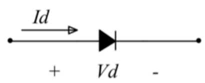
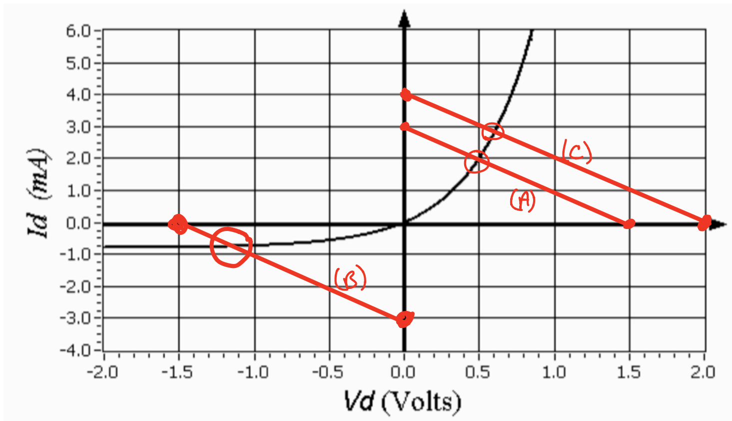
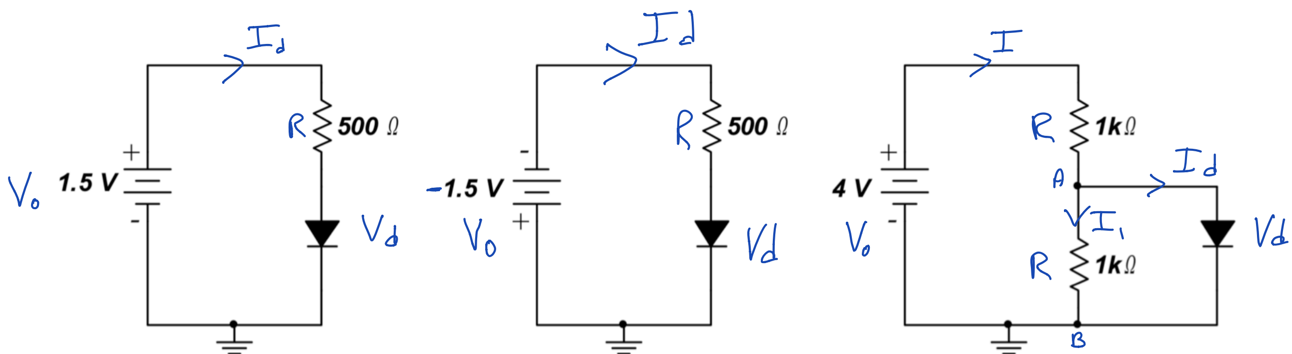
Phys2610 (2019) Assignment 4 solutions

1. The graph below shows the I-V characteristic curve of a certain diode. The diode is used in the following circuits. Draw on the plot and label, the load-line you would use for each circuit in order to obtain the diode voltage and current. Do not use an equivalent circuit for the diodes for this purpose. You should get an equation for I_d as a function of V_d. Is the result approximately consistent with the result you expect from replacing the diodes with a suitable equivalent model?







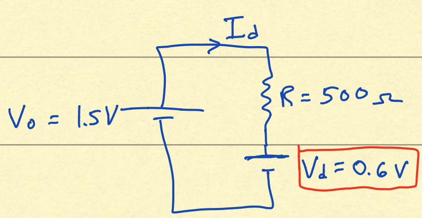
(A) (B) (C)

A) $V_o - I_d R - V_d = 0 \rightarrow I_d = \frac{V_o}{R} - \frac{V_d}{R}$ or $\boxed{I_d = 3.0\,mA - \frac{V_d}{500\,\Omega}}$

$\rightarrow$ line connecting points $(V_d, I_d) = (V_o, 0)$ and $(0, \frac{V_o}{R})$ or $(1.5\,V, 0)$ + $(0, 3\,mA)$

$\rightarrow$ op. point: $\boxed{V_d = 0.5\,V,\ I_d = 2\,mA}$ from load line analysis

