Section	
Bench No.	

ECE110 Introduction to Electronics

Experiment 5: Time-Varying Signal

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Experiment 5: Time-Varying Signal

Learning Objectives

• Build a circuit by following the design specified on a circuit schematic
• Learn to control the duty cycle of a time-varying signal using a turn pot and diodes
• Use observations of your circuit to discern the change of certain components.
• Gain a deeper understanding of benchtop equipment designed for time-varying signals: the function generator and oscilloscope.

Background

Recall the square-wave oscillator that we built earlier. By placing a capacitor at the input of the inverter (see Figure 1), discharging the capacitor will cause the output of the inverter to be near the battery voltage. By charging the capacitor, the output of the inverter will be near 0 volts. By inserting a resistor between the output and the input (where the capacitor sits), the output does the job of both charging and then discharging the capacitor, thus forming an oscillator. An **oscillator** is a device that changes values over time in a periodic manner.

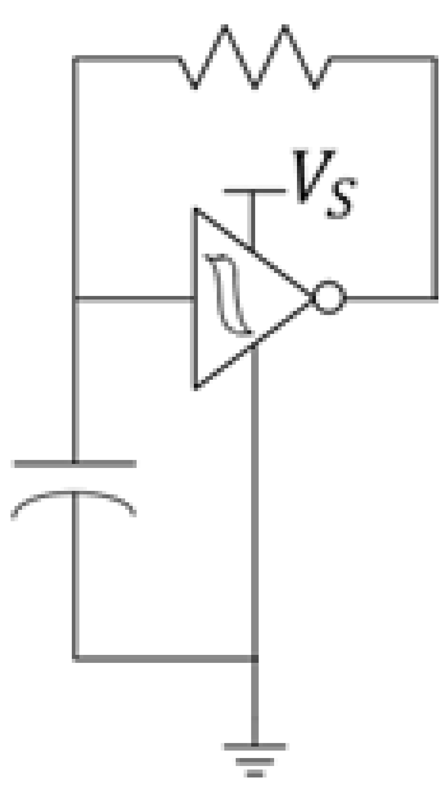


Figure 1*: Circuit schematic of a square-wave oscillator producing a beacon.*

To gain a deeper appreciation for the operation of the oscillator, we first need to understand 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. 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.

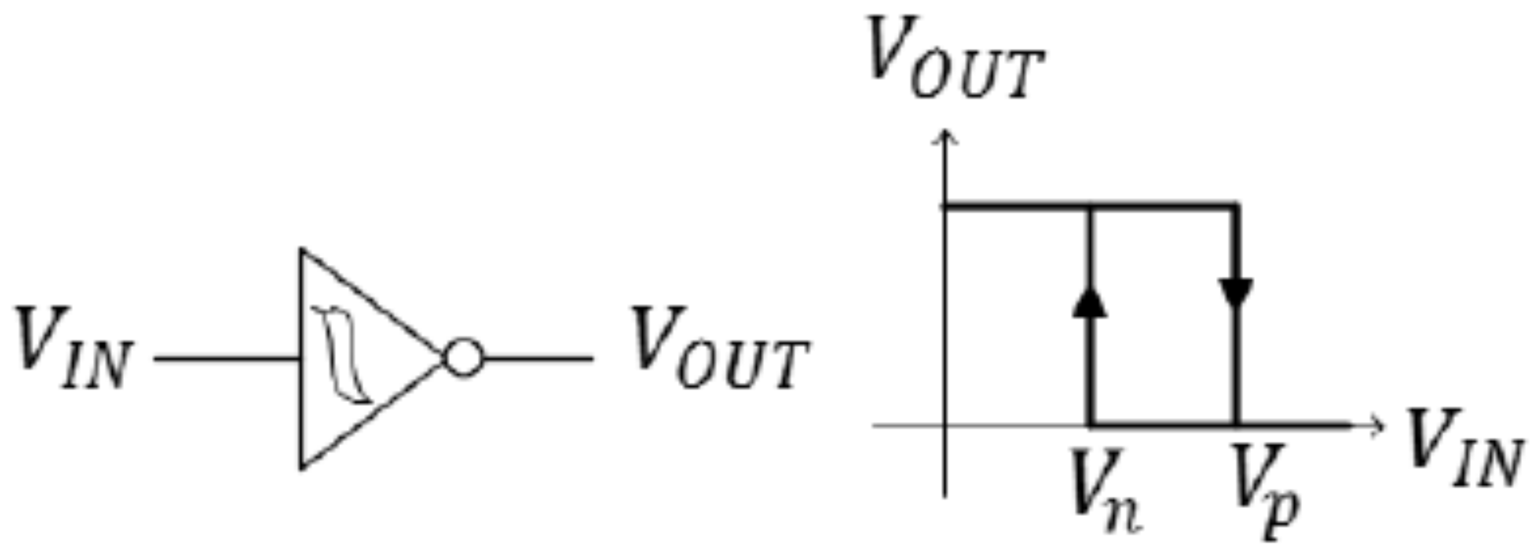


***Figure 2**: The input/output relationship of the Schmitt trigger from Texas Instruments, the TI 40106.*

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. For the *output* of the Schmitt trigger, we will need two models to each correspond with the two 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). 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 the oscillator circuit can be modelled by Figure 3b.

