Name Spring 2022 Exam Solutions

Problem 1. (10 points)

Assume you have a triangular wave with peak-to-peak amplitude of $12V$ and +1V DC shift.

a) Design a diode waveform shaping circuit such that when this input signal is applied to the diode circuit, at the output, the amplitude of the output voltage signal is never above $5V$ and is never below $-2V$.

b) Parametrically solve your designed circuit.
   a. Find the transfer function of the circuit.
   b. Draw the transfer function graph.

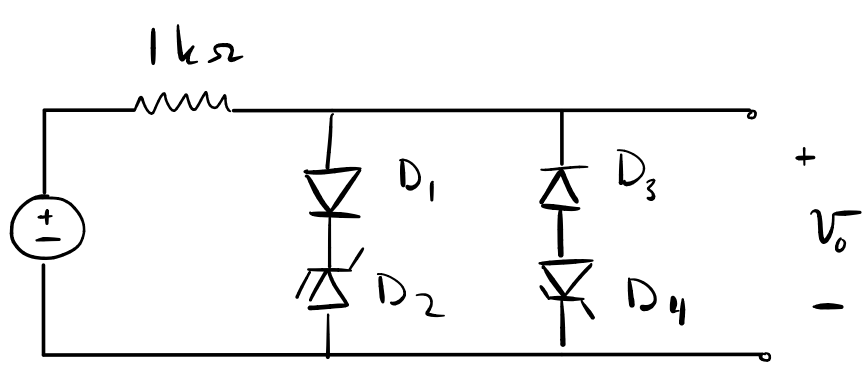
c) Draw two cycles of the input and output signals. You can choose any period that you want for the input signal.

Assume you have access to regular PN junction diodes ($V_{D0} = 0.7\ V$), Zener diodes (any desired V_Z), and other circuit elements.

Make sure to use Zener diode(s) in your design.

Show your work.

1a)



V_z for D_2 = 4.3 V

V_z for D_4 = 1.3 V

Remember: When in Zener mode of operation V_D of the diode = $-V_Z$!

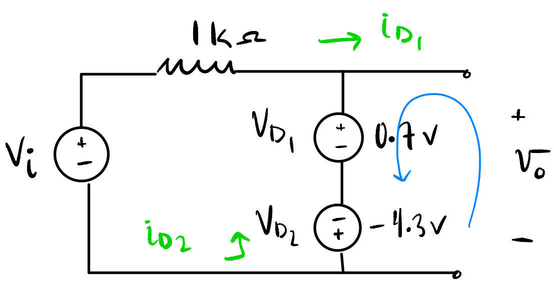
1b)

Two Cases:

Case 1: D_1 ON, D_2 Zener, D_3 OFF, D_4 OFF

Case 2: D_1 OFF, D_2 OFF, D_3 ON, D_4 Zener

CASE 1)



- $V_{D_0} = 0.7\,V$
- $V_{D_2} = -V_Z = -4.3\,V$

For Zener region: $i_{D_2} \le 0$

For FWD BIAS: $i_{D_1} \ge 0$

$$i_{D_1} = -i_{D_2}$$

$$i_{D_1} = \frac{V_i - V_{D_1} + V_{D_2}}{R} \ge 0$$

But $V_{D_2} = -V_Z = -4.3\,V$!

$$i_{D_1} = V_i - 0.7 - 4.3 \ge 0$$

$$V_i - 5 \ge 0$$

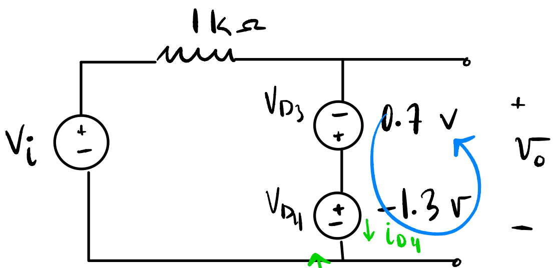
For $V_i \ge 5V$;

$$V_o = V_{D_0} - V_{D_2}$$

$$V_o = 0.7 + 4.3\,V = 5V$$

$$\rightarrow V_o = 5V$$

CASE 2)