The diode is forward biased (on) so a simple equivalent circuit is



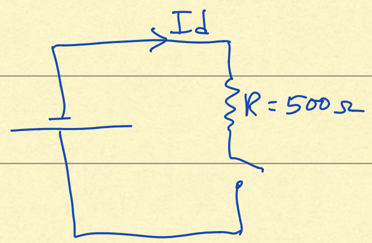
$\Rightarrow I_d = \frac{V_o - V_d}{R} = \boxed{1.8\,mA}$ from eq. cct. analysis

B) $V_o - I_d R - V_d = 0 \rightarrow I_d = \frac{V_o}{R} - \frac{V_d}{R}$ or $\boxed{I_d = -3.0\,mA - \frac{V_d}{500\,\Omega}}$

Here, $V_o = -1.5V$, so the line connects $(-1.5V, 0)$ + $(0, -3\,mA)$

$\rightarrow$ op. point: $\boxed{V_d = -1.2\,V,\ I_d = -0.7\,mA}$ load line

The diode is reverse biased, so a simple equivalent circuit is open switch:



$\boxed{\therefore I_d = 0 \text{ and } V_d = -1.5\,V}$ eq. cct.

C) Applying KVL on the outer loop: $V_o - IR - V_d = 0$

and KJL at point A: $I = I_d + I_1 = I_d + \frac{V_d}{R}$ (using $I_1 = \frac{V_d}{R}$)

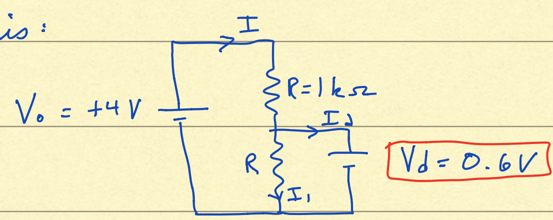
Eliminate I: $V_o - (I_d + \frac{V_d}{R})R - V_d = 0$

Solve for Id: $I_d = \frac{V_o}{R} - \frac{2V_d}{R}$ or $\boxed{I_d = 4\,mA - \frac{V_d}{500\,\Omega}}$

$\rightarrow$ line between $(V_d, I_d) = (\frac{V_o}{2}, 0) + (0, \frac{V_o}{R})$ or $(2V, 0)$ + $(0, 4\,mA)$

$\rightarrow$ op. point: $\boxed{V_d = 0.6V,\ I_d = 2.8\,mA}$ load line

If the diode were not there, the voltage between A + B would be $+2V$, so with the diode in place, it is turned on. So a simple equivalent circuit is:



$\therefore I = \frac{V_o - V_d}{R} = \frac{3.4V}{1k\Omega} = 3.4\,mA$

$I_1 = \frac{V_d}{R} = 0.6\,mA$

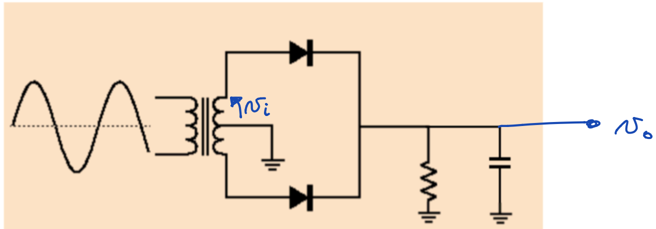
$\Bigg\}\ I_d = I - I_1 = \boxed{2.8\,mA}$ eq. cct

2. Calculate the approximate peak-to-peak ripple and the ripple factor for a centre-tapped full-wave rectifier. The two outer taps of the secondary coil have a peak voltage of 170 V with respect to the centre tap, and the frequency is 60 Hz. The output is filtered using a 3000 μF capacitor and the load resistance is 200 Ω.

