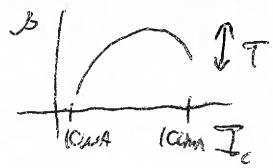


rev. active

$$I_c = I_S\left(e^{v_{BE}/\phi_{th}} - 1\right) - \frac{I_S}{\alpha_R}\left(e^{v_{BC}/\phi_{th}} - 1\right)$$

$$I_E = -\frac{I_S}{\alpha_F}\left(e^{v_{BE}/\phi_{th}} - 1\right) - I_S\left(e^{v_{BC}/\phi_{th}} - 1\right)$$

Ebers-Moll



Current mirrors?