AUSTRALIAN NATIONAL UNIVERSITY
Department of Engineering

ENGN 2211 Electronic Circuits and Devices
Problem Set #8 BJT CE Amplifier Circuits

Q1

Consider the common-emitter BJT amplifier circuit shown in Figure 1.

Assume $V_{CC} = 15$ V, $\beta = 150$, $V_{BE} = 0.7$ V,
$R_E = 1$ kΩ, $R_C = 4.7$ kΩ, $R_1 = 47$ kΩ, $R_2 = 10$ kΩ, $R_L = 47$ kΩ, $R_s = 100$ Ω.

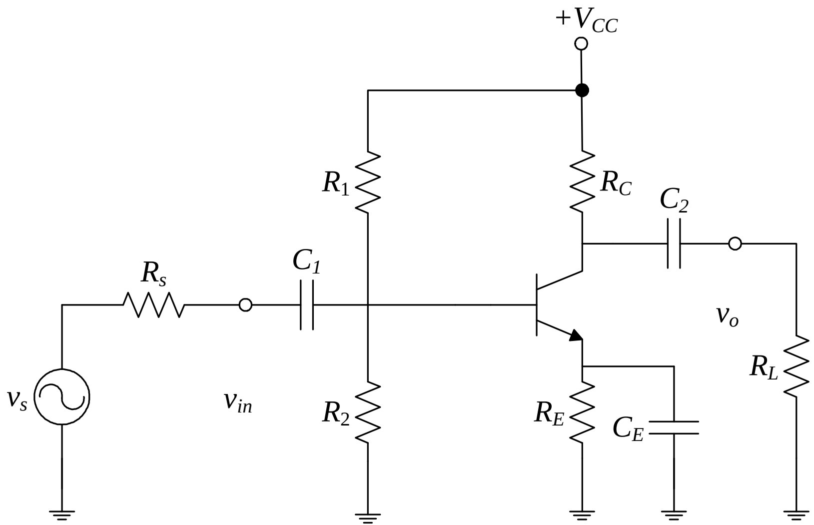


Figure 1: The circuit for Question 1.

(a) Determine the Q-point.
(b) Sketch the DC load-line. What is the maximum (peak to peak) output voltage swing available in this amplifier.
(c) Draw the AC equivalent circuit and determine the AC model parameters.
(d) Derive expressions for R_{in}, R_{out}, A_{voc}, A_v, A_i, G.
(e) Find R_{in}, R_{out}, A_{voc}, A_v, A_i, G.
(f) Find the output voltage waveform if $v_s = 10 \times 10^{-3} \sin(2\pi 5000t)$. Sketch the source and output voltage waveforms.
(g) Determine whether clipping will take place if $v_s = 25 \times 10^{-3} \sin(2\pi 5000t)$.

Q2

Consider the common-emitter BJT amplifier circuit shown in Figure 2.

Assume $V_{CC} = 15$ V, $\beta = 150$, $V_{BE} = 0.7$ V,
$R_E = 2.7$ kΩ, $R_C = 4.7$ kΩ, $R_1 = 47$ kΩ, $R_2 = 10$ kΩ, $R_L = 47$ kΩ, $R_s = 100$ Ω.

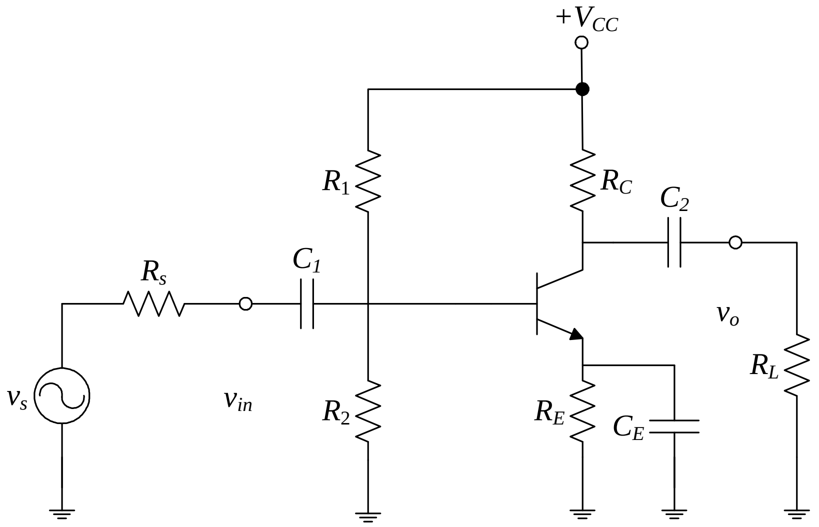


Figure 2: The circuit for Question 2.

