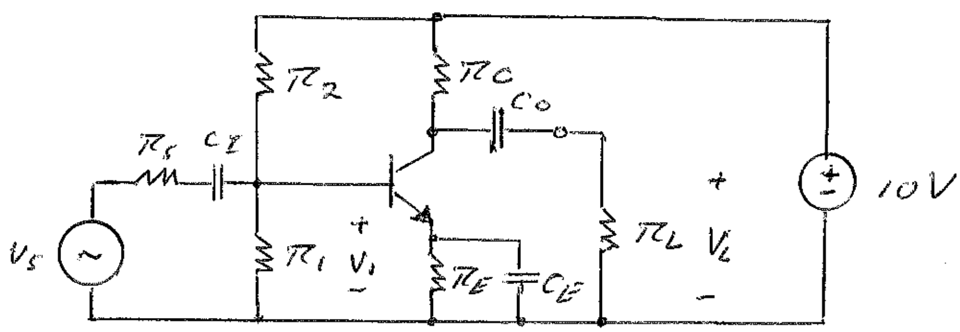
CE Amplifier Example

Given: | Supply Voltage 10V | $R_L = 10k\Omega$ |

Required: | $|A_V| > 100$ | 100Hz - 100kHz Passband |

Transistor:
$100 < \beta < 400$
$V_{BEQ} \cong 0.7V$
$nV_T \cong 30mV$
$V_A \cong 80V$

Topology



$$\left| A_V = \frac{V_L}{V_1} \right|$$

Note: C_I, C_O and C_E are dc decoupling caps. Their values will depend on the required frequency band of the amplifier and the operating point (Q-point) values of the transistor.

To simplify the analysis, we will first assume that they act as <u>shorts</u> for all frequencies of interest. Subsequently, we will determine their proper values.

Step 1 Select Q-point

e.g. $\begin{vmatrix} I_{CQ} \cong 1mA \\ V_{CEQ} \cong 5V \end{vmatrix}$

Step 2 Determine values of biasing resistors.

$$\left| \begin{aligned} I_{CQ} &= \frac{V_{CC}\frac{R_1}{R_1+R_2} - V_{BEQ}}{\frac{R_1 \| R_2}{\beta} + (1+\frac{1}{\beta})R_E} \\ \\ V_{CE} &= V_{CC} - I_{CQ}\left[R_C + (1+\tfrac{1}{\beta})R_E\right] \end{aligned} \right|$$

Since you have 4 free parameters, namely R_1, R_2, R_C and R_E, there exists no unique solution!
We will use the 2 degrees of freedom to optimize the circuit performance with regard to Q-point stability and (possibly) power dissipation. The first objective requires $R_B = R_1 \| R_2$ to be much smaller than βR_E, the second would require R_B to be large (less current)

Practical Compromise: $\left| \begin{array}{l} R_1 = 10k\Omega \\ R_2 = 47k\Omega \end{array} \right|$

$\therefore R_B \cong 8.2k\Omega$

$|R_E = 1k\Omega|$

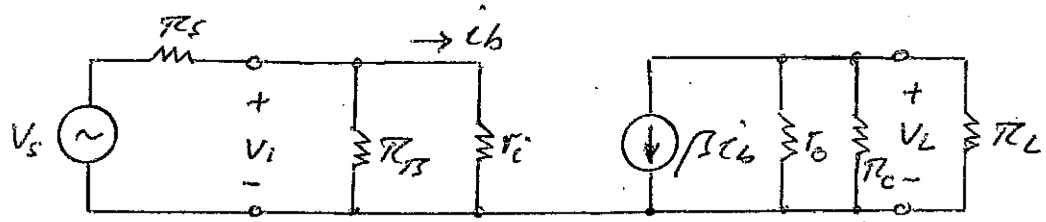
$\left| \begin{array}{l} I_{CQ}(\beta = 100) = 0.97\ mA \\ I_{CQ}(\beta = 400) = 1.03\ mA \end{array} \right| \therefore \| I_{CQ} = 1.00 \pm 0.03mA \|$

