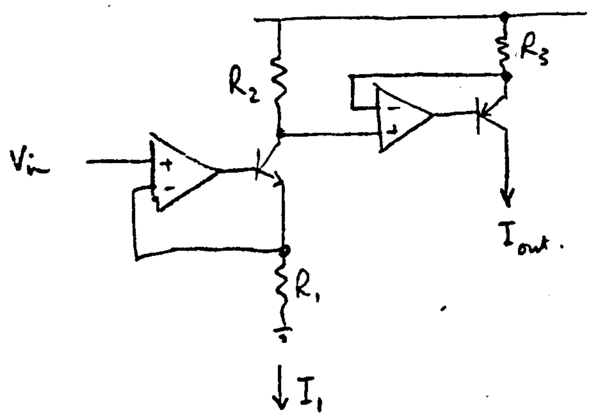
CH 4 SOLUTIONS

OP AMPS

CHAPTER 4 PROBLEMS

3.1



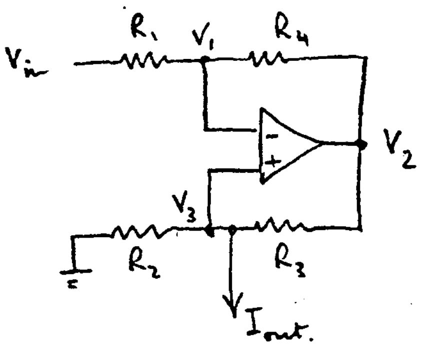
$$I_1 = \frac{V_{in}}{R_1}$$ since + & − inputs are at same potential.

Voltage across $R_2 = V_{R_2} = I_1 R_2$

$$I_{out} = \frac{V_{R_2}}{R_3} \quad \text{(as above)}$$

$$I_{out} = \frac{I_1 R_2}{R_3} = \frac{V_{in} R_2}{R_1 R_3}$$

3.2



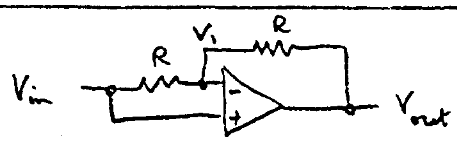
when op amp is balanced $V_1 = V_3$

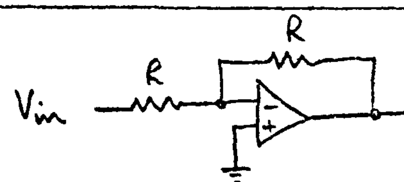
$$\frac{V_{in} - V_1}{R_1} = \frac{V_1 - V_2}{R_4}$$

$$I_{out} + \frac{V_1}{R_2} = \frac{V_2 - V_1}{R_3} = \left(\frac{V_1 - V_{in}}{R_3}\right)\frac{R_4}{R_1}$$

$$\frac{R_4}{R_3 R_1} = \frac{1}{R_2} \text{ by choice} \Rightarrow I_{out} + \frac{V_1}{R_2} = \left(\frac{V_1 - V_{in}}{R_2}\right) \Rightarrow I_{out} = \frac{-V_{in}}{R_2}$$

3.3 a)



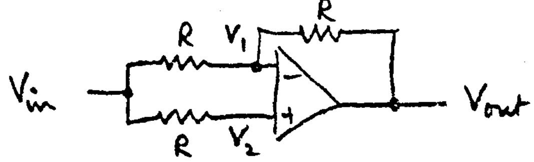


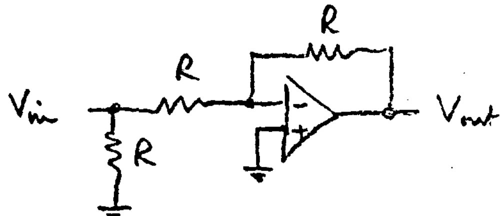
$V_1 = V_{in}$ balance

$$\left.\frac{V_{in} - V_1}{R} = \frac{V_1 - V_{out}}{R}\right\} \Rightarrow V_{out} = V_{in}$$

$$\frac{V_{in}}{R} = \frac{-V_{out}}{R} \Rightarrow V_{out} = -V_{in}$$

b)





