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CSE 350: Digital Electronics and Pulse techniques

Exp-06: Analysis of Triangular Wave Generator

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Objectives

1. To analyze a bipolar triangular wave generator.

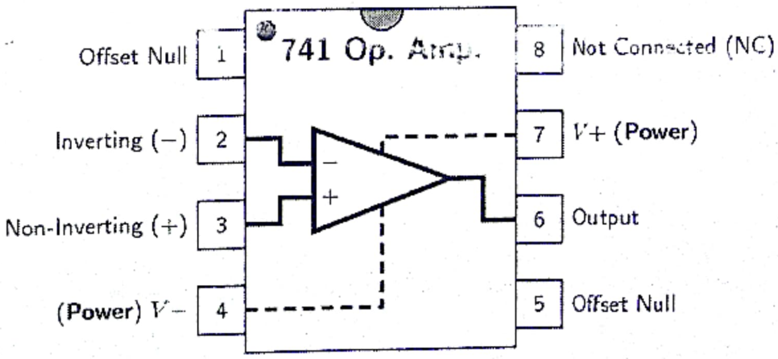
Equipment and component list

Equipment

1. Oscilloscope
2. Trainer board

Component

- Operational amplifier - UA741 - x2 piece
- Capacitor ($0.47\mu F$) - x1 piece
- Resistors -
  - 10 KΩ - x2 pieces
  - 4 KΩ - x1 piece



