Lecture 24: Common Emitter Amplifier

- Announcements:
- HW#7 online and due Friday via Gradescope
- Lab#5 online (this is your first project)
  - Due Tuesday, Oct. 30, 5 p.m.
- Shortly after lecture last time, my hard drive died
  - Lost the PowerPoint and video
  - Rewrote the PowerPoint – this is online
  - Looking for a video from ETS … we'll see
- Next Monday: No lecture
  - I will be on travel (as indicated in the schedule shown on the first day)
  - Lecture will be by video
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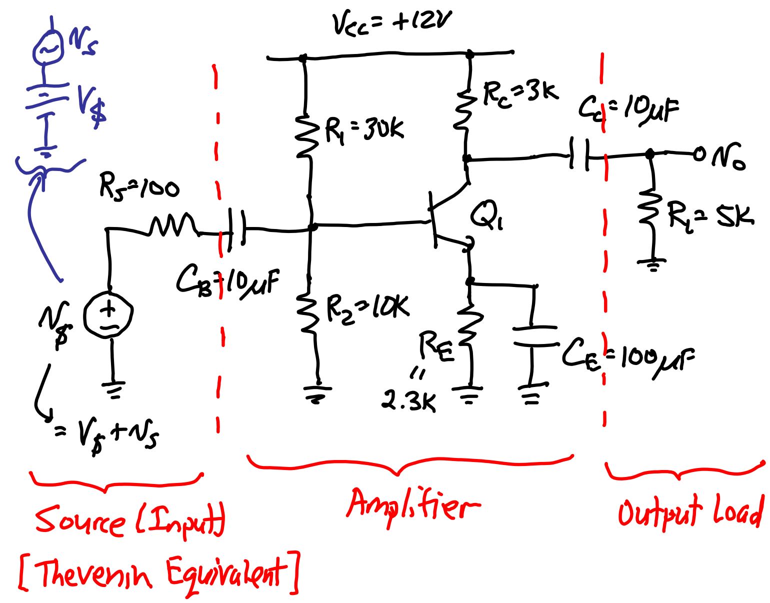
- Lecture Topics:
  - Example: Common Emitter Amplifier
  - Frequency Response
- ------------------------------------
- Last Time:
- Going through a Common Emitter Amplifier small-signal analysis example
- Now, continue with this …

Procedure for Small-Signal Analysis

- (Common Emitter Example)



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

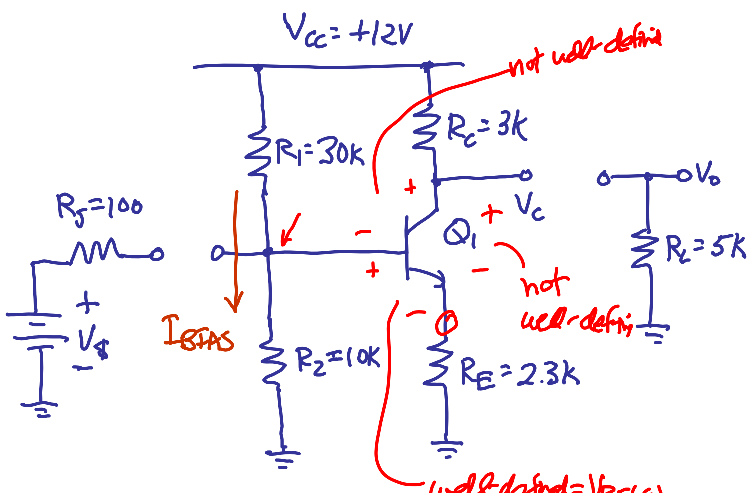
Find the voltage gain, $\frac{v_o}{v_s}$.

Draw the collector voltage waveform for

$$v_S = \underbrace{(0.014)\cos\omega_0 t}_{\text{AC small-signal component}} + \underbrace{1V}_{\text{DC component}}$$

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:

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

$R_{BB} = 10k \| 30k = \underline{7.5K}$

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

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

$\therefore I_E \approx 0.97mA \approx 1mA$

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

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

$V_C = V_{CC} - I_C R_C = 12 - 3 = \underline{9V}$

≈ ✓

Faster Way:

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

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

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

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

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

$I_{BIAS} = \frac{V_{CC}}{R_1+R_2} = \frac{12}{40k} = 0.3mA > 10 I_B$ ✓

For stable bias pt.

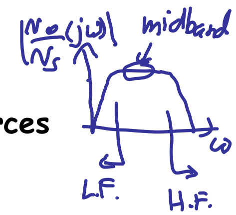
② Determine the elements in the small-signal transistor model(s)

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

$g_m = \frac{I_C}{V_T} = \frac{1m}{25m} = 0.04\,\Omega$ $\quad r_o = \frac{V_A}{I_C} = \frac{100}{1m} = 100\,k\Omega$

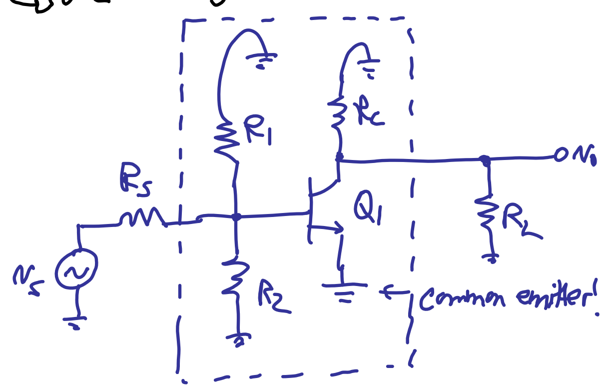
$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.04} = 2.5\,k\Omega$ $\quad r_e = \frac{\alpha}{g_m} \simeq \frac{1}{g_m} = 25\,\Omega$

I_C gives all of these!

