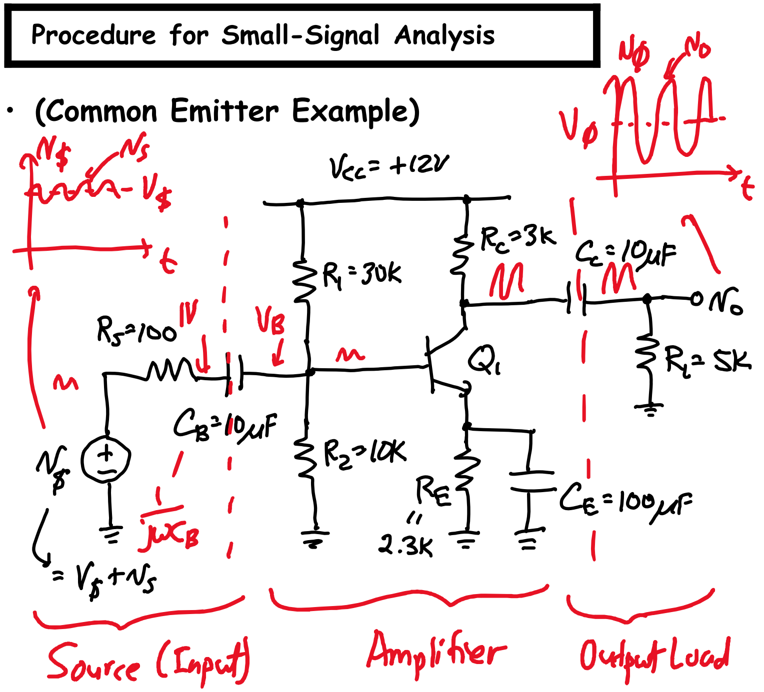
Lecture 22: Common Emitter Amplifier

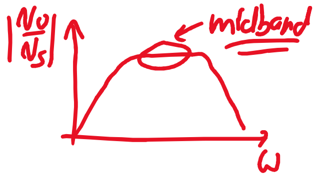
- **Announcements**:
- HW#7 online and due Friday via Gradescope
- Lab#5 online (this is your first project)
  - ↳ Due Tuesday, Nov. 12, 5 p.m.
- Graded Midterm and solutions passed back last time … but I also have the leftovers and solutions today that you can pick up at the end of class
- Z scores also coming back today
- ------------------------------------
- Lecture Topics:
  - ↳ Example: Common Emitter Amplifier
  - ↳ Frequency Response (if we get this far)
- ------------------------------------
- **Last Time**:
- Going through a Common Emitter Amplifier small-signal analysis example
- Now, continue with this …

Procedure for Small-Signal Analysis

- (Common Emitter Example)



[Thevenin Equivalent]



