UILD THIS
MAGNETIC FIELD METER

Determine your exposure line-frequency magnetic-fields with our easy-to-build portable ELF gaussmeter.

REINHARD METZ

IF YOU ARE ONE IN A GROWING number of people who are concerned about the potentially harmful effects of exposure to magnetic fields, you will be interested in this important construction project. Now you can build your own gaussmeter, and determine the magnitude of magnetic flux densities in and around your home. Our hand-held, battery-operated magnetic-field meter is sensitive from 0.1 microtesla (μT) to 20 milliteslas (mT), and has a frequency range from 50 Hz to 20 kHz.

Why all the worry?

Magnetic fields are all around us. They occurr from the generation, distribution, and use of 50 and 60-Hz electricity, electronic equipment, and even from Earth's magnetic field, which has always been present throughout Man's evolution. Man has been "tuned" into Earth's steady magnetic field of about 30 μT (at sea level) for millions of years. Some sources of excessive magnetic fields that have caused the greatest public concern include power-distribution substations, power lines, CRT terminals, and use of appliances.

Magnetic field intensities can vary greatly, depending on the exposure source and the distance from that source. The rate at which the field intensity falls off with distance can vary from one source to another, depending on how well the current-carrying lines are balanced, or how well the opposing lines of magnetic flux cancel each other out. Fields from coils, magnets, or transformers drop off rapidly with distance by a factor of $1/r^3$. In power lines, if currents flow in opposite directions, the drop-off is $1/r^2$ because of partial field canceling. When unbalanced current exists, the field intensity falls off less rapidly as $1/r$.

Figure 1-*a*, -*b*, and -*c* show drop-off rates of $1/r$, $1/r^2$, and $1/r^3$, respectively. Figure 2 lists some of the many sources of magnetic field exposure, with their range of intensities and drop-off rates.

Although a great deal of controversy still prevails, many people in the scientific community believe that exposure to magnetic fields of extremely-low frequency (ELF fields of 1–100 Hz) may pose a risk to human health. Some disturbing findings of exposure to ELF fields include a significant increase in serum triglycerides (a possible stress indicator) in humans, disorientation of chicks (a result suggesting that bird migration could be affected), and a slowed reaction time in monkeys.

A study conducted by epidemiologist Nancy Wertheimer and physicist Ed Leeper, found that exposures to magnetic fields as small as 0.25 μT correlated with a rise in cancer rates. In the study, the researchers examined wiring and transformers in the neighborhood of birth homes of children who had died of leukemia between 1950 and 1975, along with those of a control group of children who did not have the disease. The results of their studies were published in *The American Journal of Epidemiology* (March, 1979). Some experts argue that other factors, such as pollution and exposure to chemical carcinogens, make interpretation of those findings very difficult.

Standards for acceptable exposure to ELF fields are emerging, as are results of studies

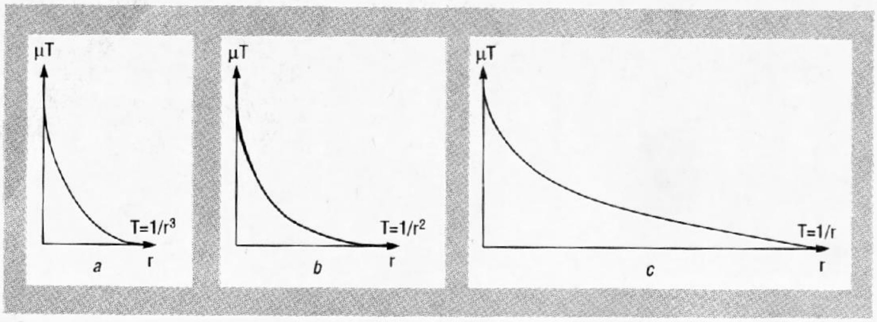


FIG. 1—MAGNETIC FIELD drop-offs. A fast drop-off of $1/r^3$ (*a*), $1/r^2$ (*b*), and a slow drop-off of $1/r$ (*c*) is typical of many sources of magnetic fields.

describing possible hazard levels. If you are more interested a detailed account of scientific findings and the political history of the effects of magnetic-field radiation, we suggest a three-part series of articles by Paul Brodeur, *The New Yorker* (June 12, 19, and 26, 1989). "60-Hz and The Human Body", *IEEE Spectrum*, Parts 1–3, Volume 27, Number 9, pages 22–35 (August, 1990) is also a good source for technical information. The Environmental Protection Agency (EPA) has published a report titled "The Evaluation of the Potential Carcinogenicity of Electromagnetic Fields", publication number EPA/600/6-90/005B. This report contains analyses of 64 scientific studies, and is currently under review by the Scientific Advisory Committee.

Well, that's enough background for now. Let's examine some of the theory behind how the ELF meter works.

Theory

The quantity of magnetic flux density, **B**, is in units of webers/meter², or tesla (T). The magnetic flux, φ, is defined by the integral

$$\phi = \int \mathbf{B} \cdot d\mathbf{s} = B \times A$$

where d**s** is the differential surface area and A is the area that the coil encloses.

