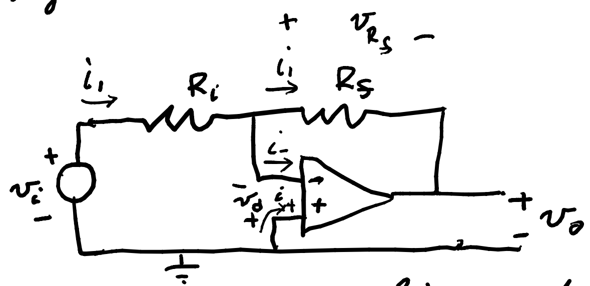
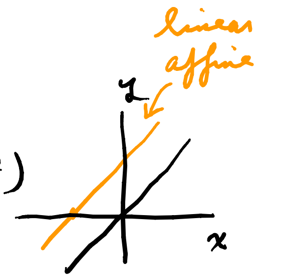
EE303 MP
09/15/09

op-amp ⇒ more details on
why a virtual input
hysteresis



assume op-amp is linear affine (off-set)



law of op-amp

$$v_o = \frac{A_0 v_d}{1 + s/\omega_0} + V_{os}, \quad i_+ = i_- = 0$$

$$v_i = R_i i_1 + (-v_d) \Rightarrow i_1 = G_i (v_i + v_d)$$

$$v_{R_S} = R_S i_1 = -(v_d + v_o) \Rightarrow i_1 = -G_S (v_d + v_o)$$

solve for v_d: $G_i v_i + G_i v_d = -G_S v_d - G_S v_o$ } if $v_d = 0$

$$(G_i + G_S) v_d = -G_i v_i - G_S v_o \qquad 0 = -G_i v_i - G_S v_o$$

$$\Rightarrow v_d = -\frac{G_i}{G_i+G_S} v_i - \frac{G_S}{G_i+G_S} v_o \qquad \Rightarrow v_o = -\frac{G_i}{G_S} v_i$$

$$v_o = \frac{A_0}{1+s/\omega_0}\left(-\frac{G_i v_i}{G_i+G_S} - \frac{G_S}{G_i+G_S} v_o\right) + V_{os}$$

$$\left(1 + \frac{A_0}{1+s/\omega_0} \cdot \frac{G_S}{G_i+G_S}\right) v_o = -\frac{A_0}{1+s/\omega_0} \cdot \frac{G_i}{G_i+G_S} v_i + V_{os}$$

$$v_o = \frac{-\frac{A_0}{1+s/\omega_0} \cdot \frac{G_i}{G_i+G_S}}{1 + \frac{A_0}{1+s/\omega_0} \cdot \frac{G_S}{G_i+G_S}} \cdot v_i + \frac{1}{1 + \frac{A_0}{1+s/\omega_0} \cdot \frac{G_S}{G_i+G_S}} \cdot V_{os}$$

Now look at $s = 0$, DC, and assume $A_0 \gg 1$

$$v_o = \frac{-A_0 \frac{G_i}{G_i+G_S}}{1 + \frac{+A_0 G_S}{G_i+G_S}} v_i + \frac{1}{1 + A_0 \frac{G_S}{G_i+G_S}} V_{os}$$

$$\approx \frac{-A_0 \frac{G_i}{G_i+G_S}}{A_0 \frac{G_S}{G_i+G_S}} v_i + \frac{G_i+G_S}{A_0 G_S} V_{os}$$

$$\approx -\frac{G_i}{G_f} v_i \quad + 0$$ i.e. here can take $v_d = 0$

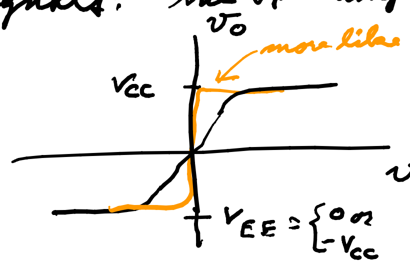
∴ at the op-amp input $v_d = 0$, $i_{in} = 0 = i_+ = i_-$

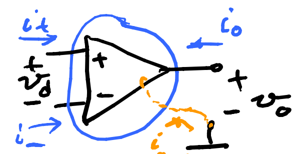
i.e. the + & the − inputs are "virtually" tied

if + is at the ground this is a virtual ground

this is for low frequencies (practically at $f < 100\,kHz$)

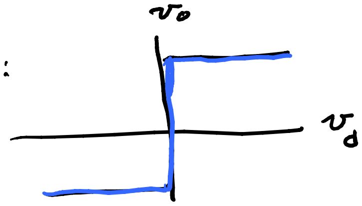
For large signals: the op-amp will saturate

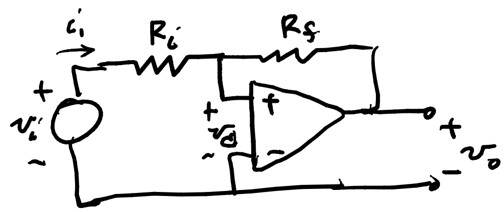




KCL: $\underbrace{i_+ + i_-}_{0} + i_o = 0$ + i_{gnd}

If a step:

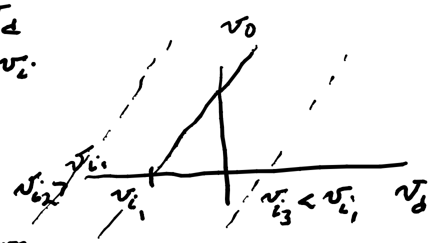


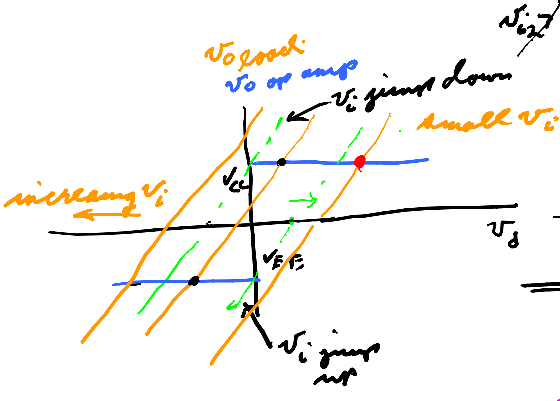


$$G_i(v_i - v_d) = G_f(v_d - v_o)$$

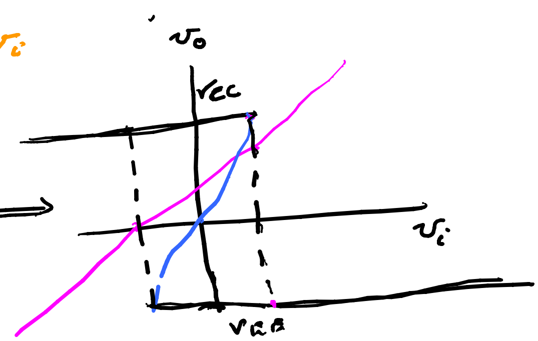
$$G_f v_o = G_f v_d - G_f v_i + G_i v_d$$
$$= (G_i + G_f) v_d - G_f v_i$$

$$\Rightarrow \quad v_o = \left(1 + \frac{G_i}{G_f}\right) v_d - v_i$$





$\Longrightarrow$



Schmitt trigger