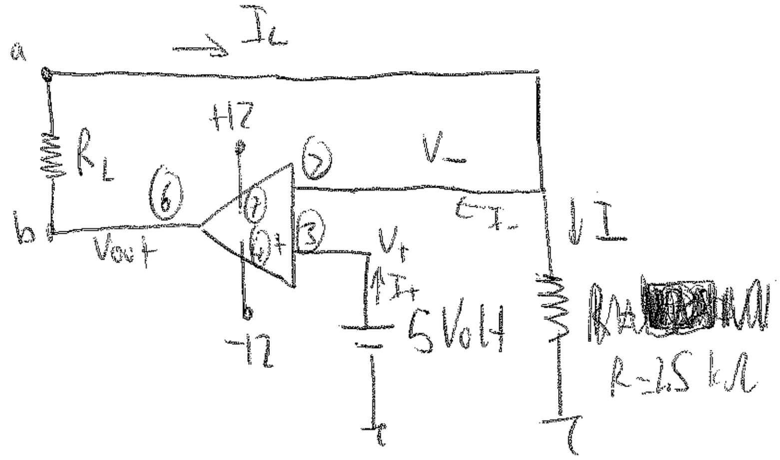
3- Miscelleneous OP-AMP circuits

(1) Constant current source



$V_{cc}=+12$
$-V_{cc}=-12$

The opamp has two operation region

* In linear region $V_- = V_+ = 5$ Volt
* In positive saturation region Vout becomes $V_{out} = V_{cc} = +12$ Volt

— In linear region

$V_+ = V_- = 5$ Volt $\quad I_+ = I_- \cong 0$ and $I_L = I = \dfrac{V_-}{R} = \dfrac{5}{R}$

* In linear region the current that changes and it is $I = \dfrac{5}{R}$

— In (+) saturation region $V_+ > V_-$, $V_{out} = 12$ Volt, and and $I_- \neq 0$

$I_L = I + I_-$

in order to find the limit value $R_{L_{max}}$ we take $I_- \cong 0$ Ampere

hence $I_L \cong I \qquad \dfrac{V_{out} - V_-}{R_{L_{max}}} = \dfrac{V_-}{R} \qquad V_- = \dfrac{V_{out}\,R}{R + R_{L_{max}}}$

when $I_- = 0$ Ampere $V_{out} = 12$ Volt ; $V_- = 5$ Volt

$$V_+ \geq V_- = \frac{V_{out}\, R}{R + R_{max}}$$

$$5 \geq \frac{12 \times 2.5}{2.5 + R_{max}}$$

$5 R_{max} \geq 30 - 12.5$

$5 R_{Lmax} \geq 17.5$

$R_{Lmax} \geq 3.5\ k\Omega$

Result

* if $0 < R_L < R_{Lmax}$, the circuit is in linear region

$I_+ = I_- \cong 0$ $\quad I = \frac{V_-}{2.5\ k\Omega}$, $V_+ = V_- = 5$, $I = \frac{5}{2.5\ k\Omega} = 2\ m$Ampere (constant current source)