For a coil immersed in a field, the induced open-circuit voltage, E, is equal to the number of turns of a coil, N, times the rate of change of flux through it.

$$E = |N \times d\phi/dt|$$

Note that the value of $N \times d\phi/dt$ is actually negative with respect to the induced voltage value, but for our purposes we will just consider the magnitude of the product. The direction of the induced current is such that its own magnetic field opposes the changes in flux responsible for producing it.

If we substitute for φ we get

$$E = N \times A(d\mathbf{B}/dt)$$

If the magnetic field of a sine wave is $\mathbf{B} = a(\sin \omega t)$, a is the amplitude in teslas and ω is the angular velocity ($2\pi f$), then

$$d\mathbf{B} = a\omega(\cos \omega t)dt, \text{ and}$$
$$E = N \times Aa\omega(\cos \omega t)$$

Since cos ωt varies from +1 to −1, the peak magnetic field is defined as

$$E = NAa\,\omega$$

For a frequency of 60 Hz, ω equals

$$2\pi \times 60 = 377$$

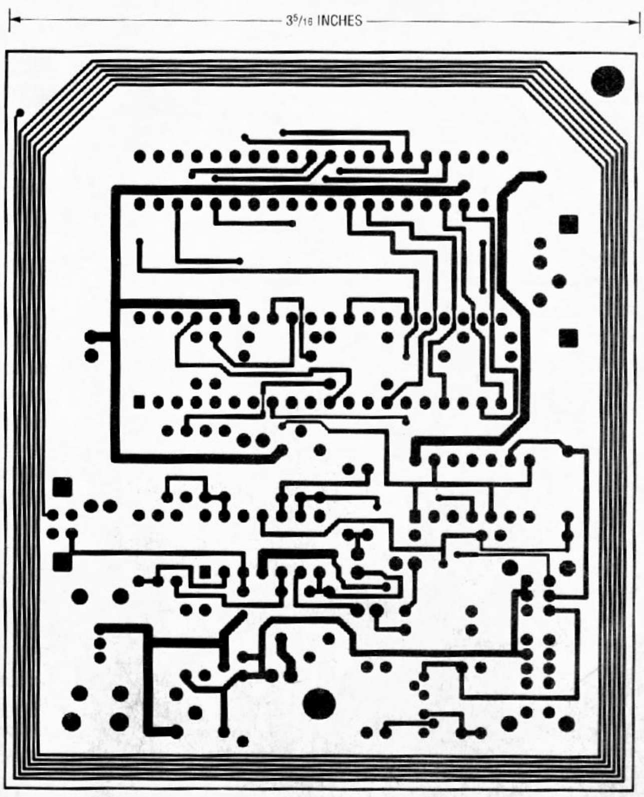
For a coil size of 3½" × 3", the area is .0068 m², and therefore

$$E = 2.56\ N \times a$$

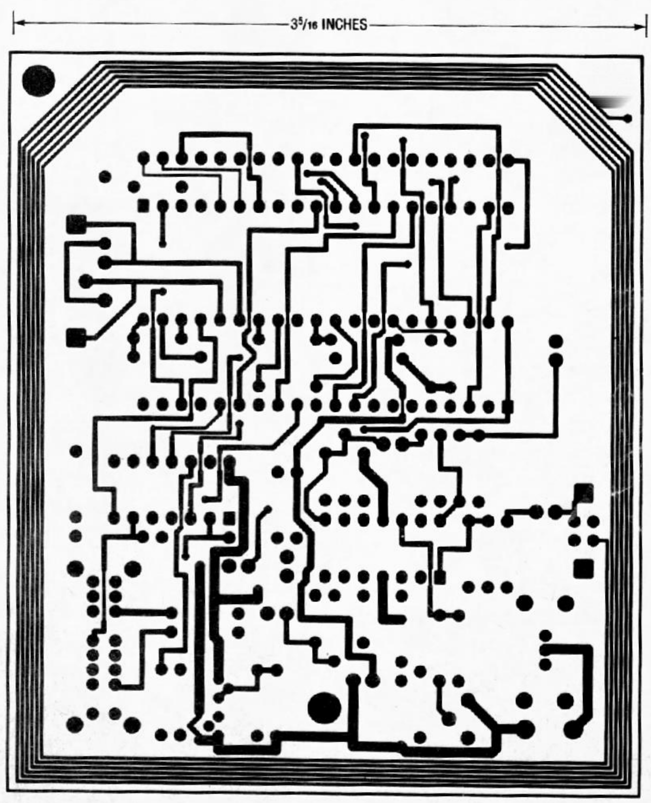
For the 12-turn pickup coil that we'll use, the sensitivity is 30 μV per μT.

Circuit description

The meter's 12-turn field pickup is integrated into the unit's circuit board. For remote sens-



COMPONENT SIDE OF THE PC BOARD.



SOLDER SIDE OF THE PC BOARD.

