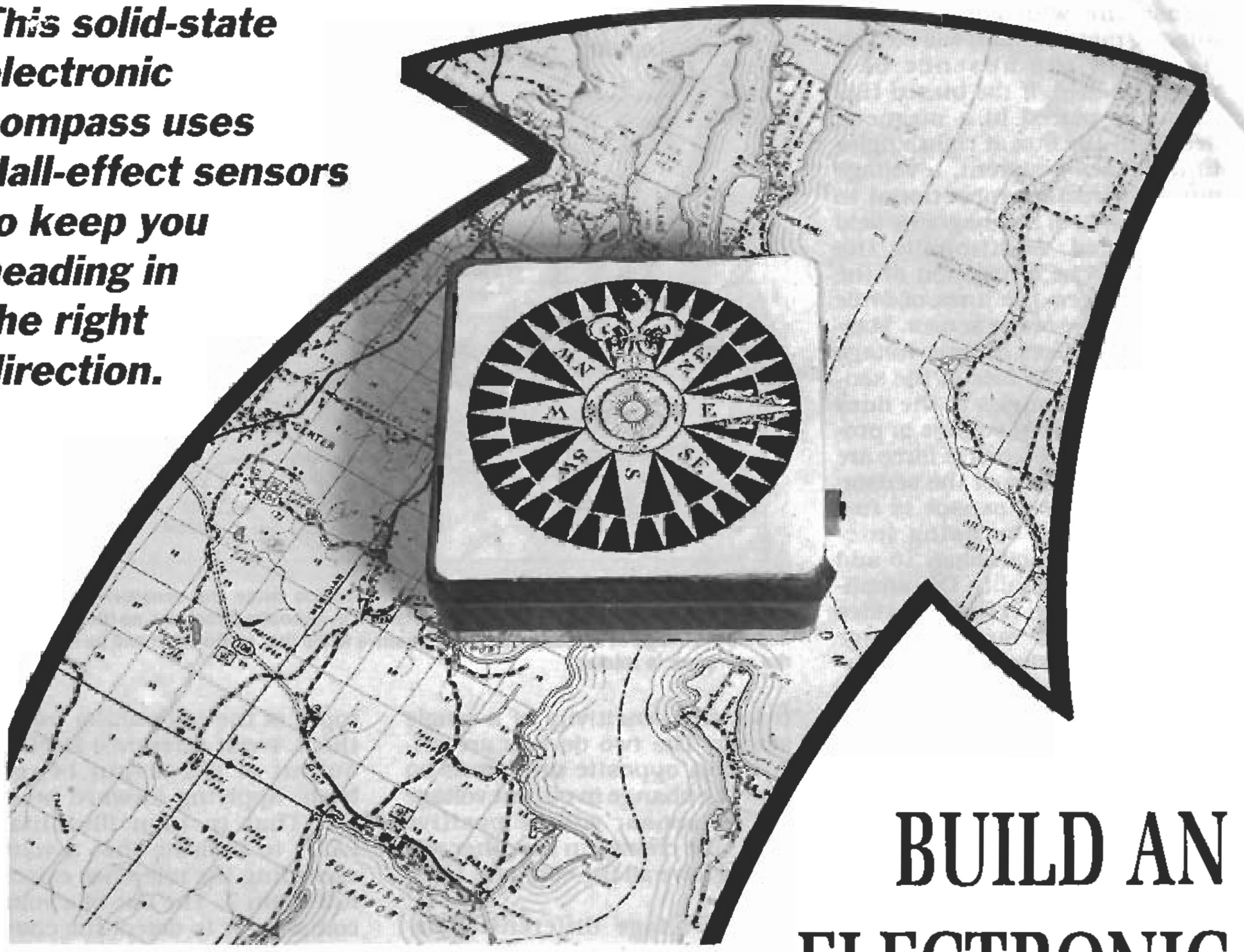
This solid-state electronic compass uses Hall-effect sensors to keep you heading in the right direction.



BUILD AN ELECTRONIC COMPASS

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MOST OF US HAVE AT ONE TIME OR another used a common magnetic compass, which often consists of a light-weight balanced magnet suspended on a pivot. The magnet, free to rotate, is affected by Earth's magnetic field, and assumes a position in which its north-seeking pole points to Earth's magnetic north pole. The geographical north pole of Earth is offset from the magnetic north pole by about 10 or 15 degrees in most areas of the United States.

