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Experimenting with Hall-Effect Sensors

For fun and knowledge.

There are times hams get involved in some interesting technological experiments. Some of those experiments develop projects that apply to electronics and ultimately to ham radio.

Because of my interest in both experiencing technology and developing test equipment to make my life easier at the workbench, I tackled Hall-Effect sensors to see what I could learn about them and perhaps find an application for ham radio.

What's a Hall-Effect sensor? I'm glad you asked that question. Hall-Effect sensors are semiconductor devices that are sensitive to the presence of a magnetic field. When in the presence of a magnetic field they provide a voltage change response as a function of the flux field intensity. In fact, the sensors are also sensitive to the flux line direction as produced by a magnet.

I have an early date code sensor made by TI and I've been told that those early sensors were subject to thermal drift — mine exhibits a little. But the sensors being manufactured today by Allegro Micro Systems are temperature-stabilized using a technique referred to as "chopper-stabilization." Perhaps the using circuit is more subject to temperature effects than is the sensor itself.

I suppose your next question is, "So what is a Hall-Effect sensor good for?" Again, that's a good question as it leads me into a discussion of them. Actually, the use/application of a Hall-Effect sensor is limited only by your imagination. They come in two types: switching and ratiometric (linear). I'll limit my discussion and experiments to the linear sensor, since it offers the greatest window of opportunity for ham project development.

Applications

My personal interest in the Hall-Effect sensor was in understanding the linear device, though switching sensors are very important contributors to many project applications. In fact, Hall-Effect switching sensors were used in some computer printers to sense the end of carriage travel. They also work well in burglar alarm window and door movement detection in addition to a multitude of other uses.

I'll cite a few applications to give you a kick-start with ideas, but you need to think of additional applications as they apply to your needs and environment. Here is just a sample of possible uses: magnetic flux indication and intensity measurement; magnetic polarity detection; current sensing (AC and DC); power sensing; current trip point detection; strain gauge sensor; movement sensing and direction of movement; rate of change (movement); proximity sensing; liquid-level sensing; noncontact sensing; RPM measurements; object speed of acceleration/deceleration; position limit detection/switching; antenna position sensor; and wind direction and velocity sensor.

Experiments

To gain an understanding of how Hall-Effect sensors function, I set up a series of experiments on my workbench to evaluate the linear device that was available to me. It was a sensor manufactured by TI, circa 1985. The first step was to set up a circuit with sufficient metering to allow interrogation of the device to see how it reacted. **Photo A** shows the top side of my test board, and **Photo B** shows the bottom side. Operating at DC levels, the only purpose of the board was to keep all of the parts conveniently flying in formation.

Having limited previous experience with Hall devices, I wasn't sure what to expect, so that metering was essential. **Fig. 1** shows the basic circuit that I used to begin experimentation. For the first experiment, the objective was

