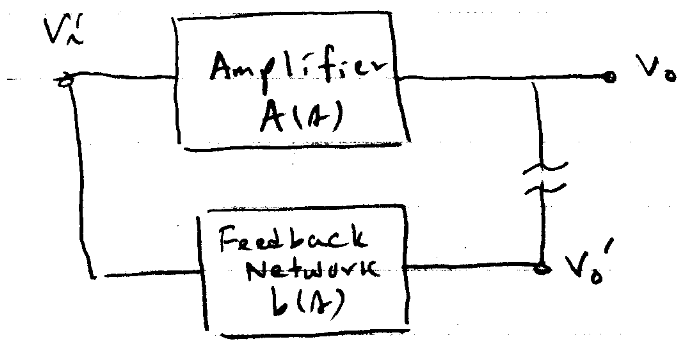
Oscillators



The loop gain is

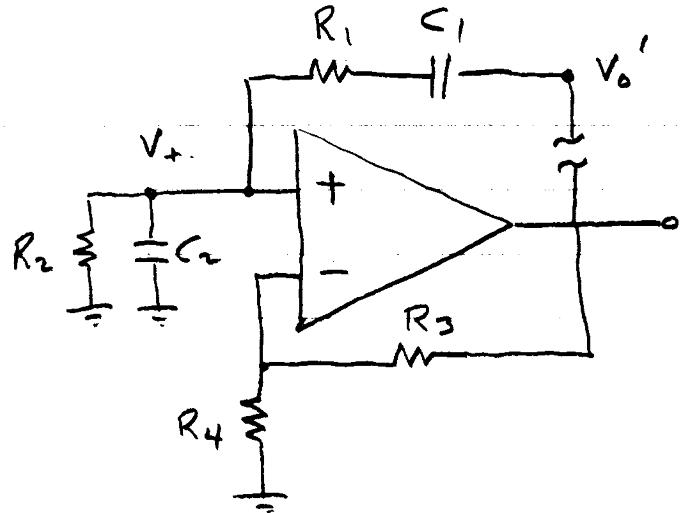
$$\frac{V_o}{V_o'} = b(s)\,A(s)$$

For $s = j\omega$, if there is an ω for which

$$b(j\omega)\,A(j\omega) = 1\angle 0^\circ$$

the circuit will oscillate at that frequency if the loop is closed.

The Wein Bridge Oscillator



$$V_o = \left(1 + \frac{R_3}{R_4}\right) V_+$$
$$= K\, V_+$$

$$V^+ = V_o' \frac{R_2 \| \frac{1}{C_2 s}}{R_1 + \frac{1}{C_1 s} + R_2 \| \frac{1}{C_2 s}}$$

$$= V_o' \frac{\dfrac{R_2 \times \frac{1}{C_2 s}}{R_2 + \frac{1}{C_2 s}}}{R_1 + \frac{1}{C_1 s} + \dfrac{R_2 \times \frac{1}{C_2 s}}{R_2 + 1/C_2 s}}$$

$$= V_o' \frac{\dfrac{R_2}{1 + R_2 C_2 s}}{\dfrac{1 + R_1 C_1 s}{C_1 s} + \dfrac{R_2}{1 + R_2 C_2 s}}$$

$$= V_o' \frac{R_2 C_1 s}{(1 + R_1 C_1 s)(1 + R_2 C_2 s) + R_2 C_1 s}$$

$$\Rightarrow \quad V^{+} = V_o' \frac{R_2 C_1 s}{R_1 R_2 C_1 C_2 s^2 + (R_1 C_1 + R_2 C_1 + R_2 C_2) s + 1}$$

$$\Rightarrow \quad \frac{V_o}{V_o'} = K \frac{R_2 C_1 s}{R_1 R_2 C_1 C_2 s^2 + (R_1 C_1 + R_2 C_1 + R_2 C_2) s + 1}$$

Let $s = j\omega$

$$\Rightarrow \quad \frac{V_o}{V_o'} = K \frac{j\omega R_2 C_1}{1 - \omega^2 R_1 R_2 C_1 C_2 + j\omega (R_1 C_1 + R_2 C_1 + R_2 C_2)}$$

For $\omega = \dfrac{1}{\sqrt{R_1 R_2 C_1 C_2}}$

$$\frac{V_o}{V_o'} = K \frac{R_2 C_1}{R_1 C_1 + R_2 C_1 + R_2 C_2} \angle 0^\circ$$