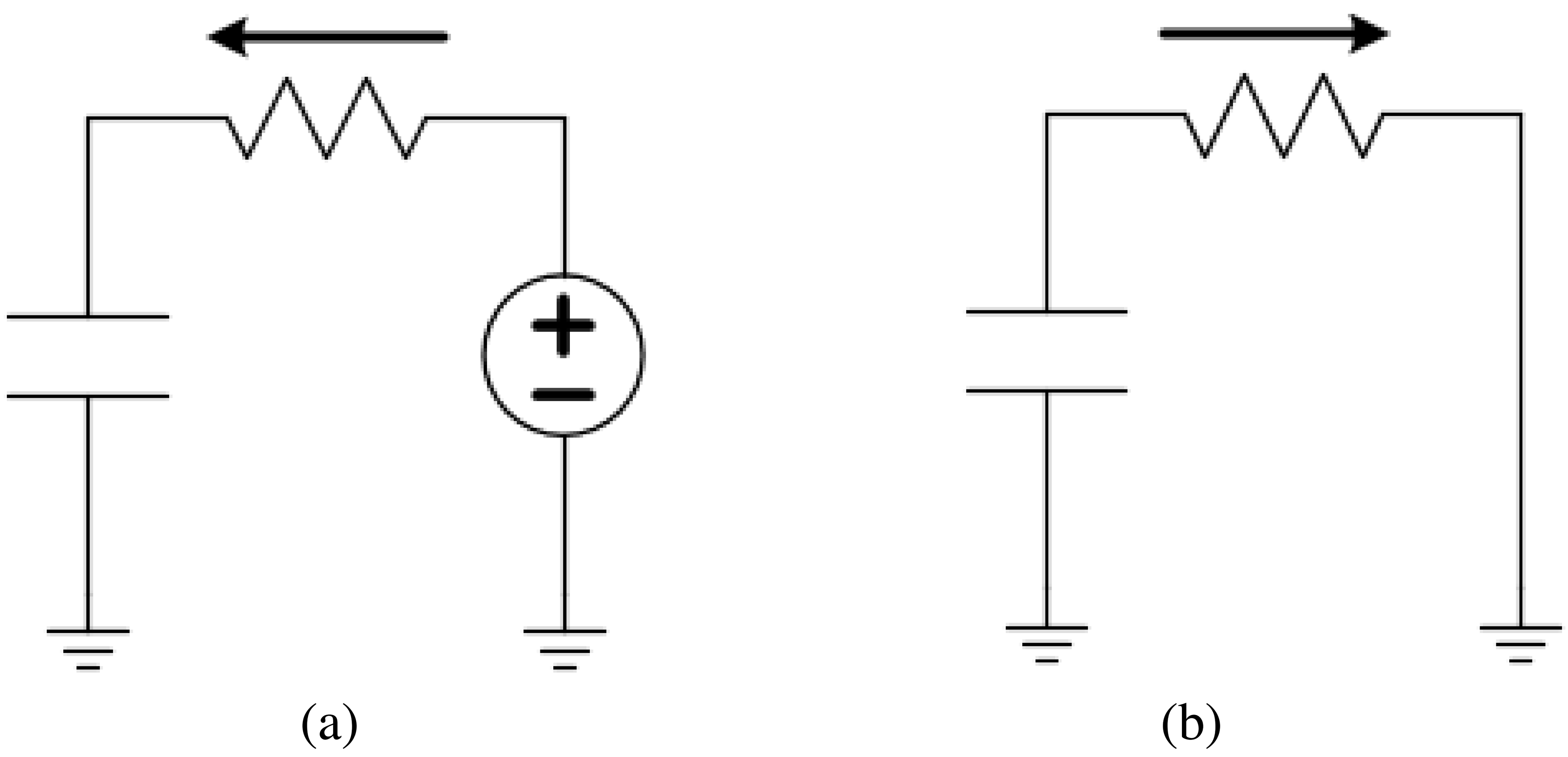


***Figure 3**: Charging (a) and discharging (b) schematics for the oscillator circuit after making modeling assumptions for the Schmitt trigger. The arrow shows the direction positive-valued current will flow as the capacitor charges and discharges, respectively.*

If we desire control over the duty cycle of our square wave, we can consider using different resistance in the charging phase than in the discharging phase of oscillation.

We can use diodes to change which resistive path is used. Consider the circuit of Figure 4.

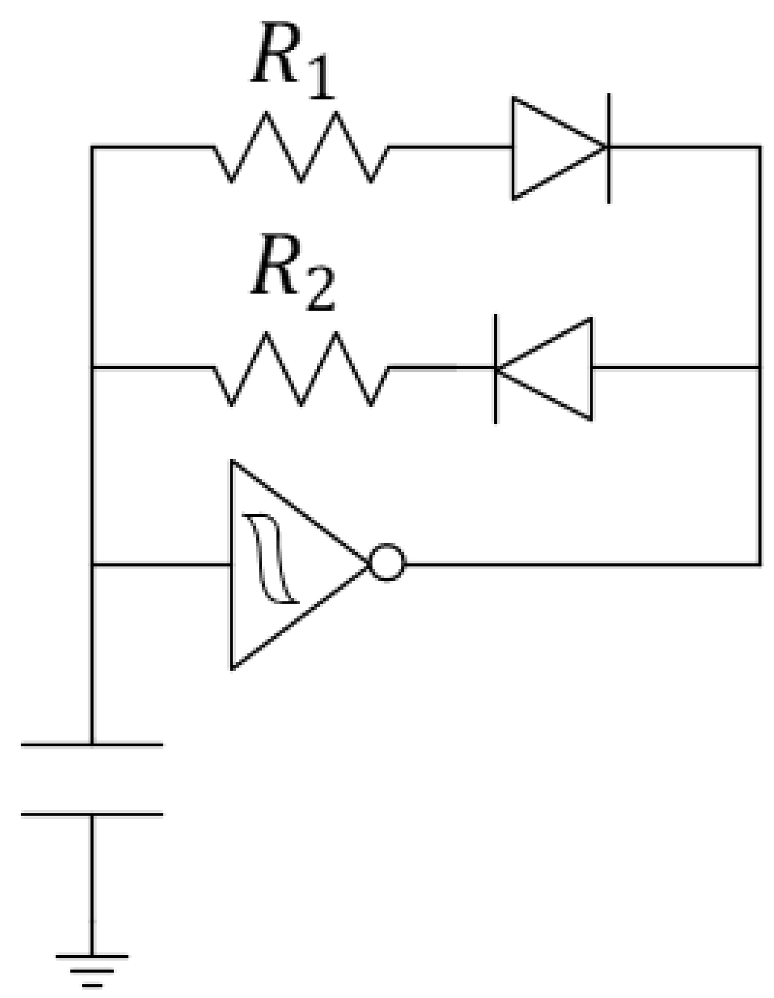
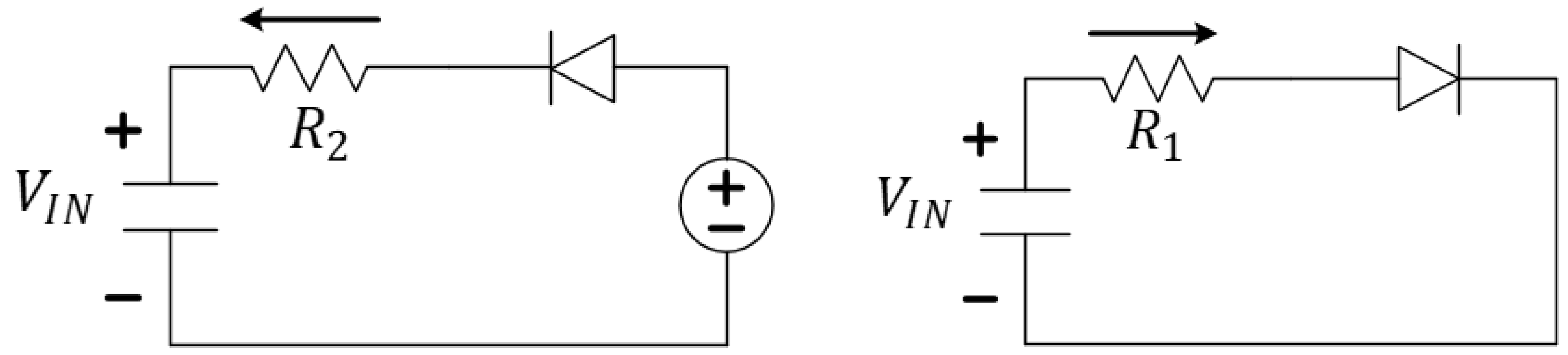


***Figure 4**: Circuit schematic of an oscillator with a selectable duty cycle.*

In this configuration, the capacitor will discharge through R_1, but charge through R_2. See Figure 5.