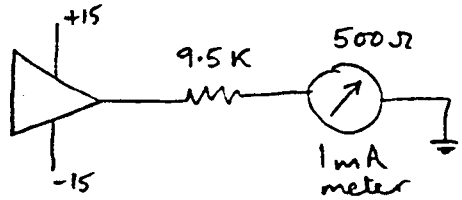
$V_1 = V_2$ balance

$V_{in} = V_2$ assuming no bias current

$$\left.\frac{V_{in} - V_1}{R} = \frac{V_1 - V_{out}}{R}\right\} \Rightarrow V_{out} = V_{in}$$

As above: $V_{out} = -V_{in}$

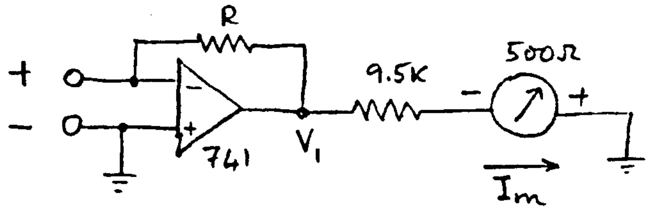
3.4 Use the following trick to ensure that the maximum overload is < ± 150%



Max output of op amp is ± 13 V (typical value).

$\Rightarrow$ max current is $\frac{\pm 13\,V}{10K} = \pm 1.3\,mA$

Now construct the ammeter:



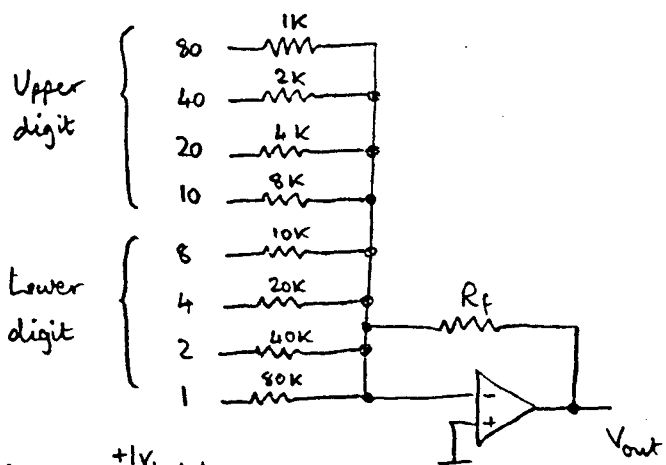
Voltage between inputs = 0 for perfect op amp.

Want to choose R so that $I_m = -1$ mA when $I_{in} = 5$ mA

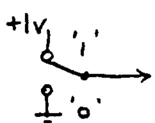
$$V_1 = 10K \times I_m = -R\,I_{in}$$

$$R = -10K\,\frac{I_m}{I_{in}} = -10K\,\frac{-1}{5} = 2.0\,K\Omega$$

3.5



Each input is:



Choice of R_f:

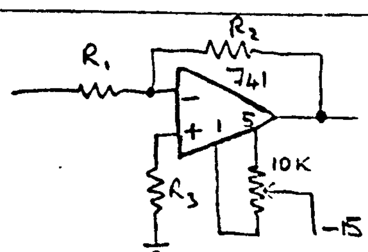
Want $V_{out} = -9.9$ V for digital input of '99'.

Thus 0.1 V is the required increase in V_{out} per digit.