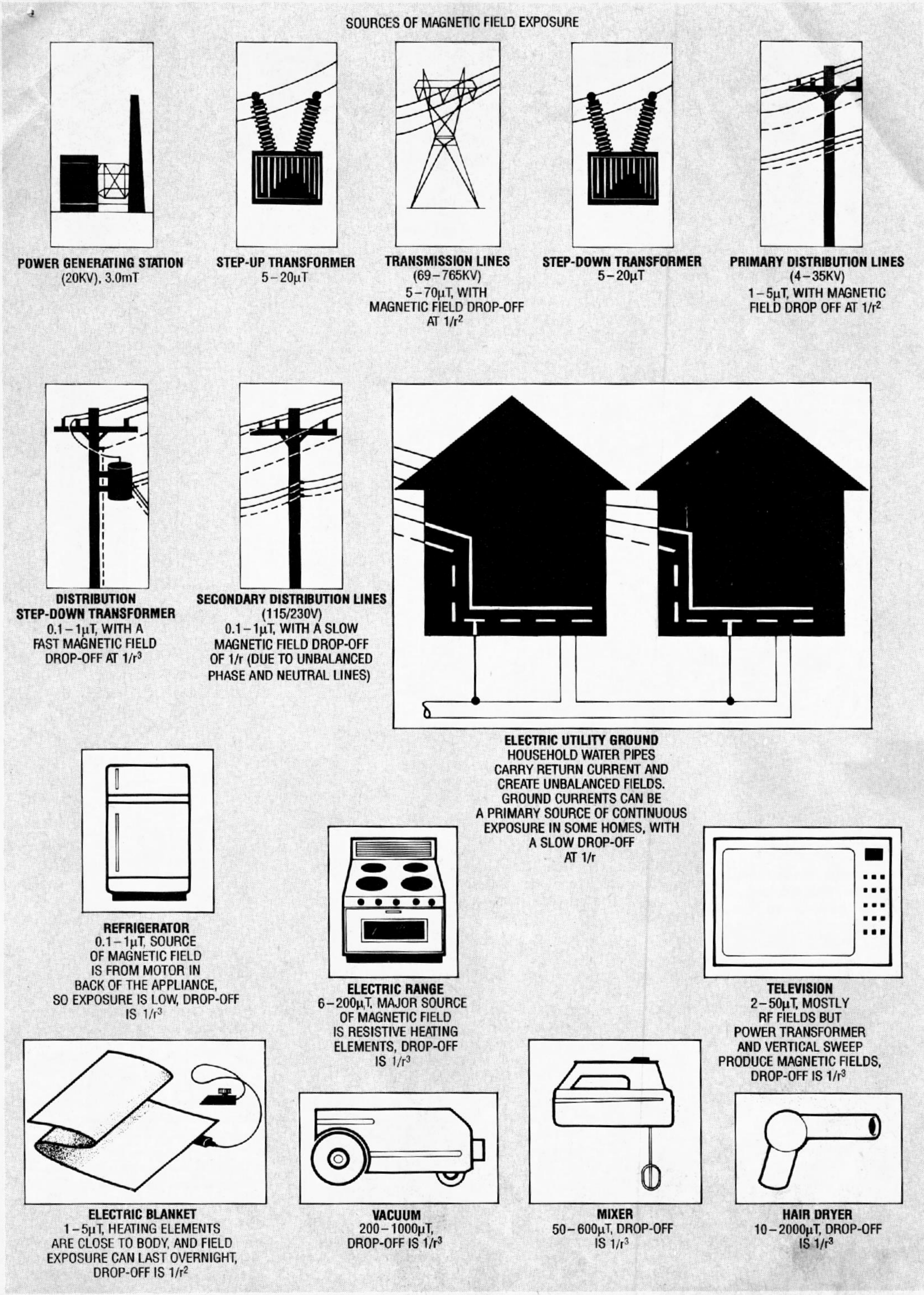


FIG. 2—HERE ARE SOME PRIMARY SOURCES of magnetic field exposure with the range of field intensity in teslas, and drop-off rates.

