Section	
Bench No.	

ECE110 Introduction to Electronics

Experiment 4: Square-Wave Oscillator

Name: 尚雅夫

Student ID: 3230112117

Instructor: 李斯

Date: Oct. 30, 2023

Teammate/Student ID: 3230112155

This part is reserved for your instructor

Score	
Instructor Signature	
Date	

Experiment 4: Square-Wave Oscillator

Laboratory Outline

This week, we continue to expand topics towards building a self-navigating car. Specifically, we will build a “cloud detector” using engineering design and voltage-divider circuits and analyze them with the aid of a function-generator and the oscilloscope.

Learning Objectives

• Learn to allow for tuning and discuss the need for conformity in testing conditions.
• Gain a deeper understanding of benchtop equipment designed for time-varying signals: oscilloscope.

At your Bench

Today we're going to start with Oscilloscope that are commonly used in laboratories.

Oscilloscope

The oscilloscope (often called an “o-scope” or “scope” for short) is a measurement device that can capture a time history of a signal. At first glance, it appears to be a very complex piece of hardware.

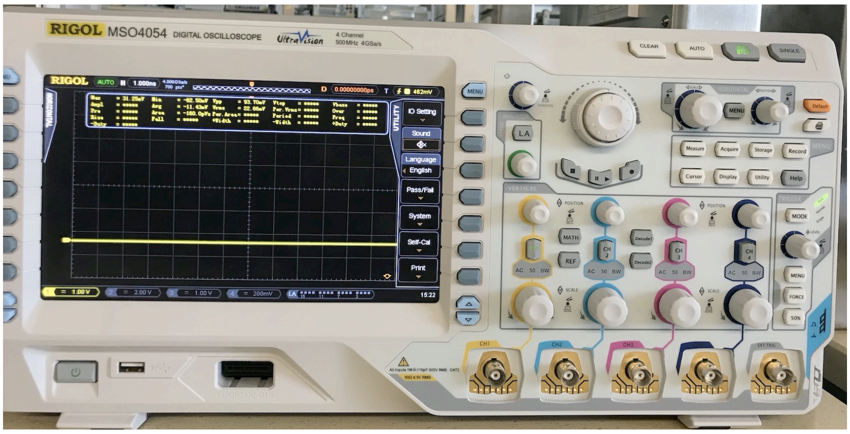


Figure 1: *The ROGOL oscilloscope that used in the lab.*

We will learn about the oscilloscope in parts. First, we will investigate just a few settings and understand that it produces a view of the voltage signal as a function of time, but not worry about how it does so. Power on your oscilloscope by pressing the power button in the lower-left corner of the instrument.

When the instrument has finished powering up, press the Default Setup button near the upper-right corner of the instrument. This button will remove any unusual settings done by the previous user and put us into a known state.

Figure 2: *The oscilloscope's Default Setting.*

Next, connect a coaxial-to-banana cable to the Channel 1 input.

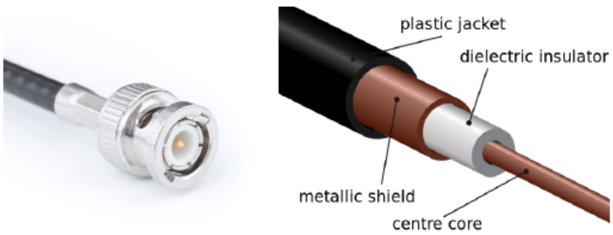


Figure 3: A coaxial cable with a BNC connector appropriate for use with the KEYSIGHT oscilloscope. Note that although the cable on the left would seem to be a single wire, the actual construction has two conductors, a core and a shield. Image Source: Wikipedia

