

# Photo-Detection and the DV1 Dual Photocell Detector Card

Joseph Norris, SER Division 15

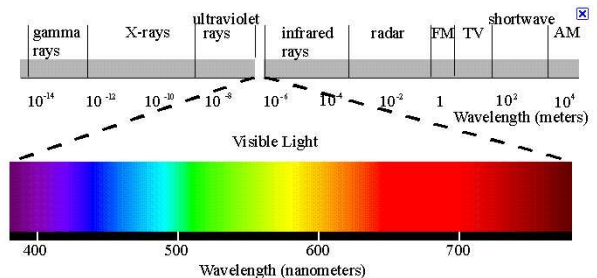
On the model railroad layout, photocell detectors are used to indicate the presence of a locomotive or rolling stock at a precise location. This detection is used to trigger another event, such as applying power to an indicator light, throwing a turnout, blocking conflicting traffic, controlling a track signal, indicating block occupancy or controlling an animated device.

The dual detector board can be used for any of these purposes. This document will discuss photo-detection in general, illustrate some applications and show how to connect the board to the layout.

## A. Photocell Sensitivity

Photocells used in model railroading usually operate in the infrared portion of the electro-magnetic spectrum. This region is invisible to the human eye but photocells can be designed to sense light in this range of the spectrum. Infrared (IR for short) light is generated by specially designed LEDs (Light Emitting Diodes), their wavelength being matched to the sensitivity of the photo cells. In this way, the IR LED and photocell perform as transmitter and receiver in the infrared spectrum.

This chart shows a broad portion of the electromagnetic spectrum. You can see that visible light makes up only a small part of the spectrum and that infrared light has a longer wavelength (a lower frequency) than visible light.



In another chart, we can see the relative sensitivity of various light sources. Note, for example, that incandescent lights (Tungsten Lamp) contain frequencies on both sides of the visible spectrum. Of special interest, its output extends well into the infrared range. Because this is so, many photocells, designed for infrared sensitivity, can be actuated by incandescent light and, as we shall see, special precautions must be taken to assure that unwanted light sources do not affect photocell operation.

Spectra From Common Sources of Visible Light

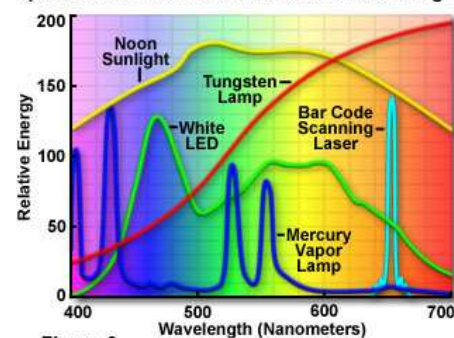
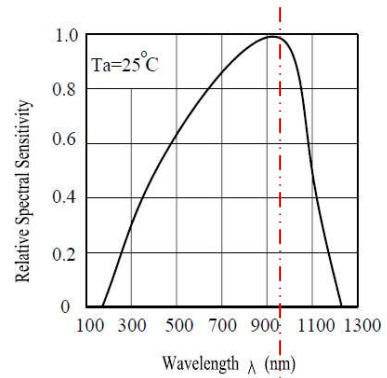


Figure 3

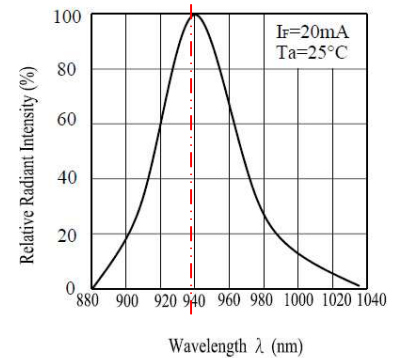
To reduce interference from non-infrared light sources, IR LEDs and photocells are designed to operate at the lower end of the infrared spectrum, in the area between wavelengths of 840 and 970 nanometers. Even at this extreme, however, there can still be interference from incandescent light.

This is made clear in the chart on the right, showing the spectra of a typical IR photocell. While its maximum sensitivity is at about 940 nanometers, it is still rather sensitive at 700 nanometers, the wavelength at which incandescent lights tend to be strongest.



Special optical filters and manufacturing techniques can be used to narrow the sensitivity of a photocell, but such devices are too costly to be practical for model railroading.

The spectrum of an IR LED can be controlled more easily. Compare this chart of an IR LED emission with the photocell above. The dotted line is drawn vertically at the 940 nanometer point.

