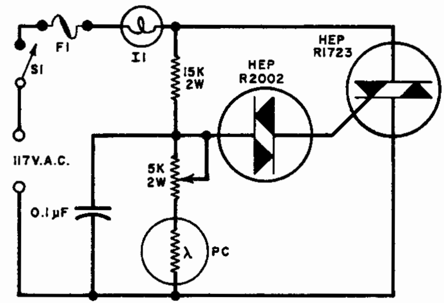
Hobby Scene

DARK-ON LIGHT

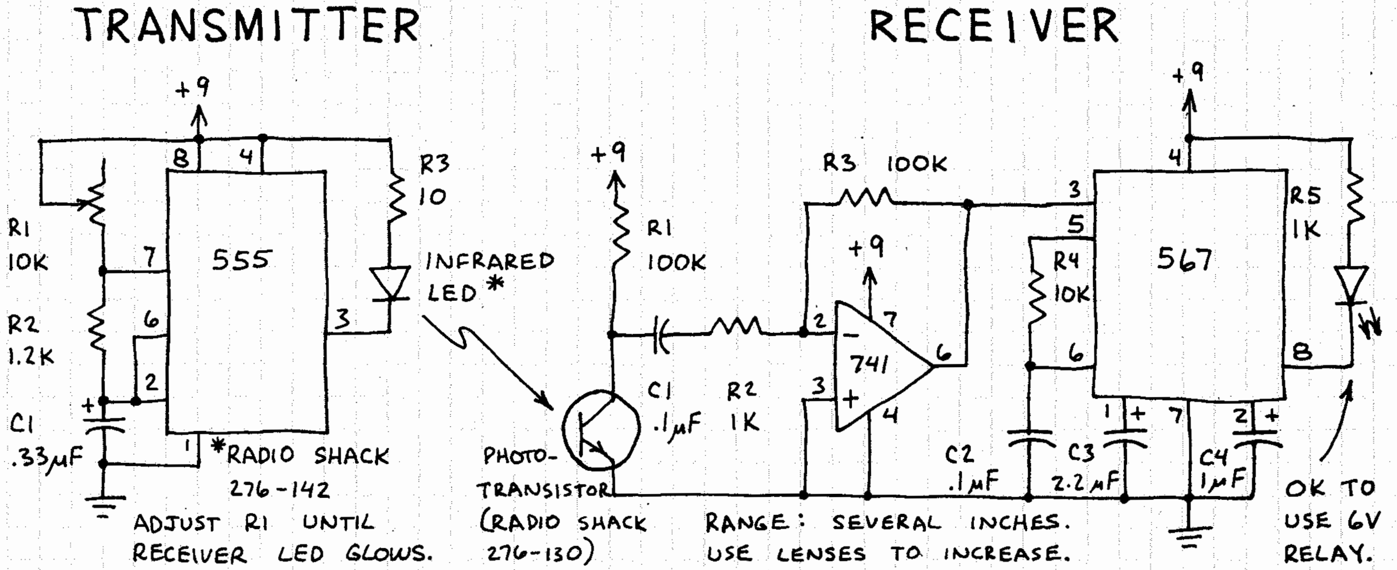
Q. ***I would like to have incandescent lights around my home which will turn on at dusk and off at dawn. Can you provide me with a circuit?***

—E. Cassidy, Los Angeles, Calif.



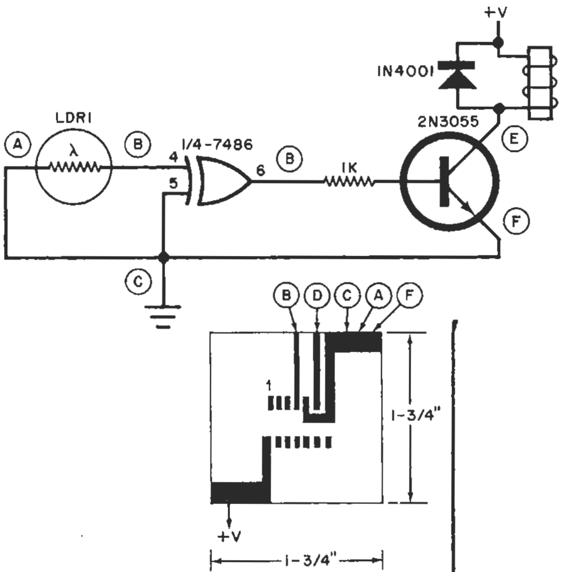
A. The circuit shown will handle up to 1000 W of power. The selection of photocell *PC* is not critical, and any of the experimenter-type CdS cells should work. The light level at which the circuit changes states can be selected by varying the potentiometer. (Its value is not critical, and will depend on the photocell used. Check your junk box.) If more than one bulb *(I1)* will be used, wire them in parallel. Choose the rating of the fuse to agree with the total load requirement. Be sure to adequately heat-sink the triac.

INFRARED REMOTE CONTROL SYSTEM



INEXPENSIVE ELECTRIC EYE

Here's an electric eye that can be built from junkbox parts. It consists of a CdS photocell, a 7486 exclusive-OR gate IC, an npn switching transistor (2N3055 or similar) and a small electric bell. When no object interrupts the light path from a lamp to photocell *LDR1*, both inputs to the ex-OR gate are low. Thus the gate's output is low and the transistor is cut off. Interrupting the light beam causes the gate output to go high and the transistor to conduct, energizing the bell. A 6-volt lantern battery can be used as a power source. All parts can be obtained for about $3 from a surplus house. A simple pc board is used, and can accommodate up to four independent circuits, each using one gate in the quad ex-OR IC. The entire alarm can be mounted on a TO-3 heat sink.—*Kenneth B. Blois, APO SF 96286.*



How optoelectronic components fit in the optical spectrum

As optoelectronic applications multiply, optical sources, detectors, and transmission media are becoming increasingly available; this guide relates the more important of them by their operating wavelengths

by Lyman Hardeman, *Communications & Microwave Editor*

☐ Many optoelectronic devices that till recently were the playthings of a few curious researchers have by now become standard building blocks to a good many design engineers. And as the growing demand further lowers prices, still more EEs will want to exploit the interaction of light and electronics in industrial and consumer as well as military equipment.

A convenient approach to surveying the optoelectronic technologies and devices that are available today is to categorize them as optical sources, optical detectors, and materials through which optical waves are transmitted. The portion of the electromagnetic spectrum over which they function extends from ultraviolet wavelengths of a few nanometers, through the visible spectrum of about 400 to 700 nm, and far into infrared wavelengths that measure up to tens of thousands of nanometers (see foldout chart on p. 115).

Optical sources

The most important sources of light are the sun, various man-made lamps, lasers, and light-emitting diodes.

The sun operates as a blackbody, or thermal, radiator which emits broadband optical energy due to its inherent temperature. But in fact any substance is a blackbody radiator and emits light with a peak intensity that gets stronger and shorter in wavelength as temperature increases (see Fig. 1). At room temperature (300° K), the wavelength of peak light intensity of a blackbody radiator is about 10 microns (micrometers), while at 6,000° K, the peak occurs around 0.5 μm. The sun's peak corresponds to a temperature of 5,900° K.

Tungsten lamps are the chief sources of man-made visible light based on blackbody radiation principles. Depending on the amount of electrical power dissipated across its filament, the typical lamp will radiate with a blackbody temperature ranging from 2,500° K to over 3,000° K. The broadband nature of this radiation, however, is the major factor that reduces the lamp's over-all efficiency in the visible spectrum to only about 3%.

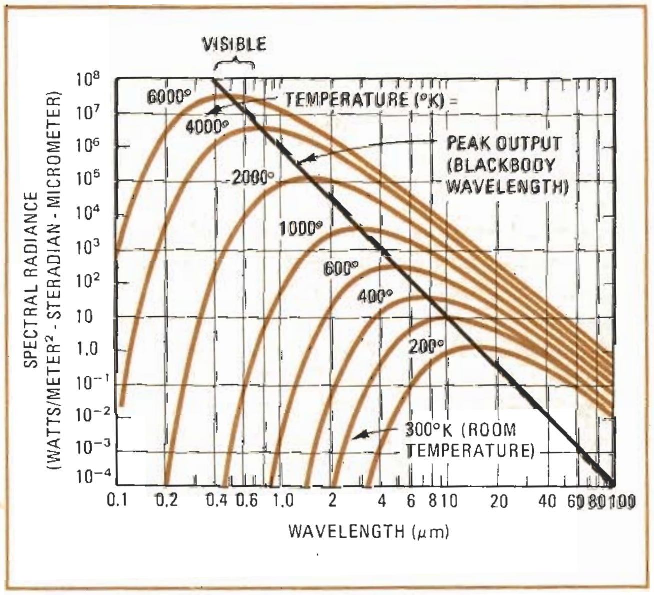
Thermal radiators are also very important in infrared applications—and becoming more so as the security barrier imposed on military infrared technology in World War II has gradually been lowered. In the last few years, many nonmilitary applications have emerged that exploit the natural infrared radiation of such sources as thermally polluted water, diseased crops in a field, or forest fires. In these applications, the sources are blackbody radiators and serve as inputs for highly sensitive remote sensors placed in aircraft or satellites.

Other artificial light sources include arc and glow discharge lamps, and fluorescent tubes. Almost all of these lamps emit in or near the visible spectrum, and each has its own applications niche. The arc and glow discharge types, for instance, are generally efficient sources of high-intensity light that serve both as illuminators in the visible spectrum and as exciters for laser sources.

Coherent sources

The only source of coherent light—the laser—yields extremely high radiance. But of the hundreds of different types of lasers that have been evaluated since the device was first shown to work in 1960, only a few have left the laboratory and entered general use.

Today's most common lasers are based on gasses such as carbon dioxide, helium-neon, argon, and krypton, or else are solid-state, using mainly either gallium-arsenide semiconductors or neodymium-doped yttrium-alumi-



1. Blackbodies. Substances emit broadband electromagnetic energy depending upon their temperature. At room temperature, the wavelength of peak intensity is in the infrared region, at about 10 micrometers, while at 5,900°K (about the temperature of the sun) peak intensity falls at just about the middle of the visible spectrum.

TABLE: LASER SUMMARY				
TYPE	PRIMARY WAVELENGTHS (μm)	TYPICAL EFFICIENCY (%)	TYPICAL POWER (W) CW/PEAK	COMMENTS/PRINCIPAL APPLICATIONS
Argon	0.49 0.52	0.1	5/100	Emits at visible blue-green; used in cutting films in artwork design; efficiency and wavelength make it useful as pump for dye lasers for tuning in the visible spectrum.
He-Ne	0.63 1.15 3.39	0.01	0.1/2	Primary spectral line at 0.63 micrometer convenient and inexpensive source of red light for precision distance measuring, communications, and plasma physics studies.
Nd: YAG	1.06 1.30	3	50/1,000	High-power laser that is easy to control; used in cutting and welding and has potential in communications.
CO_2	10.6	20	200/75,000	Practical high-power laser; used extensively in cutting and welding; possible source for nuclear fusion
HeCd	0.44 0.33	0.5	0.1/2	Recently became commercially available for applications requiring blue light; is being considered for use as light source in facsimile equipment.
Ruby	0.69	1	5/50	Material used in first laser demonstrated in 1960; used some in cutting and melting.
GaAs	0.91	1	0.04/1	Promising solid-state laser for communications, but must improve reliability.
Krypton	0.64	0.1	5/100	Source of red and green light.

num-garnet. Primary operating wavelengths of each of these sources, along with their main application features, are summarized in the table.

Lasers are finding the bulk of their commercial applications in manufacturing and the construction industry. Here, they are useful for drilling holes, cutting, measuring precise distances, and surveying. But as optical component performance and modulation techniques advance, lasers will be used more in such areas as communications, optical data storage, and pollution control.

LEDs offer lower costs, higher speed

Light-emitting diodes have also made remarkable inroads the last few years. They are found in displays for everything from digital panel meters to pocket calculators. Their low cost, high reliability, and switching speeds on the order of a few tens of nanoseconds also make them attractive for use in optical isolators and as transmitters in fiber-optic communications systems.

While light-emitting diodes can be made from many semiconductor materials, gallium-arsenide-phosphide and gallium-phosphide diodes are much the most advanced. The wavelength of GaAsP LEDs can theoretically be varied from about 560 to 910 nanometers by growing crystals of varying ratios of concentration of arsenide and phosphide. But practical GaAsP devices—those used in most of today's LED displays—are constructed to operate in the red region, at 655 nanometers, a wavelength that represents the optimum tradeoff between the device's operating efficiency and the response of the human eye. Bandwidth of the light emitted from GaAsP devices is approximately 30 nm.

GaP diodes, however, are being made in increasing quantities, for green and yellow as well as for red displays. GaP is always doped, partly to increase its illuminating efficiency and partly to extend the bandwidth or alter the wavelength of the light it can emit. Doped with nitrogen, it will emit a broad range of wavelengths in the green and yellow portion of the visible spectrum. Doped with zinc-oxygen, it emits red light.

Another important type of LED is made from GaAlAs and is found in fiber-optic communication systems. The operating wavelength of this semiconductor is determined by the particular combination of aluminum and arsenide chosen. In these devices, practical efficiencies of approximately 3% are achieved over a range of wavelengths from 800 to 900 nm.

Optical detectors

Light sensors fall into three basic categories—photoemitters, photoconductors, and junction devices. In addition, several broadband temperature-sensing devices, such as the thermocouple, bolometer, and Golay cell, are used in light measurements, but these serve mainly laboratory and calibration purposes.

The photoemissive-type light sensor measures light by converting the energy of incident photons directly into free electrons, which are then accelerated in a vacuum under a strong electric field. Applications are chiefly in the visible and ultraviolet region—examples are the photocathode coating at the input of photomultiplier tubes, image-converter tubes, and low-light-level image intensifiers.

The more popular photoemissive materials today are silver-cesium oxide (AgCsO), cesium antimonide (CsSb), potassium-cesium-antimonide (K-Cs-Sb, referred to as a bialkali photoemitter) and sodium-potassium-cesium-antimonide (Na-K-Cs-Sb, a trialkali). Recently, GaAs photoemitters have become available and have stirred much interest among electro-optic system designers mainly because of their high sensitivity, especially at wavelengths between 600 and 900 nm.

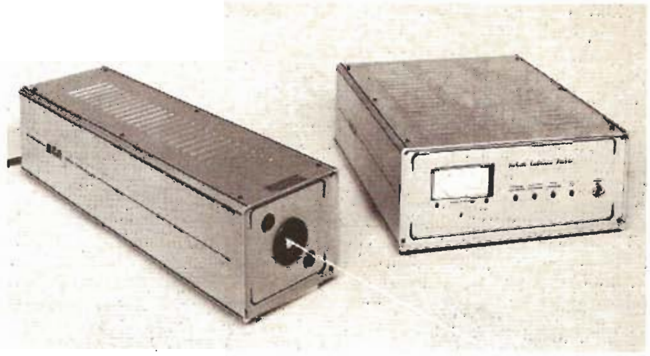
A convenient measure of performance of a photoemissive-type detector is its quantum efficiency, or ratio of output electrons to input photons. The theoretical maximum of one electron per photon defines a quantum efficiency of 100%. The quantum efficiencies for several commercially available photoemissive materials are plotted in Fig. 4 as a function of wavelength. The S-code numbers refer to standard devices defined by the Electronic Industries Association.

Both the quantum efficiency and the long wavelength cutoff of a photoemitter are determined by the semiconductor material it uses. Short wavelength cutoff is determined primarily by the cutoff wavelength of the window material through which light must pass before interacting with the photoemitter in a vacuum.

Photoconductors for longer wavelengths

As seen in Fig. 4, most photoemissive materials have a long-wavelength cutoff near the infrared edge of the visible spectrum, in the 600-800-nm region. Photoconductive-type detectors extend these detectable wavelengths well into the infrared range.

In a photoconductive detector, incident photons cause an increase in the current from an external biasing circuit to flow through the detector. The detector may be either intrinsic, with its sensing properties inherent in the photoconducting material itself, or extrinsic, in which case one material—usually germanium—is doped with one of a group of elements to make it sensitive to light at longer wavelengths.



2. Commercial lasers. Numerous lasers have been introduced in the past few years at prices below $3,000. The He-Cd unit shown can be operated at one of two spectral outputs (442 nm or 325 nm) and is expected to find applications in facsimile recording systems.

Intrinsic photoconductors include lead sulfide (PbS), lead selenide (PbSe), indium arsenide (InAs), and indium antimonide (InSb), all of which operate in the visible spectrum and to longer wavelengths out to about 3 to 5 μm at room temperature. The long-wavelength sensitivity of these detectors is increased when they are cooled to the temperatures of dry ice and liquid nitrogen. InAs and InSb are generally more expensive than PbS and PbSe, but take only microseconds instead of milliseconds to turn on.

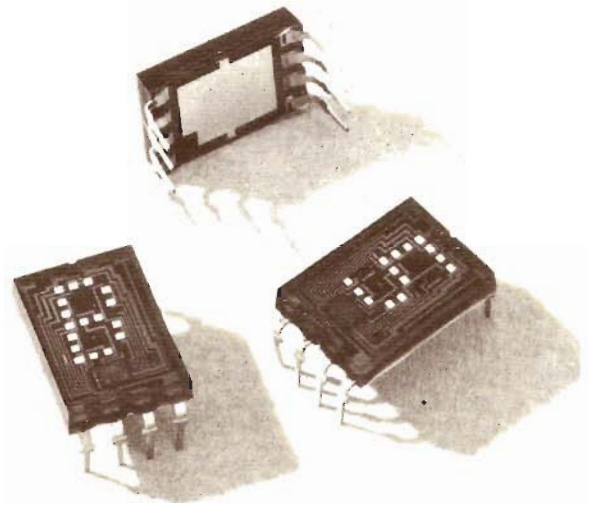
For applications in the visible spectrum—in camera light meters, home furnaces, and automatically operated street lights—cadmium sulfide (CdS) and cadmium

Photometry-radiometry units

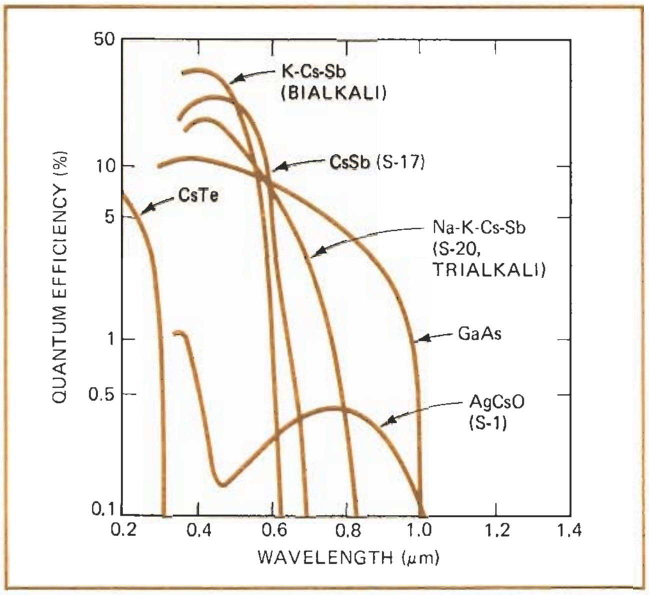
The many terms that have been developed to define properties of propagating radiant energy are summarized in the table. For a detailed discussion of the units of photometry (light radiation normalized to the response of the human eye) and radiometry (radiation at any spectral frequency), and how these quantities are measured, see *Electronics,* Nov. 6, 1972, p. 91.

Definition	Radiometric			Photometric		
	Name	Symbol	Unit*	Name	Symbol	Unit*
Energy	radiant energy	Q	joule	luminous energy		lumen-s
Energy per unit time=power=flux	radiant flux	P	watt	luminous flux	F	lumen
Power input per unit area	irradiance	H	W/m^2	illuminance	E	lm/m^2 (lux)
Power output per unit area	radiant exitance	W	W/m^2	luminous exitance	L	lm/m^2
Power per unit solid angle	radiant intensity	J	W/steradian	luminous intensity	I	candela
Power per unit solid angle per unit projected	radiance	N	W/m^2 steradian	luminance	B	candela/m^2

*All units are metric.



3. Display breakthrough. Advances in semiconductor production techniques in the last few years have helped bring down the costs of GaAsP and GaP light-emitting diodes so that they are now widely used for display applications ranging from digital panel meters to pocket calculators. Recent alphanumerical digits come in many colors and sizes, some with built-in drive circuitry.



4. Photoemitter response. Photoemitter-type detectors are used at untraviolet and visible wavelengths. Material performance is typically compared in terms of quantum efficiency—the ratio of actual electron output to the maximum output possible determined by photon flux. S-code numbers refer to standards designated by the Electronic Industries Association.

selenide (CdSe) are also used extensively and are supplied by several manufacturers. CdS has the greater sensitivity, CdSe responds at longer visible wavelengths, and both function at room temperature.

Two other intrinsic photoconductors—mercury cadmium telluride (Hg-Cd-Te) and lead tin telluride (Pb-Sn-Te)—have been developed more recently as detectors to operate to wavelengths out to about 14 μm when cooled to liquid-nitrogen temperatures (77° K). Such a spectral response makes these detectors attractive for use with the CO_2 laser, which emits at 10.6 μm.

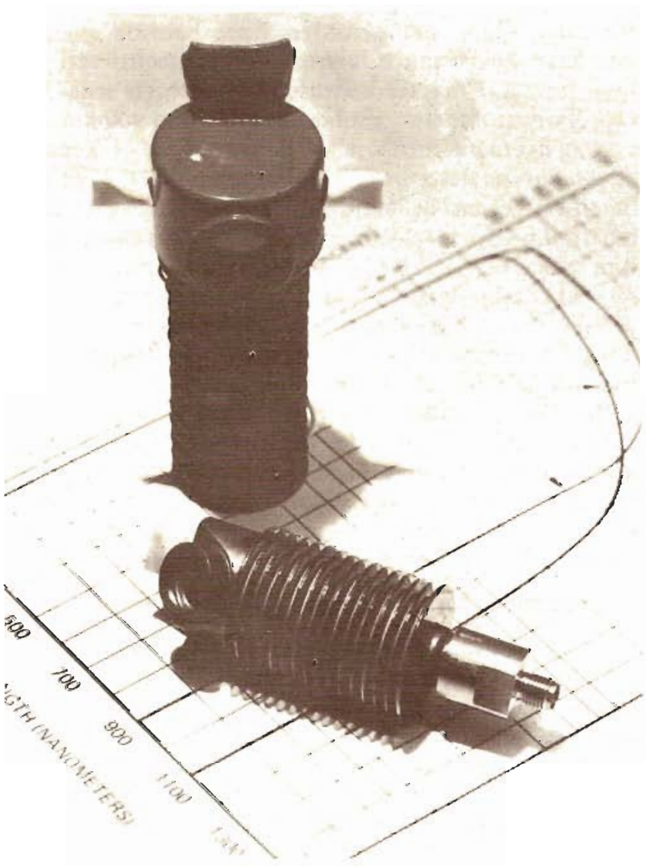
Extrinsic photoconductors must usually be cooled to liquid-nitrogen temperatures or cooler and can be sensitive at still longer infrared wavelengths. Most practical extrinsic photoconductors employ a germanium host crystal. Depending on dopant and operating temperature, infrared wavelengths to over 100 μm can be detected (see foldout chart).

Junction-type detectors

Light-sensing devices that depend on a semiconductor pn junction include photovoltaic devices, photodiodes, and phototransistors. In the photovoltaic sensor, a voltage is generated across the junction as a function of the light impinging on the junction. The photovoltaic cell, or simply photocell, is usually made of selenium or silicon and is most notably used in space, where the relatively high cost of the device is offset by the fact that it is the only self-generating light sensor available (i.e., one that requires no external power supply).

Photodiodes and phototransistors are finding increasing popularity at visible wavelengths. Because of their faster response and the high gains achievable when biased in a transistor circuit, these devices are competing more and more with photomultipliers operating to wavelengths as long as about 1.1 μm.

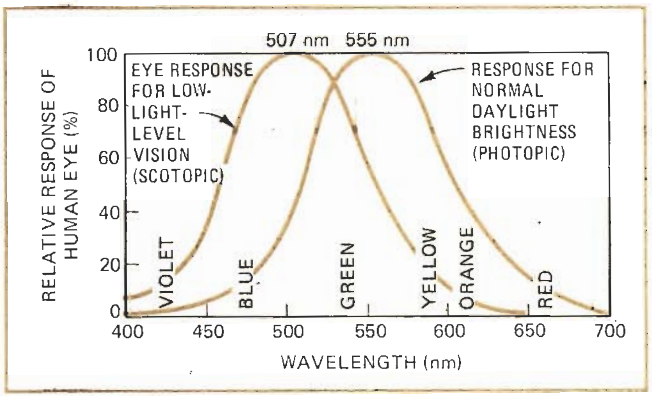
5. Photomultiplier edge. To stay half a step ahead of recent developments in solid-state detector technology, makers of photomultiplier tubes have recently introduced units with improved photocathode materials to achieve unprecedented combinations of speed, broad bandwidth and high quantum efficiency. Applications include optical-character readers and fiber-optic communications.



Reverse-biased silicon photodiodes typically respond to reset times of about 100 ns. Other semiconductor materials, including germanium, indium arsenide, and mercury-cadmium-telluride, are also used in making photodiodes, mainly to extend response to longer wavelengths, but often at a loss in response speed.

Seeing the light

As evident in the spectrum chart and the discussion so far, the wavelengths to which the human eye is sensitive form a middle reference area in the over-all optical spectrum. As a photodetector, the human eye has some peculiarities that become important in the context of photometry.



6. Day and night. Peak optical response of the human eye shifts about 50 nm as the eye adjusts from the brightness of normal daylight (photopic vision) to nighttime starlight levels (scotopic vision). There is no color perception under scotopic conditions.

The retina contains two types of receptors, responsive to two different ranges of wavelengths (Fig. 6). In daylight, one set of receptors responds to wavelengths from about 400 to 700 nanometers, with a peak response centered in the green region at 555 nanometers. This is the eye's light-adapted or photopic response.

When adapted to darkness, the other set of receptors comes into play, with a peak response at 507 nm. This dark-adapted or scotopic eye is color-blind, whereas the light-adapted eye is able to discriminate between color wavelengths. Photometric units of light intensity (see "Photometry and radiometry defined," p. 111) are weighted by the photopic eye's normalized response.

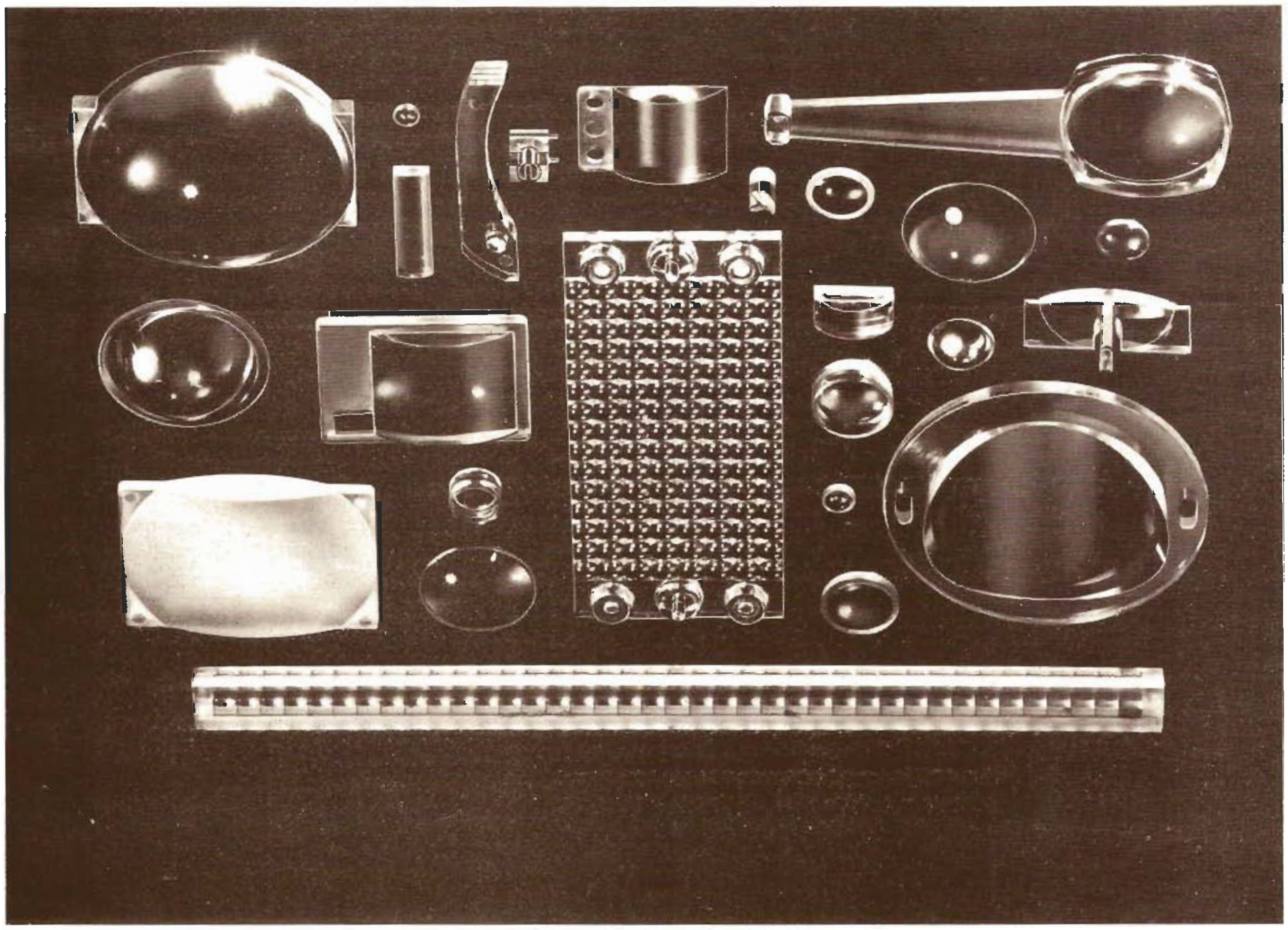
Transmission materials

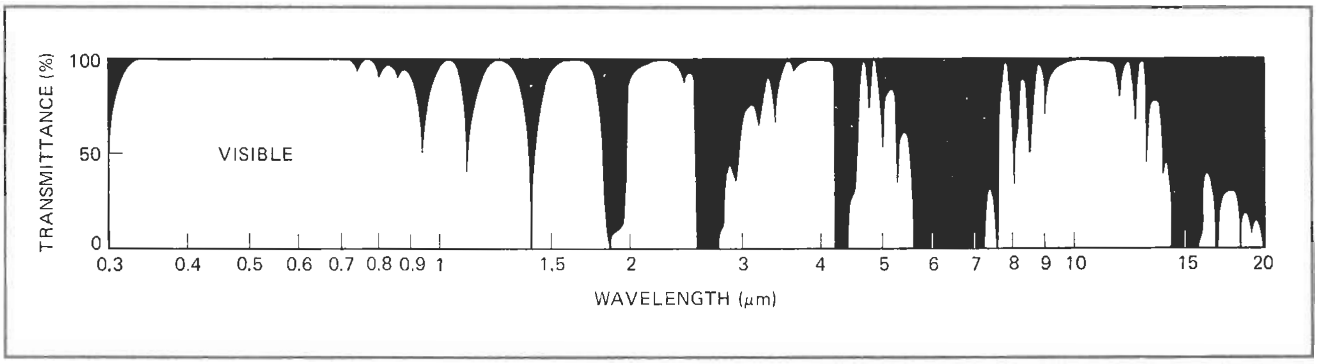
Light travels between a source and a detector through a transmission medium which may substantially alter the light's properties and usually passes only a portion of the optical spectrum. Transmission materials include glass, plastics and other transparent compounds, and function as protective windows, lenses, or optical filters.

In the visible portion of the spectrum, common soda-lime glass is used extensively as a window material. Its transmittance is very nearly 100% over the entire visible range, but falls off quite rapidly on each end (30% transmittance cutoff points are approximately 350 and 3,000 nm).

Injection-molded plastics, however, are ousting glass in many applications in the visible spectrum [*Electronics*, July 3, 1972, p. 77]. While plastic is more susceptible to temperature and abrasion than glass, its low cost of

7. Plastic optics. For an increasing number of production applications, the low cost of molded plastic lenses and windows more than offsets their high-performance limitations when compared to glass or other optical transmission materials.





8. Atmospheric windows. Transmittance through 1,000 feet of atmosphere is high throughout the visible spectrum, but periodically falls to zero in the infrared region between 1 and 20 micrometers. Window from about 8 to 13 μm is region of special interest to equipment designers; it peaks at about 10.6 micrometers, which is also the wavelength of the CO_2 laser.

production more than compensates for these limitations in many commercial and industrial electro-optic systems. The most popular plastics—acrylic, polystyrene, and polycarbonate—transmit over the entire visible spectrum, and some plastics become transparent again at the very long infrared wavelengths past 50 to 100 μm.

Widening the window

Since glass and plastic are opaque to ultraviolet wavelengths below about 350 nm, more exotic window materials must be found for equipment operating in the ultraviolet region. For this purpose, fused quartz, sapphire, and lithium or magnesium fluoride are commonly used.

Fused quartz passes ultraviolet wavelengths as low as 180 nm, besides being transparent at all visible wavelengths. It is relatively inexpensive and is commercially available from several manufacturers. Sapphire (Al_2O_3) and lithium fluoride (LiF) are more expensive. Sapphire is the most abrasion-resistant of all windows and has good ultraviolet transmitting properties to 180 nm, and lithium fluoride is most attractive for applications requiring transmittance at wavelengths down to about 104 nm.

As for far-infrared wavelengths beyond about 4 μm, one optically good material is sodium chloride, NaCl. Windows or lenses made of NaCl transmit IR wavelengths to a little beyond 20 μm, but because they absorb moisture from the air, must be frequently replaced or stored in dessicators to keep them dry.

A more durable group of IR transmission materials is the commercially available line called Irtran, developed by Eastman Kodak Co. The spectral transmittance of these materials is approximated on the foldout chart, and they are made of MgF_2, ZnS, CaF_2, ZnSe, MgO, and CdTe respectively for Irtran-1 through Irtran-6.

Other infrared-transmitting materials include barium fluoride, cesium iodide, and thallium bromide. Barium fluoride is often used in systems operating at 10.6 μm, the wavelength of frequently used CO_2 lasers. Cesium iodide and thallium bromide both transmit at wavelengths to about 50 μm.

Atmospheric properties

Depending on its wavelength, light energy is selectively scattered, absorbed, or refracted as it passes through the earth's atmosphere. These effects can be severe in optical communications, infrared radiometry, and, in fact, viewing by the human eye, whenever the atmospheric path extends more than just a short distance.

For gas molecules and particles that are extremely small in relation to the light wavelength, the degrading process is known as Rayleigh scattering. Such scattering is the cause of the blue of the midday sky and the red of sunsets. Rayleigh scattering is wavelength-dependent, increasing with shorter wavelengths, and it has a negligible effect on infrared wavelengths longer than about 1 μm.

For larger aerosol particles, the process is called Mie scattering and is relatively independent of wavelength. The nonselective nature of Mie scattering is what makes fog and clouds appear white. Its effect on visibility is to reduce contrast to the point where an object's outline can no longer be resolved. Visibility in haze, then, is commonly defined as the distance at which contrast is reduced below 2%.

Attenuation through the atmosphere is never constant. It depends on such parameters as temperature, pressure, and amount to water vapor and other impurities. However, a typical attenuation as a function of wavelength is shown in Fig. 9. The attenuations shown are for a 1,000-foot atmospheric path, at sea level, containing relatively little moisture and impurities. The curve identifies the important atmospheric window in the visible region from 400 to 700 nm. It also shows the 6-μm-wide window centered at about 11 μm, which is of much current interest to infrared systems designers.

Tight fit

In conclusion, it's interesting to note the relationship between the (humanly speaking) most important source, detector, and transmission medium found in nature. The peak spectral output of the sun (about 555 nm) coincides with the center of a major optical window in the earth's atmosphere. The peak response of the human eye is conveniently adapted to this wavelength. ☐

ACKNOWLEDGMENT
Electronics gratefully acknowledges the assistance of the numerous individuals, especially technical staff members at Bell Telephone Laboratories, Murray Hill, New Jersey, and at RCA's David Sarnoff Research Center, Princeton, New Jersey, who provided inputs for this report and the foldout chart that follows.

FIBERS
Simple testing methods give users a feel for cable parameters

by R.B. Chesler and F.W. Dabby
Fiber Communications Inc., Orange, N.J.

Mechanical as well as optical charcteristics play an important part in the design of optical-fiber systems. In particular, it's necessary for the designer to understand how to prevent mechanical stresses from breaking fibers or causing too much attenuation and how to check cable parameters like tensile strength, attenuation, and numerical aperture.

The risk of breakage is perhaps the major concern of the optical-fiber user, though the availability of cabled fibers has certainly made it less of a worry. Basically, fibers break under too heavy an axial load or when bent in too small a radius. The two breakage modes are related, and determining one breakage point sets the level for the other.

Stress levels

From the cross-sectional area of the fiber and the minimum safe bending radius, the maximum load bearing capability of an unjacketed, uncabled fiber can be calculated. Increasing a fiber's cross-sectional area makes it stronger but also, by increasing its radius, r, limits its minimum bending radius, R_{min}, before breakage. The relationship describing this tradeoff is:

$$S_T = E(r/R_{min})$$

where E is Young's modulus, typically 10^7 psi.

For an uncabled low-loss fiber, which consists of a core and cladding to protect the core material, a reasonable maximum tensile load-bearing level, S_T, is 50,000 pounds per square inch for about a 1-km length. The tradeoff of tensile strength with minimum safe bending radius usually limits the diameter of commercially available fiber to between 2 and 8 mils. A 3.5-mil uncabled fiber, for example, can be tied into a circle less than 3/16 inch in radius.

One common method of measuring the tensile strength of uncabled fiber is to clamp a length of fiber at both ends and measure the load needed to break the fiber. This method has the advantage of stressing the entire length of fiber between the clamps. Considerable care, however, is required to assure that clamping or misalignment of the clamps does not cause premature failure of the fibers under loading.

If the necessary stress-measuring equipment isn't available, an alternate approach yields usable data. In this method the fiber is tied into a simple overhand knot. Then, as the knot is tightened, the resulting circle is monitored. The minimum safe radius occurs just before the fiber breaks. From this value and the fiber radius the maximum tensile load-breaking ability of a fiber can be easily calculated from the above equation.

Cabling each fiber individually increases its load-bearing capability. At present, several materials are commercially available for cabling low-loss optical fibers in fiber-bundle, multi-fiber and single-fiber cables. Currently, single-fiber cables with diameters as small as 1/20 in. can withstand tensile load-bearing levels of 475 pounds—better than some multiple-fiber and fiber-bundle cables.

Besides fiber breakage, bends cause losses. They increase the attenuation by reflecting out of the fiber core some of the many light modes that should propagate within it. As these modes encounter a region of bends in a fiber, they enter the core-cladding interface at a larger angle than the one critical for total internal reflection.

The leakage becomes more pronounced as a fiber-core diameter increases or as numerical aperature decreases. But reducing the core diameter to minimize bending loss results in less light being coupled to the fiber—coupling efficiency being proportional to the square of the core diameter. Increasing the numerical aperture also decreases bending loss, but reduces the information-carrying capacity of an optical-fiber waveguide.

In general, commercially available, low-loss optical fibers with glass core and cladding have numerical apertures of between 0.1 and 0.3. Commercial fibers with higher values of numerical aperture have higher attentuation, which in the case of glass-core, plastic-clad fibers, increases drastically in humid or watery environments.

Flat finish

Optical polishing of fiber ends is used only for terminating fiber bundles (see p. 99 and p. 101). With single-fiber cable, cleaving the ends is fast and easy and all that's necessary. Properly cleaved surfaces are flat and perpendicular to the fiber axis and are well suited for coupling to sources and detectors or to other lengths of fiber.

The first step in cleaving a fiber end is to remove any cabling or jacketing material from 3 or 4 inches of fiber. Next the bare fiber is grasped at two points, about half an inch apart, between the thumb and forefinger of each hand. This half-inch section is held taut and gently drawn across the hard edge of a suitable scribing surface, such as a sapphire crystal, so as to scratch the glass fiber but not break it. Then a gentle tug will snap the fiber at the scratch. The fiber must be pulled straight without any bending.

The quality of the cleaved surfaces is then checked under a microscope. A good cleave also produces a circularly symmetric output light pattern when light from the fiber viewed on a screen about a foot away.

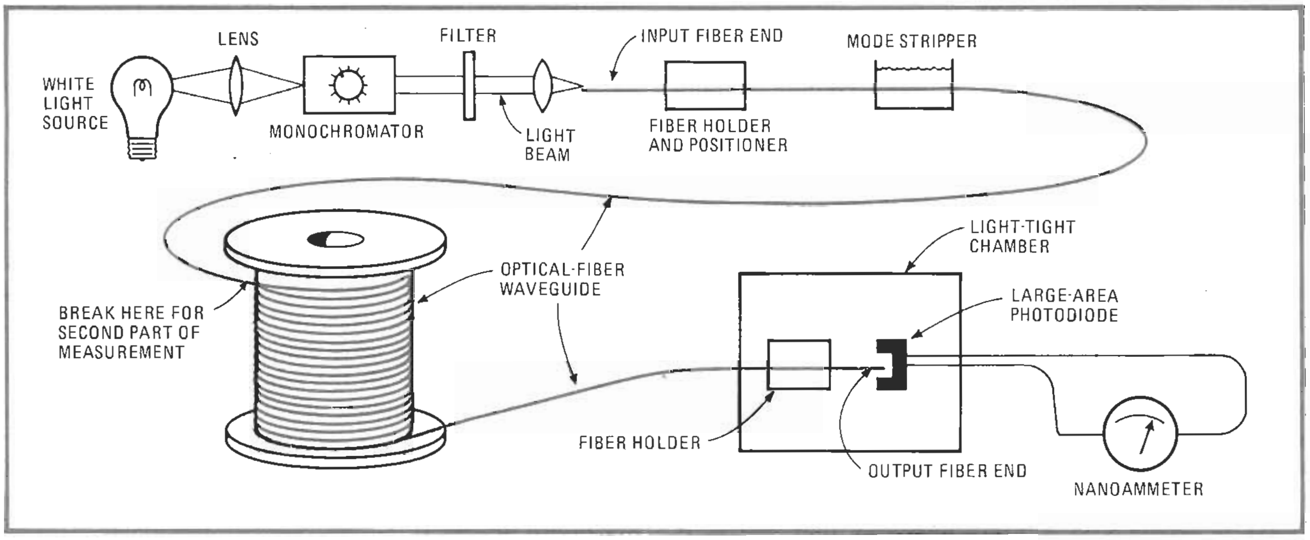
The cleaving technique works well for fiber diameters up to approximately 5 mils. Fibers with larger diameters must be bent around a mandrel and cleaved under tension. Simple instruments and tools for fiber cleaving are available commercially.

Looking for loss

Comparing the magnitude of transmitted light power at two points along a fiber waveguide eliminates the need for measurements of absolute optical power and light coupling efficiency. The typical setup shown in Fig. 1 makes it possible to determine the attentuation spectrum over an entire length of fiber.

Both ends of the entire length of optical fiber, L, to be evaluated are cleaved. One end is mounted in a movable holder, which is later adjusted to maximize the light input to it, and passed through a mode-stripping liquid placed near the input measuring point. Mineral oil or any other liquid with a refractive index close to that of the cladding (between 1.42 and 1.47) may be used. Doing this eliminates the unwanted "cladding" modes—those launched into the fiber because the numerical aperture of the input light beam is greater than the fiber's numerical aperture. This arrangment gives a fairly uniform illumination of all the desired fiber waveguide modes.

The other end of the fiber is placed into an output holder near a detector located in a light-tight chamber. The fiber holder at the input end of the length of cable is then adjusted to maximize detector current as read on the nono-ammeter, and the maximum amount of photodetector current for each wavelength of interest selected



1. Finding fiber loss. This test setup makes it possible to find the attenuation of a long length of fiber directly, without having to worry about measuring either the absolute optical power of the source or the efficiency of the light-coupling arrangement.

by the input monochromator is recorded.

To obtain a consistent set of maximum readings at the desired wavelengths, several readings must be taken, with the fiber being recleaved at the detector end after each reading to eliminate inaccuracies caused by bad cleaves, dust particles on he fiber end, etc. Isolated low readings will occur because of imperfectly cleaved fiber ends, and these should be discarded.

The fiber is then cut about 3 meters from the input end of the fiber without disturbing the positioning of the input end so that the same coupling is maintained. The cut end of the 3-meter-long section is then cleaved and placed into the output fiber holder. Again, measurements at other wavelengths of interest are repeated to obtain another set of consistent data. From these two sets of data, the attenuation, A, expressed in dB/km, of the entire fiber length less 3 meters is calculated for each wavelength:

$$A = (10 \log_{10} f)/L$$

where L is the final length of fiber in kilometers less the 3-meter section that was cut from the initial length of cable, and f is the ratio of the measured input optical power to the measured output optical power of any particular wavelength of light. For cables longer than several hundred meters, L can be assumed to be the initial cable length.

The numerical aperture of an optical fiber waveguide describes the maximum angle about the fiber axis through which light can propagate in the fiber. It is defined as the sine of the half-cone angle of the rays measured in air, and it generally varies with fiber length, because of fiber attenuation characteristics that modify the initial distribution pattern of the light.

Numerical-aperture measurement

Most manufacturers specify the numerical aperture of low-loss fibers by measuring the radiation pattern of a 3-meter-long fiber with all modes excited. This can be done simply and without elaborate equipment. The fiber is excited in the visible region, and the light emerging from the end is displayed on a screen placed several inches to a foot away. A solid circle of light is seen if all fiber modes have been excited; if not, a ring of light results.

Since the boundary of the circle of light is not perfectly sharp, some convention for determining the edge must be adopted. A common choice is the point where the light intensity is 10% of the maximum value. Actually the eye makes a good discriminator, and all that need be done is to measure the diameter or the circle of light with a ruler. Dividing that number by twice the distance from fiber end to the screen gives the value of numerical aperture.

COUPLING

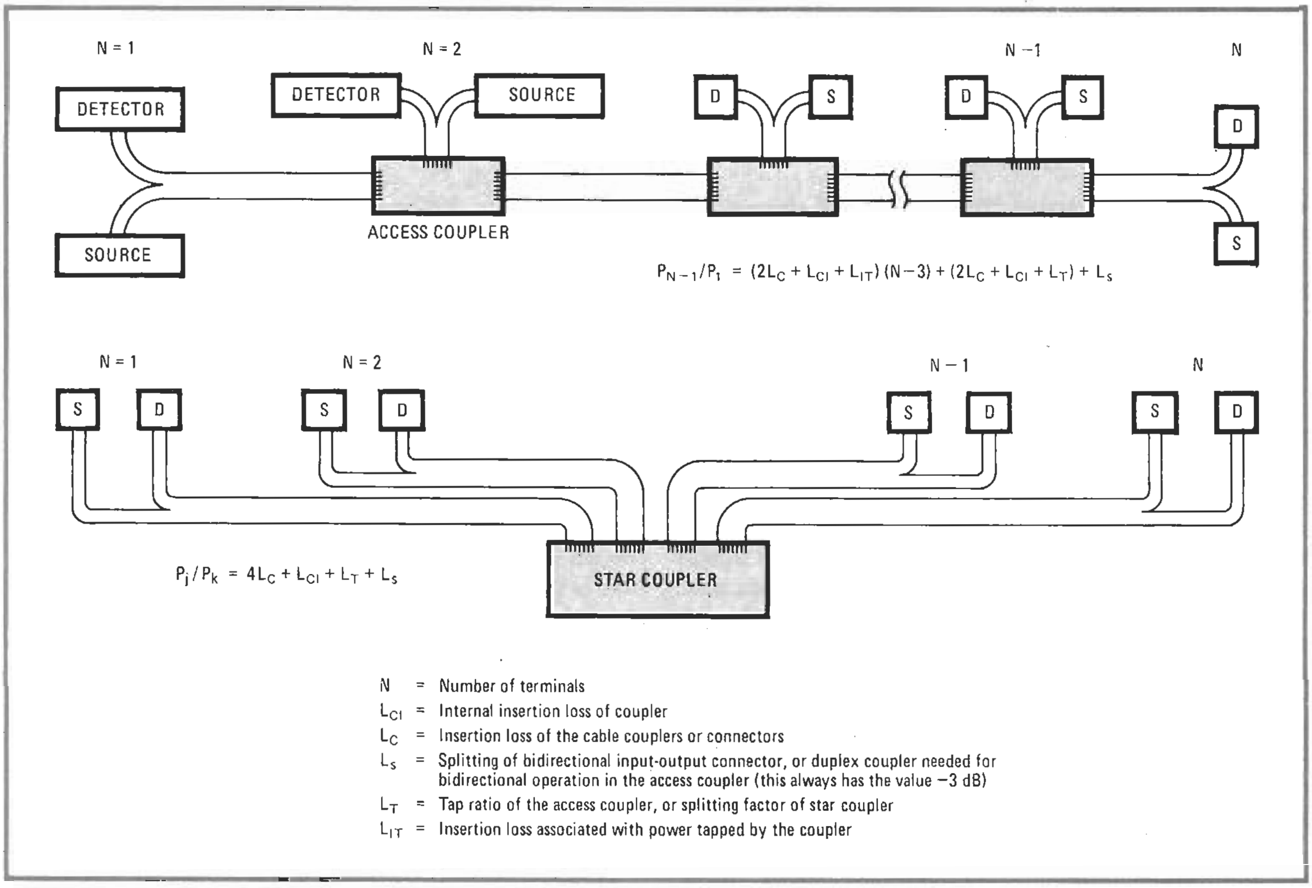
In systems with 20 or more terminals, star couplers outperform 'tee' types

by M. K. Barnoski
Hughes Research Laboratories, Malibu, Calif.

In a multiterminal fiber-optic communications network, light signals have to be tapped at intermediate points along the data bus. The problem is how to tap them most efficiently.

Currently, two fiber-coupling configurations are used for such data-distribution systems, one employing access or "tee" couplers and the other using a radial-arm or star coupler. The equations in Fig. 1 enable their performance to be compared in terms of the loss introduced between pairs of remote terminals by the distribution system itself. These equations show that, in a serial system with access couplers having a constant tap ratio, the optical power decreases as the signal travels through more couplers, while in a parallel system using a star coupler, the optical power is independent of the pair of system terminals being considered.

The distribution-system losses (omitting fiber loss) for both serial and parallel configurations are plotted as a function of the number of terminals in Fig. 2. Several different sets of parameters were employed for each format, including the use of multimode-fiber bundles as well as single multimode fibers. As a limiting case, curves are included for both parallel and serial systems when all couplers and connectors are assumed lossless. In



1. Coupling comparisons. The difference in performance between a serial distribution system and a parallel system is partly due to the terminal-to-terminal loss introduced between pairs of remotely spaced terminals by the distribution network itself.

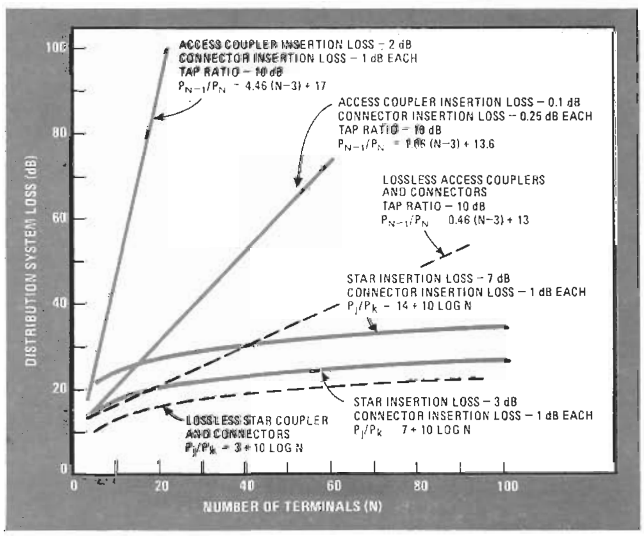
this idealized case, the distribution-system losses result only from dividing power among the various terminals.

The comparison clearly shows that, as the number of terminals in a system increases, the distribution losses of the serial format grows rapidly while those of the parallel format increase only gradually. This signal-level advantage further increases as higher-insertion-loss cable connectors and the access couplers are used, but is relatively insensitive to insertion loss of the star coupler. In a serial system based on fiber bundles, the minimum access-coupler and connector-insertion loss will be limited by the packing-fraction loss of the bundled fibers. As a result, the steep curve plotted in Fig. 2, which uses an access-coupler loss of 2 dB and connector-insertion loss of 1 dB, is very close to what can be expected from fiber bundles having good packing fractions.

Nevertheless, with low-loss connectors and couplers for single fibers, serial-distribution systems should be able to handle at least 20 remote terminals without consuming an unreasonable proportion of the available power budget. For fewer than 20 terminals, the power savings achieved by the star system are not so very large.

However, as more terminals are added and use more of the available optical power budget, the picture changes. Receivers in a serial system must have not only a large dynamic automatic-gain-control range, to handle both strong signals from adjacent terminals and weak signals from remote terminals, but also low enough noise levels not to degrade the weak signals.