Select $R_C = 4.7k\Omega$

$\left| \begin{array}{l} V_{CEQ}(\beta = 100) = 4.45V \\ V_{CEQ}(\beta = 400) = 4.11\ V \end{array} \right| \therefore \| V_{CEQ} = 4.28 \pm 0.17V \|$

<u>step 3</u> Small Signal Analysis

Linear equivalent circuit (capacitors shorts)



where $r_i = \beta \frac{nV_T}{I_{CQ}}$ <u>Note</u>: $\beta i_b = g_m V_1$

$r_o = \frac{V_A}{I_{CQ}}$ $g_m = \frac{I_{CQ}}{nV_T}$

simplify: $r_o \| R_C \| R_L = \tilde{R}_L = 3.07k\Omega$

$$\left| v_i = i_b r_i = i_b \frac{\beta}{g_m} \right| \qquad \left| v_c = -\beta i_b \tilde{R}_c \right|$$

or

$$\left| v_c = -g_m v_i \tilde{R}_c \right|$$

$$\left\| A_v = \frac{v_c}{v_i} = -g_m \tilde{R}_c = -\frac{I_{CQ}}{n V_T} \tilde{R}_c \right\|$$

$$\left| \begin{array}{l} I_{CQ} = 1.00\,mA \\ n V_T = 30\,mV \\ \tilde{R}_c = 3.07\,k\Omega \end{array} \right| \quad \therefore \left\| A_v \cong -102.3 \pm 3 \right\|$$

<u>Note</u>: If magnitude of voltage gain would have been too small, we could have increased the bias current, I_{CQ}.

e.g.

$$\left| \begin{array}{l} I_{CQ} \cong 2\,mA \\ R_C \cong 2.2\,k\Omega \\ R_E \cong 500\,\Omega \\ \tilde{R}_c \cong 1.73\,k\Omega \end{array} \right| \quad \left| V_{CEQ} \cong 3.9V \right| \quad \therefore \left\| A_v \cong -115V \right\|$$

or

$$\left| \begin{array}{l} I_{CQ} \cong 5\,mA \\ R_C \cong 1\,k\Omega \\ R_E \cong 200\,\Omega \\ \tilde{R}_c \cong 860\,\Omega \end{array} \right| \quad \left| V_{CEQ} \cong 3.3V \right| \quad \therefore \left\| A_v \cong -144 \right\|$$

To keep Q-point β independent, R_1 and R_2 have to be reduced accordingly in the latter 2 cases.

Step 4 Determine values of decoupling caps

All 3 decoupling caps form a highpass filter with their respective resistor counterpart, that is

C_I and $r_{in} \cong 2.2-5.2k\Omega$

C_O and $R_L \cong 10k\Omega$

C_E and $R_E \parallel \frac{1}{g_m} \approx \frac{1}{g_m} \cong 33\Omega$

for $I_{CQ} = 1mA$

Since C_E turns out to have the smallest resistor counterpart, we select it to set the low frequency corner at 100Hz

