# EXPERIMENTING WITH MAGENTIC SENSORS

In the June, 1998 issue of **Electronics Now**, we introduced the FGM-x series of flux-gate magnetometer sensors from Speake & Co. Ltd. These relatively low-cost devices are made in the United Kingdom, but are distributed in the United States by Fat Quarters Software (24774 Shoshonee Drive, Murrieta, CA 92562; Tel: 909-698-7950; Fax: 909-698-7913; Web: www.fatquarterssoftware.com). For those not with us then, lets quickly review some of the important features of the FGM-3, which is used in the projects that are described in this article.

The FGM-3 is a three-terminal device (see Fig. 1 A) that will measure magnetic fields over the range 0.5 oersted (50 µteslas). It can be used in a wide variety of magnetometer and gradiometer circuits. The three terminals on the FGM-3 are: RED: POWER (+5 VDC); BLK: GROUND (0V); and WHT: SIGNAL.

The output signal is a train of TTL-compatible pulses with a period that ranges from 8 to 25 mS, or a frequency range of 40 to 125 kHz. The magnetic field strength is indicated by the frequency produced, and can be read on a variety of display devices including digital frequency counters, digital period counters, analog meters, and even computers. It is relatively easy to interface the FGM-3 device to microcontrollers — such as the Parallax BASIC Stamp or Micromint PicStic devices — using a line of interface chips offered by Speake and Fat Quarters.

The sensitivity pattern of the FGM-3 device is shown in Fig. 1B. It is a figure-8 pattern with its maxima along the major axis of the FGM-3, and minima orthogonal to the major axis. At other angles, the sensitivity drops off as the cosine of the angle from the major axis.
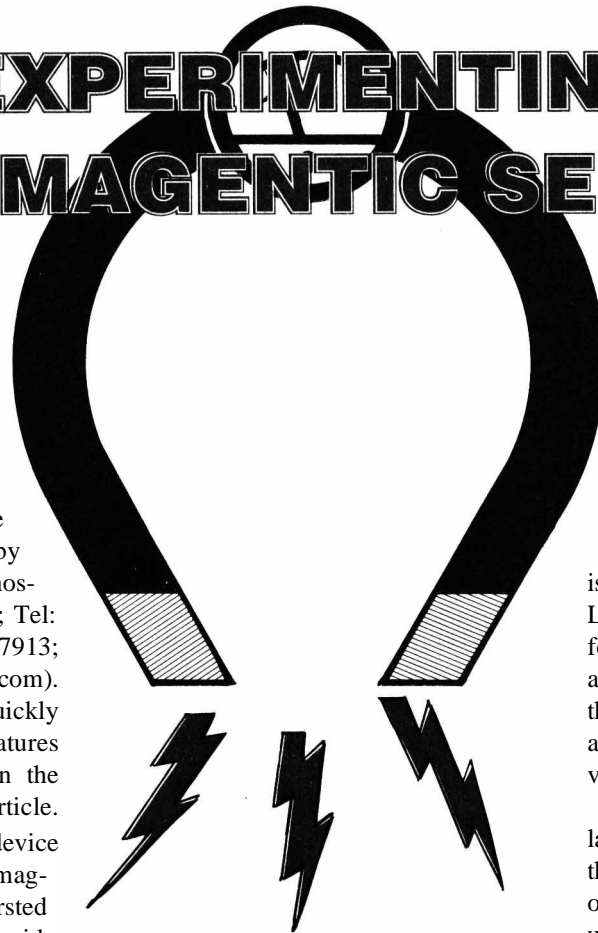
This month, we put our flux-gate sensors to work and build a practical magnetometer and gradiometer.

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Analog Interface to FGM-3.

Figure 2 shows a method for providing an analog interface to the FGM-3 and its relatives. The output of the sensor is a 40- to 125-kHz frequency that is proportional to the applied magnetic field. As a result, we can use a frequency-to-voltage (F/V) converter such as the LM2917 to render the signal into a proportional DC voltage. That voltage, in turn, can be used to drive an analog or digital voltmeter or milliammeter. The LM2917 is used here because it is widely available at low cost from mail-order parts distributors.