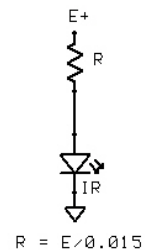


Components with similar sensitivities are said to be *matched* and will work well together. Typical examples are the Everlight IR204-A LED (left in photo) and PT204-6B photo-transistor (right in photo).

Note: When purchasing IR LEDs and photocells or phototransistors from surplus houses, one must be careful to note the sensitivity specifications, to be sure they will match. Frequently this specification is not stated.

### B. Connecting IR LEDs and Photo-transistors

IR LEDs are wired just like ordinary LEDs. They require a current-limiting resistor in series with the LED. The current requirement lies between 10 and 30 milliamperes (10-30mA) and the resistor value can be computed using Ohm's Law,  $R = E/I$ . For example, if the voltage ( $E$  in volts) is 12 volts DC and the current is to be 15 mA ( $I$  in amperes), then  $R = 12 / 0.015$  or 800 ohms. The electronic schematic is shown on the right.



Note: The nearest standard value would be 820 ohms, giving a current of 14.6 mA. The Dual Photo-detector board IR LED is powered from 4.8 volts through a resistor of 220 ohms, giving a current of 25 mA. This current is sufficient to project a solid beam 3 feet.

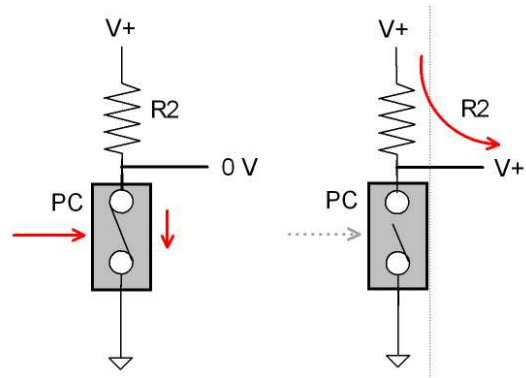
It doesn't matter which component, the resistor or the IR LED, comes first in the chain; that is, the LED could be at the top and the resistor at the bottom if it would be more convenient. A 1/8 or 1/4 watt resistor is sufficient.

Note: While we mention *photocell* and *photo-transistor* both in this paper, we will be using photo-transistors, a specific kind of photocell. In the past, cadmium photocells (photo on the right) were often used on the layout, being activated by overhead lighting. They have been generally replaced by photo-transistors, which are less costly, more sensitive and more versatile than the cadmium photocell.



A resistor is also placed in series with the photo-transistor as shown here. The photo-transistor is a variable resistor that works like a switch: it is either open or closed or somewhere in between.

In the leftmost diagram, light is shining on the photo-transistor; its resistance is very low and in switch terminology, the switch is 'closed.' The output is taken at the point where the resistor and photo-transistor meet and will be 0 volts, or close to it.

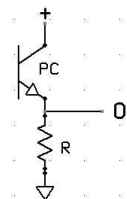


When the light beam is interrupted, as in the diagram at the far right, the photo-transistor resistance is high, and the output voltage will be close to V+ (the applied excitation voltage) and the switch will be 'open.'

This on and off output voltage can be used to power another device, such as a LED indicator light or a relay.

Note: To be accurate, the degree to which the switch is open or closed depends on the amount of light entering the photo-transistor. A little bit of light will lower its resistance only a little bit, perhaps not enough to provide sufficient output. When using IR LED/photo-transistor circuits, care must be taken to insure a clean and positive switch action.

As with the IR LED, the position of the resistor and photo-transistor can be reversed, as shown here. In this case the output is reversed: When light is shining on the photo-transistor, the output will be at V+; when the beam is interrupted, the output will be 0 volts or close to it.



This configuration is suitable for small distances between the IR LED and photo-transistor, say, 1-4 inches, but is not sensitive enough for distances much longer than that.

Photo-transistor current requirements are much lower than those of IR LEDs, and can be as low as 5 micro-amperes (0.000005 amperes). With the resistor at the bottom, a resistor of 47,000 ohms (47K) seems to work best. With the resistor at the top, values between 100,000 (100K) and 1,000,000 ohms (1M) are typical.

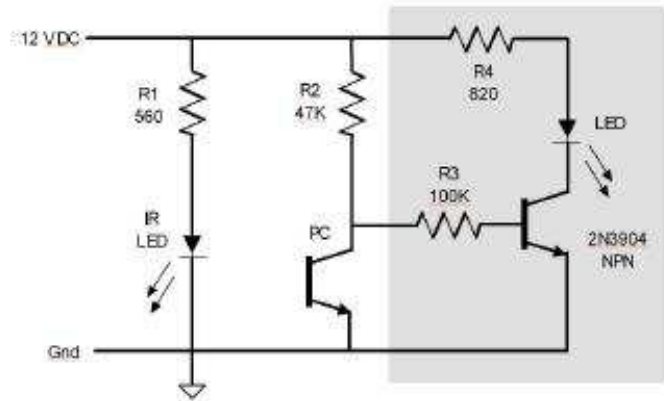
Note: The Dual Detector board uses a value of 220,000 ohms (220K). Combined with the IR LED current, this provides good switching action over a component separation of 3 feet and more.

