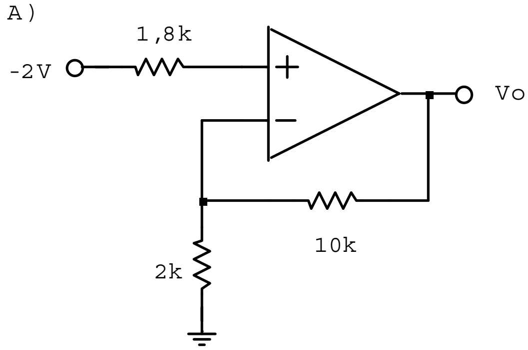
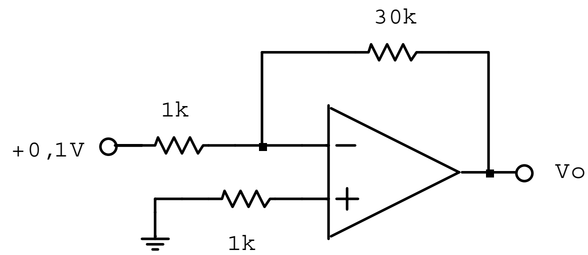
EXERCISE IDEAL OP AMP ANALYSIS

No.1 Assuming ideal op amps, determine V_O for each and every circuit shown below.

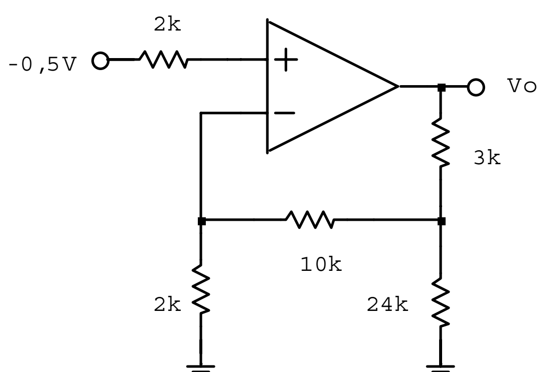
A)



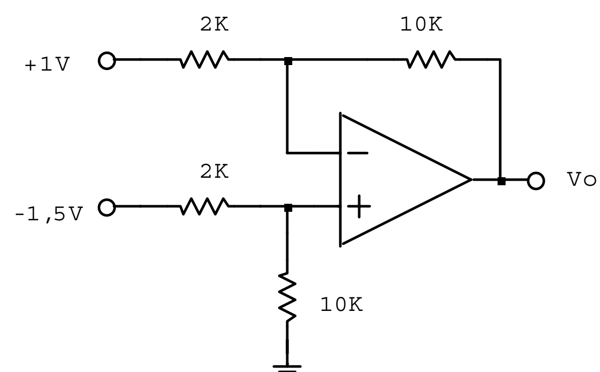
B)



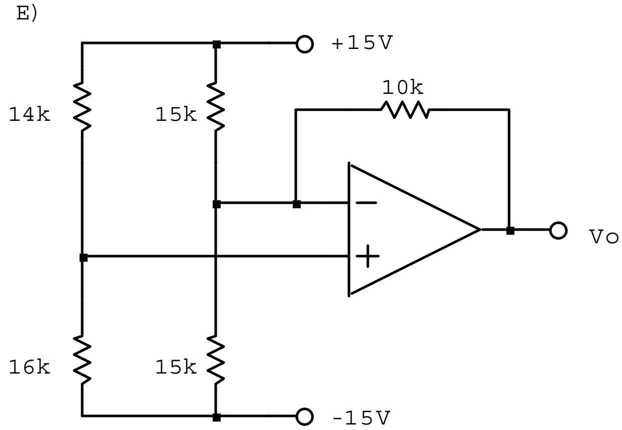
C)



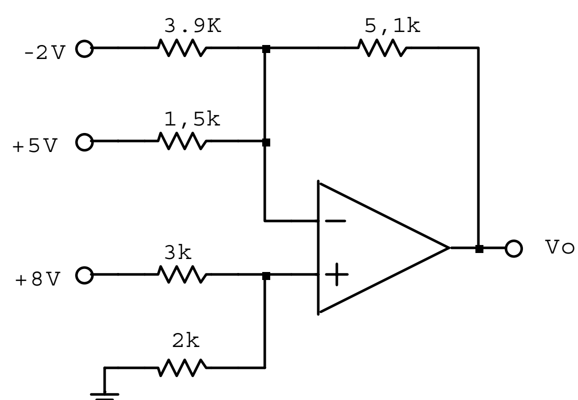
D)



E)



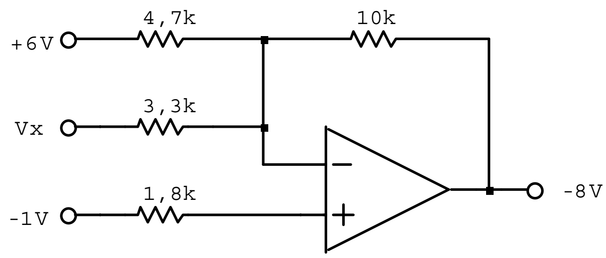
F)



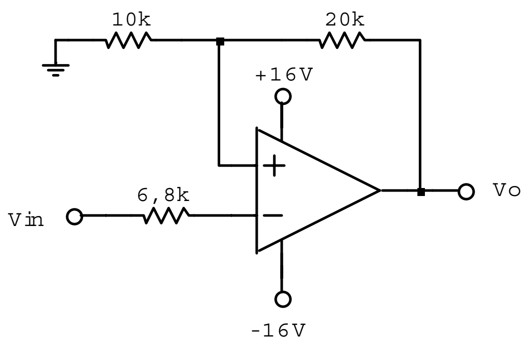
No.2 Assume typical op amp data for circuits A through E and worst case values for circuit F.

Op amp parameters for V_{SUP}=±15V	minimum	typical	maximum
O/P voltage swing	±12V	±13,5V	-
I/P voltage range	±11V	±12,5V	-
Short circuit current	±12 mA	±20 mA	-

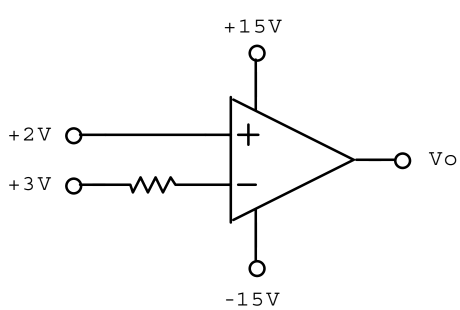
A) Determine V_x.



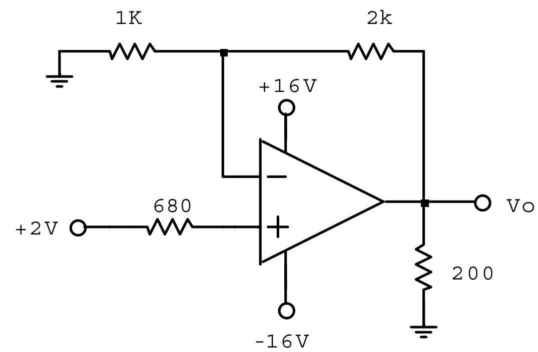
B) Determine V_o for V_{in}=+6V and V_{in} =-6V.



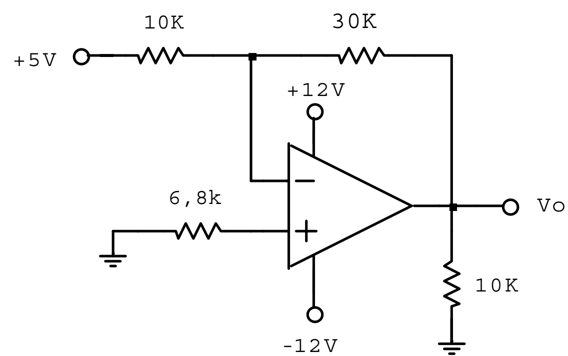
C) Determine V_o.



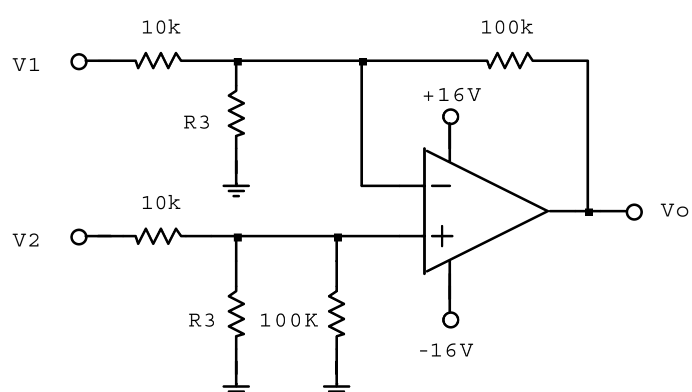
D) Determine V_o.