(a) Determine the Q-point.
(b) Sketch the DC load-line. What is the maximum (peak to peak) output voltage swing available in this amplifier.
(c) Draw the AC equivalent circuit and determine the AC model parameters.
(d) Derive expressions for R_{in}, R_{out}, A_{voc}, A_v, A_i, G.
(e) Find R_{in}, R_{out}, A_{voc}, A_v, A_i, G.
(f) Find the output voltage waveform if $v_s = 10 \times 10^{-3} \sin(2\pi 5000t)$. Sketch the source and output voltage waveforms.

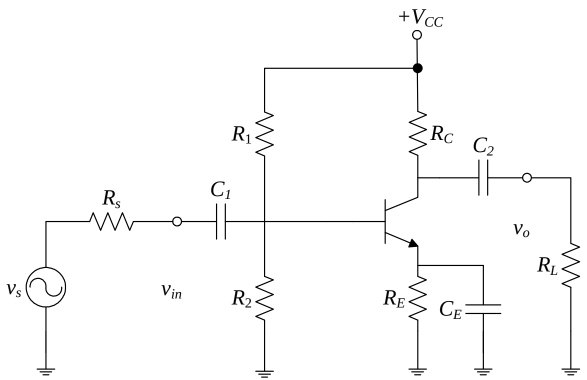
AUSTRALIAN NATIONAL UNIVERSITY
Department of Engineering

ENGN 2211 Electronic Circuits and Devices
Problem Set #8 Solution

Q1

Complete Solution

Given that $V_{CC} = 15$ V, $\beta = 150$, $V_{BE} = 0.7$ V,
$R_E = 1$ kΩ, $R_C = 4.7$ kΩ, $R_1 = 47$ kΩ, $R_2 = 10$ kΩ, $R_L = 47$ kΩ, $R_s = 100$ Ω.



(a)

Analyzing the DC Voltage-divider bias circuit, we have

$$
\begin{aligned}
V_{TH} &= \frac{R_2}{R_1 + R_2} V_{CC} \\
&= \frac{10\text{k}}{10\text{k} + 47\text{k}}(15) = 2.63 \text{ V} \\
R_{TH} &= \frac{R_2 R_1}{R_1 + R_2} \\
&= \frac{(10\text{k})(47\text{k})}{10\text{k} + 47\text{k}} = 8.2456 \text{ k}\Omega \\
I_B &= \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta + 1) R_E} \\
&= \frac{2.63 - 0.7}{8.2456\text{k} + (151)(1\text{k})} = 12.12\ \mu\text{A} \\
I_C &= \beta I_B \\
&= (150)(12.12\mu) = 1.8179 \text{ mA} \\
I_E &= (\beta + 1) I_B \\
&= (151)(12.12\mu) = 1.83 \text{ mA} \\
V_E &= I_E R_E \\
&= (1.83\text{m})(1\text{k}) = 1.83 \text{ V} \\
V_C &= V_{CC} - I_C R_C \\
&= 15 - (1.8179\text{m})(4.7\text{k}) = 6.456 \text{ V} \\
V_{CE} &= V_{CC} - I_C R_C - I_E R_E \\
&= 15 - (1.8179\text{m})(4.7\text{k}) - (1.83\text{m})(1\text{k}) = 4.626 \text{ V}
\end{aligned}
$$

As $I_B > 0$ and $V_{CE} > 0.2$ V, the transistor is in active region of operation.

The Q-point lies at

$$\begin{aligned} I_{CQ} &= 1.8179 \text{ mA} \\ V_{CEQ} &= 4.626 \text{ V} \end{aligned}$$

(b)

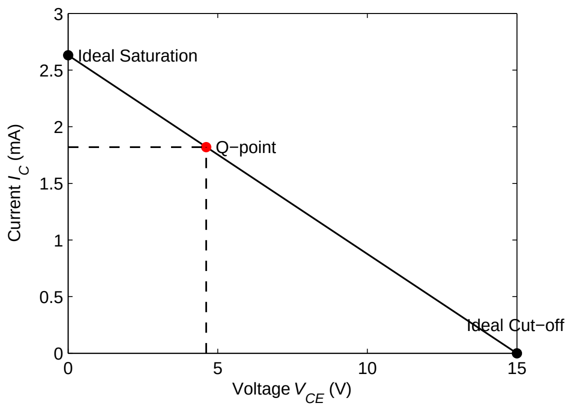
For ideal cut-off

$$V_{CE(off)} = V_{CC} = 15 \text{ V}$$

For ideal saturation

$$I_{C(sat)} = \frac{V_{CC}}{R_C + R_E} = \frac{15}{5.7\text{k}} = 2.63 \text{ mA}$$

