

The Alarm, Sensor & Security Circuit Cookbook

Thomas Petruzzellis

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Contents

Acknowledgments	<i>ix</i>
Introduction	<i>xi</i>
❖ 1 Sensors and detection circuits	1
High-gain amplifier	1
Touch switch	5
Static-electricity detector	7
Electroscope	8
Light/dark switch	9
Temperature sensors	13
Hall-effect metal/ magnetic sensors	19
ac-magnetic field detector	25
Bridge sensors	27
Maxwell bridge	31
Pyroelectric detector	33
Pressure sensor	36
Toxic-gas sensor	40
Humidity sensor	42
Fiberoptic sensing	44
Optical rotary encoder	47
Film strip position sensor	50
Tiltmeter	52
Earth-movement sensor	59
❖ 2 New film sensor technology	63
Piezo film sensors	63
Force and position-sensing resistor	72

❖ 3	New sensors, ICs, and gas-sensing technology	79
	Piezo accelerometer	79
	Optical transceiver	81
	Proximity detector	83
	Smoke detector	85
	Fluid detector	87
	Over/under current detector	89
	Tachometer/speed detector	91
	Position-sensitive detector	94
	Twilight sensor	97
	Multiplexed Hall-effect sensor	98
	Videophone	103
	Gas-sensing technology	105
❖ 4	Computer interfacing	125
	Joystick interfaces	125
	Serial interface	127
	Mouse and trackball interface	128
	Analog-to-digital interface	129
❖ 5	Describing and surveying alarm systems	133
	Window foil	133
	Magnetic switches	134
	Holdup switch	135
	Sensor mats	136
	Motion sensors	136
	Smoke and fire sensors	145
	Cameras	147
❖ 6	Alarm-system design philosophy	151
	Doors, keys, and locks	151
	Designing your alarm	153
	Installation and wiring tips	154
	Alarm history	156
	High-tech control boxes	159
	Sirens, strobe lights, and phone dialers	160
	Wireless alarm systems	160
	Fire reporting	162
	Digital telephone dialers	163
	Lighting for crime prevention	164
	Detecting bugs	166

❖ 7 Alarm circuits and systems	169
Basic latching alarm	169
Remote sensing	171
Window/door alarm	173
Alarm system with location display	175
Multipurpose alarm	178
Auto burglar alarm	181
Bar-graph auto voltmeter	183
Auto immobilizer	184
Digital antitheft auto lock	186
Power-line fault detector	188
Automatic emergency-lighting system	190
Adjustable-rate siren	191
Alarm strobe flasher	193
Telephone line monitor	195
Automatic telephone recorder	196
rf sniffer	198
Home guard	201
Optical motion detector	205
Capacitive proximity sensor	207
Microwave motion detector	209
Carrier-current control systems	211
Ultrasonic-sensor system	217
High-performance alarm	220
❖ 8 Unique, high-tech security projects	223
Piezo vibration alarm	223
Camp alarm	226
Pyroelectric sensor	230
Chimney alarm	235
DTMF alarm system	240
Portable alarm	247
Storm warn	258
Video sentry	264
Appendix Suppliers	275
Index	279

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Introduction

MOST PHYSICAL PHENOMENA CAN BE DETECTED BY SENSORS, monitored by amplifiers and trigger circuits, and then presented by meters, bells, sirens, chart recorders, or personal computers. Measurement and protection systems utilize sensors and detectors that can be used to detect light, temperature, pressure, speed, vibration, proximity, infrared, metal/magnetism, acceleration, and toxic gases.

One of the aims of this book is to present the many types of sensors that can be used in measurement and protection circuits in a “cookbook” of ideas and circuits that can be called upon when a particular problem or application arises. This book should appeal to engineers, technicians, alarm installers, and hobbyists.

Many new ideas and integrated circuits are introduced, so you can become familiar with the latest sensors, detection circuits, and integrated circuits available. The scope of this book includes both sensing and measurement devices, as well as stand-alone alarm circuits. Many of the sensors shown can be wired together to form more complex protection or alarm circuits.

The first chapter begins with the high-gain amplifier and how it can be used in a multitude of sleuthing applications, including detecting light, sound, motion, radiation, magnetism, and rf energy. You might not have realized just how many phenomena can be sensed with the lowly amplifier. Following the high-gain amplifier, many types of sensors are shown, such as a static-electricity detector, light and heat detectors, temperature sensors, and metal and magnetic sensors. The measurement-bridge circuit is described next and it is shown in a variety of different configurations. An ac Maxwell bridge follows. It can

measure unknown capacitance or inductance. It is shown as an automobile metal sensor, which can detect cars passing over a driveway. Hall-effect sensors are presented next; and they can detect metal, magnetism, speed, pressure, and current flow. The next detectors include a pyroelectric or infrared body-heat sensor, pressure sensors, a toxic-gas detector, optical encoders, and tiltmeters.

Chapter 2 presents the revolutionary piezoelectric film. This new material can be used in a spectacular array of sensing applications. The piezo film is now used in many types of sensors including vibration switches, magnetic switches, infrared sensors, fluid sensors, microphones, hydrophones and accelerometers, and the list is growing. We will suggest how you may obtain a sample of this amazing material. Chapter 2 also introduces the new force-sensing resistance sensors.

Chapter 3 introduces a number of new integrated circuits that can be used to build low-cost, minimum-component sensing systems, such as a proximity sensor, speed detector, smoke detector, and precision position detector. We also present a new video transceiver chip, which can be configured into a high-resolution videophone or the unique video sentry described in Chapter 8. Chapter 3 also discusses gas sensors and recent trends in gas-sensing technology.

Chapter 4 is devoted to computer interfacing. A number of low-cost methods are described to help you interface sensing and measurement circuits to the personal computer so you can collect, store, and display your measurement data.

Chapter 5 surveys some of the most often used alarm-system sensors. An overall view of each sensor is presented, and strengths and weaknesses are discussed. Recommendations are made for the most suitable use for each device.

Chapter 6 is a short course on the philosophy of alarm-system design. Useful tips are discussed, as well as the pitfalls of alarm systems. Thoughts on how burglars think and how to outsmart the common thief are presented.

Chapter 7 includes diagrams of alarm systems that can protect your home or office. Shown first is the basic latching alarm, which is the heart of most alarm systems. Next, is a remote sensing system that can be used to take measurements of light, temperature, and speed and send the data over a wire or radio-frequency (rf) link to a remote monitoring site. A low-cost window/door alarm is shown, which can be configured to protect most doors and windows. Next is a unique security system

that displays each alarm location and status. It can call the local police department. Next is a multipurpose, dual-channel alarm system that can monitor both fire and alarm conditions. Last, a number of circuits, including low-cost automobile alarms, emergency lighting, strobes, sirens, phone circuits, and motion sensors are presented.

In the last chapter, a number of novel, high-tech detection and alarm projects are covered. Each circuit includes a circuit board layout to aid in constructing the particular project. The first circuit is a sensitive piezoelectric vibration sensor, which can be implemented as a complete stand-alone travel alarm or wired with other sensors for a more complex alarm system. The next project is a self-contained camping alarm system, followed by a pyroelectric infrared body-heat detector. The pyroelectric sensor is one of the most sensitive and trouble-free detectors available. It can sense humans or large animals up to 50 feet away.

A unique high-chimney alarm is the next project. The chimney alarm senses an overheating chimney, triggers the alarm, calls the fire department, and extinguishes the chimney fire, all simultaneously. The tone-identification alarm is a useful project that identifies a particular location which has been activated by sending a Touch Tone signal from one of the trigger modules to the decoder/display unit. The beauty of this system is that it can be used over either a hard-wire or rf link.

The portable alarm is one of my favorite projects. It is a wireless infrared system that alerts your friends or neighbors when an intruder has entered your home or cabin. A pyroelectric sensor that can detect humans up to 50 feet is used to trigger a transmitter that sends an alerting tone to an FM receiver or scanner for 20 seconds. After the 20-second time period, a sensitive microphone is connected to the transmitter, allowing your neighbor or friend to "listen in" to your home for up to five minutes, at which time the system resets. During this five-minute period, your neighbor could investigate or call the police, if necessary.

Next is the storm-warn project. It can disconnect computers or antennas during an electrical storm.

The last project is the video sentry, a sophisticated audio/video security/surveillance system that permits you to monitor both audio and video from a distant location where the video sentry is installed, using the public telephone network. You can monitor your office while you are away or keep tabs on your babysitter or old folks as well. This modern-day infinity trans-

mitter operates over any geographic distance and it is simple to operate. Simply dial the phone number where the video sentry was installed, press a Touch Tone function key on your phone, and the video sentry at the remote location will instantly and automatically answer the phone line without even ringing the phone. The video sentry also allows you to control remotely a number of devices such as bells, sirens, tape recorders, lamps, and home appliances. The video sentry is possible because of a new videophone chip, which sends high-resolution still pictures over a twisted pair in less than 12 seconds. The PMC videophone chip produces the best picture of any videophone offered to date.

Sensors and detection circuits

SENSORS ARE THE WINDOWS TO THE WORLD! THE HUMAN SENSES are limited to a narrow range of audio and video frequencies. For us to detect the broad range of physical phenomena all around us, we often rely on the magic of electronics. Electronic sensors provide us with the means to augment the human senses to detect pressure, motion, radiation, infrared, gases, etc.

High-gain amplifier

A simple but highly effective means to sense or monitor physical phenomena can be accomplished by using a high-gain amplifier, as shown in Figs. 1-1 and 1-2. You can easily become a real sleuth using the sensitive amplifier. This lowly device can monitor all sorts of things. Everyone is aware that connecting a microphone to an amplifier permits you to listen to nearby sounds and placing a microphone at the focus point of a parabola allows you to hear distant sounds. But did you know you could connect a small crystal earphone to the input of a high-gain amplifier and by epoxying the earphone to a nail pounded halfway through a wall you would have an extremely powerful listening device, one that could listen through walls?

Have you ever thought about connecting a ceramic phono cartridge to a high-gain amplifier? You can epoxy an 8 to 10 inch brass rod to a phono cartridge to create a vibration monitor, which you could use to listen for a bad bearing in a motor. Try winding a small 100-turn coil of 28-gauge enameled wire around a ferrite or iron core. Connect the coil to your high-gain amplifier and you can “listen in” to ac wiring inside walls to help locate hidden wiring (see Fig. 1-3). If you placed the same coil near a telephone,

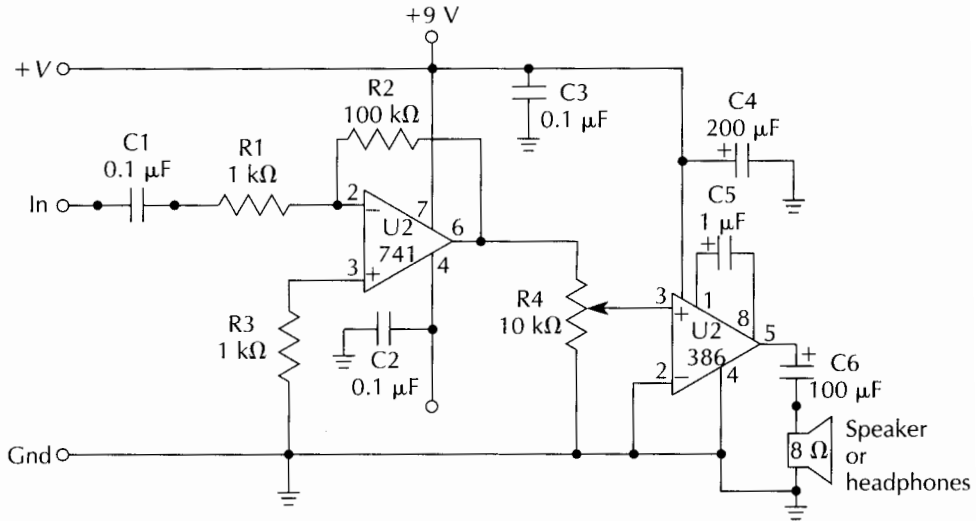


Fig. 1-1 High-gain amplifier.

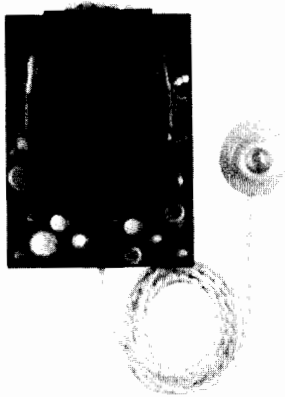


Fig. 1-2 Microphone and high-gain amplifier.

you would have a telephone amplifier that would amplify a long-distance phone call or perhaps provide a remote ringer in another room. If you placed a magnet at a 30 to 40° angle as shown in Fig. 1-4, you could listen for hidden nails in a plaster wall.

Listening to nature's sounds can be accomplished quite easily by connecting six to eight turns of 26-gauge wire wound on a 3 × 5-foot loop placed outside. You can listen to a "dawn chorus" or lightning flashes, atmospheric whistlers, even auroras. The basic high-gain amplifier can also be used to detect radio frequency (rf) energy from radio or television transmitters, so you

Fig. 1-3 Telephone listening coil.

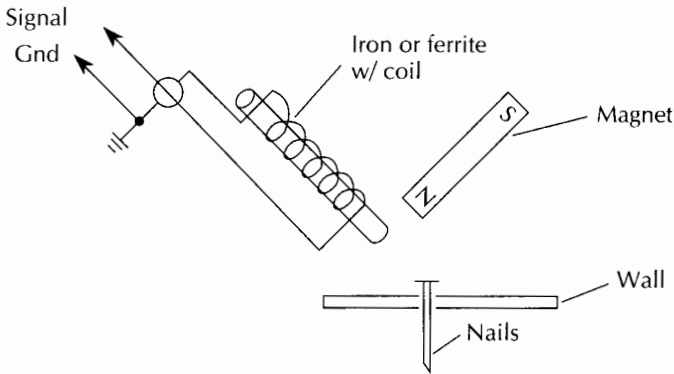
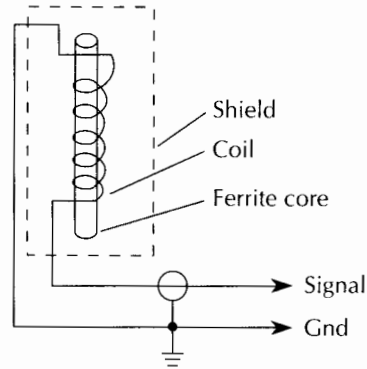


Fig. 1-4 Metal detector.

now have a “bug” detector or a field-strength meter. Connect a single loop coil antenna to a high-frequency diode to the input of your high-gain amplifier. As shown in Fig. 1-5, you can sniff rf energy. By connecting a hydrophone (a ceramic underwater microphone) to the high-gain amplifier, you can construct a fish finder, a pool splash detector, or a marine engine detector.

If you connect a solar cell as a sensor to the high-gain amplifier as shown in Fig. 1-6, you can use the silicon solar cell to sense the speed of a propeller or any rotating object by shining a light on the rotating object and placing the solar cell in view of the rotating object. A solar-cell detector can be used to detect lights in the night sky by placing a telescope or lens in front of the solar cell. You can also “listen” to airplane strobe lights or perhaps you could construct a moonlight detector to steer your telescope.

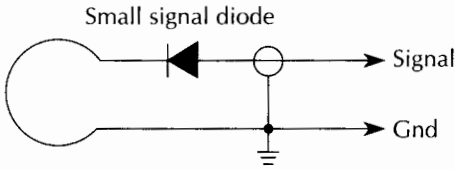


Fig. 1-5 rf detector.

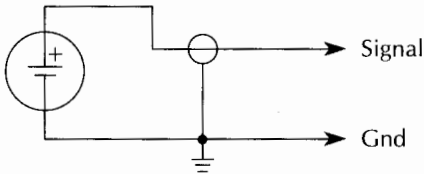


Fig. 1-6 Light detector.

You can even measure radiation with the aid of a high-gain amplifier. One of the most sensitive forms of radiation detectors is the scintillator. When radiation strikes a crystal, it scintillates, emitting a small amount of light. That light can be detected by a silicon solar cell, as shown in Fig. 1-7. A simple detector can be constructed by using two microscope slides, a solar cell, and some zinc sulfide, which is easily obtainable. Mix the zinc sulfide into a slurry, using ordinary tap water. Then place the slurry on one of the microscope slides. When the slide is dry, place the other slide over the coating and tape the two slides together at the edges. Then position the scintillator in front of the silicon solar cell and place the detector in a dark enclosure. Allow 10 minutes to recover from the ambient light. This detector arrangement allows you to detect gamma rays by listening to clicks in a headphone connected to your high-gain amplifier.

The next time you need to sniff out a problem, don't forget your trusty friend, the high-gain amplifier.

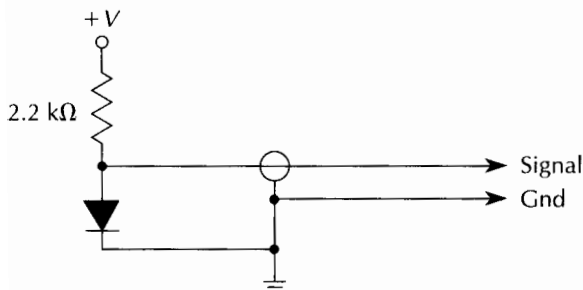


Fig. 1-7 Radiation detector.

High-gain amplifier parts list

Quantity	Part	Description
2	R1, R3	1-k Ω , 1/4-W resistor
1	R2	100-k Ω , 1/4-W resistor
1	R4	10-k Ω potentiometer, 1/2W
3	C1, C2, C3	0.1- μ F, 25-V capacitor
1	C5	1- μ F, 25-V capacitor
1	C6	100- μ F, 25-V electrolytic capacitor
1	C4	200- μ F, 25-V electrolytic capacitor
1	U1	UA741 op amp
1	U2	LM386 audio amplifier
1	SP	8- Ω speaker

Touch switch

A touch switch is a useful circuit that can be used to detect humans or protect small objects, such as antiques. It can be used to turn on a lamp or as an annunciator to sound a buzzer when someone comes near a door or table. The touch switch, or capacity switch, can also be used to start a moving display sign. A touch switch is shown in Fig. 1-8, and it can be activated by touching a small metal plate connected to pin 2 of the 555 timer chip. Once triggered, the load remains on until reset. A low logic level applied to pin 4 resets the circuit. The output is on pin 3, which is used to drive an LED.

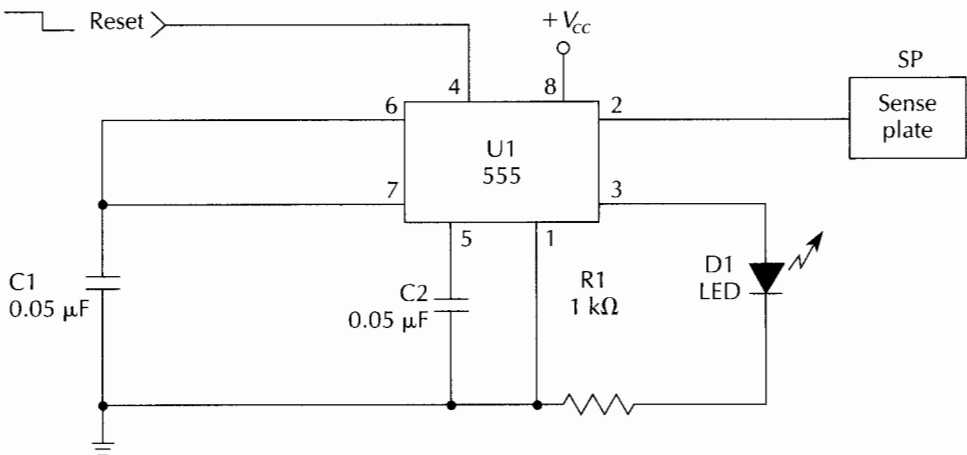


Fig. 1-8 Touch switch—manual reset.

Another variation of the touch switch is depicted in Fig. 1-9. This touch switch also uses the ubiquitous 555 chip. The circuit is configured as a monostable multivibrator. The load remains on for a time period determined by the R1/C1 combination. After the time period elapses, the circuit turns off until triggered again. The sense plate is connected to a capacitor placed in series with pin 2 of the IC timer to increase the charge accumulation.

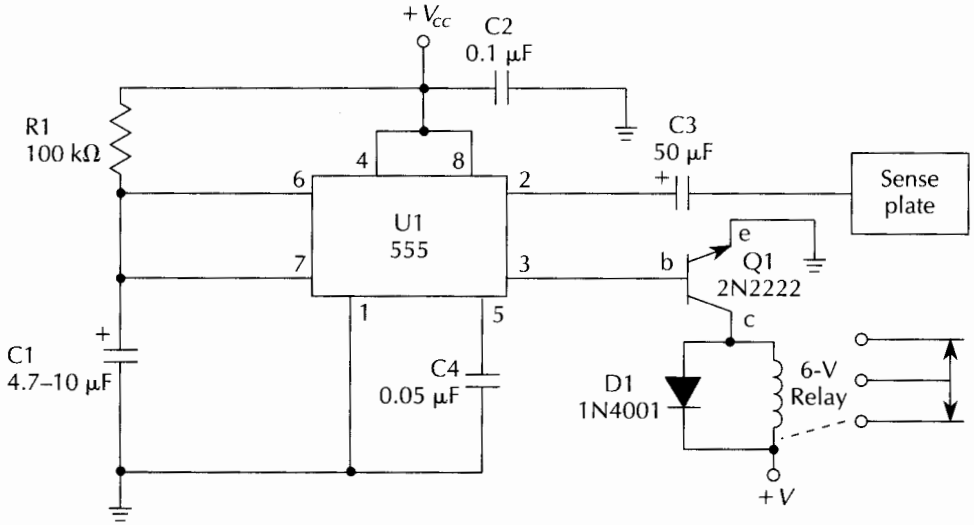


Fig. 1-9 Touch switch.

The touch switch relies on the “stray capacitance effect” of a human body from the sense plate to a lower potential, i.e., ground. By completing a path to ground through the human body, the switch magically appears to turn on a light or external load. Always power your touch switch either with batteries or with a power supply that uses a transformer to ensure you are not in the direct path to a 110- V_{ac} line.

Touch switch with manual reset parts list

Quantity	Part	Description
1	R1	1-k Ω , ¼-W resistor
2	C1, C2	0.5- μ F, 25-V capacitor (disk)
1	D1	Red LED
1	U1	555 timer IC
1	S1	Sense-plate copper circuit board

Touch switch parts list

Quantity	Part	Description
1	R1	100-k Ω , ¼-W resistor
1	C1	4.7–10- μ F, 25-V electrolytic capacitor
1	C2	0.1- μ F, 25-V capacitor
1	C4	0.05- μ F, 25-V capacitor (disk)
1	C3	50- μ F, 25-V electrolytic capacitor
1	D1	1N4001 silicon diode
1	Q1	2N2222 pnp transistor
1	U1	555 IC timer
1	Ry-1	6-V SPST relay
1	S1	Sense-plate copper circuit board

Static-electricity detector

The static-electricity detector shown in Fig. 1-10 is a simple tester designed to detect nearby static-electricity fields. You can easily demonstrate a static field by walking across a carpet and then touching the sensor probe. When the detector is placed next to a television screen or computer monitor, it is activated by the high voltage that accelerates electrons in the picture tube. A cellophane tape roll also generates a static charge. Place the probe wire near where the tape comes off the roll. Then pull the tape through the dispenser and the meter will move.

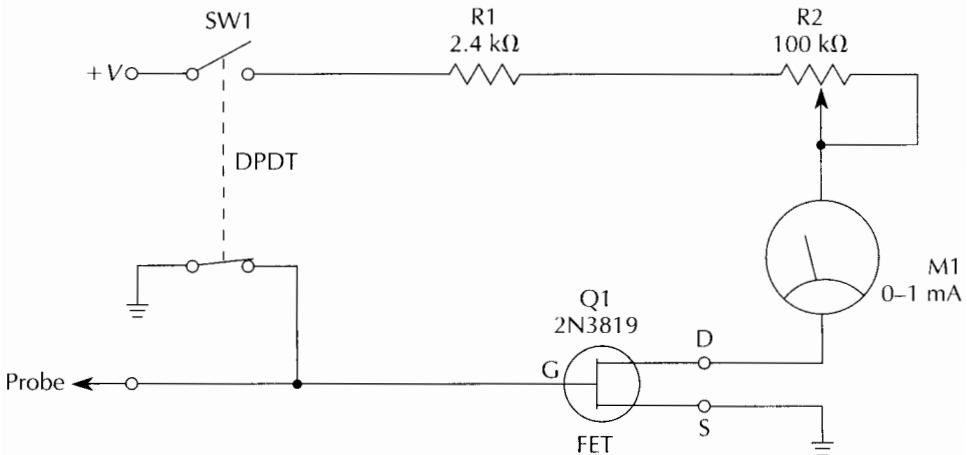


Fig. 1-10 Static-electricity detector.

A 2N3819 field-effect transistor is used as the static field sensor. A shore wire or small telescoping radio antenna is connected to the gate of the FET. The source lead is connected to ground and the drain lead is connected to a 0–1-mA meter. The remaining meter lead is coupled to a 3.3-k Ω resistor, which is fed to the positive post of a 9-V transistor-radio battery. Note that the FET can be easily damaged with a high static field while it is being handled. The FET leads should be shorted together as it is soldered in place and a grounded soldering pencil should be used. A grounded wrist band is also recommended. The static sensor would make a great addition to any static-electricity science-fair project, or could be a handy sensor on your test bench.

Static-electricity detector parts list

Quantity	Part	Description
1	R1	2.4-k Ω , ¼-W resistor
1	R2	100-k Ω , ¼-W resistor
1	Q1	2N3819 FET
1	M	0–1-mA meter
1	SW-1	DPST toggle switch
1	ANT	Whip antenna or wire

Electroscope

The electroscope pictured in Fig. 1-11 can be used to display static energy charges from sources such as TV sets, electrostatic generators, carpet cruising, and hair combing. The electroscope is the sophisticated cousin of the static-electricity detector shown in Fig. 1-9. The electroscope would make an excellent science-fair project or addition to your electronics bench.

The heart of the electroscope circuit is the two FETs, Q1 and Q2, connected in a balanced bridge configuration. The gate of Q1 is connected to the wire pick-up antenna via a 1.5- Ω resistor, and the gate of Q2 is tied to the circuit's common ground through the other 1.5- Ω resistor. This type of bridge circuit offers excellent temperature stability. Q1 operates in an open-gate configuration. The 500- Ω potentiometer balances the null bridge circuit. The 5-k Ω potentiometer and capacitors C1 and C2 help reduce stray 60-Hz pickup and increase the stability of the circuit. The 1-mA meter connected between the drain pins of Q1 and Q2 indicates an electrostatic field. The electroscope requires little current consumption, and therefore, it can be operated from a 9-V transistor-radio battery.

