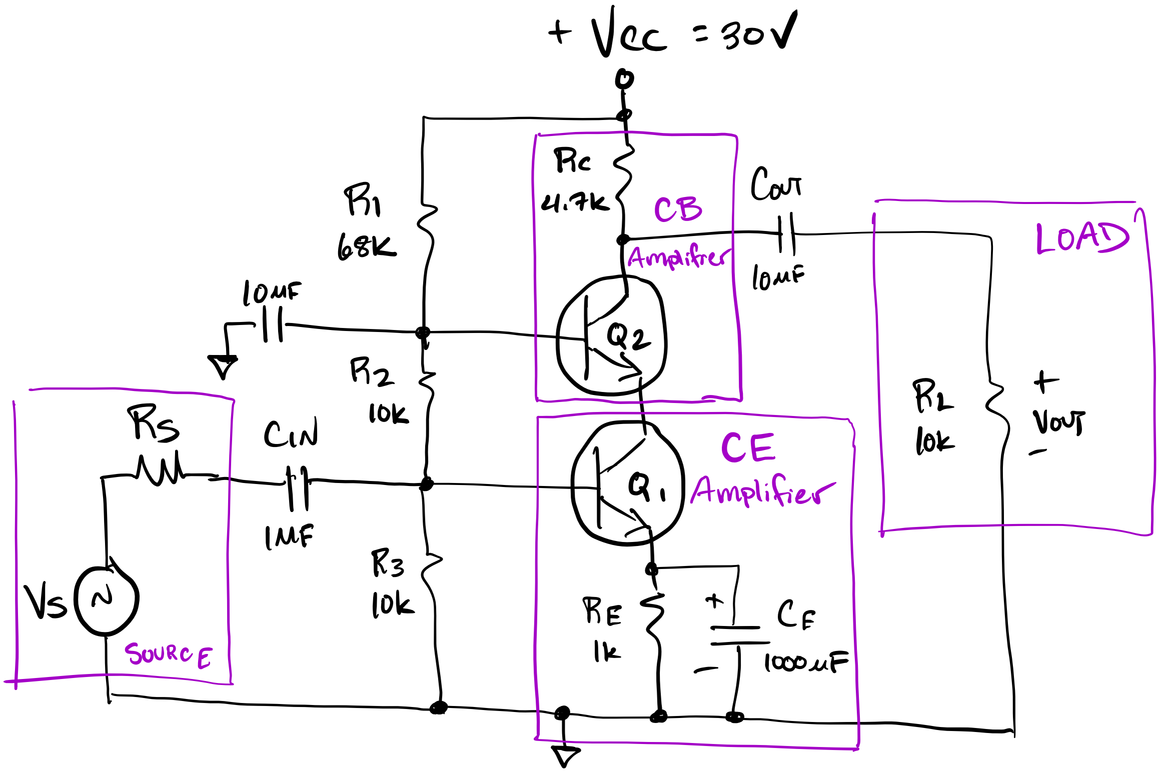
The Cascode Amplifier



- combining CE and CB amplifiers in one compound amplifier stage offers high gain and high R_{IN} (not really) of CE with better HF response of CB!

- in the vacuum-tube era, when this circuit was developed, the anode of the common-cathode stage was cascaded into the cathode of the common-grid stage

...thus, cascode.

-- quick D.C. analysis, assuming high β:

$$V_{B_1} = V_{CC}\left[\frac{R_3}{R_1 + R_2 + R_3}\right] = 30\left[\frac{10k}{68k + 10k + 10k}\right]$$

$$V_{B_1} = \underset{\sim}{3.4V} \quad \therefore V_{E_1} = 3.4 - 0.7 = \underline{2.7V}$$

$$I_{E_1} \approx \underbrace{I_{C_1} = I_{E2}}_{\text{D.C. Coupled!}} \approx I_{C_2} = \frac{V_{E1}}{R_E} = \frac{2.7}{1k} = \underset{\sim}{2.7\,mA}$$

$$V_{B_2} = V_{CC}\left[\frac{R_2 + R_3}{R_1 + R_2 + R_3}\right] = 30\left[\frac{10k + 10k}{68k + 10k + 10k}\right]$$

$$V_{B2} = 6.8V; \quad \therefore V_{E2} = V_{C_1} = 6.8 - 0.7 = \underline{6.1V}$$

$$V_{CE_1} = V_{C_1} - V_{E_1} = 6.1 - 2.7 = \underline{3.4V}$$

$$V_{C_2} = V_{CC} - I_{C_2}R_C = 30 - 2.7 \cdot 4.7 = 17.3V$$

$$\therefore V_{CE2} = V_{C2} - V_{E2} = 17.3 - 6.1 = \underline{11.2V}$$

-- note that V_{CE2} is more than three times V_{CE_1}

.. more later!

