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TRANSISTOR PROJECTS

Volume 3

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Transistor Projects
Volume 3

by

Forrest M. Mims, III

Radio Shack®
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PREFACE

This new volume of *Transistor Projects* includes several circuits I've been particularly anxious to write about. Experimenters should have fun with the xenon flashtube project in Chapter 5. Very few battery-powered strobe circuits have appeared in magazines and books for experimenters, and I think you will find this one to be a simple yet very workable approach.

Radio Shack has recently introduced a new phototransistor and several new light-emitting diodes (LEDs), and I have used both these component categories in several of the projects. If you haven't yet used either of these optoelectronic devices, now is the time to try them out. I think you will find them very useful devices, and you will no doubt come up with many new applications.

As I have said in other Radio Shack publications, the best way to learn about electronics is to combine study with practical experience. Therefore, I do hope you will build at least some of the projects in this new book.

After you have gained some experience working with transistors, you will want to check out the integrated circuit (IC) field. ICs permit you to assemble highly complex circuits with a minimum of components—as you can find out for yourself by purchasing a copy of any or all of the three volumes of this series' companion books, *Integrated Circuit Projects*.

FORREST M. MIMS, III

CONTENTS

CHAPTER 6

CHAPTER 7

CHAPTER 8

CHAPTER 9

CHAPTER 1

ELECTRONIC ASSEMBLY TIPS AND TECHNIQUES

An initial chapter on electronic assembly tips and techniques has been included in each volume of Transistor Projects. Even if you have assembled one or more transistorized projects, I think you will find the information in this chapter helpful. There are sections on reading and understanding circuit diagrams, electronic tools and test equipment, electrical safety, component selection, soldering, and power supplies. Some of this information will help you convert relatively straightforward perforated board projects into attractive and useful sophisticated devices. And all the information will help you successfully build and operate the projects described in this third volume of Transistor Projects.

Many experimenters have problems getting a newly constructed project to operate because they used incorrect soldering procedures, failed to read a circuit diagram correctly or improperly substituted one component for another. Read this chapter before beginning work on the projects described in this book, and you should then have few, if any, problems.

COMPONENT SELECTION

The first step in assembling an electronic project is purchasing the components. Wrong! Before selecting the components for a project you must first determine the amount of space that will be available, decide whether there are voltage or power restrictions upon various components, and any other factors which may bear upon your final choice of any or all the components. For example, if a parts list calls for an SPDT switch, make sure its contacts are rated according to the amount of voltage and current the switch will be required to handle. Also, don't spend extra money on a subminiature switch when a standard variety will do the job. Similarly, don't try to cut financial corners by using a large switch in a miniaturized project.

All the projects described in this and previous volumes of Transistor Projects include parts lists which specify at least one Radio Shack catalog number for each component. Since all the components are available from Radio Shack, you will have no problem collecting the parts for a particular project. But make sure you have planned ahead if you decide to use a different component than the one specified or if the parts list gives you a choice. This is particularly important if you intend to assemble the project in a cabinet or housing.

When you have planned the physical layout of your project and noted any particular requirements that may apply to some of the components, you are ready to proceed with component selection. Here are some tips that will help you select the components you need.

Resistors

The most common component in a solid-state circuit is the resistor. Resistors are used to divide voltages into smaller values and to limit current. For example, for proper operation a transistor frequently requires a small bias voltage at its base lead. This voltage could theoretically be provided by a small battery, but since very little current is required to do the job a separate battery is wasteful in terms of size, cost, and inconvenience. A single resistor can be used to effectively supply the required bias current directly from the circuit's main battery or power supply.

Sometimes a particular resistor value specified in a parts list will be temporarily out of stock and a substitution must be made. This particularly applies to such common values as 1000, 10,000, and 15,000 ohms. Fortunately substitutions are acceptable in many circuits so long as the substituted value is within 10 or 20 percent of the specified value. For example, a 47-ohm resistor can be substituted for a 50-ohm unit. Most resistors used in transistor circuits have a tolerance or error range of plus or minus 10 percent anyway.

Some circuits require a more precise resistance value and substitutions may be unacceptable. For example, light-emitting diodes generally require a series resistor to limit current through the diode to a safe value. Usually no harm will result if this resistor has a value which falls within 10 percent of the one specified, but deviations which *reduce* the specified resistance by more than 10 percent may cause the LED to overheat and be damaged. For example, substituting a 47-ohm resistor for a 69-ohm unit in a light-emitting diode series circuit would be unwise since the smaller value is well over the 10-percent limit. If the 68-ohm resistor cannot be located, you can simply connect two or three resistors *in series* to reach the specified tolerance range. For example, a 47-ohm unit connected in series with a 22-ohm unit gives a total resistance of 69 ohms, only one ohm above the specified value.

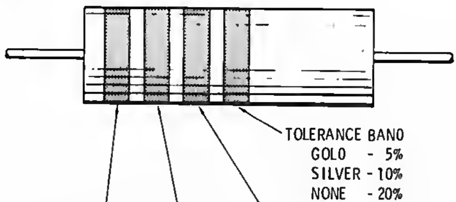
Transistor circuits usually operate at low power levels, and ½-watt resistors are almost always suitable. Higher-powered circuits may require 1- or 2-watt resistors, so consult the parts list for guidance. *Always* use a resistor with the specified power rating since smaller units may overheat and be damaged or destroyed.

Almost all resistors are marked for identification with three or more color bands around one end. The color-coding scheme is more useful than numbers printed on the resistor's outer case since it permits the value of resistors soldered into a circuit to be quickly determined from any angle. If the resistor was identified with a printed number, identification would be difficult or impossible if the component was installed with the number toward the circuit board side.

Figure 1-1 shows the resistor color code. The code is easy to use, and if you work with electronics for any length of time you will soon memorize it. The code is used by reading the color bands beginning on one end of the resistor. The resistor case will probably be colored dark brown or sometimes dull white.

To see how the code works, let's identify a resistor with four bands colored brown, green, orange, and silver. The first band (brown) is one and the second (green) is five. The third band gives the multiplier which, in this case, is 1000. Therefore the value of the resistor is 15 × 1000 or 15,000 ohms. The fourth band (silver) indicates the resistor has a tolerance of 10 percent.

Frequently you will see resistors given in a K or M value. The K means the resistor value is multiplied by 1000 while the M means the value is multiplied by 1,000,000. For example, a 23K resistor is 23,000 ohms while a 1M resistor is 1,000,000 ohms. As you can readily see, the K and M designations provide a handy form of electronic shorthand.



COLOR	FIRST BAND	SECOND BAND	THIRD BAND (MULTIPLIER)
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	

Figure 1-1. Resistor color code.

Capacitors

Capacitor values also vary from their specified value so substitutions are permitted in most cases. Tolerances of from 20 to 100 percent are relatively common so, for example, you can usually substitute a 0.22-μF unit for a 0.1-μF unit if the latter value is out of stock are otherwise unavailable.

This book includes a couple of projects which utilize capacitors having a specified voltage rating. For example, Chapter 5 describes a portable xenon strobe unit which utilizes three capacitors with a specified voltage rating of 250 volts. Don't be tempted to substitute a unit you may have on hand which has a lower voltage rating since the capacitor will probably be damaged by an effect called *dielectric breakdown.* This effect occurs when the voltage across the capacitor penetrates the insulating material which separates the capacitor's plates. To prevent dielectric breakdown, always use capacitors rated higher than the circuit's voltage, and at least as high as the specified value.

Applications for capacitors include filtering pulsating signals into steady ones and bypassing AC signals from one part of a circuit to another. Capacitors are also used to block DC signals and to selectively pass AC signals having a desired frequency range. Chapter 5 describes a circuit which uses capacitors for both energy storage and high-voltage generation.

Diodes

Diodes are like one-way electronic values since they pass a current in only one direction. For this reason they are very useful in converting alternating current (AC) to direct current (DC), blocking unwanted signals, and demodulating radio-frequency signals. Special-purpose diodes can be used to generate light (light-emitting diode or LED), regulate voltage levels (zener diode), or act as a negative-resistance device (four-layer diode). Certain specially fabricated LEDs called laser diodes can be used to generate partially coherent light.

Radio Shack stocks LEDs, zener diodes, high-voltage rectifiers, and conventional diodes in a wide variety of sizes and configurations. Substitutions are usually okay so long as you observe voltage ratings and stay within the general diode families. For example, don't try to substitute a computer-type switching diode or zener diode when a high-voltage rectifier is specified.

You can buy untested diodes from Radio Shack for as little as four cents each in quantities of fifty. While some of these diodes may be unusable many will be perfectly adequate for experimenter projects. The diodes can be easily tested with a multimeter since a good diode has a high resistance in one direction and a low resistance in the other. Chapter 9 in this book describes a very simple but effective transistor tester which can also be used to check diodes. The condition of the diode (good, open, or shorted) is specified by two LEDs.

Transistors

Radio Shack sells 34 carefully selected, high-quality transistors which can replace more than 20,000 different transistors.

All of these are brand new, first class semiconductors and none are factory rejects. Additionally, Radio Shack offers more than 15 other transistors ranging from programmable unijunctions (PUTs) and power units to a silicon phototransistor.

A few simple rules will help you select and substitute transistors. If possible, try to use the unit specified, but if the unit is not available follow the guidelines given below:

1. Stay in the same transistor family when making substitutions. For example, don't substitute a bipolar transistor (PNP and NPN types) for a unijunction (UJT) or field-effect transistor (FET).

2. Observe polarity and don't substitute PNP devices for NPN transistors and vice versa.

3. Always substitute transistors for ones having a similar application for best results. For example, avoid using audio transistors in high-speed switching circuits.

4. Make sure the substitute transistor meets or exceeds the voltage and power ratings of the originally specified unit. For example, substituting a small plastic or even metal packaged transistor for a power transistor will almost certainly cause problems.

In previous volumes of *Transistor Projects* I have used UJTs, FETs, phototransistors, power units, and both germanium and silicon transistors. This volume utilizes the latter three transistor types and you may want to see volumes one and two for circuits which use FETs and UJTs. For more information on transistor substitution, see the *Transistor Substitution Handbook,* another Radio Shack publication. Also see the current Radio Shack catalog.

Chapter 9 in this book describes a simple transistor tester which quickly sorts NPN and PNP units while identifying shorted and opened junctions. The tester uses four LEDs to indicate a transistor's polarity and status. The tester is particularly handy for sorting through bargain transistors purchased in quantities.

Transformers

Three of the projects in this book use at least one transformer. One circuit uses a transformer to convert household line voltage into a low voltage suitable for operating a battery charger. Another uses two transformers to produce the high voltages necessary to operate a xenon flashtube circuit. Still another circuit uses transformers to couple audio signals from one stage of a transistor amplifier to the next stage of the amplifier.

Transformers consist of two or more coils of wire wound around a common core. The core may be air, powdered iron mixed in a binder cement, or layers of thin metal plates called *laminations*. Most of the transformers used in this book use laminations and one uses a powdered-iron core (a high voltage trigger coil used to produce the 4000 volts necessary to ionize a xenon flashtube).

Transformers can convert an AC or pulsed DC voltage into a higher or lower value at the expense of current. If the voltage is increased, which occurs when a small voltage is introduced into a relatively short winding and a higher voltage appears at a relatively long winding, its current is reduced. Conversely, if the voltage appearing on the winding is reduced its current is boosted upward.

Two particularly important applications for transformers are isolating one section of a circuit from another, and impedance matching. In the latter application, for example, transformers are used to match the relatively high output impedance of most amplifiers to the very low impedance of most speakers.

Transformers usually have color-coded leads which are clearly labeled or specified in projects in which they are used. Be careful when handling transformer leads since they are fragile.

Relays

The relay is simply an electromagnetic switch. In other words, a relay is a conventional switch capable of being actuated by an electronic signal. This book includes several circuits which use a Radio Shack relay which triggers on only a 4.5-milliampere signal.

Relays are very useful as automatic switching and control devices. Avoid using a relay to switch more than the voltage and current its contacts are rated for, or they will possibly be damaged or welded together. Also, make sure you make the proper connections when installing a relay into a circuit. It's easy to connect the switching contacts in place of the coil leads if you don't refer to the relay's wiring guide.

Switches

A switch is often more than a switch and to prove it I refer you to any Radio Shack catalog. An amazing variety of switches is available to both engineers, serious experimenters, and amateurs. Radio Shack, for example, supplies pushbutton, push-on/push-off, magnetic reed, toggle, knife, rocker, rotary, slide, and lever types. Most nonrotary switches are labeled SPST, SPDT, or DPDT. These abbreviations describe the switch's function. SPST (single pole, single throw) units have one pair of contacts and are commonly used as on-off switches.

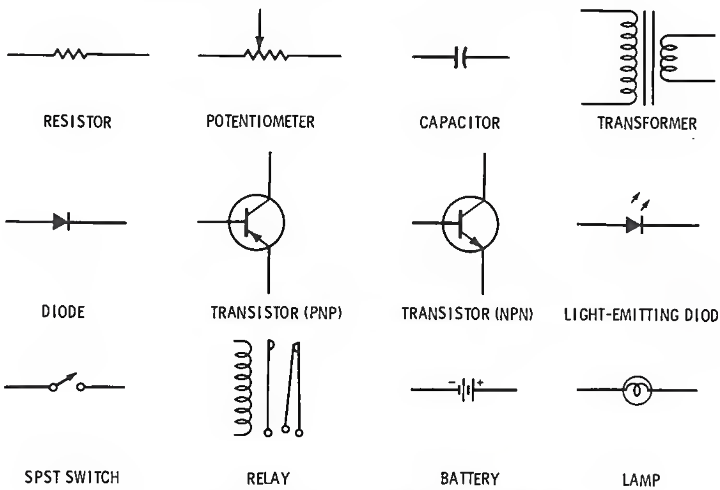


Figure 1-2. Common schematic symbols.

SPDT (single pole, double throw) units have two on positions, while DPDT (double pole, double throw) units contain a pair of SPDT contacts.

UNDERSTANDING CIRCUIT DIAGRAMS

An understanding of circuit diagrams is essential for successfully building transistor and integrated circuit projects. Sometimes called *schematics*, circuit diagrams can be used to illustrate any electronic circuit. Besides aiding in the construction of an electronic project, a circuit diagram frequently helps you visualize how a project works.

Most of the common circuit symbols used in this book are shown in Figure 1-2. All the symbols have a logical interpretation and this will help you memorize them. For example, the lamp symbol shows a circle (the glass bulb) containing a loop (the filament). Semiconductor symbols are particularly useful since transistors, diodes, and other solid-state components must almost always be connected according to their polarity. The circuit symbols for diodes and transistors indicate polarity with arrows pointing in the direction of positive current flow.

For more information on circuit diagrams and symbols, see the *Realistic Guide to Schematic Diagrams,* another Radio Shack publication.

CIRCUIT BOARDS

For clarity in the illustrations and to permit more projects to be included in the available space, I have built all the projects in this and other Radio Shack books in this series on perforated boards. This construction technique is popular with beginners and advanced experimenters alike since it provides a reliable and relatively neat appearing circuit. It also permits new components to be added or substituted into the circuit with little or no difficulty, and also eases troubleshooting. Many professional circuits go through at least one perforated board stage before ending up on printed-circuit boards.

Several different types and sizes of perforated board are available from Radio Shack. I use both alternate and regular grid for the projects in this series. Alternate grid board such as Radio Shack catalog number 276-1392 is sturdy and the hole spacings are adequate for most components. Regular grid board such as catalog number 276-1394 with 0.1-inch hole centers is ideal for use with integrated circuits and miniaturized projects, but it is weaker than alternate grid board.

Whichever board you use, you can improve the appearance of a completed project by using rubber feet or small strips of wood cemented or screwed to each corner or side of the board as shown in Figure 1-3. This construction technique also prevents possible shorts by keeping the soldered connections away from your workbench.

Printed-circuit construction is ideal for some projects, particularly if you plan to make several copies of one board layout.

A printed or etched circuit replaces the tangle of connection wires beneath a perforated board with a neat pattern of copper foil.

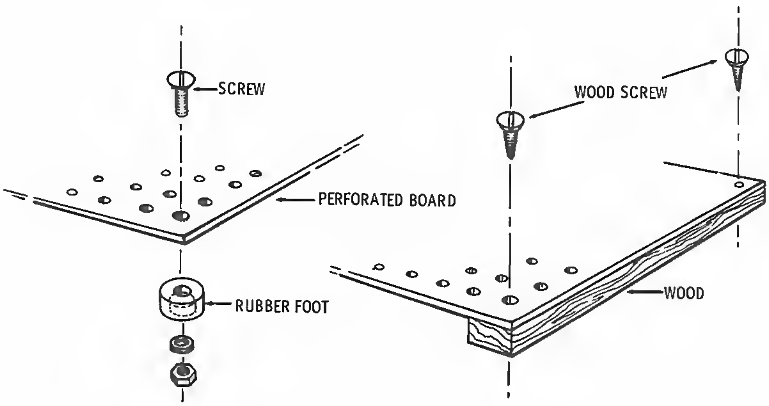


Figure 1-3. Installing feet on a perforated board.

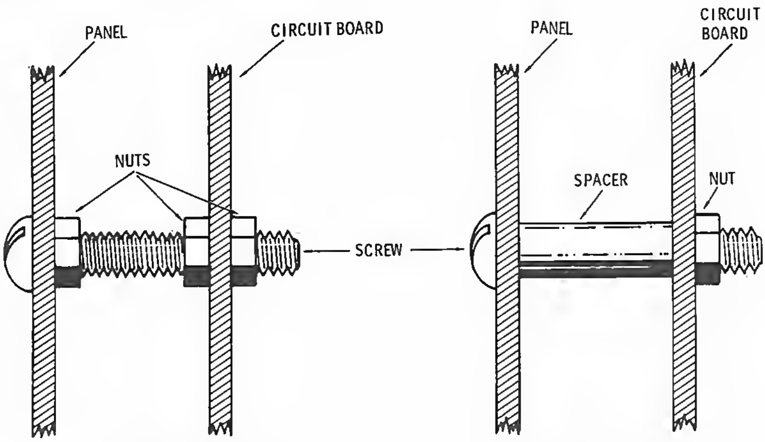
A printed-circuit kit containing copper-clad boards, etchant, resist ink, resist pen, drill bit, scouring pad, and tape circles and strips is available from Radio Shack for about seven dollars (catalog number 276-1576). You can make professionally appearing circuit boards and circuits with this kit and a little patience if you faithfully follow the enclosed directions.

PACKAGING

Perforated boards are ideal for many experimental circuits and projects, but for permanent use you will want to consider installing the board in a protective housing or cabinet. This is particularly true if the circuit uses household line current or if high voltage is otherwise present. Besides providing electrical safety, a housing protects delicate components, keeps foreign matter out of the wiring, and enhances use of the device itself.

