Application Note 3
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Infra-Red Remote Control and Data Transmission

An Introduction to Photodiodes - Load Circuits and Applications

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Introduction

The use of short range remote control and data transmission systems in both consumer and industrial products is growing rapidly. Already common-place in items such as Televisions, Teletext and Viewdata controllers, toy model control etc, these systems are now being used for the remote control of High Fidelity Units, Garage Doors, Light Dimmers, Slide Projectors, and in Teaching Aids, Data links, Burglar alarms etc.

In the past, short range remote control systems have mainly relied on Radio or Ultrasonic links to effect control. However, these methods have serious disadvantages. Radio links often require licensing, they can give excessive range and are prone to electrical interference. Ultrasonic links suffer from multipath interference which limits their useable data range, and interference from numerous everyday objects that produce sound at ultrasonic frequencies, such as keys, coins, bells, electrical apparatus etc. Infra-Red (IR) light links can be used for short range remote control and their freedom from many of these problems, in part, explains their rapidly growing popularity.

Generally IR links consist of a modulation source driving a light emitting diode that radiates at a wavelength of 850 to 970nm. This light is detected by a photodiode, and the resulting signal is amplified and decoded to recover the transmitted information. Since IR light is used, licensing is not required; the radiation is easily confined to a single room since walls and doors block these wavelengths, and electrical interference is easily rejected. Also, multipath interference does not significantly degrade the signal, and there are few domestic light sources emitting IR that flicker at a frequency high enough to corrupt a modulated signal. (Compact Fluorescent or “energy saving” lamps are a possible problem, though manufacturers do try to avoid common IR data transmission frequencies).

The main limitations of an optical system result from the low power output available from an IR light emitting diode (LED), combined with noise generated in the photodiode by current flowing in the device due to ambient lighting and leakage. These factors control the operational range of a system and the ambient light levels it can tolerate.

The transmitted power can effectively be increased by using lenses to concentrate the IR LED's light output, but this narrows the transmission beam width making alignment too critical for some applications. The receiver signal to noise ratio can be optimised by using a very low leakage, high sensitivity photodiode in conjunction with an optical filter, which only passes wavelengths emitted by IR light emitting diodes.

The Zetex BPW41D photodiode has been developed specifically for use in IR links. It is a high speed, low capacitance device enclosed in a package which acts as a highly selective IR pass filter.

Infra-Red Photodiodes

The Zetex BPW41D photodiode, is a low leakage silicon p.i.n. (p-intrinsic-n) device of planar construction and possesses an active area of 7.5 mm^2. The device has a silicon nitride layer over the chip which acts both as a passivating and an efficient anti-reflection coating. The plastic housing of the BPW41D contains a dye which transmits well in the near infra-red part of the spectrum (800 nm to 1100 nm) but which strongly absorbs visible light (400 nm to 700 nm). The insensitivity of the device to visible light and it's response to infra-red radiation are aided by the silicon spectral response, which is low in the blue-green regions and high in the infra-red.

The BPW41 die is also available in a clear encapsulated package as the BPW41C. A smaller die geometry version of the device, the ZPD200, is ideal for short range and low cost IR systems.

Planar construction is used to keep the reverse leakage current low which is important in small signal applications. The p.i.n. structure gives two main advantages. Firstly, capacitance per unit area is lower than that of a conventional p.n. diode, leading to a higher speed of response. Secondly, the minority carrier lifetime is, in general, higher than in heavily doped silicon giving somewhat greater IR sensitivity. (Please refer to Appendix for selected BPW41D data).

Photodiode Load Circuits

[Although originally produced with respect to the BPW41, the following comments and circuits are equally applicable to other photodiodes such as the ZPD200, with minimal or no change to component values].

When used in typical remote control links, the BPW41D can provide useable signal to noise ratios with signal levels that can only produce photocurrents of the order of 10nA. However, to detect such levels, the load used for the photodiode must be carefully chosen to suit the particular operating conditions.

Simple Resistive Loads

The simplest load that can be used is a resistor as shown in Figure 1. In this circuit the photodiode is connected reverse biased across the power supply with a resistor R in series. Any signal current produced by the photodiode will develop a voltage across R which can then be amplified to give the required output.

