Use of Phototransistors

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Jan. 8, 2001, rev. Feb. 3, 2008

Introduction

This note is a brief overview of phototransistor characteristics and usage taken from a variety of manufacturer data sheets and application notes and the author's experience with these devices. Complete information is available at various manufacturer web sites.

The phototransistor

A phototransistor is an ordinary transistor that has been modified in two ways: (1) there is a transparent window so that light can shine on the junctions and (2) the structure has been modified to maximize the light capture area. Some phototransistors have an external base lead; others do not. If there is an external base lead, it is often left floating or connected to a high impedance bias source to bias the collector current to a specific value for the no light condition.

Base current is formed by light photons striking the junction. The phototransistor converts received power to a collector current. The units of this transfer function are Amperes per Watt. A more common unit that does not require that the user know the effective surface area is milliamperes per watt per square centimeter. This unit of sensitivity is much easier to use since all one has to know is the power density. Typical values for sensitivity (measured at the wavelength of peak response) range from about 0.4 to 2.0 mA /(mW / cm^2) for ordinary phototransistors up to about 20 mA /(mW / cm^2) for Darlington connected phototransistors.

Common phototransistors can operate with a collector current up to about 20 mA. This means that the typical maximum light level that can be handled is about 20 mW/cm^2 (this seemingly small number is the same as 200 Watts/meter^2 which is very intense) assuming a transfer function of 1 mA / (mW / cm^2). Note that these are all rough numbers and vary from device to device.

To put things into perspective, the student should confirm the following relations. Note that the parentheses are not technically required but greatly assist in clarity.
1 mW / cm^2 = 10 W / m^2
1 mA / (mW / cm^2) = 0.1 mA / (W / m^2)

Note that the aperture of a typical 5 mm diameter phototransistor is roughly 0.2 cm^2 (this is a bit optimistic since not all of the area is useful for reception). Thus, a device with a sensitivity of 1 mA / (mW / cm^2) can also be expressed as having a sensitivity of 1 mA / (0.2 mW) or 5 mA / mW. Depending on how a problem is structured it is either simpler to work with power density or absolute power.

Use of Phototransistors

Phototransistors are sensitive only to a certain range of wavelengths of light. The spectral response factor is normalized to 1.0 at the wavelength of peak response. The sensitivity of the phototransistor is measured at the wavelength of peak response. The response at other wavelengths is then relative to this. There are three types of phototransistor spectral responses.

> **Visible block**: This phototransistor is specially made to not respond to visible light. These types have a response factor practically zero for wavelengths shorter than 700 nm. The response factor peaks at about 850 nm with the -3dB wavelengths at about 780 and 940 nm. The response factor drops to less than 0.1 for wavelengths longer than about 1100 nm.
>
> **Visible**: This phototransistor is made to have useful response from infrared through the visible spectrum although the response factor in the visible spectrum is not very high. The response factor peaks at about 800 nm with the -3 dB wavelengths at about 680 and 920 nm. The response factor at 500 nm is down to about 0.1 to 0.2 and the response factor at 400 nm is practically zero. The infrared response extends to about 1100 nm where the response factor is about 0.05 to 0.15.
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> **Blue enhanced**: This phototransistor is specially made to have significantly more response at shorter wavelengths thus making it more useful for visible light applications. The response factor peaks at about 800 nm with -3 dB wavelengths at about 710 and 920 nm. The infrared response extends out to about 1100 nm where the response is less than 0.1. The response factor at 660 nm is in the neighborhood of 0.45 and the response at 400 nm is around 0.3. This type is ideally suited for visible light applications.

Phototransistors typically have a built-in lens made of a transparent epoxy. Depending on how the lens is made, the phototransistor will have an angular response that ranges from about +-6 degrees for a narrow acceptance device up to about +-50 degrees for a wide acceptance device. Narrow angle devices are ideal for rejecting potential off axis interference sources. Wide angle devices are ideal when the phototransistor must be capable of detecting light from a source that is significantly off the central axis.

The collector current will be the product of the received power density, sensitivity, spectral response factor, and angle response.

Phototransistors also have a time domain response. Typical response times of an ordinary phototransistor with a low impedance load range from about 5 to 50 microseconds. The response time increases as load impedance is increased. Although a Darlington connected phototransistor is much more sensitive, its response time is much slower – typically around 400 microseconds.

Use of Phototransistors

Phototransistors have a non-zero collector current known as dark current when the device is in absolute darkness. This current is very temperature dependent and is in the range of about 100 nA at room temperature. The existence of this current limits the minimum static light level that can be reliably detected. A pulsating light is more easily detected since a changing collector current can be differentiated from a static background.