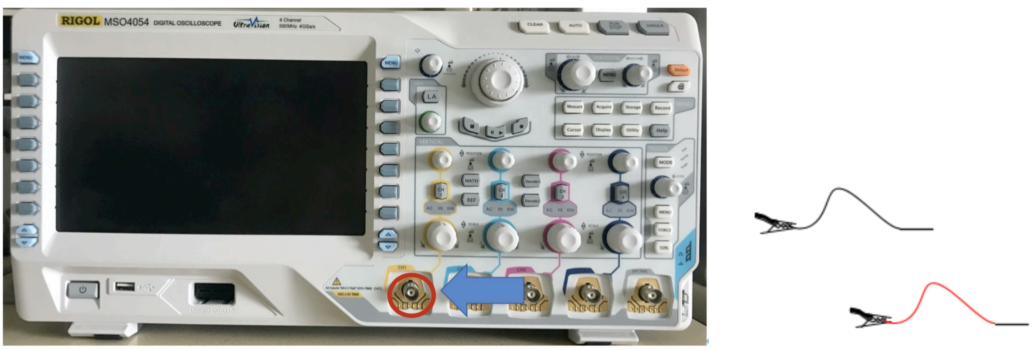


Figure 4: The oscilloscope's Channel 1 input.

You will primarily use two controls on the oscilloscope to improve your view…the vertical scale adjust and the horizontal scale adjust. If the display appears to be "untriggered" (ie. scrolling past), try turning the triggering threshold knob (Figure 6), first counter-clockwise, until the horizontal triggering line slices through the signal.

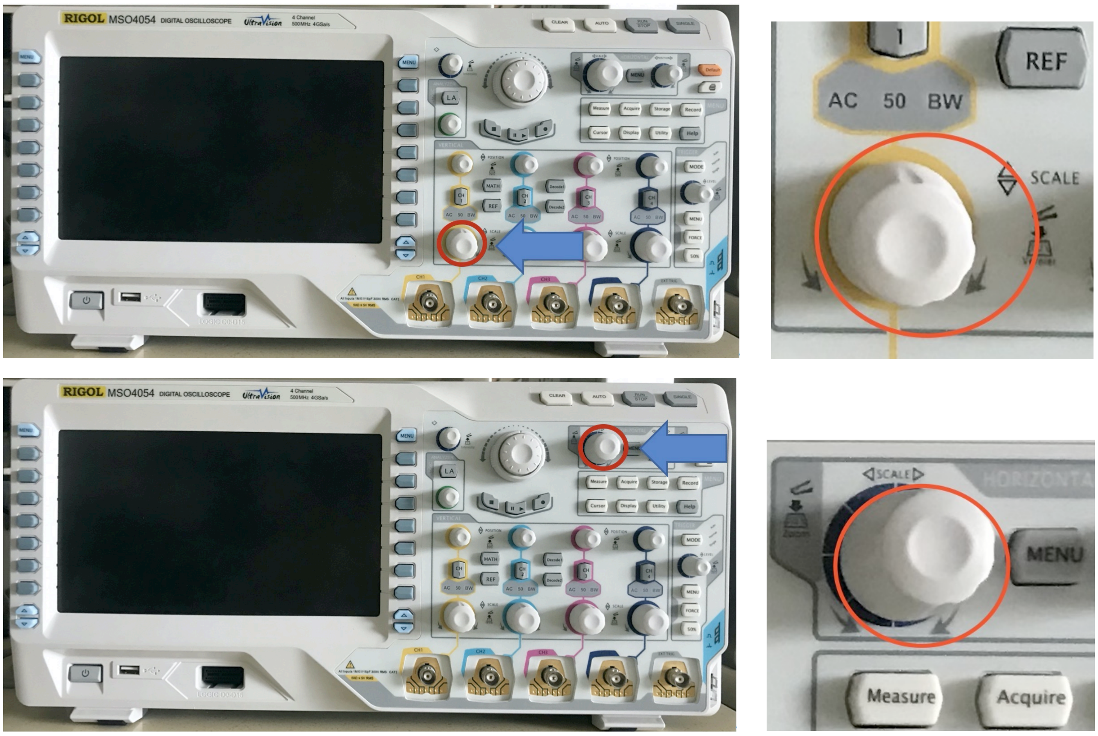


Figure 5: Adjust the view using the vertical scale adjust (visible height of the signal) and the horizontal scale adjust (amount of time shown on the screen).