Since the parallel system needs only a single mixing point, it doesn't suffer signal-level or dynamic-range problems. The more constant signal level available with parallel systems minimizes the complexity of both trans-



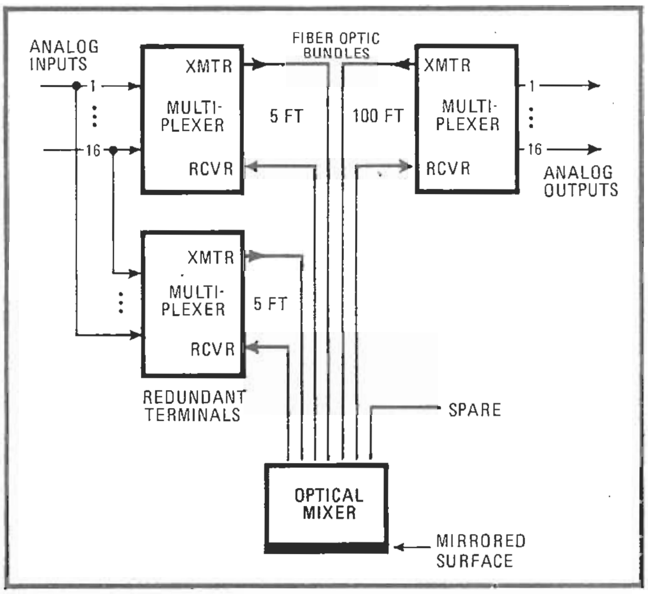
2. System losses vary. Several sets of parameters were used to plot the distribution-system losses as a function of the number of terminals. In the idealized case, distribution losses result only from the splitting power among various terminals.

mitter and receiver design. But the cost of this uniformity is offset by the additional amount of fiber cable needed. The star-coupled data bus, in essence, shortens the main bus length to a single-point mixer, but extends the length of each terminal arm.

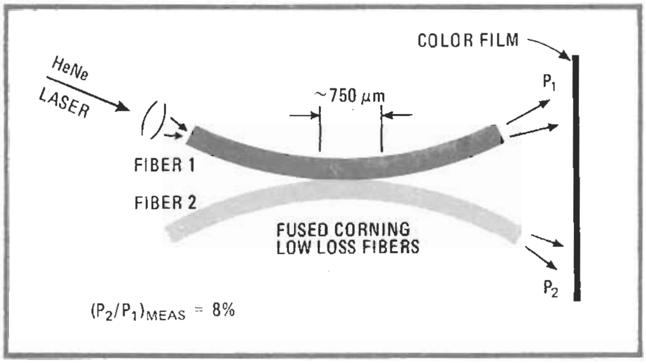
A star coupler or optical mixer was basic to a prototype, fiber-optic multiterminal aircraft data link for carrying flight control signals from cockpit to controls. The optical bus operated for the full duration of a 40-minute flight test aboard an Air Force C-131 aircraft without any detectable errors.

The system used three terminals (one for redundancy) to multiplex and demultiplex 16 analog electrical signals (Fig. 3). It was "wired" with Corning fiber bundles, each containing 61 multimode low-loss glass fibers loosely packaged in an extruded polyvinyl chloride jacket. Two of these bundles entered each terminal, one for the transmitter and one for the receiver. Maximum terminal-to-terminal spacing was about 100 feet, but since each terminal in the system monitored its own transmission, the longest path traversed by an optical signal was 200 ft.

Commercially available components were used: gallium-arsenide light-emitting diodes as sources, silicon p-i-n devices as photodetector/amplifiers, and modified BNC connectors for input and output coupling. Nominal optical output power incident on the receiver photodiodes was −28 dBm. Source power was about +11 dBm. Although the optical bus was designed for a 10-megahertz bandwidth, the actual information transfer rate was determined by other system considerations and



3. Flight-tested. A three-terminal redundant system for carrying flight control signals aboard a C-131 aircraft used a star coupler and seven fiber bundles to multiplex and demultiplex the 16 analog electrical fly-by-wire signals.



4. Mixing modes. One method of coupling light between single fibers is to bring the cores of the optical fibers so close together for a selected interaction length that the light modes of one fiber mix with those of the other fiber.

was only 0.5 megabit per second for all three transmission systems evaluated.

Although fiber bundles were used in this feasibility demonstration, a single-fiber configuration could service a network of 427 terminals (61 fibers times 7 bundles). For such a network, the distribution loss extrapolated from Fig. 2 would be 40 dB, assuming 1-dB cable connector loss and 7-dB star-coupler insertion loss.

However, in systems using a single fiber as a communication channel, it should also be possible to use serial distribution of data, since packing fraction loss is no longer a factor. Of course, adequate techniques of coupling between single fibers would first have to be developed.

One possible approach to fabricating such an access coupler (Fig. 4) parallels the techniques used in integrated optics. In essence, two multimode fibers are laid side by side and fused together for part of their length, and this fused region subverts (as it were) the tendency of each to keep all its light to itself. For in this situation, since light propagates in these fibers in many modes, the modes in one fiber mix with those in the other, producing coupling between mode groups. The exact degree of coupling is determined by the core-to-core spacing and the interaction length (the fused region). When one end of one fiber was excited with a laser beam, radiation was observed from the opposite ends of both fibers. For the coupler used in this experiment the ratio of power emitted from the access channel fiber to that of the main channel was 8%.

It's worth noting how neatly this approach avoids the need for the critical mechanical alignment tolerances that are essential in access couplers using conventional optical components like lenses and beam splitters. In fact, several research laboratories are currently investigating fabrication processes for such a "tee" fiber coupler. The preliminary results indicate that the insertion loss of single-strand access couplers could come down to about 0.1 dB or 0.2 dB, so all that remains is to produce practical low-cost versions of these experimental devices. □

Well-designed splices, connectors must align fibers exactly

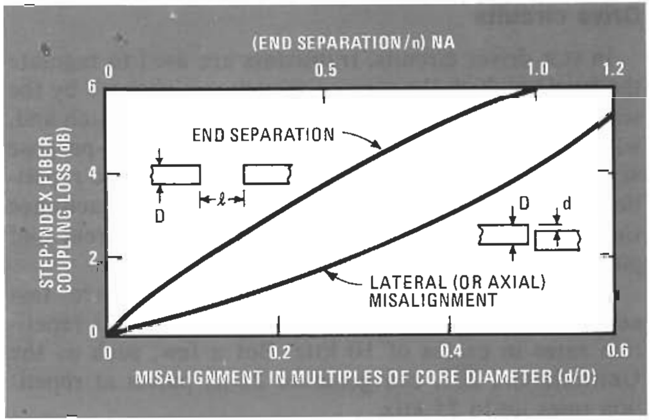
by J. F. Dalgleish
Bell Northern Research, Ottawa, Canada

Splices for joining lengths of optical-communications cable in the field must provide low-loss, quick but permanent connections, and also be small, lightweight, and rugged. Except for the permanency, the same requirements hold for the connectors that couple the cable to terminal equipment.

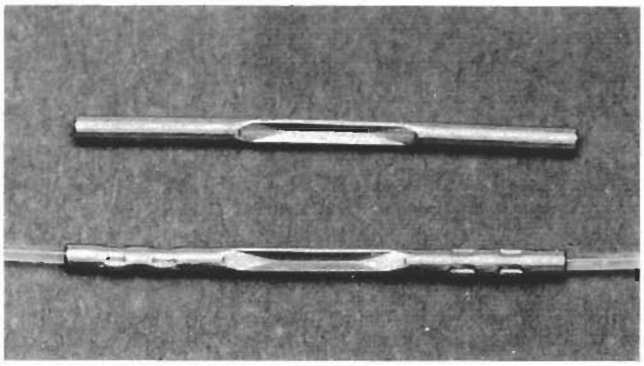
Single-fiber splicing losses of less than 0.1 decibel have been reported in the laboratory but have yet to be demonstrated in the field. Nevertheless, total splicing loss in a given length of fiber both can and should be much less than the fiber attenuation.

The most critical parameter, variously called axial or lateral alignment, is also one of the most difficult to control. Slight offset between the two fiber ends dramatically increases optical loss (Fig. 1). Alignment accuracy in the order of micrometers is needed, thus requiring similar machining tolerances of the associated hardware.

One splicing technique in widespread use is the preci-



1. Fiber offset causes loss. Any slight offset between two fiber ends increases optical coupling loss. An axial displacement equal to half the fiber core diameter causes greater than a 4-dB loss; separating the fiber by that amount produces a 6-dB loss.



2. Fiber guide. A precision sleeve or tube that conforms exactly to the outer fiber diameter positions both fibers. Once both fiber ends are butted together in the splice sleeve, the sleeve ends are crimped into the fiber's plastic coating.

sion sleeve or tube, which, by conforming precisely to the outer diameter of the fiber, guides it into position and then holds it there. This requires individual handling of fibers and is most suitable for single fibers or small cables. Sleeves may be of metal or glass, and an entrance funnel aids fiber insertion. Once the fiber ends are prepared and the two fibers butted together in the splice, the outer jacket of the fiber is clamped or, in some cases, a metal sleeve is crimped around it.

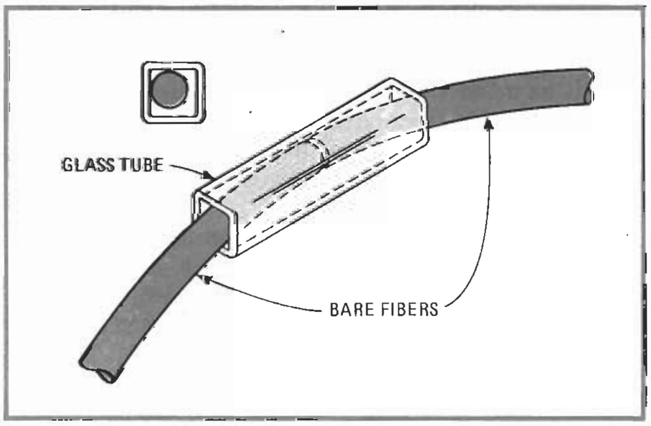
A fiber splice developed by Bell Northern Research is based on this technique (Fig. 2). A stainless steel preform tube has a center alignment bore that fits the bare fiber diameter closely. The prepared fiber ends are guided into the alignment bore by tapered sections, and the ends of the splicing element are then crimped into the fibers' plastic coating for permanent assembly. Because the plastic coating extends inside the tube, no other mechanical protection is needed. With a silicone fluid pre-injected into the splicing element, insertion losses average 0.3 decibel from a LED source.

Another technique reported by Bell Telephone Laboratories—the loose tube splice—may be suitable for field use because it uses inexpensive components. It exploits the self-aligning tendency of fibers in a "V" groove (Fig. 3). Prepared fiber ends are inserted into a rectangular tube already filled with index-matching epoxy. The fibers are slightly bent, forcing the tube to rotate so that their ends travel along a corner. Once butted together, the ends are held in place until the epoxy cures. Losses average about 0.1 dB when a laser source is used.

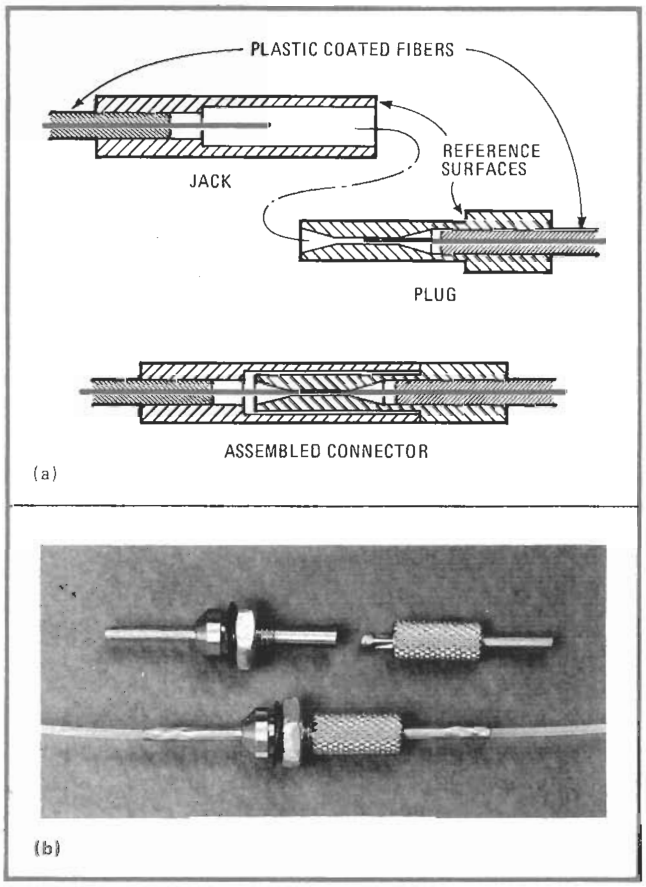
Connectors have an added requirement: they must be able to mate repeatedly without degrading too much in coupling efficiency or mechanical integrity. They should also be simple to use, like electrical connectors.

A single-fiber connector, developed by Bell Northern Research for use with plastic-coated multimode fibers, is a variation in the precision-sleeve splicing element (Fig. 4). The connector plug has tapered funnels at each end leading into a central alignment bore (the only critical dimension). The longitudinal position of each fiber is accurately located with respect to a reference surface on each housing. This is done using a special fixture. Both the plug and its mating jack are mounted separately on a fixture, and prepared fiber ends are inserted into each connector half until they butt against the fixture's stops. Crimping the stainless-steel tubing into the fibers' plastic coating holds them firm. When mated, the reference surfaces are in contact and the fibers are separated by a small gap.

During mating, the fit between plug and jack insures that the jack fiber enters the tapered opening of the plug. Once mated, the plug and the jack are



3. Self-aligning. The loose-tube splice, as it's called, makes use of the self-aligning tendency of the fibers. When the fibers within the tube are slightly bent, the tube rotates, holding the fiber ends in place until an epoxy positions them permanently.

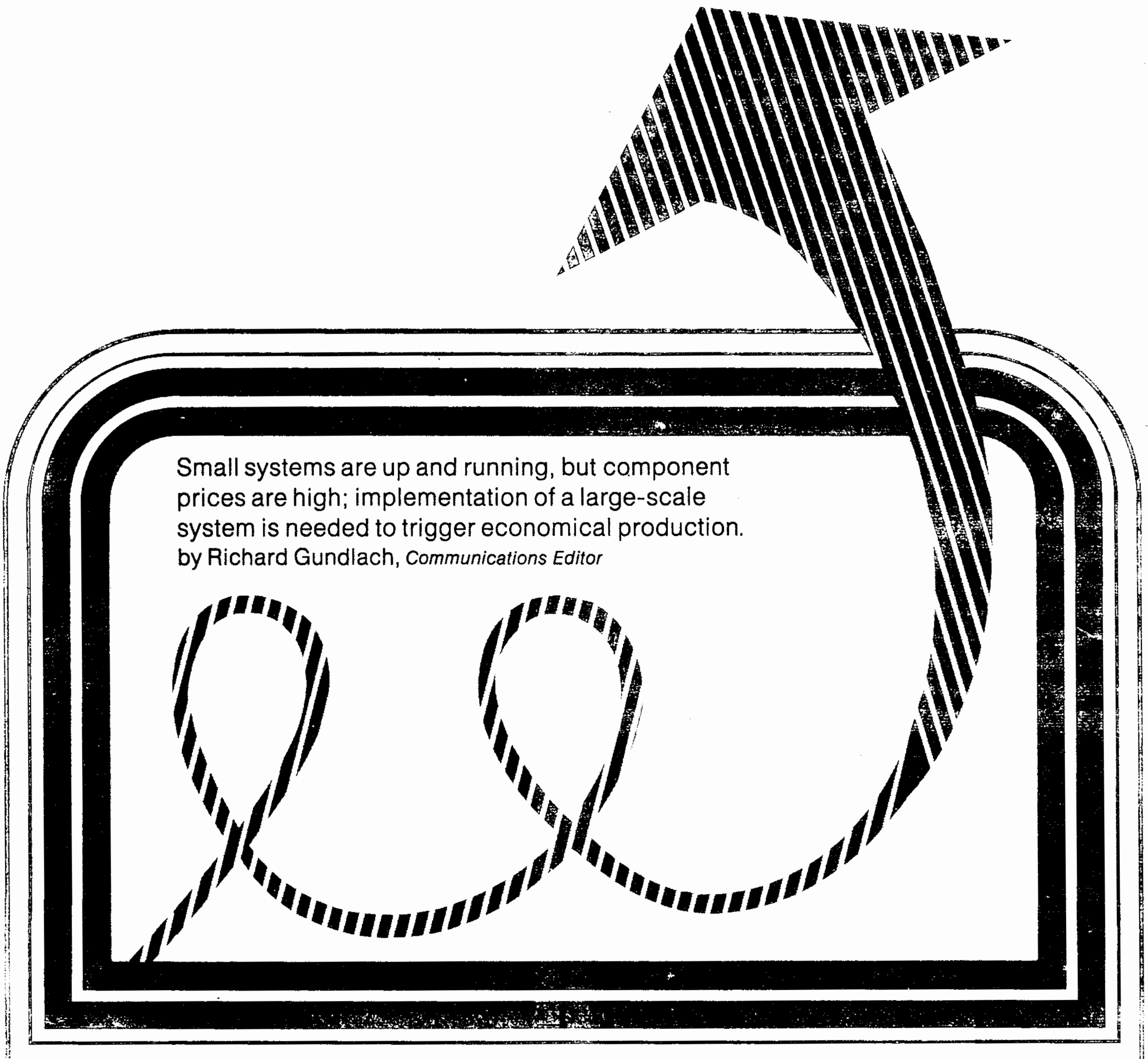


4. Variation on a theme. Bell Northern Research's single-fiber connector adapts the precision-sleeve splicing principle. Once mated, the connector is only 2 centimeters long and, when unmated, the plug and jack housings protect the fiber as shown.

held together with a knurled coupling nut (a bulkhead panel mount is provided on the jack). When unmated, the housing configurations of both the jack and plug sections are such as to protect the fiber ends.

Typically, rematable insertion loss of the connector is 1 dB when an index-matching fluid and a LED source are used. Smaller losses have been reported with experimental connectors, but this device is more practical, in that its standard-diameter alignment bore can accommodate manufacturing tolerances in fiber diameter. When installed in prototype fiber-optic systems, both with and without index-matching fluid, these connectors showed typical insertion loss variations of less than 0.2 dB, after being remated up to 100 times.

FIBER-OPTIC DEVELOPMENTS SPARK WORLDWIDE INTEREST



Small systems are up and running, but component prices are high; implementation of a large-scale system is needed to trigger economical production.

by Richard Gundlach, *Communications Editor*

□ The advances made in the last year in fiber-optic communications have delighted even the most optimistic. New systems have done better than expected in rigorous field trials. Improved components—more efficient light sources, less noisy photodetectors, and more rugged cables—have become available off the shelf. Single-fiber cables, plus matching connectors, are starting to surface, while production techniques are attracting the kind of attention that's the due only of nearly mature technologies.

Commercial applications, in fact, have leapt into prominence, both in the U.S. and overseas, and the military remain as dedicated as ever to the pursuit of the interference-free, lightweight attractions of fiber-optic systems. For the time being, to be sure, cost remains a problem. Other difficulties include a lack of standards (though several groups are already at work in this area) and the unfamiliarity of the wider engineering community with such a new technology. However, there seems to be no doubt that by the 1980s optical fibers will often be a practical alternative to copper wire.

When that time comes, one of the major fiber-optic users will be the telephone system, and John deButts, chairman of AT&T has apparently firmly committed the Bell System to developing fiber optics. "I anticipate that by the early 1980s cables of glass fibers will be carrying thousands of simultaneous messages between major switching centers in our cities," he recently stated. The fibers not only offer large bandwidths for such multichannel transmissions but, more important initially, they easily interface with existing telephone equipment. With their lower losses, too, repeaters can be more widely spaced than is possible with present conductive-cable systems. This aspect is also attractive to Bell Canada. It will probably use fiber optics to obtain repeaterless connections between telephone exchanges, according to W. C. Benger, group vice president of Northern Telecom Ltd., a major supplier to the Canadian telephone company.

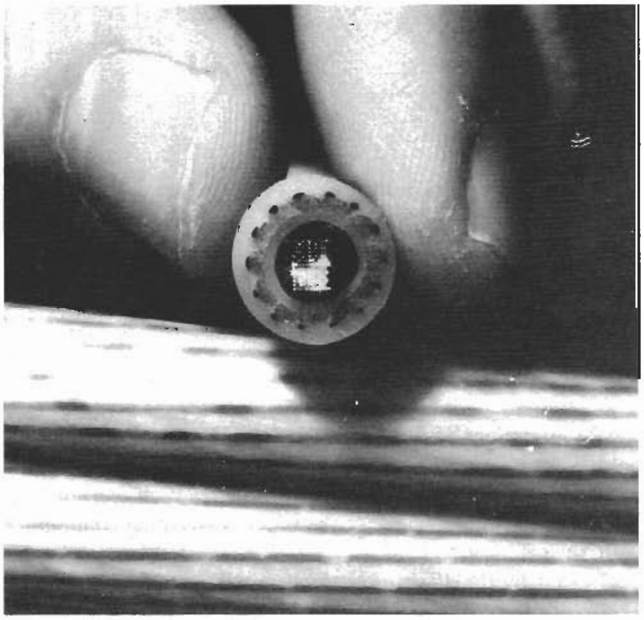
For large data-processing systems, on the other hand, the large bandwidth capability and the freedom from electromagnetic interference are perhaps the biggest attractions of optical-fiber cable, which is already being used to link central processors to peripherals. The absence of the spark hazards of electrical signals will be a major asset in many industrial processing applications. Other applications will be won over, eventually, by the cost savings of glass fiber over coaxial cable.

In sum, the appeal of fiber optics is multifaceted and could (say the top analysts) rocket demand to billion dollar heights before the 1980s are out.

The actuality

This vision of the technology's future gains substance from several systems already in existence, particularly an experimental fiber-optic telephone link started by Bell in Atlanta, Georgia, last January. There, a team from Bell Laboratories and Western Electric managed to put together, using as many as 18 low-loss splices, a 10.9-kilometer repeaterless link. The system encountered no problems when transmitting data at 44.7 megabits per second. Average loss of the cable when in place was 6 decibels/km—2 dB better than the design goal. The experiment proved that it's possible to run fiber-optic links long enough to avoid the need to put repeaters in manholes every mile or so, as is necessary with coaxial-cable systems in large metropolitan areas like New York or Chicago. Just as important, the link interfaced successfully with existing telephone equipment, as the technology will have to do when it first enters the present telephone network.

Also eliminated by the experiment was the uncertainty whether practical connectors could be produced to splice together

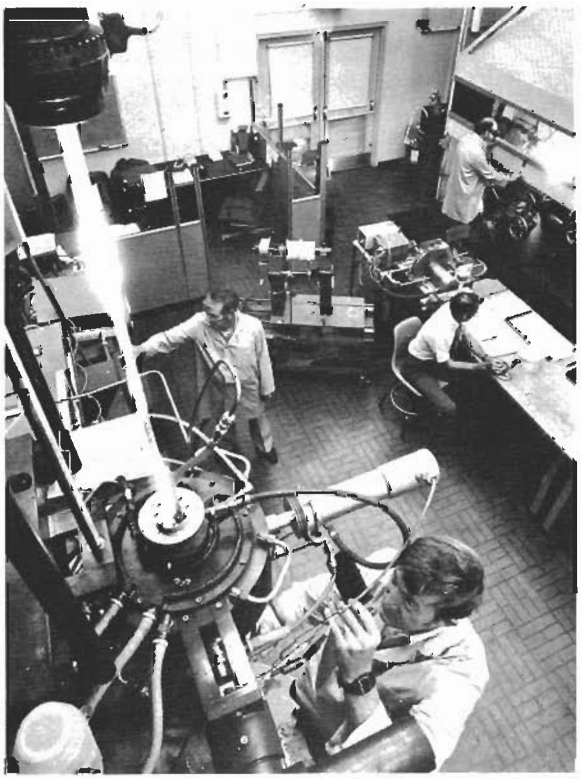


1. Looking into fibers. The optical-fiber cables used in Bell's field experiment in Atlanta are only half an inch in diameter, yet their 144 fibers operating at a 44.7-Mb/s data rate can carry the equivalent of over 48,000 simultaneous telephone conversations.

Making fibers

A Western Electric pilot production line for optical fibers is already in operation. Making the fibers takes several hours, and the slightest variation in the process at any point renders the fiber unusable. First, oxides are deposited by chemical vaporization on the inside of a 3-foot-long tube of quartz glass, called a preform (shown upper right). Next, the preform is collapsed and pulled into a hair-thin optical fiber. A torch heats the preform as it moves at a preset rate. This builds up the several core layers of germanium-doped silicon dioxide that are needed to produce the varying refractive index of a graded-index fiber.

These high-silica-content glass preforms are then softened in a furnace (shown upper left) and pulled under slight tension into thin glass fibers. The pure fibers are coated before reaching the take-up reel with a polymer to preserve their strength. Although glass in the pure state is stronger than steel, any impurities that touch it before the protective coating is applied degrades its strength considerably.



in the field cable containing 144 separate fibers, each a mere 2 mils in diameter. The answer was a kind of club sandwich connector, with a dozen 12-fiber ribbons as the filling and 13 precisely grooved aluminum chips as the slices of bread.

Another fiber-optic system carries television signals. TelePrompTer Manhattan Cable Television Cable Inc. just recently installed an 800-foot fiber-optic link to carry cable TV signals from a roof antenna to its head-end equipment 34 floors below. And General Telephone and Electronics Corp. is firming up plans for its scheduled field trials later this year that will carry actual commercial voice traffic between operating telephone exchanges in California. It will use cable made by General Cable Corp. of Greenwich, Conn.

Over in France—to focus on just one major overseas application of fiber optics—the Centre National d'Etudes des Télécommunications has already completed one experimental digital transmission system. (It's the start of an ambitious effort to develop the hardware and systems know-how that the government-run telephone network will need for the fiber-optic links it plans to have in full service by the mid 1980s.) The CNET's first optical system used 3 km of Corning fibers and, after running for some 20 months at 2 Mb/s, has been modified to accept data at 8.4 Mb/s. Now the CNET also has parts of a 3.4-Mb/s system working and hopes to have firm specifications for its first trial system by early 1978, with operation starting in 1980.

Nor have the military, back in the U.S., been idle. All three services were from the beginning attracted by the small size, light weight and freedom from interference of optical fiber—all major concerns aboard aircraft or ships or for secure tactical and strategical links under water or on land. The Navy and Air Force naturally concentrated on data busing for signal transmission in aircraft and on ships, while the Army is concerned mostly with secure land communications links.

More specifically, a fiber-optic sonar link recently underwent trials aboard a submarine [*Electronics*, May 27, p. 39], while a fiber-optic telephone system has now operated without failure in the fiber-optic portion for three years aboard the U.S.S. Little Rock. "Fiber installations have proved very successful," sums up Don Williams, program manager at the Naval Electronics Laboratory Center in San Diego.

Williams estimates that the 450 pounds of copper wire now used in fighter aircraft could be replaced with only 50 pounds of fiber cable. In the Navy A-7 aircraft, for example, 13 optical-fiber cables have supplanted 115 wire signal channels representing 302 separate conductors, almost a mile of electric cable being replaced with only 224 feet of fiber. Williams also points to the fiber-optic link used between antenna and transceiver of the AN/PPS-18, a general battlefield-surveillance radar. "If funding comes through, this would be the first military system to go into production using fiber optics."

As for the Army, its budget for fiber-optic development in fiscal 1977 has increased "significantly" over last year, according to Larry Dworkin, acting chief of advanced techniques at the Army Electronics Command, Fort Monmouth, N.J. He points to several contracts they are close to letting—one for field-deployable optical-fiber cables for use in ground tactical and strategic telecommunications, and another to develop connectors for six-fiber cables that can withstand the rigors of military environments.

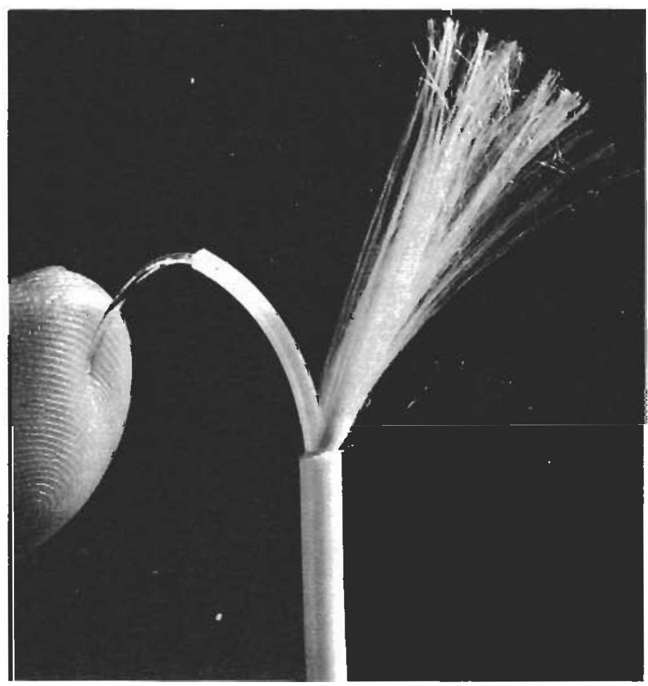
According to Dworkin, RCA has a contract with the Combat Surveillance and Target Acquisition Laboratories to investigate high-radiance light-emitting diodes and lasers operating in the 820-nanometer range that is typical of fiber-optic systems. He also adds that the Army is about to embark on its first major production-type commitment—an investigation of methods of manufacturing light sources (LEDs and lasers) and photodetectors (silicon p-i-n diodes and avalanche photodetector devices).

Meanwhile, the Air Force is developing, among other things, multiple fiber-optic systems with optical switching at data rates of less the 50 Mb/s.

Great growth

It's as a result of this kind of work that fiber optics has aroused industrywide interest. Individual applications, particularly in computers, will be described later. Overall, so encouraging are the signs that Gnostic Concepts Inc., a Menlo Park, California-based market-research firm, is predicting that the world market for fiber-optic systems will grow to over \$1.58 billion by 1990. Jeff D. Montgomery, Gnostic's vice president, foresees initial growth in applications where the unique advantages of fiber optics justify its slightly higher price. But within the next decade or so he predicts an explosive growth in the use of optical components in production systems. "In the U.S. this number should reach \$64 million by 1980 from a little over \$1 million in 1975, and should jump to \$833 million by 1990," says Montgomery. At that time he sees the major markets as follows: commercial communications will account for 74% of those applications, up from 54% in 1980; commercial computers, although dropping from 17% in 1980 to 9% in 1990, will have a much larger volume, and the market for industrial process control will remain steady at 7%, but again this will account for increased dollars.

Martyn F. Roetter, technical director of Arthur D. Little Inc.'s program on optical technology and markets, pretty much agrees with the major growth areas singled out by Montgomery. However, he points out that much of what happens worldwide



2. Flexible fiber. Although most people think of thin glass fibers as extremely brittle, Du Pont's new pure-silica-core fibers illustrate the toughness possible—this 8-mil-diameter cabled fiber does not break even when bent in a radius of less than 0.125 inch.

will depend on the policy set by Bell in the U.S. and the telephone companies overseas. He thinks it will be 1981 before Bell is sufficiently convinced that fiber cables in the ground can last 20 years and implements such systems. However, he does see new computers introduced within the next several years and industrial control systems as nearer high-growth areas.

As part of its investigations, Arthur D. Little is developing digital and analog optical-fiber communications systems to carry voice, data and video signals for short-haul use. This the firm sees as the most promising near-term application of fiber optics. "We feel that the benefits and applications of the technology cannot be realized without a greater understanding and experience in design, construction, testing and total costing of such systems," says Herb Elion, Arthur D. Little's program manager. And, one might add, greater understanding and experience of the components of fiber-optic systems.

The components

Even though light sources and detectors, splices and connectors are essential elements in fiber-optic communications, it's been the optical fiber that has paced its progress. And only as the cost of the fiber becomes competitive with existing coaxial cabling, will fiber-optic technology really catch on, whether in systems that must perform well in high-voltage areas or in instrumentation linking remote sensors with central processing units, whether within mainframes of computers or in linking computers to peripherals in noisy environments.

For some high-performance applications even now, optical-fiber cable is preferable to existing coaxial transmission systems. For example, presently available coaxial-cable loss in a 100-Mb/s-system can be as high as 30 dB/km, whereas for the same bit rate a graded-index optical fiber has a loss of about 5 dB/km. Low-loss optical fibers with increased bandwidth capability in lightweight cabling make them ideal for communications links where crowded cable ducts now pose a problem—the lower signal attenuation allows longer cable runs before any signal processing is needed. In weight-sensitive applications, over a ton of wire cables can be replaced with fiber cables weighing less than 1% of that. Moreover, wherever miles of cable are used in conjunction with low-level digital signal transmission, electromagnetic interference becomes a horrendous problem. Here, interference-free optical fibers eliminate the costly transformer isolation and cable shielding needed for conventional wire conductors.

Different direction

With the rapid progress being made in fiber-optic technology, attention is shifting from the more theoretical aspects to operational and manufacturing problems. For example, the emphasis is now less on reducing the loss of fibers and more on the production of fibers with tighter tolerances and low-cost cables that are rugged in the field. A number of good, low-cost p-i-n detectors are already available, but the development direction is toward low-voltage avalanche photodetectors for more demanding applications. Still missing are economical light sources with long life, which are essential to all potentially major users, especially the telephone companies.

And one of the biggest problems is the scarcity of inexpensive yet reliable single-fiber-per-channel connectors suitable for use by unskilled workers in the field. Within the last year both metal- and plastic-shelled connectors have been available for bundle fibers, but only recently have commercially available single-fiber-per-channel connectors surfaced. These connectors are designed to couple fiber to fiber, fiber to source, and fiber to photodetector.

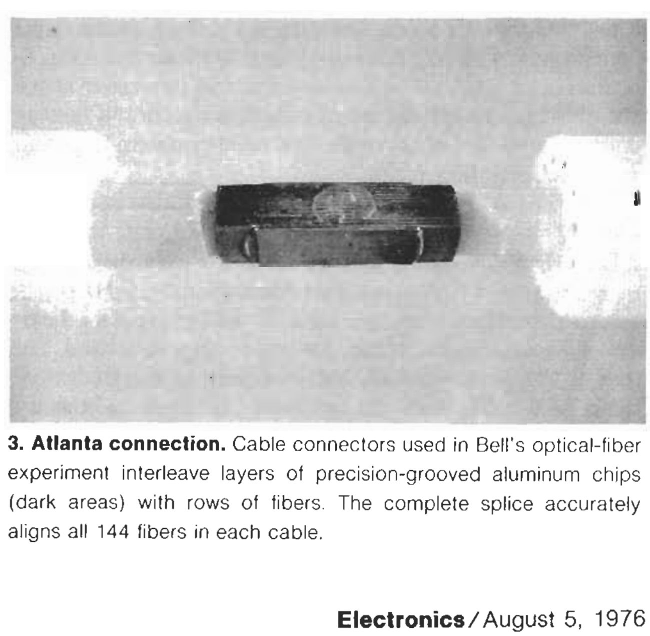
Setting standards

With the very small diameter of single fibers, connector tolerances in the order of 0.1 mil are required to keep losses low. This, in itself, creates production problems, but with fiber and cable dimensions not yet tight enough and the proliferation of different fiber sizes from many different manufacturers, most connector makers feel they cannot design inexpensive, practical devices until the fiber makers get together on some standard. That would have to involve companies such as Corning, ITT, Galileo, Valtec, Fiber Communications Inc., Du Pont, Polyoptics, and Fiber Optic Cable Corp., as well as several overseas suppliers.

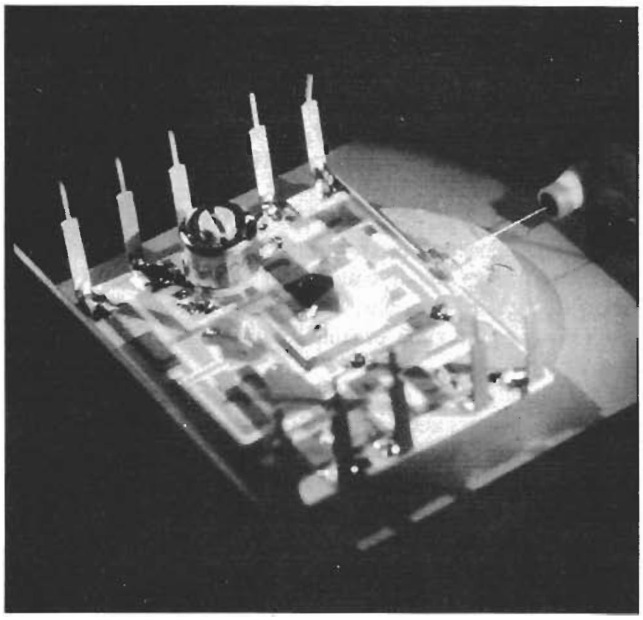
Sets of standards, in fact, are needed for all fiber-optic components, not just for fibers and connectors. Several agencies

Fiber optics in the car

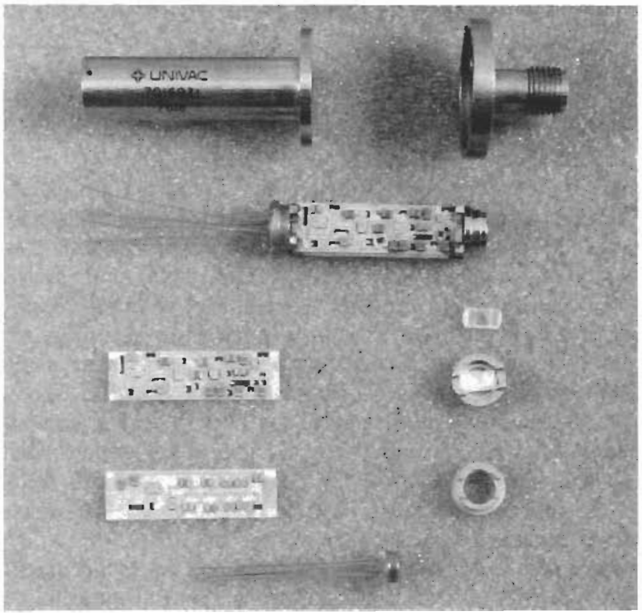
Fiber-optic communications systems are not only immune to the high noise levels of automobiles—they can reduce cabling harness weights, material cost, and processing time. An experimental fiber-optic harness system has been developed by General Motors Engineering to transmit vehicle control signals over a single-optical-fiber link, instead of over conventional wires. Such a system, perhaps built into the steering column or into a modified turn-signal control arm, would transmit separate signals over the fiber to an optical receiver, which would then convert them into electrical signals so as to switch on headlights or control turn signals, windshield wipers, and the hazard blinker. Such a system, once it passes the experimental stage, should open up a tremendous market for fiber optics.



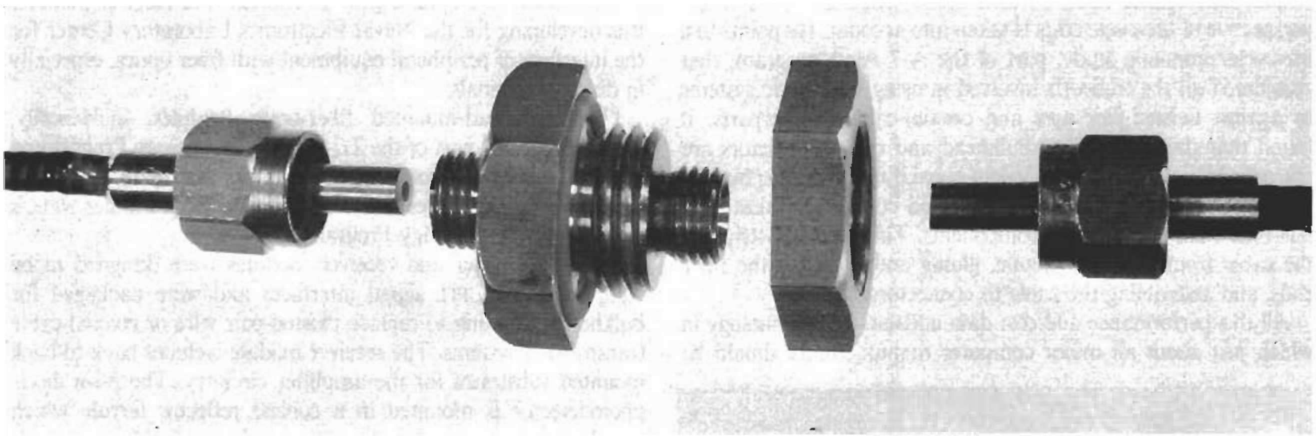
3. Atlanta connection. Cable connectors used in Bell's optical-fiber experiment interleave layers of precision-grooved aluminum chips (dark areas) with rows of fibers. The complete splice accurately aligns all 144 fibers in each cable.



4. Light coupling. The tiny optical fiber can be seen as it enters the Bell Laboratories' experimental transmitter module. The light generated by the source is coupled with not only the fiber but also a feedback circuit on the substrate to maintain constant output.



5. Matched pair. Sperry Univac's fiber-optic receiver and transmitter were designed to replace existing wire transmission systems. The receiver shown uses hybrid circuitry on substrates; p-i-n photodiode mounts in a conical ferrule that attaches to the substrates.



6. One of a kind. The first optical-fiber connector to be MIL qualified was developed by the Naval Electronics Laboratory Center for use with fiber-bundle cables and is fully compatible with other fiber-optic components and hardware under development by the Navy.

have groups working on the problem. The Electronic Industries Association, Washington, D.C., has a task force concerned with all phases of development and trends in fiber-optic terminations and junctions. This group, chaired by Philip Dann of IBM Federal Systems, Oswego, N.Y., is committed to meeting the Department of Defense's goal of having standards available by 1980. And DOD itself has in operation a tri-service group working to develop standards for all the services for fiber-optic systems.

At the Society of Automotive Engineers, too, another group is developing test procedures for optical-fiber cables. Under the guidance of W.D. Watkins of the Naval Avionics Facility, Indianapolis, Ind., this group will supply information to DOD to enable it to issue preliminary military specifications on optical-fiber cables in 1977. There is close liaison among groups.

As for sources, reliability is also a headache. For practical optical-communications applications, their lifetimes should reach at least 100,000 hours and, although extrapolated test data for both lasers and LEDs points to this being possible, the big question is when. Work on the problem is in progress at Bell Labs, which has the formidable task of developing practical long-lived lasers for the Bell System's greater-than-20-year life requirements. And such companies as RCA, BNR, TI, HP, ITT, Monsanto, Spectronics, Laser Diode Laboratories, Plessey, GE, and Fairchild are among those that have LED and laser sources commercially available.

The cost factor

Second only to the need for standards is the problem of cost. A major contractual commitment to a large-scale system or systems needs to be made, whether by Bell, IBM, or the military, since otherwise it's likely that practical components will remain expensive and not widely available.

The cost of today's fiber-optic components doesn't reflect what could happen in a volume business. A go decision by the telephone company, for instance, would trigger a tenfold shift downward in the cost of fibers, says Charles J. Lucy, general manager of the Telecommunications Products division of Corning Glass Works, Corning, N.Y. "Graded-index fibers with under 5-dB loss and greater than 500-MHz bandwidth could cost as little as 5 cents per meter in 500,000-km lengths in about five years," claims Lucy. This is close to the cost of cabled copper wire today, and the cost of copper is certain to have risen by then. And Richard A. Cerny, marketing manager for advanced fiber communications at Valtec Corp., West Boylston, Mass., thinks there will be sufficient demand by 1978 to bring prices down to around 25 cents per meter for cabled low-loss fiber channels. Prices now range from about $1.50 to $2.50/m of graded-index-fiber cable in quantities of up to 50 kilometers. Step-index fibers are less expensive.

According to Martyn Roetter of Arthur D. Little Inc., lasers could drop similarly to about $25 each in production quantities of 100,000. He bases this prediction on what has happened with other microwave devices.

The Navy's Don Williams is in full agreement with this kind of thinking. "It will not be long before we can compare fiber and wire costs on a foot-by-foot basis," he says. But even now, he emphasizes, optical fiber is economically superior if the larger perspective of life-cycle costs is taken into account. He points to a life-cycle/economic study, part of the A-7 Aloft program, that considered all the tradeoffs involved in using fiber-optic systems as against twisted-pair wire and coaxial-cable counterparts. It found that the optical-fiber bulkhead and cable connectors are not only half the cost of equivalent coaxial terminations, but the assembly time of optical fiber-cable and connectors takes 30% less time than with coaxial components. This included stripping the cable from the fiber bundle, gluing and polishing the fiber ends, and assembling the cable to connectors.

All this performance and cost data adds up to a technology in which just about all major computer manufacturers should be interested. And they are. Optical fibers offer them the large bandwidth needed to move massive blocks of data at high speeds and then throw in small size and weight, too. The ease of installing optical-fiber cable compared to multiple coaxial cables, along with its immunity to the large electromagnetic interference levels in and around computers, are other factors in its favor.

The computer connection

Computer hookups need wires routed through conduit to prevent sparking, and it costs about $4/foot to lay conduit. Fibers don't need conduits. In fact, no wiring changes are required to equip some existing computers with optical-fiber links.

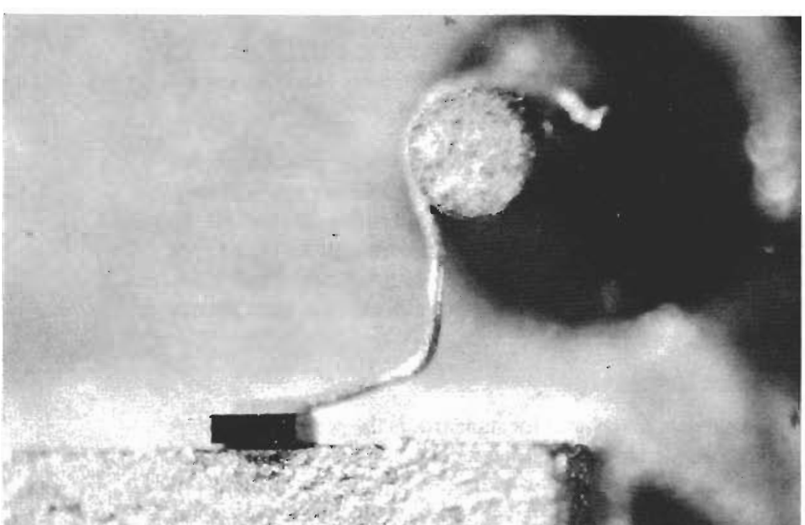
Consequently, fiber optics will be widely used for interconnecting mainframes and peripherals. Moreover, the trend toward distributed data systems is certain to create the need for much greater bandwidth as numerous intelligent terminals, minicomputers and more memories are all interconnected. Initially, though, a computer could have a hybrid interface with one or two parallel coaxial lines and the remainder in serial fiber optics.

Du Pont, for instance, is looking into replacing the four-wire cable and conduit connecting two Digital Equipment Corp. PDP-11 minicomputers with two optical-fiber channels.

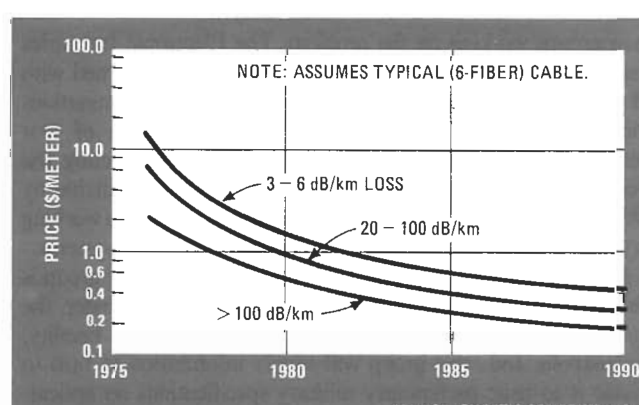
And Sperry Univac's Fiber Optic/Hybrid Component Development Group at St. Paul, Minn., is looking into using the miniaturized fiber-optic digital transmitter and receiver modules it is developing for the Naval Electronics Laboratory Center for the interface of peripheral equipment with fiber optics, especially in display terminals.

(The bulkhead-mounted fiber-optic modules, incidentally, were designed as part of the Tri-Service Technology Program on standard fiber-optic components. The modules mate with standard optical-fiber cables and connectors developed under NELC's Fiber Optics Technology Program.)

Both transmitter and receiver modules were designed to be compatible with TTL signal interfaces and were packaged for bulkhead mounting to replace twisted-pair wire or coaxial-cable transmission systems. The receiver module includes back-to-back mounted substrates for the amplifier circuitry. The p-i-n diode photodetector is mounted in a conical reflector ferrule which attaches to the substrates. The other end mates with an optical-fiber cable. The transmitter module is physically similar to the



7. **Tiny sources.** RCA's experimental continuous-wave gallium-aluminum-arsenide laser diode is shown mounted on a TO-46 header. The laser chip is attached to a metal block to dissipate heat and is connected to the header pin by a small wire.



8. **Downward trend.** The cost of all single-fiber-per-channel cable will continue to drop. For instance, by 1990 a typical six-fiber cable with an attenuation of from 20 to 100 decibels per kilometer should cost less than 30 cents per meter—down from about $6 today.

receiver. It uses a hybrid driver circuit mounted on ceramic substrates and, for military environments, is hermetically sealed in a cylindrical case similar to the receiver's.

Many overseas companies are thinking of fiber optics in terms of high-capacity telecommunications lines. U.S. companies are more inclined to look at fiber-optic links as replacements for short-haul trunking and lower-priced communications systems now, although eventually they will displace existing high-capacity lines as well. But at present, the main thrust is towards telecommunications applications like interoffice trunking and commercial applications like short-haul data transmission between computer peripherals, machine tools, and programed instruments.

Other applications abound

One such system designed by AEG-Telefunken of Germany, called V300P, is already on the market [*Electronics*, Feb. 20, 1975, p.40]. And a follow-up system intended for high bit-rate color-TV signal distribution within large apartment buildings is in the works. Other applications for the system are to link computers and peripherals, to distribute CATV signals, or to carry signals from sensors to a process-control computer.

In England, Rediffusion Engineering Ltd., a TV rental and distribution company, last April installed what it claims is the first operational fiber-optic link carrying live traffic over a 1.5-km stretch of two-fiber cable buried in the pavement and grassland at Hastings, Sussex. The cable carries two full-bandwidth color-TV channels amplitude-modulated on the lower sideband of an 8.9-MHz carrier, the same signal as is used by the company for normal coaxial-cable traffic. "It's serving 34,000 subscribers and has been working constantly with no deterioration of anything," says Kenneth C. Quinton, the firm's director of research.

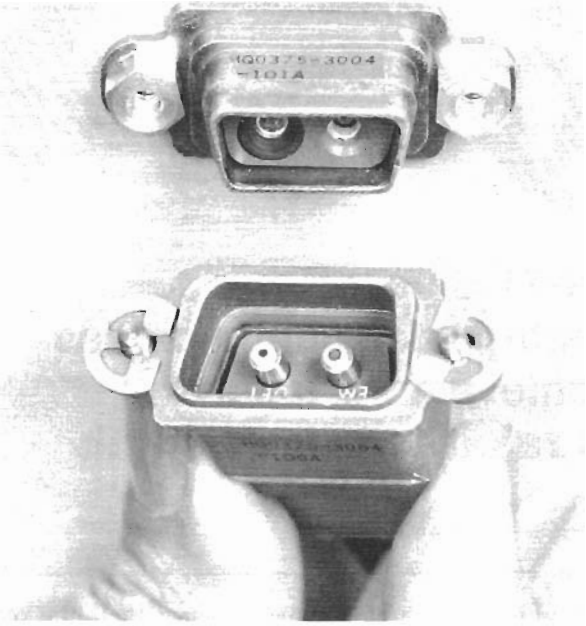
In Japan, fiber optics is being considered for telecommunications applications and has actually been used to control power facilities. The cables are threaded through tunnels containing high-voltage power lines and will replace microwave systems whose signals are often blocked by tall buildings and the like [*Electronics*,Aug. 7, 1975, p.45]. Nippon Electric Co. Ltd. carried out a field test recently in the high-voltage power station in Tokyo.

To round out the list, an experimental optical-fiber communications link is planned for the city of West Berlin jointly by Germany's post office authorities and ministry for research and technology [*Electronics*, Nov. 13, 1975, p.56].

Off the shelf

Within the last year analog and digital fiber-optic systems have been offered by many companies, such as ITT's Electro-Optical Products division, Roanoke, Va., and Harris Electronic Systems division, Melbourne, Fla., not to mention Meret Inc., Santa Monica, Calif., Spectronics Inc., Richardson, Texas, Bell Northern Research, Ottawa, Canada, Valtec Corp., West Boylston, Mass.

Typical examples come from ITT and Harris. ITT's system is capable of data rates of up to 25 Mb/s over several hundred feet. Input and output are TTL-compatible with amplitude-regenerated data out. The analog system has one wideband channel, plus two narrowband channels that are fm-multiplexed onto the wideband channel so that only one optical channel is needed for transmission. Harris's 32-channel digital data link, on the other hand, is geared to computer-to-peripheral installations of up to 1,500 feet at data rates of 16 Mb/s.



