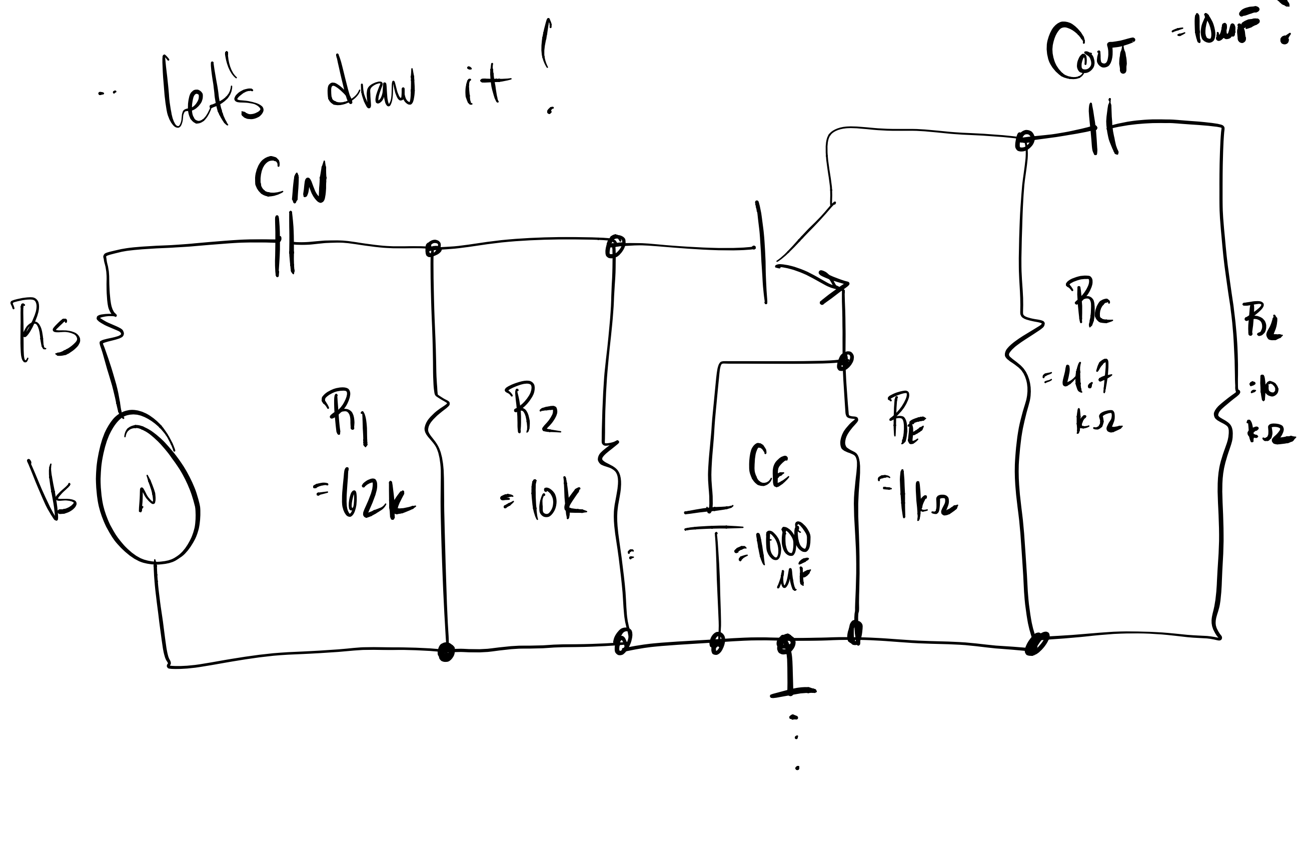
Low-Frequency AC Circuit

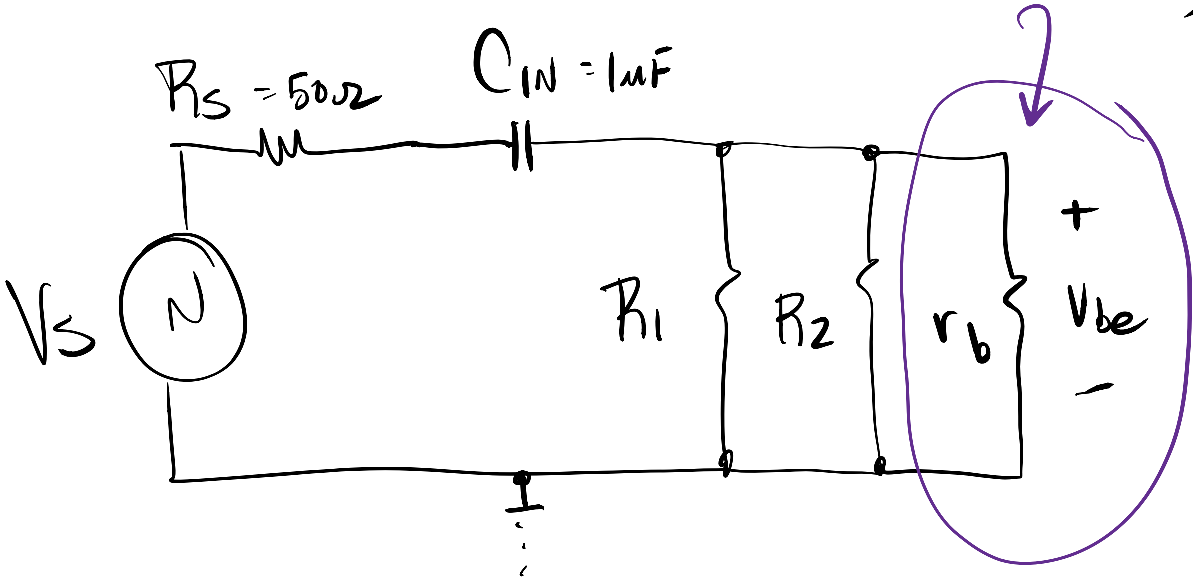
.. at low frequencies, the impedances of the capacitors can no longer be considered non-zero!

(power supply is still "ground!")