741 IC pin diagram

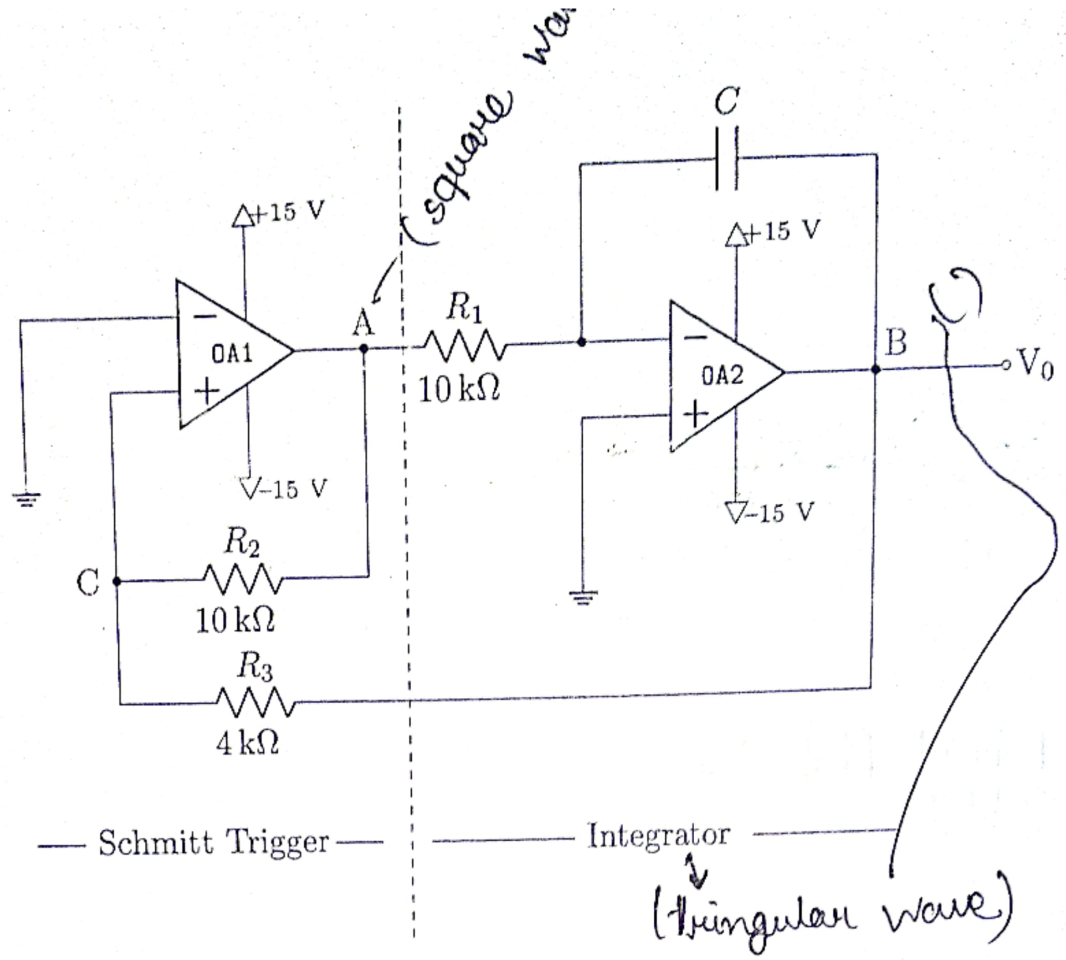


Figure 1: Bipolar Triangular wave generator

Task-01: Bipolar Triangular Wave Generator

THEORY

As can be seen in the figure, the triangular wave oscillator is composed of a Schmitt Trigger circuit and an integration circuit whose operation is explained below. Notice that the output of Scrnitt Trigger (A) is connected to the input of the integrator and the output of the integrator (B) is in turn connected to an input terminal of the Schmitt Trigger through resistor R_3 at point C. We shall observe a square wave at point A and a triangular wave at point B. Whenever point B will rise towards a High value, point A will fall LOW and vice versa.

The integrator circuit is composed of a capacitor, a resistor and an op-amp (**OA2**) in the negative feedback configuration. In negative feedback operation, there are two very important rules to remember. Firstly, no current flows either into or out through the input terminals of the op-amp. Secondly, the voltages of the two input terminals of the op-amp are equal. As the non-inverting input terminal of **OA2** (op-amp 2) is connected to ground, both this and the inverting input terminal of the op-amp will be at zero volt. Hence, the left terminal of the capacitor will always be fixed at zero volt.

Now let us shift our focus to the Schmitt Trigger for a moment. Here, the op-amp **OA1** is in positive feedback configuration unlike **OA2**. In this mode. the op-amp acts like a comparator. It compares the voltages of the two input terminals and sets the output voltage accordingly. If the voltage of the positive terminal is greater than the negative terminal ($V+ > V-$), then the output (A) will be HIGH. As the negative input terminal is connected to ground, the output A will be HIGH whenever the voltage at the positive terminal becomes greater than zero. In case of turning on, the output of the Schmitt circuit (point A) becomes equal to either the positive or negative saturated voltage. In the following explanation, we will assume that initially the output at point A is at the positive saturated voltage (+15V). As a result, electric current starts flowing from point A toward point B through the resistor R1.

Remember that as **OA2** is in negative feedback configuration, there is no current flow either in or out through the input terminals of **OA2**. Hence, all the current flows through the capacitor C to point B when the A point becomes positive. Due to this current flow form A to B, the electric charge begins to store up in the left side of the capacitor. Consequently, the voltage of the left side must rise higher than the right side. However, the left terminal of the capacitor is fixed at zero volt due to the negative feedback of **OA2**. Hence, the voltage of the right side of the capacitor (point B) starts to fall. Thus, when the output of Schmitt Trigger (A) is HIGH, the voltage of the output (B) of the integration circuit falls gradually. This rise-drop can be seen in the wave of figure 2 between time T_0 and T_1.

Now point B is in turn connected to the positive input terminal of Schmitt Trigger circuit (**OA1**) at point

