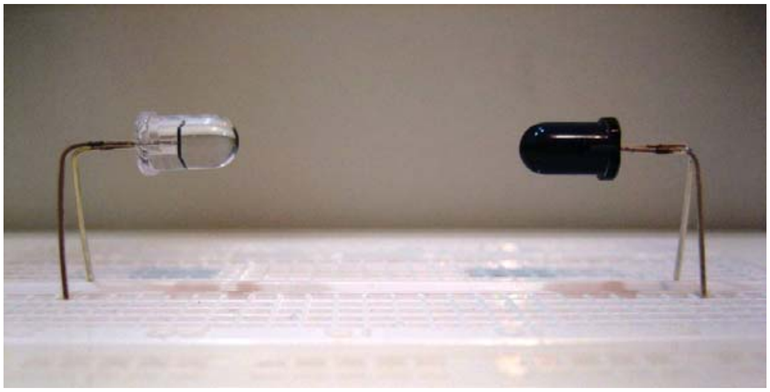
Photogate



A photogate sensor is a timing device used for very precise measurements of high-speed or short-duration events. Typical applications include free fall acceleration, the period of a pendulum, or the velocity of a ball rolling down a track. A photogate consists of a light source and a light detector. Whenever an object moves through and blocks the beam of light between the source and the detector, a signal is produced which can be detected by a Vernier interface to start and stop timing operations.

DESIGN OBJECTIVES

- Build a photogate using an infrared phototransistor and LED
- Construct a simple voltage-divider circuit
- Use a Vernier Digital Breadboard Cable to make the necessary connections between the photogate circuit and the lab interface
- Use Logger *Pro* to time an event

MATERIALS

Vernier computer interface	infrared LED
Vernier Logger *Pro* software	3.3 kΩ resistor
computer	220 Ω resistor
USB cable	breadboard
Vernier Digital Breadboard Cable (BB-BTD)	jumper wires for breadboard
NPN infrared phototransistor	(optional) multimeter

BACKGROUND

In a photogate sensor, a phototransistor often serves as the light detector. It has very high resistance (over 100 kΩ) when it is in the dark, but the resistance drops to only a few hundred ohms when light shines on it. In this application, the phototransistor will act as a light-sensitive switch. When a light beam aimed at the phototransistor is interrupted by an object, the voltage at the switch input decreases. For best results, the light source should have a narrow beam directed at the phototransistor. An infrared light-emitting diode (LED) is a good choice for this purpose, because they are inexpensive and durable. Since they require very little current, they can be powered directly from the Vernier interface. Infrared light has a longer wavelength than our eyes can see, but the phototransistor is able to detect this light. The complete photogate circuit incorporating both an infrared phototransistor and LED is shown below. Notice that a 220 Ω resistor is used to limit the flow of current to the LED so that it does not overheat.

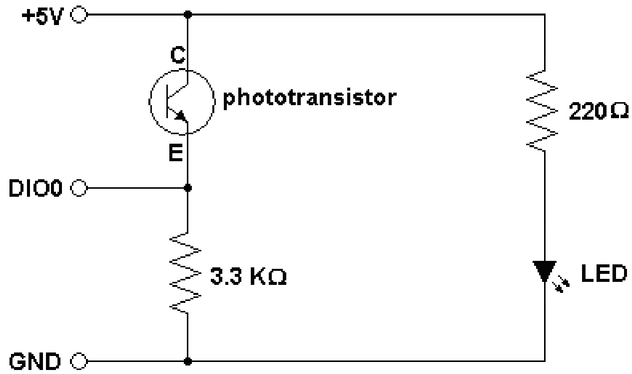


Figure 1 Photogate circuit

With this system, the Vernier interface will be able to detect when an object moves through the space between the LED and the phototransistor. Whenever the beam is blocked, the phototransistor is "off" and the voltage signal is low. When the beam is unblocked, the voltage signal will be high, since the resistance of the phototransistor is much less than that of the 3.3 kΩ resistor.

A Vernier LabQuest, LabQuest Mini, or LabPro can be used with Logger *Pro* software for many different types of timing, including Motion, Pulse, Gate, Pendulum, and Photogate Timing:

- Motion Timing – This mode is appropriate for a picket fence, bar tape, or pulley experiment (a "picket fence" is a strip of clear plastic striped with evenly-spaced opaque bars). During operation, times are recorded as the leading opaque edges of the picket fence, bar tape, or pulley spoke pass through the photogate beam. These times are displayed in a data table. If you enter the distance between the leading edges of the opaque bands into the Length of Object field, the program can analyze the times, and calculate velocities, displacements, and accelerations.