(a) *(b)*

***Figure 5**: Charging (a) and discharging (b) schematics for the oscillator circuit including the diodes.*

To clean this circuit up and make the duty cycle easily controllable, we might rearrange it as in Figure 6 where a single turn pot becomes the control knob.

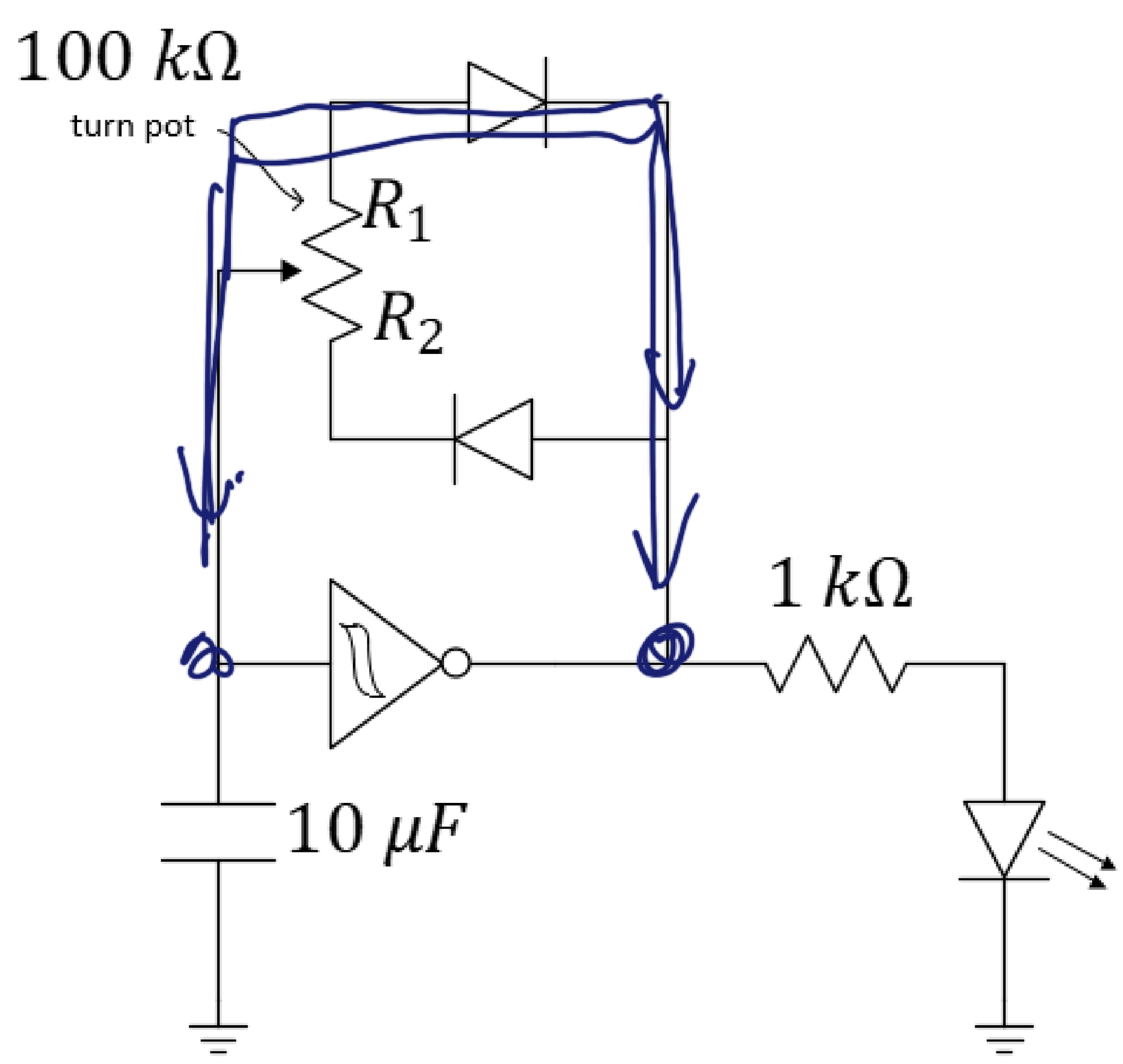


***Figure 6**: Circuit schematic of an oscillator with a selectable duty cycle.*

Build the oscillator circuit as shown in Figure 6. Use an LED to complete the design with a visible output. Your LED should be flashing every one to three seconds. Turn the knob and watch how the duty cycle of the yellow LED changes.

Turn your knob fully counterclockwise.

Question 1: Estimate the duty cycle of your LED. Turn your knob fully counterclockwise.

1 %

Turn your knob fully clockwise.

Question 2: Again, estimate the duty cycle of your LED.

100%

Think about the charging and discharging phases of your oscillator as described in Figure 5. The resistors R_1 and R_2 control the rates at which the capacitor discharges and recharges.

Question 3: When you turn your knob counterclockwise, which resistor, R_2 or R_2, is being made small? Explain based on your observations in the above questions.

R1 is smaller, Because when turning knob countclockwise, $\tau = RC$, is approaching to zero

so R1 is getting smaller

Question 4: On Figure 7, mark the "loop" through which the capacitor discharges. Label that loop "L1".

