Build the HANDI-Finder!

This hand-held direction finder is great for "fox hunting"! Simply connect it to the antenna input of your H-T or FM scanner and you can locate AM or FM sources over the range of 45 to 470 MHz.

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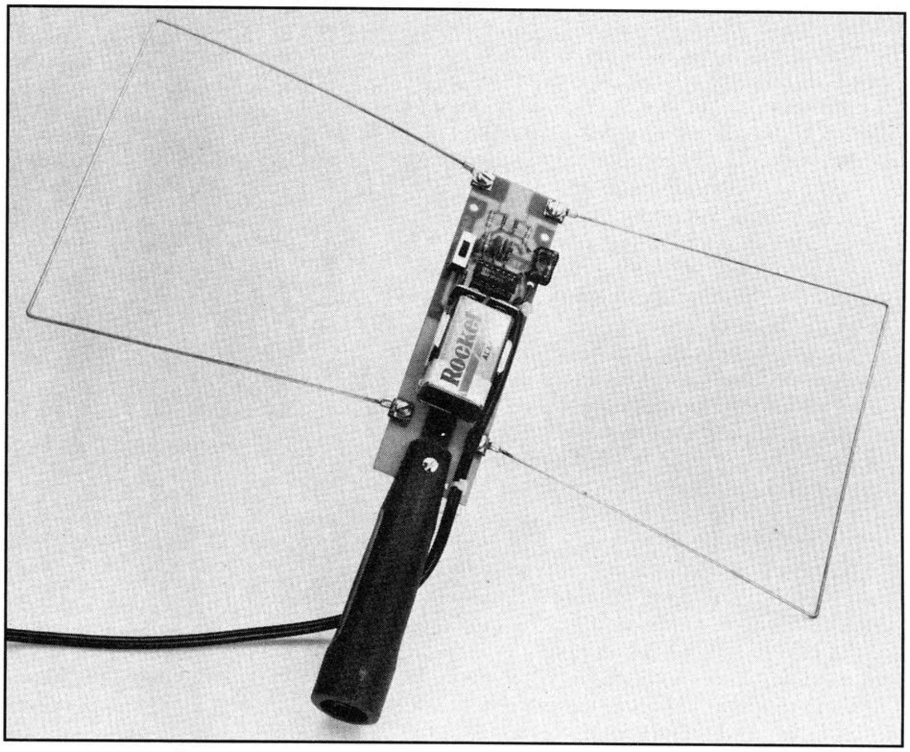

Inevitably, every Amateur Radio community experiences its share of repeater jammers. Tempers flare. A new generation of hams gets interested in direction finding. Car roofs start sprouting outlandish antenna arrays, looking more like tuna boats with every antenna addition. Fox hunts are scheduled for practice—and the jammers quickly become more evasive!

When that happened in our area a few years back, Rich James, N8FIL, of the Cuyahoga Amateur Radio Society (CARS), organized members from several area clubs into the "Bozo-Busters," and I resurrected four DOP-SCAN units[1] supplied by the Lake Erie Amateur Radio Association (LEARA). A few dedicated hams soon found themselves getting called out at all hours and driving all over town. When the gasoline bills started mounting up, we figured there had to be a better way!

Thought: Instead of a *few* hams outfitted with *special* equipment, why not have *many* hams equipped with *simple* direction finders? The units would have to be readily available to get a quick bearing whenever some troublemaker appeared with a strong signal on the repeater input near their location.

Inspired by a United States Coast Guard Auxiliary direction finder[2] and *The ARRL Antenna Book*,[3] I designed something simple, inexpensive, compact and practical. I call it the HANDI-Finder:[4] the *HAN*dheld *DI*rection-*Finder*. When equipped with open-loop wire antennas and a short handle, it stores flat (it'll fit in a briefcase) ready for use. An easy-to-build beginner's project, the HANDI-Finder is a good foundation for further experimentation by those with more experience. It's an easy way to introduce FM communications equipment users to the principles of direction finding. The basic circuit board can also be used to implement the similar DFing equipment described in the references, but with much lower power consumption. The HANDI-Finder makes a great club project![5]

How It Works

Refer to Fig 1. An electronic switch, formed by alternately forward-biasing diodes D1 and D2, connects one of two antennas to the feed line attached to the antenna input of an FM receiver tuned to the frequency of interest. Antenna switching is done at an audio rate, well within the receiver's audio passband and usually in the range of 400 to 1500 Hz, nominally 1000 Hz.

