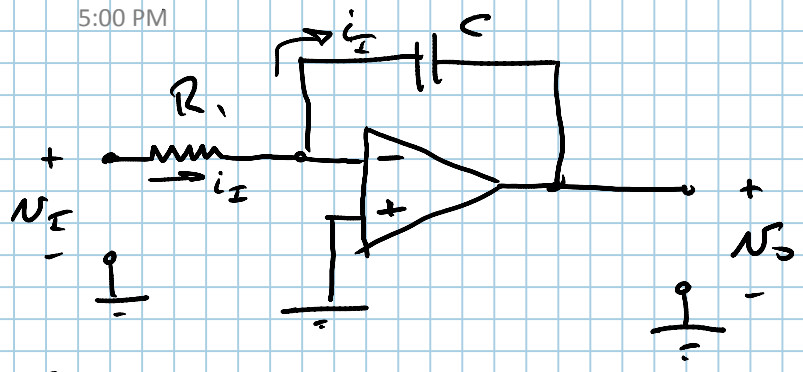
Op-Amp Integrator

Thursday, June 04, 2015
5:00 PM

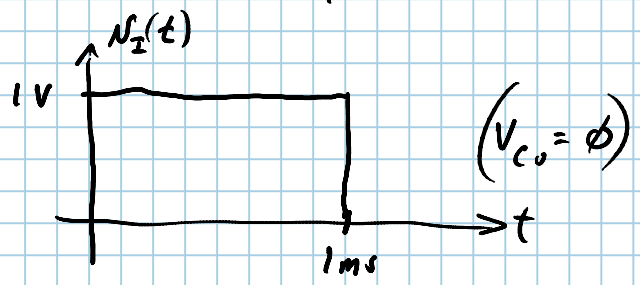


$$V_o = -\frac{1}{RC}\int_0^t V_I(t)\,dt + V_{c_0}$$

$V_{c_0} \equiv$ Initial condition of capacitor voltage

EXAMPLE: $C = 10\,nF$

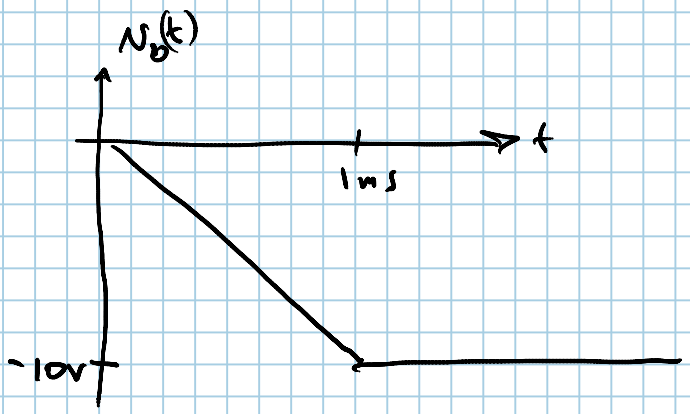
$R_1 = 10K\Omega$



$(V_{c_0} = 0)$

$$V_o = -\frac{1}{(10\times10^3\Omega)(10\times10^{-9}F)}\int_0^t 1\,dt$$

$$V_o = (-10\times10^3)t = -10t, \quad 0 \le t \le 1ms$$



$$A_{CL} = \frac{V_o}{V_I} = \frac{-1}{j\omega RC} \Rightarrow \left|\frac{V_o}{V_I}\right| = \left.\frac{1}{\omega RC}\right|_{\omega=0 \Rightarrow D.C.}$$