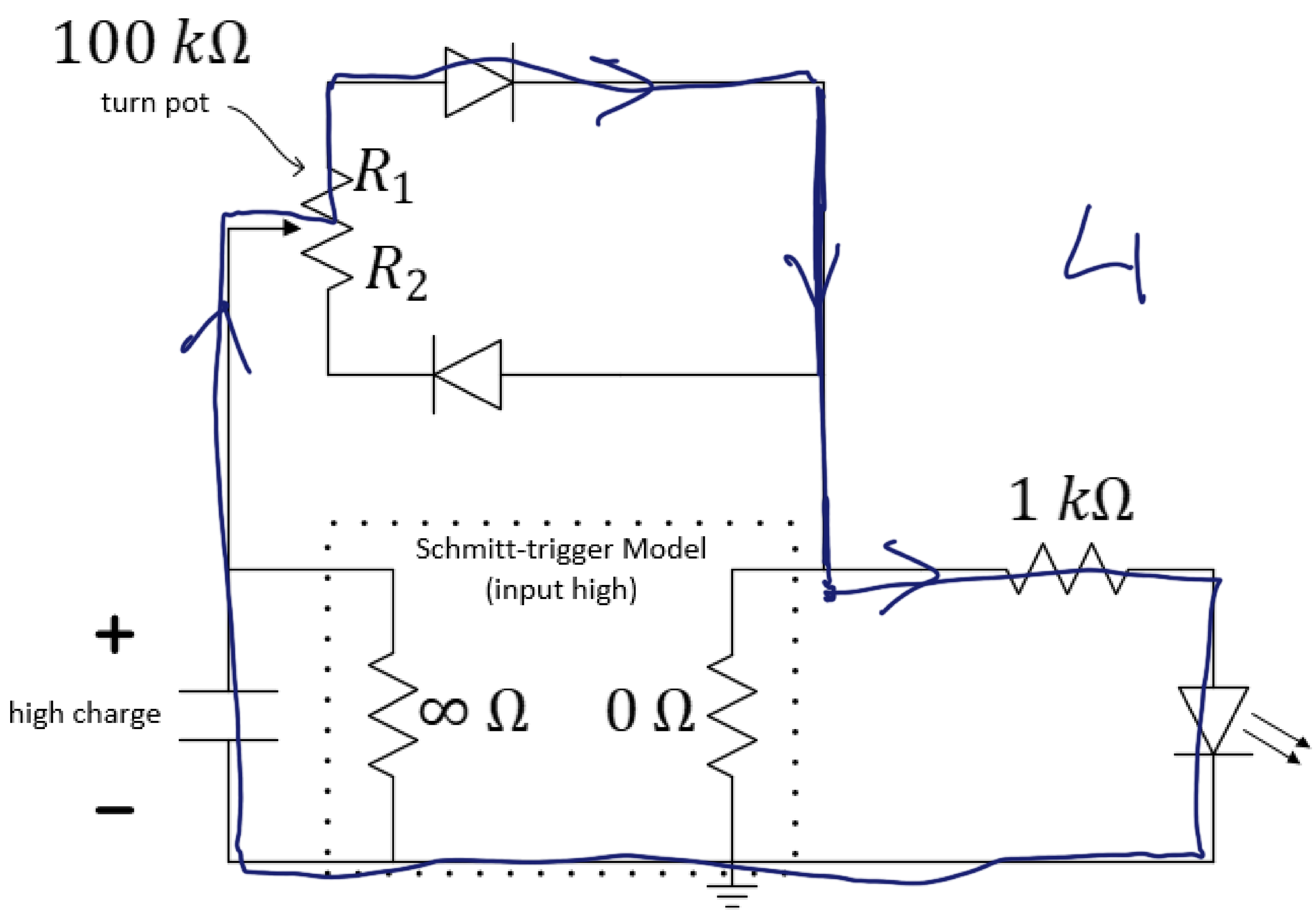


***Figure 7**: Oscillator with Schmitt-trigger modeled for "input high".*

Question 5: On Figure 8, mark the "loop" through which the capacitor charges. Label that loop "L2".

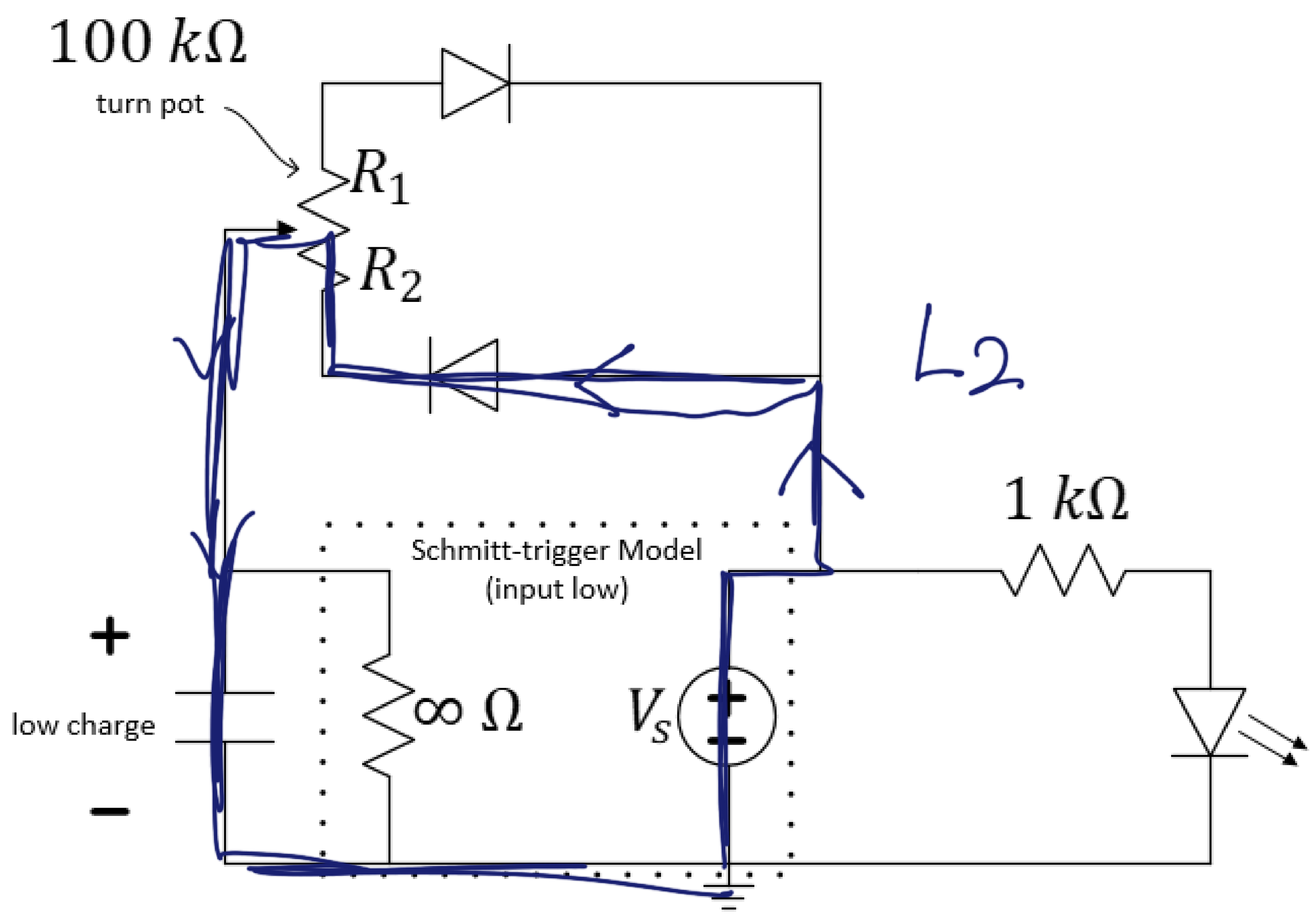


Figure 8: Oscillator with Schmitt-trigger modeled for "input low".

