Name PID

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Electrical and Computer Engineering Department

ECE 65 – Fall 2022

Components and Circuits lab

Final Exam Solutions

- Closed books, two one-sided cheat sheets, and calculators are allowed
- Electronic devices are not allowed.
- Please put all answers in the provided sheets.
- You can use the back of every page as a scratch paper.
- Please scan your anwers and cheat sheets and submit them to Gradescope by 11:40 am.

Please do not begin until you are told to do so.

Show your work and good luck!

Name PID

Problem 1.

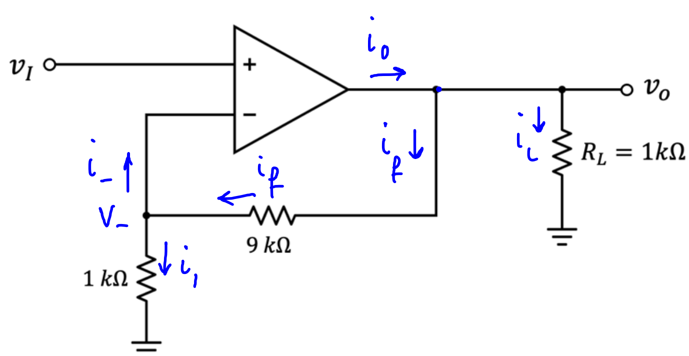
Consider the following op-amp circuit. Assume an ideal op-amp.

Choose the op-amp saturation voltage, maximum output current, and an AC input voltage such that the output voltage would be distorted because of op-amp's maximum output current.

a) What are your selected saturation voltage, maximum output current, and AC input voltage?

b) Analyze the circuit and show why the output voltage is distorted.

c) Draw the input and output waveforms.



There is more than one correct answer to this problem.

Show your work.

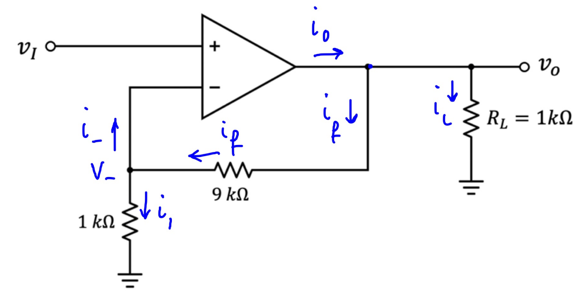
op-amp is ideal: $i_+ = i_- = 0$

there is negative feedback: $V_+ = V_- = V_I$

KCL at the inverting input terminal: $i_f = i_1 + i_- = i_1$

$$\frac{V_o - V_-}{9k} = \frac{V_-}{1k} \rightarrow V_o = 10\ V_-$$

Name PID



$V_o = 10\ V_-$ and $V_+ = V_-$

$V_o = 10\ V_I$ when we have linear amplification

KCL at the output node: $i_o = i_f + i_L$

$$i_f = \frac{V_o - V_-}{9k} \quad \text{and} \quad V_o = 10\,V_- \implies i_f = \frac{V_o - 0.1\,V_o}{9k} = \frac{0.9\,V_o}{9k} = \frac{V_o}{10}\ (mA)$$

$$i_L = \frac{V_o}{1}\ (mA)$$

$$i_o = \frac{V_o}{10} + \frac{V_o}{1}\ (mA) = 1.1\ V_o\ (mA)$$

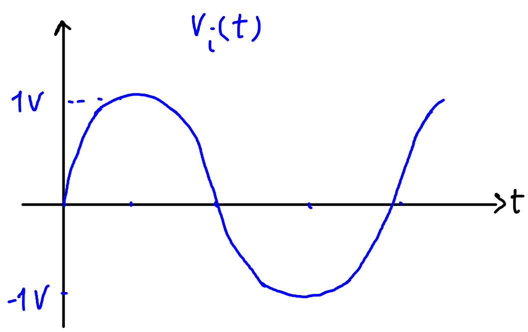
choose some values for V_{sat}, I_{omax} and choose V_I:

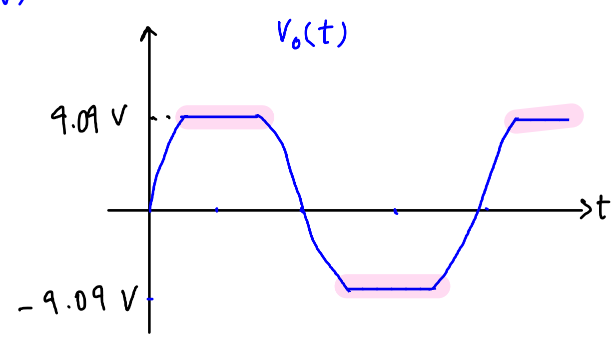
$V_{sat} = \pm 12V$, $V_I = 1\ (V) \sin \omega t$ → linear amplification will not be limitted by the saturation voltage

if $I_{omax} = 10\ mA$ → to have $\hat{V}_o = 10V$, we need $\hat{i}_o = 11\ mA$, which can not supplied