Putting all this information together, we can draw a simple schematic diagram to show how the IR LED and photo-transistor are connected, and, to illustrate how they operate, a drawing representing a string of cars passing between them on a length of track.

The circuit is rather simple. It is powered by 12 volts DC. R1 keeps the current through the IR LED at a good level, in this case at about 21 milliamperes (0.021 amperes, 21 mA). The section in the gray area is just a driver for a LED to show when the beam is being interrupted. R4 limits the current to the LED to 15 mA.

Note: For a 5 volt power supply, change R1 to 220 ohms and R4 to 330 ohms. All other values can stay the same.

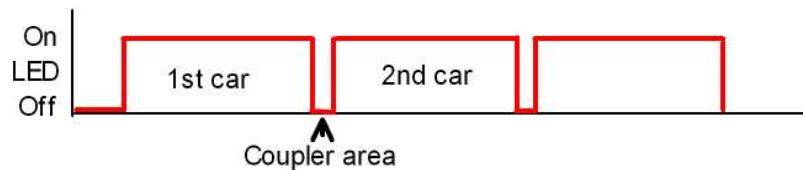
The transistor can be almost any NPN transistor. This is an easy circuit to construct on perforated board. All the parts are available from Radio Shack and similar distributors. This circuit will work even with poorly matched IR LEDs and photo-transistors.



To test the circuit, we use a length of track and mount the IR LED and photo-transistor on either side as shown in the sketches. You will notice that the number of beam interruptions with a passing car will depend on the height of the detector parts. A good height is one that will be interrupted by the body of a flat car.

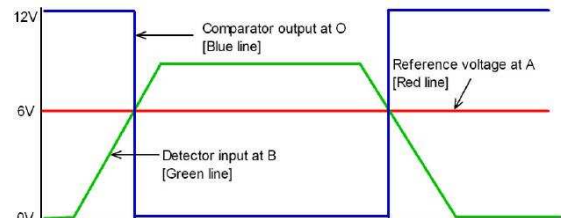
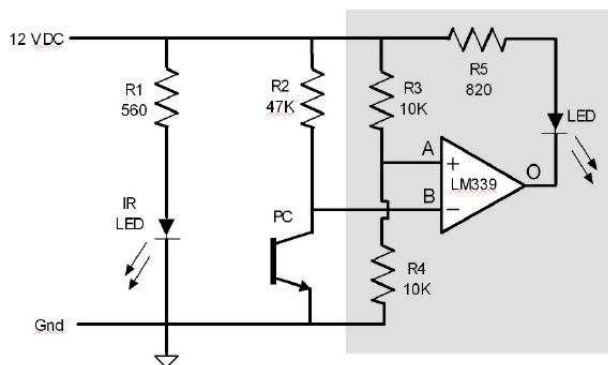


The indicator LED turns on as each car passes and stays on as long as the beam is interrupted. The chart below shows the effect.



This blinking indicator LED can have a useful function on the layout. It can detect movement of a consist in hidden areas, such as a staging area or inside a mountain. It can be helpful to know that the consist is moving as it should.

While the circuit in the gray area of our schematic 'works,' there is a more sophisticated method of turning the indicator LED on and off. It uses a chip known as a *comparator*. This device has two inputs as shown below on the left. The graph on the right illustrates the operation of the comparator.



When the beam is not interrupted, the comparator output (blue line, point O) is said to be 'high,' meaning its output voltage, in this case, is 12 volts and the indicator LED cannot light.

Resistors R3 and R4 form a voltage divider, setting the voltage at point A to half the supply voltage, in this case 6 volts. This is called the *reference* voltage (red line).

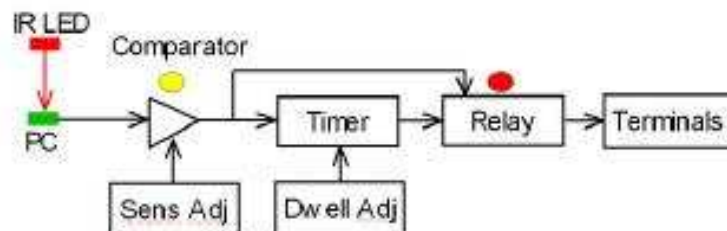
As the voltage from the detector (green line) rises, the comparator output stays 'high' until the detector voltage exceeds the reference. At this point, the comparator output (point O) drops instantly to 0 volts and the indicator LED lights.