Adjust R_3 & R_4 such that

$$K = 1 + \frac{R_3}{R_4} = \frac{R_1 C_1 + R_2 C_1 + R_2 C_2}{R_2 C_1}$$

$$= 1 + \frac{R_1}{R_2} + \frac{C_2}{C_1}$$

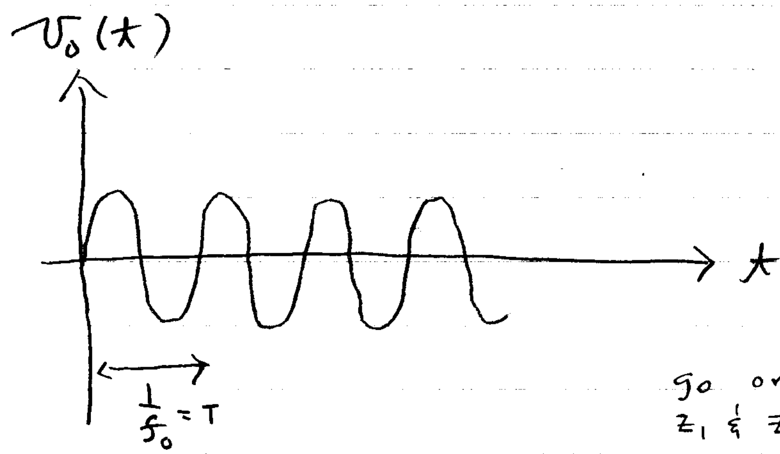
$$\Rightarrow \quad \frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1}$$

In this case

$$\frac{V_o}{V_o'} = 1 \angle 0^\circ$$

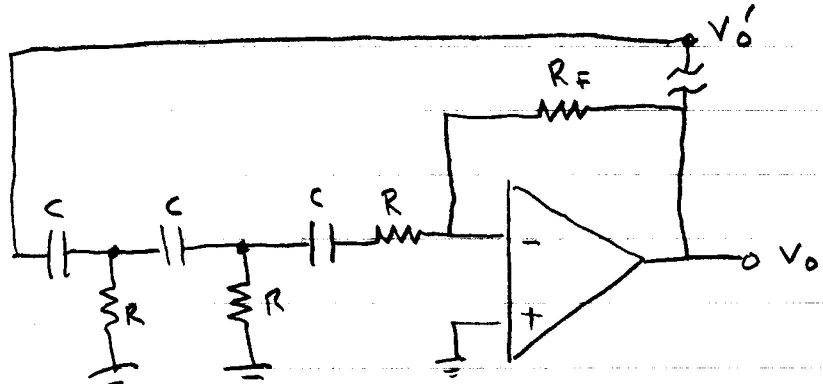
and the circuit will oscillate at the freq

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$



go over ckt with Z_1 & Z_2 reversed.

Phase Shift Oscillator



It can be shown that

$$\frac{V_o}{V_o'} = -\frac{R_F}{R}\,\frac{(RCs)^3}{(RCs)^3 + 6(RCs)^2 + 5(RCs) + 1}$$

Let $s = j\omega$

$$\frac{V_o}{V_o'} = -\frac{R_F}{R}\,\frac{-j(\omega RC)^3}{1 - 6(\omega RC)^2 + j\left(5\omega RC - (\omega RC)^3\right)}$$

Let $\omega = \omega_o = \dfrac{1}{RC\sqrt{6}}$

$$\frac{V_o}{V_o'} = +\frac{R_F}{R}\,\frac{(\omega_o RC)^3}{5\omega_o RC - (\omega_o RC)^3}$$