Voltage gain for '10' input is therefore −1.0

$\Rightarrow R_f = 8K\Omega$

3.6

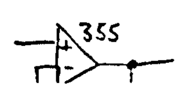


$Z_{in} = R_1 = 10K$ by choice

$$\text{Gain} = \frac{-R_2}{R_1} = -100 \Rightarrow R_2 = 1M\Omega$$

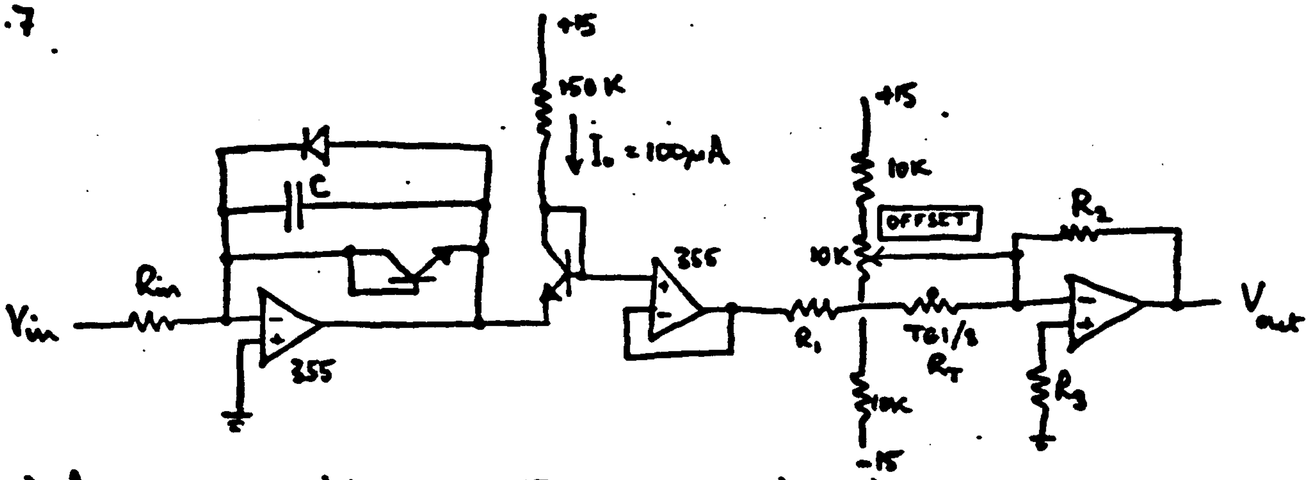
$R_3 = R_1 \| R_2 = 10K$

Add follower on input



$Z_{in} > 100\,M\Omega$

3.7



a) A simple resistor to +15 V is an adequate current source as the required compliance range is very small.

b) Want combined resistance of $R_T + R_1$ to have a tempco of $\frac{1}{300}$ = 0.33% degree^{-1}. Then the gain will have the same tempco

$$\left.\begin{aligned} R &= R_1 + R_T \\ \frac{\Delta R}{\Delta T} &= \alpha R_T \end{aligned}\right\} \qquad \frac{1}{R}\frac{\Delta R}{\Delta T} = \frac{\alpha R_T}{R_1 + R_T} = 0.33\%$$

(α = temperature coefficient)

α = 0.7%
R_T = 2.7 K (308K)
⇒ R_1 = 2.4K

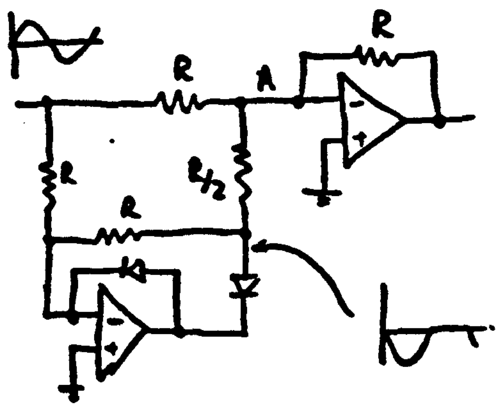
$R = R_1 + R_T$ = 5.1 K with the desired .33% tempco.

Want gain of final stage to be $\frac{1\text{ V decade}^{-1}}{-60\text{mV decade}^{-1}} = -16.7$

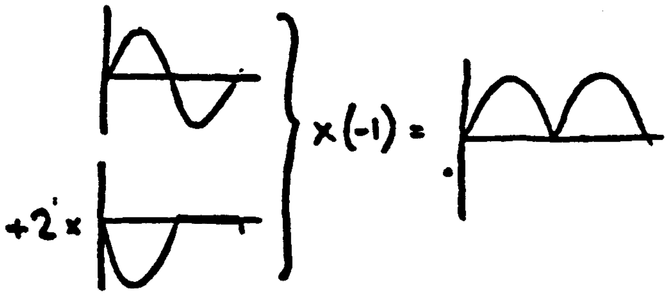
⇒ R_2 = 16.7 × R = 82K

⇒ R_3 = 82K ‖ 5.1K ‖ 15K ‖ 15K ≃ 3 KΩ.