The advantage of using the detector is that, by adjusting the reference voltage, we can control just how much interference with the IR LED beam we want before the output of the comparator changes. This is called a *sensitivity* adjustment and can be used to offset the effect of ambient light (light not from the IR LED) on our detector.

### C. Detection with the Dual Photo-transistor Detector

The DV1 contains two independent photo-transistor detectors, operated from the same power supply. Its input circuit is much like those described thus far. A timer has been added to the detector that extends its 'on' time a certain amount, even when the beam is no longer interrupted. This means that when first activated by a broken beam the output will continue as the open areas of a consist pass the detector, such as the space between rolling stock where the couplers are located.

A block diagram, representative of each of the two detectors, is shown here.



When the photo-transistor is receiving sufficient IR illumination, the yellow comparator light is illuminated. A sensitivity potentiometer (SENS) adjusts the point at which this occurs. As stated before, this adjustment can be used to reduce the effects of ambient light, to be sure the detector is working from the IR LED. If the IR LED and photo-transistor are far apart, this adjustment can be very critical.

When the beam is interrupted, the yellow light extinguishes, the relay closes and the timer is started. Note that either the comparator or the timer can close the relay.

The timer has a dwell adjustment (DWELL), which determines how long the timer (and the relay) will stay 'on' after the beam is restored. The red LED lights while the relay is 'on.' The screw terminals are connected to the single pole, double throw (SPDT) relay contacts and can be connected to any external device.

Each time the beam is interrupted, the timer 'resets' and starts timing over again. This is why the momentary restoration of the beam will not turn off the relay. If a consist is moving past the beam, the brief restoration of the beam between cars will not affect the output. This is a very different kind of result than we had with the simple circuit on page 4.

The timer can be adjusted to stay 'on' between 2 and 60 seconds after the beam is restored.

## D. Installation

### 1. Power Supply

The Dual Photo-Detector (DV1) is provided with a 5.5 volt, 300 mA, regulated, wall mount power supply that plugs into home outlets. The positive wire is colored with a black and white stripe. The negative or 'ground' lead is all black. These two wires connect to the "+5V" and "Gnd" terminals on the two-terminal strip.

If the power supply wires are not sufficiently long, they may be extended with any insulated stranded wire of 18 gauge or less, such as 'lamp cord.' Runs of up to 12 feet are acceptable.

This power supply can power up to three DV1 detector boards by wiring the power terminals in parallel.

### 2. Securing the Circuit Card

Each card has four holes, one in each corner, that accept a #4 screw. A rubber grommet or similar spacer can be used to hold the circuit card up from its mounting surface if desired, but this is not usually necessary.

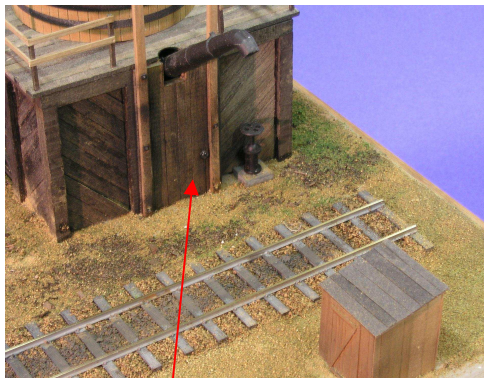
The circuit card should be located as close as possible to the location of the IR LED and photo-transistor on the layout. Leads to the IR LED and photo-transistor can be up to several feet long, but the shorter – the better. Long leads should be twisted together if possible.

### 3. Locating the IR LED and Photo-transistor

Position the height of these two elements so that they are directed to one another in a straight line. As mentioned before, their height will determine what part of rolling stock will interrupt the beam. With the timer 'dwell' set appropriately, they can be set just above the top of track rail and actuated by the wheels of rolling stock. A sufficient timer setting will negate the resulting frequent interruption of the beam.

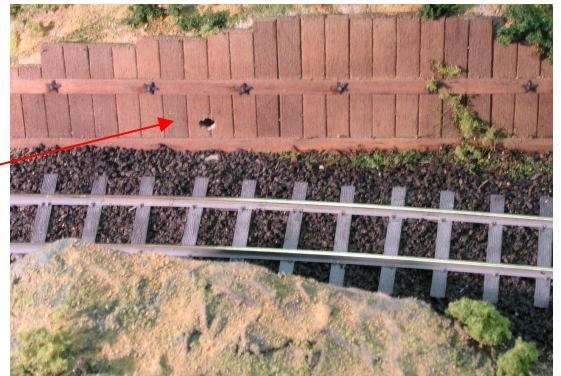
Position the photo-transistor so that it is protected from ambient light sources, as shown in this sketch.