9. Two-way. The bulkhead side of Spectronics' optical-fiber pluggable interface connector houses both the light-emitting-diode source and p-i-n photodiode detector needed to send and receive signals in a duplex fiber-optic transmission system.

Perhaps Charles P. Sandbank, manager at the advanced Communication Systems division of Standard Telecommunications Laboratories, Harlow, Essex, England, sums it up best: "Fiber optics was once a matter of 'if to' and 'when,' but it will soon be a matter of 'when' and 'how much'." Worldwide commitment is very great indeed. And the rugged low-cost fiber cables and other needed optical components are just about here to support the accelerated growth that's now happening. It's therefore important that design engineers become familiar now with all available components for such systems.

The necessary knowledge

It's partly the sheer unfamiliarity of fiber optics, in fact, in addition to its still rather high cost and the lack of standards, that is delaying the widespread adoption of this exciting new communications technology. Potential users need a better understanding of what fiber optics can do for them, and system designers need to overcome their resistance to change—much as an earlier generation did in making the switch from tubes to transistors.

To help remedy this state of affairs, the following nine articles will bring the engineer up to date in fiber-optic technology. They detail what's available in fiber-optic components and how to work with each of them. All are written by leading experts in their respective fields and have been structured to give the engineering community an in-depth, timely perspective on fiber cables, light-emitting and laser diodes, connectors, photodetectors and optical coupling techniques.

Subsequent issues of *Electronics* will include articles that focus on the systems design considerations with fiber optics. They will translate user specifications into systems, and their focus will be on the steps needed to specify optical fibers and components that best fit the overall requirements for both analog and digital fiber-optic communications systems.

Reprints of this Special Report, including the following nine articles, will be available at $3.00 each. Write to Electronics Reprint Dept., P.O. Box 669, Hightstown, N.J. 08520.

FIBERS
High-performance cables achieve zero failure at rated tensile strength

by R. Love
Corning Glass Works, Corning, N.Y.

Optical waveguides have come far since 1970, the year in which fiber attenuation was finally brought within range of high-speed data-transmission requirements. Today, some commercial large-bandwidth graded-index fibers achieve an attenuation of only 5 dB/km—a quarter that attained in the laboratory six years ago. In the meantime, light sources have also been improving, and by now it seems generally agreed that single-fiber system configurations represent the best cost-performance tradeoff for most applications.

A rugged optical-fiber cable with six single fibers introduced in 1975 proved cost-competitive with coaxial cables in a number of communications applications and, in many cases, offered much better system performance. Now second-generation single- and multiple-fiber cables reduce incremental fiber attenuation due to cabling to less than 2 decibels per kilometer and, for the first time, are warranted for zero failure at the rated tensile strength. The important parameters of several optical fibers recently introduced by Corning Glass Works are listed in the table.

Starting from strength

Glass is inherently much stronger than metal—tiny strands of glass theoretically can withstand tensile loads upwards of a million pounds per square inch of cross section. But in field use, glass has seldom revealed much more than a hundredth of the fracture strength predicted of it. This strength, it has now been determined, is severely limited by the presence of infinitesimal surface flaws, and fracture always involves two independent processes: flaw initiation, and flaw propagation. Because of the random nature of flaw depth and spatial distribution, the probability of failure for a glass fiber depends upon its length. Also, since failure always occurs at the weakest flaw, or deepest crack, two seemingly identical fibers of equal length will not fail at the same stress level, or at the same time for an equally applied stress, unless the weakest flaws are also identical in depth.

In short, the strength of optical fibers, unlike that of copper wire, is an inherently statistical phenomenon. Therefore conventional strength parameters such as tensile strength or yield stress are not easily applicable to them.

A better approach is to characterize glass fibers in terms of their failure probability, by carrying out fast-fracture and time-to-failure experiments on a large number of fibers of the same gauge length. From the resulting data, failure probability for various combinations of applied stress, time, and fiber length can be derived on the basis of fracture-mechanics theory.

Alternatively, a minimum time to failure under constant load may be specified if fibers have been subjected to on-line screen testing. This involves applying a uniform tensile stress to the fiber at the time of manufacture and prior to final reeling. Survival of the screen test guarantees that no flaws greater than a certain depth exist in the final fiber, since otherwise failure would have occurred.

From the viewpoint of fracture-mechanics theory, screen testing sets the initial condition on flaw depth. If other material constants are known, the minimum time to failure as a function of applied stress can be calculated. Screen-test stress levels required to guarantee zero failure in 20 years are plotted as a function of service stress. This approach to characterizing fiber strength doesn't depend on fiber length. The long-term service stress for zero failure is analogous to the yield stress properties of copper wire in electrical cables.

Microbends multiply losses

During the early phases of optical cable development, it was observed that numerous "microbends" (small axial distortions in fiber geometry) caused a significant

SOME SECOND-GENERATION OPTICAL FIBERS

Product No.	Index profile	Minimum bandwidth (MHz at 1 km)	Maximum attenuation, λ = 820 nm (dB at 1 km)	Core diameter (μm)	Numerical aperture (± 0.02)
1150	Graded	200	10	62.5	0.16
1156	Graded	200	6	62.5	0.16
1151	Graded	400	10	62.5	0.16
1157	Graded	400	6	62.5	0.16
1152	Graded	200	10	62.5	0.20
1158	Graded	200	6	62.5	0.20
1153	Graded	400	10	62.5	0.20
1159	Graded	400	6	62.5	0.20
1025	Step	20	10	85	0.18
1028	Step	20	6	85	0.18

Corguide fiber diameter (μm) 125 ± 6 EVA buffer diameter (μm) 250 ± 25 increase in fiber attenuation. Microbends tend to continually couple light energy back and forth between low- and high-order modes. The latter are more highly attenuated and may even be scattered out of the fiber entirely. Continuous axial distortions, as small as 1 micrometer in amplitude and spaced 1 millimeter apart, are sufficient to cause 20 dB/km of incremental attenuation.

(It is important to distinguish between this effect and the attenuation due to "bending" losses described on page 91. An occasional small-radius bend in a fiber merely radiates out higher-order modes, occasioning a low, one-time loss. Provided light energy is not coupled back into these modes, no further increase in attenuation will result when additional bends are encountered.)

To minimize microbending losses, optical cable is designed to mechanically isolate the fibers from small material or geometrical irregularities in the cable structure. In this, the new second-generation optical cables are particularly successful—any of the fibers listed in the table can be cabled with less than 2-dB/km excess attenuation. They are encapsulated in ethylene vinyl

Looking into fibers

Although three types of fiber exist—single-mode, step-index multimode, and graded-index multimode—only the last two have gone public. Single-mode fibers can propagate optical signals with a very low loss at extremely large bandwidths but are still in the research stage.

Of the other two, the less costly step-index fiber consists of a glass core of uniform refractive index surrounded by a cladding glass of slightly lower index of refraction. The more costly graded-index fiber has a core with a refractive-index profile that is radially symmetric and approximately parabolic in shape, being highest at the center of the core and decreasing parabolically till it matches the cladding refractive index at the core-clad interface.

Light launched into the core of either fiber at an angle less than the critical acceptance angle (numerical aperture) is reflected internally upon striking the core-cladding interface and therefore continues to propagate within the fiber core.

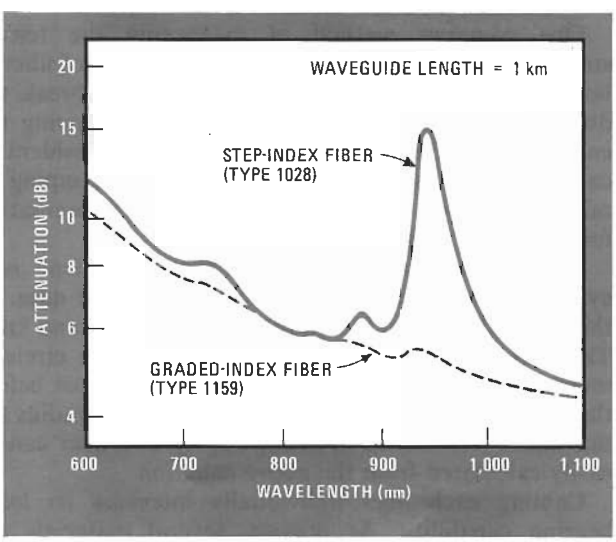
In both step- and graded-index fibers, the light signal is carried in a large number of modes, each with a characteristic velocity and propagation time. Graded-index fibers, however, because they minimize the propagation delay differences between various modes, can handle large bandwidths. As a rule of thumb, commercially available step-index fibers can handle data rates of up to 50 megabits/km, and graded-index fibers up to 500 Mb/km. The as-yet experimental single-mode fibers are capable of still greater things—more than several gigabits per kilometer.

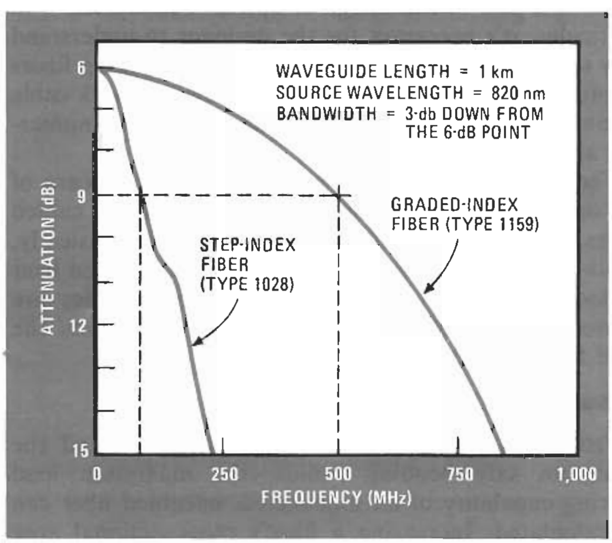
As with electrical conductors, the signal-transmission properties of optical waveguides are characterized in terms of attenuation versus frequency. This transfer function depends on fiber attenuation (absorption and scattering) and signal dispersion (pulse spreading).

Both parameters depend in part on fiber materials. For example, absorption in the near-infrared portion of the spectrum is due mainly to OH radical vibration bands. On the other hand, Rayleigh scattering from the thermal fluctuations of constituent atoms is the primary scattering mechanism. Spectral attenuation curves include the effects of all these parameters.

The spectrum width of the light source and material dispersion in the fiber determine pulse spreading. For example, a 1-km length of a doped-silica optical fiber driven by light-emitting-diode with a spectral width of 50 nanometers exhibits a pulse spreading of approximately 3 nanoseconds. With laser diodes having spectral widths of about 2.5 nm, pulse spreading drops to about 0.3 ns.

To determine the transfer function of an optical fiber, attenuation and pulse spreading measurements are carried out on a standardized but arbitrary length, usually 1 km. The transfer function of an available Corning fiber results from superimposing the signal dispersion, which depends on frequency, on the fiber attenuation due only to scattering and absorption of light.





acetate to isolate them mechanically and buffer them against any small geometrical irregularities or distortions found in the jacketing or reinforcing components. The encapsulation also helps protect the fibers from damaging impact or abrasion during the reeling and handling operations. Their rated tensile strength is based on fiber screen-test stress, which may be derated with respect to time and applied load. As a rule of thumb, long-term (more than 20 years) tensile stress rating for zero failure is about one third of the fiber screen-test stress (Fig. 1).

Virtually any degree of tensile strength or crush resistance can of course be provided by appropriate reinforcing components and armoring. But just as in wire cables, ruggedness must be traded off against cable flexibility and cost.

Coax contrasted

Optical cables are installed in the ground in much the same manner as wire cables, except that a longer pull length for the same rated tensile strength is possible. For example, Corguide cable can be pulled through straight ducts longer than 1 km. This is because frictional forces are proportional to cable weight, and optical cables of the same diameter as coaxial cables are approximately four times lighter.

Moreover, beyond bandwidth requirements of a few megahertz, graded-index fiber cables are far superior to all but the most expensive, largest-diameter, coaxial cables. And lower-bandwidth-capability step-index fiber cables outperform all but RG-17/U coax cables up to 100 MHz.

Also the dielectric nature of optical fibers makes them immune to electromagnetic interference. They do not conduct electricity, thus avoiding ground loop problems and offering a degree of transmission security. Moreover, in ordinary cable environments, optical cables show much less change in their transmission properties (attenuation, pulse distortion) than their metallic counterparts.

Performance data shows that optical cable is superior to coaxial cable on a single-channel basis, above a few megahertz. In addition, 10 or more fibers (channels) can be packaged in a single cable the size of RG-63/U with cross talk more than 80 dB down over a 1-km length. Cost on a per-channel basis now ranges between $0.60/ft and $2/ft for optical cables compared to $0.15/ft to $1.50/ft for coaxial cables.

BY CARL J. BERGQUIST

Experiments With Laser Light

ONE OF THE MAJOR PURPOSES OF THIS MONTH'S COLUMN IS TO INTRODUCE FIRST-TIME LASER ADVENTURERS, AS WELL AS SEASONED EXPERIMENTERS TO SOME THE THOUSANDS OF WAYS THAT LASERS CAN AID,BENEFIT, and even entertain you. Hands on experiments and demonstrations are great ways to display the wonders, and applications of this unique light form. We hope to give you a far better understanding of the laser and to offer many new ideas for it's use. These should give you some ideas of your own and we invite you to share them with us. Send your ideas to *Laser Applications Editor, Electronics Now magazine, 500 Bicounty Boulevard, Farmingdale NY 11735, or via E-mail to lartronics@aol.com.*

Light beam modulation

The term Modulation is a controlled change of an otherwise constant signal to convey information or data. There are two ways to modulate a laser beam: mechanically and electronically. Let's explore the mechanical methods first, as they produce the most dramatic effects.

If you shine the beam onto a reflective surface that can be moved, the resulting beam traces patterns caused by that movement. One interesting way to do this is to get the surface to move in tandem with speech, music, or other sounds. There are commercially available X-Y modulators and axis generators that do a great job at converting sound to patterns. They sell for $100 and up. An easy and far less expensive approach is to used an old 3- or 4-inch, 8-ohm speaker, together with a 1½- to 2-inch length of flexible spring, and a ¾-inch square of thin but rigid aluminized mylar.

FIG. 1—A SPEAKER MODULATOR using flex-wire for positioning, and a small speaker with cone still intact.

You can use the speaker as is. I did, as you can see in Fig. 1. To reduce the sound output, which you might find disturbing, cut the cone out of the speaker, leaving the frame and the center circle covering the voice coil assembly. Use a dab of epoxy or silicon cement to attach one end of the spring to the center circle of the speaker—the less cement the better. When the cement is dry and the spring is in place, attach a corner or edge of the square of mylar to the loose end of the spring. Then mount the speaker on a stand with a swivel joint so the angle can be set anywhere within a 360-degree pattern, and you have a simple, but effective X-Y axis generator. A close-up photograph of the completed device is in Fig. 1.

To use your axis generator, connect the modified speaker to the output of a stereo, TV, radio, or other sound source. Then direct the angle of the speaker so that a laser beam aimed at the mylar creates a reflection that bounces back

WARNING! ! !

This article deals with and involves subject matter and the use of materials and substances that may be hazardous to health and life. Do not attempt to implement or use the information contained herein unless you are experienced and skilled with respect to such subject matter, materials and substances. Neither the publisher nor the author make any representations as for the completeness or the accuracy of the information contained herein and disclaim any liability for damages or injuries, whether caused by or arising from the lack of completeness, inaccuracies of the information, misinterpretations of the directions, misapplication of the information or otherwise.

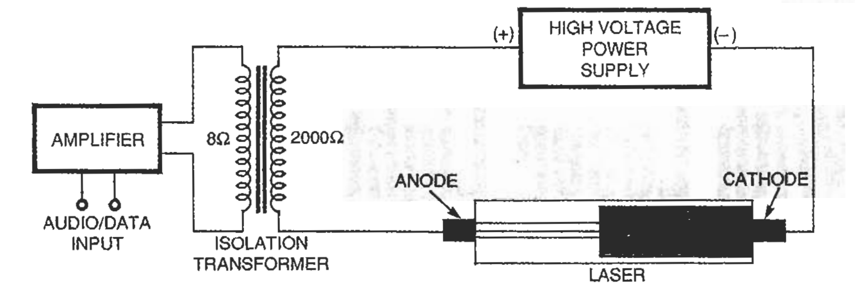


FIG. 2—ELECTRONIC MODULATION of a laser beam can be handled in this fashion. Obviously, the transformer you use must be able to handle the high voltage from the laser power supply without breaking down.

TABLE 1—LASER SUPPLIERS

American Science and Surplus
3605 Howard Street
Skokie, IL 60076
(708) 982-0870

Electronics & Computers Surplus City
1490 West Artesia Blvd.
Gardena, CA 90248
(310) 217-1922

Electronic Rainbow, Inc.
6254 LaPas Trail
Indianapolis, IN 46268
(317) 291-7262

Information Unlimited
Box 716
Amherst, NH 03031
(603) 673-4730

Midwest Laser Products
Box 2187
Bridgeview, IL 60455
(708) 460-9595

MKW Industries
1269 Pomona Road
Corona, CA 91720
(800) 356-7714

Timeline, Inc.
23605 Telco Avenue
Torrance, CA 90505
(301) 784-5488

onto the surface you want it to strike—a movie screen, wall or ceiling. Now when music or some other audio signal is fed to the speaker, its center vibrates making the spring and mylar vibrate too. The reflected beam will swirl, circle, trace ovals, elongated shapes, and create broken and pulsating lines and patterns(no two designs ever seem to be quite the same. Viewing this produces hours of fascination and relaxation. Even though you have removed the speaker cone, a bit of the audio will be heard. If you want greater volume, don't cut the cone out. If you want to muffle the sound more, put the speaker assembly into an insulated box and cut a small window for the reflected laser beam.

HOLOGRAM KITS

METROLOGIC INSTRUMENTS, INC.
143 Harding Avenue, P.O.Box 307
Bellmawr, NJ 08031

MIDWEST LASER PRODUCTS
P.O.Box 2187
Bridgeview, IL 60455
(708) 460-959524p20

Electronic modulation is the second way to control the output beam. Figure 2 is a block diagram of the setup to vary the intensity of the laser light. The data, sound, or other information to be carried by the beam is fed into the amplifier's input. Its output is connected to the primary of the isolation transformer. The secondary winding is connected in series with the laser's anode lead, between the high-voltage power supply and the laser. The laser's cathode lead remains unchanged. With this arrangement the beam intensity stays constant when there is no modulating signal. When a signal is applied to the amplifier, the impedance of the isolation transformers primary winding changes and in turn, changes the impedance of the secondary. These changes vary the voltage applied to the laser and make the laser beam brighter or darker. In this way any form of information that can be converted into sound energy can be transmitted over the laser beam.

The amount of change is minute and often cannot be seen by the human eye. That's why a receiver consisting of a photosensitive transistor and amplifier is needed to decode the transmitted information. Figure 3 is the schematic of a simple general-purpose audio amplifier to use as either the data input or data decoder. If you don't want to make your own amplifier you can buy a small modular style amplifier package at an electronics distributor. They are self contained, complete with speaker and jacks for input and output.

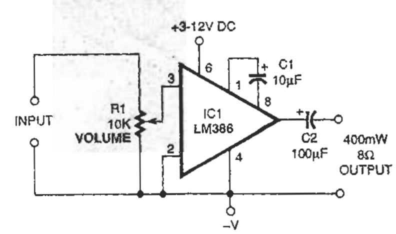


FIG. 3—SIMPLE IC AMPLIFIER for increasing gain of the received signal.

Light-communications experiments

Once you have both a modulator and a receiver, you can use them to make an efficient "free air" light communications systems. Thanks to the intensity and collimation of the laser beam, these signals can be sent quite a distance, even in bright sunlight.

Beyond the line-of-sight free-air method of transmission, you can try a number of other interesting experiments involving reflecting and receiving laser light. For starters, try aiming the beam at various objects in and around your location. Buildings, windows, automobiles, signs, trees and other plants may amaze you with the variety of reflections they produce. Be sure and try this experiment both during the day and at night, as the results can be quite different. With the help of a friend, you can measure beam divergence or spread at various distances. Make a chart of your measurments and keep it with your laser.

Most 1-mW lasers will project a beam that will reach low clouds, up to about 2,000 feet. At night, the reflection and slight diffussion will create an eerie, almost UFO effect as the clouds move and change shape. Another fascinating observation calls for project-

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GLOSSARY

anode —The positive (+) connection of a laser tube or diode.

ambient light—Existing light in and around a location.

beam—The narrow light emission from the anode of a laser.

beam splitter—An optical device used to divide the beam of light into two beams. Either prisms or partial mirrors.

cathode—The negative (-) connection of a laser tube or diode.

collimation—The property of laser light that keeps the beam from spreading out as it moves away from the laser.

collimator—A lens, or lens assembly that focuses the light into a beam.

coherence—The property of laser light where the beam emitted is largely of one frequency or color. In the case of the Helium-Neon laser, this color is red at 632.9 nm.

concave—The shape of a negative lens or mirror that allows for the spread of light. The surface curves inward.

convex—The shape of a positive lens or mirror that allows for the concentration of light. The surface curves outward.

diode—An electronic device that conducts in one direction only. In some applications, it changes alternating current to a pulsating direct current. The positive side of the diode is the anode, and the negative side the cathode.

electrode—A metal contact point for electrical connection as in the anode and cathode of the laser.

electron—The negatively charged particles of an atom that orbit the nucleus. It's the action of the particles, jumping back and forth in the orbits, that creates the laser light.

fiber optic—Plastic or glass rods that transmit light from one end to the other. Allows for bending of the beam.

focus—Also referred to as focal point, it is the distance from a lens, or lens assembly, where the light comes to a point or apex.

helium—The elemental, inert gas with atomic number 2 and the symbol He.

hologram—A photograph, made with laser light that appears to have three dimensions.

holography—The science and technique of producing holograms.

infrared (IR)—A form of electromagnetic radiation, between visible red and the microwave range, with a frequency of 780 nm to 100,000 nm.

laser—An acronym for Light Amplification by Stimulated Emission of Radiation. This electrical or mechanical device produces a very straight and narrow beam of light, usually visible, of one dominant color.

nanometer (nm)—A term used to describe the wavelength of light, it is equal to a 1×10^{-9} meter.

neon—The elemental, inert gas with atomic number 10 and the symbol Ne.

optics—Any device used to control or manipulate light. Usually made of glass or plastic, these include lenses, mirrors, prisms, and filters.

photon—A quantum of light emitted by any source.

population inversion—The condition when more atoms are in an upper energy level than in a lower one.

refraction—The bending of light at the boundry of two surfaces.

spectrum—The entire range of electromagnetic energy. When applied to light, and/or lasers, it includes the frequencies from short wave ultraviolet through infrared energy.

ultraviolet (uv)—Light, invisible to the eye, from purple up, beginning at about 400 nm.

visible light—Electromagnetic radiation, from about 400 nm to 880 nm,

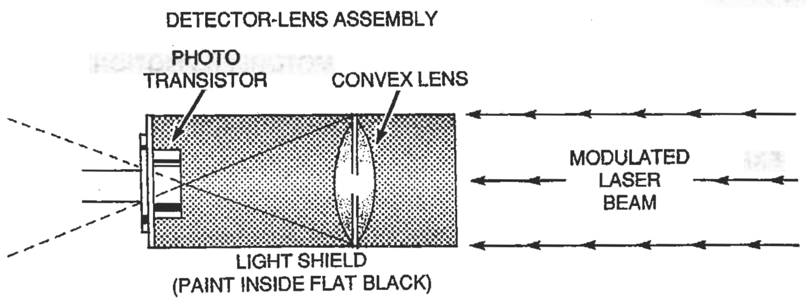

FIG. 4—DETECTOR-LENS ASSEMBLY is housed inside a tube that will fit the lens.

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ing the beam through rain drops at night. Shining the beam out across a field during a mild rain shower is a very pretty sight, even during daylight. The same applies to fog. With the right angle, the beam will be visible only in the areas where it encounters the fog.

While you bounce the beam off various surfaces, you will probably notice that the light sometimes reflected back towards the source. The intensity of the reflection depends on the surface of the reflector. This property is what makes the next three experiments work. In each one a form of modulation comes into play. Once you can receive a returning beam of varying strength you can transfer information and, at the same time, demonstrate the principle of data transmission via reflector movement.

Because the reflected light is less intense, you will need a more sensitive receiver. You will also need an with considerably higher gain. The detector assembly has to be far more efficient in collecting the returning light and concentrating it on the phototransistor. The problem of light collection/concentration can be solved by using a combination light shield and lens holder (see Fig. 4).

You can make one from either a cardboard, plastic, or metal tube. When properly focused, this lens condenses the collected light into a small spot on the photo-sensitive surface of the detector. If you need more sensitivity, use a cluster of phototransistors wired in parallel. Figure 5 shows how that is done. With the lens focused appropriately, this can be used to increase the photosensitive area. Paint the inside of the tube flat black to reduce ambient light interference. If this still does not adequately increase sensitivity, install a medium-density red filter at the front of the tube. Since the HeNe (Neon Helium) beam is red, it passes through the filter while green and blue light are rejected. This should reduce the ambient light to one third of its strength without the filter.

The amplifier shown in Fig. 6 is a four-stage, operational amplifier (op-amp) circuit wired in a cascade arrangement. Potentiometer R2 acts as the gain control for the initial amplifier stage. It serves two functions. First it helps set volume. Second it inhibits distortion that might otherwise be caused by excessive gain. By feeding the output of the first stage into the inverting (negative) input of stage two, amplification is increased further. Stages three and four also boost gain. Potentiometer R10 is the final volume control for the signal being fed to the speakers or headphones. The final output can also be connected to a relay or some alarm device. If this is done, R10 acts as a sensitivity control.

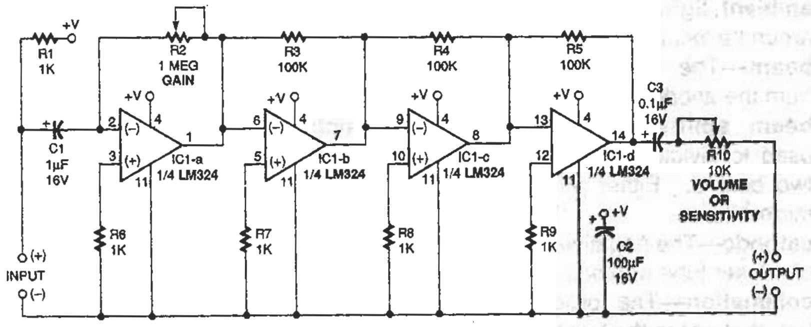


FIG. 6—FOUR-STAGE HIGH-GAIN amplifier uses a single LM324 quad amplifier.

Once the detector and amplifier are completed, mount the LM324 circuit in a small project box. Position the detector assembly on the outside so it can be aimed at the returning light beam. The amplifier is powered by a standard 9-volt battery. Mount an on-off toggle switch and an "on" indicator, together with an output jack, on the project box.

You are now ready to start working on some practical projects. **EN**

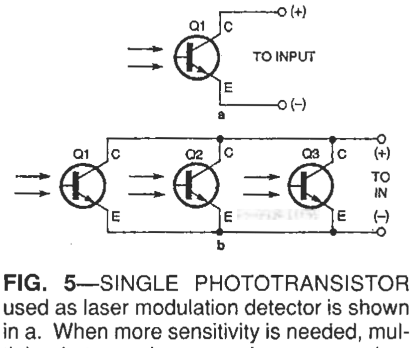


FIG. 5—SINGLE PHOTOTRANSISTOR used as laser modulation detector is shown in a. When more sensitivity is needed, multiple phototransistors can be connected as shown in b.

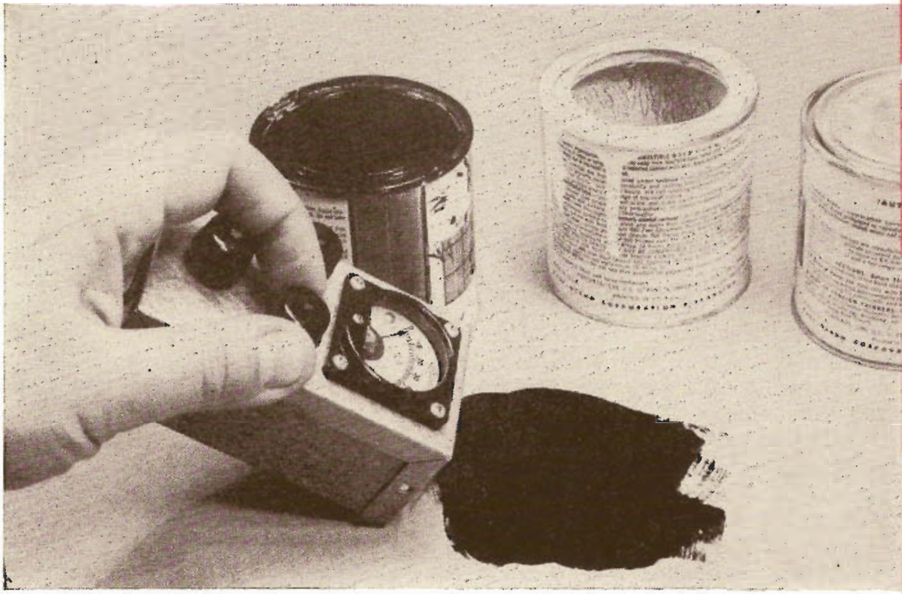
LENS F NUMBERS

"Experimenting With Light-Beam Communications" (April 1975) appears to contain an error. Author Forrest Mims states that the term f/number is used to define the ratio of diameter to focal length and is expressed as f/no, which is equal to d/fl, where d is the lens diameter and fl is the focal length. This part of the text should read, "The term f-number (this is the proper designation—not f/no) is used to define the ratio of focal length to lens diameter and is expressed as f-no equal to fl/d.

DANIEL J. NETTO
Los Angeles, Calif.

You are correct. The f-no of a lens is equal to the focal length divided by the diameter of the lens. The formula d/fl is the divergence of the projected beam, or receiver field of view, in radians. —Author

ELECTRONIC COLOR MATCHER

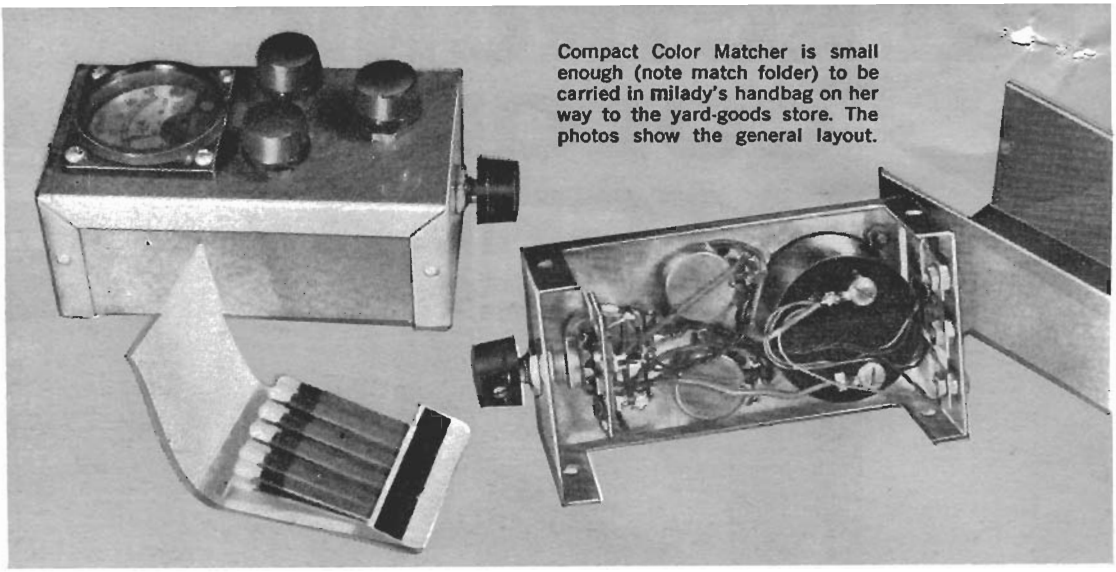


Ever tried to touch up a scraped fender? This interesting, easy-to-build gadget will tell you what shade paint to use

By RUFUS P. TURNER

ARE YOU doing a patch-up paint job? Do you mix inks or other colored fluids? Have you tried to match materials at the dry-goods store? If your answer is yes to any of these questions, you're in the market for a color meter. These devices are seldom found outside laboratories and can be quite costly, but the electronic "Color Matcher" described here can be built at a new-parts cost of $15.00, and is more than adequate for most purposes. Measuring just 4″ x 1⅝″ x 2⅛″, it weighs only 12 ounces; no batteries or power supply are needed.

How Color Meters Work. The action of a color meter circuit is the same as that of a simple light meter, except that in the latter the light must pass through either a red, green, or blue filter on its way to the photocell(s). Colors are compared by illuminating the first sample with white light (sunlight, for example), switching to the "red" position and setting the "red"



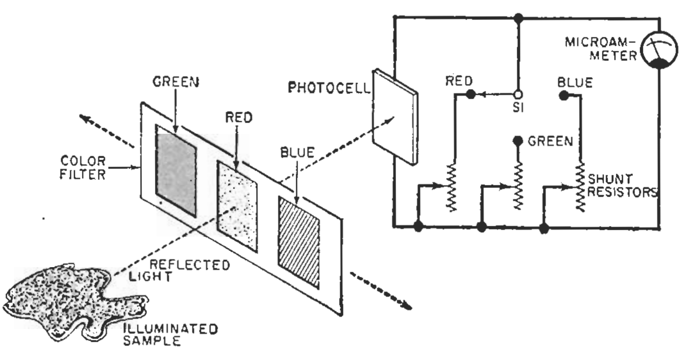
Compact Color Matcher is small enough (note match folder) to be carried in milady's handbag on her way to the yard-goods store. The photos show the general layout.

shunt for a selected deflection, then making the same adjustment for green and blue. When another color sample is substituted, the three readings will be the same if the color is the same, or will indicate a mismatch and excesses or deficiencies of red, green, and blue. The three controls can also be set for a standard deflection while viewing a plain white surface; relative red, green and blue readings will then be obtained with color samples.

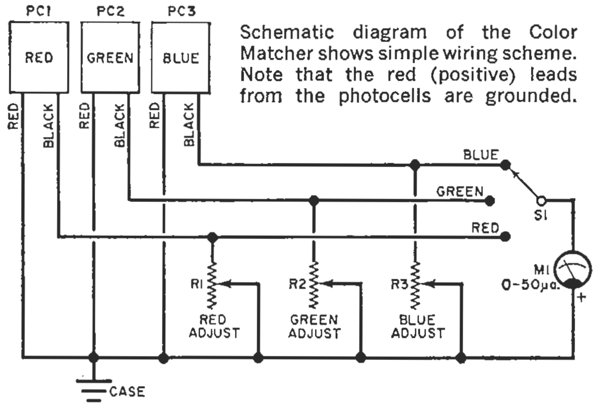
Color Matcher Design. Although some commercial models use a single photocell and sliding filters, the Color Matcher was built around three International Rectifier B2M photocells (*PC1*, *PC2*, and *PC3*). Also needed are three subminiature 50,000-ohm potentiometers (*R1*, *R2*, *R3*), a three-position switch (*S1*), and a 0-50 d.c. microammeter (*M1*).

Using a 1½" socket punch, cut a hole for the meter at one end of the top of a 4" x 2⅛" x 1⅝" Minibox. At the same end, cut in the side a 1¾" x ⅞" window for the photocells. The best tool for this job is a thin-bladed coping saw; start it through a ⅛" hole. Finally, drill *M1*'s mounting holes, three ¼" holes for the controls, and a ⅜" hole for *S1* in the end of the box opposite the "window."

To make the photocells sensitive to color, get some Wratten gelatin filters at a camera store. They come in 2" x 2" thin transparent sheets, and sell for 60 cents each. The red is Eastman Kodak No. 25A, the green No. 58, and the blue No. 47. Cut a ½" x ¾" strip of each color and tape it to one of the three photocells. Use narrow strips of Scotch tape, masking as little of the film and cell surface as possible. The film must rest flat against the cell face. Avoid touching the

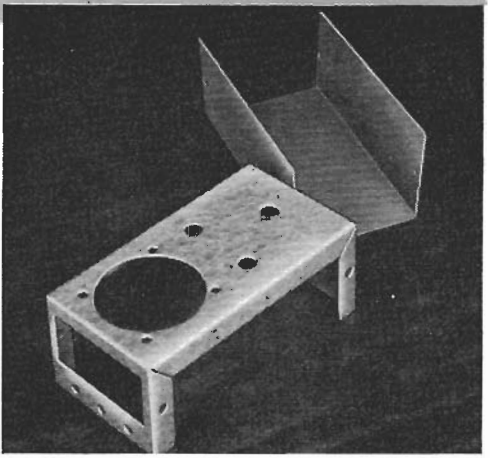


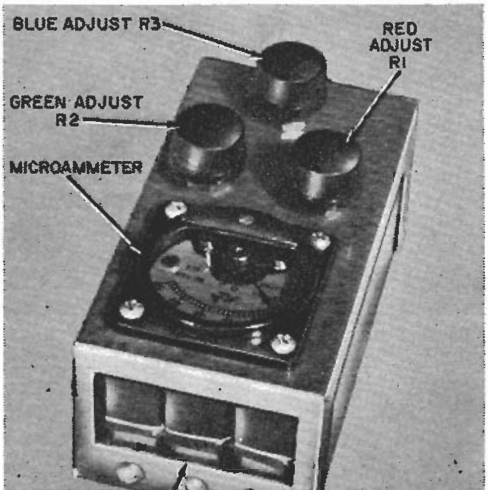
Basic color meter circuit is shown at left; its operation is similar to that of a light meter. The author's model differs in detail—three photocells with fixed filters are used, making a cumbersome, costly, filter switching arrangement unnecessary.



Schematic diagram of the Color Matcher shows simple wiring scheme. Note that the red (positive) leads from the photocells are grounded.

The photographs below show the exterior of the unit. A 1¾" x ⅞" window is cut in the chassis for the photocells, a hole punched for the meter, and mounting holes drilled. Out of sight at the other end of the box is switch **S1**.





PARTS LIST

M1—Miniature 0-50 d.c. microammeter (Lafayette TM-200 or equivalent)
PC1, PC2, PC3—Miniature selenium photocells (International Rectifier Type B2M)
R1, R2, R3—50,000-ohm subminiature potentiometers (Lafayette VC-36 or equivalent)
S1—Single-pole, three-position, miniature non-shorting wafer switch (Centralab 1461)
3—Wratten gelatin filters, 1 red, 1 green, 1 blue (Eastman Kodak #25A, #58, #47)
1—4" x 2⅛" x 1⅝" Minibox
Misc.—3 miniature knobs for ⅛" shafts, 1 for ¼" shaft; 6-32 hardware, wire, etc.

film and cell surfaces—work with tweezers.

Wiring and Mounting. The wiring is straightforward, but be sure to observe the polarity of the photocells and ground the red *positive* leads. This is necessary because the red leads are shorted internally to the mounting brackets.

Mount each cell with a *6-32* screw, and cement a 1⅛" x 2" panel of clear plastic over the photocell window to protect them. The last step is to put drops of red, green and blue paint on *R1*, *R2*, and *R3*, respectively, and on switch *S1* to show which cell is connected to the meter.

While not a high-precision instrument, the Color Matcher will give good, dependable service as long as the light source (sunlight is good) is uniform, the distance between meter and samples remains the same, and the samples tested have a similar texture. —30—

Why not a cascode optocoupler? Here's why not

On this page on March 2, 1978, S. Ashok suggested that the cascode connection of phototransistors has been overlooked. Not so, replies John Carroll of Dynamics Measurement Corp. in Winchester, Mass.—it has been tried and found wanting. "I couldn't make it work well enough to be worth bothering with, and I suspect others have run into the same roadblock," he says.

The problem, according to Carroll, is that a phototransistor acts like a conventional transistor with a photodiode across the collector junction. Even though the cascode circuit holds the collector-to-emitter voltage constant, the base-to-emitter voltage must change to switch the transistor on and off. The photodiode charges the junction capacitances until the transistor turns on, and then the base current must discharge the same capacitances to turn the transistor off again. With rather poor photon collection and a very high beta transistor, **response times in the circuit tend to be in the range of tens of microseconds to milliseconds.** There just isn't very much current available to charge and discharge these capacitances. Carroll suspects that a cascode scheme might work better with a photodiode instead of a phototransistor—but then there would be a problem building up the extremely small output current into a logic swing with good speed.

AUTOMATIC LIGHT CONTROLLER FOR CARPORT

MY WIFE WORKS EVENINGS AND GETS home well after dark. Because no one is at home to greet her upon her return, we used to leave the carport light on for many energy-wasting hours, just so she could avoid tripping over bicycles or stepping on the dog's tail when she returned in the evening.

To save my marriage—and conserve electricity—I devised the following circuit. It is simply a 555 timer IC, operating in the one-shot mode, that is triggered by light striking photoresistors. These normally have a resistance of several megohms but, in the presence of light, that resistance drops to several hundred ohms, permitting current from the six-volt source to flow in the circuit. The R–C combination shown gives an on-time of about two minutes. Photoresistors PC3 and PC4 are mounted at headlight-height on the carport wall (one for each of our two cars).

Now, when my wife pulls into the carport at night, the headlights illuminate the photoresistor, and the timer starts. That actuates a relay, RY1, in parallel with the carport light switch, and the lights are turned on long enough for her to get safely into the house. The lights are automatically turned off when the timer's two minutes are up.

We also have a push-button switch mounted inside the house and, when we go out at night, that allows us to turn on the outside lights to see our way out to the car, knowing they'll turn themselves off after we've left.

Photoresistors PC1 and PC2 are mounted on the outside of the house where they are in the sun much of the time. That keeps the timer from triggering during daylight hours. Resistors R1 and R2 establish the thresholds for proper on/off control.

My unit has been in service for over a year and has not given me any problems. I've also installed quite a few of these for friends, and they are pleased as can be.

All the components used are stock items.—*Ronald Picard*

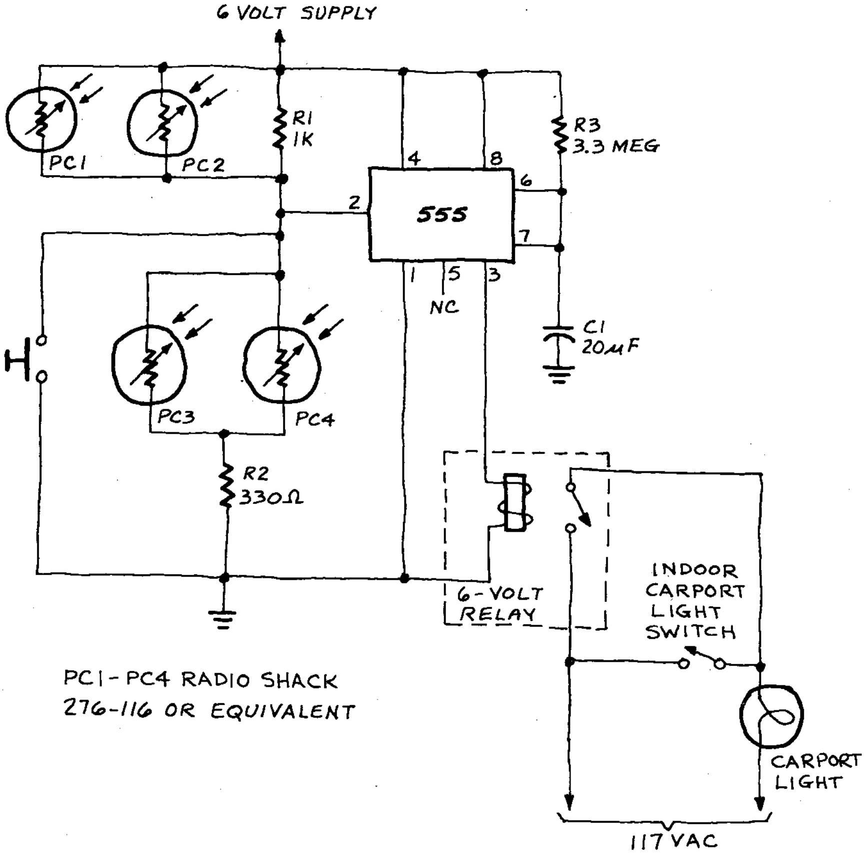


FIG. 1

Bootstrapping a phototransistor improves its pulse response

by Peter J. Kindlmann
Engineering and Applied Science Dept. Yale University, New Haven, Conn.

Although the operating speed of a phototransistor cannot be improved simply by connecting a second one in the cascode configuration [*Electronics*, March 2, p. 132, and April 27, p. 154], its response may be improved by employing a standard transistor in a bootstrap circuit in order to reduce the effective value of the phototransistor's junction capacitance. By introducing bootstrap feedback to the base of the input optodevice, the switching speed of a cascode-connected phototransistor can be increased by as much as 10 times over that of a uncompensated one.

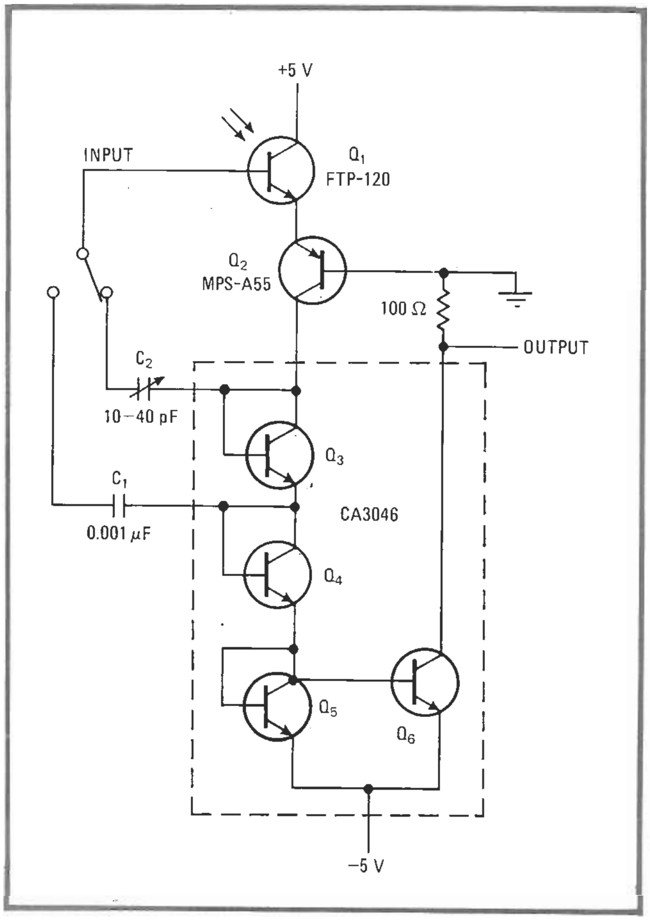
Phototransistor Q_1 and Q_2, a pnp transistor, form the conventional cascode arrangement, as shown in the figure. Generally, when an input signal is detected, the photocurrent step produced begins to charge the capacitance associated with Q_2's base-emitter and base-collector junctions. The voltage across the base-emitter junction has a magnitude comparable to that across Q_2's base-emitter junction, and therefore a way must be found to compensate for the two V_{be} drops produced, in order to ultimately reduce the effective junction capacitance of the phototransistor.

In theory, the V_{be} drops may be cancelled by making use of the pn drops across two forward-biased diodes of comparable transconductance. Here, diode-connected transistors Q_3–Q_5, which are part of the CA3046 transistor array, are available for use. Using the CA3046 ensures that these transistors will be closely matched.

Feedback from Q_4's collector to Q_1's base through C_1 constitutes the normal bootstrap path, supplying an in-phase current to Q_1's base. This causes a rapid charge of the junction capacitance, and therefore the input photocurrent sees a lower value of capacitance than actually exists. Because Q_1 has a β of several hundred, its base-emitter transconductance is less than that of the lower-β devices, Q_4 and Q_5, used in the feedback path. As a result, the amount of feedback is well below unity loop gain (undercompensated condition).

By using Q_3, however, with feedback applied through C_2, an additional pn drop is gained and compensation becomes almost perfect. For a given quiescent photocurrent, C_2 should be adjusted to a value just above that which will cause oscillation in the circuit.

Fairchild's FTP-120 (Q_1) has a typical rise time and fall time of 18 microseconds when used in the typical emitter-follower configuration specified for a 100-ohm load. With C_1-path compensation, the switching time is about 5 μs. With C_2-path compensation, the switching time is about 2 to 3 μs. □



Compensation. Junction capacitance of Q_1, which is not sufficiently reduced despite cascode connection (Q_1, Q_2), is greatly lowered by applying feedback to base. This allows a rapid discharge of Q_1's base-to-emitter capacitance during signal conditions, which acts to increase the phototransistor's high-frequency response.

Designer's casebook is a regular feature in *Electronics*. We invite readers to submit original and unpublished circuit ideas and solutions to design problems. Explain briefly but thoroughly the circuit's operating principle and purpose. We'll pay $50 for each item published.

Low-cost fiber-optic link handles 20-megabit/s data rates

by A. Podell and J. Sanfilippo
Loral Electronic Systems, Yonkers, N. Y.

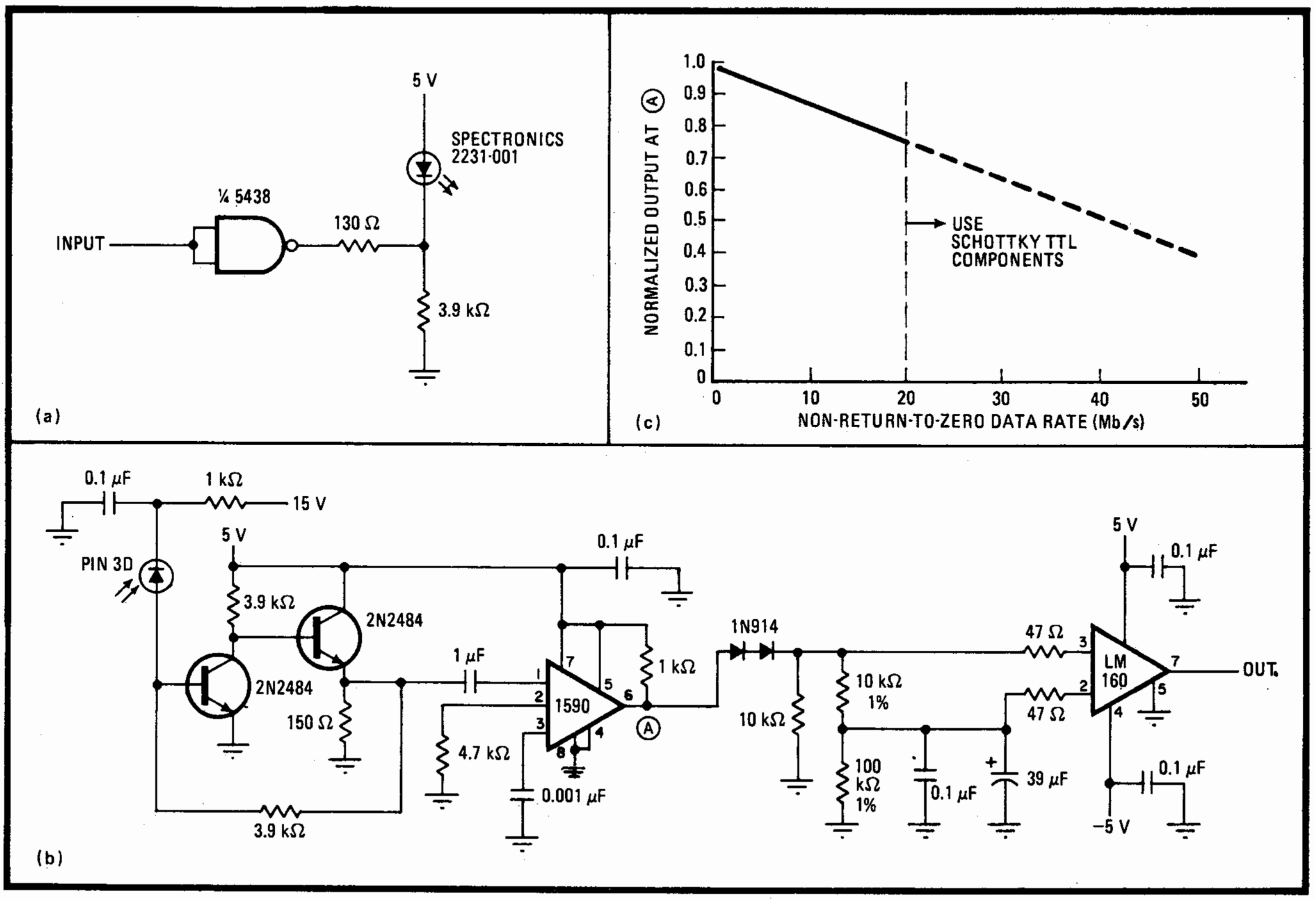
Providing an inexpensive link for the transmission and detection of digital signals over short distances, this fiber-optic system handles data rates in excess of 20 megabits per second. The system, which can be built for about $90, including cable, processes all types of data—a continuous-wave clock waveform, a burst of N clock cycles, handshaking signals, or a non-return-to-zero (NRZ) stream.