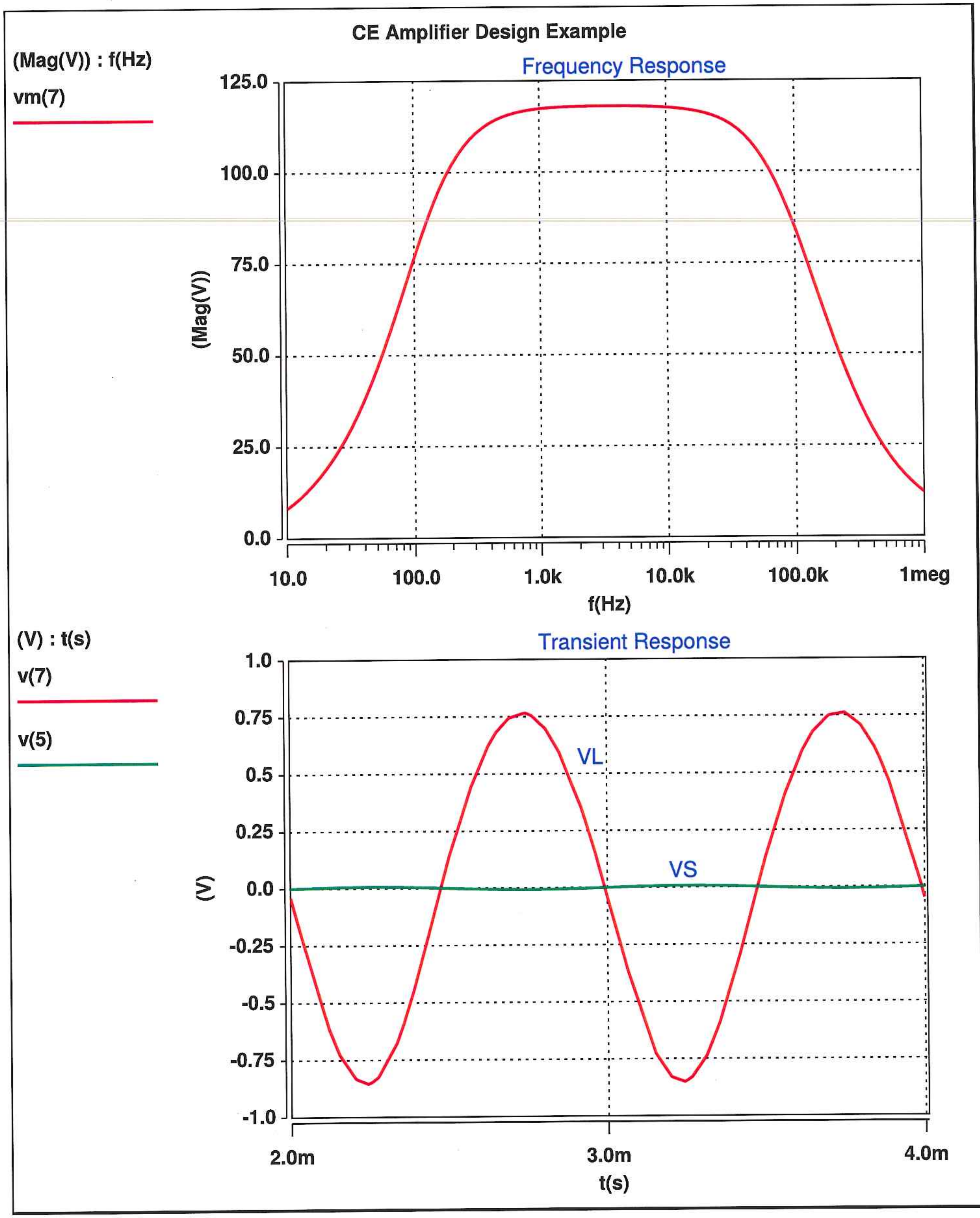
$$\boxed{C_E = \frac{g_m}{2\pi f_L} = 48\mu F}$$

To avoid overlap with the corner frequency f_L, we select the values of C_I and C_O such that they form a corner at around 1/10 of f_L. Hence