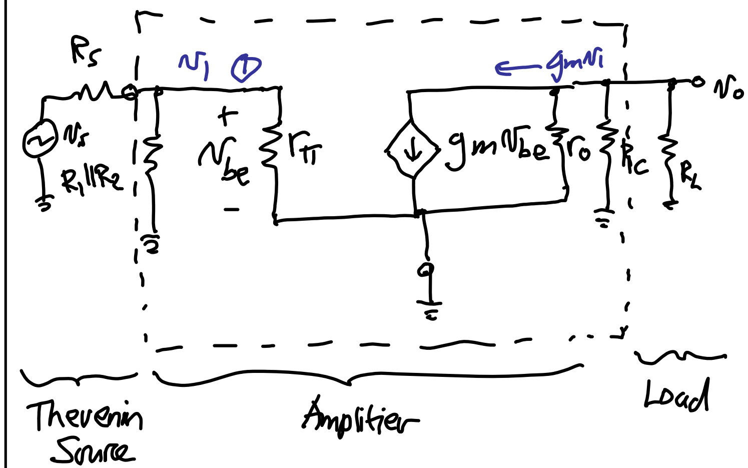


③ Obtain the small-signal circuit

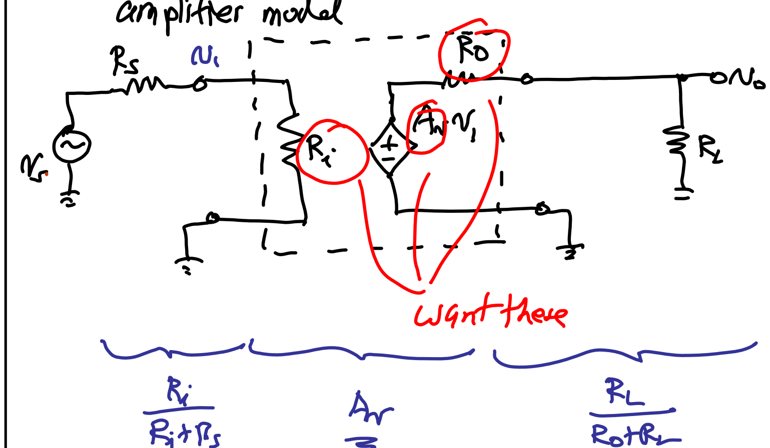
- Eliminate independent DC sources
  - Short DC voltage sources
  - Open DC current sources
- Short large coupling capacitors (C's > 10 nF)
- Use small-signal Xsistor models



⇓ replace the Xsistor w/ S.S. model



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



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

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

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

Amplifier Gain –

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

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

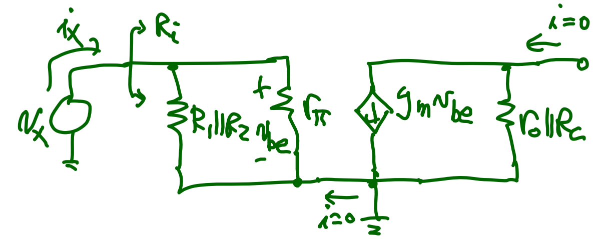
$$A_v \approx -g_m R_c = -120$$

($r_o \gg R_c$)

⇒ max gain occurs when $R_c = \infty$:

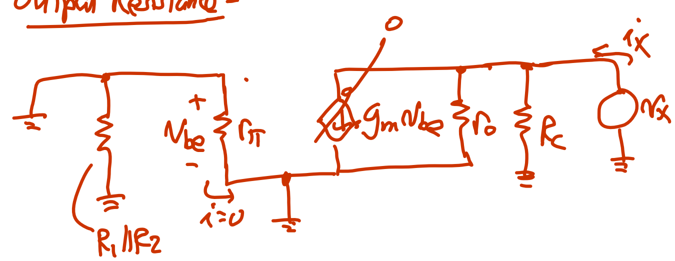
$$\text{Max Gain} = -g_m r_o = -\frac{I_C}{V_T}\frac{V_A}{I_C} = -\frac{V_A}{V_T} = \text{Max Gain}$$

Input Resistance –



$$R_i = \frac{v_x}{i_x} = r_\pi \| R_1 \| R_2 = 1875\,\Omega$$

Output Resistance –



$$R_o = \frac{v_x}{i_x} = r_o \| R_c \cong R_c = 3\,k\Omega$$

$[r_o \gg R_c]$

For the Total Ckt:

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

$$= \frac{r_\pi \| R_1 \| R_2}{r_\pi \| R_1 \| R_2 + R_s} (-g_m R_c) \left(\frac{R_L}{R_L + R_c} \right)$$

$= R_c \| R_L$

$$= -\frac{r_\pi \| R_1 \| R_2}{r_\pi \| R_1 \| R_2 + R_s} g_m (R_c \| R_L)$$

$$= -\frac{1875}{1875 + 100} (0.04)(3k \| 5k)$$

$$= \boxed{-71.2 = \frac{v_o}{v_s}}$$