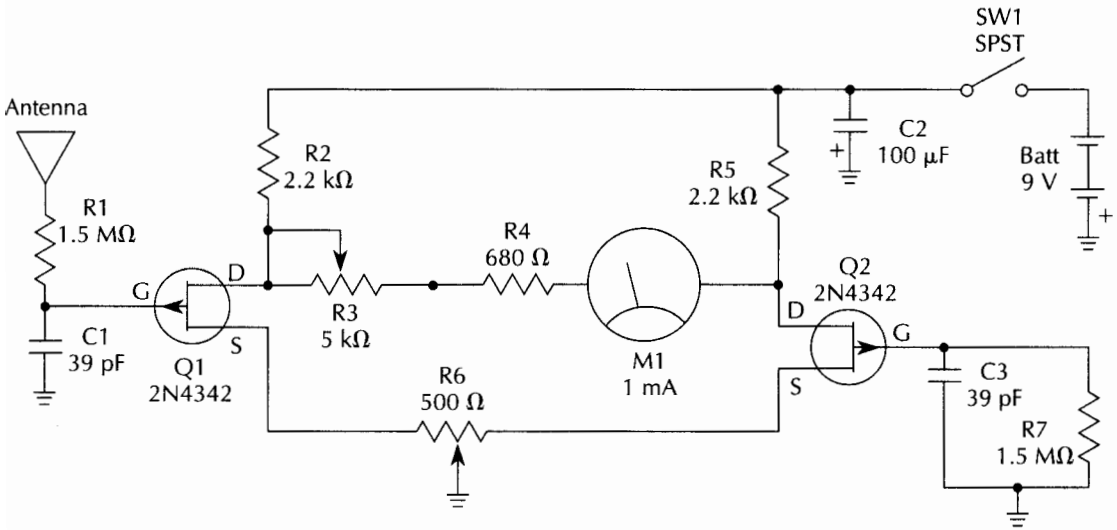


Fig. 1-11 Electroscope.

Electroscope parts list

Quantity	Part	Description
2	R1, R7	1.5- Ω , ¼-W resistor
2	R2, R5	2.2-k Ω , ¼-W resistor
1	R3	5-k Ω , ¼–12-Watt potentiometer
1	R4	680- Ω , ¼-W resistor
1	R6	500- Ω , ¼-Watt potentiometer
2	C1, C3	39-pF, 25-V capacitor
1	C2	100- μ F, 25-V electrolytic capacitor
2	Q1, Q2	2N4342 FET
1	M	0–1-mA panel meter
1	SW-1	SPST toggle switch
1	ANT	Telescoping whip antenna
1	BATT	9-V transistor-radio battery

Light/dark switch

The light/dark switch can be used in many sensing or alarm circuits. The light/dark switch shown in Fig. 1-12 can detect an intruder passing through a light beam or a person moving through a normal ambient-light room by keeping the lighting constant. The light/dark detector can also be used as an annunciator to inform you of an approaching customer in a retail store. The circuit can

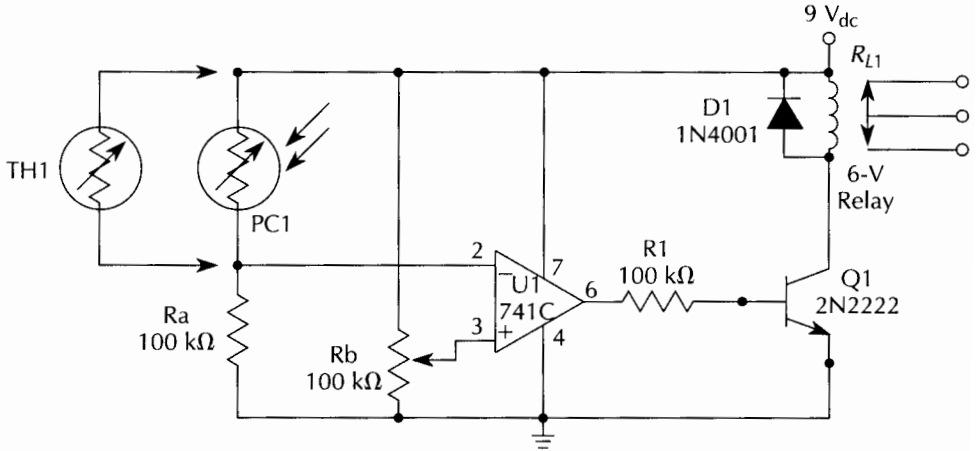


Fig. 1-12 Light/dark detector.

also detect your automobile headlamps as you approach your home and turn on your home's lights. The light/dark sensor can wake you at dawn or start your coffee pot in the morning. You can use the light/dark sensor as the heart of a laser tag game for your children. Various types of light sensors are shown in Fig. 1-13.

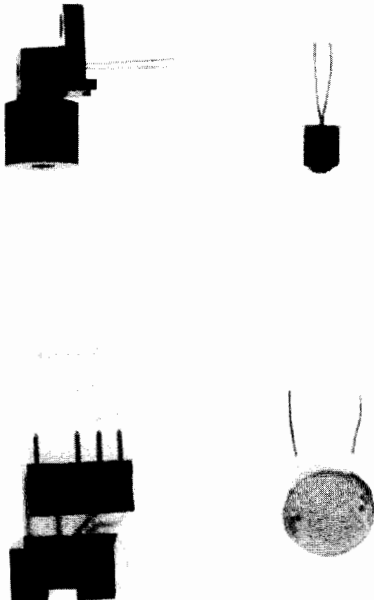


Fig. 1-13 Light detectors.

The light/dark switch uses an LM741 op amp as a comparator. You can substitute an LM339 or any general purpose op-amp pin in this design. The adjustable-threshold detector is controlled by Rb, a 100-k Ω potentiometer. Rb sets the threshold value between the voltage divider of PC1 and Ra, a 100-k Ω resistor. When the light intensity at PC1 is increased, its resistance decreases. This increases the voltage on pin 2 on the op amp's inverting-input pin. When the reference voltage at pin 3 has been exceeded by the input voltage on pin 2, the comparator will present an output on pin 6. The output drives Q1, a 2N2222 transistor, which can be used to drive a small relay. To make your detector more efficient, consider using a black plastic or cardboard tube with the sensor mounted at one end of the tube (see Fig. 1-14). The tube reduces the field of view and helps to prevent unwanted ambient light from reaching the detector. To use the sensor with ambient light as the input source, use a small light tube. To create a "beam type detector" system, use a long light tube. To construct a long-range detector, place a lens in front of the detector inside the light tube. The focal distance is determined by the lens you select. The same light/dark sensor circuit can also sense temperature by using a negative-temperature coefficient thermistor. A room-temperature resistance of 20–50 k Ω is needed for the thermistor. The accuracy of your temperature switch is determined by your selection of components and the method of calibration.

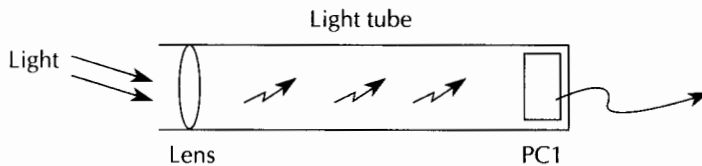


Fig. 1-14 Light tube.

A light-detector circuit that detects specific levels of light is shown in Fig. 1-15. When the light level goes above or below the desired set values, the window comparator circuit activates a low-current relay, which can be connected to an alarm buzzer. The window comparator circuit uses two sections of an LM339 op amp to act as a specific-level light detector. R1 and R3 are the high/low-value potentiometers. The op-amp outputs are wired

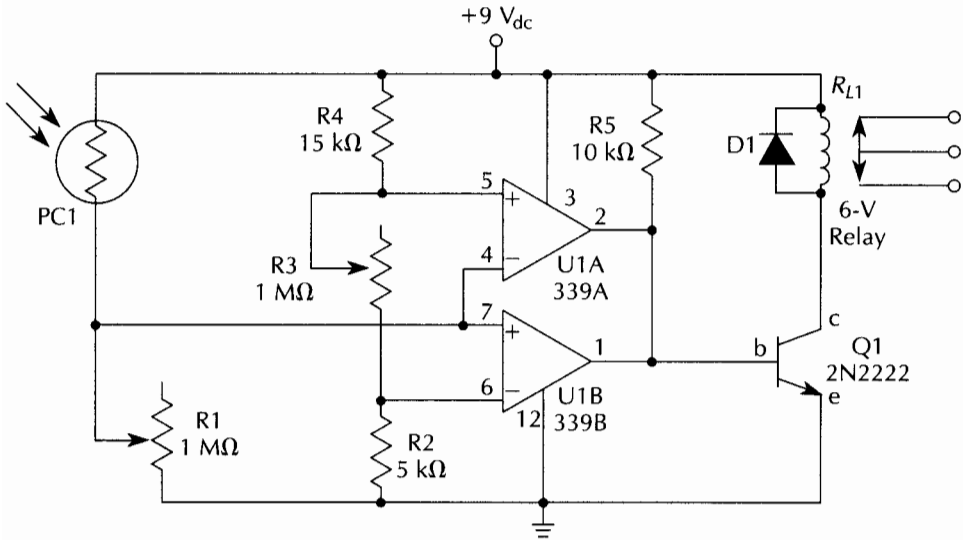


Fig. 1-15 Light-level detector.

together and drive a 2N2222 transistor, which can drive a low-current relay. The comparator circuit can be powered by a 9 to 12-V power source or a common 9-V battery, if desired. Simply adjust R1 and R3 to the set-point values so that the relay pulls in when the light level at PC1 is above or below the desired value.

Light/dark detector parts list

Quantity	Part	Description
1	TH1	Thermistor
1	PC1	Cadmium photoresistive cell
3	RA, RB, R1	100-kΩ, ¼-W resistor
1	D1	1N4001 silicon diode
1	Q1	2N2222 pnp transistor
1	U1	UA741C op amp
1	RY-1	6-V SPST relay

Light-level detector parts list

Quantity	Part	Description
2	R1, R3	1-MΩ potentiometer (trim)
1	R2	5-kΩ, ¼-W resistor
1	R5	10-kΩ, ¼-W resistor
1	R4	15-kΩ, ¼-W resistor

1	PC1	Cadmium photoresistive cell
1	D1	1N4001 silicon diode
1	Q1	2N2222 pnp transistor
1	U1	LM339A comparator IC
1	RY-1	6-V SPST relay

Temperature sensors

The need to measure temperature often arises and temperature sensing has become easy with many new precision temperature sensors. Figures 1-16 and 1-17 illustrate a number of thermistors and thermocouples. The LM34 is a precision Fahrenheit temperature-sensing IC and the LM35 is a precision centigrade temperature sensor. Both sensors require no external calibration and have accuracies of better than $\pm 1.2^\circ$ at room temperature. The LM34/35 draws only $70 \mu\text{A}$ and has a low output impedance. Both sensors operate from 5 to $30 V_{\text{dc}}$.

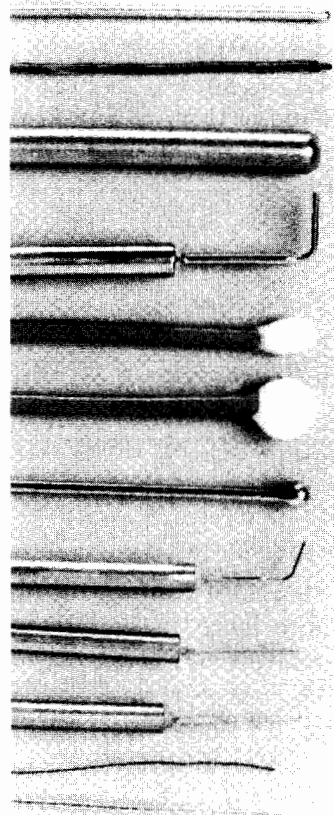


Fig. 1-16 Thermistors.

good thermal-transfer characteristics to bond the sensor to the heat-source surface.

Figure 1-21 depicts how the LM34/35 temperature sensors could be connected to a personal computer via a parallel data input. An LM34 is connected to a signal conditioner, such as a 75- Ω resistor and 1- μ F capacitor. An op amp sets up a voltage reference to the A/D converter, an ADC0804 8-bit A/D chip. A parallel data stream and the control signals \overline{CS} , \overline{RD} , \overline{WR} , and \overline{INTR} are sent to the computer.

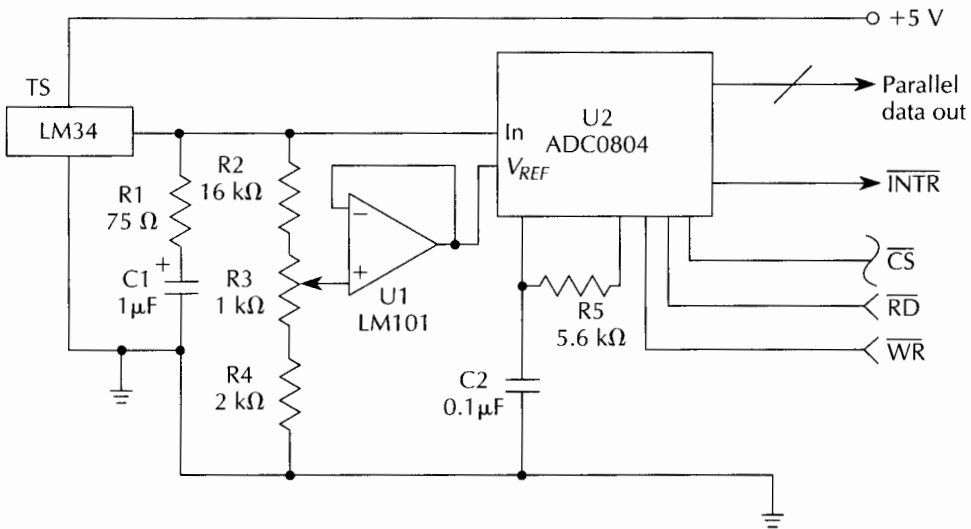


Fig. 1-21 Computer interface for temperature sensor.

Next, a high-precision temperature sensor, an LM135, operates as a zener diode. The LM135 has a breakdown voltage directly proportional to absolute temperature 10 mV/ $^{\circ}$ K. The device has a 1- Ω impedance and operates from 400 μ A to 5 mA with less than 1 $^{\circ}$ C error over a 100 $^{\circ}$ C range. The low output impedance and linear output make this detector a good choice for temperature-sensing applications (see Fig. 1-22).

Calibration of the LM135 requires a 10-k Ω potentiometer placed across the sensor, as shown in Fig. 1-19. The calibration voltage should be 2.98 V at 25 $^{\circ}$ C.

The last example of a temperature sensor circuit uses the LM335 precision temperature sensor, which is coupled to an LM311 op amp via pin 3. A voltage reference and adjustment is

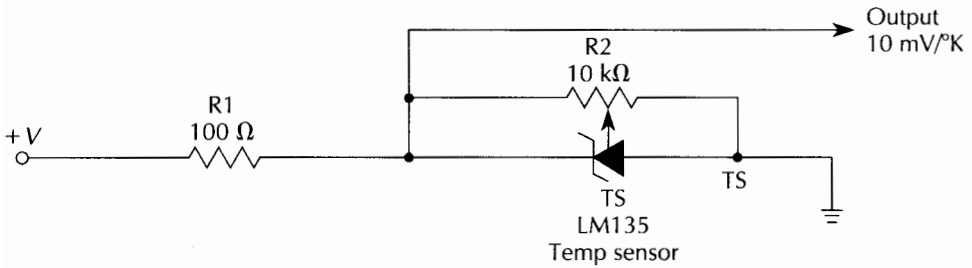


Fig. 1-22 Adjustable temperature sensor.

set up using an LM329 electronic zener diode and a 10-k Ω potentiometer connected to pin 2 of the IC (see Fig. 1-23). The output of the LM311 is then coupled to an LM395 power npn transistor, which can drive a heating element or motor. Further application assistance can be obtained by calling National Semiconductor at 1-800-272-9959.

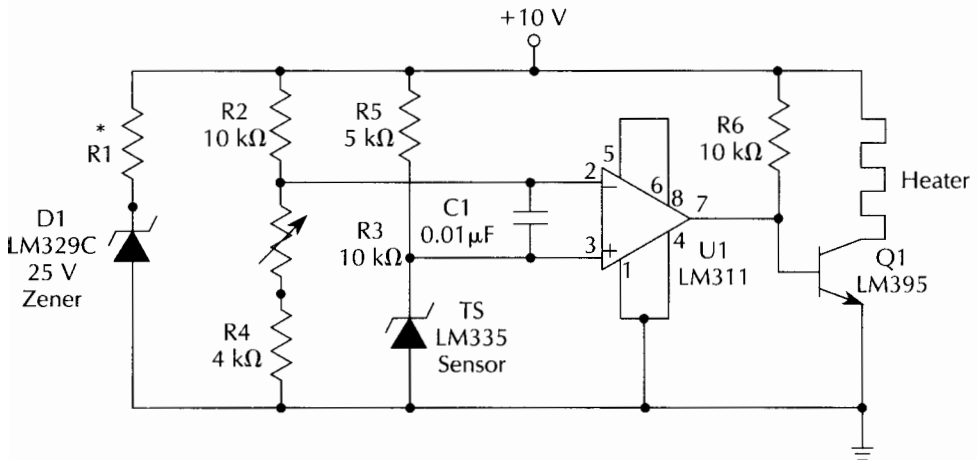


Fig. 1-23 Temperature-controlled heater.

Temperature sensor parts list

Quantity	Part	Description
1	TS	LM34 temperature sensor (National Semiconductor)
1	R1	10-k Ω , 1/4-W potentiometer
1	M	100- μ A panel meter

Extended-range temperature sensor parts list

Quantity	Part	Description
1	TS	LM34 temperature sensor (National Semiconductor)
1	R1	2-k Ω , ¼-W resistor
1	R2	10-k Ω , ¼-W resistor
1	R3	260-k Ω , ¼-W resistor
1	D1	2.5-V sensor diode
1	M	0–100-mA panel meter

Computer interface for temperature sensor parts list

Quantity	Part	Description
1	TS	LM34 temperature sensor
1	R1	75- Ω , ¼-W resistor
1	R2	16-k Ω , ¼-W resistor
1	R3	1-k Ω , ¼–½-W potentiometer
1	R4	2-k Ω , ¼-W resistor
1	R5	5.6-k Ω , ¼-W resistor
1	C2	0.1- μ F, 25-V capacitor
1	C1	1- μ F, 25-V capacitor
1	U1	LM101 op amp
1	U2	ADC0804 A/D converter (National Semiconductor)

Adjustable temperature sensor parts list

Quantity	Part	Description
1	R1	100- Ω , ½-W resistor
1	R2	10-k Ω , ½-W potentiometer
1	TS	LM135 temperature sensor (National Semiconductor)

Temperature-controlled heater parts list

Quantity	Part	Description
1	TS	LM335 temperature sensor (National Semiconductor)
1	R1	100–500- Ω , ½-W resistor
1	R2	10-k Ω , ½-W resistor
1	R3	10-k Ω , ½-W potentiometer
1	R4	4-k Ω , ½-W resistor
1	R5	5-k Ω , ½-W resistor

1	C1	0.01- μ F, 25-V capacitor (disk)
1	D1	LM329C zener diode (National Semiconductor)
1	Q1	LM395 transistor (National Semiconductor)
1	H	Heater coil

Hall-effect metal/magnetic sensors

The Hall-effect sensor can detect the presence or absence of magnets or metal surfaces and can solve a number of measurement and alarm problems. We will illustrate some of these applications. Three different types of Hall-effect sensor are presented. Hall-effect sensors can be used for tilt switches, counters, proximity detectors, metal detectors, pressure sensors, current sensors, and gaussmeters.

A basic low-cost Hall-effect sensor is the Sprague UGN3020T, shown in Fig. 1-24. This sensor includes a Hall cell, voltage regulator, signal amplifier, and Schmitt trigger. The circuit shown can protect instruments, antiques, or windows/doors by placing a small magnet on the item you wish to protect. The sensor is then placed in close proximity to the magnet. When the magnet is moved past the sensor, an output activates a relay. The sensor drives a 2N5812 transistor for an on-off type output. A DPST relay could be used to sound a local alarm, or the circuit could be con-

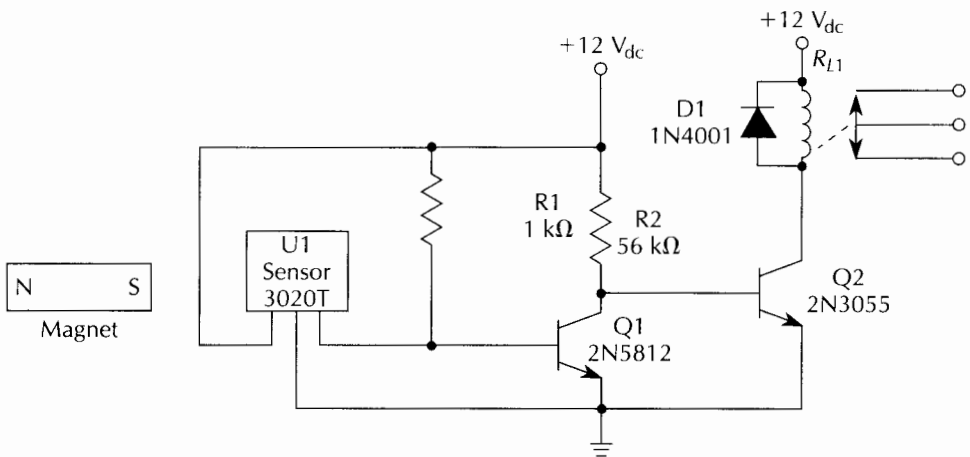


Fig. 1-24 Hall-effect switch.

nected to a central alarm panel. The same basic Hall sensor could be used for counting moving objects or as a wind-speed indicator.

The diagram in Fig. 1-25 depicts an ac Hall switch that can control 115-V_{ac} loads such as motors and lamps, upon detecting the presence or absence of a magnet. The Sprague UGN3501T Hall sensor is more flexible because it provides an analog output. The 3501T Hall sensor is a single-ended output device, which can sense small changes in a magnetic field. The 3501T includes a Hall cell, linear amplifier, emitter-follower output, and a regulator.

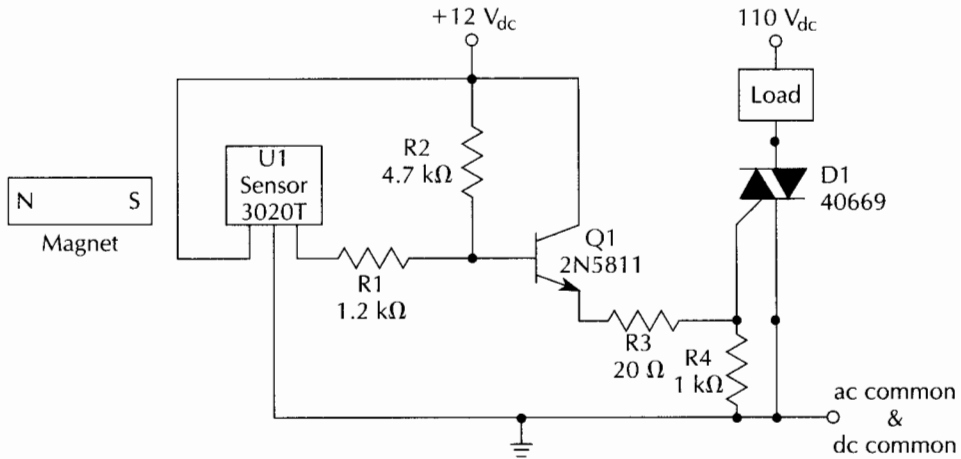


Fig. 1-25 Hall-effect ac switch.

A ferrous metal detector, shown in Fig. 1-26, can detect metal objects passing the sensor. A magnet is placed with its north pole facing the 3501T sensor. As a metal object passes the detector assembly, the signal is amplified by an LM741C op amp. The output drives a relay. This detector circuit can be used for sensing or counting metal parts, as well as pressure sensing. The output is linear and can provide a continuous display output. The 3501T sensor can also detect the absence of metal objects, as shown in Fig. 1-27. The 3501T can also be used for a tilt-angle sensor, as well as a vibration sensor.

The next Hall-effect sensor is the UGN3501M, which is ideal for accurately measuring and controlling current, velocity, position, weight, and thickness. The UGN3501M is a linear differential-type sensor that includes a Hall cell, a differential amplifier, an emitter follower, and a regulator. Figure 1-28 illustrates a cur-

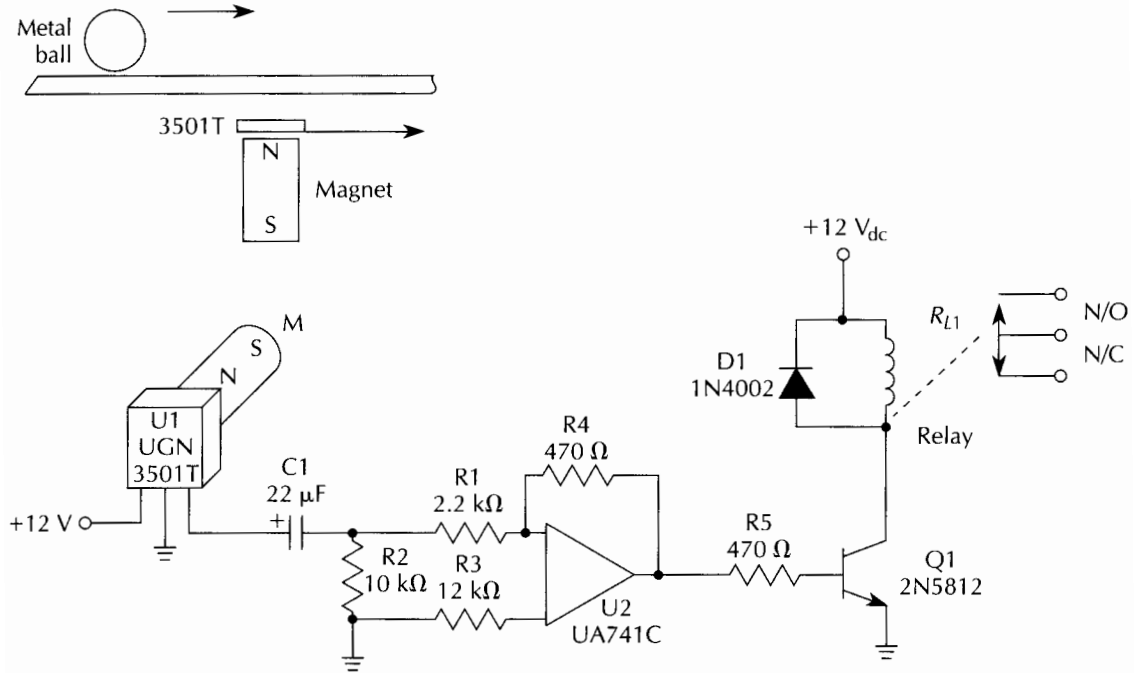


Fig. 1-26 Hall-effect metal-presence switch.

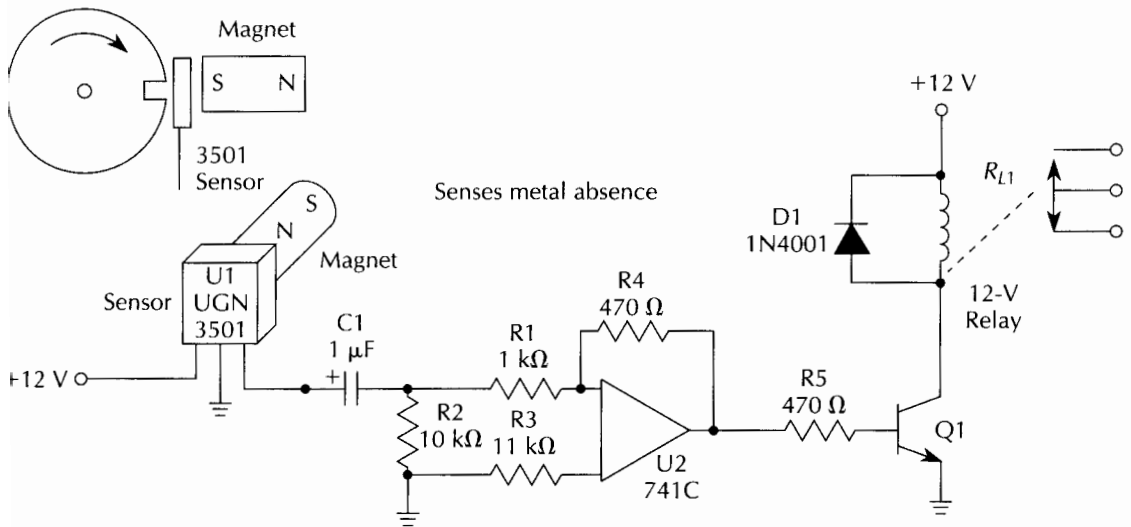


Fig. 1-27 Hall-effect metal-absence switch.