$$= +\frac{R_F}{R}\,\frac{1}{\frac{5}{(\omega_o RC)^2} - 1}$$

The circuit will oscillate at ω_o if

$$\frac{R_F}{R}\,\frac{1}{\frac{5}{(\omega_o RC)^2} - 1} = 1$$

$$\Rightarrow \quad \frac{R_F}{R} = \frac{5}{(\omega_o R C)^2} - 1$$

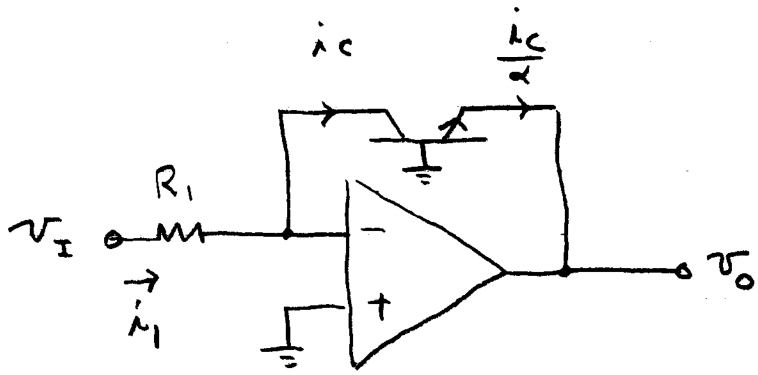
$$= 30 - 1$$

$$= 29$$

$$\Rightarrow \quad R_F = 29 R$$

Non-Linear Circuits

The Log Converter



$$i_C = i_1 = \frac{v_I}{R_1}$$

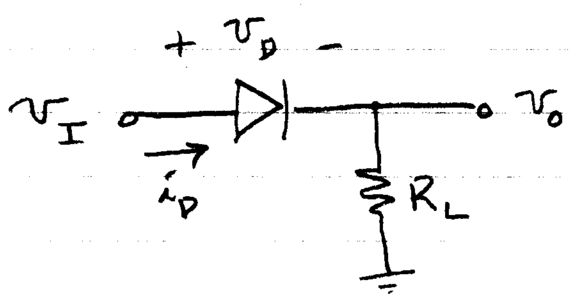
But $i_C = I_S e^{v_{BE}/V_T} = I_S e^{-v_O/V_T}$

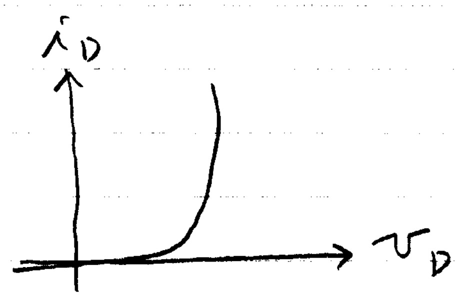
$\Rightarrow \quad \frac{v_I}{R_1} = I_S e^{-v_O/V_T}$