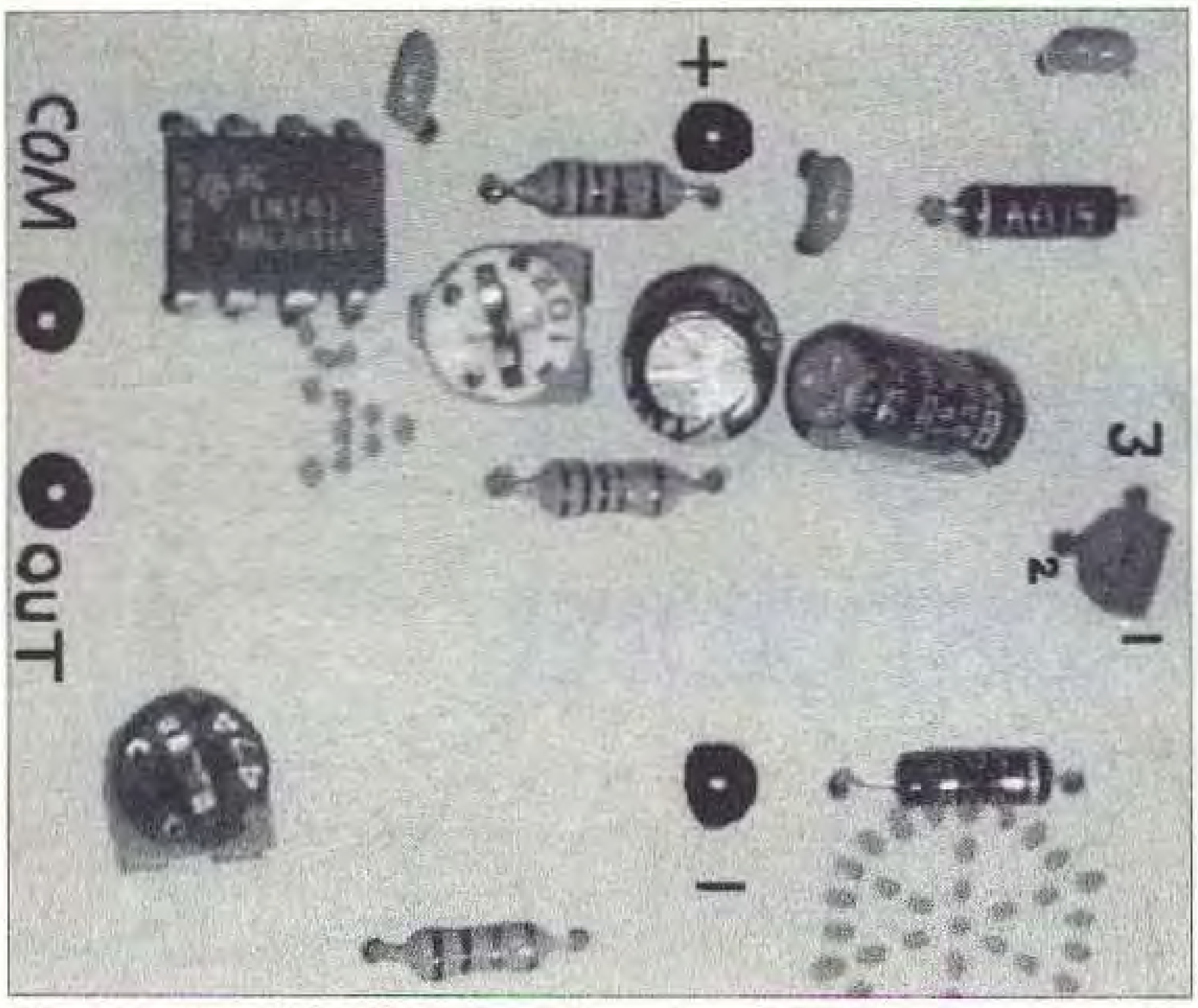


Photo A. *Top side of the circuit board used for experimenting with Hall-Effect linear sensors.*