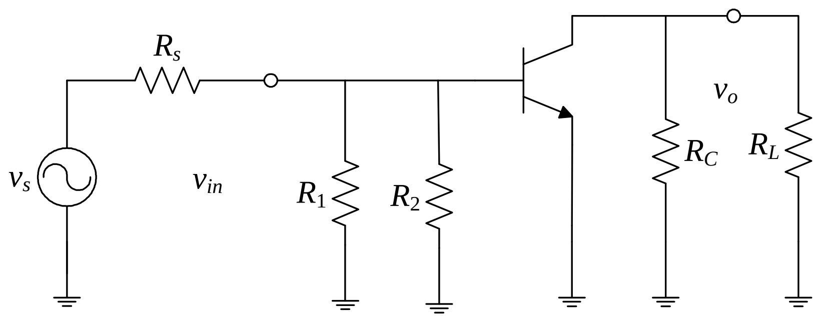
The plot of DC load line is shown in figure below



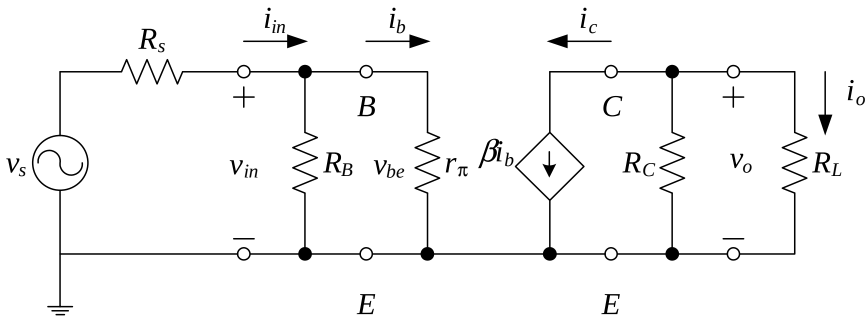
We see that the Q-point lies closer to saturation ($V_{CE} = 0.2$ V) than cut-off ($V_{CE} = 15$ V).
Hence the maximum available peak to peak output voltage swing $= 2(V_{CEQ} - 0.2) = 8.852$ V.

(c)

Replacing the capacitors by short circuits and V_{CC} by virtual AC ground, the AC equivalent circuit is



Replacing the transistor by the small-signal AC equivalent circuit, we have



The AC Model parameters are

$$
\begin{aligned}
r_e &= \frac{26\text{ mV}}{I_{EQ}} \\
&= \frac{26}{1.83} = 14.207\,\Omega \\
r_\pi &= (\beta+1)r_e \\
&= (151)(14.207) = 2.1453\text{ k}\Omega \\
R_B &= R_1||R_2 \\
&= 8.2456\text{ k}\Omega \\
R_L^{'} &= R_L||R_C \\
&= (47\text{ k})||(4.7\text{ k}) = 4.27\text{ k}\Omega
\end{aligned}
$$

(d)

For derivations, please see Lecture 13.

(e)

The BJT CE amplifier parameters are

$$
\begin{aligned}
R_{in} &= R_B||r_\pi \\
&= (8.2456\text{ k})||(2.1453\text{ k}) = 1.7024\text{ k}\Omega \\
R_o &= R_C \\
&= 4.7\text{ k}\Omega \\
A_{voc} &= -\frac{R_C\beta}{r_\pi} \\
&= \frac{(4.7\text{ k})(150)}{2.1453\text{ k}} = -328.62 \\
A_v &= -\frac{R_L^{'}\beta}{r_\pi} \\
&= \frac{(4.27\text{ k})(150)}{2.1453\text{ k}} = -298.56 \\
A_i &= A_v\frac{R_{in}}{R_L} \\
&= (-298.56)\frac{1.7024\text{ k}}{47\text{ k}} = -10.81 \\
G &= A_iA_v \\
&= (-10.81)(-298.56) = 3228.69
\end{aligned}
$$

(f)

Finding the equation for output voltage with load, we have

$$\begin{aligned}
v_s &= 10 \times 10^{-3} \sin(2\pi 5000t) \\
v_{in} &= \frac{R_{in}}{R_s + R_{in}} v_s \\
&= \frac{1.7024\,\text{k}}{100 + 1.7024\,\text{k}} v_s \\
&= 0.9445 v_s \\
v_o &= A_v v_{in} \\
&= (-298.56)(0.9445\, v_s) \\
&= (-298.56)(0.9445)(10 \times 10^{-3} \sin(2\pi 5000t)) \\
&= -2.82 \sin(2\pi 5000t)
\end{aligned}$$

The required peak to peak output voltage swing = 2(2.82)=5.64 V.
The maximum available peak to peak output voltage swing $= 8.852$ V > 5.64 V.
Hence no clipping will take place.