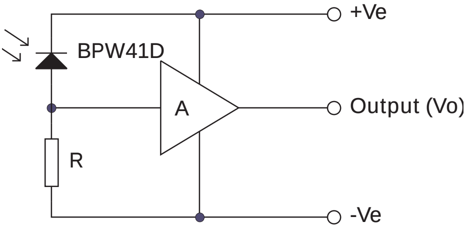

Figure 1
Simple resistive load photodiode detection circuit.

There are various constraints in choosing the value of R. The lower R is made, the smaller will be the signal voltage appearing across it. For a given output voltage this means the gain of amplifier A will have to be higher, making it's noise contribution more significant, and interference rejection and stability harder to achieve. As a result, if R is made too small the operating range of the IR link is reduced.

With a high input impedance amplifier the bandwidth of the circuit will be controlled by the capacitance of the photodiode and the value of R. As R is increased the cut-off frequency falls. Since most IR links use short duration light pulses for control, the receiver circuit must have sufficient bandwidth to detect these pulses without significant attenuation. This gives one limitation on the maximum value of R.

A second and possibly more stringent limitation to the maximum value of the load resistor, is caused by photocurrent in the BPW41D due to ambient lighting. Although the BPW41D includes a selective optical filter to reject light below 700nm, many light sources give significant proportion of their energy output above these wavelengths. The effect of these sources on the photodiode is to cause a steady d.c. current to flow through the device, developing a voltage across R.

This reduces the reverse bias applied to the photodiode, increasing it's capacitance and so reducing the bandwidth. Also, if R is much too large, the voltage developed by ambient light photocurrent can exceed the supply voltage, with the photodiode becoming forward biased. In this condition any signal current detected will be dissipated in the forward biased shunt resistance of the photodiode, and so the signal output level will be severely attenuated.

As a result of these problems the simple resistor load is mainly used in applications where ambient light levels are low. For instance, it is sometimes used in the remote control of television receivers where it's obvious simplicity keeps cost down, and it's inability of operating efficiently in high light levels is unimportant as the television is unlikely to be operated under such conditions. The values of R typically used in remote control systems range from 100kΩ to 300kΩ giving circuit cut-off frequencies of 30kHz to 100kHz and an ability to handle ambient light levels that cause 30µA to 100µA of photocurrent. This corresponds to a reasonably well lit room using tungsten filament lamps.

The simple resistor load can be modified to handle higher light levels without a large sensitivity loss with the circuit shown in Figure 2.

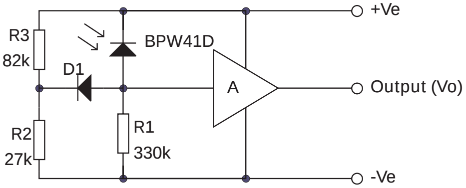

Figure 2
Modified resistive load photodiode circuit to allow high ambient light levels.

At low ambient light levels this circuit will operate with the 300kΩ resistor as the photodiode load, giving a similar sensitivity to the simple load. At high light levels the voltage across the 300kΩ resistor exceeds the voltage set up by the potential divider R2, R3. This causes diode D1 to conduct so that the effective load of the photodiode is the potential divider circuit which has a resistance of approximately 20kΩ. This gives a x15 loss in sensitivity, but the circuit will continue to work in ambient light levels approaching direct sunlight. If the photodiode is not prevented from becoming forward biased by this, or alternative circuits, the loss in sensitivity at high levels will be in the order of x1000.

Inductive Loads

The optimum load for a photocell in a remote control circuit has a high impedance at signal frequencies and a low impedance at any other frequencies including d.c. These load characteristics can be achieved with an inductive load.

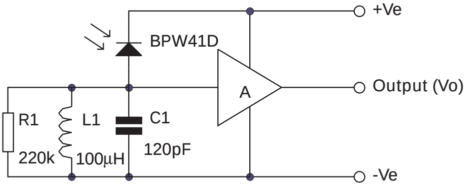

Figure 3
Inductive load photodiode detection circuit.

The inductive load shown in Figure 3 can provide a signal frequency impedance of 100kΩ whilst still giving a very low d.c. current resistance path for photocurrent caused by ambient lighting. As a result, it will operate well over a wide range of ambient light levels. The inductor is normally tuned to match the input frequency, and damped with a resistor to suppress ringing.

