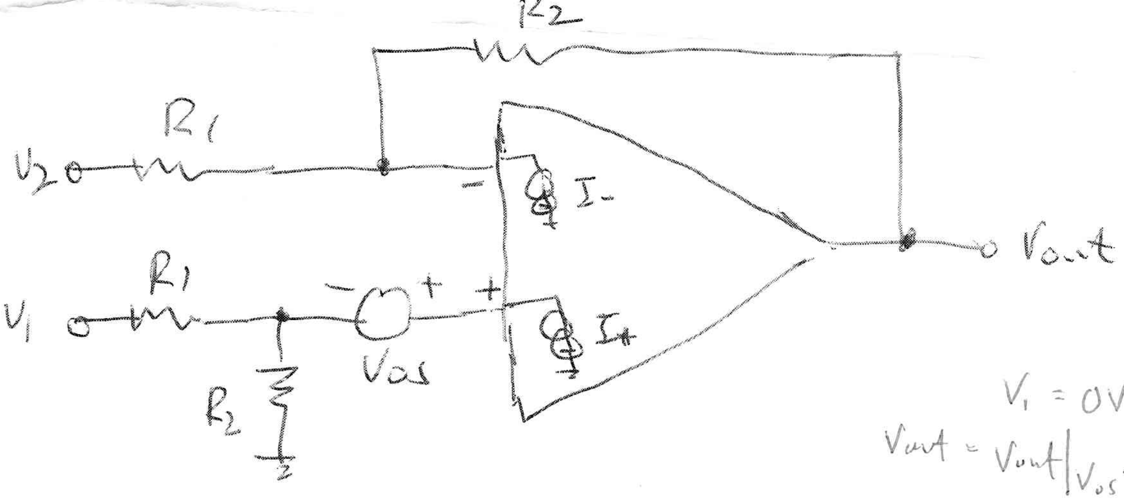
EE2002 Tutorial 2

(1)

