Lab 5 Part A – Triangle Oscillator Design

GOAL

The overall goal of Lab5 is to demonstrate a battery powered LED night light. LED brightness is controlled using a phototransistor and PWM.

OBJECTIVES

Lab5a: (1) Design the triangle wave generator, photosensor, and comparator.
(2) Simulate your design in Multisim.

Lab5b: (1) Build a prototype on a breadboard.
(3) Test your prototype to validate your design.

Lab5c: (1) Build a soldered version.
(2) Demonstrate and hand in a working system.

GENERAL GUIDELINES

1) Students are allowed (even encouraged) to work together. **However, you must turn in your own work!**

INTRODUCTION

The overall goal of Lab5 (two weeks) is to build a battery-powered LED night light. The LED brightness depends on the ambient light level. You get to keep the soldered version of your circuit (includes battery pack)! The overall specifications are the following:

1) $+V_{CC} = 4.5$ V (three AA batteries) and $-V_{EE} = 0$ V
2) Lamp is a single white LED
3) Automatic dimmer: A light sensor (phototransistor) measures the ambient light level. High ambient light will cause the LED to turn off. Low ambient light will cause the LED to become bright.
4) LED dimming is performed with PWM, where the PWM signal is implemented with a triangle wave generator and comparator.

Some other circuit features are the following:

1) Use a LM358 chip, which contains TWO op amps (suitable for single-supply operation).
2) Use a LM311 voltage comparator (suitable for single-supply operation with output current up to 50 mA).
3) The phototransistor is the SFH3310, which is good for detecting visible wavelengths.
4) The white LED is the C503B-WAN made by Cree.
5) The peak current of the LED should be $I_{LED} \approx 20$ mA (can be slightly higher or lower).
6) You can directly drive the LED with the LM311 comparator – this keeps the parts count low (nice!).

TUTORIAL: SINGLE-SUPPLY TRIANGLE WAVE GENERATOR

- Many triangle wave generator designs are possible, but a good approach uses a feedback loop consisting of a non-inverting Schmitt trigger and an integrator. As discussed in Professor Buma's Lab 5 Notes (on the WEB), the square wave (Schmitt trigger output) goes from $+V_{SAT}$ to $–V_{SAT}$ while the triangle wave goes between $–V_{TH}$ to $+V_{TH}$.

- This lab requires a slightly different circuit because the **single-supply** op amps are powered with $+V_{CC}$ and 0V. How does this affect circuit design? **The triangle wave output now oscillates between $V_{REF} + V_{TH}$ and $V_{REF} – V_{TH}$** (see Fig. 1).

  - **The "reference voltage" V_{REF} is half-way between $V_{SAT(+)}$ and $V_{SAT(-)}$.**
    a) The LM358 powered with $+V_{CC}$ and 0V typically has $V_{SAT(+)} = +V_{CC} – 1$ and $V_{SAT(-)} = 0V$.
    b) This means $V_{REF} = 0.5\,(V_{CC} – 1)$, which is half-way between $+V_{CC} – 1$ and 0V.
    c) Example: When $V_{CC} = 9V$, $V_{REF} = 4.0V$.

  - For single-supply operation, the threshold voltage is now $V_{TH} = 0.5V_{SAT(+)}\,{}^{R_1}/_{R_2}$

    Example: Suppose $+V_{CC} = 9V$, $R_1 = 10$ kohm, and $R_2 = 20$ kohm.

    a) This means $V_{SAT(+)} = 8V$ and $V_{SAT(-)} = 0V$.
    b) Therefore, $V_{REF} = 4V$ and $V_{TH} = 2V$.
    c) As a result, the triangle wave oscillates 2V above and below $V_{REF} = 4V$.

  - **A voltage divider can be used to produce V_{REF}.** As shown in Fig. 1, the (-) input of op amp A1 is now connected to a voltage divider (R5-R6) instead of ground. The (+) input of op amp A2 is also connected to the same voltage divider.