.. let's draw it!

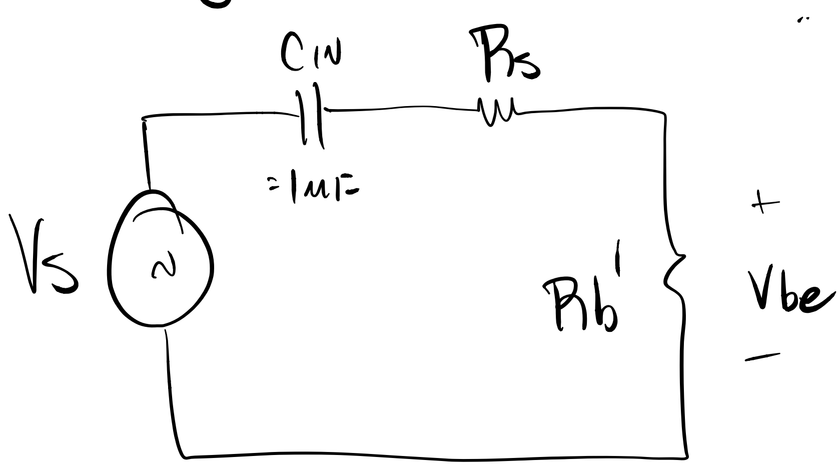


C_{IN}: (back to small-signal BJT model!)



$$R_1 \| R_2 \| r_b = R_b' = 1.735\ k\Omega$$

∴ slightly redraw circuit:



∴ 1st-order HPF w/ scaling factor!

$= A_{v_1}$!!!