$\Rightarrow \quad v_O = -V_T \ln\left(\frac{v_I}{I_S R_1}\right)$

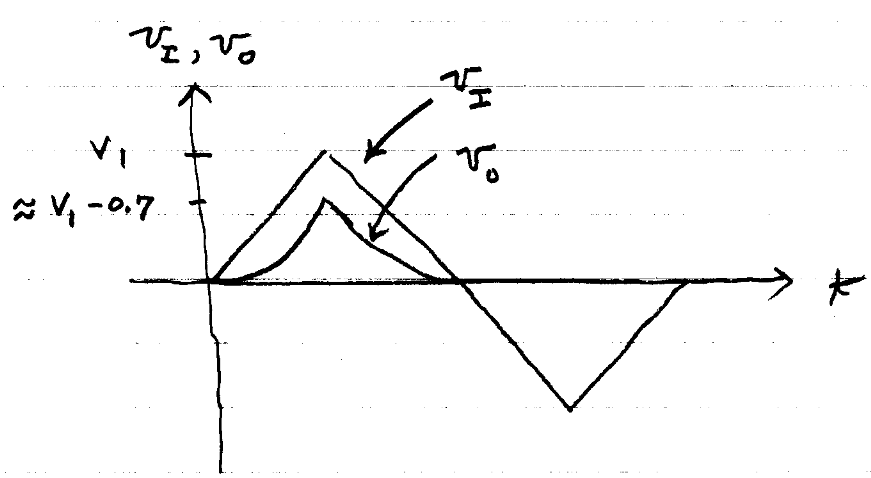
The Precision Rectifier

First, let us look at a diode rectifier

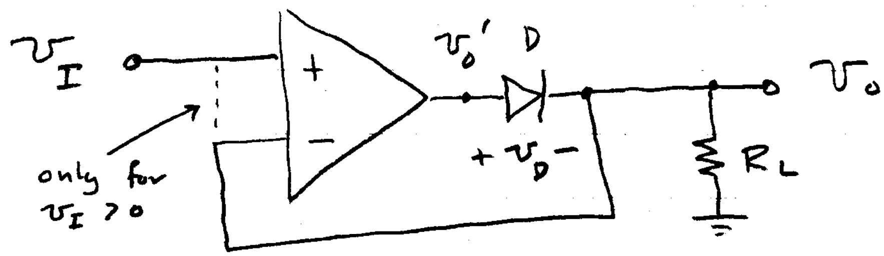




Let v_I be a triangle wave



For a better rectifier, we can use an op amp circuit as follows



$v_I > 0 \Rightarrow v_o' > 0 \Rightarrow$ D on

$\Rightarrow v_o = v_I$ because the op amp has feedback

$$v_o' = v_o + v_D$$

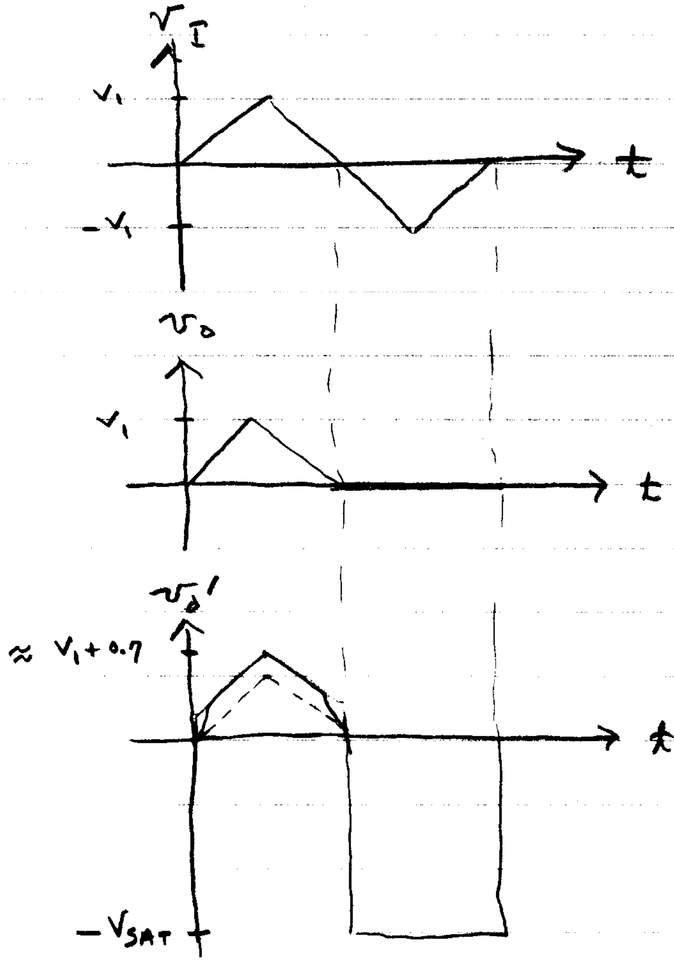
$v_I < 0 \Rightarrow v_o' < 0 \Rightarrow$ D off

the op-amp loses feedback and v_o' drops to

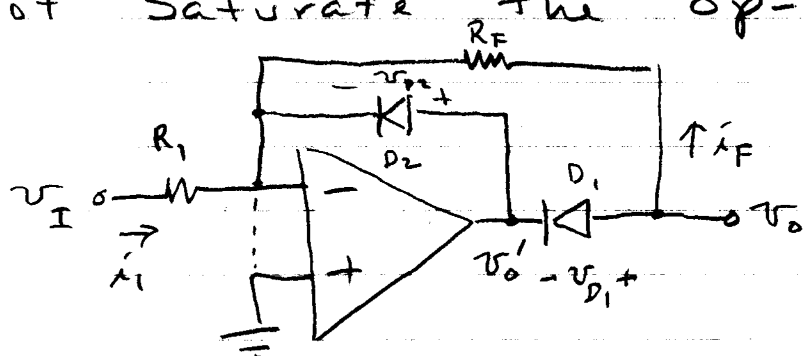
$v_o' = -V_{SAT}$ (the neg. sat. volt.)

$v_o = 0$ because D is off

Let v_I be a triangle wave.



An inverting rectifier which does not saturate the op-amp



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(5)

$v_I > 0 \Rightarrow v_o' < 0 \Rightarrow D_1$ on D_2 off

$i_1 = \frac{v_I}{R_1} \quad i_F = \frac{v_o}{R_F}$

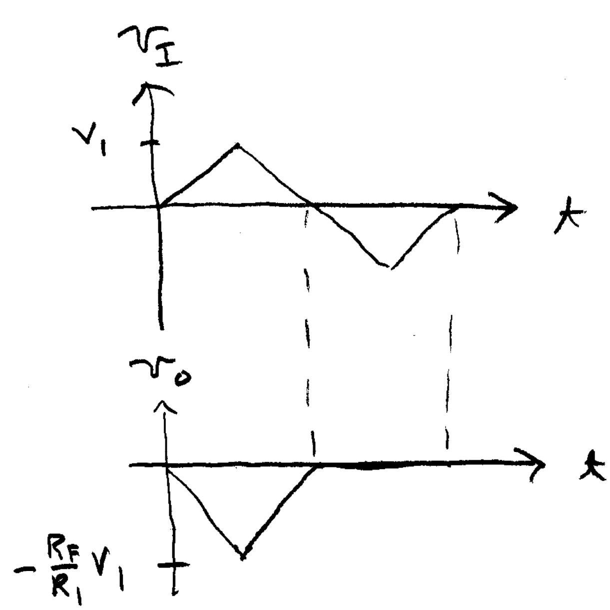
$i_1 + i_F = 0 \Rightarrow \frac{v_I}{R_1} + \frac{v_o}{R_F} = 0 \Rightarrow v_o = -\frac{R_F}{R_1} v_I$

