Design Problem correction

- $R_{in} = 1k\Omega$
- Tend to max R_{out} b/c reduces g_m for A_v
- Highlight I_C, V_{SW}, A_v link again
- ~~Low harmonic content~~

Emitter Degeneration

- Mid band track ok
- to split I_C & ϕ_{th}
- I_C & r_{in} still linked ... awkward
- Try emitter degen.
  - ↓ R_{in}
  - ↓ A_v
  - ↘ R_{out}

Emitter Follower

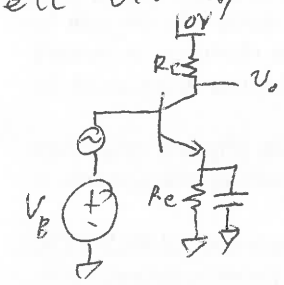
- What if we want low R_{out}?
- Try EF
  - ↓ R_{in}
  - ↓ R_{out}
  - ↘ A_v

multistage amp

- High A_v & low R_{out}
- Hook CE to EF
- Loading effects
- Accounting for source & load impedance
- Max power xfer thm ?

odds & ends: V_{SW} harmonic content, bias point stability

Left off w/ amp. design



Given

$V_B = 3.2V$

$\beta = 100$

$V_{CE,SAT} = 0.3V$

Constraints

$R_{in} \approx 1k\Omega$ ← usually greater than; but I had a sign bug

$R_{out} < 2k\Omega$ ← Often want max allowed R_{out} in a CE b/c $A_v = g_m R_C = \frac{I_C}{\phi_{th}} R_C$

lower I_C for fixed A_v w/ big R_C

↳ approx $r_o \| R_C$ as R_C

$A_v = ?$

$V_{SW} > 4V$

– Found easy constraint in R_{in} equality

$$R_{in} = r_\pi = \frac{\beta}{g_m} = \frac{\beta \phi_{th}}{I_C} = 1k\Omega \rightarrow I_C = 2.5mA$$

& $g_m = 100mS$

– Propagated

- $V_E = V_B - 0.7 = 2.5V$

↳ b/c $I_C \approx I_E$, know $\frac{2.5V}{R_E} = I_C \rightarrow R_E = 1k\Omega$

- Need to pick V_o so that $V_{max} = V_o + \frac{V_{SW}}{2} < V_{CC}$ (doesn't cut off BJT)

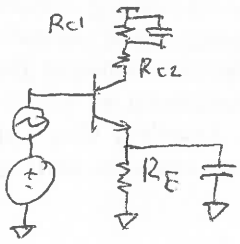
and $V_{min} = V_o - \frac{V_{SW}}{2} > V_E + V_{CE,sat}$ (doesn't saturate BJT)

↳ $10V > V_o > 4.8V$ so $800 < R_C < 1020$ and $80 < A_v < 208$

Want to set V_o separate from A_v ~ some amps could call for it

↳ Note that if we dont $A_v = g_m R_c = \frac{I_c R_c}{\phi_{th}}$ & $\Delta V_o = I_c R_c \rightarrow A_v = \frac{\Delta V_o}{\phi_{th}}$

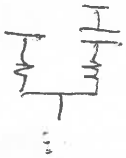
Trick #1 ~ Leverage mid-band



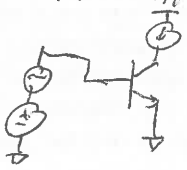
- $V_o = V_{cc} - I_c(R_{c1} + R_{c2})$
- $A_v = g_m R_{c2}$

— set separate values for V_o & A_v

— similar parallel trick to move V_o up



Trick #2 ~ Active load

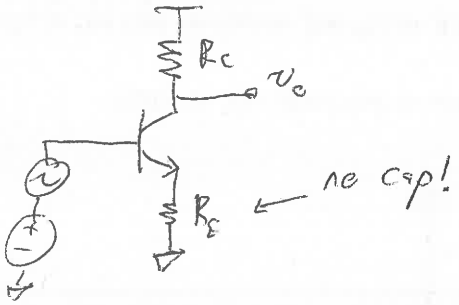


- current mirrors
- important
- we do later

Big issue: Throwing away gain to get swing w/o any benefit other than V_o shift ... R_{in} & R_{out} unaffected