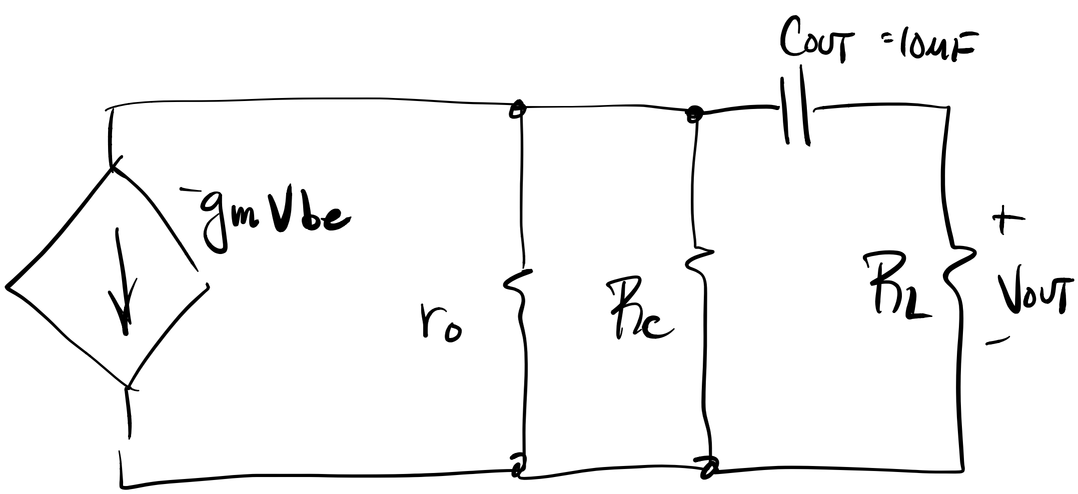
∴ corner frequency of input HPF :

$$f_{c_{IN}} = \frac{1}{2\pi C_{IN} (R_S + R_b')}$$

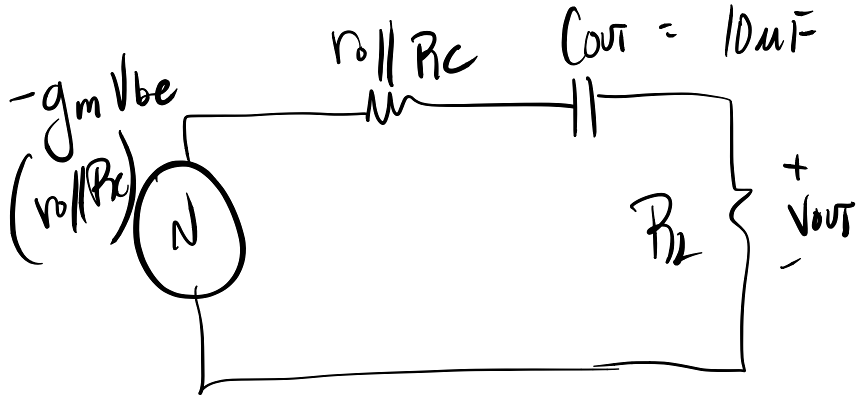
$$= \frac{1}{2\pi \cdot 1 \times 10^{-6} (50 + 1735)}$$

$$\underline{f_{c_{IN}} = 89.2 \text{ Hz}}$$

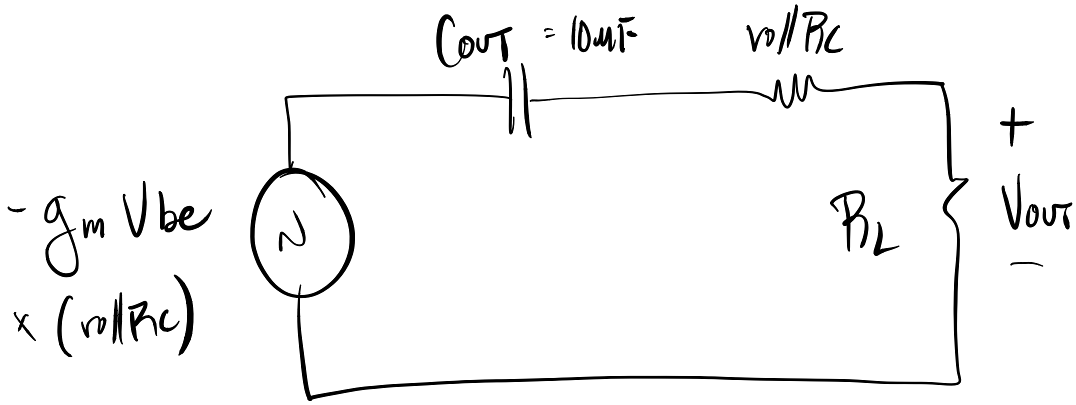
C_{OUT} : output half of small-signal model !