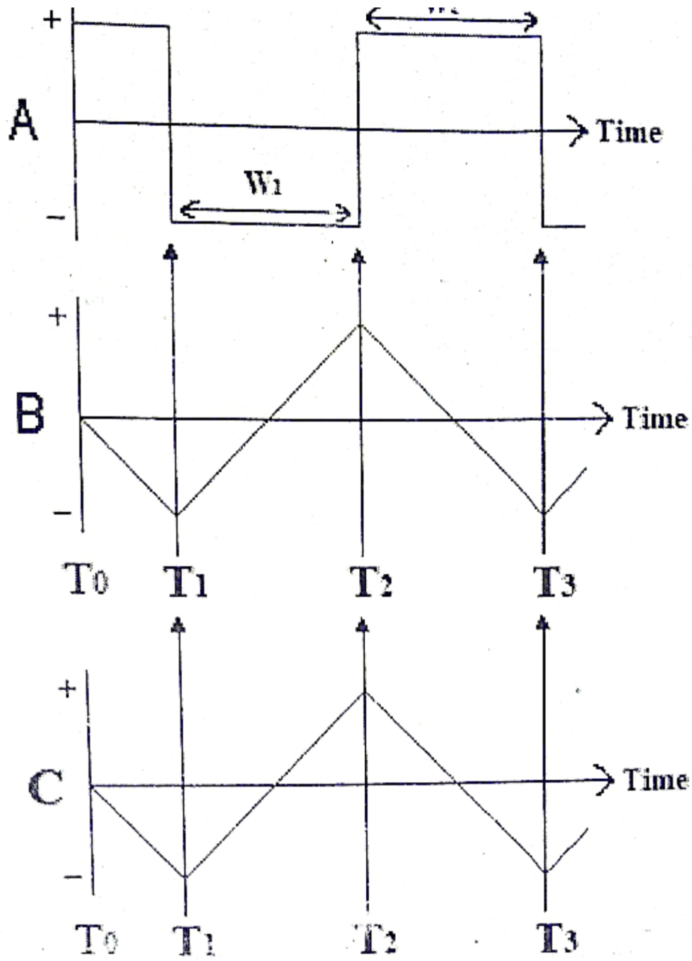


Figure 2: Bipolar Triangular Waveshape

C through the resistor R_3. Due to this connection, the voltage at this point C (V_C) will also fall along with the fall of point B. After a certain time, V_C will fall below zero. At this time, the op-amp **OA1** will sense that the voltage of the positive input terminal has fallen below the negative input terminal (0V) and so, the output of **OA1** will now become equal to the negative saturated voltage (-15V) rapidly. **(For the voltage of the C point to fall below 0 V, the condition of $R2 > R3$ is necessary.)**

As point A is now negative, the process discussed upto now will be inverted. The current will now flow from point B towards point A through the capacitor and R_1. This current flow will force the capacitor to charge in the opposite direction from before. Meaning, the right side of the capacitor must rise above the left side. Hence, the right side of the capacitor (B) will now gradually rise. This is the rising portion of the triangular wave between time T_1 and T_2 in figure 2.

Similar to the process discussed before, the rise of point B will cause an increase in the voltage of point C. When this voltage rises above 0V, the op-amp OA_1 senses this and sets its output A at a HIGH value. Thus, the output of the Schmitt circuit (A) again changes into the positive saturated voltage as we initially assumed. **(The condition of $R2 > R3$ is necessary for the voltage of the C point to rise above 0 V, too)**

Now the process will repeat and the current will flow from point A to point B forcing the voltage at point B to become negative again. This is the falling portion of the triangular wave between time T_2 and T_3 in figure 2. This operation is repeated continuously. The voltages of points A and B influence each other to rise and fall cyclically and thus, the square wave is generated at the A point and the triangular waveform is generated at the B point.

We can find that the frequency of oscillation is defined by the expression:

$$F = \left(\frac{1}{4 \times R_1 \times C}\right) \times \left(\frac{R_2}{R_3}\right) \tag{1}$$

The time period will simply be the inverse of the frequency. This indicates how long it takes for the wave to complete one cycle and repeat itself. In figure 2, a cycle or period is between T_1 to T_3. As we can see, a wave is both HIGH and LOW during a complete period. When the signal is high, we call this "on time". To describe the amount of "on time", we use the concept of duty cycle. Duty cycle is measured in percentage. The percentage duty cycle specifically describes the percentage of time a digital signal is HIGH during a complete period. If a digital signal spends 7 seconds as HIGH and 3 seconds as LOW, we would say the digital signal has a duty cycle of 70%. We can define the duty cycle of the square wave and triangular wave in figure 2 by the expressions:

$$Triangular\ Wave,\ D_T = \left(\frac{W_1}{W_1 + W_2}\right)\times 100\% \tag{2}$$

$$Square\ Wave,\ D_S = \left(\frac{W_2}{W_1 + W_2}\right)\times 100\% \tag{3}$$

Procedure:

1. Construct the circuit as shown in figure 1.
2. Connect the outputs of the op-amp 1 (A) and op-amp 2 (B) with the two channels of the oscilloscope.
3. Observe the wave shapes and collect the plots from the oscilloscope. Measure the frequency F and time period T of the waves on the oscilloscope.

Data Tables

Fill up the table for the Triangular Wave.

Theoretical Frequency	Experimental Time Period, T (ms)	Experimental Frequency, F (Hz)	HIGH Time (ms)	LOW Time (ms)
9.6	9.739	102.8	4.75	4.83

Table 1: Data Table for Triangular Wave Generator

Signature

Please answer the following questions briefly in the given space.

1. Draw the output wave shapes at point A and B in the given graph paper. Keep the time in the horizontal axis and the voltage in the vertical axis.

2. Measure the HIGH and LOW times of the two waves and calculate the duty cycles. Explain if there is any relation between the two values

Ans.

From the experiment,

High time, $W_1 = 4.75$

Low time, $W_2 = 4.85$

Time period, $T = W_1 + W_2 = 9.6$ ms

For triangular wave,

Duty cycle, $D_T = \left(\frac{W_1}{W_1 + W_2}\right) \times 100\% = \left(\frac{4.75}{9.6}\right) \times 100\%$

$= 49.479\%$

For square wave, $D_T = \left(\frac{W_2}{W_1 + W_2}\right) \times 100\% = \left(\frac{4.85}{9.6}\right) \times 100\%$

$= 50.52\%$

There is a relation between the high time value and low time value of the two waves as the high time of square wave = the low time of triangular wave.