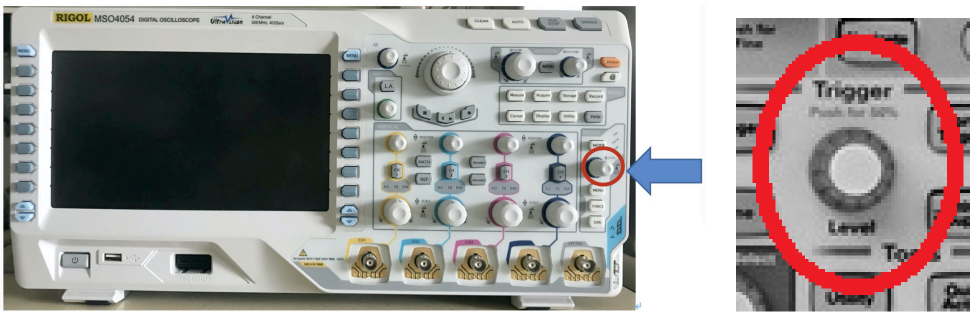


Figure 6: Adjust the trigger such that the horizontal trigger line that appears sits between the two voltage values across the motor.

Question 1: Briefly discuss the function of each the vertical scale and the horizontal scale adjustments.

As you learn to use it, however, you will learn that most common adjustments use only a few of the controls present on the front panel of the device. The horizontal control changes the scale of the time axis allowing you to see more and less time range of the waveform as needed. The vertical control changes the scale of the voltage axis allowing you to shrink the display's height of the waveform so that it fits within the screen or expand it to better fill the screen and make a more-accurate voltage measurement. A third menu consists of the triggering controls. The description of the trigger is less intuitive than scale so we will spend much more time investigating its key role. For now, just remember that **the oscilloscope's trigger aids in displaying voltage waveforms in a human-readable format.**

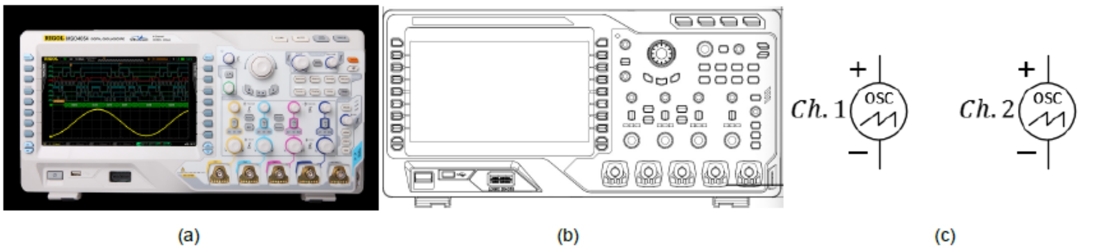


Figure 7: A photo of the RIGOL oscilloscope, our physical model of it, and common schematic symbols for two channels. In ECE110, often only a label (and no symbol) will be used.

The simplest way to trigger the oscilloscope is to press the **Single** button in the upper right of the oscilloscope's front panel. The screen should go blank as the oscilloscope is *waiting for an event* to tell it something interesting has occurred. For the oscilloscope in default mode, triggering means for the oscilloscope to wait for **a voltage that rises above a set threshold**.

On the oscilloscope, press the **Default** setup, then **attach Channel 1 and Channel 2** of the scope to the circuit locations shown in the schematic below. **Turn the "Trigger" knob** clockwise until the horizontal trigger line on the oscilloscope is near 2V.