∴ <u>one</u> source transformation:



∴ slight redraw:



∴ another HPF w/ scaling factor!

$$f_{c\,OUT} = \frac{1}{2\pi C_{OUT}(r_o \| R_C + R_L)}$$

$$f_{c\,OUT} = \frac{1}{2\pi \cdot 10\times10^{-6}\left(38.02k \| 4.7k + 10k\right)}$$

$$\Downarrow$$

$$\underbrace{14.183\,k}$$

$$f_{c\,OUT} = 1.12\ Hz$$

∴ now we deal w/ C_E

∴ it's complicated!

∴ beyond the scope of this course, the Thévenin resistance seen by C_E is

$$R_{C_E} = \frac{1}{g_m} \| R_E$$

$$\frac{1}{g_m} = \frac{1}{92.05 \times 10^{-3}} = \underline{10.9\,\Omega}$$

1k!

... since $\frac{1}{g_m} \lll R_E$,

$$\underline{R_{CE} \approx \frac{1}{g_m}}$$

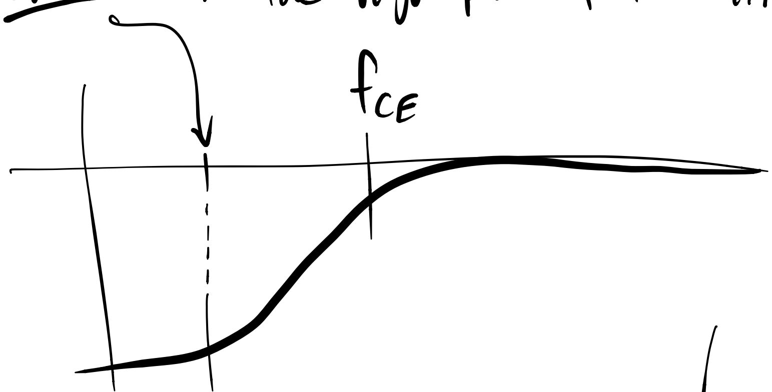
$$f_{CE} = \frac{1}{2\pi \cdot C_E \cdot R_{CE}}$$

$$= \frac{1}{2\pi \cdot 1000 \times 10^{-6} \cdot 10.9}$$

$$= \underline{14.6\ Hz}$$

... but then another thing happens that is a little less obvious.

∴ at some even lower frequency, $Z_{CE} \gg R_E$
and a shelf in the high-pass filter appears



∴ in this class: don't worry about it!

∴ so we have three low-frequency cutoffs, creating a third-order high-pass filter
(2nd if you include that shelf!)

third-order → 18 dB/oct

∴ because $f_{c\,IN}$, $f_{c\,OUT}$, and f_{CE} are spaced by a factor of ≈ 5 or better, the approximate −3dB of the system is $f_{c\,IN}$!

∴ this concept is called a dominant pole.