There are generally two types of phototransistor circuits, binary and linear. The binary circuits detect the presence of some light level and output a logic signal corresponding to whether the light level is above or below the detection threshold. The circuit can be inverting – produce a logic '0' when the light level is above the detection threshold or non-inverting – product a logic '1' when the light level is above the detection threshold. Hysterisis can be added as desired to reduce multiple switching when the light level is slowing changing about the detection threshold. Using a comparator as shown in Figure 1 provides flexibility in sensitivity and hysterisis.

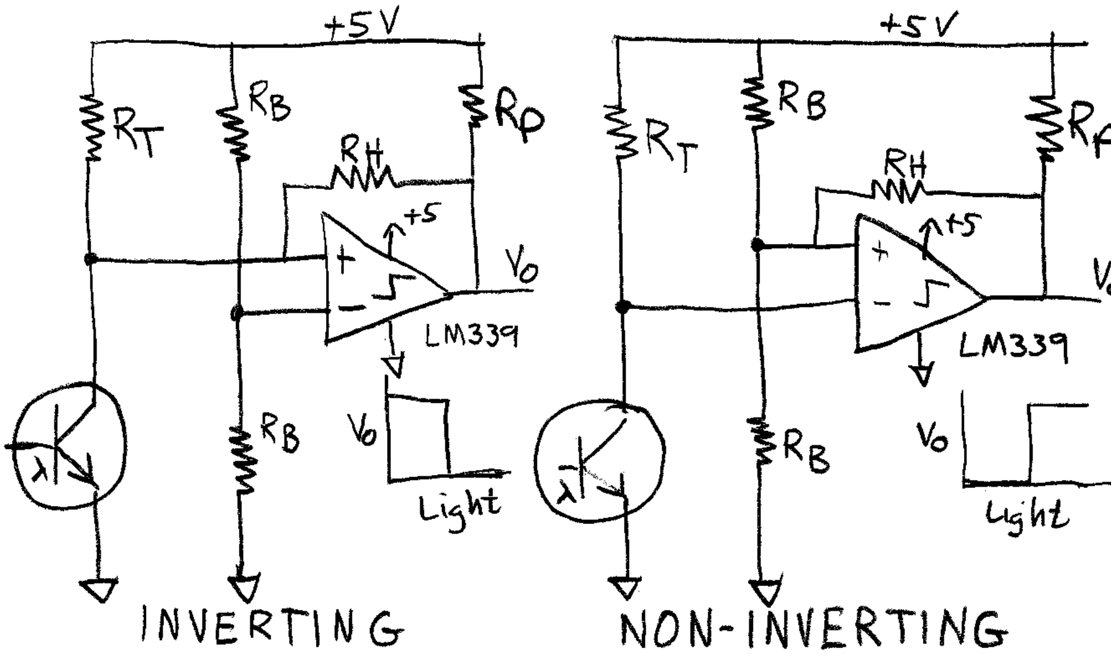

Figure 1: Binary light detectors

RT is chosen to set the detection threshold. A low value (a few thousand ohms) of RT sets a high threshold level for the light to exceed before switching takes place – i.e. the circuit is insensitive. A high value (roughly in the low one-hundred thousands of ohms) sets a low threshold level for the light to exceed before switching takes place – i.e. the circuit is very sensitive. Good practice is to set the detection threshold to be only a reasonable margin lower than needed. Making circuits too sensitive makes them too responsive to noise and interference.

Use of Phototransistors

RB is roughly twice RT if bias current compensation is needed – not normally done unless RT is very large for high sensitivity. Normally, RB can be something like a pair of 10 K resistors.

RP is the pull-up resistor on the output of the comparator. Many comparators have open-collector outputs and require an external pull-up resistor for operation. For the circuit shown, RP might typically be 4.7K or 10K.

RH is an optional resistor and is used if hysterisis is desired. If RH is present then there is a light level at which the comparator switches to one logic state and a different light level at which the comparator switches to the other logic state. When used, typical values for RH are in the ten to one-hundred times either RT or RB – whichever is connected to the non-inverting input on the comparator. The lower the value of RH, the wider the hysterisis zone.

The circuit in Figure 2 is a simplified version using a standard Schmitt trigger (for hysterisis) logic unit. Because of the higher input current of the logic unit, RT generally must be no higher than several ten thousand ohms. Thus, the sensitivity of the circuit in Figure 2 is not as good as can be attained in Figure 1 – but some applications do not need high sensitivity and simpler circuits are preferred.