Many low-cost compasses leave something to be desired in their performance, which can be affected by any tilt of the case or friction in the pivot. However, with the development of solid-state magnetic detecting devices, called Hall-effect generators, it is possible to construct a low-cost, reliable magnetic compass which has no moving parts and eliminates the disadvantages of inexpensive mechanical types. Because the project contains no moving or mechanically sensitive parts, it is an extremely rugged device that can tolerate all potential stresses encountered when hiking or traveling through rough terrain. Taking a reading on the compass is quick, easy, and very reliable.

This solid-state compass uses a unique detection system that produces two sharply defined points centered on the direction of magnetic north, as indicated by an LED. That permits a quick, accurate reading. The project, housed in a plastic enclosure, is small and lightweight, and is powered by a common 9-volt battery. Since the compass circuit is energized only when it is used to take a reading, the battery's useful life approaches that of its shelf life.

About the circuit

Development of a magnetically sensitive solid-state compass is made possible through a phenomenon called Hall effect, which was discovered in 1879 by Edwin Hall; he observed that a small voltage was developed at the edges of a current-carrying gold foil when the foil was exposed to a magnetic field. Solid-state technology now provides small, low-cost Hall-effect devices, which are very sensitive and able to detect Earth's extremely weak magnetic field.

The basic Hall-effect sensor, shown in Fig. 1, is a small sheet of semiconductor material in which a bias current flows. The Hall-effect output of the sensor takes the form of a voltage measured across the width of the conducting material, and will be negligible in the absence of a magnetic field. If the biased Hall sensor is placed in a magnetic field with the flux at right angles to the flow of current, a voltage output directly proportional to the intensity of the magnetic field is produced. Additionally, the voltage will be a function of the angle between the lines of force and the plane of the sensor. Maximum Hall-effect output voltage occurs when the face of the sensor is at right angles to the lines of force, and zero voltage is produced when the lines of force are parallel to the face of the sensor.

The Hall-effect sensor is further enhanced by using integrated-circuit technology to add a stable high-quality DC amplifier to the device. It then provides a usable linear output voltage which is sensitive enough to react to Earth's magnetic field (about ½ Gauss).

Referring to the schematic in Fig. 2, The Hall-effect generators (IC3 and IC4) are three-terminal linear devices which are driven by a regulated 5-volt supply provided by fixed-voltage regulator IC1. The output of each of the sensors is a DC voltage that varies linearly from a quiescent value of 2.5 volts as their position with respect to the lines of force of the magnetic field changes. A typical sensor has an output-voltage sensitivity of about 1.3 millivolts per Gauss.

Two Hall-effect generators are used in the circuit to provide twice the sensitivity of a single sensor. The two devices are oriented in opposite directions so that the change in output voltage of one sensor will be positive while the change in the other will be negative as the compass is rotated.

The voltage differential between the two output terminals of the sensors is a representation of the magnetic field intensity and direction. The voltage differential produced by the Hall generators is fed to a differential amplifier, IC2-a. As a result, the output of IC2-a (pin 1) will be a minimum (null) when the compass is facing the magnetic north pole, and a maximum when it faces the south pole.

The change in output voltage of IC2-a is too small to allow a simple method of determining the null voltage as the compass is rotated. Therefore, IC2-b is used as an inverting amplifier with a gain of 100 to further increase the change in voltage. A DC offset, provided by sensitivity-adjust potentiometer R9 and voltage follower IC2-c, permits the DC output voltage of IC2-b to be set to a usable level to drive the next stage.

Op-amp IC2-d is used as a voltage comparator with a fixed reference of about 3.4 volts fed to its negative input. Thus, when the output of IC2-b fed to the positive input of the comparator exceeds the 3.4-volt reference level, the output of IC2-d (pin 14) goes high, applying forward bias to Q1. That in turn illuminates LED1 to indicate that a voltage exceeding the reference exists at IC2-b pin 7. The use of a voltage comparator to detect the change in output voltage of IC2-b (pin 7) produces two sharply defined points and allows a more accurate determination of the magnetic north pole.

As shown in Fig. 3, the LED will be illuminated over a small arc as the compass is rotated full circle, and will remain off over the rest of the 360-degree span. The sensitivity control (R9) allows adjustment of the width of

