Engineer's Mini-Notebook

Optoelectronics Circuits

Forrest M. Mims III
ENGINEER'S MINI-NOTEBOOK

OPTOELECTRONIC CIRCUITS

BY

FORREST M. MIMS III

FIRST EDITION

FIFTH PRINTING-1998

A SILICONCONCEPTS™ BOOK

COPYRIGHT © 1986 BY FORREST M. MIMS III

ALL RIGHTS RESERVED

PRINTED IN THE UNITED STATES OF AMERICA
ABOUT THE MINI-NOTEBOOK SERIES

WHERE TO FIND PARTS

Electronic parts in this book are available from Radioshack Stores or from Radioshack Unlimited (RSU). Some parts have more than one designation. For example, the popular 2N2222 transistor can be replaced by the 2N2222A, the MPS2222 and the MPS2222A.

PLEASE READ THIS

This book includes standard circuits and circuits designed by Forrest M. Mims III. Each circuit was built and tested at least twice. Variations in components and construction methods may give results that differ from those described here. Therefore the author and Radioshack are not responsible for the suitability of the circuits for any application. Since we have no control over the use of information in this book, we assume no liability for such use. It is your responsibility to determine if commercial use, sale or manufacture of any device based on information in this book infringes any patent, copyright or other rights.

FOR MORE INFORMATION

Due to the many inquiries received by the author and Radioshack, it is impossible to provide custom circuit designs and technical advice. You can learn more about electronics by reading electronics magazines. Also see Radioshack's "Getting Started in Electronics" and other mini-notebooks in this series. You can also find information on the Internet newsgroup sci.electronics.
# CONTENTS

## INTRODUCTION

## THE OPTICAL SPECTRUM

## OPTICAL COMPONENTS

- SIMPLE LENSES
- POSITIVE LENS
- NEGATIVE LENS
- FILTERS
- LIGHT SHIELDS
- OPTICAL FIBERS

## LIGHT SOURCES

- INCANDESCENT LAMPS
- GAS-DISCHARGE LAMPS
- LIGHT-EMITTING DIODES
- LIGHT SOURCE SPECTRA
- HOW TO USE LEDs
- SAMPLE LED CIRCUIT
- LOGIC CIRCUIT LED DRIVERS
- AC/DC POLARITY INDICATOR
- VOLTAGE-LEVEL INDICATOR
- LED BRIGHTNESS CONTROL
- LOGIC PROBE
- HOW TO USE TRI-COLOR LEDS
- HOW TO USE FLASHER LEDS
- BASIC LED FLASHERS
- DUAL LED FLASHER
- POWER FLASHER
- SINGLE LED FLASHER
- DUAL LED FLASHER
- INCANDESCENT LAMP FLASHER
- NEON LAMP FLASHER
LIGHT SENSORS

PHOTOELECTRIC SENSORS
SOLAR CELLS
PHOTOTRANSISTORS
SENSOR SPECTRAL RESPONSE
HOW TO USE LIGHT DETECTORS
PHOTOELECTRIC SENSORS
SOLAR CELLS
PHOTOTRANSISTORS
SIMPLE LIGHT METERS
ULTRA-SIMPLE LIGHT METER
SOLAR BATTERY CHARGER
SOLAR-POWERED CIRCUITS
LIGHT-SENSITIVE OSCILLATORS
LIGHT-ACTIVATED RELAYS
DARK-ACTIVATED RELAYS
DARK-ACTIVATED LED FLASHERS
LIGHT/DARK-ACTIVATED ALERTER

LIGHTWAVE COMMUNICATIONS

SUITABLE COMPONENTS
OPTICAL FIBER LINKS
FREE-SPACE LINKS
LIGHTWAVE TONE TRANSMITTERS
SIMPLE LIGHTWAVE RECEIVERS
THE PHOTOPHONE
AM LIGHTWAVE TRANSMITTER
AM LIGHTWAVE RECEIVER
BREAK-BEAM DETECTION SYSTEM

OPTOELECTRONIC LOGIC

BUFFERS
INVERTERS
AND CIRCUITS
OR CIRCUITS

SOURCE/SENSOR PAIRS

INTEGRATED SOURCE/SENSORS
OPTOCOUPLER CIRCUITS

4

18
18
19
19
20
20
21
21
22
23
24
25
26-27
28
29
30
31
32
32
33
34
35
36-37
38
39
40-41
42
42
43
43
44
45
46-48
INTRODUCTION

Optoelectronics is the term for the combined technologies of optics and electronics. Electronic devices that emit or detect optical radiation are called optoelectronic components. Optoelectronic circuits have widespread applications in communications, sensing, control, and readouts. Many kinds of solid-state optoelectronic components are available at reasonable prices from Radio Shack. So is "Getting Started in Electronics," a book that will help you assemble the circuits in this book.