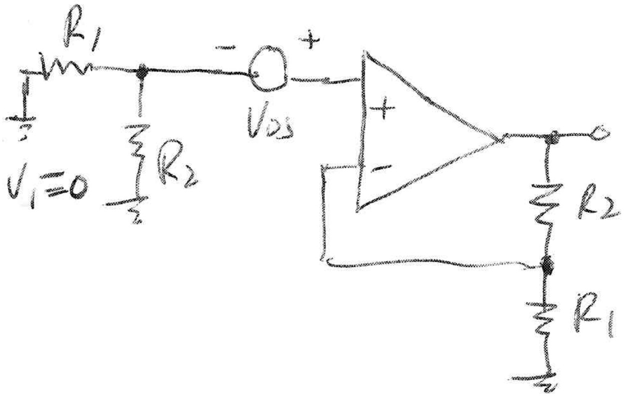


$V_1 = 0V$

$V_{out} = V_{out}\big|_{V_{os}} + V_{out}\big|_{I_+} + V_{out}\big|_{I_-}$

$V_{out}\big|_{V_{os}}$

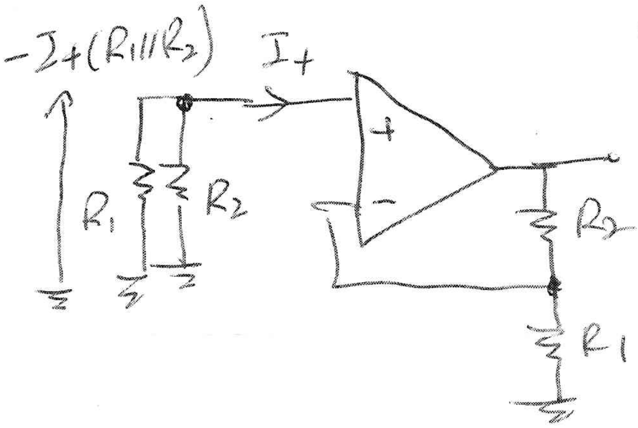
$\Downarrow$



$V_{out1} = V_{os}\left(1 + \frac{R_2}{R_1}\right)$

$V_{out}\big|_{I_+}$

$\Downarrow$

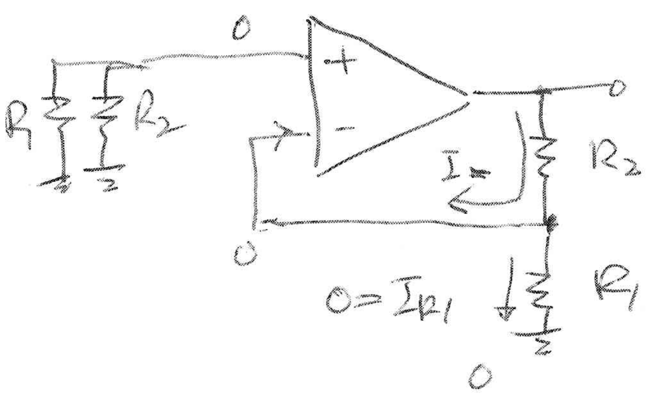


$$V_{out_2} = -I_+(R_1 \parallel R_2)\left(1 + \frac{R_2}{R_1}\right)$$

$$= -I_+\left(\frac{R_1 \cdot R_2}{R_1 + R_2}\right)\left(1 + \frac{R_2}{R_1}\right)$$

$V_{out}\big|_{I_-}$

$\Downarrow$



$V_{out3} = I_- R_2$

$\therefore\ V_{out} = V_{out1} + V_{out2} + V_{out3}$

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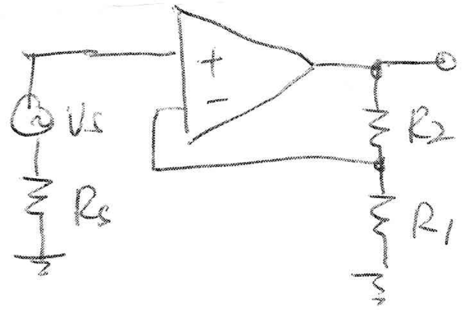
2(a)

Ideal

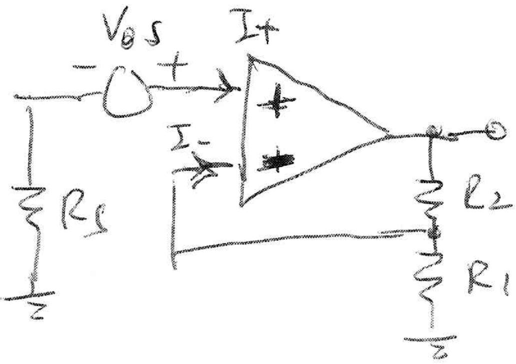


$$V_{out} = V_s \times \left(1 + \frac{R_2}{R_1}\right)$$

2(b)

Non-Ideal

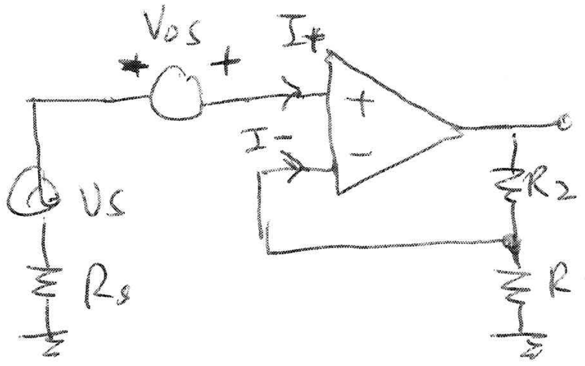
$V_s = 0$



$$V_{out\,dc} = V_{out}\Big|_{I_+} + V_{out}\Big|_{I_-} + V_{out}\Big|_{V_{os}}.$$

$$V_{out\,dc} = V_{os} \times \left(1 + \frac{R_2}{R_1}\right)$$
$$+ (-I_+) R_s \left(1 + \frac{R_2}{R_1}\right)$$
$$+ (I_-) \cdot R_2$$