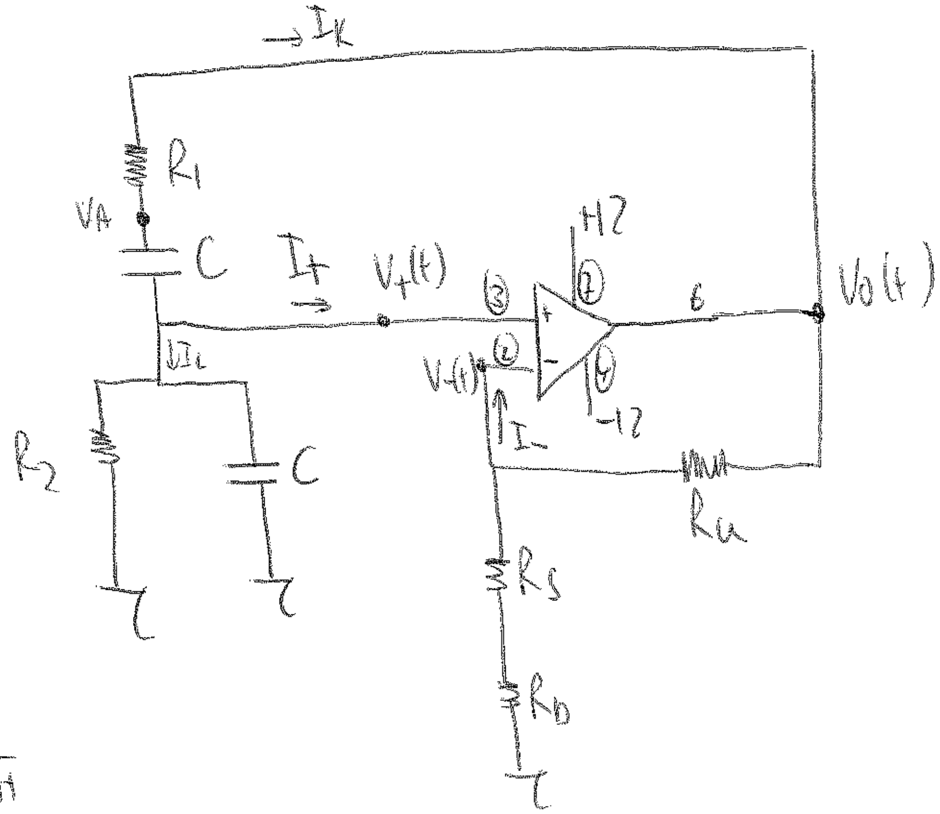
, $V_{out} < \underbrace{V_{cc}}_{12\ Volt}$,

* if $R_L > R_{Lmax}$, the circuit is in positive saturation region

$I_- \cong 0$ $\quad I = I_L + I_-$ $\quad V_+ > V_-$ $\quad I = \frac{V_-}{R} = \frac{V_{cc}}{R_L + R}$ (no more constant current)

$5 > V_-$

2 - Sinusoidal Oscillator



$I_+ \cong I_- \cong 0$ Ampere

$V_+ \cong V_-$ (in linear region)

Hence

$$V_- = V_+ = V_0 \frac{R_s + R_b}{R_a + R_s + R_b}$$

$$D = \frac{d}{dt}$$

$$I_K + I_L + I_+ = 0 \qquad I_+ \cong 0 \longrightarrow I_K + I_L = 0$$

$$I_L = \frac{V_+}{R_2} + C\frac{dV_+}{dt} \qquad I_K = C\frac{d(V_+ - V_A)}{dt} = \frac{V_A - V_0}{R_1}$$

$$I_L = \left[\frac{1}{R_2} + CD\right]V_+ \qquad C\frac{dV_+}{dt} - C\frac{dV_A}{dt} = \frac{V_A}{R_1} - \frac{V_0}{R_1}$$

$$\boxed{I_L = \left[\frac{1}{R_2} + CD\right]\frac{R_s + R_b}{R_a + R_s + R_b}V_0} \qquad C\frac{dV_+}{dt} + \frac{V_0}{R_1} = C\frac{dV_A}{dt} + \frac{V_A}{R_1}$$

$$CDV_+ + \frac{1}{R_1}V_0 = \left(CD + \frac{1}{R_1}\right)V_A$$

$$V_A = \frac{CDV_+ + \frac{1}{R_1}V_0}{CD + \frac{1}{R_1}} \Rightarrow I_K = \frac{V_A - V_0}{R_1}$$

$$V_A = \frac{R_1 CDV_+ + V_0}{R_1 CD + 1} \qquad I_K = \frac{\frac{R_1 CDV_+ + V_0}{R_1 CD + 1} - V_0}{R_1}$$

$$\boxed{V_0 - V_+} = V_0 \frac{R_a}{R_a + R_s + R_b} \qquad \boxed{I_K = \frac{R_1 CDV_+ - R_1 CDV_0}{R_1[R_1 CD + 1]}}$$

$$I_L = -I_K$$

$$\left[\frac{1}{R_2} + CD\right]\frac{R_s + R_b}{R_a + R_s + R_b} V_0 = \frac{R_1 CD[V_0 - V_+]}{R_1[R_1 CD + 1]} =$$