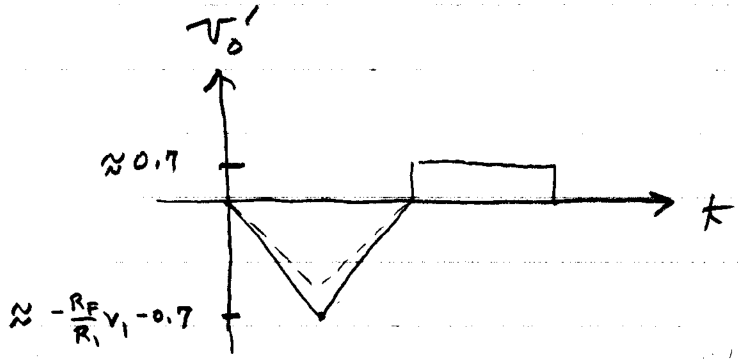
$v_o' = v_o - v_{D1}$
$< v_o$

$v_I < 0 \Rightarrow v_o' > 0 \Rightarrow D_1$ off D_2 on

$\Rightarrow v_o = 0$

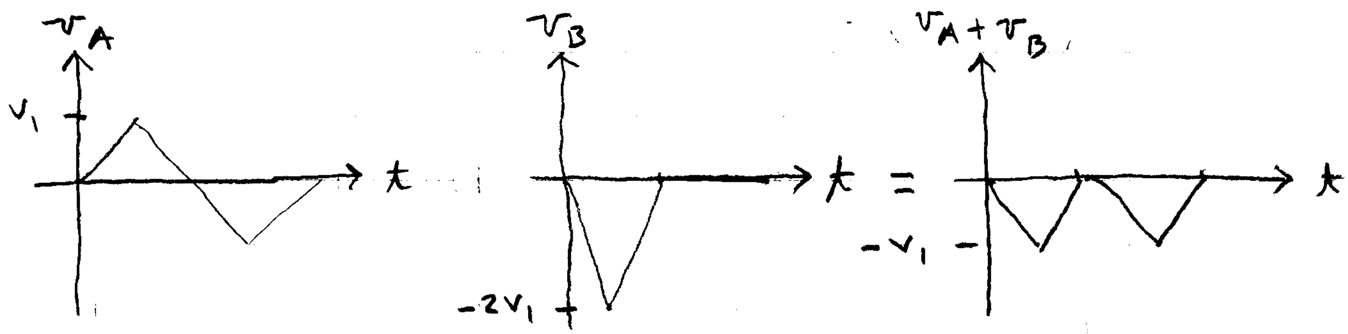
$v_o' = + v_{D2}$
> 0

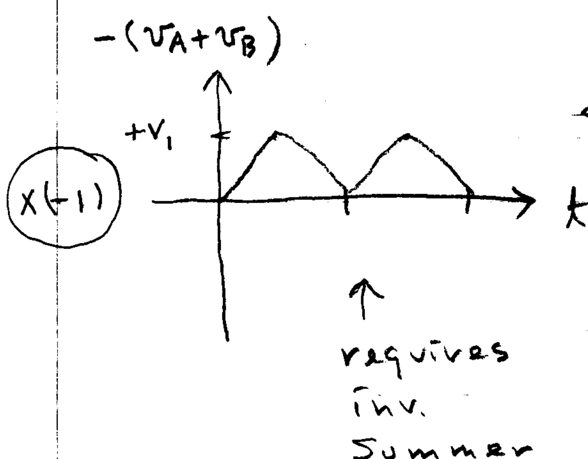




A Full Wave Rectifier

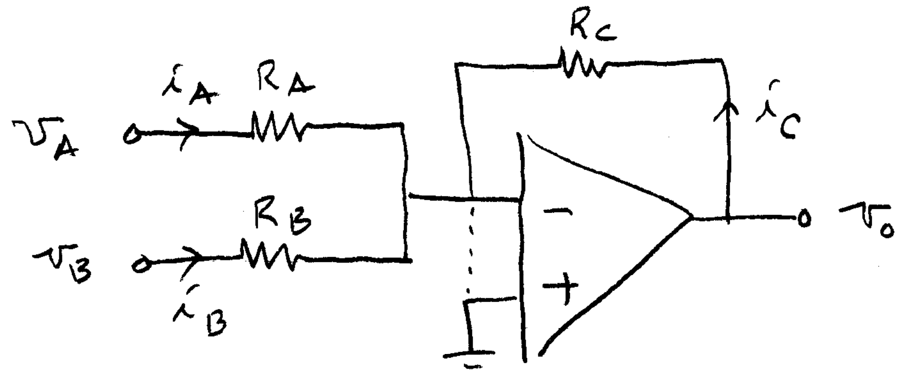
Basic Scheme





2 operations can be done with an inverting summer