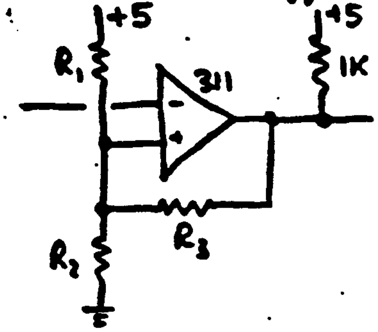
3.8



Summation of signals at A:



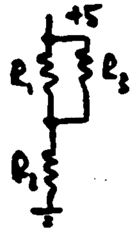
3.9 Schmitt Trigger:



Lower threshold

$$V_L = \frac{5\,(R_2 \| R_3)}{R_1 + (R_2 \| R_3)} = 1.0$$

Upper threshold



$$V_U = \frac{5\,(R_2)}{R_2 + (R_1 \| R_3)} = 1.5$$

assuming $R_3 \gg 1K$

(It is always hard to avoid a lot of math with these problems!)

$$\frac{R_2 R_3}{R_2 + R_3} = 0.2\left[R_1 + \frac{R_2 R_3}{R_2 + R_3}\right] \Rightarrow 0.8\,\frac{R_2 R_3}{R_2 + R_3} = 0.2\,R_1 \quad (1)$$

$$R_2 = 0.3\left[R_2 + \frac{R_1 R_3}{R_1 + R_3}\right] \Rightarrow R_2 = \frac{1}{0.7}\left(\frac{R_1 R_3}{R_1 + R_3}\right) \Rightarrow \frac{1}{R_2} = 0.7\left(\frac{1}{R_1} + \frac{1}{R_3}\right)$$

Substitute into (1):

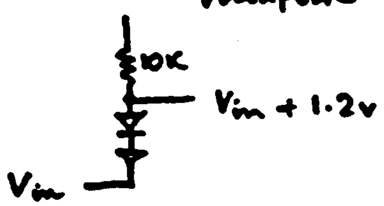
$$4 = R_1\left(\frac{1}{R_2} + \frac{1}{R_3}\right) = R_1\left(0.7\left(\frac{1}{R_1} + \frac{1}{R_3}\right) + \frac{1}{R_3}\right) = 0.7 + 1.7\,\frac{R_1}{R_3}$$

$3.3 = 1.7\,\frac{R_1}{R_3}$ Choose $R_3 = 22K \Rightarrow R_1 = 43K \Rightarrow R_2 = 20K$

Math-saving trick (exam questions only!):

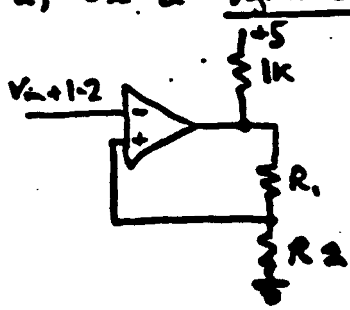
i) shift level to centre of output swing

Here: midpoint of threshold = 1.25 V; midpoint of output = 2.5 V } shift up 1.25V.



or use an op. amp level shifter

ii) Use a <u>symmetric</u> schmitt trigger. Here:



Want hysteresis = 0.5V

$$\Rightarrow \frac{R_2}{R_1 + R_2} = \frac{0.5\,V}{5\,V}$$

$R_1 = 18K$
$R_2 = 2K$

3.10 Gain = $\left(1 + \frac{27.8K}{R_1}\right)(-1)$

Variable gain set to max.

	1st Stage	2nd stage.	
Scale	R_1	Gain	
0 dB	∞	−1	1
10	13.0K	−3.14	$\sqrt{10}$
20	3.09K	−10.0	10
30	909Ω	−31.6	$10\sqrt{10}$
40	280Ω	−100.3	100

b) +5v reference → potential divider → 0–5v variable → ×2 amplifier → optional inverter ('offset pol')

±10v variable added with equal weight (equal R_{in}) at summing (−) input of IC_2.