THE OPTICAL SPECTRUM

$\text{nm} = \text{nanometer} \quad (1 \text{ nm} = .000000001 \text{ meter})$

$\mu = \text{micrometer} \quad (1 \mu = .000001 \text{ meter})$

$\text{mm} = \text{millimeter} \quad (1 \text{ mm} = .001 \text{ meter})$

Violet

Blue

Green

Orange

Red

Near-Infrared

400nm 500nm 600nm 700nm 800nm

Visible Light

X-Rays

Ultraviolet

Infrared

Microwaves

Wavelength

1nm 10nm 100nm 1µ 10µ 100µ 1mm 10mm
OPTICAL COMPONENTS

OPTICAL COMPONENTS CONDUCT, BEND, OR CHANGE THE CHARACTERISTICS OF LIGHT. MANY OPTICAL COMPONENTS CAN BE FOUND AROUND THE HOME OR OFFICE. OTHERS MUST BE PURCHASED FROM SCIENCE SUPPLY COMPANIES.

SIMPLE LENSES

LENSES MADE OF GLASS OR PLASTIC ARE AMONG THE MOST IMPORTANT OPTICAL COMPONENTS.

POSITIVE (CONVEX) LENS

FOCAL LENGTH

FOCAL POINT

FOCUSES PARALLEL RAYS TO A POINT

COLLIMATES SPREADING RAYS INTO A BEAM

FOCAL POINT IS AT LAMP’S FILAMENT

NEGATIVE (CONCAVE) LENS

EXPANDS (DIVERGES) PARALLEL RAYS
FILTERS

Filters transmit a narrow band of optical wavelengths. Use colored cellophane for visible light or developed color film for infrared.

LIGHT SHIELDS

Tube lined with black paper or coated with flat black paint keeps external light away from detector.

OPTICAL FIBERS

Glass and silica fibers are the most transparent. Plastic fibers are cheaper and easier to use.

Optical fibers conduct light by internal reflection, as shown here, or by continually refocusing incoming rays toward center of the fiber.
LIGHT SOURCES

Many light sources are available for optoelectronic projects. The most important sources include:

INCANDESCENT LAMPS

An incandescent lamp is made by enclosing a thin tungsten wire (the filament) in an evacuated glass envelope. An electrical current passed through the filament causes it to become incandescent (white hot). The operating life and brilliance of an incandescent lamp can be increased by filling the envelope with a gas such as argon, nitrogen, or krypton. The ultra-bright halogen lamp has a quartz envelope filled with a halogen gas like iodine or bromine. The gas combines with tungsten on the envelope wall and deposits it on the filament.

GAS-DISCHARGE LAMPS

The simplest gas-discharge lamp, the neon glow lamp, is a glass envelope filled with neon gas. When the voltage across two electrodes in the envelope exceeds 60-70 volts, the ionization or breakdown voltage of neon, an electrical discharge is established between the electrodes, and the neon emits an orange glow. Other gas-discharge lamps are the xenon flash lamp and the mercury vapor lamp.
LIGHT-EMITTING DIODES

The light-emitting diode (LED) is a semiconductor PN junction diode that emits visible light or near-infrared radiation when forward biased. Visible LEDs emit relatively narrow bands of green, yellow, orange, or red light. Infrared diodes emit in one of several bands just beyond red light. LEDs switch off and on rapidly, are very efficient, have a very long lifetime, and are easy to use. LEDs are current dependent sources, and their light output is directly proportional to the forward current.

LIGHT SOURCE SPECTRA

- NEON GLOW LAMP (ORANGE)
- HALOGEN LAMP (WHITE)
- GaAsP LED (RED)
- AlGaAs LED (IR)
- GaAs:Si LED (IR)
- STANDARD TUNGSTEN LAMP (WHITE)

WAVELENGTH (NANOMETERS)

$\leftarrow$ VISIBLE $\rightarrow$ INFRARED $\leftarrow$
HOW TO USE LEDS

LIGHT-EMITTING DIODES ARE VERY RUGGED, LONG-LIVED OPTICAL SOURCES. THE LIGHT THEY EMIT HAS AN INTENSITY THAT IS LINEAR WITH RESPECT TO THE FORWARD CURRENT THROUGH THE LED. TO PREVENT IRREVERSIBLE DAMAGE, ALWAYS OPERATE AN LED WITHIN ITS RATINGS.

USE A SERIES RESISTOR ($R_s$) TO LIMIT THE CURRENT THROUGH AN LED TO A SAFE VALUE.

$$R_s = \frac{V_{in} - V_{led}}{I_{led}}$$

$I_{led}$ IS THE SPECIFIED FORWARD CURRENT.

