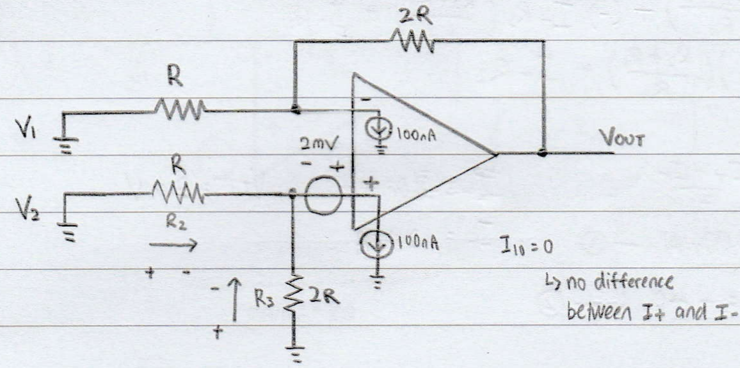
Esmund Lim AE Tutorial 2

1) Difference Amplifier with a gain of 2 $\left(\frac{R_F}{R_I}\right)$



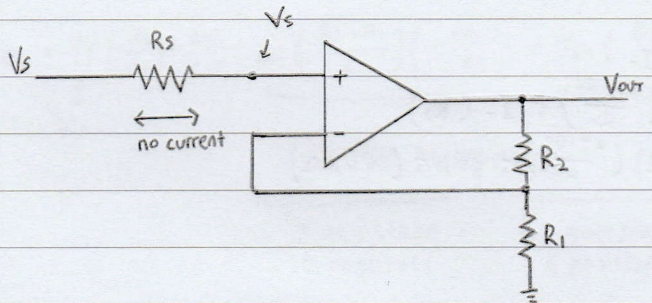
* Difference amplifier (Pg 43)
= scaling subtractor

$R_F = R_3$ $\quad R_I = R_2$

$$\begin{aligned}
V_{OUT} &= V_{OUT}|_{V_{IO}} + V_{OUT}|_{I_+} + V_{OUT}|_{I_-} \\
&= V_{IO}\left(\frac{2R+R}{R}\right) + (-)\, I_+ (2R // R)\left(\frac{2R+R}{R}\right) + I_-(2R) \\
&= V_{IO}\left(\frac{2R+R}{R}\right) - I_+\left(\frac{2R\,(R)}{\cancel{2R+R}}\right)\left(\frac{\cancel{2R+R}}{\cancel{R}}\right) + I_-(2R) \\
&= V_{IO}\left(\frac{2R+R}{R}\right) - I_+(2R) + I_-(2R) \\
&= V_{IO}\left(\frac{2R}{R} + \frac{R}{R}\right) - I_+(2R) + I_-(2R) \\
&= V_{IO}(2+1) - I_+(2R) + I_-(2R) \\
&= V_{IO}(3) - 100nA(2R) + 100nA(2R) \\
&= V_{IO}(3) \\
&= 2mV(3) \\
&= 6mV
\end{aligned}$$

2)

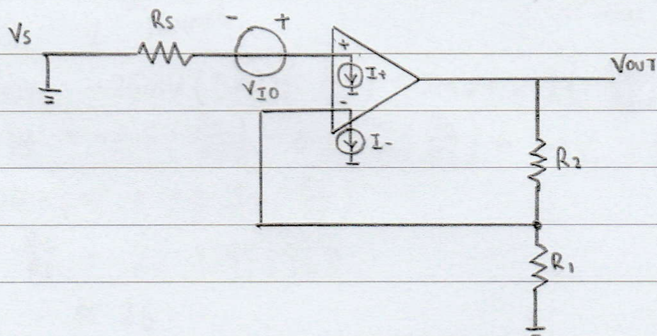
a)



op-amp is ideal

$$V_{OUT} = V_s\left(\frac{R_2+R_1}{R_1}\right)$$

b)



$$\begin{aligned}
V_{OUT} &= V_{IO}\left(\frac{R_2+R_1}{R_1}\right) + (-)\, I_+ (R_s)\left(\frac{R_2+R_1}{R_1}\right) + I_-(R_2) \\
&= V_{IO}\left(\frac{R_2+R_1}{R_1}\right) - I_+ R_s\left(\frac{R_2+R_1}{R_1}\right) + I_- R_2
\end{aligned}$$