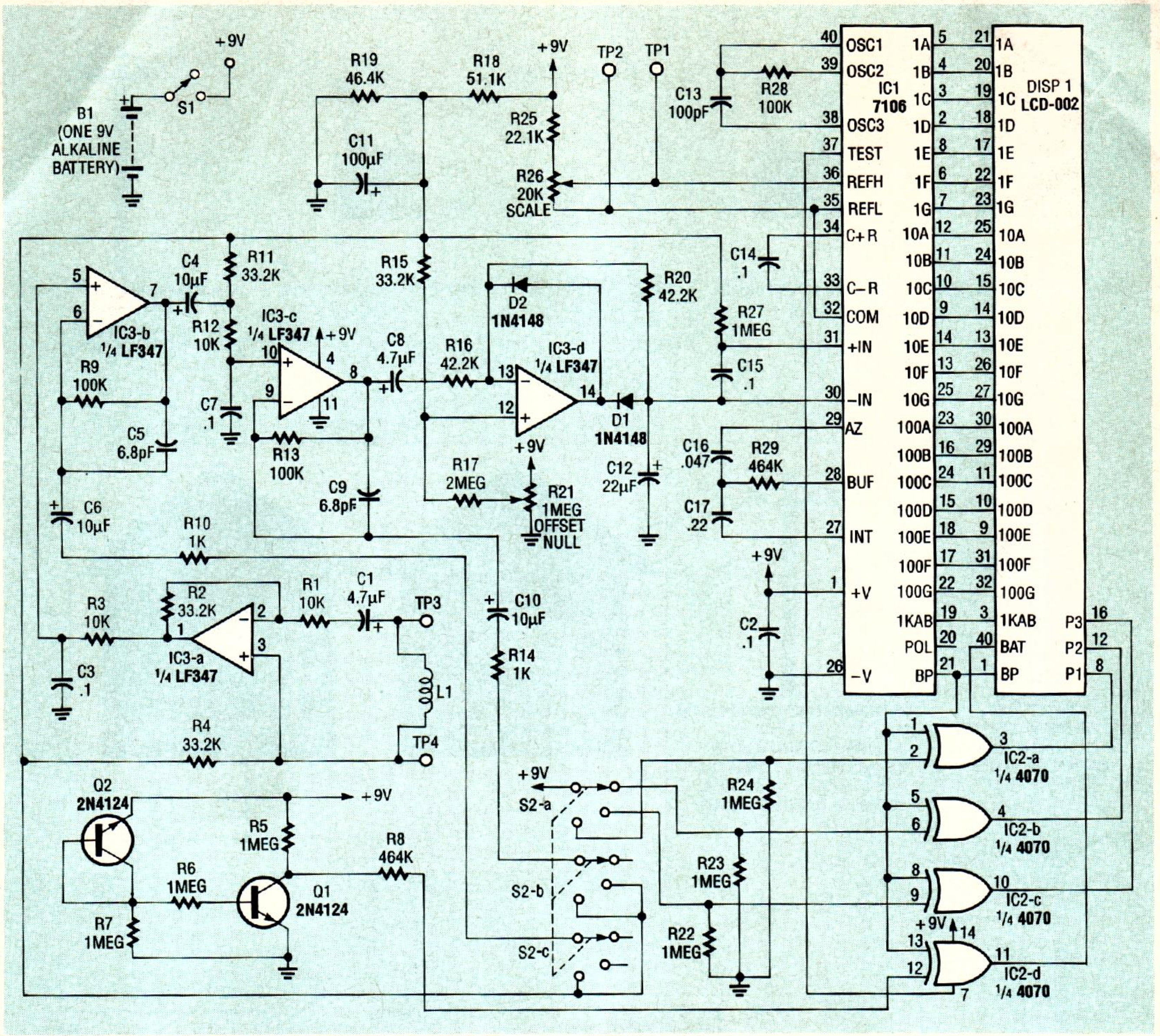


FIG. 3—SCHEMATIC OF THE MAGNETIC FIELD METER. The magnetic field is picked up by L1 and appears as a voltage that is proportional to the field strength at the input of IC3-a, which amplifies the signal to 100 µV per µT. The signal is then further amplified by IC3-b and IC3-c to achieve the three tesla ranges.

PARTS LIST

All resistors are ¼-watt, 1%, unless otherwise indicated.

R1, R3, R12—10,000 ohms
R2, R11, R15—33,200 ohms
R4—10 ohms
R5-R7, R22-R24, R27—1 megohm
R8, R29—464,000 ohms
R9, R13, R28—100,000 ohms
R10, R14—1000 ohms
R16, R20—42,200 ohms
R17—2 megohms
R18—51,100 ohms
R19—46,400 ohms
R21—1-megohm potentiometer, 5%
R25—22,100 ohms
R26—20,000-ohm potentiometer, 5%

Capacitors

C1, C8—4.7 µF, 10 volts, electrolytic
C2, C14—0.1 µF, electrolytic or polyester
C3, C7, C15—0.1 µF, polyester
C4, C6, C10—10 µF, electrolytic
C5, C9—6.5 pF, ceramic disc or mica
C11—100 µF, 10 volts, electrolytic
C12—22 µF, 10 volts, electrolytic
C13—330 pF, polyester
C16—0.047 µF, polyester or ceramic disc
C17—0.68 µF, polyester

Semiconductors

D1, D2—1N4148 switching diode
Q1, Q2—2N4124 NPN transistor
IC1—ICL 7106 A/D converter
IC2—4070 or 4030 quad 2-input exclusive-OR gate
IC3—LF347 quad JFET input op-amp
DISP1—LCD-002 liquid crystal display

Other components

S1—MSS1200, SPST (Alco)
S2—MSS4300, SPDT (Alco)
L1—18 turns, 3" diameter remote-sensing coil (optional, see text)
B1—9-volt alkaline battery, with connector
Case—Pac-Tec, HPS-9VB

NOTE: The following items are available from A & T Labs, P.O. Box 552, Warrenville, IL 60555: A kit of all parts including PC board and case, without battery, $85.00; an etched, drilled and plated through PC board with solder mask and silk-screened parts placement, $15.00; a fully assembled and tested unit, $109.00. Add 6.75% sales tax for Illinois residents, 5% shipping and handling in U.S., 12% shipping and handling in Canada. Check or money order (UPS COD in contiguous U.S. only) is accepted.

ing, an external field coil probe can be used. Figure 3 shows the complete schematic of the circuit. The magnetic field picked up by the coil appears as a voltage, which is proportional to field strength and frequency at the input of a cascaded amplifier IC3-a, -b, and -c. With a first stage amplifier gain of 3.3 set by R12-R10, the overall sensitivity is 100 μV per μT, or 100 mV per mT. The meter sensitivity is nominally 2 volts full scale, leading to the lowest level sensitivity of 20 mT full scale.