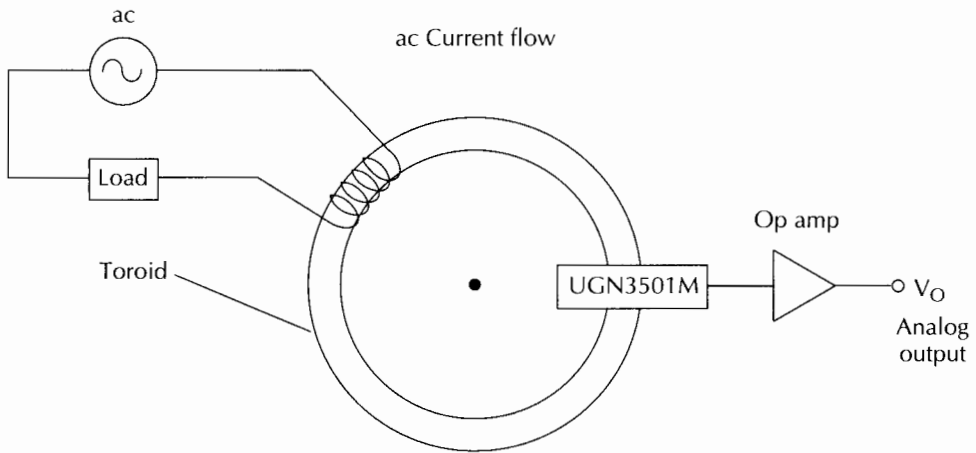


Fig. 1-28 Current-sensing Hall-effect sensor.

rent-measurement circuit using the UGN3501M sensor. A wire carrying ac current connected in series with a load is wrapped around a toroid. A UGN3501M sensor is placed on the toroid and its output drives a 741 op amp. The resultant output can indicate the varying current when connected to a current meter, or the signal could be applied to an analog-to-digital (A/D) converter card in a personal computer. The differential sensor can also be used as a basic gaussmeter, as shown in Fig. 1-29. As the magnetic field is moved closer to the Hall sensor, an output can be displayed on a voltmeter. A 200- Ω potentiometer zeros the cir-

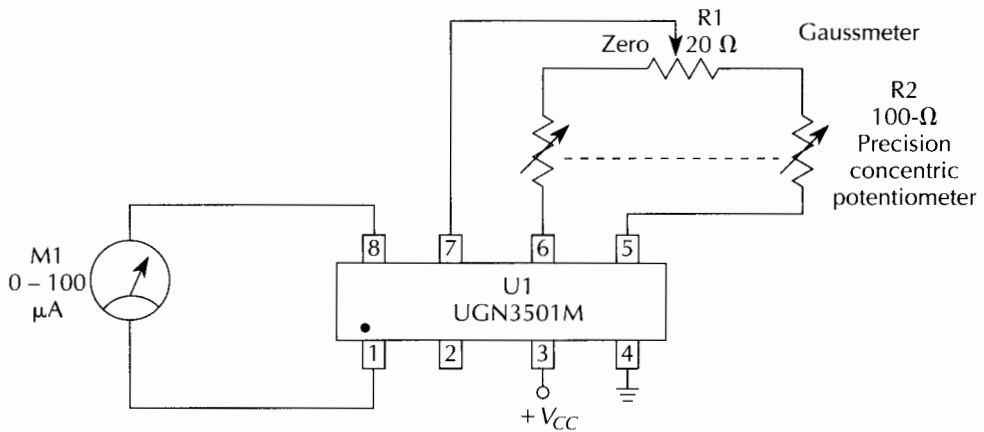


Fig. 1-29 Gaussmeter.

cuit. This simple gaussmeter is suited to many ac field applications and can be constructed quite inexpensively.

The output of the gaussmeter is on pin 3 and pin 1 of the UGN3501M. The output could also drive an op amp such as an LM741, which will amplify the output of the sensor. A pressure sensor could be fabricated by attaching a linear Hall-effect sensor to a magnet, as shown in Fig. 1-30. As the metal disk travels toward the sensor, a proportional pressure output is displayed. A pressure sensor of this type would be used in a nonmetallic tank or vessel. The linear Hall-effect sensor can also be used for an analog tilt indicator or vibration sensor.

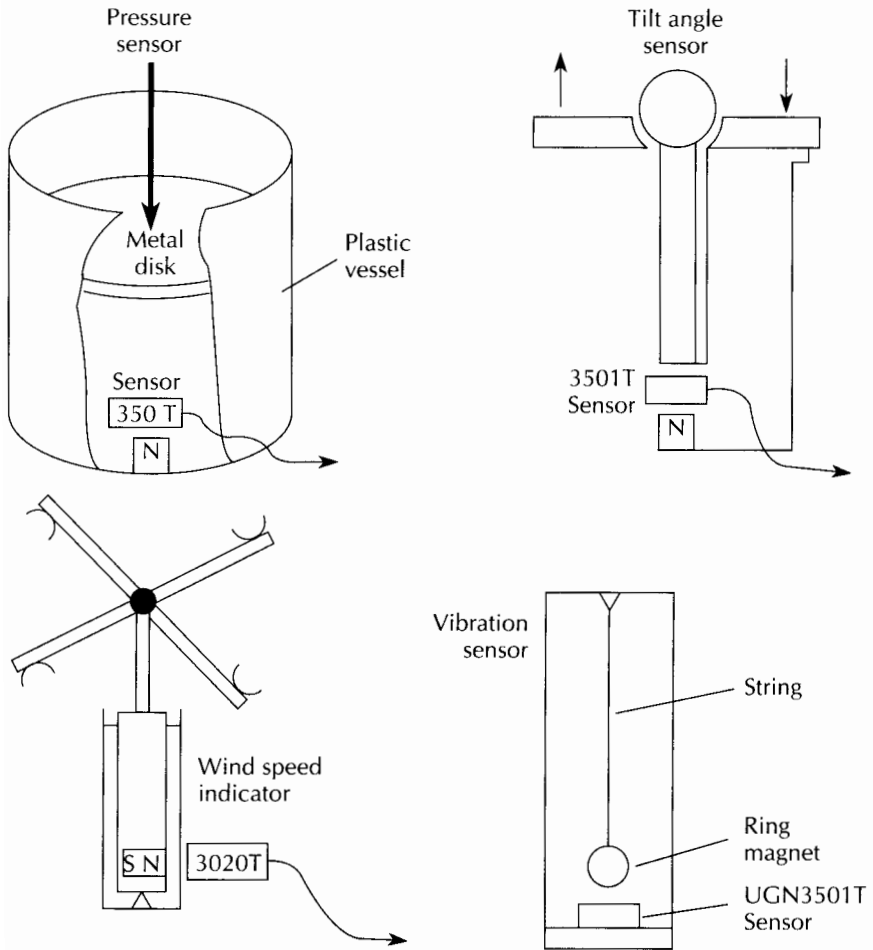


Fig. 1-30 Hall-effect sensor applications.

The Hall-effect sensor can be used in many applications in self-contained systems, or the sensor outputs can be connected to a central alarm panel, such as in a security system.

Hall-effect switch parts list

Quantity	Part	Description
1	R1	1-k Ω , ¼-W resistor
1	R2	56- Ω , ¼-W resistor
1	D1	1N4001 silicon diode
1	Q1	2N5812 transistor
1	Q2	2N3055 transistor
1	U1	UGN3120 Hall cell (Allegro Microsystems)
1	RY-1	9–12-V relay
1	MAGNET	Bar or cylinder magnet

Hall-effect ac switch parts list

Quantity	Part	Description
1	R1	1.2-k Ω , ¼-W resistor
1	R2	4.7-k Ω , ¼-W resistor
1	R3	120- Ω , ¼-W resistor
1	R4	1-k Ω , ¼-W resistor
1	Q1	2N5811 transistor or equivalent
1	D1	40669 triac
1	U1	UGN3120 Hall switch (Allegro Microsystems)

Hall-effect metal presence switch parts list

Quantity	Part	Description
1	R1	2.2-k Ω , ¼-W resistor
1	R2	10-k Ω , ¼-W resistor
1	R3	12-k Ω , ¼-W resistor
1	R4	470-k Ω , ¼-W resistor
1	R5	470- Ω , ¼-W resistor
1	C1	22- μ F, 25-V electrolytic capacitor
1	D1	1N4002 silicon diode
1	Q1	2N5812 transistor
1	U1	UGN3503 5-V Hall cell (Allegro Microsystems)
1	U1	UGN3501 12-V Hall cell (Allegro Microsystems)

1	U2	UA741 op amp
1	RY-1	5–12-V relay
1	MAGNET	Bar or cyclinder magnet

Hall-effect metal absence switch parts list

Quantity	Part	Description
1	R1	1-k Ω , ¼-W resistor
1	R2	10-k Ω , ¼-W resistor
1	R3	11-k Ω , ¼-W resistor
1	R4	470-k Ω , ¼-W resistor
1	R5	470- Ω , ¼-W resistor
1	C1	1- μ F, 25-V capacitor
1	Q1	2N5812 transistor or equivalent
1	U1	UGN3501 12-V Hall cell (Allegro Microsystems)
1	U1	UGN3503 5-V Hall cell (Allegro Microsystems)
1	U2	UA741C op amp
1	D1	1N4001 silicon diode
1	RY-1	5–12-V SPST relay
1	MAGNET	Bar or cylinder magnet

Gaussmeter parts list

Quantity	Part	Description
1	R1	20- Ω , ¼-W resistor
1	R2	100- Ω , precision concentric potentiometer
1	U1	UGN350M Hall cell (Allegro Microsystems)
1	M	0–100- μ A panel meter

ac-magnetic field detector

A magnetic field detector is a sensitive indicator of a moving or dynamic ac field. This detector might be of interest if you are concerned about radiation from magnetic fields for safety reasons. The magnetic field detector is shown in Fig. 1-31. The detector can also indicate if a relay is energized or if a high-voltage transformer is operating. Any device with a transformer may be detected readily. The ac-magnetic field detector measures a single-axis field. Therefore, position the detector in each desired axis or build two similar coils and either switch them into the circuit or build three display units to monitor all three axes at once.

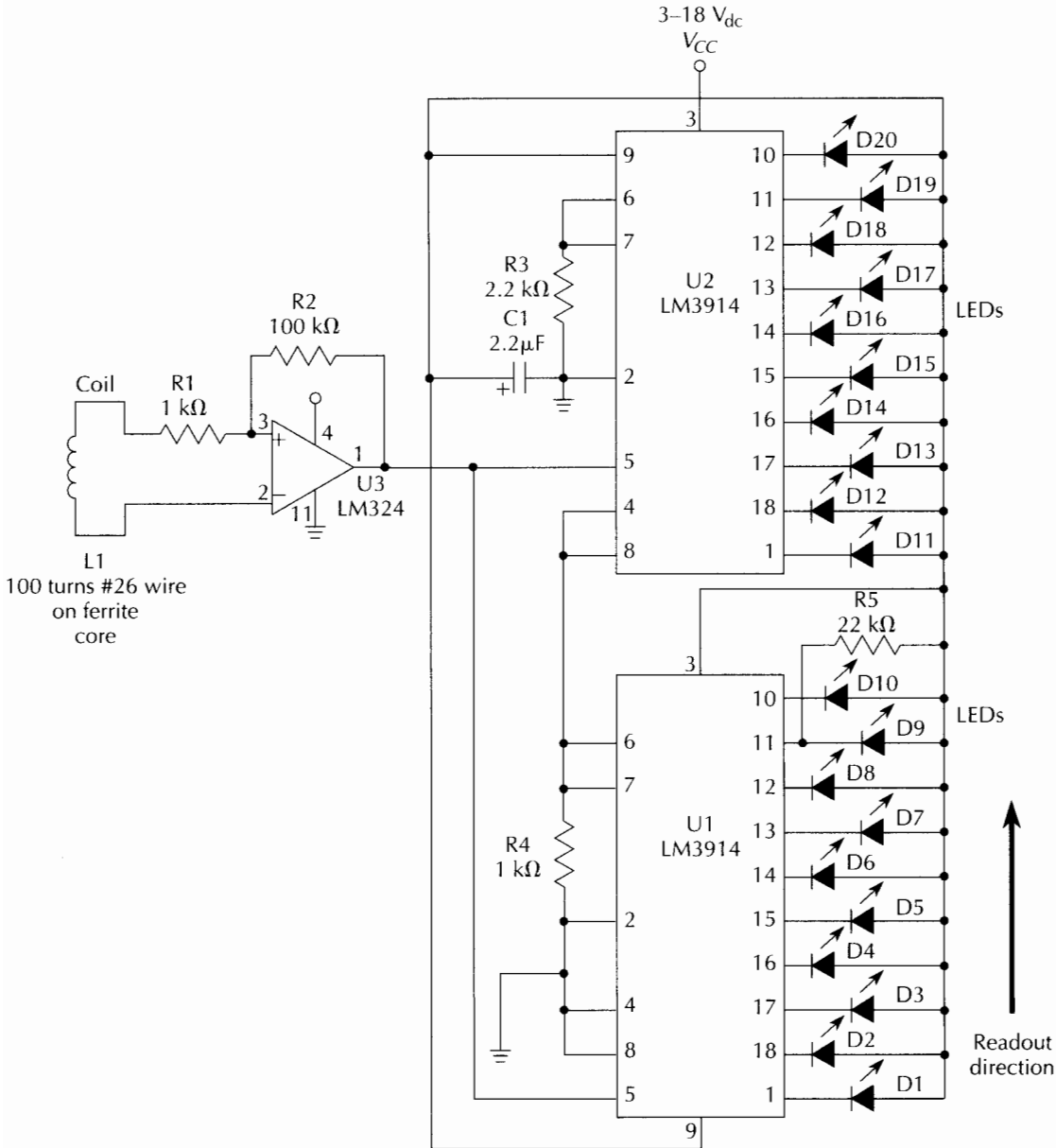


Fig. 1-31 Bar-graph ac magnetic field detector.

The experimental field detector begins with a sense coil. The sense coil consists of 100–200 turns of 28-gauge enameled wire wound on a plastic form covered with aluminum foil and placed inside a plastic film container. The coil is coupled to an LM324 op

amp via a 1-k Ω resistor. A 100-k Ω feedback resistor is connected between pins 1 and 3. By switching in different feedback resistors, various sensitivity ranges can be selected. The heart of the ac field meter is two LM3914 DOT/BAR display driver chips, wired so that the first chip drives the second one for a 20-LED sequential display. Two 10-position LED display packages can simplify construction. The LM324 was used because it is a single-supply device. Power is applied to pins 4 and ground to pin 11. The gaussmeter can be powered by a 9-V transistor battery.

Calibration of the ac field meter is accomplished by connecting an ac milliammeter, an 8.2 V_{ac} transformer, and a 100- Ω potentiometer in series with a calibration coil. A calibration coil consists of 110 turns of 26-gauge enameled wire. The sensor coil is placed inside the calibration coil. The calibration formula is: gauss equals turns per meter times the ac amperes of coil current. Then, coil amperes equals gauss divided by the number of turns per meter, multiplied by 20. For example, 110 turns \times 20 = 2,200 turns per meter. (Note: a 5-cm coil is 5% of a meter.) Now, 2,200 turns per meter times the ac current in milliamperes equals the field in gauss. The gaussmeter can detect the presence of magnets, but, since it is not a moving field, you have to sweep the magnet or the coil past each other to see an indication.

Bar-graph ac-magnetic-field meter parts list

Quantity	Part	Description
2	R1, R4	1-k Ω , 1/4-W resistor
1	R2	100-k Ω , 1/4-W resistor
1	R3	2.2-k Ω , 1/4-W resistor
1	R5	22-k Ω , 1/4-W resistor
1	C1	2.2- μ F, 25-V electrolytic capacitor
1	L1	100 turns 26-gauge enameled wire on ferrite core
2	U1, U2	LM3914 display drive ICs
20	D1-D20	Red LEDs

Bridge sensors

A bridge circuit measures the electrical property of a circuit element indirectly by comparing against a known similar element. The two primary ways of operating a bridge circuit are as a null detector and as a device that directly reads a voltage or current.

Null detectors are primarily used in feedback systems involving electromechanical movement. These systems seek to force the active resistive element, such as a thermistor or strain gauge which is connected to a mechanically coupled potentiometer, to balance the bridge. The null is independent of the excitation voltage.

A basic bridge is shown in Fig. 1-32, and illustrates a null condition when $R1/R4 = R2/R3$. Figure 1-33 shows a bridge with all resistors equal, but one of them, R1, is a variable active sensing element, such as thermistor or light-sensitive resistor.

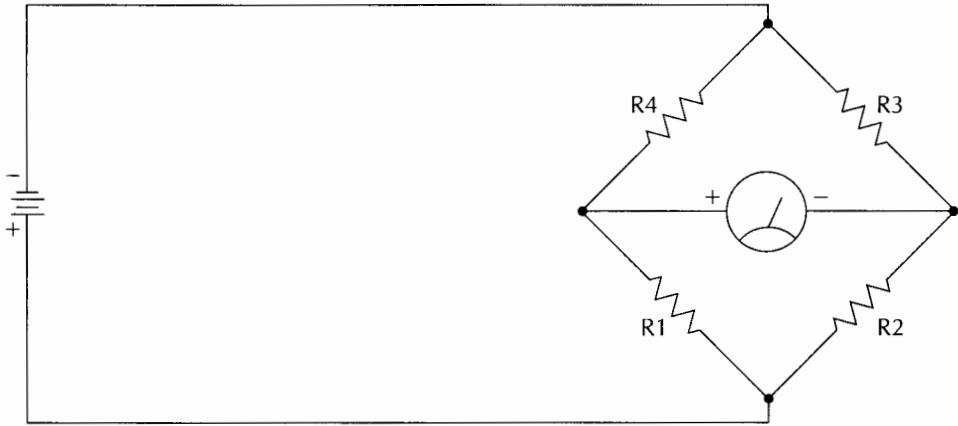


Fig. 1-32 Simple dc bridge circuit.

The sensitivity of a bridge is the ratio of the excitation voltage to the maximum change in the output of the circuit. The sensitivity can be doubled if two identical variable elements are used in positions R1 and R3, as shown in Fig. 1-34. An example would be two identical strain-gauge resistive-type sensors aligned in a single pattern. The resultant output would be double.

A special doubling configuration is shown in Fig. 1-35, which consists of four variable resistive sensor elements. Two of the elements increase, i.e., R1 and R3, as the other two elements, R2 and R4, decrease in the same ratio. Two identical two-element strain gauges or sensors are attached to opposite faces of a thin carrier or substrate to measure its bending properties. The output of such a bridge arrangement would be four times the output of a single-element sensor. The complementary resistance changes would result in a linear output.

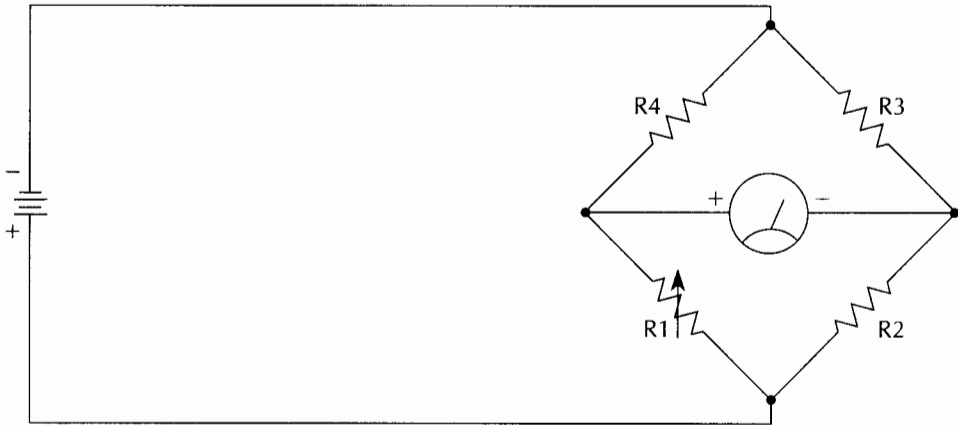


Fig. 1-33 Single variable dc bridge.

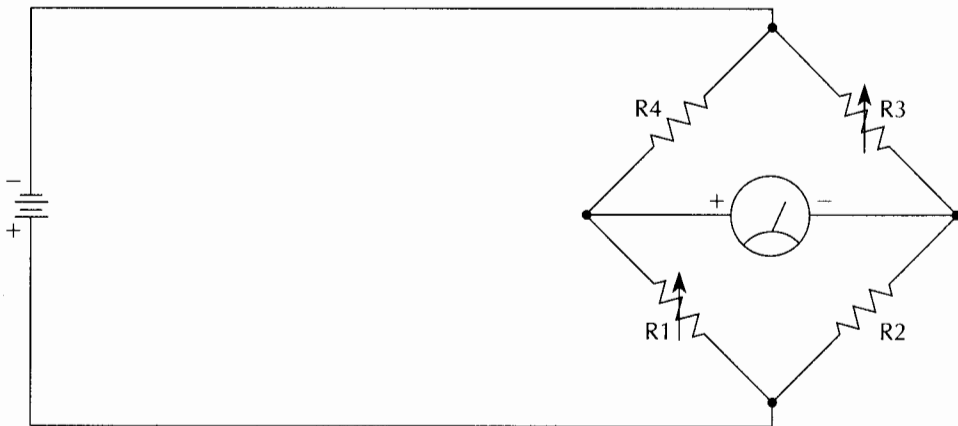


Fig. 1-34 Dual variable dc bridge.

Most instrumentation systems rely on a form of the basic bridge circuit to monitor all types of physical phenomena, using light-sensitive resistors, RTD sensors, and pressure, strain, and flow sensors. Many precision instrumentation systems utilize a precision op amp or chopper-stabilized amplifier. The output of the op amp can be directed to a digital panel meter or an A/D converter card inside a personal computer.

A precision instrumentation bridge circuit is shown in Fig. 1-36. A resistive sensor, R_4 , unbalances the bridge, producing a

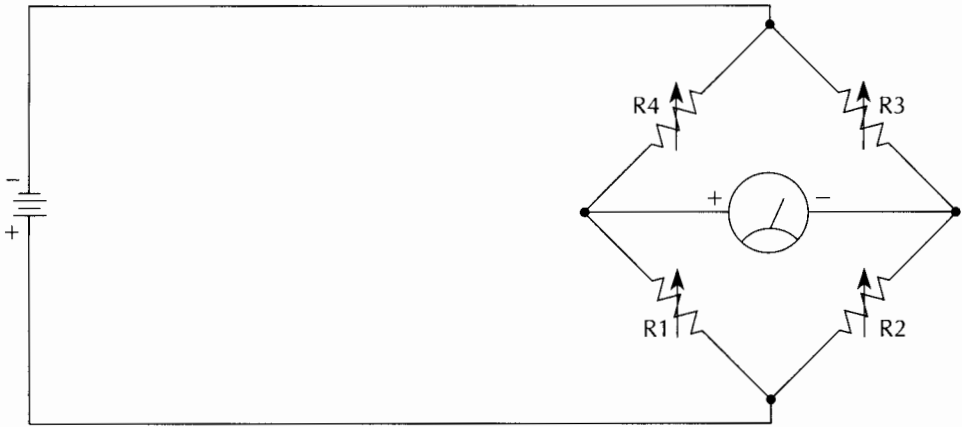


Fig. 1-35 Quad variable dc bridge.

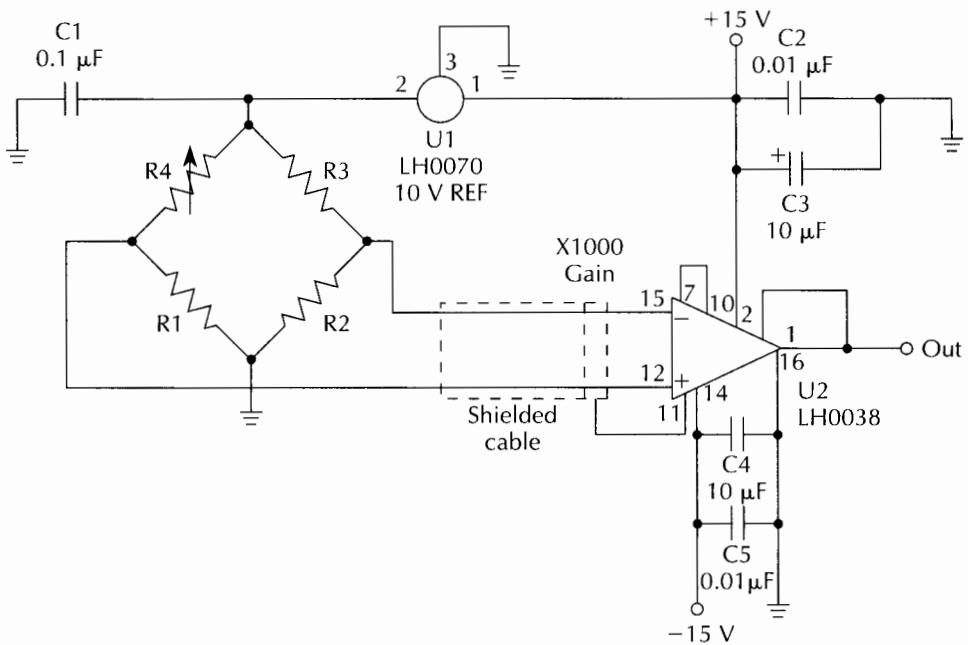


Fig. 1-36 Instrumentation-grade bridge circuit.

tiny output that is coupled to a National Semiconductor LH0038 three-stage precision instrumentation-amplifier chip with internal gain resistors. The amplifier has a gain factor up to 2000. A 10-V reference produced from the LH0070 is applied to the bridge to provide an accurate source voltage or reference. The system has

excellent common-mode rejection and can be used in precision measuring applications. A shielded cable should be used when connecting the sensor if it is not located near the electronics. Any resistive-type sensor could be substituted for a strain gauge, such as a pressure sensor or light-detection circuits. The bridge amplifier is used in many precision measurement circuits, including seismology, water/resource management, ballistics, etc.

Instrumentation-grade bridge amplifier parts list

Quantity	Part	Description
3	R1, R2, R3	10-k Ω , 1/4-W resistor
1	R4	10-k Ω resistive sensor
2	C2, C5	0.01- μ F, 25-V capacitor (disk)
1	C1	0.1- μ F, 25-V capacitor
2	C3, C4	10- μ F, 25-V electrolytic capacitor
1	U1	LH0070 10-V reference (National Semiconductor)
1	U2	LH0038 instrumentation amplifier

Maxwell bridge

The basic bridge circuit is not limited to resistive dc circuits. A device called the Maxwell bridge can measure an unknown capacitance or inductance. A Maxwell bridge is shown in Fig. 1-37. IC1 and IC2 form an oscillator that can be made to oscillate between 1 and 10-kHz. A small 3:1 ratio transformer couples the drive circuit to the measuring circuit. An unknown coil value can be determined by placing the coil at LX. The value of an unknown capacitor can be measured by connecting the capacitor to A and B.