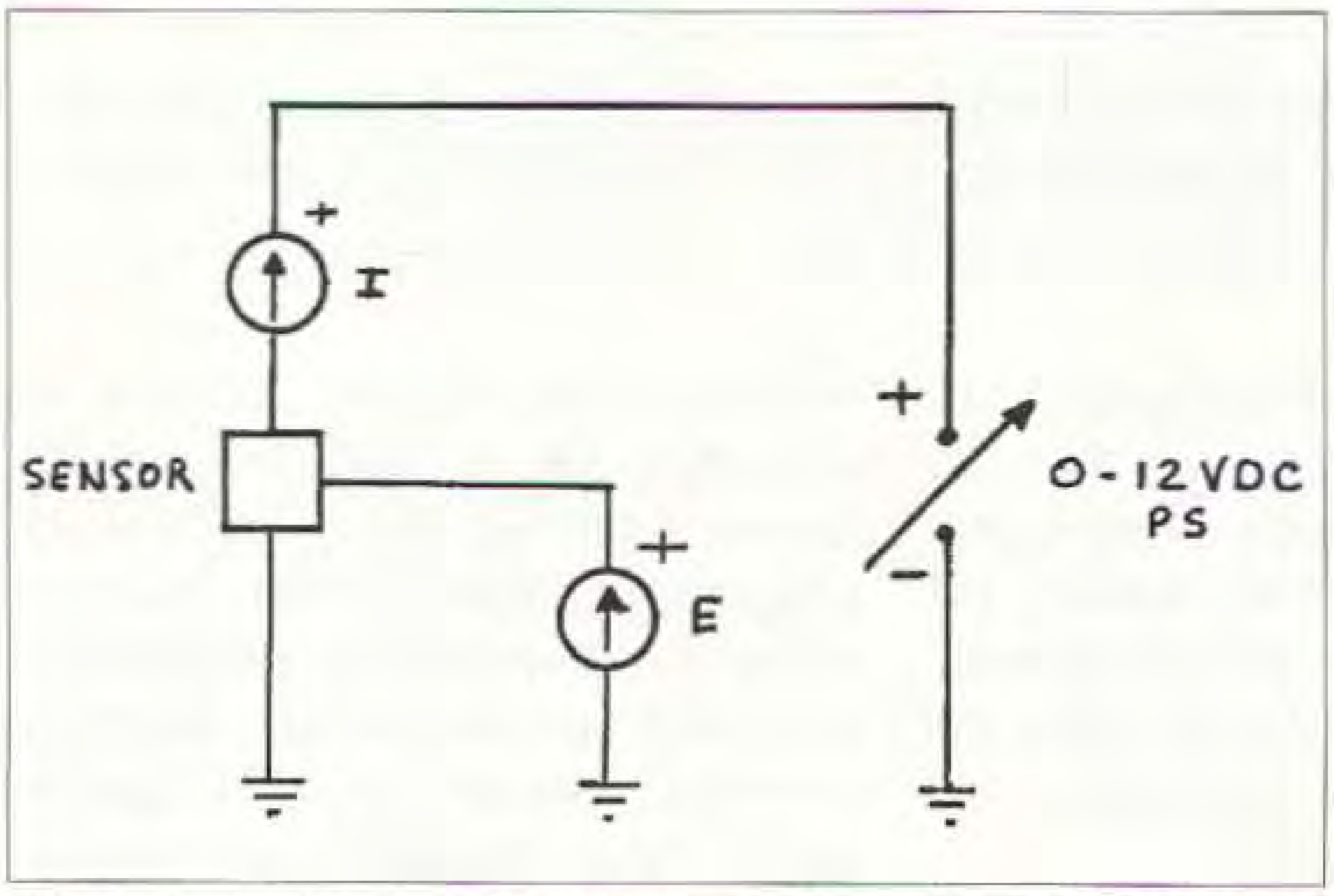


Fig. 1. *Basic circuit used for the first tests performed with a Hall-Effect sensor.*

Photo B. *Bottom side of the circuit board.*

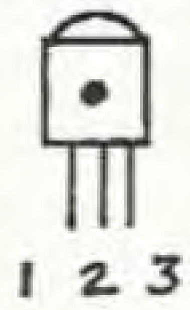
to determine device pin functions and to apply a suitable voltage to see how the device would respond. After doing an Internet search I determined that no test or technical data was available for my sensor. However, I did obtain comparable data from Allegro Micro Systems. **Fig. 2** shows the basic empirical spec information that I discovered through experimentation, allowing the TL173C sensor to be used in a project.

Once power was applied I determined that the nominal output voltage was approximately Vcc/2, and that was a good sign, but at that moment I didn't know what else to expect in the way of a response to a magnetic field. I did note that the sensor's output voltage was subject to change as a function of Vcc. Therefore, stabilizing the Vcc value with a regulator would be required for solving any serious stability issues. But for my experiments, only a small amount of regulation was used.

Knowing that a Hall device is sensitive to a magnetic field, I did wave a magnet close to the sensor and got an indication, though at a magnitude well below that expected. What I expected was the output voltage to swing between Vcc and ground during the test — but a much lesser swing was observed. **Fig. 3** shows the second test that I performed and the response obtained. The graph shows a generalized operational curve and a voltage swing away from QOP (Quiescent Operating Point) along the curve relative to the presence of a magnetic field.

It occurred to me that the magnetic lines-of-force had to pass through the device for it to respond properly. As I determined later, the Hall device that I was using provided a response perhaps in the range of 1–2 mV/gauss. Devices available from Allegro Micro Systems vary in detection sensitivity by device and provide an output from about 1 mV/gauss up to 5 mV/gauss.

With a VOM set to the 3-volt range and attached to the output pin of the sensor, a horseshoe-shaped magnet was



1 Output

2 Ground/common

3 + Vcc

Derived information

Vcc	3-5.5VDC
Vcc max	6V
Ic	4ma nominal
Sensitivity	Estimated to be 1-2mv/gauss
•	"sweet spot" for max sensitivity
Output swing	+/- 35mv
Gauss response	Linear
Response time	43 microseconds
Package	TO-92

Fig. 2. *The above data on the TL173C linear Hall-Effect sensor was derived empirically from experiments performed during bench testing.*