Radio Shack stocks a wide variety of plastic and metal cabinets, many of which are ideal for housing projects described in this book. All the cabinets incorporate removable panels or covers. If you like the convenience of having the project components readily available for test and other purposes, Radio Shack's P-Box® and Perfbox® are ideal. Both these housings incorporate a perforated board mounted on the front of a plastic or bakelite case.

You can mount a perforated board in a housing using standoffs or spacer nuts as shown in Figure 1-4. Radio Shack stocks aluminum standoff spacers in several lengths which are ideal for this purpose (catalog number 270-1393). For a neat appearance, install standoff screws from the *bottom* side of the cabinet wall if possible. Speakers, meters, phone jacks, switches, indicator lamps, and potentiometers should be installed on the front panel.



(*A*) *Spacer nuts.* (*B*) *Tubular standoff.*

Figure 1-4. Perforated board installation techniques.

Of course you don't have to install a project in a housing, but remember that a cabinet mounted project is both attractive and convenient to operate. It will also last longer.

TOOLS

The availability of proper tools can greatly simplify the assembling of an electronic project. I have seen some projects, few of which operated, which were assembled with heavy duty soldering irons, conventional pliers, and other tools intended for mechanical applications. Usually these projects looked as bad as they worked, and the builders could have achieved much better results with an economical, one-time investment in some very useful tools intended for electronics assembly.

You can buy a basic tool assortment for a few dollars from Radio Shack. For starters purchase a low-wattage soldering iron (more about this later), a diagonal wire cutter, a needle nose pliers, a wire stripper and some screwdrivers. As you gain more experience, you may wish to purchase other useful tools such as a nutdriver set, ratchet socket set, drill, files, etc.

The projects described in this book can be built from nothing more than a perforated board and the necessary components. For installing a project in a housing, however, you will need such items as mounting hardware, electrical tape, and possibly a tape labeler.

SOLDERING

Good soldering practices are essential for reliable operation of any electronic circuit. If you have had prior soldering experience, read the following procedures over just for a review. If you are a soldering novice, read the procedures very carefully and practice soldering some lengths of scrap wire together before attempting to solder actual components to one another.

1. Don't use a heavy duty soldering gun or high-wattage iron when assembling transistorized circuits, since the high heat may damage semiconductors and other components. Instead, obtain a "pencil" soldering iron rated from 25 to 40 watts and tin the tip in accordance with the manufacturer's instructions.
2. Never use acid-core solder for soldering electronic components since it is corrosive and may damage electronic parts. Always use rosin-core solder—the type sold by Radio Shack.
3. Ensure a low resistance, permanent bond by removing all grease, oil, paint, wax, and other foreign matter covering parts to be soldered together. If necessary, use a solvent or an abrasive such as sandpaper.
4. Begin soldering a connection by first heating the joint where solder is to be applied. When the connection has been heated for a few seconds, leave the iron in place and apply solder to the connection (not the iron).
5. Allow the solder to flow throughout and around the connection for a second or so before removing the iron. Don't apply excessive solder or move the connection before it has cooled.
6. Keep the tip of the iron clean. Wipe off accumulations of solder with a damp sponge or cloth.

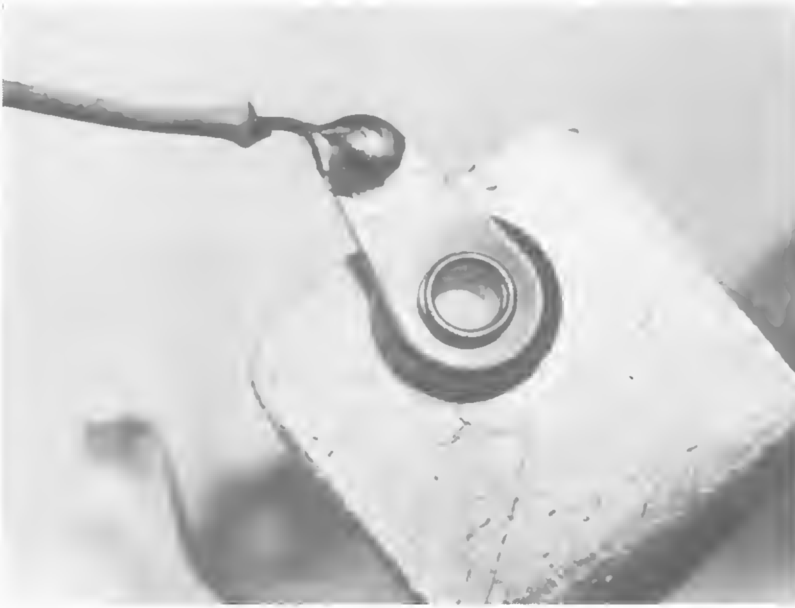


Figure 1-5. A good solder connection.

Figure 1-6. A poor solder connection.

If these six steps are followed, a good solder connection is easily made. A good connection will appear smooth and shiny like the one in Figure 1-5, but a poor connection will appear dull and rough like the one in Figure 1-6. If your connection looks more like the latter than the former, try again.

BATTERIES

Most of the projects described in this book are battery powered. Both 1½-volt cells and 9-volt batteries are employed. Only one project, the battery charger described in Chapter 4, is powered by household line current. You should select your project's power source carefully since its operation is dependent upon a reliable power supply. Batteries are by far the most convenient and safest power supply, but line power is more economical in the long term. By the way, just because a project is powered by batteries don't assume it's electrically safe. The xenon flashtube project described in Chapter 5, for example, is powered by a single flashlight cell but produces up to several hundred volts.

Radio Shack markets a wide variety of conventional and high-efficiency batteries. Their Nova cells incorporate standard carbon-zinc construction with a specially processed electrolyte and last up to 3.6 times longer than conventional zinc-carbon cells in high drain applications and 3 times longer in moderate drain circuits.

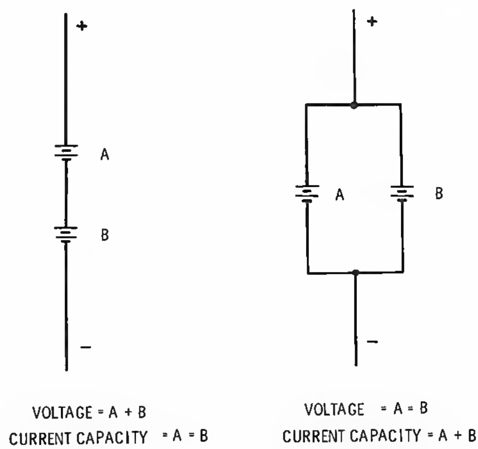
Alkaline cells are also available from Radio Shack. While more costly than conventional carbon-zinc cells, alkaline cells have greater life under heavy loads. For example, a 1½-volt "D" size alkaline cell costing 90 cents may last from 5 to 10 times longer than an equivalent carbon-zinc cell costing 21 cents. Assuming the lower life figure, the alkaline cell is at least 15 cents cheaper and requires replacement only a fifth as often.

Alkaline cells are particularly useful in high current drain projects such as the xenon flashtube circuit described in Chapter 5. In a high current consumption circuit such as this, an alkaline cell will last from 7 to 10 times longer than a standard carbon-zinc cell.

Radio Shack also stocks Enercell (TM) nickel-cadmium rechargeable cells in the popular AA penlight cell configuration. The initial cost of a nickel cadmium cell may seem high, but since they can be recharged up to 500 times, the long term cost is very low. Radio Shack sells several chargers for nickel-cadmium cells, and Chapter 4 presents construction details for a charger you can easily assemble.

Batteries are always easier to use if installed in a holder or connected to a clip. Radio Shack markets a variety of metal and plastic battery holders and a popular clip which is used with 9-volt transistor radio batteries. The clip is supplied with self-contained color-coded leads (red for positive and black for negative).

Figure 1-7 shows how you can connect two or more batteries in series to produce a voltage equal to the sum of the separate voltages. Figure 1-7 also shows how you can double the current capability of a single cell by connecting it in parallel with another cell. Prepackaged batteries rated at more than a few volts actually consist of a series or series-parallel string of small cells enclosed within a protective package. You can see the construction of this type of battery by opening a discarded 9-volt transistor radio battery.



(A) Series. *(B) Parallel.*

Figure 1-7. Series and parallel battery circuits.

POWER SUPPLIES

Battery power is convenient and safe, but line-operated power supplies provide much more economical operation. Variable-voltage power supplies are particularly nice since you can operate circuits which require different voltages and perform tests on experimental projects.

You can either build or buy a line-operated power supply. Radio Shack sells several fixed-voltage power supplies and a regulated, variable-voltage unit. This latter supply (catalog number 22-126) has an output variable from 0-24 volts in two ranges with an output capability of 1.0 ampere continuously and 1.5 amperes surge. A panel meter shows both the output voltage and current drain.

Figure 1-8 shows a circuit diagram for an easily assembled 9-volt power supply. This circuit, which is described in detail as a construction project in Transistor Projects, Volume 1 (Chapter 2, pages 17-26), can be built in a few hours or less by beginners having little or no previous electronics experience. While the initial cost of the power supply is higher than battery power, the long-term operating expense is much cheaper than batteries.

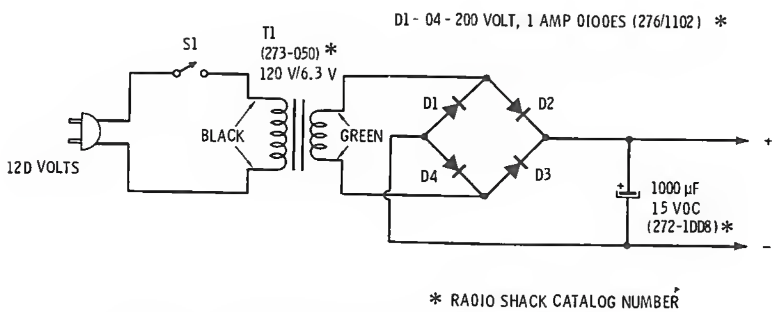


Figure 1-8. A simple 9-volt DC line-operated power supply.

Operation of the power supply shown in Figure 1-8 is straightforward. The primary side of the 120/6.3-volt AC transformer is connected to household line current by an insulated power cord; 6.3 volts of AC then appears at the transformer's secondary winding. Besides reducing the voltage level, the transformer isolates the hazardous AC line from the power supply circuit—and from you.

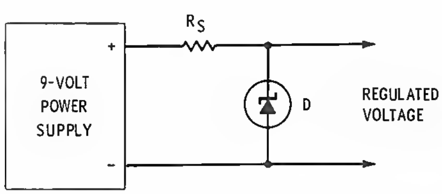
The four diodes serve to rectify the AC voltage from the transformer into DC. One diode in series with one transformer secondary winding lead could also be used, but the diode would block half the available AC and its output would be pulsating.

The four-diode arrangement, which is called a *full-wave bridge rectifier*, converts all the available AC into DC with less pulsations or ripple than would a single diode.

The capacitor serves as a filter to smooth out the ripple superimposed on the DC coming from the rectifier bridge. The capacitor also acts as a temporary storage device to provide extra power when needed by the circuit being operated by the supply.

You can use the power supply shown in Figure 1-8 to obtain less than 9 volts by connecting a zener diode and series resistor to the supply, as shown in Figure 1-9. The zener diode has the remarkable property of absorbing voltage over the diode's rated value. For example, a 6-volt zener diode can be connected to the circuit to give a 6-volt output. Suitable zener diodes are available in ½- and 1-watt units from Radio Shack.

See details on construction of the power supply project in Volume 1. If you build the supply, be sure to carefully insulate the 120-volt transformer connections to prevent dangerous electrical shock.



D *	R_S
4 VOLTS	45 OHMS
6 VOLTS	27 OHMS

* (USE 1 WATT ZENER DIODE)

Figure 1-9. Power-supply voltage regulation using a zener diode.

TEST EQUIPMENT

You can build each of the projects in this book without the help of a single piece of electronic test equipment. But you can go much further by purchasing some simple, economical, and very useful test equipment.

The volt-ohm-milliammeter (VOM), multitester, or multimeter is the most basic test instrument available. VOMs permit you to conveniently measure resistance, voltage, and current, check continuity, and even test diodes and transistors. You can purchase a basic VOM from Radio Shack for less than $10. This will give you an instrument having eight test ranges, and typical ranges for a Radio Shack VOM in this price region are as follows: 0-15-150-1000 AC or DC volts, 0-150 milliamperes, and 0-100,000 ohms.

For a little more money you can purchase an even better-quality VOM having more ranges. Since VOMs will last for years if treated properly, you might want to consider purchase of a better-quality unit. The top-of-the-line Radio Shack VOM is a first class instrument having 27 ranges. A dual field-effect transistor input provides very high input impedance.

Other Radio Shack test equipment which you will find handy in designing and building electronic projects includes a resistance-capacitance substitution box (22-001), signal injector (22-4032), signal tracer (22-010), and transistor tester (22-024). You can build your own transistor tester by following the instructions in Chapter 9. Ultimately you will want to consider purchase of an oscilloscope. This instrument is exceptionally versatile and useful since it provides a visual display of a signal on a televisionlike screen.

ELECTRICAL SAFETY

If you want to be around long enough to enjoy the fruits of your labor when constructing a project, treat electricity with the respect it deserves. This applies to both electrically powered tools and the project itself. Electronics is fun and educational, but electricity can be dangerous.

Never work on line-powered projects unless the power cord is removed from its receptacle. If the circuit contains capacitors, *never* touch their leads or terminals unless you have first used an insulated clip lead attached to a screwdriver to short any voltage the capacitor may contain. This is done by *carefully* clipping the lead to one terminal of the capacitor and then touching the screwdriver to the other terminal. Capacitors may appear harmless, but large capacity units can store a lethal charge.

Most battery-operated equipment is quite safe, but use caution if a circuit is known to produce a high voltage. For example, the xenon flashtube circuit described in Chapter 5 produces several hundred volts in one section, and a brief pulse of 4000 volts in another from a *single* $1\frac{1}{2}$-volt cell! When working with such circuits, turn off the power and discharge all high-voltage capacitors before touching their leads. If you are uncertain about the presence of high voltage, proceed with caution and keep one hand *in your pocket*. This will prevent a dangerous shock from passing from one hand, through your body, to the other hand.

Finally, don't ever play around with electricity! If you must shock someone, give him a five dollar bill. Treat electricity casually and you might not be around long enough to enjoy its benefits.

CHAPTER 2

OPTOELECTRONIC LOGIC CIRCUITS

Thanks to recent advances in solid-state semiconductor lasers and light-emitting diodes, there is considerable interest in optoelectronic logic circuits. Already, integrated-circuit construction methods have been employed to make miniature logic circuits which employ light to trigger various logic actions.

The simplest optoelectronic logic circuit is a simple YES circuit called an opto-isolator. This device consists of an LED or other light source which triggers the light sensor. Since there is no electrical connection between the light source and detector, almost total electrical isolation between two circuits can be achieved. Opto-isolators are usually packaged in metal cans or plastic housings to provide shock resistance and to keep external light from activating the sensor. For high-voltage isolation, special insulating plastics are frequently used.

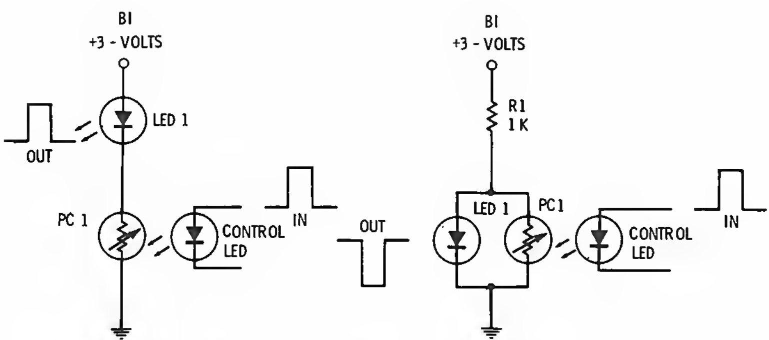
This chapter describes two simple logic circuits which demonstrate both optical isolation *and* the YES and NOT logic functions. The circuits can be assembled in minutes and provide an interesting and educational demonstration of optoelectronic logic.

HOW THEY WORK

Figure 2-1 shows the circuit diagrams for both optoelectronic logic circuits. Both circuits demonstrate optical isolation since there is no electrical connection between the input LED and light sensor.

Figure 2-1A is a converter or YES circuit. When the control LED is on (logic 1), the resistance of the light sensor decreases and permits LED 1 to glow (logical 1 = logic 1). This circuit configuration is frequently used in optical isolators.

Figure 2-1B is an inverter or NOT circuit. When the control LED is off (logic 0), the resistance of the light sensor is very high and since LED 1 has a relatively low forward resistance it turns on (logic 1). When the control LED is turned on (logic 1), however, the resistance of the light sensor falls sharply and diverts the current from LED 1. LED 1 then turns off (logical 1 = logic 0).



(*A*) *Converter* (YES *circuit*). (*B*) *Inverter* (NOT *circuit*).

Figure 2-1. Optoelectronic logic circuits.

Both circuits must be operated with the control LED very close to the light sensor for best results. Also, the room lighting must not be too bright or the light sensor will be affected.

CIRCUIT ASSEMBLY

The parts list is given in Table 2-1. These two circuits are so simple no pictorial view is needed for their construction. Instead, refer to the photographs of the assembled prototypes in Figures 2-2 and 2-3 for construction details.

Assemble the converter by inserting the control LED in a perforated board as shown in Figure 2-2. Solder two lengths of insulated wire to the LED's leads to supply operating current. Next, install the light sensor and its output LED as shown in the photograph.

Table 2-1. Optoelectronic Logic Circuit Parts List

Item	Description
B1	Battery, 3 volts
LED	Light-emitting diode (276-041 or 276-026)
PC1	Cadmium sulfide photocell (276-116)
R1	Resistor, 1000 ohms (inverter only)
Misc.	Control LED (see text), perforated board (276-1392), hookup wire, solder

Radio Shack catalog numbers are shown in parentheses.

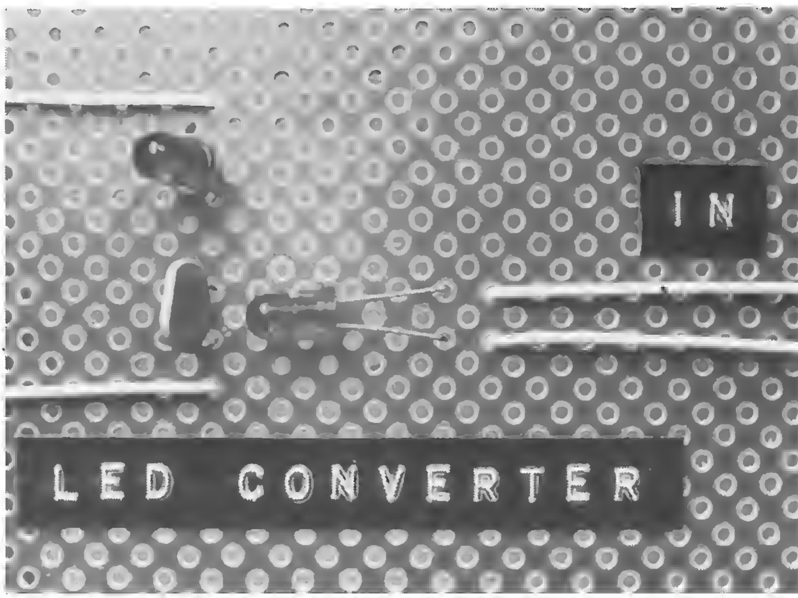


Figure 2-2. Assembled optoelectronic converter.

