ECE 1250
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Laboratory 4:
Explanation of PWM Circuit

***Abstract*-This document explains the three circuit sections that constitute the Pulse-Width Modulation (PWM) circuit: a Schmitt trigger, an integrator, and a comparator.**

I. PWM CIRCUIT OVERVIEW

Fig. 1 shows the schematic (sans power supply connections) for the Pulse-Width Modulated (PWM) circuit of Lab 4. Boxes are drawn around the three circuit sections that constitute the PWM circuit: a Schmidt trigger, an integrator, and a comparator. The first two circuit sections work in tandem to produce a triangle waveform, while the third circuit section compares the triangle waveform with a reference voltage to produce a the PWM waveform. Fig. 2 shows the waveforms at the output of each section superimposed over time.

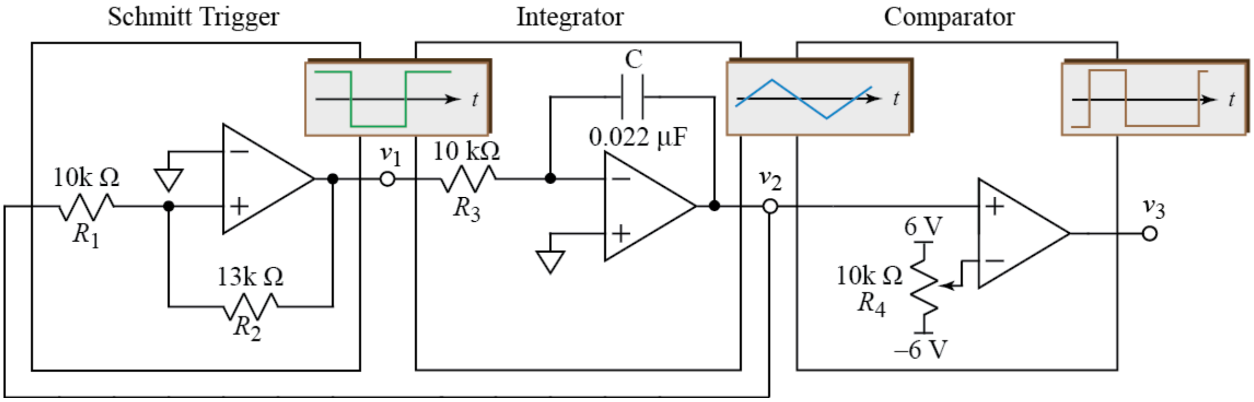

Figure 1. PWM circuit schematic.