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c) $V_{OUT} = V_{OUT}|_{V_S} + V_{OUT}|_{V_{IO}} + V_{OUT}|_{I+} + V_{OUT}|_{I-}$

$= V_S\left(\frac{R_2+R_1}{R_1}\right) + V_{IO}\left(\frac{R_2+R_1}{R_1}\right) + (-)\, I_+ R_S\left(\frac{R_2+R_1}{R_1}\right) + I_- R_2$

$= (V_S + V_{IO} - I_+ R_S)\left(\frac{R_2+R_1}{R_1}\right) + I_- R_2$

d) $R_1 = 25\,k\Omega$ $\quad I_{BIAS} = \frac{I_+ + I_-}{2}$ $\quad I_+ = 80\,nA$ $\quad V_{IO} = 2\,mV$

$R_2 = 100\,k\Omega$ $\quad = 100\,nA$ — ① $\quad I_- = 120\,nA$

$I_+ - I_- = -40\,nA$ — ②

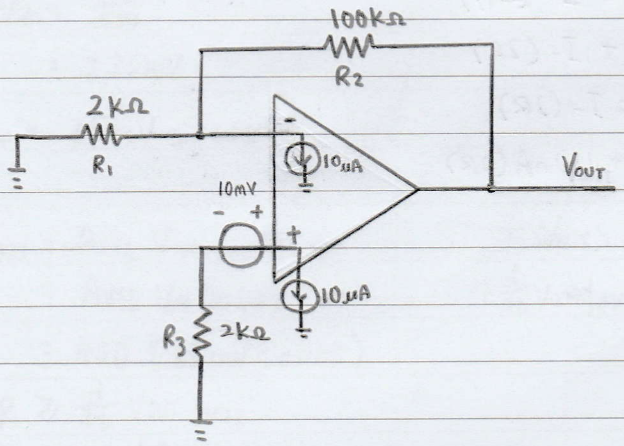
$V_{OUT} = V_{IO}\left(\frac{R_1+R_2}{R_1}\right) - I_+ R_S\left(\frac{R_2+R_1}{R_1}\right) + I_- R_2$

$0 = 2\,mV\left(\frac{25\,k\Omega + 100\,k\Omega}{25\,k\Omega}\right) - 80\,nA\,(R_S)\left(\frac{100\,k\Omega + 25\,k\Omega}{25\,k\Omega}\right) + 120\,nA\,(100\,k\Omega)$

$4\times10^{-7} R_S = 0.022$

$R_S = 55\,k\Omega$

3)



slew rate = 1 V / μs

↳ not used in this question as this question is for DC component and slew rate is for AC signal that is moving

$V_{OUT} = V_{OUT}|_{V_{IO}} + V_{OUT}|_{I+} + V_{OUT}|_{I-}$

$= V_{IO}\left(\frac{R_1+R_2}{R_1}\right) + (-)\, I_+ (R_3)\left(\frac{R_1+R_2}{R_1}\right) + I_- (R_2)$

$= 10\,mV\left(\frac{2+100}{2}\right) + (-)\, 10\,\mu A\,(2\,k\Omega)\left(\frac{2+100}{2}\right) + 10\,\mu A\,(100\,k\Omega)$

