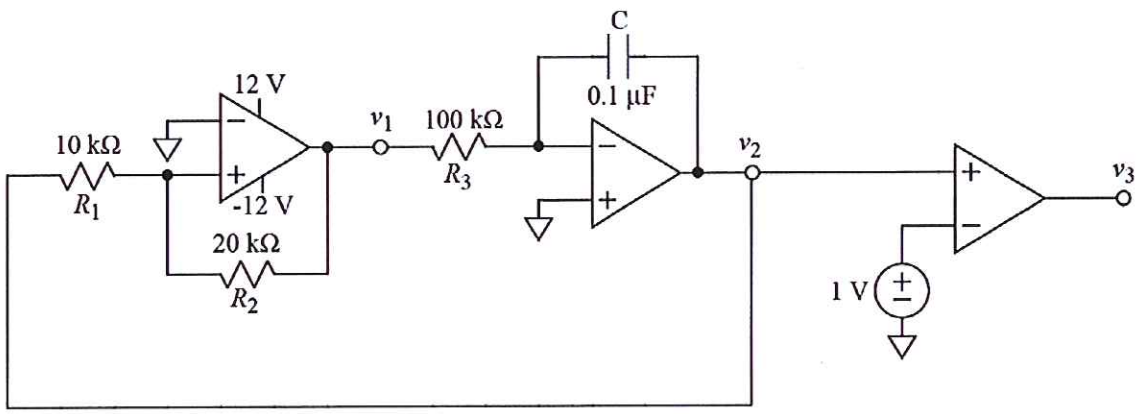
Ex:



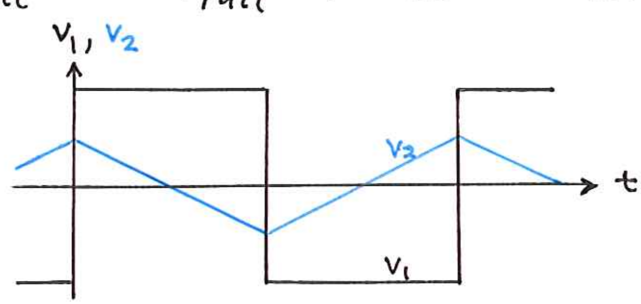
The above circuit is from Lab 4, but some of the component values have been changed. Note that voltage v_2 is a triangle waveform, and v_3 is a Pulse-Width Modulation (PWM) waveform.

a) Find the peak voltage reached by v_2, (i.e., the highest voltage reached by v_2).

b) Find the period of the square wave, $v_1(t)$. Note that the period is one full cycle of high and low voltage.

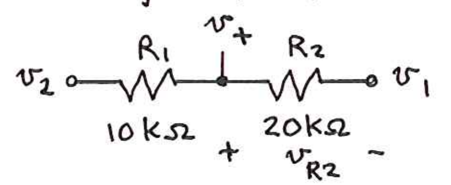
c) Find the duty cycle of $v_3(t)$. That is, find what fraction of each period $v_3(t)$ is high.

sol'n: a) The first stage is a Schmitt trigger that produces square wave v_1 that goes from $+v_{rail}$ to $-v_{rail}$ or $+11V$ to $-11V$.



v_1 switches from + to − when v_2 (triangle wave shown above) causes $v_+ = 0V = v_-$ for first op-amp.

v_+ is determined by the voltage divider involving R_1, R_2, v_1, and v_2.



We have $v_{R2} = (v_2 - v_1)\dfrac{R_2}{R_1 + R_2} = (v_2 - v_1)\dfrac{20k\Omega}{30k\Omega}$

or $v_{R2} = \frac{2}{3}(v_2 - v_1)$

Now, $v_+ = v_1 + v_{R2} = v_1 + \frac{2}{3}(v_2 - v_1)$

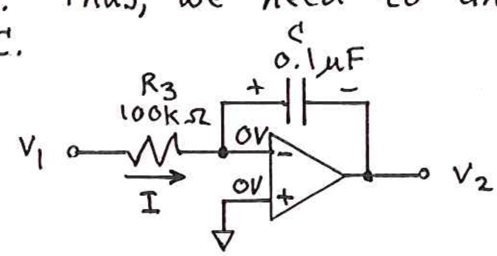
or $v_+ = \frac{1}{3}v_1 + \frac{2}{3}v_2 = 0V$ at switch pt

When $v_1 = -11V$, we solve for v_2:

$$\frac{1}{3}(-11V) + \frac{2}{3}v_2 = 0V$$

or $v_2 = \frac{11}{2}V = 5.5V$ = peak value of v_2.

b) To find the period of v_1, we need to find the slope of v_2 as it rises from $-5.5V$ to $5.5V$. Thus, we need to analyze the charging of C.



We have $v_- = v_+ = 0V$ because of the negative feedback. Current $I = v_1 / R_3 = C\,\Delta v_c/\Delta t$ since I flows into C (not into op-amp).

Since $v_2 = -v_C$, the slope of v_2 equals

$$\frac{-\Delta v_C}{\Delta t} = -\frac{v_1}{R_3 C} = \frac{-(-11V)}{100k\Omega \cdot 0.1\mu F} = \frac{11V}{10\ ms}$$

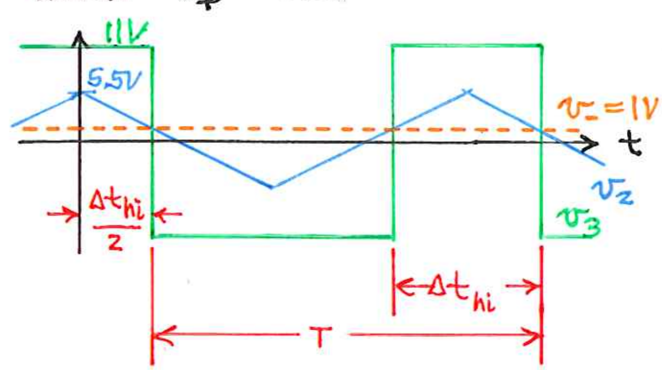
The time it takes v_2 to rise from $-5.5V$ to $5.5V$ is half the period, T:

$$\frac{T}{2} = \frac{5.5V-(-5.5V)}{\text{slope of } v_2} = \frac{11V}{11V/10ms}$$

or $\frac{T}{2} = 10\ ms$

or $T = 20ms$ = period of v_1 (and v_2)

c) The comparator that produces v_3 trips when $v_+ = v_- = 1V$. The output, v_3, is high when $v_+ > v_-$.



The duty cycle is $\Delta t_{hi}/T$. $T = 20ms$ from (b).

We solve for $\frac{\Delta t_{hi}}{2}$:

$$5.5V - \underset{\frac{-11V}{10ms}}{\text{slope } v_2} \cdot \frac{\Delta t_{hi}}{2} = 1V$$

or $\Delta t_{hi} = (5.5V - 1V)(2)/(+11V/10ms) = \frac{90}{11}\ ms$

Duty cycle is $\Delta t_{hi}/T = 90/11(20)\ ms = 0.409$