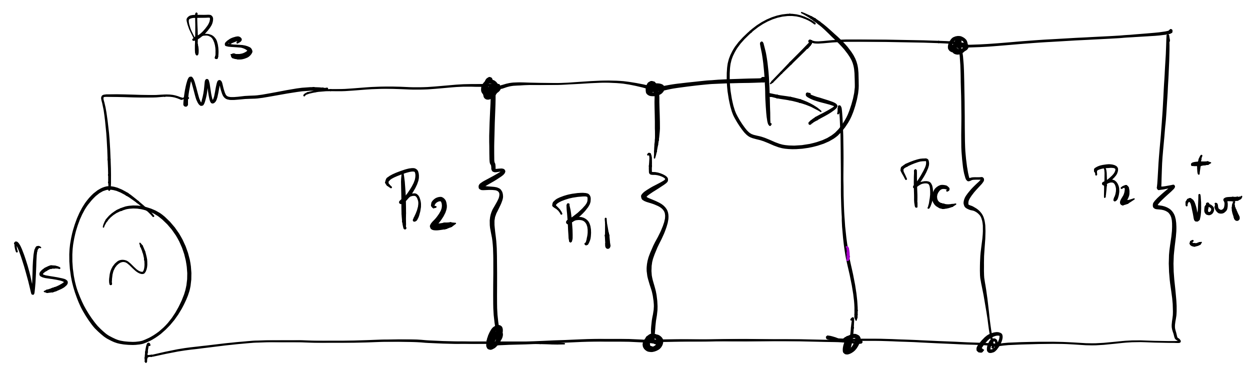
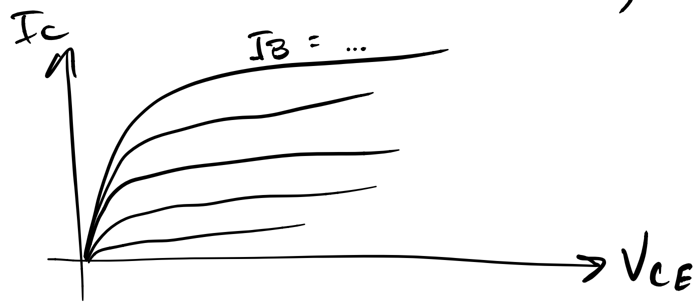
last time : mid-frequency AC Circuit

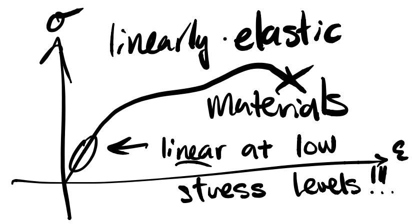


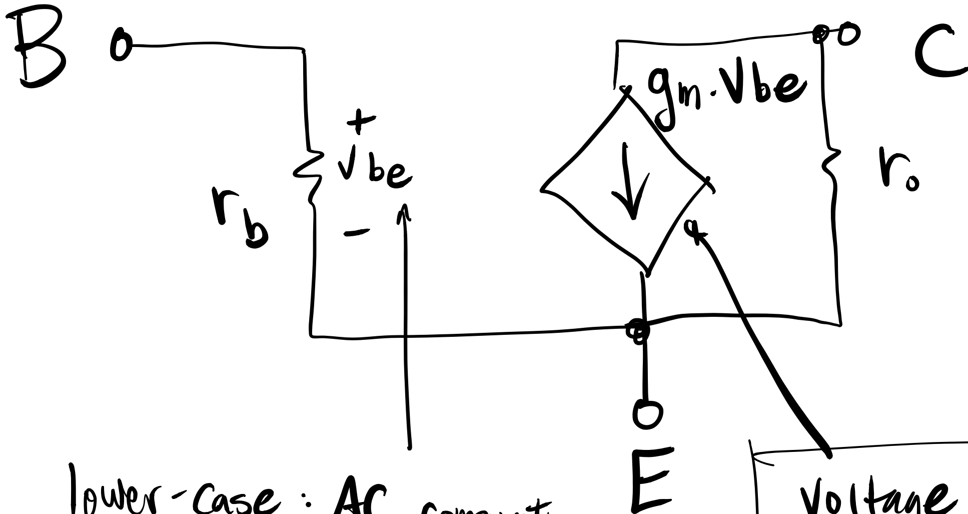
∴ how do we compute the gain of this amplifier?