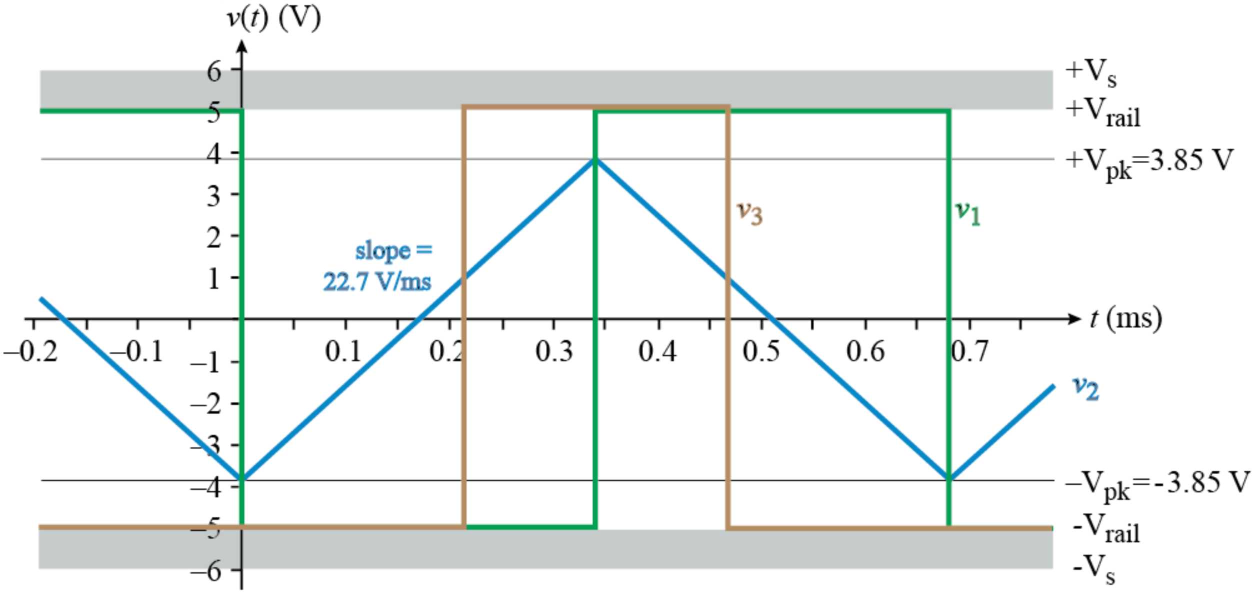

Figure 2. PWM circuit waveforms.

The remainder of this document touches upon the operation of each circuit section in turn.

II. INTEGRATOR

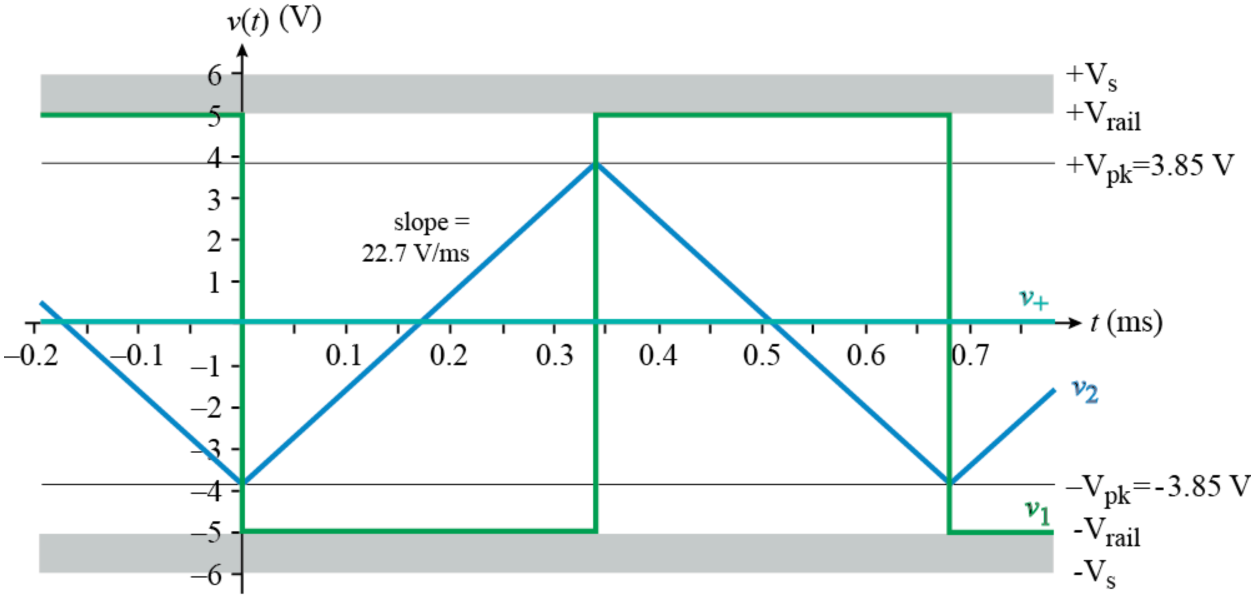

Figure 3. Integrator waveforms.

The output of the Schmitt trigger, v_1, is always either high or low. The current in R_3 is constant and positive or constant and negative. When the current is positive, it fills C with charge. When the current is negative, it drains C of charge. The C acts like a tank being filled and emptied. The left side of the C stays at zero volts. The op-amp adjusts v_2 so as to make the left side of C stay at zero volts. If we think of C as a tank storing charge, it is as though the top of the water stays at ground level, and the bottom of the tank moves up or down as water goes into or out of the tank.