The output of the circuit when pulsed with IR light is shown in Figure 4. It consists of a damped sine wave that takes several cycles to decay. Unfortunately this ringing reduces the maximum data rate the circuit will support, since delays must be included in the receiver decoder to avoid detecting multiple pulses as the sine

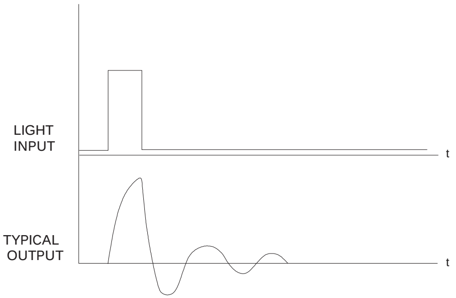

Figure 4
Output response of inductive load photodiode detection circuit.

wave decays. Some ringing is unavoidable due to the capacitance of the photodiode and other stray effects acting with the inductive load, so that the best solution is to tune the load to match the signal, and dampen with a resistor that does not significantly reduce the impedance of the load.

The circuit does have other disadvantages which limit it's usefulness. It is difficult to wind the inductor without it's natural self capacitance bringing the self resonant frequency below the operational frequency required. To keep it's mechanical size small, it is necessary to use a ferrite core to reduce the number of turns in the inductor. However d.c. current flowing in the inductor due to ambient light photocurrent can saturate the ferrite core if the light level is high and the core volume small, thereby reducing the inductance of the coil and lowering the impedance of the load at signal frequencies. This problem adds further restrictions on the design of the inductor.

The inductive load circuit is used in the remote control of television receivers as an alternative to the simple resistive load. It can give a sensitivity similar to that of the resistive load, has better high ambient light level tolerance, but a lower data transmission rate.

Active Loads

The optimum load characteristic of high impedance at high frequencies, yet low impedance at low frequencies and d.c., can be achieved with an active load. Three configurations of the same basic active load circuit, but with differing output polarities and output impedances are given in Figures 5, 6 and 7.

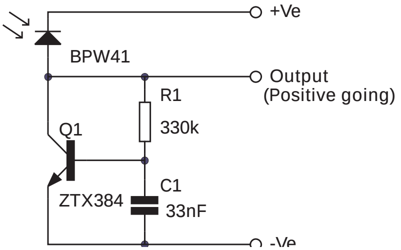

Figure 5
Active load photodiode circuit -1.

Consider the circuit shown in Figure 5. In this circuit, current passed by the BPW41D flows through the 330kΩ resistor to the base of ZTX384 transistor. This causes the transistor to conduct, shunting the photodiode current directly to the negative supply and so reducing the base drive to the transistor. An equilibrium point is reached in which the transistor holds it's collector voltage at approximately 0.8V by acting as a constant current generator that exactly matches current fed to it by the photodiode. This equilibrium is maintained for d.c. or slowly varying photocurrents, so giving the photodiode a very low impedance load under these conditions.

The current dump transistor has a capacitor connected to it's base, which restricts the speed at which the load circuit can respond to a sudden change in photocurrent. As a result, the current matching equilibrium of the load circuit is not maintained for rapidly changing photocurrents. This makes the high frequency impedance of the load very much higher than it's low frequency impedance.

With the component values given, the load presented to the photodiode under steady state conditions is approximately 1kΩ. At high input frequencies the load impedance is dominated by the base resistor of the transistor and approaches 250kΩ (at a frequency of 50kHz).

The high frequency impedance of the load drops slightly under high ambient light levels, but the main disadvantages of the circuit shown in Figure 5 are it's noise contribution and susceptibility to interference at high light levels. Both of these problems stem from the extremely high amplification given to any signal generated in the base-emitter circuit of the load transistor under high ambient lighting conditions.

The voltage gain given to a signal generated in the base emitter circuit is approximately:

Gain $\approx R_c/r_e$,

where R_c is the collector load impedance i.e. 250kΩ, and r_e is the intrinsic emitter resistance. $r_e = 25\ \Omega/I_e$ where I_e is the transistor emitter current (in mA).

i.e. Gain $\approx R_c \times I_e/25$ (I_e in mA)

If ambient lighting causes a photocurrent of 5µA to flow through the load (Eg.current through the photodiode in a dimly lit room), then:

Gain $\approx 250 \times 10^3 \times 5 \times 10^{-3} /25 = 50$ for 5µA photocurrent.