2(c)



$$V_{out} = V_{out}\Big|_{V_s} + V_{out}\Big|_{V_{os}} + V_{out}\Big|_{I_+} + V_{out}\Big|_{I_-}$$

$$V_{out} = V_s \times \left(1 + \frac{R_2}{R_1}\right)$$
$$+ V_{os} \times \left(1 + \frac{R_2}{R_1}\right)$$
$$+ (-I_+) R_s \left(1 + \frac{R_2}{R_1}\right)$$
$$+ (I_-) \cdot R_2$$

2(d) From 2(c), $V_{out\,dc} = 0$

$$\therefore\ 0 = V_{os}\left(1 + \frac{R_2}{R_1}\right) + (-I_+) \cdot R_s \cdot \left(1 + \frac{R_2}{R_1}\right) + (I_-) \cdot R_2$$

$$\therefore\ R_s = \frac{V_{os} \cdot \left(1 + \frac{R_2}{R_1}\right) + (I_-) \cdot R_2}{(I_+) \cdot \left(1 + \frac{R_2}{R_1}\right)}$$

Given: $I_{BIAS} = \dfrac{I_+ + I_-}{2} = 100\,nA$

$I_{IO} = I_+ - I_- = -40\,nA$

$\dfrac{R_2}{R_1} = \dfrac{100K}{25K} = 4$, $V_{os} = 2\,mV$

Solve I_+ and I_- and R_s

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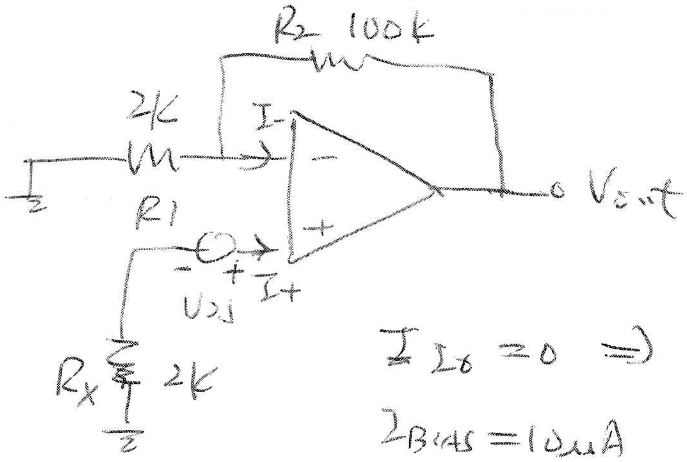
(3)



$I_{os} = 0 \Rightarrow I_+ = I_- = 10\mu A$

$I_{BIAS} = 10\mu A$

$$V_{out} = \underbrace{\left(1+\frac{R_2}{R_1}\right)V_{os}}_{1} + \underbrace{\left[(-I_+)\cdot R_x \cdot \left(1+\frac{R_2}{R_1}\right)\right]}_{2} + \underbrace{(I_-)\cdot R_2}_{3}$$

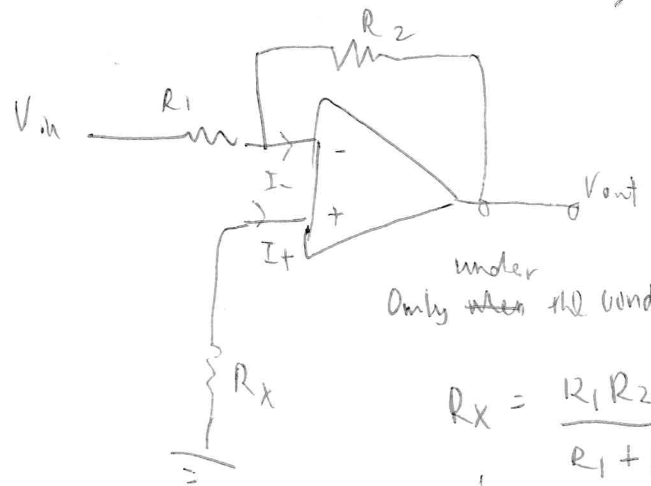
$$= \underbrace{500mV}_{1} \underbrace{- 1.02V}_{2} \underbrace{+ 1.0V}_{3}$$