Generally, an analog meter would be connected to points x and y as shown. The null value can then be determined on the meter. Calibration is performed with RA and RB. A null or fine tuning is then accomplished with potentiometer R3.

We can construct a metal detector or automobile/truck sensor with this bridge. A coil or pickup device can be constructed by winding 75 to 100 turns of 26-gauge enameled wire, random wound on a 1-foot square coil form. The coil should be constructed so that it is protected from the elements, because it is intended to be buried in a driveway. Connect an LM311 comparator, as shown, to points x and y. The LM311 is coupled to a 2N3904 npn transistor, which can drive a small relay (Radio Shack 275-240). After connecting the coil, a null first must be obtained by ad-

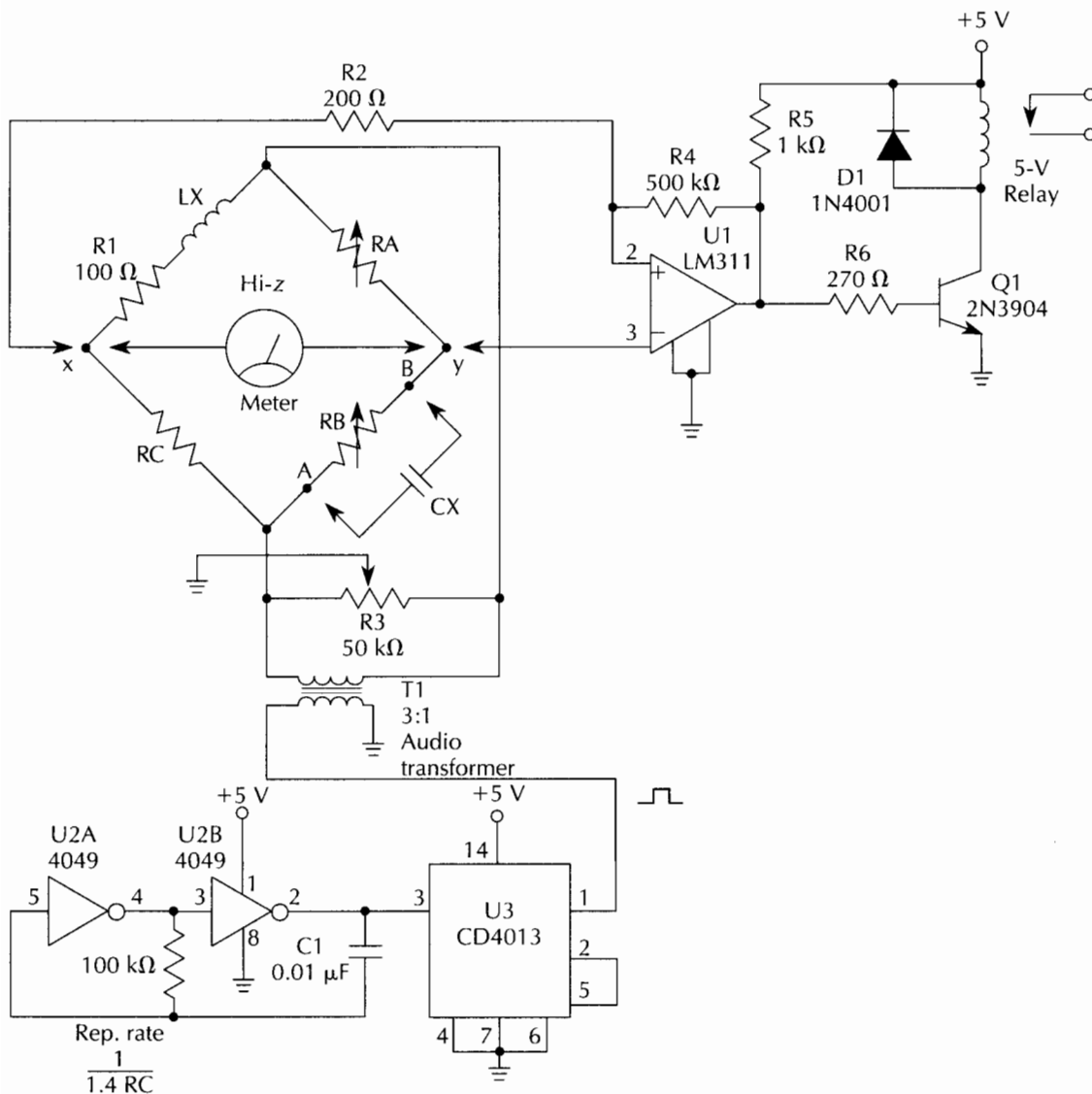


Fig. 1-37 Maxwell ac bridge circuit.

justing RA and RB. A final null is made with R3 as described previously. R3 is adjusted so no output is present at points x and y. As a large metal object or car approaches, the null condition will become upset and the resultant change is then applied to the comparator, which could activate a buzzer. The metal detector could also be used to locate hidden pipes in the ground, by carrying the coil on a plastic pole and holding the coil parallel to the ground as you search the suspected area.

Maxwell ac/dc bridge parts list

Quantity	Part	Description
1	RA	100- Ω , 1/2-W potentiometer
1	RB	100- Ω , 1/2-W potentiometer
1	RC	100- Ω , 1/2-W resistor
1	R1	100- Ω , 1/2-W resistor
1	R2	200- Ω , 1/2-W resistor
1	R3	50-k Ω potentiometer (trim)
1	R4	500-k Ω , 1/4-W resistor
1	R5	1-k Ω , 1/4-W resistor
1	R6	270- Ω , 1/4-W resistor
1	R7	100-k Ω , 1/4-W resistor
1	LX	Known if unknown CX
1	CX	Known if unknown LX
1	C1	0.01- μ F, 25-V capacitor (disk)
1	D1	1N4001 silicon diode
1	Q1	2N3904 transistor
1	U1	LM311 op amp (National Semiconductor)
1	U2	CD4049 CMOS HEX inverter
1	U3	CD4013 CMOS flip-flop
1	T1	3:1 miniature transformer
1	M	20-k Ω /V multimeter or panel meter
1	RY-1	5-V relay

Pyroelectric detector

The pyroelectric or body-heat, detector can sense humans or large animals up to 50 feet away. The pyroelectric or passive infrared sensor requires no external field excitation, as needed by ultrasonic or microwave detectors. Only a human IR source is needed to trigger a pyroelectric sensor. Pyroelectric detectors are inexpensive and very reliable and have become the preferred alarm sensor in the security industry. When used with a discriminator circuit, the systems become virtually free of false alarms. The coverage of the pyroelectric sensor can be either short range, i.e., an 8 to 10-foot-square area in front of the sensor, or long range out to 50 feet but with a narrow beamwidth. A small plastic Fresnel lens placed in front of the sensor determines the actual range of the sensor (see Fig. 1-38). The sensor can be used without a lens as a touch switch to detect human hands or fingers.

A number of plastics and unsymmetrical crystals, such as lithium tantalate, can provide the pyroelectric effect. A thin wafer

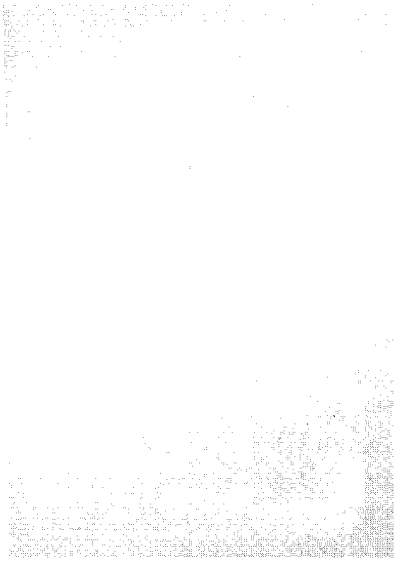


Fig. 1-38 *Pyroelectric sensor and lens.*

of this material is sandwiched between two electrodes, and an internal field is generated and the charge across the crystal can be monitored. To detect the charge, a high-impedance field-effect transistor and an internal matching resistor are placed together with the lithium-tantalate crystal in a TO-5 size transistor case. A sense window in front of the crystal is covered with an infrared filter. The internal FET amplifies the incoming signal, which is fed directly to a 741 op amp, as shown in Fig.1-39. The ELTEC 406 series single-crystal sensor is coupled to the inverting input of the op amp on pin 2 (see Fig. 1-40). When the voltage level on pin 2 has exceeded the threshold voltage on pin 3, which is controlled by a 100-k Ω potentiometer, an output signal on pin 6 drives a small relay via a 2N2222 npn transistor. The output can directly drive a buzzer or can be used to trigger a latching alarm by substituting the transistor with an SCR. The circuit can also activate a central alarm panel. Other sensor configurations are available, including dual sensors configured in parallel or opposed parallel for increased discrimination and stability. Flame sensors are also available, which can detect pilot lamps in heaters or furnaces. Samples of the devices are available upon request by giv-

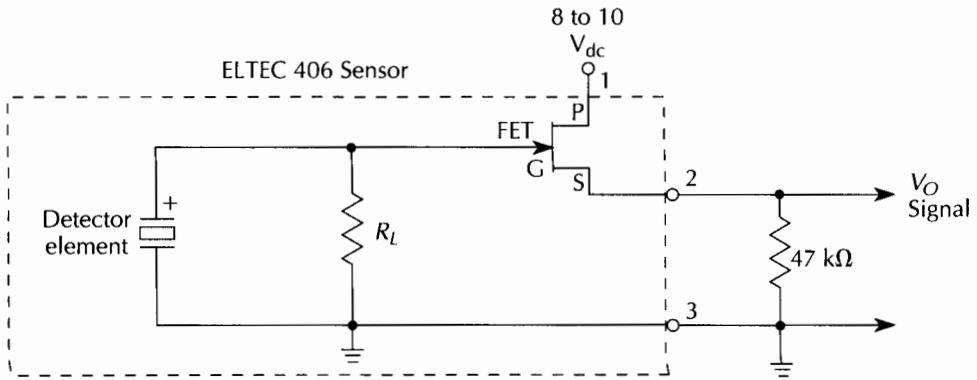


Fig. 1-39 Pyroelectric sensor diagram.

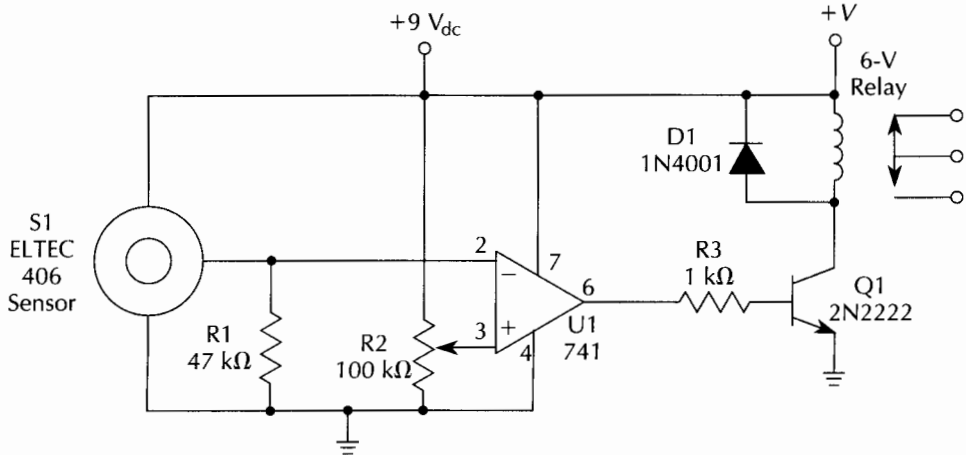


Fig. 1-40 Pyroelectric sensor and switch circuit.

ing your company name and application. A pyroelectric detector with dual opposed parallel detectors for increased discrimination is described with a construction project in the last chapter.

Pyroelectric sensor and switch circuit parts list

Quantity	Part	Description
1	R1	47-kΩ, ¼-W resistor
1	R2	100-kΩ, ¼-W resistor

Quantity	Part	Description
1	R3	1-k Ω , ¼-W resistor
1	D1	1N4001 silicon diode
1	Q1	2N2222 pnp transistor
1	U1	UA741C op amp
1	RY-1	6-V SPST relay
1	S1	ELTEC 406 pyroelectric sensor

Pressure sensor

Pressure sensors can be used to measure a variety of physical parameters, including wind speed, liquid velocity, barometric pressure, altitude, and the speed of rotational objects such as bicycles and automobiles. Pressure sensing in the past has required very costly sensors, but recently many new sensitive, low-cost models have become available. A low-cost pressure sensor is shown in Fig. 1-41. A new catalog from Sensym offers many different types of pressure sensors that can measure absolute, differential, and gauge pressures.

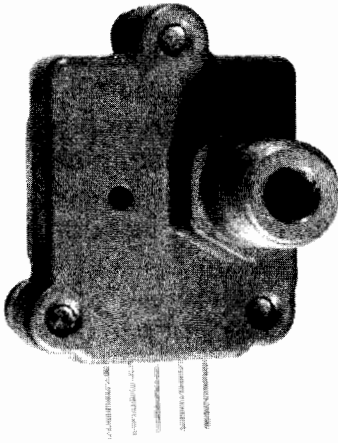


Fig. 1-41 Pressure sensor.

Absolute-pressure sensors measure changes in barometric pressure and are commonly used in altimeters. These applications require a reference to a fixed pressure and cannot be simply referenced to the ambient pressure. Absolute pressure is defined as the pressure measured relative to a perfect vacuum; i.e., 10 psi is 10 pounds per square inch above a perfect vacuum.

Differential pressure is the pressure difference measured between two pressure sources. When one source is used for measurement, the ambient source is known as relative or gauge

pressure, measured in pounds per square inch or psig. Gauge pressure is simply a special case of differential pressure, with pressure measured differently but always relative to the local ambient pressure. A simple sensitive pressure switch is shown in Fig. 1-42.

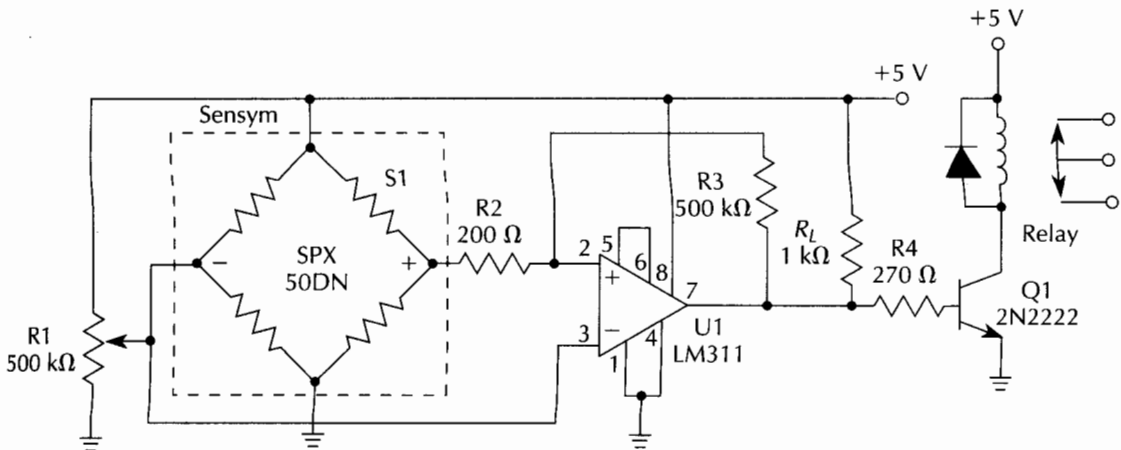


Fig. 1-42 Pressure switch.

The pressure switch uses a Sensym SPX500N sensor bridge coupled to an LM311 comparator via a 200- Ω resistor. A 500-k Ω potentiometer is the sensitivity or threshold control. The output of the comparator on pin 7 is directed to Q1, a 2N2222 transistor. The output transistor can drive a low-current relay, which can activate a motor or buzzer or trigger an alarm panel.

Many pressure applications require an analog output or display. Figure 1-43 illustrates an analog pressure system that drives an analog LED bar-graph display. An analog or digital meter module could be substituted for the bar graph if desired. Many low-cost digital panel meters or modules are available from suppliers listed in the Appendix. A chart is provided to help select the proper sensor and feedback resistors for your application. Two resistors, R_g and R_p , select the feedback or gain parameters.

An instrument-grade pressure measurement system is shown in Fig. 1-44. This system uses a precision-grade bridge sensor with a precise voltage reference source coupled to the bridge. The signal is amplified and processed by A1-A4, four Linear Technology LT1014 integrated op amps. The analog voltage output of A3 is very accurate. The precision output is connected directly to an ADC0804 8-bit analog-to-digital (A/D) converter, which can be

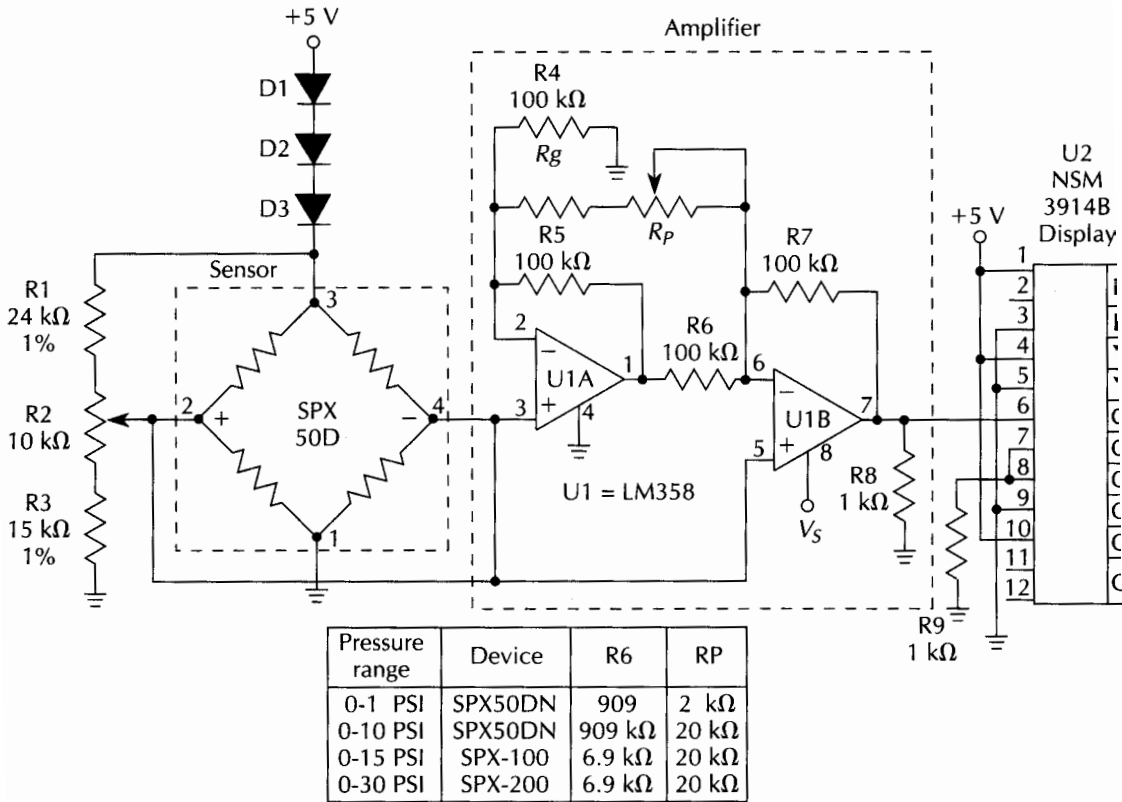


Fig. 1-43 Analog bar-graph pressure sensor.

connected to an 8-bit parallel input on a personal computer. The analog output at A3 could also be applied to an A/D converter card placed inside a computer, to act as a multichannel pressure data logger by combining a number of sensor channels.

Pressure switch parts list

Quantity	Part	Description
1	R1	500-kΩ potentiometer
1	R2	200-Ω, ¼-W resistor
1	R3	500-kΩ, ¼-W resistor
1	R4	270-Ω, ¼-W resistor
1	RL	200-Ω, 1-kΩ, ½-W resistor
1	D1	1N4002 silicon diode
1	U1	LM311 op amp
1	Q1	2N2222 pnp transistor
1	RY-1	5-V SPST relay
1	S1	Sensym SPX50DN pressure sensor

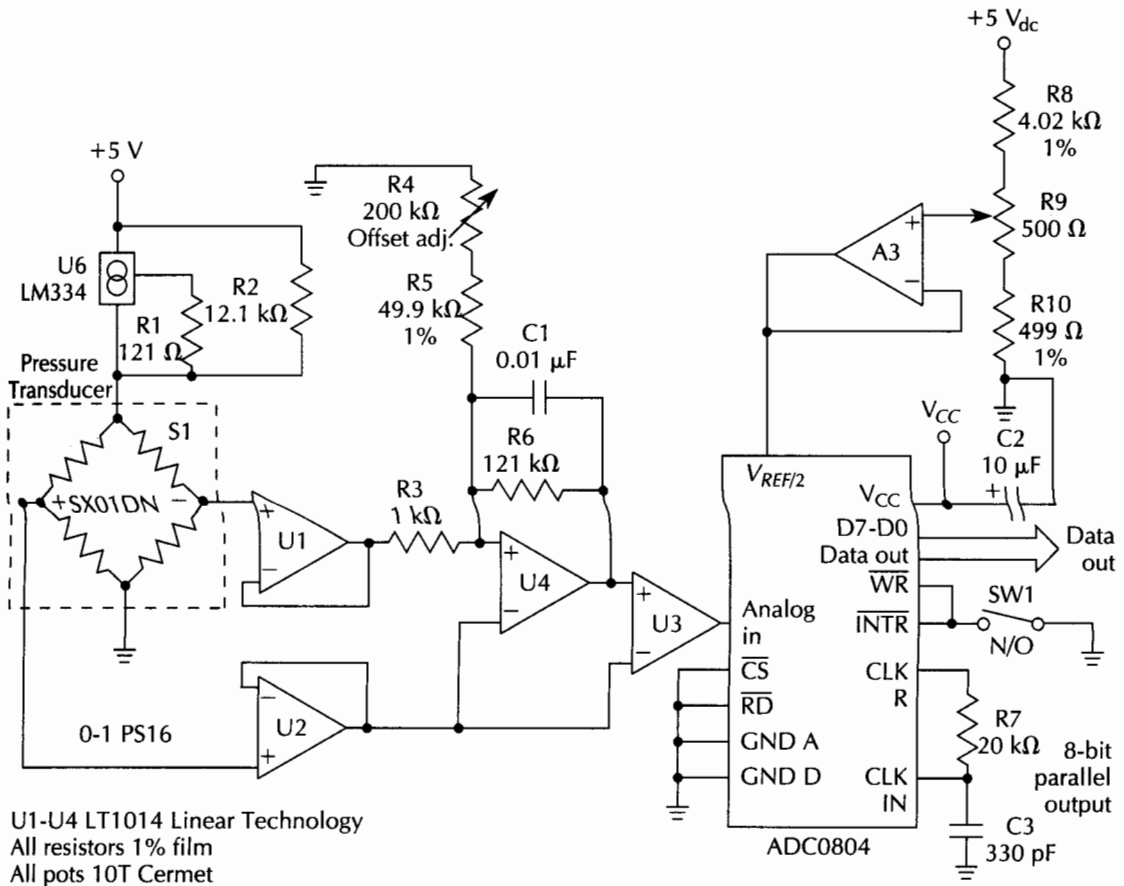


Fig. 1-44 Pressure sensor with computer interface.

Analog bar-graph pressure sensor parts list

Quantity	Part	Description
1	R1	24-kΩ, 1%, ¼-W resistor
1	R2	10-kΩ, ¼-W potentiometer
1	R3	15-kΩ, 1%, ¼-W resistor
1	R4, R5, R6, R7	100-kΩ, ¼-W resistor
1	R8	1-kΩ, ¼-W resistor
1	R9	3.3-kΩ, ¼-W resistor
1	Rp	See table (scaling)
1	Rg	See table (scaling)
1	U1	LM358 op amp
1	U2	NSM3914B LED dot display driver
1	S1	Sensym SPX50DN pressure sensor

Pressure sensor with computer interface parts list

Quantity	Part	Description
1	R1	121- Ω , 1%, 1/4-W resistor
1	R2	12.1-k Ω , 1%, 1/4-W resistor
1	R3	1-k Ω , 1/4-W resistor
1	R4	200-k Ω , 1/4-W resistor
1	R5	49.9-k Ω , 1%, 1/4-W resistor
1	R6	121-k Ω , 1/4-W resistor
1	R7	20-k Ω , 1/4-W resistor
1	R8	4.02-k Ω , 1%, 1/4-W resistor
1	R9	500- Ω trim pot
1	R10	499- Ω , 1%, 1/4-W resistor
1	C1	0.01- μ F, 25-V capacitor (disk)
1	C2	10- μ F, 25-V electrolytic capacitor
1	C3	330-pF, 25-V capacitor (disk)
1	U1-U5	LT101A op amp (Linear Technology)
1	U7	ADC0804 A/D IC (National Semiconductor)
1	U6	LM334 op amp (National Semiconductor)
1	SW-1	SPST toggle switch
1	S1	Sensym SX01DN pressure sensor

Toxic-gas sensor

A danger always exists when combustible gases such as propane or gasoline are confined in a small area. The toxic-gas alarm shown in Fig. 1-45 uses a tin-oxide-semiconductor sensor. A thin filament coil is heated from a 12-V battery via IC1 and IC2, which pulses the voltage to the sensor coil, thus saving a considerable amount of energy. Zener diode D1 provides a constant filament-supply voltage to the sensor coil. The sensor's resistance lowers as the sensor is exposed to toxic gases, such as hydrogen, carbon monoxide, and propane. As the sensor's resistance decreases, the gate voltage to the SCR increases. When the threshold voltage on the gate is reached, the SCR fires and an alarm buzzer is activated. Once triggered, the buzzer sounds and switch S1 must be used to reset the alarm. Because the sensor has a fair amount of thermal inertia, S1 should be in the OFF or OPEN position for about three or four minutes upon initial power-up, allowing the sensor to stabilize, thus preventing false alarms. The sensitivity control R7 is adjusted to the desired value prior to triggering the SCR.