Op-amp IC3-a amplifies the signal to a normalized level of 100 μV per 1 μT. That voltage is further amplified by 1, 100, or 10,000 by IC3-b and -c. The three amplifier stages provide the three magnetic field ranges of 2 mT, 200 μT, and 2 uT (full scale). Components R3-C3 and R12-C7 establish a frequency roll-off characteristic that compensates for the frequency-proportional sensitivity of the pickup coil, and set the 20-kHz cut-off point.

Finally, IC3-d is a precision rectifier and peak detector. Its output drives IC1, a combination analog-to-digital (A/D) converter and LCD driver. Components R25–R29 and C13–C17 are used by IC1 to set display-update times, clock generation, and reference voltages. The decimal points are driven by IC2, as determined by the range-select switch S2. Transistors Q1 and Q2 serve as a low-battery detector, and turn on the battery annunciator in the LCD when the battery voltage drops below 7 volts.

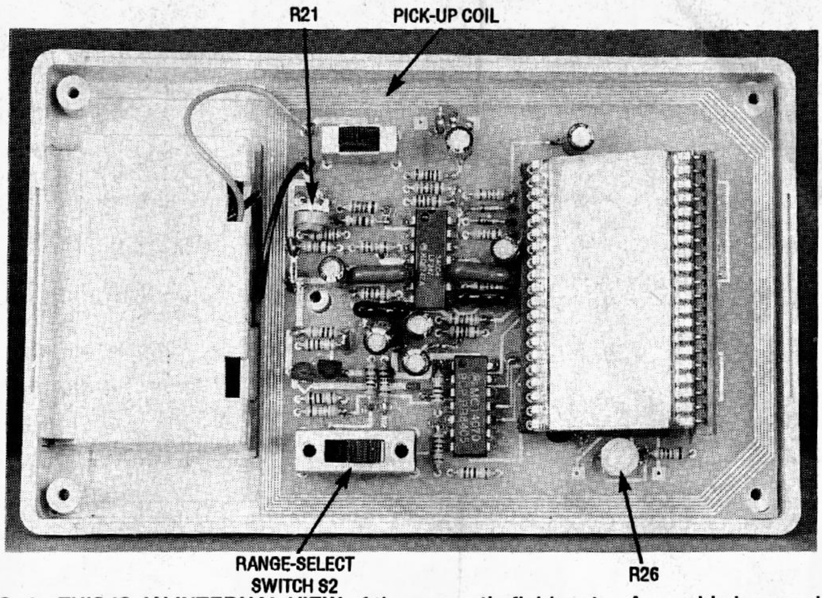


FIG. 4—THIS IS AN INTERNAL VIEW of the magnetic field meter. Assembly is easy, just install all components below the LCD first.

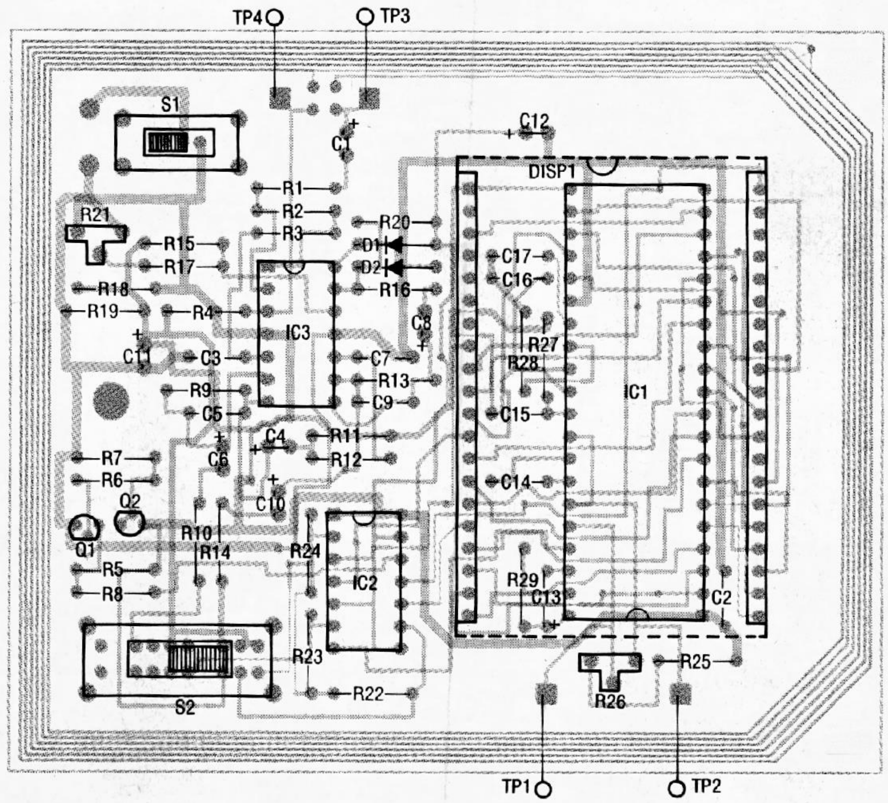


FIG. 5—PARTS PLACEMENT DIAGRAM.