Both the IR LED and photo-transistor can be disguised by placing them inside structures on the layout. Just be sure that they are pointed to one another without an unintended obstruction. In this photograph of a small diorama the photo-transistor is hidden in the shack on the right and the IR LED in the water tower (arrow).

Here is another photo showing concealment in an earth mound and behind a fence.



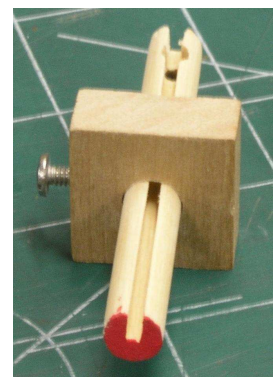
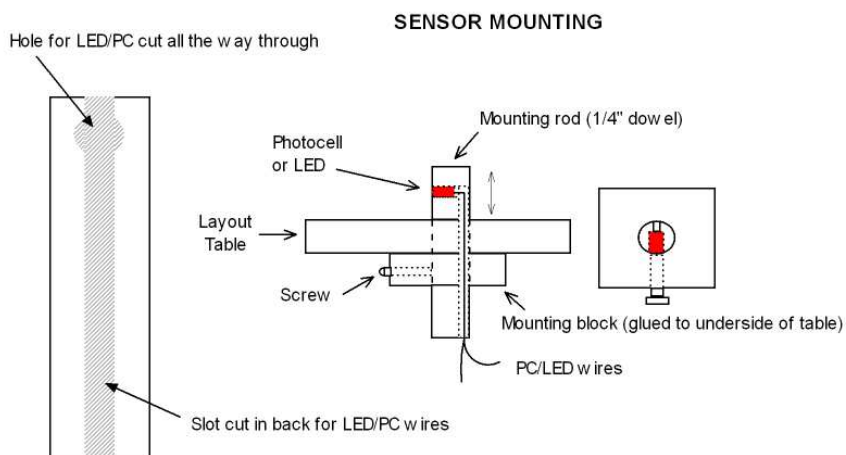
In both photos the photo-transistor is facing away from the fascia of the diorama. The structures need not be so close to the track, although the photo-transistor will give the best results if the beam is interrupted within an inch or so.



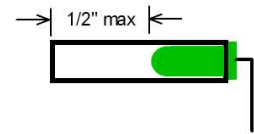
Beware of interrupting the beam with objects that can reflect ambient light back on the photo-transistor. One way to avoid this is to set the sensitivity of the DV1 very low so that only a strong IR beam can activate it.

In the photo on the left, the IR LED and photo-transistor are inside a building, placed close to the track. This detector marks the end of the track.

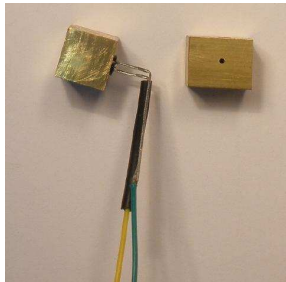
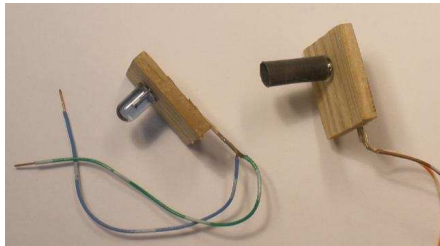
A dowel was used to support the devices. Once their position is correct, the screw in the square block is tightened to hold them securely. A 1/4" dowel was used.



The detector can be operated over distances as long as three feet, and perhaps even more with proper ambient light shielding. At these distances, alignment is critical and the sensitivity must be carefully adjusted. The photo-transistor should be protected by a length of brass tubing with an internal diameter of about 1/8". The tubing can extend as far as 1/2" in front of the photo-transistor. The back end of the photo-transistor must be protected as well to keep light away.



Here are some examples of photo-transistor mounting.



Left: A hole is cut in a block of wood large enough to let the leads pass through. The photo-transistor is attached to the block with epoxy, CA or a 'sticky' adhesive. It is then shielded with a length of shrink tubing – unshrunk, since it is a snug fit over the photo-transistor.

Center: A block of brass is drilled almost all the way through with a 1/8" bit. The hole is opened to the front side with a tiny drill. This limits the receptive field to a diameter of thousandths of an inch.