∴ all active devices are non-linear;



∴ however, at small signal amplitudes, we may use a linear model for the transistor!





lower-case: AC component
(wiggle)

Voltage-controlled current source

⇓

∴ crucial feature of small-signal model!!...

∴ the small-signal AC voltage between base and emitter (V_{be}) controls AC collector current by a parameter called mutual conductance,

g_m (a/k/a transconductance)

unit: A/V, or mA/V ∴ not mho or ℧!!... ∴ not siemens!

∴ for Si transistors @ $I_C < 100\,mA$,

$$g_m \cong 35\, I_C$$

∴ where I_C is the DC collector current

[Ebers / Moll Equation]

∴ now we see why we do DC analysis first!!!

∴ there are also a couple resistances in the model we need to deal with:

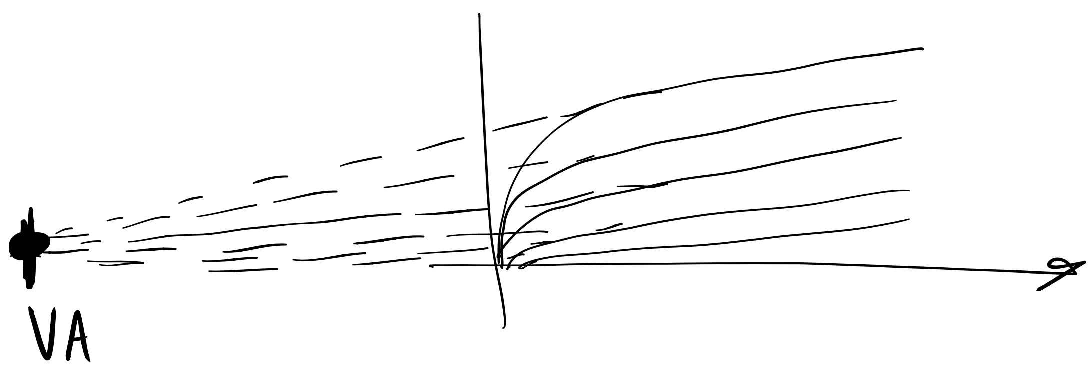
r_b : small-signal resistance between base and emitter