The output circuit consists of a bridge made up of R1-R3 and the output of the LM2917. A resistive voltage divider (R2/R3) produces a potential of 1/2(V+) at one end of the 22,000-ohm sensitivity control (R4). If the voltage produced by the LM2917 is the same as the voltage at R4, then the differential voltage is zero and no current flows. But if the LM2917 voltage is not equal, then a difference exists and current flows in R4 and Ml. That current is proportional to the applied magnetic field. Meter Ml and R4 can be replaced with a digital voltmeter, if desired.

The DC power supply uses two regulators, one for the FGM-3 and one for the LM2917. Even better results can be obtained if an intermediate voltage regulator, say a 78L09. is placed between the V+ source and the inputs of IC2 and IC3. That results in double-regulation, and produces better operation.

Digital Heterodyning.

A different interface method is shown in Fig, 3. It results in a more sensitive measurement over a small range of the sensors total capability. In other words, that circuit makes it possible to measure small fluctuations in a relatively large magnetic field.

In that circuit, a D-type flip-flop is used to "mix" the frequency from the FGM-3 with a reference frequency (FREF). The FGM-3 literature calls that process "digital heterodyning," although it is quick to point out that it is really more like the production of alias frequencies by undersampling than true heterodyning.

Two types of frequency sources can be used for FREF. For relatively crude measurements, such as a passing-vehicle detector, the CMOS oscillator of Fig. 4A is suitable. This circuit is based on the 4049 hex inverter connected in an astable multivibrator configuration.

The exact frequency can be adjusted using R2, a 10,000-ohm, 10-turn potentiometer.

Where a higher degree of stability is needed, for example when making Earth-field variation measurements or testing magnetic materials, a more stable frequency source is needed. In that case, use a circuit such as the one in Fig. 4B. That circuit uses a crystal-controlled oscillator feeding a binary divider network. Crystal oscillators can be built, or if you check the catalogs you will find that a large number of frequencies are available in TTL- and CMOS- compatible formats at low enough costs to make you wonder why you would want to build your own. I've seen them sold for about the price of a crystal alone in many mail-order catalogs (Digi-Key, etc.).

The reference frequency is adjusted to a point about 500 Hz below the mean sensor frequency. That frequency is measured when the sensor is in the east-west direction. That arrangement will produce a frequency of 0 to 1,000 Hz over a magnetic field range of 500 gamma.

A Magnetometer Project.

Figure 5 shows the circuit for a simple magnetometer based on the FGM-3 flux-gate sensor. A PC board, the sensor, the ICs, and most other parts (but no power supply, enclosure, or switch S1) can be obtained from Fat Quarters Software (contact them directly or see their Web page for more information). That circuit takes the output frequency of the FGM-3, passes it through a special interface chip (IC1), and then to a digital-to-analog converter to produce a voltage output.
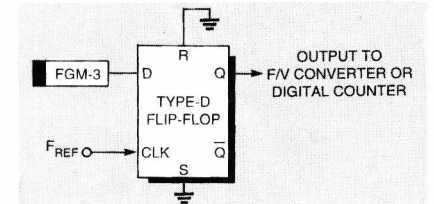
Fig. 3. To provide a more sensitive measuring capability, but over a smaller range, a type of "digital heterodyning" can be used.

The heart of the circuit, other than the FGM-3 device, is the special interface chip, Speake's SCL006 device. It provides the circuitry needed to perform magnetometry, including Earth-field magnetometry. It integrates field fluctuations in one-second intervals, producing very sensitive output variations in response to small field variations. It is of keen interest to people doing radio-propagation studies, and those who need to monitor for solar flares. It also works as a laboratory magnetometer for various purposes. The SCL006A is housed in an 18-pin DIP IC package.

The D/A converter (IC2) is an Analog Devices type AD557. It replaces an older Ferranti device seen in the Speake literature because that older device is no longer available. Indeed, being a European device, it was a bit hard to find in unit quantities required by hobbyists on this side of the Atlantic. The kit from Fat Quarters Software contains all the components needed, plus a printed circuit board. The FGM-3 device is bought separately.