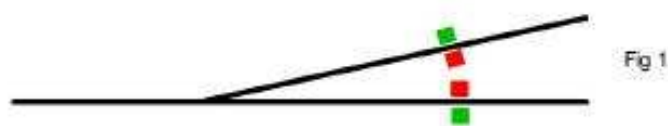
Right: Here the photo-transistor is secured inside a square tube. A round tube, compressed to an opening of 0.002" is inserted in the front end and sealed all around with an opaque adhesive.

## E. Applications

There are many ways to employ the DV1. Here are a few practical examples of its use on the layout.

### 1. Turnout Protection

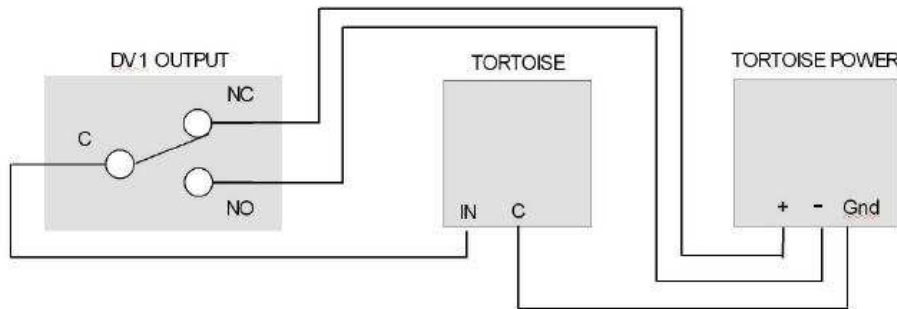
A turnout can be made to switch to the 'active' track on the approach of a train. The sketch shows a detector for each track,



but one of the tracks can be considered a 'default' route such that the turnout is normally in the default position and a single detector moves the turnout to the alternate track only when a train is present.

This can easily be implemented with a turnout motor like the Tortoise®, using a dual power supply to the Tortoise and the SPDT output of the DV1 to drive it.

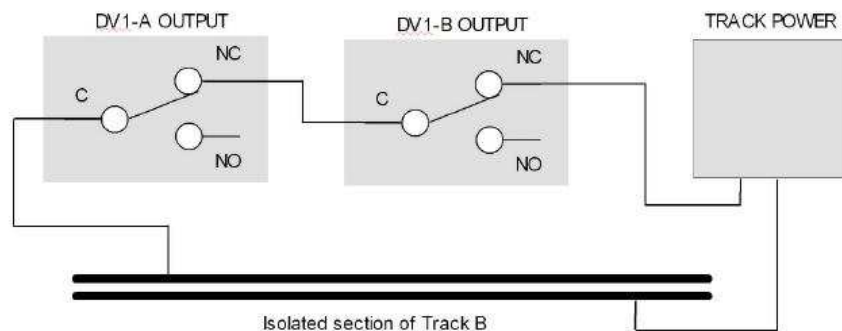
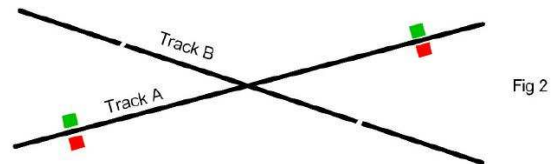
The timer on the DV1 must be set to allow the longest consist to clear the turnout before it times out and the turnout is returned, again, to its default position.



When positive voltage is applied to the Tortoise through the NC (normally closed) contacts of the DV1, the turnout will be in the 'default' position. When the DV1 is activated, negative voltage is applied to the Tortoise, moving the turnout to the alternate position through the NO (normally open) contacts on the DV1.

## 2. Crossover Protection

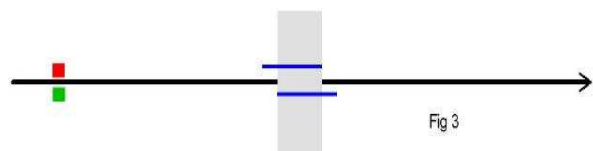
Assuming Track A has the right-of-way, power to the isolated section of Track B can be removed when a train approaches the crossing in either direction. The timer on both halves of the DV1 need only be set to the length of time it will take the slowest consist to pass between the detectors.



If either detector is activated, power to the isolated section of Track B is removed.

## 3. Crossing Protection

Crossing protection is provided for one-way traffic only by a single detector. Once activated, the detector output can operate crossing gates or signals. The DV1 timer must be set to allow enough time for the longest consist to clear the crossing.



For a two-track line, one detector is employed on each track. This assumes that traffic on each track moves only in one direction.