The toxic-gas alarm is sensitive to less than 100 ppm of carbon monoxide. This simple gas alarm is useful for boats, basements,

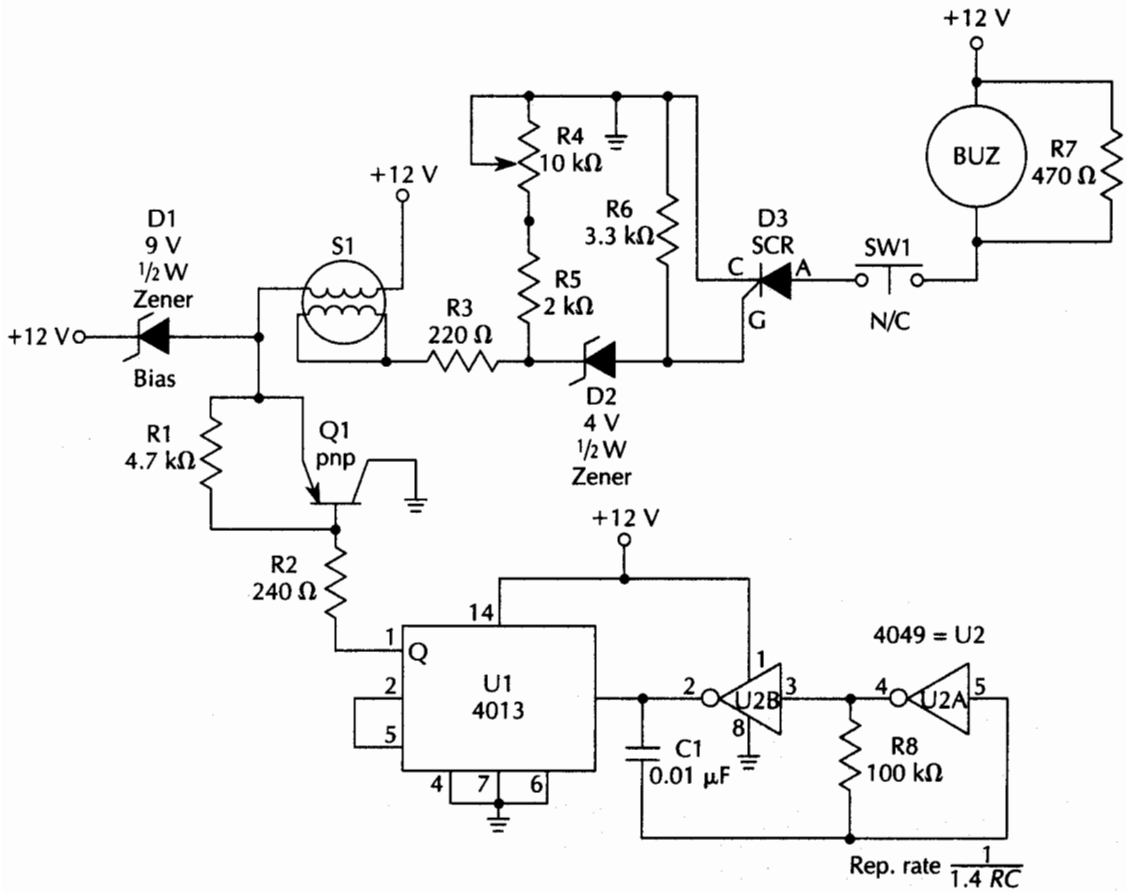


Fig. 1-45 Toxic-gas sensor.

and cabins. It could save a life. Some of the companies listed in the Appendix offer plans and kits for various toxic-gas sensors.

Toxic-gas sensor parts list

Quantity	Part	Description
1	R1	4.7-k Ω , 1/4-W resistor
1	R2	240- Ω , 1/4-W resistor
1	R3	220- Ω , 1/4-W resistor
1	R4	10-k Ω , 1/4-W potentiometer
1	R5	2-k Ω , 1/4-W resistor
1	R6	3.3-k Ω , 1/4-W resistor
1	R7	470- Ω , 1/4-W resistor
1	R8	100-k Ω , 1/4-W resistor

Quantity	Part	Description
1	C1	0.01- μ F, 25-V capacitor (disk)
1	D1	9-V zener diode (NTE139A)
1	D2	4-V zener diode (NTE5068A)
1	D3	SCR (NTE5408)
1	Q1	2N2222 transistor
1	U1	CD4013 CMOS flip-flop
1	U2	CD4049 CMOS hex inverter
1	BUZ	6–9V piezo buzzer
1	S1	Toxic-gas sensor TGS203 (Figaro or equivalent)

Humidity sensor

The recently introduced *hygristor* allows the design of low-cost, rapid-response, humidity-sensing devices. A hygristor is a sensing device that changes its electrical resistance with changes in the ambient humidity. Typical applications for the hygristor include portable weather instruments, weather sondes, greenhouse sensors, environmental sensors, dew-point sensors, and soil and agriculture monitoring devices. Our sample hygristor, shown in Fig. 1-46, was a 2-inch \times ½-inch deposited-film, plastic-type sensor that measures relative humidity from 0 to 100% within a 2-second response time. The hygristor operates from -40°C to $+50^{\circ}\text{C}$, with an operational resistance that varies from 10 k Ω to 100 k Ω .

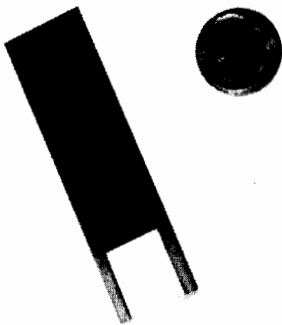


Fig. 1-46 Humidity sensor.

The circuit shown in Fig. 1-47 depicts a typical hygristor connected to an ohms-to-voltage converter. The humidity sensor is coupled through a 100-k Ω resistor to one half of an LF353 op amp. Pin 3 of the op amp is clamped via the two 1N914 diodes. The output of section A of the op amp is then fed to section B via pin 5. A

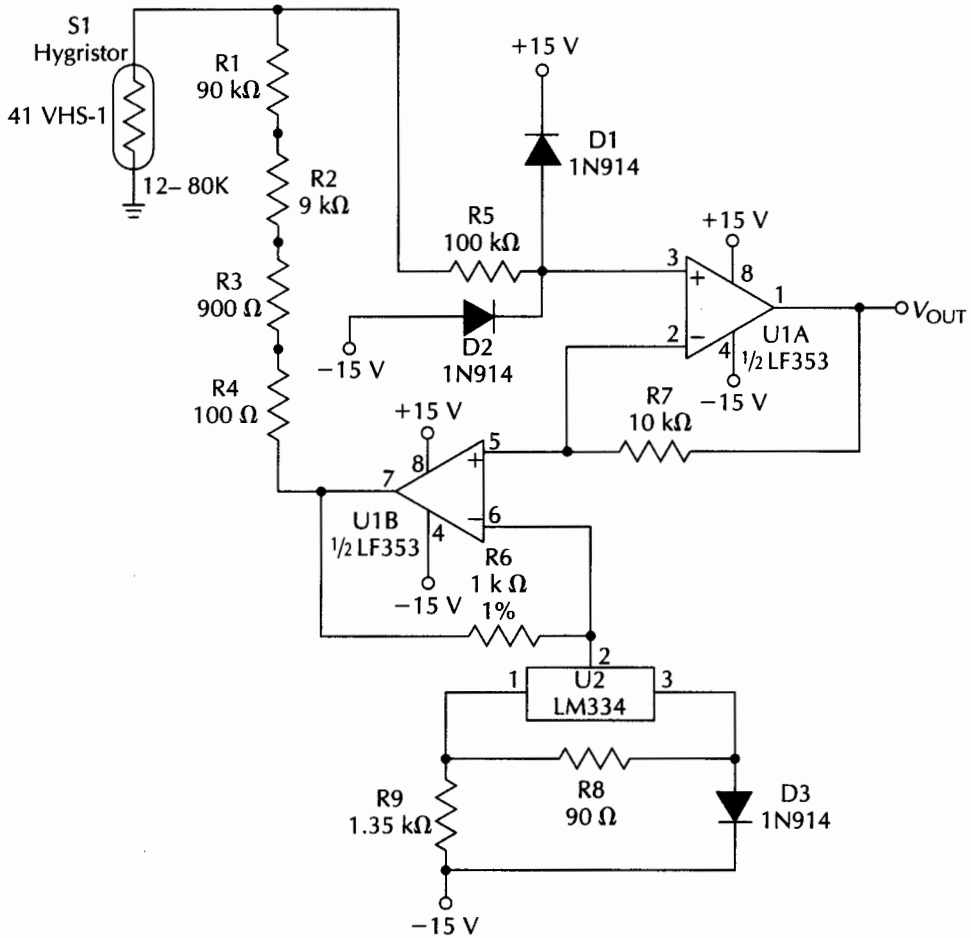


Fig. 1-47 Humidity sensor diagram.

100-k Ω resistive ladder couples the sensor to pin 7 of the LF353. A compensation network is connected to pin 6 of the IC. Note the 1-k Ω , 1% resistor between pins 6 and 7. The output of the op amp on pin 1 is a dc voltage that can be read with a digital panel meter, a data logger, or an A/D card placed in a computer. A plus-and-minus power supply is required for this circuit.

The manufacturer of the hygistor offers various custom resistance values and a variety of mechanical packages. Calibrating the humidity sensor circuit and converter can be accomplished by using a known reference source. Samples of the hygistors are available directly from the manufacturer listed in the Appendix.

Humidity sensor parts lists

Quantity	Part	Description
1	R1	90-k Ω , 1%, 1/4-W resistor
1	R2	9-k Ω , 1%, 1/4-W resistor
1	R3	900- Ω , 1%, 1/4-W resistor
1	R4	100- Ω , 1%, 1/4-W resistor
1	R5	100-k Ω , 1%, 1/4-W resistor
1	R6	1-k Ω , 1%, 1/4-W resistor
1	R7	10-k Ω , 1%, 1/4-W resistor
1	R8	90- Ω , 1%, 1/4-W resistor
1	R9	1.35-k Ω , 1%, 1/4-W resistor
3	D1, D2, D3	1N914 silicon diode
1	U1	LF353 op amp (National Semiconductor)
1	U2	LM334 op amp (National Semiconductor)
1	S1	41-VHS-1 hygristor (Victory Engineering)

Fiberoptic sensing

Counting and position sensing can be implemented using a bifurcated fiberoptic light pipe (see Figs. 1-48 and 1-49). Two polished fiberoptic pipes are fused together at the junction of the two light pipes. A single emerging light pipe is used as a sensing head, which can be used to count very small parts or calibrated markings or rulings such as microscope gradations. The fiberoptic sensor can be used to keep track of both linear and rotary tables or stages.

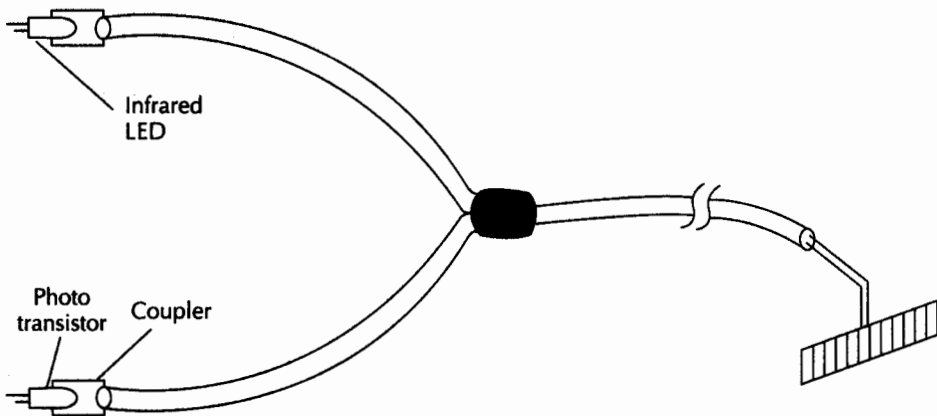
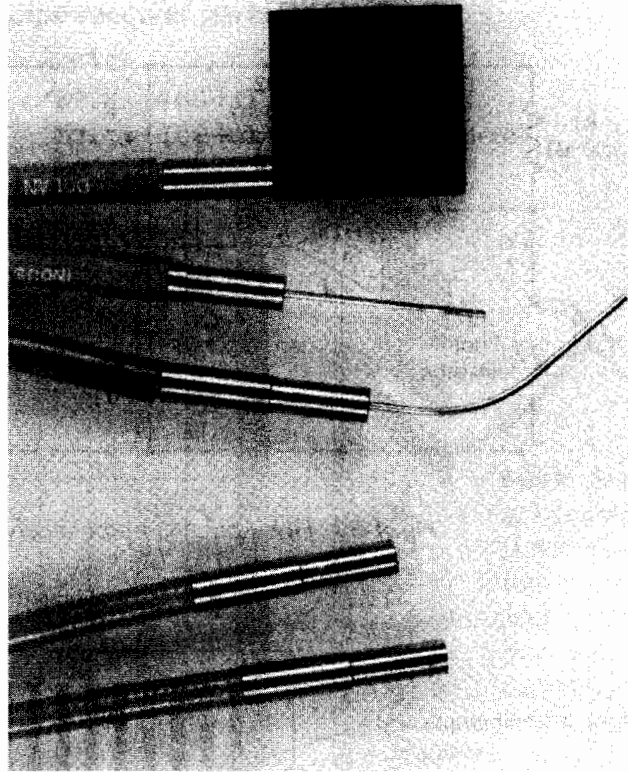


Fig. 1-48 Bifurcated light-pipe drawing.

Fig. 1-49 *Bifurcated light pipes.*



An infrared LED is placed at one end of the two light pipes as shown. A phototransistor is then placed at the other end of the two light pipes. The output of the phototransistor is coupled to a light-detector interface, shown in Fig. 1-50. The phototransistor is fed to the 741 op amp, which amplifies the phototransistor's output signal. The output of the op amp is then passed to a 555 timer IC, which outputs a precise 5-V pulse. The output of this pulse shaper can be sent to an I/O counter card placed in a personal computer.

To provide direction or position data, a second light-pipe assembly would be needed. The two light-head assemblies are placed next to each other. One sensing head would be aligned on an opaque ruled line. The second light-pipe head assembly would be mounted precisely in between the next ruling or marking, as shown in Fig. 1-51. By using the two light-pipe assemblies, we have created a rotary optical encoder with quadrature output, which can sense direction and counts in one operation. The two light-interface outputs could be connected to the input of the rotary optical interface to obtain steering logic, which determines directional data.

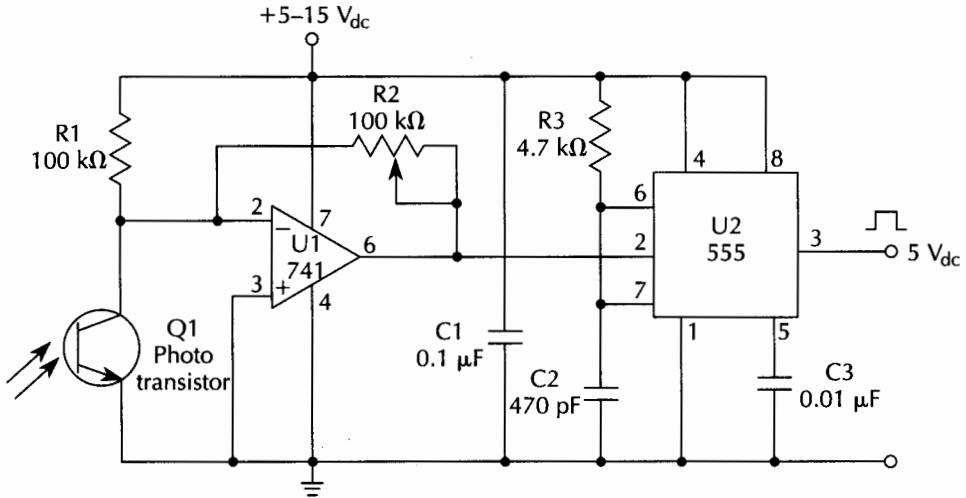


Fig. 1-50 *Fiberoptic light-pipe receiver.*

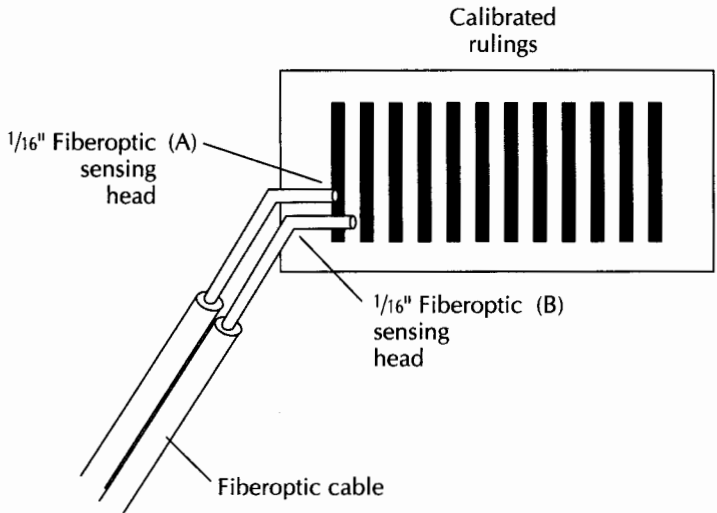


Fig. 1-51 *Direction-sensing light pipes.*

As noted earlier, if you were to obtain a more expensive type of PC counting card, this steering-logic circuit could be eliminated and the light interfaces could be coupled directly to the counter card, which has built-in quadrature-input sensing. The bifurcated light pipes are available in many configurations from 1/8-inch round and square types to the long-nosed micro 1/16-inch-type heads. These fiberoptic sensing heads are ideal for micro-positioning, optical microscope stages, etc.

Fiberoptic light-pipe receiver parts list

Quantity	Part	Description
1	R1	100-k Ω , ¼-W resistor
1	R2	100-k Ω , ¼-W potentiometer
1	R3	4.7-k Ω , ¼-W resistor
1	C1	0.1- μ F, 25-V capacitor
1	C2	470-pF, 25-V capacitor (disk)
1	Q1	Phototransistor (NTE3031)
1	U1	UA741 op amp
1	U2	555 IC timer

Optical rotary encoder

The optical rotary encoder is ideal for digital panel controls or in position-sensing applications where long life, reliability, high resolution, and precise linearity are critical. Rotary optical encoders are often used in computer-aided design/computer-aided manufacturing (CAD/CAM) counting circuits, instrumentation, motor speed controls, and machine tools. The Bourns EN series optical encoder, as shown in Figs. 1-52 and 1-53, is a 1-inch-square device that converts rotary input into electrical signals that can be used by microprocessors without the use of A/D converters.

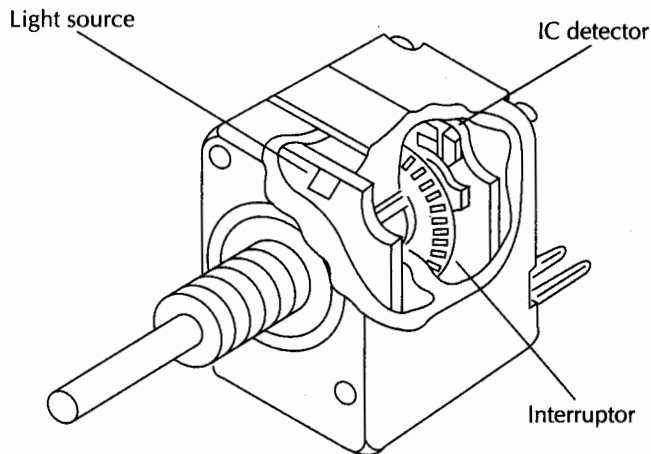


Fig. 1-52 Optical rotary encoder.

Optical rotary encoders (OREs) combine an LED light source, a photo interrupter disk, and an IC light receiver. Light passing through the slots in the interrupter are sensed and translated into

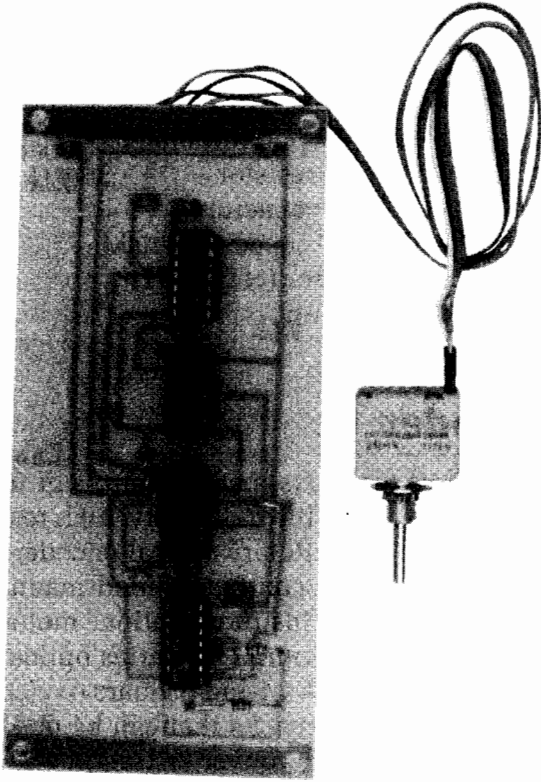


Fig. 1-53 Encoders and interface.

digital pulses by the phototransistor detector. The ORE has no contacts or wipers that create electrical noise, and they can be operated at high speeds. The EN series encoders use a standard $\frac{1}{4}$ -inch shaft for easy panel mounting.

The ORE provides a quadrature, or two-channel output, as shown in Fig. 1-54. Channel A is shown leading channel B by 90 electrical degrees. ORE outputs are compatible with both CMOS and TTL systems. Up to 256 quadrature output cycles per shift revolution are provided with this system. The quadrature output allows the ORE to determine direction and produce counting pulses with additional electronics, as shown in Fig. 1-55. The quadrature output of the ORE's are $5 V_{dc}$. The A and B signal outputs from the encoders are coupled to two Schmitt triggers that, in turn, feed three NAND gates. Gates A and B connect to a 7474 flip-flop that provides direction output. NAND gate C of the steering logic connects to a Schmitt gate and then to a series of inverters to provide a small time delay. The output from the 74LS04 is then available to provide counting pulses. The resultant 5-V pulses can drive an I/O card in a personal computer.

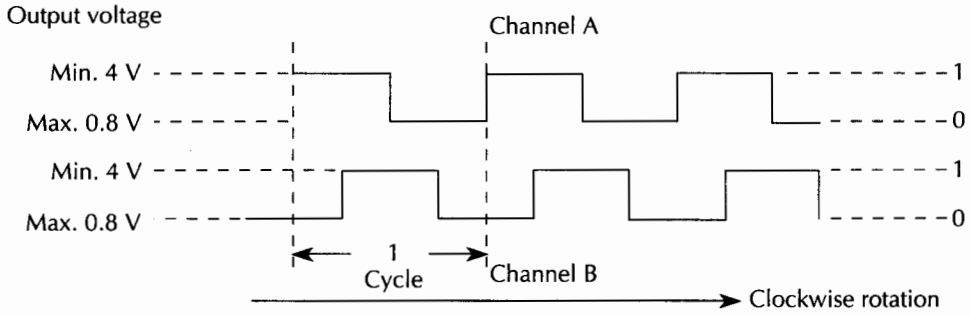


Fig. 1-54 Quadrature-output logic diagram.

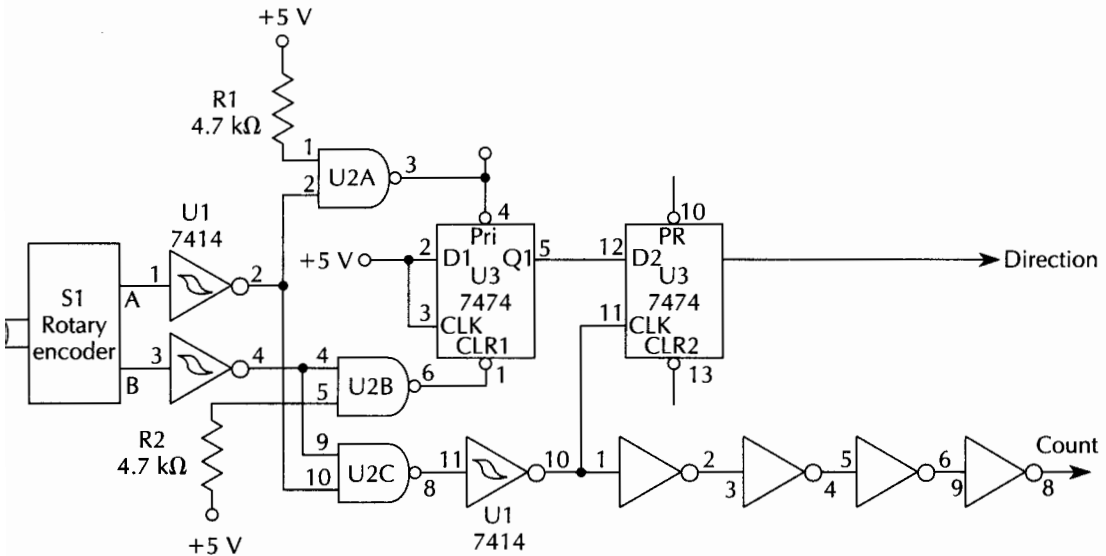


Fig. 1-55 Rotary-encoder steering logic diagram.

Counting cards are available to direct rotary encoder input, thus eliminating the interface shown. The Bourns optical rotary encoders are available in various resolutions and mounting assemblies. Optical rotary encoders are used extensively in position-sensing applications where a gear could be pieced on the encoder shaft, allowing it to interface with moving tables, rotating shifts, or stepper motors.

Rotary-encoder steering logic parts list

Quantity	Part	Description
2	R1, R2	4.7-k Ω , 1/4-W resistor
1	U1	7414 hex Schmitt trigger

Quantity	Part	Description
1	U2	7400 quad NAND gate
1	U3	7474 flip-flop
1	U4	7404 hex inverter
1	S1	Bourns optical rotary encoder

Film strip position sensor

A low-cost film strip position sensor is easy to construct. It can be used to make measurements on devices that will not tolerate loading or drag. Most sensors such as linear variable differential transformers (LVDTs) and resistive encoders inherently cause loading. The film position sensor can be placed in very small spaces, where other types of sensors would be too large, as in micropositioners or microscope stages.

The principle of the film strip position sensor is quite simple. First construct the film strip, which varies linearly in opacity along its length. Then attach the film strip to a moving part and position it so it can modulate the light beam of a slotted optical switch. Generally, it is quite difficult to make a film strip with precise linearly varying density. However, a simple solution to this problem consists of a pattern of opaque bars spaced on 0.01-inch centers, as shown in Fig. 1-56. Varying the spacing from 0 to 100% from one end of the strip to the other essentially creates an optical-pulse-width-modulated output. The 0.01-inch spacing appears to be adequate for this type of detector, because the LED and phototransistor dice or substrate are about 0.05 inch apart.

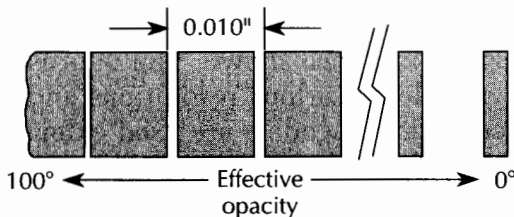


Fig. 1-56 Film strip position sensor.

The film-strip pattern can be manually drawn or computer generated on paper or mylar and then photographically reduced. A high-quality image is not required for this sensor to operate.

Figure 1-57 illustrates placement of the film strip in a typical optical switch assembly. The width of the slot is 0.01 inch; therefore mechanical tolerance is not critical. The electronic interface for the film strip position sensor is shown in Fig. 1-58. An LM317L voltage regulator provides a constant 20 mA of current to the LED in the optical switch. At this level, the full-scale current of the phototransistor may vary from 0.2 mA to 1 mA. The 5-k Ω potentiometer is adjusted to provide 1 V full scale. To obtain the best linearity for the system, the voltage across the 5-k Ω potentiometer should be kept to a low value. The voltage from the 5-k Ω pot is then sent to an LM358 op amp. The voltage is amplified by the op amp to provide a full 0–10 V_{dc} output. The gain of the op amp is set by the ratio of RA and RB. The output of the interface can then be connected to a digital panel meter or an A/D card placed in a personal computer. The film strip position sensor is ideal for miniature devices that can be loaded by external components and where low cost is of great importance.

