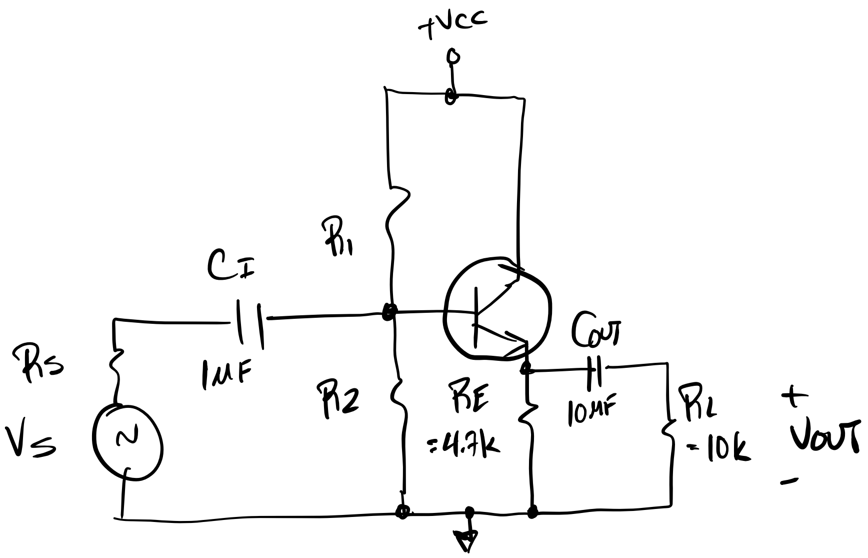
Voltage Followers

.. let's consider an alternate way of configuring our common-emitter voltage amplifier :



.. note the 4.7k collector resistor has been moved to the emitter and, more importantly, the output is now taken here.

.. because the output voltage may be considered the small-signal emitter voltage v_e, and we know amplifier output is a function of $g_m v_{be}$, then :

$$V_{OUT} \propto v_{be} = v_b - v_e$$

$$V_{OUT} \propto V_{IN} - V_{OUT}$$

∴ thus, this configuration works with <u>100% negative feedback</u>,

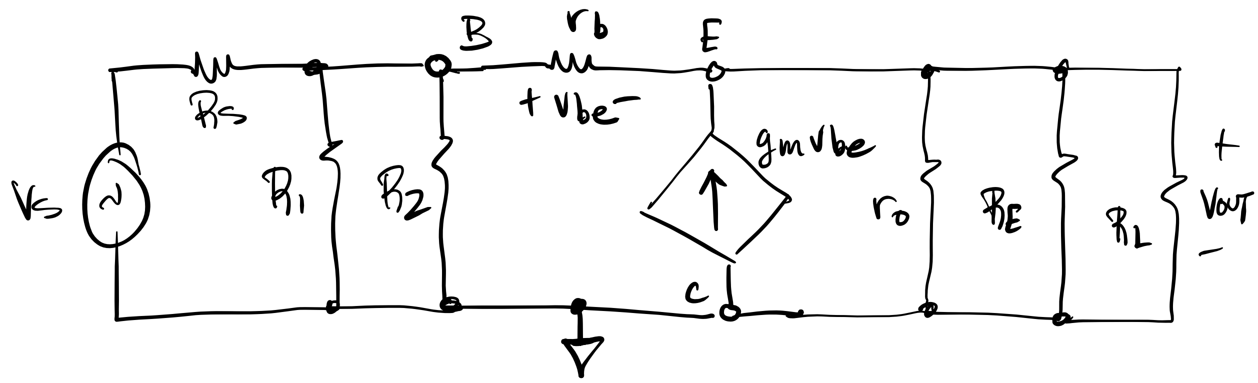
i.e., $\beta = 1$!

∴ with the collector no longer used as an output terminal, we can connect it directly to V_{CC}, which is at AC ground; thus, it is a

<u>Common-collector amplifier</u>

∴ <u>entire</u> output subtracted from input

Mid-Frequency Small-Signal Model of CC



∴ because AC emitter current $[g_m v_{be}]$ causes a <u>positive</u> V_{OUT} across $r_o \| R_E \| R_L$, the common-collector amplifier is <u>non-inverting</u>.

abstract concept

- the <u>open-loop gain</u> of the amplifier, temporarily ignoring the 100% local feedback mechanism and the effects of r_b (more later), is:

$$A_{vo} = g_m (r_o \| R_E \| R_2)$$

- this is reduced by feedback to:

$$A_v = \frac{A_{vo}}{1+\beta A_{vo}} = \frac{g_m (r_o \| R_E \| R_2)}{1 + 1 \cdot g_m (r_o \| R_E \| R_2)}$$

- if A_{vo} is sufficiently high in value, then

$$A_v \approx \cancel{\frac{g_m (r_o \| R_E \| R_2)}{g_m (r_o \| R_E \| R_2)}} \approx 1$$

or 0dB, non-inverting

- checking this, our common-emitter amplifier with identical circuit values had an open-loop gain of <u>263.3</u> (ignore the inverting part)

yep, ≈ 1!