3.12 Input presented at − pin of IC_1 is $\frac{4.7}{44+4.7} V_{in} = 0.1 V_{in}$

DC voltage added to input at − pin is $\frac{R_3}{R_4} = \frac{4.7K}{10M} \times 5 = 2.5mV$ (when input is near zero)

Hysteresis $\left(\frac{R_6}{R_5}\right)$ = $\begin{cases} \frac{4.7K}{4.7M} \times 5v = +5mV. \text{ (upper)} \\ \frac{4.7K}{4.7M} \times 0v = 0 \text{ (lower)} \end{cases}$

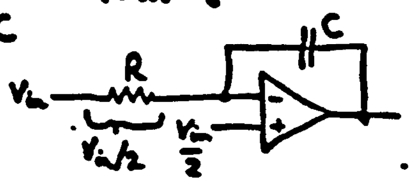
Thus thresholds are ±2.5mV to signals at the − pin

÷(0.1) → ±25mV to signals at the input.

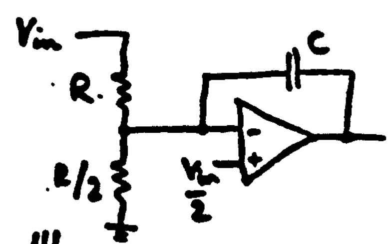
3.11 Rate of change of voltage at integrator output

$= \pm \frac{V_{in}/2}{RC}$ volts s^{-1}

Switch open:



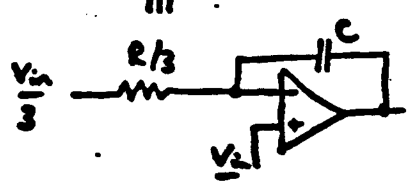
Switch closed:



Rate (open) = $\frac{V_{in} - \frac{V_{in}}{2}}{RC} = \frac{V_{in}/2}{RC}$.

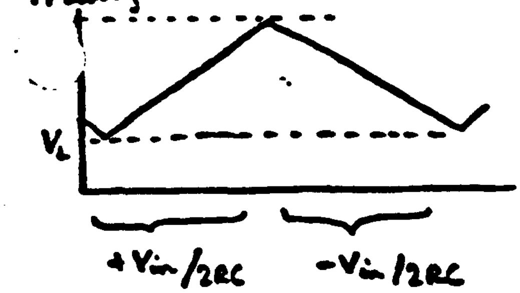
Rate (closed) = $\frac{\left(\frac{V_{in}}{3} - \frac{V_{in}}{2}\right)}{\frac{R}{3}C} = \frac{-V_{in}/2}{RC}$.

≡

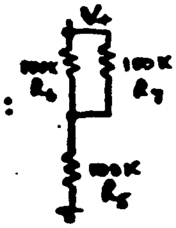


(3.11 contd.)

Triangle out:

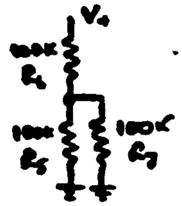


V_U :



$V_U = \frac{2}{3} V_+$

V_L



$V_L = \frac{1}{3} V_+$

Time for up transition $= (V_U - V_L) \cdot \left(\frac{2RC}{V_{in}}\right)$

Time for down transition $= (V_L - V_U) \cdot \left(\frac{-2RC}{V_{in}}\right)$

} Period, $T = \frac{4RC}{V_{in}} (V_U - V_L) = \frac{4RCV_+}{3V_{in}}$

$\Rightarrow$ Frequency $f = \frac{1}{T} = \frac{3V_{in}}{4RCV_+} = \frac{3}{4 \times 10^5 \times 5 \times 10^{-8}} \frac{V_{in}}{V_+} = 150 \frac{V_{in}}{V_+}$ here.

CHAPTER 3 BAD CIRCUITS

Adj. clamp : no current limit on diode.

✓ AC. ×10 amp : no path for bias current to + input.

✓ ⋀⋁ generator : no drift protection on integrator — needs large resistor.

✓ Current source : circuit here is a current limited <u>voltage</u> source.

✓ DC amplifier : wrong input polarities

200 mA current source : zener circuit will not provide enough current
Should replace 260Ω with < 50Ω.

Op amp output stage : must bias the − input at a voltage near the quiescent point of the first stage output (7.5V).

Schmitt trigger : wrong input polarities.

+15V regulator : op amp output has to be ·6V <u>above</u> V_+.