Question 6: How would the charge and discharge phases of the oscillator be compromised if the input resistance of the Schmitt trigger was small instead of large (say ~100 Ω instead of ∞ Ω)? Would oscillation be likely to occur? Explain.

No, Because it will only go to the input resistance of the Schmitt trigger, the capacitor is shorted ∴ Thus the capacitor would not be charged

Now we use oscilloscope to observe the time-varying signal. Place the probe of channel 1 between the circuit ground and the output of the inverters as shown in the figure 9. After pressing the **Default Setup** button on the scope, adjust the scope **vertical, trigger, and horizontal settings**, respectively, to get a nice view of the waveform.

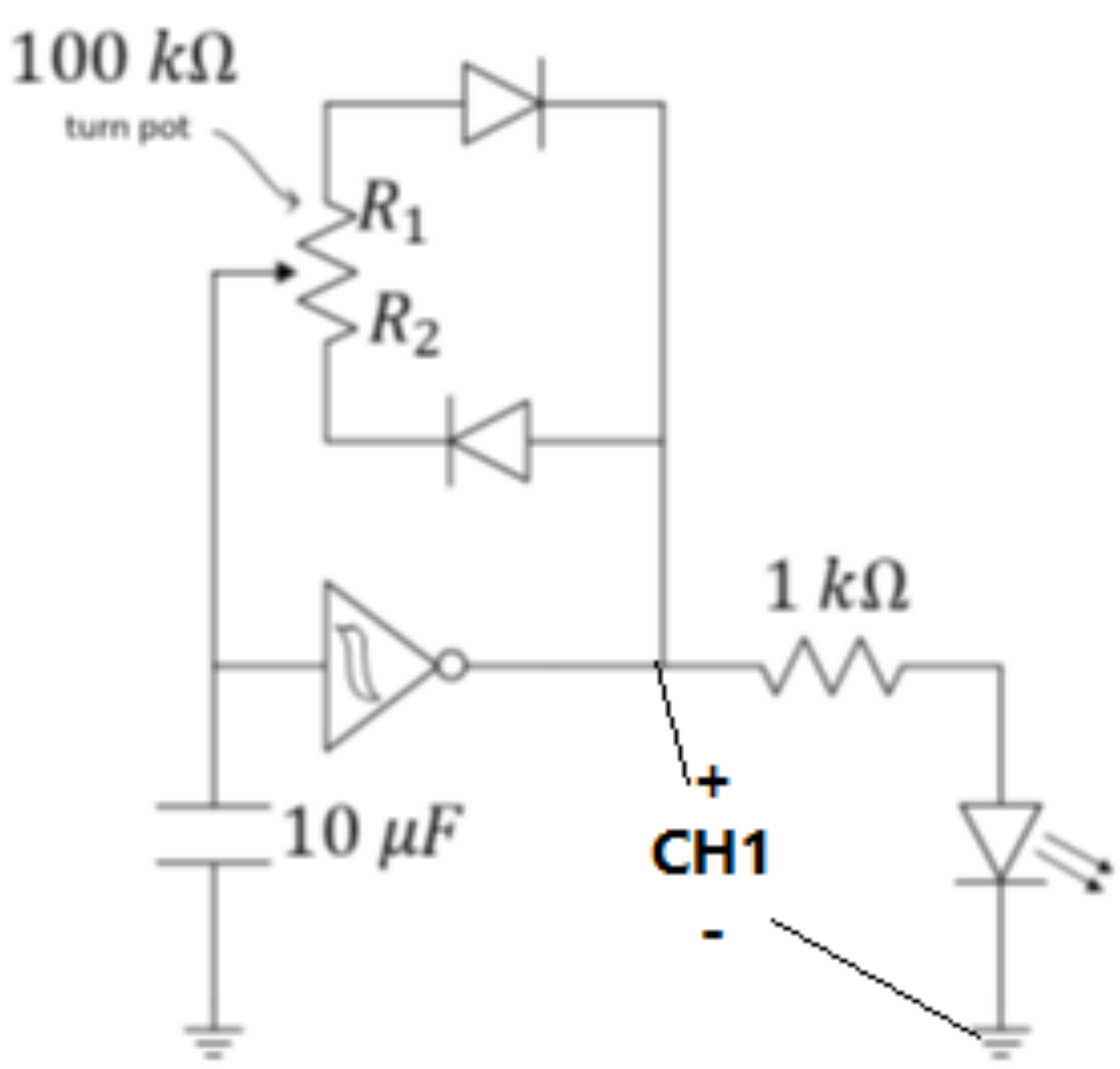


Figure 9: Use oscilloscope to observe the time-varying signal.

Question 7: Use your potentiometer to adjust the duty cycle so that channel 1 is at **40%**.

Sketch the waveform in the figure below.　(Note: Label coordinates and units)