$$r_b = \frac{\beta}{g_m}$$

r_o : small-signal resistance in parallel w/ current source

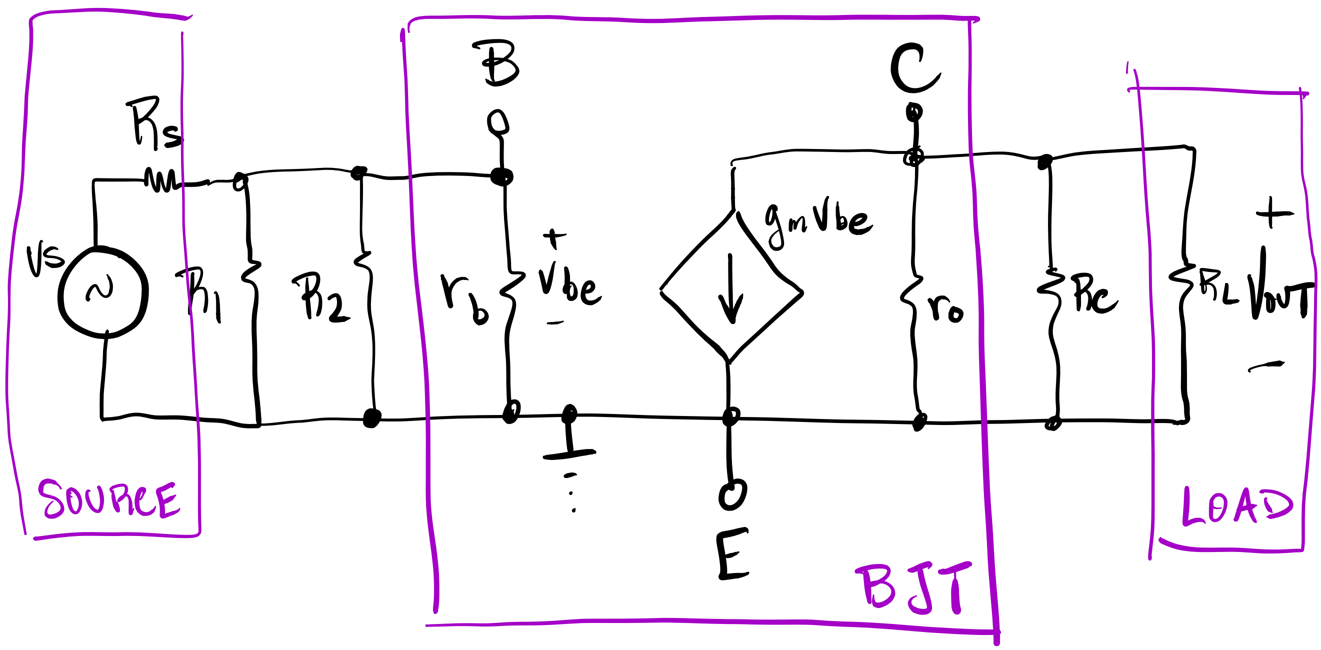
$$r_o = \frac{|V_A|}{I_C}$$

∴ V_A is called the Early voltage



∴ we'll use $V_A = 100V$ in this class!

∴ we have enough information to draw a complete mid-frequency AC model of the common-emitter voltage amplifier:



∴ note: R_E is not in the model, because it is shorted by C_E at mid frequencies!

∴ We want to determine $\dfrac{V_{OUT}}{V_S}$.

That's the gain.

∴ we do this in two parts:

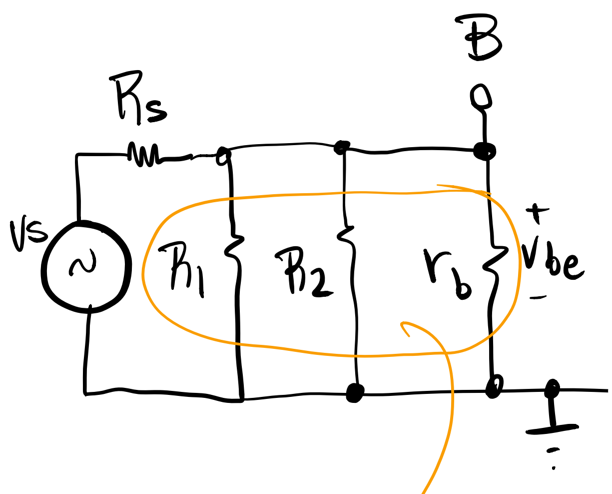
input stuff

and output stuff

- input stuff (A_{v_1}) tells us the relationship between V_s and V_{be} ; $A_{v_1} = \frac{V_{be}}{V_s}$

- output stuff (A_{v_2}) tell us the relationship between V_{be} and V_{OUT}; $A_{v_2} = \frac{V_{OUT}}{V_{be}}$

- let's do A_{v_1} first.



- just voltage division !!!