E) Determine V_o.

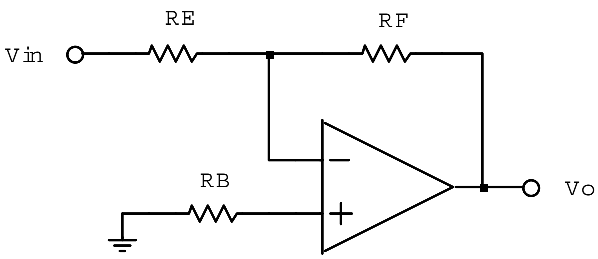


F) Determine the maximum value of R_3 if we do nc want to saturate the inputs of the op amp given and V2 range from 80V to100V .

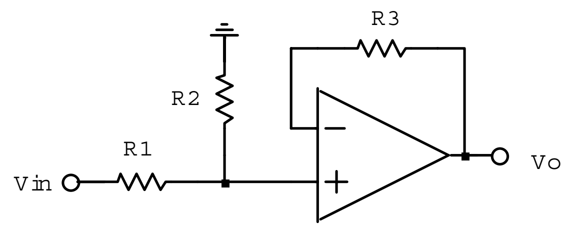


No.3 Assume ideal op amps for each of the following circuits. Do not use any formulas, you must be able to derive them on your own. <u>Mark up the circuit diagrams thoroughly for solutions.</u>

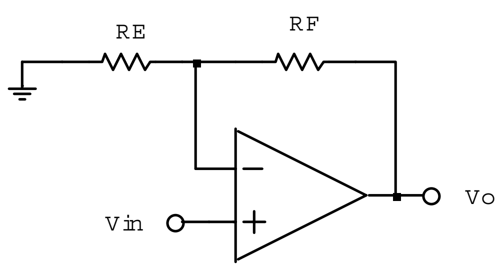
A) Determine R_B, A_{Vf} and Z_{If}



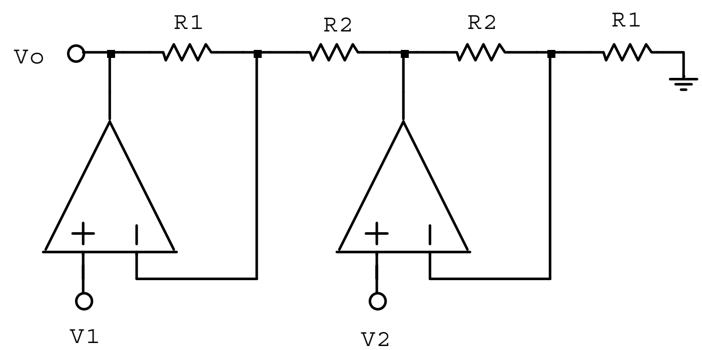
B) Determine R_3, A_{Vf} and Z_{If}



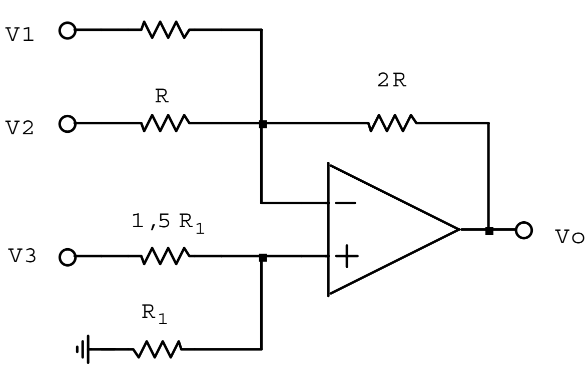
C) Determine A_{Vf} and Z_{If}



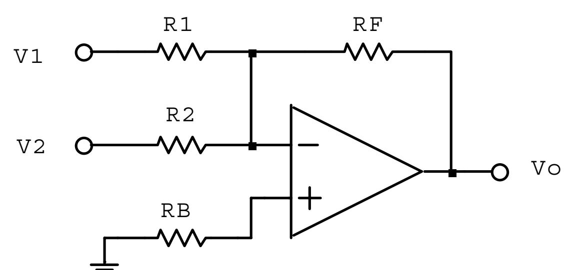
D) Determine V_O and Z_{If} seen by each I/P.



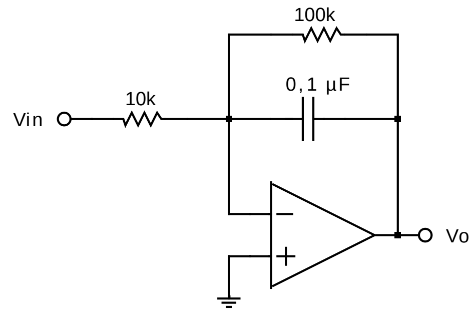
E) Determine V_O and Z_{If} seen by each I/P.



F) Determine R_B, V_O and Z_{If} seen by each I,



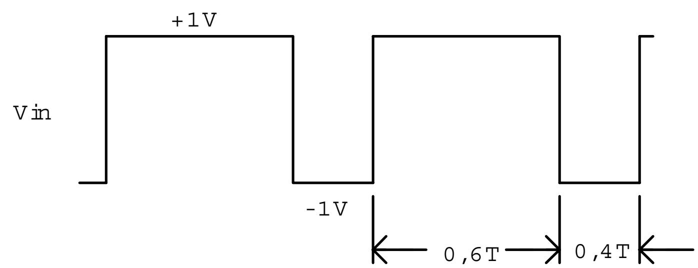
No.4



$$\Delta V_{o(PP)} = V_{o(t_2)} - V_{o(t_1)} = -\left(\frac{1}{R_E C_F}\right)\int_{t_1}^{t_2} V_{in(AC)}\,dt \quad \text{if } \omega > \frac{10}{R_F C_F}$$

$$V_{in(ave)} = V_{in}^{+}\left(\frac{PW}{T}\right) + V_{in}^{-}\left(\frac{SW}{T}\right)$$ for a squarewave

A) Draw the output waveform with respect to V_{in} shown for frequencies of 50 Hz, 100 Hz, 1 kHz and 10 kHz - label waveforms with AC and DC values as well as PW and SW.



B) If V_{in} is a 2 V_{pp} squarewave with a 50% duty cycle, calculate the frequency of V_{in} that will produce V_o = 1 V_{pp}

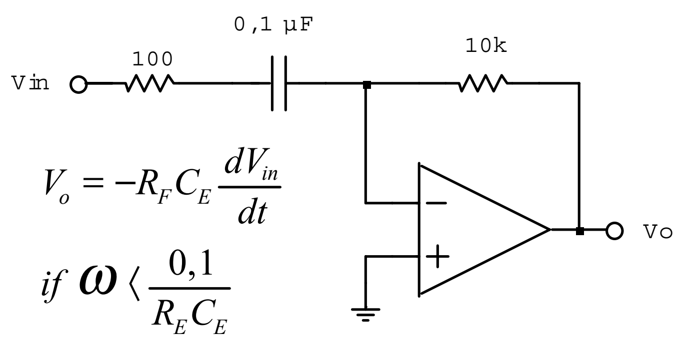
C) Repeat step B for 75% duty cycle.

D) If V_{in} is a 10 V_{pp} triangular wave with a frequency of 5 kHz, draw the expected O/P waveform with respect to V_{in}.

No.5 A) Determine the output waveform relative to an input triangular wave with a 10 V_{PP} amplitude and a frequency of 250 Hz.

B) Determine the output waveform relative to an input square wave with a 2 V_{PP} amplitude and a frequency of 250 Hz.

C) What is the function of the 100Ω resistor?

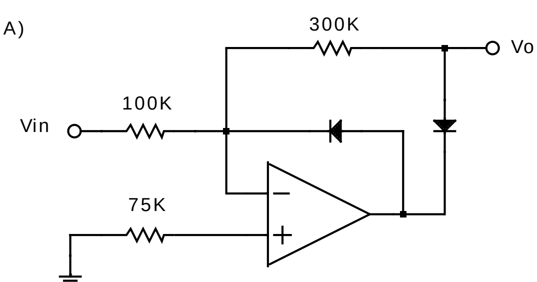


$$V_o = -R_F C_E \frac{dV_{in}}{dt}$$

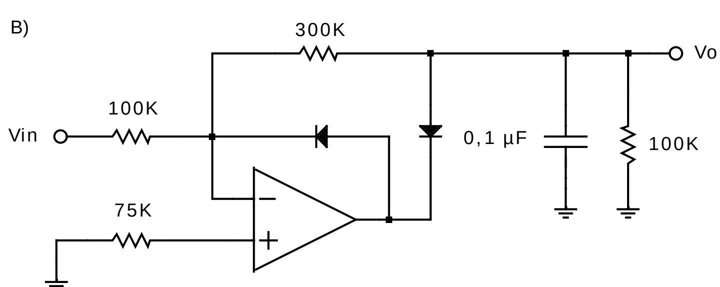
$$if\ \omega < \frac{0,1}{R_E C_E}$$

No.6 Determine the O/P waveform relative to an input 2V (rms) 1 kHz sinewave for each circuit shown below.