  Tip: *When using a picket fence or bar tape, the width of each opaque band should be at least 0.5 cm. The distance between leading edges of the opaque bands should be at least 3 cm if the object will be moving rapidly (such as in free fall). A closer spacing can be used if the object will be moving slowly.*

- Pulse Timing – In this mode, the timing begins when the photogate is first blocked and continues until the photogate is blocked again.

- Gate Timing – This mode is often used to measure the velocity of a moving object, such as a cart or ball moving down an inclined track. The timing begins when the photogate is first blocked and continues until the gate is unblocked. If the length of the object is entered into the Length of Object field, the velocity is calculated.

- Pendulum Timing – This mode measures the time for one complete swing of a pendulum or other oscillating object. The timing begins when the photogate is first blocked, and continues until the photogate is blocked twice more (back-and-forth-and-return).

- Photogate Timing – In this mode, only a time and a Gate State are displayed. The Gate State registers a "1" when the photogate is blocked and a "0" when it is unblocked. You may add other calculated columns if desired.

CONSTRUCTION

Build the photogate

1. Plug the Breadboard Cable into a breadboard.

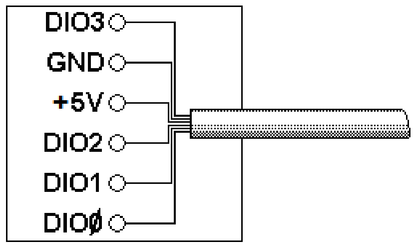


Figure 2 Vernier Digital Breadboard Cable pin-out

2. Connect the 3.3 kΩ resistor between the DIO0 pin and the GND pin on the Digital Breadboard Cable.

3. Connect a 220 Ω resistor between the +5 V pin on the cable and an unused row of pins on the breadboard.

4. Connect the positive lead on the infrared LED to this same row of pins.

   Tip: *The positive lead (wire) on an LED is usually longer than the negative lead. Also the lens on the negative side of the LED is flat or notched.*

5. Connect the negative lead on the infrared LED to the GND pin on the cable.

6. Connect the collector lead of the phototransistor to the +5 V pin on the cable.

   Tip: *Consult your manufacturer's data sheet to identify the collector and emitter leads on the phototransistor. The collector lead on the Radio Shack phototransistor has a shorter wire and a flat side on the lens.*

7. Connect the emitter lead of the phototransistor to the DIO0 pin on the cable.

8. Before connecting your photogate, it is a good idea to do a preliminary test with a digital multimeter. Attach the meter to read the resistance between the +5 V pin and the DIO0 pin on the cable. The positive lead of the multimeter should be on the +5 V pin. With the meter connected in this way, you should notice a large change in the resistance reading when the phototransistor is exposed to bright light (a flashlight or the sun). The resistance should be several hundred thousand ohms in the dark and less than a thousand ohms in bright light.

Connect the sensor to the interface

1. Connect the Digital Breadboard Cable to the first DIG port on the interface.

2. Connect the interface to the computer.

SOFTWARE SETUP

1. Start Logger *Pro*.
2. Choose Set Up Sensors from the Experiment menu.
3. From the DIG/SONIC1 list, select Choose Sensor, then select Photogate.
4. Select the timing mode from the DIG/SONIC1 list. (The default is Motion Timing.)