$V_{led}$ IS THE LED VOLTAGE DROP. IT RANGES FROM ABOUT 1.3 VOLTS (940 nm INFRARED EMITTERS) TO ABOUT 2.5 VOLTS (GREEN EMITTERS).
SAMPLE LED CIRCUIT

\[ I_{LED} = 20 \text{ mA} \]

\[ R_s = \frac{6 \text{ V} - 1.7 \text{ V}}{0.02} = 215 \text{ ohms} \]

220 \( \Omega \) is closest standard value.

LOGIC CIRCUIT LED DRIVERS

TTL:

\[ R_s = 220 \Omega \]

\[ I_{LED} = 15 \text{ mA} \]

TTL OR CMOS:

A simple but effective logic probe can be made from this circuit. Apply input signal

VALUES OF \( R_s \) are for typical red LEDs.
AC/DC POLARITY INDICATOR

VOLTAGE-LEVEL INDICATOR

LED will glow when +V exceeds the breakdown voltage of the Zener diode. Note that D1 is reverse biased.

LED BRIGHTNESS CONTROL

SELECT Rs as if R1 not present

LOGIC PROBE

Use this probe to monitor the logical status of logic gates.

<table>
<thead>
<tr>
<th>IN</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>ON</td>
</tr>
<tr>
<td>LOW</td>
<td>OFF</td>
</tr>
</tbody>
</table>
HOW TO USE TRI-COLOR LEDs

TRI-COLOR LEDS ARE MADE BY INSTALLING A RED AND GREEN LED CHIP IN THE SAME PACKAGE. THE TWO CHIPS ARE USUALLY CONNECTED IN REVERSE-PARALLEL.

\[ R_T = R_1 + R_2 \]

\[ I_R = \text{RED LED CURRENT} \]

\[ I_G = \text{GREEN LED CURRENT} \]

<table>
<thead>
<tr>
<th>V</th>
<th>COLOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>RED</td>
</tr>
<tr>
<td>-</td>
<td>GREEN</td>
</tr>
<tr>
<td>AC</td>
<td>YELLOW</td>
</tr>
</tbody>
</table>

\[ R_T = \frac{+/-V-V_R}{I_R} \]

\[ R_1 = \frac{+/-V-(V_G+V_D)}{I_G} \]

\[ V_R = \text{RED LED FORWARD VOLTAGE (ABOUT 2V)} \]

\[ V_G = \text{GREEN LED FORWARD VOLTAGE (ABOUT 2V)} \]

\[ V_D = \text{D1 FORWARD VOLTAGE (0.6V)} \]

SAMPLE CALCULATION:

ASSUME +/-V = 5 VOLTS AND I_R & I_G = 20 MILLIAMPERES.

\[ R_T = \frac{5-2}{.02} = 150 \text{ OHMS} \]

\[ R_1 = \frac{5-(2+.6)}{.02} = 120 \text{ OHMS} \]

\[ R_2 = R_T - R_1 = 30 \text{ OHMS} \]

SELECT STANDARD RESISTANCE VALUES CLOSEST TO THESE.
HOW TO USE FLASHER LEDs

FLASHER LEDs INCLUDE IN THE LED PACKAGE A MINIATURE INTEGRATED CIRCUIT THAT CAUSES THE LED TO FLASH FROM 2 TO 6 TIMES EACH SECOND. CAN BE USED WITHOUT A SERIES RESISTOR.

BASIC LED FLASHERS

FLASH RATE DECREASES AS FORWARD VOLTAGE INCREASES.

USE THIS CIRCUIT WHEN VOLTAGE EXCEEDS SAFE VALUE. D1 IS A ZENER DIODE.

HOW TO DRIVE FLASHER LED FROM A TTL GATE. THIS WILL WORK WITH HIGH-OUTPUT CMOS.
DUAL LED FLASHER

When the supply voltage is 6 volts, the LEDs will flash alternately. The standard LED will remain on when the supply voltage falls below 6 volts.

POWER FLASHER

This circuit will permit a low-current LED flasher to switch a relay off and on. Use separate power supplies for reliable operation.

CAUTION: Do not use this circuit to flash line-powered lamps, do not exceed the current rating of the relay's contacts.
SINGLE LED FLASHER

NOTE THAT THIS CIRCUIT DRIVES THE LED EVEN THOUGH THE SUPPLY VOLTAGE IS LESS THAN THE LED FORWARD VOLTAGE (~1.7 V).

DUAL LED FLASHER

+3 TO +9 V

INCREASE C1 AND C2 TO SLOW FLASHING.
INCANDESCENT LAMP FLASHER

L1 IS A PR13 OR SIMILAR MINIATURE LAMP. L1 WILL FLASH 1-2 TIMES PER SECOND. IF L1 STAYS ON, Q2 WILL OVERHEAT AND BE DESTROYED.