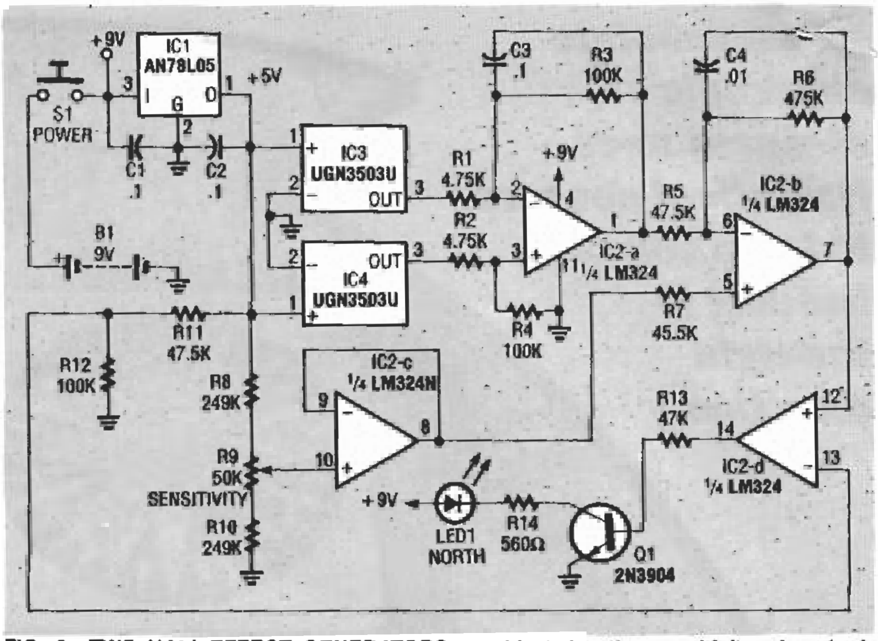


FIG. 2—TWO HALL-EFFECT GENERATORS provide twice the sensitivity of a single sensor. The two devices are physically oriented in opposite directions so that the change in output voltage of one sensor will be positive while that of the other will be negative as the compass is rotated.

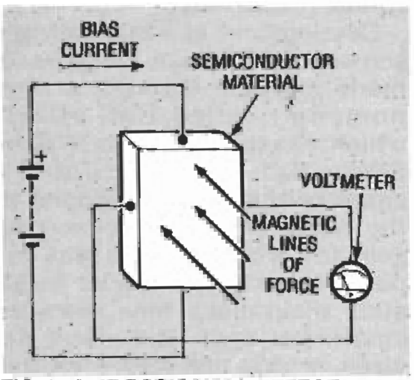


FIG. 1—THE BASIC HALL-EFFECT sensor is a small sheet of semiconductor material in which a bias current flows. The output voltage, measured across the width of the conducting material, is negligible in the absence of a magnetic field. If placed in a magnetic field, the output is directly proportional to the intensity of the magnetic field.

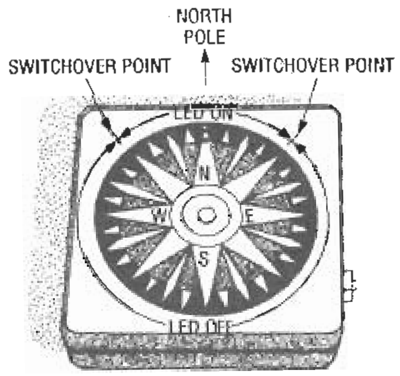


FIG. 3—THE LED WILL BE ILLUMINATED over a small arc as the compass is rotated full circle. True magnetic north is the position at the center of the arc.

the arc. Once the two LED switching points are determined, true magnetic north is then the position at the center of the arc.

Power is provided by a common 9-volt battery. The circuit draws about 25 mA and, since it's usually powered for only a few seconds at a time, battery life is extremely long; several hours of continuous compass operation is also possible. Circuit stability with a falling battery voltage is ensured by the 5-volt regulator, IC5. When the battery is exhausted and cannot deliver sufficient current to operate the circuit, the LED will appear dim or will not illuminate at all.

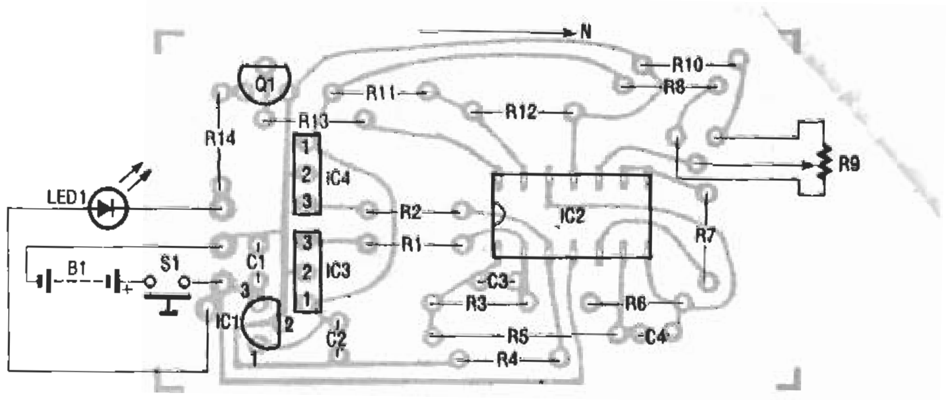


FIG. 4—PARTS PLACEMENT DIAGRAM. The Hall generators must be placed in opposite directions and exactly parallel as shown. Pin 1 of the Hall sensors is on the left side when looking at the markings on the face of the device.