Inverting Summer



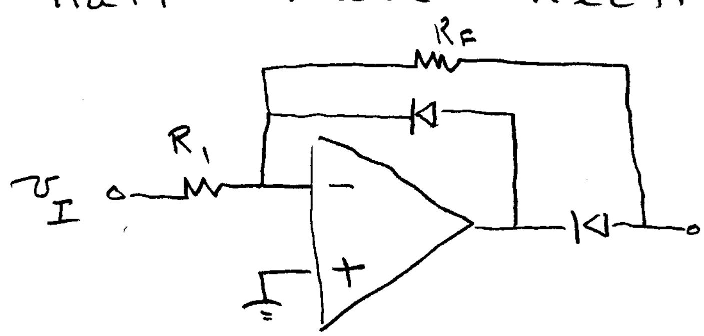
$$i_A + i_B + i_C = 0$$

$$\Rightarrow \frac{v_A}{R_A} + \frac{v_B}{R_B} + \frac{v_o}{R_C} = 0$$

$$\Rightarrow v_o = -\frac{R_C}{R_A} v_A - \frac{R_C}{R_B} v_B$$

Let $R_A = R_B = R_C = R_2$

Half Wave Rectifier



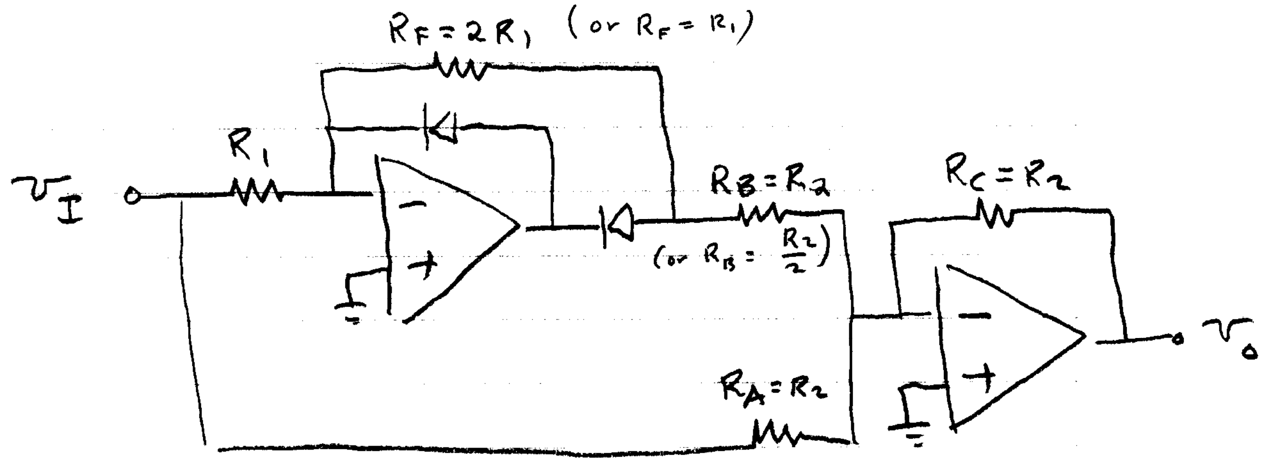
$v_B = -\frac{R_F}{R_1} v_I$ for $v_I > 0$