∴ final -3dB LF point is $\approx f_{c_{IN}}$

$$f_L \approx 89.2 \text{ Hz}$$

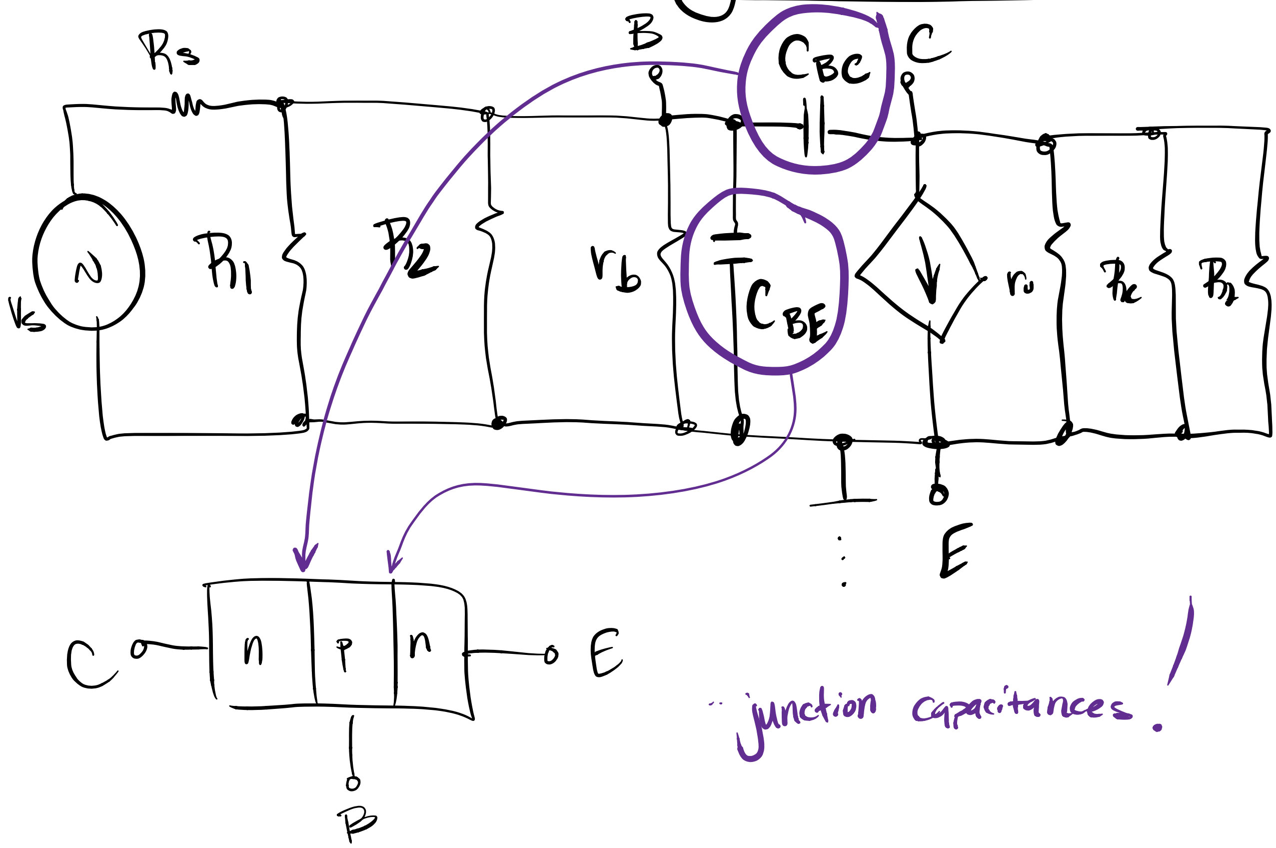
High-Frequency AC Circuit

∴ at high frequencies, the impedances of C_{IN}, C_{OUT}, and C_E are sufficiently low that we treat them as shorts, just like at mid-frequencies

∴ so, what's the problem?

∴ now we have transistor capacitances to deal with (great!)

BJT High-Frequency Small-Signal Model



- junction capacitances!

- note: no significant capacitance between collector and emitter! So that's good!

- slight issue: C_{BC} and C_{BE} change with quiescent operating point

  (but we can approximate them)

from 2N3904 datasheet:

$C_{BCO} = 4\ pF$

@ $I_E = 0$; actual value higher @ some I_E

$C_{BEO} = 18\ pF$

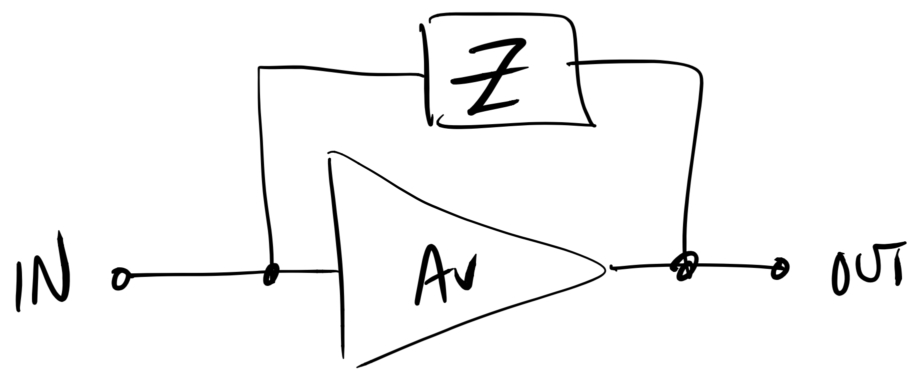
∴ C_{BE} looks like it would form a low-pass filter w/ input resistances, but what about C_{BC}?