$$\left[\frac{1 + R_2 CD}{R_2}\right]\frac{R_s + R_b}{R_a + R_s + R_b} V_0 = \frac{CR_a DV_0}{R_a + R_s + R_b\,[R_1 CD + 1]}$$

$$[1 + R_2 CD](R_s + R_b)[R_1 CD + 1]V_0 = R_a R_2 CDV_0$$

$$(R_s + R_b)R_1 R_2 C^2 (D^2 V_0) + \left[(R_s + R_b)(R_1 C + R_2 C) - R_a R_2 C\right] DV_0 + (R_s + R_b)V_0 = 0$$

$$R_1 R_2 C^2 \frac{d^2 V_0}{dt^2} + \left[(R_1 + R_2) - \frac{R_a R_2}{R_s + R_b}\right] C \frac{dV_0}{dt} + V_0 = 0$$

$$* \quad \frac{d^2 V_o}{dt^2} + \frac{C\left[(R_1+R_2) - \frac{R_a R_2}{R_s + R_b}\right]}{R_1 R_2 C^2} \frac{dV_o}{dt} + \frac{1}{R_1 R_2 C^2} V_o = 0$$

if $R_1 + R_2 = \frac{R_a R_2}{R_s + R_b}$ then $*$ turns to

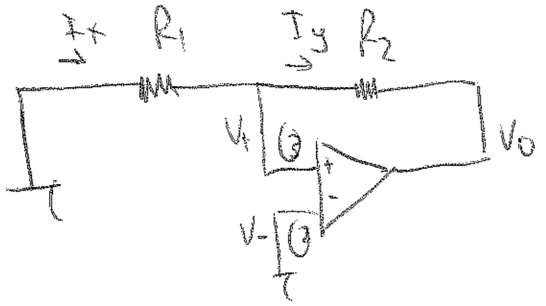
$$\frac{d^2 V_o}{dt^2} + \frac{1}{R_1 R_2 C^2} V_o = 0 \quad **$$

The solution of $**$

$$V_o(t) = K_1 \sin(\omega t) + K_2 \cos(\omega t) \quad \left[\text{A sinusoidal oscillator}\right]$$

$$\omega = \sqrt{\frac{1}{R_1 R_2 C^2}} = \frac{1}{C\sqrt{R_1 R_2}}$$

(3) Creating Hysterasis Loop using bistable circuit



$I_x = I_y$ in linear region

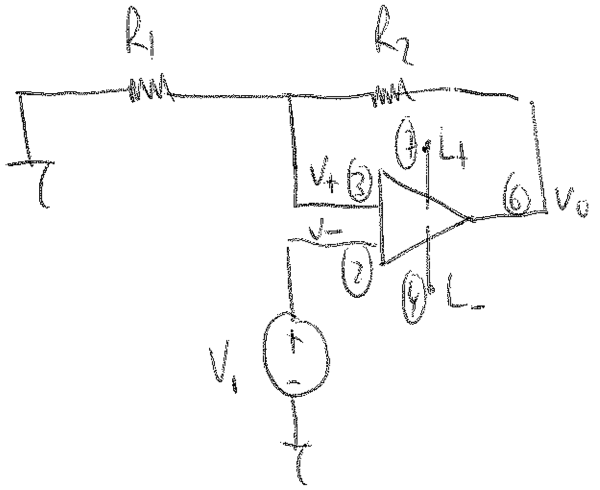
$$\frac{0 - V_+}{R_1} = \frac{V_+ - V_o}{R_2}$$

