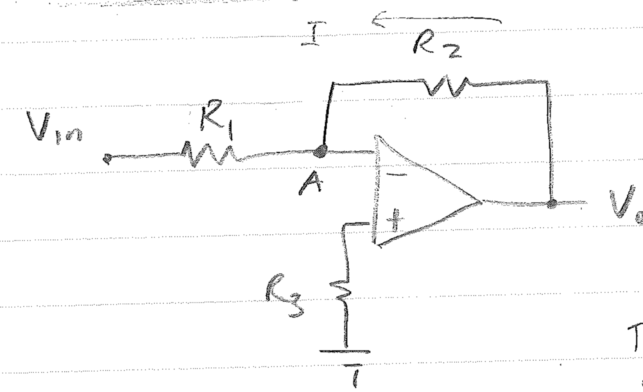
Homework #11 Solutions

6.1)



$R_1 = 10\,k\Omega$

$R_2 = 100\,k\Omega$

$R_3 = 10\,k\Omega$

This is a classic op-amp inverting amp

Use ideal op-amp rules.

No current drawn through R_3

$$\Rightarrow V_A = V_+ = V_- = 0$$

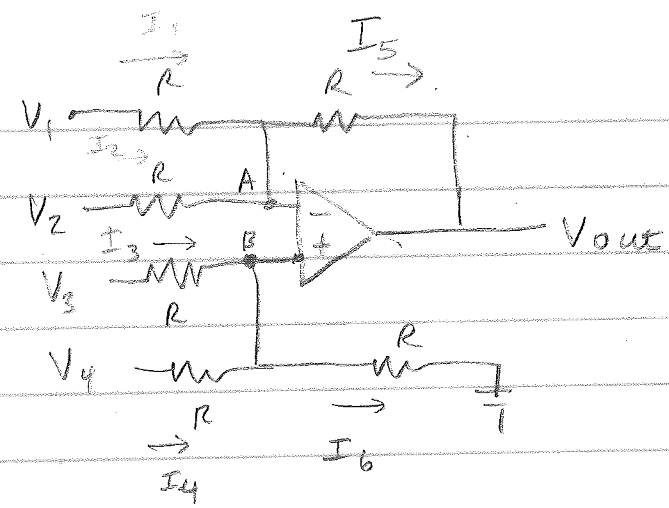
$$\frac{V_{out} - V_A}{R_2} = \frac{-V_{in}}{R_1}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} = -10$$

$$\underline{V_{out} = -10\,V_{in}}$$

$$Z_{in} = \frac{V_{in}}{I_{in}} = \frac{I_{in} R_1}{I_{in}} = R_1 = \underline{10\,k\Omega}$$

6, 2)



Inputs of op-amp draw no current

$I_5 = I_1 + I_2$

$I_6 = I_3 + I_4$

$V_A = V_B$

$$\frac{V_B}{R} = I_6 = \underbrace{\frac{V_3 - V_B}{R}}_{I_3} + \underbrace{\frac{V_4 - V_B}{R}}_{I_4}$$

$$V_B = V_3 - V_B + V_4 - V_B$$

$$3V_B = V_3 + V_4$$

$$\Rightarrow V_B = (V_3 + V_4)/3$$

$$\frac{V_A - V_{out}}{R} = \frac{V_1 - V_A}{R} + \frac{V_2 - V_A}{R}$$

$$V_A - V_{out} = V_1 + V_2 - 2V_A$$

$$\Rightarrow V_{out} = 3V_A - V_1 - V_2 = 3\left(\frac{V_3 + V_4}{3}\right) - (V_1 + V_2)$$

$$\Rightarrow \boxed{V_{out} = (V_3 + V_4) - (V_1 + V_2)}$$

6.4) 741 op-amp with $\pm 15\,V$ power supplies:

For a 741, $V_{sat}^{+} \sim V_{cc}^{+} - 1V = 14V$

$V_{sat}^{-} \sim V_{cc}^{-} + 1V = -14V$

So maximum pp is $\sim \underbrace{\pm 14V}_{\text{max output swing}}$ so $\sim \underline{\underline{28V}}$

$I_{max} = 25\,mA$

at max current

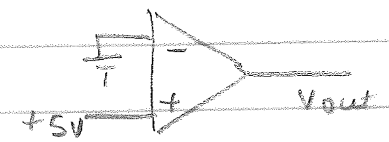
$\Rightarrow$ Min resistor it could drive is

$R_{min} = \dfrac{14\,V}{25\,mA} = \underline{\underline{560\,\Omega}}$

④

Saturation $V_{sat}^{\pm} = \pm 10\,V$

6.5)



<u>Open Loop</u>

$V_{out} = A_{OL}(V_{in}^{+} - V_{in}^{-})$

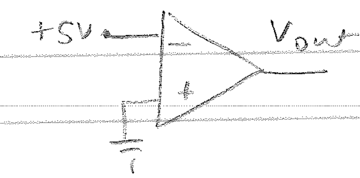
↓

but saturated for ~5V inputs

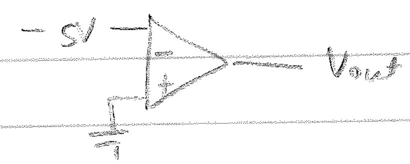
+5V for $V_{in}^{+} > V_{in}^{-}$

−5V for $V_{in}^{+} < V_{in}^{-}$

This has $V_{in}^{+} > V_{in}^{-} \Rightarrow V_{out} = \underline{\underline{+10\,V}}$

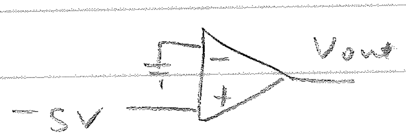


This has $V_{in}^{+} < V_{in}^{-} \Rightarrow V_{out} = \underline{\underline{-10\,V}}$



This has $V_{in}^{+} > V_{in}^{-}$

$\Rightarrow V_{out} = \underline{\underline{+10\,V}}$

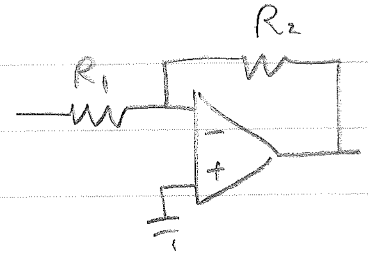


this has $V_{in}^{+} < V_{in}^{-}$

$\Rightarrow V_{out} = \underline{\underline{-10\,V}}$

6.6) Inverting amp w/ $R_1 = 5\,k\Omega$

Gain $= -75$



$$\text{Gain} = -\frac{R_2}{R_1} = -75$$

$$\Rightarrow R_2 = (5\,k\Omega)(75) = \underline{\underline{375\,k\Omega}}$$

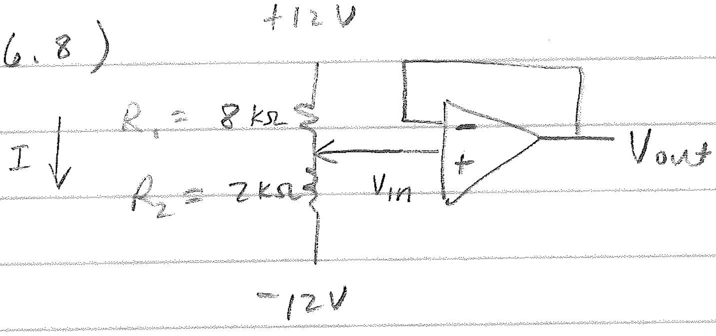
6.7) $V_{CC}^{\pm} = \pm 12\,V$

$V_{sat}^{\pm} \sim \pm 11\,V$ maximum output voltage

So when $V_{in} = \frac{11\,V}{75} = \underline{\underline{147\,mV}}$

6.8)

a)