- define $R_b' = R_1 \| R_2 \| r_b$

∴ then $v_{be} = V_s \left[\frac{R_b'}{R_s + R_b'} \right]$

∴ need small-signal resistances and mutual conductance.

$$g_m = 35\, I_C$$

$$= 35 \cdot 2.63$$

$$g_m = 92.05\ mA/V$$

$$r_b = \frac{\beta}{g_m} = \frac{200}{92.05}$$

$\xrightarrow{}$ 2N3904

$$r_b = 2.173\ k\Omega$$

$$r_o = \frac{|V_A|}{I_C} = \frac{100}{2.63}$$

$$r_o = 38.02\ k\Omega$$

original circuit!

$$R_b' = R_1 \| R_2 \| r_b = 62k \| 10k \| 2.173k$$

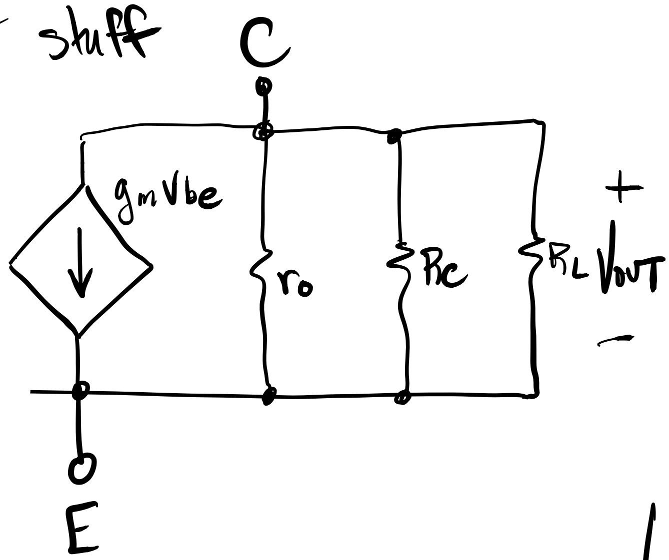
$$R_b' = 1.735\ k\Omega$$

then $A_{v_1} = \frac{V_{be}}{V_s} = \frac{R_b'}{R_b' + R_s} = \frac{1.735\ k}{1.735k + 50}$

Signal generator impedance in lab!

$$A_{v_1} = 0.97$$

∴ now, output stuff



∴ just current w/ parallel resistance !

direction of current source ∴ important !!!!!

$$V_{OUT} = -g_m V_{be} (R_C')$$

where $R_C' = r_o \parallel R_C \parallel R_L$

$= 38.02k \parallel 4.7k \parallel 10k$

$R_C' = 2.949 \ k\Omega$

$$A_{v_2} = \frac{V_{out}}{V_{be}} = -g_m \cdot R_c'$$

$$= -\underset{\cancel{mA/V}}{92.05} \cdot \underset{\cancel{k\Omega} \, \cancel{= V/A}}{2.949}$$

$$A_{v_2} = -271.5$$

final gain : $\frac{V_{out}}{V_s} = A_{v_1} \cdot A_{v_2}$

$$= 0.97 \cdot -271.5$$

$$A_v = -263.3$$

or 48.4 dB, inverting

- why does this amplifier invert ?