A)



B)



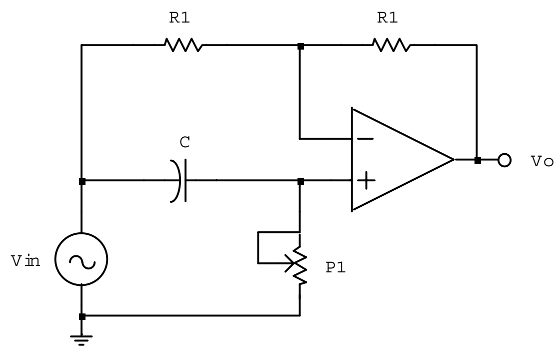
No.7 **PHASE SHIFTER**

Using ideal op amp analysis, prove that

$$A_{VF} = \frac{P1 + jX_C}{P1 - jX_C}$$

$$|A_{VF}| = 1$$

$$\underline{/A_{VF}} = 2\arctan\frac{X_C}{P1}$$



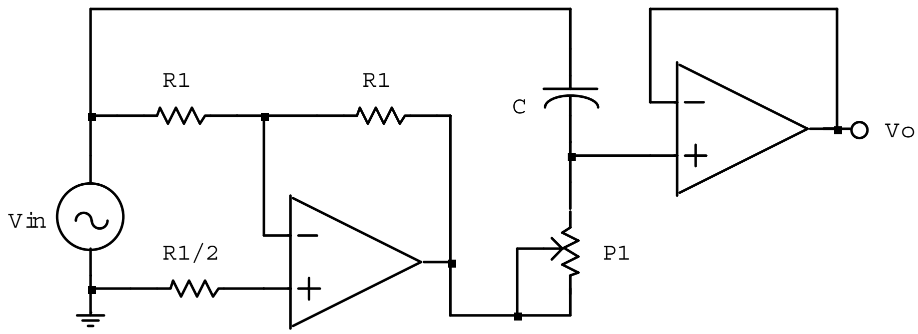
No.8
PHASE SHIFTER

Using ideal op amp analysis, prove that

$$A_{VF} = \frac{P1 + jX_C}{P1 - jX_C}$$

$$|A_{VF}| = 1$$

$$\underline{/A_{VF}} = 2\arctan\frac{X_C}{P1}$$

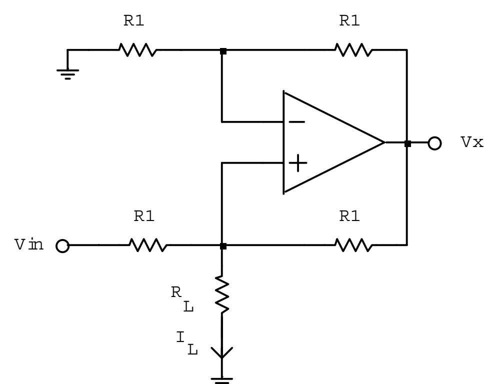


No.9
Howland current source

Prove that the load current is given by the following equation:

$$I_L = \frac{V_{in}}{R1}$$

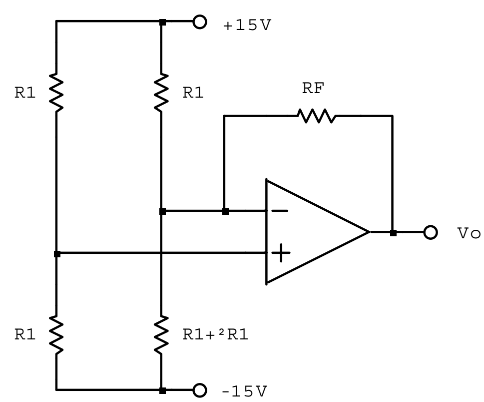
Hint: Work out currents in terms of V_{in} and unknown V_x.



No.10
BRIDGE AMPLIFIER

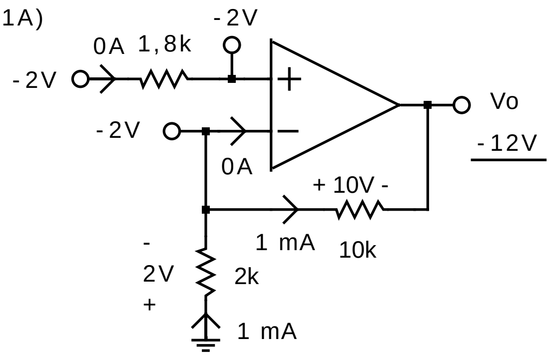
Prove that V_o is given by the following equation:

$$V_o = \frac{-15 * \Delta R_1}{R_1(R_1 + \Delta R_1)} R_F$$

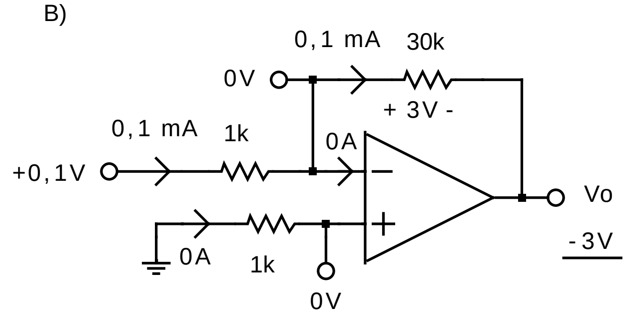


SOLUTIONS

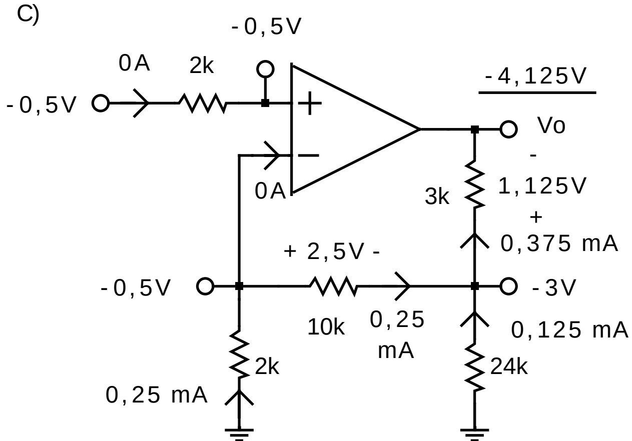
No.1A)



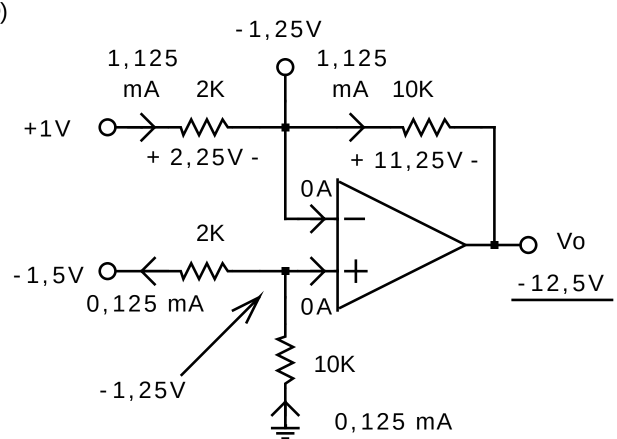
B)



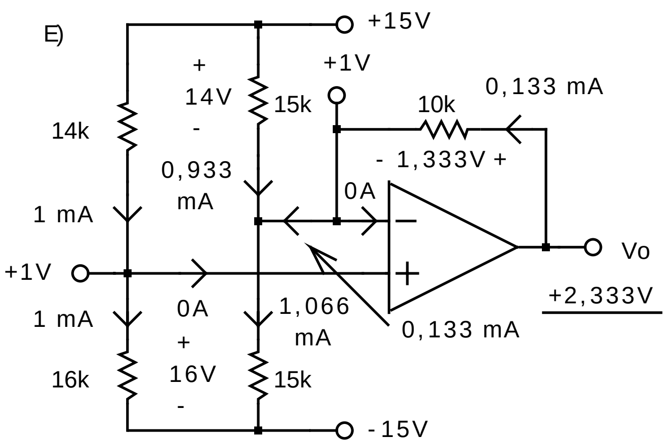
C)



