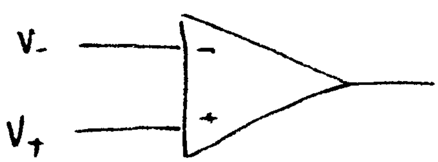
Homework Set #5
Electronics

1.) Input resistance amp: $R_{in} \to \infty$
Amplification factor amp: $A \to \infty$

2.) a.)

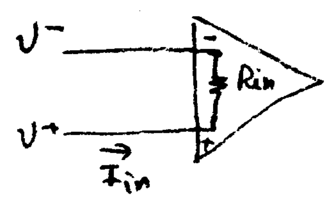


$$V_o = A(v_+ - v_-)$$

For V_o to be less than the limits set by the power supply,

$$(v_+ - v_-) < \frac{V_{limit}}{A}. \quad \underline{\text{as } A \to \infty,\ v_+ - v_- \to 0}$$

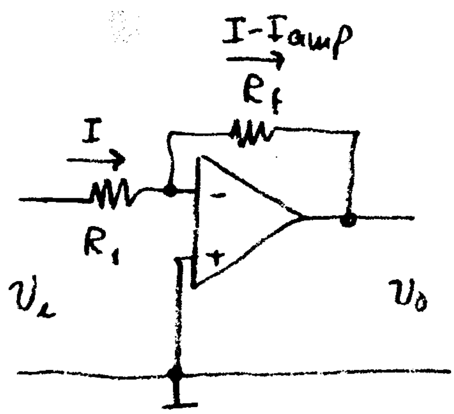
b.)



$$I_n = \frac{v_+ - v_-}{R_{in}}$$

$$\boxed{\lim_{R_{in}\to\infty} I_n = \lim_{R_{in}\to\infty}\left(\frac{v_+ - v_-}{R_{in}}\right) = 0}$$

3.)



Since $v^+ = 0$, and $v^- = v^+$, $v^- = 0$. thus

$$I = \frac{v_i - v^-}{R_1} = \frac{v_i}{R_1}$$

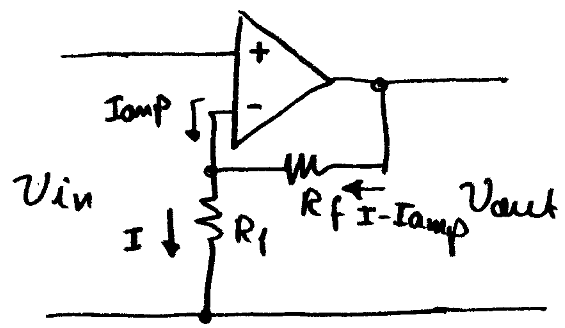
Since $I_{amp} = 0$, $I - I_{amp} = I$.

$$v_o = -IR_f = -\frac{v_i R_f}{R_1}$$

$$\boxed{G = \frac{v_o}{v_i} = -\frac{R_f}{R_1}}$$

set #5, cont

4.)



Since $v_+ = v_{in}$, and $v_+ = v$, $v_- = v_{in}$, and $I = \dfrac{v_{in}}{R_1}$.

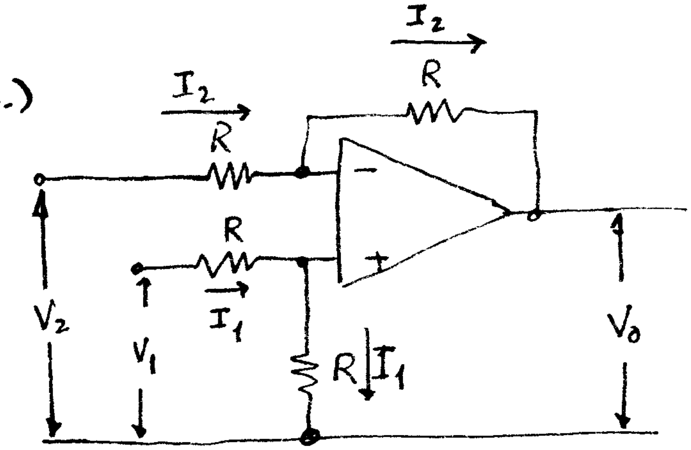
Since $I_{amp} = 0$, $I - I_{amp} = I$,

and $v_{out} = I(R_1 + R_f)$

$= \dfrac{v_{in}}{R_1}(R_1 + R_f)$

so $\boxed{G = \dfrac{v_{out}}{v_{in}} = 1 + \dfrac{R_f}{R_1}}$

5.)