However if the ambient light level approaches direct sunlight:

Gain $\approx 250 \times 10^3 \times 1 /25 = 10{,}000$ for 1mA photocurrent.

This very high amplification given to noise generated in the load transistor degrades the performance of this load circuit when operated at high ambient light levels.

The gain at high photocurrents can be significantly reduced by including a resistor in the emitter of the current dump transistor as shown in Figure 6. The performance at low light levels is unaffected, but the voltage gain given to noise signals in the base emitter circuit of the load is much lower when ambient light levels are high.

$$\begin{aligned} \text{Gain} &\approx R_c/(r_e + R_e) \\ &= 250 \times 10^3 /(25+1.5 \times 10^3) \\ &\approx 160 \text{ for 1mA photocurrent.} \end{aligned}$$

The added resistor restricts the maximum gain given by the load transistor, so limiting the noise and interference introduced by the circuit.

The emitter resistor also increases the impedance of the load at low frequencies, and so it's value is a compromise between minimum noise contribution and minimum d.c. voltage drop at high photocurrents. The value used in Figure 6 ensures that the noise generated by the load is less than that of the photodiode, yet the circuit can still operate in direct sunlight.

To take advantage of the high impedance of these load circuits, the amplifier connected across the load must have a high input impedance.

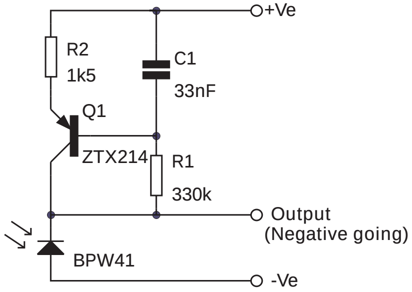

Figure 6
Active load photodiode circuit -2.

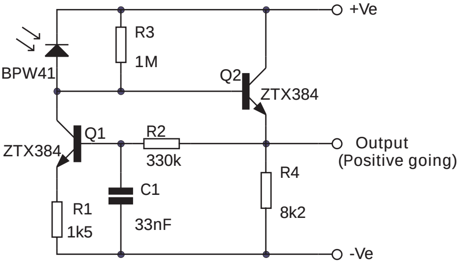

Figure 7
Active load photodiode circuit - 3.

If a low impedance amplifier is to be used, an emitter follower buffer can match the photocell load to the amplifier as in Figure 7. The emitter follower is d.c. coupled to the load to eliminate the coupling and biasing components that otherwise would have been required. It has an output impedance of approximately 2kΩ at small signal levels.

All three loads may be modified to give signal outputs of opposite polarity simply by exchanging ZTX214C transistors for ZTX384C and vice versa, and reversing the power supply connections and those of the BPW41D.

Remote Control using the BPW41D and similar Photodiodes

It is a vital requirement that remote control circuits cannot be triggered by spurious signals. To achieve this immunity without sacrificing range of operation, coded transmissions are normally used so that only received signals of a pre-determined sequence are allowed to alter control outputs. Effective coding and decoding requires elaborate circuitry if constructed using standard logic devices. However, numerous dedicated integrated circuits have been developed for this task. These systems make use of separate encoder and decoder ICs. The encoder performs a scanning function on a matrix configured keypad, and on detecting a key press, generates a corresponding coded string. The string is repeated until the key is released.

The output of the IC typically drives a bipolar transistor that in turn drives either a single, or an array of IR light emitting diodes. To maximise range these diodes are pulsed at 1 to 2A, but as the duty cycle is so low the average current drain on the battery is low. It is important to pay attention to PCB layout to maintain a low resistance and low inductance path for the diode/driver/supply. To allow higher battery capacity/volume, and hence longer lifetime, means that these systems are more efficient with lower voltage battery packs, typically two cells (3V). In these cases, and to allow the IR LED to be pulsed effectively from logic IC outputs, the use of Darlington transistors is excluded.

This is due to their inherent high $V_{CE(sat)}$ introducing a severe on-state loss to the driver. An alternative is to use Super-β bipolar devices, that possess very high current gains (around 500 to 800 mid-band) that allow direct drive from logic, but also exhibit a very low $V_{CE(sat)}$ to ensure a high transfer of energy to the diode. Typical transistors would be the ZTX688B or FMMT617.