Construction

The circuit, when built on the printed circuit board (for which we have provided the foil pattern), is very compact; the prototype is housed in a 2½-inch square by 1-inch high plastic enclosure, that has sufficient room to accommodate both the board and the 9-volt battery. A metal enclosure must *not* be used for this project—it can attenuate or distort Earth's weak magnetic field. The power switch and sensitivity control are mounted on the side of the enclosure to allow easy operation of the compass.

Figure 4 shows the parts layout. The position of all polarized components (especially the Hall sensors) must be followed exactly as shown. The operation of the project depends upon the Hall generators being placed in opposite directions and exactly parallel as indicated in Fig. 4. Note that the orientation of the sensors is determined by the marked face of the device, with pin 1 being on the left side when looking at the markings. The sensors must be positioned so that they are aligned square with the rectangular shape of the printed circuit board. That way the compass direction will be accurate when the project is assembled into the enclosure. (Use the "north" indication of Fig. 4 to determine the relationship between the PC board and compass scale when final assembly is done.)

Many of the resistors specified in the parts list are metal-film types. The use of such components ensures maximum stability of the circuit with varying ambient temperature changes, and reduces the need to periodically adjust the sensitivity control. Ordinary carbon resistors are not temperature-stable and should not be used in place of metal-film types. Also, it's a good idea to use a socket for IC2.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.

R1, R2—4750 ohms, 1% metal film
R3, R4, R12—100,000 ohms, 1% metal film
R5, R7, R11—47,500 ohms, 1% metal film
R6—475,000 ohms, 1% metal film
R8, R10—249,000 ohms, 1% metal film
R9—50,000-ohm, potentiometer
R13—47,000 ohms
R14—560 ohms

Capacitors

C1–C3—0.1 µF, 50 volts, ceramic disc
C4—0.01 µF, 50 volts, ceramic disc

Semiconductors

IC1—AN78L05 5-volt regulator
IC2, IC3—Sprague UGN3503U Hall generator
IC4—LM324N quad op-amp
LED1—red light-emitting diode
Q1—2N3904 NPN transistor

Other components

B1—9-volt alkaline battery
S1—SPST pushbutton switch, normally open

Miscellaneous: Plastic enclosure, battery clip, control knob, IC socket, wire, solder, etc.

Note: The following items are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463: An etched and drilled PC board, $9.95; set of two Hall sensors, $9.75; IC1, $2.00; IC2, $2.00; set of 11 metal-film resistors, $4.95. Please add $2.50 postage/handling.

It is recommended that you use a miniature momentary pushbutton switch for S1. That will ensure that battery power will never be inadvertently left on when the project is not in use. The sensitivity control, R9, may be placed on the side of the enclosure to allow circuit adjustment when necessary. You should use a battery clip for B1. If desired, a suitable clip can be obtained from a discarded 9-volt battery (just peel away the metal case and rip the top off). Be very careful to wire the battery clip with the correct polarity.

When the circuit board is completed, examine it very carefully for shorts, opens, and cold solder joints. It is much easier to correct problems at this stage rather than later on if you discover that your project does not operate. A photo of the finished board is shown in Fig. 5.

Use a photocopy of the artwork in Fig. 6 for the top of the compass; you can simply glue it in place. Indicator LED1 is placed at the north indication of the compass by drilling a suitable size hole in the plastic top where the letter N would be. Be very careful when drilling; some plastics will shatter if subjected to excessive stress. Be sure to properly orient the top of the enclosure in accordance with the final position of the PC board.

Checkout

When you are satisfied that all wiring is complete and correct, the checkout procedure must be performed, and be sure to use a fresh 9-volt battery. Checkout requires a DC voltmeter connected to ground and the output terminal of IC1. Apply power to the circuit check for +4.75 to +5.25 volts. Measure the resistance between the 5-volt bus and ground; a normal reading is about 600 ohms. Measure the terminal voltage of the battery to be sure that it is delivering at least 7 volts under load to IC1. Replace a weak battery if necessary.

Next, measure the output voltage of IC2 pin 1, and verify the voltage range of potentiometer R9. (Compass orientation is not important at this time.) The voltage should be about 2 to 3 volts DC. Measure and record the DC voltage that you observe at IC2-a pin 1.