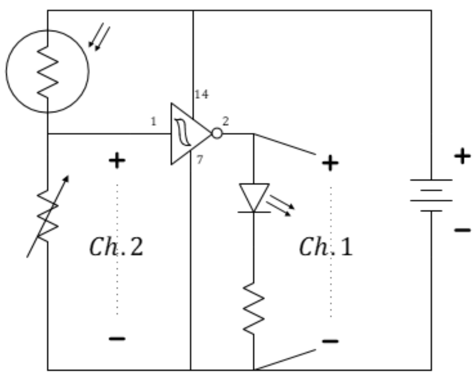


Figure 8: Use the oscilloscope to view the time-varying input and output of the cloud detector, Channel 1 is the output.

Question 2: Use the oscilloscope as shown in Figure 8 to measure the input and output of the (Schmitt trigger) inverter by using the Single run mode. Sketch in Figure 9 the waveform you see on the oscilloscope after your hand passes across the sensor. Verify that the oscilloscope's 2-volt trigger is the value the plotted voltage reaches in the center of the screen.

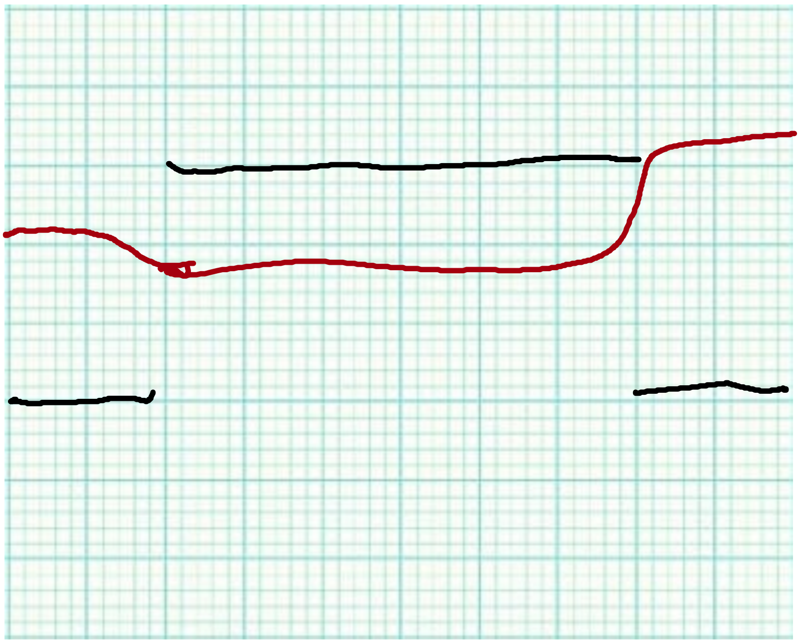
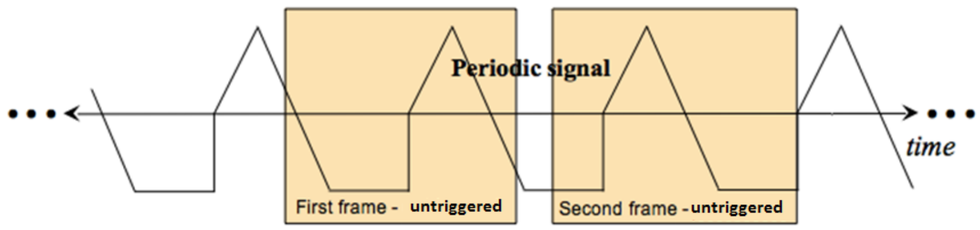


Figure 9: *Plot the cloud detector's input and output. Please include time and voltage labels.*