The -ve sign indicates that output voltage is 180° out of phase with input voltage (inverting amplifier).

The time period is $T = \frac{1}{5000} = 0.2$ ms.
The sketch of input and output voltages is shown in figures below:- (Note y-axis has different units in the two figures)

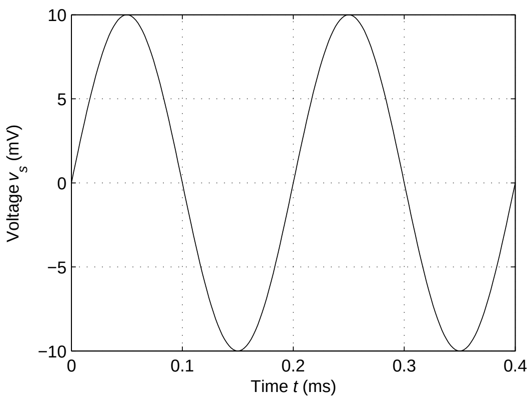


Figure 3: Source voltage $v_s(t)$.

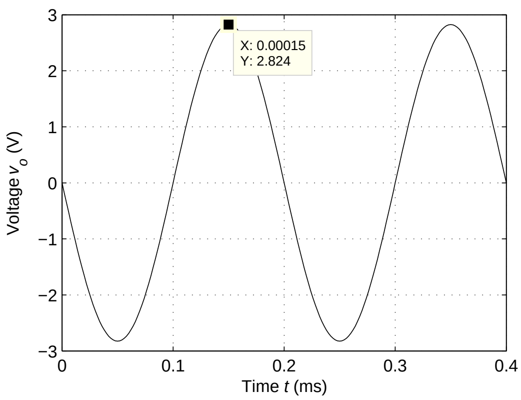


Figure 4: Output voltage $v_o(t)$.

(g)

For $v_s = 25 \times 10^{-3} \sin(2\pi 5000t)$, we have

$$\begin{aligned}
v_o &= A_v v_{in} \\
&= (-298.56)(0.9445\, v_s) \\
&= (-298.56)(0.9445)(25 \times 10^{-3} \sin(2\pi 5000t)) \\
&= -7.05 \sin(2\pi 5000t)
\end{aligned}$$

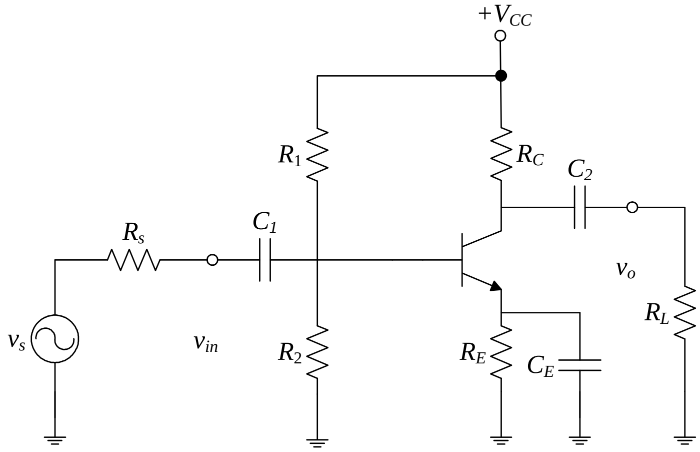
The required peak to peak output voltage swing = 2(7.05)=14.1 V.
However the maximum available peak to peak output voltage swing $= 8.852$ V < 14.1 V.
Hence clipping will take place.

See `ProbSet08_Q1.sch`.

Q2

Solution

Given that $V_{CC} = 15$ V, $\beta = 150$, $V_{BE} = 0.7$ V,
$R_E = 2.7$ kΩ, $R_C = 4.7$ kΩ, $R_1 = 47$ kΩ, $R_2 = 10$ kΩ, $R_L = 47$ kΩ, $R_s = 100$ Ω.