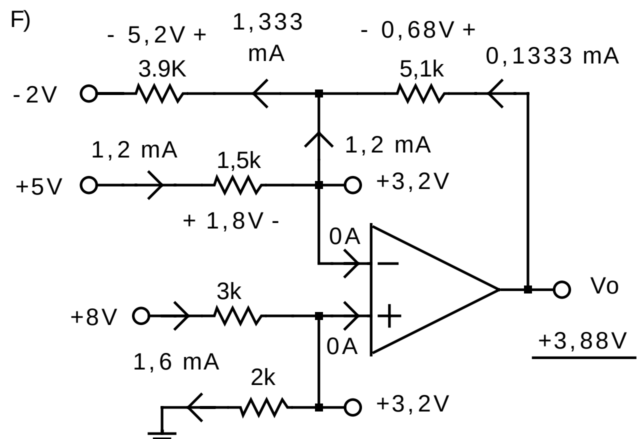
D)



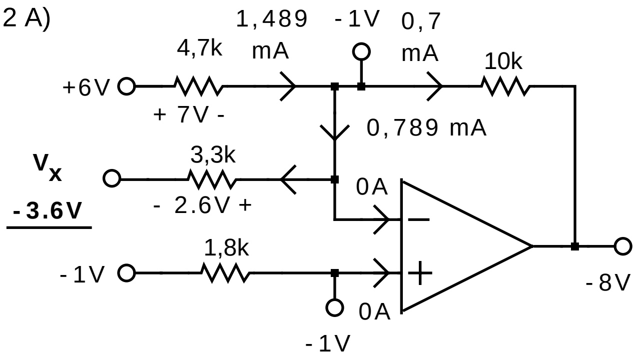
E)



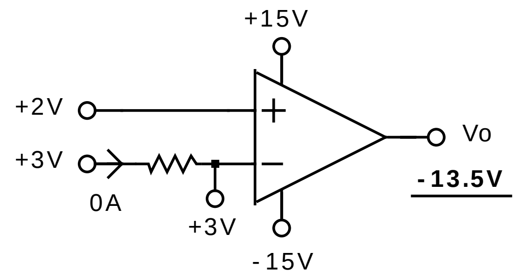
F)



No.2 A)



C)

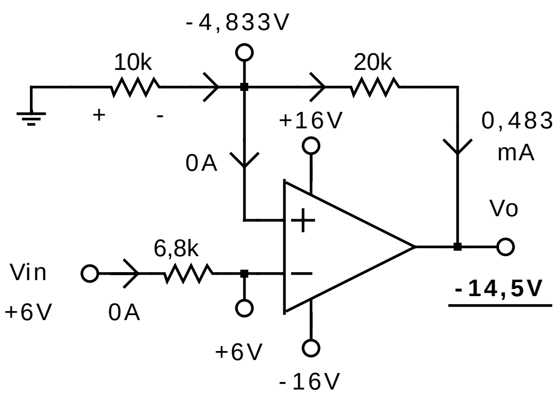


No feedback, the output saturates with a polarity determined by the sign of the differential I/P voltage:

$V_o = A_d\,(V^+ - V^-) = \quad (2-3) = -$

$\mathbf{V_o = -V_{sat} = \underline{-13{,}5V}}$

B)

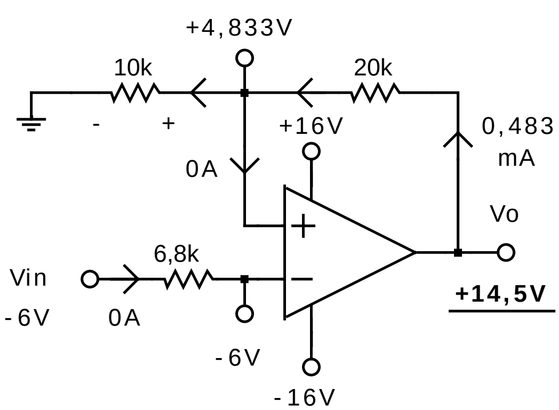


Positive feedback will make the output saturate with a polarity determined by the sign of the differential I/P voltage. With +6V applied to the -ve I/P of the op amp, the O/P should be of the opposite polarity, therefore <u>assume</u>

$\mathbf{V_o = -V_{sat} = -14{,}5V}$ and determine the V^+ and verify the sign of the differential I/P voltage in order to validate your assumption of $V_o = -V_{sat}$, that is:

$V_o = A_d\,(V^+ - V^-) = \quad (-4{,}83-6) = -$

therefore the assumption was valid.



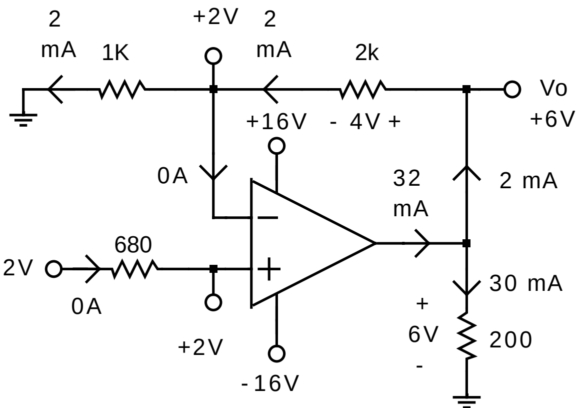
Same procedure here, except now V^- is negative, therefore the O/P polarity is expected to be positive:

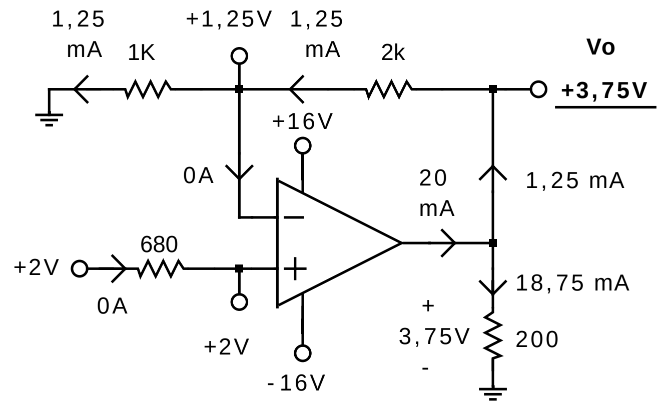
$\mathbf{V_o = +V_{sat} = +14{,}5V}$

Verify assumption with sign of $V_d = (V^+ - V^-)$

$V_o = A_d\,(V^+ - V^-) = \quad (+4{,}83-(-6)) = +$

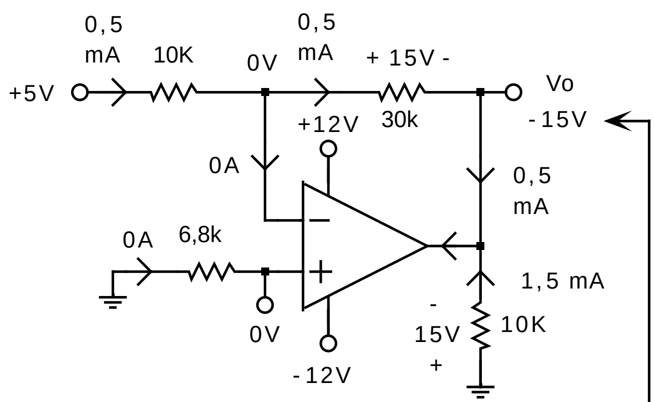
2 D)



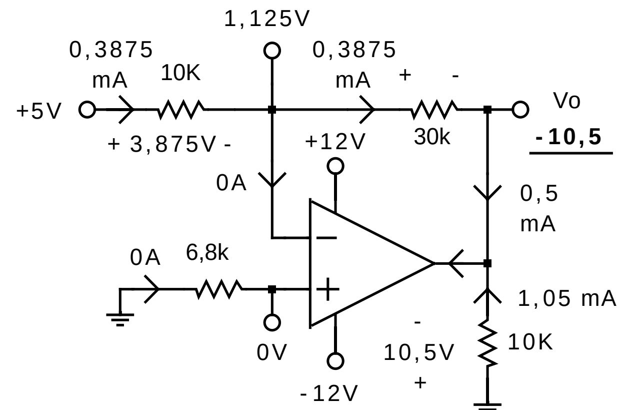


Output of op amp has reached current limit, notice that V^- V^+ and -ve feedback is rendered ineffective not forcing $V^- = V^+$

E)