A length of insulated hookup wire soldered to the LED 1 anode lead becomes the positive battery-connection lead, and a similar wire soldered to the light sensor's remaining lead becomes the negative battery-connection lead. The control LED should be mounted close to or in contact with the light sensor for best results.

Assemble the inverter circuit on the same perforated board as the converter. Install the control LED, and then mount the light sensor output LED 1. Output LED 1 is soldered to each of the sensor's leads. The anode lead of LED 1 is then soldered to a 1000-ohm resistor (brown-black-red). The other resistor lead becomes the positive battery terminal. LED 1 cathode and light-sensor junction becomes the negative battery terminal.

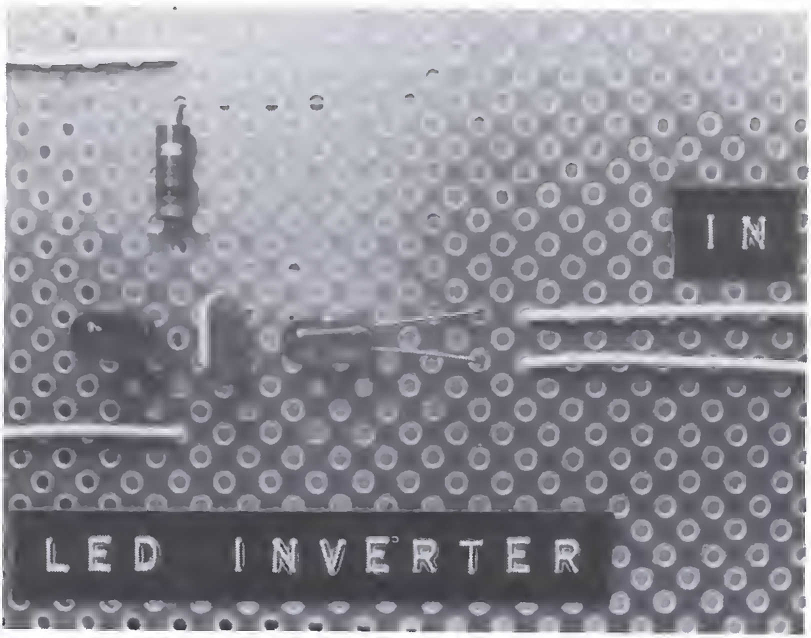


Figure 2-3. Assembled optoelectronic inverter.

TESTING AND OPERATION

Test the circuits by connecting a 3-volt battery to the battery connection leads. Then activate the control LEDs by connecting the cathode leads to the negative terminal of a 3-volt battery and the anode leads to a 220-ohm resistor (red-red-brown) connected to the positive terminal of the 3-volt battery. You can use the same battery to power both the control and output sections of both circuits, but the demonstration is more impressive and electrical isolation is preserved by using separate batteries.

When the converter's control LED is activated, its output LED 1 should glow $(1 = 1)$, and when the inverter control LED is activated, its output LED 1 should stop glowing $(1 = 0)$. For best results, make sure the control LED is relatively close to the light sensor and the room lights are dimmed.

GOING FURTHER

You can couple both these optoelectronic logic circuits into a fascinating demonstration circuit by assembling both on the perforated front panel of a Radio Shack Perfbox or P-Box together with a UJT clock triggered astable or monostable multivibrator. Connect the control LEDs to logic-status indicators connected to the 1 and 0 outputs of the multivibrator so one LED will flash on when the other flashes off. The LEDs will provide the optical control signal for both the optoelectronic circuits and the following logic principles will be automatically demonstrated: digital clock, multivibrator operation, optical isolation, optoelectronic conversion, and optoelectronic inversion.

CHAPTER 3

LED LIMIT SWITCH

The advent of economical phototransistors and light-emitting diodes makes possible a great variety of unusual optoelectronic projects. The LED limit switch is one such project. Besides demonstrating several optoelectronic principles, this project can be readily adapted to several practical applications. These include automatic end-of-tape detection for tape recorders, proximity detection, and various types of movement sensors.

HOW IT WORKS

The circuit for the LED limit switch is shown in Figure 3-1. The circuit can be operated in either a reflection or transmission mode, and both operating modes will be described. The LED is powered by a 9-volt battery. R1 serves to protect the LED by limiting the current supplied to the LED. R1's value is selected according to the following formula:

$$R1 = \frac{V_{in} - V_{LED}}{I_{LED}}$$

where,

V_{in} is the power supply voltage,
V_{LED} is the LED forward voltage drop,
I_{LED} is the maximum LED forward current.

For example, a red LED made from the semiconductor compound gallium arsenide phosphide (GaAsP) has a maximum voltage drop of about 3 volts. Since V_{in} is 9 volts, $V_{in} - V_{LED}$ is 6 volts. A typical value of forward current for an LED is 20 milliamperes or 0.02 ampere. This divided into 6 volts gives 300, the resistance in ohms of the required series resistor. For a 50-mA diode, R1 would be 120 ohms. If the required value for R1 is not available, you can substitute the next closest value. You can also connect two resistors in series to get a new resistor whose value is the sum of the individual resistors. For

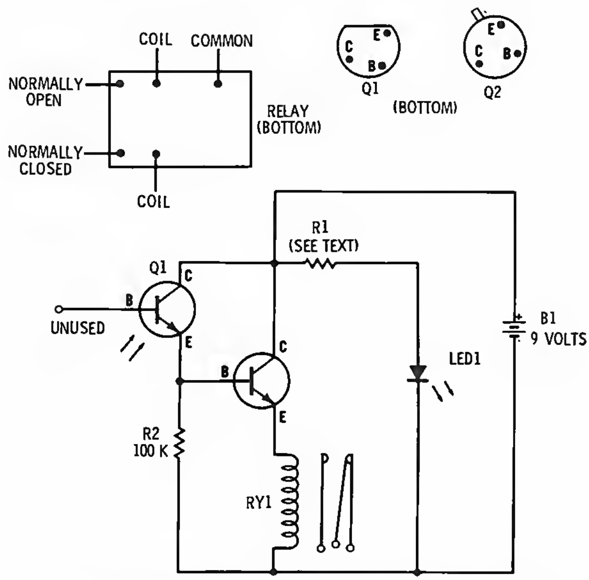


Figure 3-1. Circuit diagram for the LED limit switch.

example, Radio Shack does not market a 300-ohm resistor, but keep in mind that a 270Ω or 330Ω 10-percent resistor falls within the tolerance. You can also employ a 270-ohm unit in series with a 27-ohm unit to come within 3 ohms of the required value.

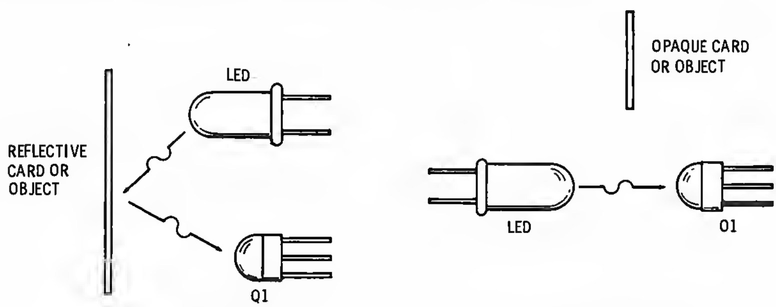
The main thing to remember about R1 is that its value is determined by three separate parameters. You already know the input voltage, and the LED forward voltage and current values are generally supplied with the device.

Q1 and Q2 comprise the receiver portion of the LED limit switch. Q1 is a sensitive silicon phototransistor encapsulated in a protective package of transparent epoxy which also serves as a lens. Since Q1's input signal is supplied by light, no connection to the base lead is required. For this reason some phototransistors have no base lead, but the base lead can be very useful for operating a phototransistor in a very sensitive detection mode.

Q2 serves to couple the amplified photosignal from Q1 to a relay. When the optical signal at Q1 is sufficiently high, the relay pulls in. It drops out when the light level is reduced.

The limit switch has two operating modes. In the reflection mode, the LED is mounted adjacent to Q1. When a reflecting surface such as a white paper card is placed near, but not touching, Q1 and the LED, sufficient radiation is reflected from the surface to cause Q1 to trigger Q2 and pull in the relay.

In the transmission mode, the LED is mounted opposite and facing Q1 so that the relay is normally pulled in. When the space between the LED and Q1 is blocked by an opaque object or card, the relay drops out. Figure 3-2 shows both the reflection and transmission mode in diagram form.



(*A*) *Reflection mode.* (*B*) *Transmission mode.*

Figure 3-2. Reflection and transmission detection modes.

CIRCUIT ASSEMBLY

Assembly of the limit switch is straightforward. The parts list is given in Table 3-1. Begin by installing Q1 at one side of a perforated board as shown in the pictorial in Figure 3-3. Refer to Figure 3-1 for Q1's lead connections and be sure to connect the collector and emitter leads properly or the circuit will not operate. When Q1 is installed, insert R2, a 100,000-ohm resistor (brown-black-yellow) into the board and solder one end to Q1 emitter lead.

Table 3-1. LED Limit Switch Parts List

Item	Description
B1	Battery, 9 volts
LED1	Red LED (see text)
Q1	FPT-100 phototransistor (276-130)
Q2	2N2222 NPN transistor (276-2009)
R1	See text
R2	100,000-ohm resistor
RY1	Miniature SPDT relay (275-004)
Miscellaneous	9-volt battery clip (270-325), perforated board, hookup wire, solder, etc.

Radio Shack catalog numbers are shown in parentheses.

Next, install Q2. Be sure to check the pin diagram in Figure 3-1 to make sure you connect its leads properly. Then solder Q2 base to the junction of Q1 emitter and R2. Next, solder Q1 collector lead to Q2 collector lead. This connection becomes the positive battery terminal for the circuit, so solder the red lead from a 9-volt transistor radio battery connector clip to this joint.

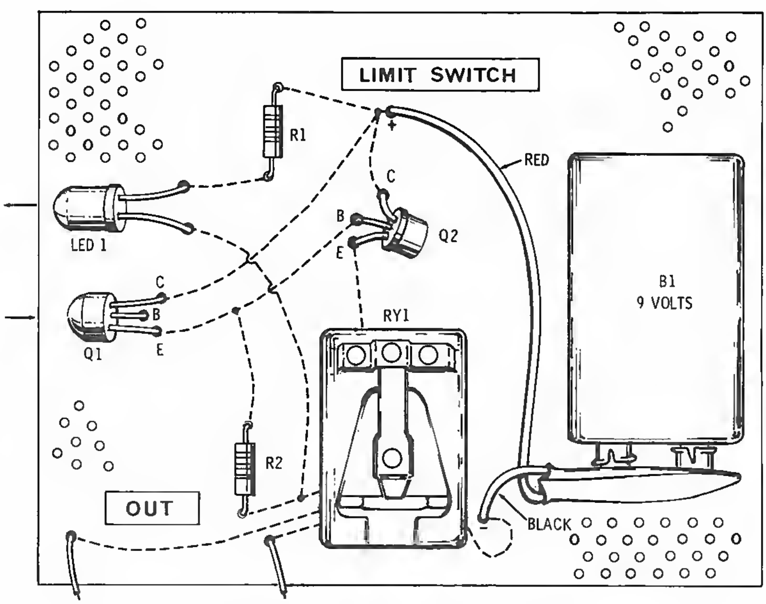


Figure 3-3. Pictorial diagram of the LED limit switch.

Examine the relay by comparing it with the wiring diagram in Figure 3-1. Install it on the perforated board by means of the leads (careful, they might break if bent too much) and connect one of the coil leads to Q2's emitter and solder in place. Then solder the remaining coil lead to R2's remaining lead. This becomes the negative battery connection point, so solder the black lead from the battery connector clip to this junction.

The receiver portion of the circuit is now complete. Assemble the light source by soldering one lead from R1 to the positive battery connection point. See the "How It Works" section for a complete discussion on the selection of R1. Be sure to use a resistor at R1 or the LED will be damaged and probably destroyed by excess current.

The LED is installed next. Mount it to the board by means of its leads if the circuit is to be operated in a reflection mode. Otherwise you may want to solder it to two lengths of flexible hookup wire to permit it to be moved about. This will permit operation in both the transmission and reflection mode. Make sure you examine the LED carefully to determine the proper lead connections. Most Radio Shack LEDs include polarity information on the sales package.

Complete assembly of the limit switch by soldering the remaining lead from R1 to the LED's anode. The LED's cathode is then soldered to the negative battery connection point. The completed circuit should resemble the photograph of the prototype in Figure 3-4.

TESTING AND OPERATION

Inspect the wiring of the circuit to make sure there are no errors and connect a fresh 9-volt battery to the battery clip. The LED should immediately turn on. If it does not, the LED is defective or installed incorrectly, the battery is weak, or R1's value is incorrect.

If the LED glows when the battery is installed, operate the circuit in a reflection mode by placing the LED adjacent to Q1 and placing a white card nearby, as shown in Figure 3-2A. As the card is brought to within a few millimeters of Q1 and the LED, the relay should pull in. You can usually hear the relay pull in a drop out (it makes a clicking sound), but for best results connect an indicator LED to the relay switch terminals

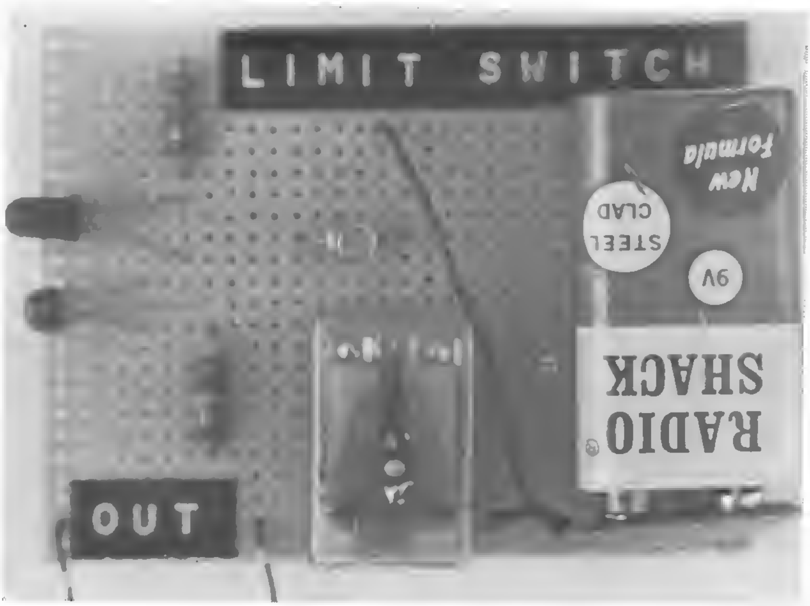


Figure 3-4. The completed LED limit switch.

as shown in Figure 3-5. The indicator LED will flash on and off each time the white card is placed near and then moved away from the device. If the circuit fails to respond to the card, try dimming the room lights. This should solve the problem, but if it doesn't the LED is probably weak or the battery may need replacement.

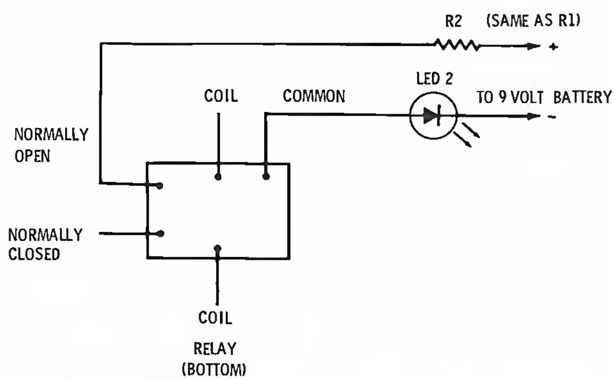


Figure 3-5. Connecting an indicator LED to the relay.

Next, operate the circuit in a transmission mode by pointing the LED at Q1. The detection range in this mode is much greater, and the prototype responded to the LED when it was over an inch away from Q1. To demonstrate operation of the circuit as a switch, block the space between the LED and Q1 with a pencil or other opaque object. The indicator LED should immediately turn off.

There are several practical applications for the limit switch. In either operating mode it can be used as an end-of-tape detector for a tape recorder. In the transmission mode, the LED is mounted on one side of the tape and Q1 on the other. The relay is connected to turn the recorder on when the LED is blocked by the tape, and off when exposed by a transparent section of tape near the end of the reel. You can use clear splicer tape for this purpose, or you can carefully scrape off a section of the oxide coating to supply a transparent section of tape.

In the reflection mode, both Q1 and the LED are mounted on the same side of the tape and a section of aluminized tape is spliced to the end of the tape. When the reflective portion of the tape passes by Q1 and the LED, the relay is actuated and the recorder is turned off.

You can use the circuit to sense the movement or proximity of an object by mounting the LED and Q1 in an appropriate position. For example, by operating the circuit in a reflection mode, you can detect the movement of a baby's crib or a door. The latter application can be used in a noncontact burglar alarm configuration. These and other applications will be enhanced by applying a section of aluminum foil, a bicycle reflector, or a length of reflective tape to the object whose movement is being sensed. In the case of a door, it might be necessary to mount the reflector to a small partition extending an inch or two from the door.

GOING FURTHER

You can greatly expand the detection range of this project by employing an infrared-emitting diode or a 222 incandescent lamp with a built-in lens. For example, the circuit will detect a white card six inches away in the reflection mode when a 222 lamp is used as a source. Radio Shack sells the 222 prefocused lamp (catalog number 272-1124) and more than a dozen other low-voltage lamps. Due to their high current consumption, it's best to operate incandescent lamps from a separate power source. For example, an excellent power supply for the 222 lamp can be made from two 1½-volt cells connected in series. You can use a Radio Shack battery holder (270-1433 or 270-1473) to mount the cells and a lamp holder (272-319 or similar) for the lamp.

Whatever light source you use, you can improve the appearance and operating ease of the circuit by installing it in a commercial enclosure. Include an on-off switch on the front panel by connecting a SPST switch (275-612, 275-1551, 275-1560, etc.) between the positive battery connection point and the red battery clip connection lead. You can facilitate operation of the relay by connecting the three contact leads to banana jacks (274-725) on the front panel. Q1 and the LED should be mounted adjacent to one another on the front panel or on one side of the case. For transmission mode operation, connect the LED to the circuit with a flexible cable made from some hookup wire.