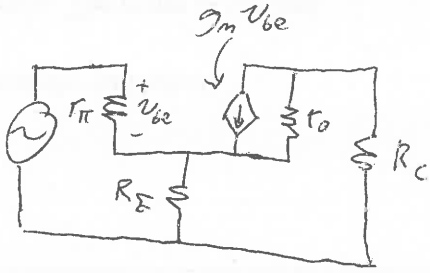
Trick #3 ~ Emitter Degeneration

— A better way to throw away gain



=

+



$I_c = \frac{V_B - 0.7}{R_E}$

- still an issue that R_E links big/small sig

— Ignoring r_o for now

— you guys won't on your HW

me find R_{in}

Apply test src @ input

$v_{be} = i_t r_\pi$

$v_E = R_e(i_t + g_m r_\pi i_t)$

$v_t = v_{be} + v_E = i_t(r_\pi + R_E + \beta R_E)$

careful! really hard to start w/ v_t & get i_t

$R_{in} = r_\pi + (\beta+1)R_E$ really big! feedback!

you find A_v ~~& Rout~~

$v_o = -g_m v_{be} R_c$

$= -g_m R_c \, v_{in}/R_{in} \cdot r_\pi$

$= -\beta R_c \, v_{in}/R_{in}$

$= \frac{-\beta R_c v_{in}}{r_\pi + (\beta+1)R_E} \approx \frac{R_c}{R_E} v_{in}$

$\boxed{\text{Bad Rout!}}$

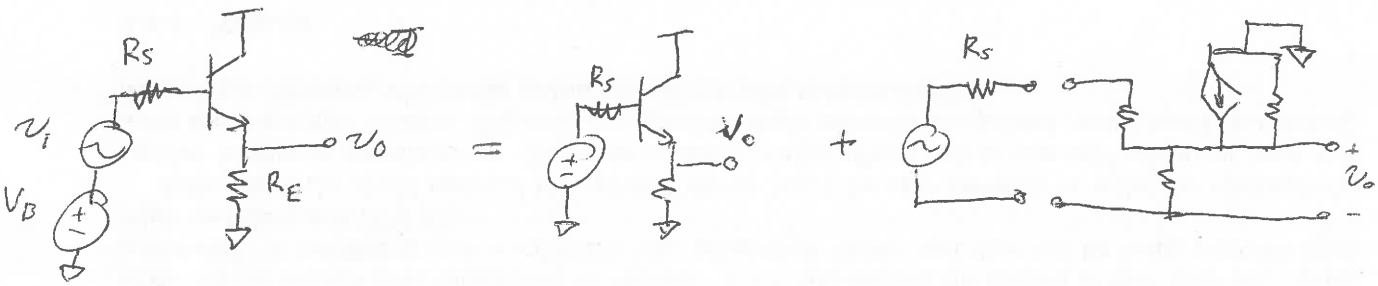
$R_{out} \neq R_L$

↳ isolated by current source

↳ test voltage has no odd stuff

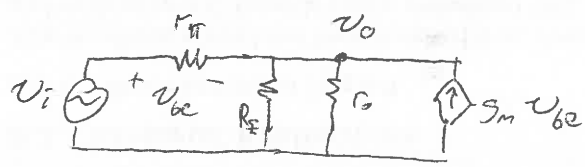
↳ no matters!

- Emitter Degen lets us trade gain for high R_{in}
- What if we want low R_{out} instead?
  → Emitter follower! ←



- Including R_s b/c, annoyingly R_{out} depends on R_s
- kind of breaks our model where we separate analysis of amp from interaction between amp & world. More in 10 min.

R_{in} - calculated w/o source



- $v_{be} = r_\pi i_1$
- $i_i = \frac{v_o}{R_E} + \frac{v_o}{r_o} + g_m v_{be}$

$i_1(\beta+1) = v_o\left(\frac{1}{R_E} + \frac{1}{r_o}\right) = v_o / R_E \| r_o$

$v_o = i_1(\beta+1)(R_E \| r_o)$

- $v_i = v_o + v_{be} = i_1\left(r_\pi + (\beta+1)(R_E \| r_o)\right)$

→ $R_{in} = r_\pi + (\beta+1)(R_E \| r_o) \approx \beta R_E$

- similar to CE w/ degen
- very hard starting w/ v_i!