The circuit is designed so that it could be run from 9-volt batteries for use in the field. A sensitivity switch, S1, provides four positions, each with a different overall sensitivity range. The output signal is a DC voltage that can be monitored by a stripchart or X-Y paper recorder, voltmeter, or fed into a computer using an A/D converter.

If you intend to use a computer to receive the data, then it might be worthwhile to eliminate the D/A converter and feed the digital lines (D0-D7) from the SCL006A directly to an eight-bit parallel port. Not all computers have that type of port, but there are plug-in boards available for PCs, as well as at least one product that makes an eight-bit I/O port out of the parallel printer port.
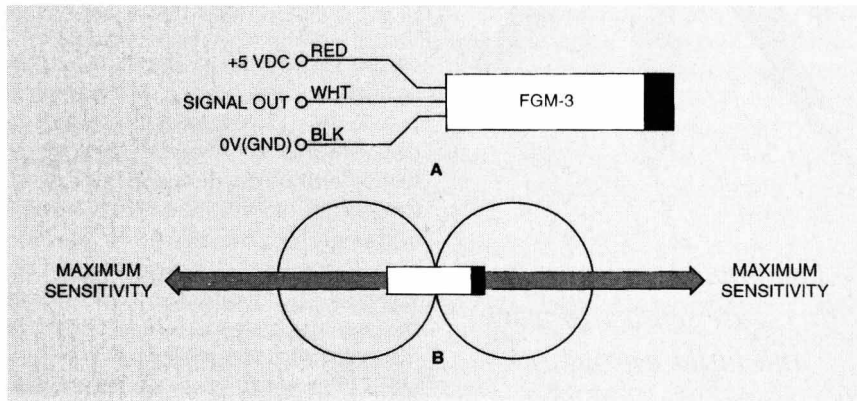
Fig. 1. The FGM-3 sensor is a three-terminal device that can be used to measure magnetic fields (A). Its sensitivity pattern is a figure-8(B).
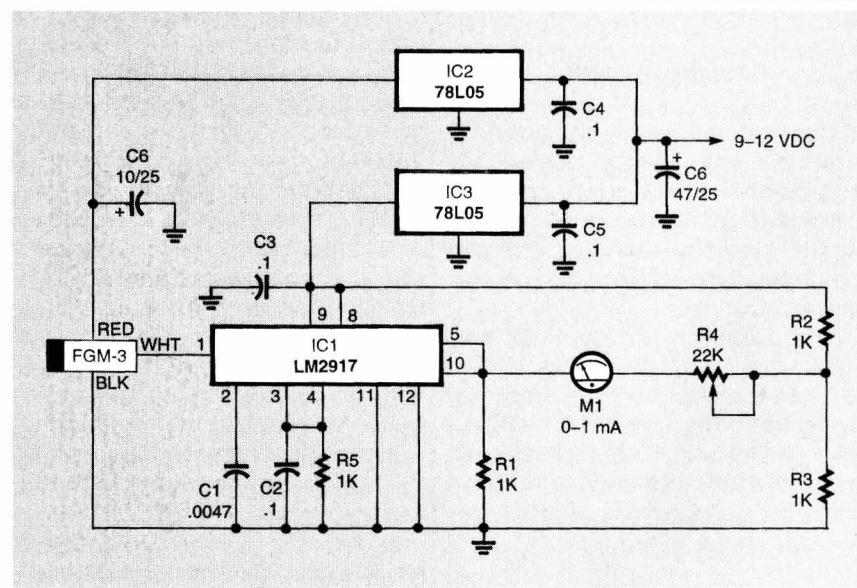
Fig. 2. This circuit can be used to provide an analog interface to the FGM-3. The heart of the circuit is an LM2917 F/V converter, which is inexpensive and easy to find.

Gradiometers.