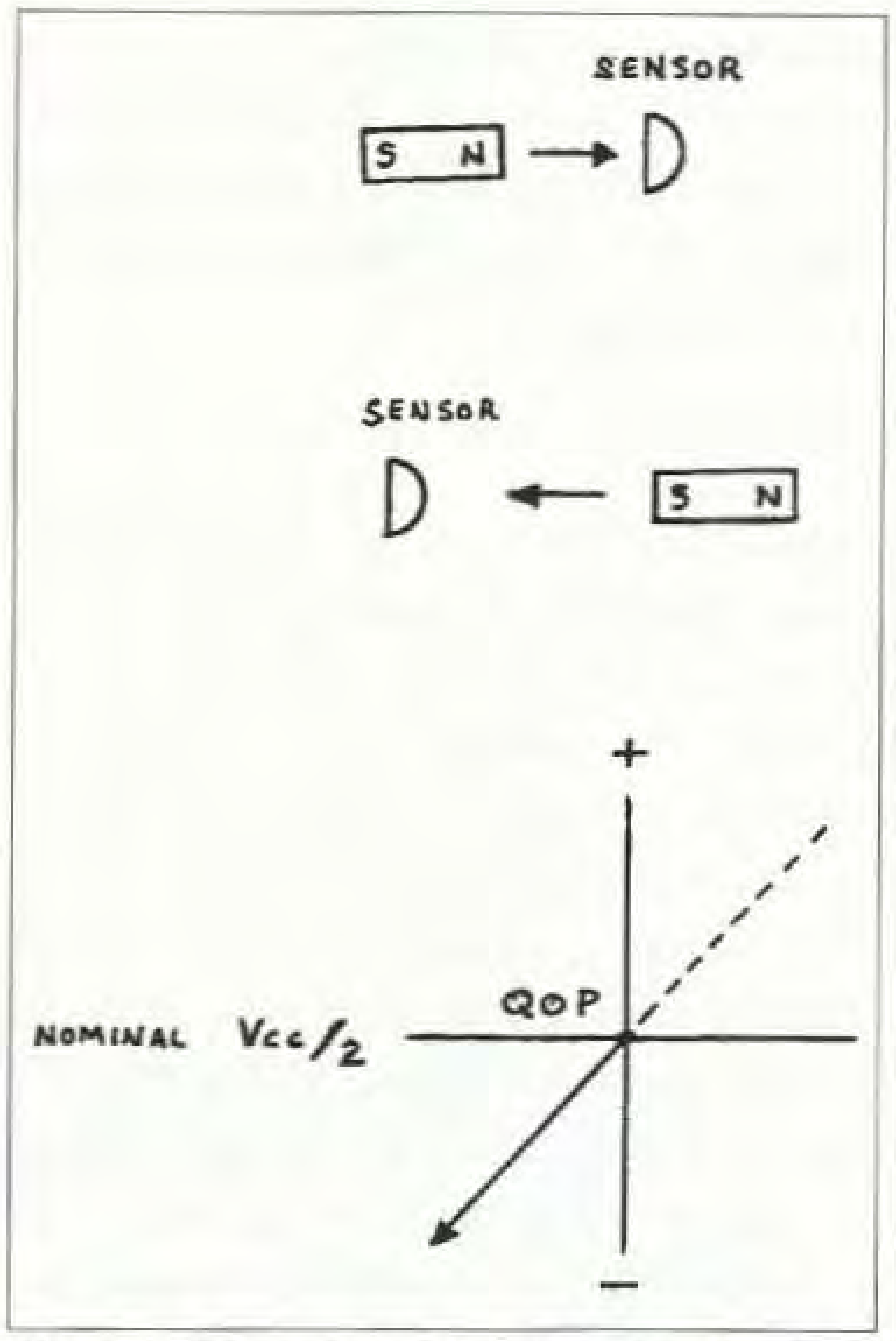


Fig. 3. Experiment showing the direction of voltage output from the sensor as a magnet of given polarity approaches the sensor. Approaching as shown, the output voltage decreases.