(a)

Analyzing the DC Voltage-divider bias circuit, we have

$$\begin{aligned}
V_{TH} &= 2.63 \text{ V} \\
R_{TH} &= 8.2456 \text{ k}\Omega \\
I_B &= 4.64\ \mu\text{A} \\
I_C &= 0.696 \text{ mA} \\
I_E &= 0.7006 \text{ mA} \\
V_C &= 11.72 \text{ V} \\
V_E &= 1.89 \text{ V} \\
V_{CE} &= 9.837 \text{ V}
\end{aligned}$$

As $I_B > 0$ and $V_{CE} > 0.2$ V, the transistor is in active region of operation.

The Q-point lies at

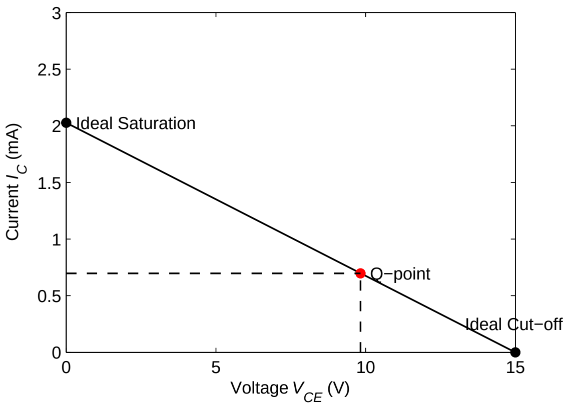
$$\begin{aligned}
I_{CQ} &= 0.696 \text{ mA} \\
V_{CEQ} &= 9.837 \text{ V}
\end{aligned}$$

(b)

For ideal saturation and cut-off

$$V_{CE(off)} = 15\text{ V}$$
$$I_{C(sat)} = 2.027\text{ mA}$$

The plot of DC load line is shown in figure below



We see that the Q-point lies closer to cut-off ($V_{CE} = 15$ V) than saturation ($V_{CE} = 0.2$ V). Hence the maximum available peak to peak output voltage swing $= 2(V_{CC} - V_{CEQ}) = 10.34$ V.

(c)

The AC Model parameters are

$$r_e = 37.11\ \Omega$$
$$r_\pi = 5.6037\text{ k}\Omega$$
$$R_B = 8.2456\text{ k}\Omega$$
$$R_L^{'} = 4.27\text{ k}\Omega$$

(d)

For derivations, please see Lecture 13.

(e)

The BJT CE amplifier parameters are

$$R_{in} = 3.336\text{ k}\Omega$$
$$R_o = 4.7\text{ k}\Omega$$
$$A_{voc} = -125.81$$
$$A_v = -114.3$$
$$A_i = -8.11$$
$$G = 926.97$$

(f)

$$
\begin{aligned}
v_s &= 10 \times 10^{-3} \sin(2\pi 5000t) \\
v_{in} &= 0.97089 v_s \\
v_o &= -1.11 \sin(2\pi 5000t)
\end{aligned}
$$

The required peak to peak output voltage swing = 2(1.11)=2.2 V.
The maximum available peak to peak output voltage swing $= 10.34$ V > 2.2 V.
Hence no clipping will take place.

The sketch of input and output voltages is shown in figures below:- (Note y-axis has different units in the two figures)

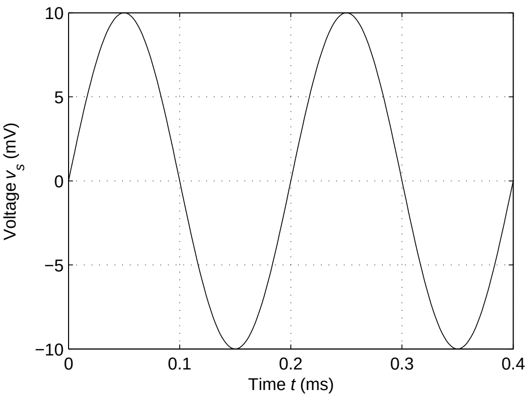


Figure 5: Source voltage $v_s(t)$.

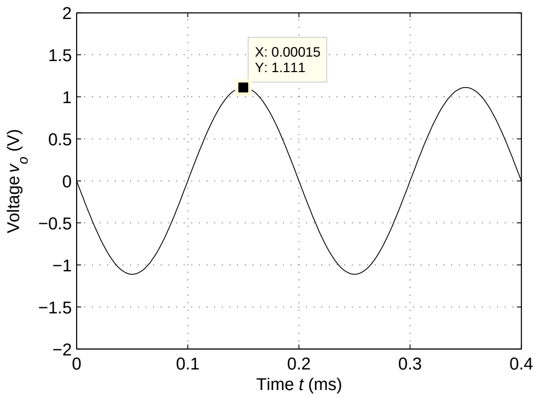


Figure 6: Output voltage $v_o(t)$.

See `ProbSet08_Q2.sch`.