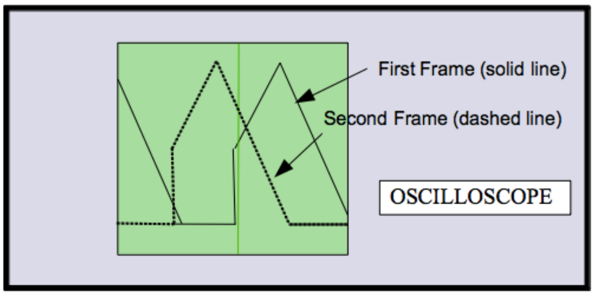
Oscilloscope Triggering

Without Triggering

Suppose we input a periodic signal into channel 1 of the oscilloscope. Without triggering, each plotted **frame** (*a short timesweep of the voltage*) will begin at arbitrary point in the waveform and, with each sweep, the signal will jump around on the time axis so fast that the plot will just look like garbage. The explanation is simple. Refer to the figure below. For the first frame, the computer inside the oscilloscope will collect a waveform (frame) starting at an arbitrary point in time. A second frame is also collected starting at a later, but at a point in time unrelated to the period of the periodic signal. The second frame will be an arbitrarily-time-shifted version of the first. It is this arbitrary time shift between consecutive frames that causes the waveform to appear on the oscilloscope placed at random time intervals. If only the oscilloscope had some way of estimating the period of the waveform, it might be able to produce a stable display of one or more periods. So we note that many "basic" period waveforms (like sinusoids, square waves, and triangular waveforms) do something specific only once or twice each cycle…like transitioning across a certain voltage value.



(a)



(b)

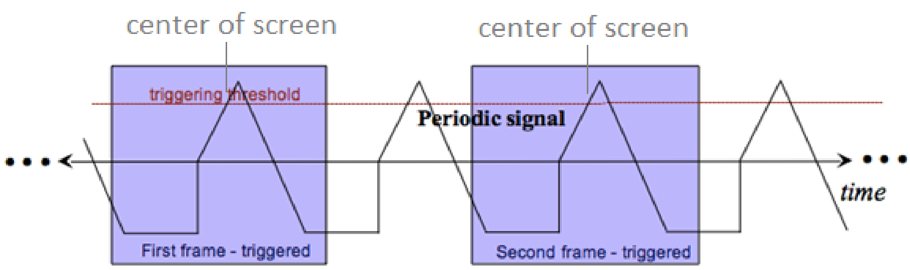
***Figure 10**: Two frames of an un-triggered periodic signal shown in time (a) and plotted simultaneously (b).*

Continuous Triggering (Run)

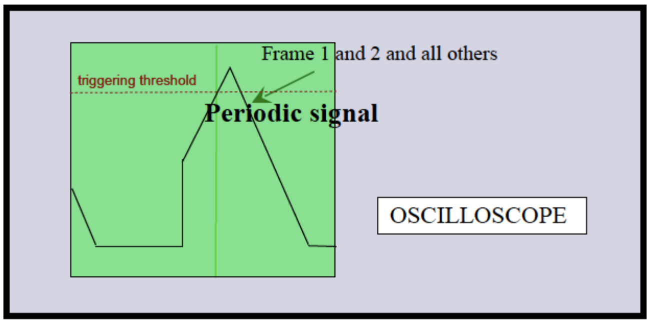
Continuous triggering allows the user to specify how the oscilloscope draws and redraws a signal on the screen. Our oscilloscopes are digital scopes. A digital scope reads the analog signal (**analog**: *continuous in time and continuous in amplitude*) applied to each channel and converts it into a series of binary numbers sampled in time that represents the original signal.

These numbers are stored in memory continuously with new numbers always replacing the old. Continuous triggering is used to tell the oscilloscope how to display the signals in a manner that underscores the periodic nature of the waveform.

The oscilloscope does not actually estimate the waveform's period (although it could). It does something clever with a "trigger". The **trigger** is *a voltage threshold that we choose*. We specify a particular voltage level and the oscilloscope starts to sketch a new frame when the voltage waveform again crosses that threshold.



(a)



(b)

***Figure 11**: Two frames of a triggered periodic signal shown in time (a) and plotted simultaneously (b).*

Since the signal is periodic, each frame will be nearly identical (even if several periods are missed between frames!). Therefore, the oscilloscope display overlays similar frames and the image it shows will be steady. With a steady display, the parameters of the waveform (amplitude, frequency, offset, etc.) will be easy to measure.

Question 3: Explain how the oscilloscope's trigger causes multiple time captures of a periodic signal to look like a static image. Put a simple example of a periodic signal in the figure below to help illustrate your explanation.