The output voltage will be distorted because of the op-amp max output current.

$$i_{o\,max} = 1.1\ V_{omax} = 10\ mA \rightarrow V_{omax} = \frac{10}{1.1} = 9.09\ (V)$$





Name PID

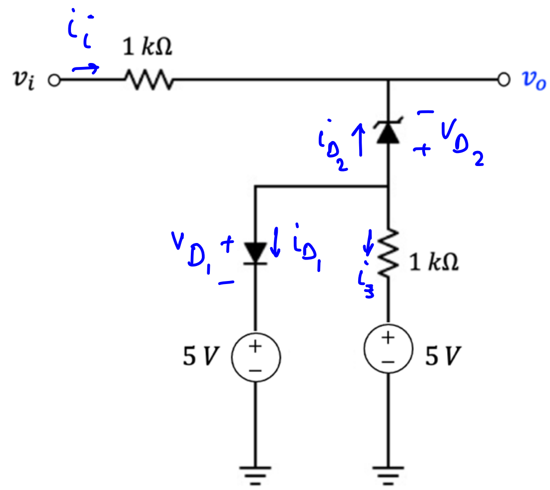
Problem 3.

The diodes in the below circuit have $V_{D0} = 0.7\ V$, and $V_Z = 8\ V$.

a) Write the possible cases of the operation of the diodes.

b) For each case, include the calculation of finding the relationship between v_o and v_i and the range of v_i.

c) Sketch the output signal when v_i is a sinusoidal signal with a peak amplitude of 1V. You do not need to label the time axis.



Show your work.

Case 1: D_2 in Zener & D_1 is off

Case 2: D_2 in Zener & D_1 is ON

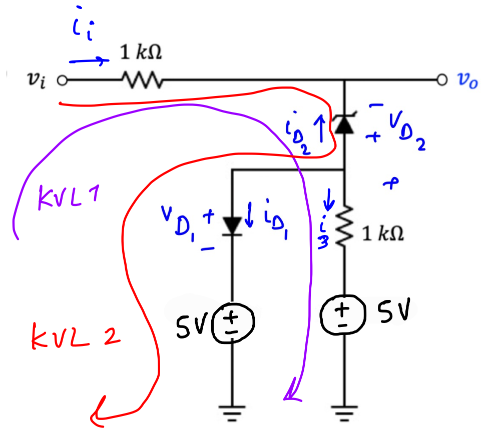
Case 3: D_2 is ON & D_1 is off

Case 4: D_1 & D_2 off

$i_i = -i_{D_2}$ and $i_{D_1} + i_{D_2} + i_3 = 0$

Name PID

Case 1 analysis:



D_2 in Zener & D_1 is off

$V_{D_2} = -V_Z$, $i_{D_2} \leq 0$, $i_{D_1} = 0$, $V_{D_1} < V_{D_0}$

KVL 1:

$V_i = 1k\Omega \times i_i - V_{D_2} + 1k\Omega \times i_3 + 5$

$i_i = -i_{D_2}$ and $i_{D_1} + i_{D_2} + i_3 = 0 \rightarrow i_3 = -i_{D_2}$

$V_i = 1k\Omega \times (-i_{D_2}) + 8 + 1k\Omega \times (-i_{D_2}) + 5$

$\rightarrow i_{D_2} = \dfrac{-V_i + 13}{2\,k\Omega}$ $\quad i_{D_2} \leqslant 0 \Longrightarrow V_i \geqslant 13V$

V_{D_1} must also be less than 0.7 V

KVL 2:

$V_i = 1k\Omega \times i_i - V_{D_2} + V_{D_1} + 5 = 1k\Omega \times (-i_{D_2}) + 13 + V_{D_1}$

$V_i = 1k\Omega \times \left(\dfrac{+V_i - 13}{2k\Omega} \right) + 13 + V_{D_1} \rightarrow \frac{1}{2} V_i - \frac{13}{2} = V_{D_1}$