- Since $I_{amp} = 0$ at input, $V_+ = \dfrac{V_1}{2R} R = \dfrac{V_1}{2}$
- Since $v_- = v_+$, $V_- = \dfrac{V_1}{2}$
- thus $I_2 = \dfrac{V_2 - V_-}{R} = \dfrac{V_2 - \frac{V_1}{2}}{R}$

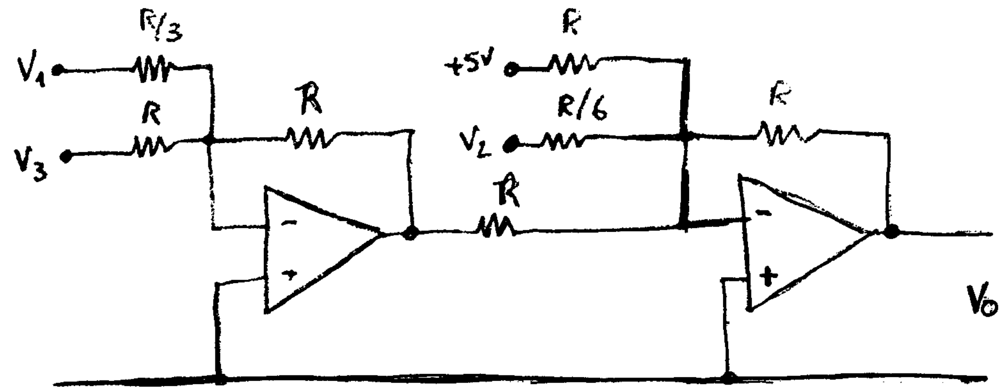
- Since $I_{amp} = 0$, I_2 also is

$I_2 = \dfrac{V_- - V_o}{R} = \dfrac{\frac{V_1}{2} - V_o}{R}$

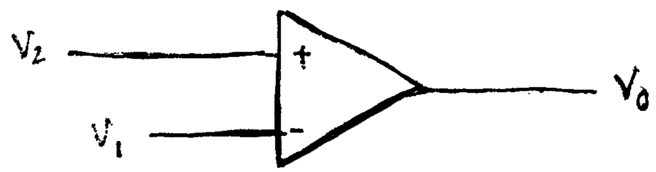
- thus $\dfrac{\frac{V_1}{2} - V_o}{R} = \dfrac{V_2 - \frac{V_1}{2}}{R} \Rightarrow \boxed{V_o = V_1 - V_2}$

Set #5, cont

6.)



7.)



Since $V_0 = A(V_2 - V_1)$ only for $|V_0| \leq$ limiting value set by the powersupply (typically ± 12 V), V_0 will be at the limit when

$$V_2 - V_1 \geq \frac{V_L}{A} \quad \left(\sim \frac{12\text{V}}{10^6} = 12\mu\text{V} \right)$$

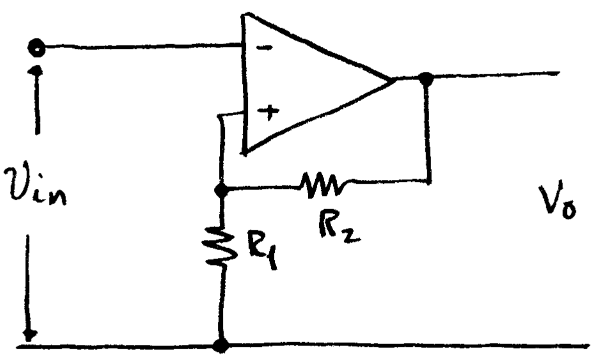
thus $V_0 = +V_L$ when $V_2 > V_1 + \frac{V_L}{A}$,

and $V_0 = -V_L$ when $V_2 < V_1 - \frac{V_L}{A}$.