Measure the voltage change at IC2-c pin 8 as the sensitivity control is rotated over its entire range. The difference between the highest and lowest readings should be about 0.45 volts. Ideally, the center of the measured voltage range should be close to the voltage recorded earlier at IC2 pin 1.

If necessary, change the value of R8 and/or R10 so that the voltage range obtained at IC2-c pin 8 is somewhat centered about the voltage reading at IC2-a pin 1. This ensures proper adjustment range of the sensitivity control for the particular pair of Hall generators that are used in your compass project.

Once the sensitivity range is correct, rotate R9 over its range while observing the LED. At one end of the setting, the LED should be extinguished, and at the other end it should be illuminated; if not, check the polarity of LED1 and the orientation of Q1. Check pin 14 of IC2-d to be certain it swings from about zero to battery voltage as R9 is rotated over its range. Check pin 13 of IC2-d for a voltage of about 3.4 volts as set by R11 and R12. Problems in this area may warrant replacing IC2 if everything else checks out alright—check your soldering before changing the IC.

When the LED operates as described, the project is ready to be tested under actual operating conditions. Before you start, make sure that there are no magnetic fields nearby, and the project is not shielded by a large mass of iron or steel.

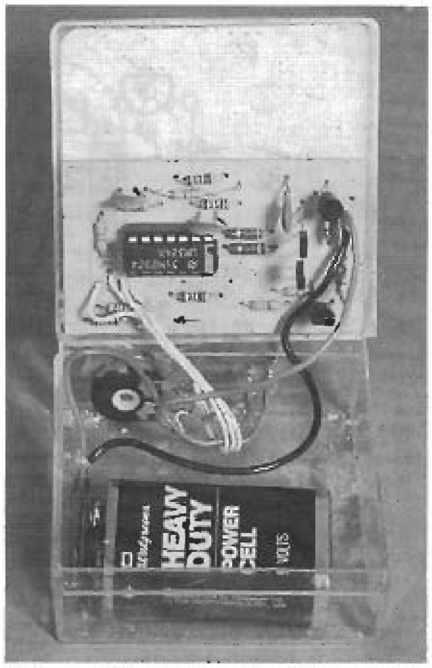
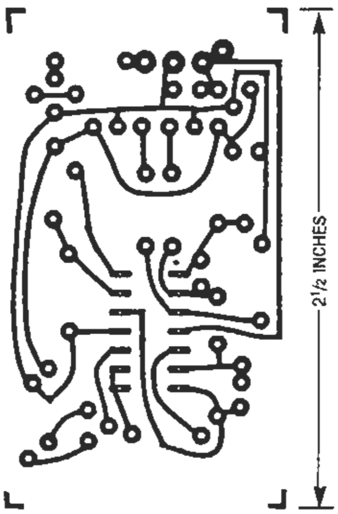


FIG. 5—EXAMINE THE COMPLETED board for shorts, opens, and cold solder joints before installing it in a plastic case.

FIG. 6—USE A PHOTOCOPY of this artwork for the top of the compass, and glue it in place on top of the case.



FOIL PATTERN for the electronic compass, shown actual size.

While holding the unit horizontally in any direction, apply power and carefully adjust R9 so that the LED is at the switch-over point between on and off; allow at least 10 seconds for the circuit to stabilize. Flicker of the LED is normal as the circuit switches back and forth. Once R9 is set, rotate the compass over a 360-degree arc (full circle) and note that the LED will be on over part of the arc, and off over the rest. If necessary, readjust potentiometer R9 very slightly to obtain this result. The optimum setting for R9 will be at the point where the arc of illumination is as small as possible.

As the compass is rotated over the illuminated arc, note the two on/off points. When the compass is positioned halfway between those points, it is facing the magnetic north pole, and the scale indications on its face indicate all other directions.

Using the compass

Always be sure that the battery is reasonably fresh, and take along an extra one before starting out on an excursion with the compass. (A weak battery will be indicated by a dim or totally unlit LED.) Avoid taking a compass reading in any area where there may be a magnetic field from a nearby device, or where Earth's magnetic field is shielded by a large mass of metal.

Hold the compass in a horizontal position and rotate it full circle while observing the LED. Adjustment of the sensitivity control is indicated if the LED is totally on or totally off as the compass is rotated. Always allow at least 10 seconds operating time for the circuit to stabilize. Once the sensitivity control is adjusted, it should not require readjustment unless the project is subjected to an extreme change in temperature.

Don't forget that the electronic-compass circuit can be used for things other than a simple direction finder. It provides an electronic means of finding north, so it should be easy to interface the compass to other devices that may need to know where north is—a robot, for example. **R-E**