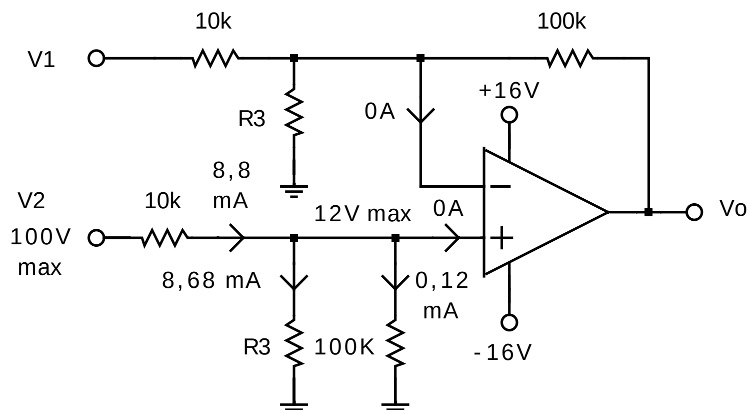


Impossible voltage, therefore $V_o = -V_{sat}$ = **-10,5V typical.**



Output of op amp has reached saturation, notice that V^- V^+ and -ve feedback is rendered ineffective not forcing $V^- = V^+$

F)

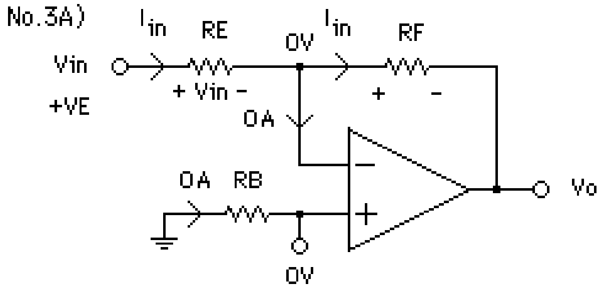


V^- or V^+ max = 16 - 4 = 12V

R_3 < 12V/8,68 mA = **1382**

R_3 should be less than 1382 in order to keep V^- and V^+ inside a safe range of ±12V.

No.3A)

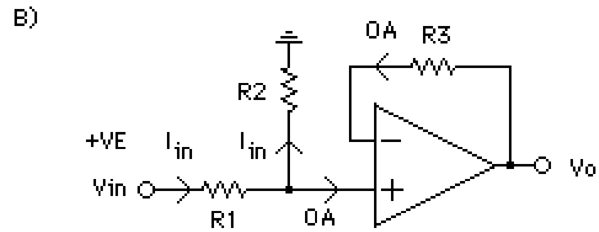


$$I_{in} = \frac{V_{in}}{R_E} \qquad R_{in} = \frac{V_{in}}{I_{in}} = R_E \qquad R_B = R_E \| R_F$$

$$V_o = V^- - I_{in}R_F = 0 - \left(\frac{V_{in}}{R_E}\right)R_F$$

$$A_{VF} = \frac{V_o}{V_{in}} = -\frac{R_F}{R_E}$$

B)

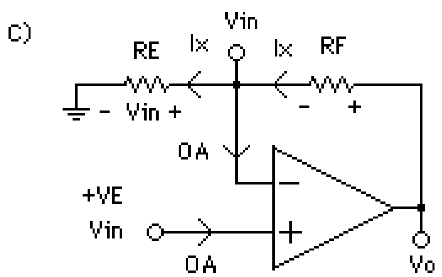


$$I_{in} = \frac{V_{in}}{R_1 + R_2} \qquad R_{in} = \frac{V_{in}}{I_{in}} = R_1 + R_2$$

$$V_o = V^- = V^+ = I_{in}R_2 = \left(\frac{V_{in}}{R_1 + R_2}\right)R_2$$

$$A_{VF} = \frac{V_o}{V_{in}} = \frac{R_2}{R_1 + R_2} \qquad R_3 = R_1 \| R_2$$

C)

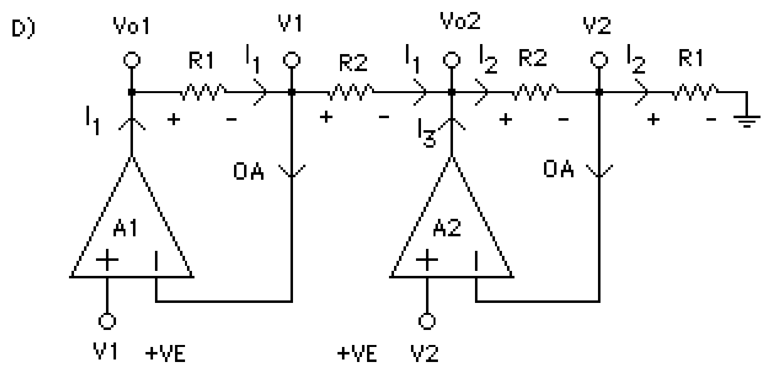


$$I_{in} = 0 \qquad R_{in} = \frac{V_{in}}{I_{in}} = \infty \qquad I_x = \frac{V^-}{R_E} = \frac{V_{in}}{R_E}$$

$$V_o = V^- + I_x R_F = V_{in} + \left(\frac{V_{in}}{R_E}\right)R_F$$

$$V_o = V_{in}\left(1 + \frac{R_F}{R_E}\right) \quad \Rightarrow \quad A_{VF} = \frac{V_o}{V_{in}} = \left(1 + \frac{R_F}{R_E}\right)$$

D)



$$Z_{if1} = Z_{if2} = \frac{V_{in}}{0\,A} = \infty \qquad I_2 = \frac{V_2}{R_1}$$

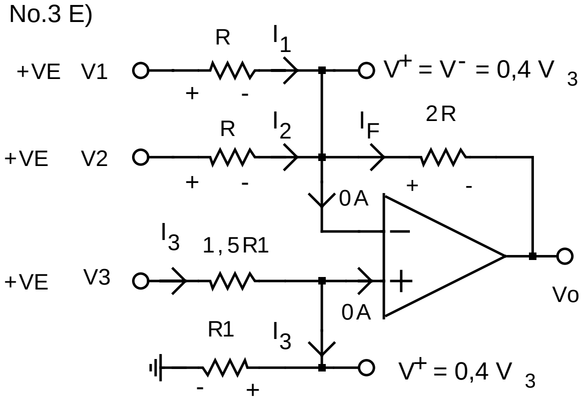
$$V_{o2} = V_2 + I_2R_2 = V_2 + \left(\frac{V_2}{R_1}\right)R_2 = V_2\left(1 + \frac{R_2}{R_1}\right)$$

$$I_1 = \frac{V_1 - V_{o2}}{R_2} = \frac{V_1 - V_2\left(1 + \left(R_2/R_1\right)\right)}{R_2}$$

$$V_o = V_1 + I_1R_1 = V_1 + \left[V_1 - V_2\left(1 + \frac{R_2}{R_1}\right)\right]\left(\frac{R_1}{R_2}\right)$$

$$\textit{After simplification} \quad V_o = \left(1 + \frac{R_1}{R_2}\right) \times \left(V_1 - V_2\right)$$

No.3 E)



$$I_3 = \frac{V_3}{2,5R_1} \quad \Rightarrow \quad V^+ = V^- = I_3R_1 = \frac{V_3}{2,5R_1} \times R_1 = 0,4V_3$$

$$Z_{if3} = \frac{V_3}{I_3} = 2,5R_1 \qquad I_1 = \frac{V_1 - V^-}{R} = \frac{V_1 - 0,4V_3}{R}$$

$$I_2 = \frac{V_2 - V^-}{R} = \frac{V_2 - 0,4V_3}{R} \qquad I_F = I_1 + I_2$$

$$I_F = \frac{V_1 - 0,4V_3}{R} + \frac{V_2 - 0,4V_3}{R} = \frac{V_1 + V_2 - 0,8V_3}{R}$$

$$V_o = V^- - I_F(2R) = 0,4V_3 - \left[\frac{V_1 + V_2 - 0,8V_3}{R}\right](2R)$$

$$V_o = 0,4V_3 - [2V_1 + 2V_2 - 1,6V_3]$$

$$V_o = 2[V_3 - V_2 - V_1]$$

$$Z_{if1} = \frac{V_1}{I_1} = \frac{V_1}{\frac{V_1 - 0,4V_3}{R}} = \frac{R}{\left(1 - \frac{0,4V_3}{V_1}\right)}$$

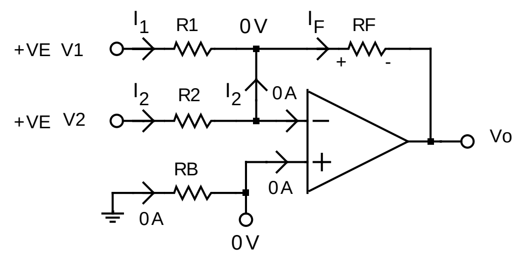
$$Z_{if2} = \frac{V_2}{I_2} = \frac{V_2}{\frac{V_2 - 0,4V_3}{R}} = \frac{R}{\left(1 - \frac{0,4V_3}{V_2}\right)}$$

to balance the inputs:

$$R \| R \| 2R = 0,4R = R_1 \| 1,5R_1 = 0,6R_1$$

$$R = 1,5R_1$$

F)



$$V_o = V^- - I_F R_F = 0 - (I_1 + I_2)R_F$$

$$V_o = -\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)R_F$$

$$V_o = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2\right)$$

$$Z_{if1} = \frac{V_1}{I_1} = R_1 \qquad Z_{if2} = \frac{V_2}{I_2} = R_2$$

$$R_B = R_1 \| R_2 \quad \textit{to balance inputs}$$

N0.3 E)

Z_{if1} and Z_{if2} are not constant, but will vary as V_3 changes. Onthe other hand, Z_{if3} is fixed and does is not affected by either V_1 or V_2.