Since $\frac{V_L}{A} \approx 0$, V_0 is the result of a comparison between V_2 and V_1, e.g., $V_0 = +V_L$ for $V_2 > V_1$ + $V_0 = -V_L$ for $V_2 < V_1$

Set 5, electronics

8.)



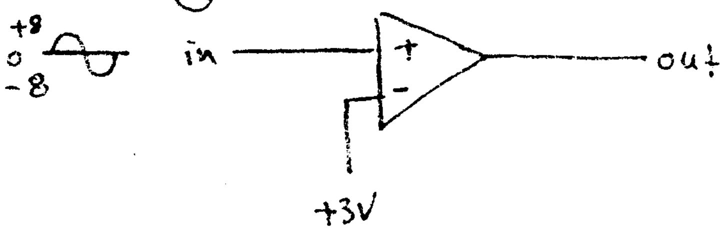
this is similar to the comparator, except that the voltage applied to the + input is derived from the output. Since the output will be either $\pm V_L$ ($V_L = V_{limit}$),

$$V_+ = \frac{\pm V_L}{(R_1+R_2)} R_1 .$$

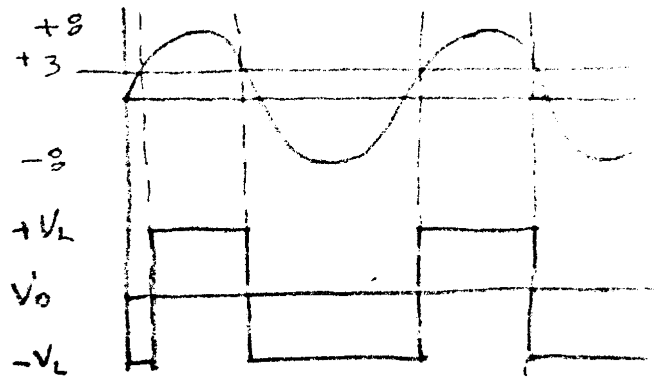
the difference between this circuit and the one of #7 is that V_{in} is compared to <u>different</u> voltages at each successive ~~tr~~ transition. Specifically, one time V_+ is compared to, e.g., $+V_L\left(\frac{R_1}{R_1+R_2}\right)$, until V_0 makes the $+V_L \to -V_L$ transition, and then V_i is compared to $-V_L\left(\frac{R_1}{R_1+R_2}\right)$.

Electronics set #5, cont

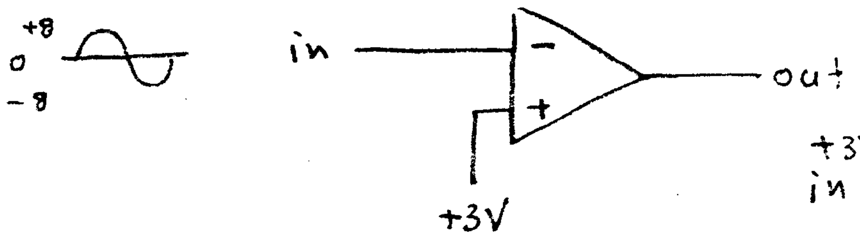
9.) (a)



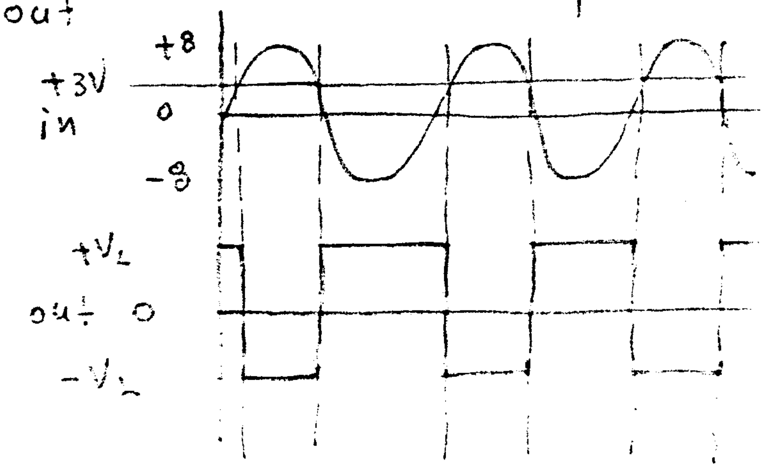
this is a comparator:



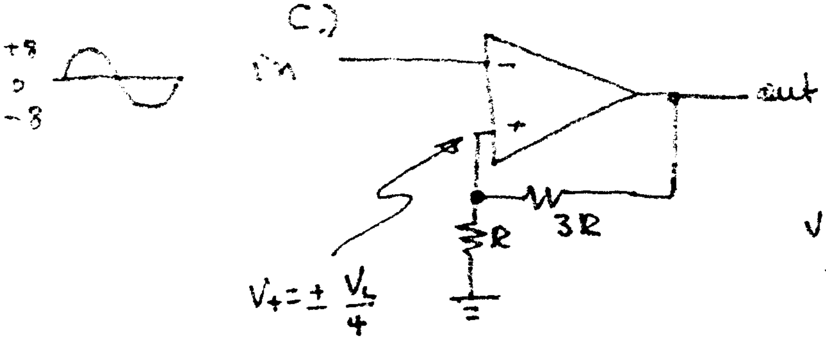
(b)



this is also a comparator:



c.)

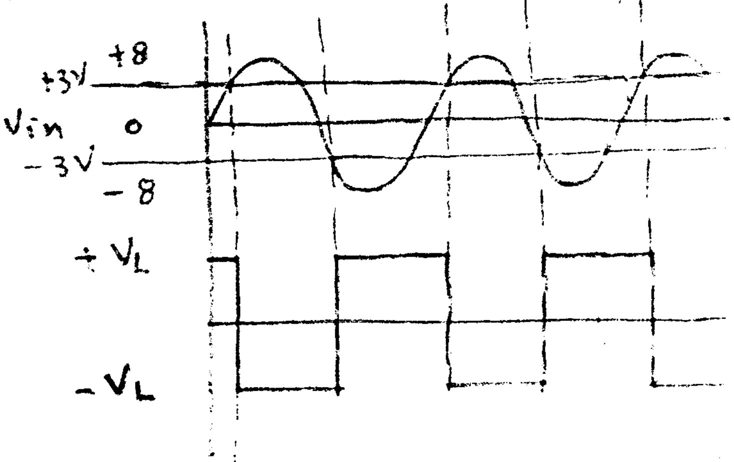


$V_+ = \pm \frac{V_L}{4}$

$V_L = 12V$ (given)

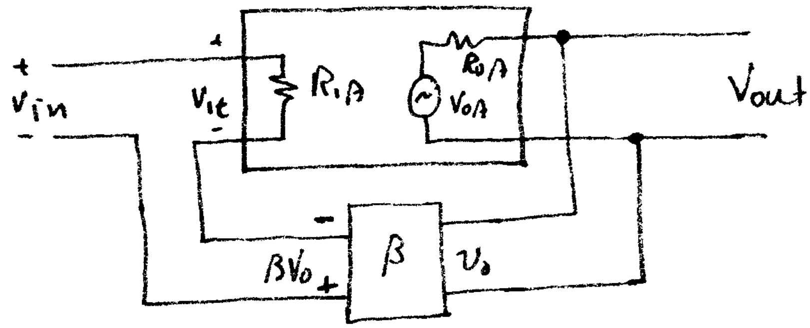
$V_+ = \pm 3V$

this is a Schmitt trigger



Homework set #5, cont

10.)