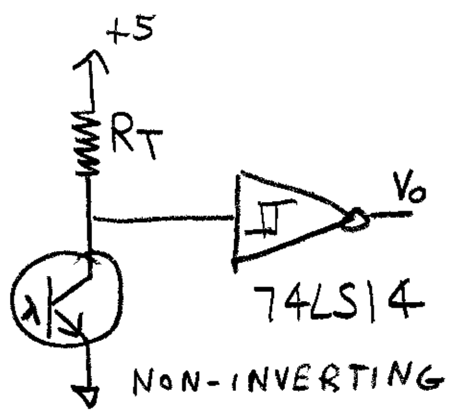

Figure 2: Binary light detector using logic Schmitt trigger

Use of Phototransistors

The circuit in Figure 3 does not work! It can work in some special cases but is very insensitive as the load resistor, R, must be small (usually under 1K). This circuit is often attempted and considerable frustration results. My advice is to avoid it completely and use the circuit in Figure 2 instead – it works considerably better.

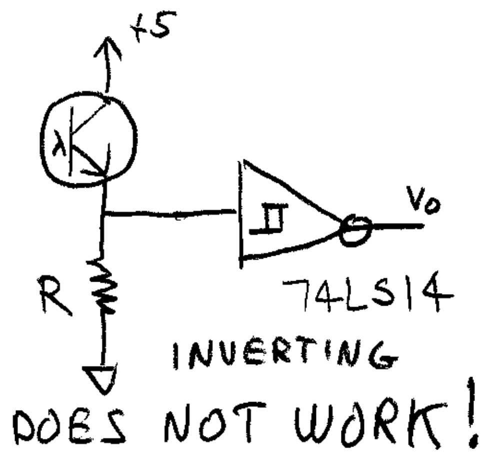

Figure 3: Binary light detector that does not work well

The circuit in Figure 4 is a simplified version of the classic trans-impedance amplifier used with photo-diodes and photo-transistors. This circuit features an output voltage that is a linear function of the light level on the photo-transistor. The gain is set by RF which could be in the millions of ohms. The capacitor, CF, sets the circuit bandwidth which should be no higher than needed. The reference voltage, VR, is typically in the -2 to -8 volt range and must be stable and noise free. Linear operation is achieved by operating the photo device with a fixed voltage drop across it. As shown the circuit works well but there are a number of advanced improvements discussed in the book, *Photodiode Amplifiers, Op Amp Solutions* by Jerald Graeme, published by McGraw-Hill. That book is required reading for anyone doing serious work in this arena. The dark current (often in the 100 nA region but is very temperature dependent) of the phototransistor limits how low a light level can be detected.

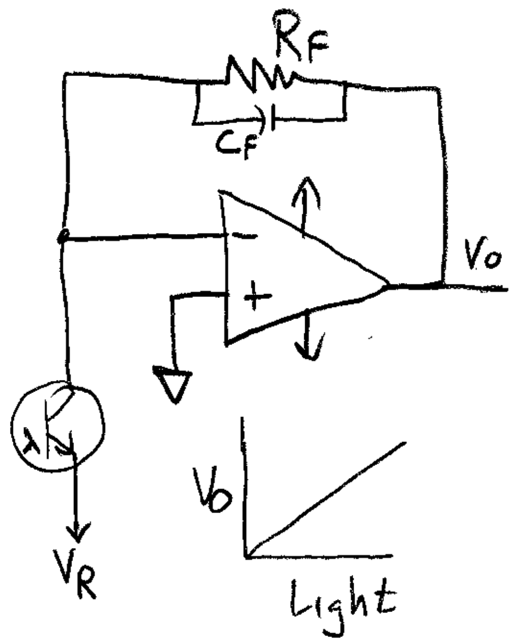

Figure 4: Linear light detector

For all the circuits shown it is very important to shield the phototransistor both optically and electrically from interference sources. Optical shielding consists of any opaque material covering all sides of the phototransistor except the desired light direction. Electrical shielding consists of a metal enclosure (could be closely wrapped metal foil on the outside of the optical shield) located as close to the phototransistor as possible and connected to the electrical ground of the phototransistor circuit.

A key fact to remember in using phototransistors is that all phototransistors are most sensitive in the infrared region and thus work best with infrared emitting diodes (IRED). There is no requirement that the wavelength of the IRED exactly coincide with the phototransistor peak response wavelength but the response factor for any deviation should be known and accounted for in the design. Generally, any spectral response factor greater than about 0.1 is considered useful.