$= 0.49\,V$

$= 490\,mV$

↳ The output has a dc voltage of 490 mV caused by the non-ideal input source

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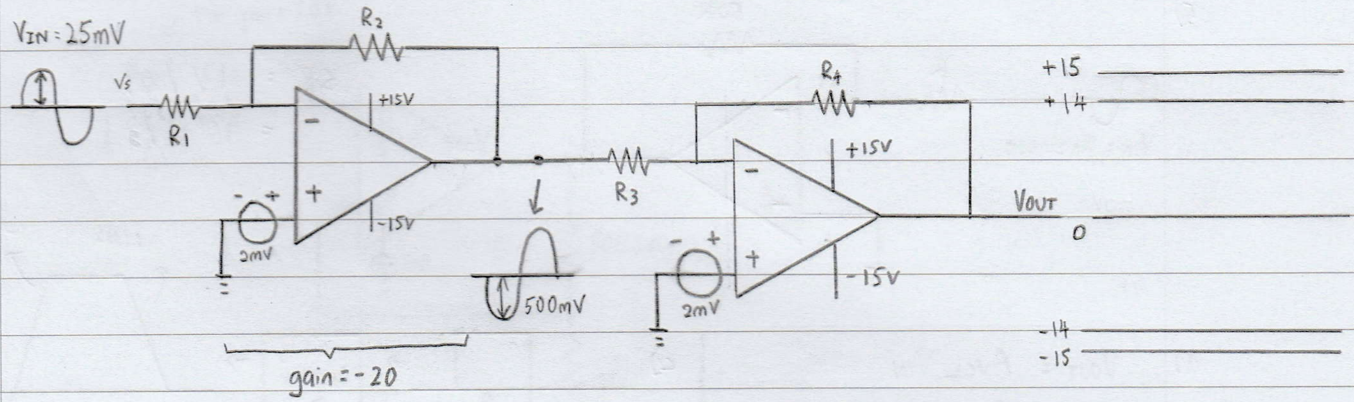
4) 

a) $$V_{OUT} = V_{OUT}|V_s + V_{OUT}|V_{IO} + V_{OUT}|V_{In}$$
$$= V_s\left(-\frac{R_2}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + V_{IO}\left(\frac{R_1+R_2}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + V_{IO}\left(\frac{R_3+R_4}{R_3}\right)$$

$$V_{OUT1} = V_s\left(-\frac{R_2}{R_1}\right) + V_{IO}\left(\frac{R_1+R_2}{R_1}\right)$$
$$V_{OUT2} = V_s\left(-\frac{R_2}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + V_{IO}\left(\frac{R_2+R_1}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + V_{IO}\left(\frac{R_3+R_4}{R_3}\right)$$
$$= V_s\left(\frac{R_2R_4}{R_1R_3}\right) - V_{IO}\left(\frac{R_1+R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right) + V_{IO}\left(\frac{R_3+R_4}{R_3}\right)$$
$$= V_s\left(\frac{R_2R_4}{R_1R_3}\right) + V_{IO}\left[\left(\frac{R_1+R_2}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + \frac{R_3+R_4}{R_3}\right]$$
$$= V_s\left(\frac{R_2R_4}{R_1R_3}\right) + V_{IO}\left[\frac{R_1}{R_1}\left(-\frac{R_4}{R_3}\right) + \frac{R_2}{R_1}\left(-\frac{R_4}{R_3}\right) + \frac{R_3}{R_3} + \frac{R_4}{R_3}\right]$$
$$= V_s\left(\frac{R_2R_4}{R_1R_3}\right) + V_{IO}\left[-\frac{R_4}{R_3} - \frac{R_2R_4}{R_1R_3} + 1 + \frac{R_4}{R_3}\right]$$
$$= V_s\left(\frac{R_2R_4}{R_1R_3}\right) + V_{IO}\left[1 - \frac{R_2R_4}{R_1R_3}\right]$$
$$= V_s\left(\frac{R_2R_4}{R_1R_3}\right) + V_{IO} - V_{IO}\left[\frac{R_2R_4}{R_1R_3}\right]$$
$$= \frac{R_4}{R_3}\left[\frac{R_2}{R_1}V_s - \frac{R_2}{R_1}V_{IO}\right] + V_{IO}$$