Monophonic Audio Link (M.A.L.)

An infra-red link capable of transferring audio signals has been constructed using the BPW41D photodiode as the receiving element. The link was designed to allow the use of monophonic headphones without the inconvenience of trailing leads. It uses a frequency modulated system to ensure that volume levels are independent of range. Depending on the ambient light levels and reflectivity of room walls, the link gives satisfactory performance up to a range of 8m. It's frequency response is from 50 Hz to 8kHz.

M.A.L. Transmitter

(Refer to Figure 8.) The audio signal to be transmitted is fed through a gain control R1 to an audio amplifier which gives the circuit an input sensitivity of 100mV RMS. As part of a noise reduction system, the audio amplifier boosts signals at high frequencies by applying 55µs pre-emphasis.

The output of the audio amplifier is capacitively coupled to two constant current generators, these being used to charge the timing capacitors of a multivibrator. Consequently, the generators control the oscillation frequency of the multivibrator. Since the constant current generators are controlled by the audio amplifier output, the multivibrator is frequency modulated by the audio input. The multivibrator runs at a central frequency of approximately 70kHz and with a mark space ratio of 1 to 1. The emitter circuit of one of the multivibrator transistors includes a ZTX651 transistor.

The ZTX651 transistor is used as a buffer to provide the high current drive necessary for the infra-red light emitting diodes, (IR LEDs). Six emitters wired in two groups of three provide the modulated light output, their peak drive current being limited to 300mA.

It is possible for simple multivibrators to attain a latch-up state in which both transistors conduct continuously in saturation, giving a loop gain too low for oscillation. In this circuit the supply for the constant current generators which bias the multivibrator transistors is derived from the collector loads of the multivibrator. As a result, if latch-up should occur, the base drive for the multivibrator will decay, bringing the transistors out of saturation, so raising the loop gain and enabling normal oscillation to occur.

The supply for the current generators is regulated by a zener diode to minimise the frequency variations resulting from power supply voltage fluctuations. The regulating zener also has the effect of restricting the multivibrator collector voltage swing to approximately 6V. This prevents the charge on the timing capacitors reaching V_{BE} breakdown levels and subsequent damage of the

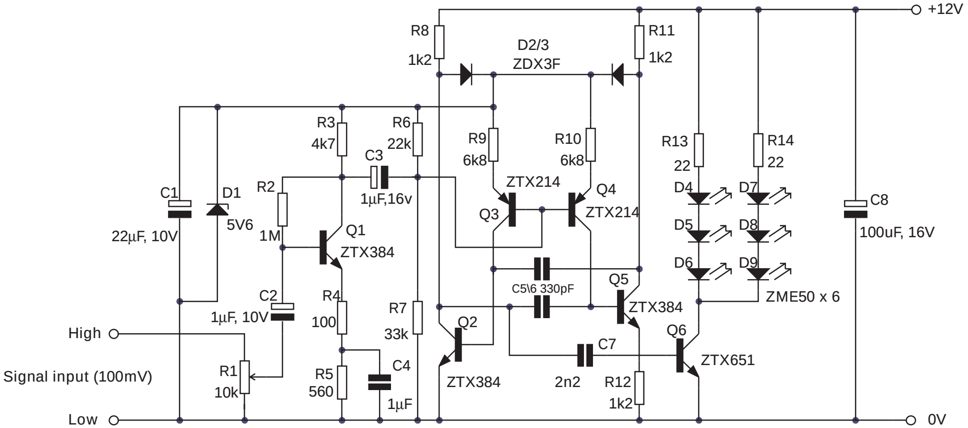

Figure 8
M.A.L. Transmitter unit.

emitter-base junctions of the multivibrator transistors. The supply for the audio amplifier is also taken from this regulator to restrict it's output swing to that required by the current generators. Construction of the transmitter is not critical.

M.A.L. Receiver

(Refer to Figure 9.) The receiver uses a BPW41D photodiode to detect the infra-red signal emitted by the transmitter. The photodiode has an active load which reduces the effects of ambient lighting. The signal voltage appearing across the load is coupled into a very high gain amplifier which boosts it to a suitable level for F.M. demodulation.