A TTL driver and a light-emitting diode serve well as the transmitter, shown in (a). The 5438 TTL driver is a two-input, open-collector NAND gate selected for its low power dissipation and 48-milliampere current-sinking capability. The LED is a gallium-arsenide device operating at 910 nanometers and provides 2 milliwatts of optical power at a forward current of 100 milliamperes. The 130-ohm resistor sets the current through the LED at about 30 mA, and so the output power is about 0.6 mW in this circuit.

The receiver (b) is also simple and sensitive. The output from the p-i-n photodiode (labeled the PIN 3D device) is several microamperes. This current is converted into a voltage by a two-transistor transimpedance amplifier. The 2N2484 transistors selected give low input capacitance, an adequate gain-bandwidth product, and the ability to detect small currents. Amplifier output is about 25 millivolts.

The MC1590 video amplifier that follows greatly boosts signal levels over a wide band (c). Two 1N914 diodes drop the output offset voltage of the single-ended amplifier, nominally at 4 volts, to within the input range of the LM160 comparater. The comparator's threshold is set by a simple voltage divider. The capacitors, across pin 2 and ground, combined with the 100-kilohm resistor, form a low-pass filter providing a threshold that varies with the comparator's supply voltage.

As for the electro-optical interface, the LED, which is contained in a TO-46 package, is easily mounted in an inexpensive window bushing made by AMP, model 530563-1. The PIN 3D photodiode can be mounted in



Light bits. Simple data transmitter (a) and a receiver (b) form the nucleus of a fiber-optic transmission system that is capable of handling all types of digital waveforms. Link operates over a wide band of frequencies (c). Cost of the 10-meter-long unit, including cable, is under $90.

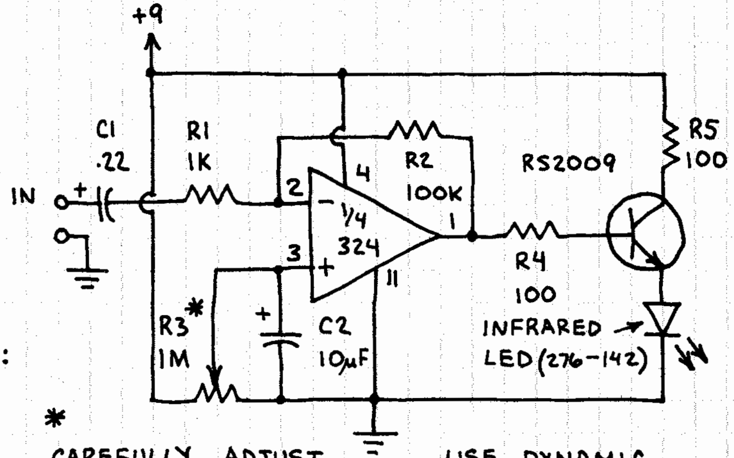
the same type of connector if desired. The need for delicate mounting adjustments is avoided here by using a fiber bundle of sufficient diameter, in this case 45 mils. Galite 2000 cable is satisfactory, and Valtec, Rank Industries, and others produce similar bundles.

The Galite cable has 210 fiber elements having an attenuation of 450 decibels per kilometer at 910 nm and a bandwidth-distance product of 15 megahertz/km. For a 10-meter-long link, therefore, the cable loss will be 4.5 dB and the bandwidth will be 1 gigahertz. With the measured loss of 1.5 dB in the LED-to-cable interface and a cable/detector interface loss of 3.9 dB, the total loss amounts to 10 dB. Thus, the 0.6-mW output of the LED is reduced to 0.06 mW at the receiver.

Transmitter layout is not critical in a one-way link. Duplex operation will require electrical isolation between transmitter and receiver components. There are several precautions to take in constructing the receiver. Notably, the lead from the anode of the detector diode to the transimpedance amp must be kept as short as possible. The output of the receiver should be isolated from all previous stages to prevent unwanted pickup. A ground plane is not a necessity, but is recommended for processing data rates greater than 10 megabits/s.

The link's signal-to-noise ratio is slightly less than 40 dB, implying a bit-error rate above 10^{-8}. The system is operational over a temperature range of −40°C to 100°C, and a supply variation of 4.5 V to 5.5 V. □

INFRARED TRANSMITTER

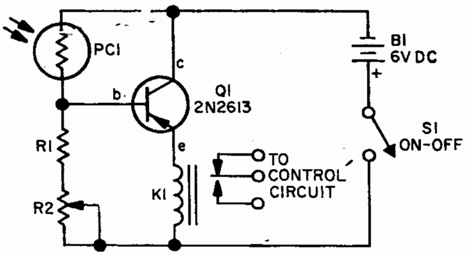


* CAREFULLY ADJUST R3 FOR BEST VOICE QUALITY. FOR MORE POWER REDUCE R5 TO 50Ω... BUT DO NOT ALLOW MORE THAN 30 mA THROUGH LED!

USE DYNAMIC MICROPHONE AT INPUT. RECEIVE SIGNAL WITH PHOTOTRANSISTOR PLUS OP-AMP.

51 Candle Power Control

With only a handful of low-cost components this photo relay turns a light on or off ac-



cording general room illumination.

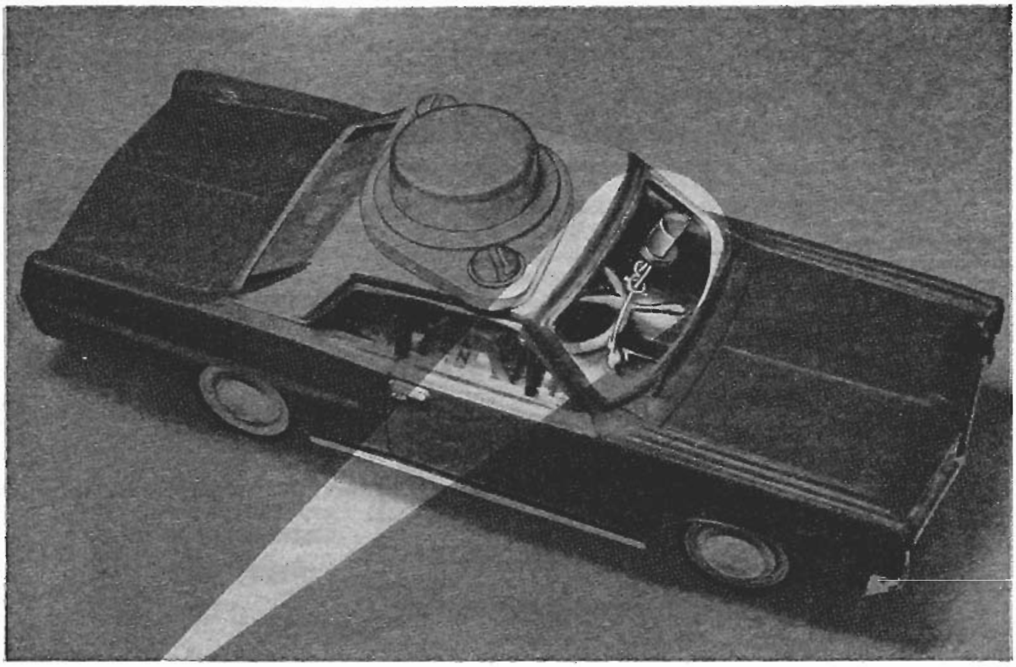
Q1 can be any general purpose pnp transistor of the 2N109 or 2N217 variety, though greater sensitivity is obtained with the 2N2613 type. Relay K1 is a high-sensitivity type like the Sigmas used by model radio control hobbyists.

Potentiometer R2, part of a voltage divider consisting of photocell PC1, R1 and R2, is set so that with normal illumination falling on PC1 the base bias current (through PC1) is just below the value needed to generate the collector-emitter current required to activate relay K1. When additional light falls on PC1, photocell resistance decreases, thereby increasing the base bias, which causes greater collector current to flow and the relay closes.

This circuit can be controlled by sunlight so K1 drops out at dusk to turn on a night light. Or use a flashlight to trip K1 for "killing" TV commercials by shorting the TV speaker connections.

PARTS LIST FOR CANDLE POWER CONTROL

B1—6-V battery
K1—1000-ohm, 2-3 mA sensitive relay
PC1—RCA 4425 photocell
Q1—2N2613 pnp transistor
R1—120-ohm, ½-watt resistor
R2—5000-ohm potentiometer
S1—Spst switch



Add LIGHT CONTROL *to Battery-Powered Toys*

JUST TWO TRANSISTORS AND A FLASHLIGHT DO THE TRICK

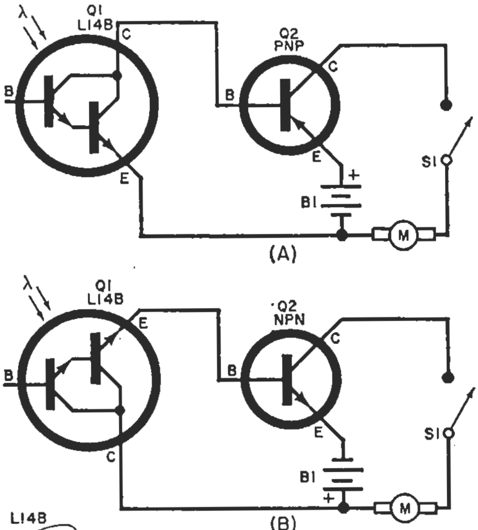
BY WILLIAM S. GOHL

BY ADDING only two semiconductors to a miniature battery-powered toy car (or any other battery-driven toy), you can control its operation with a conventional flashlight at distances up to 15 feet or more. Two circuits are shown in Fig. 1, one for *pnp* power transistors (a), and one for *npn* power transistors (b). Regardless of which type of power transistor you elect to use, operation is similar.

Phototransistor *Q1* is an *npn* photo-Darlington amplifier (General Electric L14B) whose emitter-collector current is a function of the light level present on the active surface of the transparent-potted transistor. Power transistor *Q2* can be any type that will carry the motor current of the toy.

When *Q1* is supplied with enough light, it causes *Q2* to saturate and act as a closed switch for the battery-powered motor. The motor will operate as long as *Q2* is saturated, or as long as light is present on the sensitive surface of *Q1*. When the light is removed from *Q1*, *Q2* cuts off to break the circuit, just like an on-off switch.

Mounting of *Q1* and *Q2* is determined by the configuration of the toy to be controlled. A heat sink for the power transistor is not required for ordinary operation—however, it is important that the round portion of the phototransistor



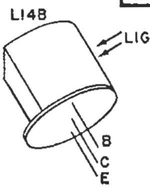
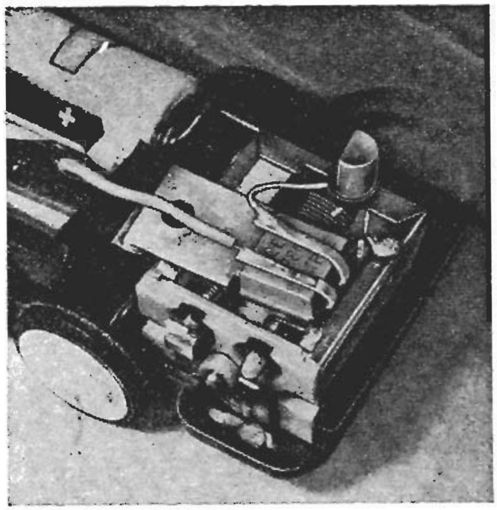


Fig. 1. Whether you use circuit (A) or (B) depends on the type of power transistor you have on hand, pnp or npn. Motor M, battery B1, and switch S1 are components within the toy itself.

be exposed as this is the light-sensitive side.

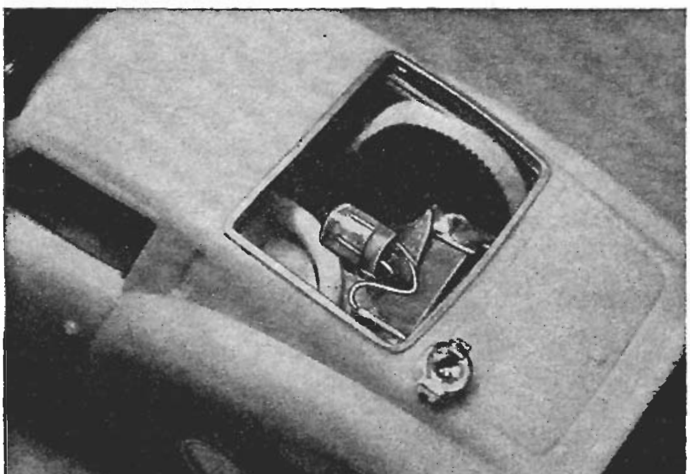
The motor, battery, and on-off switch (*S1*) are an integral part of the toy. The easiest installation procedure is to break the lead from the battery terminal to the on-off switch and connect the power transistor as shown in either Fig. 1(a) or (b).



Plastic-encapsulated transistor saves space and gives neat appearance to station wagon installation.

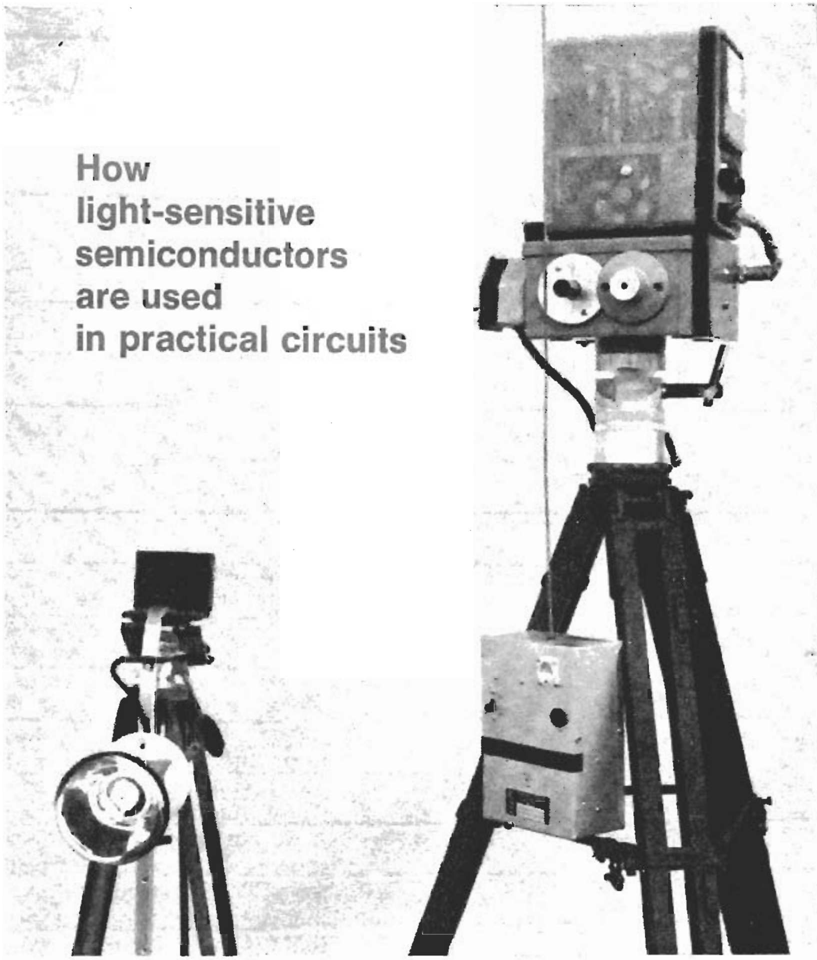
Approximately 52 footcandles are required to start the car, with 12 footcandles as a running minimum. The car should not be used in bright sunlight, as it will "run away" due to the amount of light striking the phototransistor. With artificial light, the problem is reduced.

As the average light level in a home is about 5 footcandles, the car can easily be controlled with a flashlight. A typical 2-cell flashlight has to be held about 3 to 6 feet away from the phototransistor to start the motor, but it will keep it running for about 15 feet. —30—



In the toy sports car at left, Q1 is bent to face through the rear window. In this toy, as in the station wagon shown above, the collector tab of the npn power transistor is soldered to the battery negative connector and the emitter lead is wired to a solder lug which fits between the battery case (negative) and its connector. The lug side facing the connector is insulated with tape. This puts the transistor in series with the battery, switch, and motor. The photo-transistor collector is soldered to the motor frame (positive), the emitter connects to Q2's base, while the base lead of Q1 and the collector lead of Q2 are removed to avoid accidental contact.

How
light-sensitive
semiconductors
are used
in practical circuits



Author's practical embodiment of electromechanical light chopper shown in Fig. 3. Calibration lamp is at left. An r-f transmitter triggers lamp.

Solid-State PHOTOCELLS FOR HOBBYISTS Part 2

BY L. GEORGE LAWRENCE

LAST month, different types of photocells and their general characteristics were discussed. Now we will illustrate how photocells are used in actual applications.

In some of the circuits described here, we use an NSL-446 (National Semiconductors Ltd., 331 Cornelia St., Plattsburgh, NY 12901). It has a light-to-dark resistance ratio of about 1:1000 (11,400 ohms in light to 12,000,000 ohms in darkness). Maximum peak voltage is 420 V at peak power of 1 watt. These specifications make it suitable for a wide range of sensing and control functions and are typical of many high-power photoconductive cells. Low-power photocells, such as the P-41,108 from Edmund Scientific Corp. (300 Edscorp Bldg., Barrington, NJ 08007), can also be used in similar circuits. For example, it can be used to control a relay with a 0.2-watt coil rating, as opposed to 1 watt for the 446.

A good way to experiment with photocells without damaging them is to use alligator clips for temporary connections. Many cells with pin-type leads are heat sensitive. Thus, both substrates and light-sensitive materials can be damaged by frequent soldering. To be on the safe side, use a simple heat-sink tool (Miller No. 80, for example) or long-nose pliers when soldering.

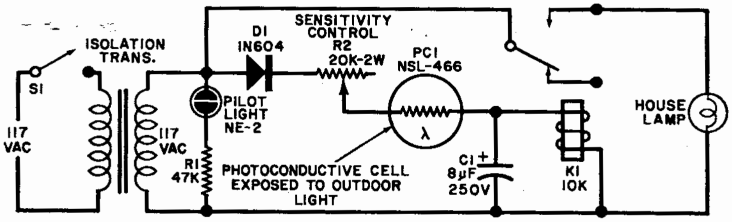


Fig. 1 Simplicity of application of photoconductive cells is demonstrated in this construction project. House Sitter stops conducting at night, making relay drop out and turn on lamp.

Daylight-Operated Controller. A basic application for the NSL-446 is the "house sitter" shown in Fig. 1. The photocell is exposed to outdoor light and it automatically turns on a lamp circuit when the sun goes down. Potentiometer *R2* and relay *K1* provide current limiting for the photocell. Half-wave rectification is provided by *D1*, and *C1* prevents relay chatter. During daylight hours, the photocell's resistance is low, and

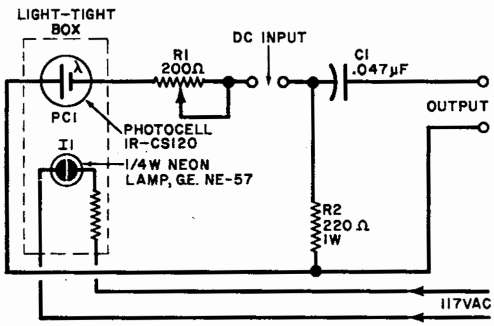


Fig. 2 Photoelectric chopper for converting dc to amplitude-variable ac for oscilloscope.

the relay is kept energized. The lamp circuit is thus turned off. When the resistance of the photocell rises with waning light, the relay drops out and the lamp circuit is energized. The neon pilot light indicates that the unit is on and ready to operate.

Choppers. When the circuit shown in Fig. 2 (called a photoelectric chopper) is used with a conventional ac-type oscilloscope, the latter can be used to display dc signals. The photocell, *PC1*, is optically coupled to a ¼-watt neon lamp, *I1*. Since the cell is gated on and off by the neon lamp's flicker frequency of 60 Hz, a dc signal applied to the input of the circuit is chopped and appears as ac across R2. High dc input provides an analog increase in the amplitude of the ac output. This arrangement works well in many non-critical applications. The excitation current can be derived from the scope's power supply.

The ac processing of a photocell's dc signal is desirable in many applications where the inherent drift of "straight" dc amplifiers (including low-cost IC's) cannot be condoned. In the setup shown in Fig. 3, for instance, a motor-driven wheel "chops" the light to the photocell. The frequency of the electromechanical chopper is determined by the number of apertures in the wheel and the speed of rotation. If, for example, the wheel is driven by a synchronous motor at 1800 rpm and has 4 holes, the effective chopping frequency is $(1800/60) \times 4 = 120$ Hz. The chopped dc (actually a square-wave signal) across *R1* is amplified and applied to a meter readout through a full-wave rectifier.

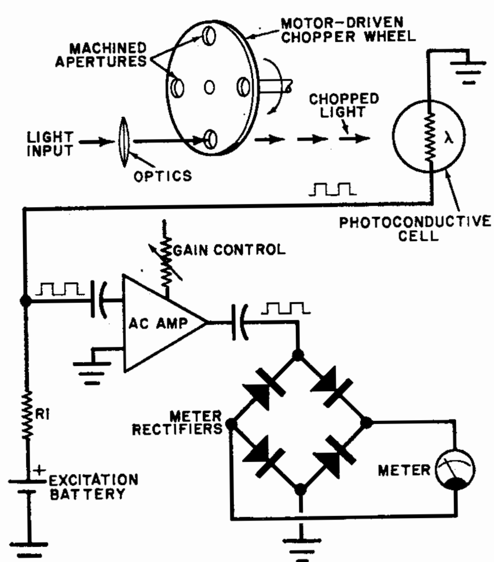


Fig. 3. Electromechanical light chopper has rotating aperture wheel, amplifier, meter.

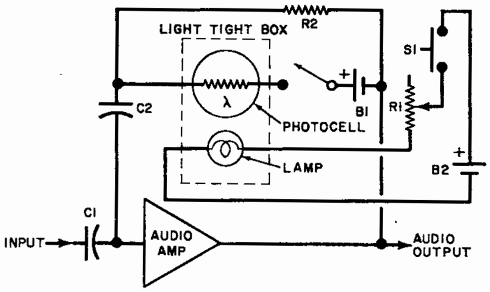


Fig. 4 Photocell feedback for audio effects.

Audio Use. Photoconductive cells can be used in many fascinating experiments and money-saving conveniences in audio work.

The circuit shown in Fig. 4, for example, provides light-controlled feedback of an audio amplifier. If the intensity of the lamp (controlled by *S1*) is sufficient to lower the resistance of the photocell, part of the amplifier's output signal is fed back to the input. Depending on the lamp's brightness, which is set by potentiometer *R1*, powerful feedback oscillations of variable intensity can be obtained. Thus, the amplifier can be converted into a single-frequency "cue" generator, an aid in cutting master tapes.

If desired, the amplifier can trigger a special-effects instrument. The photocell can be activated by the dominant light of a color organ during original deep bass sequences, with the photocell's output triggering a solenoid-operated drum.

In the circuit shown in Fig. 4, *R2* provides a "keep-alive" current path for the cell. Since its own resistance is high, no feedback will ensue unless resistive circuit values are lowered by the activated photocell. Best results can be obtained by actual experimentation.

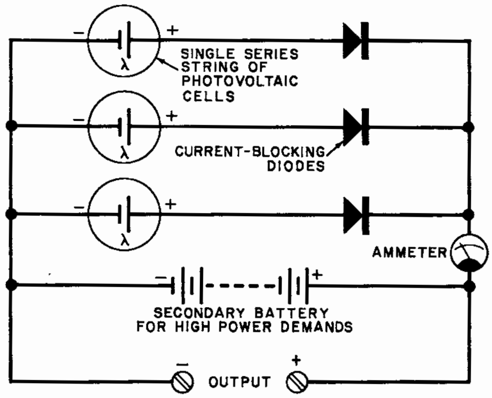


Fig. 5 Solar cells in series-parallel array.

Power Generators. Photovoltaic cells are used primarily as sources of dc power. An excellent application is in the generation of power for emergencies. As shown in Fig. 5, silicon or selenium cells in series can furnish charging currents to a secondary battery, with current-blocking diodes to protect the cells from reverse current. The ammeter (optional) indicates the total amount of charge.

Since the output of the cells is governed by the amount of ambient sunlight, special allowances must be made in computing charging rates and effective load resistances. An excellent guide for this purpose is International Rectifier's handbook, *Solar Cells and Photocells* (HB-30), which is available for $2.00 from most electronics distributors.

In typical applications, solar batteries act as trickle chargers for conventional batteries that furnish high dc power (100 A or more) for a few minutes at a time. This concept is used in satellite applications, with silicon photocells assembled in arrays on the satellite.

An excellent hobby project is the sun-powered emergency radio receiver shown in

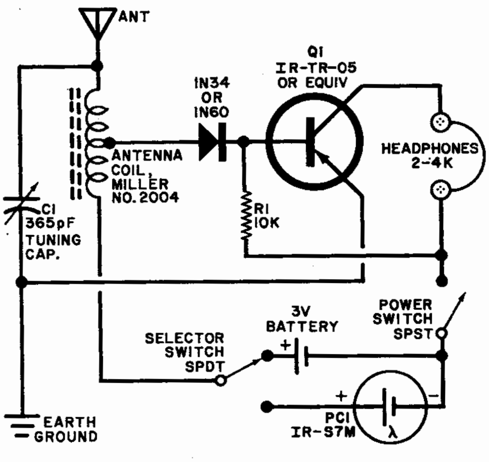


Fig. 6. Sun-powered emergency radio receiver.

Fig. 6. It is simple and reliable, with a 3-volt standby battery (two C or D cells in series) for sunless days. For use on land or at sea, the receiver works best with a true earth ground and a long antenna. The ground can be a metal frame or a submerged metal plate in the case of a boat. A small transistor amplifier can be added to improve the power output. Wiring and layout are not critical, but the electronic components should be housed in a sturdy metal container. ◈

LIGHT PROBE FOR THE BLIND

THE optical light probe to be discussed has been successfully used in teaching laboratory science to a blind student and enabled him to perform ordinary laboratory experiments, using conventional test equipment, without the aid of a sighted partner. The device was developed by Dr. Thomas R. Carver of Princeton University.

It was immediately obvious that most problems could be solved by a small photoelectric light sensor which could focus at short object distances as a microscope, at intermediate distances as a "flag" for moving objects, and at infinity for certain optical experiments. It was also obvious that the readout had to be an audio tone.

The basic circuit, shown in Fig. 1, consists of a two-transistor *RC* feedback oscillator in which photoresistor *R*1 acts as a bias resistor for transistor *Q*2. Variations in the light level reaching the photoresistor produces a broad range of frequency change. Audio output is *via* a small magnetic earphone.

Different optical functions are performed by a set of interchangeable lenses which can be attached to the main tube. One lens has a focal length of 2 inches and an object distance of infinity and is useful for general guidance and location functions. The second lens has a ½-inch diameter and an object distance of about 6 inches in front of the lens and is useful in timing a moving object passing in front of the lens, as well as "reading" the explanatory diagrams on the blackboard and tracing wiring on a benchtop.

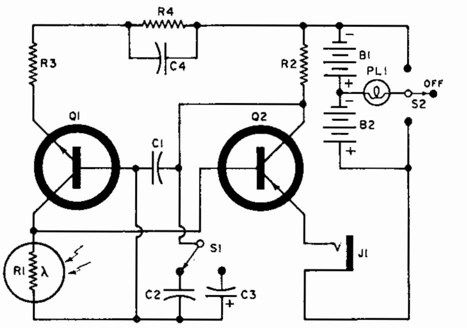
The third lens has a short focal length and is used with a 5-power magnifier having an object distance only ⅜ inch from the first surface of the lens. This is used to scan an oscilloscope screen, locate fluid levels, and find punched holes in paper tape or cards. It is also useful in determining whether or not the equipment pilot lamps are lit.

The fourth lens is similar to the third lens except that it contains a semi-reflecting beamsplitter at 45°, between the lens and the photoresistor, in order to provide axial self-illumination from an internal light bulb. This last lens is useful for reading fluid level in a conventional thermometer, and sensing the location of meter pointers.

Because the oscillator operates reliably on 2.5 to 3 V, but the tiny grain-of-wheat lamp operates at 1.25 V, switch S2 is provided so as to connect only one cell to the lamp. With 225 mA/h batteries, operating life is about 12 hours with the lamp in use, and about 5 days when the lamp is not used. Switch S1 is provided to adjust the center frequency of the oscillator to the ambient light which happens to be present in any particular area. ▲

Fig. 1. Circuit and parts list for the audio/light probe.

R1—Photoresistor (Clairex CL904L or equiv.)
R2—150 ohm, ¼-watt res.



R3—620 ohm, ¼-watt res.
R4—16,000 ohm, ¼-watt res.
C1—500 pF capacitor
C2—0.01 μF capacitor
C3—1 μF, 6-volt elec. capacitor
C4—0.1 μF capacitor
S1—S.p.d.t. switch
S2—S.p.3-pos. switch
PL1—1.25 V pilot lamp
J1—Phone jack (also "on/off" switch)
B1, B2—1.25 V rechargeable battery
Q1—2N207 transistor
Q2—2N706 transistor

INSTALL A "HOUSE-SITTER" in your home

by GEORGE PANKOW,
Sales Manager, National Semi-Conductors

It's a pleasant feeling to come home late at night and have a light on somewhere in the house. Light actuated switches can provide this convenience without needless waste of power. You can construct such a switch from parts readily available from your local Electronics Distributor. The heart of the device is a Cadmium Sulphide photoconductive cell which is especially designed for the automatic control of street lights.

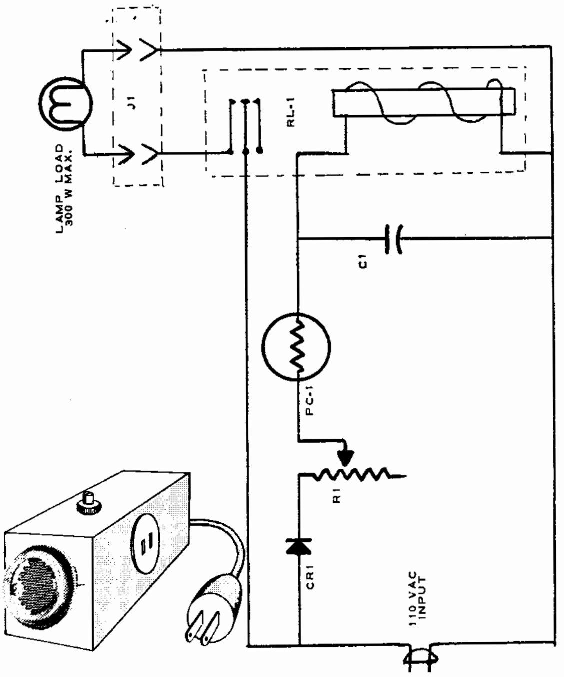
Circuit operation is simple. During daylight photocell PC-1 has a low resistance and relay RL-1 operates, opening the NC contact. As darkness approaches the resistance of the photocell increases. At a preselected light level the relay will de-energize closing the NC contact and your light will go on. The rectifier and capacitor provide the dc supply this relay needs. Ac only circuits generally suffer from buzz. The variable resistor provides a sensitivity control; at minimum resistance your light will go on at approximately 1 Footcandle (this is the light level at which most street lights are turned on). Higher resistance means a higher turn-on light level, maximum in this circuit is about 10 Footcandles.

The photocell must be exposed to day light, usually through a window. Keep in mind that any kind of visible light will operate this switch providing the light level is higher than the switch-on point. Especially avoid the condition where the light you are controlling strikes the photocell. This will cause your light to flash on and off all night.

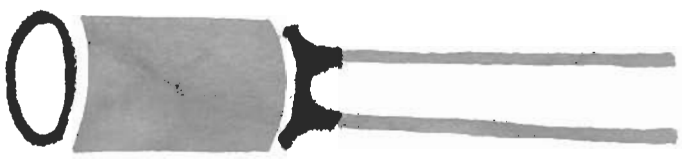
PARTS LIST

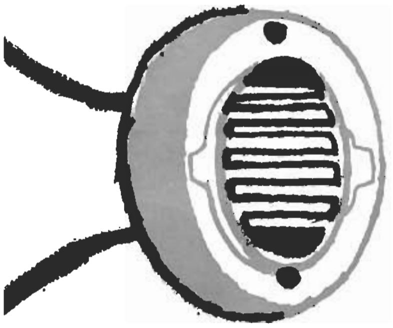
PC-1	Photocell Type NSL-46 National Semiconductors Limited, 230 Authier St., Montreal 9, Que.
RL-1	Potter & Brumfield Type LB5 — 10,000 Ohms
CR-1	Silicon Rectifier IN604, 400 PIV — 600 MA
R-1	IRC — Q11-119 — 20 K linear taper
C1	Cornell-Dubilier Electrolytic Capacitor BBR-8-250, 8MFD, 250 volt.
J1	Amphenol type 61F, AC Receptacle

Suggested Mounting Box
Hammond Type 1411D



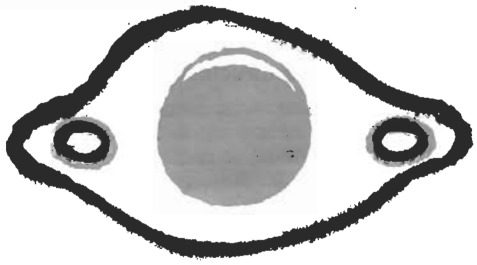
Novel Uses For Photoconductive Photocells





By JOHN POTTER SHIELDS

Construction of a simple light-operated relay, an automatic night light, and a daylight alarm are all possible with inexpensive cadmium sulphide photocells.



SEVERAL years ago a number of inexpensive cadmium sulphide photoconductive photocells were put on the market and have since found wide industrial and domestic application. Due to their small physical size and extremely rugged construction, they can be used in many environments where the conventional gas or high-vacuum tube photocell would be totally unsatisfactory. In addition, the sensitivity of the cadmium sulphide (CdS) photocell is much greater than gas or high-vacuum tube types so that, in many instances, no amplifier is required between a CdS cell and the relay or other device to be controlled.

Characteristics

The CdS photocell may be considered, for all practical purposes, as a light-sensitive resistor; the resistance of the average unit varying from many megohms in total darkness to several hundred ohms under conditions of high illumination, such as in bright sunlight. In most cases, the current through the CdS cell is proportional to the amount of illumination to which the cell is exposed. It should be noted that cells by different manufacturers will vary somewhat in this respect.

The spectral response of the average CdS photocell is such that its sensitivity is excellent throughout the visible light range and extends slightly into the infrared region. The spectral response peak, at approximately 6800 to 7000 Angstroms, can be seen in Fig. 1 for a typical cadmium sulphide photocell.

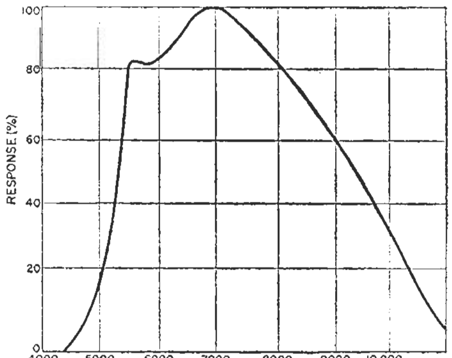


Fig. 1. Spectral response of typical CdS photocell—Polaris Type MAJ-1.

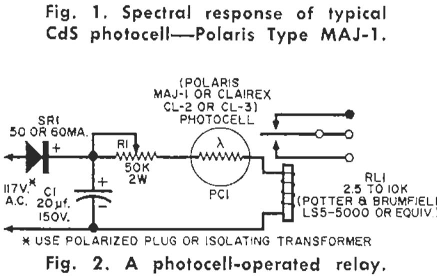
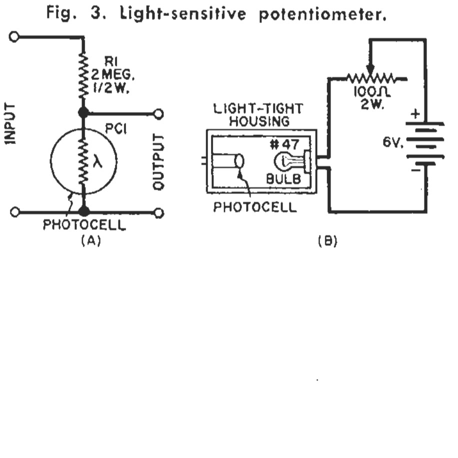


Fig. 2. A photocell-operated relay.

Fig. 3. Light-sensitive potentiometer.



As is the case with most good things, CdS cells have their limitations. For example, the frequency response of a CdS cell is so poor as to make it practically useless in such applications as optical sound-track reproduction and "light-beam" communications. These cells also possess what might be termed an "inertia effect." When a CdS cell is exposed to intense illumination which is then suddenly removed, a finite time is required for the cell's internal resistance to change to its original value. This effect is less pronounced as the intensity of illumination is decreased, therefore for maximum speed of response, as little illumination as possible should be used.

As is the case with any resistive device, the CdS cell has a maximum dissipation rating—generally expressed in fractional wattage at a given ambient temperature. Therefore, in designing equipment employing these cells, both the ambient temperature in which the circuit will be operating and the maximum electrical power which they can dissipate must be considered.

Most CdS photocells have an internal capacitance of between 8 and 20 $\mu\mu$f. which allows their use in wide-band video circuitry as would be the case if one were to be employed in an automatic contrast control circuit of a TV set.

Practical Uses

Now for a look at some practical applications for the CdS photocell. As a starter, Fig. 2 shows one of the most obvious applications for a CdS cell—a photocell-operated relay. As can be seen from the schematic, the circuit is simplicity itself, requiring only a selenium rectifier (SR_1), a sensitivity control (R_1), a filter capacitor (C_1), a CdS photocell (PC_1), and a relay (RL_1). The relay coil resistance should be between 2500 and 10,000 ohms. In operation, SR_1 and C_1 provide a source of low-ripple d.c. which is applied to the sensitivity control, R_1, the CdS cell, and the relay coil—all of which are connected in series. The sensitivity control is adjusted so that when light strikes the cell, dropping its resistance, sufficient current will flow through the relay coil to energize the relay. Since the current drain of this circuit is quite small, a 90-volt "B" battery can be used to operate the circuit if, at any time, portable application is desired.

A rather unique application of the CdS photocell is as a "light-sensitive potentiometer," as shown in Fig. 3A. Here a 2-megohm fixed resistor (R_1) is connected in series with the CdS cell (PC_1). The input signal is applied across both R_1 and PC_1. The output is taken from their junction and the low side of PC_1, which is also common to the input. Assuming that the dark resistance of the CdS cell is 10 megohms, then the output voltage will be 83 per-cent of the applied input voltage when the cell is not illuminated. If the cell is now sufficiently illuminated so as to drop its resistance to, say, 200 ohms, then the output voltage will be only 1/10,000th of the applied input signal.

This type of potentiometer has many useful applications. For example, it can be combined with a light bulb in a small housing to form a complete potentiometer control assembly, as shown in Fig. 3B. This type of assembly could find application where it is desired to insert a pot in a high-impedance circuit; the pot being controlled from a point remote from the circuit.

As an example, Fig. 4 shows such an assembly used as a volume control in a typical radio receiver. The CdS cell and associated resistor, R_1, replace the conventional volume control. The "control lamp" is connected by a piece of ordinary two-conductor "zip cord" to a simple rheostat and battery located at the desired point of control. The obvious advantage of this setup is that no high-impedance signal appears on the control cable; allowing the use of an unshielded cable of almost unlimited length. Incidentally, this same type of control setup would be ideal for use with a stereo system where it is always advisable to have the volume and balance controls located by the listener's side.

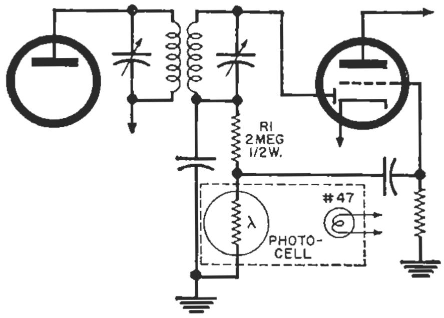


Fig. 4. Light-operated volume control.

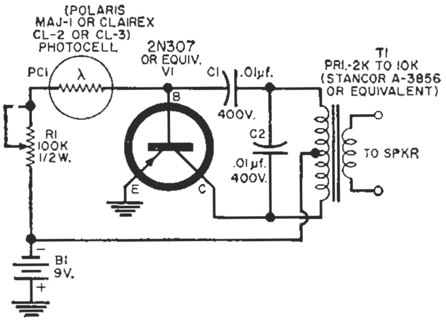


Fig. 5. An "electronic alarm clock."

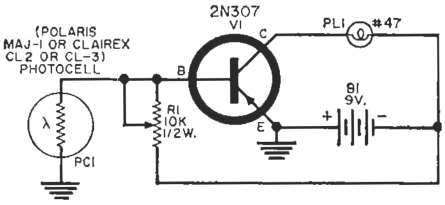


Fig. 6. Automatic night-light circuit.

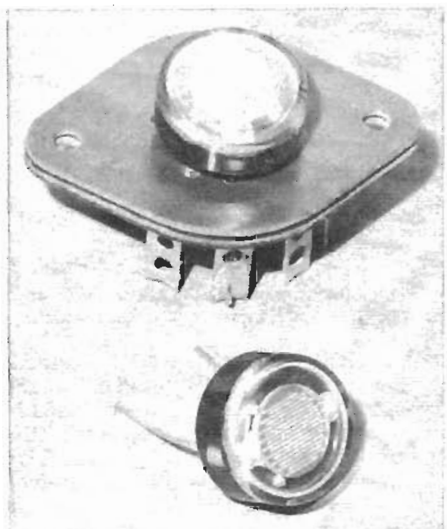
An a.c. supply may be used to excite the light bulb in the circuit of Fig. 4 if the cell is not placed in a circuit which is followed by large amounts of amplification. The reason that an a.c. supply may often be used in many circuits is that the light bulb filament possesses a certain thermal lag, that is, during each alternation of applied current, the bulb's filament doesn't have time to cool off completely. A low-voltage (2.5 volt) bulb is to be preferred over a higher voltage bulb as its filament is heavier and, as a result, has a greater thermal lag.

Another, although not quite so obvious, application of the photocell-light bulb combination is in instances where it is desired to use the CdS cell as part of a high-potential circuit, while keeping the control circuit at or near ground potential. Since the bulb and cell are completely isolated electrically, this type of operation would present no problem.

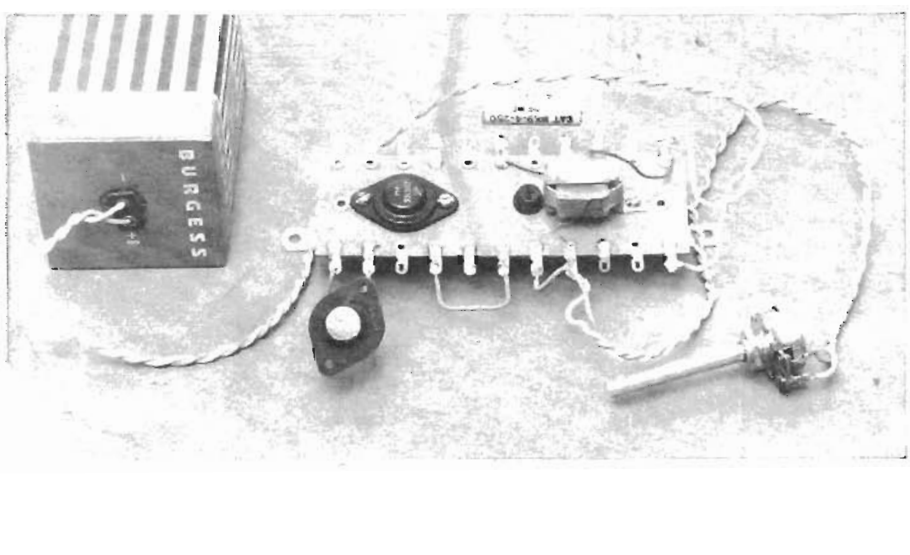
Other Novel Uses

Fig. 5 shows a rather novel application of a CdS cell. Transistor V_1 is connected in a series-fed Hartley oscillator circuit consisting of T_1, C_1, C_2, R_1, and PC_1. The base bias of V_1 is determined by R_1 in series with the CdS cell, PC_1. When PC_1 is not illuminated, its internal resistance is in megohms so that V_1 can draw no base-bias current—preventing it from oscillating. If PC_1 is illuminated, its resistance will drop sharply allowing V_1 to break into oscillation by virtue of now obtaining base-bias current. A small speaker can be connected to the secondary of T_1 to reproduce the tone. This gadget can be used as an "electronic alarm clock"—sounding a soft tone at the arrival of daylight. R_1 can be adjusted to vary the amount of illumination that is required to trigger the oscillator.

Fig. 6 is another circuit which can be adapted to use as an automatic night light. A #47 pilot light is connected in the collector circuit of V_1. The CdS cell, in conjunction with R_1, form a voltage divider network which supplies base current to V_1. When PC_1 is not illuminated, its resistance is extremely high, thereby shunting very little current to ground. As a result, V_1 receives sufficient base-bias current to conduct; lighting the pilot light. When PC_1 is illuminated, its resistance drops to a point where it shorts the transistor's base current to ground, causing it to cease drawing enough current to light the bulb.


Some typical CdS photocells along with improvised tube-socket mounting.

Needless to say there are countless other applications for CdS photocells. The examples given here are meant merely as illustrations and are not intended to stifle the imaginations of the readers. -30-

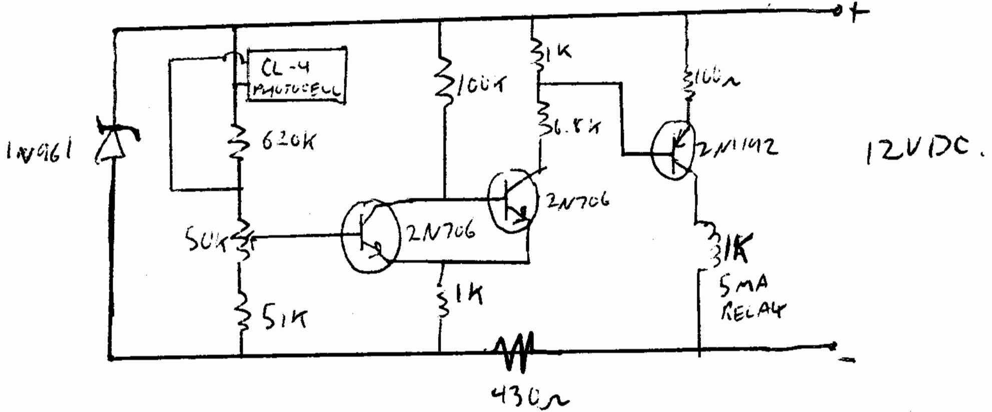
The author's breadboard test setup for evaluating CdS photocell circuits.


Engineer's newsletter

Light-level sensor puts a bridge between two LEDs

Here's a neat way to build a sensitive light-level sensor that indicates either an increase or a decrease from a preset level. Put two light-emitting diodes back to back across a balanced bridge, says Calvin Graf of San Antonio, Texas, and make one of the legs of the bridge a photocell. This photocell and a 1-kilohm resistor form the high end of the bridge, which is connected to a 3-to-12-v source, while a 1-kilohm resistor and a 1-megohm potentiometer form the grounded side. Next, balance the bridge by adjusting the pot for a null (neither LED lit). Now, **if the amount of light hitting the photocell changes, unbalancing the bridge, one or the other LED will turn on,** depending on whether the light level has increased or decreased.

LIGHT ACTIVATED RELAY



The In-Out Annunciator

GETS THEM COMING AND GOING

BY JOHN S. SIMONTON, JR.

THE ELECTRIC "EYE" has been a faithful, reliable workhorse in all sorts of burglar alarms and counting systems since before the word "electronics" was coined. Even today, it is extensively used in these applications. But too often it is used in circuits that are far from up-to-date.

The "In-Out Annunciator" described here is, in fact, an electric eye system—using a highly sophisticated circuit. Designed for the special case where it is not enough to know simply that someone or something has interrupted the beam of light, the Annunciator tells you whether the person was entering or leaving the passage-way covered.

Uses of the Annunciator include monitoring one-way-only garage doors, operating automatic doorbells or chimes that do not sound when a visitor is leaving, guarding high-security areas, and discriminating sizes of objects. It also makes an interesting, attention-getting Science Fair project.

Two inexpensive resistor-transistor logic IC's are at the heart of the Annunciator, containing enough electronics to provide the amplification needed for good sensitivity in high ambient light areas and the logic necessary to distinguish between objects passing in either of two directions.

Theory of Circuit Design. Before going into a detailed examination of the operation of the Annunciator's circuit, it is useful to point out that gate pairs *G1/G3* and *G2/G4* in *IC1*, as shown in Fig. 1, are wired with regenerative feedback through resistors *R1* and *R2*, respectively. This feedback arrangement adds hysteresis to the response of the circuit so that slight changes in ambient light level will not be misinterpreted by the circuit and generate "false" counts. Capacitors *C3* through *C6*, by rolling off the high-frequency

John S. Simonton, Jr. is a graduate electrical engineer who now spends most of his time developing unusual projects.

response of *IC1*, reduce the sensitivity of the circuit to transients. Also, *G3* and *G4* are cross-coupled to form a set-reset latch.

The steady-state outputs of the NOR gates with both *LDR1* and *LDR2* fully illuminated are: *G1* and *G2*, high; *G3* and *G4*, low; *G5* and *G6*, high; and *G7* and *G8*, low.

Now, suppose the light source is interrupted on first *LDR1* and then on *LDR2*. By darkening *LDR1*, its internal resistance increases and causes a high input to be presented to *G1*. In turn, the output of *G1* goes to low. Since both inputs to *G3* are now low, the output of this gate goes to high and is then inverted by *G5*. The output of *G3* is also applied to one of the inputs of *G4* to guarantee that this gate's output will remain low.

Gate *G7* now has one of its inputs at low and the input from *G2* at high; so, its output it still low. When *LDR2* is darkened, the output of *G2* goes to low, applying a second input to *G7* and causing the output of *G7* to go to high. As a result, *Q1* conducts and energizes *K1*. The state of *G4* does not change because the output of this gate is held low by the high output of G3.

As the light again illuminates *LDR1*, the state of the circuit does not change by virtue of feedback from *G7* which holds the output of *G1* at low. When the light illuminates fully *LDR2*, the output of *G2* goes to high and, consequently, the output of *G7* goes to low, unlocking the loop formed by *G1*, *G3*, and *G5*.

Objects passing between the light source and the system so that *LDR2* is darkened first, followed by the darkening of *LDR1*, generate a similar chain of events to energize *K2*.

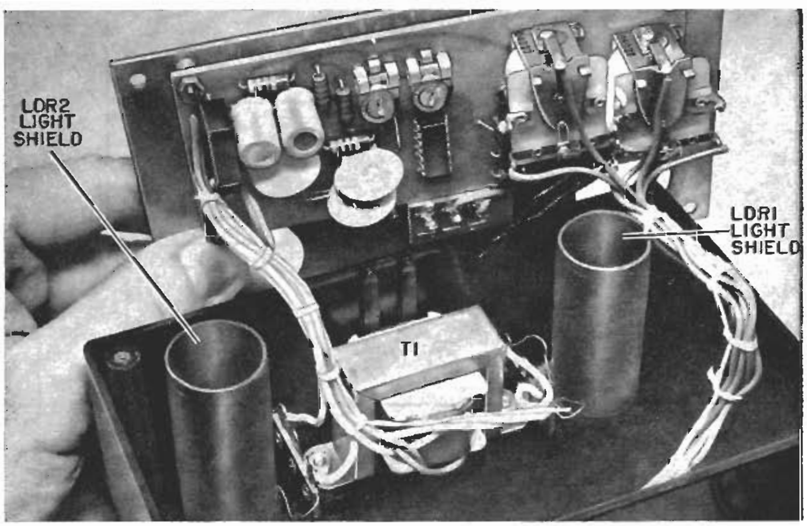
Construction. Since integrated circuits are used in the Annunciator, printed circuit board construction is the only realistic approach to assembly. You can etch and drill your own circuit board by carefully following the actual size etching guide provided in Fig. 2, or you can purchase a ready-to-use board from the source given in the Parts List.

Begin assembly by mounting the components on the board (see Fig. 2). Be careful to orient properly polarized components, and use heat from a 35-watt soldering iron sparingly. Also, as you solder, take pains to avoid solder bridges between closely spaced foil conductors—particularly around the IC solder pads.

Mount *K1* and *K2* on the circuit board with 4-40 machine hardware. Then use insulated jumper wires to connect the relay coils to the appropriate solder points on the foil pattern of the circuit board.

When mounting trimmer pots *R5* and *R6*, bend their leads to position the adjustment slot directly over the ¼″-diameter holes in the circuit board. This allows the system to be adjusted through access holes in the plastic cabinet once final assembly is complete.