∴ positive change in V_S

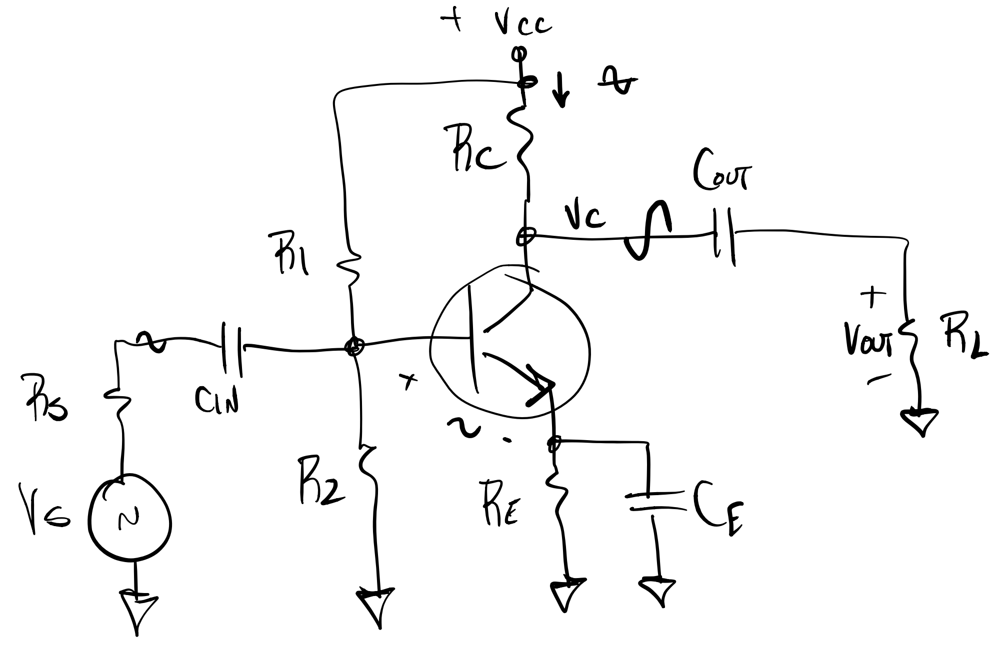
→ positive change in V_{BE}

→ " " in I_C

→ more drop across R_C

∴ subtracts from V_{CC} more!!!