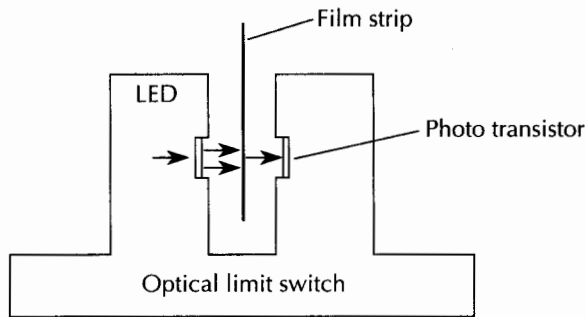


Fig. 1-57 Optical position switch.

Optical-position light-wave receiver parts list

Quantity	Part	Description
1	R1	62- Ω , 1/4-W resistor
1	R2	5-k Ω potentiometer
1	RA	1-k Ω , 1/4-W resistor
1	RB	9.1-k Ω , 1/4-W resistor
1	U1	LM317L op amp (National Semiconductor)
1	U2	LM358 op amp (National Semiconductor)
1	OC-1	M5T-8 optical coupler

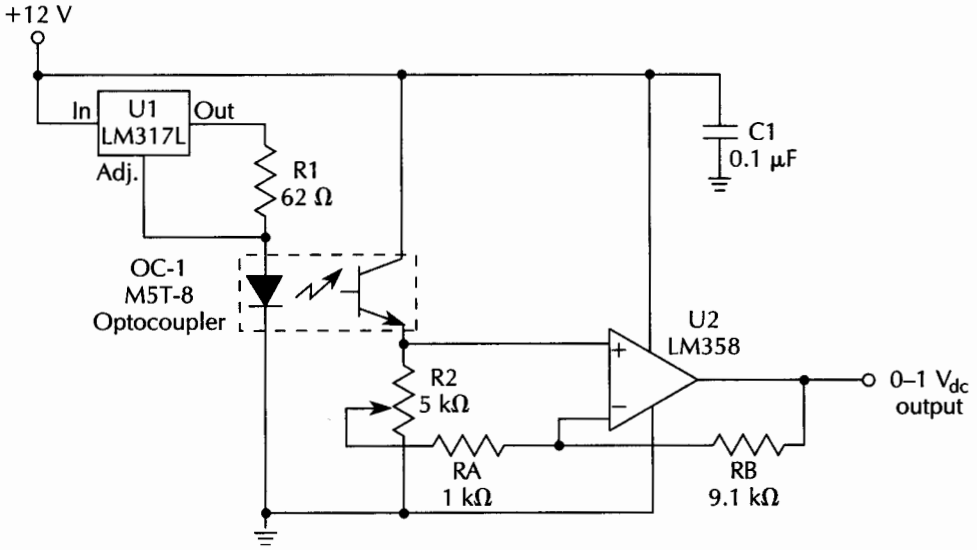


Fig. 1-58 Optical position light-wave receiver.

Tiltmeter

Electronic tiltmeters and levels have been around for about 40 years. However, most people know little about them and most have seldom seen or used them in sensing applications. Figure 1-59 illustrates a simple electronic level. This novel level uses two common mercury switches, two LEDs, and two penlight cells. Mount the two mercury switches on a 1½- x-6-inch-long,

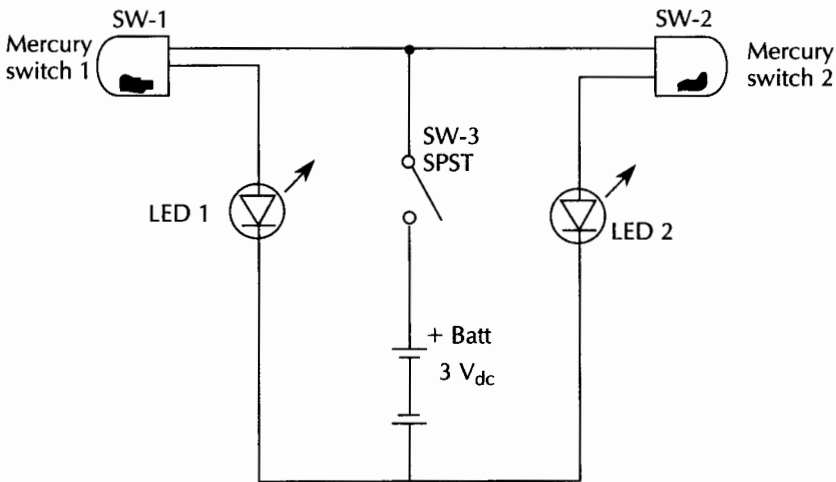
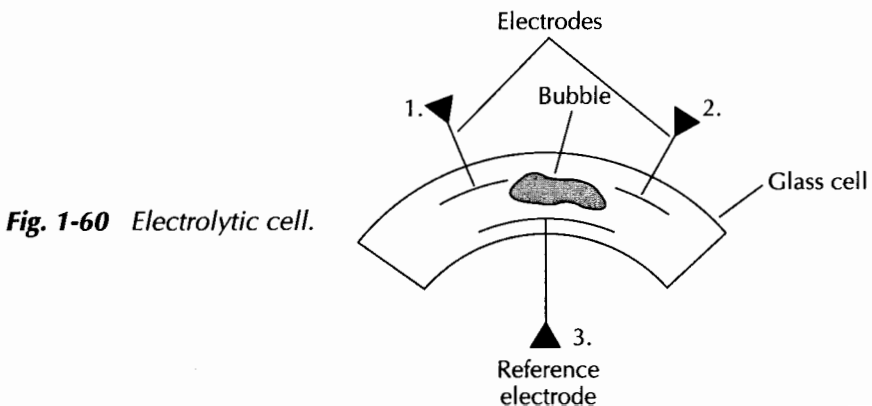


Fig. 1-59 Electronic level.

absolutely flat board, one at each end of the board. The LEDs, switch, and batteries are mounted in a small plastic box attached to the center of the level board. Place the level on an unknown surface. If one LED lights, the surface is not level. If both LEDs light, the surface is level. This type of on-off level is often used to level or position large machinery.

Electrolytic levels and tiltmeters have been around since the late 1930s and early 1940s. They were originally developed for bomb-sighting equipment and aircraft navigation. In recent years, electrolytic or bubble tiltmeters have been used in drilling equipment, seismic sensors, crane leveling, and navigation systems.

The electrolytic cell is composed of a glass cell or enclosed tube with three internal platinum electrodes. The platinum electrodes are partially sheathed with a thin glass bead. The bead insulates a portion of the electrodes to ensure that the bubble will ride on the undistorted portion of the vial, because the vials are usually curved. The glass vials are hand constructed. After the electrodes are installed, the vial is partially filled with a conductive fluid (electrolyte) and then hermetically sealed. A typical electrolytic cell is shown in Fig. 1-60. The glass cell is constructed in such a way that one of the electrodes is always immersed in the electrolyte. This reference electrode is usually placed at the bottom of the vial. The remaining two electrodes are placed on the top of the cell so that either electrode is immersed in liquid, depending on the tilt angle. Thus, a change is established between either electrode and the reference electrode. The many variations of the electrolytic-bubble tiltmeters have slightly different characteristic curves and linearities, including the precision toroid tiltmeter cell, which is highly resistant to vibration and movement and is often used in helicopters for attitude control.



One method of measuring tilt angles is to use an LVDT (linear variable differential transformer) signal-conditioner integrated circuit paired with an electrolytic tiltmeter cell (see Figs. 1-61 and 1-62). The heart of the precision tiltmeter is the Analog Devices AD598 integrated circuit. This signal-conditioner chip is commonly used with a coil assembly to measure precise linear displacement. The tiltmeter circuit shown substitutes the electrolytic cell for the coil assembly. The 20-pin LVDT signal-conditioner chip contains a low-distortion sine-wave oscillator, a decoder, divider, summer, filter, and amplifier. The sine-wave output drives the electrolytic cell. The decoder then determines the ratio of difference between the signals on pins 10 and 11. The signals are then divided and summed into one signal that is then filtered and amplified. A precise dc voltage output is proportional to the tilt-angle of the electrolytic cell. The tilt-angle output voltage is presented on pins 16 and 17. This novel circuit can be combined with a digital voltmeter, or the circuit could be connected to a data logger or to an A/D card placed in a personal computer.

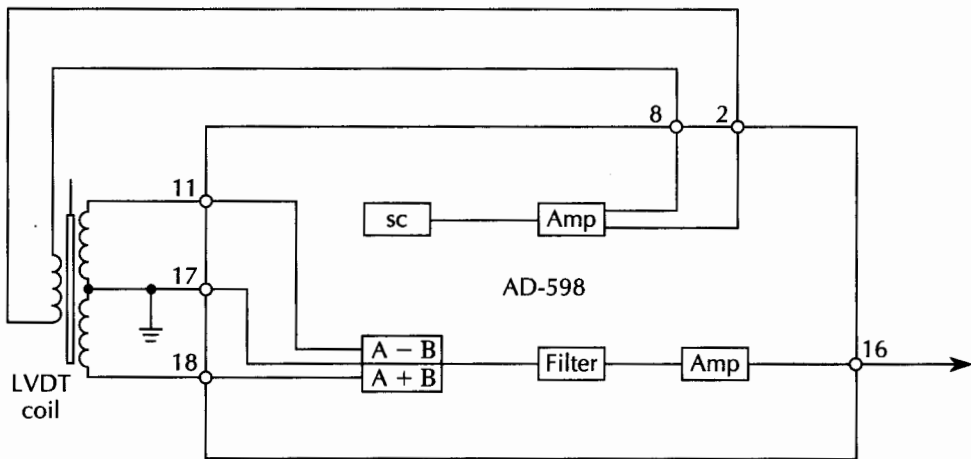


Fig. 1-61 LVDT signal-conditioner chip.

A simple magnetic tiltmeter can be fabricated using a small magnet suspended from a movable cylinder that is free to swing to and fro. The cylinder is attached to both ends of a small box via a bearing set on each side of the box, as shown in Fig. 1-63. The magnet is allowed to swing over a linear Hall-effect sensor. The Hall-effect sensor, an Allegro Systems UGN3501, consists of a Hall cell, a linear amplifier, a voltage follower, and a voltage regulator, all packaged in a three-lead device. The Hall-effect

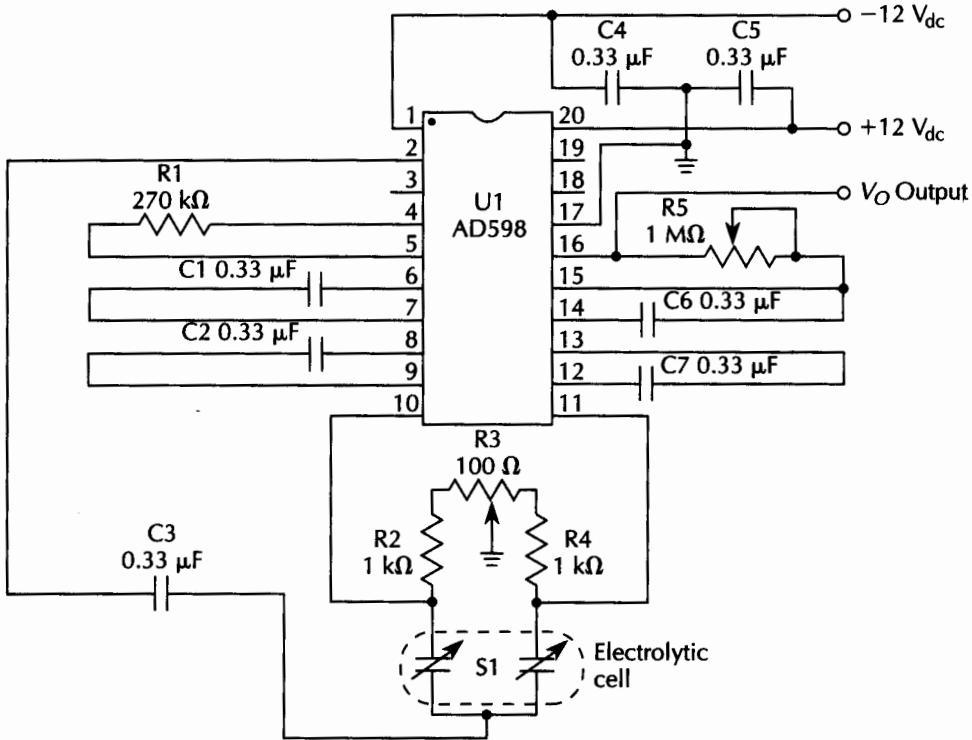
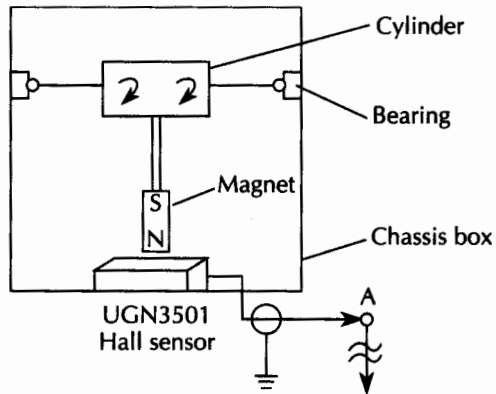


Fig. 1-62 LVDT tiltmeter system.

Fig. 1-63 Magnetic tiltmeter.



sensor is coupled to an LM741 op amp as shown in Fig. 1-64. The output of the op amp provides a proportional dc voltage that depends upon the tilt of the magnet over the Hall cell.

Yet another approach to measuring tilt angles uses a micro-power LED suspended over a position-sensitive detector (PSD) mounted in a small light-tight enclosure (see Figs. 1-65 and 1-66).

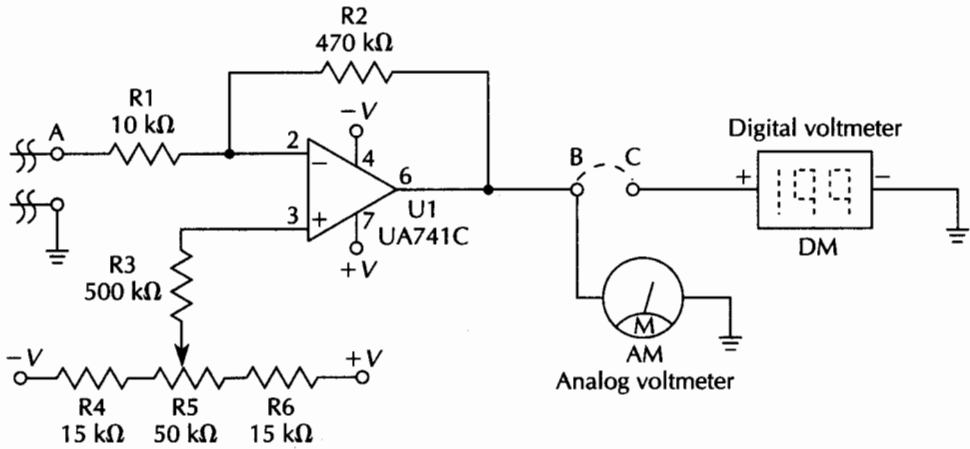


Fig. 1-64 Magnetic-tiltmeter electronic circuit diagram.

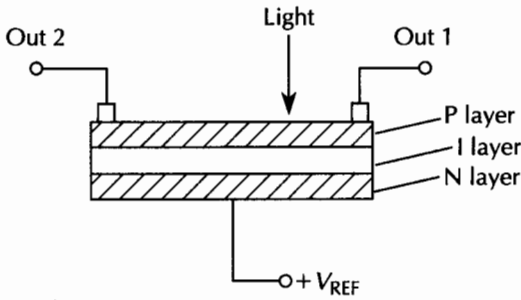


Fig. 1-65 Position-sensitive detector.

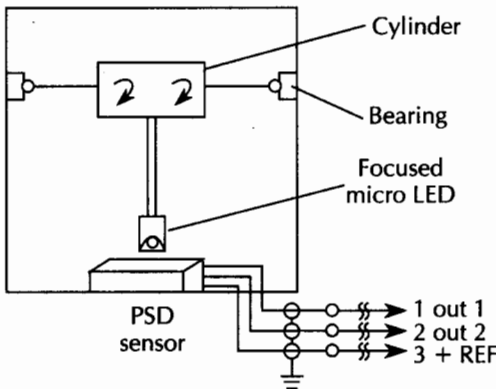


Fig. 1-66 PSD tiltmeter.

The PSD is a linear-displacement sensor, which produces a dc voltage proportional to position of the light source over the sensor. This device is discussed elsewhere in this book. The PSD displacement sensor is a three-lead device that requires some additional support circuitry, as shown in Fig. 1-67. The op-amp circuit

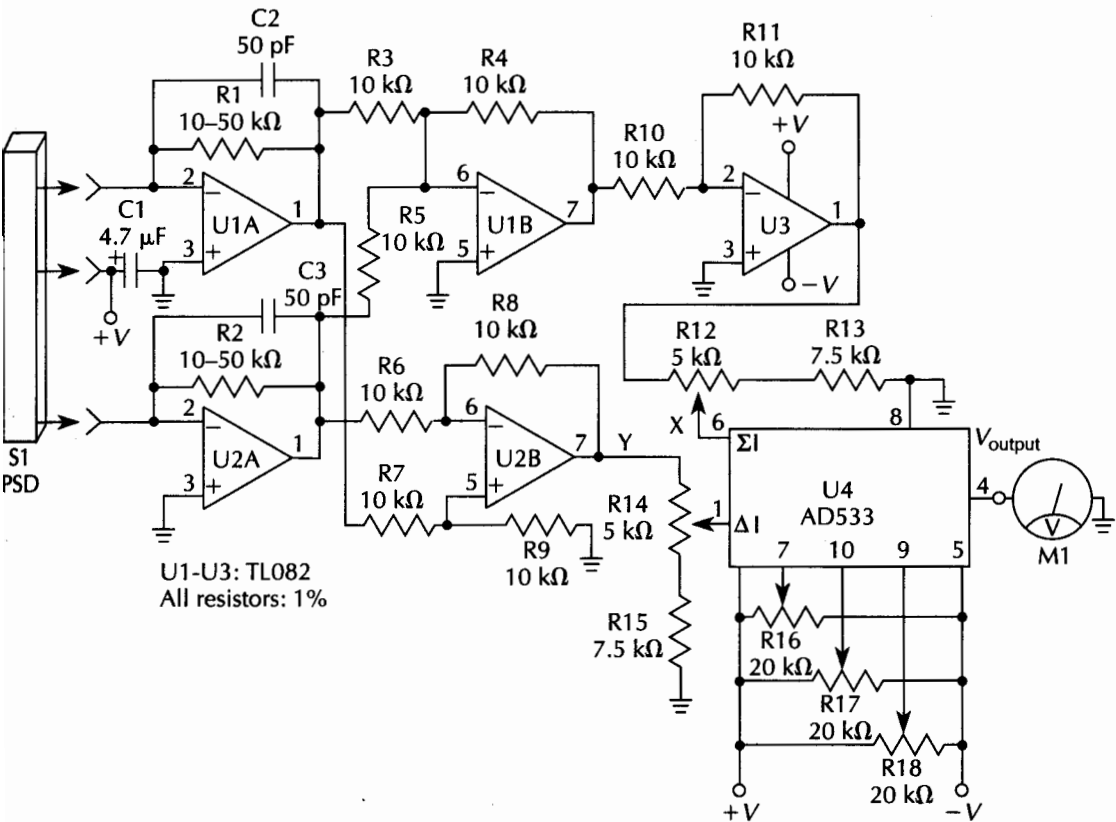


Fig. 1-67 PSD-tiltmeter interface.

uses an Analog Devices AD533 multiplier/divider integrated circuit. The 10-k Ω to 50-k Ω input resistors are adjusted per your particular circuit parameters. This circuit requires 1% resistors for precision output voltages. The output of the PSD signal conditioner yields a proportional dc voltage between 1 and 10 V. The output could be coupled to a digital meter or A/D card if desired.

Other approaches to measuring tilt angles include resistive displacement and capacitive measurements. Tiltmeters are used in many applications all around us, but they are seldom visible and are therefore taken for granted.

Electronic level parts list

Quantity	Part	Description
2	SW-1, SW-2	Glass mercury switches
1	SW-3	SPST toggle switch
2	LED-1, LED-2	Red LEDs

Quantity	Part	Description
2	BATT	AA penlight cells
1	BH	Battery holder for two batteries

Tiltmeter system parts list

Quantity	Part	Description
1	R1	270-k Ω , 1/4-W resistor
2	R2, R4	1-k Ω , 1/4-W resistor
1	R3	100- Ω , 1/4-W potentiometer
1	R5	1-M Ω , 1/4-W potentiometer
7	C1-C7	0.33- μ F, 25-V capacitor
1	U1	AD598 LVDT signal conditioner (Analog devices)
1	S1	Electrolytic sensor (Fredericks)

Magnetic tiltmeter electronics parts list

Quantity	Part	Description
1	R1	10-k Ω , 1/4-W resistor
1	R2	470-k Ω , 1/4-W resistor
1	R3	500-k Ω , 1/4-W resistor
2	R4, R6	15-k Ω , 1/4-W resistor
1	R5	50-k Ω , 1/4-W trim pot
1	U1	UA741C op amp
1	AM or DM	1–10 V _{dc} Analog voltmeter 1–10 V _{dc} Digital voltmeter

PSD Tiltmeter parts list

Quantity	Part	Description
2	R1, R2	10-k Ω –50-k Ω scaling resistors
9	R3-R11	10-k Ω , 1%, 1/4-W resistors
2	R12, R14	5-k Ω , trim pots
2	R13, R15	7.5-k Ω , 1%, 1/4-W resistors
3	R16, R17, R18	20-k Ω , 1/4-W trim pots
1	C1	4.7- μ F, 25-V electrolytic capacitor
3	U1-U3	TL082 op amp (T1)
1	U4	AD533 (Analog Devices)
1	M	1–10 V _{dc} voltmeter

Earth-movement sensor

A seismometer is an intriguing device. It's hard to believe that a sensor could be sensitive enough to detect ground vibrations halfway around the earth. A seismometer, or earth-movement sensor, is shown in Fig. 1-68.

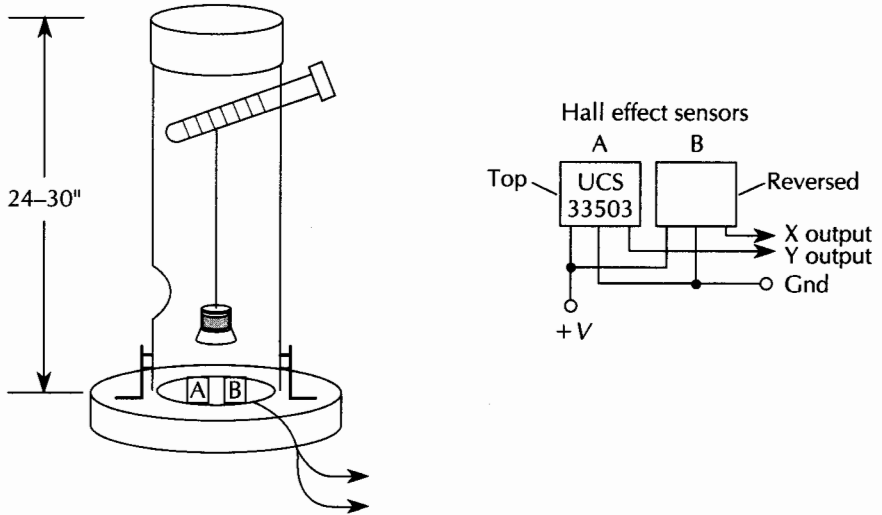


Fig. 1-68 Earth-movement sensor.

The seismometer is an uncomplicated but sensitive magnetic pendulum detector. While this sensor will not pick up earthquakes on the opposite side of the globe, it has been used to pick up nuclear underground testing a few states away. The heart of the pendulum detector is a 3-foot-long \times 3-inch diameter PVC tube that houses the pendulum detector. The pendulum must be free to swing unaffected by air currents or movements of the PVC outer tube. The pendulum must be placed in a draft-free, quiet, stable location to operate correctly. The easiest solution to these requirements is a PVC housing mounted to a large round plywood base that is anchored to a concrete slab. Place a cap on the top end of the PVC tube. Next, drill a hole near the cap to accept a long screw that goes through the tube, as shown, to adjust the pendulum height above the detector. Drill a second hole near the bottom of the tube to provide viewing and sensor alignment.

Place a small clear plastic cover over this hole to prevent air currents from affecting the pendulum. Attach a large round plywood base treated with a protective coating, to the PVC. Use three right-angle brackets to attach the tube to the plywood base. Secure the wooden base to a concrete slab to prevent the wooden base and sensor from "dancing" about on the floor in the case of a strong motion event.

The electronics of the earth-movement sensor include two Hall-effect sensors (see Fig. 1-69). Place the two or three-lead Hall sensors at the base of the PVC tube assembly. Place both sensors flat-side down next to each other. Place one face up, i.e., writing up, and flip over the other sensor and connect the leads as shown. Sensor A has a positive output while sensor B produces a negative output with a zero magnetic field. At the center position of the pendulum, the two outputs cancel. These two outputs provide a difference signal, which is further amplified via a TI TLC251 op amp. The gain of the op amp is set for 20. Connect the op-amp's output to a zero-centered voltmeter or bridge circuit. The earth movement will be displayed as a plus and minus swing of the meter.

Next, attach a small magnet to a length of fine string or thread. Wind the free end of the thread around the long screw at the top of the PVC tube. Allow the magnet to hang freely over the Hall sensors at the base of the PVC tube. Adjust the pendulum length so that the magnet is just over but not touching the sensors. Most seismic sensors use a damping scheme to quench excessive swinging movement. This can be accomplished either mechanically or electronically. One approach to damping the pendulum is to place a glass petri dish, filled with mineral oil, on top of the Hall sensors. Adjust the pendulum so that the magnet can swing freely in the mineral oil. The earth-movement sensor is now ready to sense ground movement. This sensor arrangement is very sensitive and, therefore, it should be located in a quiet site away from active living spaces, because it will pick up passing trucks and general nearby movement.

The electronics portion of the earth-movement sensor can also be used as a compass to detect magnetic north. Mount the sensors and the electronics in a small plastic box. Affix a compass rose to the top of the plastic box. Mount the sensors next to each other, perpendicular to the top of the box; i.e., the first side of the sensors are perpendicular to the around. The meter could then be read as the box is rotated. An indication will be given as the box is moved through north, and the compass rose will indi-

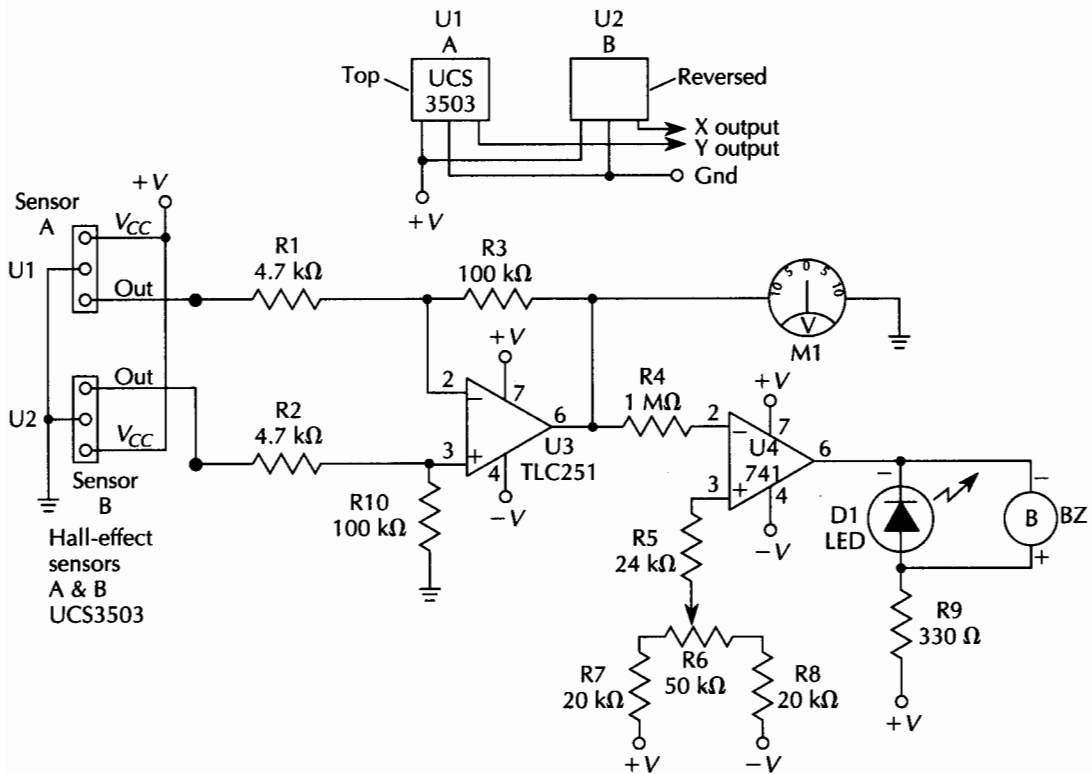


Fig. 1-69 Earth-movement-sensor electronics.

cate the other directions. An LED could be substituted for the meter in this application.