No.4

$$If \quad F \rangle \frac{10}{2\pi\, R_F C_F} = \frac{10}{2\pi\, 100k \times 0{,}1\mu} = 159\ Hz \quad then \quad \Delta V_{o\,(PP)} = -\left(\tfrac{1}{R_E C_F}\right)\int_{t_1}^{t_2} V_{in\,(AC)}\, dt$$

A)

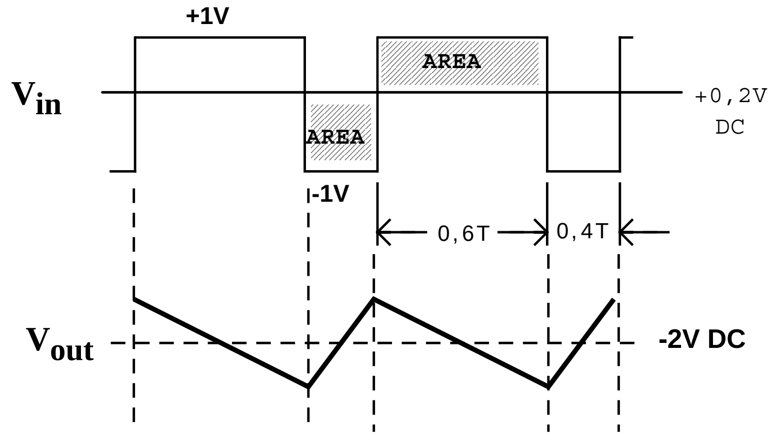
$$V_{(ave)} = V^{+}\left(\tfrac{PW}{T}\right) + V^{-}\left(\tfrac{SW}{T}\right)$$

$V_{in(DC)}$ = +0,2V

$$\Delta V_{o\,(PP)} = -1000 \int_{t_1}^{t_2} V_{in\,(AC)}\, dt$$

$$\Delta V_{o\,(PP)} = -1000 \times area$$

Integral does not apply for 50 Hz and 100 Hz.



ΔV_{out} = 0,48V_{pp} at 1 kHz
and 48 mV_{pp} at 10 kHz

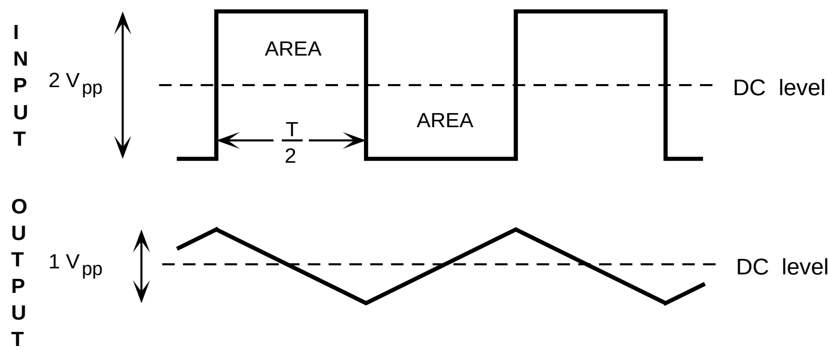
B)

$$\Delta V_{o\,(PP)} = -1000 \int_{t_1}^{t_2} V_{in\,(AC)}\, dt$$

$$\Delta V_{o\,(PP)} = -1000 \times area$$

$$= 1000 \times \frac{T}{2} = \frac{1000}{2F} = 1\, V_{PP}$$

F = <u>500 Hz</u>
F > 159 Hz integral OK.



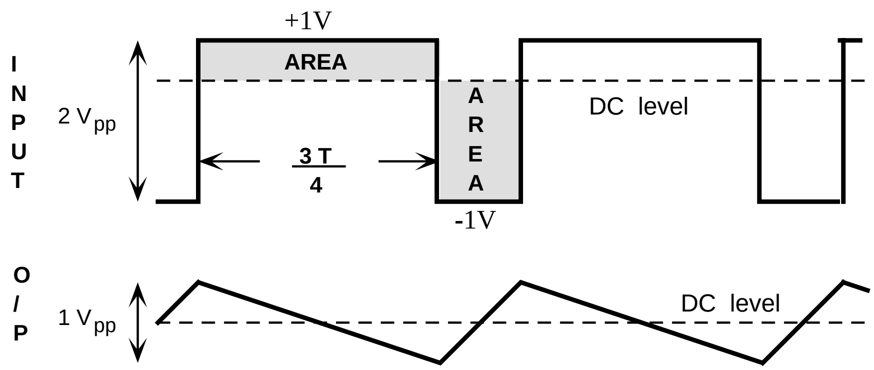
C)

$$\Delta V_{o\,(PP)} = -1000 \int_{t_1}^{t_2} V_{in\,(AC)}\, dt$$

$$\Delta V_{o\,(PP)} = -1000 \times area$$

$$= 1000 \times \left(0{,}5 \times \frac{T}{2}\right) = \frac{250}{F} =$$

$$F = 250\ Hz$$

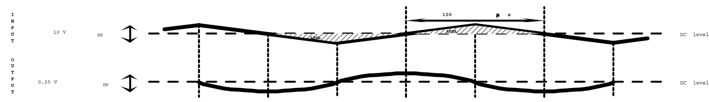


F > 159 Hz integral OK.

$$V_{(ave)} = V^{+}\left(\tfrac{PW}{T}\right) + V^{-}\left(\tfrac{SW}{T}\right)$$

$V_{in(DC)}$ = +0,5V

No.4 D)



$$\Delta V_{o(PP)} = -1000 \int_{t_1}^{t_2} V_{in(AC)}\, dt$$

$$\Delta V_{o(PP)} = -1000 \times area$$

$$= 1000 \times \left(\frac{100\mu \times 5}{2} \right)$$

$$\Delta V_{o(PP)} = 0{,}25 V_{PP}$$

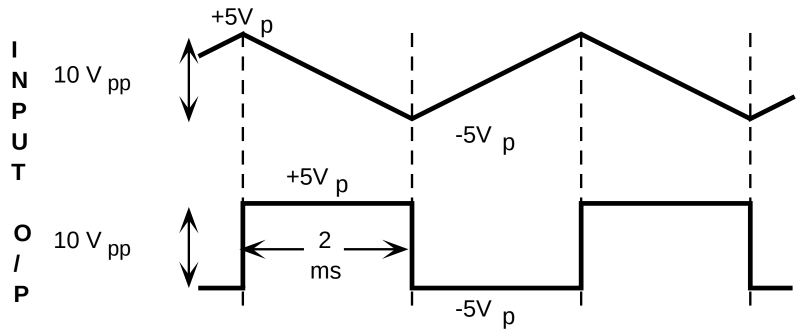
O/P is a parabolic wave, not a sine wave.