When $v_1 = -\mathrm{V}_{\mathrm{rail}}$, we have the following current flowing toward the minus input of the second op-amp and through the capacitor:

$$I = \frac{V_{\text{rail}}}{R_3} = C\frac{\Delta V_{\text{C}}}{\Delta t} \tag{1}$$

We solve for the slope of v_2, which is the slope of the voltage on the capacitor, since $v_- = 0\text{V}$.

$$v_2 \text{ slope} = \frac{\Delta V_{\text{C}}}{\Delta t} = \frac{V_{\text{rail}}}{R_3 C} \approx \frac{5\,\text{V}}{10\text{k}\cdot 0.022\,\mu\text{s}} = \frac{5\,\text{V}}{0.22\,\text{ms}} \approx 22.7\,\text{V/ms} \tag{2}$$

To find the peak value of v_2 we analyze the Schmitt trigger.

III. SCHMITT TRIGGER

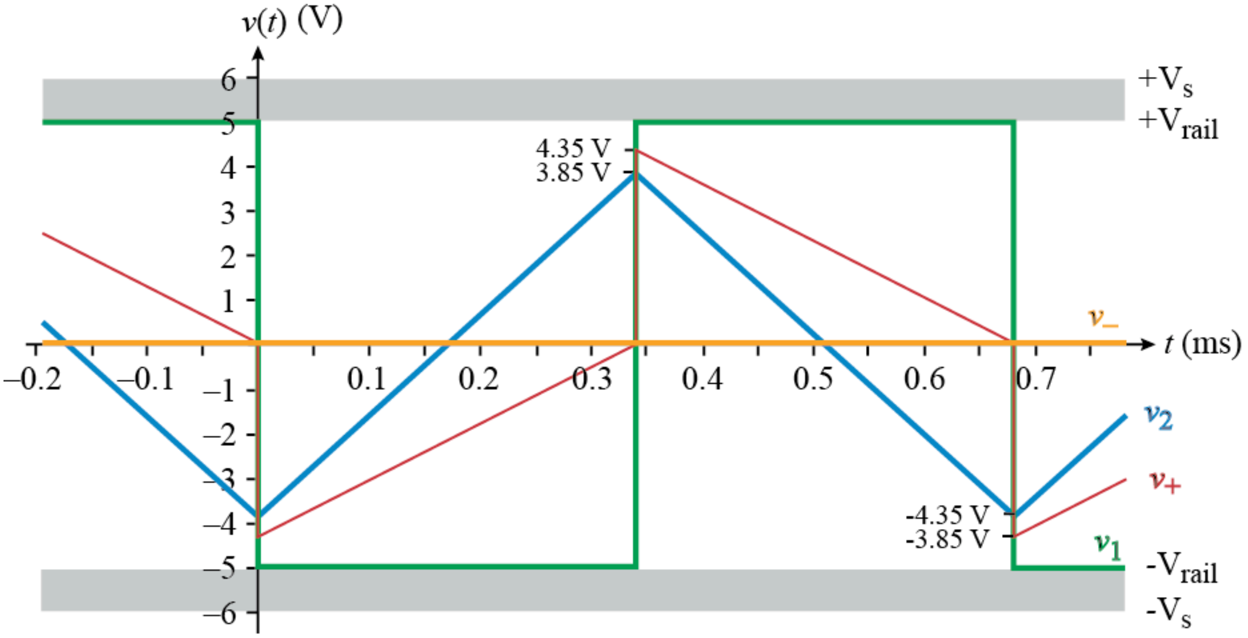

Figure 4. Schmitt trigger waveforms.

