

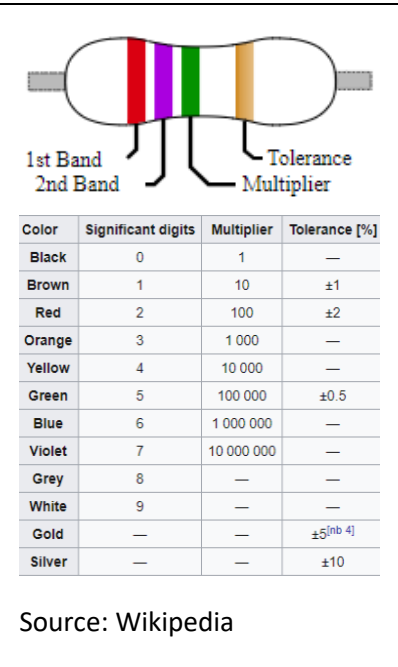
Square-Wave Oscillator

Learning Objectives

- Build a circuit by following the design specified on a circuit schematic
- Learn the applied definitions of synchronous and asynchronous, coherent and non-coherent.
- Use an LED as visible circuit output.
- Apply knowledge of time constants to a new application.
- Use the oscilloscope to record with precision our observations.

Background

In the Cloud Detector, we used a voltage divider that utilized a photoresistor to create a voltage that responds to the level of ambient light. An LED with a current-limiting resistor was used as an output to indicate passing shadows. We used an inverter (specifically, a Schmitt trigger) to both buffer the voltage divider from the LED so that both circuits worked as designed without “loading” the other in a way that compromised its design. In this exercise, we will again use the inverter but in a new way. By placing a capacitor at the input of the inverter (see Figure 1), charging the capacitor will cause the output of the inverter will be near 0 volts. Discharging the capacitor (at the input of the inverter) will cause the output of the inverter to approach the battery voltage. By inserting a resistor between the output and the input (where the capacitor sits), the output does the job of both providing a charging voltage and then a discharging path for the capacitor, thus forming an oscillator. An **oscillator** is a device that changes values over time in a periodic manner.



The diagram shows a resistor with four color bands: Red, Purple, Green, and Orange. Labels indicate the 1st Band (Red), 2nd Band (Purple), and Multiplier (Orange). A tolerance band is also shown.

Color	Significant digits	Multiplier	Tolerance [%]
Black	0	1	—
Brown	1	10	±1
Red	2	100	±2
Orange	3	1 000	—
Yellow	4	10 000	—
Green	5	100 000	±0.5
Blue	6	1 000 000	—
Violet	7	10 000 000	—
Grey	8	—	—
White	9	—	—
Gold	—	—	±5 ^[nb 4]
Silver	—	—	±10

Source: Wikipedia

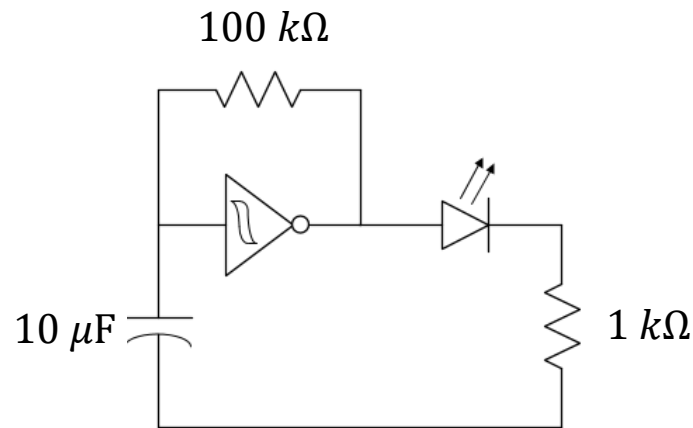


Figure 1: Circuit schematic of a square-wave oscillator producing a flashing beacon. The Schmitt-trigger IC is a powered device, but the battery connection between pins 7 and 14 are not explicitly shown in this schematic.