NEON LAMP FLASHER

T1 - MINIATURE 6.3V: 120V OR 12.6V (CENTER TAP): 120V

CAUTION:
DO NOT TOUCH OUTPUT LEADS FROM T1!
LIGHT SENSORS

Many light sensors are available for optoelectronic projects. The most commonly used sensors include:

PHOTORESISTORS

The electrical resistance of a dark photoresistor is ordinarily very high, up to 1,000,000 ohms or more. The resistance may fall to as little as a few hundred ohms when the photoresistor is illuminated. The most common semiconductor used to make photoresistors is cadmium sulfide (CdS). It is primarily sensitive to green light. Photoreistors exhibit a "memory effect" in that they may require a second or more to return to their high-resistance state after a light source is removed. Though this slows their response time, they are very sensitive and easy to use.

SOLAR CELLS

Though solar cells are generally used in solar power supplies, they are also useful as detectors of visible light and near-infrared radiation. They are available in many different sizes and shapes. Since a typical solar cell responds to changes in light intensity within 20 microseconds, solar cells can detect voice modulated lightwave signals.
PHOTOTRANSISTORS

All transistors are light sensitive. Phototransistors are designed to exploit this phenomenon. Though a bipolar transistor has three leads, a phototransistor may not have a base lead. Most phototransistors are NPN devices with a base region much larger than that of a standard NPN transistor. They have a response time of 1 microsecond in some circuits. The Darlington phototransistor includes a second on-chip transistor to amplify the signal generated by the phototransistor. It gives more sensitivity but is slower.

SENSOR SPECTRAL RESPONSE

[Graph showing normalized response vs. wavelength (nanometers) for Cadmium Sulfide (CdS), Normal Human Eye, Typical Silicon Solar Cell, Typical Silicon Phototransistor.]

WAVELENGTH (NANOMETERS)

ULTRAVIOLET → BLUE → GREEN → RED → NEAR INFRARED →
HOW TO USE LIGHT DETECTORS

Light detectors can be operated in one or more of these modes:

1. PHOTOEPISTIVE - the resistance of the detector varies with the light level.

2. PHOTOVOLTAIC - the detector generates a current when illuminated.

3. PHOTOCOCONDUCTIVE - the detector allows current from an external power supply to flow in response to light.

PHOTOEPISTORS

Photoresistors are photoresistive detectors. They can often be substituted for fixed or variable resistors to make an existing circuit sensitive to light.

The variable resistance of a photoresistor can be changed to a variable voltage by means of a simple voltage divider circuit.

\[ V_{\text{out}} = V_{\text{in}} \left( \frac{R_2}{R_1 + R_2} \right) \]
SOLAR CELLS

SOLAR CELLS ARE PRIMARILY PHOTOVOLTAIC DEVICES, BUT THEY ARE SOMETIMES USED IN A PHOTOCONDUCTIVE MODE. USE THEM TO POWER A CIRCUIT OR SENSE LIGHT.

SOLAR CELLS MAY BE SUPPLIED WITH OR WITHOUT LEADS. THOUGH SOLAR CELLS ARE FRAGILE, IT IS RELATIVELY EASY TO SOLDER WIRE LEADS TO THEM. USE A LOW-WATTAGE SOLDERING IRON AND WRAPPING WIRE FOR BEST RESULTS. FIRST WARM THE ELECTRODE ON THE CELL FOR A FEW SECONDS. THEN MELT A SMALL PUDDLE OF SOLDER ONTO THE ELECTRODE. PLACE THE EXPOSED END OF A LENGTH OF WRAPPING WIRE IN THE SOLDER AND HOLD IT IN PLACE UNTIL THE SOLDER COOLS.

PHOTOTRANSISTORS

OPTIONAL BASE LEAD

THE SIMPLEST WAY TO USE A PHOTOTRANSISTOR IS TO CONNECT IT TO A SERIES RESISTOR. IT THEN FUNCTIONS AS A PHOTOCONDUCTIVE DETECTOR.

USE A LARGE VALUE (~100K TO 1M) FOR Rs TO GIVE HIGH SENSITIVITY. USE A SMALL VALUE (~10K) FOR FAST SIGNALS.
SIMPLE LIGHT METERS

THOUGH VERY SIMPLE, THESE LIGHT METER CIRCUITS ARE VERY SENSITIVE.

PHOTOSENSOR

R1 100K
OK TO TRY OTHER BATTERY VOLTAGES.
AVOID RAPID INCREASE IN LIGHT THAT MIGHT HARM THE METER!

*S Analog Multimeter

SOLAR CELL

R1 1K
TWO OR MORE SOLAR CELLS IN PARALLEL WILL GIVE HIGHER SENSITIVITY.

PHOTOTRANSISTOR

R1 1K
THE BASE-COLLECTOR JUNCTION OF Q1 FORMS A PHOTODIODE OR MINIATURE SOLAR CELL.