Assembly and checkout

The finished unit shown in Fig. 4 uses a double-sided PC board, which is available from the source mentioned in the parts list. We also show the component side and solder side of the PC board if you choose to make it yourself. You can, however, build the circuit on a perforated construction board if you like, but remember to include the 18-turn remote sensing coil, L1, as indicated in the Parts List. Mount all parts below the LCD display first. It's easier to fix assembly problems if a socket is used with the LCD. Install all parts as shown in Fig. 5 paying attention to component valves and capacitor polarities. If you are using the internal sensing coil, install jumpers between L1-TP3 and L1-TP4.

If you are using the case specified in the parts list, raise and angle the display as necessary with wire-wrap IC sockets. Make holes in the front panel for S1 and S2. Mount the finished PC board in the case using a spacer for the single screw holding the center bottom of the board, and attach the battery connector. You are now ready for power-up and checkout.

With power on, adjust R26 for 1.000 volt between TP1 and TP2. Then, select the 20 mT range and short the pickup coil with a very short lead between TP3 and TP4. Adjust offset-null potentiometer R7 for a display of 0.00. Remove the jumper, and the meter is complete.

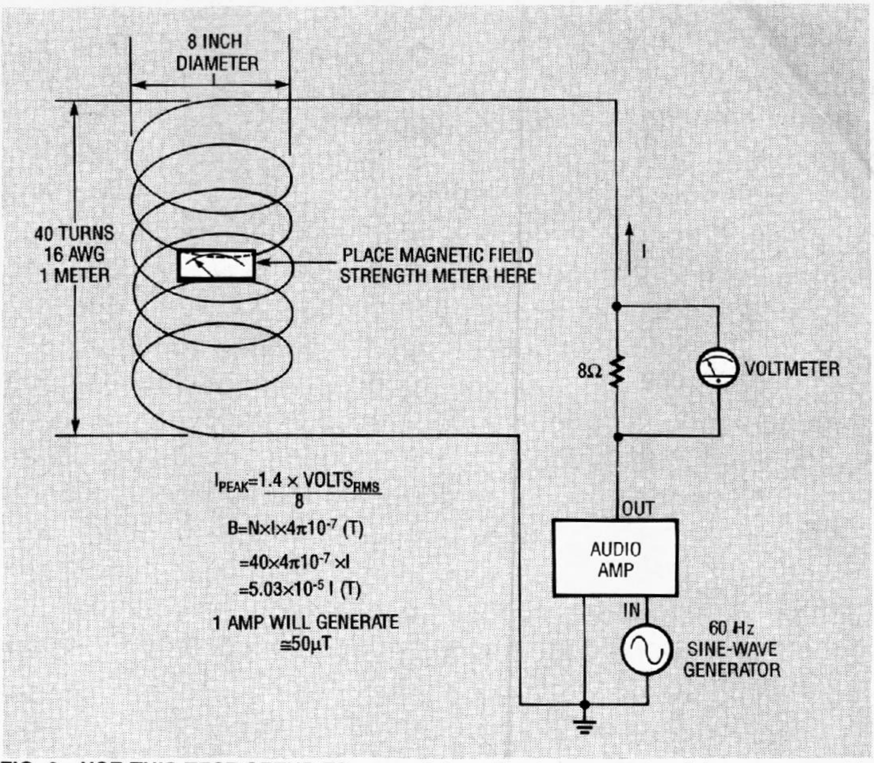


FIG. 6—USE THIS TEST SETUP TO accurately calibrate your meter. A known current is passed through a coil whose field intensity is known. A sine-wave generator provides the 60 Hz frequency, and an audio amplifier is coupled to the coil by an 8-ohm resistor. Measure the voltage across the resistor, and use the calculations shown.

Calibration

Calibration of the meter is basically determined by the pick-up-coil characteristics, amplifier gains, and meter reference-voltage setting. The amplifier gains, as we previously discussed, are chosen to match the coil characteristics as closely as possible.

If you desire to calibrate your meter more exactly, you will need to generate a known magnetic field intensity. One way to do that is to pass a known current through a coil configuration whose field pattern characteristics are known. Figure 6 shows such a calibration setup. A good controllable signal source is a sine-wave generator and an audio amplifier, whose output is coupled to a coil through an 8-ohm resistor. Measuring the voltage across the resistor gives the current. Then, calculate the magnetic field according to Fig. 6. (Note that while all references to field strength here are made in teslas, gauss are also commonly used. The conversion is easy: 1 tesla = 10,000 gauss.)