3. Suppose, we need a square wave which is HIGH when The Triangular wave is rising and is LOW otherwise. Could we feed our observed square wave as input to one of the circuits from our previous experiments for this?

Ans.

Our observed square wave from the oscilloscope is remain low, when the triangular wave is rising as well as the square wave is remain high, when the triangular wave is decresing or falling. That's why we could not feed our observed square wave as input to one of the circuits, because it is completely opposite of the mentioned ~~question~~ case in the question.

4. What will be the frequency of the output Triangula wave if R_2 is 2kΩ? Explain briefly. [hint: read the theory carefully!]

Ans. Given, $R_1 = 10k\Omega$, $R_2 = 2k\Omega$, $R_3 = 4k\Omega$ and $c = 0.47\ \mu f$

$$\Rightarrow F = \left(\frac{1}{4R_1C}\right) \times \left(\frac{R_2}{R_3}\right) = \left(\frac{1}{4\times10\times10^3\times0.47\times10^{-6}}\right)\times\left(\frac{2\times10^3}{4\times10^3}\right) = 26.59\,Hz$$

So, the frequency of the output will be very low if the $R_2 = 2k\Omega$ instead of $10k\Omega$. Here, we must have to maintain $R_2 > R_3$ for the triangular wave voltage to rise above 0V and fall below 0V. But, if $R_2 = 2k\Omega$, it doesn't maintain it as $R_2 < R_3$ in this scenario and that's why the frequency will be low as 26.59 Hz compared to the previous frequency.

5. Can it be possible to use the above circuit to create a variable frequency wave generator? Justify your answer.

Ans. The frequency of the above circuit, $F = \left(\frac{1}{4R_1C}\right)\left(\frac{R_2}{R_3}\right)$. Here, for a specific R_1, R_2, R_3 and capacitor the frequency is fixed. So it is possible to use the above circuit to create a variable frequency wave generator. For example, If we keep R_2 and R_3 constant for the circuit and use a potentiometer to vary the R_1, we can create variable frequency wave generator. Because, when R_2 and R_3 are constant, the frequency is basically depends on the R_1 and capacitor. So, we can vary the R_1 by using the potentiometer as well as by changing the value of capacitor, it is possible to create a variable frequency wave generator.

6. Change the value of R_1 to 22KΩ and measure the frequency of the output waves. Does the effect on frequency match with the theory?

Ans.

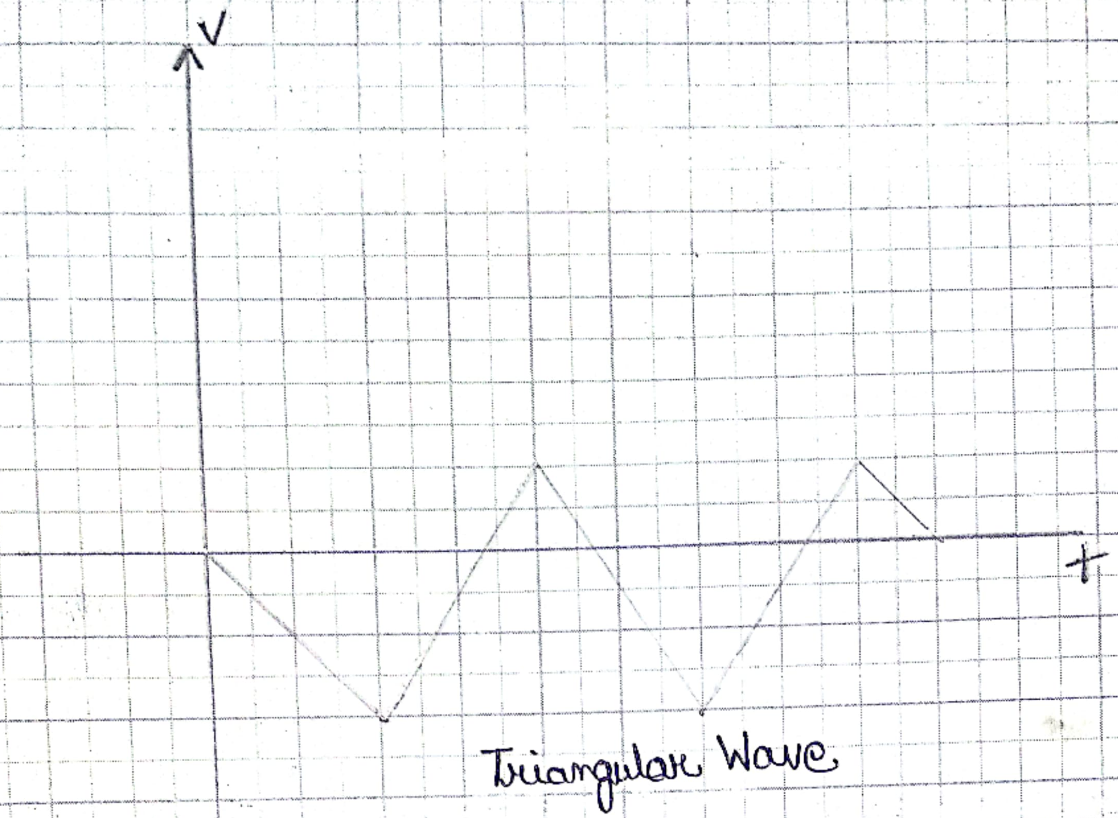
If, $R_1 = 22k\Omega$; From the experiment, $F = 66.17\,Hz$