Q1 PHOTOTRANSISTOR

M1* 0-1 mA
ULTRA-SENSITIVE LIGHT METER

0.002 µF
10 MΩ
FULL SCALE READINGS (SWITCH S1)
1 - 100 mA
2 - 10 mA
3 - 1 mA
4 - 0.1 mA
5 - 0.01 mA

0.02 µF
1 MΩ

0.2 µF
100 kΩ

2.2 µF
10 kΩ

22 µF
1 kΩ

THIS CIRCUIT IS VERY SENSITIVE. ALWAYS SET SWITCH S1 TO POSITION 1 BEFORE THE CIRCUIT IS SWITCHED ON. CAREFULLY ADJUST R1 TO SET METER TO 0 WHEN THE SOLAR CELL IS TOTALLY DARK. YOU MAY HAVE TO ADJUST R2 TO PROPERLY ZERO THE METER.

KEEP BATTERY LEADS SHORT!

SOLAR CELL

-9 V

R1 5 kΩ

R2 10 kΩ

CAUTION: EXCESSIVE LIGHT WILL "SLAM" THE METER'S NEEDLE.

M1 0-1 mA METER

IF ULTRA-HIGH SENSITIVITY IS NOT REQUIRED, Omit the upper resistors and use the lower two or three.
SOLAR BATTERY CHARGER

AN ARRAY OF SOLAR CELLS WILL RECHARGE ONE OR MORE NICKEL-Cadmium (NiCd) STORAGE CELLS. FOR EXAMPLE, NINE SOLAR CELLS CONNECTED IN SERIES WILL CHARGE TWO NiCd CELLS CONNECTED IN SERIES:

D1
1N914

NiCd
STORAGE
CELLS (2)

D1 PREVENTS THE CELLS FROM DISCHARGING THROUGH THE SOLAR CELLS DURING TIMES OF DARKNESS.

A SINGLE SILICON SOLAR CELL PRODUCES AN OPEN-CIRCUIT POTENTIAL OF FROM 0.45 TO 0.5 VOLT. A SINGLE CELL CAN PRODUCE A CURRENT OF AN AMPERE OR MORE DEPENDING ON THE AREA OF THE CELL AND THE SUNLIGHT INTENSITY. IMPORTANT: THE SOLAR CELL CURRENT MUST NOT EXCEED THE SAFE CHARGING RATE OF THE NiCd CELLS. THE OUTPUT VOLTAGE OF CELLS IN SERIES IS THE SUM OF THE CELL VOLTAGES. SOLAR CELLS ARE FRAGILE. CONNECT THEM WITH WRAPPING WIRE. MOUNT WITH SILICONE SEALANT.
SOLAR-POWERED CIRCUITS

ULTRA-SIMPLE LIGHT RECEIVERS

These three receiver circuits require no source of power beyond the lightwave signal they receive. They will transform an audio-frequency modulated light beam directly into sound. They can be used to check infrared remote control transmitters and to receive voice or tone lightwave signals.

T1 is a miniature audio-output transformer. PRI - PRIMARY SEC - SECONDARY

This circuit has the loudest output.

SUN-POWERED OSCILLATOR
LIGHT-SENSITIVE OSCILLATORS

These simple circuits are sometimes called audible light probes. If the circuit is adjusted so the oscillation just ceases when the sensor is dark, the circuit will emit clicks in response to a candle flame up to 100 feet away.

TRANSISTOR

TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.
This circuit can easily be installed in a very small plastic enclosure.

PC - CDS PHOTOCELL (PHOTORESISTOR)

LM3909

TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

PC - CDS PHOTOCELL (PHOTORESISTOR)
555 (Basic Oscillator)

+9V

PC

R1 1K

C1 0.1μF

555

R2 220

Speaker

Tone frequency increases with light intensity.

Circuit below shows how to use piezo-buzzer output.

Increase C1 to reduce frequency.

555 (Voltage-Controlled Oscillator)

+9V

Two operating modes possible.

Piezo buzzer element

Red

Black

R1 10K

PC

R2 100K

R3 1K

C1 0.01μF

Tone frequency increases with light. Exchange R1 and photocell to reverse this operating mode.

Adjust base frequency via R2.
LIGHT-ACTIVATED RELAYS

PHOTOSENSOR

+9V

R1 1K

R2 4.7K

Cds PHOTORESISTOR

Q1 2N2222

ADJUST R1 TO CHANGE SENSITIVITY. PHOTORESISTORS HAVE SLOW RESPONSE, SO RELAY WILL REMAIN ACTUATED BRIEFLY AFTER LIGHT IS REMOVED.

RELAY 500 Ω
6-9 V

PHOTOTRANSISTOR

+9V

Q1 PHOTOTRANSISTOR

Q2 2N2222

ADJUST R1 TO CHANGE SENSITIVITY. THIS CIRCUIT Responds MUCH FASTER THAN THE ONE ABOVE.