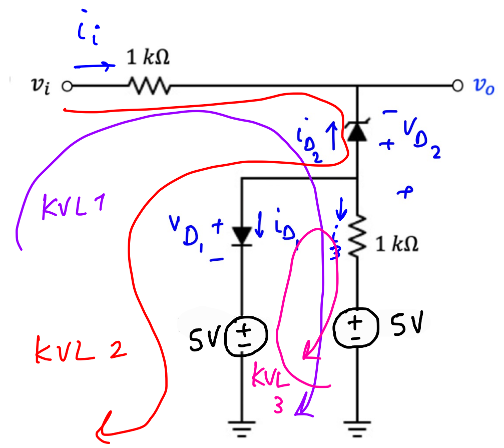
$V_{D_1} < V_{D_0} \longrightarrow \frac{1}{2} V_i - 6.5 < 0.7V \longrightarrow V_i < 14.4\ V$

the range of V_i for this case is $13 \leqslant V_i < 14.4$

$V_0 = -V_{D_2} + 1k\Omega \times i_3 + 5 = 8V + 1k\Omega \times (-i_{D_2}) + 5 = 13V + 1k\Omega \times \dfrac{V_i - 13}{2k\Omega}$

$V_0 = \frac{1}{2} V_i + 6.5$

Name PID



Case 2 analysis:

D_2 in Zener & D_1 is ON

$V_{D_2} = -V_Z$, $i_{D_2} \leq 0$, $i_{D_1} \geq 0$, $V_{D_1} = V_{D_0}$

KVL 1:

$V_i = 1k\Omega \times i_i - V_{D_2} + 1k\Omega \times i_3 + 5$

$i_i = -i_{D_2} = i_{D_1} + i_3$

KVL 3:

$-5 - V_{D_1} + 1k\Omega \times i_3 + 5 = 0 \implies 1k\Omega \times i_3 = V_{D_0}$

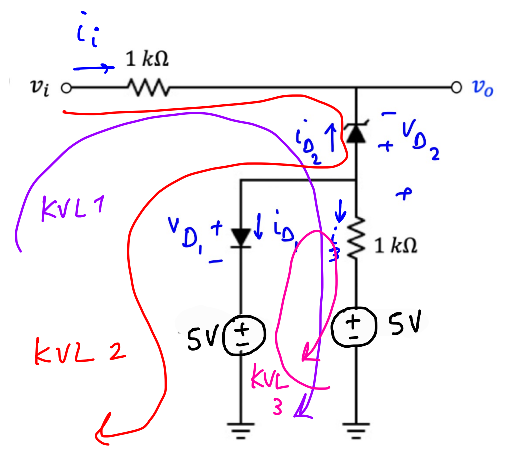
$V_i = 1k\Omega \times (i_{D_1} + \frac{0.7}{1k\Omega}) + 8 + 0.7 + 5 \rightarrow i_{D_1} = \frac{V_i - 14.4}{1k\Omega}$

$i_{D_1} \geq 0 \rightarrow V_i \geq 14.4\ V$

the range of V_i for this case is $V_i \geq 14.4\ V$

$V_o = -V_{D_2} + V_{D_1} + 5 = 13.7\ V \rightarrow V_o = 13.7\ V$

Name PID



Case 3 analysis:

D_2 is ON & D_1 is off

$V_{D_2} = V_{D_0}$, $i_{D_2} \geq 0$, $i_{D_1} = 0$, $V_{D_1} < V_{D_0}$

KVL 1:

$$V_i = 1k\Omega \times i_i - V_{D_2} + 1k\Omega \times i_3 + 5$$

$$i_i = -i_{D_2} \quad , \; i_3 = -i_{D_2}$$

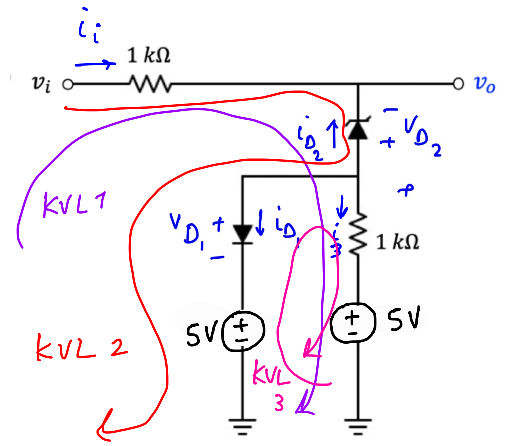
$$V_i = 1k\Omega \times (-i_{D_2}) - 0.7 + 1k\Omega \times (-i_{D_2}) + 5$$

$$\rightarrow i_{D_2} = \frac{-V_i + 4.3}{2k\Omega} \qquad i_{D_2} \geq 0 \Longrightarrow \boxed{V_i \leq 4.3\ V}$$

$$V_o = 1k\Omega \times (-i_i) + V_i = 1k\Omega \times (i_{D_2}) + V_i = \frac{-V_i}{2} + \frac{4.3}{2} + V_i = \frac{1}{2} V_i + \frac{4.3}{2}$$

$$\boxed{V_o = \frac{1}{2} V_i + \frac{4.3}{2}\ V}$$

Name PID



Case 4 analysis:

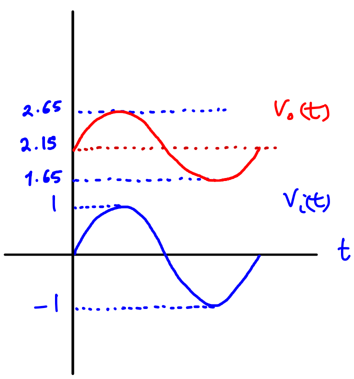
D_2 & D_1 are off

$-V_2 < V_{D_2} < V_{D_0}$, $i_{D_2} = 0$, $i_{D_1} = 0$, $V_{D_1} < V_{D_0}$

$4.3 < V_i < 13$

$V_0 = 1k\Omega \times (-i_i) + V_i = V_i \longrightarrow V_0 = V_i$

c) $V_i(t) = \sin\omega t \longrightarrow$ The amplitude of V_i will change between $-1V$ and $1V$. D_1 will be off and D_2 will be ON.



$$V_0 = \frac{1}{2} V_i + \frac{4.3}{2} V$$

$V_i = 1 \longrightarrow V_0 = 0.5 + 2.15 = 2.65$

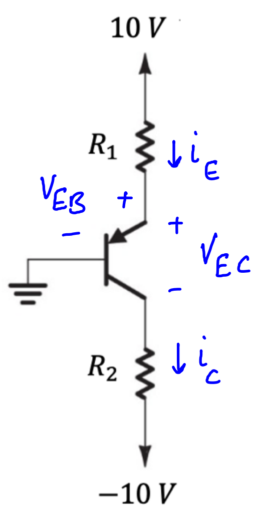
$V_i = -1 \longrightarrow V_0 = -0.5 + 2.15 = 1.65$

Name PID

Problem 4.

Design the following circuit to have the BJT operate in the active mode.

Assume $\beta = 100$, $V_{sat} = 0.2\ V$, and $V_{D0} = 0.7\ V$



BJT ON and in active mode:

$V_{EB} = V_{D_0} = 0.7\ V$

$i_C = \beta\, i_B$ and $V_{EC} \geq V_{D_0}$

$i_E = i_C + i_B$

$i_E = \frac{1+\beta}{\beta}\, i_C$

Show your work.

$V_{EB} = 0.7\ V$ and $V_B = 0 \rightarrow V_E = 0.7\ V$

choose $V_{EC} = 4V \rightarrow V_E - V_C = 4V \rightarrow 0.7 - V_C = 4V \Rightarrow V_C = -3.3V$

choose $R_2 = 1k\Omega \rightarrow i_C = \frac{V_C - (-10)}{R_2} = \frac{-3.3+10}{1k\Omega} = 6.7\,mA$

$i_E = \frac{1+100}{100}\, i_C = 1.01 \times 6.7\ mA \simeq 6.77\ mA$

$R_1 = \frac{10 - V_E}{i_E} = \frac{10-0.7}{6.77} \simeq 1.37\ k\Omega$

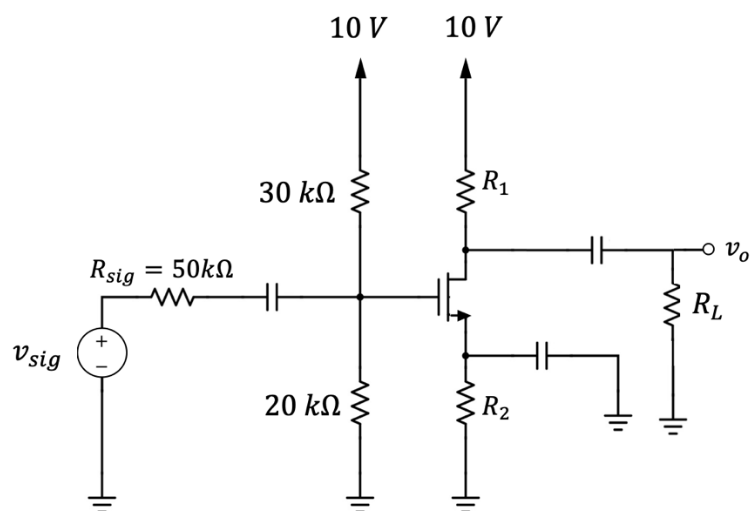
Name PID

Problem 5

Design the following amplifier circuit for $\boldsymbol{I_D = 2\ mA}$, and show the effect of the load resistor value on the total circuit voltage gain.

a) Design the circuit and find the Bias point.
b) Find the small signal parameters and draw the signal circuit.
c) Analyze the circuit and show why and how the total circuit voltage gain changes when the load resistor value changes.
d) Assume $R_L = 10\ k\Omega$ and V_{sig} is a sine wave with the peak to peak amplitude of $28\ mV$ and DC voltage of zero. Find and draw the instantaneous (total) drain to source voltage.