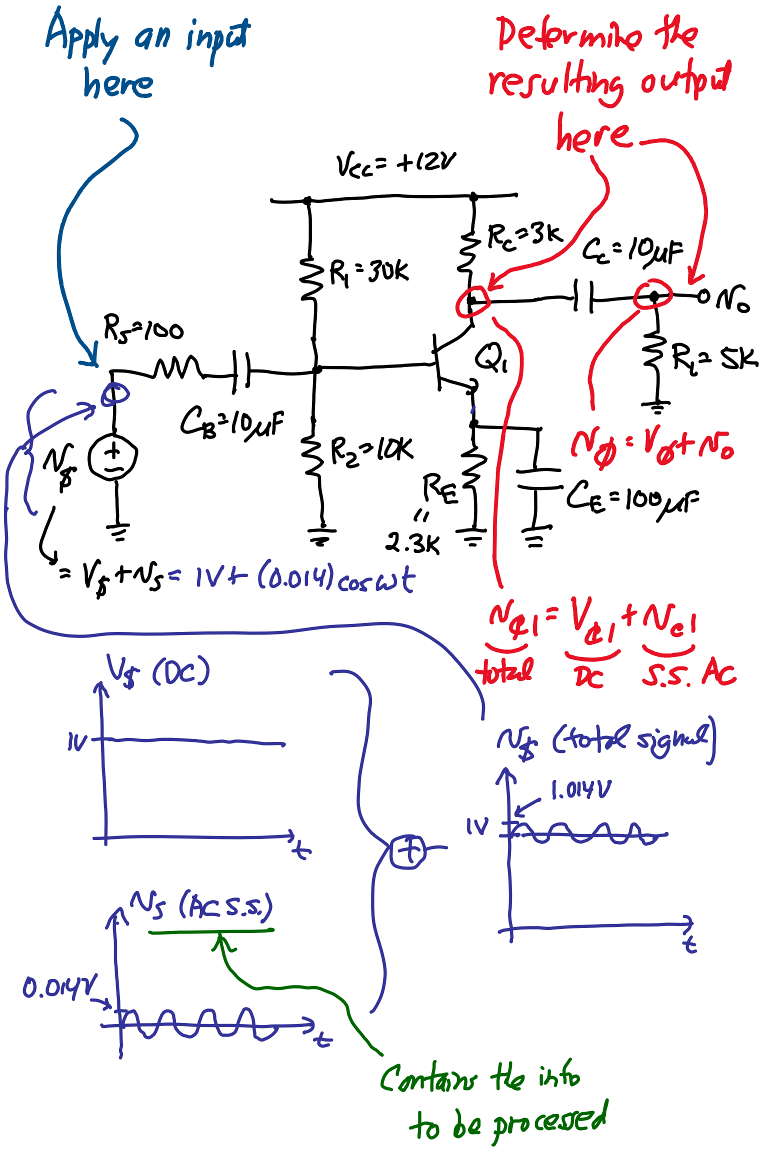
For Q: $\beta = 100$, $V_A = 100V$

Find the voltage gain, $\frac{v_o}{v_s}$.

Draw the collector voltage waveform for

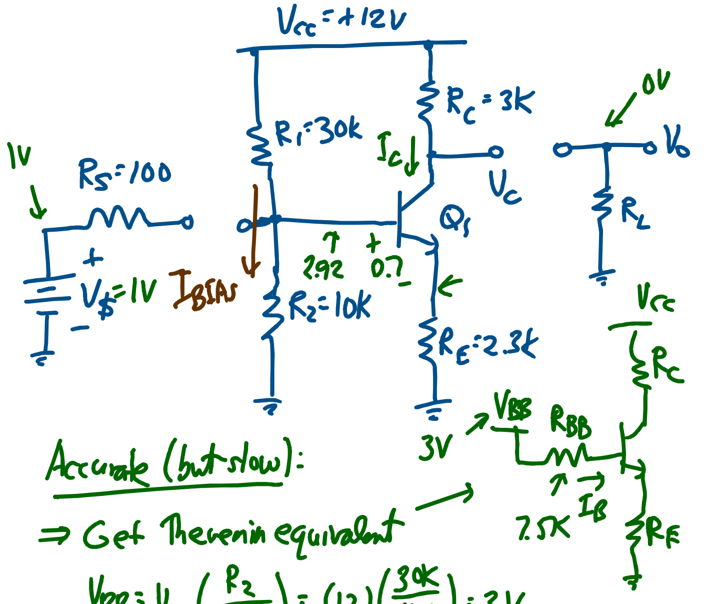
$$v_S = \underbrace{(0.014)\cos\omega_o t}_{\text{AC small-signal component}} + \underbrace{1V}_{\text{DC component}}$$

Graphically, here's what we're looking to do:



① Determine the DC operating point

- i.e., find the relevant DC voltages at all nodes and DC currents through all branches
- Draw the DC circuit
  - Eliminate independent AC small-signal sources
    - Short AC voltage sources
    - Open AC current sources
  - Open all capacitors (in particular, open the bypass/coupling capacitors)
  - Use DC transistor models
    - this might entail nonlinearity in some cases, but approximations can alleviate



Accurate (but slow):

⇒ Get Thevenin equivalent

$$V_{BB} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right) = (12)\left(\frac{30K}{40k}\right) = 3V$$

$$R_{BB} = R_1 // R_2 = (10k) // (30k) = 7.5K$$

$$I_C = \frac{V_{BB} - V_{BE}}{\frac{R_E}{\alpha} + \frac{R_{BB}}{\beta}} = \frac{3 - 0.7}{\frac{2.3K}{1} + \frac{7.5K}{100}} = 0.97mA \approx \underline{1mA}$$

$$I_B = \frac{I_C}{\beta} = \underline{0.01mA}$$

$$\therefore I_E \approx 0.97mA \approx \underline{1mA}$$

$$V_B = V_{BB} - I_B R_{BB} = 3 - (0.01m)(7.5K) = \underline{2.92V}$$

$$\therefore V_E = 2.92 - 0.7 = \underline{2.22V}$$

$$V_C = V_{CC} - I_C R_C = 12 - (1m)(3K) = \underline{9V}$$

$\approx$ ✓

Faster Way:

$$\text{Ignore } I_B \rightarrow V_B = V_{CC}\left(\frac{R_2}{R_1 + R_2}\right) = 3V$$

$$V_E = V_B - V_{BE(on)} = 3 - 0.7 = 2.3V$$

$$\therefore I_E = \frac{V_E}{R_E} = \frac{2.3}{2.3K} = \underline{1mA} = I_C$$

$$I_B = \frac{I_C}{\beta} = \frac{1m}{100} = \underline{0.01mA}$$

$$V_C = V_{CC} - I_C R_C = \underline{9V}$$

$$I_{BIAS} = \frac{V_{CC}}{R_1 + R_2} = \frac{12}{40K} = \underbrace{0.3mA > 10 I_B}_{\text{For a stable bias pt.}} \checkmark$$

② Determine the elements in the small-signal transistor model(s)