$v_i = V_0 \sin \omega t$

$V_0 = 170\,V$

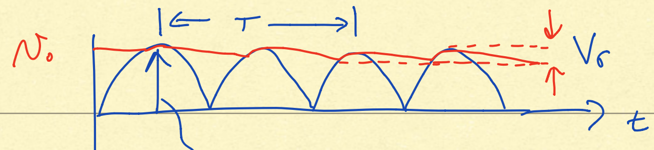
$\omega = 2\pi\,(60\,Hz)$



$R = 200\,\Omega$

$C = 3000\,\mu F$

Output



$V_p = V_0 - V_t \cong V_0 = 170\,V$

Time constant for decay of output is $\tau = RC = (200\,\Omega)(3000\,\mu F) = 0.6\,s$

Period of the input : $T = 1/f = 1/60\,Hz = 16.7\,ms$

Output period : $T_0 = T/2 = \frac{1}{2f} = 8.33\,ms$

Output voltage $= v_0 = V_p e^{-t/\tau} \cong V_p(1 - T_0/\tau)$ (because $T_0 << \tau$)

Amplitude of ripple: $V_r = v_o(t=0) - v_o(t=T_0) = V_p - V_p(1 - T_0/\tau) = \frac{V_p T_0}{\tau}$

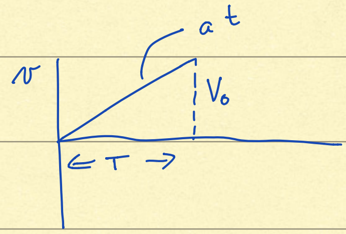
$= \frac{V_p}{2fRC} = \frac{170V}{2(60Hz)(0.6s)} = 2.36\,V$

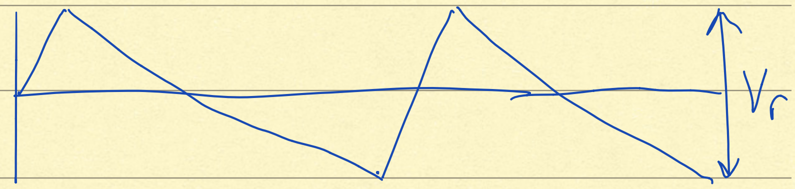
Ripple factor: $r = \frac{V_{rms}(ac)}{V_{dc}}$

Approximating the output by a triangular wave with peak-to-peak amplitude equal to $V_r = 2.35V$, the rms voltage is $\frac{V_r}{2\sqrt{3}}$ * $= \frac{2.36V}{2\sqrt{3}} = 0.68\ V$

The dc average voltage is $V_{dc} = V_p - \frac{V_r}{2} = 170V - \frac{2.35V}{2} = 169V$ $(\cong V_p)$