- with 100% negative feedback, this is $A_v = \frac{263.3}{1+1 \cdot 263.3} = \underline{0.9962}$

- another way to look at the operation of a common-collector amplifier: consider that a silicon BJT's base-to-emitter voltage is nearly <u>constant</u> @ 0.7 V.
  - thus, an applied AC signal at the base will cause the emitter to "follow" this waveform, just 0.7 V more negative
  - another term for this amplifier:

emitter follower

- the common-drain/source follower using FETs works exactly the same way
- <u>both</u> are known as <u>voltage followers</u>, as is the op-amp version [next section!]
- because the feedback is taken in <u>parallel</u> with the output and in <u>series</u> with the input, it is <u>parallel-derived</u> / <u>series-applied</u>

$\downarrow$ lowers Rout $\qquad$ $\downarrow$ raises Rin

Input Resistance of CC/Emitter Follower

.. we showed that R_{in} for a CE amplifier was:

$$R_{in} = R_1 \| R_2 \| r_b$$

small-signal base-to-emitter resistance

.. series-applied negative feedback only increases r_b, because R_1 and R_2 are external to the feedback mechanism.

thus, $r_b' = r_b (1 + \beta A_{vo})$

$= 2.173\text{k} (1 + 1 \cdot 263.3)$

$r_b' = 574.3\ \text{k}\Omega$

.. now $r_b' \ggg R_1 \| R_2$; so R_{in} has been usefully increased to

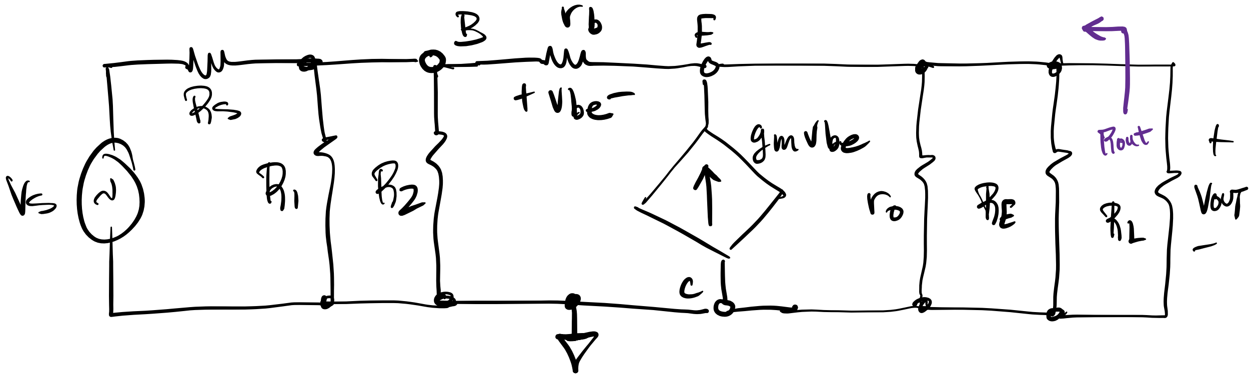
$$\boxed{R_{in}' \approx R_1 \| R_2}$$

.. remember, r_b is dependent on BJT beta; good riddance !!!

.. this is a moot point with FET source followers; no r_b!

.. self-biased JFET can acheive $G\Omega$-range R_{in} !!!

Output Resistance of CC / Emitter Follower



-- from the perspective of R_L, the open-loop output resistance (again, abstract concept!) is $R_E \| r_o$; this is reduced due to shunt-derived negative feedback to:

$$R_{out} = \frac{R_E \| r_o}{1 + \beta A_{vo}}$$

-- the open-loop gain A_{vo} from the perspective of R_L is $g_m (R_E \| r_o)$;

$$\therefore R_{out} = \frac{R_E \| r_o}{1 + 1 \times g_m (R_E \| r_o)}$$

-- as usual, if A_{vo} is a high value, then

$$R_{out} \approx \frac{\cancel{R_E \| r_o}}{g_m \cancel{(R_E \| r_o)}} \rightarrow \boxed{R_{out} \approx \frac{1}{g_m}}$$

- remember looking into the emitter from the perspective of C_E? Yep, $\frac{1}{g_m}$.

- for this follower, $R_{out} = \frac{1}{92.05\,mA/V}$

$= 0.0186\ k\Omega$

or $R_{out} = 10.86\,\Omega$ (wow!)

- same deal w/ FETs; $\frac{1}{g_m}$.

- note that due to $\simeq$ unity gain, Miller Effect input capacitance is not a thing

- we can perform HF small-signal analysis to show that HF input capacitance is

$$\boxed{C_{IN(HF)} \cong C_{bc}}$$

collector is at AC ground.
not amplified/inverted

- negative feedback nullifies C_{be} the same way it greatly increased r_b

- thus, for 50Ω source resistance, the HF cutoff would be

$$f_H \simeq \frac{1}{2\pi \cdot R_S \cdot C_{IN(HF)}} = \frac{1}{2\pi \cdot 50 \cdot 4p} = \underline{795.8\ MHz}$$

- what do we do with an amplifier that provides no voltage amplification, but has high R_{in} and low R_{out}, and low input C?