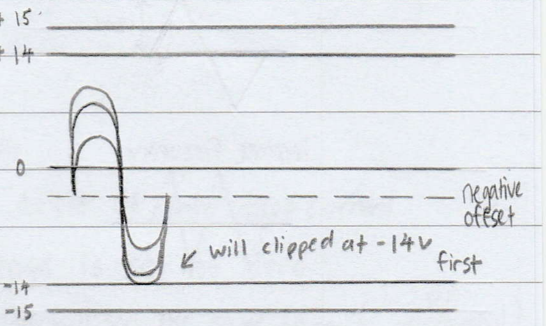
b) $$V_{OUT} = \underset{\downarrow}{V_s}\left(-\frac{R_2}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + \underbrace{V_{IO}\left(\frac{R_2+R_1}{R_1}\right)\left(-\frac{R_4}{R_3}\right) + V_{IO}\left(\frac{R_3+R_4}{R_3}\right)}_{\text{DC component}}$$

Vin

2 gain stage (negative)

1 gain stage (positive)

net value = negative DC offset



negative because inverted

$$V_{OUT} = -25mV(-20)\left(-\frac{R_4}{R_3}\right) + 2mV(21)\left(-\frac{R_4}{R_3}\right) + 2mV\left(1+\frac{R_4}{R_3}\right)$$
$$-14 = -0.5\left(\frac{R_4}{R_3}\right) - 0.042\left(\frac{R_4}{R_3}\right) + 2mV + 0.002\left(\frac{R_4}{R_3}\right)$$
$$-14 - 2mV = -0.54\left(\frac{R_4}{R_3}\right)$$
$$\frac{R_4}{R_3} = 25.92962963$$
$$\approx 26$$

$\therefore$ second-stage gain = 26 V/V

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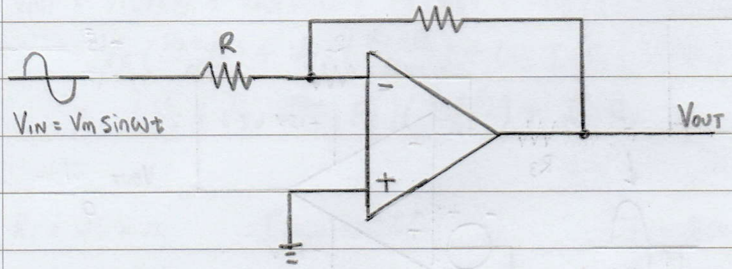
5)



$SR = 1V/\mu s$
$= 10^6 V/s$

a) $V_{OUT} = A_{VCL} V_{IN}$

$= A_{VCL} V_m \sin\omega t$

$\frac{d}{dt} V_{OUT} = \omega A_{VCL} V_m \underbrace{\cos\omega t}_{max=1}$

$SR = \left|\frac{d}{dt} V_{OUT}\right|_{max}$

$= \omega A_{VCL} V_m (1)$

$SR \geq \frac{d}{dt} V_{OUT}|_{max}$

$SR \geq \omega A_{VCL} V_m$

$\omega_{max} = \frac{SR}{A_{VCL} V_m}$ (max frequency that the signal can go through without distortion)

$f = \frac{\omega}{2\pi}$

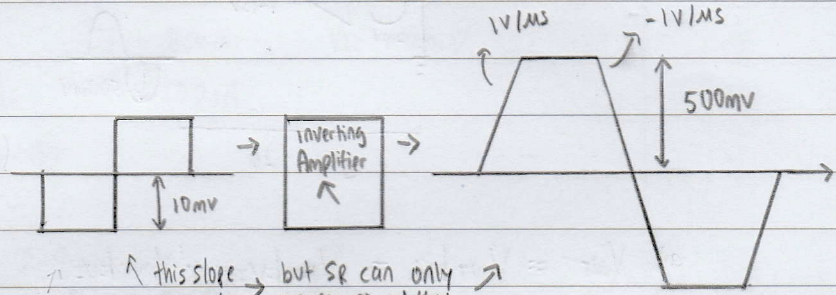
$f_{max} = \frac{SR}{2\pi A_{VCL} V_m}$

$= \frac{10^6 V/s}{2\pi (50)(10mV)}$

$= 318.3098862 \times 10^3$ Hz

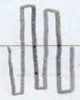
$= 318$ kHz

c)