$\therefore\ r = \frac{V_{rms}}{V_{dc}} = \frac{0.68}{169} = \boxed{0.0040}$





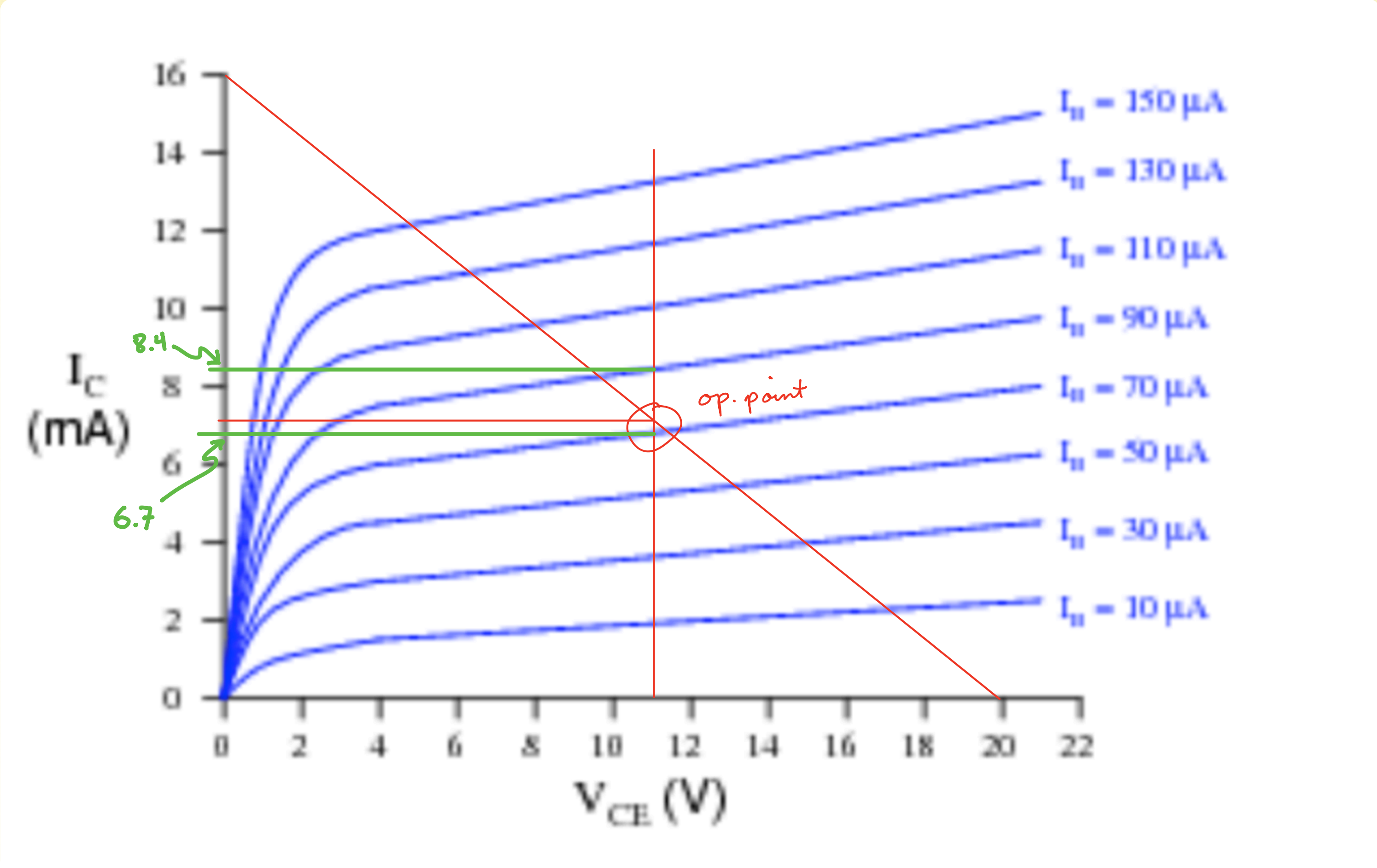
For any linear voltage with peak V_0, the rms value is

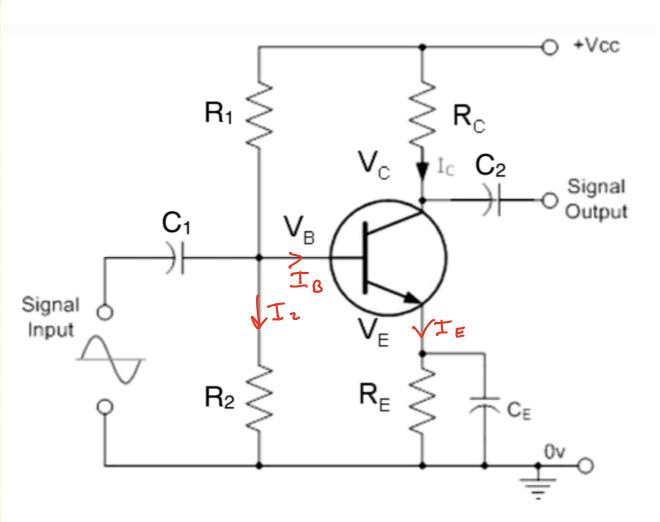
$$V_{rms} = \left[\frac{1}{T} \int_0^T v^2 \, dt \right]^{1/2} = \left[\frac{1}{T} a^2 \frac{t^3}{3} \Big|_0^T \right]^{1/2}$$

$$= \sqrt{\frac{a^2 T^2}{3}} = \frac{aT}{\sqrt{3}} = \frac{V_0}{\sqrt{3}}$$

Therefore, for connected segments with peak-to-peak voltage $V_r = 2V_0$, the rms voltage is $V_{rms} = \dfrac{V_r}{2\sqrt{3}}$

3. Design an H-biased common emitter amplifier circuit that will set a reasonable operating point for a transistor with the characteristics shown below.





