SIEMENS

Applications of Optocouplers
Appnote 2

The IL1 is the first in a family of optocouplers. These products are also called photon coupled isolators, photocouplers, photo-coupled pairs and optically coupled pairs. All of the characteristics of the IL1 are electrical: it has no external optical properties. Hence optoisolators are not *optoelectronic devices*; they are in fact one of the simplest of all *electro-optical systems*.

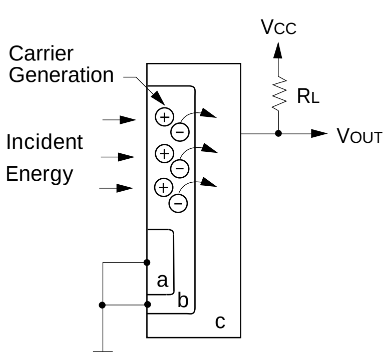
The IL1 consists of a Gallium Arsenide infrared emitting diode, and a silicon phototransistor mounted together in a DIP package.

When forward current (I_F) is passed through the Gallium Arsenide diode, it emits infrared radiation peaking at about 900 nm wavelength. This radiant energy is transmitted through an optical coupling medium and falls on the surface of the NPN phototransistor.

Phototransistors are designed to have large base areas; and hence a large base-collector junction area; and a small emitter area. Some fraction of the photons that strike the base area cause the formation of electron-hole pairs in the base region. This fraction is called the *quantum efficiency* of the photodetector.

If we ground the base and emitter, and apply a positive voltage to the collector of the phototransistor, the device operates as a photo diode.

The high field across the collector base junction quickly draws the electrons across into the collector region. The holes drift towards the base terminal attracting electrons from the terminal.

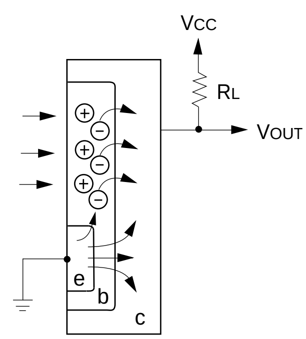


Thus a current flows from collector to base, causing a voltage drop across the load resistance (R_L).

The high junction capacitance, C_{cb}, results in an output circuit time constant $R_L C_{cb}$, with a corresponding output voltage rise time.

The output current in this configuration is quite small and hence this connection is not normally used.

The commonest circuit configuration is to leave the base connection open. With this connection, the holes generated in the base region cause the base potential to rise, forward biasing the base-emitter junction. Electrons are then injected into the base from the emitter, to try to neutralize the excess holes. Because of the close proximity of the collector junction, the probability of an electron recombining with a hole is small and most of the injected electrons are immediately swept into the collector region. As a result, the total collector current is much higher than the photogenerated current, and is in fact β times as great.



The total collector current is then several hundred times greater than for the previous connection.

This gain comes with a penalty of much slower operation. Any drop in collector voltage is coupled to the base via the collector-base capacitance tending to turn off the injected current. The only current available to charge this junction capacitance is the original photocurrent. Thus, the rate of change of the output voltage is the same for both the diode and transistor connections. In the latter case, the voltage swing is β times as great, so the total rise time is β times as great as for the diode connection. Thus the effective output time constant is $\beta R_L C_{cb}$.

For the IL1 a typical 2 µs rise time for 100 Ω results.

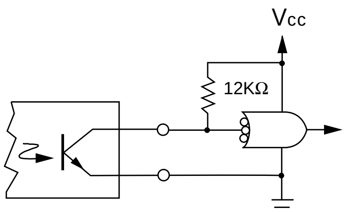
The ratio of the output current from the phototransistor (I_C or I_E), to the input current in the Gallium Arsenide diode is called the Current Transfer Ratio (CTR). For the IL1, CTR is specified at 20% minimum with 35% being typical at I_F=10 mA.* Thus for 10 mA input current the minimum output current is 2 mA. Other important parameters are V_F typically 1.25V at 60mA I_F.

Digital Interfaces

Output Sensing Circuits

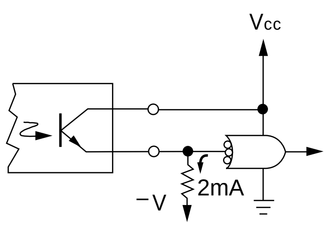
The output of the phototransistor can directly drive the input of standard logic circuits such as the 7400 TTL families. The worst case input current for the 74 series gate is –1.6 mA for V_{IN}=0.4 Volts. This can be easily supplied by the IL1, with 10 mA input to the infrared diode.

TTL Active Level Low (7400)

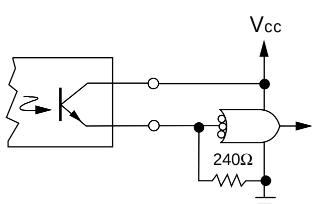


Note: Use smaller pull up resistor for higher speed.