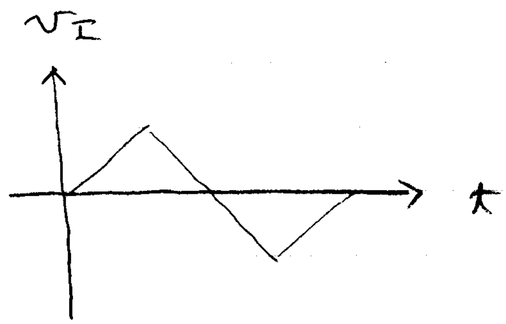
$= 0$ for $v_I < 0$

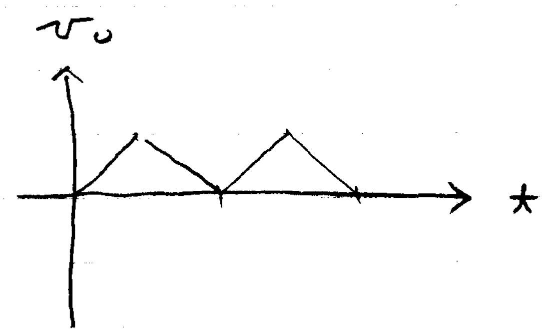
Let $R_F = 2R_1$

$\Rightarrow v_B = -2v_I$ for $v_I > 0$

Final Circuit

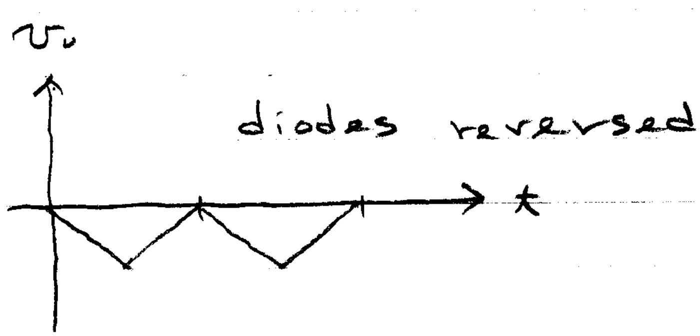




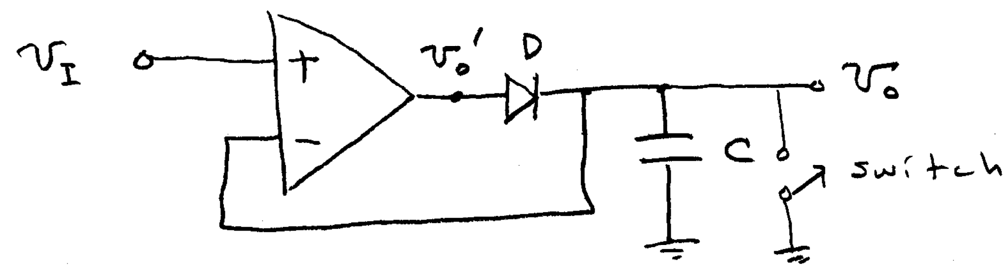


Could also make $R_F = R_1$ & $R_B = \frac{R_2}{2}$ for same output - is preferable to minimize clipping

If the diodes are reversed, v_o is inverted

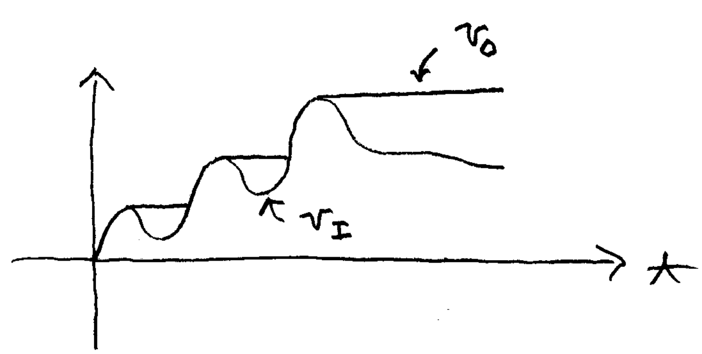


Peak Detectors



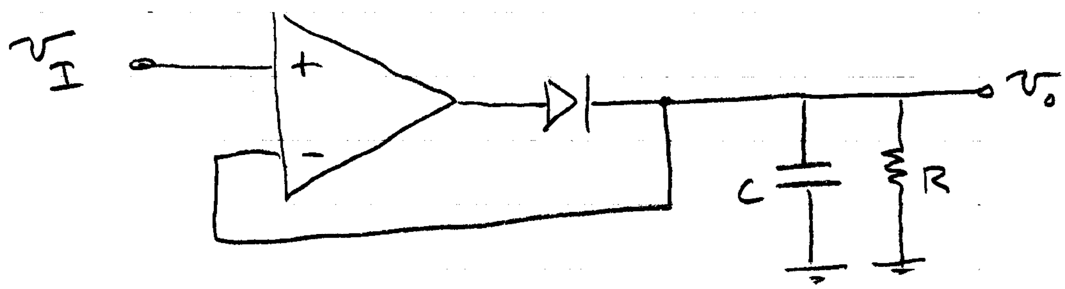
$v_I < v_O \Rightarrow$ D OFF, the op amp loses feedback $\Rightarrow v_o' = -V_{SAT}$. v_O cannot change because the capacitor current is zero.

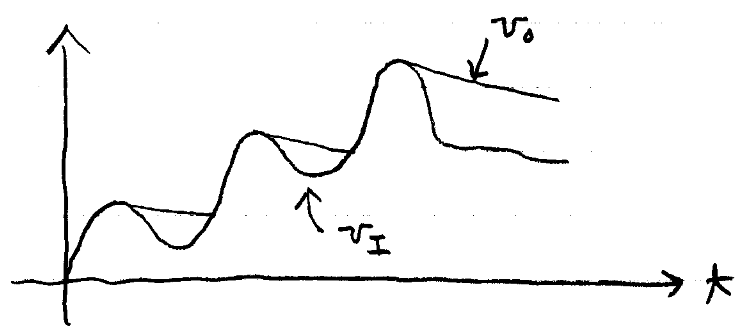
$v_I > v_O \Rightarrow$ D ON, the op amp has feedback. The capacitor charges until $v_O = v_I$.