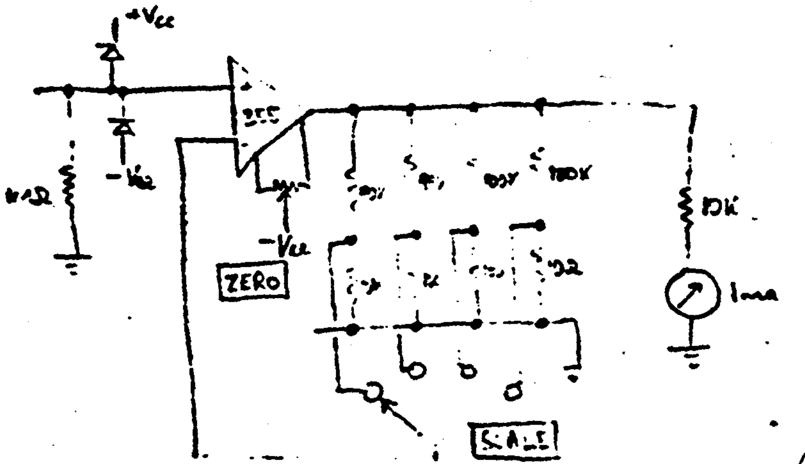
×10 Audio amp : output quiescent point is 0V, can't swing negative

DC Amplifier : Z_{in} of buffer stage = 1K severely loads range divider. Should use non-inverting configuration

Zero crossing detector : unprotected input (!)

+15V regulator : V_+ is too low.

CHAPTER 3 ADDITIONAL EXERCISES.



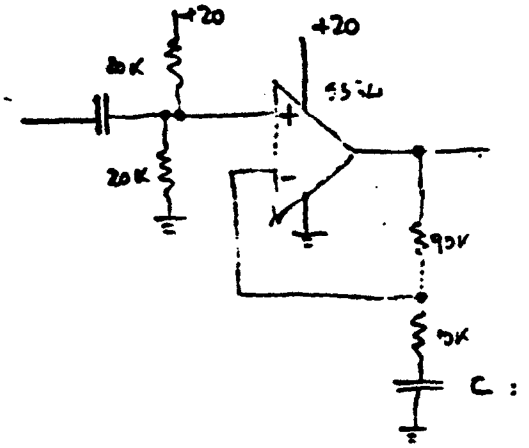
SORRY!

[illegible] current on '–' input [illegible] 30μV [illegible]

[illegible] of [illegible] Z [illegible]

This is read at the output.