If I put the trigger around the black line, for each time the voltage goes below the line, the machine

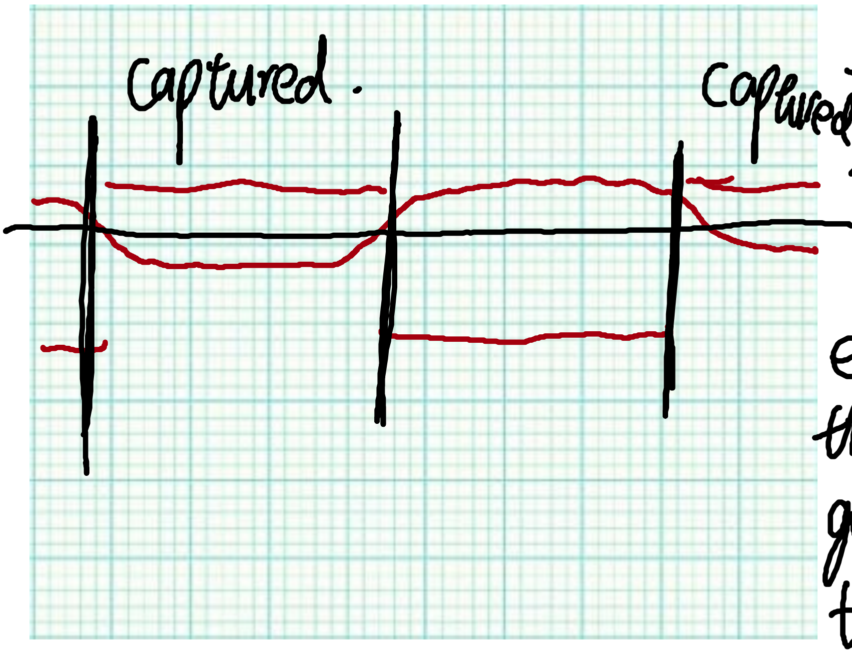


***Figure 12**: Illustration of the oscilloscope's trigger operation.*

stares Capture, and ends while it goes over it. It will lead tu identical graphs captured each time.

oscillator

In prelab, we built 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 prelab exercise, we will again use the inverter but in a new way. By placing a capacitor at the input of the inverter (see Figure 13), charging the capacitor will cause the output of the inverter will be near 0 volts. Discharging the capacitor will cause the output of the inverter to be near 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.

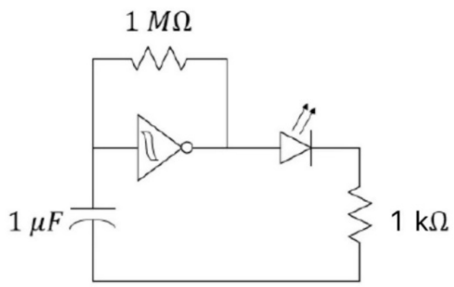


Figure 13*: Circuit schematic of a square-wave oscillator producing a flashing beacon.*

NOTE: 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*10^4 pF or, equivalently, 0.1μF. 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.

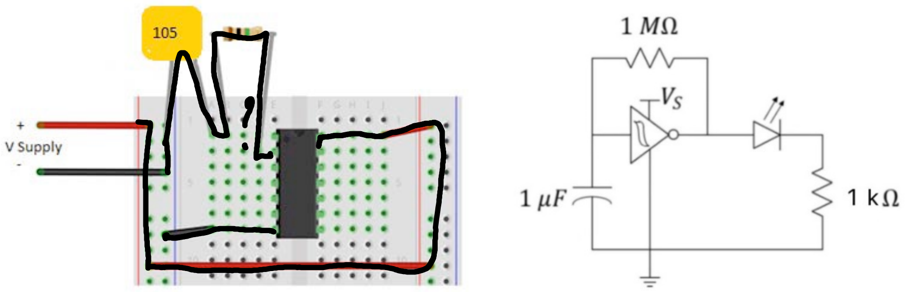


Figure 14*: Physical diagram and circuit schematic of a prototype oscillator circuit. The diode and current-limiting resistor are not shown in the prior. Note that you must place the* ***negative side of the capacitor*** *at the lower voltage if using an electrolytic capacitor (this one is not polarized).*

Build the oscillator circuit as shown in Figure 14. Use a blue LED to complete the design. Be sure to connect the battery + and – connections as shown. Your blue LED should be flashing every one to three seconds.

