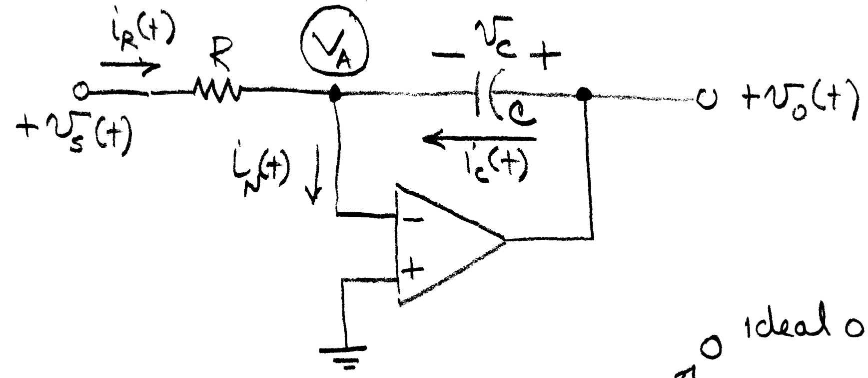
6-3 Dynamic Op-Amp Circuits



ideal op-amp

KCL @ node A $\quad \sum_{in} i = 0 \quad i_R(t) - \cancel{i_N}(t) + i_C(t) = 0$

$$i_R(t) = \frac{v_S(t) - \cancel{v_A(t)}}{R}$$

since $v_N = v_P = 0$

$$i_C(t) = C\frac{dv_C}{dt} = C\frac{d}{dt}\left[v_o(t) - \cancel{v_A(t)}\right]$$

$$\frac{1}{R}v_S(t) + C\frac{dv_o(t)}{dt} = 0$$

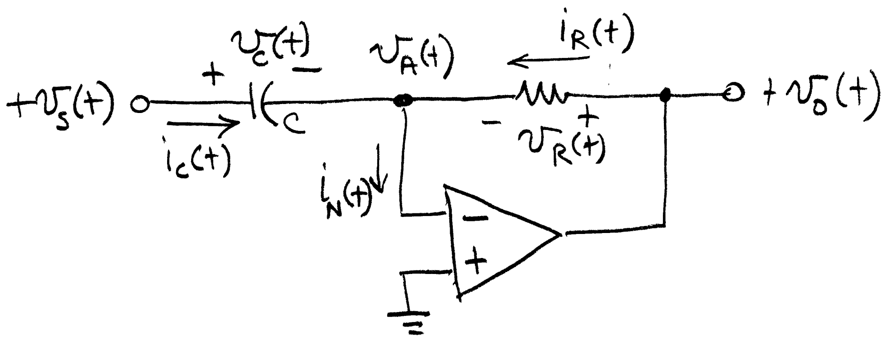
$$dv_o = -\frac{1}{RC}v_S(t)\,dt$$

$$\int_{v_o(0)}^{v_o(t)} dv_o = -\frac{1}{RC}\int_0^t v_S(x)\,dx$$

If $v_C(t=0) = 0$ then $v_C(t) = v_o(t)$ so $v_o(t=0) = 0$

$$\therefore \; v_o(t) = -\frac{1}{RC}\int_0^t v_S(x)\,dx$$

This is an integrator!
(technically an inverting integrator).



doing KCL @ node A $\sum_{+in} i = 0$ $\qquad i_c(t) - \cancelto{0}{i_N(t)} + i_R(t) = 0$

$$i_R(t) = \frac{v_o(t) - \cancelto{0}{v_A(t)}}{R}$$

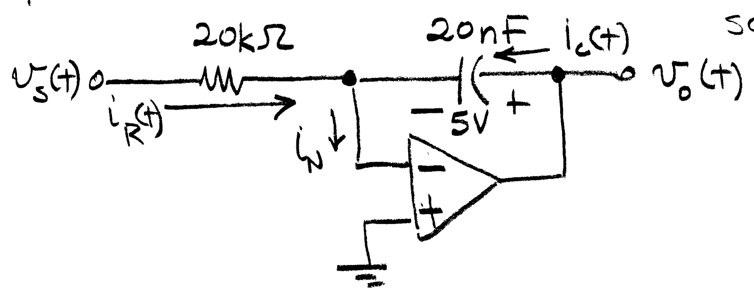
$$i_c(t) = C\frac{dv_c}{dt} = C\frac{d}{dt}\left[v_s(t) - \cancelto{0}{v_A(t)}\right] = C\frac{dv_s(t)}{dt}$$

$$C\frac{dv_s(t)}{dt} + \frac{1}{R}v_o(t) = 0$$

$$v_o(t) = -\frac{1}{RC}\frac{dv_s(t)}{dt}$$

This is an inverting differentiator.

Example 6-9 For $v_s(t) = 10u(t)$ find $v_o(t)$. The OPAMP saturates at $v_o = \pm 15$.



$\sum i = 0$ $\quad i_R(t) - i_N(t) + i_c(t) = 0$

+in

$$\frac{v_s(t) - 0}{R} - \cancel{i_N}^{\,0}(t) + C\frac{d}{dt}\left[v_o(t) - 0\right].$$

$$\frac{1}{RC} v_s(t) = -\frac{dv_o(t)}{dt}$$

$$dv_o = -\frac{1}{RC} v_s(t)\, dt$$

$$\int_{v_o(0)}^{v_o(t)} dv_o = -\frac{1}{RC}\int_0^t v_s(t)\, dt$$

$$v_o(t) - \underbrace{v_o(0)} = -\frac{1}{(20\times10^3)(20\times10^{-9})}\int_0^t 10\,dt$$

$$v_o(0) = +5 \text{ volts}$$

$$v_o(t) = 5 - \frac{1}{4\times10^{-3}}\,10(t-0) = 5 - 25000t$$

This is a negative going ramp. This will reach saturation when $v_o(t) = -15$.

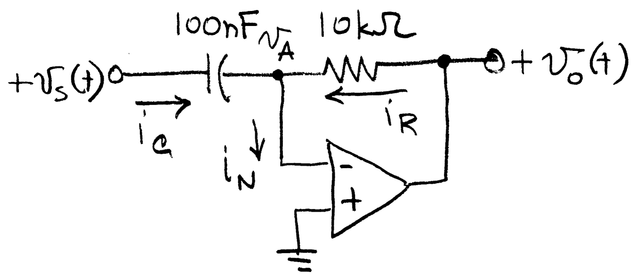
$$5 - 25000t = -15$$

$$25000t = 15 + 5 = 20$$

$$t = \frac{20}{25000} = 0.8\times10^{-3} = 0.8 \text{ msec.}$$

Example 6-10

Find the circuit's output to the given trapezoidal waveform.
The OP-AMP saturates for $v_o(t) = \pm 15V$.



$$\sum_{+in} i = 0 \qquad +i_c + i_R - \cancelto{0}{i_N} = 0$$

$$C\frac{d}{dt}\left[v_s - \cancelto{0}{v_A}\right] + \frac{1}{R}\left[v_o - \cancelto{0}{v_A}\right] = 0$$

$$RC\frac{dv_s}{dt} + v_o = 0$$

$$v_o(t) = -RC\frac{dv_s}{dt}$$

$$= -(10^4)(10^2 \times 10^{-9})\frac{dv_s}{dt}$$

$$= -\frac{1}{1000}\frac{dv_s}{dt}$$