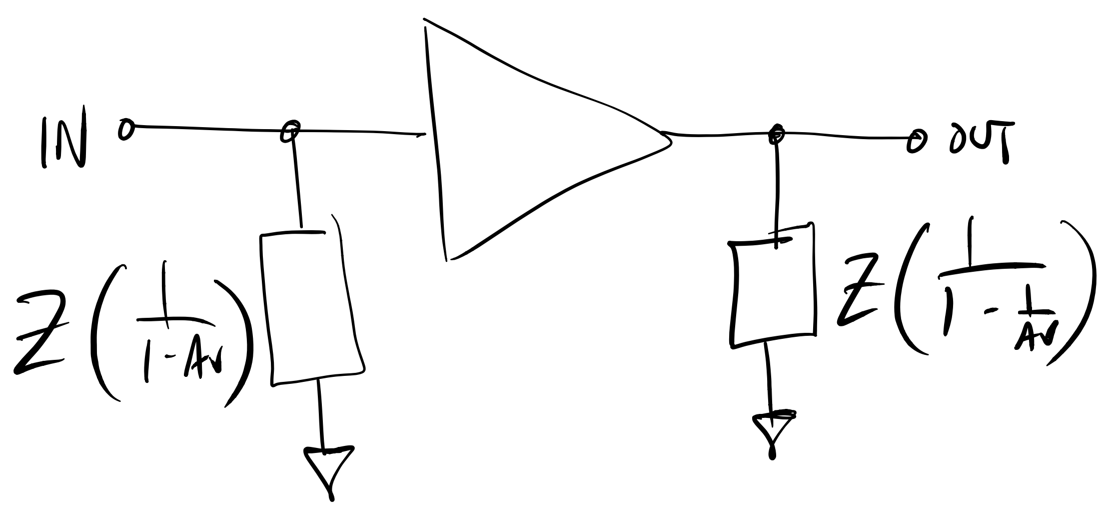
∴ doesn't look like any filters we know!

∴ It's Miller Time!

(Dr. Kazimierczak!)

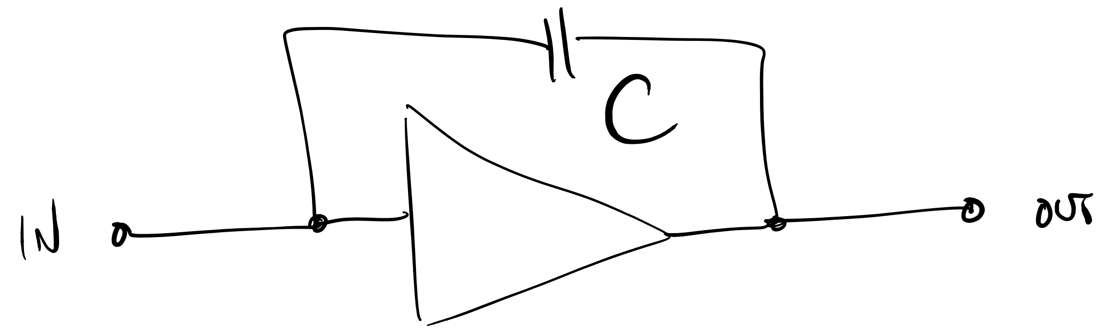
Miller's Theorem





... now we're getting somewhere!