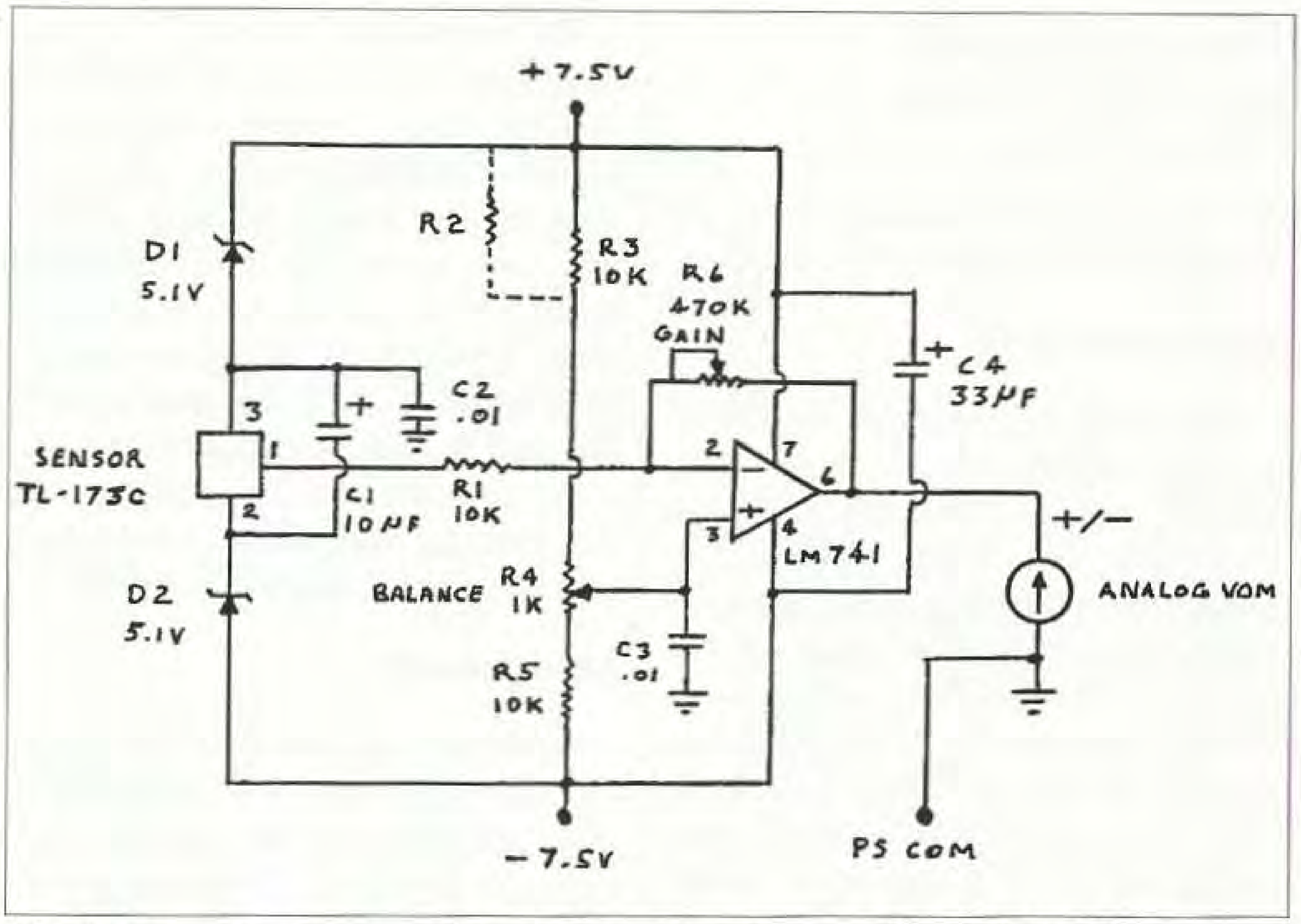


Fig. 4. A complete circuit used for testing and evaluating a TL173C Hall-Effect sensor. An op amp is used to raise the sensor's output voltage swing sufficiently to drive an analog VOM. Resistor R2 is used to create a balanced input into the op amp.

slipped over the Hall sensor. The output responded sufficiently to be evident, but not at a desirable level. However, the response was markedly greater than when only a single magnetic pole approached. My particular sensor provided a direct output voltage swing in the range of 25–30 mV. To obtain a larger output voltage swing, I assembled an amplifier using an LM741 op amp. A complete test circuit is shown in **Fig. 4**. Details of the amplifier will be discussed in another section. Now, knowing what to expect from the device made the remaining experiments much easier.

Several setups using magnets utilized in various positions provided some really interesting insight into possible device applications. During the initial experiment, a horseshoe-style magnet was used. A "sweet" spot was determined to exist at the near center of the device package. Another experiment involved placing a fixed magnet on one side of the sensor while approaching the sensor with a different magnet from the opposite side. The first magnet biased the sensor and shifted QOP along the response curve. Although the biasing magnet caused the output voltage to shift up or down (flux polarity) the operational curve, the detection sensitivity appeared to remain constant. Biasing the sensor to one side of its operational curve allows the device more room to swing in a given direction, placing the output voltage above or below the nominal Vcc/2 value. With an approaching magnet, the output would change as a function of field strength and distance to the opposite voltage value (if biased below, it would swing to a value above nominal).