If one of the two antennas is closer to an interference source, it receives the wavefront a fraction of a second earlier than the other antenna. This constitutes a *phase difference* between the signals received by each antenna. The switching action imposes *phase modulation* on the incoming signal. This phase modulation is detected by the receiver and you hear it as a tone equal to the switching frequency. As the physical separation of the two antennas increases up to a half wavelength, the audio-signal amplitude increases.[6] The audio-signal pitch remains the same as the switching frequency.

When the antenna array is rotated so that the plane of the two antennas is perpendicular (or broadside) to the signal direction, both antennas receive the signal simultaneously and in phase. Because there is no longer a phase difference, the audio tone disappears. You perceive this as a rather sharp audio null as the array is rotated into a position perpendicular to the signal direction.

One disadvantage of this direction finder is that it exhibits 180-degree ambiguity, but that problem quickly disappears in the process of taking multiple bearings. This single disadvantage is offset by several advantages:

- It works on a *nulling*—rather than a *peaking*—principle. The null is sharp and much easier to detect than a peak in signal strength.
- The *audio tone* is nulled. This is unlike a conventional loop antenna or cardioid array that nulls the *carrier*. It's much easier to determine an audio null than a carrier null, especially if the carrier is unmodulated.
- Because audio is being nulled, you don't have to watch a field-strength meter—you just listen to the tone. That's something you can do while driving or hiking.
- Even with strong signals, *no attenuator is required* because this method uses phase, rather than amplitude, information. By comparison, the signal from directional gain

[1]Notes appear on page 38.

antennas must be progressively attenuated to keep the received signal within the range of the S meter as you, the hunter, get close to the source.

Technical Overview

The HANDI-Finder employs a single CD4047B CMOS IC. This IC contains an oscillator and a flip-flop to automatically provide complementary symmetrical square-wave outputs without special adjustments. To set the frequency, you need but a single resistor and capacitor.

Very little current is used to bias the switching diodes, so the total circuit current drain is only 1.7 mA at 9 V. (No power-on indicator is used because even an LED draws 10 mA or more!) You get good service from an alkaline transistor-radio battery, and there's no need for an external power source. This has the additional benefit of eliminating the need for noise filtering and a voltage regulator—requirements when a vehicular battery is used.

All the parts—including the battery and two open-loop antennas—are mounted on a single PC board. There are no ground-plane or vertical dipole elements, no complex packaging items to fabricate and no flexible "rubber ducky" antennas to buy.

Circuit Description

U1's oscillation frequency (determined by R1 and C1) is divided by the flip-flop to produce complementary square-wave outputs at pins 10 and 11. These outputs swing close to the 9-V rail and ground. When pin 10 is high and pin 11 is low, current flows from the battery through R6, D2, R5 and R3, forward-biasing D2. D2 connects Antenna 2 through C5 to the receiver feed line. The 9-V drop across a total of 12 kΩ results in a bias current of only 0.75 mA. That current produces a drop of 0.75 V across R6. Meanwhile, D1 is biased off. No current flows through R2 and R4, so there is no voltage drop across them. As a result, D1's cathode is at a potential of 9 V. The voltage at the anode of D1 is 0.75 V lower than 9 V, so the reverse bias is equal to this difference of 0.75 V.

Similarly, when pin 10 goes low and pin 11 goes high, D1 is forward biased, D2 is reversed biased, Antenna 1 is connected and Antenna 2 is disconnected. C6 and C7 block current flow from the antenna connection path that would interfere with the biasing action. (In applications where there is no dc path in the antenna circuit, C6 and C7 can be eliminated; see the following "Antennas" section.) C2, C3, and C4 are RF bypass capacitors, producing an ac ground at the bottom of R6, R5 and R4, respectively. Thus, each node in the RF-switching section is 1 kΩ above ac ground. C3 and C4 also act in combination with R2 and R3, respectively, to form a low-pass filter and round off the sharp edges of the switching waveform. This reduces the modulation bandwidth superimposed on strong out-of-band carriers and minimizes radiation back into the receiver passband.[7]