Place the meter inside the coil and turn it on. Use the highest sensitivity scale that does not overrange the display. An over-range is indicated by a display of 1 followed by three blanks. In most cases, the 2 μT range is satisfactory.

Measurement interpretation

A great deal of controversy exists in the emerging understanding of potential health hazards of low-frequency magnetic fields. The International Radiation Protection Association (IRPA) has set some interim standards based on 1984 World Health Organization guidelines. Those IRPA standards specify a continuous maximum magnetic field exposure for the general public of 100 μT, and 500 μT as the maximum occupational exposure allowed over the entire working day.

Some European countries have already adopted strict magnetic field emission requirements for video display terminals, but the United States is taking a more cautious approach about developing and enforcing such guidelines.

Whatever studies and data you think are accurate, now you have a way to measure your own exposure and take whatever action you believe is prudent. **R-E**

TOM GORDON
Berkeley, CA

USING THE MAGNETIC FIELD METER

I was happy to see the "Magnetic Field Meter" project in the April issue of **Radio-Electronics**. The meter allows a quick (and inexpensive) assessment of home and business magnetic-field conditions for those of us who are unwilling to wait for U.S. standards to be established. I have some additional suggestions regarding the calibration use of such a coil-based meter.

For both calibration and use, the orientation of the coil is critical. The single-coil design is sensitive only to fields in one of three axes. The "right-hand rule" gives the relationship between the direction of field-producing current flow and the orientation of the coil axis for maximum sensitivity. For the calibration technique shown in Fig. 6 of the article, the meter pick-up coil should be at right angles to the current flow, hence parallel to the axis of the transmitting coil.

When conducting a survey, the meter coil axis should be oriented along each of three perpendicular axes and the strongest reading used for analysis. The external coil option would make that easier. The field strength due to monitors and due to unbalanced wiring usually has a strong maximum in one direction. The more expensive, professional meters typically use three perpendicular coils (or three Hall-effect devices) and electronically develop the true maximum field.

I would also like to provide some reference points of EMF field strengths to augment the values given in the article. The typical unbalanced current flow in the center-tap ground of a 240-volt drop to a house is 0–4 amps at 60 Hz. That corresponds to a magnetic field of 0–2 μT (0–20 milliGauss) at 1 inch from the current. The current usually flows down the outside wall of the house and through the cold water pipe along the basement ceiling. The quickest solution to such fields is to move furniture such as beds and cribs away from the area so that exposure time is reduced. The current could also be rerouted by an electrician with suitable copper ground strapping.

The new Swedish EMF guidelines for computer monitors (VDT's) are:

- 50 cm (20 in.), 5 Hz–2 kHz: 0.25 μT (2.5 mG)
- 50 cm (20 in.), 2 kHz–400kHz: 0.025 μT (0.25 mG)

Source: *VDT News*, Nov./Dec. 1990

Several manufacturers are now making low-radiation color monitors for the U.S. market, including all IBM's made since September 1989 and the new NEC 3Ds model. Many monitors exhibit low fields already, and can be tested with the Gaussmeter before purchase.

WILLIAM SNYDER
Rochester, NY

NOBODY'S FOOL

I just finished reading the article on making a laser printer out of a monitor and a copier (**Radio-Electronics**, April 1991). It's a good idea in theory, but in practice you could have a problem. Some copiers will not run with the lamp removed. If you have that problem, you are going to have to create a path for the lamp voltage to "fool" the circuit.

RICK SCHWILL
Phoenix, AZ

R-E

LETTERS

Write to Letters, Radio-Electronics, 500-B Bi-County Blvd., Farmingdale, NY 11735

AUDIOPHILE ATTITUDES

My thanks to **Radio-Electronics**, and especially to Larry Klein, for his excellent series of articles about audiophile attitudes and equipment. His well-reasoned and fully documented data are long overdue.

The level of foolishness in the consumer-audio and audiophile markets should be an embarrassment to all professionals in the electronics field. Beliefs in things ranging from absurd speaker cables to "greening" of CD's are no more legitimate than Creation Science, and the audio faithful who are willing to part with $10,000 or more for an antiquated tube amplifier must surely qualify as the all-time champions of gullibility. Thanks again.

PAUL J. CARLSON
Pittsburgh, PA

MAGNETIC FIELD METER QUERIES

I really enjoyed Reinhard Metz's article, "Build this Magnetic Field Meter" (**Radio-Electronics**, April 1991). I thought the issues of possible health risks, magnetic field theory, and the pictures of sources of magnetic-field exposure were presented very well.

For the last year I have been involved in evaluating problems concerning ELF magnetic fields and remedial solutions. Part of my work was directed to evaluating Gauss meters and magnetic-field measurement systems.