Mid-Frequency Analysis of CE Stage

$$g_{m_1} = 35\, I_C = 35 \cdot 2.7 = \underline{94.5\ mA/V}$$

$$r_{b_1} = \frac{\beta}{g_m} = \frac{200}{94.5} = \underline{2.116\ k\Omega}$$

$$r_{o_1} \longrightarrow \text{ignore}$$

$R_{b_1}' = R_2 \| R_3 \| r_{b_1} = 10k \| 10k \| 2.116k = \underline{1.487\ k\Omega}$

$$A_{v_1} = \frac{V_{be_1}}{V_s} = \frac{R_{b_1}'}{R_{b_1}' + R_s} = \frac{1.487}{1.487 + 50}$$

$$\underline{A_{v_1} = 0.97} \quad \leftarrow \text{same as CE example}$$

- since the collector of Q_1 is direct-coupled to the emitter of Q_2, $R_{c_1}' = R_c \| R_L$ is now replaced by the input resistance of the CB amplifier:

$$r_{e_2}' \approx \frac{1}{g_{m_2}}$$

$$A_{v_2} = \frac{V_{c_1}}{V_{be_1}} = -g_{m_1} \cdot \frac{1}{g_{m_2}}$$

- since $I_{c_2} \approx I_{c_1}$, $g_{m_2} = g_{m_1}$

$\therefore \underline{A_{v_2} = -1}$ or $\underline{0\text{dB inverting}}$

say what?

- thus, the CE amplifier provides no voltage gain (important later!)

-- side note: remember when we noted in CE D.C. analysis that V_{CE} should ensure adequate "wiggle room" for small-signal amplification?

-- the CE stage of the cascode doesn't need much wiggle room due to no amplification!

-- that's why we allow $V_{CE2} > 3 \times V_{CE1}$

$$\underset{11.2V}{V_{CE2}} > 3 \times \underset{3.4V}{V_{CE1}}$$

Mid-Frequency Analysis of CB Stage

-- we already know the gain between V_s and V_{be2}

-- only need the output transfer, which we'll call A_{v3}.

$$A_{v3} = \frac{V_{OUT}}{V_{c1}} = \frac{V_{OUT}}{V_{e2}} \leftarrow \text{input of CB stage}$$

-- our CB amplifier output gain was given as

$$\frac{V_{OUT}}{V_{be}} = -g_m (R_c \| R_L)$$

-- BUT, since V_{b2} is grounded, $V_{be2} = 0 - V_{e2} = -V_{e2}$

$$\therefore A_{v3} = \frac{V_{OUT}}{V_{e2}} = \frac{V_{OUT}}{-V_{be2}} = +g_m (R_c \| R_L)$$

-- remember, CB is non-inverting!

$$A_{v3} = 94.5\,(4.7k \parallel 10k)$$

$\hookrightarrow$ 3.197k

$$A_{v3} = 302 \quad \text{or} \quad 49.6\ \text{dB}$$

thus, $A_{v1} \times A_{v2} \times A_{v3} = 0.97 \cdot -1 \cdot 302$

$$= -293 \quad \text{or} \quad 49\ \text{dB}$$

(inverting)

∴ same gain as CE!

∴ no 15 dB loss of CB from 50Ω source

Low-Frequency Analysis of Cascode Amplifier

∴ C_{IN}, C_E, and C_{OUT} essentially have same LF characteristics as CE amplifier

$$f_{LIN} = \frac{1}{2\pi \cdot C_{IN}\,(R_s + R_b')}$$

$$= \frac{1}{2\pi \cdot 1\times10^{-6}\,(50 + 1.487k)}$$

$$f_{LIN} = 103.5\ \text{Hz}$$

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

$$= \frac{1}{2\pi \cdot 10\times10^{-6}\,(4.7k + 10k)}$$

$$f_{L\,OUT} = 1.083\ Hz$$

$$f_{LE} \cong \frac{1}{2\pi \cdot C_E \cdot \frac{1}{g_m}}$$

$$= \frac{1}{2\pi \cdot 1000\times10^{-6} \cdot \frac{1}{94.5m}} \quad \frac{1}{94.5m} = 10.6\Omega$$

$$f_{LE} = 15\ Hz$$

∴ dominant pole is $f_{LIN} = 103.5\ Hz \simeq f_L$

HF Analysis of Cascode Amplifier

∴ this is where the reduction in gain of CE stage to unity becomes helpful!

∴ We know that for a CE amplifier,

$$C_{BC(IN)} = C_{BC}\,(1 - A_{V2}) \text{ due to Miller Effect}$$

$$C_{BC(IN)} = 4\,(1 - {-1}) = 8\ pF$$ ← Compare to CE example of over 1nF!!!

$$f_{H\,IN} = \frac{1}{2\pi\,(C_{BE} + C_{BC\,IN})(R_s \,\|\, R_b')}$$

$$f_{H\,IN} = \frac{1}{2\pi\,(18p + 8p)(50 \,\|\, 1.487k)}$$

$$f_{H\,IN} = 126.5\ \text{MHz}$$

.. over 40 times better than 2.97 MHz of non-cascoded CE !

.. high frequency response at coupling between CE and CB stages may be assumed to be sufficiently high due to low emitter resistance $\left(\frac{1}{g_m}\right)$ and no Miller Effect that we may ignore it

-- at the output of the amplifier, it is simply the HF response of CB :

$$f_{H\,OUT} = \frac{1}{2\pi \cdot \underbrace{C_{BC}}_{4pF}\,(\underbrace{R_C \,\|\, R_L}_{3.147k})}$$

$$f_{H\,OUT} = 12.4\ \text{MHz} \simeq f_H \quad (\text{dominant pole})$$

.. Summary : cascoding retains the gain and R_{IN} of CE, but superior HF response of CB.