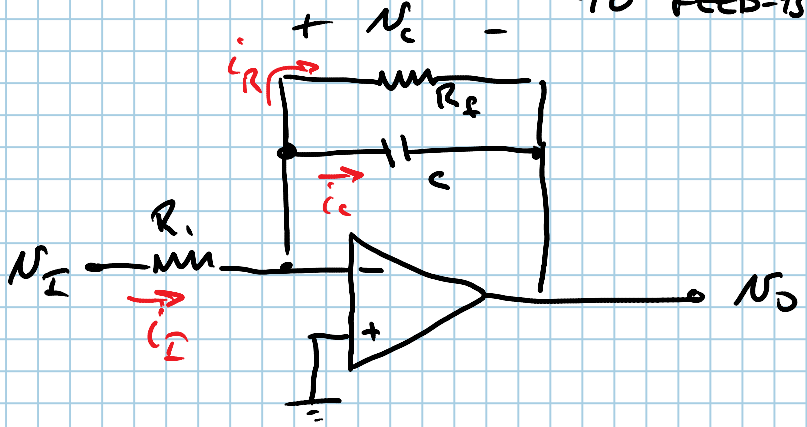
$\hookrightarrow |A_{CL}| = \infty$

$\phi = +90°$

$$V_I(t) = A + B\sin(\omega t)$$

Thursday, June 04, 2015
5:19 PM

Correct Gain Saturation by Adding Resistor in Parallel to Feed-back Capacitor



$v_c = 0 - v_O = -v_O$

$i_I = \frac{v_I - 0}{R_1} = \frac{v_I}{R_1}$

$i_c = C\frac{dv_c}{dt} = -C\frac{dv_O}{dt}$

From KCL: $i_I = i_c + i_R$

$i_R = \frac{v_c}{R_f} = -\frac{v_O}{R_f}$

$$\frac{v_I}{R_1} = -C\frac{dv_O}{dt} - \frac{v_O}{R_f}$$

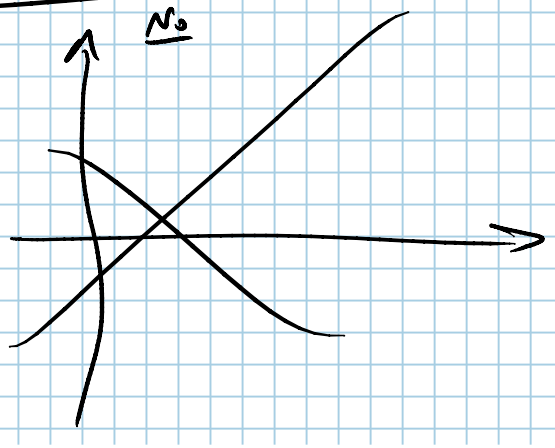
$$\mathcal{L}\left[C\frac{dv_O}{dt}\right] = CsV_O \Rightarrow \frac{V_I}{R_1} = -CsV_O - \frac{V_O}{R_f} = V_O\left(-sC - \frac{1}{R_f}\right)$$

$$\frac{V_I}{R} = -V_O\left(sC + \frac{1}{R_f}\right)$$

$$\frac{V_O}{V_I} = \frac{-1}{sRC + R/R_f} \left| \begin{array}{c} R_f/R \\ R_f/R \end{array} \right.$$

$$\boxed{\frac{V_O}{V_I} = \frac{-\frac{R_f}{R}}{sR_fC + 1}, \quad s = j\omega}$$

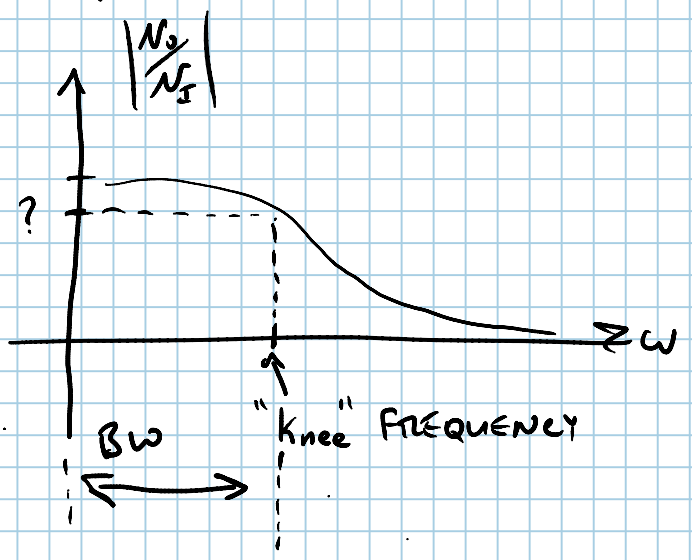
$$\boxed{A_{CL} = \left.\frac{V_O}{V_I}\right|_{\omega \to 0} = \frac{-R_f}{R}}$$



Thursday, June 04, 2015
5:31 PM

$$\frac{V_o}{V_I} = \frac{-\frac{R_f}{R}}{sR_fC + 1}$$

$$\left|\frac{V_o}{V_I}\right| = \frac{\frac{R_f}{R}}{\left[(\omega R_f C)^2 + 1\right]^{1/2}}$$