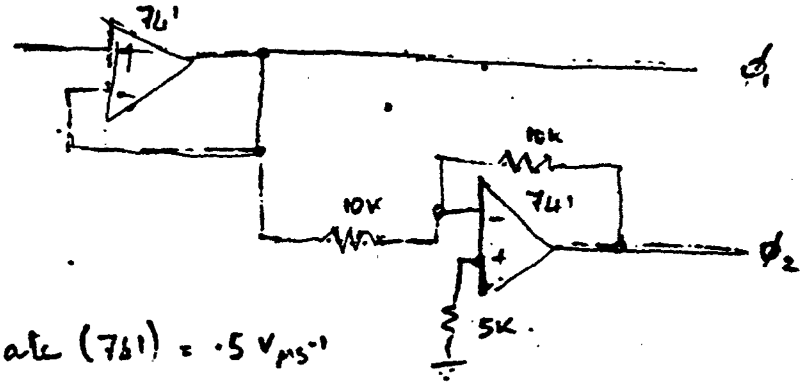
AE2



$$\frac{1}{2\pi CR} = f_0$$

$$C = \frac{1}{2\pi f_0 R} = \frac{1}{[illegible]} = 1\mu F$$

AE3

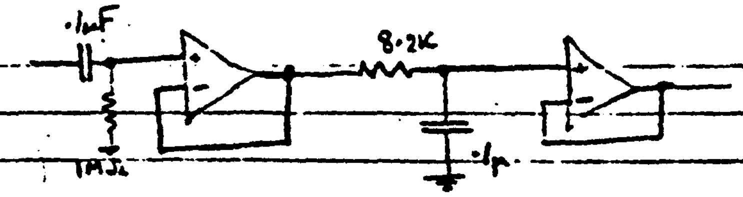


· slew rate (741) = ·5 $V\mu s^{-1}$

27 V_{pp} sine wave slews at $27\pi f$ = ·5 $V\mu s^{-1}$

→ f . ·5

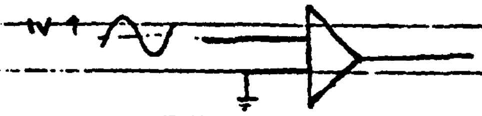
AE4

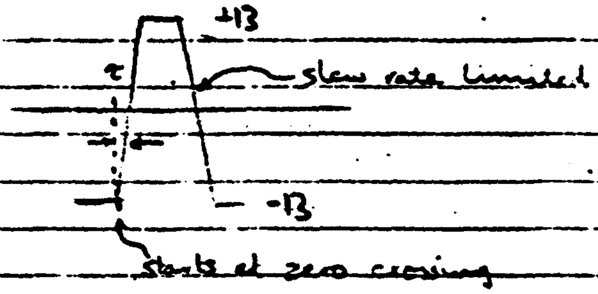


$$RC = \frac{1}{2\pi \cdot 2K} = \cdot 8 \times 10^{-3}$$

$$R = \frac{\cdot 8 \times 10^{-3}}{\cdot 1 \times 10^{-6}} = 8 \times 10^{3}$$

AE5:



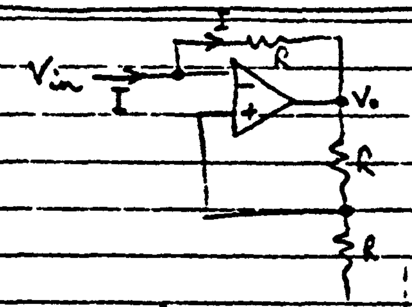


$$\tau = 13V / \cdot 5V\mu s^{-1} = 26\mu s$$

1KHz: sine wave slews at $2\pi Af\ Vs^{-1} = 2\pi . 1 . 10^{3}\ Vs^{-1}$

in 26μs input has risen $2\pi\ 10^{3} \times 26 \times 10^{-6}\ V = 170 \times 10^{-3} V = \cdot 17V$

AE6 a)



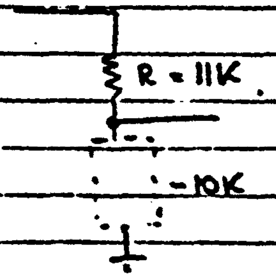
$$V_{in} = \frac{V_o}{2} \quad (1)$$

$$I = \frac{V_{in} - V_o}{R} = \frac{V_{in} - 2V_{in}}{R} = -\frac{V_{in}}{R}$$

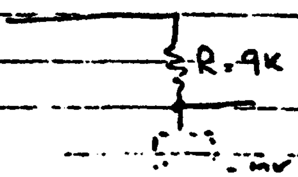
$$Z = \frac{V_{in}}{I} = -R$$

b) $\frac{V_-}{2} < V_{in} < \frac{V_+}{2}$ tolerated (from (1))

AE7

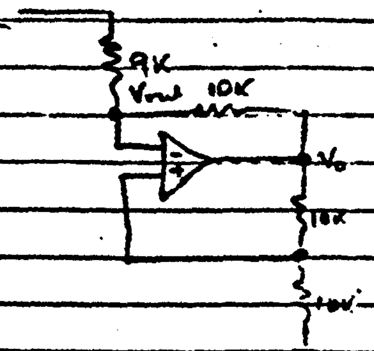


$$G = \frac{-10}{R-10} = -10$$



$$G = \frac{-10}{R-10} = +10\ ?$$

Consider



Start at $V_{in} = 0$ and $V_{out} = 0$.

$V_o = 0$

$V_{in} \uparrow$, $V_o \downarrow\downarrow$ (polarity of op amp)

$\Rightarrow V_{out} \downarrow$ double +ve feedback situation

unstable

Feedback here is the wrong sense for stable operation.
$V_{in} = 0$ is a point of unstable equilibrium, from which op amp output will move to saturation

(end CH. 4 (old 3)
(op amp)
SOLUS)