No.5 A)

$$V_o = -R_F C_E \frac{dV_{in}}{dt}$$

$$V_o = -10K \times 0{,}1\mu \left(\pm \frac{10V}{2ms} \right)$$

$$V_o = \mp 5 V_P$$



B) On edges we have:

$$V_o = -10K \times 0{,}1\mu(\pm\infty)$$

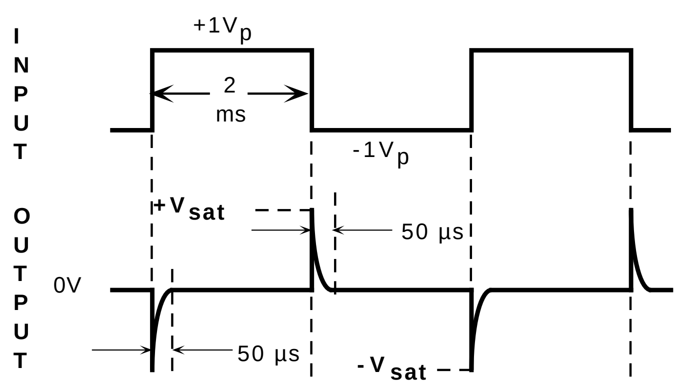
$$V_o = \mp\infty \quad \Rightarrow \quad \mp V_{sat}$$

On flat portions we have:

$$V_o = -10K \times 0{,}1\mu(\pm 0)$$

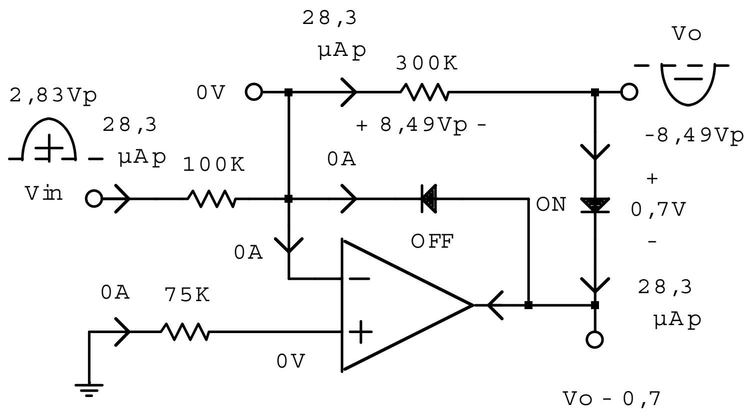
$$V_o = 0$$

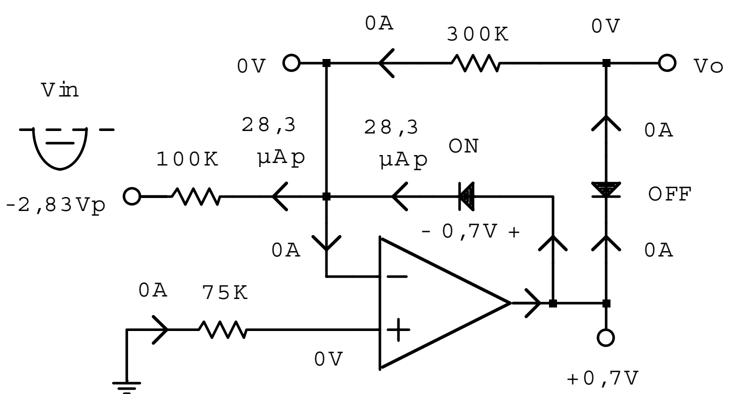
The O/P spikes settle down in $5\tau = 5R_E C_E = 50\ \mu s$

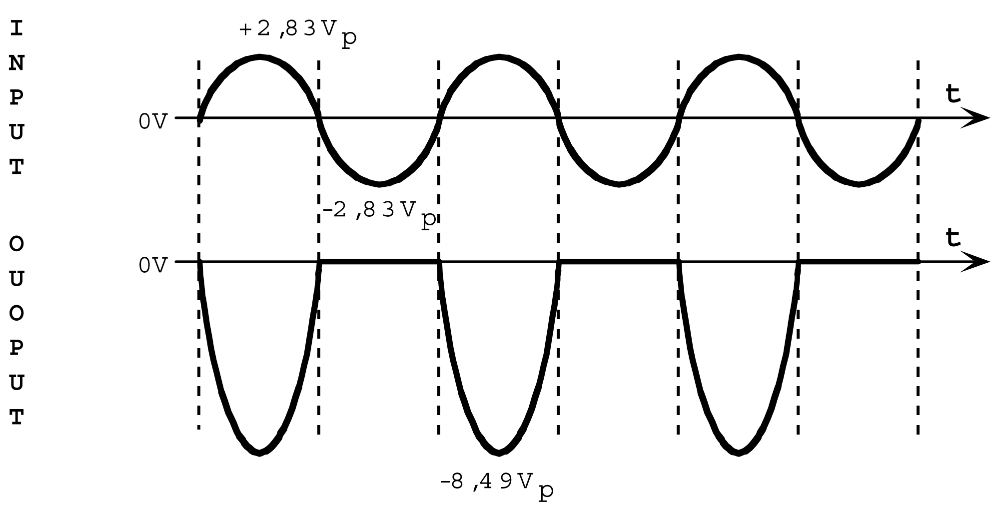


C) To stabilise negative feedback in order to avoid self oscillations from the circuit.

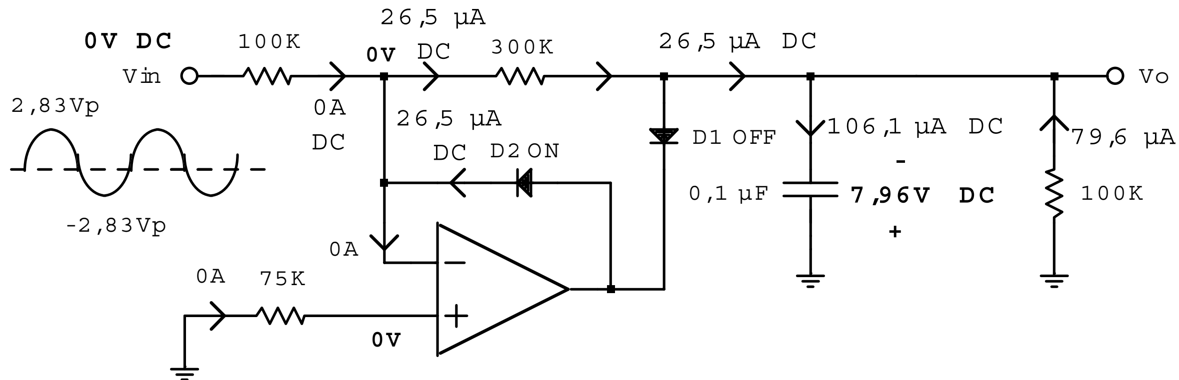
No.6 A)

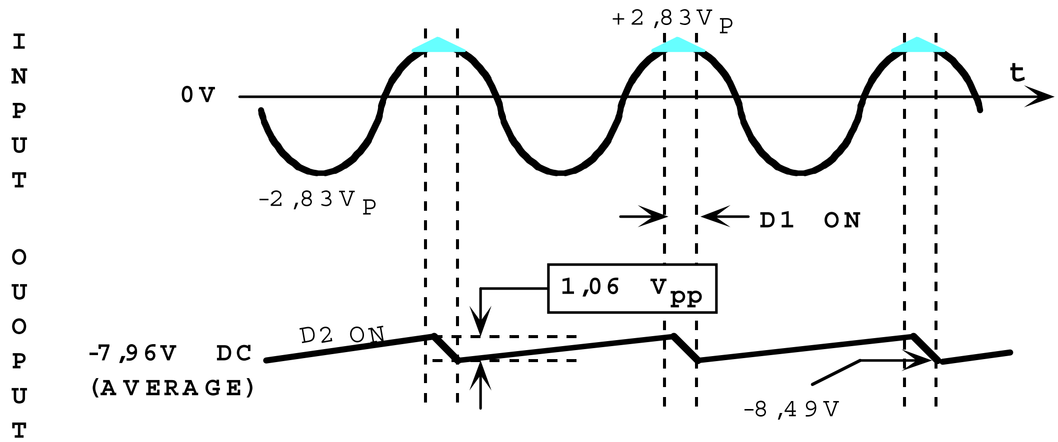

28,3
µAp
300K
Vo
2,83Vp
0V
+ 8,49Vp -
-8,49Vp
28,3
µAp
100K
0A
Vin
+
0,7V
-
ON
OFF
0A
0A
75K
28,3
µAp
0V
Vo - 0,7


0A
300K
0V
0V
Vo
Vin
28,3
µAp
28,3
µAp
ON
0A
100K
-2,83Vp
OFF
- 0,7V +
0A
0A
0A
75K
0V
+0,7V


INPUT
+2,83Vp
0V
t
-2,83Vp
OUOPUT
0V
t
-8,49Vp

N0.6 B)





NOTE: The bottom of the O/P waveform will not be exactly -8,49V in practice.