Several applications for the limit switch were discussed under "Testing and Operation." A rather specialized application which might make an interesting science fair or research project is use of the circuit to measure the effectiveness of various types of materials to trigger the unit in a reflection mode. Several types of commercial marked card readers which employ LEDs and phototransistors in a reflection mode are in widespread operation, and it might be possible to survey a wide variety of papers, cards, labels, etc., in order to specify those best suited for reflection mode sensing.

A similar project would be to study the ability of the unit to detect lines and other markings on white paper. For best results, use a soft, dark pencil instead of ink since many inks are almost transparent to the near infrared radiation emitted in great quantity by infrared diodes and incandescent lamps. This brings up still another possible research project—which ink and pencil markings are the most opaque? Which are the most reflective? Which are the most transparent?

Use your imagination and you will come up with even more applications for the LED limit switch. It's an interesting project which has practical applications and teaches several important optoelectronic principles. I hope you have fun with it.

CHAPTER 4

NICKEL-CADMIUM BATTERY CHARGER

Want to save some money by spending some money? Buy a pair of Radio Shack Enercell (TM) nickel-cadmium AA cells and use them to power flashlights, toys, radios, electronic calculators, and just about anything else that requires a 1½-volt AA penlight cell.

Unlike conventional zinc-carbon and alkaline cells, nickel-cadmium cells are rechargeable. In fact, the Enercell can be recharged up to 500 times. Though the initial cost of the nickel-cadmium Enercell is about four times higher than that of an alkaline Enercell, the former can be used over and over again. True, it does cost something to buy or build and then operate the charger for the rechargeable cell, but for my money the convenience of always having fresh penlight cells on hand is hard to beat.

You can buy a factory assembled battery charger from Radio Shack for less than ten dollars (270-1529), but why not build your own? Besides ending up with a useful piece of electronic equipment, you will learn something about the design and construction of a transistorized power supply.

HOW IT WORKS

The battery charger described here is simply a one-transistor power supply capable of charging two or four AA nickel-cadmium Enercells at about 50 milliamperes. Figure 4-1 is the charger's circuit diagram. In operation, transformer T1 con-

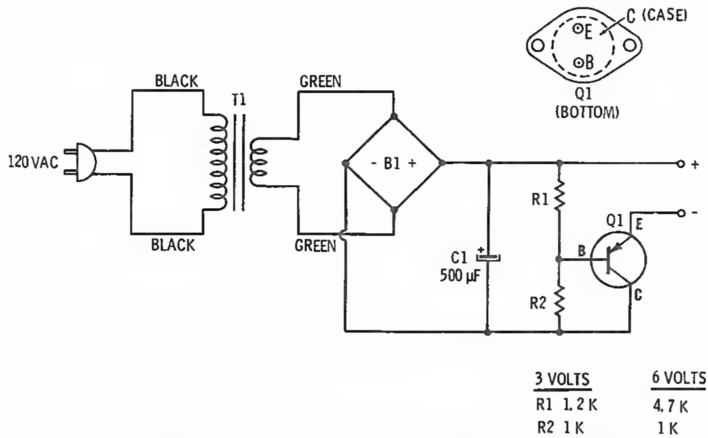


Figure 4-1. Circuit diagram of the battery charger.

verts the 120-volt line voltage into 6.3 volts. The transformer does not affect the alternating (AC) nature of the line voltage, so rectifier bridge B1 is used to convert the 6.3 volts AC into pulsating DC. C1, a 500-μF capacitor, filters the pulsating DC into a more steady voltage.

R1 and R2 form a voltage divider which biases Q1 to produce the desired collector-emitter current flow. Q1 is a PNP germanium or silicon power transistor.

CIRCUIT ASSEMBLY

I assembled the prototype charger on a perforated board to help you visualize the layout, but since the circuit is powered by household current it should be housed in a protective cabinet. The parts list for the project is given in Table 4-1. Begin assembly by mounting T1 to a perforated board with 6-32 hardware. The primary leads of T1 are color coded black, and the secondary leads are color coded green. Refer to the pictorial view in Figure 4-2 and install T1 with its *black* leads near one edge of the circuit board. Drill a ¼-inch hole in the board and thread the two black leads through it. The power cord will be soldered to these leads later.

Table 4-1. Battery Charger Parts List

Item	Description
B1	Full-wave bridge rectifier (276-1147)
C1	500-μF, 16-volt capacitor (272-1007)
Q1	PNP power transistor (276-2006)
R1	See text
R2	1000 ohms
T1	Filament transformer, 1.2 amperes (273-050)
Miscellaneous	Battery holder (see text), power cord (278-1255), perforated board, cabinet, hookup wire, solder, black electrical tape, etc.

Radio Shack catalog numbers are shown in parentheses.

Next, examine rectifier bridge B1 and note that two opposite corners are marked with a plus and minus signs aligned as shown in Figure 4-2. Enlarge two holdes in the perforated board adjacent to B1 and thread one of the green secondary leads from T1 through each hole. One lead is soldered to one of B1's unmarked terminals and the other green lead to the

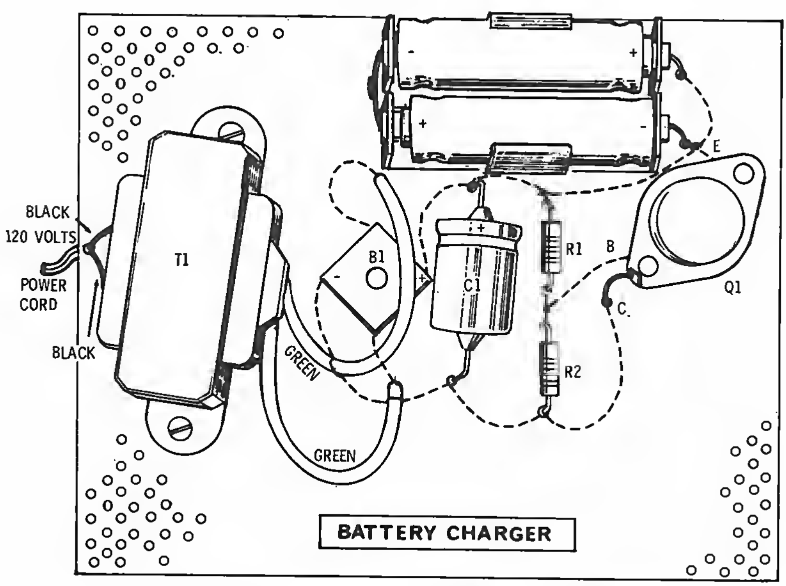


Figure 4-2. Pictorial diagram of the battery charger.

remaining unmarked terminal on B1. Remove excess lead lengths with a wire cutter.

Install capacitor C1 next. Note that one end of C1 is marked with a plus sign, printed ring, or indentation. The lead from this end of the capacitor is soldered to the B1 plus terminal. Solder the other lead from C1 to the negative terminal of B1.

Install R1 and R2 next. Use a 1200-ohm resistor (brown-red-red) for R1 when the charger is intended to charge two Enercells. Use a 4700-ohm resistor (yellow-violet-red) for R1 when the charger is intended to charge four Enercells. Install R1 and R2 as shown in Figure 4-2. One end of R1 is soldered to the positive terminal of B1 and C1, and the other lead is soldered to R2. R2's other lead is then soldered to the negative side of B1 and C1.

Install Q1 next. The transistor specified is a PNP power transistor with a TO-3 or TO-66 pin outline. Refer to the pin diagram in Figure 4-1 and install Q1 as shown in Figure 4-2. Solder a short length of hookup wire from the junction of R1 and R2 to Q1 base. Then solder another length of hookup wire from Q1 case (collector) to the negative junction of B1, C1, and R2.

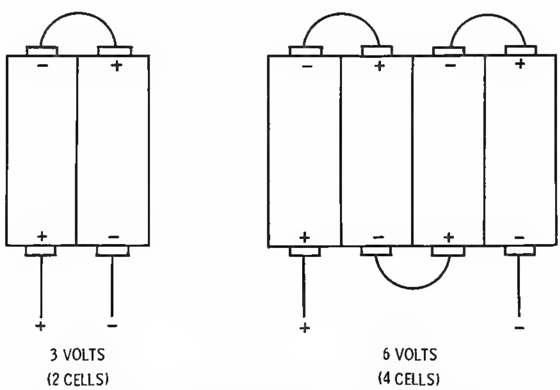


Figure 4-3. Connection diagram of battery holder.

Mount a two or four AA cell holder on the cabinet with 4-40 or 6-32 hardware and solder the terminals as shown in Figure 4-3. In the case of a two-cell holder, solder two of the terminals together by simply rotating one terminal toward the other until the two make physical contact. The remaining two terminals become the positive and negative connection points for the charger. Mark one of the terminals with a bright red plus sign and solder a length of connection wire between it and the positive junction of B1, C1, and R1. Solder another length of wire from the remaining terminal on the holder to Q1 emitter.

A four-cell holder is connected by soldering two adjacent terminals on one side of the holder to one another. The remaining terminals are connected to one another as shown in Figure 4-3. Be sure to mark a red plus sign on or near the positive terminal.

Complete assembly of the charger by drilling a ⅜-inch hole in the side of the cabinet where the power cord is to exit (in the vicinity of T1's primary leads). Insert a 7/16-inch vinyl grommet (64-3025) into the hole and insert the power cord. Pull the cord through the hole and tie a knot in it several inches from the exposed end on the inside of the cabinet. This will help prevent the cord from being accidentally pulled loose.

This done, solder one free end of the power cord to one of T1's black leads. Wait for the joint to cool and neatly wrap the

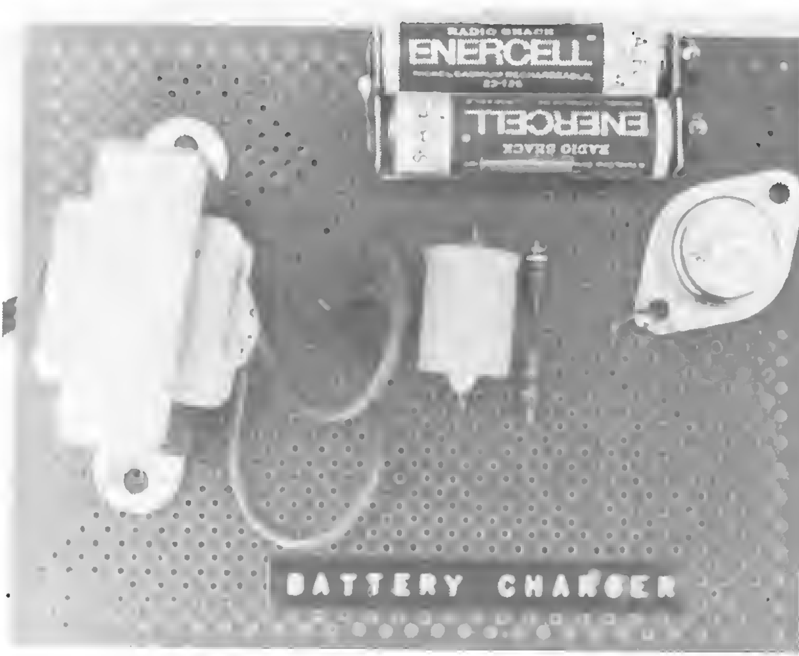


Figure 4-4. The completed battery charger.

connection in black electrical tape. Then repeat this procedure with the remaining power cord and transformer leads.

The circuit board should now be mounted in the cabinet by means of standoffs and appropriate hardware. See Chapter 1 for details on mounting a circuit board in a cabinet. Figure 4-4 is a photograph of the completed prototype charger.

TESTING AND OPERATION

Always check the wiring of a line-powered project very carefully before connecting the power cord to a 120-volt receptacle. Did you connect the transformer properly? Is B1 installed correctly? Have you properly insulated the power-cord connections with black electrical tape? And did you use a protective rubber grommet at the point where the power cord enters the cabinet? Don't take any shortcuts when working with household line current or your project may be damaged or you may receive a dangerous electrical shock.

When you have completed the inspection of the project, install two (or four) nickel-cadmium Enercell's in the battery holder. Be sure to install the cells as shown in Figure 4-3. Reverse polarity may permanently damage the cells. Also, do not attempt to use any other cells (alkaline, zinc carbon, mercury, etc.) in the charger as the charger is designed to charge nickel-cadmium units only.

When the cells are in place, plug the power cord into a receptacle and charging should begin. The charger is designed to supply from 40 to 50 milliamperes to the cells, so charge them for from 10 to 14 hours for a full charge.

This charger will charge most AA-size nickel-cadmium cells. If you are unsure about the optimum charging time, check with your source of supply. Remember to never charge nonrechargeable cells. Also, for best results do not overcharge nickel-cadmium cells.

You can verify the charging rate by connecting a multimeter in series with the charger and Enercells. Simply place a piece of bond paper between the positive terminal of the charger's battery holder and the Enercell. Then set a multimeter to a current range greater than 50 milliamperes (for example, set the Radio Shack 22-201 multitester to the 0-150-mA scale). With the charger turned on, touch the positive (red) probe from the multitester to the battery holder's positive terminal and touch the negative (black) probe to the positive terminal of the Enercell separated from the battery terminal by the paper. You can now read the charge rate directly.

The basic battery charger needs no power switch since it can be turned on and off by simply inserting or removing the power cord from its socket. In the next section I'll show you how to add an on-off switch and other improvements.

GOING FURTHER

Ideally the battery charger should be assembled into a protective housing. This not only improves its appearance and ease of operation, but it provides protection from possible electrical shock.

You can increase the versatility of the charger by making it capable of charging either two or four Enercells by using the circuit in Figure 4-5. This circuit includes both values of R1 necessary for each charging rate and a SPDT switch to select the charging mode. You can use virtually any SPDT switch in this application, but be sure to connect it into the circuit properly. For example, the Radio Shack 275-402 SPDT slide switch has three solder terminals. The two values of R1 should be connected to the two end terminals on the switch while Q1's base should be connected to the center terminal. The same procedure applies to most SPDT toggle switches.

Figure 4-5 also includes an on-off power switch. This permits the charger to be turned on and off without having to re-

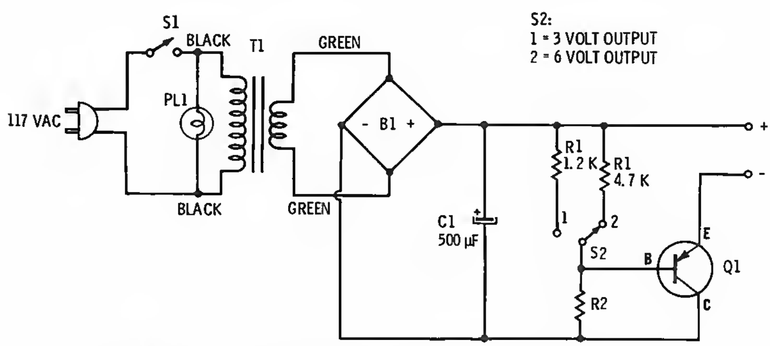


Figure 4-5. Circuit diagram of an improved battery charger.

move the power cord from its receptacle. Use any SPST toggle switch rated at 125 volts, 3 amperes for this switch. Suitable switches are Radio Shack's 275-602, 275-612, 275-615, etc.

An on-off panel light is also included in Figure 4-5 to provide a positive indication of when the charger is on. Radio Shack markets several modular panel lamp assemblies ideally suited for the charger. Typical examples are catalog numbers 272-328, 272-1501, and 272-338. Since the panel lamp is soldered to the high voltage (primary) side of T1, be sure not to install it when the power cord is plugged into a receptacle. In fact, you should never attempt to work on this or any other line powered project unless the power cord is removed from its receptacle.

CHAPTER 5

BATTERY-POWERED XENON STROBE UNIT

Probably the most interesting circuit in this book is the battery-powered xenon strobe unit described in this chapter. Since the project incorporates a DC to DC converter circuit, you will learn something about portable, high-voltage power supplies by building it. You'll also learn about energy storage, capacitor charging and discharging, high-voltage ionization, high-voltage pulses, and xenon flash tubes. Sound interesting? Then warm up your soldering iron and read on.

HOW IT WORKS

In Chapter 4 a transformer was used to convert 120 volts AC into 6.3 volts AC. This project uses an identical transformer connected in reverse to obtain a high voltage from a low voltage. The low voltage is supplied in the form of brief DC pulses from a simple two-transistor pulse generator. Since the transformer is an inductive device, you cannot achieve voltage or current modification by feeding in a steady DC voltage. You must use either alternating current or pulsed DC. The high voltage generated by the transformer is stored in a capacitor until discharged through the flashtube. The flashtube discharge sequence is initiated by applying a brief high-voltage pulse to a miniature trigger coil which ionizes the gas in the flashtube and permits the main discharge to take place. This is a very simple explanation of the circuit's operation, and a more detailed version follows.

Figure 5-1 is the circuit diagram for the complete strobe unit. Q1 and Q2 form a direct-coupled regenerative amplifier operated as a pulse generator. Operation of the pulse generator is straightforward. Initially, both Q1 and Q2 are nonconducting. R1, however, supplies sufficient base bias to turn Q1 on which then causes Q2 to be turned on. When Q2 is on, the 6.3-volt secondary winding, which we are using as a primary winding in this application, is connected directly across the battery terminals with only the low resistance collector-emitter junction of Q2 in between. Since Q2 turns on very rapidly, a very fast pulse of current surges into the 6.3-volt transformer winding and a resultant high voltage spike appears at the 120-volt primary (secondary in this circuit) winding.

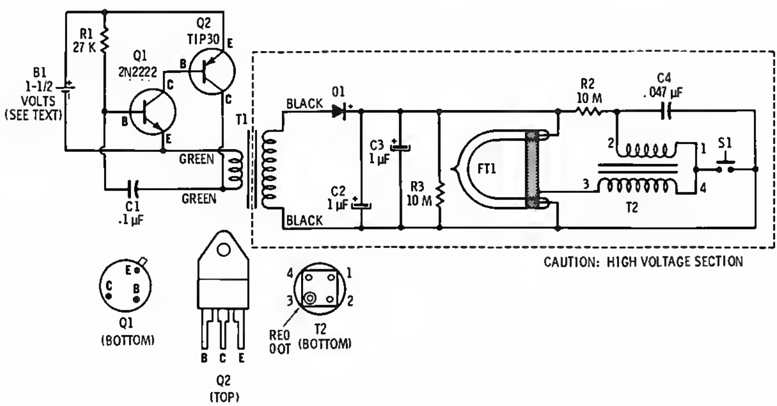


Figure 5-1. Circuit diagram of the xenon flasher.

When both Q1 and Q2 are on, capacitor C1 begins to charge through R1 until its charge is high enough to bias Q1's base into an off condition. Since Q1 controls Q2, Q2 also turns off and current no longer flows through the 6.3-volt transformer winding. The rapid cessation of current flow indicates still another high voltage spike in the 120-volt transformer winding.

When Q2 is off, Q1 remains off until the capacitor (C1) discharges itself through the 6.3-volt transformer winding and Q1's base-emitter junction. When C1 is discharged, Q1 is again biased into conduction by R1, Q2 turns on, and the cycle repeats.