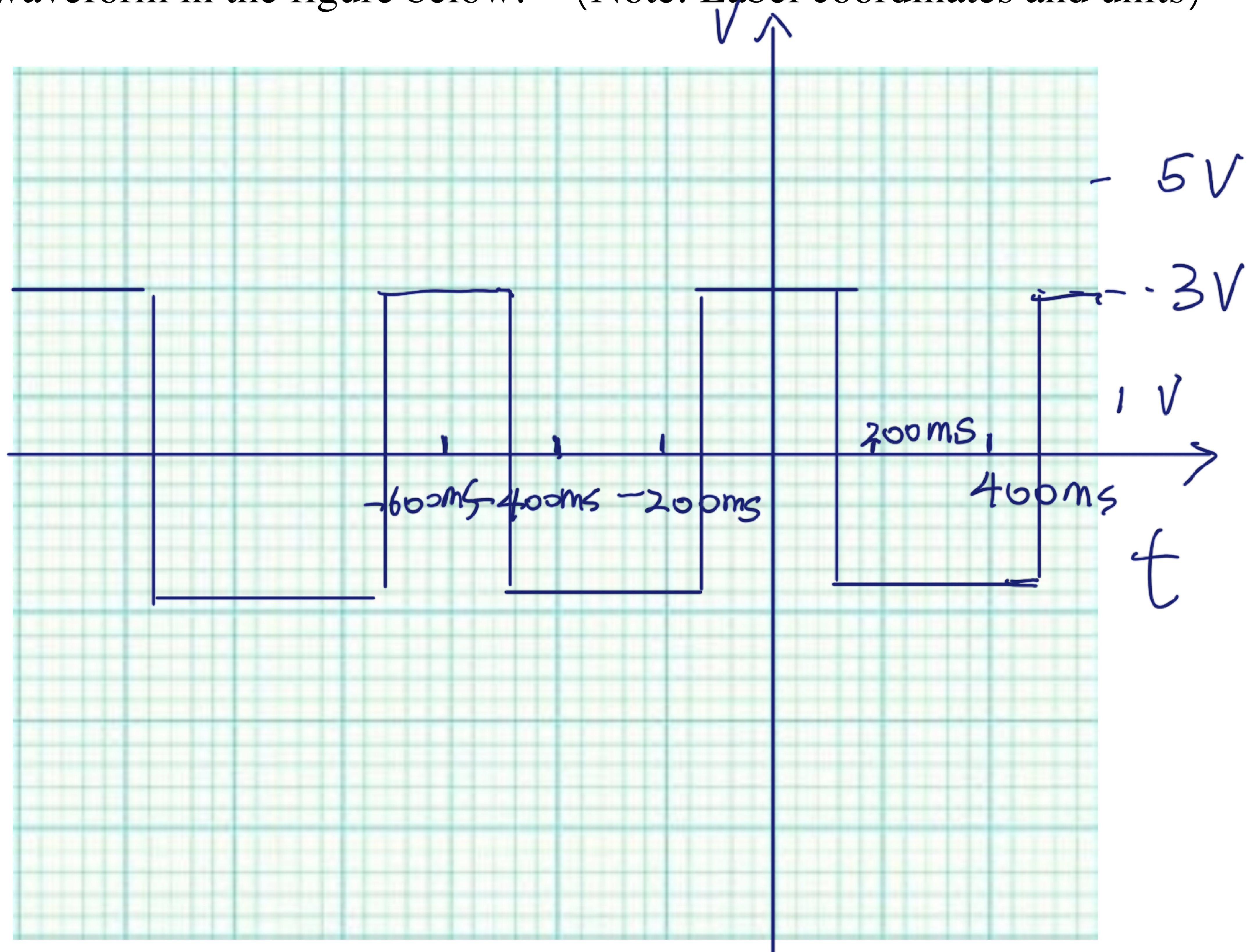


Figure 10*: Time-varying signal from channel 1.*

Function Generator

A function generator is a piece of equipment that outputs an electrical voltage waveform that can vary in time, in contrast to the DC power supply that can only output a constant voltage. The output waveform of our function generator is periodic. The waveform's shape can be chosen from a predetermined "function" list. Besides the waveform's shape, the front panel buttons allow the user to alter other parameters of the waveform like frequency, amplitude, offset, and duty cycle.

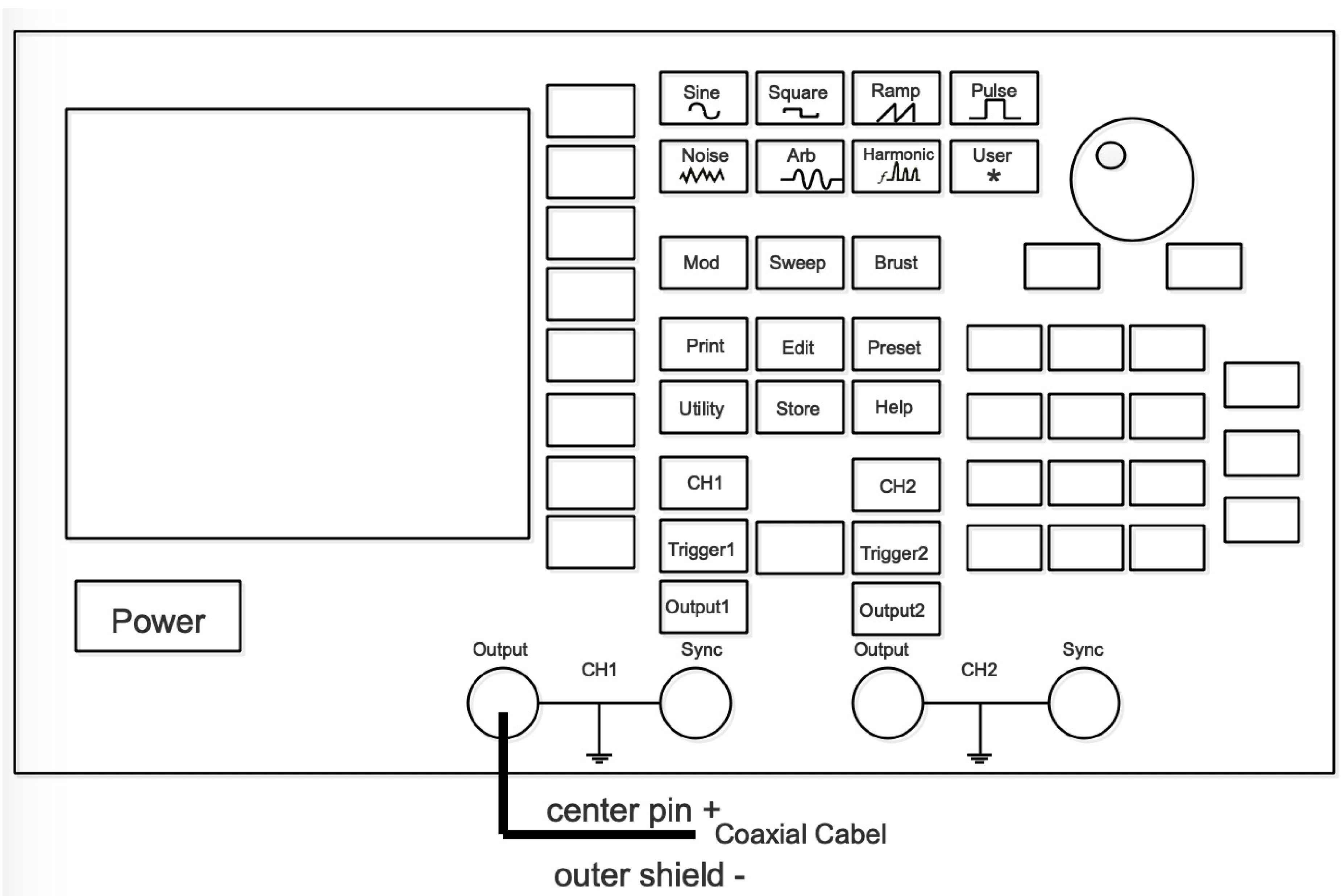


Figure 11*: The front panel of the DG4202 function generator. At the BNC output, the center pin is the positive voltage reference while the outer shield is the negative (often the "ground" reference).*

The waveform output is generated inside the device from functions stored in memory in digital form. The list of binary numbers that specify the waveform are applied to a Digital-to-Analog (D/A) converter and output as an analog waveform through the bottommost BNC connector that is labeled OUTPUT. The circuit symbols for several different functions are provided in Figure below.