A standard 6¼″ × 3¾″ × 2″ Bakelite case makes for an exceptionally compact project. However, steps must be taken to keep

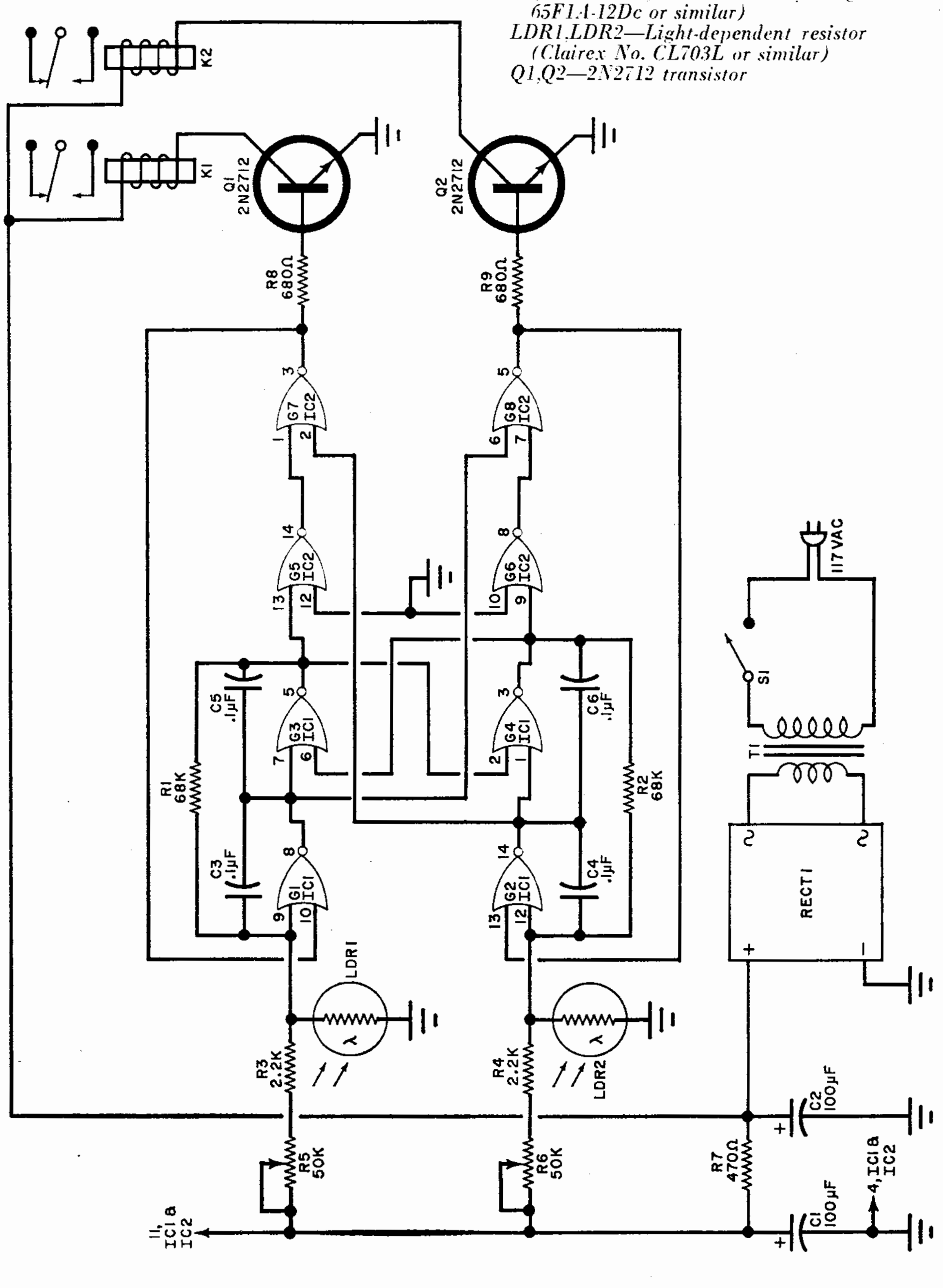


All components except power transformer, on/off switch, and LDR's mount on printed circuit board. Spacers and 4-40 machine hardware fasten circuit board to case top.

Fig. 1. Two quad two-input gate digital IC's supply all functions for proper bidirectional operation of Annunciator system. Relays control counters and/or signalling devices.

PARTS LIST

C1,C2—100-µF, 15-volt electrolytic capacitor
C3-C6—0.1-µF disc capacitor
IC1,IC2—Integrated circuit (Motorola MC-724P)
K1,K2—12-volt, 1640-ohm relay (Sigma No. 65F1A-12Dc or similar)
LDR1,LDR2—Light-dependent resistor (Clairex No. CL703L or similar)
Q1,Q2—2N2712 transistor



R1,R2—68,000-ohm
R3,R4—2200-ohm
R7—470-ohm
R8,R9—680-ohm } *All resistors, ½-watt, 10% tolerance*
R5,R6—50,000-ohm trimmer potentiometer
RECT1—50 PIV, 1-ampere rectifier bridge assembly (Motorola MDA942A-1 or similar)
S1—Spst switch
T1—12.6-volt, 300-mA filament transformer
Misc.—Printed circuit board, terminal strips (2), line cord and strain relief; ¼"-long spacers; 6¼" × 3¾" × 2" plastic or Bakelite box; 5-dram pill containers (2); hookup wire; 4-40 hardware; solder; etc.
Note: The following items can be obtained from PAIA Electronics, Inc., P.O. Box 14359, Oklahoma City, OK 73114: etched and drilled circuit board No. 5701pc for $3.50 postpaid; complete kit of all parts, including circuit board and unfinished case, No. 5701K for $19.75 plus insurance and postage on 2 lb.

components and assemblies from interfering with each other. The following general assembly sequence should be followed as closely as possible.

Begin mechanical assembly by drilling the mounting holes for transformer *T1*. Locate the transformer so that it is in contact with one of the long sides of the case. (Note that the same machine hardware used to fasten *T1* in place is also used to anchor the terminal strips which serve as tie points for the leads of the LDR's.)

Position the light shields (5-dram pill containers) at opposite ends of the transformer, and use a pencil or scoring tool to mark their outlines on the Bakelite case. Then remove and set aside the shields. Locate the centers of the light shield outlines and slowly and carefully drill first a $1/16''$ hole, following it up with a $1/4''$ bit to enlarge the holes. At this point, you can use a multiple-drilling tech-

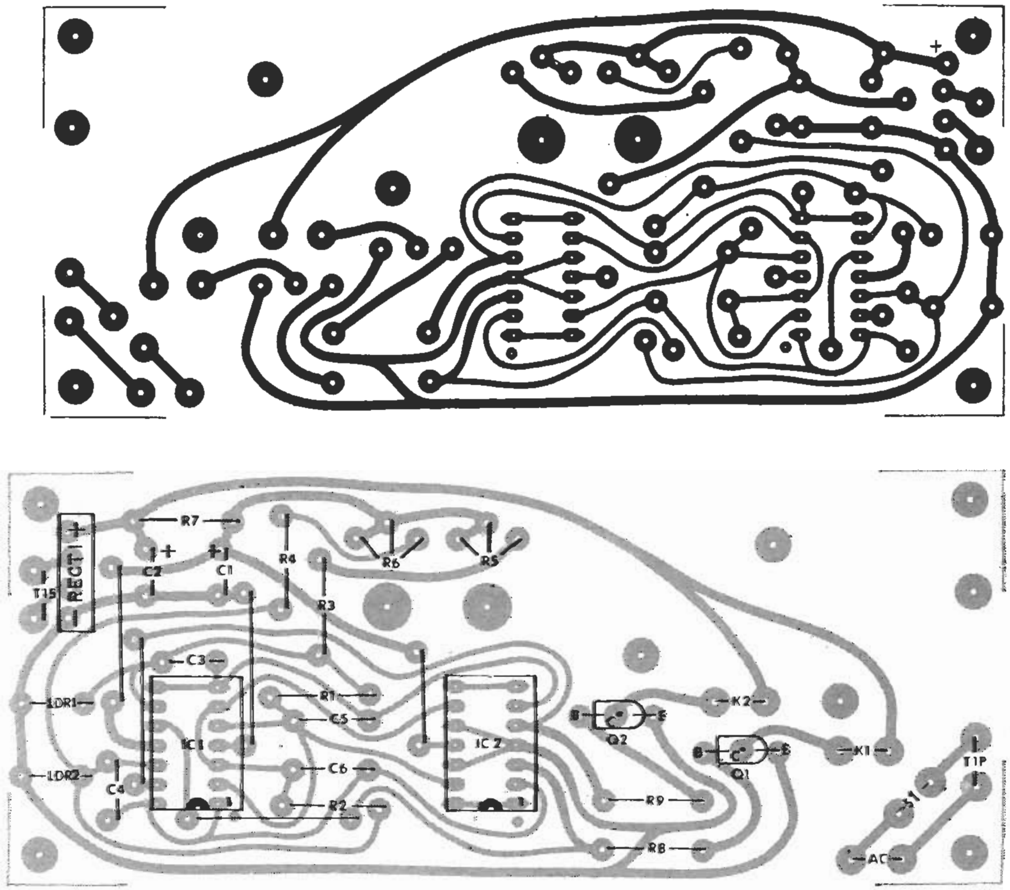


Fig. 2. At top is given actual size etching and drilling guide for fabricating the printed circuit board. In the component location and orientation guide (above) note particularly orientations of IC's.

nique, a nibbling tool, or a chassis punch to enlarge the holes or cutouts so that they are slightly larger in diameter than the shields.

The mounting holes for power switch *S1* and the circuit board, and the access holes for the slots of *R5* and *R6* trimmer pots can now be accurately located and drilled. Position the circuit board as close as possible to the front of the case to obviate any possibility of the lugs on *S1* from contacting *T1*.

When all front-panel holes are drilled, paint and label the panel as desired. Allow sufficient time for the paint to dry; then drill a hole for and mount the line cord—via its strain relief—and the terminal block on the rear of the case.

Drill two #60 holes, about 30° apart and as close as possible to the bottom of each pill container. Then use flat black paint to coat the interior surfaces of both containers. When the paint dries, use a pin to clear the #60 holes of paint. Insert the leads of the LDR's through the holes, daub a drop of epoxy cement on the undersides of the LDR's, and press the LDR's to the bottoms of the containers.

Slip the light shield assemblies into their respective cutouts, taking care not to tear off the LDR leads. Run a thin bead of epoxy cement around the lip of each shield; then seat the shields squarely in their cutouts and allow the cement to set at least overnight.

Interconnect all components and assemblies as shown. Then mount the circuit board inside the case with 4-40 machine hardware and 1/4"-long spacers.

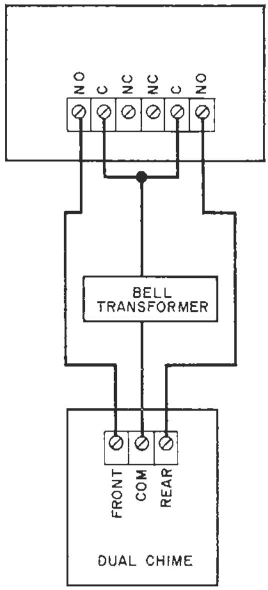
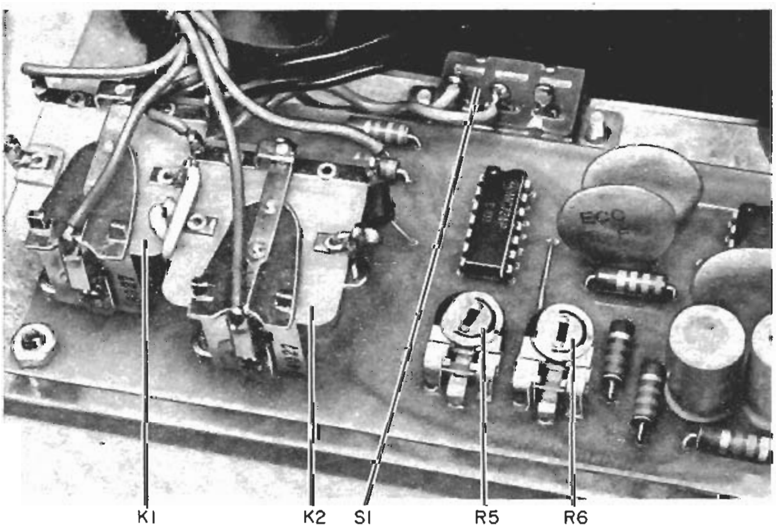


Fig. 3. When wiring dual chimes into system, use only normally open and common contacts on relays.

Setup and Use. Rotate *R5* and *R6* fully clockwise (viewed from the component side of the board). Point the LDR's at a relatively bright light source, plug the power cord into a convenient ac outlet, and close *S1*. Use a piece of opaque cardboard to completely cover *LDR1*; neither relay should be energized. With *LDR1* still covered, place another piece

(*Continued on page* 92)



Access to contacts on K1 and K2 is through solder lugs mounted on small phenolic boards which are on relay frames facing toward on/off switch S1 in photo.

ANNUNCIATOR

(*Continued from page* 52)

of cardboard over *LDR2*; now *K1* should immediately be energized.

Alternately exposing and covering *LDR2* should cause *K1* to open and close. Leaving *LDR2* covered, illuminate *LDR1*; *K1* should remain energized. Removing the cover from *LDR2* should cause *K1* to deenergize.

The reverse of this procedure to test *K2* is as follows: cover *LDR2* (*K1* and *K2* open);

cover *LDR1* (*K2* closes); illuminate *LDR2* (*K2* remains energized); illuminate *LDR1* (*K1* and *K2* open). While the system is operating properly, it should be impossible for both relays to energize simultaneously.

Although the system employs two LDR sensors, it is not necessary, in most cases, to use two light sources. A single light source and a flashlight reflector can be used to illuminate both LDR's satisfactorily if the distances are reasonable. Of course, if the distance between light source and Annunciator is excessive, a two-light source system would be required.

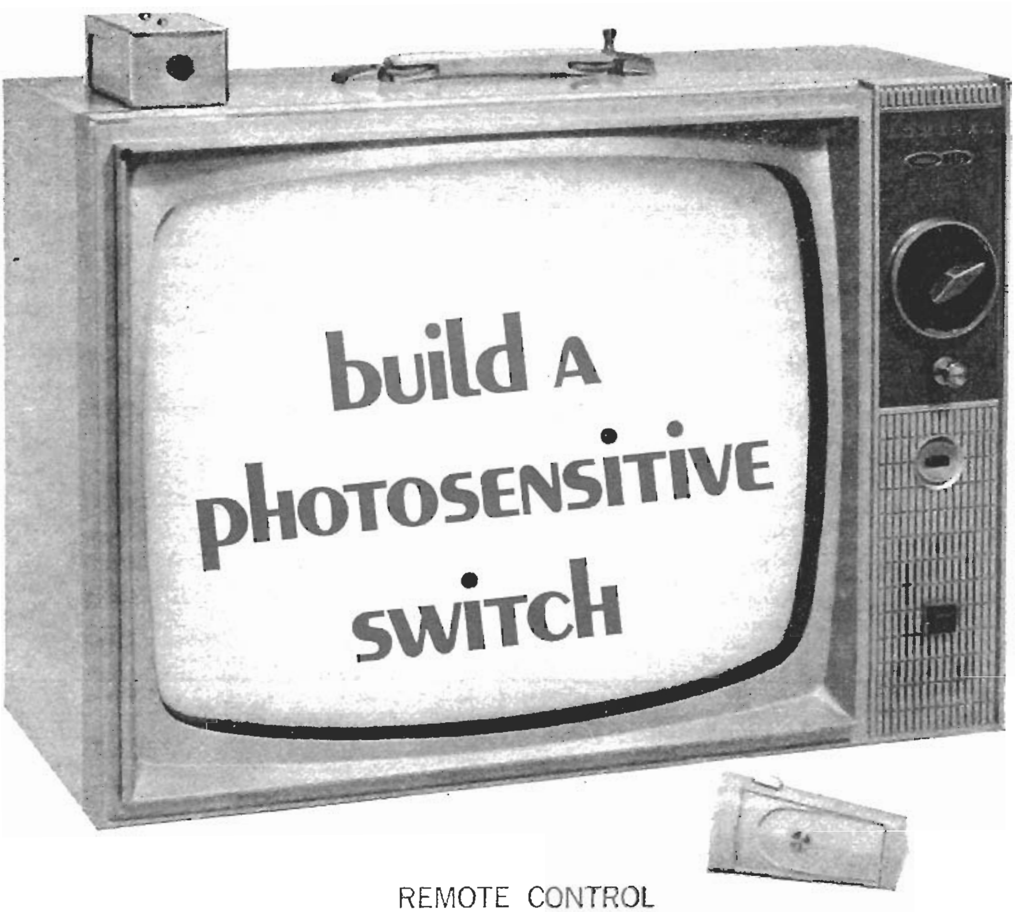
When you get ready to set up your system, orient it so that the minimum amount of ambient light reaches the LDR sensors. Avoid pointing the LDR's toward windows or bright room lighting, and do not set up the system so that an opening door will trigger it. Finally, when counting people passing by, it is a good idea to locate light sources and sensors about 54" from the floor so that swinging arms will not produce multiple counts.

Now, turn on the system and orient the setup for maximum illumination of the LDR's. If necessary, you can use mirrors to bend the light beam around corners so that more than one area can be surveyed.

Adjusting *R5* and *R6* is simple. Rotate both controls fully counterclockwise (viewed from the front of the case). Temporarily mask *LDR1* from the light source and rotate *R6* until *K1* pulls in; then back off until *K1* just opens. Interrupt the beam to *LDR2* once or twice with your hand to check that *K1* opens and closes properly.

Remove the mask from *LDR1* and place it in front of *LDR2*. Rotate *R5* until *K2* energizes; then back off until the relay just de-energizes. The controls are now set for maximum sensitivity.

The relay contacts can be used to activate a variety of alarms or counters. In simple one-way systems, use the normally open contacts of the appropriate relay to turn on the system. A slightly more elaborate system, using both relays and a dual door chime is shown in the wiring diagram in Fig. 3. People passing in one direction will cause the chime to sound once; people passing in the opposite direction will cause the chime to sound twice. This same basic arrangement can be used as a secure area monitor by substituting two counters. Anyone entering the area will be registered on one counter, while those leaving the area will be registered on the other counter. In this way, you can tell if someone has gone into the area and has not come out. —30—



build a photosensitive switch

REMOTE CONTROL
FOR MANY APPLICATIONS

BY H. R. MALLORY

REMOTE CONTROL comes in handy in many applications around the house and workshop. It silences loud or disturbing TV commercials, turns on garage lights when a car enters the driveway, turns on lights in a remote building, and so forth—anything you can't or don't want to get up and do yourself. There are also many ways of activating remote controls—sound, light, r.f., etc.

If most remote control systems sound too complex for your needs and construction capabilities, here's one that is simplicity itself and easy to build. This photoresistive switch is activated by a common flashlight and, unlike most light-controlled devices it is bistable—one flash of light turns it on, and it remains on until another flash turns it off.

Construction. The circuit of the switch is shown in Fig. 1. It can be built in a separate metal box ($4'' \times 2\frac{1}{8}'' \times 1\frac{5}{8}''$ will do) or you can build it inside your radio or TV cabinet. For the unit shown in the photographs a tube socket was mounted on one end of the chassis for the external connections with a matching plug for the wiring.

The photographs also show one way to assemble the components though this is not critical. Just be sure that the photoresistor is placed so that light can be shown on it directly.

Only two construction details are important: mount the photoresistor in a length of opaque tubing so that only light from directly ahead can activate the cell (not ambient room light); and, if you can't get the capacitor for $C2$

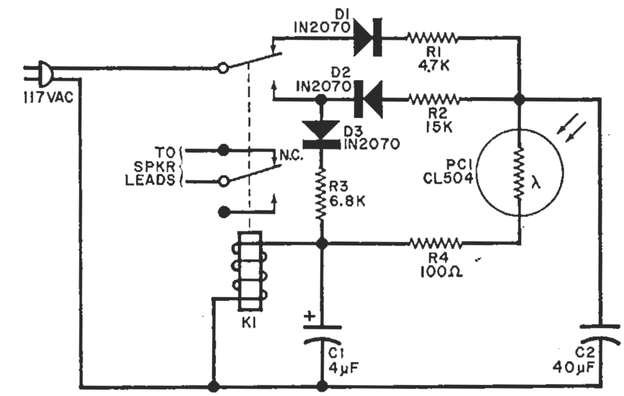


Fig. 1. To make non-polarized capacitor for C2, connect two 80-µF, 150-volt electrolytics in series positive lead to positive lead; or connect a pair of 40-µF, 150-V electrolytics in series positive lead to positive lead and connect a diode across each capacitor with the anode to the negative end and cathode to the positive end.

PARTS LIST

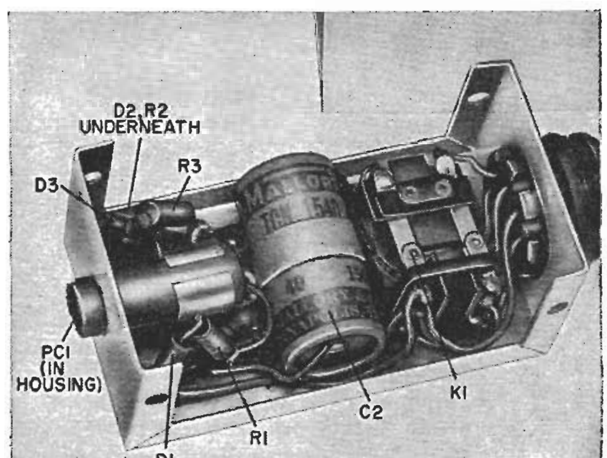
C1—4-µF, 150-volt electrolytic capacitor (Mallory TT150x4 or similar)
C2—40-µF, 150-volt, non-polarized electrolytic capacitor (Mallory TCN1540 or similar, see text)
D1-D3—1N2070 diode (400-PIV, 750-mA)
K1—117-volt relay (Brumfield KA11AY or similar)
PC1—Photoresistor (Clairex CL504 or similar)
R1—4700-ohm, 1-watt resistor
R2—15,000-ohm, ½-watt resistor
R3—6800-ohm, 1-watt resistor
R4—100-ohm, ½-watt resistor
Misc.—4" x 2⅛" x 1⅝" metal enclosure, tube socket and matching plug (optional), tube for photoresistor, mounting hardware, etc.

HOW IT WORKS

When power is applied, capacitor *C2* is charged up through *D1* and *R1* to approximately 75 volts with the upper terminal (as shown in Fig. 1) positive. When light strikes photoresistor *PC1*, its resistance drops and the charge on *C2* flows off through low-resistance *R4* to the relay coil. When the relay is energized, the incoming power is switched to the circuit containing *D3* and then to the relay coil so that it remains energized.

With the relay locked in, *C2* is now charged up in the opposite direction through *D2* and *R2*. (This is why *C2* must be non-polarized.) Now when the light beam is flashed onto the photoresistor, the reverse charge from *C2* is applied to the relay coil so that it is de-energized.

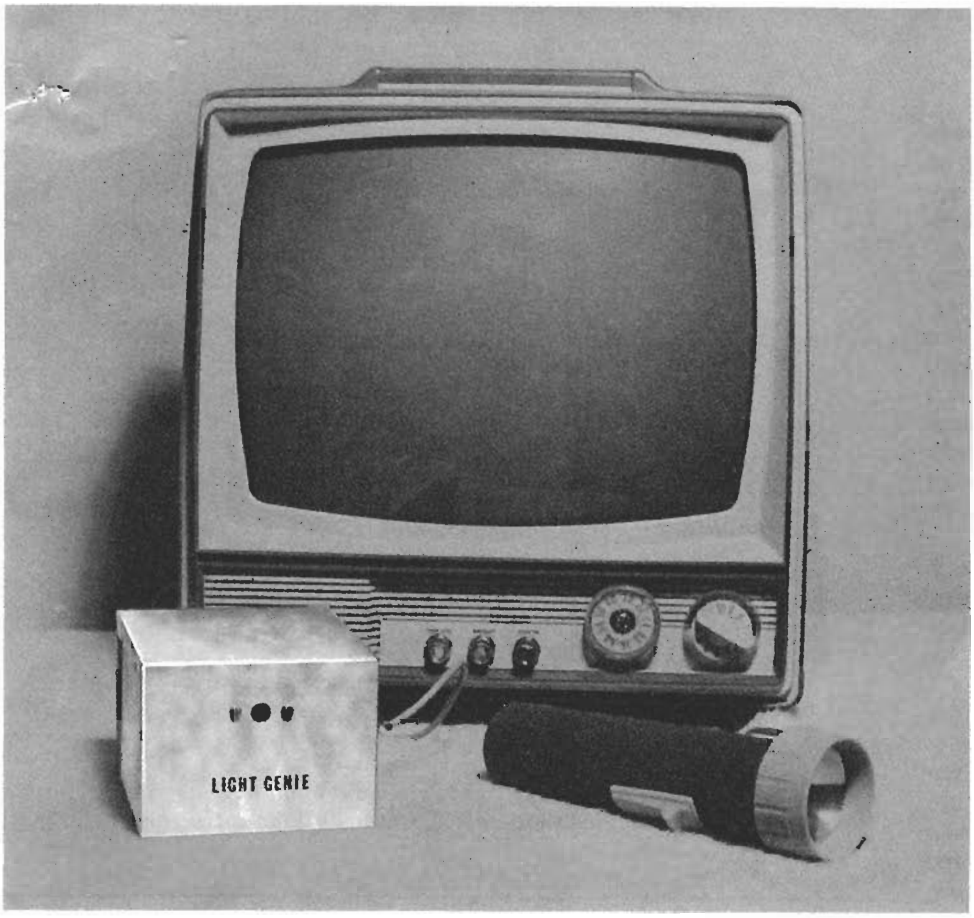
The switch can handle many different kinds of loads, as long as the power rating of the relay contacts is not exceeded.



Most any method of housing can be used. It is important that PC1 is "hidden" in light-tight tube.

called for in the Parts List, use two 80-µF, 150-volt electrolytics connected in series with the two positive ends connected together.

Operation. Mount the chassis at a convenient spot and aim the photoresistor in the desired direction. Connect the relay contacts to the device to be controlled. In the case of a TV set, open one lead going to the speaker from the output transformer, and connect the two ends to the normally closed relay contacts. The TV sound will be normal until the flashlight beam strikes the photoresistor. You can also mount the switch in the rear of your garage so that when the headlight beam strikes it, it turns on the overhead garage lights. —30—



BY MAYNARD GRADEN

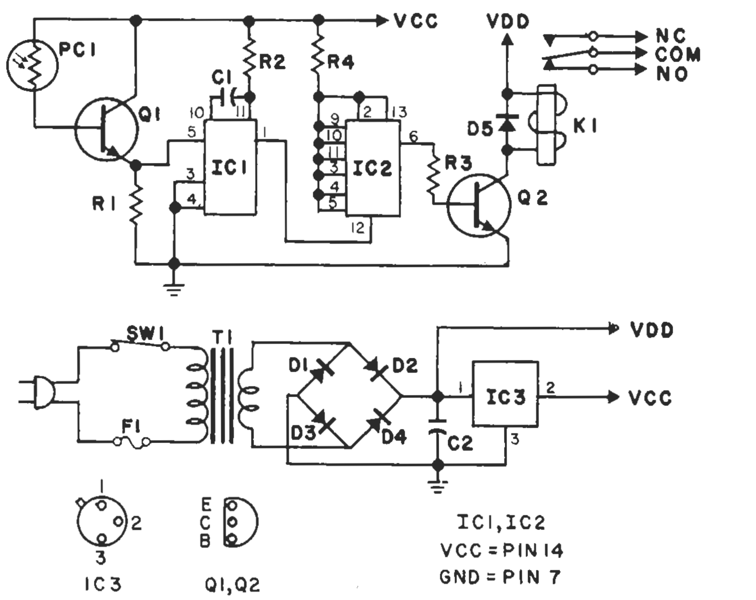
Handheld photoelectric system turns electrical equipment on or off.

BUILD THE "LIGHT GENIE"

ALADDIN was a lucky fellow. When he wanted a job done, all he had to do was rub his magic lamp and a genie would do his bidding. With the "Light Genie," you can do almost the same thing. You can use it to silence annoying TV commercials or change your stereo system from tuner to tape deck. In fact, the Genie will control just about anything that has a switch.

A small penlight will operate the Genie at distances up to 12 feet (3.6 m), while a regular flashlight extends the range to greater than 30 ft (9.1 m). High ambient room light will not interfere with the Genie's operation.

Circuit Operation. The schematic diagram of the Genie is shown in Fig. 1. A light shield is used to prevent random ambient light from striking the photocell, *PC1*. The latter provides base bias for emitter follower *Q1*. Small, relatively constant amounts of light only vary the quiescent operating point of the circuit.



PARTS LIST

C1—10-µF, 10-volt electrolytic capacitor
C2—500-µF, 15-volt electrolytic capacitor
D1 through D5—1N4001 rectifier diode
F1—¼-ampere fuse (see text)
IC1—74121 integrated circuit
IC2—7472 integrated circuit
IC3—LM309H 5-volt regulator IC
K1—6-volt dc relay with spdt contacts (Sigma No. 65F1A-6DC or similar—see text)
PC1—Clairex CL702L photoresistive cell
Q1,Q2—2N3704 transistor
The following resistors are ¼-watt, 10%:
R1—470 ohms
R2—39,000 ohms
R3—220 ohms
R4—1000 ohms
SW1—Spst toggle or slide switch
T1—6.3-volt, 1.2-ampere transformer (see text)
Misc.—Metal utility box; fuse holder; line cord with plug; 9-pin shielded tube socket; ¾" flat washers (2); matte black construction paper; tape; glue; hookup wire; solder; machine hardware; etc.

Fig. 1. Circuit is activated to energize K1 when light beam strikes PC1 directly.

However, when a beam of light is directed at the Genie so that it falls directly on the photocell, the resistance of *PC1* rapidly decreases and sends *Q1* into conduction.

Integrated circuit *IC1* is a monostable multivibrator. A time constant of 250 ms, which prevents multiple triggering from a slowly changing light source, is provided by *C1* and *R2*. The output from *IC1* is a clean square pulse that is used to clock *IC2*. As flip-flop *IC2* toggles, transistor *Q2* is either driven into saturation or cut off to energize or de-energize relay *K1*, respectively.

The power supply is also shown in Fig. 1. It provides power for the relay and regulated 5 volts, through *IC3*, to operate the logic.

Construction. To construct the light shield, use a piece of 8″ × 4″ (20.3 × 10.1 cm) matte black construction paper. Form a tube by rolling it around two ¾″ flat washers. Insert a washer inside the paper tube at the halfway point and perpendicular to the central axis. Drop in a small amount of glue to secure it in place. Use tape to hold the tube together, as shown in Fig. 2.

Remove the Bakelite base from the frame of a nine-pin shielded tube socket. (The two pieces are usually held together by small metal tabs that can be bent to separate the two parts.) Using the frame as a template, mark and drill mounting holes on the front of the box. Locate the center of the frame and drill a third ¼″ (6.35 mm) hole at this point. Attach the frame to one end of the paper tube. This will be the mounting bracket for the light shield.

Mount the photocell and two 12″ (30.5 cm) lengths of wire on the tube base using two of the pins as tie points. Adjust the photocell so that it is parallel to the base of the tube. Complete the light shield by cementing the photocell assembly to the other end of the paper tube.

The circuit can be assembled using perforated board and point-to-point wiring or a printed circuit board that can be made using Fig. 3. In either case, the board should be mounted vertically on one side of the box so that ample space remains for installing any additional parts that may be required for various switching applications.

Uses. The Light Genie can be used to silence television commercials as shown in Fig. 4. The value of *RL* should be equal to the impedance and wattage of the speaker. If there is enough room

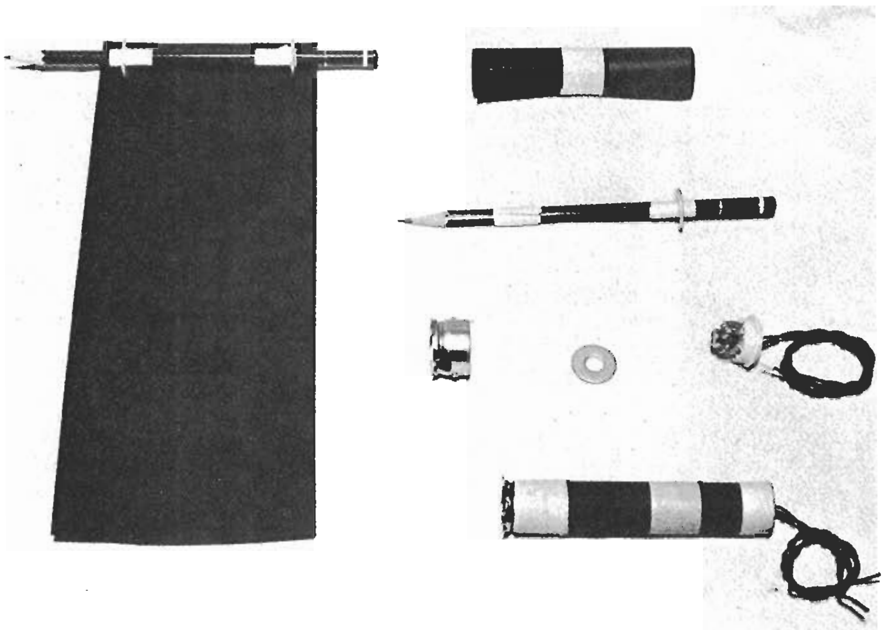


Fig. 2. Photo shows how to make light shield out of black construction paper. Base from a 9-pin shielded tube socket is used as a mounting bracket.

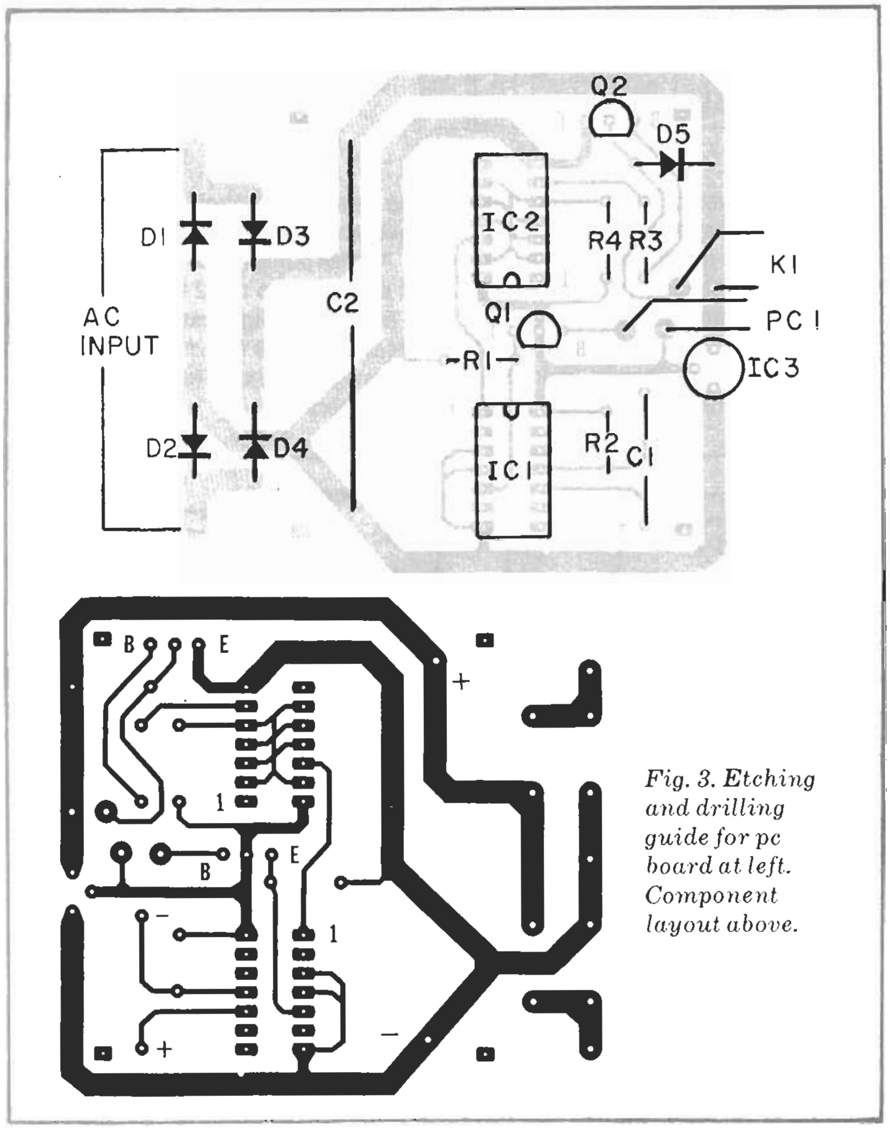


Fig. 3. Etching and drilling guide for pc board at left. Component layout above.

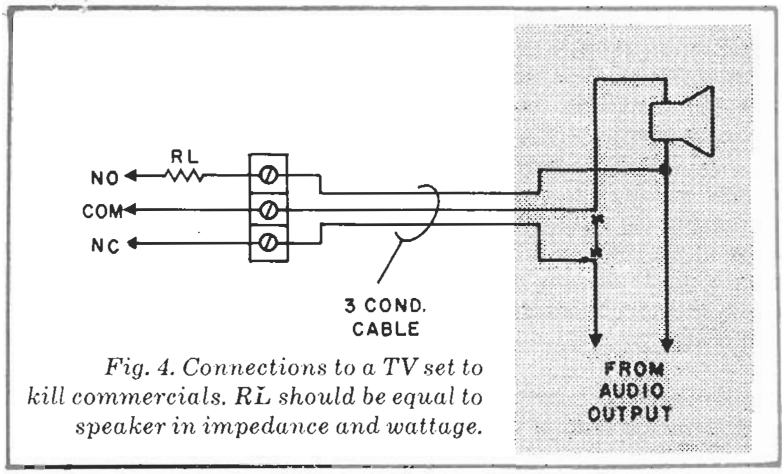


Fig. 4. Connections to a TV set to kill commercials. RL should be equal to speaker in impedance and wattage.

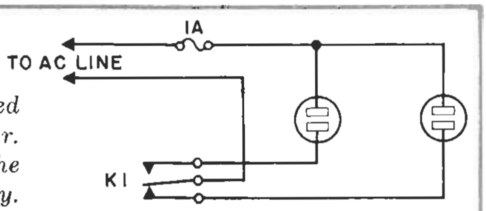


Fig. 5. Using two chassis-mounted ac receptacles to switch power. Fuse shown is separate from the one in Genie power supply.

inside the TV receiver, the entire circuit can be placed inside the cabinet behind a small hole that allows unobstructed access to *PC1* for the light beam. If the Genie is to be an outboard unit, mount a terminal block on the outside of the box and use a length of three-conductor wire to make the interconnections.

An application using two chassis-mounted ac receptacles to switch power is shown in Fig. 5. The relay specified in the Parts List will handle a 1-ampere resistive load. If a heavier load is to be controlled, substitute a relay with a higher contact rating, or have the specified relay drive a 117-volt ac relay with sufficiently heavy contacts. The fuse is separate from the power supply fuse and should be equal to the current capacity of the relay contacts.

It is possible to perform complex switching functions by using one relay to control several other relays as shown in Fig. 6. Here, relay *K1* is used to control two other relays, which choose between two components in a stereo system with the same output level, impedance, and required equalization characteristics.

The preceding examples begin to demonstrate the versatility of the Light Genie in two-state switching applications. Sequential switching functions can just as easily be implemented using stepping relays. ◇

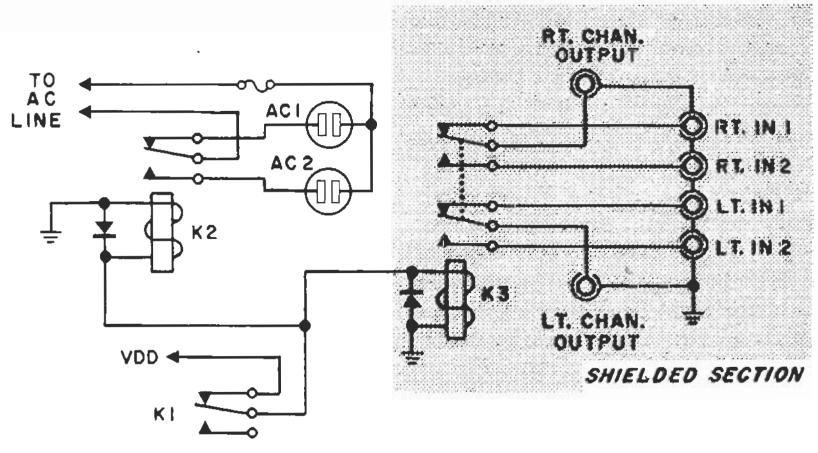


Fig. 6. Performing complex switching functions by using one relay to control several others.

PHOTOELECTRIC SENSOR

DETECTS (AND COUNTS) ENTRANCES & EXITS

In/out detection system counts events (up and down) and can be used to control lights, appliances, etc.

BY DAVID MARKEGARD

MOST photoelectric entry detectors are unidirectional. They can detect when an individual enters a given area but not when he leaves. A more practical system, from both a security and a convenience point of view, would be able to detect motion in both directions. A store owner would then know whether or not all customers who entered his premises had left by the close of the day. In the home, such a system could be used to automatically turn on and off lights as you enter and leave a room.

The in/out detection system described here is a relatively simple and inexpensive approach that takes advantage of readily-available TTL IC's. It not only turns on the room lighting (or any other electrical device) when the first person enters the monitored area, it also keeps tabs on the number of people entering and leaving the area. The system turns off the electrical device only after the last person has passed the sensor while exiting the area.

The basic circuit is designed to count up and down a maximum of nine events. However, it can easily be modified to count 99, 999, etc., events simply by adding extra IC's and diodes. Additionally, the system can accommodate two or more sets of sensors should you have more than one doorway to monitor.

About the Circuit. In the circuit shown in Fig. 1, the UP and DOWN sections of the system operate in an identical manner, the only difference being in the direction of the count. Since operation is identical, we will discuss the sequence of events in only the UP section.

When an external light beam shines on *LDR1*, the resistance of this light-dependent resistor is a low 100 ohms (approximately). Consequently, the input to pin 13 of *IC1* is low, making the output of this inverter stage, at pin 12, high. Now, when the beam to *LDR1* is broken, the light-dependent resistor's characteristic resistance rapidly increases to several megohms, placing a relatively high positive voltage at the pin-13 input of *IC1* to generate a low output at pin 12. The steep edge of the rapidly falling voltage at pin 12 is differentiated by *C1, R2*, and *R3* to produce a sharp negative pulse whose width remains constant regardless of how long the light path to *LDR1* is broken.

Resistor *R2* also serves as a "pull-up" for the input of *IC2*, a timer integrated circuit that is connected as a one-shot multivibrator. When triggered, *IC2* generates a positive-going pulse at its pin-3 output. This pulse is then inverted by another inverter stage in *IC1*, after which it is passed to the "count-up" input (pin 5) of up/down counter *IC4*, registering a one-count increase. With each successive breaking of the beam to *LDR1*, the system registers another up-count (to a maximum 9 count, after which the system automatically resets to 0).

The same inverted signal that is applied to the pin-5 input of *IC4* is also applied to the reset input (pin 4) of *IC3*, another timer integrated circuit connected as a one-shot multivibrator. This inhibits the output of *IC3* and prevents any possibility of generating a false down-count in the system. Bear in mind that *LDR1* and *LDR2* in the finished project are mounted physically close to each other so that a common light beam can be used for both. This means that when an opaque body passes between the beam and *LDR1*, a discrete interval later it passes between *LDR2* and the beam. Hence, if *IC3* were not inhibited, the system would count up and almost immediately count down as the beam to first one and then the other LDR is broken. The system must, therefore, respond to the count generated by the first LDR to be activated—in this case, *LDR1*—for true bidirectional performance.

The four outputs from *IC4* are coupled through isolating diodes *D1* through *D4* and current-limiting resistor *R10* to the base of transistor *Q1*. The transistor is held in cutoff whenever all the outputs of *IC4* are low and conducts whenever any one or more outputs are high. When *Q1* is conducting, relay *K1* is energized and operates whatever external device is connected to its contacts.

As noted earlier, the basic system is configured for a maximum count of 9 in either direction. If you wish to increase the count range, you can add one or more 74192 up/down counter IC's to the basic circuit as shown in Fig. 2. Each added 74192 IC will then provide a one-decade increase in range. For example, two 74192's increase the maximum count to 99, three 74192's to 999, etc. When up/down counters are added, the "carry" and "borrow" pins (pins 12 and 13) of each preceding counter become the inputs to the next counter in line. Note also that all "clear" inputs (pin 14) of the counters must connect to CLEAR switch *S1*.

An adequate light source for the system can be obtained by using a low-voltage power transformer with an appropri-

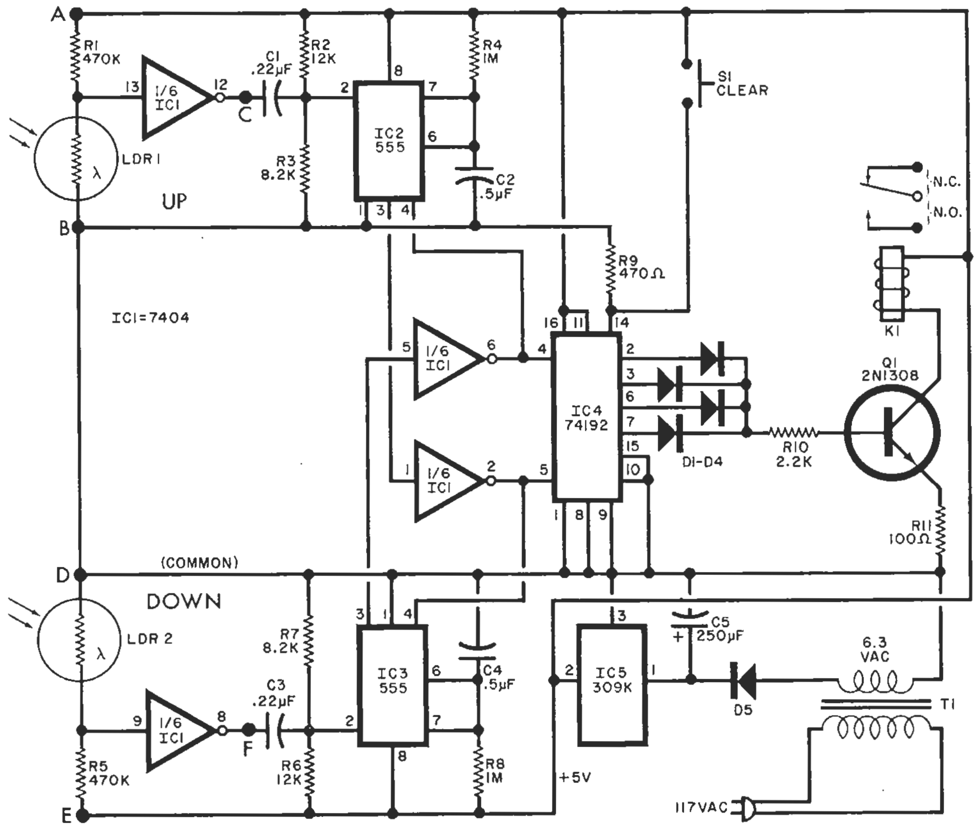


Fig. 1. Any sudden change in light on LDR1 causes an output pulse which is counted to drive relay K1. Two one-shots are cross-coupled so that only the first one activated is counted.

PARTS LIST

C1, C3—0.22-μF capacitor
C2, C4—0.5-μF capacitor
C5—250-μF, 25-volt electrolytic capacitor
D1 through D5—1N4001 rectifier diode
IC1—7404 hex inverter IC
IC2, IC3—555 timer IC
IC4—74192 up/down counter IC
IC5—309 5-volt regulator IC
K1—3-volt, 25-mA relay (Calectro No. D1-965 or similar)
LDR1, LDR2—Light-dependent resistor with 1-megohm maximum, 100-ohm minimum resistance (Radio Shack No. 276-116 or similar)
Q1—2N1308 or similar transistor
The following resistors are ½-watt, 10%:
R1, R5—470,000 ohms
R2, R6—12,000 ohms
R3, R7—8200 ohms
R4, R8—1 megohm
R9—470 ohms
R10—2200 ohms
R11—100 ohms
S1—Spst momentary-action pushbutton switch
T1—12-volt, 300-mA power transformer
Misc.—IC and transistor sockets (optional); heat sink for IC5; perforated board; suitable box to house circuit; line cord; hookup wire; chassis-mounting ac receptacle; sheet of insulating plastic; materials for making light source (see text); rubber grommet; machine hardware; solder; etc.

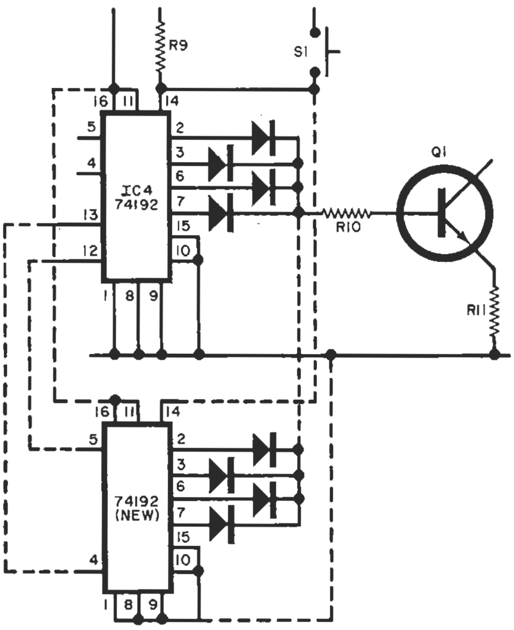


Fig. 2. Count can be increased by adding another up/down counter.

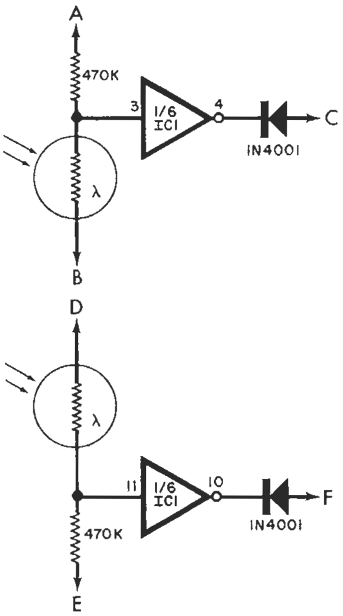


Fig. 3. Second pair of counting inputs can cover another entry.

ate panel lamp connected across its secondary winding. By wiring a 100-ohm potentiometer in series with one of the transformer's secondary leads and the lamp, you can vary the intensity of the beam to suit conditions. The lamp can be set into an ordinary flashlight reflector to focus the light into a narrow beam.

If it is necessary to cover a second doorway, the system will accommodate an extra pair of UP/DOWN counting inputs, connected as described in Fig. 3. This will use up the remaining two inverters in the 7404 hex inverter used for *IC1*. In the event that more than two doorways must be covered, extra UP/DOWN counting inputs can be used, provided that you add as many inverter pairs as there are LDR pairs.

Construction. There is nothing critical about circuit layout or lead routing. The entire circuit can be assembled on a 5" × 4" (12.7 × 11.4 cm) piece of perforated board, as shown in Fig. 4. It is

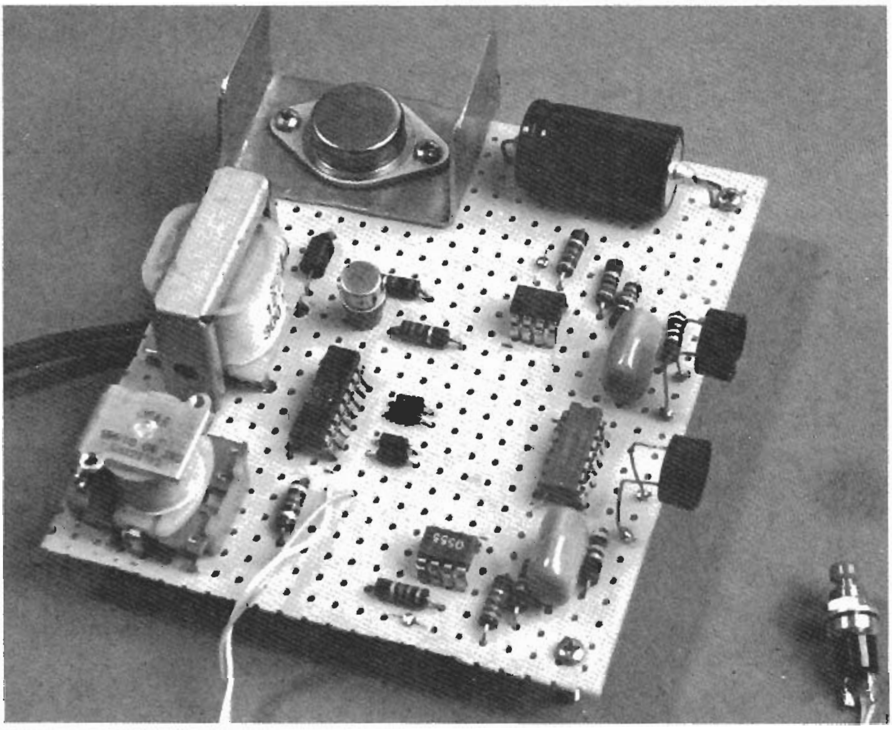


Fig. 4. The prototype of the photoelectric sensor was assembled entirely on perforated board. LDR's are on right side of board. CLEAR switch is connected by twisted leads.

advisable to use sockets for the IC's and transistor. Note also the need for a heat sink with *IC5*.