I have three questions about the meter. First, I wonder if the unshielded coil on the PC board might be sensitive to the electric as well as the magnetic fields, and because of the differing vectors, give ambiguous readings? Second, the article stated that the meter is usable in a frequency range from 50 Hz to 20 kHz. Is the meter reasonably flat with frequency over its entire dynamic range? I know that this can be a serious problem and can lead to substantial errors in measurement. Third, I worry that the relative insensitivity (0.1 μF) of this meter, along with its high (20 mT) range, might cause people to expose themselves to those 10–20 mT fields while making measurements. Perhaps a note cautioning against that would have been wise. If the meter range had been 0.001–20 μT, overranging would tend to prevent possibly hazardous exposure.

I hope I'm not being overcritical of the meter. Again, I'd like to thank Mr. Metz and **Radio-Electronics** for presenting this important information to the public.

JOHN MILLS
Ben Lomond, CA

Thank you for your kind comments about my article. In response to your questions: First, while the magnetic field pickup coil might be considered an antenna for the electric fields, its small size would make it efficient as such only at relatively high frequencies, where the op-amps are ineffective. At lower frequencies, the electric field pickup appears primarily as common-mode voltage, and should not get amplified. Tests of the unit have been successfully conducted in RF fields up to 20 volts/meter.

Second, in regard to frequency range and flatness of response, while it was stated that the response was from 50 Hz to 20 kHz, it was in fact optimized for power-line frequencies and their third harmonics. If your are interested in optimal flatness to 20 kHz, I would suggest changing the following component values: R3 becomes 16K and R12 becomes 80 ohms (or C7 becomes 800 pF).

Finally, I'm not sure how the 20-mT range of the meter would "cause" a person to expose themselves to fields in that range, unless they deliberately set out to create them for the sake of a meter deflection. That certainly would not be advised. However, to the extent that they may exist in some places and are detected by the meter, I agree that people should use that information to avoid further potentially hazardous exposure.

REINHARD METZ

CORRECTIONS

There was a slight error in the circuit that was sent in to us from Johnny Bruyns of Port Shepstone, South Africa (Letters, January 1991). There should be a 4.7K resistor between the +V supply line and pin 7 of IC2. The direct connection that was shown should be replaced by the 4.7K resistor.

ELECTRONICS BEHIND BARS

I'd like to thank **Radio-Electronics** for keeping alive my interest in electronics for the last eleven years. Without your magazine, I would not have been able to keep abreast of the massive changes in the industry. You see, I am a prisoner serving 15 years for committing a crime of passion. Since I entered prison in 1980, I have relied on your magazine to keep me informed of the changes. Had I not received a monthly issue, I would find myself upon release to be totally out of touch. All this time, without so much as seeing a soldering iron, your magazine has helped me to keep the faith.

In two years, I will be returning to a new life. Before leaving here, I hope to impart an enthusiasm for electronics to other prisoners. For five years, I have struggled to establish an electronics hobby club. Last week I was given permission. Most of the people I met in prison have not had the advantages I've had in my life. I know in my heart that fostering an interest in electronics and giving some of the other prisoners the basics of electronics will lead to a confidence in their abilities that will aid in reformation.

I'm asking for help from any of your readers who might have old copies of **Radio-Electronics**, **Popular Electronics**, **Hands-on Electronics**, or other electronic publications to send them to me. We'd also appreciate any plans or projects that they'd like to share, as well as old books, specification sheets, or helpful hints. Perhaps the most important thing I hope your readers can send is support—support in the form of let-

FOILED BY COILS

The project entitled "Build This Magnetic Field Meter" (**Radio-Electronics**, April 1991) brought to mind a difficulty I have always had with the archaic "art" of coil winding. Factory-made coils are constructed using highly specialized jigs and fixtures, so that their specified values are usually reliable. Since the average hobbyist is equipped with a maximum of two hands, it is not illogical to presume that a fairly complex home-built device is required to lay down magnetic wire on a coil form with acceptable results. (Acceptable, to me, means rigidly anchored, evenly spaced windings that conform to 95% of a comparable factory standard. In other words, why stuff a circuit board with high-quality silicon if the interfacing discrete components are not approximately equal in quality reliability?)

The one-meter-long coil shown in Fig. 6 of the article raises my coil-winding hackles to a fever pitch! The extremely wide variations in tolerance that would surely result from fabricating that elephantine coil makes me wonder about using that circuit to calibrate the Gaussmeter.

At the same time, I understand that hand-wound coils have been used for several decades by countless electronics enthusiasts with satisfactory results. Maybe I'm looking for precision in every aspect of my work, even when it's not required.

DAVID KATZNELSON
Willingboro, NJ

I appreciate and agree with your concern over the difficulties of winding the large calibration coil. I offer the following suggestions: Wind the coil concentrically first on a fixed form, and then stretch it out to the one meter length; or use an alternative non-solenoid design, such as two separate coils in a Helmhotz-type arrangement. Please note that, in recognition of exactly your kind of concerns, the meter's pickup coil is integrated in the PC board.

REINHARD METZ

BATTERY TESTERS

Thank you for the "Battery Testers" section in *Hardware Hacker* (**Radio-Electronics**, April 1991). It was short, yet provided a lot of useful information. However, I would like to point out that the tester included with