The voltage at the v_+ input of the Schmitt trigger is found by using a voltage divider driven on two sides, by v_1 and v_2. Note how the resistor values enter into the calculation.

$$v_+ = \frac{13\,\mathrm{k\Omega} \cdot v_{2\mathrm{pk}} - 10\,\mathrm{k\Omega} \cdot V_{\mathrm{rail}}}{13\,\mathrm{k\Omega} + 10\,\mathrm{k\Omega}} = \frac{13 v_{2\mathrm{pk}} - 50\,\mathrm{V}}{23} \tag{2}$$

The Schmitt trigger output changes when the value v_- crosses $v_+ = 0$ V. Using this idea allows us to calculate the value of v_2 when the output of the Schmitt trigger changes.

$$v_2 = 0\,\mathrm{V} \Rightarrow v_{2\mathrm{pk}} = \frac{50\,\mathrm{V}}{13} = 3.85\,\mathrm{V} \tag{2}$$

We use the slope of v_2 to calculate the time at which the peak value of v_2, (which occurs when v_1 switches), will occur.

$$t_{\mathrm{pk}} = \frac{3.85\,\mathrm{V} - -3.85\,\mathrm{V}}{22.7\,\mathrm{V/ms}} \approx 0.34\,\mathrm{ms} \tag{2}$$

When v_1 switches, the value at v_+ of the first op-amp jumps to a new value. We use the voltage divider formula again to calculate that value.

$$v_+ = \frac{13\,\mathrm{k\Omega}(3.85\,\mathrm{V}) + 10\,\mathrm{k\Omega}(5\,\mathrm{V})}{23\,\mathrm{k\Omega}} \approx 4.35\,\mathrm{V} \tag{2}$$

IV. COMPARATOR

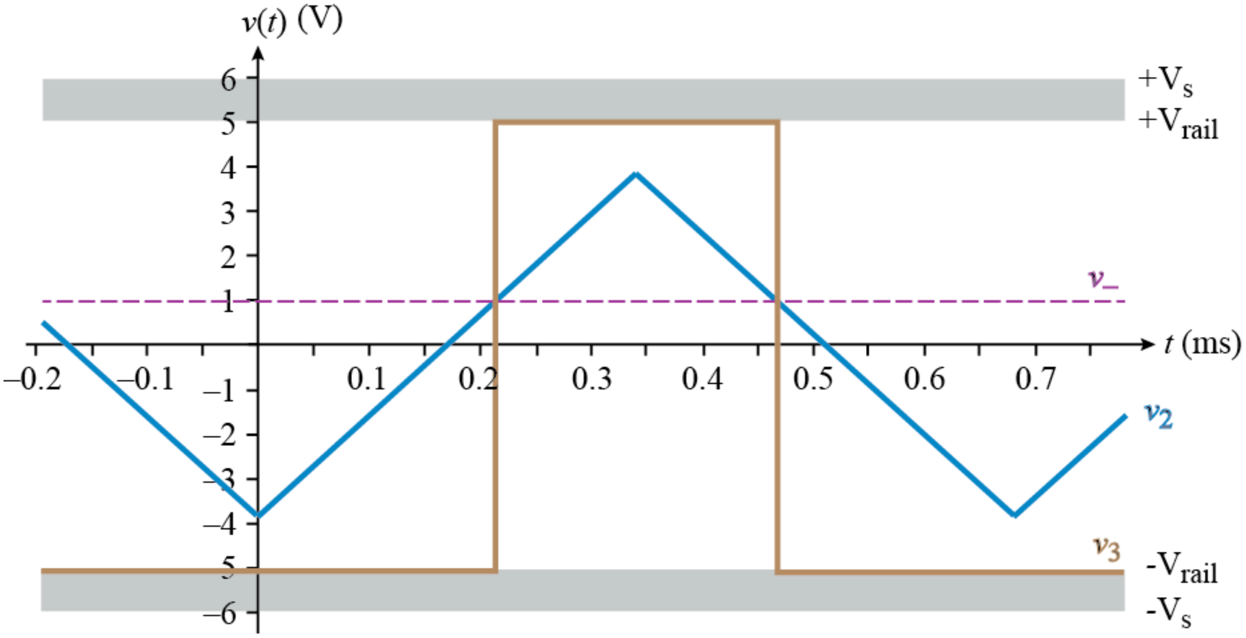

Figure 5. Comparator waveforms.

The comparator output is high when v_2 is higher than the v_- input voltage of the last op-amp. The value of v_- is set by potentiometer R_4. Note that the potentiometer creates a voltage divider. Adjusting R_4 changes the voltage at the v_- input. In Fig. 5, the voltage is shown as 1 V. The higher the value of v_-, the shorter the time v_3 stays high.