Question 4: Use a timer to see how many seconds it takes your LED to flash 20 times. Divide the number of flashes, 20, by the amount of time that passed to determine the flash frequency in units of flashes/second(*Hertz*). Show your work.

$$f = \frac{20}{39.98} \approx 0.5\,Hz .$$

Question 5: *Think about it*. Your lab mates are also building the same circuit. Will theirs have exactly the same flashing frequency as yours? Explain.

Yes, if all components are identical, because there is nothing out of the circuit that changes the frequency of flash.

On the LED circuit, **swap** your 1 $M\Omega$ resistors with 10 $k\Omega$ resistors and your 1 μF capacitors with 0.1 μF capacitors (they will have **104** printed on the side) as shown in Figure 15.

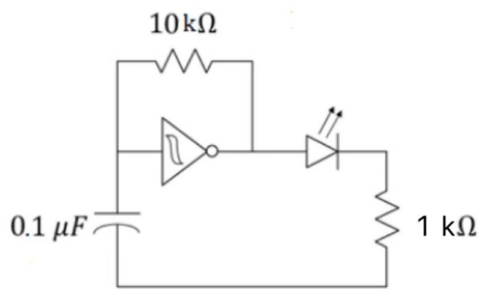


Figure 15: An oscillator with a 10 kΩ resistor and 0.1 μF capacitor.

Question 6: Does your blue LED light still blink? Discuss as a group, then write your thoughts on what affect the swap of components had on your circuit's operation.

No. The affected the frequency of the flash, it's too fast to be seen.

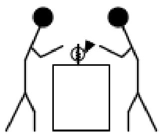
Despite the fact that each of you followed the same design procedure, you will find that there are distinct variations in the frequency of oscillation. If you think about clocks (a form of oscillator) running independently in two different geographic locations, you will probably expect them to be somewhat "out of sync".

Question 7: Go around the table and discuss what each of you found regarding the definitions of synchronous and asynchronous (alt. coherent and non-coherent). In the space below, try to explain *why* your devices are non-coherent.

the total resistance of the circuit,
the capacity of the capacitor, the voltage in the circuit.

As engineers-in-training, we need to recognize the value of our engineering tools. In the breakout session, we made a change to our circuit that limited our ability to assess the circuit's behavior. Now we will utilize the oscilloscope to open a window into our time-varying circuit. We should learn that the oscilloscope is as vital to the electronics engineer as the microscope is the microbiologist! It will be the go-to tool for just about every analysis you do through the remainder of the semester. If you have a question about your circuit and your TA does not see you using your oscilloscope, do not be surprised if they first ask you to use this tool to try to solve your own puzzle before they provide additional aid! **In every future lab, always have your oscilloscope at the ready!**

Oscilloscope Sleuthing



Use the oscilloscope to **view simultaneously**, the voltage between **the output of each inverter** and the negative side of the battery. To do so, follow these steps:

Reset the scope to the **default** setting. With two coax-to-banana cables, use your alligator clips to connect channel 1 to the blue LED circuit of one lab partner and channel 2 to the blue LED circuit of the *other* lab partner. The black probe of each scope should be connected to the negative terminal of each battery. (These negative terminals are now actually connected to each other by the scope itself!)

Adjust the horizontal and vertical scales until the signal on Channel 1 is clearly displayed. Increase the trigger level to about 3 volts so that the Channel 1 signal remains steady.