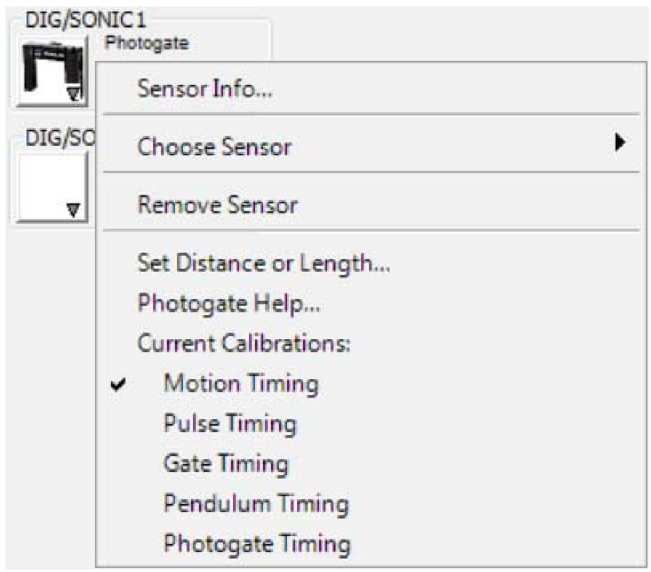


Figure 3 Logger Pro Set Up Sensors dialog box

Tip: *You can check the Gate State in the status bar in the upper left corner.*

5. Click Collect to begin using your photogate.

TIPS

1. Radio Shack sells an infrared emitter and detector in one package (catalog #276-142). You can also find infrared phototransistors and LEDs at online electronics stores, such as Mouser and Digikey.
2. The negative lead on an LED will have a shorter wire and/or a flat side or notch on the lens.
3. Consult your manufacturer's data sheet to identify the collector and emitter leads on the phototransistor. The collector lead on the Radio Shack phototransistor has a shorter wire and a flat side on the lens.
4. When you use your photogate, do not expect to see the LED glow brightly. The infrared LED emits very little visible light. If you are in an absolutely dark room, you may see a very faint red light.

TROUBLESHOOTING

1. Check all resistors against the resistor color code to ensure you are using the correct size.

2. Check the polarity on the infrared photoresistor and LED to ensure the positive and negative leads are connected in the proper direction.

3. Your photogate support should have a separation distance of about 8-10 cm between the phototransistor and LED. If the components appear to be aligned but you are still not registering an unblocked state, try moving the components a little closer to one another.

4. It is essential that the phototransistor and LED be aligned. Bend the leads on the components until Logger *Pro* registers an unblocked state.

5. A different resistance value may be needed in the phototransistor circuit. Replace the 3.3 kΩ resistor with a 10 kΩ potentiometer (variable resistor). With the phototransistor and LED aligned, carefully adjust the potentiometer until the photogate works.

6. Ambient room light may be interfering with the phototransistor. Place a small column of black tape around the lens to block out stray light.

MAKING THE PHOTOGATE MORE USEFUL

You can make the photogate more durable for timing by soldering the components together and mounting the components on a rigid frame as shown below. Use short sections of wire to extend from the breadboard to the photogate frame. Bend the leads on the phototransistor and LED at right angles so that the leads can be taped to the support with the two components facing each other. Tape the resistors and extra wire to the support. If the support is metal, be careful not to allow any of the exposed wire to touch it.

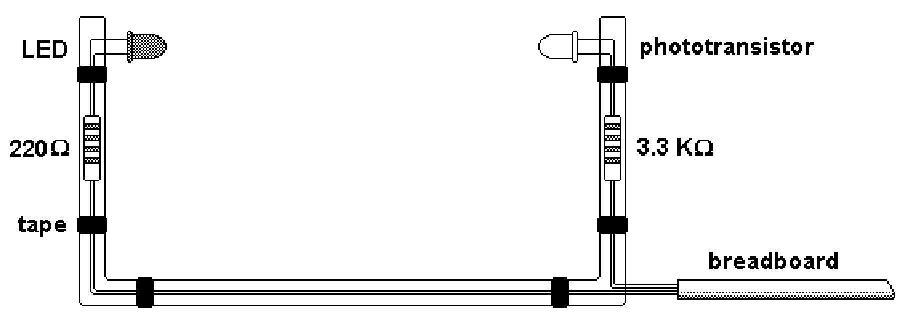


Figure 4 Photogate support

APPLICATIONS

1. Use your photogate to do a complete study of a pendulum. Investigate how the period of a pendulum (the length of time for one complete swing) is affected by changes in the length, mass, and angle of swing of the pendulum.

   Tip: *Use a pendulum with two support strings (like the chains on a children's swing set). This keeps the pendulum bob swinging in the same plane and keeps it from hitting the photogate.*

2. Measure the velocity of a moving object. If the object is wider than the photogate, tape a length of cardboard to the object so that it can pass between the arms of the gate.

3. Measure the acceleration due to gravity by dropping a picket fence through the arms of the photogate. Be careful how you release the picket fence. If it rotates from vertical or strikes the side of the gate, your results will be in error.

4. Measure the flash rate of a strobe lamp. Block the light from the LED and aim the strobe light at the phototransistor. You may have to dim the room lights.

5. Build a phototachometer to determine the frequency of a rotating object. Mount a disk with a hole in it onto a rotating shaft. Place the disk between the arms of the photogate so that the disk blocks the gate except when the hole rotates through the beam.

6. Use your photogate to measure the “hang time” of a volleyball or basketball player’s jump. Replace the LED with a pen laser as a light source. The laser produces a concentrated light, which should allow you to place it several meters away from the phototransistor. Have the jumper stand between the phototransistor and the laser so that his or her shoes are blocking the beam.

7. Measure the initial velocity of a projectile with your photogate. Use this velocity to predict where the projectile will land.