The SYNC port is used to synchronize the “clocks” of multiple devices. We will not use it in ECE110. Be careful not to accidentally confuse it with the OUTPUT port.

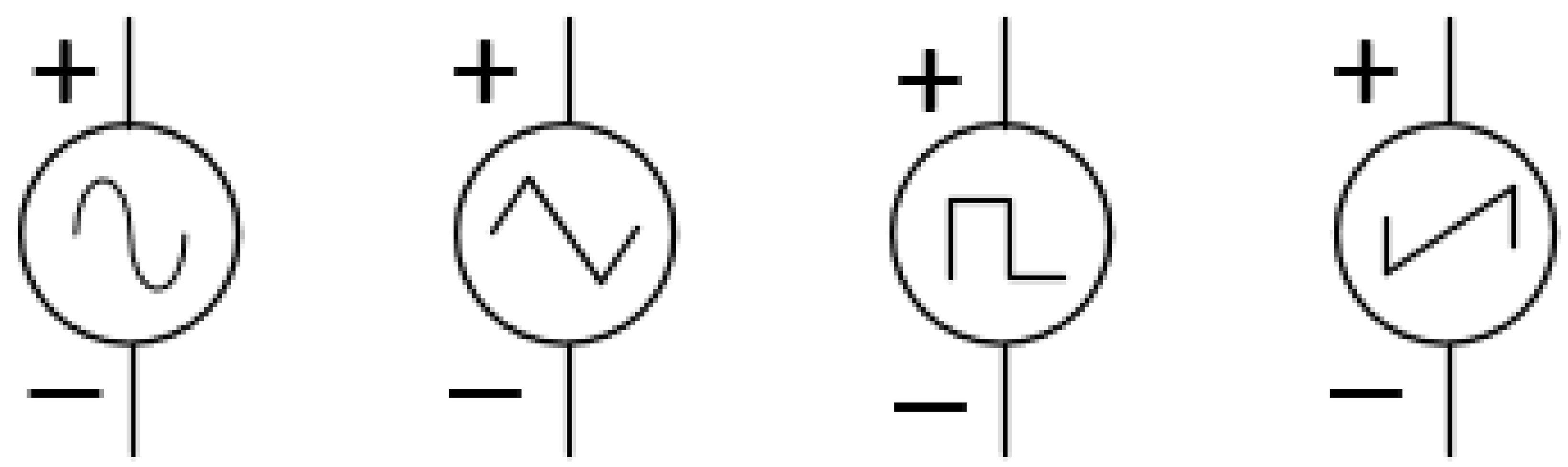


Figure 12*: Circuit symbols for the sine, triangular, square, and sawtooth waveforms, respectively.*

When discussing periodic signals, we often refer to parameters like amplitude and frequency and period. **Amplitude** is the height of the voltage (commonly in units of volts or millivolts). It might be given as the peak-to-peak height (the difference between the largest voltage the waveform takes and the smallest voltage) or, often for a signal that symmetrically takes on positive and negative voltages, the zero-to-peak voltage (half of the peak-to-peak). **Period** is the amount of time, often in seconds, it takes for a signal to complete one cycle and return to its starting point. Frequency is the rate at which the periods (or cycles) appear measured in cycles/second or “Hertz”. Frequency is actually just the inverse of the period.

Two other parameters are quite common as well. A periodic signal like a sinusoid or square wave is generated by a device like the function generator to be symmetrical around 0 volts (takes on evenly positive and negative voltage values relative to its “ground” reference). Adding a “**DC-offset**” to the signal can shift it upwards or downwards. Often the goal is to shift the signal upwards so that the voltage produced always falls between 0 volts and the peak-to-peak amplitude. For a square-wave signal, **duty cycle** is the ratio of the time in each period the signal is at its maximum value divided by the amount of time in one period. For a duty cycle of 1%, the waveform almost never leaves its minimum value and for a duty cycle of 99%, the waveform is nearly always at its maximum value. A duty cycle of 50% is what most people think of as a square wave signal. A signal in which the duty cycle is adjustable, often in response to some outside stimulus, is referred to as a pulse-width modulation (PWM) signal.

Setup the Function Generator (DG4202) to output a square wave with a frequency of 1000Hz, a 5V peak-to-peak amplitude, and an offset of 2.5V. Here are the instructions:

Set the following parameters of the output by pressing the corresponding button and turning the large knob if necessary.

☐ **Function** – press the button on the function generator that shows a **square wave**.

☐ **Amplitude** – Press the *Ampl* button. This shows you the default amplitude value in the display. To quickly change the amplitude, enter the value by the number keyboard, or turn the dial in the upper right corner. Either control changes the digit blinking on the display. A different digit can be made to blink by using the left/right arrow keys.

☐ **Frequency** – Press the *Freq* button. Adjust settings with the dial or number keyboard.

☐ **Offset** – Press the *Offset* button. Adjust settings with the dial or arrows.

Validate your signal by connecting it to the oscilloscope (there are BNC-to-BNC cables in the cabinet). Are you surprised by what you see? READ ON! …

There is one hidden problem with the function generator. We cannot treat it as an ideal voltage-signal generator. It turns out that it was designed to have a 50Ω internal resistance. This cannot be changed, but the designer of the function generator also recognized that the most typical "loads" the function generator would see would be either 50Ω (an equipment *standard*) or a much larger resistance like 1 $M\Omega$ (another equipment standard and the default value on our oscilloscope). In their wisdom, the designer of the function generator has allowed us to select the device to be in either the default **50 Ohm** mode or in the so-called **High Z** (high-impedance) mode. Nothing physically changes within the function generator while changing between these two modes, however, the digital display will report either the generated voltage, $v(t)$, or half of that voltage, 1/2 $v(t)$. See the figure below.