  - **buffer** sensitive sources from problematic loads

ex: What if, instead of $R_L = 10k\Omega$, our common-emitter amp needs to drive

cable capacitance

$$\underbrace{R_L = 600\,\Omega \text{ in parallel with } C_L = 2nF}_{\text{very realistic scenario!}}$$

- recall that the gain of the CE amplifier is

$$\approx A_{v2} = -g_m (R_C \| r_o \| R_L)$$

  - now we have reduced R_L significantly!

$$A_{v2} = -92.05\,(4.7k \| 38.02k \| 0.600k)$$

new R_L!

$$= -48.3 \text{ or } 33.7\text{ dB}$$

-- We just lost 15 dB of gain; itself bad enough, probably means less gain available for negative feedback, increasing distortion and worsening freq. response

-- plus, that 2nF cable capacitance "sees" an equivalent resistance of CE Rout ($\approx R_C$) in parallel w/ R_L; together, this forms a LPF:

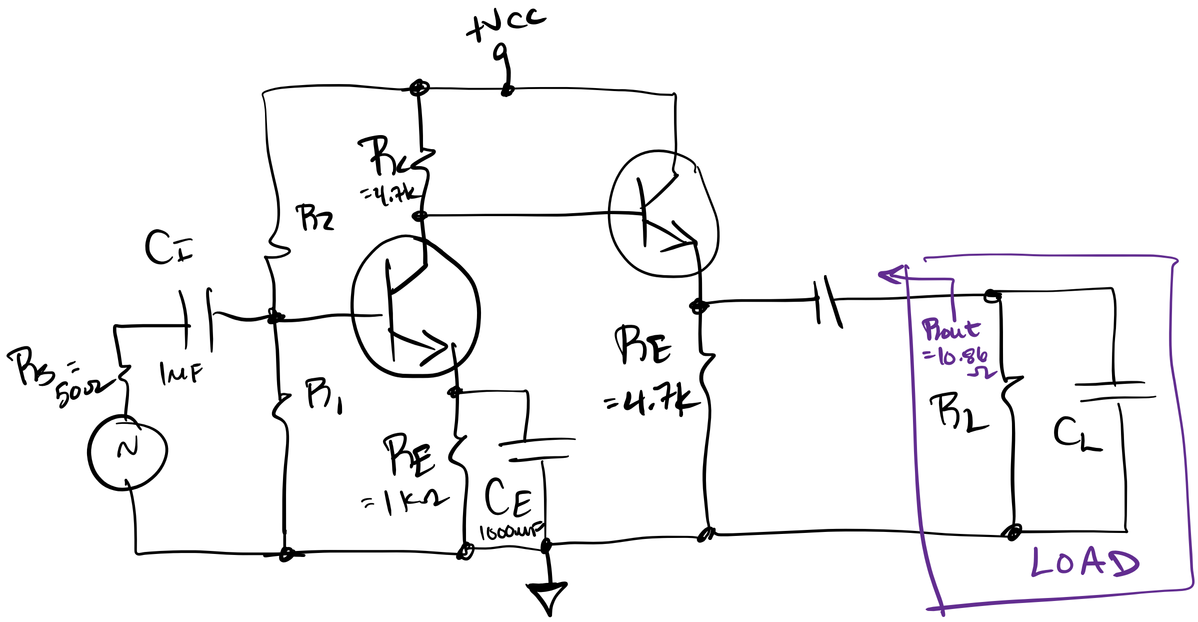
$$f_{H(C_L)} = \frac{1}{2\pi \cdot C_L \cdot (R_C \| R_L)}$$

$$= \frac{1}{2\pi \cdot 2n \underbrace{(4.7k \| 0.600k)}_{= 532.1\,\Omega}}$$

$$= \underline{149.6 \text{ kHz}}$$ ← dominates system; not good!

-- instead, use an emitter follower to buffer the CE amplifier from nasty Z_L; CE now sees negligible loading (no R_L in gain equation, no bias network if direct-coupled, negligible load capacitance)

∴ harsh Z_L of $600\Omega \| 2nF$ is now driven from R_{out} of follower



∴ practically no loss of gain between $R_{out} = 10.86\Omega$ and $R_L = 600\Omega$, and C_L "sees" an equivalent resistance of $R_L \| R_{out} = 600\Omega \| 10.86\Omega$

$$\simeq 10.86\Omega$$

$$f_{H(OUT)} \cong \frac{1}{2\pi \cdot C_L \cdot R_{out}}$$

$$= \frac{1}{2\pi \cdot 2n \cdot 10.86}$$

$$f_{H(OUT)} = 7.32\ MHz$$

much better!

∴ so we have analyzed an amplifier configuration that uses shunt-derived / series applied negative feedback with $\beta = 1$ or 100% to create a voltage follower that can be a powerful solution for driving difficult loads

∴ Negative feedback FTW !!!