How it Works

To gain a deeper appreciation for the operation of the oscillator, we need to improve our understanding of the operation of the Schmitt trigger inverter. The [datasheet](#) for the CD40106 Schmitt Trigger Inverter will describe a hysteresis (a form of memory) within the device where the input/output relationship for changing input values will depend on the time history of the input. The CD40106B device consists of six Schmitt-Trigger inputs. Each circuit functions as an inverter with Schmitt-Trigger input. The trigger switches at different points for high to low and low to high signals. The difference between the high to low voltage (V_P) and the low to high voltages (V_N) is defined as hysteresis voltage (VH).

For example, if the input voltage V_{IN} starts at 0 volts (ground) and climbs, the output voltage V_{OUT} will remain high until the input voltage reaches the value V_p , as demonstrated in Figure 2. At this point, the output voltage will drop to 0 volts. As the input voltage then falls back below V_p , the output voltage persists in staying low (0 volts) until finally the input falls below a value of V_n . This means that there is not a one-to-one relationship between V_{IN} and V_{OUT} like we are mostly accustomed to in previous math courses. This relationship is graphed in Figure 2. We consider V_p to be the positive-going threshold voltage and V_n to be the negative-going threshold voltage of the Schmitt Trigger.

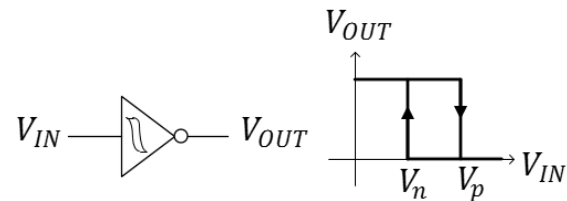


Figure 2: The input/output relationship of the Schmitt trigger from Texas Instruments, the TI 40106. **The power connections to the inverter are often not explicitly shown in a circuit schematic.**

Knowing that the *input* of the Schmitt trigger inverter has a high resistance, we can ignore it for purposes of determining how the capacitor and resistor of the oscillator interact. With this high-resistance model, the capacitor is attached to the resistor and the effects of the Schmitt-trigger input are gone. For the *output* of the Schmitt trigger, we will need two models, each will correspond with the two possible output voltages of Figure 2.

- 1) When the input voltage, V_{IN} , is small, the output of the Schmitt trigger output is high (near the supply voltage, V_S). The output of the Schmitt trigger acts like an ideal voltage source. Therefore, for the charging cycle, the oscillator circuit can be modeled by Figure 3a.
- 2) When the input voltage is high, the Schmitt trigger output is low (near ground voltage, 0 V) and behaves much like the ground node. The oscillator circuit can be modelled by Figure 3b.

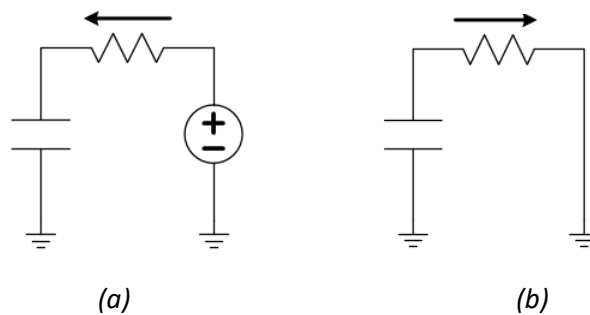


Figure 3: Charging (a) and discharging (b) schematics for the oscillator circuit after making modeling assumptions for the Schmitt trigger (a voltage source and a short). The arrow shows the direction positive-valued current will flow as the capacitor charges and discharges, respectively.