In addition, with a biased sensor, as shown in **Fig. 5**, the approaching metal needn't be a magnet as long as it is ferrous. I tried approaching the sensor with a nonmagnetized metal shaft of a screwdriver, and the sensor was able to detect both the presence and movement of the shaft. This experiment implied that a biased sensor would work well as a tachometer or as a position sensor of a rotating antenna system.

Fig. 6 shows how the sensor may be used as a "null" or "off-null" sensing device. Any movement of the magnet right or left of the null point will cause the sensor's output to create a voltage

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and polarity change appropriate to the direction and magnitude of the response.

Temperature drift

During my experiments, some heating drift was noted; it was traced to the TL173C sensor. The drift occurred only during the first 2–3 minutes following the application of power before stabilization occurred. Pinching the device with my fingers reduced the internal heat level and that effect was noted in the output voltage indication. Drift occurred until the sensor again stabilized at a temperature value. Judging from the Allegro Micro Systems' published information, sensors manufactured by them are chopper-stabilized to reduce or stop the tendency for thermal drift susceptibility.

Response linearity

From my experiments, I was able to determine two very important facts that relate to any application of the device. The output response is absolutely linear within the limits of the device as a function of gauss level. The assumption is that any open gap between the sensor and metal flux conductor remains constant as the gauss level varies.

The second fact relates to the magnetic gap. If the gauss level remains constant, the output response is nonlinear as a function of the gap width change. My method of measurement was very crude, but it did definitely prove the effect. For this measurement, I placed a plastic measurement scale in front of the sensor to identify physical movement distances. Magnet location distances were plotted against the indicated output voltage creating a curve approximating the letter "S".

Field polarity

What was interesting to me during the experiment was the determination that the direction of the magnetic field (flux line direction) was detectable. As shown in **Fig. 3**, reversing the magnetic poles caused the output voltage to reverse direction. As an example, if the output was indicating a positive offset of 1 volt from QOP (VOM reading), reversing the magnetic polarity caused the output voltage to drop 1 volt from QOP. This experiment also supported the theory of a linear response as a function of flux density.

Frequency response

Hall sensors are sensitive to motion that translates to an AC function. But what is the highest frequency that can be detected by a sensor? Actually, the frequency response is very low as compared to most ham radio applications where RF is involved. The highest-response frequency, from what I've been able to determine, was 23 kHz for the TL173C device. Perhaps newer sensor designs will allow for an increase in response frequency. For non-RF applications, a response of 23 kHz is generally fast enough to be usable as a movement sensor/detector. The frequency of 23 kHz translates to a response time of 43 µsec. For most any ham application, that response time is perhaps sufficient to meet most needs.