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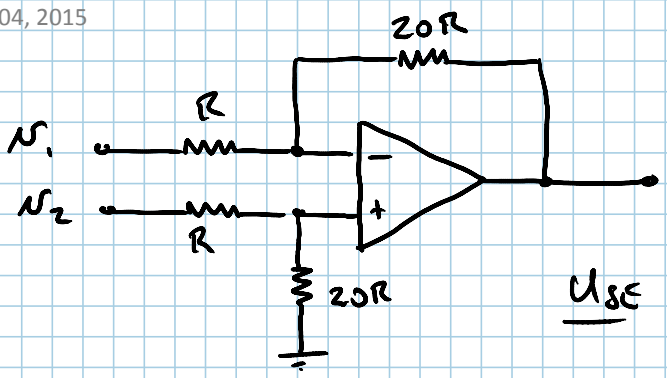
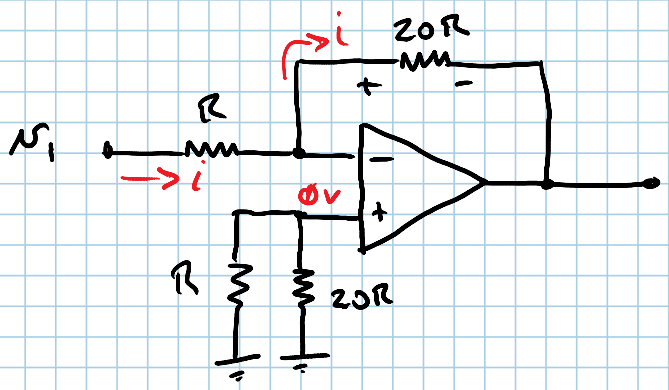
Thursday, June 04, 2015
5:38 PM



$V_o = f(V_1, V_2)$

Use Superposition

① Ground V_2



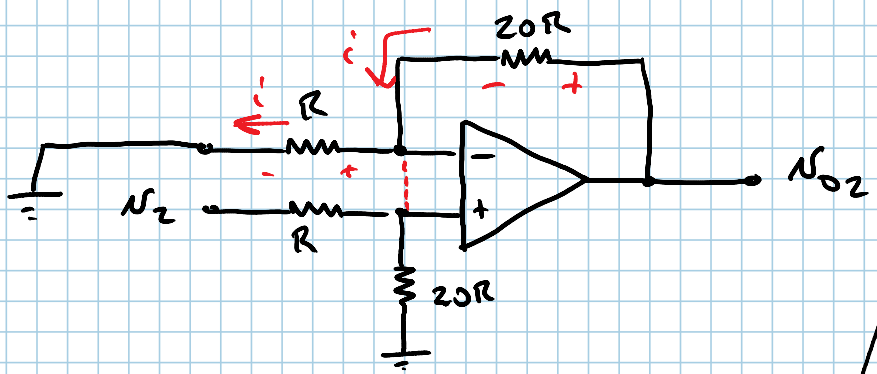
$i = \frac{V_1 - 0}{R} = \frac{V_1}{R}$

$i = \frac{0 - V_o}{20R} = \frac{-V_o}{20R}$

$i = i \Rightarrow \frac{V_1}{R} = \frac{-V_o}{20R}$

$V_{o1} = -20V_1$

② Ground V_1, UN-Ground V_2



In general, $V_o = \left(\frac{R_2}{R_1} + 1\right) V_I$

$V_I = V^+ = \left(\frac{20R}{R + 20R}\right) V_2$

$R_2 = 20R$

$R_1 = R$

$V_{o2} = \left(\frac{20R}{R} + 1\right)\left(\frac{20R}{21R}\right) V_2$

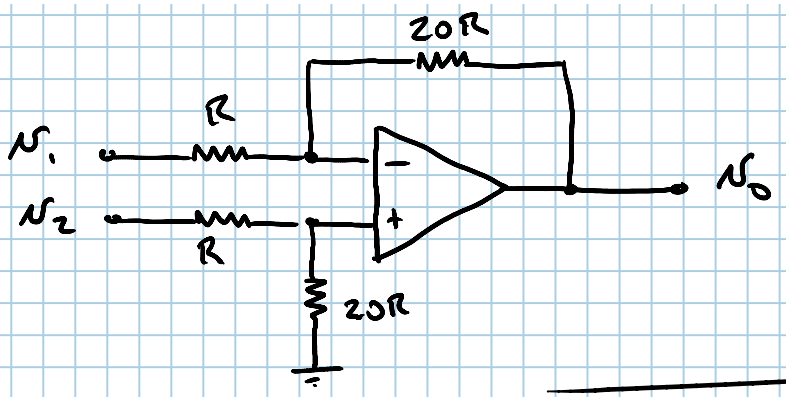
$V_{o2} = (21)\left(\frac{20}{21}\right) V_2 = 20V_2$