Q2 turns on and off so rapidly that the two voltage spikes at the transformer's 120-volt winding merge into a single voltage spike. For example, when the circuit is powered by a 1½-volt flashlight cell, the initial portion of the pulse has a peak potential of about 170 volts and a width of about 40 microseconds. The remainder of the pulse drops to a potential of about 100 volts. Total width of each output pulse is about 110 microseconds. The circuit operates at a pulse-repetition rate of about 500 Hz when powered by a 1½-volt cell and *not* connected to a load.

The high-voltage pulses appearing at T1's 120-volt winding are stored in a capacitor formed from two 1-μF capacitors in parallel (C2 and C3). Diode D1 does not rectify the pulses since they are of only one polarity. Instead, D1 prevents the charge stored in C2 and C3 from being discharged through the 120-volt transformer winding. R3, a 10,000-ohm resistor, is connected directly across the high-voltage leads and serves to bleed the stored voltage from C2 and C3 when the circuit is turned off. R3 therefore serves as a safety feature which helps prevent accidental shock, since C2 and C3 would otherwise hold their charge for a considerable length of time.

C2 and C3 are connected directly across the terminals of flashtube FT1. The tube does not glow, however, since the xenon gas it contains requires a very high potential ionization pulse of approximately 4000 volts. Once the gas is ionized, it becomes conductive and the charge stored in C2 and C3 is then rapidly dumped through the flashtube. The result is a brilliant flash of white light which lasts for a few microseconds or more. The flash is brief since the charge on C2 and C3 is depleted much faster than it can be restored.

The high-voltage ionization pulse required to fire the flashtube is supplied by a miniature high-voltage trigger coil (T2), C4, and R2. While C2 and C3 are being charged by T1, C4 is charged to the same potential through R2. Since C4 is much smaller in value than C2 and C3, it would normally charge very rapidly. R2, however, slows down the charge rate to about the same time as that of C2 and C3. This prevents an undue load on T1 and a resultant lack of charging efficiency for capacitors C2 and C3.

T2 is a miniature trigger coil which operates in the same manner as an automobile spark or induction coil. Like T1, T2 has a very high turns ratio, and an incoming pulse of about 300 volts will produce a 4000-volt output pulse. The several hundred volts required for T1's primary are supplied by C4. When push-button switch S1 is pressed, C4 dumps its charge through T1's primary and the very-high voltage spike appearing at T2's secondary is passed to FT1's central electrode. This electrode is merely wrapped around either end of the glass tube

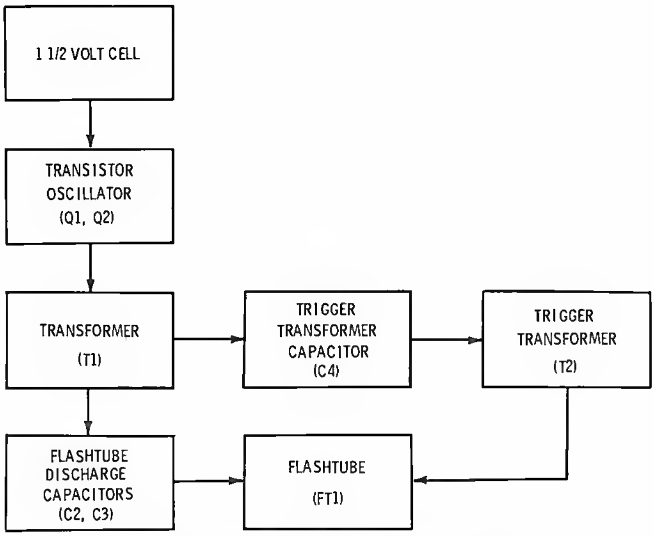


Figure 5-2. Block diagram of the xenon flasher.

containing the xenon gas and it causes the gas to be ionized. Once the tube is ionized, C2 and C3 are rapidly discharged through the tube in a brilliant burst of white light. The entire process can be repeated in several seconds, the time required for the DC to DC converter circuit to recharge C2, C3, and C4. Figure 5-2 is a block diagram which summarizes the operation of the strobe circuit.

CIRCUIT ASSEMBLY

Even though this circuit can be powered by one or two penlight cells, it produces and stores enough voltage to give a potent electrical shock. Therefore treat the circuit with respect and construct and operate it in accordance with these instructions.

Table 5-1. Xenon Flashtube Circuit Parts List

Item	Description
B1	Battery (one or two 1½-volt cells; see text)
C1	0.1-μF capacitor (272-1069)
C2, C3	1.0-μf, 250-volt capacitors (272-1055)
C4	0.047-μF, 250-volt capacitor (272-1052)
D1	600-volt rectifier diode (276-1104)
FT1	Xenon flashtube (272-1145)
Q1	2N2222 NPN transistor (276-2009)
Q2	TIP30 power transistor (276-2026)
R1	27,000-ohm resistor
R2, R3	10,000,000-ohm resistors
S1	Normally open SPST push-button switch (275-1547)
T1	Filament transformer, 300 mA (273-1384)
T2	Flashtube trigger transformer (272-1146)
Miscellaneous	Battery holder, perforated board, hookup wire, solder, etc.

Radio Shack catalog numbers are shown in parentheses.

The parts list is given in Table 5-1. Begin assembly by constructing the DC to DC converter. Q1 is an NPN silicon switching transistor (2N2222 or similar). Insert its leads into a perforated board as shown in the pictorial view in Figure 5-3. Next install R1 and C1 as shown in Figure 5-3. Solder Q1's base lead to one lead from both R1 and C1. Next, install Q2, a PNP power transistor as shown in Figure 5-3. Solder Q1 collector lead to Q2 base pin. Solder Q2's emitter pin to the free end of R1. This point becomes the positive battery connection terminal, so solder a length of hookup wire to this point to serve as the positive power-supply lead.

Continue assembly by soldering the remaining lead from C1 to Q2 collector. Then mount transformer T1 to the board with 6-32 hardware as shown in Figure 5-3. I used a heavy duty 6.3-volt/120-volt transformer (273-1510), but you can use a miniature (273-1384) or standard (273-050) size. Enlarge two perforations with a drill and insert each of the green leads into one of the holes. Solder one green lead to the junction of C1 and Q2 collector. Solder the other green lead to Q1 emitter. This becomes the negative battery connection point, so solder a length of hookup wire to the point to serve as the negative power-supply lead.

The DC to DC converter portion of the circuit is now complete and ready for a preliminary operating test. Connect a neon glow lamp to the two black leads of T1 by simply wrapping the leads of the former around those of the latter. Then connect a $1\frac{1}{2}$-volt flashlight cell (C or D size) to the power leads. The glow lamp should glow with a bright orange-red light. If the

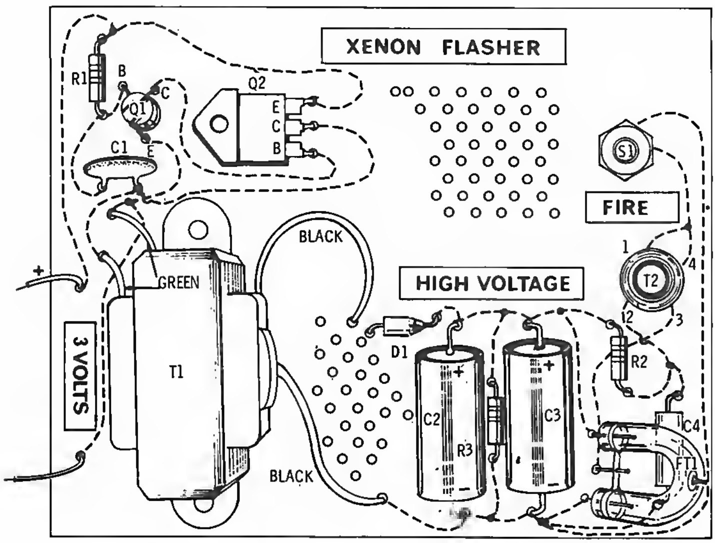


Figure 5-3. Pictorial diagram of xenon flashtube circuit.

lamp fails to glow, remove the flashlight cell and carefully recheck all the wiring. Make sure Q1 and Q2 are installed properly. Also, make sure T1's leads are connected correctly. Be sure to check the flashlight cell since a weak cell will not power the circuit. If everything checks out and the neon lamp still fails to glow, try using two flashlight cells in series to power the circuit. The lamp should now glow if all the components are good and there are no wiring errors.

When the lamp is working, note which electrode is surrounded by the orange-red glow. This is the *negative* electrode. Turn off the circuit and temporarily mark the transformer lead connected to the negative electrode with a piece of masking tape.

During this preliminary test, use caution to avoid touching either or both of the black transformer leads or the neon lamp or its terminals. The circuit is producing several hundred volts and though the current is low a hefty shock will be had by touching the live high voltage leads of T1 or the lamp.

The flashtube circuit is assembled next. Install the two 1-μF discharge capacitors first. Do not use capacitors rated at less than 250 volts or they will be damaged. Capacitors with more capacity will tend to load down the DC to DC converter and render it inoperative. Solder the negative and positive leads of C2 and C3 to one another. If the capacitors do not have polarity markings, just orient each one in the same position and solder the leads together. Solder the negative lead from T1, the one marked with the masking tape, to the negative junction of C2 and C3. The remaining lead from T1 goes to the anode lead from diode D1. Be sure to use the diode specified in the parts list since units rated at a lower voltage may be destroyed by the high voltage. Solder D1 cathode lead to the junction of C2 and C3. When C2 and C3 are installed, insert R3, a 10,000,000-ohm resistor (brown-black-blue), into the board and solder its leads directly across the high-voltage terminals (across C2 or C3).

The flashtube is installed next. Use care when handling the tube since it is relatively fragile. Be especially careful to avoid striking the tube with a tool or allowing it to fall to the workbench or floor. The flashtube is polarized and must be connected into the circuit according to the polarity of its terminals. Examine the electrodes inside the tube and note that one has a screenlike structure attached to it while the other is simply a bare wire. The former is the negative electrode while the latter is the positive electrode. The center wire lead connected to the metal band wrapped around each leg of the U-shaped tube is the trigger connection.

Carefully insert the tube's three leads into the perforated board as shown in Figure 5-3, and gently bend the negative lead toward the negative junction of C2, C3, and T1. Solder the lead to this point and remove excess lead length with a wire cutter. Repeat this procedure for the positive lead of FT1 and the remaining junction of C2, C3, and T1.

The firing circuit is installed next. Insert C4 into the board adjacent to FT1 (see Figure 5-3) and solder its negative lead (if marked) to the negative connection point for C2, C3, T1, and FT1. Then insert R2, a 10-megohm resistor (brown-black-blue), into the board and solder one of its leads to C4's positive lead. The remaining lead from R2 is soldered to the positive junction of D1, C2, C3, and FT1.

The trigger coil is installed next. If you examine the bottom portion of the coil, you'll see that one of the four pins is marked with a red dot. This pin is the one which should be connected to FT1's trigger lead. Insert T2 into the board as shown in Figure 5-3 and solder FT1's trigger lead to the pin on T2 marked with a red dot. You may have to use a short length of insulated hookup wire to connect the two leads together. In any event, do not allow the wire to come within half an inch of any other wire or component or the high-voltage trigger pulse may arc to ground without ionizing the flashtube.

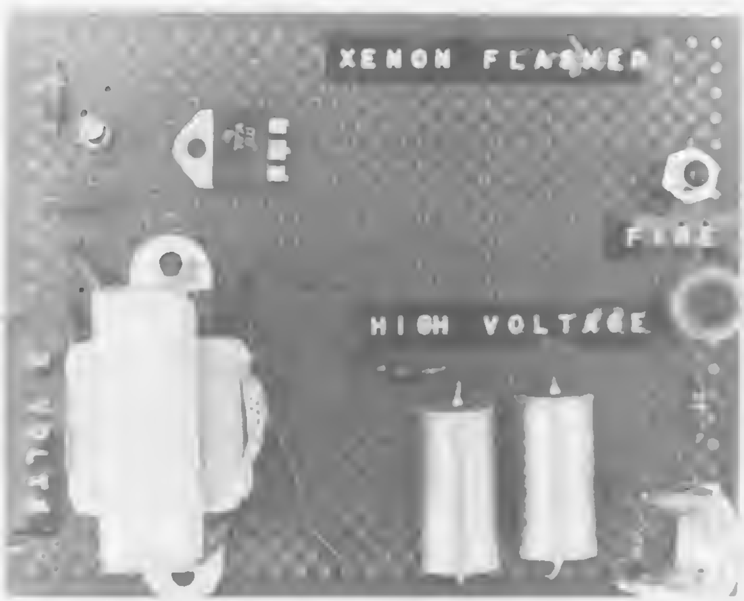


Figure 5-4. Completed xenon flashtube project.

Solder a short length of hookup wire from pin 2 of T2 to the junction of C4 and R2. Now solder pins 1 and 4 on T2 together (see Figure 5-1) and solder a short length of hookup wire to the resulting junction. S1, a SPST push-button switch, is installed in a ¼-inch hole drilled in the board. Solder the hookup wire connected to pins 1 and 4 on T2 to one terminal of S1. Solder a second length of hookup wire from the remaining switch terminal to the negative junction of C2, C3, FT1, and T1. The circuit is now complete and should resemble the photograph of the prototype shown in Figure 5-4.

TESTING AND OPERATION

This seemingly simple circuit packs an electrical wallop and several important safety considerations must be followed when it is in operation. First, *never* touch any portion of the circuit except S1's insulated push button when the circuit is on. This particularly applies to all components of the flashtube discharge circuit. Second, capacitors C2, C3, and even C4 can hold a high-voltage charge for a long period of time *after* the circuit has been turned off. R3 bleeds off this charge eventually when the circuit is turned off, but since R3 has such high resistance do not touch the high voltage components for a few minutes after the circuit is turned off.

Most of the charge on these capacitors is drained off when FT1 is fired, so always fire the lamp one time *after* the circuit is turned off. Finally, avoid staring directly at FT1 when it is fired to avoid possible harm to your eyes. Follow these simple precautions and you will have no problem operating the strobe circuit, but touch a high-voltage lead and you wil receive a hefty electrical shock. If the shock doesn't cause injury directly, you may bump into something when your body's reflexes jerk the offending finger away from the circuit.

Before operating the circuit inspect all the wiring to make sure there are no errors. The DC to DC converter must be operating properly since you have already tested it, so concentrate on the flashtube discharge and firing circuit. Pay particular attention to the polarity of FT1 and T2 since incorrect connections will cause the circuit to be inoperative. Make sure the trigger lead from T2 and FT1 does not touch or come within half an inch of any other component or wiring.

Place the circuit board on an insulating material (a sheet of waxed paper will do) and without touching any part of the circuit except the power leads, connect a 1½-volt C or D cell to the circuit. You should immediately hear a whining sound emerging from T1 and caused by the vibration of its laminations in response to the pulsating current flowing in its windings. When the whining sound reaches a high pitch or after a few seconds, press S1 with one finger. FT1 should immediately produce a dazzling flash. A popping noise may accompany it.

If one flashlight cell fails to operate the circuit, try two connected in parallel. If this still fails to work, use two cells in series and the circuit will operate. Table 5-2 shows the current consumption and output voltage for several input voltages. The table is only valid when C2 and C3 total 2 μF. Note that 3-volts input produce 435 volts from T1. This exceeds the ratings for FT1, C2 and C3, but since the circuit draws 200 milliamperes at this input voltage two flashlight cells in series will put out only about 2 volts.

Table 5-2. Input Voltage Vs. Output Voltage

Input (Volts)	Output (Volts)	Current Drain (Milliamperes)
1.5	170	80
2.0	220	100
2.5	320	140
3.0	435	200

You can measure the output voltage of your version of the strobe by connecting a high impedance multimeter such as Radio Shack's 27-range field-effect transistor VOM (22-206) to the positive and negative sides of C2. Be sure to set the meter to the proper range when making this test or the high voltage may damage it. Also, avoid touching the circuit with your fingers when touching the test probes to C2. Other multimeters may also work, but less expensive, low-input impedance units will possibly load down the circuit and give an erroneous reading.

Never operate the circuit with more than two flashlight cells in series or the excessive output voltage may damage FT1, T2, C2, C3, and C4. FT1 is rated at a maximum of 300 volts and while it will operate at somewhat higher voltages its life will be considerably shortened. When operated within specified limits, FT1 will produce more than 8000 flashes. Capacitors are easily damaged by dielectric breakdown (internal arcing) when their voltage rating is exceeded. The same holds for transformers and trigger coils.

GOING FURTHER

The strobe circuit has a variety of applications. To study the lightninglike discharge that occurs within the flashtube, replace C2 and C3 with a single 0.01-μF, 250-volt capacitor (272-1051). Before removing C2 and C3, turn off the circuit, press S1 to discharge the flashtube, and touch a screwdriver with an insulated handle across C2's terminals. With the 0.01-μF capacitor in place, turn on the circuit and observe FT1 in a dimly illuminated room. Each time you press S1, which can be more often than when C2 and C3 are in place, a filamentary, lightninglike arc discharge will be clearly seen within the tube. Use the same precautions when operating the circuit without C2 and C3 as you would with them in the circuit, since the same high voltage is present.

Since this flash unit produces very fast light pulses, you can use it to photograph high speed events. Though it doesn't produce nearly as much light as commercial photographic flash units, it produces a much faster light pulse. This is because commercial units employ discharge capacitors (C2 and C3 in our unit) having a capacitance of several hundred microfarads *or more*. This produces a very bright pulse up to a few milliseconds long while the circuit described here produces a dimmer pulse whose width is measured in microseconds.

You can use the strobe unit for photography without modification, but for best results install the complete circuit board in a plastic cabinet. Mount S1 on a side panel and add an SPST switch in series with the positive battery holder terminal and R1 and Q2's emitter. The flashtube should extend through a rectangular hole cut in the cabinet which exposes all but the metal trigger electrode. An aluminum foil reflector should be cemented around the flashtube opening to reflect to the subject otherwise wasted light.

To use the strobe to photograph a high speed object such as a moving motor shaft or fan blade, position a camera in an appropriate position and point the flash unit toward the subject. Extinguish all room lights, set the camera shutter for time exposure, press the shutter, trigger the lamp, release the shutter, and turn the room lights back on. This sequence might seem complicated at first, but once you have gone through it several times you'll be taking pictures in seconds.

For best results, measure the optimum lens f/stop setting for your camera when paired with the flash unit and a particular film by making a series of exposures of the same subject one f-stop apart. Select the best exposure after the film is developed and use that f-stop for future shots. Remember that you will have to open the lens more as you move the camera and strobe farther from the subject. Since the light output of the strobe isn't as high as that available from commercial strobes, you'll have better results using a fast film such as Tri-X.