* For exact I_{BIAS} offset cancellation, 2 = 3

$\therefore \quad (-I_+)\cdot R_x \cdot \left(1+\frac{R_2}{R_1}\right) + (I_-)R_2 = 0$

$$\Rightarrow R_x = \frac{R_1 \cdot R_2}{R_1+R_2} = 1.96\,k\Omega < 2k\Omega$$

Slew Rate SR is independent of V_{os}



Only ~~when~~ under the condition where $I_- = I_+$

$$R_x = \frac{R_1 R_2}{R_1+R_2} \quad (R_1 // R_2)$$

This formula help to find the value of R_x So that it ~~can~~ offset ~~the~~ the will become zero

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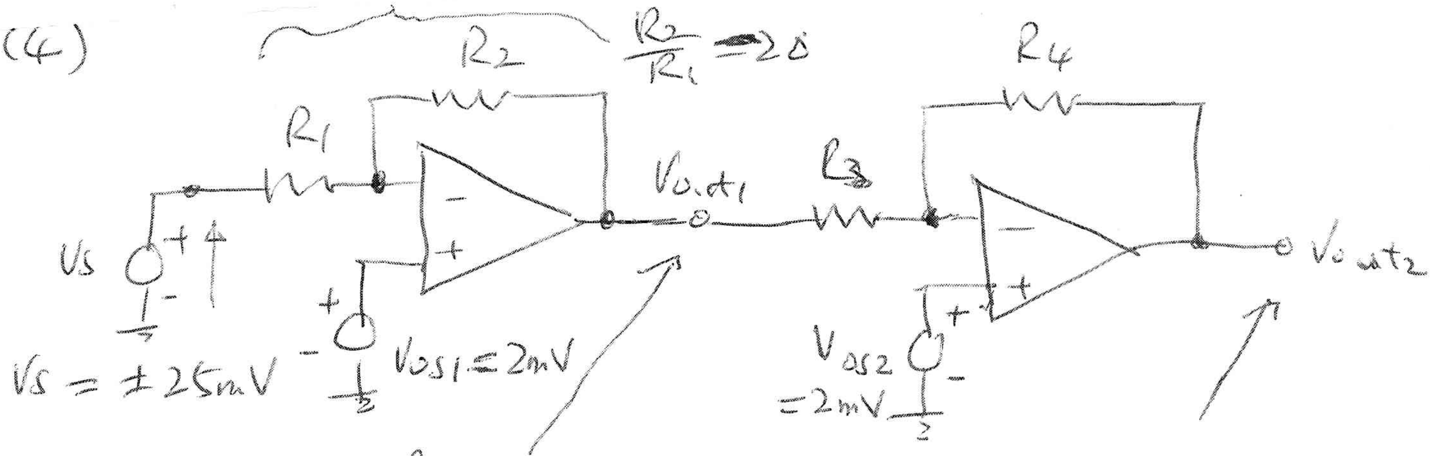
(4)



$$V_{out1} = \left(-\frac{R_2}{R_1}\right)\cdot V_s + \left(1+\frac{R_2}{R_1}\right)V_{os1}$$

$$V_{out2} = \left(-\frac{R_4}{R_3}\right)\cdot V_{out1} + \left(1+\frac{R_4}{R_3}\right)\cdot V_{os2}$$

$$\therefore V_{out2} = \left(\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right)V_s - \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right)\cdot V_{os1} + \left(1+\frac{R_4}{R_3}\right)V_{os2}$$

$$V_{out2} = \left(\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right)V_s - \left(\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right)V_{os1} - \cancel{\left(\frac{R_4}{R_3}\right)V_{os1}} + V_{os2} + \cancel{\left(\frac{R_4}{R_3}\right)V_{os2}}$$

$\boxed{\text{If } V_{os1} = V_{os2}}$

Worst case happens when $V_s = -25mV$, $V_{out2} = -14V$

$$\therefore \left(\frac{R_4}{R_3}\right) = \frac{V_{out2} - V_{os2}}{\left(\frac{R_2}{R_1}\right)(V_s - V_{os1})} =$$