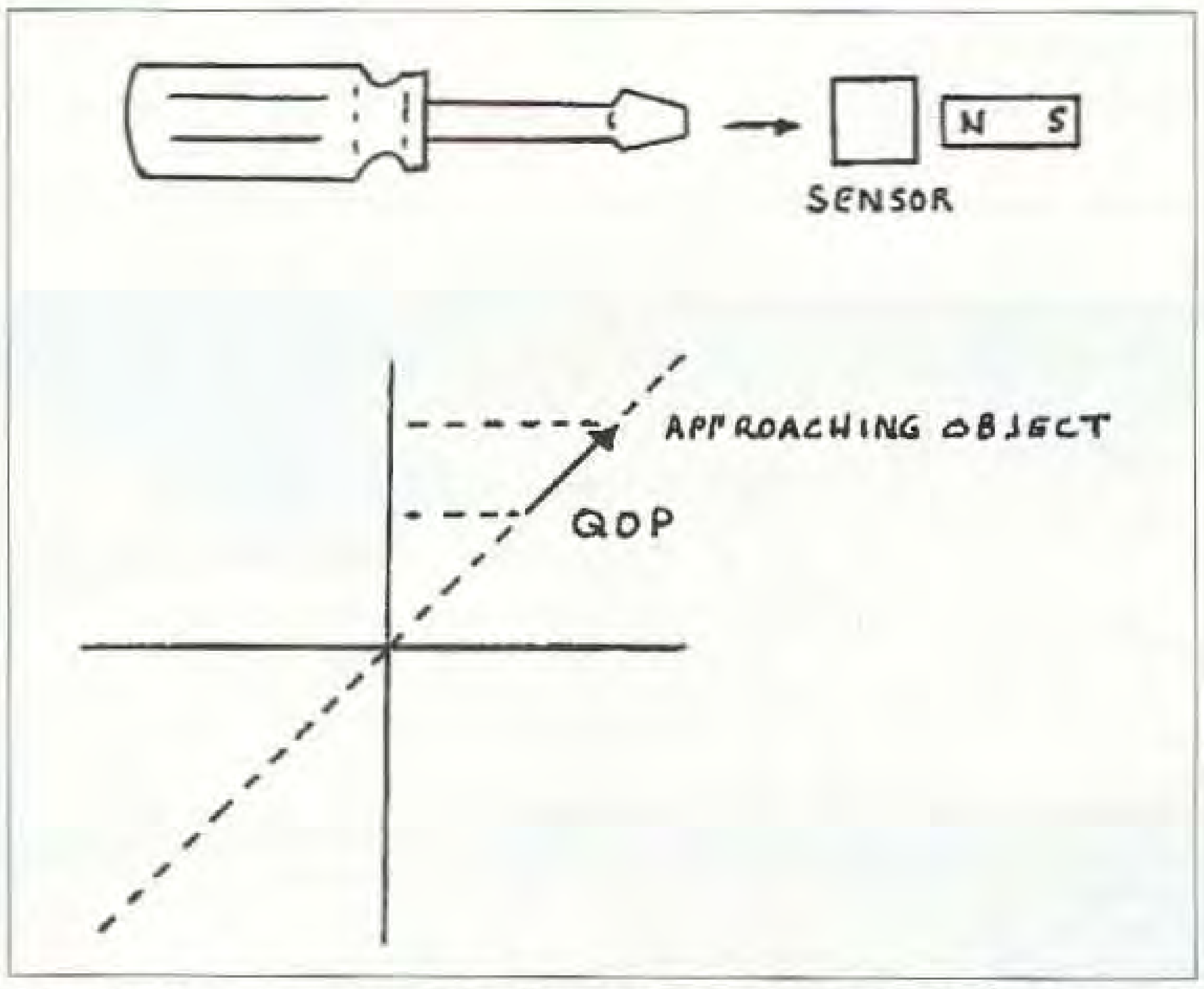

***Fig. 5.** Experiment showing how the sensor responds to the movement of a non-magnetized ferrous object. A biasing magnet is placed on the opposite side of the sensor from the ferrous object.*

Amplifier

Because the voltage output swing from the TL173C sensor was in the range of 25-30 mV, I elected to increase the output level using an LM741 op amp. My objective was to drive an analog VOM operating on the 3-volt range to a discernible level. That objective was achieved with the circuit shown in **Fig. 4**. Using my particular test magnet, the output voltage would swing up to 2+ volts from QOP.

Knowing that op amps generally exhibit some output offset, and my TL173C produced an output voltage of approximately 1 volt above Vcc/2, I elected to equip the amplifier with two potentiometers. One pot was to provide a voltage to balance the offsets, and the other was for gain control. With the nearly 1 volt offset of the sensor's output voltage, I found it necessary to parallel the upper resistor, R3, with a shunting resistor, R2. When