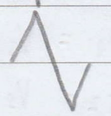


this slope is infinite → but SR can only process signal that is lower than 1V/μs

* if frequency increase



output



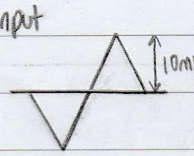
end up triangle wave

frequency = answer in part B 500KHz

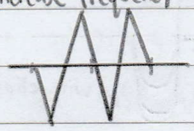
increase beyond this → amplitude drop

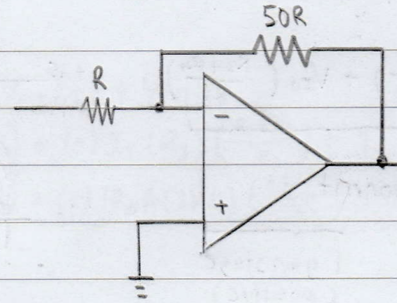
input → output not linear related

b) input

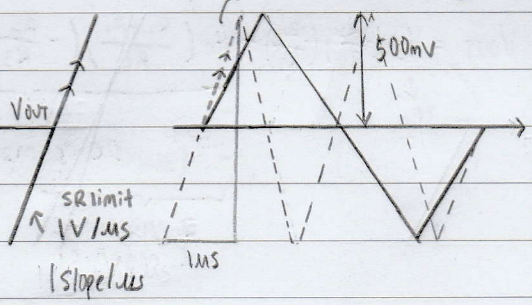


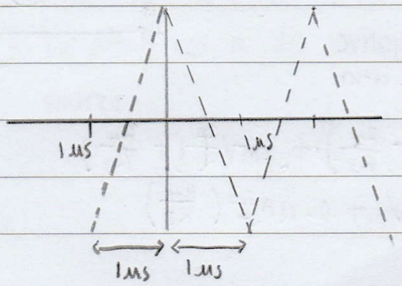
increase frequency





once it is parallel with SR slope reached SR limitation (maximum without distortion)





$f = \frac{1}{T}$

$= \frac{1}{2\mu s}$

$= 500$KHz

$f \leq 500$kHz

sine wave = 318kHz

triangle wave = 500kHz

why?

Sine wave zero crossing a lot steeper than triangle wave

∴ triangle wave can move on to a higher frequency

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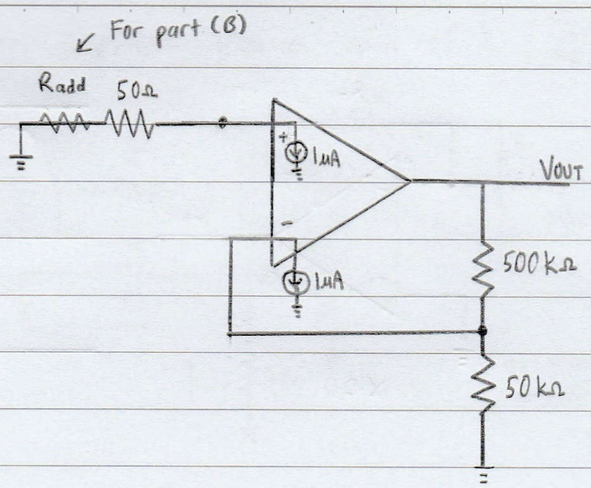
6)