$i_{D_3} = -i_{D4}$

- $V_{D0} = 0.7\,V$
- $V_{D4} = -V_Z = -1.3\,V$

For FWD Bias: $i_{D_3} \geq 0$

For Zener region: $i_{D4} \leq 0$

Recall: $V_{D4} = -V_Z = -1.3\,V$

$$i_{D3} = \frac{-V_i + V_{D4} - V_{D3}}{R} \geq 0$$

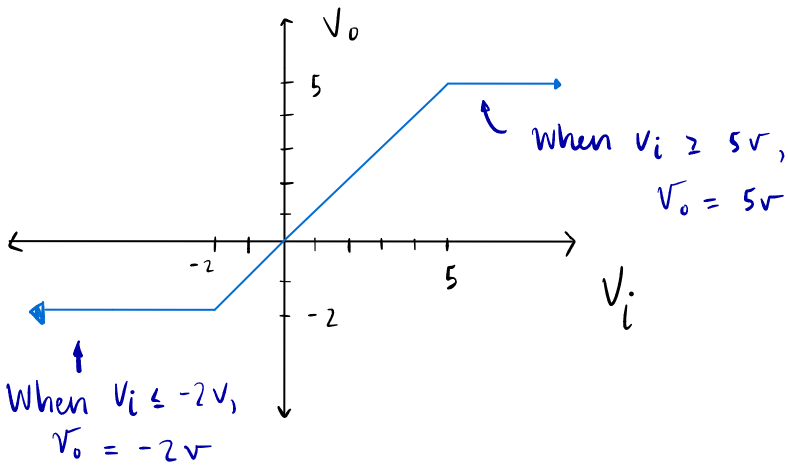
$$-V_i - 1.3 - 0.7 \geq 0$$

For $V_i \leq -2\,V$;

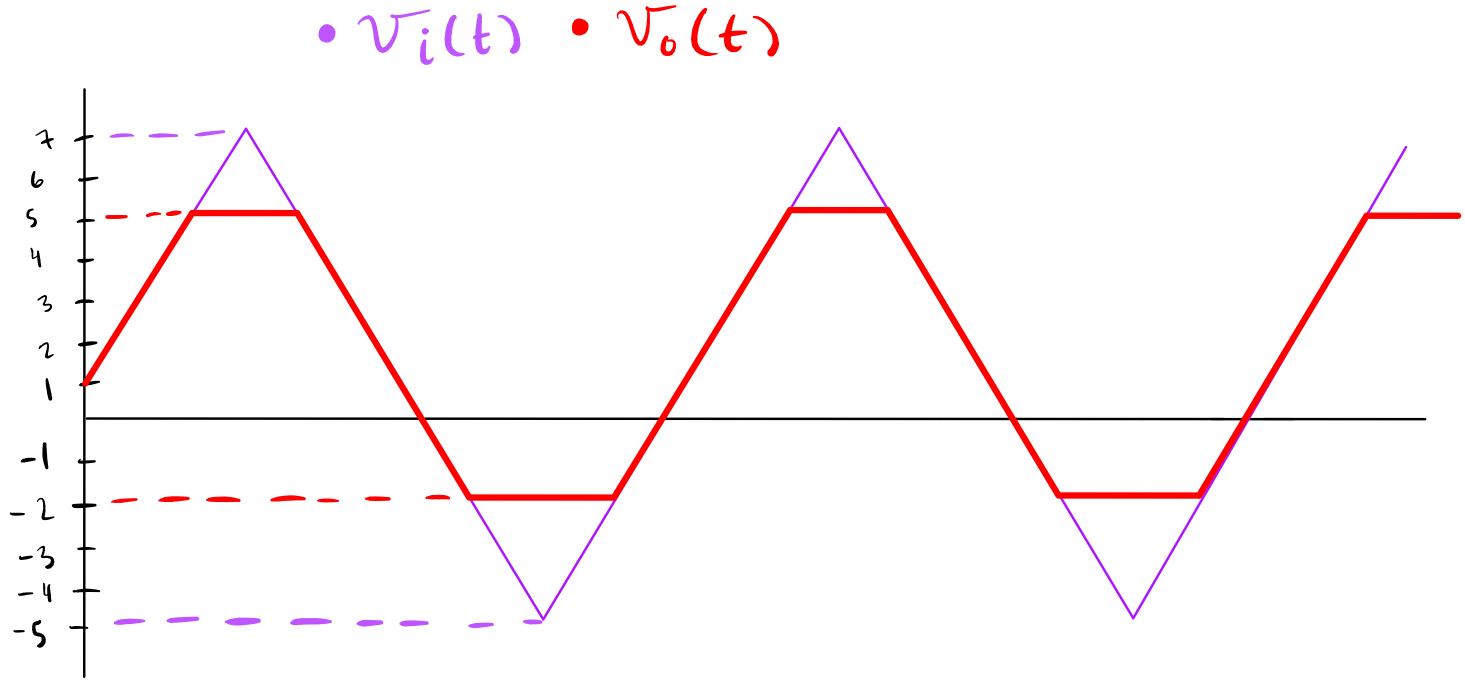
$$V_o = V_{D4} - V_{D0}$$

$$= -1.3 - 0.7 = -2\,V \rightarrow V_o = -2\,V$$

Transfer function:



1(c) Output waveform:



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Problem 2. (10 points)

Additionally, check other regions of operation.