a.) • by a loop analysis,

$$v_{in} = -\beta V_o + v_{it} \rightarrow v_{it} = v_{in} + \beta V_o$$

• $$V_o = A\,v_{it} = A\left(v_{in} + \beta v_o\right)$$

$$\Rightarrow V_o\,(1 - A\beta) = A v_{in}$$

$$\boxed{G = \frac{V_o}{V_{in}} = \frac{A}{1-\beta A}}$$

b.) $$R_{in} = \frac{V_{in}}{I_{in}} \quad ; \quad \text{but} \quad I_{in} = \frac{V_{it}}{R_{iA}}$$

also, $$V_{it} = V_{in} + \beta V_o = V_{in} + \beta G V_{in} = V_{in}\left(1 - \frac{\beta A}{1-\beta A}\right)$$

so $$V_{it} = \frac{1}{1-\beta A} V_{in}.$$

$$\therefore\ R_{in} = \frac{V_{in}}{I_n} = \frac{V_{in}}{V_{it}} R_{iA} = R_{iA}\frac{\cancel{V_{in}}}{\cancel{V_{in}}\left(\frac{1}{1-\beta A}\right)} = \boxed{R_{iA}(1-\beta A)}$$

10c) the relation given comes from Thevenin's theorem. Calculation of the numerator is basically as was done for (a): (negative feedback is assumed)

$$V_{iT} = \frac{V_o}{A} = V_{in} + \beta V_o \Rightarrow V_o\Big|_{open} = V_{in}\frac{A}{1-\beta A}$$

this step assumes $V_o = V_{oA}$, or that no current flows in the output loop

the denominator requires the same procedure, but care in noticing the effect on things when the output is shorted.

$$I_{out}\Big|_{short} = \frac{V_{oA}}{R_{oA}} = \frac{A V_{iT}}{R_{oA}}$$

note that $V_{iT} = V_{in} + \beta V_o$, but $V_o = 0$ when the output is shorted. So

$$V_{it}\Big|_{\substack{out\\shorted}} = V_{in} + 0 = V_{in}$$

and

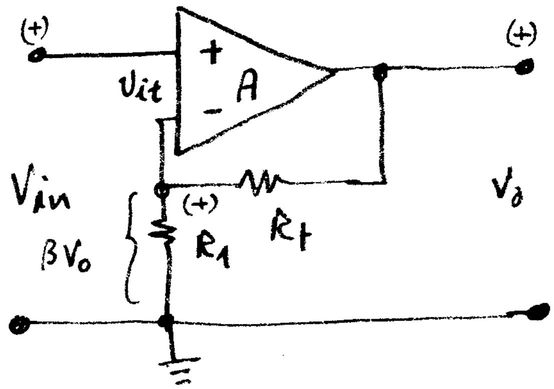
$$I_{out}\Big|_{short} = \frac{AV_{it}}{R_{oA}} = \frac{AV_{in}}{R_{oA}}$$

so

$$\boxed{R_o = \frac{V_o|_{open}}{I_o|_{short}} = \frac{\left\{V_{in}\frac{A}{1-\beta A}\right\}}{\left\{\frac{AV_{in}}{R_{oA}}\right\}} = \frac{R_{oA}}{1-\beta A}}$$

Homework Set #5, cont.

11.)



• $\beta V_o = \left(\frac{R_1}{R_1+R_f}\right) V_o \implies \beta = \frac{R_1}{R_1+R_f}$

so. $V_{it} = V_{in} - \beta V_o$; $V_o = A V_{it} = A(V_{in} - \beta V_o)$

$$V_o = V_{in} \frac{A}{1+A\beta}$$

• $$\boxed{\frac{V_o}{V_{in}} = \frac{A}{1+A\beta} = \frac{A}{1+A\left(\frac{R_1}{R_1+R_f}\right)}}$$

• $\lim_{A\to\infty} G = \lim_{A\to\infty} \frac{A}{1+A\beta} = \lim_{A\to\infty} \frac{1}{1/A+\beta} = \frac{1}{\beta}$

thus $$\boxed{\lim_{A\to\infty} G = \frac{1}{\beta} = \frac{R_1+R_f}{R_1} = 1+\frac{R_f}{R_1}}$$