RELAY 500 Ω
6-9 V

NOTE: USE LIGHT SHIELD AT DETECTOR OF BOTH CIRCUITS TO PREVENT FALSE TRIGGERING.
DARK-ACTIVATED RELAYS

PHOTO RESISTOR

Adjust R1 to change sensitivity. The relay will be actuated when the photoresistor is dark.

PHOTOTRANSISTOR

Adjust R1 to change sensitivity. When Q1 is dark, the relay is actuated. This circuit responds faster than the one above.
DARK-ACTIVATED LED FLASHERS
LM3909

PC

C1

22 μF

LM3909

B

6

LED

+1.5V

LED FLASHES WHEN PC IS DARK.

PC-CdS
PHOTOCELL
(PHOTORESISTOR)

Q1

C1

22 μF

LM3909

B

6

LED

+1.5V

LED FLASHES WHEN Q1 IS DARK.

Q1- PHOTOTRANSISTOR

FLASHER LED

R1

10K

Q1

2N2222

+5V

PC

FLASHER LED

Q1

PHOTO-TRANSISTOR

R1

47K

Q2

2N2222

+5V

Q1

PHOTO-TRANSISTOR
LIGHT/DARK ACTIVATED ALERTER

WHEN S1 IS AT POSITION L, THE PIEZO BUZZER IS ACTIVATED WHEN LIGHT STRIKES THE PC. WHEN S1 IS AT POSITION D, THE BUZZER IS ACTIVATED WHEN THE PC IS DARK.

THIS CIRCUIT AND THE ONE BELOW CAN BE USED TO DETECT OPEN CASH DRAWERS AND REFRIGERATOR DOORS.

PIEZO BUZZER

PC - CAS PHOTOCELL (PHOTOELECTRIC)

LIGHT-ACTIVATED TONE

PC - CAS PHOTOCELL (PHOTOELECTRIC)

R1* GIVES HIGH TONE FREQUENCY.

*OK TO OMIT R1.
LIGHTWAVE COMMUNICATIONS

It is relatively easy to transmit voice or signals by means of visible light or infrared radiation. The radiation can be sent directly through the air or channeled through an optical fiber. The information on these two pages will assist you in using the lightwave communication circuits that follow.

SUITABLE COMPONENTS

Small incandescent lamps can be used to send voice and audio-frequency signals. For best results, use high-power, near-infrared-emitting diodes. Suitable detectors include photodiodes, phototransistors, and solar cells.

OPTICAL FIBER LINKS

![Diagram of optical fiber link]

Use razor knife to cleave the fiber.

Infrared-emitting diode

LEDs and detectors installed in plastic receptacles like these simplify short-range fiber links. Alternatively, connect fiber directly to LEDs and detectors with epoxy and heat-shrinkable tubing. Phototransistor
FREE-SPACE LINKS

A pair of lenses will greatly increase the range. Use lenses from magnifying glass or order from science supply firm.

For best results shield detector from external light with hollow tube lined with black paper or coated with flat black paint. A piece of developed color film makes a good near-infrared filter.

Practice focusing an infrared LED by first using a red LED. Note that raw beam from clear encapsulated LED shows bright square (the chip) inside diffuse red halo. The halo is not eliminated by an external lens. Typical beam.

Focusing and aligning an infrared free-space link is tricky. Mount the transmitter on a tripod for best results. Doubling the diameter of the receiver lens will approximately double the maximum range. For more details, see “A Practical Introduction to Lightwave Communications” (Forrest Mims, SAMS, 1982).
LIGHTWAVE TONE TRANSMITTERS

Simple lightwave tone transmitters are very useful when testing lightwave receivers and as code and remote control transmitters. These circuits and the one on page 40 can be built in small plastic boxes.

555 TRANSMITTER

R1 controls pulse rate. Use infrared-emitting diode for best results. Duty cycle is about 50%.

LM3909 TRANSMITTER

+1.5 to 3V

Omit D1 if red LED used.

Use infrared-emitting diode for best results.
SIMPLE LIGHTWAVE RECEIVERS

CIRCUITS CAPABLE OF RECEIVING MODULATED LIGHTWAVE SIGNALS ARE EASY TO BUILD. THREE ADVANCED RECEIVERS ARE SHOWN ON THE FOLLOWING PAGES. HERE ARE TWO VERY SIMPLE RECEIVERS (ALSO SEE PAGE 25):

"INSTANT" LIGHTWAVE RECEIVER

CONNECT THE SOLAR CELL DIRECTLY TO THE INPUT JACK OF THE AMPLIFIER. THE SPEAKER MAY BE BUILT-IN OR EXTERNAL. THIS RECEIVER WILL DETECT TONE AND VOICE MODULATED SIGNALS.