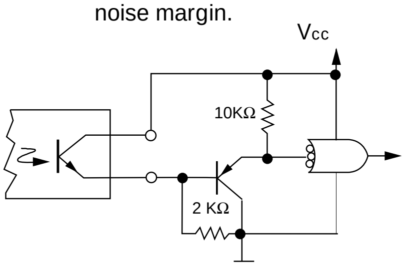
It is more difficult to operate into TTL gates in the active level high configuration. Some possible methods are as follows:



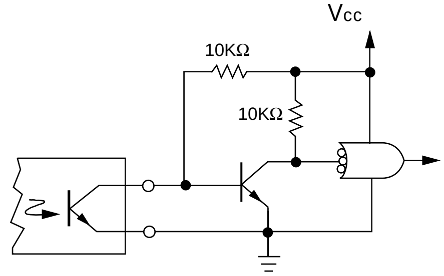
Note: Best method if negative supply is available.



Note: Requires 10 mA from transistor and sacrifices noise margin.

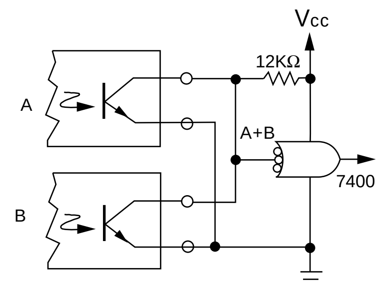


Note: High sensitivity but sacrifices noise margin. Needs extra parts.

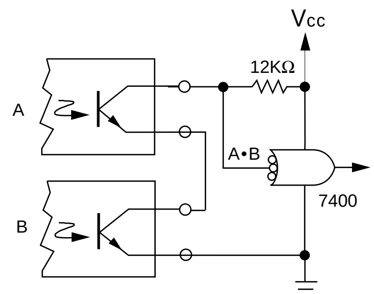


Note: Extra parts cost but high sensitivity.

Obviously, several optocoupler output transistors can be connected to perform logical functions.



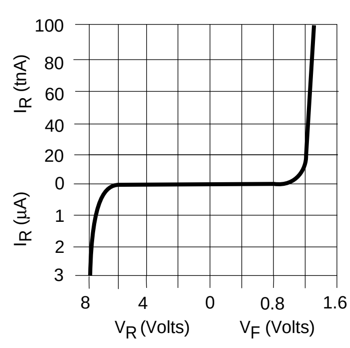
Note: Logical OR connection.



Note: Logical AND connection.

Input Driving Circuits

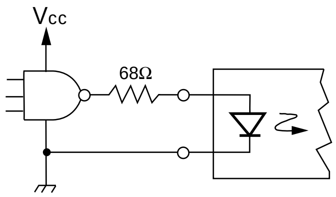
The input side of the IL1 has a diode characteristic as shown.



The forward current must be controlled to provide the desired operating condition.

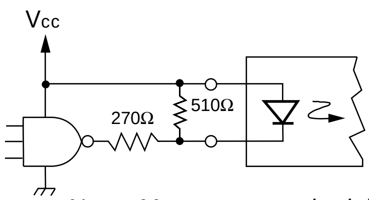
The input can be conveniently driven by integrated circuit logic elements in a number of different ways.

TTL Active Level High (7400 Series)

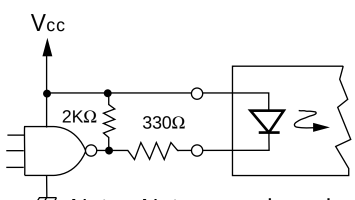


Note: Can omit resistor for about 15 mA into diode.

TTL Active Level Low (7400 Series)



Note: More parts required than above.



Note: Not as good as above circuit. Not recommended.

There are obviously many other ways to drive the device with logic signals, but the commonest needs can be met with the above circuits. All provide 10 mA into the LED giving 2 mA minimum out of the phototransistor. The 1 Volt diode knee and its high capacitance (typically 100 pF), provides good noise immunity. The rise time and propagation delay can be reduced by biasing the diode on to perhaps 1 mA forward current, but the noise performance will be worse.

All previous configurations show medium speed digital interfaces. These circuits have various advantages over other ways of doing the task.

(1) They can replace relays and reed relays, giving much faster switching speeds, no contact bounce, better reliability, and usually better electrical isolation except for special configurations. However relays have high current capability, higher output voltage, lower on resistance and offset voltage and higher off resistance.

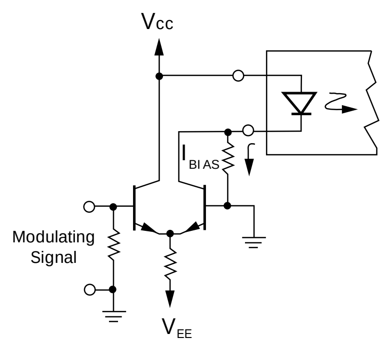
(2) They can replace pulse transformers in many floating applications. Opto-isolators can transmit DC signal components and low frequency AC, whereas pulse transformers couple only the high frequency components, and a latch is required to restore the DC information. Pulse transformers have faster rise time than phototransistor optocouplers.