$\underline{\textit{first iteration}}$

$$\textit{Assume } |V_{o(ave)}| = 8,49V \quad \Rightarrow \quad I_{C(ave)} = \frac{8,49}{100K} + \frac{8,49}{300K} = 113,2\ \mu A$$

$$\Delta V_{o(PP)} = \frac{\Delta Q}{C} = \frac{I_{C(ave)} \times \Delta t}{C} \approx \frac{I_{C(ave)} \times T}{C} = \frac{113,2\ \mu \times 1m}{0,1\mu} = 1,132\,V_{PP}$$

$\underline{\textit{second iteration}}$

$$|V_{o(ave)}| = |V_{o(peak)}| - \frac{\Delta V_{o(PP)}}{2} = 8,49 - \frac{1,132}{2} = 7,924$$

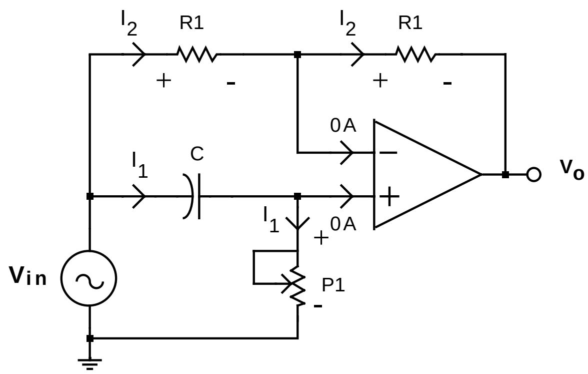
$$I_{C(ave)} = \frac{7,924}{100K} + \frac{7,924}{300K} = 105,65\ \mu A$$

$$\Delta V_{o(PP)} = \frac{I_{C(ave)} \times T}{C} = \frac{105,65\ \mu \times 1m}{0,1\mu} = 1,056\,V_{PP}$$

$\underline{\textit{third iteration (not necessary)}}$

$$|V_{o(ave)}| = 8,49 - \frac{1,056}{2} = 7,96V$$

No.7 **Phase Shifter**



$$V^{+} = V_{in} \times \frac{P_1}{P_1 - jX_C} = V^{-} \qquad I_2 = \frac{V_{in} - V^{-}}{R_1}$$

$$V_o = V^{-} - I_2 R_1 = V^{-} - \left(\frac{V_{in} - V^{-}}{R_1} \right) R_1 = 2V^{-} - V_{in}$$

$$V_o = 2V_{in} \times \frac{P_1}{P_1 - jX_C} - V_{in} = V_{in} \times \left[\frac{2P_1}{P_1 - jX_C} - 1 \right]$$

$$A_{VF} = \frac{V_o}{V_{in}} = \left[\frac{2P_1}{P_1 - jX_C} - 1 \right] = \frac{2P_1 - (P_1 - jX_C)}{P_1 - jX_C}$$

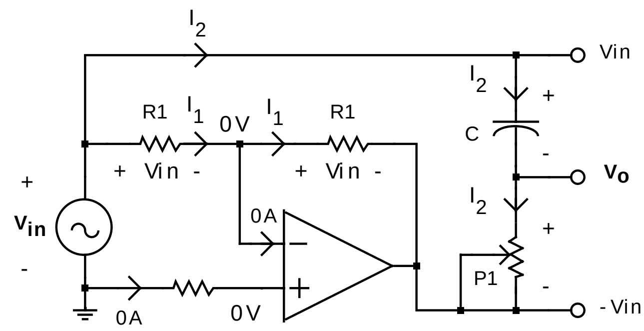
$$A_{VF} = \frac{V_o}{V_{in}} = \frac{P_1 + jX_C}{P_1 - jX_C}$$

$$|A_{VF}| = \frac{\sqrt{P_1^2 + X_C^2}}{\sqrt{P_1^2 + (-X_C)^2}} = 1$$

$$\underline{/A_{VF}} = ATAN\left(\frac{X_C}{P_1} \right) - ATAN\left(\frac{-X_C}{P_1} \right)$$

$$\underline{/A_{VF}} = 2 \times ATAN\left(\frac{X_C}{P_1} \right)$$

No.8 **Phase Shifter**



$$I_2 = \frac{V_{in} - (-V_{in})}{P_1 - jX_C} = \frac{2\,V_{in}}{P_1 - jX_C}$$

$$V_o = -V_{in} + I_2 P_1 = -V_{in} + \left(\frac{2\,V_{in}}{P_1 - jX_C} \right) P_1$$

$$V_o = V_{in} \times \left[-1 + \frac{2P_1}{P_1 - jX_C} \right]$$

$$A_{VF} = \frac{V_o}{V_{in}} = \left[\frac{2P_1}{P_1 - jX_C} - 1 \right] = \frac{2P_1 - (P_1 - jX_C)}{P_1 - jX_C}$$

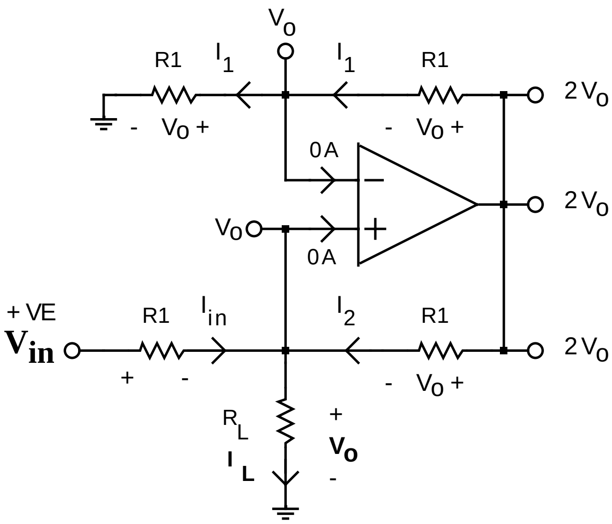
$$A_{VF} = \frac{V_o}{V_{in}} = \frac{P_1 + jX_C}{P_1 - jX_C}$$

$$|A_{VF}| = \frac{\sqrt{P_1^2 + X_C^2}}{\sqrt{P_1^2 + (-X_C)^2}} = 1$$

$$\underline{/A_{VF}} = ATAN\left(\frac{X_C}{P_1} \right) - ATAN\left(\frac{-X_C}{P_1} \right)$$

$$\underline{/A_{VF}} = 2 \times ATAN\left(\frac{X_C}{P_1} \right)$$

No.9 Howland current source

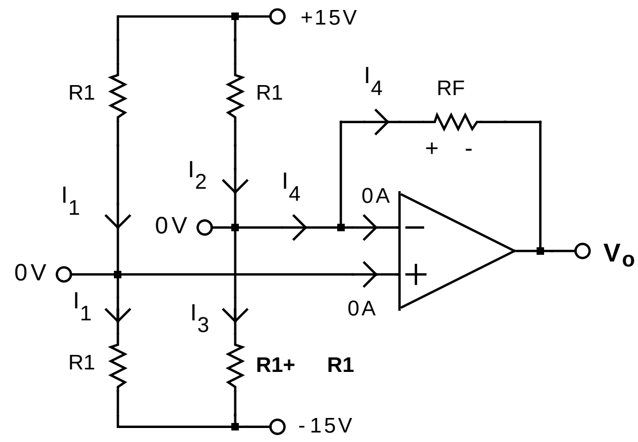


From the circuit diagram, we have:

$$I_L = I_{in} + I_2 = \frac{V_{in} - V_o}{R_1} + \frac{V_o}{R_1}$$

$$I_L = \frac{V_{in}}{R_1} - \frac{V_o}{R_1} + \frac{V_o}{R_1} = \frac{V_{in}}{R_1}$$

No.10 Bridge Amplifier



From the circuit diagram, we have:

$$I_4 = I_2 - I_3$$

$$I_4 = \frac{15}{R_1} - \frac{15}{R_1 + \Delta R_1}$$

$$I_4 = \frac{15R_1 + 15\Delta R_1 - 15R_1}{R_1 \times (R_1 + \Delta R_1)}$$

$$I_4 = \frac{15\Delta R_1}{R_1 \times (R_1 + \Delta R_1)}$$

$$V_o = 0 - I_4 R_F$$

$$V_o = -\left(\frac{15\Delta R_1}{R_1 \times (R_1 + \Delta R_1)}\right) R_F$$

Filename: OPA-ASS
Directory: C:\CLAUDE\ELE-2
Template: C:\WINDOWS\Application Data\Microsoft\Templates\Normal.dot
Title: OPA-AN
Subject: 99FALL
Author: CLAUDE SAURIOL
Keywords:
Comments:
Creation Date: 9/18/00 4:20 PM
Change Number: 2
Last Saved On: 9/18/00 4:20 PM
Last Saved By: ALGONQUIN COLLEGE
Total Editing Time: 1 Minute
Last Printed On: 9/18/00 4:21 PM
As of Last Complete Printing
Number of Pages: 16
Number of Words: 670 (approx.)
Number of Characters: 3,821 (approx.)