Light-dependent resistors *LDR1* and *LDR2* should be mounted about 1" (2.54 cm) apart so that a single light beam will suffice for both. If you are using extra UP/DOWN counting inputs, mount their LDR's on a small piece of perforated board. Cut holes in a small box to allow light-beam access to the LDR pair, mount the LDR board inside the box, and interconnnect this assembly with the main board via twisted cable.

The box that houses the main circuit board should be large enough to accommodate the main circuit board, a chassis-mounting ac receptacle, and CLEAR pushbutton switch *S1*. Drill holes in the box as required to mount all components in place and to provide light-beam access to *LDR1* and *LDR2*. Mount *S1* and the receptacle in their respective holes. You can use ordinary hookup wire to interconnect *S1* with the circuit board, but it is advisable that you use a length of regular line cord to interconnect the relay contacts and the receptacle. Slip the free end of the line cord through a rubber-grommet-lined hole in the case and solder it to the appropriate points in the circuit. A sheet of insulating plastic should be placed between the box and the bottom of the board before the latter is finally bolted down. This will obviate the possibility of the live ac on the primary side of *T1* fr0m shorting out against the metal box.

Testing the Circuit. Plug the system's line cord into a convenient ac receptacle and direct a beam of light onto *LDR1* and *LDR2*. The relay should immediately energize. Depressing the CLEAR button (*S1*) should cause the relay to immediately deenergize. Now, block the light beam by passing your hand in front of first *LDR1* and then *LDR2*. The relay should again energize. With the relay still energized, passing your hand in front of first *LDR2* and then *LDR1* should cause *K1* to drop out.

Pass your hand several times from *LDR1* to *LDR2*. The relay should immediately energize on the first pass and remain energized with each successive pass. Now pass your hand an equal number of times from *LDR2* to *LDR1*. The relay should remain energized for all but the last pass. On the last pass, the relay should deenergize. This procedure checks the up and down counting operation of the circuit.

The relay specified for *K1* in the Parts List can safely handle up to 3 amperes of current. If you wish to operate a device that requires a greater amount of current, you will have to substitute a low-voltage, low-current relay whose contacts can handle the current drain. Alternatively, you can use the specified relay to drive a higher-current relay. ◇

your own private OWL

AUTOMATIC "OUTSIDE WELCOME LIGHT" TO GREET YOU AND YOUR FRIENDS

BY JAMES A. ARCHER

PUT AN OWL in your driveway! Not an owl that goes "who" at you but an OWL (Outside Welcome Light) that turns on the front- or back-porch light when you pull the car into the driveway and turns it off again after you're safely in the house. That way you don't have to stumble over the kid's toys on the porch steps or fumble for your keys in the dark.

The OWL will also greet a visitor when he turns his car into your driveway and the system can even be hooked up to your front doorbell to turn on the light when the bell is pushed.

The system is activated when the photocell, mounted near the driveway is momentarily illuminated by the headlights of a car. It is designed to respond only to a sudden increase in light—and is not activated by daylight.

The principal components in the OWL are a resistor photocell, an SCR, two relays and a unijunction timing circuit. The device is relatively easy to construct and should cost no more than $25.

Construction. The system is in two major sections: a control circuit and a power supply. Each is housed in a 3″ × 4″ × 5″ metal enclosure, although any other method of packaging can be used (both circuits can be placed in one large package, for instance). The control circuit is shown in Fig. 1. When wired point-to-point on a perf board, it is as shown in Fig. 2. Resistor *R4* determines the sensitivity of the overall system, and its value is selected to suit the particular installation. A good value to start with is 10,000 ohms. Once the circuit has been wired and checked for possible wiring errors, the perf board is mounted in its chassis with spacers at each corner. A seven-terminal barrier strip can be used to make connections to the external circuits.

Power relay *K2* is usually mounted close to the point where the power is actually to be switched. Put it in a small metal enclosure and connect its coil to the control circuit as shown in Fig. 1.

The schematic of the power-supply circuit is shown in Fig. 3. Also shown are the optional circuit for the doorchime system and its associated components. The outputs of the power supply are 20 and 15 volts d.c. The former is used by the control circuit; the latter by the chime coils. If you are not using the doorchime arrangement, do not use *D3, D4, R1,* and *C2* in the power supply. Diode *D3* can also be eliminated from the

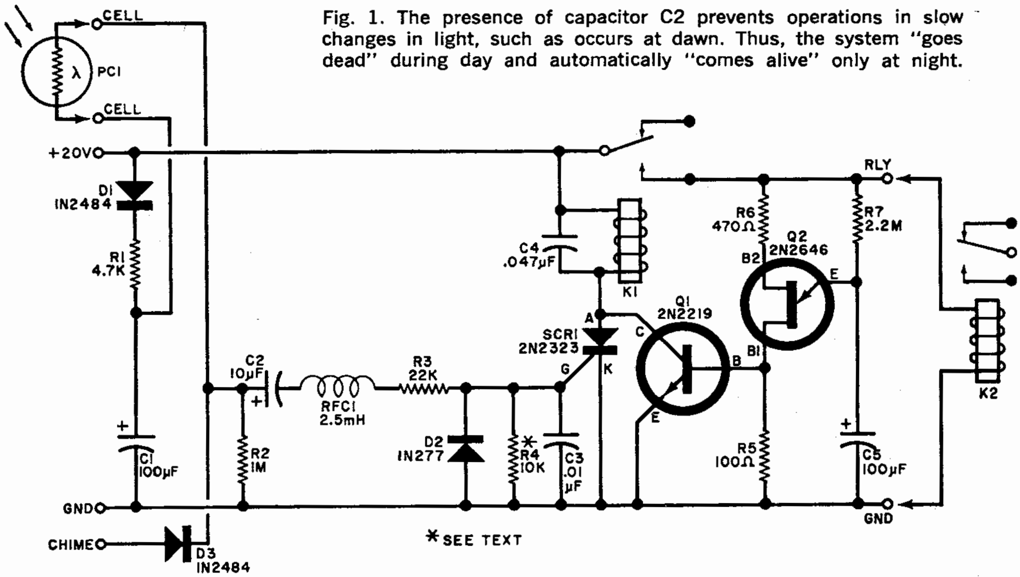


Fig. 1. The presence of capacitor C2 prevents operations in slow changes in light, such as occurs at dawn. Thus, the system "goes dead" during day and automatically "comes alive" only at night.

PARTS LIST

C1,C5—100-µF, 25-volt electrolytic capacitor
C2—10-µF, 25-volt electrolytic capacitor
C3—0.01-µF, 25-volt capacitor
C4—0.047-µF, 25-volt capacitor
D1,D3—1N2484 diode
D2—1N277 diode
K1—24-volt d.c. coil, single-pole relay
K2—10-ampere, 24-volt d.c. coil, enclosed relay (Knight KN115-1C-24D or similar)
PC1—Cadmium-sulphide photocell (Lafayette 19T2101 or similar)
Q1—2N2219 transistor
Q2—2N2646 unijunction transistor
R1—4700-ohm
R2—1-megohm
R3—22,000-ohm
R4—10,000-ohm (see text)
R5—100-ohm
R6—470-ohm
R7—2.2-megohm
(All resistors ½-watt)
RFC1—2.5-mH r.f. choke
SCR1—2N2323 silicon controlled rectifier
Misc.—3" x 4" x 5" metal enclosure; 7-terminal barrier strip (or similar); 7-pin tube socket for K1; spacers; mounting hardware; small, clear plastic medicine (pill) bottle; clear potting compound; length of weatherproof twin-conductor cable; pipe (optional); 22,000-ohm resistor (optional shunt); etc.

control circuit. Figure 4 shows the layout that the author used for the power supply.

If you are using the doorchime option, remove the low-voltage transformer from the case in which the chimes are located. The low-voltage for the chimes is taken from *T1* in the power supply. Mount *D3*, *D4*, *R1*, and *C2* on a terminal strip within the chime case. Use a multi-contact barrier strip to make connections to the external circuit.

The photocell can be mounted in any place where it will catch the direct beam of the car headlights. This may be indoors or outside; but if it is to be mounted outside, the photocell must be made weatherproof. To accomplish this, connect a piece of heavy-duty outdoor cable to the control-circuit chassis and cut the cable long enough to reach the mounted position of the photocell. Carefully strip and solder the outside ends of the cable to the photocell. Insulate the soldered connections with electrical tape.

To protect the photocell completely, it must be encased in a transparent mold, but this is not as difficult as it seems. Start with a small plastic pill bottle. If the bottom of the bottle is less than ¼" thick and reasonably transparent, seat the sensitive surface of the photocell on the bottom inside of the bottle. Fill the tube with epoxy glue or other transparent potting compound. Of course, any other type of mold can be used—just make sure that not more than ¼" of the transparent potting compound covers the sensitive surface of the photocell. Otherwise, light sensitivity may be hampered.

The outside of the finished mold can be painted black (or any other dark col-

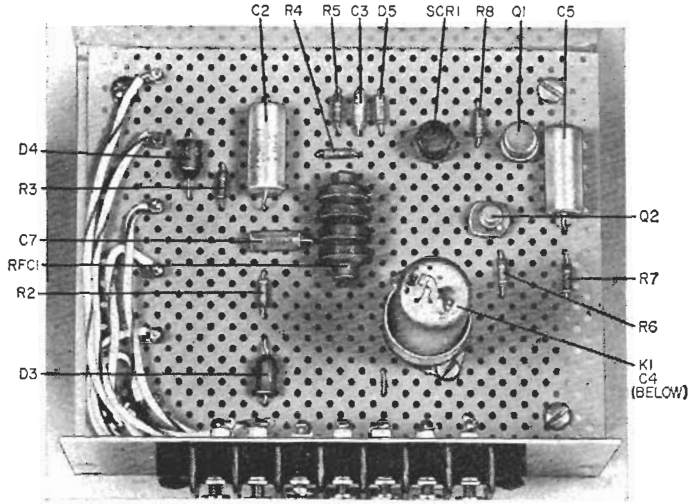


Fig. 2. Though the author used perf-board construction with layout shown, most any construction technique is sufficient.

or) to reduce light pickup from the sides. If the cell must be highly directional, the mold can be mounted at the end of an open length of pipe or tubing so that the pipe can be aimed in the desired direction. Be sure the potting compound covers an inch or two of the cable to make a good weatherproof seal.

When the entire system has been checked out for possible wiring errors, connect it together as shown in Fig. 5. This diagram also shows two ways of connecting *K2* to existing wiring for the outside light. All external electrical wiring must conform to your local electrical codes.

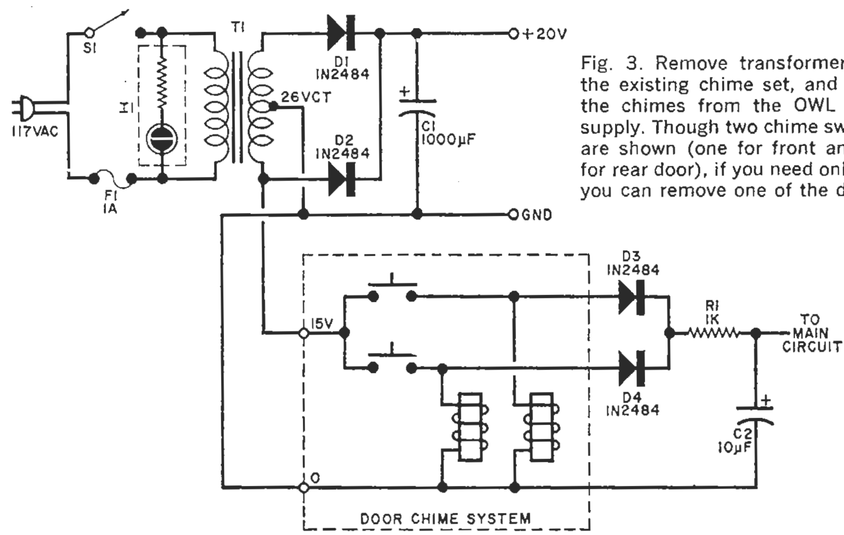


Fig. 3. Remove transformer from the existing chime set, and power the chimes from the OWL power supply. Though two chime switches are shown (one for front and one for rear door), if you need only one, you can remove one of the diodes.

PARTS LIST

C1—1000-µF, 25-volt electrolytic capacitor
C2—10-µF, 25-volt electrolytic capacitor
D1-D4—1N2484 diode
F1—1-ampere fuse and holder
I1—117-volt neon lamp assembly (optional)
R1—1000-ohm, ½-watt resistor
S1—S.p.s.t. switch
T1—Power transformer, 26.8-volt, 1-ampere secondary (Triad F-40X or similar)
Misc.—Doorchime assembly (internal low voltage transformer removed, see text); suitable metal enclosure for power supply; mounting hardware; 4-terminal barrier strip; etc.

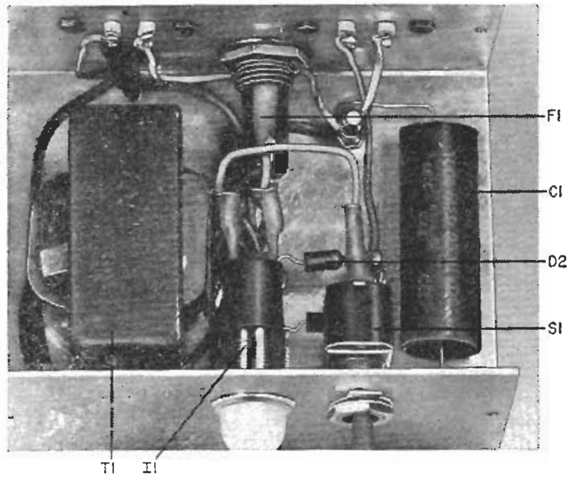


Fig. 4. The power supply can be built in one end of the chassis and made compact.

Testing and Use. Before making any tests, it is suggested that *R7* (2.2 megohms) of the control circuit be shunted by a 22,000-ohm resistor to speed up the response time of the system. This temporary modification reduces the normal 5-minute response time to a few seconds.

With the system hooked up and connected to a power source, connect a conventional lighting fixture to the contacts of *K2* as shown in Fig. 5. The light should be off. Place the palm of your hand over the sensitive surface of the photocell and aim the photocell toward a source of light. When you remove your hand, the relay should be energized and the light should come on. The light should come on. The light should remain on for a few seconds and then automatically turn off, even if the photocell is still exposed to the ambient light. If the circuit works properly under these conditions, remove the temporary resistor across *R7* to restore the 5-minute delay.

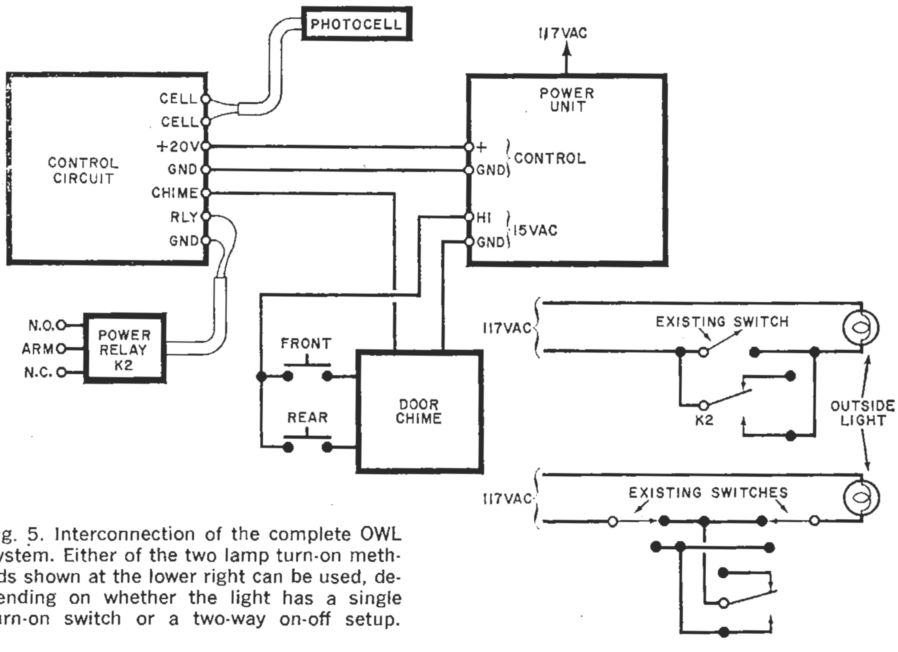


Fig. 5. Interconnection of the complete OWL system. Either of the two lamp turn-on methods shown at the lower right can be used, depending on whether the light has a single turn-on switch or a two-way on-off setup.

HOW IT WORKS

Photocell *PC1* and resistor *R2* are connected together to form a voltage divider. The photocell is a light-sensitive variable resistor whose resistance changes from about 15 megohms when it is in total darkness to less than 1000 ohms when it is exposed to a bright light. As a result, the voltage applied to *C2* ranges from 1.5 volts when *PC1* is in darkness to about 22 volts when *PC1* is in bright light. Capacitor *C2* blocks the steady-state d.c. from the rest of the circuit so that, under normal conditions, there is no gate signal on *SCR1*.

When *PC1* is abruptly illuminated, the voltage on *C2* rises sharply and is applied to the gate of *SCR1* as a positive going pulse. The SCR is turned on by the pulse and relay *K1* is energized. When *K1* is energized, power is supplied to energize *K2*, whose contacts can carry the current required by the outside light, and to the timing circuit consisting of *Q1* and *Q2*. The emitter circuit of *Q2*, a unijunction transistor, takes about five minutes to charge up to the point where *Q2* fires. Once *Q2* fires, the drop across *R5* turns on *Q1*. With *Q1* conducting, the drop across the SCR is lowered and the SCR is turned off and relay *K1* is de-energized.

Diode *D1*, resistor *R2*, and capacitor *C1* form a decoupling network to prevent accidental triggering from power line transients. R.f. choke *RFC1* and capacitor *C3* prevent false triggering by r.f. interference. Diode *D5* shunts negative-going pulses, while *R3* and *R4* determine circuit sensitivity.

Activation of the doorchime system is essentially similar, in that a voltage pulse is applied to *C2* from the chime circuit rather than from the photocell circuit. When the doorchime circuit is activated during the daytime, the voltage at *C2* is already high due to the low resistance of the photocell so no voltage pulse can occur and the system remains off.

Retest the system. Now the light should remain on for five minutes or so before switching off.

Install the photocell where it can "see" an automobile headlight as the car comes up your driveway. Make sure that it cannot see any random headlights due to traffic in the street. Install the electronics in a protected area where they won't get wet and connect the photo cell to the circuit using the weatherproof cable.

If you find that the system needs more sensitivity (depending on your car's headlights and the location) increase the value of *R4* in the control circuit. If the system is too sensitive, decrease *R4*. –30–

A second photo eye reduces counting errors

by Jack D. Howell
Los Angeles, Calif.

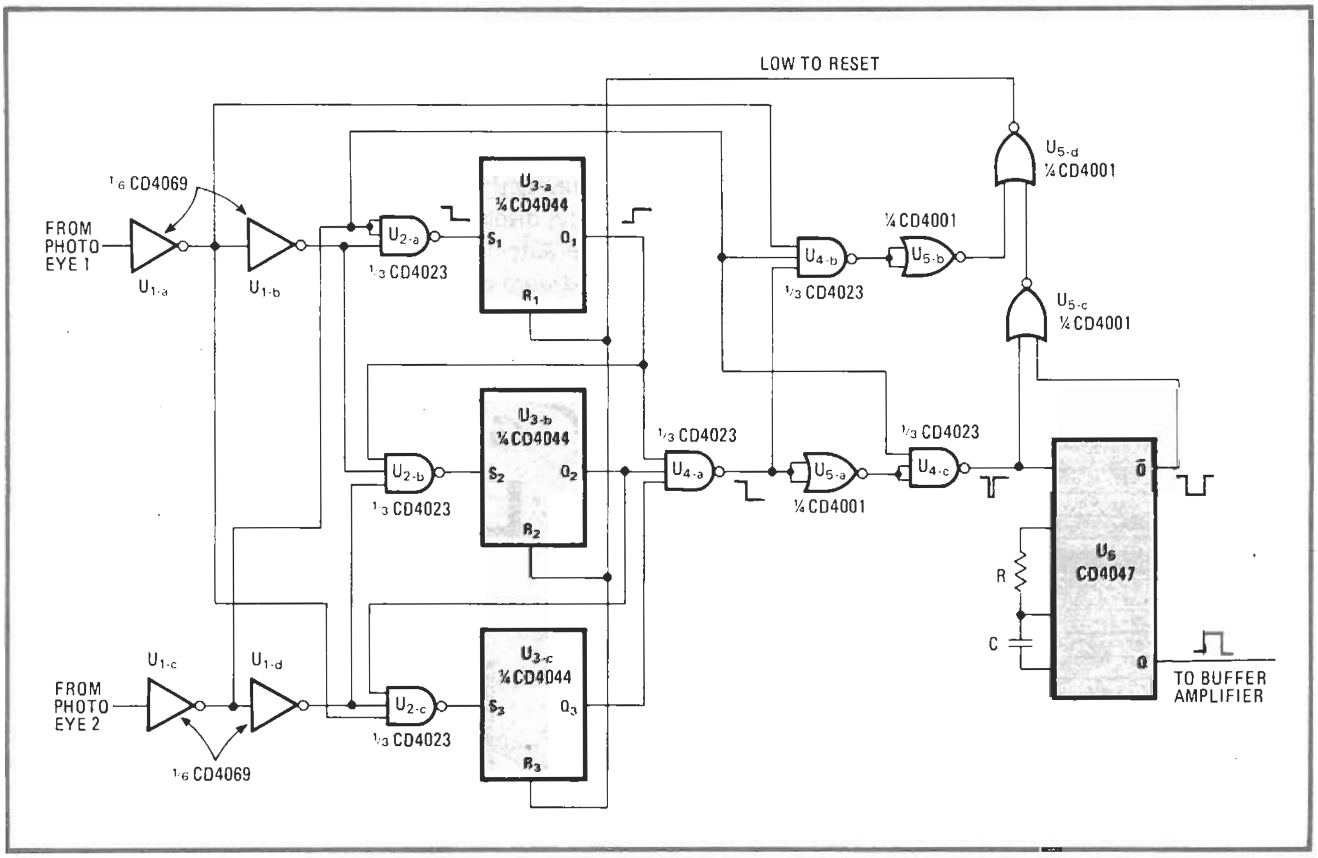
At low speeds, single–photo-eye systems very often fail to count packages quite accurately: miscellaneous debris, vibration, reflections, damaged packages, foreign material, and a great many other, undiscovered causes commonly produce margins of error as high as 0.5%. But the addition of a second photo eye and a logic circuit can prevent all erroneous counts and, therefore, all extraneous errors.

The logic circuit (Fig. 1) functions primarily as a three-stage sequential memory, so the signals generated by the photo eyes follow a set sequence and produce an output pulse. When the sequence is not correct, the circuit rejects it and monitors the input signals to find the correct sequence from start to finish.

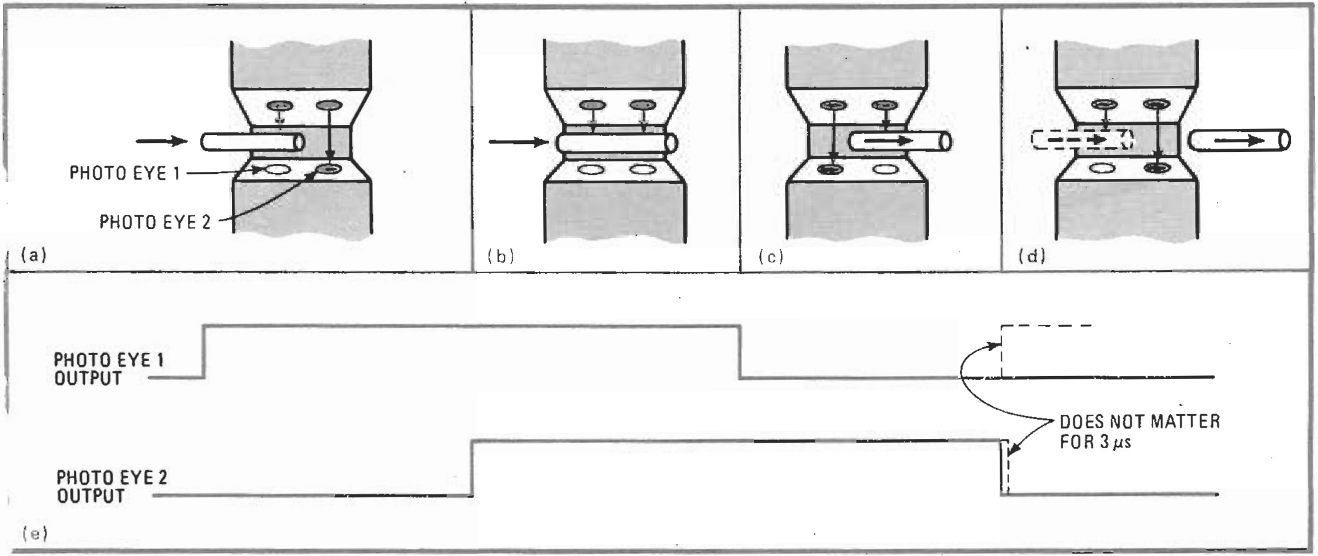
Inverters $U_{1\text{-}a}$–$U_{1\text{-}d}$ couple the photo-eye outputs to the logic gates $U_{2\text{-}a}$–$U_{2\text{-}c}$ with proper polarity. In the package position shown in Fig. 2a, $U_{2\text{-}a}$ generates an output that sets latch $U_{3\text{-}a}$, which (along with the input signals resulting from the package position in Fig.2b) sets $U_{3\text{-}b}$ through NAND gate $U_{2\text{-}b}$. Should an unwanted signal condition occur during this time, $U_{4\text{-}b}$ produces an output that resets the entire circuit to the initial condition.

In the package position shown in Fig. 2c, the signal is combined with the set output of $U_{3\text{-}b}$ to enable gate $U_{2\text{-}c}$, which in turn sets latch $U_{3\text{-}c}$. The three outputs from the three latches, respectively, now cause the output of NAND gate $U_{4\text{-}a}$ to go low. This low output is inverted and, along with the signal generated by photo eye 2 (as a result of the arrangement shown in Fig. 2d) passed through the gate $U_{4\text{-}c}$. The gate's output triggers monostable multivibrator U_6. The $\overline{Q}$ output is used to reset the circuit, while the Q output of the multivibrator supplies the count pulse. This reset lasts for less than 3 microseconds (e).

Once the three latches are set, $U_{4\text{-}b}$ is locked through $U_{4\text{-}a}$, and only the count pulse can cause a reset. This reset condition ensures that all desirable sequences are converted into count pulses and that all undesirable sequences are rejected. □

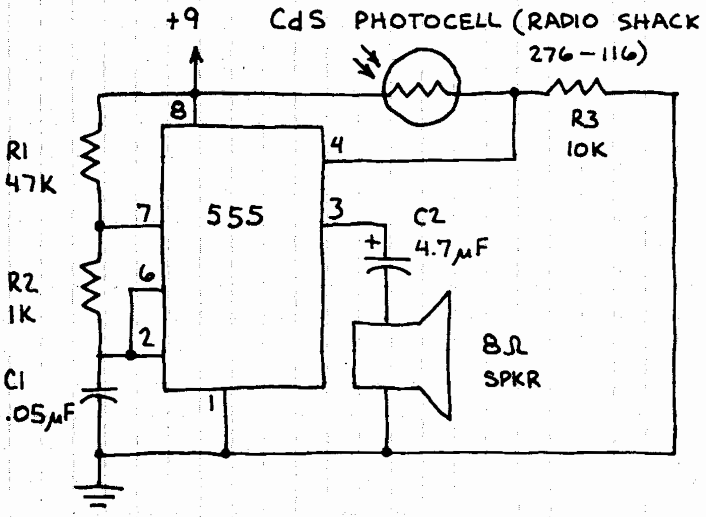


1. Counting. With the aid of a second photo eye, this logic eliminates counting errors that show up at low speeds. The circuit functions as a three-stage sequential memory and produces a count pulse only when the input signal follows the sequence correctly. When the latches are set, the circuit triggers U_6, whose Q output then gives the count pulse, while its output at $\overline{Q}$ resets the circuit to prevent erroneous counts.



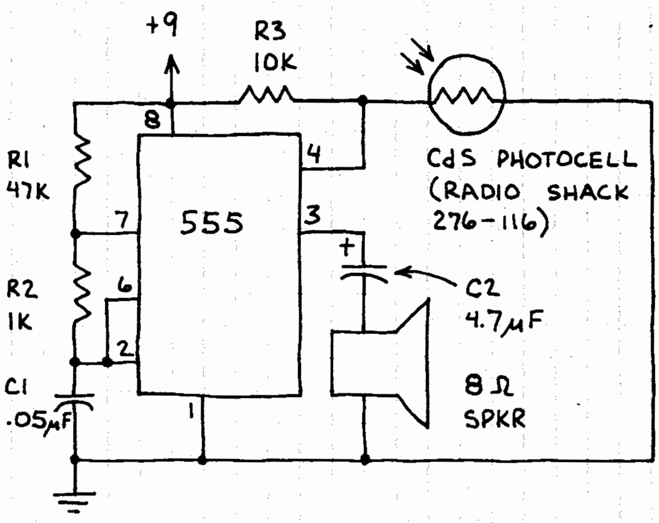
2. The right sequence. The blocking of a photo eye generates a signal that triggers the logic circuit. For the package conditions shown in (a) through (d), photo eyes 1 and 2 generate signals (e) in a sequence that produces a count pulse. If this sequence is not followed, the circuit rejects the erroneous signals and looks for the correct sequence.

LIGHT DETECTOR



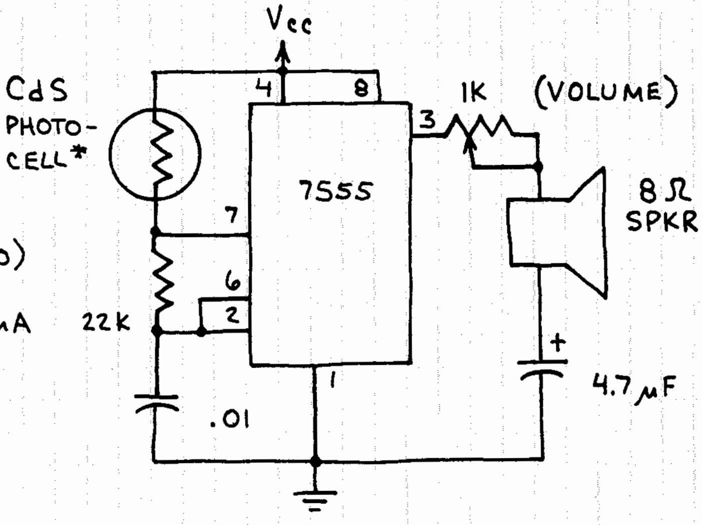
PRODUCES WARNING TONE WHEN LIGHT STRIKES PHOTOCELL. MAKES A GOOD OPEN DOOR ALARM FOR REFRIGERATOR OR FREEZER.

DARK DETECTOR

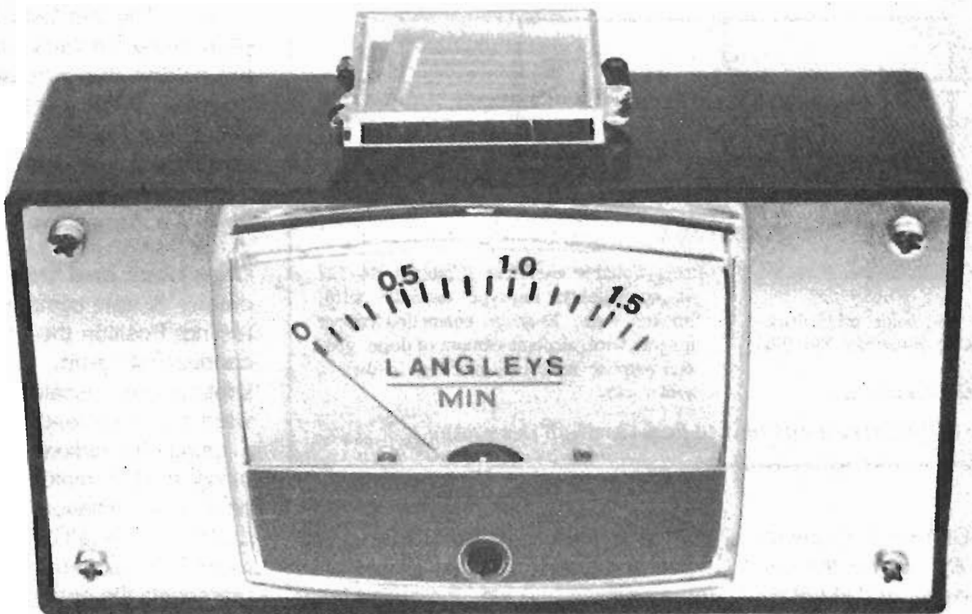


SILENT WHEN LIGHT STRIKES PHOTOCELL. REMOVE LIGHT AND TONE SOUNDS. FASTER RESPONSE THAN ADJACENT CIRCUIT.

LIGHT PROBE FOR BLIND



* RADIO SHACK 276-116



Measure the sun's energy with
A SOLAR RADIOMETER

BY WARREN JOCHEM

WITH INTEREST in alternate sources of energy at an all-time high, a definite need exists for simple, reliable instruments to aid the experimenter. This project—a solar radiometer—is one such device. It will enable you to plan and set up solar energy converters with maximum efficiency.

Solar radiometers are by no means new. Many of us have seen Crookes radiometers, which are partially evacuated glass bulbs containing rotating vanes silvered on one side and darkened on the other. When exposed to bright light, temperature imbalance causes the vanes to spin. The brighter the light source, the faster the vanes will move. But such devices are really "conversation pieces." Commercial instruments which measure solar radiation accurately are very expensive. But this project, composed of a silicon solar cell, a milliammeter, and a shunt resistor, will measure the amount of sunlight falling on a given area. It will do so with reasonable accuracy (about 5% if the specified components are used).

Circuit Theory. The solar cell used as a light detector in the radiometer is really a large pn junction (like a diode) with one side exposed to light. Leads are attached to each side of the junction. In the presence of light of the proper wavelength, a voltage will be generated across the two leads. When a silicon cell is placed in bright sunlight, a high-impedance voltmeter will measure about 0.6 volt across it.

If a resistance (in this case a meter and shunt resistor) is connected to the output leads, a current will flow. Reducing this resistance to a very small value (0.3 ohm in this circuit) means that the solar cell is effectively working into a short circuit. It can be shown that the short-circuit current is directly proportional to the intensity of the light falling on the cell. Also, the short-circuit current is largely independent of temperature. This is important to the accuracy of the meter if it is exposed to a wide range of ambient temperatures. Actually, the current does increase slightly with heating. If the meter is left in the bright sun for a while, its readings might be a bit on the high side.

The radiometer is calibrated in "Langleys per minute," a unit which might be unfamiliar to some readers. This unit was chosen because it is the standard used in most solar research today. Accordingly, you will find comparisons of your experimental data with existing records a very simple process as no conversions are necessary. By definition, one Langley per minute is equivalent to one gram calorie of energy falling on a surface area of one square centimeter for one minute. In other words, one Langley per minute represents enough energy falling on one square centimeter in one minute to raise the temperature of one gram of water one degree Celsius. This statement is expressed mathematically by the equation:

$$\frac{1\ \text{Langley}}{\text{minute}} = \frac{1\ \text{gram calorie}}{\text{cm}^2\ \text{minute}}$$

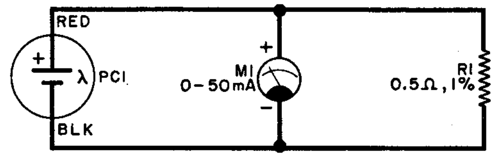
For those who do not yet want to go metric, and who are more familiar with BTU's, the equation is:

$$\frac{1\ \text{Langley}}{\text{minute}} = \frac{221\ \text{BTU}}{\text{ft}^2\ \text{hour}}$$

In words, this means that one Langley per minute represents the energy falling on one square foot in one hour required to raise the temperature of 221 pounds of water one degree Fahrenheit.

The peak insolation (incident solar radiation) measured at sea level is about 1.6 Langleys per minute. With this maximum in mind, the circuit has been designed so that the meter reads 1.7 Langleys/minute full scale in 0.1-Langley/minute increments. Over the course of one year at the author's New Jersey location, the peak insolation varies from about 0.7 to 1.2 Langleys/minute. Using the meter at your location, you can estimate how much solar energy is available for conversion.

The radiometer circuit is shown sche-



PARTS LIST

M1—0 to 50-mA dc milliammeter (Calectro D1-914)
PC1—Silicon photovoltaic solar cell (Calectro J4-800 or Herback & Rademan TM 20K 187)
R1—0.5-ohm, 1% resistor (see text)
Misc.—Suitable enclosure (Calectro H4-722 or equivalent), lug-type terminal strip, hookup wire, 30-gauge enamelled copper magnet wire, airplane cement or dope, general-purpose adhesive, machine hardware, solder, etc.

Fig. 1. The solar cell causes a current to flow through the meter

matically in Fig. 1. Current from photovoltaic (solar) cell *PC1* flows through *M1*, a 0 to 50-mA meter, and shunt resistor *R1*. This resistor, consisting of a length of 30-gauge magnet wire wound on the body of a 2-watt, 1-megohm carbon resistor, bypasses some of the current around the meter, thereby expanding the range of light intensity to which the meter will respond. A new meter face calibrated in Langleys per minute is applied over the old one for direct insolation readout. Note that the prototype was calibrated only for the parts specified. Do not substitute any others or the accuracy might be adversely affected. However, you should have no problem finding the parts listed because they were chosen for their availability.

Construction. Begin by carefully removing the cover of meter *M1*. The cover should snap off. Remove the two small Phillips head screws that hold the face plate in place. Cut out the new scale shown in Fig. 2 and cement it over the old scale using a general-purpose adhesive. Then *carefully* reattach the plate (after the adhesive has set) to the meter body, securing it with the two small screws. Snap the meter cover back on the meter assembly, making sure to position the cover's zero-adjust screw in the thin metal slot on the meter movement. Fashion a 1.75-inch (4.4-cm) diameter mounting hole on the center of an appropriate enclosure's face plate and mount the meter in it.

Remove the solar cell and padding from the small plastic box it comes in and drill two small holes in the black bottom of the box. Position the holes to allow the leads from the solar cell to pass directly through the box when the cell is centered in it. Then center the box—black side down—on top of the enclosure (see photo). Drill two holes on the top of the enclosure to line up with those in the photocell box. Replace the foam padding and feed the output leads of the solar cell through the small plastic box into the project enclosure. Center the solar cell—blue side up—making sure it is level. Then close the transparent lid of the box. Glue the bottom of the box to the top of the enclosure, making sure that it is centered and that the cell leads pass freely into the case.

Mount a lug-type terminal strip on the left inside wall of the enclosure.

You now need a 0.5-ohm, 1% resistor. If you can find a commercial component, you can use it. If not, you can make one yourself. Prepare a 57-inch (144.8-cm) length of 30-gauge enamel-covered copper magnet wire, scraping the insulation from both ends so the wire can be soldered. Then solder one end to a 2-watt, 1-megohm carbon resistor. (Actually, any 2-watt, carbon resistor greater than or equal to 100,000 ohms is suitable.) Coil the wire around the body of the resistor and solder the free end to the other side of the resistor. Coat the wire with model airplane dope or glue to hold it in place.

When the dope is dry, attach the resistor leads to two lugs of the terminal strip. Connect short lengths of hookup wire from both sides of the resistor to the meter terminals. Then attach the solar cell leads to the lugs observing proper polarity. The red lead from the cell is positive and should be connected to the lug holding the wire attached to the + terminal of the meter. Secure the lug connections by soldering them. Reassemble the enclosure by attaching the front panel to the enclosure body, securing it with the hardware provided.

Checkout and Use. The solar radiometer is now complete and ready for testing. Position the project near an incandescent lamp. The meter needle should move upscale. If it deflects downward, the meter leads are reversed.

Using the radiometer is easier than using a light meter. To measure the peak solar radiation at a particular moment, aim the cell directly at the sun and record the maximum reading. This value represents the energy one square centimeter of a solar panel would receive if it were pointed directly at the sun. But very few solar panels are built to track the sun—most are pointed south and tilted upward at an angle approximately 10° greater than the local latitude. By positioning the radiometer in this manner, you can measure how much solar energy a panel would receive in practice.

To calculate the total energy reaching this type of installation over the course of a day, mount the radiometer on the top surface of the panel. Take meter readings frequently throughout the day.

Plot the radiometer readings (*L*) versus time (*t*) on Cartesian graph paper. The *L* axis should be scaled with 0.1-Langley/minute increments, and the *t* axis should have 10-minute increments. If these scaling factors are used, one block on the graph paper represents one calorie per square centimeter. To determine the amount of energy per square centimeter that reached the solar panel in the course of the day, you must "integrate" the curve by finding the total area under it. The simplest way to do this is to count the number of boxes and fractions of boxes lying under the curve. This total will be all the energy falling on one square centimeter of the panel for that

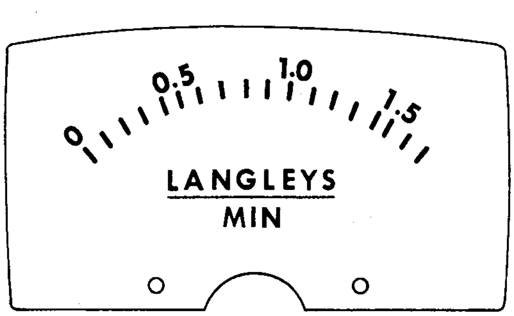


Fig. 2. Cut out this scale for the meter and attach it to the meter faceplate.

day. To find out how much energy was available to the entire panel, multiply the area under the curve (in calories/cm^2) by the total area of your solar panel (in cm^2).

It should be stressed that the total *available* energy is not the total energy output of the solar energy converter. Solar heating panels are never 100% efficient, but average 70 to 80% for flat-plate water heaters. Any good physics or solar energy book will outline steps to measure actual efficiency. Remember that, due to variations in components and measurement techniques, your measurements will be accurate to about ±5% at best. This is fine, however, for "backyard experiments."

Other Uses. There are several other applications for this project. It can be used as a transmittance/reflectance meter to measure the percentage of solar energy transmitted or reflected by a particular material or surface. The radiometer can also be used as a pyranometer to measure radiation from the sky. Simply point the solar cell straight up. Readings taken over the course of the day should now correspond with standard meteorological data.

Relative efficiencies of lamps and other light sources can be determined. You can easily measure the electric power input (or use manufacturer's data), and the radiated output power can be calculated using this relationship:

$$\frac{1 \text{ Langley}}{\text{minute}} = \frac{0.0698 \text{ watt}}{\text{cm}^2}$$

From this data, efficiency (power out/power in) can be obtained.

Another interesting experiment uses the radiometer as an air pollution indicator. Record direct readings of solar energy as the sun is setting. On a pollution-free day, a plot of this data versus time should fall off smoothly as the length of the sun's rays' path through the atmosphere increases. However, if a large cloud of smog is hanging over a city to the west, the readings might dip sharply as the sun goes "behind" the smog cloud. This is only a relative indication, but comparisons over a period of days might point to some sort of pattern. By determining the angle above the horizon at which the readings start to dip and the distance to the city, you should be able to calculate the approximate height of the smog cloud by trigonometry. The technique will also be applicable looking east in the morning.

With a little imagination, you will surely find other applications for this useful project. ◇

BUILD LITE-COM!

Photo-transistor receiver and LED transmitter work on visible or invisible light, with or without fiber optics.

by C. R. Lewart

AT THE SAME TIME that food and drink prices keep going up, and UP, the cost of electronic components keeps going lower and lower. You can now communicate over a beam of light for less than ten dollars using two electro-optical semiconductors which weren't even available except in development labs a few years ago. These transducers* convert electrical signals into light, and then convert light back into electrical signals. Thus you can use the Lite-Com to send messages and music over a beam of light without most of the previously-required circuitry.

Less-sophisticated light detecting devices have been available to the experimenter for some time. There are photocells made of selenium and of cadmium sulfide which have been off-the-shelf items for years. They are used in light meters and in cameras to measure light. However, their response time is much too slow for accurate transmission of sound. Photo-transistors, on the other hand, have excellent audio frequency-response characteristics, and are ideal for the project which we describe here.

The Lite-Com uses two electro-optical transducers: the *photo-transistor*, which converts light variations into electricity, and the LED (Light-emitting diode), which converts electrical signals into changes in light intensity. Lite-Com is an easy-to-construct project using those transducers which will give you the basic circuitry for many other projects you will think of after you've put it together and seen how well it works. Combining these two circuits with other equipment should make some interesting Science Fair and other experimental (and practical) systems.

Light Detector. The basic detector used in the Lite-Com is the photo-transistor. Every transistor is sensitive to light when its cover is removed. Light falling on the base region of a transistor has the same effect as electric current being "pumped" between its base and emitter. This effect was recognized early in the development of transistors. Because transistors were not intended to be light-sensitive in their original applications (how would you like your radio to quit when exposed to light?) they are mounted in hermetically-sealed, non-transparent metal or plastic enclosures.

You could of course cut through the transistor enclosure to make a regular transistor into a photo-transistor but in the process more likely than not you would destroy the transistor. But for little more than a dollar you can buy a photo-transistor specially designed to do the job. It is hermetically sealed but has a small glass window on top to permit light to fall directly on its base region. Most commercially-available photo-transistors use the NPN config-

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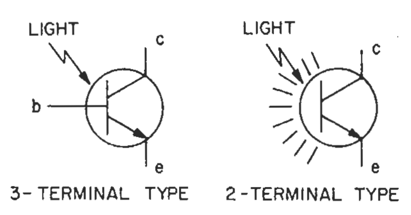
* A *transducer* is any device which accepts energy in one form, such as heat, light, or electricity, and converts it into some other form of energy, such as mechanical motion. Telephone receivers (and transmitters) as well as loudspeakers, are widely-used transducers.

uration. Some photo-transistors have three terminals, emitter, base and collector, while others have only two terminals, the emitter and collector. In either case light falling on the transistor generates the base-emitter current.

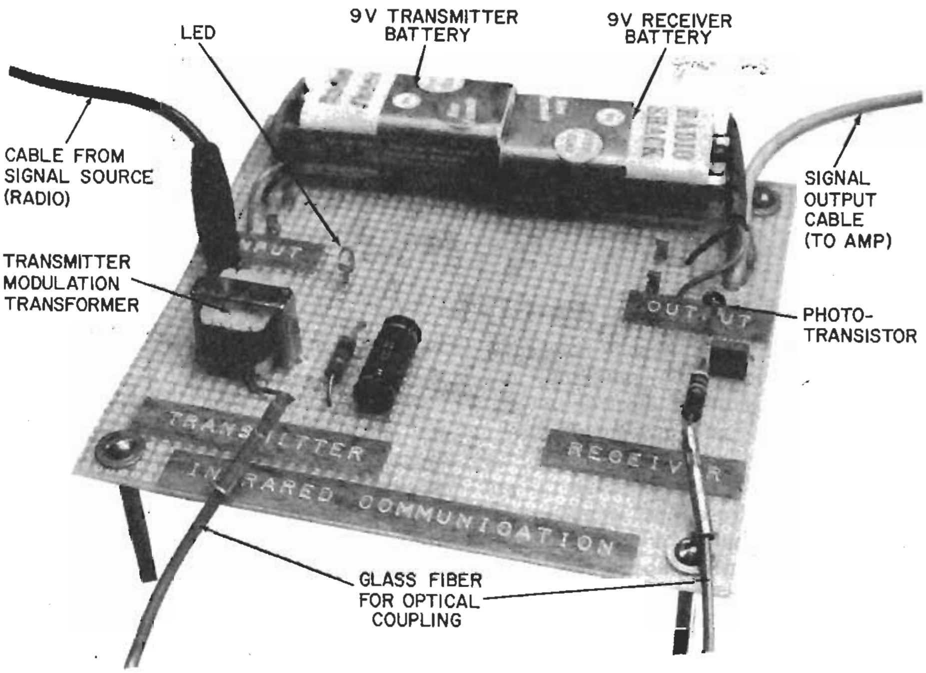
In a three-terminal photo-transistor there are other ways to control the base-emitter current. You can bias it by connecting a resistor between the base and collector, or you can vary the light sensitivity of the photo-transistor by connecting a potentiometer between the base and emitter. However, for Lite-Com either a two- *or* a three-terminal photo-transistor will do the job. Another option the photo-transistor designer has lies in the light region for which the photo-transistor is most sensitive. The two usual choices are in the visible light spectrum or in the infrared region as shown in the Spectral Response Graph To be able to operate with "invisible" infrared light we selected an infrared sensitive transistor with its peak sensitivity at 0.9 microns.* The visible light region extends from about 0.4 microns to 0.7 microns (violet to purple). If you want to experiment with visible light our infrared transistor will still work, as its sensitivity stretches into the visible region. However, a different photo-transistor (see the Parts List) will give you better results with visible light.

Light Sources. To generate a signal proportional to the sound energy Lite-Com uses an infrared LED. The LED generates light when it is forward-biased. That is, when its anode (+) is connected to the positive battery terminal (and its cathode, of course to the negative). Be careful, however, not to connect an LED (or any other diode) *directly* to a source of positive voltage. Doing so will burn the diode out at once, because it will draw too much current. This is because the LED (just as other diodes) has a very steep voltage/current curve. Unless you put a

*one micron = 10^{-6} meters (one millionth of a meter)



Ordinary transistor—light-sensitive, if open. Phototransistor has clear window, omits base connection.



Closeup of transmitter and receiver built on one chassis for demonstration. Units may be separated by any distance provided light path is provided from transmitter's LED to receiver's phototransistor.

current-limiting resistor in series with the diode any battery voltage larger than about 1.5 volts will cause the current drawn to exceed the maximum allowable value, and the diode will burn out. When in doubt always figure the size of the resistor required, using Ohm's law:

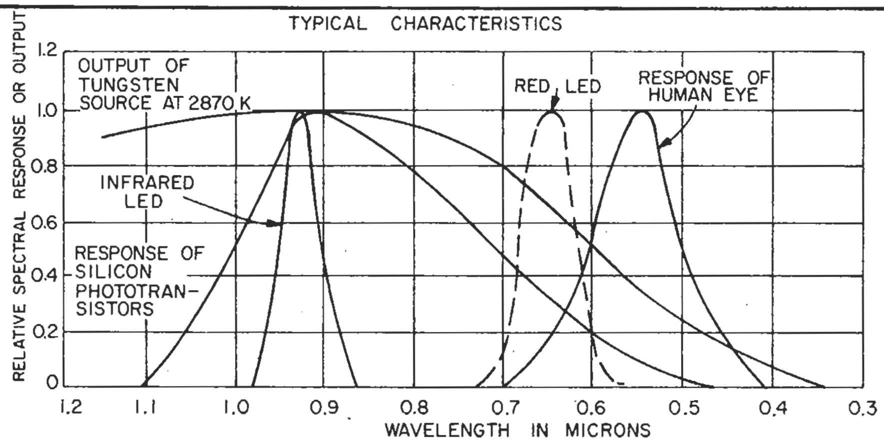
$$R = \frac{E(\text{volts})}{I(\text{amps})}$$

For example, for a battery voltage of 9 V, with the maximum allowable current through the diode 30 mA, assume a voltage drop across the diode of 1.5V. The limiting resistor value in this case would be found by using these figures in the formula:

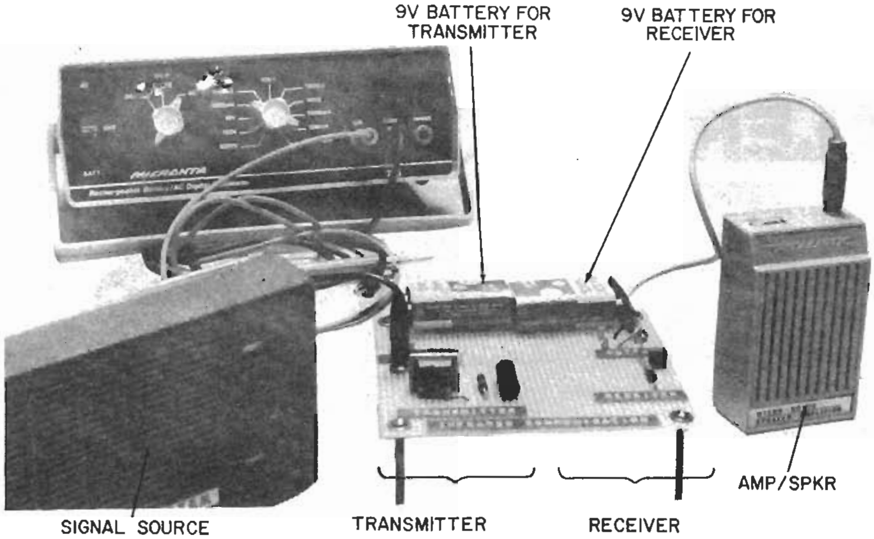
$$R = \frac{(9-1.5)}{0.030} = 250 \text{ ohms}$$

Just as photo-transistors can work in various light regions, LEDs can also be designed for various light frequencies or colors. Currently you can buy red, orange, green, and infrared LEDs. Light-emitting diodes generating invisible infrared light are particularly useful for building burglar alarms, or in areas where ambient light would be disturbing. Under such conditions an infrared filter can be used to attenuate the visible ambient light and pass only the infrared radiation. Common features of LEDs, as compared to incandescent light sources, are fast response up into *megahertz* region, and low power consumption. Thus they are ideally suited to transmission of voice frequencies.