(3) Integrated circuit line drivers and receivers are used to transmit digital information over long lines in the presence of common mode noise. The maximum common mode noise voltage permissible is usually in the 30 Volt range. There are many practical situations where common mode noise voltages of several hundred Volts can be induced in long lines. For these applications, optocouplers provide protection against several thousand volts.

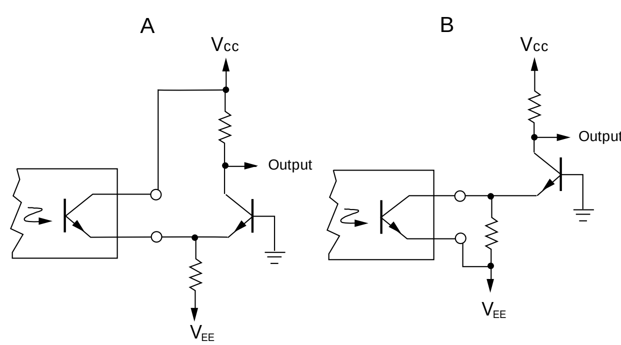
Linear Applications

The curve of input current versus output current for the IL1 is somewhat non-linear, because of the variation of β with current for the phototransistor, and the variation of infrared radiation out versus forward current in the GaAs diode. The useful range of input current is about 1 mA to 100 mA, but higher currents may be used for short duty cycles.

For linear applications the LED must be forward biased to some suitable current (usually 5 mA to 20 mA). Modulating signals can then be impressed on this DC bias. A differential amplifier is a good way to accomplish this.

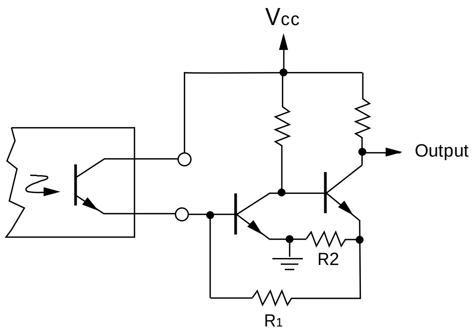


Sensing in linear applications can be done in several ways depending on the requirements. For high frequency performance, the phototransistor should be operated into a low impedance input current amplifier. The simplest such scheme is a grounded base amplifier.



The circuit will work equally well either way, with a phase inversion between the two. Obviously a PNP transistor would work as well.

A feedback amplifier could also be used to get a low impedance input.



The current gain is

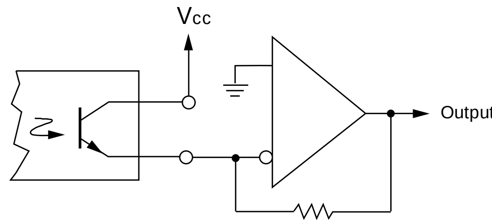
$$\left(1 + \frac{R_1}{R_2}\right)$$

The input impedance is approximately

$$\left(\frac{R_1}{1 + \frac{V_{CC} - 2V_{BE}}{.026}}\right)$$

For example if R1=900 Ω, R2=100 Ω, V_{CC}=5 V, we would have a current gain of 10 and an input impedance of about 6.3 Ω. This would give a considerable speed improvement over a 100 Ω load.

A high speed operational amplifier could be used to give excellent performance.



Note that in all cases the output can be taken from either the collector or the emitter of the phototransistor depending on the polarity desired. The operating speed is the same in either case.

Conclusion

This appnote covers the most commonly used ways of applying phototransistor optocouplers. The design engineer will see many ways to expand on these circuits to achieve his end goals. The devices are extremely versatile, and can provide better solutions to many systems problems than other competing components. Special designs are possible to optimize certain parameters such as coupling capacitance, or transfer ratio.

Properties of Signal Coupling Devices

Device	Advantages	Disadvantages
Optocoupler	Economical Solid state reiiability Medium to high speed signal transmission DC & low frequency transmission High voltage isolation High isolation impedance Small size DIP Package No contact bounce Low power operation	Finite ON Resistance Finite OFF Resistance Limited ON state current Limited OFF state voltage Low transmission efficiency (Low CTR)
Relays	High power capability Low ON resistance DC transmission High voltage isolation	High cost High power consumption Unreliable Very slow operation Physically large
Pulse Transformers Differential Line Drivers and Receivers	High speed signal transmission Moderate size Good transmission efficiency Solid state reliability Small size DIP package High speed transmission DC transmission Low cost	No DC or low frequency transmission Expensive for high isolation impedance or voltage Very low breakdown voltage Low isolation impedance