One of the problems with magnetometers is that small fluctuations occur in otherwise very large magnetic fields, and those fluctuations can sometimes be important. A further problem with single-sensor systems is that they are very sensitive to orientation. Even a small amount of rotation can cause unacceptably large, but spurious, output changes. The changes are real, but are not the fluctuations that you are seeking.

A gradiometer is a magnetic instrument that uses two identical sensors that are aligned with each other so as to produce a zero output in the presence of a uniform magnetic field. If one of the sensors comes into contact with some sort of small magnetic anomaly, then it will upset the balance between sensors, producing an output. The gradiometer gets its name from the fact that it measures the gradient of the magnetic field over a small distance (typically 1 to 5 feet).

These instruments can be used for finding very small magnetic anomalies. For example, the metallic firing pin of plastic land mines buried a few inches below the surface, or a shipwreck buried deep in the ocean silt. Archeologists use gradiometers to find artifacts and identify sites. Also, people who explore Civil War battlefields, western mining camps, and other sites often use gradiometers to facilitate their work.

Figure 6 shows the construction details for a simple gradiometer based on the FGM-3 device. It is built using a length of PVC pipe. One sensor is permanently mounted at one end of the pipe, using any sort of appropriate non-magnetic packing material. In one experiment, I used standard 0.5-inch adhesive-backed window-sealing tape, which is used in colder areas of the country to keep the howling winds out of the house in wintertime. It worked nicely to hold the permanent sensor in place.

The other sensor is mounted in the opposite end of the tube using an O-ring that fits snugly into the tube. Four positioning screws made of non-magnetic materials are used to align the sensor.
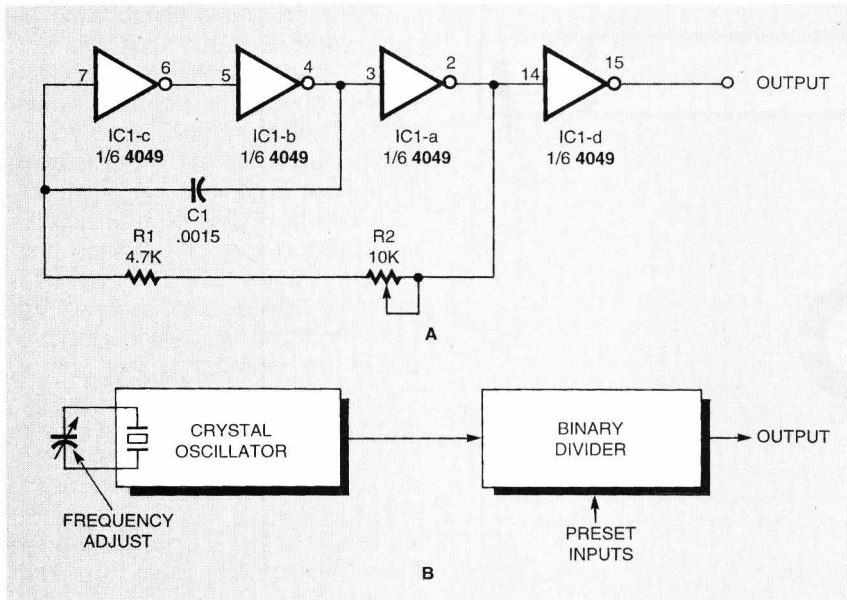