$$V_+(R_1 + R_2) = V_o R_1$$

$$V_+ = \frac{R_1}{R_1 + R_2} V_o$$

$V_+ = \beta V_o$ β = feed_fraction

$$\beta = \frac{R_1}{R_1 + R_2}$$



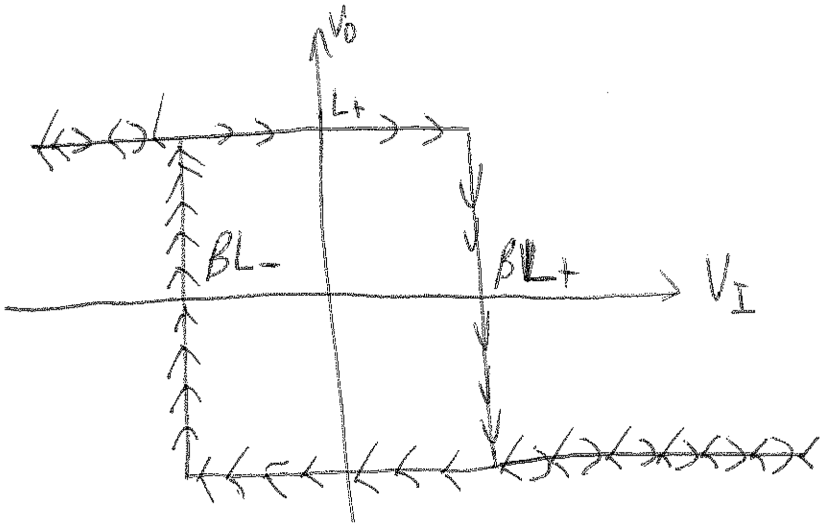
$L_+ = 12$ Volt

$L_- = -12$ Volt

if $V_o = L_+ \Rightarrow V_+ = \beta L_+$ now increase V_I if V_I exceeds $V_+ = \beta L_+$ then $V_- > V_+$ and $V_o = L_-$, if $V_o = L_-$ then $V_+ = \beta L_-$

if $V_o = L_- \Rightarrow V_+ = \beta L_-$ now decrease V_I if V_I become lower than $V_+ = \beta L_-$ then $V_- < V_+$ and $V_o = L_+$; if $V_o = L_+$ then $V_+ = \beta L_+$

the characteristics of
biotable circuit

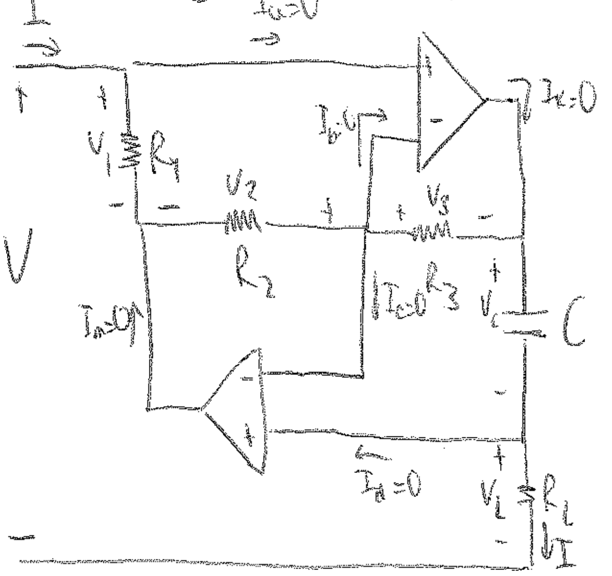


$$\beta = \frac{R_1}{R_1 + R_2}$$

$L_+ = 12$ Volt

$L_- = -12$ Volt

4- Inductor using two opamps



$V_1 = V_2$

$V_3 + V_L = 0$

$V_L = R_L I \qquad I = C\dfrac{dV_c}{dt}$

$V_L = R_L C \dfrac{dV_c}{dt} \longrightarrow V_c = -V_3$

$V_L = -R_L C \dfrac{dV_3}{dt} \qquad V_3 = I R_3$

$V_L = -R_L C R_3 \dfrac{dI}{dt} \qquad V_2 = -I R_2 \qquad V_L = -\dfrac{R_L C R_3}{R_2}\left(\dfrac{d(-V_2)}{dt}\right)$

$V_L = \dfrac{R_L C R_3}{R_2}\dfrac{dV_2}{dt} \qquad V_L = \dfrac{R_L C R_3}{R_2}\dfrac{dV_1}{dt} \rightarrow V_L = \dfrac{R_L C R_3 R_1}{R_2}\dfrac{dI}{dt}$

$V_1 = R_1 I$

$$\boxed{V_L = V = \frac{R_L C R_3 R_1}{R_2}\frac{dI}{dt}}$$

$$\boxed{L = \frac{R_L C R_3 R_1}{R_2}}$$