Assume $V_t = 1\ V$, $\mu C_{ox}\frac{W}{L} = 1\ mA/V^2$, and $\lambda = 0$.



There is more than one correct answer to this problem.

Show your work.

Name PID

$V_G = \frac{2}{5} \times 10 = 4\,V$

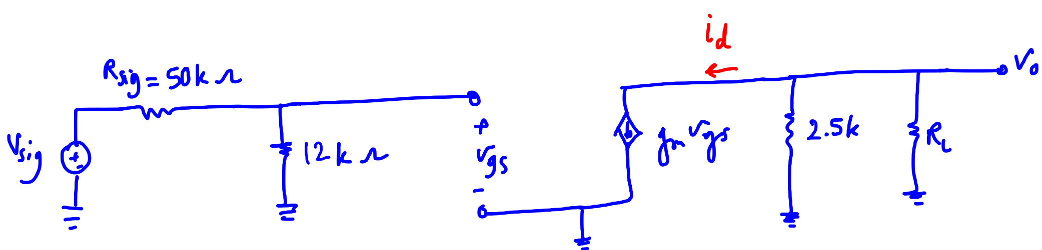
$I_D = \frac{1}{2} \times 1 \times V_{ov}^2 = 2\,mA \rightarrow V_{ov} = 2\,V$

$V_{GS} - V_t = 2 \rightarrow V_{GS} = 3\,V$ $\quad V_G - V_S = 3 \rightarrow V_S = 1\,V$

$R_2 = \frac{1-0}{2mA} = 0.5\,k\Omega$

$V_{ov} = 2V$, choose $V_{DS} = 4\,V \rightarrow V_D = 5\,V \rightarrow R_1 = \frac{10-5}{2} = 2.5\,k\Omega$

$g_m = \frac{2 I_D}{V_{ov}} = \frac{4\,mA}{2\,V} = 2\,mA/V$, $r_o = \infty$, $R_G = 20\,k\Omega \,||\, 30\,k\Omega = 12\,k\Omega$



total circuit gain $= A = \frac{V_o}{V_{sig}} = \frac{V_o}{V_{gs}} \times \frac{V_{gs}}{V_{sig}}$

$V_o = -g_m (2.5\,k\Omega \,||\, R_L)\, V_{gs} \rightarrow \frac{V_o}{V_{gs}} = -2m(A/V) \times (2.5\,k\Omega \,||\, R_L)$

$V_{gs} = \frac{12k\Omega}{12\,k\Omega + 50\,k\Omega} \times V_{sig} \rightarrow \frac{V_{gs}}{V_{sig}} = \frac{6}{31}$

$A = \frac{-12}{31} (mA/V) \times (2.5\,k\Omega \,||\, R_L) \Rightarrow$ As R_L decreases the total circuit gain will decrease

Name PID

$$i_d = g_m v_{gs} \quad , \quad v_{gs} = \frac{6}{31} v_{sig} \longrightarrow \hat{v}_{gs} = \frac{6}{31} \hat{v}_{sig}$$

$$\hat{v}_{sig} = 14\ mV \longrightarrow \hat{v}_{gs} = 2.71\ mV$$

$$\hat{i}_d = g_m \hat{v}_{gs} \longrightarrow \hat{i}_d = 2\frac{mA}{V} \times 2.71\ mV = 5.42\ \mu A$$

$$i_D = I_D + i_d = 2\ mA + 5.42\ \mu A \sin(\omega t)$$

$$\hat{v}_d = \hat{v}_o = -(2.5k\Omega \parallel 10k\Omega) \times \hat{i}_d = -2\ k\Omega \times 5.42\ \mu A \sin(\omega t)$$

$$= -10.84\ (mV) \sin(\omega t)$$

$$v_D = V_D + v_d = 5V - 10.84\ (mV) \sin(\omega t)$$

$$v_s = 0V \quad , \quad V_S = 1V \longrightarrow v_S = 1\ V + 0V = 1\ V$$

$$v_{DS} = v_D - v_S = 5V - 10.84\ (mV) \sin(\omega t) - 1V = 4\ V - 10.84\ (mV) \sin(\omega t)$$