If high speed photography intrigues you, try replacing S1 with the relay contact from the sound activated switch described in Chapter 2. With this combination, you can trigger a high speed pulse from the sound of a high speed event. If you have enough patience to set up the equipment properly, you can use this equipment to photograph such high speed events as a hammer striking a nail, an air-driven pellet bursting a balloon, and other fast events accompanied by sound. Always use care when photographing moving devices or projectiles to avoid physical injury to you or your apparatus.

CHAPTER 6

LED VOLTAGE INDICATORS

Low-voltage transistor and IC circuits frequently operate from small, economical batteries. Here's a set of novel circuits which use low cost light-emitting diodes to help you monitor the output voltage of a battery, provide an automatic warning if battery voltage exceeds a certain point, determine polarity, and indicate the presence of an AC voltage. These circuits are so inexpensive and useful you will want to consider incorporating some of them directly into transistorized equipment.

LEDs

The light-emitting diode (LED) is a semiconductor solid-state lamp. A true diode which passes current in only one direction, LEDs emit light when excited electrons recombine with holes after crossing the potential barrier formed by the diode PN junction. LEDs are available which emit infrared as well as visible light. Infrared units emit far more radiant power than do visible units (milliwatts for the former and microwatts for the latter) so they find widespread use in invisible-beam optical communicators. Visible units are widely used as status indicators and digital readouts.

LEDs can be made which emit visible hues ranging from green to red by varying the composition of the semiconductor compound which forms the active light-emitting region. For example, gallium arsenide phosphide (GaAsP) emits red, while gallium phosphide (GaP) emits green. Even these two materials can be modified to cause the former to emit yellow and the latter red. Since the light generation process in an LED is dependent upon the energy band gap of the semiconductor being employed, longer wavelength colors, such as red, require less forward voltage than do shorter wavelength colors, such as green. This characteristic means simple voltage indicators using green and red LEDs can be easily fabricated.

Use care when operating an LED to avoid sending too much current through the device. Excess current causes heating which degrades the light generation process and may even melt the semiconductor chip which forms the LED, or sever the electrical bonding connection. Most red LEDs are designed for a maximum operating current of from 10 to 50 milliamperes. Infrared devices can usually take up to 100 milliamperes. Both types can withstand much more current if it is supplied in the form of brief pulses.

Always consult manufacturer's literature before connecting a new LED into a circuit. Make sure you know the proper polarity of the device, the required forward voltage, and the maximum forward current. Very inexpensive LEDs can be purchased in small lots from Radio Shack. Due to their low price, no data is supplied with these diodes, but you can usually determine the operating requirements as follows:

1. *Polarity*—Many LEDs from similar manufacturers use similar polarity marking signs (e.g., flat area on one side of device, color dot on a lead, one lead shorter than the other, etc.). Compare the economy LEDs with data for more costly diodes you may already have. If this doesn't help, go ahead and connect red LEDs to a 3-volt battery in series with a 47-ohm resistor. If the diode doesn't glow, reverse the connections and try again. Be sure to record the diode's polarity symbol or sign for future reference.

2. *Color*—Most visible LEDs are encapsulated in translucent epoxy having the same color as the LED. Clear epoxy usually (but not always) means a red unit. Some red units are made from GaP and require more forward voltage than GaAsP diodes. You can determine if a unit is made from GaP or GaAsP by referring to the manufacturer's literature or by connecting the diode to a variable-voltage power supply and advancing the voltage until the diode begins to glow. GaAsP units will

have a forward voltage of about 1.6 to 1.8 volts, while GaP units will have a forward voltage of about 2.1 volts.

3. *Forward Current*—Most red LEDs will take 20 milliamperes and many will go to 50 milliamperes. Be safe and check the manufacturer's literature. If none is available, be safe and don't apply more than 20 or possibly 50 milliamperes. If the diode is warm to the touch, back off on the current.

You can learn more about LEDs by using them in practical circuits, so let's leave the theory behind for a while and move on to some interesting, and useful, LED indicator circuits.

POLARITY INDICATOR

Figure 6-1 is the circuit diagram for this simple circuit, a pair of LEDs which indicate the polarity of an applied voltage. The circuit consists of two LEDs connected in parallel. Since one is connected backwards, only one diode will light for an applied DC voltage. If the polarity of the voltage is reversed the other diode lights.

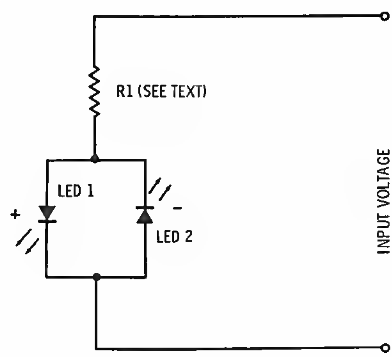


Figure 6-1. Circuit diagram of a simple LED polarity indicator.

Besides indicating polarity, the circuit can signal an AC voltage by causing *both* LEDs to glow. This application is useful for detecting unwanted AC voltages in a circuit.

The two LEDs can be any common low-cost units such as Radio Shack's 276-042, 276-041, 276-026, etc. Make sure both LEDs are identical to one another for best results.

R1 is a series resistor which protects the LEDs from excessive current. R1 is determined by the following formula:

$$R1 = \frac{V_{in} - V_{LED}}{I_{LED}}$$

See Chapter 3 for a detailed discussion of this formula and its use.

TRISTATE POLARITY INDICATOR

The previous circuit is fine for most applications, but one or both LEDs must be marked to signify its polarity. The circuit shown in Figure 6-2 solves that problem by using color to provide a true polarity indication. The circuit employs a red and green LED connected in parallel. As in the previous circuit, one of the diodes is connected backwards so only one will light for each polarity condition. In the circuit shown in Figure 6-2, the red LED denotes positive polarity while the green diode signifies negative polarity.

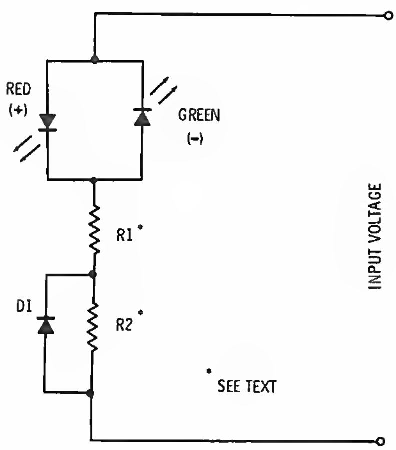


Figure 6-2. Tristate LED polarity indicator.

Since red and green LEDs have significantly different forward voltage requirements, current limiting resistors must be selected accordingly. The circuit in Figure 6-1 is unsatisfactory since R1 limits current to a safe level for only one type of diode. If a red and green diode were connected to a single series resistor selected to provide optimum current for only the red diode, the green diode would not light. Conversely, if the resistor was selected to provide optimum current for only the

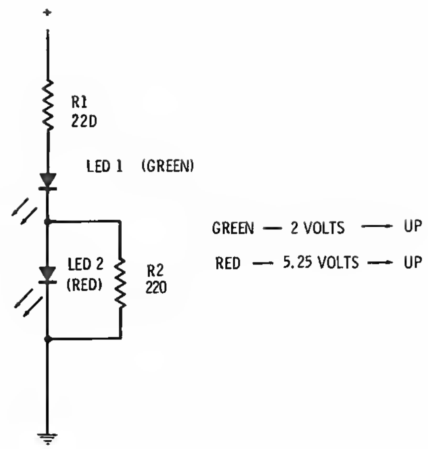


Figure 6-3. A 5-volt warning light circuit.

green diode, the red diode would receive excess current and would possibly be destroyed.

The circuit in Figure 6-2 solves this problem by using *two* series resistors in series with one another. A standard diode is used to bypass resistor R2 in one direction only. Therefore,

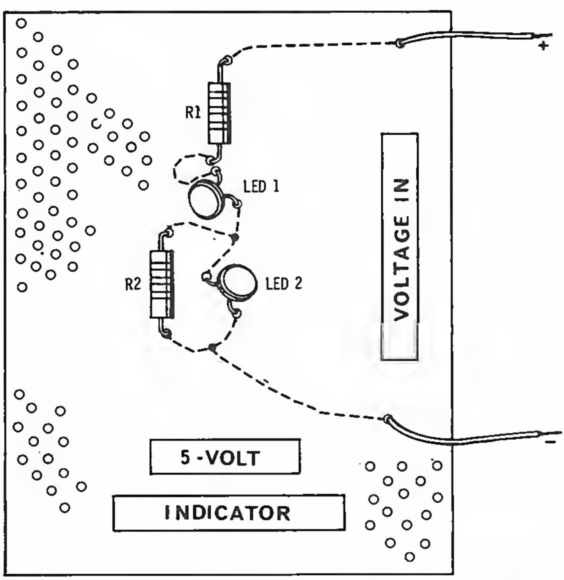


Figure 6-4. Pictoriol diagram of the 5-volt warning light.

the series resistance for the red LED is the sum of R1 and R2 while the series resistance for the green LED is R1 plus the very low forward resistance of the bypass diode. In this manner both the red and green LEDs can be properly current limited.

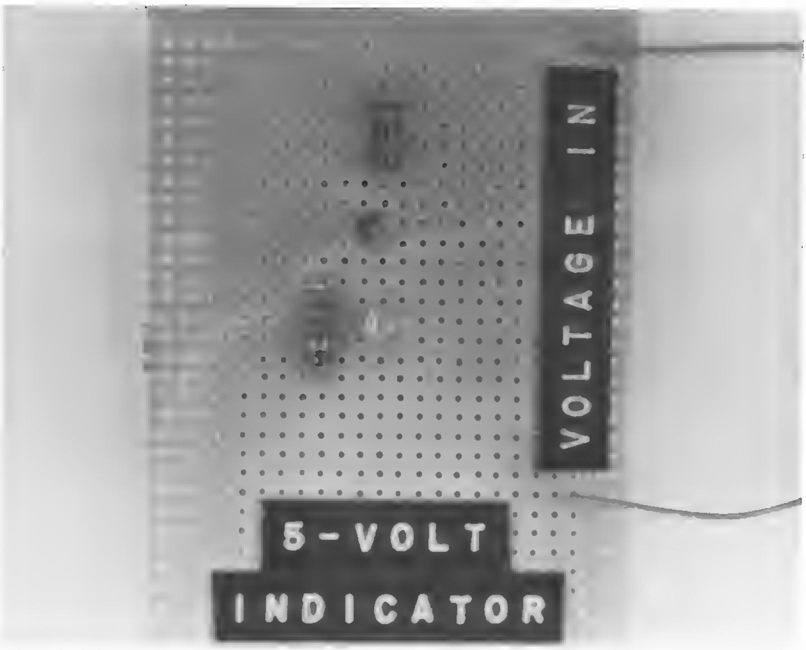


Figure 6-5. The completed 5-volt warning light.

For best results, use LEDs housed in similar packages for this project. For example, a good choice would be Radio Shacks 276-041 (red) and 276-043 (green). Both these diodes are packaged in identical epoxy packages having the color of the light emitted by the encapsulated LED chip.

R1 and R2 must be selected according to the desired forward current. The Radio Shack LEDs described above are designed for a forward current of about 20 milliamperes. To achieve this current level with a 6-volt signal requires a 102-ohm resistor for R1 and a 68-ohm resistor for R2. Naturally these exact values may not be readily available, but a standard 100-ohm 10-percent resistor will do for R2. Radio Shack sells both this and the 68-ohm value in its 271-000 series.

D1 can be any general-purpose diode. For example, Radio Shack's 276-821 assortment is good for this application.

FIVE-VOLT WARNING LIGHT

Here's a novel LED circuit which provides a color-coded warning when the applied voltage exceeds 5 volts. Many transistor and IC circuits are operated at about 5 volts, so this circuit can be used in practical applications.

The circuit, which is shown in Figure 6-3, uses two LEDs in *series* rather than in parallel. LED1 is a green emitter while LED2 is a red unit. R1 limits the current applied to the two LEDs. In operation, an applied voltage in excess of 2 volts causes the green LED to glow. The red LED has a lower forward voltage, but R2 prevents it from glowing. As the applied voltage is increased, the voltage drop across R2 reaches a point where LED2 begins to glow. When R2 is 220 ohms, this occurs at about 5.25 volts. Summarizing, the green LED indicates a "safe" voltage (2.0 to 5.25 volts) while the red LED indicates an "unsafe" voltage (5.25 volts or more).

Figure 6-4 is a pictorial view of a prototype 5-volt indicator. Construction is obviously straightforward. For best results, use similar red and green LEDs such as Radio Shack's 276-041 (red) and 276-043 (green). Figure 6-5 is a photograph of the completed prototype 5-volt indicator.

You can modify the 5-volt indicator for other voltage levels by changing R2. Smaller values of R2 *increase* the red LED's turn-on threshold while larger values *reduce* it. Since LED forward voltages vary, one good way to determine R2's value for a desired threshold voltage is to connect a 1000-ohm potentiometer (271-226) in place of R2. Adjust the pot until the red LED begins to glow at a particular applied voltage level, disconnect the pot from the circuit, measure its resistance with a multimeter, and connect a fixed resistor of similar value into the circuit.

CHAPTER 7

LIGHT-ACTIVATED PHOTOTRANSISTOR RELAY

Here's a circuit that's ideal for those of you who need a sensitive light-activated relay for experimental applications, counting, detection, reflection studies, light-beam communications, and burglar-alarm applications. The circuit uses Radio Shack's new NPN silicon phototransistor. Similar to the Fairchild FPT-100, this phototransistor is encapsulated in a transparent epoxy package which acts as a light-collecting lens to increase sensitivity. Peak sensitivity of the FPT-100 is 800 nanometers, and it has excellent sensitivity to the 670 nanometers of most red LEDs.

HOW IT WORKS

Figure 7-1 is the circuit diagram for the phototransistor relay. Q1 and Q2 form a two-stage direct-coupled switching amplifier. Though phototransistor Q1 is supplied with a base lead, it is not needed in this circuit since the incoming light beam supplies ample base bias. Q2 passes the amplified signal into the coil of relay RY1. RY1 is a sensitive relay which pulls in with as little as 5 milliamperes of current at 2½ volts. With Q1 in the dark, R1 biases Q2 into conduction and RY1 pulls in. When Q1 is illuminated, its collector-emitter junction provides a low resistance shunt which turns Q2 off and causes RY1 to drop out. In the dark (RY1 actuated) the circuit con-

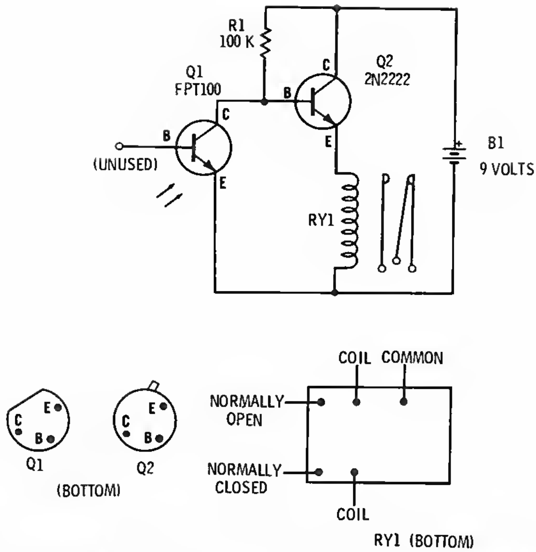


Figure 7-1. Circuit diagram of the light-activated phototransistor relay.

Table 7-1. Light-Activated Phototransistor Relay Parts List

Item	Description
B1	Battery, 9 volts
Q1	FPT-100 phototransistor (276-130)
Q2	2N2222 NPN transistor (276-2009)
R1	100,000-ohm resistor
RY1	Miniature SPDT relay (275-004)
Miscellaneous	Perforated board, 9-volt battery clip (270-325), solder, hookup wire, etc.

Radio Shack catalog numbers are shown in parentheses.

sumes 5 milliamperes from a 9-volt transistor radio battery. In the light, current consumption drops to practically zero.

CIRCUIT ASSEMBLY

I constructed the prototype phototransistor relay on a perforated board. The parts list is given in Table 7-1. The circuit uses only four components plus a battery and is easy to duplicate. Begin assembly by installing Q1 and Q2 in the board as shown in the pictorial in Figure 7-2. Check the base diagram in Figure 7-1 to make sure the transistors are properly oriented.

I have specified a 2N2222 for Q2 (276-2009), but you can substitute any general-purpose NPN switching transistor you have available.

Solder Q1 collector lead to Q2 base lead and remove excess lead lengths with a wire clipper. Then install R1, a 100,000-ohm resistor (brown-black-yellow) and solder one of its leads to the junction of Q1 collector and Q2 base.

Continue assembly by soldering the remaining lead from R1 to Q2 collector. This becomes the positive battery connection terminal, so solder the red lead from a 9-volt transistor radio battery clip to this junction.

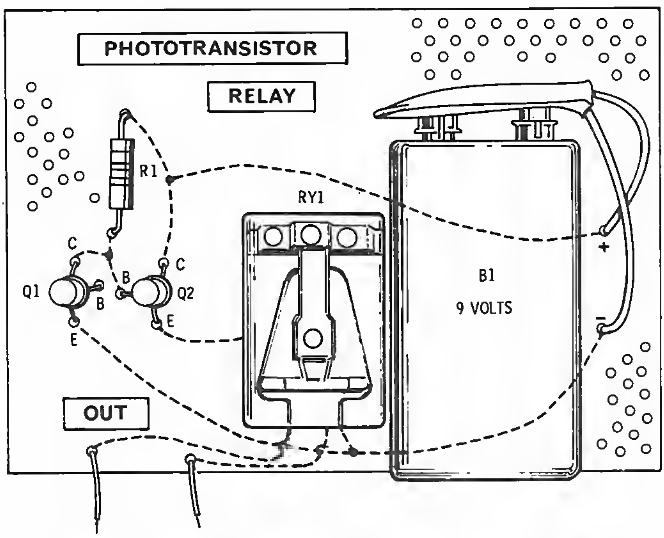


Figure 7-2. Pictorial diagram of the phototransistor relay.

Compare RY1 with the lead diagram in Figure 7-1 or the one supplied with the relay at time of purchase. Insert the relay leads into the board and solder one coil lead to Q2 emitter. Be sure the exposed leads do not touch other leads under the circuit board. Then solder the remaining coil lead to Q1 emitter. Clip excess lead lengths when complete. Since Q1 base lead is unused, you can clip it also to avoid possible false triggering. Since Q1 is a true transistor, noise signals at its base lead may cause the relay to drop in and out. (You can demonstrate this by merely touching Q1's base lead with a finger when the circuit is connected to a battery. If sufficient 60-Hz noise from power lines is present, the relay will chatter at a 60-Hz rate.)

The phototransistor relay is now complete and should resemble the photograph of the prototype shown in Figure 7-3. Before connecting an external circuit to the relay contacts, read the next section.