Transmission Medium. Both infra-



Wavelength of infrared LED, visible-light LED, and tungsten filament emissions, compared with wavelengths of silicon phototransistor and human retina.

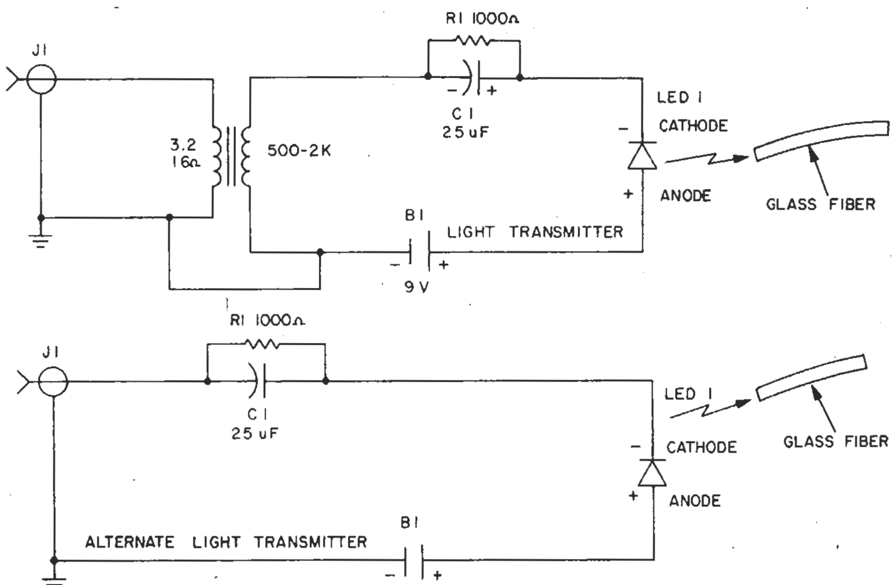


Lite-Com uses electrical signals from radio (or other source) to modulate infra-red LED transmitter. Receiver phototransistor senses infra-red light variations, feed external amplifier/speaker. LED and photo-transistor may be coupled directly, with lenses, or with glass fiber optics.

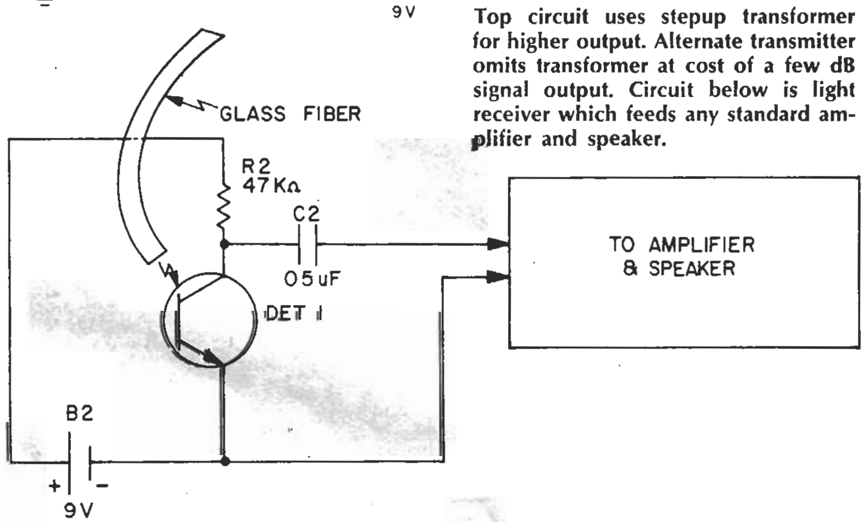
red and visible light propagate along straight lines through the air. This path can be bent by prisms, mirrors, lenses or bundles of glass fibers. In fact you will have the most fun by using one or more glass fibers between the transmitting LED and the receiving photo-transistor. You can tie the glass fibers in knots and they will still pass the visible or infrared light energy. Our Parts List gives suppliers of glass fibers for experimenters. You can even use just one glass fiber about 1/16-inch in diameter, and any convenient length.

Setting It Up. To use the Lite-Com we modulate the output of the LED with sound signals such as the output of a radio, a tape machine (connect from the earphone output jack), a ceramic phono pickup, or a microphone and mike amplifier. The light can be transmitted directly (by placing the LED face-to-face with the photo-transistor), or more conveniently by transmitting the light signals through a glass

(Continued on page 93)



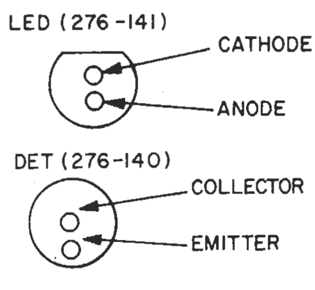
Top circuit uses stepup transformer for higher output. Alternate transmitter omits transformer at cost of a few dB signal output. Circuit below is light receiver which feeds any standard amplifier and speaker.



PARTS LIST FOR LITE COM

AMP—transistor amplifier with speaker (Radio Shack 277-1008 or equiv.)
B1, B2—9 V transistor radio batteries
C1—25-uF, 35-V capacitor (Radio Shack 272-1026 or equiv.)
C2—0.5-uF, 35 V or more capacitor (Radio Shack 272-1071 or equiv.)
DET 1—Infrared photo-transistor (Radio Shack 276-140 or equiv.) or photo-transistor for visible light (Radio Shack 276-130 or equiv.)
J1—phono jack (Radio Shack 274-336 or equiv.)
LED 1—infrared light-emitting diode (Radio Shack 276-141 or equiv.), or visible light LED (Radio Shack 276-026 or equiv.)
R1—1000-ohm, ½-watt resistor (Radio Shack 271-000 or equiv.)
R2—47K-ohm, ½-watt resistor (Radio Shack 271-1000 or equiv.)
T1—audio output transformer. Primary may be anywhere from 500 to 2000 ohms, secondary between 3.2 and 16 ohms (Radio Shack 273-1380 or equiv.)
Misc.—Perf board, battery connectors. A selection of glass fibers (also called **fiber optics**) can be obtained from Radio Shack (page 72 in the 1976 catalog) or from Edmund Scientific, Barrington, N.J. 08007. Edmund also carries many optical components for the hobbyist.

PIN CONNECTORS



Lite-Com

(Continued from page 63)

fiber. The signal output of the phototransistor is then amplified by an external amplifier to drive a loudspeaker.

Although we used a handy pocket-size amplifier with built-in speaker (see the Parts List), there's no reason you can't design and build your own small amplifier. You can also use the *Tape* or *Aux* input on your hi-fi receiver or amplifier. Try bending the light fibers, and you can show how light goes around corners.

Simple Circuits. Lite-Com's two circuits are quite simple and straightforward. Resistor R1 and the DC resistance of T1's secondary winding determine the quiescent current through the LED (5-10 mA). C1 bypasses R1

PROJECT OF THE MONTH

Dark/Light Detector

BY FORREST M. MIMS

HERE IS a simple but useful circuit that can function as either a light detector or a dark detector. The circuit's photosensor is a standard cadmium-sulfide (CdS) light-dependent resistor. When the project is operating in its light-detection mode and the photosensor is dark, there is no output. When light strikes the sensitive surface of the LDR, the speaker emits a tone. When the circuit is in its dark-detection mode and the LDR is illuminated, the speaker is quiet. It emits a tone when the photosensor is dark.

The circuit is actually an astable oscillator operating as a tone generator. The oscillator is designed around a 555 timer chip whose reset input (pin 4) is the key to the project's two modes of operation. When pin 4 is at or close to $+V_{cc}$, the circuit will oscillate. When pin 4 is grounded, however, *C1* is discharged and the circuit ceases oscillation.

In both the light- and dark-detection modes, the light-dependent resistor and *R3* form a voltage divider whose center node is connected to pin 4 of the timer IC. When *S1*, a dpdt toggle switch, is placed in position L, the photosensor is connected between pin 4 of the IC and $+V_{cc}$. When the level of ambient light increases sufficiently, the resistance of the photosensor decreases to a low value, pin 4 approaches $+V_{cc}$ and the circuit oscillates. This is the circuit's light-detection mode.

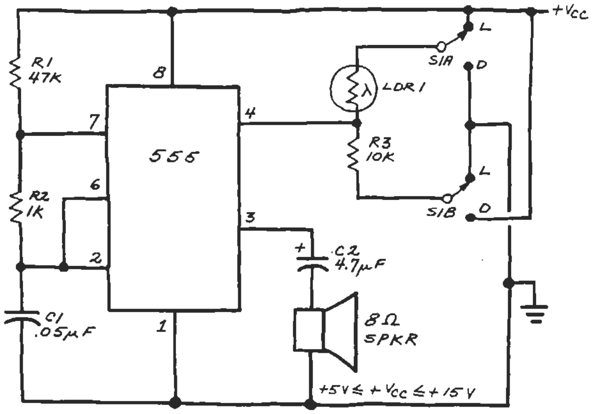
When *S1* is placed in position D, the photosensor is between pin 4 and ground and fixed resistor *R3* is between pin 4 and $+V_{cc}$. Now, when sufficient light strikes the photosensor, pin 4 approaches ground potential and the circuit ceases to oscillate. The project thus functions as a dark detector because removing light from the LDR permits the 555 to oscillate.

The circuit is easily modified. For example, increasing the value of *C1* will decrease the frequency of oscillation. Reducing the capacitance of *C1* will increase the frequency. For more volume, the speaker can be driven by an audio amplifier whose input is capacitively coupled to pin 3 of the timer IC. If only light (or dark) detection is desired, *S1* can be eliminated. The photosensor and *R3* should then be permanently in the positions corresponding to the desired operating mode.

This project has many useful applications. In its light-detection mode, for example, it can be used as an open-door alarm for a refrigerator or freezer or an open-drawer alarm for a cash register. The circuit makes a simple annunciator when used in its dark-detection mode. A source of steady light (artificial or sunlight) beamed at the photosensor inhibits the tone. An interruption of the light beam, such as occurs when a physical object passes between the light source and the sensor, stimulates oscillation.

Both operating modes make interesting day/night indicators. In the light-detection mode, the speaker will sound when the sun rises; and in the dark-detection mode, it will sound when the sun sets.

Laser Transmitter. In a previous column, I briefly described a miniature semiconductor laser transmitter I had built. Complete with battery, driver circuit and lens, the transmitter is not much bigger than a lipstick holder. Many readers have requested construction details for this laser. Unfortunately, however, the 4-layer diode which switches current through the laser diode is no longer available in small quantities. If an economical source for a 4-layer diode with a 20-to-25-volt switching level can be found, plans for the transmitter will appear as a future Project.



Light-Wave Voice Communicator

BY FORREST M. MIMS

THIS MONTH'S project is an amplitude-modulated light-wave voice communicator that you can assemble from inexpensive, readily available components. You can use the communicator to send and receive high-quality voice signals over distances of hundreds of feet through the atmosphere or through an optical fiber "waveguide."

The Transmitter. The transmitter, which is shown schematically in Fig. 1, employs a 741 op amp as a high-gain audio amplifier which is driven by a microphone. The output of the 741 is coupled to *Q1*, which serves as the driver for a LED. Potentiometer *R1* is the amplifier's gain control. Miniature trimmer resistor *R6* permits adjustment of the base bias of *Q1* for best transmitter performance.

Gain control *R1* can be eliminated if *C1* and *R2* are connected directly to pin 2 of the 741. For maximum sensitivity, increase the value of *R2* from one to ten megohms and use a crystal microphone with a large diaphragm such as the Radio Shack Model 270-095. The miniature crystal microphones sold by many parts suppliers will also work, but they generate less output.

If you prefer, fixed resistors *R5* and *R7* and potentiometer *R6* can be replaced with two fixed resistors after *R6* has been adjusted for best transmitted voice quality. Disconnect *R5* from +9 volts and *R7* from ground, measure the resistance between the wiper of *R6* and the disconnected ends of *R5* and *R7*, and substitute fixed resistors having similar values.

The transmitter works best with near-infrared emitting GaAs, GaAlAs and GaAs:Si LEDs. GaAsP red LEDs can also be used, but they emit considerably less optical power and therefore are best suited for optical fiber links.

Whichever LED you select, it is important to limit its forward current to a safe operating level. A reasonable range of quiescent current is from 10 to 40 milliamperes. High-level audio inputs will raise the current substantially. Resistor *R8* determines the quiescent current, and its resistance should be 100 or more ohms. In my prototype, 330 ohms gave a standby current of 22 milliamperes.

For best results, insert a milliammeter between the emitter of *Q1* and the LED's anode and substitute a 1000-ohm potentiometer for *R8*. Adjust the potentiometer until the desired current level is achieved. Then remove the pot, measure its resistance, and replace it with a fixed resistor.

The Receiver. The light-wave receiver, which is shown in Fig. 2, consists of a 741 operated as a preamplifier and an LM386 power amplifier. Potentiometer *R2* is the gain control.

You can use various kinds of detectors as the front end of the receiver. Phototransistors are very sensitive, but they do not work well in the presence of too much ambient light. Note that a 100,000-ohm series resistor is required if you use a phototransistor. Solar cells and photodiodes work well. So do LEDs of the same semiconductor as the transmitter.

An interesting aspect of using LEDs as detectors is that, although they are not as sensitive as phototransistors, they are much less sensitive to the adverse swamping effects of ambient light. Using a LED as a detector also means you can switch the LED's anode between the input of the receiver and the output of the transmitter to form a light-wave voice transceiver capable of bidirectional communications through a single optical fiber. Of course, you'll need two complete transceivers to fully use this operating mode.

Going Further. This transmitter and receiver system will send voice across a room without the need for external optics. For ranges of hundreds of feet, you must use a lens to collimate the light from the LED. You must also use a lens to collect and focus light on the receiver's detector. For more information on the use of lenses and related subjects, see *Light-Beam Communications* (F. Mims, Howard W. Sams & Co., 1976).

It's difficult to align the invisible beam from an infrared transmitter LED, but you can eliminate this problem *and* communicate around corners by using an optical fiber. See this month's "Experimenter's Corner" for more about this subject. ◇

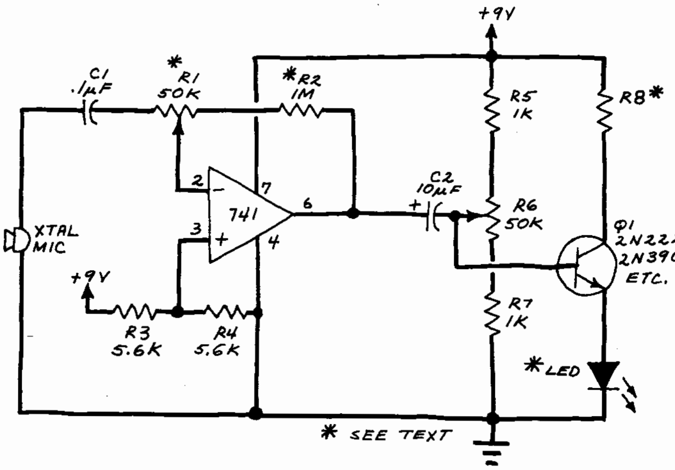


Fig. 1. Schematic of a light-wave voice transmitter.

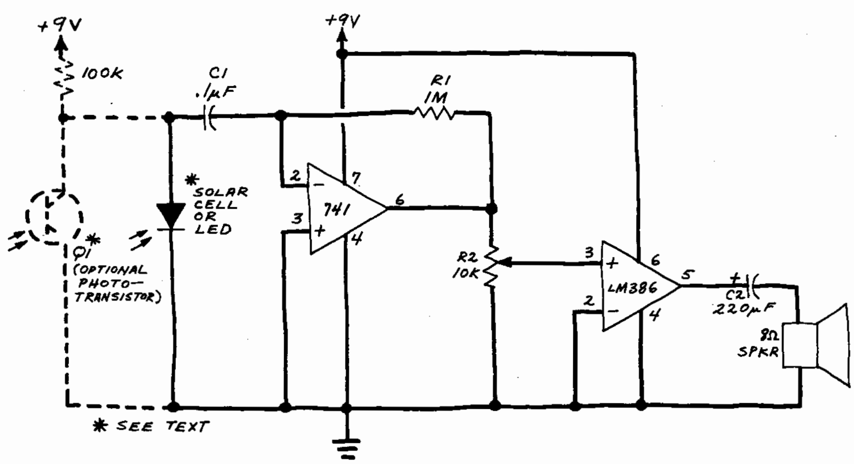


Fig. 2. A light-wave receiver to go with the transmitter.

Light-Operated Bistable Switch

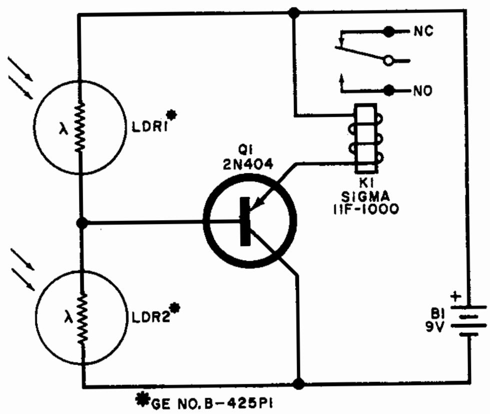
BY DAVID C. CONNER

A SWITCH that can be operated by a light beam from remote loocations of up to 30 feet is a handy device to have around the house or in the workshop. Such a switch, especially if it can be operated under wide ambient light extremes, is used to turn appliances on and off, silence the audio on a TV receiver during commercials, and serve as a remote switch in a garage or basement. You can readily see how much of a work saver and safety provider a light-operated remote switch can be.

As shown in the schematic diagram, the remote switch described here is a simple device, employing a pair of light-dependent resistors (*LDR1* and *LDR2*) which provide on and off bias for a simple transistor amplifier (*Q1*). The amplifier load is a relay which is energized or de-energized depending on the conduction state of the transistor. The relay has a double-throw contact arrangement so that an appliance or device can be connected to either the normally open or normally closed contacts, depending on the operating condition desired. (These contacts will handle up to 1 ampere of current at 117 volts ac. If higher power is required for a particular device, *K1* can be used as a control relay to drive an appropriately rated power relay.)

In operation, illumination of *LDR2* causes *Q1* to conduct sufficient current to energize *K1*. Once *K1* is pulled in, it remains energized even after the light is removed from *LDR2* because the solenoid of the relay is normally biased near its pull-in point during its de-energized period. Hence, although the energizing current must exceed a certain level, the holding current is within the biasing current range.

Now, by illuminating *LDR1*, the bias condition at the base of *Q1* changes, causing the transistor to conduct less heavily—this time sufficiently below the holding current of *K1* to allow it to drop out. Again, the situation is such that the normal standby current through *Q1* and *K1* allows the relay to remain de-energized even after the light is removed from *LDR1*.



Relay K1 closes and opens when LDR2 and LDR1, respectively, are illuminated. Sufficient current is normally available to latch K1 in desired state.

Background changes from total darkness to full brightness will not cause false operation of the remote switch since the resistance ratio between *LDR1* and *LDR2* will not change and, as a result, the biasing scheme is unaltered. However, the amount of light reaching both LDR's mdst be the same at any given time for this to be true.

When assembling the remote switch, bear in mind that the LDR's must be physically separated so that they can be illuminated selectively (by a flashlight, for instance). Experimentally, a separation of about 7 inches provided reliable operation at distances up to 30 feet. —30—

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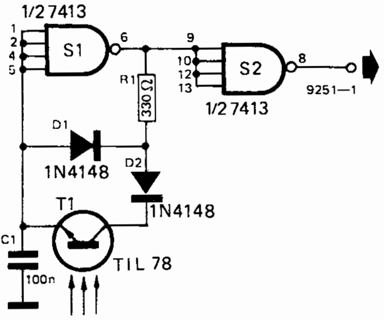

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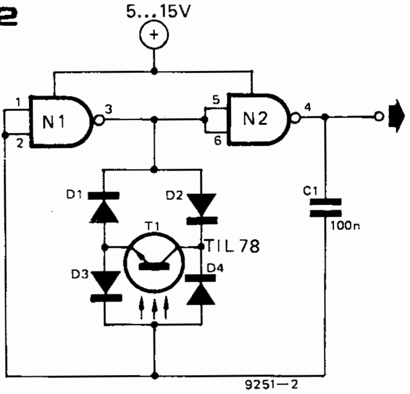

N1, N2 = ½ x 4011

D1...D4 = 1N4148

A circuit using CMOS gates and analogous to figure 1 is shown in figure 3. The phototransistor is connected in a feedback loop around N1 and since the phototransistor will be reverse-biased when the output of N1 is low it controls only the half-cycle of the waveform when the output of N1 is high. The duty-cycle therefore varies with light intensity. This can be cured in this circuit by using an LDR (e.g. ORP12)

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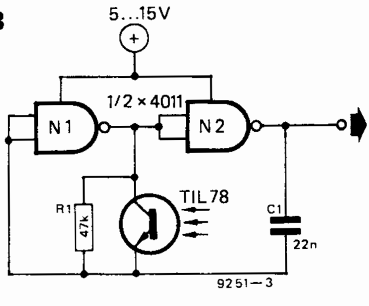

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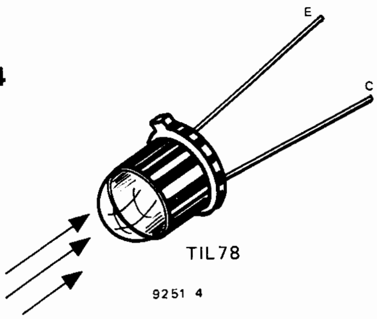


elementary Electronics MAY-JUNE 1972

Light-Comm

All Solid-State Light Beam Communicator Uses Infrared Light Emitting Diode

by Forrest Mims

Light beam communications have been around since prehistoric man first used a chunk of shiny mica to signal a buddy. Fortunately for us, electronics has considerably improved things; today all it takes is a handful of components for you to assemble your own sophisticated, invisible light communicator. With our plans, your unit will operate in the infrared portion of the electronic spectrum to transmit voice up to nearly a thousand feet.

Unlike radio, optical communications make use of relatively narrow beams of light, and because the wavelength of light is so high, engineers have shown how a tremendous amount of data can be packed on a single beam. Since the beam can be invisible—like the infrared system used in the communicator described here—transmission is completely private and undetectable. Interestingly enough, the light beam communications idea originally developed by stone age man is being given a real boost with electronic techniques.

Here's your chance to jump in with both feet. Get the feel of tomorrows communication techniques today with Light-Comm—e/e's project that features invisible light from a solid-state lamp.

Get the LED Out. The revived interest in optical communications shown recently is the result of significant progress in the field of electro-optics. Several types of lasers show great promise for optical communication applications, but the light emitting diode (LED) is currently one of the most practical contenders. The LED, usually made of gallium arsenide, is a semiconductor which emits infrared light when forward biased. It was invented more than ten years ago, but only recently has the price of commercial units dropped to the point where they can be purchased by experimenters.

How it Works. The communicators consist of two self-contained units, one a transmitter and the other a receiver. Our units are assembled in a plastic lantern light case, but any convenient enclosure will do. In fact, both a transmitter and receiver can be assembled in

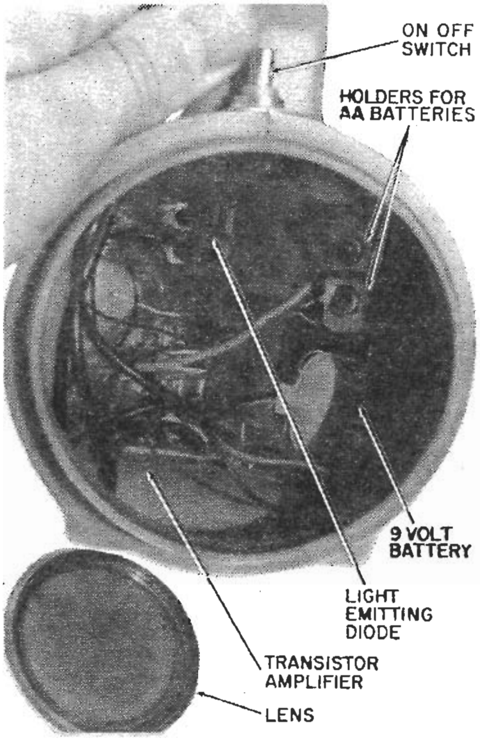
the same enclosure to fabricate a transceiver.

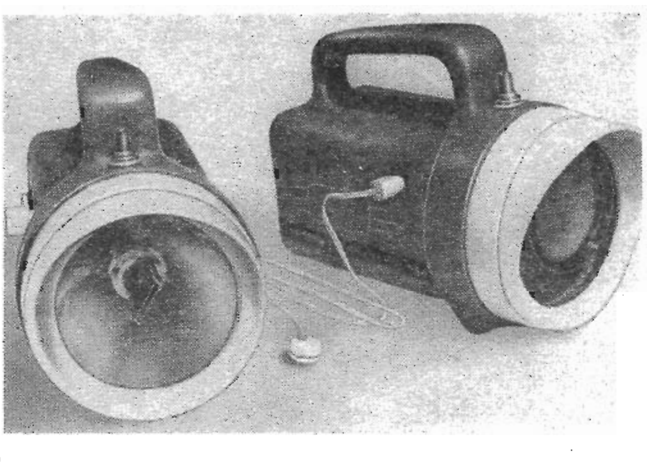
The LED is modulated by means of a pre-assembled miniature transistor amplifier. It is connected to the amplifier's output transformer through a single transistor coupling stage. Two penlight cells provide the LED's driving voltage. Excessive current can degrade or damage a LED, so current limiting is provided by a 100-ohm resistor (R2).

An amplifier similar to the one used in the transmitter is used in the receiver. But a pair of silicon solar cells are connected to the amplifier's input and serve to convert the optical signal to a corresponding audio signal. The amplifiers are available from most mail order electronics distributors, but usable amplifiers can often be salvaged from discarded portable transistorized tape recorders or players.

Transmitter Construction. Begin construction of the transmitter by drilling three 1/32 inch holes in an open space on the output end of the amplifier board. Insert transistor Q1 into the holes and solder its base and emitter leads to the appropriate terminals on the printed circuit board. If necessary, use short lengths of insulated tubing to prevent Q1's leads from shorting against other wiring. Q1 can be practically any general purpose PNP transistor. (Note: the Radio Shack amplifiers used here have a positive ground. If an amplifier with a negative ground is used, Q1 can be any general purpose NPN transistor. See the circuit diagram for additional information.) Q1's collector lead should be left unconnected in preparation for the next step.

Next, cut a 2-in. x 3/4-in. rectangle of perforated board and mount two fahnestock clips on it with appropriate hardware. The board's purpose is to permit you to mount the LED in a position where its light is unobstructed and to mount one or two other components. Drill a 1/8-in. hole in the output end of the amplifier board and mount the perforated board to the amplifier with an aluminum bracket. Place the bracket so that it doesn't short against any of the amplifier's printed wiring. Insert a





Dr. Leakey's illusive rock-in-hand ape man couldn't operate these space age goodies even if he had a pair. But you can build and operate your own if you wish by starting with low cost lantern cases and filling them with transmitter parts shown above. See open receiver and parts location drawings later in article. Finished units, left, show collimating lens in transmitter and solar cells in receiver reflector.

100-ohm resistor in the perforated board below the clips and solder it in place according to the circuit diagram. Where necessary, use lengths of hook-up wiring to reach distant portions of the circuit. Also, solder Q1's collector lead to the appropriate terminal of the LED clips.

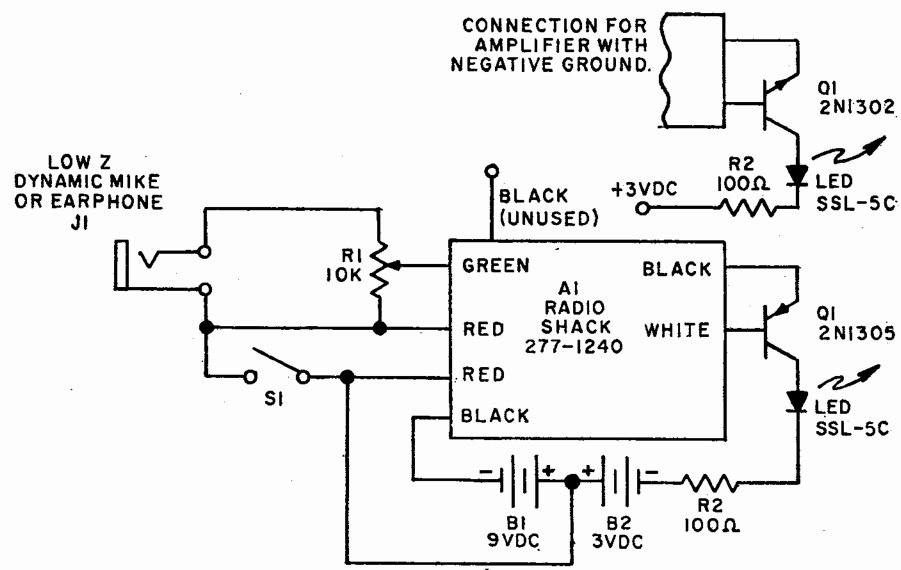
Screwdriver Drift. The 10K gain control potentiometer can be mounted on the inside of the plastic case, or, since adjustment is infrequent, to the perforated board. The latter approach was used in the prototype; a ¼-in. hole drilled into the back of the flashlight case permits the pot to be adjusted with a screwdriver. If the pot is mounted to the perforated board, be sure to drill an appropriately spaced and sized hole in the board before mounting it to the amplifier.

Before mounting the amplifier-LED assembly in the enclosure, install the battery holders. Use AA penlight cell holders for both the penlight cells and the nine volt battery. The latter holder should be modified by sawing the terminal end off and using a standard clip connector to make contact with the battery connectors.

When the battery holders are installed, mount the amplifier-LED assembly inside the enclosure. First, insert the LED into the clips and carefully orient it so that it will face toward the portion of the enclosure where a collimating lens will be installed.

Get it Focused. The amplifier board is mounted to the enclosure with 4-40 hardware. Cut a pair of slits in the bottom of the enclosure so the focus of the LED can be varied by simply moving the entire amplifier-LED assembly in the case. Also at this point, connect leads to the circuitry for the microphone jack and switch. Be sure to leave battery holder, microphone jack, and switch leads long enough to permit the amplifier-LED assembly to be removed for servicing.

Our communicator used a plastic lens with a focal length of about 4½-in. to collimate the infrared light from the LED



PARTS LIST FOR TRANSMITTER

A1—100mW Audio amp. (Radio Shack 277-1240 or equiv.)
B1—9 volt transistor radio battery
B2—3 volts (two AA penlight cells)
J1—Microphone jack
LED—SSL-5C light emitting diode (General Electric Co., Miniature Lamp Dept., Cleveland, OH 44112, $7.15 each)
Q1—Transistor, 2N1305, HEP-629
R1—10,000-ohm potentiometer
R2—100-ohm, ¼ watt resistor
S1—Push button switch, normally open

A partial kit consisting of the following components is available for $10.00 (add $1.00 postage and handling) from MITS, Inc., 2016 San Mateo SE, Albuquerque, NM 87110: Transmitter—LED, Q1, J1, R1, R2, low impedance earphone (for use as microphone), lens, and battery holders. Receiver—J1, P1, R1, and battery holder.

into a narrow beam. An identical lens is available from a source listed in the Parts List. Actually, almost any convex lens can be used to focus the light beam; just be sure the focal length is several inches and the lens diameter is sufficient to intercept the entire beam from the LED. Edmund Scientific Company (see their ad in this issue for address), sells many lenses which work well with the communicator, and most department stores carry a variety of inexpensive magnifiers which can also provide an appropriate lens.

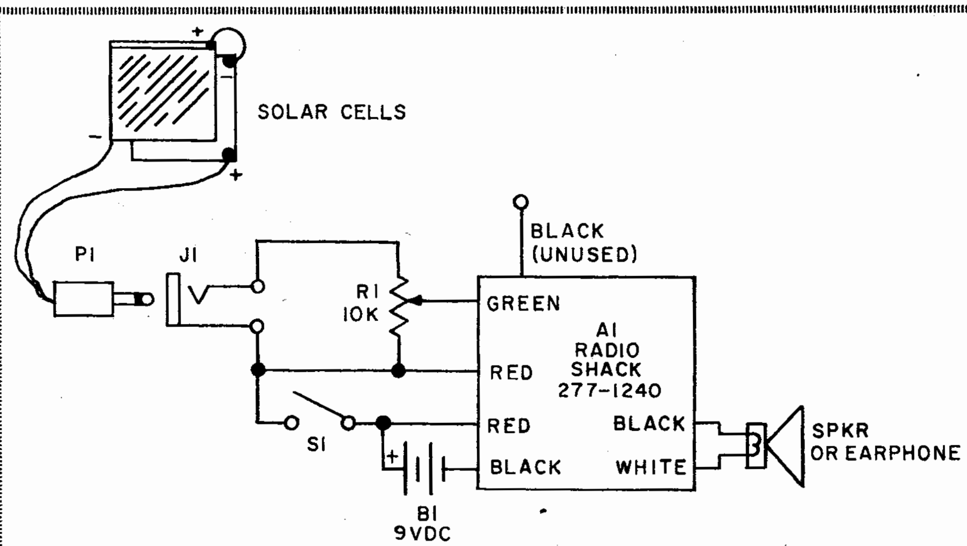
The plastic dust cover which protects the flashlight's parabolic reflector is used to mount the lens. Since it is not required, remove the reflector and set it aside for use in another project. Cut a hole in the clear plastic dust cover for the lens; if the plastic lens available from the source in the parts list is used, the hole should be 2-in. in diameter. A plastic shoulder on this lens permits easy mounting. Insert the lens and glue its edges to the dust cover.

Receiver Construction. Assembly of the receiver is similar to that of the transmitter. The amplifier board can be mounted in a fixed position, however, and there is no need for an additional circuit board. Mount the battery holder and volume control on the inside of the case. A speaker was included on our unit (along with an earphone jack), but it can be eliminated in favor of an earphone if desired.

The infrared light from the transmitter is detected by a pair of back-to-back solar cells in the receiver. The cells, which must be the silicon type, are mounted in the receiver's parabolic reflector by their wire leads. Mount the cells back-to-back by *very* carefully soldering a small wire from the positive terminal (along the front side of one cell) to the negative terminal, which covers the entire back surface of the other cell. Silicon solar cells can be purchased economically in kits that include silicon, cadmium and selenium cells. Or, International Rectifier type S1M cells can be used if the case is opened and the wafer of cells inside is removed.

The remaining positive and negative leads are used to hold the two cells in position; feed them through the reflector's aperture, and wrap them around the protruding neck. A small plug is soldered to the leads, and

(Continued on page 94)



PARTS LIST FOR RECEIVER

- A1—100mW Audio Amp. (Radio Sack 277-1240 or equiv.)
- B1—9 volt transistor radio battery
- J1—Miniature jack
- P1—Matching plug for above
- R1—10,000-ohm potentiometer
- S1—Push button switch, normally open
- SO1—Silicon solar cells, unmounted (see text)
- SPKR—8-16 ohm speaker
- Misc—Hardware, battery holder, flashlight case (Burgess "Dolphin" lantern or equiv.), hook-up wire, optional earphone and jack.

LIGHT-COMM

Continued from page 32

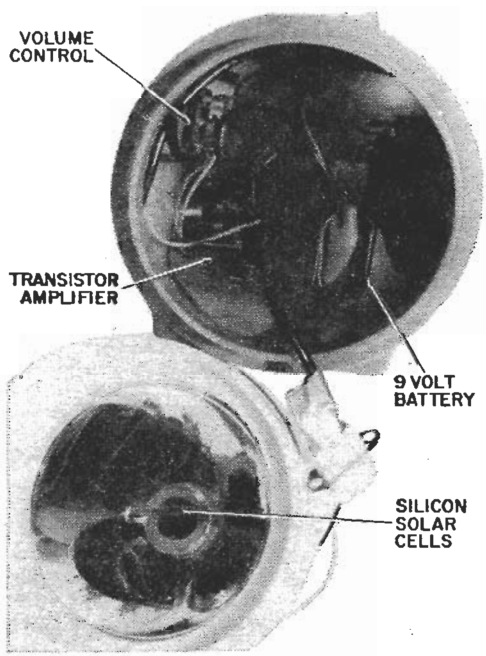
a jack is soldered to the amplifier input so that the detector-reflector assembly can be quickly disassembled if necessary.

Note. When soldering to the solar cells, use a 30 watt soldering pencil. Do not use a soldering gun. With reasonable care, the experimenter with average soldering ability should have no trouble soldering the leads to the cells. If it is preferred not to solder to the cells, make use of the wire leads already soldered to the cells. Also, it is not absolutely necessary to use two cells since the cells are mounted in a reflector to capture a fairly large quantity of signal. It is more efficient to use two of them, but just one cell may be used.

Getting On The Air. When the receiver is assembled, insert a nine volt battery in its holder, clip on the terminal snaps, and place the detector-reflector assembly back on the unit. With the reflector pointed toward a standard room lamp (incandescent or fluorescent) a 60 Hz tone should be heard from the speaker or earphone. If the tone is heard, the receiver is operating properly and the transmitter can be checked out. If not, carefully check the circuit for wiring errors. Also, make sure the battery is fresh.

To check the transmitter for proper operation, insert the batteries, turn the unit on, and point it at the receiver. Speak into the microphone and listen for the received signal in the receiver. If the signal is heard and the voice is reasonably good audio quality, the units are both operational and ready for field testing. If the voice is not heard or is of poor quality, turn the transmitter off and check for possible wiring errors. Pay particular attention to possible shorts and polarity reversal. Also, make sure the batteries are fresh.

The Long Reach. Range test the completed communicators for maximum DX with the help of a friend. First, align the optical elements of both transmitter and receiver. For the transmitter, adjust the position of the amplifier board until the LED fills the



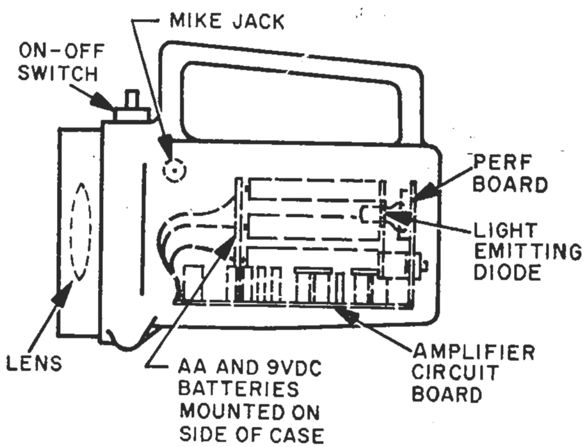
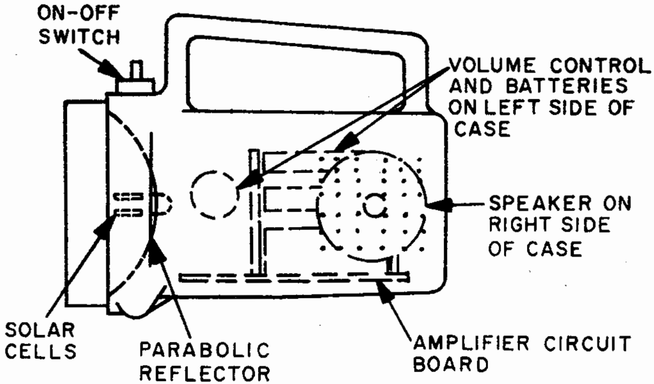


Photo on page 94 shows inside view of receiver with quick disconnect plug for solar cell separation. X-ray views show suggested parts location in detail AA batteries in transmitter power LED. 9-volt battery in each unit provides amplifier power.



aperture of the lens when the lens is observed several feet distant. Adjust the receiver's solar cells so that the entire reflector takes on the dark color of the cells when observed straight-on. This means that all light striking the reflector will be reflected to the cells.

When the units are aligned, leave the transmitter and its operator at a fixed location, and slowly walk away while directing the receiver toward the point of maximum signal. Instruct the transmitter operator to count into the microphone. As the range is increased, reception will be more difficult (because of alignment), but the signal from the transmitter should be receivable at about 1,000 feet at night. Range will be dependent on the size of the receiver's reflector. Daylight operation will result in considerably reduced range due to saturation of the detector solar cells. The problem can be partially alleviated by placing a cardboard tube over the front of the receiver to shield the detector from stray sunlight. Reception can be further improved by placing an infrared filter over the receiver detector. Edmund Scientific Co. sells several inexpensive filters. These optical shielding techniques will also reduce effects of buzz and hum from artificial light sources. ■

SOURCES
High-radiance LEDs have linear response to analog inputs

by F.D. King
Bell Northern Research, Ottawa, Canada

For optimum performance, a fiber-optic communications system depends heavily on a light source that can efficiently couple maximum power with adequate bandwidth into the optical fiber. Its wavelength should suffer only minimum attenuation in the fiber and should match the maximum responsivity of the photodetector.

Both light-emitting diodes and laser diodes are highly compatible with doped silica fibers and silicon photodetectors, so the decision which to use depends on other system requirements. LEDs, unlike laser diodes that suffer modal instability, can produce a much more linear power output, making them better suited for analog applications. They also cost less and are much less affected by temperature changes than laser diodes. On the other hand, they are not as fast, and their output power is spread over a wider angle, so that less of it succeeds in entering an optical fiber.

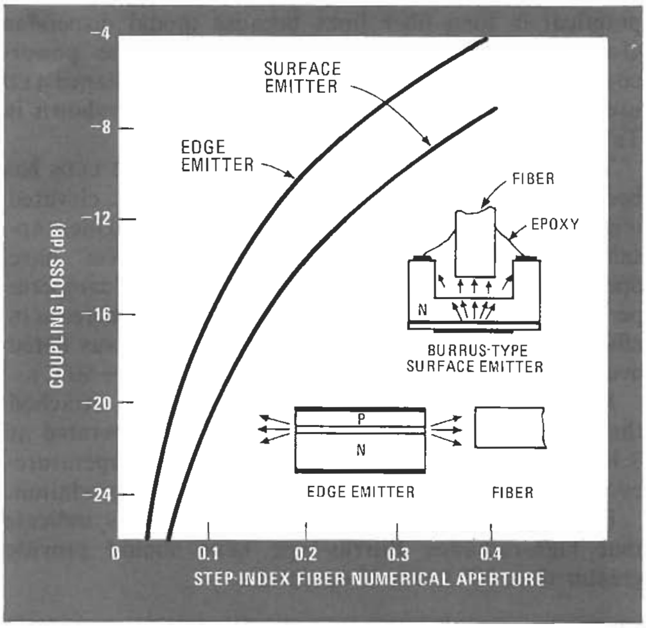
To be more specific, gallium-aluminum-arsenide LEDs produce light at high efficiency (10%) at an 840-nanometer wavelength where the attenuation of silica fiber is as low as 2 decibels per kilometer and the responsivity of silicon photodetectors is a high 0.55 ampere/watt. Their output power is 5 to 20 milliwatts either in a 120°-by-40° beam (edge-emitting type) or in a lambertian pattern (surface-emitting type). Fiber coupling loss is high—for a fiber with a numerical aperture of 0.14, losses are about 14 dB for edge emitters and 19 dB for surface emitters. Only the best (and most costly) LEDs can be modulated at rates of 200 megahertz.

Typical laser diodes, on the other hand, can be modulated at speeds up to 1 gigahertz. They also produce from 5 to 20 mW over a 40°-by-10° beam with a loss of about 3 dB when coupled into a fiber with a numerical aperture of about 0.14.

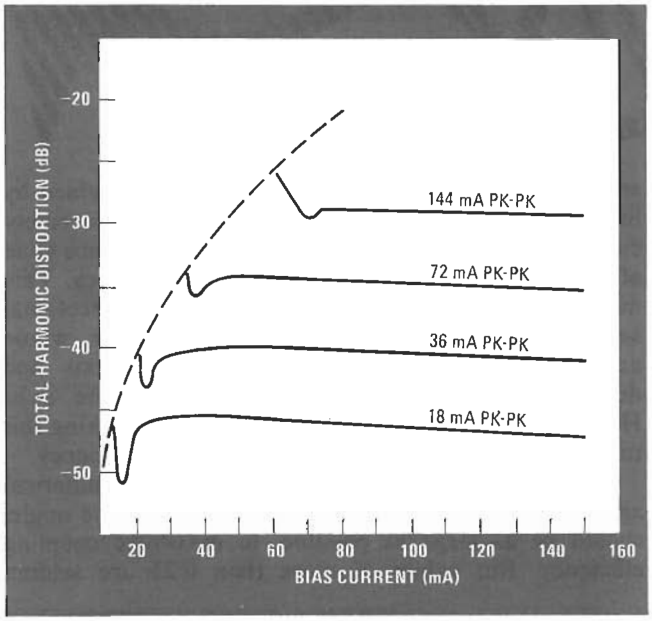
Different types

High-radiance LEDs designed for optical communications are, as already indicated, either surface emitters (usually those of the "Burrus" type first developed at Bell Laboratories) or edge emitters (developed at RCA Laboratories). Although the edge emitter is inherently capable of better coupling efficiency (especially with a cylindrical lens) than a surface emitter, the inferior coupling efficiency of the surface emitter is more than compensated for by its higher total radiated power. Both are shown in Fig. 1.

The most promising use a double-heterojunction design, being fabricated by sandwiching a thin active



1. Charting coupling loss. Power coupled from a LED into an optical fiber depends on the numerical aperture of the fiber. Typical LEDs produce light over very wide beam patterns that make the fiber's light acceptance angle and placement critical.



2. Determining distortion. Source linearity is very important in analog systems. From curves taken at different modulation depths for several BNR LEDs, it is possible to determine the optimum dc bias for minimum total harmonic distortion.

TABLE 1
HIGH-RADIANCE LED CHARACTERISTICS

BNR device	External quantum efficiency (%)	Radiant intensity (at 150 mA dc) mW/sr	Response time (10–90%) (ns)	3 dB electrical bandwidth (MHz)	Spectral half width (nm)	Max. power launched into 0.2 numerical aperture step-index fiber, 150 mA dc (mW)
(A)	7	3	14	25	40	370
(B)	4.6	1	4	88	45	250
(C)	2.3	2	7	50	45	125

TABLE 2
COUPLING CHARACTERISTICS OF HIGH-RADIANCE LEDS

Characteristic	Fiber			
	BNR 7-1-A	BNR 7-2-A	Corning	BTL
Numerical aperture	0.20	0.22	0.19	0.22
Core diameter (μm)	100	100	85	50
Type	Step	Graded	Step	Graded
Coupled power (μw)	370	280	340	140

Current density = 4.5 kA/cm^2 Emitting area = 65 μm diameter

layer of gallium arsenide between two layers of GaAlAs that absorb no energy and (in the case of edge-emitter types) act as light guides. The peak emission wavelength of double-heterojunction GaAlAs LEDs can be varied from 850 nm to 780 nm by increasing the aluminum content with no significant change in device efficiency. This allows the system designer to match fiber and source for minimum attenuation. Both peak emission wavelength and half-power spectral width show little change with drive current.

On the assumption that a fiber-optic-system designer opts for a LED source, the best device depends not only on total coupled power but also on speed, reliability, spectral width, cost, and (in analog applications) linearity.

Tradeoffs

Harmonic distortion curves are shown in Fig. 2, and other performance characteristics of typical high-radiance LEDs are listed in Table 1. The three devices illustrate the tradeoff between efficiency and speed of response. Device A is optimized for total light output and device B for speed of response, whereas device C represents a compromise between the two. By reducing device capacitance, LEDs with response times of less than 2 ns have been fabricated.

These devices all have nearly linear light-versus-current characteristics up to 250 milliamperes in continuous operation and a 1-ampere, 10-microsecond pulse in pulsed operation at 10^5 pulses per second. The temperature dependence of the light output of these devices is typically 0.2% per °C.

In wideband communication over long distances, chromatic dispersion in the fiber may limit repeater spacing. Because the velocity of light varies with wavelength, the different spectral components separate out as the light propagates down the fiber. The optical bandwidth-length product at which this effect becomes significant is determined by the spectral width of the light source. The spectral half-width of a typical BNR LED, for example, is 35–45 nm at 840 nm. This would limit the optical bandwidth-length product to 100–140 MHz-km.

The optimum coupling efficiency between a surface-emitting LED and an optical fiber is usually obtained by butting the fiber to the emitting area. But extremely close butting is unnecessary if the light-acceptance cone of the fiber encloses all of the LED emitting area. This means that the ratio of source-to-core cross-sectional area can be optimized for graded-index fiber, whose acceptance angle is largest at the fiber axis and decreases with increasing distance from the axis. However, for a close-butted step-index fiber, making this ratio less than 1 does not improve coupling efficiency.

It would seem to follow from this that the numerical aperture of a fiber, which defines its acceptance angle, should be as large as possible, to maximize coupling efficiency. But values of more than 0.25 are seldom practical in long fiber links because modal dispersion also increases with numerical aperture. The power-coupling characteristics of a typical high-radiance LED used with several types of low-loss fibers are shown in Table 2.

The reliability of high-radiance Burrus-type LEDs has been investigated at room temperature, at elevated temperatures, and during temperature cycling. Unencapsulated devices, following a qualification test, have operated for longer than 3,000 hours at 3 kiloamperes per square centimeter and 130°C without any decrease in efficiency. Moreover, no change in efficiency was noted over temperature cycling (20 cycles, −40° to +80°C).

Packaged encapsulated devices with fibers attached that passed further qualification tests were operated at 3 kA/cm^2 and 25°C for 10,000 hours and temperature-cycled (5 cycles, −30° to +30°C) without degradation.

Extrapolations from accelerated aging tests indicate that high-radiance Burrus-type LEDs should provide greater than 10^5 hours of operation.

LIGHT UP YOUR CIRCUITS WITH LED'S

How light-emitting diodes work and some tips on where to use them

BY WALTER G. JUNG
Contributing Editor

IN JUST a few short years, the light-emitting diode (LED) has found its way into innumerable circuits and devices as a "state" indicator. Not too long ago, there was only one type of LED (red); but today there is such a wide variety from which to choose that selection can become confusing.

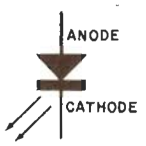


Fig. 1. Schematic symbol for LED is standard diode with arrows for light output.

To correct this, let's take a look at what a LED is, how it works, what electrical and optical characteristics are available, and how to make the best use of them.

What Is a LED? A LED is a pn-junction semiconductor device specifically designed to emit light when forward biased. This light can be one of several colors—red, amber yellow, or green—or it may be infrared and thus invisible. The schematic symbol for a LED is shown in Fig. 1. It is similar to the symbol for a conventional diode except that the arrows are added to indicate light emission.

Electrically, a LED is similar to a conventional diode in that it has a relatively low forward voltage threshold. Once this threshold is exceeded, the junction has a low impedance and conducts current readily. This current must be limited by an external circuit, usually a resistor.

The amount of light emitted by the LED is proportional to the forward current over a broad range, thus it is easily controlled, either linearly or by pulsing. The LED is extremely fast in its light output response after the application of forward current. Typically, the rise and fall times are measured in nanoseconds. Because of this fast response, LED's make excellent high-speed switched sources of light for

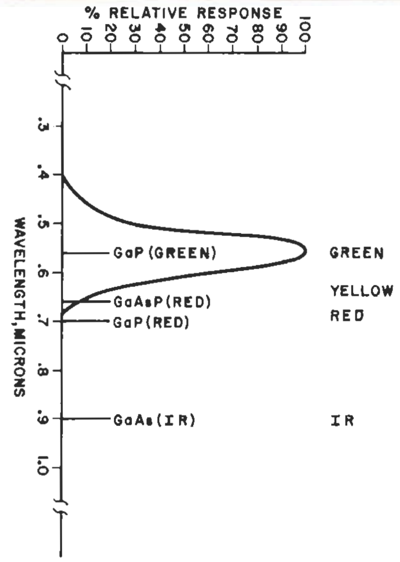


Fig. 2. Response of the human eye to various types of LED light emissions.

use in multiplexing, strobing, and optical communications systems.

LED's are small in size compared to conventional incandescent lamps; and, in fact, a LED actually consists of a tiny "chip" a few thousandths of an inch across mounted in a relatively large plastic package. As you might expect, a LED is also very light in weight.

Because of their low operating voltage and low current drive requirements, LED's consume very little power—about 30 mW (20 mA at 1.6 V being typical). Consequently, LED's generate little heat. A side benefit of the low power requirement permits interfacing LED's with most digital and linear IC's or low-power transistor stages.