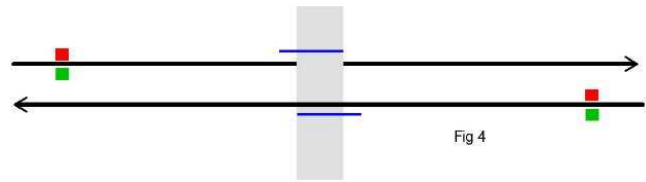


Fig 4

Note: Two-way protection on a single track with the DV1 is possible only with some additional external components. There are a few commercial products that provide this functionality (see Section G).

#### 4. Track Occupancy Detection

The sketch below shows the positioning of the detector elements for track occupancy detection. For small scales (Z, N, HOn3, HOn30) this arrangement can only cover about 70% of the distance between the elements. It works best when the IR LED and photo-transistor are placed close to the rails and at about flat car body height.

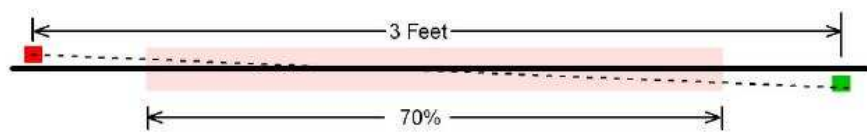


Fig 5

Occupancy detection on sidings can be achieved using the same arrangement. It is somewhat imperfect in that the beam on the lower spur will be interrupted when a consist is traveling to the upper spur. This anomaly will last only a short time, however.



Fig 6

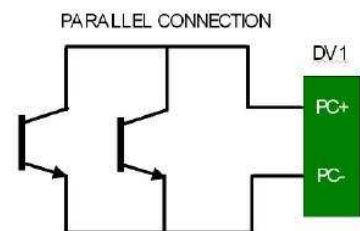
#### 5. Sound Effects and Animation

The DV1 relay contacts can be used to actuate layout lighting, opening and closing of doors, and many commercial animation products such as sound effects. Most of these products operate on switch closures which the relay contacts emulate. The timing properties of the DV1 can be used to determine how long these effects last.

### F. Kitbashing the DV1

#### 1. Adding Photo-transistors

The DV1 is designed to have one photo-transistor connected to each of the two inputs. It may be useful in some applications to have the input activated by the action of two or more photo-transistors. Additional devices may be added in two different configurations.



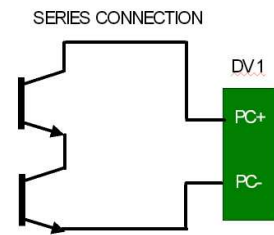
#### Parallel Photo-transistors

Photo-transistors in parallel act in such a way that the beam must be interrupted on both devices to activate the detector. The connections are shown in this sketch. As many as four photo-transistors may be connected in parallel.

The photo-transistors may both be activated by the same IR LED or by different IR LEDs. They may even be placed in entirely different places on the layout, with any separation.

### Series Photo-transistors

Photo-transistors in series act in such a way that an interruption of the beam on either one or on both devices will activate the detector. The connections are shown in the sketch on the right.



As with the parallel connection, the photo-transistors may both be activated by the same IR LED or by different IR LEDs. They may even be placed in entirely different places on the layout, with any separation.

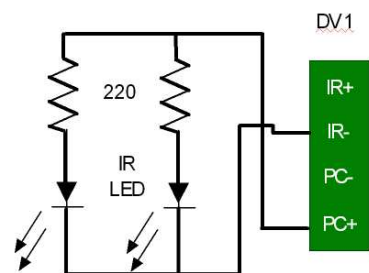
This configuration can be used to extend the length of occupancy detection by overlapping the areas covered by each photo-transistor. This results in detection if *either one or the other* beam is interrupted. It is recommended that no more than two photo-transistors be connected in series.

### 2. Adding IR LEDs

*Only one* IR LED may be connected to the IR LED terminals on the DV1. Each additional IR LED must have its own current limiting resistor placed in series and connected to + voltage and ground. This resistor is normally 220 ohms and can be ¼ watt or higher.

Positive voltage is available at the PC+ terminals of either channel and the +5V power supply terminal. 'Ground' is available at the IR - terminal of either channel and the 'Gnd' power supply terminal.

The sketch shows two additional IR LEDs connected to the DV1, each with its own series resistor. Up to 10 additional IR LEDs may be connected in this way.

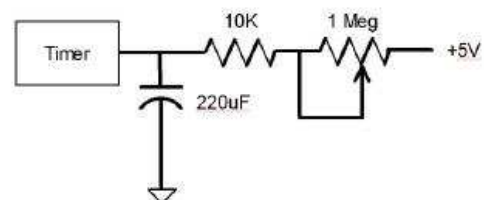


Note: The series resistance of 220 ohms is optimal for the IR LED used in the DV1. If the IR LED and photo-transistor are within 4" of one another, the resistor value may be increased to 470 ohms to reduce current drain on the DV1.