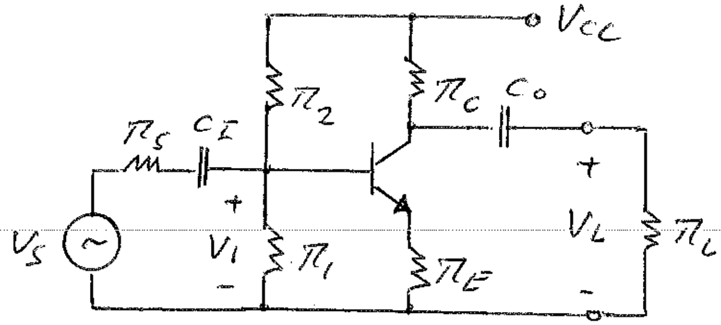
$$C_I \cong \frac{10}{2\pi f_L r_{in}} \cong 5.3\mu F$$

$$C_O = \frac{10}{2\pi f_L R_L} \cong 1.6\mu F$$

CE-6


CE Amplifier Design Example
(Mag(V)) : f(Hz)
vm(7)
Frequency Response
125.0
100.0
75.0
50.0
25.0
0.0
(Mag(V))
10.0
100.0
1.0k
10.0k
100.0k
1meg
f(Hz)
(V) : t(s)
v(7)
v(5)
Transient Response
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
-1.0
(V)
VL
VS
2.0m
3.0m
4.0m
t(s)

CE Amplifier with Emitter Degeneration



Transistor

$\beta = 150$

$V_A = \infty$

$V_{BEQ} \cong 0.7V$

$nV_T \cong 30mV$

$V_{CC} = 10V$ $\quad$ $R_1 = 10k\Omega$

$R_C = 10k\Omega$ $\quad$ $R_2 = 75k\Omega$

$R_L = 10k\Omega$ $\quad$ $R_E = 1k\Omega$

Find:

- Q-point (I_{CQ}, V_{CEQ}) $\quad$ DC Analysis
- $A_V = \frac{V_L}{V_I}$ $\quad$ AC Analysis

Step 1: DC Analysis

$|R_B = 8.8k\Omega|$

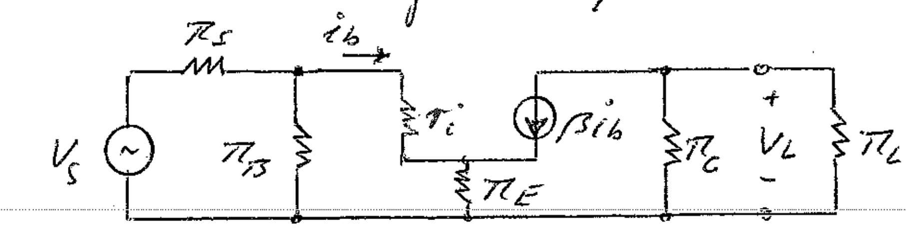
$(R_B = R_1 \parallel R_2)$

$$I_{CQ} = \frac{V_{CC}\frac{R_1}{R_1+R_2} - V_{BEQ}}{\frac{R_B}{\beta} + (1+\frac{1}{\beta})R_E} \cong 0.52mA$$

$$V_{CEQ} = V_{CC} - I_{CQ}(R_C + [1+\frac{1}{\beta}]R_E) \cong 4.3V$$

<u>Step 2:</u> AC Analysis (Caps act as shorts)

Small Signal eq. Circuit



$r_i = \frac{\beta}{g_m} \cong 8.7k\Omega$

Equations:

$$\begin{vmatrix} (1) & V_i = i_b r_i + (1+\beta) i_b R_E \\ (2) & V_L = -\beta i_b \tilde{R}_L \end{vmatrix}$$

$\tilde{R}_L = R_C \| R_L = 5k\Omega$

$$\therefore A_V = -\frac{\beta \tilde{R}_L}{r_i + (1+\beta) R_E}$$

$$= -\frac{\tilde{R}_L}{1/g_m + (1+\frac{1}{\beta}) R_E}$$

$$\left\| A_V \cong -\frac{\tilde{R}_L}{\frac{nV_T}{I_{CQ}} + R_E} = -4.7 \right\|$$

<u>Note:</u> The emitter resistor R_E significantly reduces the gain. In return, it keeps the output voltage (V_L) <u>more linear</u> since the denominator of the voltage gain varies less with I_{CQ}