TWO-TRANSISTOR RECEIVER

THIS CIRCUIT CAN BE BUILT INTO A SMALL PLASTIC BOX AND USED TO MONITOR LIGHTWAVE TONE OR VOICE TRANSMITTERS. TO USE AN 8 Ω SPEAKER, REPLACE BUZZER ELEMENT WITH PRIMARY OF 1K; 8 Ω AUDIO TRANSFORMER. CONNECT SPKR TO 8 Ω SIDE.
THE PHOTOPHONE

ON FEBRUARY 19, 1880, ALEXANDER GRAHAM BELL AND SUMNER TAINTNER, PROF. BELL'S LABORATORY ASSISTANT, BECAME THE FIRST PEOPLE TO TRANSMIT THEIR VOICES OVER A BEAM OF ELECTROMAGNETIC RADIATION. BELL CALLED HIS INVENTION THE PHOTOPHONE AND SAID IT WAS FUNDAMENTALLY A GREATER INVENTION THAN THE TELEPHONE. THE PHOTOPHONE IS EASILY DUPLICATED.

PHOTOPHONE TRANSMITTER

VOICE

TAPE

TIN CAN OR PAPER TUBE
(OPEN AT BOTH ENDS)

ALUMINUM FOIL OR ALUMINIZED MYLAR
(SHINY SIDE OUT)

THE ALUMINUM FOIL OR ALUMINIZED FILM SHOULD BE STRETCHED TIGHT OVER THE CAN OR TUBE AND HELD IN PLACE WITH TAPE OR A RUBBER BAND. BE SURE THE SHINY SIDE OF THE FOIL OR FILM FACES OUTWARD. TEST THE TRANSMITTER BY REFLECTING SUNLIGHT FROM IT TO A WALL SOME DISTANCE AWAY. THE REFLECTED SUNLIGHT SHOULD FORM A DISTINCT SPOT. IF NOT, THE FOIL OR FILM IS NOT TIGHT ENOUGH. FOR BEST RESULTS, MOUNT THE TRANSMITTER ON A PHOTOGRAPHER'S TRIPOD TO SIMPLIFY AIMING THE BEAM.
PHOTOPHONE RECEIVER

Bell's photophones used a selenium detector in series with a battery and telephone receiver.

This photophone receiver uses a silicon solar cell so no lens is necessary. To use a phototransistor, see page 39.

Caution: Both transmitter and receiver operators must wear dark sunglasses and avoid staring at reflected sunlight!

Solar cell

Use light shield

Important: The speaker may emit very loud sounds! Therefore do not place your ear close to the speaker.

OK to use any audio amplifier in place of this circuit.

C1 0.1μF

C2 prevents oscillation.

+9V

C2 0.1μF

R1 1M

R2 10K

R1 - gain control

R2 - volume control

8Ω SPKR

37
AM LIGHTWAVE TRANSMITTER

R1 - GAIN CONTROL
R6 - LED BIAS CONTROL. ADJUST R6 FOR BEST SOUND QUALITY.
R8 - LIMITS CURRENT APPLIED TO LED.

THE 741 AMPLIFIES VOICE SIGNALS FROM THE MICROPHONE AND COUPLES THEM THROUGH C2 TO MODULATOR TRANSISTOR Q1. USE A HIGH-BRIGHTNESS RED OR HIGH-POWER INFRARED LED FOR BEST RESULTS. FOR A FREE-SPACE RANGE OF UP TO 1,000 FEET (AT NIGHT), USE A LENS TO COLLIMATE THE LED BEAM. OR USE THIS CIRCUIT AS AN OPTICAL FIBER TRANSMITTER.
AM LIGHTWAVE RECEIVER

This receiver works best in subdued light or at night when used for free-space communications. Always place a shield over the detector if sunlight or bright artificial light is present. An infrared filter should be used for best results (developed color film works well) unless the transmitter LED emits visible light.

Caution: This circuit can produce loud sounds. Do not place speaker close to your ear.

Circuit Diagram:

- R1 100K
- C1 0.1μF
- Q1 Phototransistor
- Lens
- 741 Op Amp
- R2 100K
- R3 10K
- R2-Gain Control
- R3-Volume Control
- C2 0.1μF
- C2 Prevents oscillation. Keep leads to battery short.
- +9V
- C3 100μF
- 8Ω Speaker
BREAK-BEAM DETECTION SYSTEM

TRANSMITTER

This simple circuit generates a stream of powerful, near-infrared pulses.

\[ \begin{align*}
R_1 & = 22\text{K} \\
R_2 & = 2.2\text{M} \\
C_1 & = 0.02\mu\text{F} \\
Q_1 & = 2N2907 \\
Q_2 & = 2N2222
\end{align*} \]

Output Pulse

C1: OK to use two 0.01\mu F capacitors in parallel.