For $V_s = +25mV$, $V_{out2} = \underline{\underline{+12V}}$

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5(a) $V_{out} = V_p A_{CL} \sin\omega t + \text{dc offset}$

$$\frac{dV_{out}}{dt} = +V_p A_{CL}\,\omega \cos\omega t = +V_p A_{CL} \cdot 2\pi f \cdot \cos\omega t$$

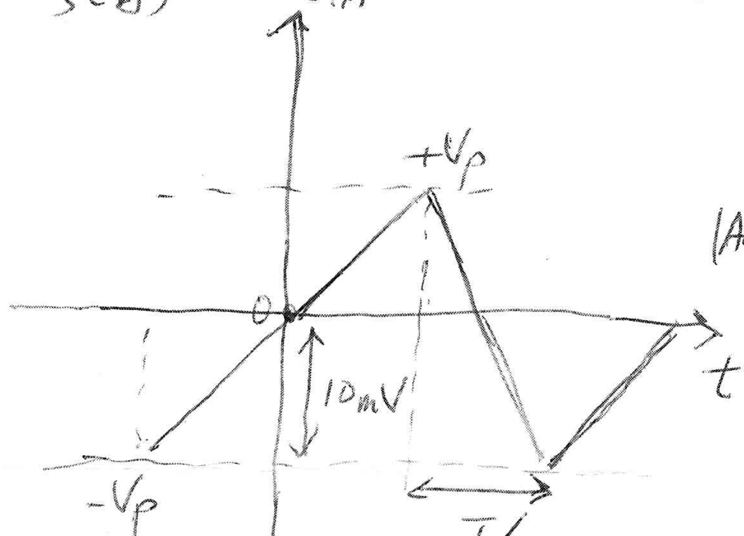
$$SR = \left|\frac{dV_{out}}{dt}\right|_{max} = V_p A_{CL}\, 2\pi f_{max}$$

$$\therefore f_{max} = \left|\frac{SR}{V_p \cdot A_{CL} \cdot 2\pi}\right|$$

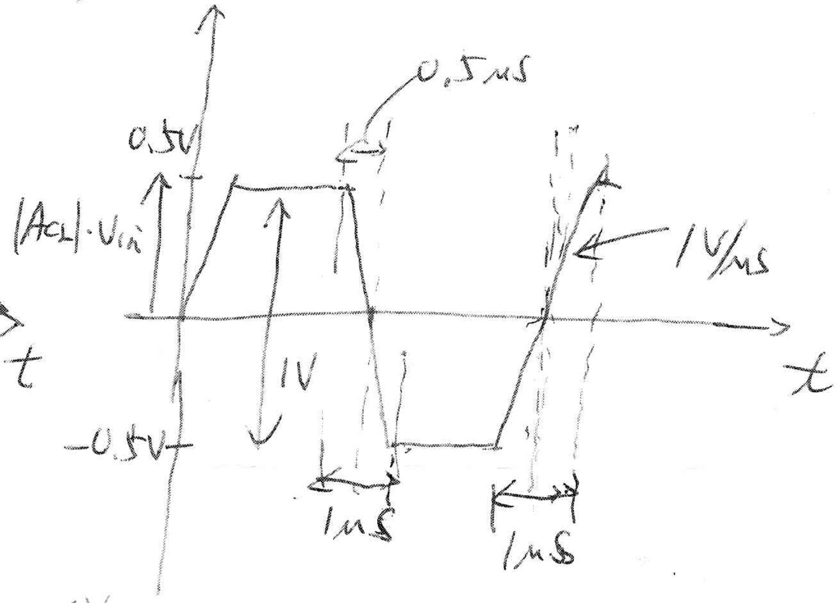
For $A_{CL} = -50$, $V_p = 0.01V$, $SR = 1V/\mu s$

$\therefore f_{max} =$

5(b)



5(c)



$$|\text{slope}| = \frac{2V_p}{T/2} = \left|\frac{dV_{in}}{dt}\right| = \frac{4V_p}{T}$$

$A_{CL} = -50$

$$\left|\frac{dV_{out}}{dt}\right|_{max} = 50\left|\frac{dV_{in}}{dt}\right| \leq S_R = 1V/\mu s \rightarrow 50\left(\frac{4V_p}{T}\right) \leq 1MV/s$$