Earth-movement sensor parts list

Quantity	Part	Description
2	R1, R2	4.7-k Ω , ¼-W resistor
1	R3, R10	100-k Ω , ¼-W resistor
1	R4	1-M Ω , ¼-W resistor
1	R5	24-k Ω , ¼-W resistor
1	R6	50-k Ω ¼-W trim pot
2	R7, R8	20-k Ω , ¼-W resistor
1	R9	330- Ω , ¼-W resistor
1	D1	LED
2	U1, U2	UCS3503 Hall cells (Allegro Microsystems)
1	M	100-0-100 μ A meter
1	BZ	Piezo buzzer

New film sensor technology

THIN FILM SENSORS ARE RAPIDLY REVOLUTIONIZING THE FIELD OF sensor technology. The new Piezo film and force/position sensing films are being used in an ever-widening variety of sensing applications and they are beginning to appear in a number of new low-cost sensing products.

Piezo film sensors

Jacque and Pierre Currie first discovered that quartz crystals produced an electrical charge when deformed. They also discovered that the same crystals changed in dimension when subjected to an electric field. They termed the phenomenon, *piezoelectricity* from the Greek “pressure electricity.” One of the first practical applications of the phenomenon was for sonar use in detecting submarines in World War I. In the 1960s, piezoelectric effects were found in organic materials, such as human bones. It was later discovered that polymers, such as polarized homopolymer vinylidene fluoride, developed a highly active piezo response. In the 1970s, Penwalt Corporation developed an exciting new product called *Kynar* or *PVDF*, a piezoelectric film, and a new family of piezo and pyroelectric sensors was born.

The PVDF film can be used in a spectacular array of sensor applications, including magnetic switches, seismic sensors, level sensors, microphones, hydrophones, infrared sensors, optical shutters, and vibration sensors. Kynar film exhibits strong piezo and pyroelectric effects with a broad dynamic range and low acoustic impedance, which makes the PVDF film very attractive for low-cost sensor applications (see Fig. 2-1). The properties of the piezo film heavily depend on the degree and type of crystal structure.



Fig. 2-1 Polymer piezoelectric sensor.

PVDF or Kynar film begins with the deformation of crystallites, stretching the extruded PVDF film at temperatures below its melting point, which causes the unit cells to be packed in parallel planes, creating a polar beta phase. Next, the beta-phase polymer must be “polled.” Polling exposes the polymer to a high electrical field at elevated temperatures. The level of piezo activity depends upon the polling time, field strength, and temperature. The polling procedure provides a permanent orientation of the molecular dipoles within the polymer, (see Fig. 2-2).

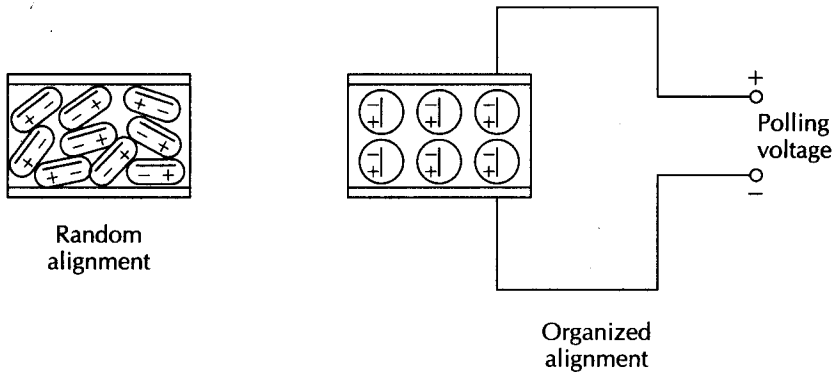


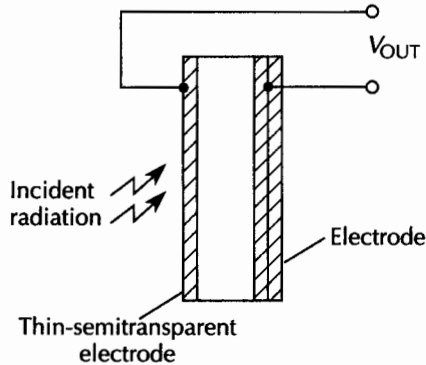
Fig. 2-2 Piezo-film process.

A working voltage applied to the electrodes of the piezo film causes the film to elongate or contract, depending on the polarity of the field. Exposing the film to an alternating field causes both contracting and elongation, one after the other in succession. Conversely, when an external force is applied to the film, the compressive or tensile strain develops a proportional voltage. Note the dual nature of piezoelectricity. The frequency response of the piezo film can vary from 0.005 Hz into the gigahertz re-

gion. Tension on the piezo film increases the volume of the material, thus changing the net charge distribution within the film. Under open-circuit conditions, the excess surface charges appear as a voltage difference between the film electrodes. Then, upon closing the circuit, electrons flow to reestablish electrical neutrality, thus producing a usable current. The piezo film requires no external electrical power and, in fact, is a voltage generator and can be used to directly trigger CMOS circuitry when used as a sensor.

The piezo film also acts as a pyroelectric transducer, which can detect thermal radiation. When thermal energy is absorbed, the film expands with the increasing temperature, resulting in a detectable deformation, and a corresponding charge is provided. The reverse effect occurs as the film is cooled. Methods of constructing a pyroelectric detector are shown in Fig. 2-3. A thin semitransparent electrode is used as a front electrode. The radiation passes into the piezo film, which strongly absorbs radiation in the 8–11 μm wavelength region. If an infrared-absorbing layer is added to the front electrode, the sensor becomes a broadband absorber of radiation (see Fig. 2-4).

Fig. 2-3 IR-sensing piezo film—type 1.



Pyroelectric-film sensors are now used extensively and are a preferred alarm sensor among alarm installers, because they generate few false alarms. Pyroelectric or infrared sensors can be made to detect humans and large animals up to 50 feet away, using a low-cost plastic Fresnel lens in front of the film sensor. Coverage can be adjusted to track a long narrow path ranging from 40 to 50 feet, or it can cover a wide area, but with a shortened distance range, depending upon the selected lens.

Piezo film is flexible, lightweight, and tough and is available in a wide variety of thicknesses and configurations. The film pro-

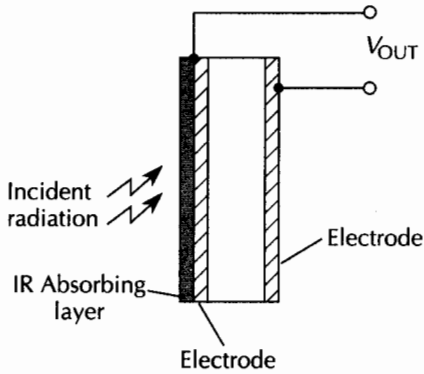


Fig. 2-4 IR-sensing piezo film—type 2.

duces a high output with a wide dynamic range, and it has excellent stability and repeatability at a relatively low cost. However, piezo film has a relatively low “Q,” which makes the film unsuitable to very low frequencies when compared to ceramic material. The Kynar film transducers are most efficient at higher frequency ranges, starting at 0.5 to 1 Hz.

A simple flex switch is shown in Fig. 2-5. A rectangular piece of metalized piezo film is bonded to a 5-mil polyester laminate. By flicking or bending the free end of the piezo film, an output is produced. The output is first positive as the polyester is stressed, then becomes negative as the stress is relieved and the film returns to its normal position.

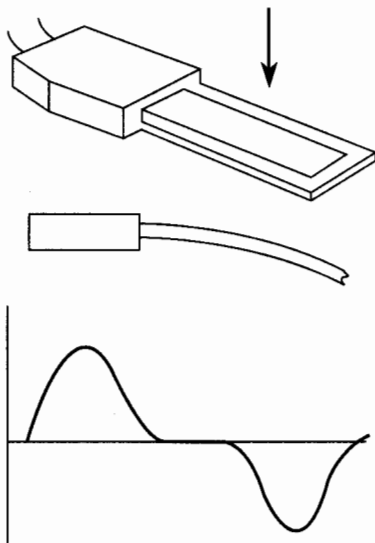


Fig. 2-5 Piezo flex switch.

The film can also be bonded to a strip of spring steel. This type of switch is appropriate when the input force is strong and constant for a period of time. A snap-action switch is shown in Fig. 2-6. Instead of flicking the switch to produce a high impact, you slowly push on the strip, to store up potential mechanical energy. When the strip no longer can withstand the mounting force, output is produced. This type of switch is formed by putting a crease or dimple in the spring-steel strip. This type of switch is also suited to temperature switching. The film is often attached to a bimetal strip, and the different temperature coefficients of the two types of metals flex the switch when heated.

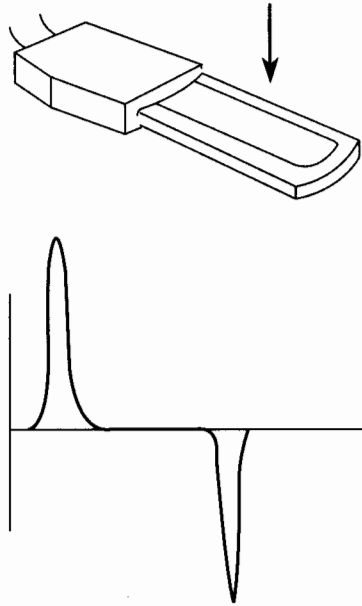


Fig. 2-6 Piezo snap-action switch.

The piezo film switch can easily be adapted into a magnetic switch by coating a polyester laminate with a ferrous layer or by bonding a metal strip to the polyester piezo film laminate. When a magnet is brought near the switch, the strip will flex, and produce an output (see Fig. 2-7). A variation to the magnetic switch is a sensor capable of measuring displacement velocity and/or acceleration. By using an aluminum strip bonded to a polyester piezo film laminate and then attaching a small weight to the free end of the strip, the device can measure vibration or acceleration.

A "singing switch" type sensor is shown in Fig. 2-8. This type of detector is a novel sensor based on two piezo film strips. One

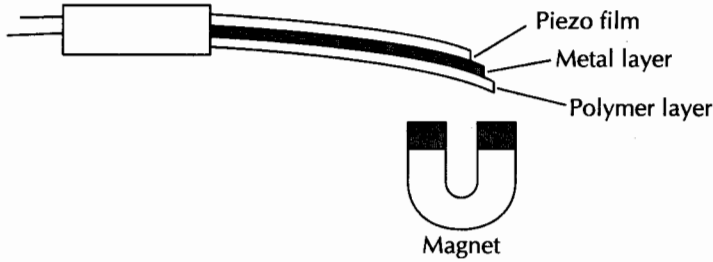


Fig. 2-7 Magnetic piezo switch.

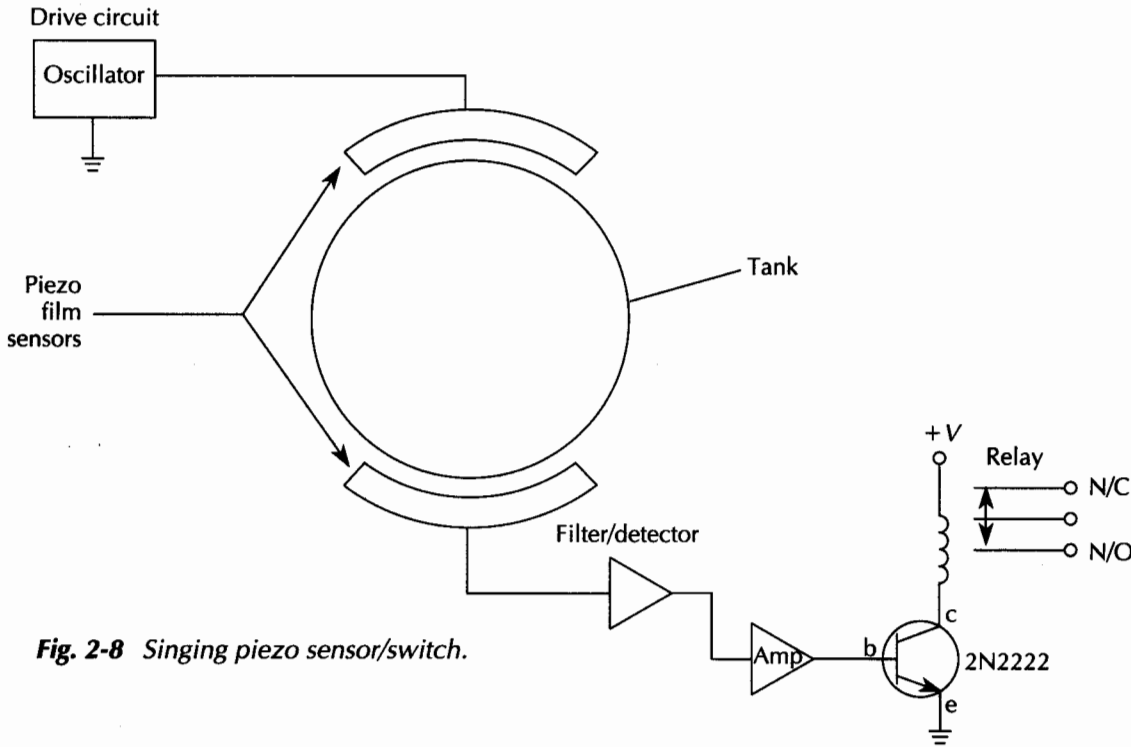


Fig. 2-8 Singing piezo sensor/switch.

piece is bonded to the inside of a tank or storage vessel, and the other strip is bonded to the outside of the container. One strip is excited with a low-frequency signal source, which is often heard in the audio range (thus, the name, "singing switch"). The second piece of piezo film is made to vibrate at its natural frequency, and it "listens" to the vibrations generated by the source. If the container is pressed (i.e., loaded or filled with a liquid), the frequency is altered and an output is created based on the frequency changes due to the liquid level changes. Picture a series of these piezo film

strips arranged vertically inside a large tank or storage vessel. A multiplexing scheme would be used to excite the film strips and interrogate the state of each of the sensor strips in succession.

By arranging a number of small piezo film strips end-to-end, it is possible to build a laser spot follower or precision position sensor. The sensor strips could be scanned and the energized piezo strip could then indicate the precise spot of a laser beam.

A few practical circuit examples employing piezo film are illustrated in Figs. 2-9 through 2-13. The first circuit in Fig. 2-9 depicts an op-amp interface acting as a charge amplifier. This circuit is best suited to small signal applications where low-level vibrations activate the film sensor. The signal level detector in Fig. 2-10, can be used in the presence of large signal-to-noise ratios. This circuit is appropriate for detecting large impacts among low-level vibrations or background noise.

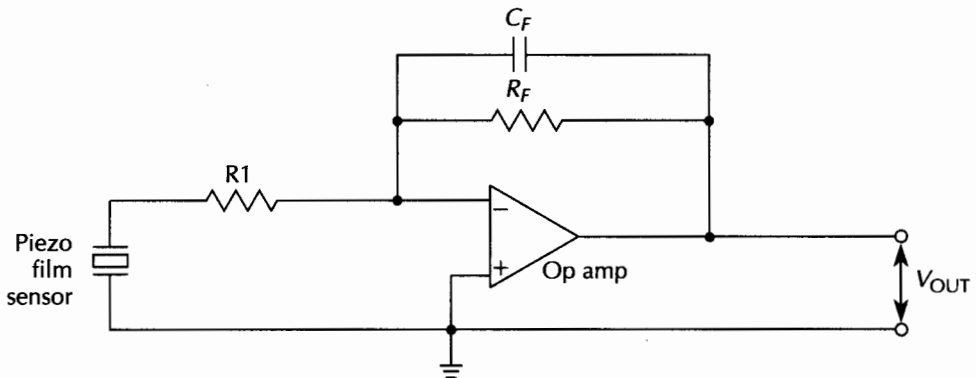


Fig. 2-9 Piezo-sensor op-amp amplifier.

Where the signal-to-noise ratios are low and where impacts or pressures must be discerned from the background, the circuit in Fig. 2-11 is recommended. This circuit uses a common mode-rejection technique based on two sensor switches that are mechanically coupled to cancel the unwanted vibrations that stimulate both sensors. An input or pressure on one switch, but not on the other, produces an output.

Figure 2-12 illustrates a CMOS circuit that senses a single impact or pressure. The flip-flop, once triggered, sounds an audio alarm. CMOS circuitry can be directly driven by the piezo sensor because the signal or voltage output is high level. Figure 2-13, shows a circuit that can sense multiple triggers or impacts and can be used in counting applications.

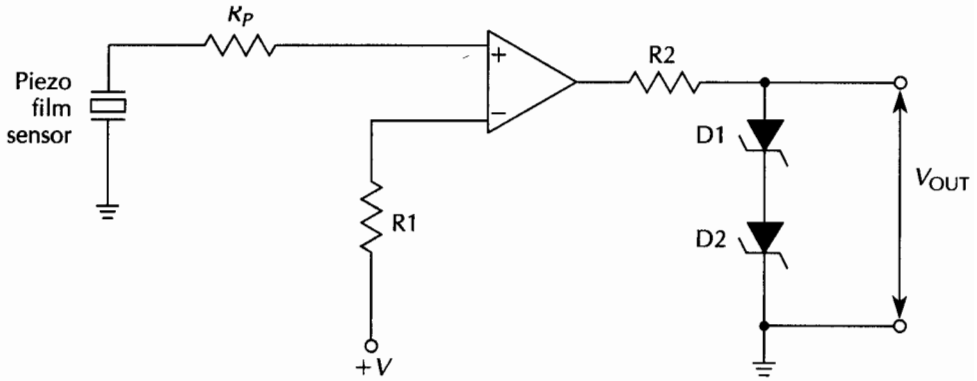


Fig. 2-10 Piezo level detector.

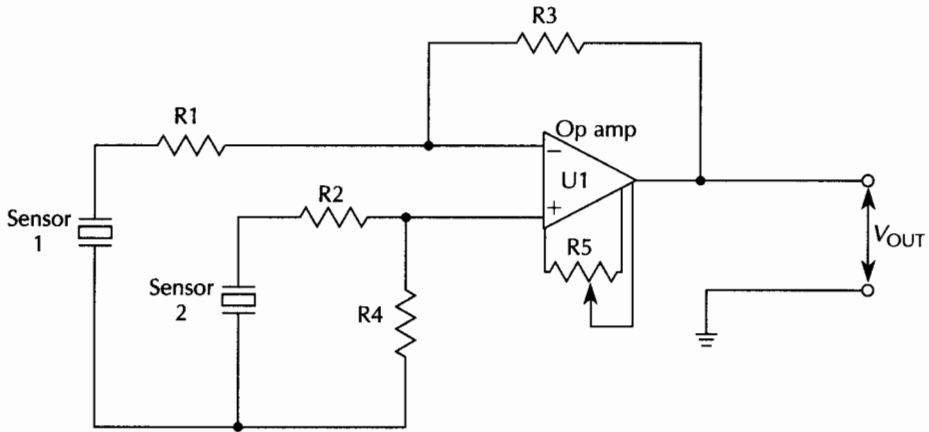


Fig. 2-11 Differential piezo op-amp amplifier.

The applications for piezoelectric film are limited only by your imagination. The following are some of the more well known applications for Kynar.

- | | |
|----------------------------|--------------------|
| Pushbutton switches | Microphones |
| Keyboards | Hydrophones |
| Magnetic switches | Transducers |
| Bimetal switches | Fence alarms |
| Vibration switches | Road switches |
| Accelerometers | Infrared sensors |
| Force | Fire/flame sensors |
| Level sensors | Optical shutters |
| Floormat security switches | Deformable mirrors |
| Fans | Speakers |
| Laser spot followers | |

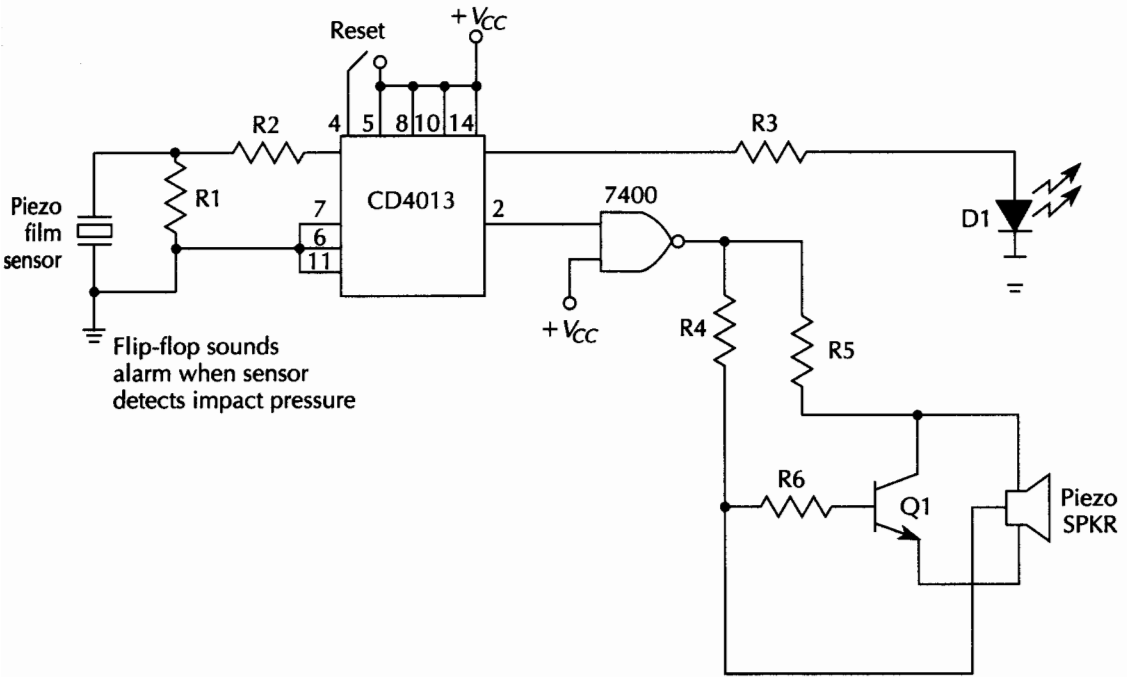


Fig. 2-12 Piezo pressure detector with audio output.

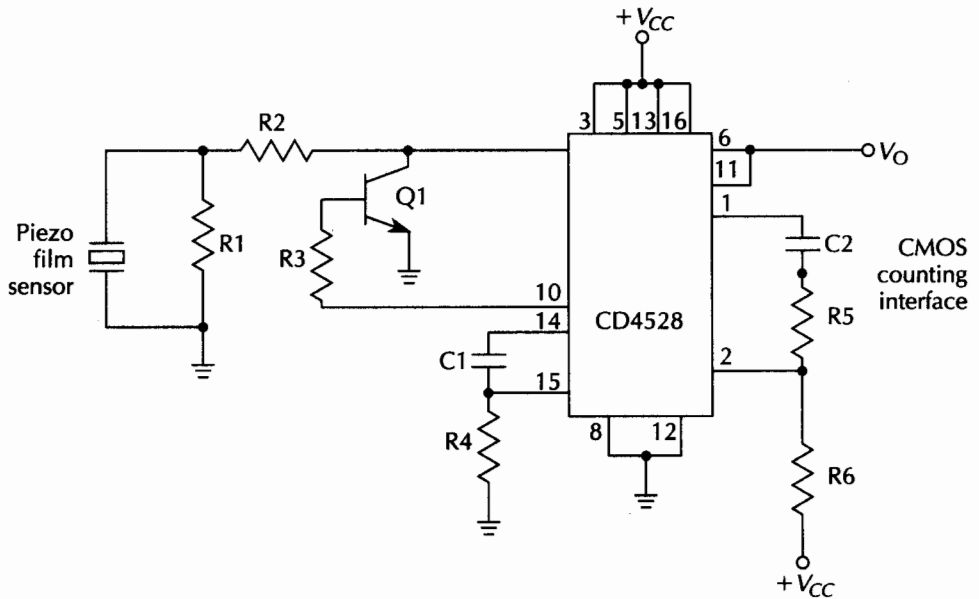


Fig. 2-13 Piezo counter interface.

A sample of Kynar film and application information is available from the Penwalt Corporation, listed in the Appendix. The sample can be configured to demonstrate a number of sensor principles. Penwalt offers many different types of low-cost piezo and pyroelectric sensors, and they can provide a wealth of application assistance.

Force and position-sensing resistor

The force and position-sensing resistor (FSR) is an emerging new sensor technology with many applications for detecting force and position in one easy operation. Various FSR sensors are shown in Fig. 2-14. The FSR was first developed for musicians who wanted their electronic pianos to play louder as the keys were pressed harder. In the past, there were two principle types of force sensors—piezo polymers and ceramic strain gauges. The fast rise times and high sensitivity of piezo polymers caused too much unwanted acoustical vibration. The new FSR devices are low cost, contain no moving parts, and are impervious to moisture, chemicals, vibration, and magnetism.

FSR devices typically exhibit three decades of dynamic resistance change with respect to force (i.e., 1-k Ω to 10-M Ω range). The FSR can be configured into many different types of switch arrays and are ideally suited to keypads, touch switches, alarm sensor mats, pressure sensors, computer pads and tablets, etc. The two basic types of force and position-sensing devices include the FSR-LP linear potentiometer, shown in Fig. 2-15, and the XYZ pad, shown in Fig. 2-16.

Constructing the basic FSR-LP begins with a conductive pattern of interdigitating electrodes deposited on a sheet of polymer. A proprietary conductive polymer is then deposited on a second sheet of mylar. The two sides or sheets of mylar are then faced together so that the conducting fingers are shunted by the conductive polymer. A typical force-VS-resistance curve is shown in Fig. 2-17.

A key element in the basic design of the FSR is the fineness of the conducting fingers. The greater number of shunted fingers produces a greater dynamic range and resolution. A voltage is generally applied between the hot lead and ground, as shown in Figs. 2-18 and 2-19. When a force is applied, the wiper contacts are shunted through the conductive sheet. The voltage output is then read from the wiper and is proportional to the distance along the resistive strip. Thus, a linear potentiometer is created.