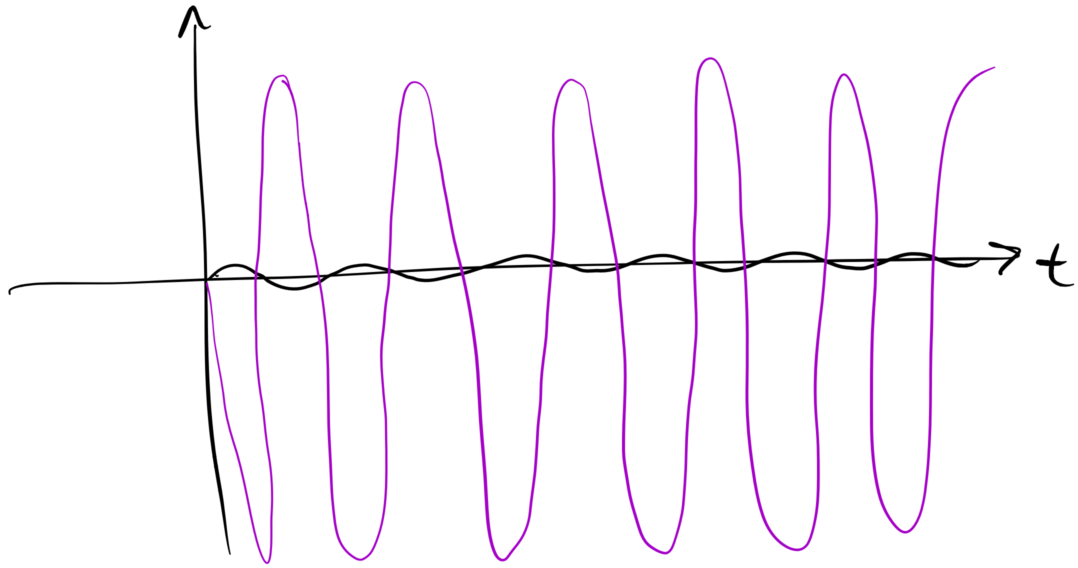
→ negative change in V_C



1kHz

ex: 10 mV$_{p\text{-}p}$ sine @ MF

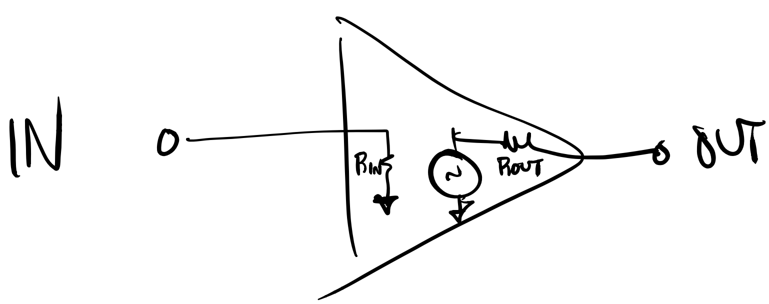
∴ V_{OUT} will be $.010 \cdot -263.3 = -2.633\ V_{p\text{-}p}$



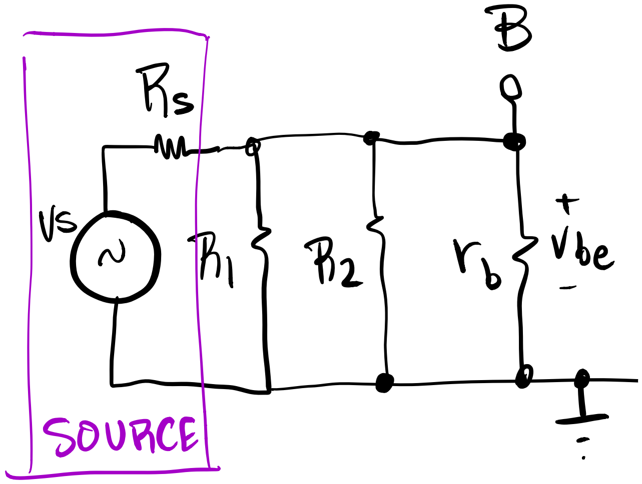
- "linear model" implies perfect output sine wave with no added harmonic components

- just as important as mid-frequency gain are the <u>input and output resistances</u>,

  i.e., how does this amplifier look to the outside world?



∴ go back to input and output circuits!

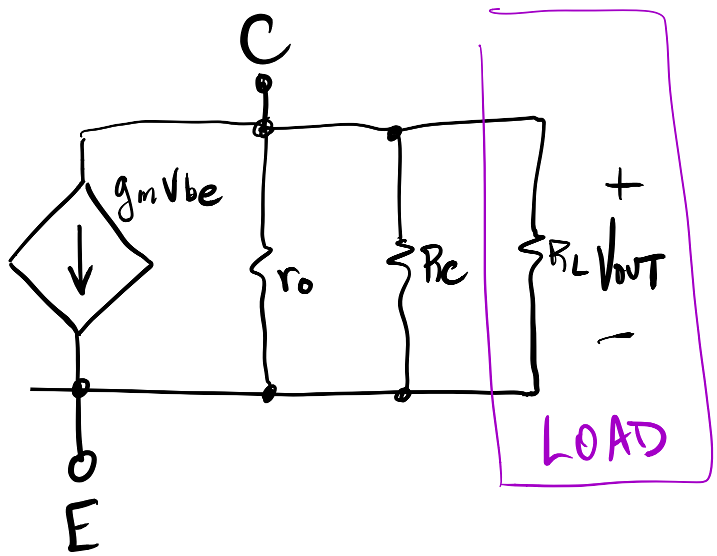


∴ from the source's perspective:

$$R_{IN} = R_1 \| R_2 \| r_b = R_b'$$

$$\therefore R_{IN} = 1.735\ k\Omega$$

∴ terrible compared to op-amps ($M\Omega$ range)



- from the load's perspective:

$$R_{OUT} = r_o \,||\, R_C$$

$$= 38.02k \,||\, 4.7k$$

$$R_{OUT} = 4.185 \text{ k}\Omega$$

- again, compared to op-amp output Z of tens of ohms, terrible. (We can fix both!)