Frequency demodulation is achieved using a standard CMOS phase locked loop (pll) logic device. The output of the amplifier is a.c. coupled into a self biasing Schmitt Trigger input in the phase locked loop. The signal is compared with an internal voltage controlled oscillator by a phase comparator, which produces an error voltage that is dependent on the phase difference. This error signal is used to adjust the frequency of the voltage controlled oscillator so that it is locked, or made identical to the incoming signal frequency. When the signal is locked, the voltage output of the phase comparator is proportional to the incoming signal frequency, and so reproduces the audio signal fed into the transmitter.

The output of the phase detector is fed through a de-emphasis network which has a time constant of 55µs. This has the effect of reducing the noise and signal amplitudes at high frequencies, since the signal at the transmitter was boosted by an identical network. The pre-emphasis and de-emphasis method gives a flat link frequency response whilst significantly reducing receiver noise.

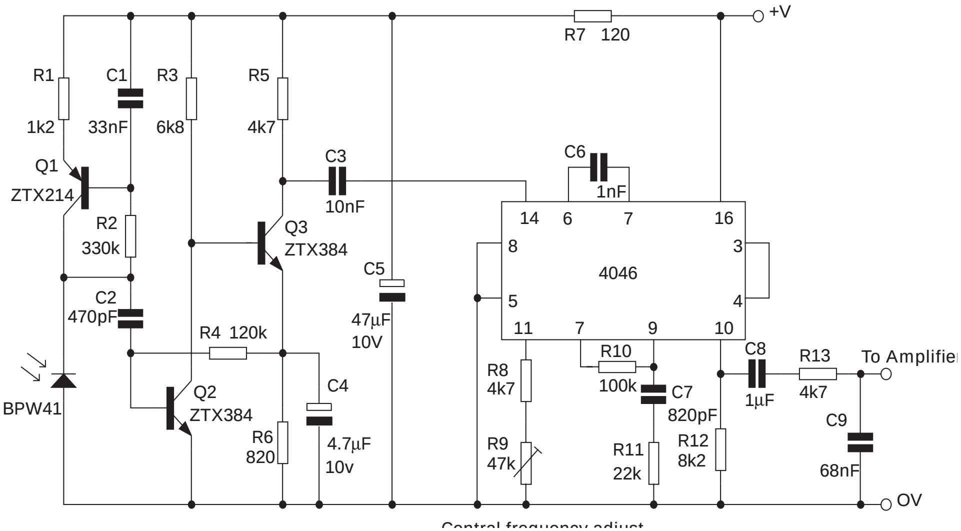

Figure 9a
M.A.L. Receiver and Detector.

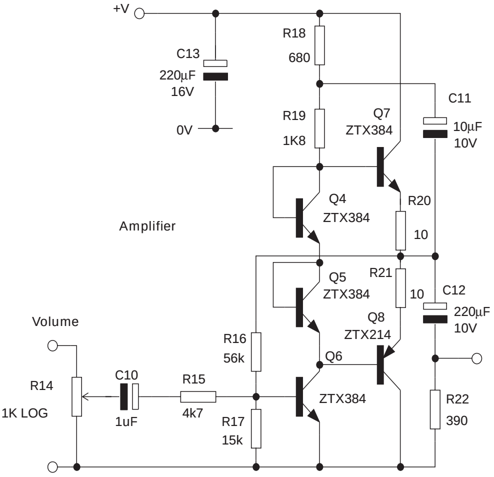

Figure 9b
M.A.L. Receiver Amplifier.

The corrected audio signal is then fed to an audio amplifier via a volume control.

The audio amplifier is intended to drive headphones with an impedance of 4Ω to 16Ω. It has a complementary push-pull output stage which employs a temperature compensated biasing circuit.

The receiver active load and amplifier circuits should be carefully laid out to minimise output to input feedback paths, otherwise instability may occur. The receiver should also be mounted in a metal case with a hole cut for light entry to the BPW41D.

M.A.L. Setting Up

The receiver phase locked loop centre frequency can be adjusted to the transmitter output frequency either by:

i) using an oscilloscope and comparing the transmitter output frequency to the frequency on the receiver pll device pin 4

or,

ii) by feeding a low level audio signal into the transmitter, gradually covering the photodiode with an opaque material and adjusting the centre frequency control for best signal recovery.