Fig. 4. For relatively crude measurements, a CMOS oscillator like the one in A can be used to generate the reference frequency. In more demanding applications, a crystal oscillator and binary divider can be used (B).
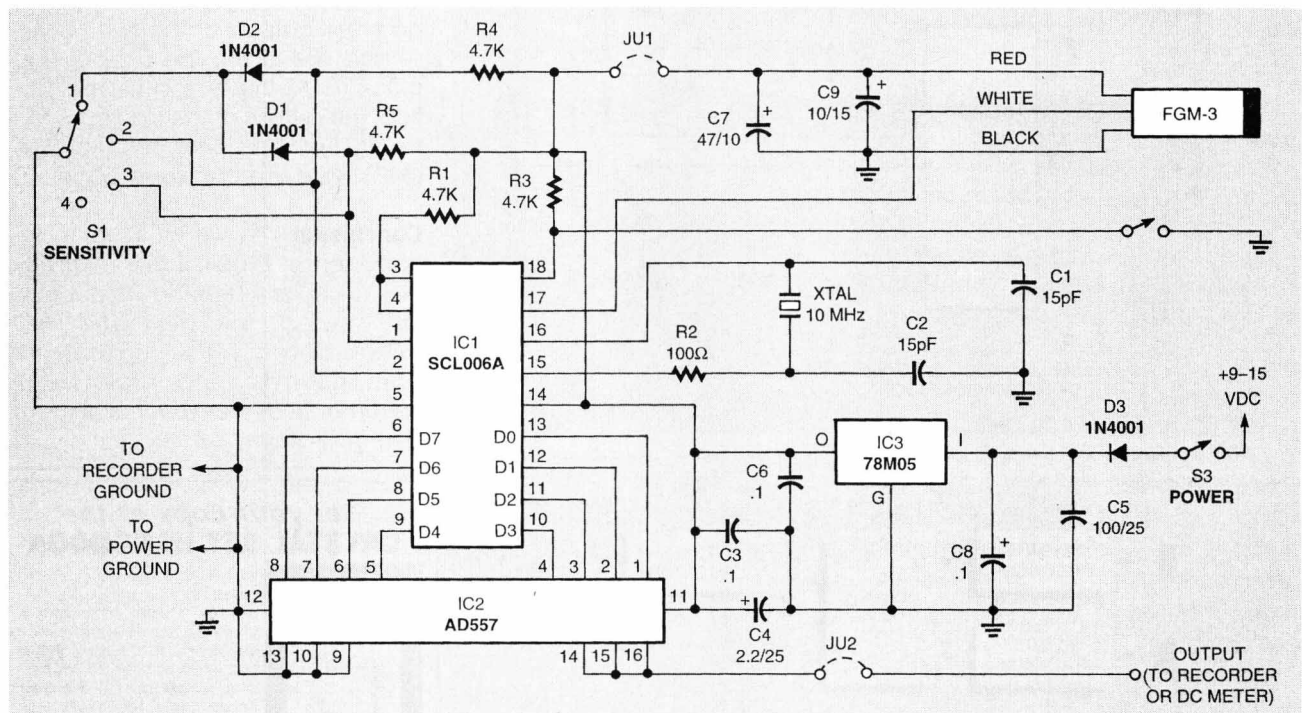