TESTING AND OPERATION

Inspect the circuit for possible wiring errors and connect a 9-volt battery to the battery clip. Dim the room lights to test the circuit's operation. When Q1's active surface is darkened, the relay should be pulled in. When a flashlight is pointed at Q1, the relay should drop out. Sensitivity of the circuit is good, and a 222 prefocused lamp will trigger the relay at a distance of about three feet. Much more range is possible by using a more concentrated light source, or a lens in front of Q1.

Figure 2-4 is a diagram of how the circuit can be used to control an external device such as a counter, lamp, or bell. By connecting the external device to the normally open relay con-

Figure 7-3. The completed light-activated phototransistor relay.

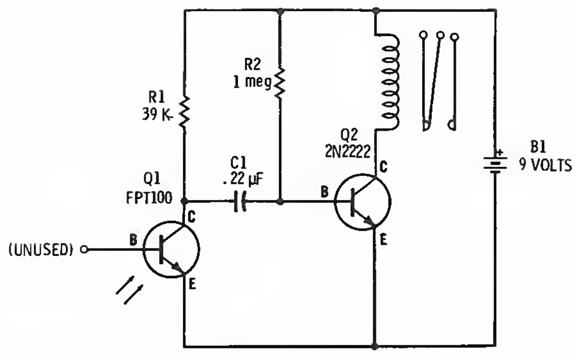


Figure 7-4 Circuit that responds to rapid light-intensity changes.

tacts, the device can be used as a break-beam counter, burglar alarm, annunciator, etc. In this operating mode, the light beam normally illuminates Q1 and RY1 is *not* actuated. When the light beam is broken, RY1 pulls in and activates the controlled device.

The circuit can also be operated in a mode which requires light to strike Q1 for RY1 to actuate a circuit being controlled. True, this means the circuit will consume 5 milliamperes in the standby mode (as compared to 0 above), but since no light source is needed until the circuit is to be actuated, a net power savings results. The savings can be significant since even a small, prefocused lamp such as the type 222 may consume 250 milliamperes from a 3-volt battery.

In this second operating mode, the device being controlled should be connected to RY1's normally open contacts also. Since the relay is normally pulled in during this operating mode, be sure to refer to Figure 2-4 for the proper connections.

Use caution when controlling line powered devices with the relay. *Never* exceed the relay's contact ratings (1 ampere at 125 volts) or the contacts may be damaged or welded in an open or closed position. For best results, house the circuit in an insulated cabinet when using it to operate line-operated devices. This will provide optimum protection from electrical shock.

GOING FURTHER

Since this project has a variety of practical applications, you might want to consider assembling a permanent unit in a plastic cabinet for more reliable operation. Be sure to mount phototransistor Q1 so light from the light source can readily strike its active surface. Front panel banana jacks (274-725) or a barrier terminal strip (274-657) will facilitate access to the relay's switching contacts. To conserve battery life, add an SPST switch (275-1560, 275-602, 275-612, etc.) between the positive battery-connection point and the red battery-connector lead.

Just for fun, you might want to experiment with the alternative version of the basic circuit shown in Figure 7-4. This new circuit incorporates the same two transistors. Capacitive coupling between stages, however, means the circuit responds only to very rapid light pulses, flickers, or interruptions. For example, the circuit will ignore gradual light changes such as sunrise, slowly moving shadows, and any gradually varying light source. Sudden light impulses such as turning the lights in a room on or off, a fast moving flashlight beam, lightning, or fast moving shadows will trigger the circuit and pull in the relay.

This circuit operates in a manner opposite that of the preceding one. When light strikes Q1 the relay pulls in and when light is removed the relay drops out.

CHAPTER 8

TRANSISTORIZED BURGLAR ALARM

The old adage that crime doesn't pay is now obsolete. Unfortunately for the average citizen, crime *does* pay. Only a small fraction of criminals are apprehended, and an even smaller percentage are convicted and receive a prison sentence. In 1969, the most recent year for which reasonably accurate statistics are available, businesses alone lost an estimated 16 billion dollars to burglars, shoplifters, arsonists, and employees.

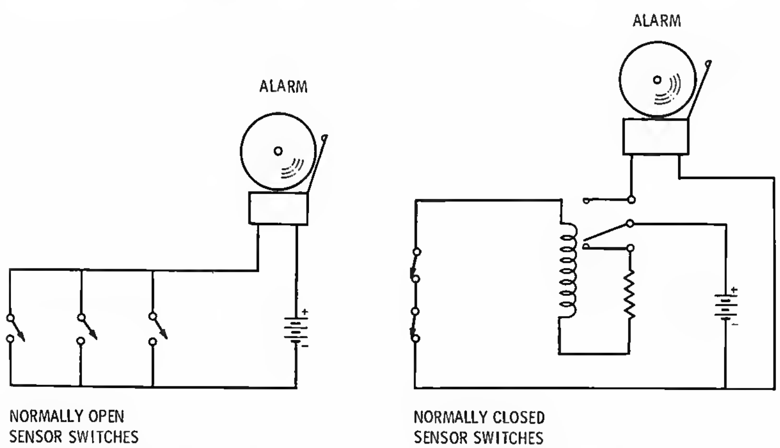
Many citizens are rightfully concerned about protecting their businesses, homes, and garages from burglars, but commercial security alarm companies charge hundreds of dollars to install alarm systems. Most of us cannot afford the money it takes to pay for a commercially installed security alarm system, but Radio Shack has recently made possible do-it-yourself alarm systems by introducing a complete line of bells, electronic whoopers, magnet switches, aluminum window foil, and a variety of central control units.

The circuit described here will permit anyone with a basic knowledge of electricity to build and install a very effective bargain-basement burglar alarm. Unlike some other alarm systems, this one has a very low standby-current drain and will therefore operate for an extended time from a 6-volt lantern battery. In fact, the 130-microampere current drain of the unit in the standby mode is so low the battery should last almost as long as its shelf life.

HOW IT WORKS

Figure 8-1 shows the two basic burglar alarm configurations: open-circuit and closed-circuit. Open-circuit alarms are simple to design and construct, but since their sensor switches are normally open they can be easily disabled by simply cutting one of the main sensor wires. Keep in mind that a normally open (NO) magnetic switch is normally open *when the magnet is next to the switch.* And a NC magnetic switch is normally closed *when exposed to the magnet.*

Closed-circuit alarms are more effective since they continually monitor the sensors and sensor wires. If a sensor is opened or a sensor wire is cut, the alarm will sound. A major disadvantage of the closed-circuit system shown in Figure 8-1 is the standby current requirement. Since the relay is constantly on, no less than several milliamperes and probably more are consumed *continuously.*



(*A*) *Open circuit.* (*B*) *Closed circuit.*

Figure 8-1. Open- and closed-circuit alarm configurations.

A single transistor circuit can be used to make a closed-circuit alarm which draws only 130 microamperes of standby current. The circuit is shown in Figure 8-2. Normally Q1 is turned off by the very low resistance base-to-ground path formed by the sensor switches and wiring. Opening a sensor switch or cutting a wire, however, permits R1 to bias Q1 into conduction. This causes relay RY1 to pull in and activate the alarm device (bell, horn, buzzer, etc.). R1 is a potentiometer having a screwdriver or thumbwheel adjustment feature. By making appropriate adjustments of R1, the circuit can be set for a wide variety of sensor-wire resistances. This is particularly useful for complex installations requiring long sensor wires.

The circuit in Figure 8-2 incorporates an automatic latching feature which prevents a potential burglar or intruder from deactivating the alarm by resetting the sensor switch. The latching feature is achieved by connecting the relay's normally closed contacts in series with the sensor switches. When the

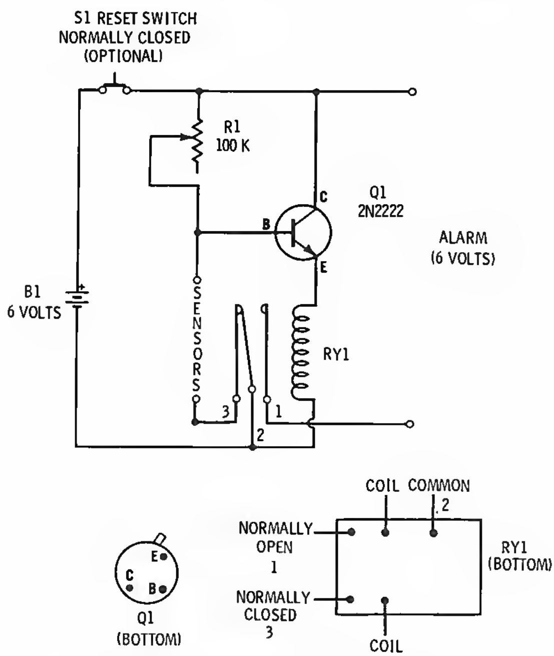


Figure 8-2. Burglar-alarm circuit diagram.

circuit is activated by opening a sensor switch or cutting a wire, the relay pulls in. Even if the opened sensor switch is reset, since the relay switch in series with the sensors is now opened the circuit remains latched. You can reset the relay by simply pressing optional pushbutton switch S1. Otherwise you must momentarily disconnect either battery terminal to reset the circuit. This removes power from the relay coil and causes its contacts to return to their normal position. Of course you cannot reset the circuit without reconnecting any broken sensor wires or resetting open sensor switches.

CIRCUIT ASSEMBLY

Figure 8-3 is a pictorial view of the prototype burglar alarm. You can duplicate the prototype if you wish, but for permanent applications you might prefer to house the circuit in a protective cabinet. Besides reducing the possibility of accidental shorts and other damage, this will help eliminate tampering by curious children and unauthorized persons.

Instructions for duplicating the prototype are given here, but only minor modifications are necessary to mount the unit in a cabinet. The parts list is given in Table 8-1. Begin assembly by drilling four 1/8-inch holes at either end of a 2½-inch by 3¼-inch rectangle of perforated board. Install a Fahnestock clip at each hole with a ¼-inch 6-32 screw and a 6-32 nut. Solder lugs will be connected to each screw later, so don't tighten the nuts yet.

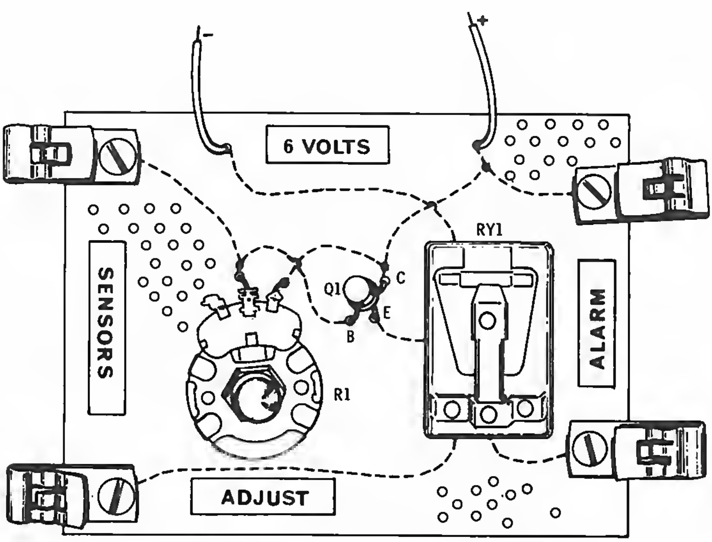


Figure 8-3. Pictorial diagram of the burglar alarm.

Table 8-1. Burglar-Alarm Parts List

Item	Description
Alarm	Alarm device (see text)
B1	Battery, 6 volt
Q1	2N2222 NPN transistor (276-2009)
R1	100,000-ohm potentiometer (271-220 or 271-092)
RY1	Miniature SPDT relay (275-004)
Sensors	Sensor devices (see text)
S1	Optional normally closed reset switch
Miscellaneous	Fahnestock clips (270-393), perforated board, hookup wire, sensor and alarm wire, solder lugs (64-3029), solder, etc.

Radio Shack catalog numbers are shown in parentheses.

Prepare R1 for installation by soldering two-inch lengths of insulated hookup wire to the center and one outer terminal. I mounted R1 to the circuit board by enlarging two perforations and threading the leads through them to provide more visibility of circuit connections in the illustrations. For best results, drill a ⅜-inch hole in the circuit board and secure R1 in place by means of its locking nut.

Q1 is installed next. I used a 2N2222 NPN unit (276-2009), but you can use practically any NPN silicon transistor. Solder Q1 base lead to the lead connected to R1 center terminal. Then solder Q1 collector to the other lead from R1.

Install the relay next. Compare the relay with the wiring guide in Figure 8-2 and install it by threading its leads through holes in the board. For permanent applications use the mounting screw supplied with the relay to secure it in place. If you prefer, you can simply cement the relay to the board with a few drops of white glue.

Referring to the relay wiring diagram in Figure 8-2, solder the relay coil lead nearest the normally closed contact lead to Q1 emitter. The other coil lead is soldered directly to the lead connected to the common switch contact (the one which moves in response to current flowing in the relay's coil). Just bend the coil lead over to the common lead, wrap one around the other, solder in place, and clip off excess lead lengths with a wire cutter.

Next, obtain four solder lugs and solder a 3-inch length of insulated wire to one and 2-inch lengths to two of the others.

Then solder the 3-inch lead to the normally closed relay contact wire where it emerges from the perforated board. Clip off and discard any excess lead length. Solder one 2-inch lead to the junction of Q1 base and R1. (You can solder this lead directly to the actual junction *or* to R1 center terminal). Solder the other 2-inch lead to the junction of Q1 collector and R1. Solder the remaining solder lug to the end of the normally open relay contact wire.

When all the lugs are installed, connect them to their respective Fahnestock clips by removing the nuts on the 6-32 screws, placing the lugs over the screws, and tightening the nuts in place. The lug connected to Q1 collector goes to the uppermost clip designated ALARM on the right side of the board (see Figure 8-3). The lug connected to RY1's normally open contact goes to the other ALARM clip.

Connect the normally closed relay contact lug to the lower clip designated SENSORS on the left side of the board. The lug connected to the junction of Q1 base and R1 goes to the remaining clip.

Complete assembly of the circuit by installing battery-connection wires. I used a 6-volt lantern battery with screw-on

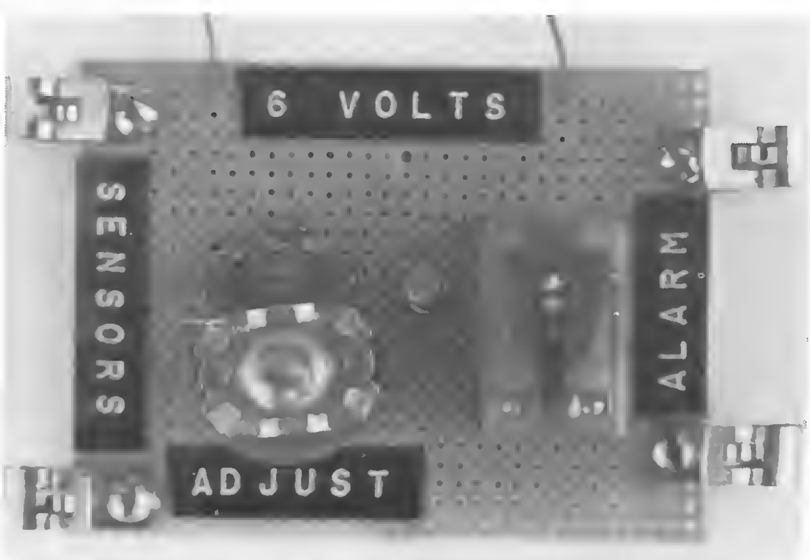


Figure 8-4. The completed burglar alarm.

terminals (Radio Shack 23-066) to power the alarm circuit and connected 6-inch insulated hookup wires from the circuit board to the battery. Solder lugs on one end of each lead to facilitate connecting the leads to the battery. The positive lead is soldered to the uppermost ALARM lug (the one connected to Q1 collector and R1). Solder the negative lead to the junction of RY1's coil lead and common switching contact.

With the exception of the battery-connection leads, the circuit is now complete and should resemble the photograph of the prototype shown in Figure 8-4. Details on battery-connection leads and the optional reset switch follow.

Depending upon your application, you might prefer to use Fahnestock clips to connect the power-supply leads to the circuit. No problem, just install two additional clips on the board near the 6 VOLTS label (see Figure 8-3). There's plenty of room. You might also want to connect a reset switch. If so, just drill a ⅜-inch hole on the right side of the 6 VOLTS label and install a miniature normally closed push-button switch (275-1548). Connect the positive battery lead to one terminal on the switch. Connect the other terminal to the uppermost ALARM Fahnestock clip.

By the way, don't be tempted to save battery expense by using a household line-operated power supply to operate the alarm. A potential intruder need only turn off the power to deactivate your alarm system. A central power failure will accomplish the same result. Battery power guarantees your alarm will work when it is needed.

TESTING AND OPERATION

Check the circuit's wiring to make sure there are no errors. Connect a 6-volt battery to the circuit (be careful to observe polarity) and rotate R1's shaft until the relay contacts just pull in. Now connect a short length of scrap wire between the two sensor terminals. Connect a 6-volt lamp to the alarm terminals. When the battery is connected to the circuit, the lamp should not light. Remove or cut the wire connected to the sensor clips, however, and the lamp should light. The lamp should stay illuminated even if you reconnect the two SENSORS clips with the wire. Repeat this operation several times to make sure the circuit works each time. If necessary, readjust R1 until the circuit operates properly each time the wire across the SENSORS terminal is cut or disconnected.

When the alarm circuit is working properly, you can install it and some appropriate sensors in the area you wish to protect. A number of intrusion sensors are available, but I suggest you stick to the old reliables—magnet switches and aluminum window foil. Here's how these sensors work.

Magnet switches consist of a miniature reed switch which is actuated by a magnetic field. The switch is usually mounted in a hollow glass tube for protection and the tube is installed in a plastic case containing two contact screw terminals and two mounting holes. Magnet switches are used in conjunction with a small but powerful magnet housed in a plastic case similar to the one used for the reed switch. In operation, the magnet is usually installed near the edge of a door or window, and the switch is installed on the door or window frame so that the two are relatively close together when the door or window is closed. This closes the switch and keeps it that way until the magnet is moved. Magnet switches and magnets (275-495) are available from Radio Shack.

Aluminum window foil is just that, a narrow strip of aluminum foil attached along the edges of windows likely to be broken in an effort to gain entry to a home, store, or office. If a protected window is broken the foil separates and triggers an alarm. You've probably seen window foil installed on the glass doors and windows of many stores and offices.

Formerly, window foil was tricky to apply since it was attached to glass by means of a varnish applied as the foil was installed. Besides being messy, the process was time consuming and tedious. Radio Shack now markets 150-foot long rolls of ⅜-inch *self-adhesive* window foil (275-502). The foil attaches directly to clean glass and can be installed with little difficulty. Radio Shack also sells foil-connector blocks (275-504) which greatly simplify the attachment of connecting leads to the foil. Like the foil, the connector blocks have a self-adhesive backing and attach directly to the glass.