Once this adjustment has been made, the transmitter input level control should be set to give the maximum audio signal output before distortion due to overloading occurs.

Beam Interruption Detectors (B.I.D.)

Beam interruption detectors have a variety of uses ranging from object counting to burglar and fire detection alarms. They generally consist of a transmitter that emits a beam of light to a detector. Should this beam be broken, the detector gives a change in output level. The detector must discriminate between the transmitted beam and other light sources. This can be achieved by using a lensed system to make the detector directionally selective, or, by modulating the transmitter output and then making the detector select only correctly modulated sources. The lensed system uses simple transmitter and detector circuitry but mechanical construction and installation alignment are necessarily critical. The modulated system has the advantage of being easier to set up, but requires more complicated transmitter and detector circuitry.

A beam interruption detector using the BPW41D photodiode in a modulated system has been developed. It includes a transmitter circuit and a choice between two detector circuits of differing range capability. All the circuits are powered from a 5V d.c. supply to facilitate their operation with standard integrated circuit logic devices.

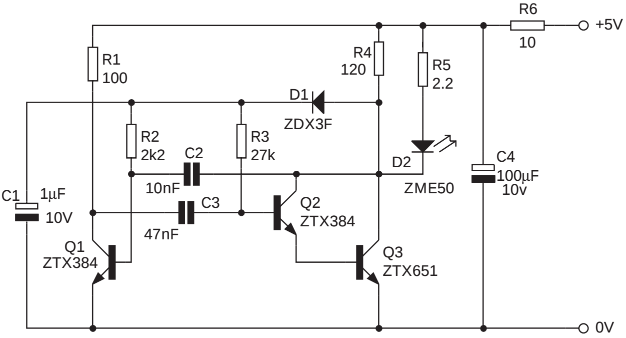

Figure 10
B.I.D. System transmitter.

B.I.D. Transmitter

The transmitter consists of an oscillator which drives a high output IR LED (ZME50). The oscillator is a sure-start multivibrator circuit which provides an output of 15 to 1000 mark-space ratio at a frequency of 1kHz. This large mark-space ratio allows the infra-red diode to be operated at a high peak current so as to maximise the range of the link. A decoupling network is included in the power supply of the transmitter to isolate it from any logic circuitry using the same 5V power source. The transmitter supply current is approximately 65mA. The circuit is illustrated in Figure 10.

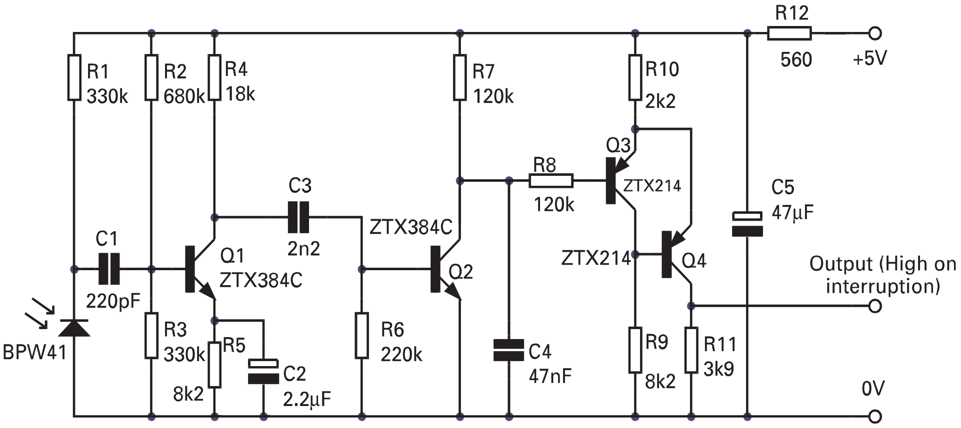

Figure 11
B.I.D. System receiver for short range duty.

Beam Interruption Short Range Detector

The short range detector circuit shown in Figure 11 is intended for use in parts counting and similar applications. A BPW41D photodiode with a simple resistor load is used to detect the transmitted beam. An active load is not used because it is usually easy to screen out interfering light sources in short range systems. The output of the photodiode is coupled to a single stage high input impedance amplifier which drives a pulse detector. The output of the pulse detector is low whilst a sufficiently strong transmitter beam is received, and high once this beam is interrupted.