Fig. 5. Here's the circuit for a practical magnetometer. Most of the components needed and a PC board can be obtained from the source mentioned in the article.
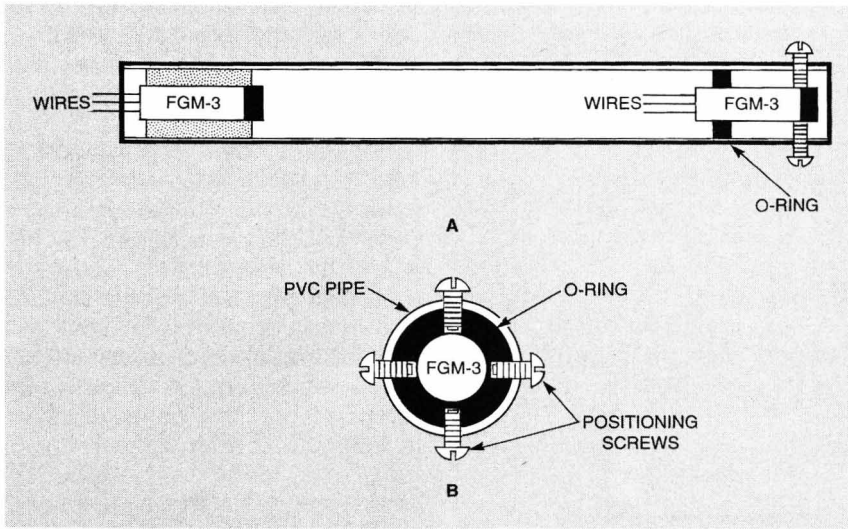
Fig. 6. This two-sensor rig forms the heart of a practical gradiometer. It is easy to build and provides excellent results.
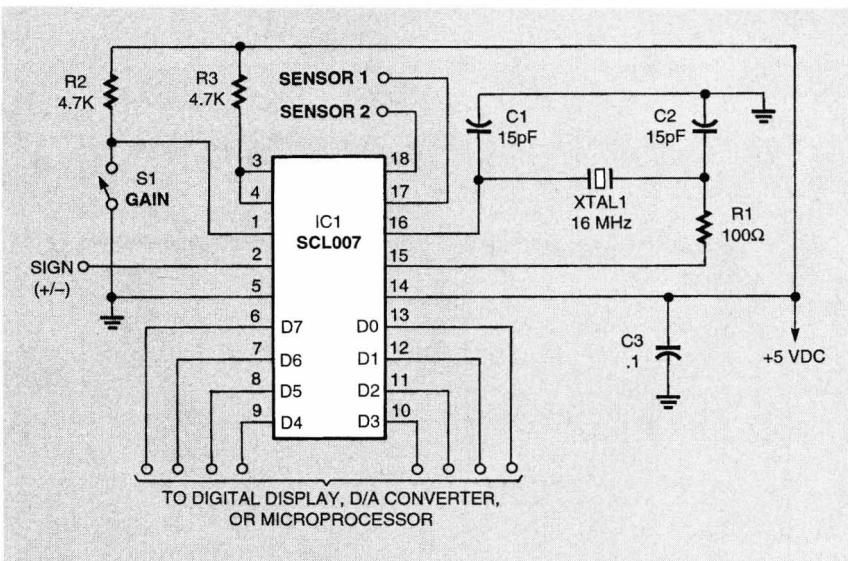

Fig. 7. Here's a circuit that converts the output of the gradiometer's sensors into a digital signal that is proportional to the field gradient.
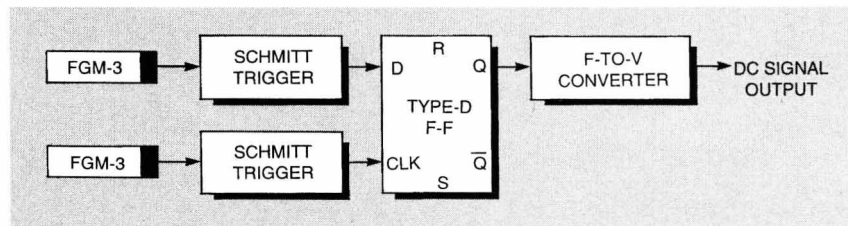

Fig. 8. Using the digital heterodyning concept discussed earlier, it is easy to build a low-cost but very sensitive gradiometer.

The position of the sensor is adjusted experimentally. The idea is to position the sensor such that the gradiometer can be rotated freely in space without causing an output variation.

The gradiometer sensor is usually held vertically such that the end with the wires coming out of the FGM-3 devices is pointed downwards. That alignment allows you to find buried magnetic objects even if they are quite small.

A practical gradiometer can be built using a special interface chip by Speake. the SCL007 device. It is an 18-pin device that accepts the inputs from the two sensors, and produces an eight-bit digital output. The circuit is shown in Fig. 7. It can receive the signals from the sensors in Fig. 6, and produce a digital output proportional to the field gradient. If you want a DC output, the same sort of D/A converter used in the magnetometer of Fig. 5 can also be used for the gradiometer.

Figure 8 shows a method of using digital heterodyning to make a very sensitive gradiometer at low cost. The outputs of the two FGM-3 sensors are fed to the D input and clock (CLK) input of a D-type flip- flop. The output of the flip-flop is fed to an F/V converter such as the LM2917 device discussed earlier.

Conclusion.

As we've seen, magnetic sensor projects are relatively easy to build when the FGM-3 sensor is used. The device is well behaved, and will serve nicely for both hobbyist and professional instruments, as well as for classroom demonstrations.