∴ Since $Z_C = \frac{1}{j\omega C}$:



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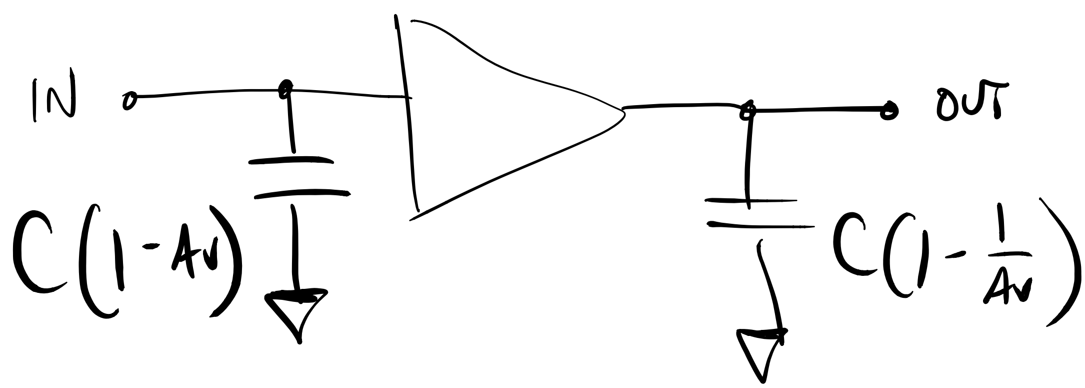


∴ this means that C_{BC}, which is between the input and output of the circuit, may be split into two components:

$$C_{BC(IN)} = C_{BC}(1 - A_{v_2})$$

A_{v_2}: gain between V_{be} and V_{out}

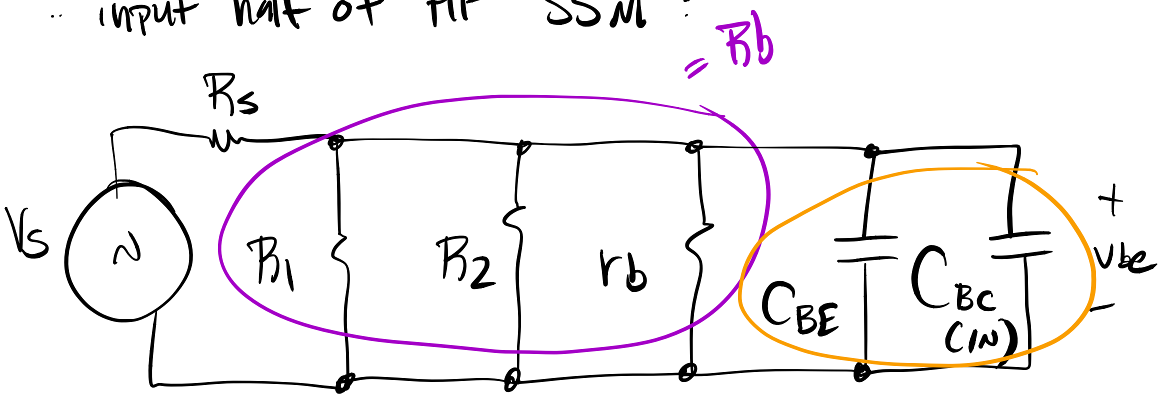
$$= 4(1-(-271))$$

$$= \underline{1084 \text{ pF}} \quad !!!!$$

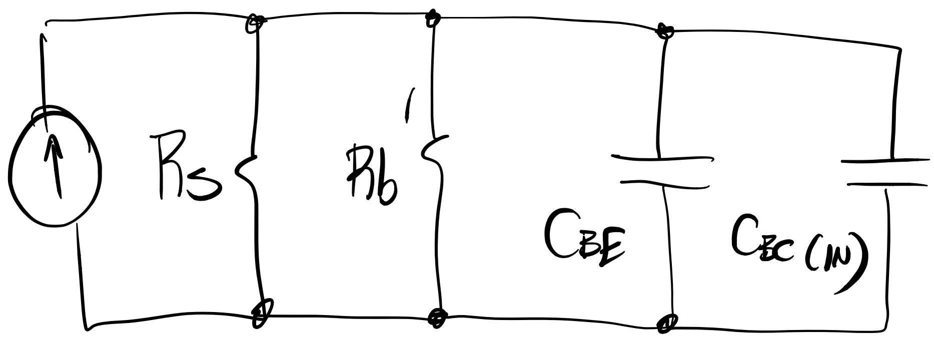
$$C_{BC(OUT)} = C_{BC}\left(1 - \frac{1}{A_v}\right) \simeq \underline{4 \text{ pF}}$$