A_v - calculated w/o source
(they do?)

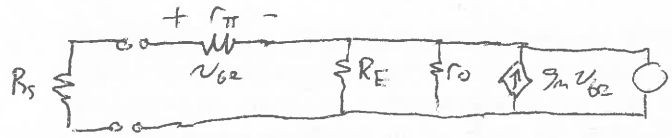
$v_o = i_1(\beta+1)(R_E \| r_o)$ from above

$= \frac{(\beta+1)(R_E \| r_o)}{r_\pi + (\beta+1)(R_E \| r_o)} v_i$ b/c $i_1 = v_i / R_{in}$

$\approx v_i$, so $A_v \approx 1$

- Makes sense in large signal b/c $v_o = v_i - 0.7$
  ↳ gain of 1 w/ level shift ↳ called a voltage buffer ↳ high current gain ($\beta+1$)

Rout - Calc w/ Rs b/c life's not fair (unilateral)



$$-v_{be} = \frac{r_\pi}{R_s + r_\pi} v_t$$ ← Start w/ v_t this time

$$i_t = \frac{v_t}{R_E} + \frac{v_t}{r_o} + \frac{v_t}{r_\pi + R_s} - g_m \frac{r_\pi}{r_\pi + R_s} v_t \cdot (-1)$$

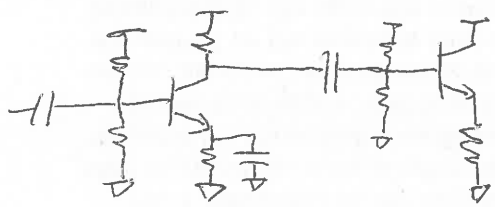
$$= v_t \left(\frac{1}{R_E} + \frac{1}{r_o} + \frac{1}{r_\pi + R_s} + \frac{\beta}{r_\pi + R_s} \right)$$

$$R_{out} = R_E \parallel r_o \parallel \frac{\beta r_\pi + R_s}{\beta + 1} \Big\} \approx \frac{1}{g_m} + \frac{R_s}{\beta + 1}$$

$$\approx \frac{1}{g_m}$$ ← low!

- Backwards gain of $\frac{r_\pi}{R_s + r_\pi}$
- we say it's small & ignore in our model

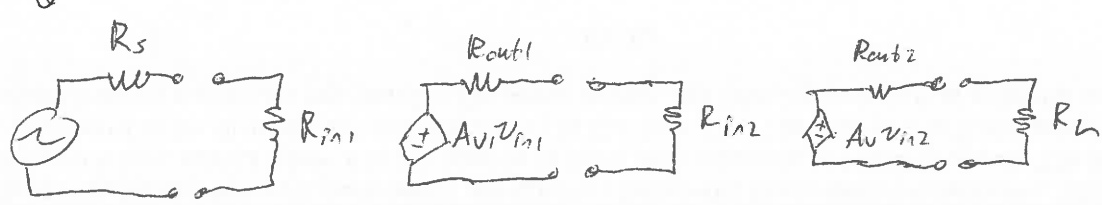
- What if we want big A_v & small Rout?
  - multi-stage amp



- Small signal model would be big and complex ... oh no!
- can use general amp model to simplify!

(- Note: some important large signal stuff @ end)

small sig



- Capture interstage loading w/ voltage div btwn R_{in} & R_{out}!

$$A_{v,total} = A_{v1} A_{v2} \frac{R_{in1}}{R_{in1} + R_s} \cdot \frac{R_{in2}}{R_{in1} + R_{in2}} \cdot \frac{R_L}{R_{in2} + R_L}$$

- R_L & R_s represent rest of world

- Large signal notes
  - cap coupling makes DC into separate probs each amp
  - DC coupling trickier design (stages link) but w/ many fewer components
  - Bias point stability
    - ↳ i_B changes w/ T, keep it small
    - ↳ R_E bias linear, R_B bias exponential
  - FFT Vout to see if Vsw met, 10dB harmonics!