This system is a very sensitive break-beam detector. It can be used to detect objects or people that interrupt the transmitter beam. The transmitter generates \( \approx 240 \) pulses per second, each 400\mu s in duration with an amplitude of 400 mA. The receiver detects the near infrared from the transmitter by means of phototransistor Q1. The photocurrent from Q1 is amplified and then sent to a threshold comparator. The 555 forms a missing pulse detector that actuates the relay and lights the LED when the infrared beam is interrupted. Range without lenses is at least several feet. Use lenses for much greater range.
RECEIVER

SHIELD Q1 TO ELIMINATE AMBIENT LIGHT. ADJUST R3 TO SET THRESHOLD. ADJUST R5 TO ACHIEVE OPTIMUM RELAY OPERATION. ALWAYS TEST CIRCUIT IN SUBDUED LIGHT TO AVOID FALSE TRIGGERING.

OK TO USE TWO 741'S IN PLACE OF 1458.

FOR MORE RANGE, USE A LENS AT Q1.

IMPORTANT:
BATTERY MUST BE FRESH. IF CIRCUIT OperATES ERRATICALLY, CONNECT RELAY LEAD AT ARROW TO SEPARATE +9V SUPPLY.
OPTOELECTRONIC LOGIC

These circuits can be used independently, in conjunction with optoisolators, or as optoelectronic computing elements.

BUFFERS ("YES" CIRCUITS)

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

INVERTERS ("NOT" CIRCUITS)
AND CIRCUITS

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

R1 47

Cds CELLS

LED

OUT

PHOTO-TRANSISTORS

R1 220

OR CIRCUITS

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

R1 220

Cds CELLS

PHOTO-TRANSISTORS

43
SOURCE/SENSOR PAIRS

Source/sensor pairs are also called opto-isolators, optocouplers, photo-isolated couplers, and photon isolators. They have many important applications in electronics. They are particularly important at providing electrical isolation between two separate circuits. Many source-sensor combinations can be used:

- LED ➔ Phototransistor or photodiode
- LED ➔ Light-activated SCR or TRIAC
- Tungsten lamp ➔ Photoresistor
- Neon lamp ➔ Photoresistor

CLOSED PAIR

![Diagram of a closed pair](image)

**Applications:**
- Solid-state relay
- Electrical isolation
- Level conversion

TRANSMISSION/SLOT PAIR

![Diagram of a transmission/slot pair](image)

**Applications:**
- Object detection
- Limit switch
- Bounce-free switch
- Opto-potentiometer
- Vibration detector

REFLECTIVE PAIR

![Diagram of a reflective pair](image)

**Applications:**
- Object detection
- Limit switch
- Reflectance monitor
- Tachometer
- End-of-tape detector
- Movement detector

---

44
INTEGRATED SOURCE/SENSORS

Many kinds of source/sensor pairs are available in miniature integrated circuit packages. Here are two typical examples:

LED/PHOTOTRANSISTOR

LED/LIGHT-ACTIVATED TRIAC

DO-IT-YOURSELF SOURCE/SENSORS

Source/sensor pairs can be easily made from individual components. For example, here is a simple LED-phototransistor pair:

HEAT-SHRINK TUBING

LED

PHOTOTRANSISTOR

The source and sensor can be installed in wood or plastic stock. Here are two of many possibilities:

W O O D D O W E L

FORM HOLES WITH DRILL.

FORM SLOT HERE FOR TRANSMISSION SENSOR

W O O D O R P L A S T I C

REFLECTION SENSOR
DEMONSTRATION SOURCE/SENSOR

THIS CIRCUIT WILL HELP YOU UNDERSTAND BASICS OF OPTO-ISOLATION.

LED 2: RED = LED1: HIGH OUTPUT RED

ADJUST R1 UNTIL LED1 FLASHES 1-2 TIMES PER SECOND. LED 2 WILL SWITCH OFF WHEN LED1 SWITCHES ON.

OPTOCOUPLER RELAY DRIVER

THIS CIRCUIT ILLUSTRATES ISOLATION AND LEVEL SHIFTING.

RELAY IS PULLED IN WHEN INPUT IS LOW.

USE HIGH-OUTPUT INFRARED OR RED LED FOR BEST RESULTS. IF NECESSARY, REDUCE R1 TO 270 Ω FOR HIGHER OUTPUT.

RELAY 500 Ω 6-9 V
BASIC ISOLATORS / LEVEL SHIFTERS

TTL→TTL ISOLATOR

Vcc1 = +5 V
Vcc2 = +5 V

R1 = 1K
R2 = 4.7K

TTL→CMOS COUPLER / ISOLATOR

Vcc1 = +5 V
Vdd1 = +5 to +15 V

R1 = 220 to 1K
R2 = 4.7K
R3 = 1K (TYPICAL)
THE BOOSTER TRANSISTOR (Q1) IN THESE CIRCUITS PROVIDES MORE POWER-HANGLING CAPABILITY THAN THE PHOTOTRANSISTORS IN MOST COMMERCIAL OPTOCOUPLECTS. R3 CAN BE REPLACED BY A LOAD SUCH AS A RELAY.