Note: The minimum resistance value must be 180 ohms, giving an IR LED current of 30 mA., its rated maximum.

### 3. Changing the Timer Range

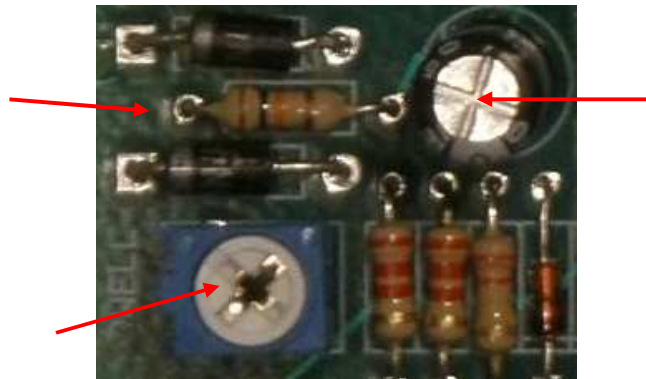
The timer in the DV1 has a range of 2 - 60 seconds. This should be adequate in most applications. This range is controlled by three components as shown here.



To reduce the minimum time to a lower value than 2 seconds, the 10K ohm resistor may be reduced to 2200 ohms minimum. This should produce a minimum time out of less than one second.

To increase the time, the 220uF capacitor may be increased to no more than 470 uF, giving a maximum time out of 2 minutes.

The location of these parts is shown in this photo.



## G. References

### 1. DV1 Specifications

Two independent detectors

Power: 5.5 volts DC at 45mA per detector max., 90 mA per card.

Note: Power can be 5 volts DC but sensitivity will be slightly reduced.

IR LED: Everlight IR204A, 940 nm. IR LED current 23mA.

Blue lens, 3mm dia., 35 deg radiation; GaAlAs (Gallium-Aluminum-Arsenide)

Mouser part number 638-IR204-A. [www.mouser.com](http://www.mouser.com)

Photo-Transistor: Everlight PT204-6B. Photo-transistor current 23 microamps.

Black lens, 3mm dia., silicon, 940 nm (range 760-1100 nm)

Mouser part number 638-PT204-6B. [www.mouser.com](http://www.mouser.com)

Comparator Reference: 0 – 1.5 volts, adjustable

Timer Dwell Time: 2-60 seconds, adjustable

Indicators: Yellow LED lights when photo-transistor is receiving sufficient light. Red LED lights when output is 'on' (when the relay is closed) and extinguishes at the end of the timing cycle.

Output: SPDT relay. Contact rating: 3 amps @ 30VDC.

Mounting: Four #4 holes.

Note: A limited number of kits for the DV1 are available from the author. The kit includes the circuit card, all parts for assembly, a power supply and instruction manual. The price is at cost, \$35.00 including shipping within the United States and Canada. Payment is by check or money order. [jnorris@storefronttech.us](mailto:jnorris@storefronttech.us)

## 2. Online Sources

Ron Paisley has contributed a wealth of circuitry on the Internet for use on model railroads. Some of these circuits use infrared LEDs and photo-transistors.

<http://home.cogeco.ca/~rpaisley4/PhotoDetectors.html>

Paisley circuits with timers

<http://www.model-railroad-infoguy.com/train-detector.html>

Mark Rollins has also made contributions:

<http://www.mrollins.com/irled.html>

## 3. Commercial Products

TMI Digital: [www.tmidigital.com/crossbuckcontrollerpr.php](http://www.tmidigital.com/crossbuckcontrollerpr.php)

Crossbuck Controller. Dual PC installation. Lights on when first PC is activated. Stays on as long as either PC is activated.

TCH Technology: <http://www.tchtechnology.com/products/sensa-trakII/>  
Straight detector. No relay. Led output only.

Dallee Electronics, Inc. <http://www.dallee.com>

Opto-DT Infra-Red Optical Detection \$59 (single) \$95 (triple);

TRAK-DT (Item #365).

Circuitron. [www.circuitron.com](http://www.circuitron.com)

DT-1, DT-2, DT-3, DF-1, DF-2, DF-3. Grade Crossing Detectors. May require additional products for full operation. Some products for DC tracks only.

DT-4, DT-5, DT-6. Rolling stock detection.

BD-1, BD-1HD. Block occupancy detector.

List of MRR electronic companies. <http://www.cwrr.com/nmra/Manb-Elec.html>