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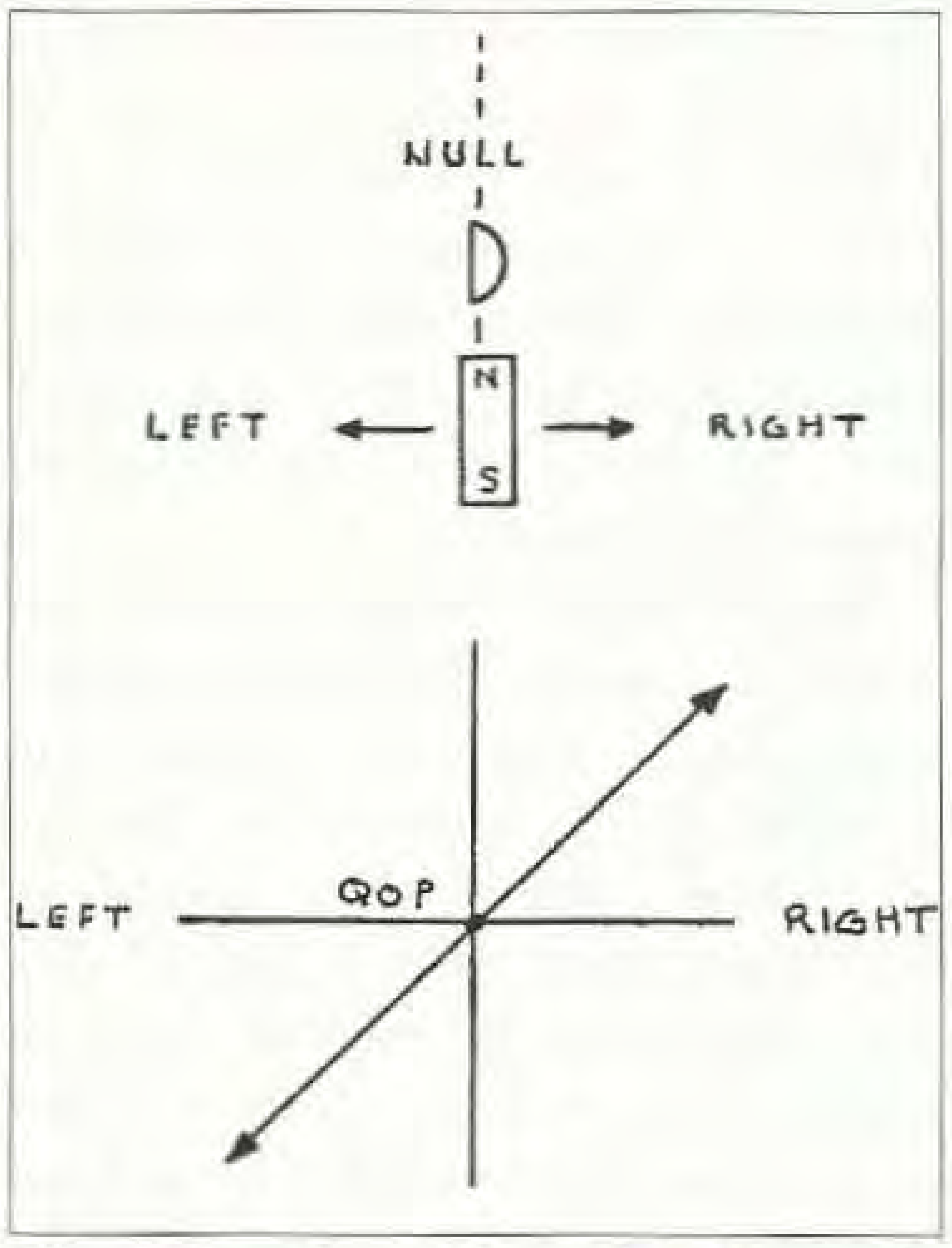

***Fig. 6.** Experiment shows the output voltage change as a function of a magnet's position. A null occurs (at QOP) when the magnetic pole is centered with the sensor. Reversing the magnetic poles also reverses the output voltage response.*

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the sensor's nominal output is high with respect to common ground, resistor R3 will require a shunt to raise the voltage at pin 3. If the output is lower than common ground, then the shunt will have to be placed across resistor R5. The actual value of the shunting resistor will have to be determined experimentally, but in my case the value was 22k.

Controlling the op amp gain would be important only if a specific sensor output voltage ratio was desired for a given experiment. For my experiments, I operated the circuit at maximum gain to achieve maximum VOM response.

For source power, I used a 15 V split voltage power supply with the intent of giving the op amp the best opportunity for a linear output response as a function of the input signal level.

Controlling the supply voltage value was also critical to the voltage applied to the sensor. In order to provide a stiff supply for the sensor, zener diodes were used to divide the supply voltage. In my experiment, I chose a pair of matching zener diodes having a voltage near 5.1 V. The ultimate objective was to place the sensor supply voltage at a value near 5.0 V and to set the sensor's QOP output voltage close to zero volts with respect to common ground. With a sensor QOP output voltage slightly above Vcc/2, balance compensation was required as discussed earlier.

Conclusion

Please examine the listing of applications for a Hall-Effect sensor and develop some uses for ham radio.

It was both fun and interesting for me to experiment with an element of technology that I hadn't experienced previously. Learning even a little bit about "strange" technology opens up your imagination for applications that will support ham radio projects and perhaps make our life easier.

My suggestion is to develop some simple experiments for devices not currently understood. You'll be amazed at the exhilaration you get with the new experience! 73