(a) Select a load line to give V_{cc} and R_C+R_E:

load line: $I_C = \frac{V_{cc}}{R_C+R_E} - \frac{V_{CE}}{R_C+R_E}$

From the graph,

for $I_C = 0$, $V_{CE} = \boxed{V_{cc} = 20V}$

and for $V_{CE} = 0$, $I_C = 16mA \rightarrow R_C+R_E = 1.25k\Omega$

(b) Choose $\boxed{R_E = 250\Omega}$ to give $\boxed{R_C = 1k\Omega}$

(c) Select an operating point to give R_1 and R_2:

From the graph, at the op. pt., $I_B = 73\mu A$, $I_C = 7.1mA$, $V_{CE} = 11V$ $\Rightarrow$ $V_E = I_E R_E \cong I_C R_E = 1.78V$

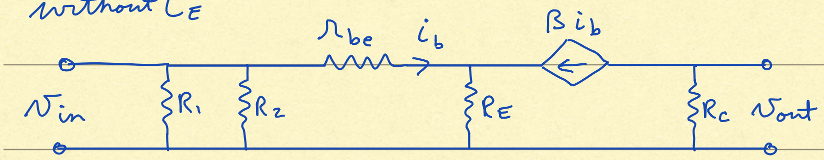
Then $V_B = V_{BE} + V_E = 0.6V + 1.78V = 2.38V$

Choose $I_2 = 20 I_B = 1.46mA \Rightarrow R_2 = \frac{V_B}{I_2} = \boxed{1.63k\Omega}$

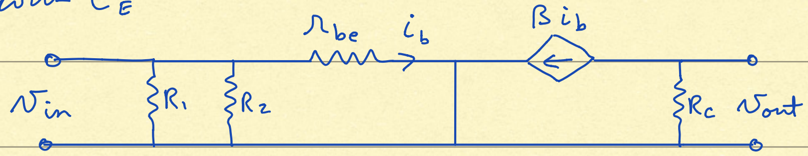
Then $R_1 = \frac{V_{cc} - V_B}{I_2} = \boxed{12.1k\Omega}$

4. Draw a simplified ac equivalent circuit for the circuit of question 3, and estimate the midband voltage gain and input and output impedances with and without a bypass capacitor across the emitter resistor. Use $r_{BE} = 2\ \mathrm{k\Omega}$.

without C_E



with C_E



From problem 3, $R_1 = 12.1\,\mathrm{k\Omega}$, $R_2 = 1.63\,\mathrm{k\Omega}$, $R_C = 1\,\mathrm{k\Omega}$, $R_E = 250\,\Omega$

(a) voltage gain without C_E:

$$a = \frac{v_{out}}{v_{in}} = \frac{-\beta i_b R_C}{i_b r_{be} + \beta i_b R_E} = \frac{-\beta R_C}{r_{be} + \beta R_E}$$

From the graph, $\beta_{ac} \cong \dfrac{(8.4-6.7)\ \mathrm{mA}}{20\ \mu\mathrm{A}} = 85$, so $\boxed{a = -3.6}$

or using $a \cong -R_C/R_E = -4$

(b) voltage gain with C_E: $a = -\dfrac{\beta R_C}{r_{be}} = \boxed{-42.5}$

(c) input impedance without C_E: $R_{in} = R_1 /\!/ R_2 /\!/ (r_{be} + \beta R_E) = \boxed{1.42\,\mathrm{k\Omega}}$

$\cong R_1 /\!/ R_2 = 1.44\,\mathrm{k\Omega}$

(d) input impedance with C_E : $R_{in} = R_1 /\!/ R_2 /\!/ r_{be} = \boxed{840\,\Omega}$

(e) output impedance : $R_{out} = \dfrac{v_{out}\ (\text{open})}{i_{out}\ (\text{short})} = \dfrac{\beta i_b R_C}{\beta i_b} = R_C = \boxed{1.0\,\mathrm{k\Omega}}$