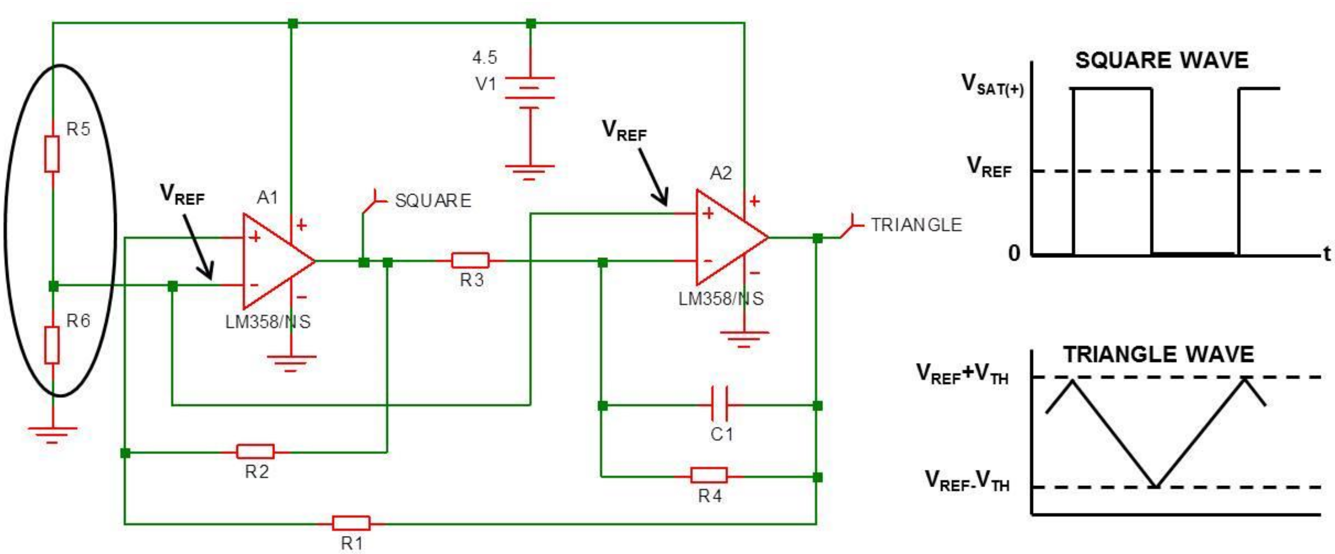


Fig. 1: Triangle wave generator using single-supply op amps.

CIRCUIT DESIGN

The triangle wave generator specifications are the following:

- Peak-to-peak amplitude between 2 V_{PP} and 3V_{PP}.
- Frequency between 500 Hz and 750 Hz.

Some helpful formulas are the following:

- Positive saturation voltage: $V_{SAT(+)} = +V_{CC} - 1$
- Triangle wave peak amplitude: $V_{TH} = 0.5V_{SAT(+)}\frac{R_1}{R_2}$
- Triangle wave frequency: $f = \frac{R_2}{4R_1R_3C}$
- Reference voltage: $V_{REF} = 0.5\ (V_{CC} - 1)$

Task 1: Compute the R_1 and R_2 necessary to achieve the desired peak-to-peak amplitude. Use standard 5% resistors.

Hint: Typical values are between 10 kohm and 1 Mohm. These values ensure the output current of op amp A1 and A2 are less than 1 mA.

Task 2: Compute the R_3 and C necessary to achieve the desired frequency.

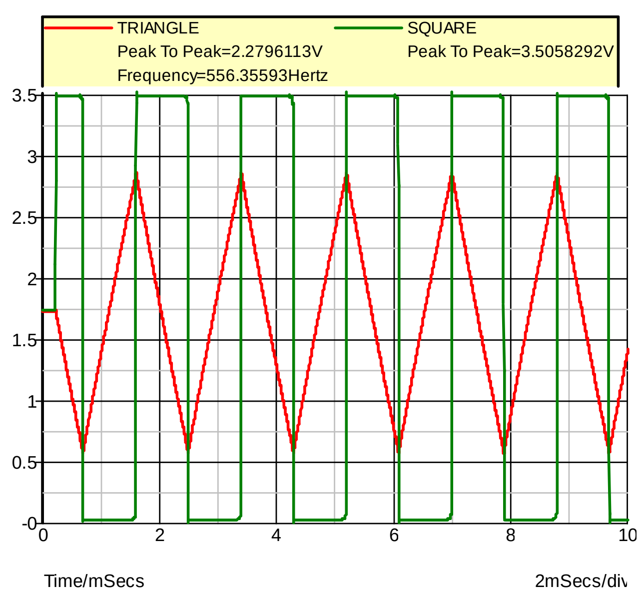
Hint: Typical R_3 values are between 10 kohm and 1 Mohm. Typical capacitor values vary from about 1 nF up to about 10 uF. Choose standard 5% resistor and 10% capacitor values.

A capacitor has infinite impedance at DC, since Z = 1/jωC. This has the unfortunate consequence that the op-amp integrator has infinite gain at DC, which leads to an unsteady DC output. To avoid this defect, most integrators have a large resistor in parallel with the capacitor (see above figure). This resistor R_4 is typically chosen to be at least 10 times higher than R_3.

Task 3: Choose a 5% resistor for R_4 that is appropriate for your circuit.

Task 4: Choose 5% resistors for the R_5-R_6 voltage divider that produces V_{REF}. Typical values are over 10 kohm to ensure low power dissipation.

Task 5: Simulate your circuit. Use the LM358/NS op amps. Make sure the simulation time is long enough to show about five cycles. Submit both the schematic and voltage waveforms (Schmitt trigger output, triangle wave output, peak-to-peak measurements, triangle wave frequency).



(End of Lab 5 Part A)