$V^+ = \left(\frac{20R}{21R}\right) V_2 = \frac{20}{21} V_2$, $V^- = V^+ = \frac{20}{21} V_2$

$i' = \frac{V^-}{R} = \frac{20}{21}\frac{V_2}{R}$, $i' = \frac{V_{o2} - \frac{20}{21} V_2}{20R}$

$i = i \Rightarrow V_{o2} = 20V_2$

Thursday, June 04, 2015
5:48 PM



$$V_o = V_{o1} + V_{o2} = -20V_1 + 20V_2 = \boxed{20(V_2 - V_1) = V_o}$$

IF $V_1 = 10\sin(2\pi \times 60t) - 0.1\sin(2\pi \times 1000t)$ V

$V_2 = 10\sin(2\pi \times 60t) + 0.1\sin(2\pi \times 1000t)$ V

$V_o = 20(V_2 - V_1)$,

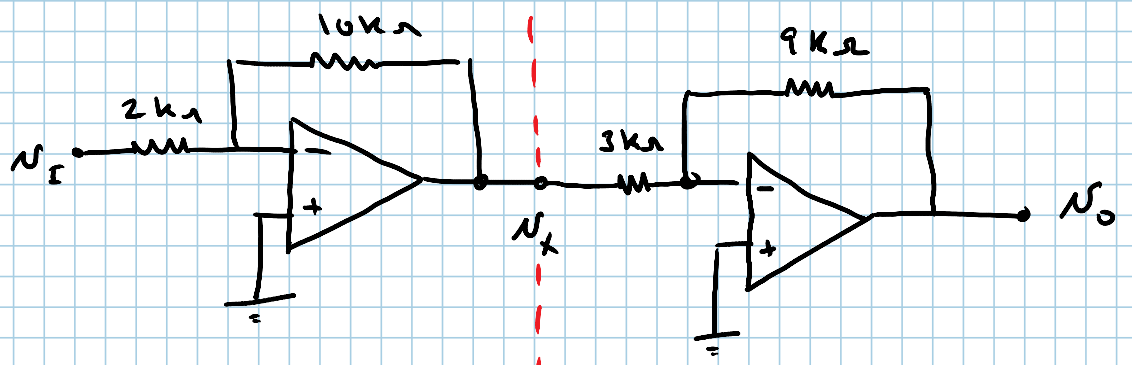
$V_2 - V_1 = \left[10\sin(2\pi \times 60t) + 0.1\sin(2\pi \times 1000t)\right] - \left[10\sin(2\pi \times 60t) - 0.1\sin(2\pi \times 1000t)\right]$

$V_2 - V_1 = 0.2\sin(2\pi \cdot 1000t)$

$V_o = 20\ V_2 - V_1 = 4\sin(2\pi \times 1000t)$ V

Cascade Op-Amp Circuits

Thursday, June 04, 2015
6:06 PM

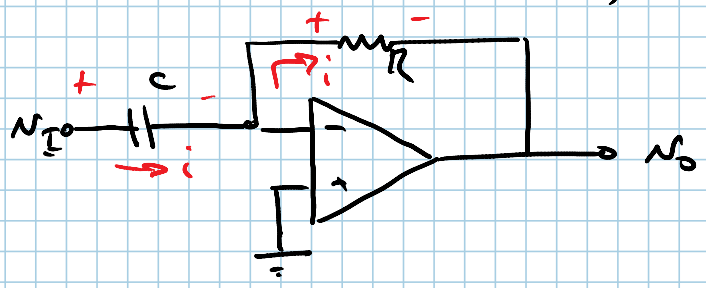


$$v_x = -\left(\frac{10k_\Omega}{2k_\Omega}\right) v_I = -5 v_I \qquad v_o = -\left(\frac{9k_\Omega}{3k_\Omega}\right) v_x = -3 v_x$$

$$v_o = -3 v_x = -3(-5 v_I) = +15 v_I$$

$$v_o = +15 v_I, \quad \frac{v_o}{v_I} = A_{cl} = +15$$

$$A_{cl} = (A_{cl_1})(A_{cl_2})$$



$$i = C\frac{dv_I}{dt}$$

$$i = \frac{0 - v_o}{R} = \frac{-v_o}{R}$$

$$v_I = 0.1 \sin(2\pi 1000 t)\ V$$

$$\frac{dv_I}{dt} = 2\pi 100 \cos(2\pi 1000 t)$$

$$\frac{v_o}{R} = -C\frac{dv_I}{dt}$$

$$\boxed{v_o = -RC\frac{dv_I}{dt}}$$