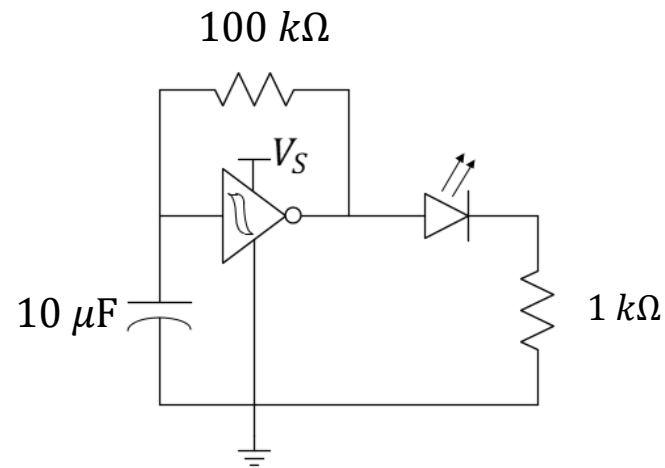


Figure 4: Physical diagram and circuit schematic of a prototype oscillator circuit. The diode and current-limiting resistor are not shown in the prior. Note that you must place the **negative side of the capacitor** at the lower voltage if using an electrolytic capacitor (yours might not be polarized).

Build the oscillator circuit as shown in Figure 4. Use a blue LED (actually, the color will not matter much) and $1\text{ k}\Omega$ resistor to complete the design. The node between the LED and $1\text{ k}\Omega$ resistor should be on an unused row of your breadboard. Finally, connect the battery + and – connections as shown by **V Supply**. Your blue LED should be flashing every one to three seconds. Answer the questions that follow.

Notes:

Capacitors often provide three or more numbers to indicate the capacitance in picoFarads (pF). The first digits are precision while the last digit represents a power of 10. For example, 104 means a capacitance of $10 \times 10^4\text{ pF}$ or, equivalently, $0.1\ \mu\text{F}$. The electrolytic capacitor **used here** is physically large enough to write out the capacitance plus the unit in addition to its rated voltage. Note that it is polarized! You must place the negative side of the capacitor at the lower voltage...in this case, the negative end of the power supply.

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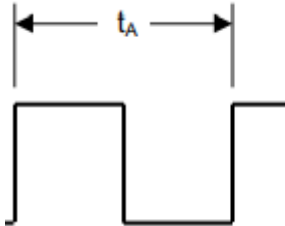
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Summary

Question 1: The charging path and the discharging path are both through the resistor in the oscillator of Figure 4. Use your knowledge of time constants to estimate the period of the flashing light (the time between when the LED turns on until the time it next turns on). Assume the capacitor voltage oscillates between 33 and 55% of the battery voltage, that is, the Schmitt trigger goes low when the input voltage reaches 55% of the battery voltage and goes high when the input falls to 0.33 V_S . From Figure 20 of the [datasheet](#) for the Schmitt trigger, the period is given by $t_A = RC \ln \left(\frac{V_P (V_S - V_n)}{V_n (V_S - V_P)} \right)$, where $\ln(x)$ is the natural log, $\log_e(x)$.



Question 2: Use the oscilloscope to measure the actual period of oscillation, T , of your device. Include a screenshot of the oscilloscope in your report that shows how you measure the frequency. Calculate the frequency in Hertz of the square wave. The frequency in flashes/second (units of *Hertz*) is found from $f_{osc} = \frac{1}{T}$.

Question 3: Replace the $100\text{ k}\Omega$ resistor with $50\text{ k}\Omega$ (you will do this by adding a second $100\text{ k}\Omega$ resistor in parallel with the first $100\text{ k}\Omega$ resistor). You should still see the oscillation. Calculate the change in the period, and comment on the trend of the change in the period. Use your understanding of RC time constants to explain it.

Question 4: Replace the two parallel $100\text{ k}\Omega$ resistors with a single $1\text{ k}\Omega$ resistor. What is different in the period? Use the oscilloscope to measure the voltage. What does the oscilloscope tell you that the LED cannot? Include a screenshot of your oscillator including the settings of the horizontal and vertical scale.

Question 5: Remove the LED from your circuit. Does the Schmitt Trigger output change before and after the LED is removed? How does the capacitor discharge? Did the LED play a role?