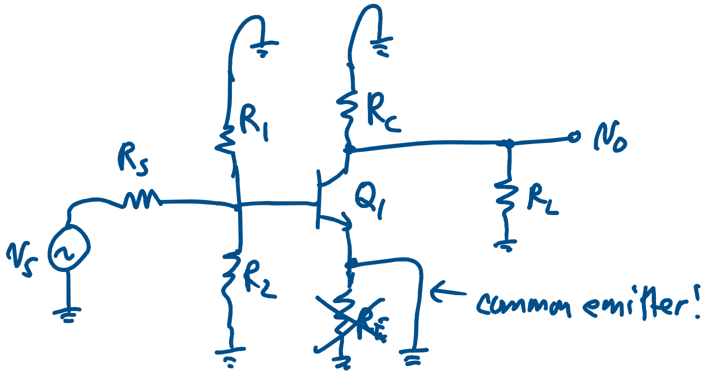
- If more than one transistor, might need to determine SS element values for several of them

$$g_m = \frac{I_C}{V_T} = \frac{1m}{25m} = \underline{0.04\mho} \qquad r_o = \frac{V_A}{I_C} = \frac{100}{1m} = \underline{100k\Omega}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.04} = \underline{2.5k\Omega} \qquad r_e = \frac{\alpha}{g_m} \approx \frac{1}{g_m} = \underline{25\Omega}$$

③ Obtain the small-signal circuit

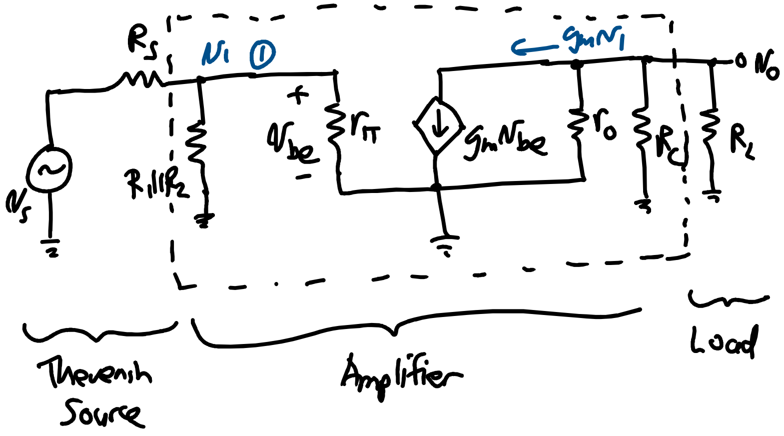
- Eliminate independent DC sources
  - Short DC voltage sources
  - Open DC current sources
  - Short large coupling capacitors (C's > 10nF)
  - Use small-signal transistor models



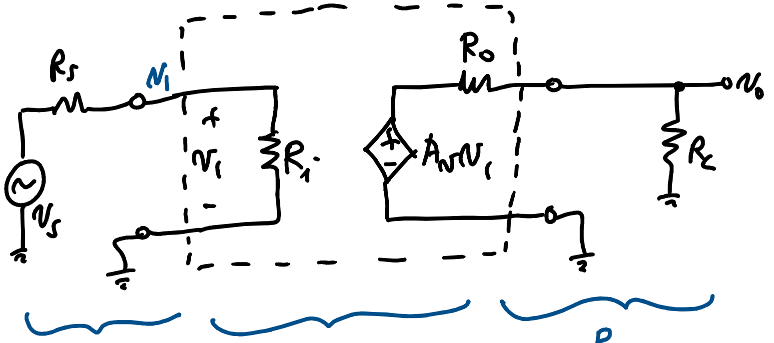
← common emitter!

S.S. Ckt.

⇓



⇒ would like to get this in the form of our simple amplifier model:



$$\frac{R_i}{R_i+R_s} \times A_v \times \frac{R_L}{R_o+R_L} = A_{tot}$$

④ Use standard circuit analysis (i.e., KCL or KVL with superposition) to determine the parameters of interest

- Usually, the parameters of interest include
  - ↳ Gain, A_v
  - ↳ Input Resistance, R_i
  - ↳ Output Resistance, R_o
  - ↳ Low Frequency Cut-off, ω_b
  - ↳ High Frequency Cut-off, ω_h
- Determine all of these during small-signal analysis
- The total gain of the simplified amplifier circuit takes the form

$$\boxed{\frac{v_o}{v_s} = \frac{R_i}{R_i+R_s} A_v \frac{R_L}{R_L+R_o}}$$

For ideal want: $R_i = \infty$ $(R_i \gg R_s)$ $R_o = 0$ $(R_o \ll R_L)$

Amplifier Gain –

$$A_v = \frac{v_o}{v_i}\bigg|_{R_L=\infty} \text{ (or } i_o = 0\text{)}$$

$$v_o = -(g_m v_i)(r_o \| R_c) \rightarrow A_v = \frac{v_o}{v_i}\bigg|_{R_L=\infty} = \boxed{-g_m(r_o \| R_c) = A_v}$$

$$\boxed{A_v \approx -g_m R_c} = -120$$

$r_o \gg R_c$