You can use magnet switches, window foil, or both as sensors for your transistorized alarm system. All that's necessary is to connect each sensor in series with the others. This guarantees activation of the alarm if only one sensor is disabled. Figure 8-5 is a diagram showing how you can connect both maget switches and window foil to the alarm circuit. If you don't want to use window foil, simply connect the magnet switches directly to the alarm circuit.

This alarm circuit will operate any alarm device requiring 6 volts. Radio Shack markets several such devices and they include an 8-inch alarm bell (275-498), electronic whooper (275-488), and a buzzer (273-049). Since the alarm circuit supplies a 6-volt output signal directly to the ALARM terminals when a sensor is actuated, no auxiliary power source is required. For best results, however, the alarm device should be mounted fairly close to the alarm circuit to avoid excessive current drop due to resistance in the connection wires.

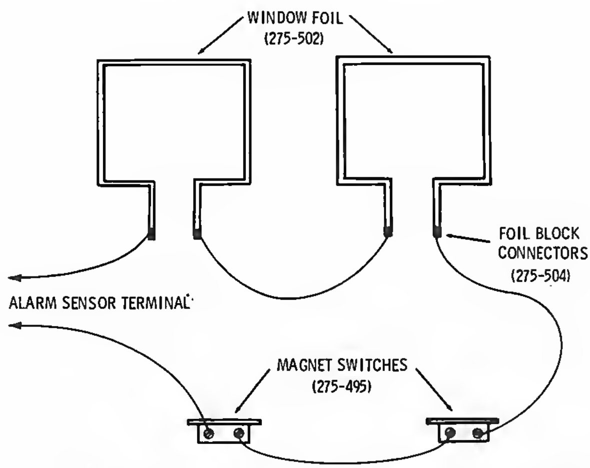


Figure 8-5. Window foil and magnet switch installation.

Installation of your alarm circuit requires great care to prevent possible discovery of the alarm by an intruder. While crime statistics show that the visible presence of some sensors (it's hard to conceal window foil) causes some potential burglars to try elsewhere, others simply look for another way to penetrate your defenses. If you want to protect your home or business while you're away, you will need to devise a secret method for activating the alarm from *outside* the building. If the alarm is activated from inside the building and you are protecting the doors with magnet switches, you will trigger the alarm when you make your exit.

Figure 8-6 shows one possible way to defeat this problem. S1 and S2 are two SPST switches connected in parallel. S2 is mounted inside the protected building to permit the alarm to be activated while you are inside (e.g., asleep at home). The other switch is concealed behind a mailbox, planter, door frame, or any other hiding place on the outside of the protected area. Use your imagination and you will probably be able to find half a dozen or more places to conceal the outside switch. How about a recessed push-on push-off switch mounted inside the protected building and operated by means of a 6-inch length of ¼-inch dowl inserted in a hole drilled in an out-of-the-way portion of the wall? Or, you could use a key switch (275-503). There are many other such possibilities.

Installing the sensors is straightforward. Magnet switches should be installed near the top of doors to prevent accidental damage. The effective separation distance of the Radio Shack switches is over half an inch, but make sure the magnet and switch are separated by no more than this distance when the protected door or window is closed. Metal doors and windows reduce the switch separation distance to about ¼ inch, so mount the magnet and switch accordingly.

Aluminum window foil should be applied to the *inside* of the windows only. Apply the foil a few inches away from the edges in neat, straight lines. Turn all corners at a 90-degree angle, if possible, to give a professional appearance to the job. Professional alarm installation companies report that many false

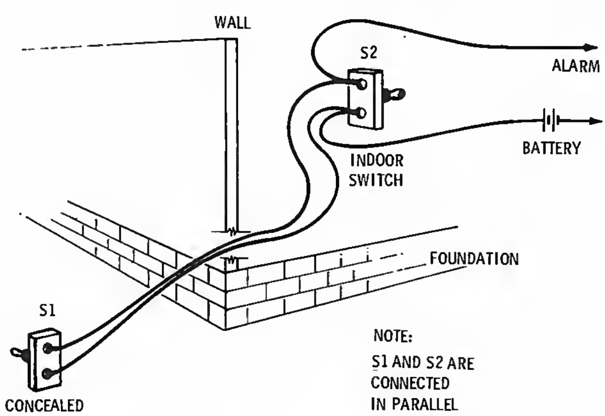


Figure 8-6. Concealed activation of the alarm.

alarms and alarm problems are caused by mischievous children (or adults) who peel away a small section of window foil during business hours in commercial establishments. You can discourage these troublemakers by coating the completed foil installation with an appropriate varnish or other tough, transparent coating.

Run all sensor connection wires along baseboards, under rugs, or in other concealed locations. When possible, I prefer to run all sensor wires into the attic. While this procedure takes more time, the sensor wires are conveniently out of the way. By the way, be careful when working in an attic. It's easy to fall through a ceiling, especially in newer homes with inferior construction.

CONNECTING THE ALARM

For best results you should mount the alarm device relatively near (5 or 10 feet) the alarm circuit and battery. This is because the resistance of the alarm-connection wires will sap away some of the current needed for efficient alarm operation if the wires are too long. If you want to protect your home or office while you are away, the alarm device will do little good if it is mounted *inside* the protected building. Instead, you must mount the alarm outdoors. This can become a major challenge, since a smart burglar need only cut a single wire to your alarm to effectively disable the entire system. The Radio Shack 8 inch alarm bell solves this problem for you by permitting you to conceal the alarm leads *behind* the bell itself. Other alarm devices must be mounted in an inaccessible location, concealed, or housed in a protective metal or wood housing having holes or louvres to permit the free passage of sound waves. You can camouflage a protective housing as a planter.

You can use any 6-volt alarm device with this alarm circuit. Several Radio Shack alarm devices were listed earlier. You can even use a 6-vole pilot lamp assembly (272-327, 272-329, etc., plus 6-volt lamp) for a *silent* alarm device.

GOING FURTHER

If the subject of burglar alarms interests you, purchase a copy of *Security for Your Home* (96 pp, softbound, $1.25) next time you are in a Radio Shack retail store. This book describes both home-made alarm systems, and several of the sophisticated alarm systems manufactured by Radio Shack. Numerous photographs and diagrams are included which illustrate installation of window foil and magnet switches, connection of alarm devices, and operation of closed-circuit, open-circuit and sophisticated noncontact alarms. The alarm circuit presented here is not included in "Security for Your Home" so you will get 96 pages of new and useful information.

CHAPTER 9

TRANSISTOR AND DIODE TESTER

Anyone who works with semiconductors needs a way to quickly identify PNP and NPN transistors, check diodes and transistors for opens and shorts, and identify diode polarity. You can use a multimeter to make these tests, but the procedure is more complicated than it needs to be since the probes must be switched from lead to lead as the tests are made. A better alternative is to use a commercial transistor tester, but if you don't need to test many diodes and transistors purchasing a commercial tester may not be good economics.

This project is a solution to the problem of quickly testing transistors and diodes at low cost. The tester described here checks both diodes and transistors for opens and shorts and identifies their polarity. The project is totally solid state (LEDs are used instead of a meter) and since it requires only six components and a transistor socket, construction is simple and fast.

HOW IT WORKS

You can see how the transistor tester operates by referring to the circuit diagram in Figure 9-1. To understand how the tester operates, remember that a diode passes a current poorly in one direction and very well in the other. The leads of a diode to be tested are inserted into the base and collector receptacles of the transistor socket. The PNP and NPN push-button switches are then pressed in succession (but not at the same time). If the PNP LED glows, the diode's anode lead is the one inserted into the transistor socket's collector receptacle. If the NPN LED glows, the anode lead is the one inserted into the transistor socket's base receptacle. If both LEDs glow the diode is shorted and if neither LED glows the diode is opened.

Since you can think of a transistor as two back-to-back diodes, the tester tests transistors in the same way as it does a single diode. The collector-base junction is one diode and the emitter-base junction is the other. With an unknown transistor inserted into the socket, the PNP and NPN pushbuttons are pressed in succession. If both PNP LEDs glow, the unit is PNP. Similarly, if both NPN LEDs glow, the unit is NPN. If only one or no LEDs glow the transistor is opened and if three or more LEDs glow one or both junctions are shorted.

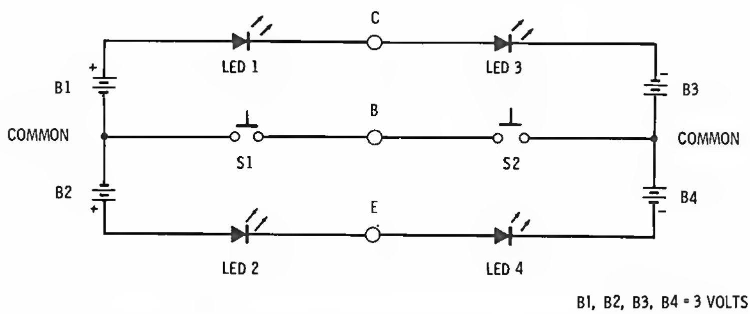


Figure 9-1. Circuit diagram of the transistor tester.

The tester is powered by four separate 3-volt batteries made from AA penlight cells mounted in two four-cell battery holders. Current-limiting resistors are not needed to protect the LEDs since the forward resistance of a diode or transistor junction provides sufficient series resistance to limit current to a safe value.

CIRCUIT ASSEMBLY

Assembly of the transistor tester is straightforward. I constructed the prototype on a perforated board as shown in the pictorial view in Figure 9-2, but you can assemble your version in a portable cabinet if you prefer. The parts list is given in Table 9-1.

Table 9-1. Transistor Tester Parts List

Item	Description
B1 to B4	Batteries (four pairs of AA penlight cells)
LED1-4	LEDs (see text)
S1, S2	Normally open push-button switches (275-1547)
Miscellaneous	Battery holders (270-1435), perforated board, transistor socket (276-548), hookup wire, solder, tape labels, etc.

Radio Shack catalog numbers are shown in parentheses.

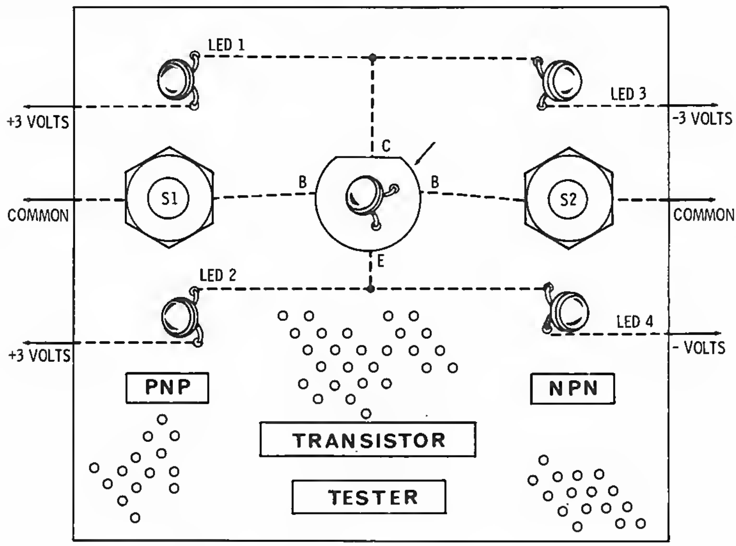


Figure 9-2. Pictorial diagram of the transistor tester.

To duplicate the prototype, refer to Figure 9-2 and drill two ¼-inch holes for the push-button switches and a ⅜-inch hole for the transistor socket. Then, install both switches and the socket. Use the mounting nuts supplied with each switch to secure the switches in place. The transistor socket should stay in place by merely pressing it into its mounting hole. (Protect the board from possible breakage by avoiding too much pressure when installing the socket.)

Next, solder a short length of insulated hookup wire from one terminal of both switches to the transistor socket's base pin. Use care when soldering to the transistor socket pins since they are fragile. If you have problems, use smaller wire.

Next, install LED1 and LED2 in the board on either side of S1 and solder the LED1 cathode lead to the transistor socket collector pin. LED2 cathode lead is soldered to the socket emitter pin. The literature supplied with the LEDs should indicate which lead is the cathode and which is the anode. If you are unsure, refer to the discussion on LEDs in Chapter 6.

Continue assembly by inserting LED3 and LED4 into the board on either side of S2. Solder the LED3 anode lead to the transistor socket collector pin and the LED4 anode to the emitter pin on the socket.

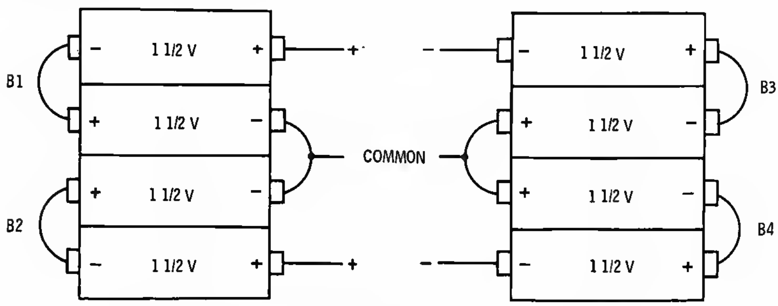


Figure 9-3. Transistor tester battery-connector diagram.

Connect the battery holders next. Refer to Figure 9-3 for guidance to avoid polarity errors and wire the holders as follows.

1. Connect alternate terminals of each four cell holder to one another as shown in Figure 9-3 and solder in place.
2. Mark the two free ends of one holder with a plus sign and the two free ends of the second holder with a minus sign.
3. Solder 6-inch lengths of insulated hookup wire to each free battery holder terminal (four) and to the junction of the center two terminals (two).
4. Solder the two PLUS leads from one holder to the anode leads of LED1 and LED2 (See Figure 9-2).
5. Solder the two MINUS leads from the other holder to the cathode leads of LED3 and LED4.
6. Solder the common lead from the holder marked with the plus sign to the remaining terminal on S1.
7. Solder the common lead from the holder marked with the minus signs to the remaining terminal on S2.

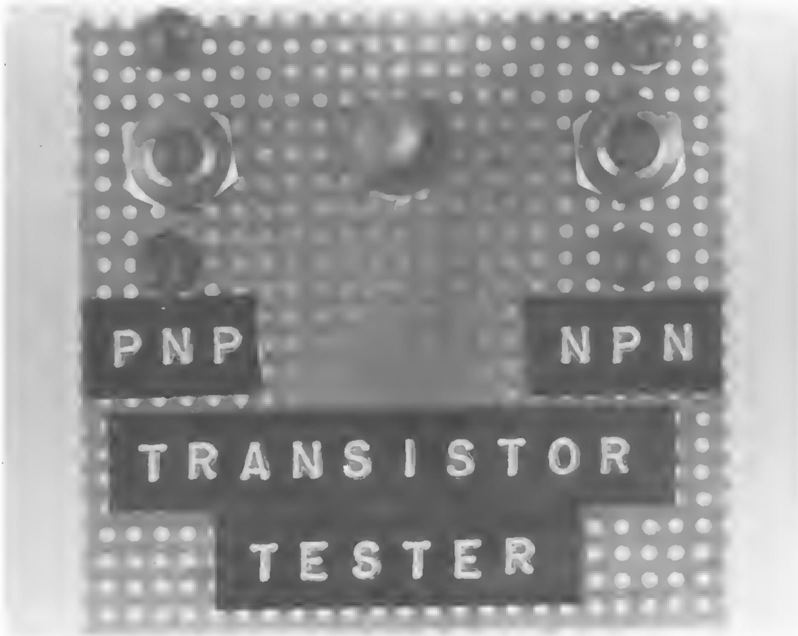


Figure 9-4. The completed transistor tester.

Complete assembly of the tester by applying labels to designate S1, LED1, and LED2 as PNP and S2, LED3, and LED4 as NPN. See the photograph of the prototype tester in Figure 9-4 for guidance on placing the labels.

TESTING AND OPERATION

Inspect the circuit for wiring errors before installing batteries in the holders. Then install the AA cells in accordance with the diagram in Figure 9-3. Make sure the cells are fresh and installed correctly or the tester will not work properly.

Insert a transistor into the socket. Make sure the leads are installed correctly or the test will show a good transistor to be bad. Figure 9-5 shows common transistor lead orientations.

Test the transistor by first pressing the PNP push-button. If only one lights, it is bad and should be discarded. If neither LED lights, press the NPN pushbutton. Both LEDs should now glow if the unit is a good NPN unit, but if only one or neither LED lights, discard the transistor.

It is important to remember that the tester checks only PNP and NPN transistors. You cannot use it to check unijunction transistors (UJTs) and field-effect transistors (FETs). If you think an unknown transistor might be a UJT or FET, check its number against a transistor listing before trying to test it.

After testing a transistor or two to verify operation of the circuit, insert the leads of a diode into the base and collector transistor socket receptacles. If the top PNP LED glows when the PNP pushbutton is pressed, the diode's anode is inserted in the collector receptacle and its cathode in the base receptacle. If the NPN LED glows when the NPN pushbutton is pressed, its anode is inserted in the base receptacle and cathode in the collector receptacle. If both LEDs light when the switches are successively pressed, the diode is shorted, and if neither LED lights the diode is opened.

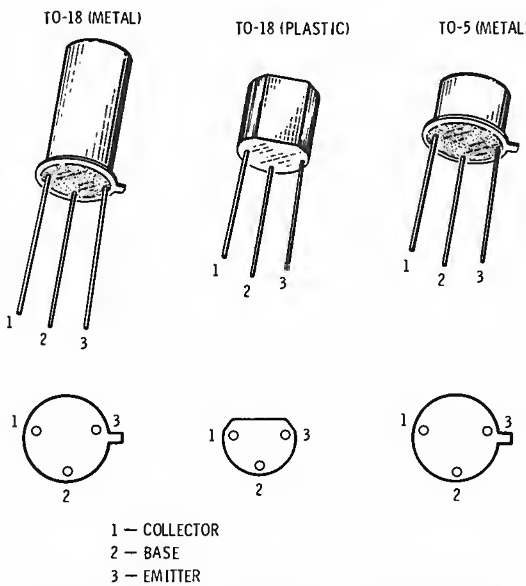


Figure 9-5. Typical transistor lead configurations.

You can use the tester to check conventional diodes and LEDs. LEDs will indicate their status by simply glcwing when the PNP or NPN switch is pressed. The tester will not check four-layer diodes, tunnel diodes, laser diodes, and most zener diodes.

GOING FURTHER

Since this project is so useful, you will probably want to house it in an appropriate cabinet. You can enhance the usefulness of the tester by connecting clip leads to the transistor socket to facilitate testing transistors and diodes which cannot be inserted into the socket. The test leads can be made from insulated alligator clips (270-378) and flexible connection wire. You can connect the leads to the tester permanently, but for best results solder a banana plug to one end of each clip lead and install banana jacks on the tester's cabinet. Connect each jack to one of the three socket pins with insulated connection wire. If possible, color code the plugs, jacks, and insulated clips for convenient testing. For example, use a black clip, plug and jack for the base and red clips, plugs and jacks for the collector and emitter.

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