$\frac{1}{A_v} \approx 1$

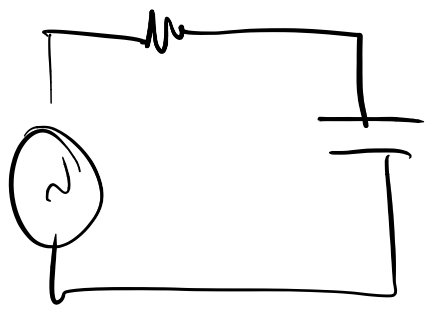
∴ input half of HF SSM :



∴ one source transformation :



$\Rightarrow$



1st-order LPF !

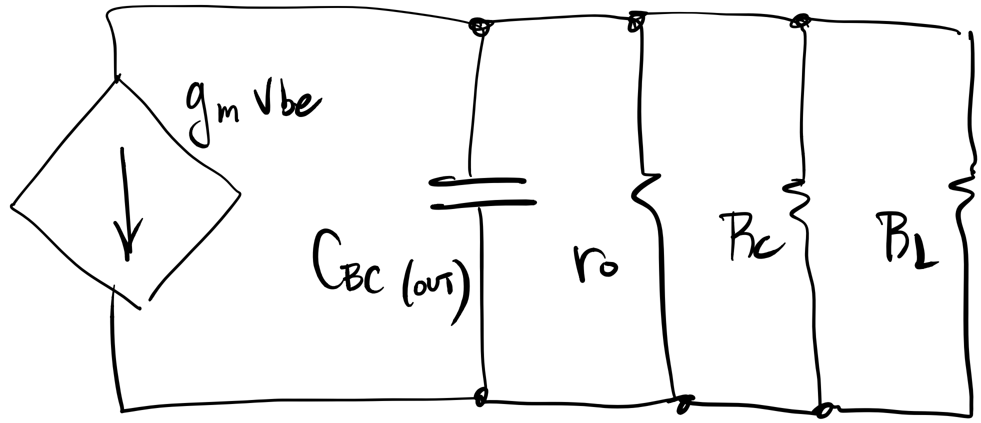
$$f_{H(IN)} = \frac{1}{2\pi \underbrace{\overbrace{\left(C_{BE} + C_{BC(IN)}\right)}^{=1084+18 \;=1102\,pF}}_{\text{caps in parallel add!}} \left(R_s \parallel R_b'\right)}$$

$= 50 \parallel 1.735k$

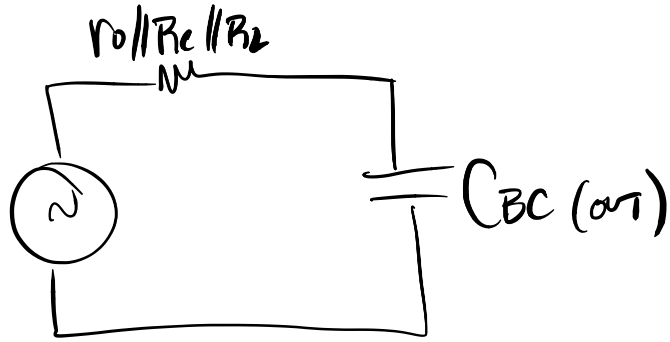
$= 48.6\,\Omega$

$$f_{H(IN)} = 2.97\ \text{MHz}$$

∴ output half of HF SSM :



$\Rightarrow$



∴ another 1st-order LPF !

$$f_{H\,(OUT)} = \frac{1}{2\pi \cdot \underbrace{C_{BC\,(OUT)}}_{\approx\, 4\,pF} \underbrace{\left(r_o \| R_C \| R_L \right)}_{38.02k \| 4.7k \| 10k}}$$

$$f_{H\,(OUT)} = 13.5 \text{ MHz}$$

∴ since $f_{H(IN)} \approx 4.5\, f_{H(OUT)}$,

it's the dominant pole

$$\therefore \; f_H \approx 2.97 \text{ MHz}$$