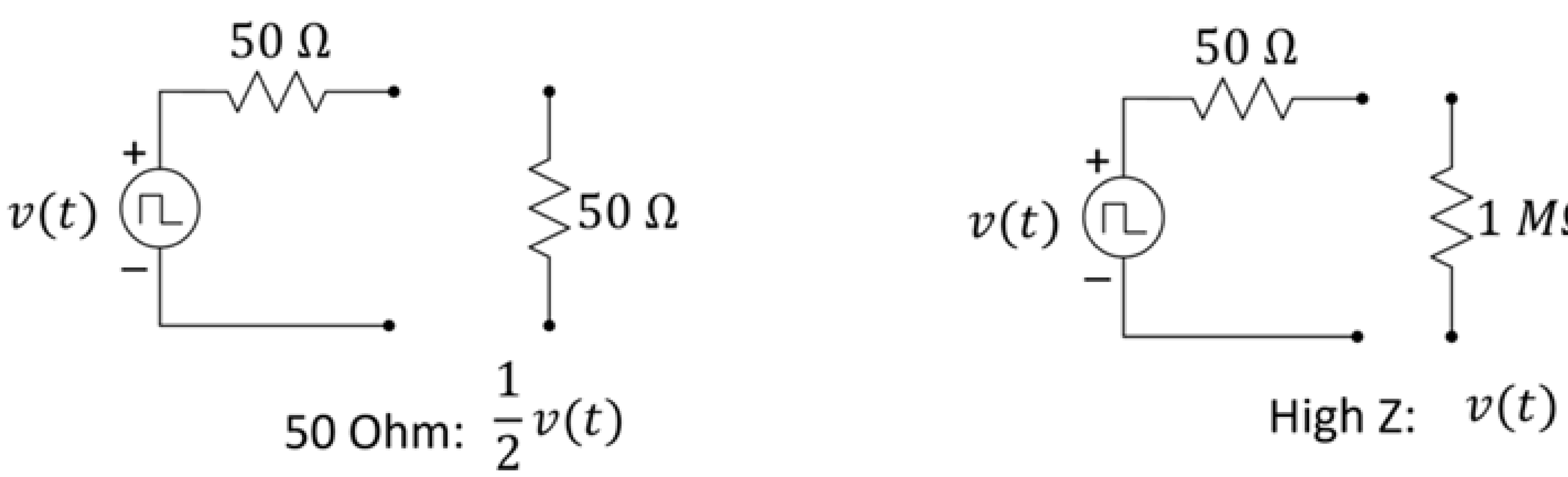


***Figure 13**: Deciding when to use the High Z vs. 50 Ohm setting of the function generator.*

Notes: In 50-Ohm mode, the function generator will display a value only 50% of the open circuit amplitude because that is what you would see across a 50-Ohm load. In High-Z mode, the function generator will display the open-circuit voltage because that is what you would see when measuring across a high resistance.

Switching between 50 Ohm and High Z modes

If you want the displayed value of the function generator to match the voltage read by a high-resistance device, you need to set the function generator to “High Z”. Do this by pressing this series of keys on the function generator: **Utility -> CH1/CH2 Setting -> impendence-> choose High Z or 50Ω**. The function generator will now show the voltage value of the “ideal internal source”. *You must do this each time you use the function generator because the 50 Ohm default setting will report 1/2v(t)*

Question 8: Configure the function generator and the oscilloscope so that they agree with each other with respect to the anticipated resistance. Sketch the signal seen on the oscilloscope on the figure below.

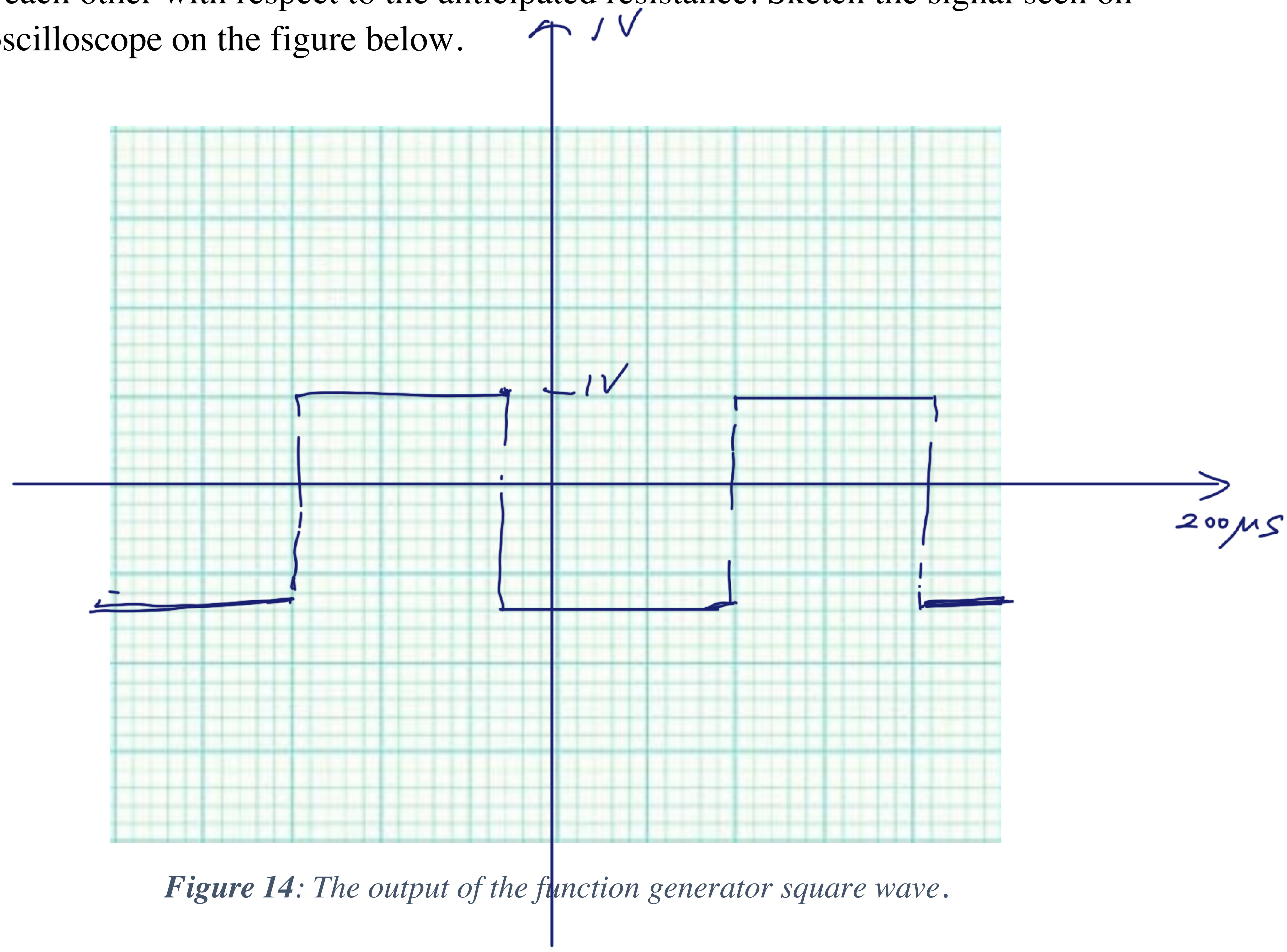


Figure 14: The output of the function generator square wave.