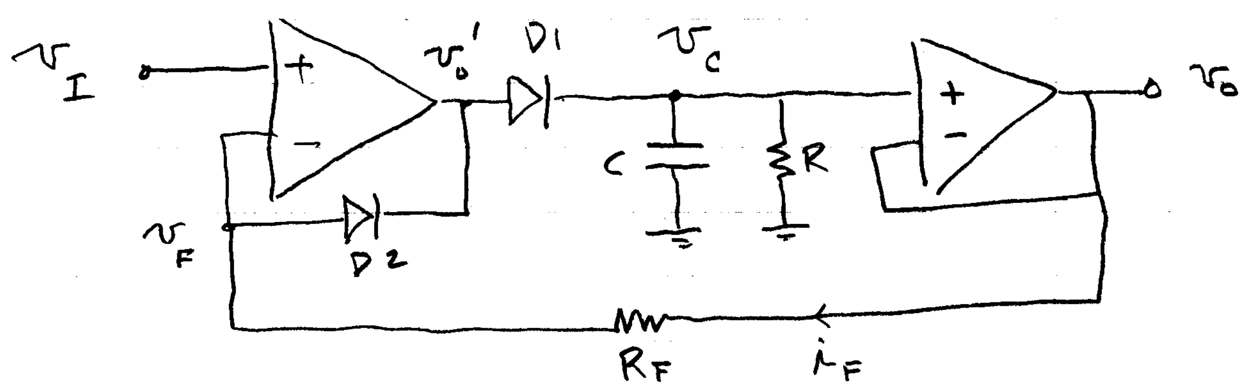
The switch can be closed to reset the circuit. Often, the switch is a FET.

In some applications, the switch is replaced with a resistor, e.g. in a VU meter.





The following circuit is better because the op amp does not saturate



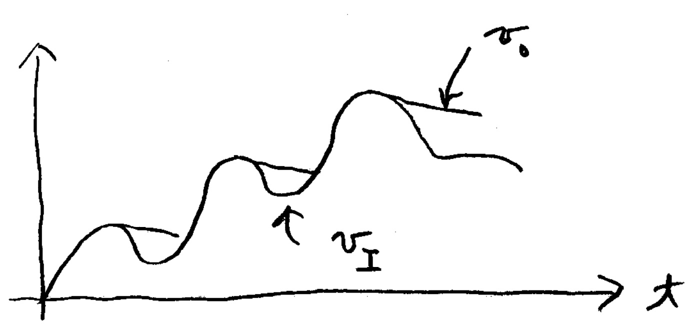
$v_I > v_o \Rightarrow v_o'$ goes positive
$\Rightarrow$ D1 ON, D2 OFF
$\Rightarrow i_F = 0 \Rightarrow$ drop across R_F is zero
$\Rightarrow v_F = v_o$

the op amp has feedback
$\Rightarrow v_F = v_I \Rightarrow v_o = v_I$

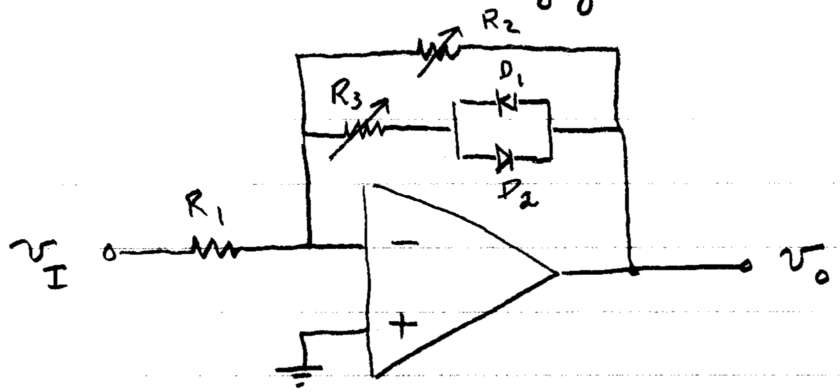
But $v_o = v_C \Rightarrow$ the capacitor charges up to v_I

$v_I < 0 \Rightarrow v_o'$ goes negative
$\Rightarrow$ D1 OFF, D2 ON
$\Rightarrow v_o' = v_F - v_{D2}$

The op amp has feedback
$\Rightarrow v_F = v_I \Rightarrow v_o' = v_I - v_{D2}$
$i_F = \frac{v_o - v_I}{R_F}$ (Note R_F cannot be 0)



A Guitar "Fuzz Box" Clipper



If $R_3 = \infty$, the circuit is an inverting amplifier with gain

$$\frac{v_o}{v_I} = -\frac{R_2}{R_1}$$

If $R_3 = 0$, the output is limited to the value $\pm v_D \cong \pm 0.7$ V.