$V_{OUT}|_{DC} = V_{OUT}|_{I+} + V_{OUT}|_{I-}$

$= -I_+(50\Omega)(11) + I_-(500k\Omega)$

$= -1\mu A(50)(11) + 1\mu A(500k\Omega)$

$= 0.49945V$

$= 499.45mV$

b) $V_{OUT}|_{DC} = V_{OUT}|_{I+} + V_{OUT}|_{I-}$

$0 = -I_+(R_{add}+50)(11) + I_-(500k\Omega)$

$= -1\mu A(R_{add}+50)(11) + 1\mu A(500k\Omega)$

$= \left[-1\mu A\, R_{add} + \left(-\frac{1}{20000}\right)\right](11) + 0.5$

$1.1\times10^{-5}\, R_{add} = -\frac{11}{20000} + 0.5$

$R_{add} = 45404.54545\Omega$

$= 45.4\, k\Omega$

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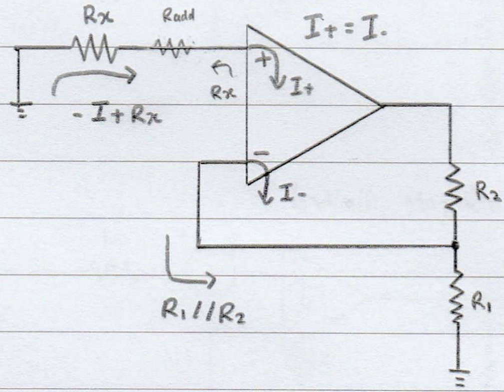

if $R_x = R_1 // R_2$

cancels the effect of input bias current

Input voltage is set to zero

↳ Both end will see the same thing (no input differential)

$V_+ = V_-$ $\quad V_+ - V_- = 0$ $\quad \therefore$ output = 0

if and only if $I_+ = I_-$

$50 + R_{add} = R_1 // R_2$

$R_{add} = R_1 // R_2 - 50$

$= 50k\Omega // 500k\Omega - 50$

$= 45.4k\Omega$

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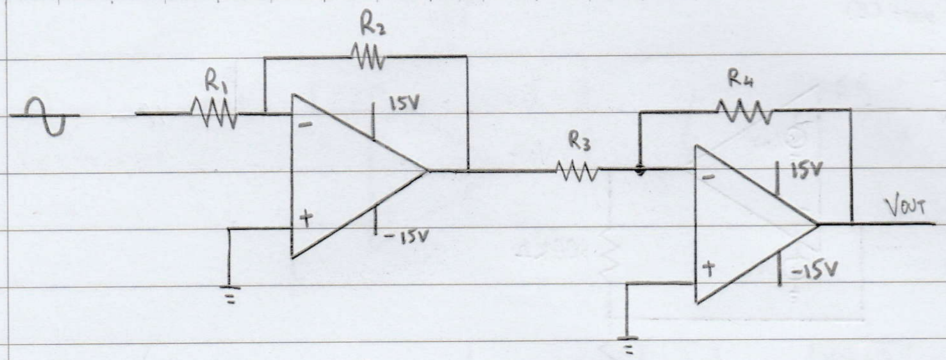
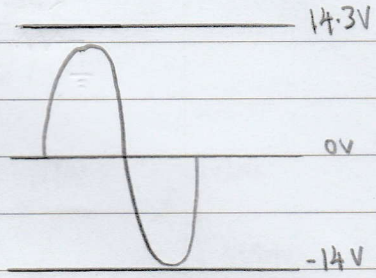
7)



X 20 X 20



$SR = 1V/\mu s$

$\pm V_{OUT} = \pm V_{in}(-20)(-20)$

$\pm 14 = \pm V_{in}(400)$

$\pm V_{in} = \frac{\pm 14}{400}$

$= \pm 35mV$

$V_{IN} = 35mV \sin\omega t$

b) $V_{OUT} = A_{VCL} V_{IN}$

$= A_{VCL} V_m \sin\omega t$

$= 400\,(35mV \sin\omega t)$

$SR \geq \frac{d}{dt} V_{OUT}|_{max}$

$f_{max} = \frac{SR}{2\pi A_{VCL} V_m}$

$= \frac{10^6}{2\pi(400)(35mV)}$

$= 11368.21022\ Hz$

$\approx 11.368\ kHz$

$\approx 11.4\ kHz$

anything higher than this the output become slew rate limited

$\frac{d}{dt} V_{OUT} = \omega A_{VCL} V_m \sin\omega t$

$\frac{d}{dt} V_{OUT}|_{max} = \omega A_{VCL} V_m$

$= 2\pi f_{max} A_{VCL} V_m$