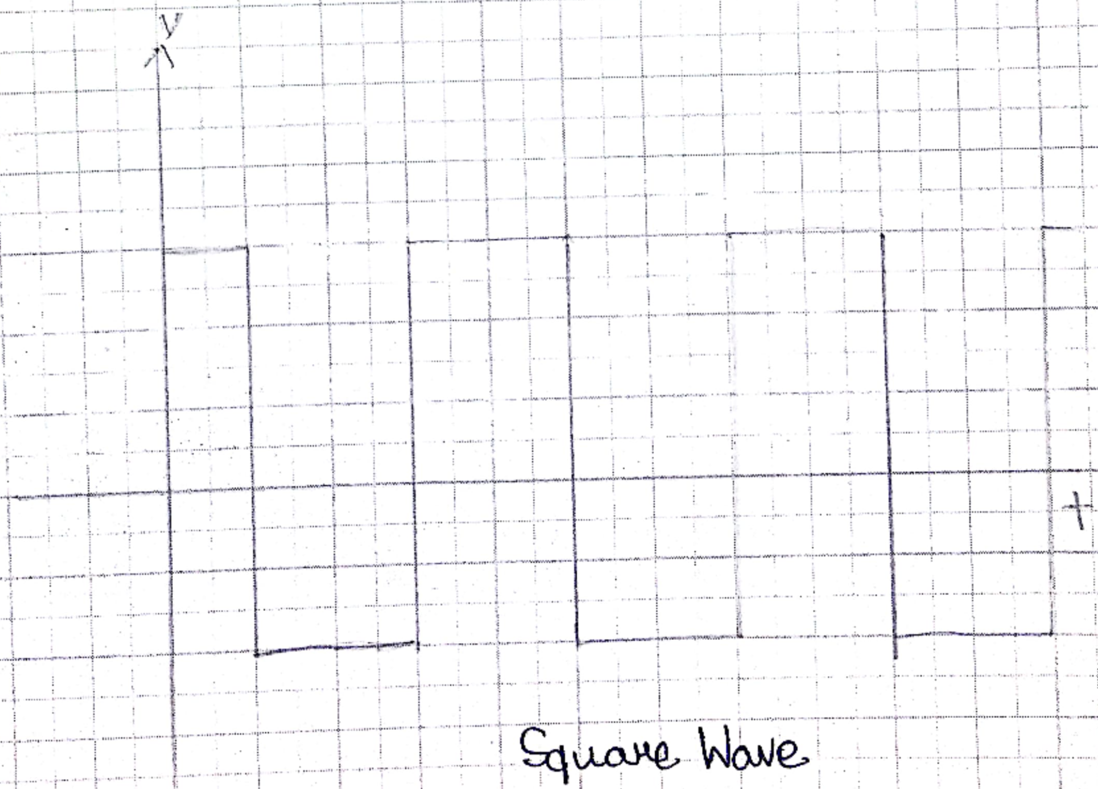
Theoratically, $F = \left(\frac{1}{4\times R_1\times c}\right)\times\left(\frac{R_2}{R_3}\right)$

$$= \left(\frac{1}{4\times22\times10^3\times0.47\times10^{-6}}\right)\times\left(\frac{10\times10^3}{4\times10^3}\right)$$

$$= 60.44\,Hz$$

Here, the frequency we got from the experiment is not exactly same as the theoritically determind frequency, but quite close.





Graph paper for Triangular and Square Wave