$V_{in} = V_{out}$ by ideal op-amp rule

$$I = \frac{V_{cc} - V_{in}}{R_1} = \frac{V_{in} + V_{cc}}{R_2}$$

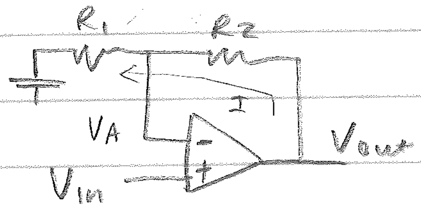
$$V_{in}\left(\frac{1}{R_2} + \frac{1}{R_1}\right) = \frac{V_{cc}}{R_1} - \frac{V_{cc}}{R_2}$$

$$V_{in} = V_{cc}\left(\frac{R_2 - R_1}{R_1 R_2}\right)\left(\frac{R_1 R_2}{R_2 + R_1}\right) = V_{cc}\left(\frac{R_2 - R_1}{R_2 + R_1}\right)$$

$$= 12\left(-\frac{6\,k\Omega}{10\,k\Omega}\right) = -7.2\,V$$

$$\Rightarrow V_{out} = \underline{\underline{-7.2\,V}}$$

b)



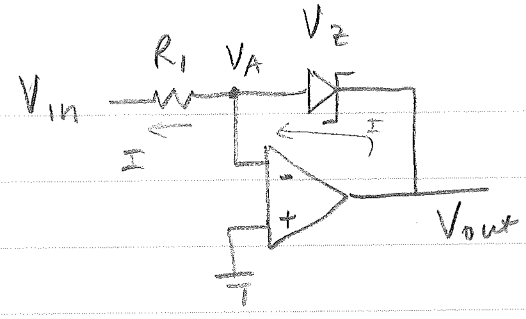
$V_{in} = +1V$
$R_1 = 1\,k\Omega$
$R_2 = 10\,k\Omega$

$$V_A = V_{in} = +1V$$

$$\frac{V_{out} - V_A}{R_2} = \frac{V_A}{R_1}$$

$$V_{out} = \frac{R_2}{R_1} V_A + V_A = 10 \cdot V_A + V_A = \underline{\underline{11\,V}}$$

c)



$V_{in} = -3V$
$R_1 = 1k\Omega$
$V_z = 6.2V$

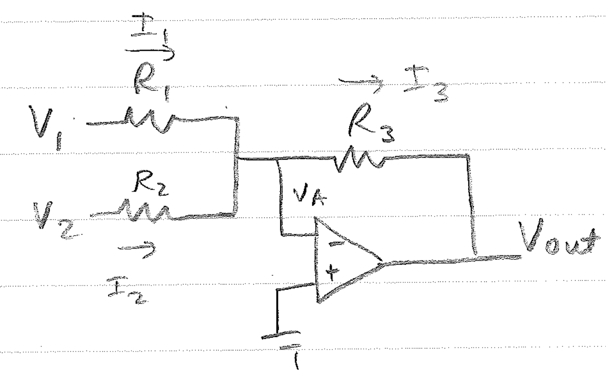
$V_A = 0$ (virtual ground)

$V_{out} = V_Z$ so long as zener is in breakdown mode

If $V_{in} = -3V$, $I = \frac{3V}{1k\Omega} = 3mA$ to left → should be going through zener

$\Rightarrow V_{out} = V_z = \underline{\underline{6.2V}}$

d)



$R_1 = 2k\Omega$
$R_2 = 2k\Omega$
$R_3 = 1k\Omega$
$V_1 = 1V$
$V_2 = 2V$

$I_1 + I_2 = I_3$

$$V_A = 0 \Rightarrow -\frac{V_{out}}{R_3} = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$

$$V_{out} = -1k\Omega\left(\frac{1V}{2k\Omega} + \frac{2V}{2k\Omega}\right)$$

$$= -1(0.5 + 1)$$

$$V_{out} = \underline{\underline{-1.5V}}$$