Press the "2" until it remains illuminated to display channel 2 as well. Both the "1" and the "2" should be illuminated. Press the **trigger** button and make sure the scope is triggering on channel 1.

Question 8: Channel 2 will be "sweeping" past while channel 1 appears to remain stationary on the screen. Explain. Use some variation of the word "coherent" in your *explanation*.

The frequency of the two circuits are different. If one is stationary, the other would appear sweping.

Press Channel **1**, then add the following four measurements: **Frequency**, **amplitude**, **Vrms**, and **+ Duty**. To add these measurements, follow this procedure:

Press: $\boxed{\text{CH1}}$ so that Channel 1 is illuminated.

Hard key: $\boxed{\text{Measure}}$ (a physical, labeled button on the right side of the oscilloscope)

Soft key: $\boxed{\text{Display All}}$ (Computer-labeled button on the right side of the screen that change with hard key choices)

Repeat for each selection on Channel 1, then repeat for Channel 2.

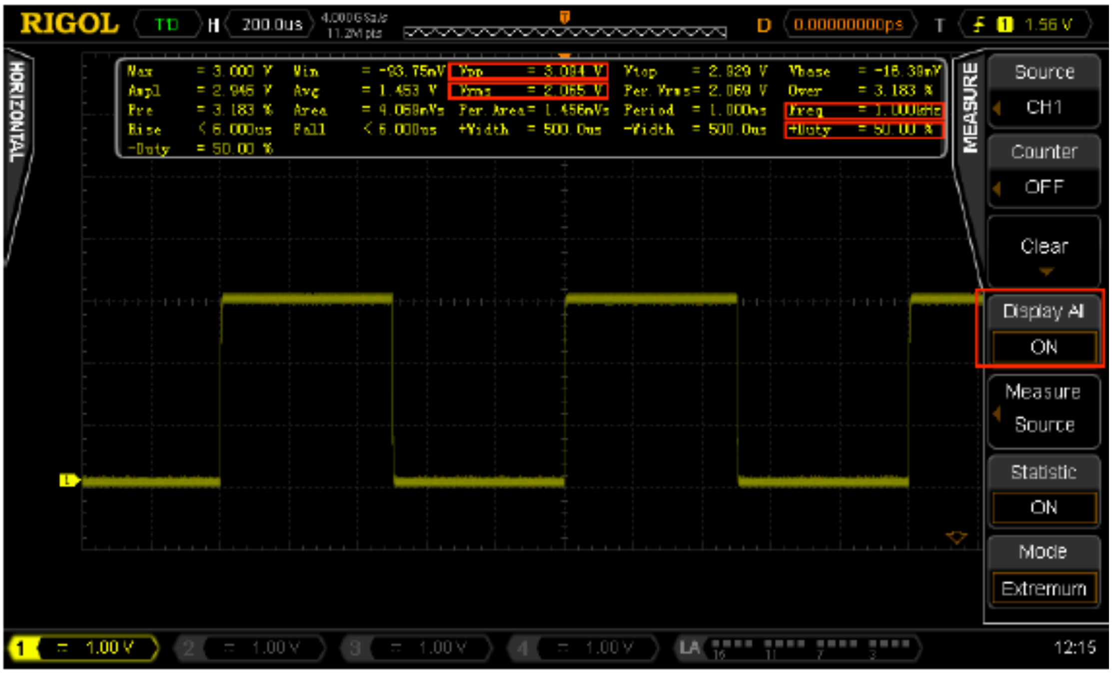


Figure 16 : *Measurement on oscilloscope*

Question 9: Record all four measurements for channel 1. Repeat for channel 2. If necessary, review the course notes about significant figures with respect to reading instruments.

CH2: Frequency 714.3 Hz. a 6.48V
V: 5.12V d 64.28%
CH1 Frequency. 735.3 Hz. a: 6.35V
Vrms: 5.12V duty 61.76%.

Comment: Small differences in values, temperatures, etc., will inevitably result in two different "clock" frequencies for two isolated circuits despite your most valiant efforts to tune.