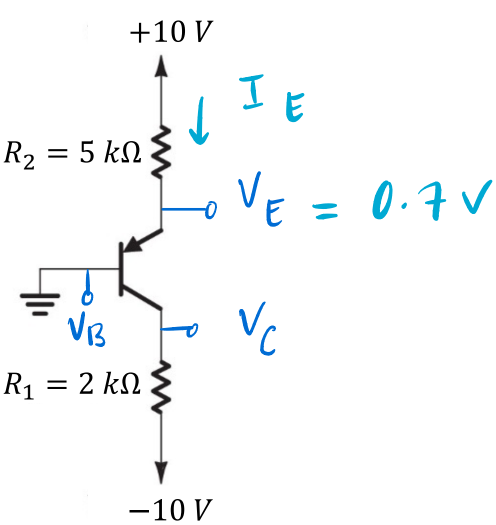
In the following circuit,

a) Find the collector current, the collector node voltage, and the emitter node voltage.

b) Find the largest value to which R_1 can be raised while the transistor remains in the active mode with the same collector current that you calculated in part a.

Assume $V_{D0} = 0.7\ V$, $\beta = 200$, $V_{sat} = 0.2\ V$.

PNP BJT



$V_B = 0\ V$

(Grounded)

$V_{EB} = 0.7\ V$

$V_E - 0 = 0.7\ V$

Show your work.

2a) Assume active mode of operation.

$\rightarrow I_C = \beta I_B;\quad I_E = (\beta+1) I_B;\quad V_{EB} = V_{D_0} = 0.7V$

$$I_E = \frac{10-0.7}{5k\Omega} = 0.00186\ A = 1.86\ mA$$

$$I_B = \frac{I_E}{\beta+1} = \frac{(1.86\,mA)}{201} = 0.00925\ mA$$

$$I_C = (200)(0.00925\ mA) = 1.851\ mA$$

$$I_C = \frac{V_C - -10}{2k\Omega} = I_C(2k\Omega) - 10 = V_C$$

$$V_C = (1.851\,mA)(2k\Omega) - 10 = -6.299\,V$$

So, $V_{EC} = 0.7 + + 6.299 = 7\,V$

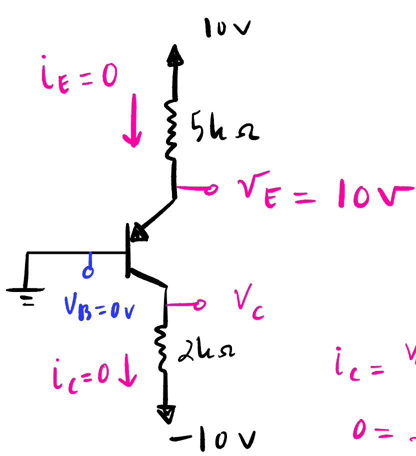
$V_{EC} > 0.7 \leftarrow$ Assumption correct!

In Summary:

$$\boxed{\begin{aligned} I_C &= 1.851\,mA \\ V_E &= 0.7\,V \\ V_C &= -6.3\,V \end{aligned}}$$

Next, the other modes of operation will be analyzed.

In Cut-off: $i_B = 0,\ i_C = 0,\ V_{EB} < V_{D_0}$



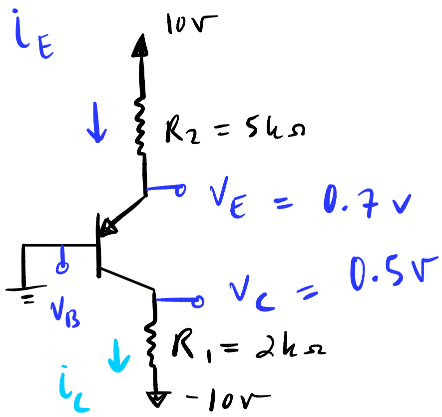
$$i_C = \frac{V_C - -10}{2k\Omega}$$

$$0 = V_C + 10 \rightarrow V_C = -10V$$

So, $V_{EB} = 10 - 0 = 10\,V \not< 0.7\,V$

Assumption wrong!

Next, check if in saturation:



$V_{EB} = V_{D0}$, $i_B \geq 0$

$V_{EC} = V_{sat}$ $i_C < \beta i_B$

$V_B = 0\ V$

$V_{EB} = 0.7V \rightarrow V_E = 0.7V$

$V_E - V_C = 0.2V$

$0.7 - V_C = 0.2V$

$-0.7 \qquad -0.7V$

$V_C = 0.5V$

$$i_C = \frac{V_C - -10}{2k\Omega} = \frac{0.5+10}{2k\Omega} = 5.25\ mA$$

Assumption wrong!

$$i_E = \frac{10-0.7}{5k\Omega} = 1.86\ mA$$

$i_E = i_B + i_C \rightarrow i_E - i_C = i_B$

$i_B = 1.86\ mA - 5.25\ mA = -3.39\ mA \rightarrow i_B \cancel{\geq} 0$

2b) Remains in active mode until $V_{EC} = V_{D0} = 0.7V$

Since $V_E = 0.7V$, V_C would have to be 0V.

So,
$$R_1 = \frac{V_C - -10}{I_C} = \frac{10}{(1.851mA)} = 5.402\ k\Omega$$

$$\boxed{R_1 = 5.402\ k\Omega}$$