A LED does not "use itself up," and has little wearout mechanism, so very long life can be expected. Some manufacturers predict 100,000 hours or more, which amounts to over 11 years of continuous use. On a practical basis, once wired in and operated within specified ratings, a LED should last forever.

Characteristics. It was once said that LED's came in three colors—red, redder, and reddest; but recent advances in semiconductor technology have changed the picture greatly. The early red LED's were made of gallium-arsenide phosphide (GaAsP) compounds. These are still the most inexpensive types available. Gallium phosphide (GaP) is now used to produce green, yellow, and red LED's.

The relative sensitivity of the human eye to the standard LED emission wavelengths is shown in Fig. 2. Note that the eye is most sensitive in the green area with the peak at 0.56 microns. The GaP red emission is at 0.69 microns, while GaAsP red is at 0.66 microns.

The light output of a LED tends to be monochromatic—of a single color (wavelength). The light output of LED's is usually specified in candelas, a measure of intensity; though sometimes it is specified in foot-lamberts, a measure of intensity per unit area.

Interpreting Data Sheets. To use a LED properly, you must have some understanding of the data sheets. A few illustrations from typical data sheets are shown in Fig. 3.

The simple curve in Fig. 3A shows that LED light output increases linearly with forward current up to 50 mA, which, incidentally, is a typical continuous maximum current for plastic-packaged devices. Figure 3B is a current/voltage characteristic, showing the "knee" where conduction starts (in this case, at about 1.65 V, which is typical for a GaAsP diode). A GaP diode has a higher knee voltage (2 to 3V), but the curve's general shape is similar. Note that the diode current increases rapidly above the knee, which is why current limiting must be used to prevent damage to the diode.

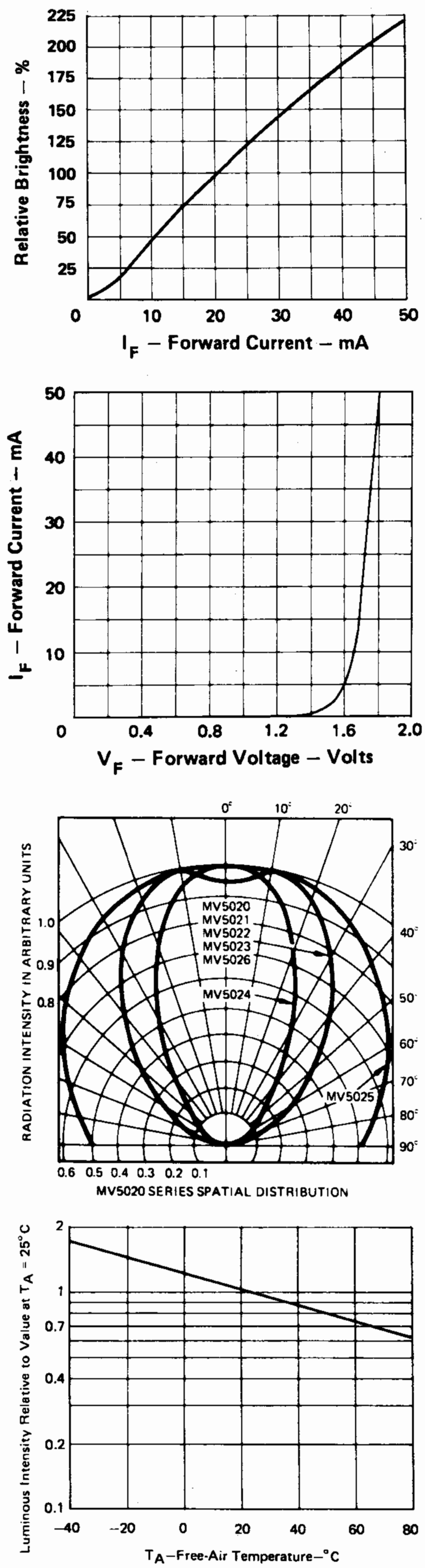


Fig. 3. Brightness (A) and voltage (B) vs current for Fairchild 100 units. (C) Intensity for various lenses (Monsanto MV5020). (D) Intensity vs temperature for TI type TIL209A.

The lensing arrangement of the diode package makes a big difference in how bright the LED appears off axis. As shown in Fig. 3C, the light can be formed into a narrow beam (as for the MV5024) or it can be wider (as for the MV5025). The beam-width used depends on the application. For example, a narrow-beam LED is correct for an optical communicator, but it is not good for a panel lamp since it will not catch the eye off to one side.

Even with a constant-current drive, temperature plays a role in the light output of a LED, as shown in Fig. 3D. However, for most hobby applications, this is not an important consideration unless a high-temperature environment is contemplated.

As a general rule, the LED should always be operated within recommended values. Maximum current can be exceeded on a *peak* basis as long as the *average* current is within specifications. The reverse voltage applied should be watched—3 volts is the usual maximum. A clamping diode can be used to prevent voltages that are too high.

Package Styles. Although LED's are manufactured in a wide variety of packages, only a few of the configurations have become favorites.

One of the most popular packages is the T-1 ¾, a ¼″-diameter, high-dome, epoxy-encapsulated style. The Monsanto MV5020 series is typical of this type. It is intended for front panel or pc board mounting, and is available with a clear lens (MV5020), a diffused lens (MV5021), a plain red lens (MV5022), or a diffused red lens (MV5023). An uncolored, clear lens produces a point source of light, while a clear diffused lens softens the effect. A red lens aids contrast if the ambient light is high. A diffused red lens spreads the beam and widens the angle of visibility, often desirable features.

These LED's are shipped in a plastic clip for insertion in a panel. The leads

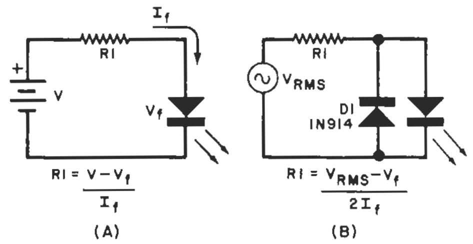


Fig. 4. Calculation of series current-limiting resistor for dc shown at (A); for ac, shown at (B).

REFERENCES ON LED'S

Book:

Light Emitting Diodes, Forrest Mims, Howard W. Sams Co., Inc., 4300 W. 62 St., Indianapolis, IN 46268.

Manufacturers' Literature:

"Optoelectronics Handbook," Fairchild
"Application Notes," Monsanto
"Optoelectronics at Work," Motorola
"The Optoelectronics Data Book," Texas Instruments
"Application Notes," Hewlett-Packard

Manufacturers' Addresses

Chicago Miniature Lamps, 4433 N. Ravenswood, Chicago, IL 60607
Dialight, 60 Stewart Ave., Brooklyn, NY 11201
Fairchild Microwave & Optoelectronic Div., 464 Ellis St., Mountain View, CA 94040
General Electric Co., E. Nela Park, Cleveland, OH 44101
Hewlett-Packard Co., 620 Page Mill Rd., Palo Alto, CA 94304
Litronix, 19000 Homestead Rd., Cupertino, CA 95014
Monsanto, 10131 Bubb Rd., Cupertino, CA 95014
Motorola Semiconductor Products, 5005 E. McDowell Rd., Phoenix, AZ 85036
National Semiconductor, 2900 Semiconductor Dr., Santa Clara, CA 95051
Opcoa, 330 Talmadge Rd., Edison, NJ 08817
Texas Instruments, Dallas, TX 75222
Xciton Corp., 5 Hemlock St., Latham, NY 12110

are square and can either be soldered or wire-wrapped. The cathode lead is identified by the flat side on the plastic base, though in some cases the cathode is identified by a shorter lead. Green and yellow LED's that complement the MV5020 red series and have the same packaging are the MV5222 and MV5322, respectively.

The Fairchild FLV 100/101/102/108 series of "button" LED's are in small plastic packages similar to the TO-106 outline, but with only two leads. The respective part numbers correspond to a point source (FLV 100), diffused wide angle (FLV 101), red diffused area source (FLV 102), and an uncolored version (FLV 108) of the FLV 102. All of these packages benefit from the contrast enhancement provided by a black case. Although these units are best suited to pc board mounting, a plastic panel-mounting clip is available.

Another useful type of LED is the Texas Instruments TIL209/TIL209A, a red LED is a miniature ⅛"-diameter T-1 lamp size. It has a diffused red lens and is visible over a wide angle. The TIL209 has round leads, while the 209A has square leads. A companion green LED (TIL211) is also a diffused source. TI is currently working on yellow LED's, which should be available soon.

Hewlett-Packard has a series of red LED's which have a built-in current-limiting resistor. This eliminates the need for an external limiting circuit. Two models that operate from a 5-volt supply (can be driven by TTL) are the 5082-4860, a red diffused unit in T-1 ¾ size, and the 5982-4468, a clear diffused unit in T-1 size. The 5087-4860 can be panel-mounted and has wrap leads.

Litronix has also incorporated a current limiter in a LED package to operate over a wide variety of supply voltages. These devices come in T-1 ¾ and T-1 sizes. They have red diffused lenses. The RLC-200 is usable at voltages up to 12.5 V maximum, while the RLC-210 works up to 16 volts.

Driving LED's. A LED can be driven by either an ac or dc source, requiring a current-limiting resistor in either case. The two basic driving circuits are shown in Fig. 4 The equations show how to determine the value of the limiting resistor.

In Fig. 4A, the positive of the voltage source is connected to the LED's anode, so a forward current, I_f, flows. The current depends on V, the LED forward voltage drop (V_f), and the value of *RI*. The forward voltage drop varies between 1.6 and 3 volts, depending on the type of LED and can be determined from the published data sheets. As an example, assume that the LED requires 20 mA, has a V_f of 1.6, and the voltage source is 5 V. Then $RI = (5 - 1.6)/0.02 = 170$ ohms. (180 ohms would the nearest standard value.) Check the required wattage of

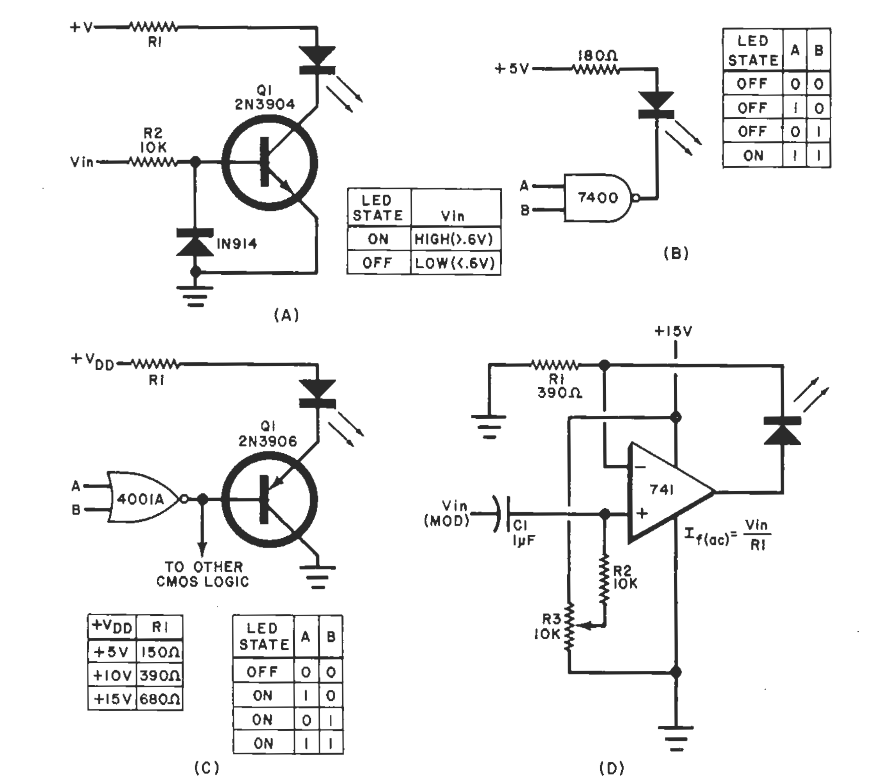


Fig. 5. (A) Saturated transistor drive and truth table. (B) and (C) are TTL and CMOS drives. (D) uses linear modulator.

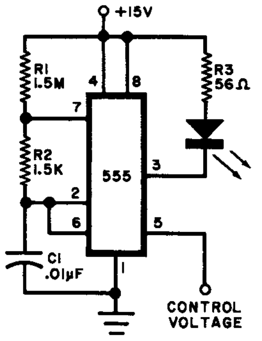


Fig. 6. Using a 555 IC to pulse-modulate LED.

the resistor since it will dissipate most of the source voltage.

In the ac circuit in Fig. 4B, the voltage source is V_{rms}, a sine wave. If the peak reverse voltage applied to the LED is over 3 V, the protective clamping diode, *D1*, is used. Any small-signal or rectifier diode can be used for *D1*. Since the LED rectifies the ac, only half of the total current contributes to useful light output. To maintain a brightness equal to that obtainable with dc, the value of the limiting resistor is cut in half—thus the 2 in the denominator of the equation.

Some practical drive circuits are shown in Fig. 5. An npn switching transistor is used in Fig. 5A. A high level on the input line switches *Q1* into saturation, supplying current to the LED. Current-limiting resistor *R1* is chosen as shown in Fig. 4A. The value of the supply voltage (+V) can be anything up to the V_{ceo} rating of *Q1*.

One of the most important uses for the LED is as a logic status indicator in digital circuits. Since TTL logic can sink up to at least 16 mA, it mates easily with a LED as shown the example in Fig. 5B. This is an AND gate so that the LED is on only when both A and B are high. Keep in mind that the current flows through the LED when the gate output is low. This, in effect, subtracts from the fanout of the stage if it is coupled to another logic stage. If the fanout is required, use a TTL buffer to drive the LED alone.

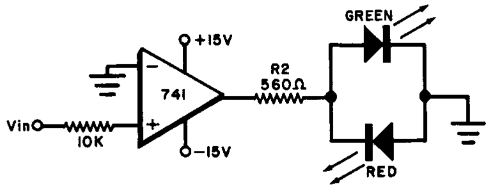


Fig. 7. Sensitive polarity indicator using op amp and two LED's of different colors.

Low-power logic such as CMOS cannot drive LED's directly so a buffer such as a CD4049 or CD4050 must be used, but current is limited. A solution is to use an emitter-follower buffer as shown in Fig. 5C. A beta of 100 for *Q1* will reduce the drive current required to 200 μA, which is compatible with the 4000A series of CMOS. The circuit in Fig. 5C is an example of OR logic since the LED is lit for a logic one on either A or B. Limiting resistor *R1* should be selected to match the supply voltage. An npn transistor could also be used for *Q1* by connecting the collector to the supply with the LED and *R1* in the emitter circuit. A basic asset of CMOS is its very high noise immunity, so a slightly reduced output swing from the gate in Fig. 5C is not a real detriment as far as driving other CMOS inputs is concerned. There are no fanout restrictions.

So far, we have discussed only on-off types of LED drives. A linear driver is shown in Fig. 5D. An op amp is used to make the LED current precisely proportional to the input modulation signal. Potentiometer *R3* determines the dc bias current in the LED since the voltage at the rotor of *R3* also appears across *R1*. If *R3* is centered, *R1* "sees" 7.5 volts and the current through the LED is 20 mA. The audio signal, through *C1*, modulates the dc bias signal to control the LED current proportionally. This circuit could be used as the transmitter end of light-beam communicator. It is simple, inexpensive and easy to set up; and none of the components is critical.

Some Applications. A pulser that is useful for on-off modulation of visible or IR LED's is shown in Fig. 6. A 555 timer IC is used as an astable oscillator which provides a 10-μs pulsed output every 10 ms (a 100-Hz rate). The circuit can be frequency modulated by applying an audio signal to pin 5. Resistor *R3* sets the peak LED current to about 200 mA; and, since the duty cycle is only 0.001, the LED is not overloaded.

Using a narrow-beam IR LED (such as the Motorola MLE60) in this circuit and a silicon detector at the receiver, an invisible light-beam communication link can be constructed.

A sensitive polarity (or null) indicator is shown in Fig. 7. The circuit uses an op amp to achieve a very low input-voltage threshold. Since the input signal is applied to the op amp noninverting input (+), the op amp output is positive when the input is positive and negative when the input is negative. A positive input lights the green LED, and a negative signal lights the red LED. The LED's can be separate devices, or a dual unit such as the Monsanto MV5491 (red/green) LED can be used.

The input threshold is the offset of the op amp used. For a 741, it is ±6 mV or less. There are no loading effects since the input draws very little current. If the added sensitivity is not needed, the op amp can be omitted and the LED's driven directly through *R2*. This is a useful option if the source impedance is low.

The circuit shown in Fig. 8 uses two high-gain comparators to determine whether a critical voltage is between two limits. In the circuit shown, the limits are +4 and +6 volts. The two comparators are wired as OR gates, so that the LED is energized if either comparator output is low. This would occur if V_{in} were less than +4 V or more than +6 V. Using this general idea, different reference voltages can be used to monitor almost any voltage level.

Conclusion. Of course, we have not covered all of the possible uses for the various types of LED's. Hopefully, some ideas have been generated. Others can be obtained from the references given in the accompanying box. ◈

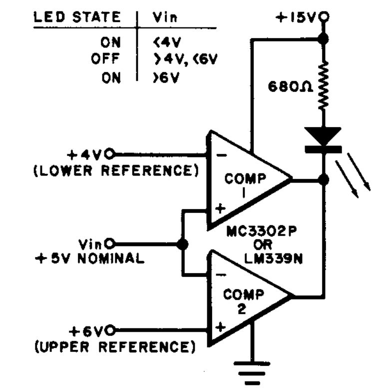


Fig. 8. Window comparator turns LED on when input exceeds predetermined limits.

SOURCES

Laser diodes provide high power for high-speed communications systems

by J.T. O'Brien
RCA Electro Optics Division, Lancaster, Pa.

The trend to optical communications systems, "wired" with single fibers rather than bundles of fibers, puts a premium on the efficient coupling of source power into the fibers. The smaller optical aperture of the single fiber requires not only the higher source power of the laser diode but construction techniques that attach the fiber directly to a laser pellet. Meanwhile, laser diodes have their uses in high-speed, high-power systems using both fiber bundles and single fibers.

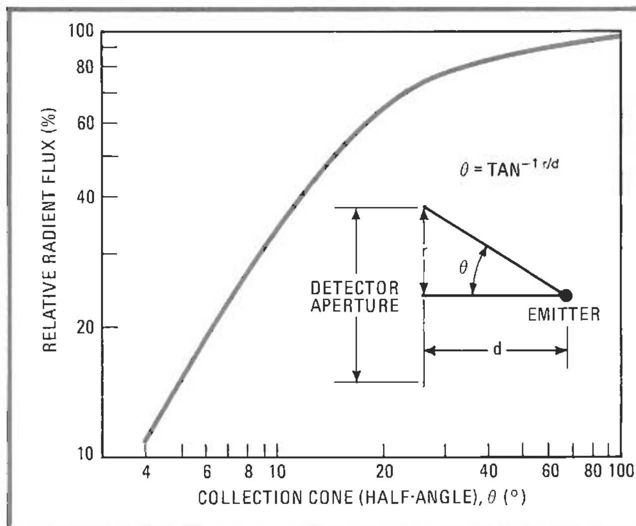
Two types

Gallium-arsenide and gallium-aluminum-arsenide laser diodes are available in single- and double-heterojunction structures. The double-heterojunction diode consists of a thin active layer of gallium arsenide, usually lightly doped with aluminum, sandwiched between two layers of GaAlAs. The single-heterojunction type has only one layer of GaAlAs along with the active layer of GaAs or GaAlAs. But the most important difference between them is the much higher data-rate capability of the double-heterojunction type (greater than 100 megahertz versus 100 kilohertz.).

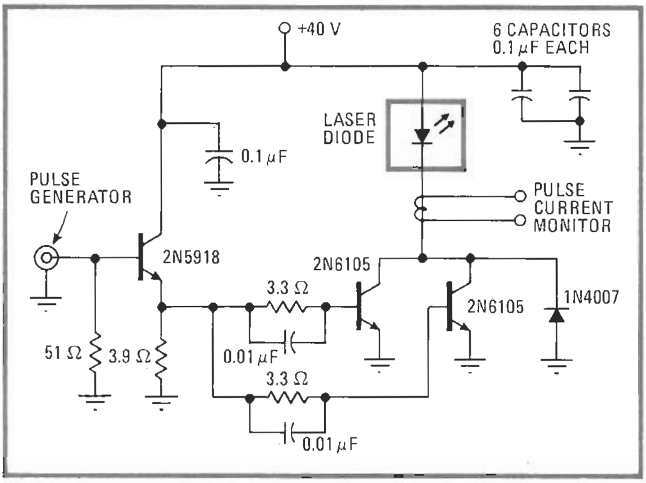
Single-heterojunction laser diodes are low-cost, off-the-shelf items used in low-duty-cycle applications requiring high output power. Peak radiant flux of these diodes is limited to approximately 1 watt per mil of emitting-junction width at a 200-nanosecond pulse width. For example, a diode with a 9-mil-wide junction, such as the RCA SG2007, is rated at a maximum of 10 W peak output. But because the diode's need to dissipate heat sets limits to its operation, a tradeoff between pulse width and pulse repetition rate must be made. Consequently, at a maximum pulse width of 20 ns and a maximum duty cycle of 0.1%, the repetition rate is limited to 5 kHz. At pulse widths on the order of 10 ns, repetition rates of 100 kHz are possible.

The double-heterojunction laser diode requires relatively low drive current and voltage (less than 400 milliamperes at 2 volts). Continuous or high-duty-cycle operation is possible at room temperature with power outputs in the 5-to-10 milliwatt range at less than 1-ns rise time. Analog or digital bandwidth capability exceeds 100 megahertz.

The semiconductor laser is essentially a line source with an emitting dimension of 0.08 mil times the emit-



1. Collecting flux. The amount of light output from a semiconductor laser incident on an optical fiber can be determined from the relative radiant flux emitted by the laser and the fiber collection angle. Data for a single-heterojunction laser is shown.



2. Switching sources. With the transistor circuit shown, pulses as short as 10 nanoseconds at repetition rates of 100 kilohertz are possible, but peak current is limited. Silicon controlled rectifier switches produce higher current but at lower repetition rates.

ting width. The wavelength of maximum intensity depends primarily on the bandgap energy of the material used and, to a much lesser extent, on junction doping. GaAs, for instance, has a center wavelength of 904 nanometers, which is temperature-sensitive. For a single-heterojunction type, the spectral bandwidth and half-angle beam spread at the 50% intensity points are 3.5 nm and 9° respectively. Both values are broad relative to other laser types and result in greater coupling loss to fibers.

The relative radiant flux collected at a detector depends on the collection angle of the laser diode. A typical curve is shown in Fig. 1.

For high peak output power, it is necessary to drive the laser with fast, high-amplitude current pulses. The pulse may be generated by discharging a capacitor through the laser using either a silicon controlled rectifier or a transistor. An SCR can switch higher peak currents than transistors, but at much lower speeds. Each has advantages and disadvantages, and the optimum drive circuit can be picked only in terms of overall system performance.

Drive circuits

In SCR driver circuits, transistors are used to regulate the level to which the storage capacitor is charged by the supply voltage. The SCR acts as the discharge switch and, when triggered, drives the laser diode. General-purpose SCRs, such as 40763 or 40555, can handle pulse repetition rates in the range of 5 – 10 kHz. The capacitance value is determined by the combination of current and pulse width desired.

Not many commercially available SCRs are fast enough to deliver narrow, high-current pulses at repetition rates in excess of 10 kHz. But a few, such as the Unitrode GA-201, can generate 25-ns pulses at repetition rates up to 25 kHz.

With a transistor switching circuit (Fig. 2), pulses as short as 10 ns at repetition rates greater than 100 kHz are possible. The maximum peak laser drive current, however, is limited to approximately 20 amperes.

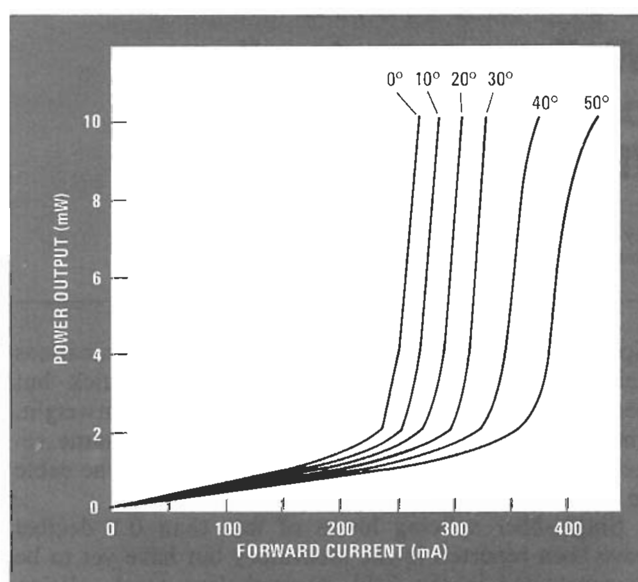
How much of the laser output actually enters a given optical fiber depends on cable as well as source parameters. From published data for a laser device, it's possible to determine what size gap there should be between it and the fiber face. The active diameter of the fiber and its numerical aperture, available on its data sheet, defines the emission angle the laser pellet should make with the fiber. The amount of laser output incident on the fiber bundle is found using the laser's relative radiant flux versus the fiber collection angle. A typical plot is shown in Fig. 1. Finally, from the bundle's packing fraction (the ratio of the useable core area to the over-all area of the bundle), the amount of power coupled into the fiber can be derived.

Usually the measured value of a laser's emitted power is slightly lower than indicated in the available specifications. However, data sheet numbers do provide a starting point.

One example

For example, from published data on the RCA C30130 double-heterojunction laser diode it can be determined that a fiber-bundle cable with an active area of 0.015 inch can be positioned approximately 0.120 in. from the laser chip. This defines an acceptance angle of about 4° with the emitting surface of the laser pellet. From a plot of radiant flux as a function of collection angle, it is determined that about 4% of the emitted flux from the diode is incident on the active diameter of the bundle. Using a value of 40% to represent the area occupied by individual fibers in the bundle indicates that a total of only 1.6% of the laser output is coupled into the fibers.

More efficient coupling is possible using a laser with the glass window removed, so that the fiber can be placed closer to the laser pellet. Measurements taken with such a nonhermetic diode and the same fiber bundle show coupling efficiencies of 35%—which is a really



3. Temperature-sensitive. The threshold current for the RCA laser types C30127 and C30130 increases rapidly above room temperature. At 60°C the peak output drops to half its room-temperature value, and in some instances lasing may stop.

dramatic improvement.

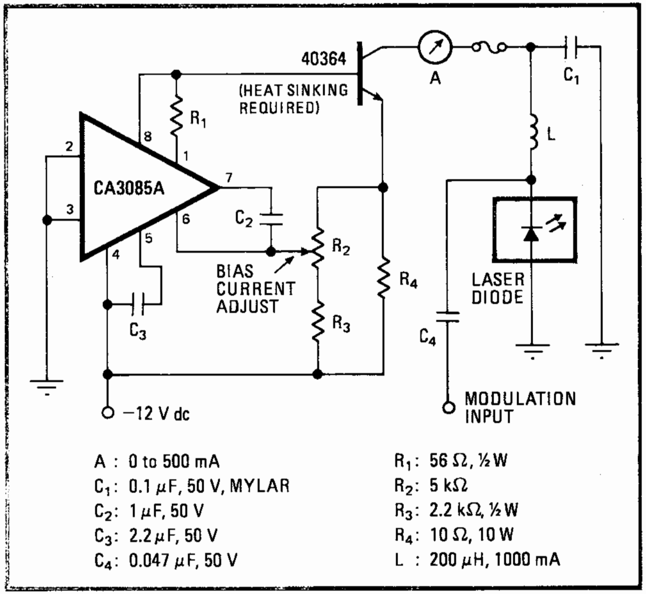
One problem with laser diodes is that relatively small changes in temperature can change their output significantly. As shown in Fig. 3, threshold current for RCA types C30127 and C30130 increases at temperatures above 27°C and doubles at about 70°C, while with constant current drive applied, the peak radiant flux at 60° drops to 50% of its room-temperature value. In fact, threshold current of the drive may increase sufficiently to prevent lasing.

Because of this heavy dependence of threshold current on temperature, the laser should be operated at some fixed temperature within its operating range temperature. A small thermoelectric heat pump will maintain the laser heat-sink temperature to within a few tenths of a degree over the expected ambient temperature range.

For analog systems, it is necessary to bias the device well above the threshold point and then superimpose the analog modulating signal on the dc drive current. Figure 4 shows a typical circuit used to measure the linearity and harmonic content of a laser diode when operated in the analog mode at 10 MHz. Approximately 350 mA of bias current is sufficient to provide a continuous output of 7 mW. A 30-mA peak-to-peak 10-MHz sine wave is coupled through capacitor C_4 and the laser output measured with a silicon photodiode. The first harmonic at 20 MHz is 40 dB below the fundamental with an ac drive current.

Laser lifetime remains another problem. It must be increased to well beyond 10^5 hours if the diodes are to find use in systems where 20-year reliability is essential. Actual laser-lifetime data isn't yet available, but data extrapolated from selected samples translates into a mean time between failures of 10 hours for some lasers with a heat-sink temperature of 22°C.

The third big problem area—efficient coupling of laser to fiber—should be alleviated with construction techniques that attach a short length of fiber directly to the laser pellet.

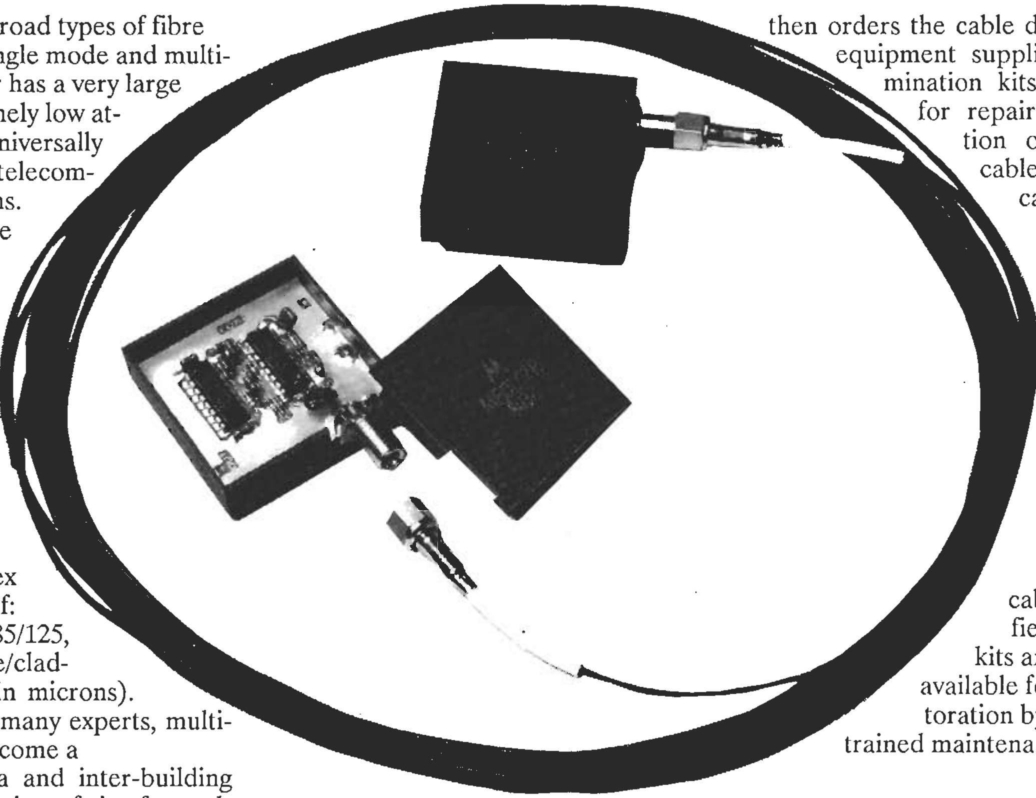


4. Measuring linearity. A 30-milliampere peak-to-peak 10-megahertz sine wave was coupled through capacitor C_4 to modulate the laser diode. The light output was measured, and the first harmonic was 40 dB below the fundamental.

Fibre Optics

The ins and outs of installing fibre optic assemblies.

By Dr. H. Virani



There are two broad types of fibre optic cable: single mode and multimode. The former has a very large bandwidth, extremely low attenuation and is universally used in long-haul telecommunication systems. Multimode is more appropriate for short-haul data/-voice communication requirements.

There are various types of multimode fibre. The predominant type being all glass, grade-index fibre in sizes of: 50/125, 62.5/125, 85/125, and 100/140 (core/cladding dimensions in microns). In the opinion of many experts, multimode fibre will become a standard for intra and inter-building installations. Selection of size for multimode fibres is not critical to a successful installation. Like the choice between 25, 24 or 22 gauge copper wire for twisted pairs, there are customer preferences and performance distinctions but fibre size is not a major installation decision. In fact, of the two most popular connector types, the same connector can be used on 50, 62.5 and 85 micron core fibres, and only an insert change is required to accommodate the 100/140 size. These fibres are available in all types of cable: indoor and outdoor; single fibre (simplex); dual fibre (duplex); and up to hundreds of fibres within a single cable sheath (Fig. 1).

Outdoor cable is available with special jell filling; steel jacketing for rodent protection; for aerial, buried or duct installations; and with a variety of sheath materials.

Connectors

There are basically two popular types of connectors used on multimode cable: SMA type and BICONICAL (Fig. 2).

Despite advances in the art of fibre optic connectors, the problems involved in properly terminating this thin filament of glass should not be underestimated. Because of the difficulty of field termination with either of the standard connectors, it is highly desirable to have connectors factory installed. This is easily handled and has worked quite successfully.

The customer typically "walks off" the distance between the two devices to be interconnected (either through the use of blue prints or physically walking this distance), adds a safety factor of perhaps 10% (to permit circumventing obstructions, etc.), and then orders the cable direct from the equipment supplier. Field termination kits are available for repair and restoration of a damaged cable, however, a cable disruption is highly unlikely.

Once installed, fibre optic cable is no more likely to be damaged than the common, copper, twisted-pair cables. However, field termination kits and training are available for on-site- restoration by relatively untrained maintenance personnel.

Test Equipment

There is a large variety of test equipment available for fibre optic systems. Some of these devices are extremely sophisticated and used primarily by telecommunication carriers where attenuation and bandwidth are highly critical to the proper functioning of a system. For short-haul fibre optic cable installations, relatively inexpensive fibre optic test equipment is available. A standard attenuation test may by all that is required to install and maintain a link. In the event that an installed fibre optic cable develops a break or discontinuity, instruments are available for locating the fault. Such instruments are quite expensive even for short-haul multimode systems but it is also possible to obtain assistance from a fibre optic supplier or rent such equipment in the unlikely event that it is needed.

Installation

One thing should be made clear about the installation of fibre optic cable. Although it is glass, it need not be handled like fine crystal glasses. The fibre is quite flexible and many fibres are available that can be tied into a loose knot without any permanent damage to the fibre.

Furthermore, fibre optic cables are provided with a high strength member (that is also dielectric) that allows the cable to be subjected to heavy pulling tension during installation. Perhaps the only caution that need be exercised is that the fibre should not be pulled around very sharp corners.

By comparison with pulling in copper cables, either multi-twisted pair or coaxial cables, fibre is much easier to install. Because of its small size it can be pulled through relatively small openings with ease. Also because of its small size, it has a small surface and thus creates very little friction when pulled in relatively confined space. It is extremely light so the reel of cable may be easily handled in one hand as opposed to the heavy and cumbersome copper cables.

In most indoor fibre optic cable installations, which are typically less than a thousand feet in length, it is usually recommended that the customer installs it themselves. The customer can order a factory terminated cable supplied on a light-weight reel (which allows it to be air expressed for emergency delivery at relatively low cost) and install it with no previous experience.

The cable may be laid in a raceway which contains either communication or power cables (remember that fibre optic cable is immune to EMI/RFI). The fibre optic cable may also be installed under a raised floor where the only precaution is that the cable may require crush protection and the use of a split plastic conduit may be recommended. The conduit also will aid in the "pulling- in" and more importantly protect the fibre against subsequent rearranging of large cumbersome copper cables. Finally, the fibre could be laid in a cable tray with other fibres and is preferably left loose, not attached to other cables or to the tray itself.

Perhaps the easiest installation method for fibre optic cable is to simply lay the fibre over a dropped ceiling providing almost a line-of-sight direct connection between the two pieces of equipment. When installing the fibre optic cable over a dropped ceiling some care must be taken to avoid pulling around sharp corners, ceiling hangers, metal studs and around areas of continuous maintenance activity (for example, away from heating vents or lighting fixtures).

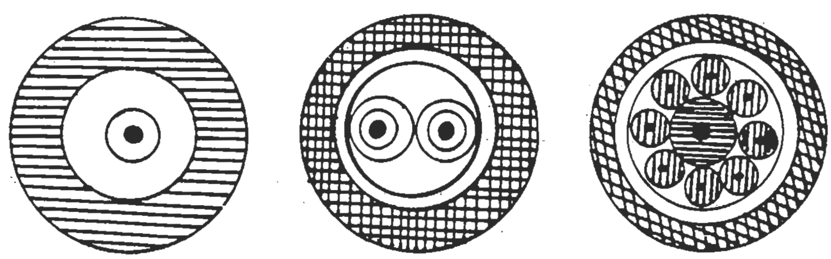


Fig. 1 A graphic representation of some various fibre configurations.

In some installations where there is a great deal of activity in the above ceiling area, a split-plastic conduit may be desirable. Fibre optic cable laid on a dropped ceiling meets building code requirements without the expense of metallic duct, trays, or conduit.

In vertical installations, fibre optic cable may be installed in an elevator shaft or a pipe chase. Since an elevator shaft is typically filled with electromagnetic energy from the rotating electrical motors that are used to move the elevator, fibre optic cables are ideal for installation without the large expense of shielded copper cable. Cable ties may be desirable to maintain the cable in an out-of-the-way position. Ties should not be crimped too tightly. Most fibre optic cables can be self-supported (without any hangars to relieve the weight of the cable itself), for a distance of up to 300 ft. or approximately 30 stories in a highrise building.

The installation of fibre optic cable outdoors is a more complex situation. In the first place, most outdoor cable installations involve greater distances, multiple buildings, and thus more planning and support. Of course, the user must have the right- of-way to install the cable. While it is the responsibility of the user to obtain such right-of-way, many local contractors can assist the user in dealing with the proper authorities. The actual physical installation of the cable may be done on telephone poles, buried, or run in ducts or conduits.

In the planning for installation of cable outdoors, the three methods of laying the cable as described above will largely determine the type of cable to

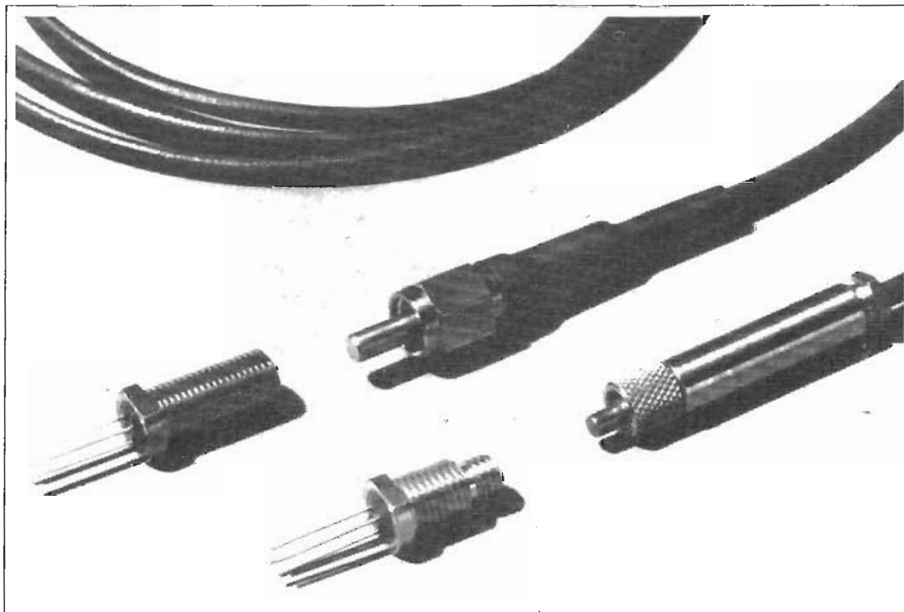


Fig. 2 The two types of popular connectors: SMA and biconical.

be selected. This selection should be done with the assistance of experienced fibre optic cable specialists. They can assist in selecting the right

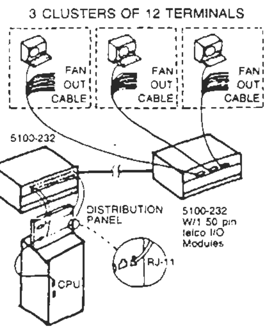


Fig. 3 Terminal clusters linked together with fibre technology.

type of fibre, cable, sheathing, diameter, connectors, splicing, and all accessories. In many "campus" fibre optic installations, it is desirable to terminate the outdoor cable at a patch panel providing manual recon-

Cable splicing is simplified using specialized test equipment, such as the LLD-220 from Performed Line Products.

figurability for restoration or rearrangement. Patch panels, patch cords, termination panels and termination boxes are available through most cables and equipment suppliers.

A typical indoor installation of fibre optic cable would be used to inter-connect a pair of RS232 fibre optic multiplexers. In this system, one multiplexer would be mounted in the computer or data processing room within a 19 in. rack. Each individual asynchronous channel on the rear panel of the multiplexers would be connected through a DB25 connector and a standard RS232 cable to a port on the computer distribution panel (see Figure 3).

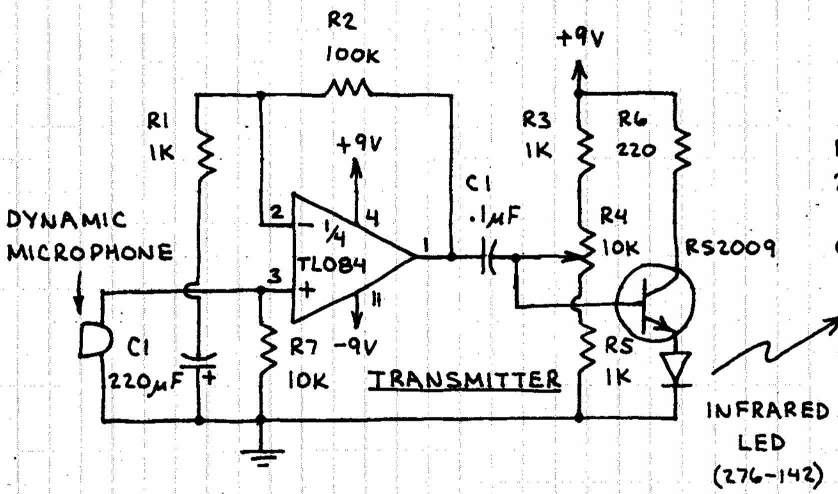
This portion of the installation is similar to that of a standard statistical multiplexer operating on copper cable. The fibre optic cable would be connected on the real panel of the multiplexer. The multiplexer is then provided with a standard SMA-type connector which mates with the SMA connectors that are factory installed on the cable. It is desirable to provide a fairly large radius, say 10 ins., of the fibre after connection to the multiplexer to prevent any undue stress or inadvertent pulling on the fibre which may disturb or damage the connection. The fibre could then be run down beneath the raised computer floor to a suitable riser that would provide access to the space above the dropped ceiling. Alternatively, the fibre could be run upward directly through an opening in the dropped ceiling. It is also possible to run the fibre optic cable, together with copper cables, through a suitable conduit that is terminated at the equipment rack to provide access out of the computer room and into a cable tray, raceway, or continuation of the conduit. Once the cable is pulled in, it is simply attached to the multiplexer at each end taking care that the transmit fibre at one end is connected to the receiver at the opposite end. In general, most fibre optic systems will have a sufficient system gain, so that the short distances normally traversed within a building will provide excess loss margin.

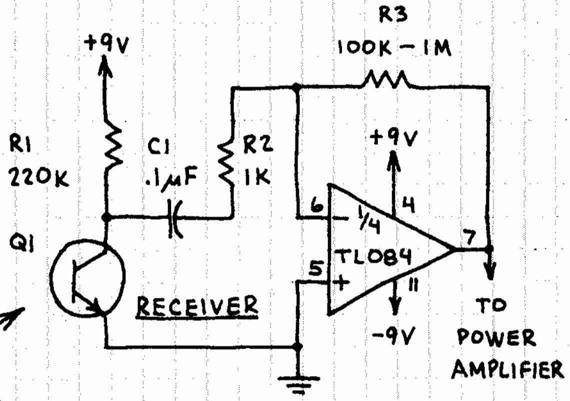
Summary

The installation of fibre optic cable is neither difficult nor time consuming. There are many suppliers for all of the system components, Motorola, GTE, Corning, HP to name a few, required for a complete turnkey installation. Training courses for personnel are readily available and experienced installation companies are available for large system requirements. Fibre optic systems are widely used throughout the telephone industry and accumulated experience with fibre optics is mounting fast. Leading edge users have committed themselves and are enjoying the benefits of this highly attractive technology.

Dr. Virani is a freelance writer from Mississauga, Ontario.

INFRARED VOICE COMMUNICATOR





POINT THE LED AT Q1 AND ADJUST R4 UNTIL BEST VOICE QUALITY IS OBTAINED. (R4 APPLIES PREBIAS TO LED.) R6 LIMITS MAXIMUM LED CURRENT TO A SAFE 40 mA.

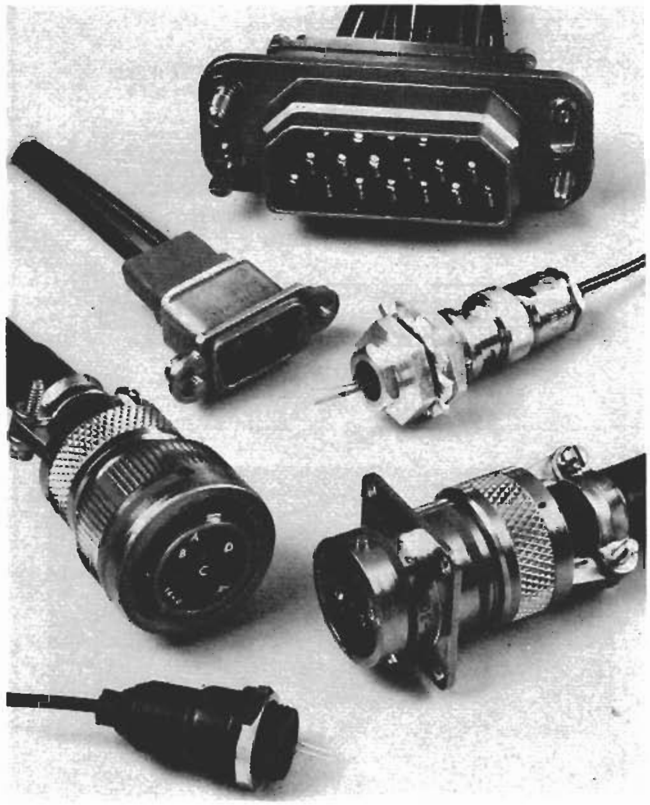
USE RADIO SHACK 276-130 PHOTOTRANSISTOR FOR Q1. MAXIMUM RANGE: HUNDREDS OF FEET AT NIGHT WITH LENSES AT Q1 AND LED. POWER AMP: SEE LM386.

Metal connectors protect fibers during termination and in the field

by K. J. Fenton
ITT Cannon Electric, Santa Ana, Calif.

Metal connectors that terminate or couple fiber bundles differ from single-fiber metal connectors both in the way they deal with fiber alignment, handling and protection and in optical end preparation.

Some requirements, though, are identical. Both types of connector must provide for terminating the jackets, strength members, and buffering materials used in fiber cables, and both must insure that loads applied to the cable are not transmitted to the terminated fiber. Moreover, optical-fiber connector designs must provide for protection of the fibers during termination and end preparation as well as after they are installed in the connector.



1. Wide selection. Connectors for fiber-bundle cables are available in both circular and rectangular shapes and can accommodate from 1 to 18 optical channels. These products can also couple either photodetectors or light sources to fibers.

Alignment critical

The alignment of a fiber bundle with a LED or laser diode source, photodetector, or other bundles is far less critical than the alignment of a single fiber for these same three connection areas. The coupling losses between pairs of fiber bundles as well as single fibers depend heavily on their degree of lateral (or axial) misalignment.

Rather less critical than lateral alignment is the size of the gap between prepared fiber ends (though there must be a gap), and less critical still, though still important, the angular alignment of their center lines.

In separable connectors it is extremely important that the prepared ends of the fibers do not touch since otherwise repeated matings of vibration and shock will chip and scratch the optical-fiber surface and degrade the optical efficiency of the connector. But the gap cannot be too large—if the coupling losses contributed by it are to stay within 0.2 decibel, it should not exceed 10% of the active core diameter of the fiber bundle or single fiber. This works out as a 75-micrometer (0.003-inch) gap for a typical 1,125-μm (0.045-in.) bundle or a 5-μm (0.0002-in.) gap for a 50-μm (0.002-in.) core for single fiber.

The loss characteristics for these gaps also vary slightly as a function of the numerical aperture of the bundle or single fiber. Angular misalignment within $\pm 1^\circ$ for bundles of optical fibers and half that for single optical fibers results in acceptable losses of from 0.1 dB to 0.2 dB.

For both bundle and single-fiber connectors, a chip-free, scratch-free, flat surface, perpendicular to the fiber centerline, is essential for good optical coupling. If any of these conditions is lacking, light scattering occurs at the fiber ends.

Fiber-bundle termination

A rather simple polishing procedure can produce a sufficiently good optical interface on a fiber bundle. When being polished, all of the fibers must be held rigid and adequately supported to prevent them from chipping or cracking.

Usually, the fiber bundle is first stripped of its jacket and fiber buffering materials, and the exposed fibers are cleansed of lubricants and contaminants. For most cables, epoxy is applied to the fibers to immobilize them, and the bundle is slipped into a termination device that packs it into a tight hexagon. The hex shape provides the optimum packing fraction (the ratio of the cross-sectional area of the fiber cores to the total area of the fiber bundle). At this point, the epoxy has cured, and any excess fiber length is cut off with wire cutters or scissors.

A two-step, wet-polishing procedure comes next. First a 400 grit abrasive is used to rough-polish the ends, and then a 0.03-micrometer paste applied with a felt wheel produces the final finish. The two steps take less than 1 minute. Additional polishing does not improve matters and often reduces optical efficiency because it may dome the fiber ends. The final step is to protect the prepared end with a thin, transparent cap supplied with the connector.

Single-fiber termination

The end preparation and termination for a single fiber is significantly different. The jacketing and fiber buffering materials are removed, as before, but the exposed fiber is then broken in a fixture to the precise length required. (Fixtures capable of producing the necessary controlled, consistent break have been developed by several manufacturers.) Also, the fiber end must be precisely located within the terminating device, and this critical step must be accomplished by other special fixtures.

Several manufacturers offer a variety of optical connectors for the termination of fiber bundles. Circular or rectangular in shape, these accommodate from 1 to 18 optical channels or combinations of electrical and optical channels. Several connectors in various sizes and mounting styles available from ITT Cannon (Fig. 1) couple standard LED or laser-diode sources to fibers, fibers to fibers, and fibers to photodetectors.

Coupling losses depend on the size and number of fibers in the bundle, the core-to-cladding ratio of each fiber, and the numerical aperture of the fiber bundle. Losses from fiber bundle to fiber fall between 2.5 decibels and 3.5 dB.

Making a match

Source-to-fiber and fiber-to-detector coupling efficiency, however, varies not only with the connector but with the device characteristics and how well the fiber is matched to either detector or source. For example, an edge-emitting laser produces a doughnut of light in the near field; if the fiber is placed in the middle, then no light is coupled into it. As for the connector's effect, using different types to couple commercially available light-emitting diodes and photodetectors to fiber-bundle cables results in a wide range of coupling losses—source-to-fiber bundle coupling loss can vary from 3 dB to 14 dB with off-the-shelf devices while fiber-bundle-to-photodetector coupling loss can vary from 0.5 dB to 8.5 dB.

In addition to selling just optical connectors, some manufacturers offer an economical bundle-termination service as well as complete cable assemblies. Most also plan to offer tooling and fixtures to terminate bundles in the factory as well as in the field.

2. New entry. Few companies as yet are marketing single-fiber-per-channel connectors, but this recently released connector from ITT Cannon Electric can be used to join two single fibers or to couple a photo or a LED or laser diode to the fiber.

OPTICAL COMMUNICATIONS

Connectors for some single-fiber cables are presently offered on a limited quantity, special-order basis. In fact, the only types available at present are for cables containing either one or six functionally different fibers. The single-fiber-per-channel connector shown in Fig. 2 is a very recent introduction.

The coupling efficiencies of these single-fiber connectors vary with fiber type, overall fiber size, core size, and the numerical aperture of the fiber. Fiber-to-fiber optical losses also vary, depending on the quality of the fiber-end preparation and accuracy of termination location within the termination device. Typically, coupling losses of from 1 dB to 2.5 dB are expected in these connectors.