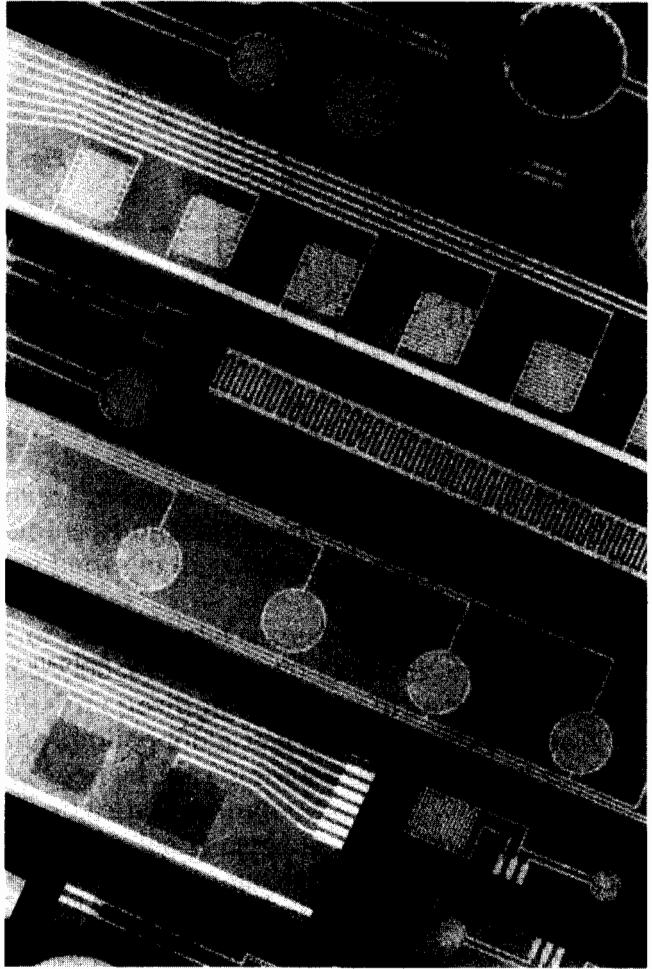


Fig. 2-14 Force-sensing resistor and resistor/switches.

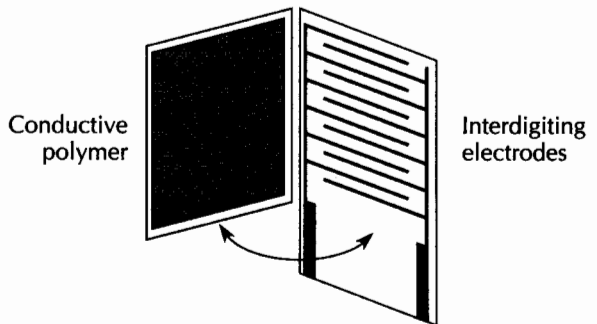


Fig. 2-15 Force-sensing resistor.

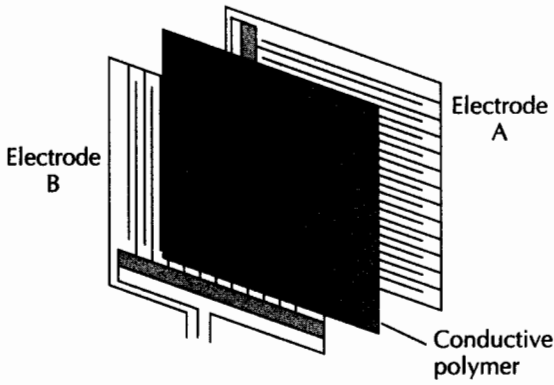


Fig. 2-16 Force and position sensing resistor pad/tablet.

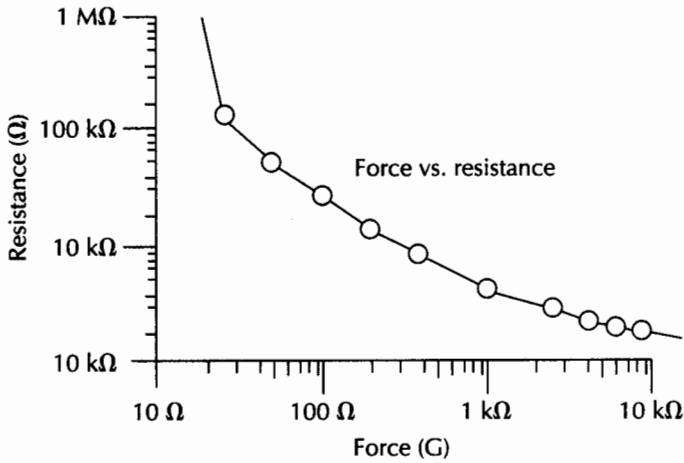


Fig. 2-17 Force-sensing resistor—force VS resistance curve.

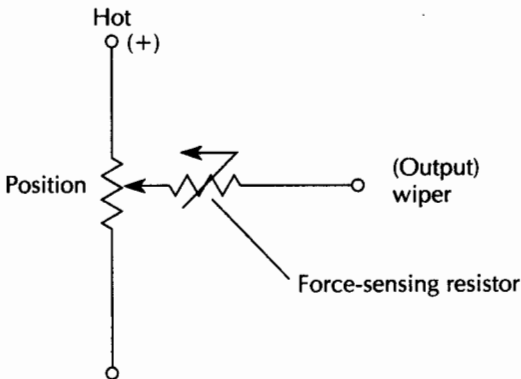


Fig. 2-18 FSR electronic symbol #1.

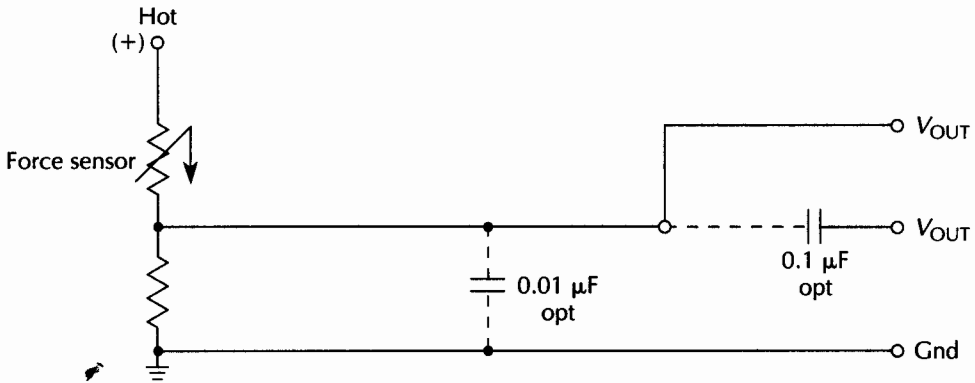


Fig. 2-19 FSR electronic symbol #2.

The contact between the wiper and the resistor itself is momentary; therefore, some sort of sample-and-hold device is needed. Usually, a capacitor between the wiper and ground is often sufficient for this purpose.

The XYZ pad, or tablet, is the second type of force and position-sensing device. Conceptually, two FSR-LPs are set back-to-back (see Fig. 2-16). The position of a force in an x-y coordinate plane, as well as the applied force, can be obtained with the XYZ pad. The XYZ pad is ideal for computer input devices such as tablets, pen stylus pads, and computer mice.

The XYZ-pad FSR device is capable of a 0.002 inch resolution and a better than 1 percent repeatability accuracy. The XYZ pad is limited to resolving a single force and position measurement at a time and cannot be used for pattern recognition.

A true force sensor gives a constant force independent of the area over which the force is applied. A true pressure sensor gives the same constant force, a reading which is inversely proportional to the area of the applied force. The FSR device in reality lies somewhere in between a true force sensor and a true pressure sensor. A typical FSR device displays a resistance of the square root of the area of the applied force.

The FSR device can be easily interfaced to a wide variety of circuitry. The simple analog interface in Fig. 2-20 displays a force-to-voltage converter, which can be used where a higher current or lower source impedance is necessary. The LF353 or TL071 IC is ideally suited to this interface. The op amp can be used either as a unity-gain buffer or to amplify the FSR's output. Offset current can be trimmed via the 500- Ω trimmer. The gain of the overall system can be set by the ratio of resistors R_f and R_s .

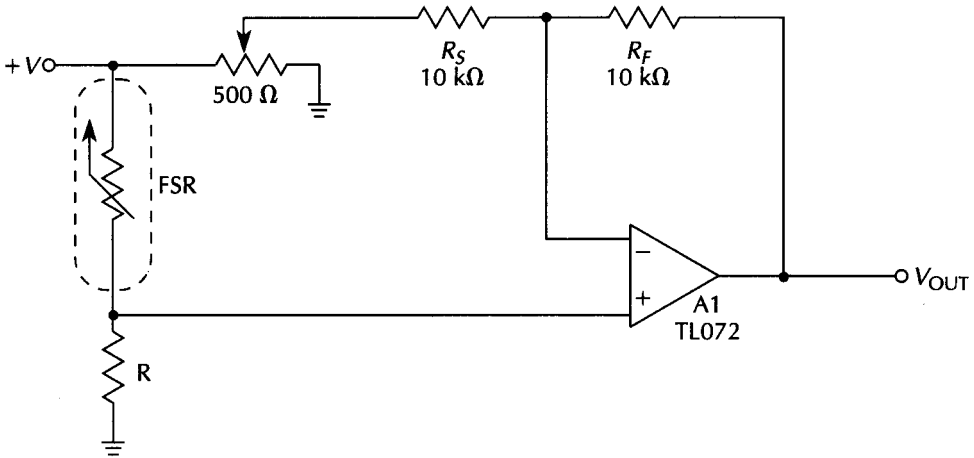


Fig. 2-20 Force-to-voltage converter.

A force-to-frequency interface is illustrated in Fig. 2-21. An oscillator is formed by the FSR and a Schmitt-trigger IC. At zero pressure, the FSR is an open circuit. Depending on the last stage of the trigger, the output remains either high or low. When the FSR is pressed, the oscillator starts up and the oscillator's frequency is increased or decreased depending on the force applied to the sensor. A 4.7-kΩ resistor limits current through the FSR. Bypassing this 4.7-kΩ resistor will cause the curve to steepen at a higher applied force. Connecting a larger value resistor in parallel with capacitor C will quench any tendency to oscillate at very low pressure. Using the oscillator circuit with additional CMOS or TTL circuitry allows you to count activation or strikes applied to the sensor by using leading or trailing edges of the output pulses.

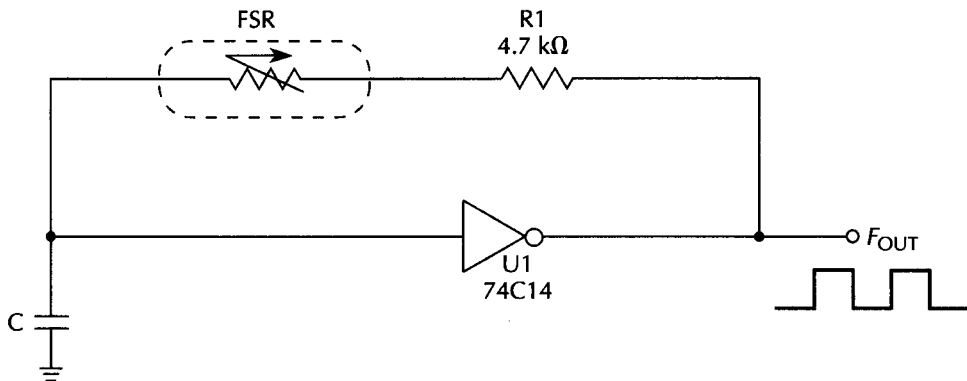


Fig. 2-21 Force-to-frequency converter.

A few caveats when using the FSR devices include using compression connectors instead of soldering directly to the polymer sensors. You must also ensure that the current through the FSR does not exceed 1 mA/cm² of footprint activation. Also, FSR devices require a backing material or piece of plastic behind the sensor for consistent activation accuracy. Elastomer overlays can greatly enhance the response characteristics by evenly spreading the activators force.

FSR devices typically respond to pressures between 0.01 to 100 psi, depending on the particular FSR chosen. The FSR sensors are available in a wide variety of sizes and shapes, and many custom devices are available upon request. Table 2-1 lists numerous applications in which the force and position-sensing resistors have been used. A sample FSR device can be obtained by writing on your company letterhead to Interlink Electronics, P.O. Box 40760, Santa Barbara, CA 93103.

Table 2-1 Force/position-sensor applications.

Graphic pads	Suspension sensors
Cursor keys	Accelerometers
Mouse devices	Water-level sensors
Pen stylus tablets	Panel switches
Pressure sensors	Digital tuning controls
Piano keyboards	Joysticks
Toner-level sensors	Game controllers
Foot pedals	Steering wheels
Gait-analysis sensors	Gas pedals
Artificial-limb force sensors	Robotic touch sensors
Dental-bite sensors	Industrial keyboards
IV-drip pressure sensor	Deadman safety switches
Bed weight-distribution sensor	Smart brake pedals
Security tiles/alarm sensors	Oil-pressure sensors
Load cells	Limit switches

New sensors, ICs, and gas-sensing technology

IN THE PAST TWO DECADES, INTEGRATED CIRCUITS HAVE PLAYED A major role in the wondrous advancements in computing and aerospace electronics. Large-scale integrated circuits now combine a multitude of functions on a single slab of silicon. Engineers, technicians, and hobbyists can now design and build electronic circuits and systems in a much shorter time and at a much lower cost than at any time in the past. The benefits of integrated circuits include speed, low noise, low power consumption, high density, and low cost. Recently, many new sensing and sensor support chips have become available. These low-cost ICs can be used to sense position, motion, speed, liquid level, acceleration, and smoke and gases.

Piezo accelerometer

We are about to see many new applications for low-cost accelerometers. The new piezoelectric-film accelerometers are now available for less than \$10. Traditional accelerometer applications include feedback and control systems, automobile airbag/braking systems, health monitors, security systems, and seismic sensors. Many different types of low-cost accelerometers are currently available. The two major sensor types are the compression sensor and the beam-design-type accelerometers. In the compression design, the inertial mass acts on the entire polymer or film surface. In the beam configuration, the strain is applied to the polymer's cross-sectional area. The beam-type sensors generally provide higher sensitivities.

A general-purpose, low-cost, single-axis compressive sensor is a Penwalt ACH-01, shown in Fig. 3-1. This sensor features

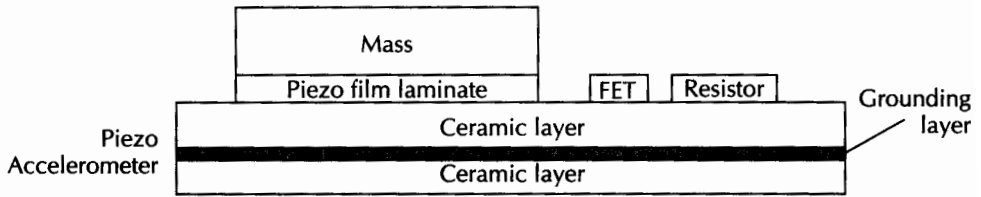


Fig. 3-1 Piezo accelerometer.

wide frequency and dynamic range with good sensitivity. The piezo film produces a linear response from 0.01 to 150 g. A small rectangular mass is mounted over a piezo laminate as shown. The alumina substrate incorporates a low-bias-current field-effect transistor for low output impedance and a high-impedance output load resistor.

Enclose the ACH-01 sensor in an EMI/RFI shielded plastic case with two mounting holes at both ends of the case. The actual usable range of the sensor is between 1 and 25 kHz, with a typical sensitivity of 12 mV/g. The sensor is a three-lead device. A positive voltage is applied to pin 1. The signal output is on pin 2 and ground is applied to pin 3. The power requirement for the ACH-01 ranges from 5 V_{dc} to 24 V_{dc} . Couple the output of the accelerometer to an LF363 BI-FET op amp, as shown in Fig. 3-2. Bias the op-amp input with a 180-k Ω resistor connected to the minus supply. A dual supply is required for this op-amp circuit. Couple the

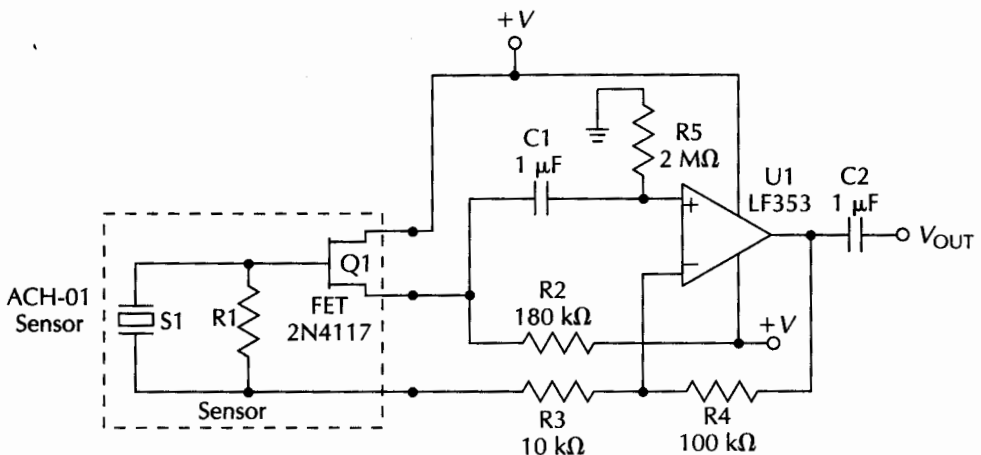


Fig. 3-2 Piezo accelerometer interface.

signal to the LF353 via a 1- μ F capacitor connected to the "+" input pin. The op-amp output can be passed onto an optional filter for additional processing as required by your application. The output could be applied to a chart recorder, datalogger, or A/D converter card placed in a personal computer. Other sensors are available, such as the ACH-06-01, which provides up to 2 V/G output, with a frequency range down to 0.01 Hz. The sensitivity of the piezo sensors is generally determined by the film thickness and the amount of inertial mass on the lever arm.

In the future we will see many more applications for these low-cost accelerometers in health systems and in automobile fuel control, braking, and airbag sensor systems.

Piezo accelerometer interface parts list

Quantity	Part	Description
1	R1	(Internal) HiZ resistor
1	R2	180-k Ω , 1/4-W resistor
1	R3	10-k Ω , 1/4-W resistor
1	R4	100-k Ω , 1/4-W resistor
1	R5	2- Ω , 1/4-W resistor
1	C1, C2	1- μ F, 25-V capacitor
1	Q1	(Internal) FET
1	U1	LF353 op amp
1	S1	ACH-01 piezo sensor (Atochem/Penwalt)

Optical transceiver

The complete optical transceiver shown in Fig. 3-3 is a new offering from Cherry Semiconductor Corporation. The bipolar LSI CS258 chip can be used in intrusion alarms, spot alarms, window/door sensors, particle/dust alarms, and industrial parts counters. An infrared LED, phototransistors, a few discrete components, and the CS258A form a complete optical transceiver that can be used as a stand-alone alarm system or as a sensor module wired to a central alarm panel. A sensor module can be created on a small printed circuit board measuring 1½×2¼ inches. The wiring from each module can be daisy-chained back to the central alarm panel.

The CS258A transceiver chip is a complete system that incorporates a three-pole filter network with a gated pulse-detection scheme that prevents false alarm conditions. When the infrared (IR) source is blocked from the detectors, no output is

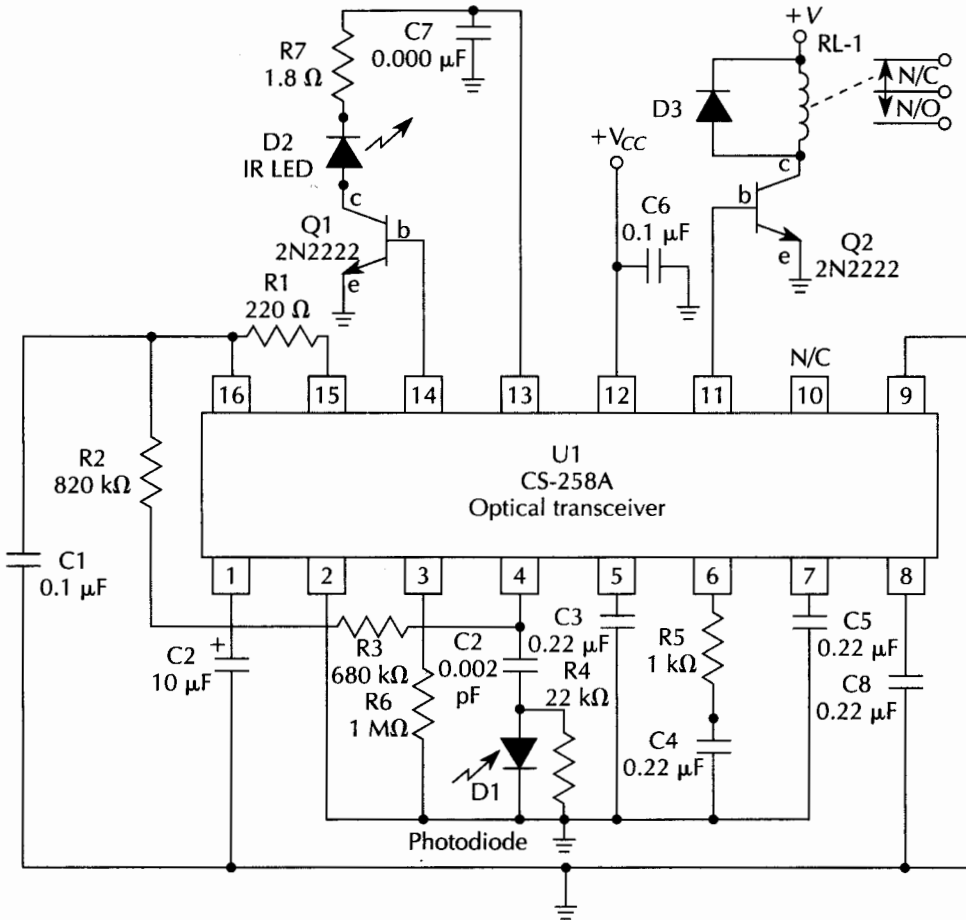


Fig. 3-3 Optical transceiver chip.

present. However, as soon as the IR beam is detected by the phototransistor, (i.e., an object is moved from the light path) an output is presented on pin 11. The output can drive a low-current relay, which, in turn can activate a siren or bell.

The CS258A transceiver can be operated from a 5-V power source and has a maximum voltage rating of $7 V_{dc}$. The external LED drive transistor in this circuit example boosts the current of D2 to increase the range between the LED and the phototransistor. The circuit is straightforward; however, pay particular attention to the dual ground system. A high-level ground on pin 9 is separate from the low-level ground on pin 2. The optical transceiver can be used in a wide range of alarm applications.

Optical transceiver parts list

Quantity	Part	Description
1	R1	220- Ω , ¼-W resistor
1	R2	820- Ω , ¼-W resistor
1	R3	680-k Ω , ¼-W resistor
1	R4	22-k Ω , ¼-W resistor
1	R5	1-k Ω , ¼-W resistor
1	R6	1- Ω , ¼-W resistor
1	R7	1.8- Ω , ½-W resistor
1	C1	0.1- μ F, 25-V capacitor
1	C2, C6	0.002- μ F, 25-V capacitor
1	C3, C4, C5, C8	0.22- μ F, 25-V capacitor
1	C7	1000- μ F, 25-V electrolytic
1	D1	Photodiode detector or optocoupler
1	D2	IR LED or optocoupler
1	D3	1N4001 silicon diode
1	Q1	2N2222 pnp transistor
1	U1	CS258A (Cherry Semiconductor)
1	RL-1	6–12-V SPST relay

Proximity detector

The new Cherry Semiconductor CS209 bipolar *proximity detector*, shown in Fig. 3-4, includes an oscillator, demodulator, level detector, output stage, and regulator. The proximity detector is versatile and can be used in counting and speed-detection applications, coin detectors, burglar alarm switches, and metal detectors. The proximity detector features an LC tank oscillator between pins 2 and 3.

To experiment with the CS209 proximity detector, purchase or wind a 100- μ H coil on a ferrite core. A 50–70-turn coil of 26-gauge enameled wire is a good beginning. Once the coil has been measured, that value can be “plugged” into the formula to obtain an optimum capacitor value. The “Q” of the LC oscillator is very important in obtaining resonance and, ultimately, the maximum range of the detector.

A resonant frequency of 200–600 Hz is recommended for best results. The frequency of the tank circuit is half the square root of capacitance (C) times inductance (L). A frequency counter can be connected between pins 3 and 8 to measure the actual frequency. The maximum range can be fine tuned by adjusting or tweaking the value of the rf resistor between pins 1 and 8.

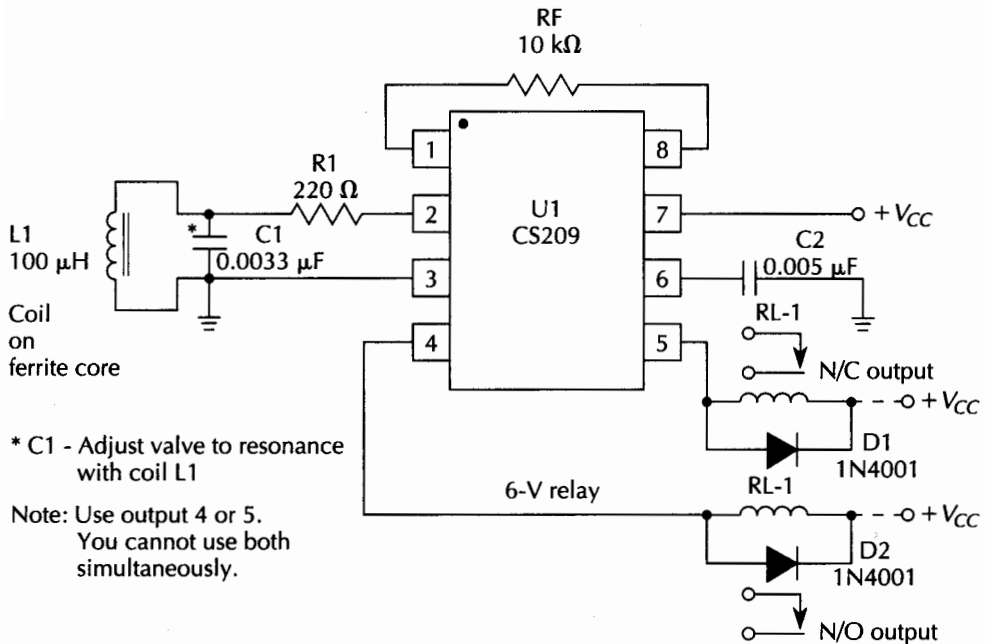


Fig. 3-4 Metal proximity-detector chip.

The CS209 detector has two active high-level outputs capable of driving a low-current miniature relay. Outputs are available on pins 4 and 5. The output on pin 4 is a normally open output and pin 5 is a normally closed output. Select either output and then connect a low-current relay between the selected output and the positive power-supply voltage. The output is TTL-level compatible and can drive logic circuits. The CS209 is a very compact eight-pin miniature DIP integrated circuit with a minimum of external components. The chip is quite versatile and can be used in many alarm sensing applications. Cherry Semiconductor provides samples and application information on request.

Metal proximity-detector parts list

Quantity	Part	Description
1	R1	220-Ω, ¼-W resistor
1	R2	10-kΩ, ¼-W resistor
1	C1	0.0033-μF, 25-V adj for resonance
1	C2	0.005-μF, 25-V capacitor (disk)
1	L1	100-μH coil on ferrite core
1	D1	1N4001 silicon diode
1	U1	CS209 (Cherry Semiconductor)
1	RL-1	5-V miniature relay