The maximum range from the transmitter over which this detector will operate is approximately 0.7m. If necessary this can be increased by using a small lens with the transmitter L.E.D. to effectively increase its output. Using a 16mm dia. lens of 10mm focal length, the range using this detector was increased to 6m. It should be remembered however, that using a lens on the transmitter will make it’s alignment more critical. The construction of this detector is not too critical, but electrical screening may be necessary in industrial environments.

Beam Interruption Long Range Detector.

This longer range detector can be used in applications such as burglar alarms, automatic door or gate controllers etc. In this circuit (shown in Figure 12) the BPW41D photodiode is used with an active load because ambient lighting conditions are much less controllable in long range systems, and this load will be unaffected by high background light levels. The improvement in range over the simple detector circuit is achieved by using a higher gain amplifier to boost the output of the BPW41D photodiode before feeding it to a pulse detector.

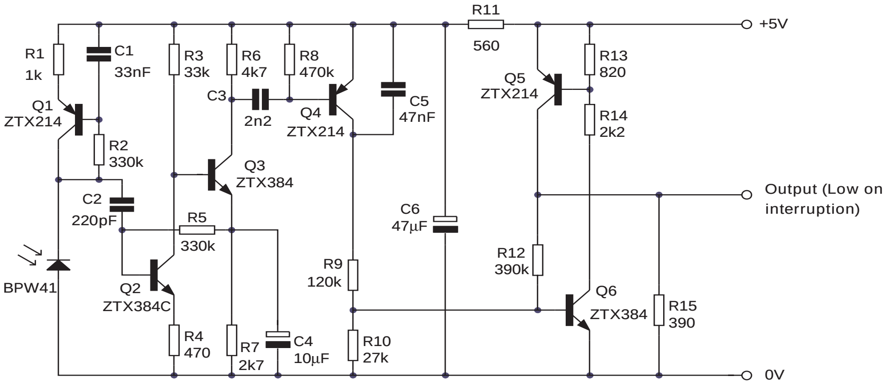

Figure 12
B.I.D. System receiver for long range duty.

The pulse detector drives a level sensor which produces a low output when the transmitter beam is broken. A small percentage of the output is fed back to the input of the level sensor to give the hysteresis necessary for noise free output switching. The level sensor output is capable of driving a normal TTL logic gate if required. The maximum range of operation with this detector is approximately 6m. Using a lens with the transmitter as described with the short range detector, a range of over 40m has been achieved.

During construction the active load and amplifier should be carefully laid out to avoid unwanted feedback. The unit should be mounted in a screened box to minimise interference.

The BPW41D is one member of the Zetex range of opto-electronic products, which includes a range of photo-diodes, photo-emitters and photo-transistors.

Appendix

Selected BPW41D datasheet charts.

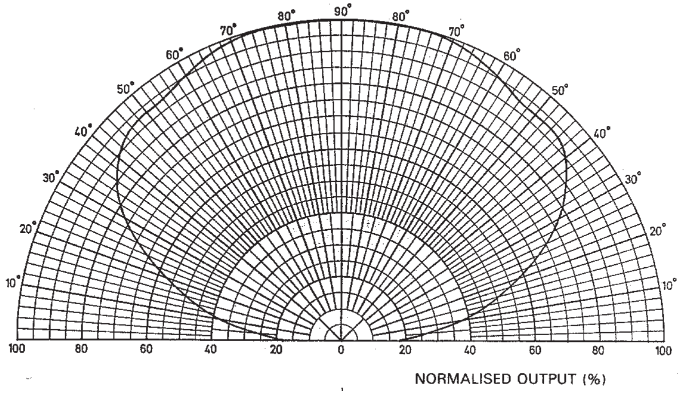

Figure 13
Polar response.

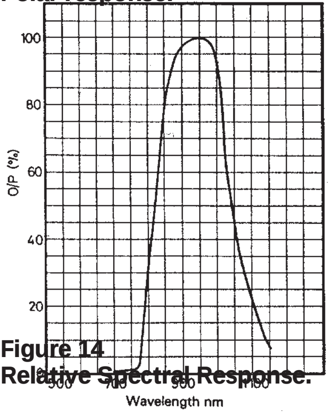

Figure 14
Relative Spectral Response.