0.01 (given)

$$\frac{4V_p}{T} \leq 1MV/s \div 50$$

$$f \leq \frac{S_R}{2000V_p} \Rightarrow f_{max} = \frac{S_R}{2000V_p}$$

$$T \leq \frac{4V_p}{1MV/s / 50}$$

$$f \leq \frac{1MV/s / 50}{4(0.01)}$$

$\therefore f_{max} = \underline{500\,kHz}$

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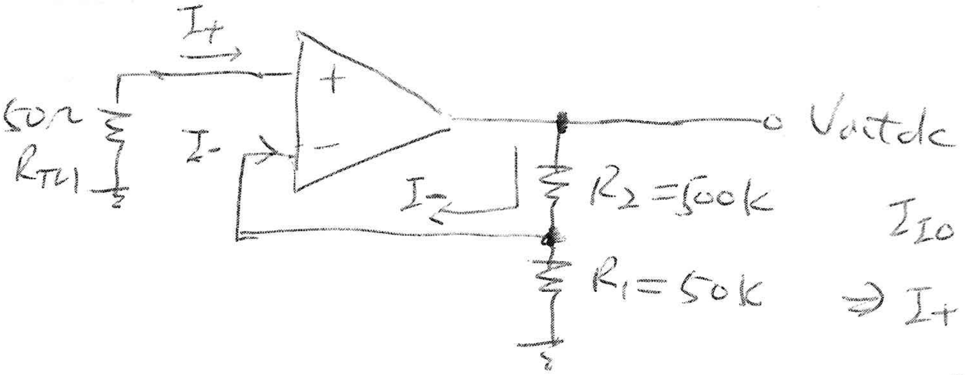
6(a)



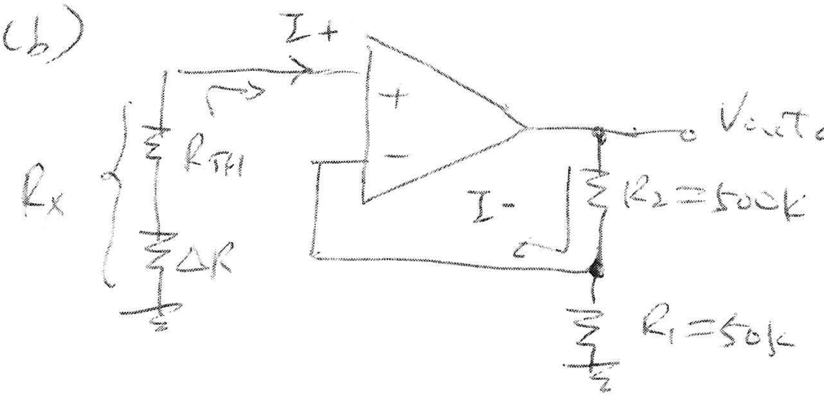
$I_{IO} = 0$

$\Rightarrow I_+ = I_-$

$= I_{BIAS} = 1mA$

$$V_{outdc} = (-I_+) \cdot R_{TH} \cdot \left(1 + \frac{R_2}{R_1}\right) + (I_-) \cdot R_2$$

6(b)



$\Rightarrow (-I_+) \cdot R_x \left(1 + \frac{R_2}{R_1}\right) = (I_-) \cdot R_2$

$\Rightarrow R_x = R_1 // R_2$

$\therefore \Delta R = (R_1 // R_2) - R_{TH}$

$=$

7(a) $A_{CL1} = A_{CL2} = -20$, $V_{sat+} = 14.3V$

$S_R = 1V/\mu s$, $V_{sat-} = -14V$

$$V_{in} = \frac{V_{out_{WE}}}{|A_{CL} \cdot A_{CL}|} = \frac{\pm 14V}{400} = \underline{\underline{\pm 35mV}}$$

7(b)

$$f_{max} = \frac{S_R}{|A_{CL1} A_{CL2}| \cdot V_p} = \underline{\underline{11.4\ KHZ}}$$