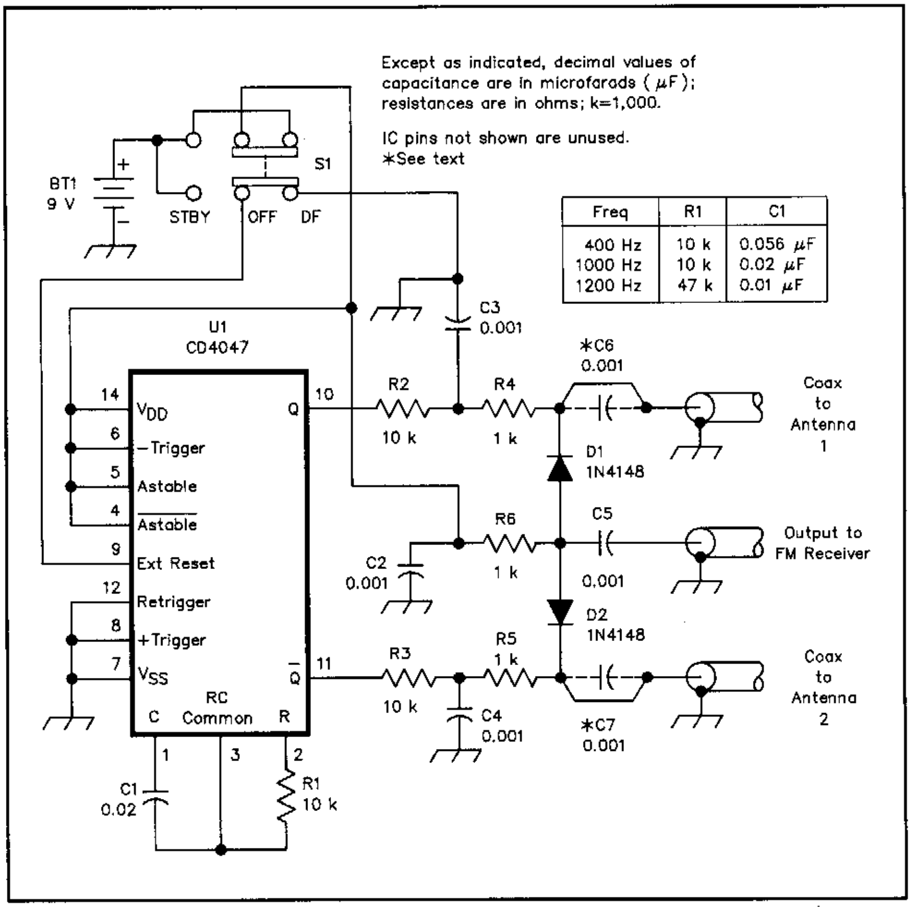

Fig 1—Schematic of the HANDI-Finder circuit; equivalent parts can be substituted. Unless otherwise specified, resistors are ¼-W, 5%-tolerance carbon-composition or film units. Capacitors are disc-ceramic, 50-V units. C6 and C7 may not be needed; see text. The inset table shows the R1 and C1 values to use for a particular oscillator frequency and corresponding tone. (Note: C1 and S1 are specified primarily because of their physical size and because on-off-on slide switches are not readily available.)

C1—0.02-µF, 50-V metallized-film capacitor (Digi-Key P4517).

S1—DPDT micro-mini slide switch (on-off-on, ALCO MHS-223), available from Newark Electronics. Newark Electronics has many locations throughout the US; check your telephone book for a branch near you. Main office: 4801 N Ravenswood Ave, Chicago, IL 06040-4496, tel 312-784-5100, fax 312-784-5100, ext 3107.

Misc: 14-pin DIP socket, battery holder (Keystone #1291), PC board (see Note 5), 9-V battery, RG-58 coax cable downlead with connector, handle, four #6-32 × ½-inch binding-head screws, flat washers, nuts and lock washers.

Assembly

Mount the IC socket, then the diodes, resistors, and capacitors, starting with the smallest items first. The **STBY/OFF/DF** switch has two frame tabs that should be soldered to the board, too. (If you use a solvent to remove soldering flux from the board, be careful not to get any on the switch; the solvent may dissolve the plastic parts!)

The battery holder is fastened to the PC board at one end by soldering its positive and negative terminal tabs to the board. The other end of the holder can be fastened to the board using ⅛-inch diameter pop rivets, or small flat-head screws. Whatever you use shouldn't protrude far enough to prevent the battery from seating properly in the holder.

Prepare one end of a length of RG-58 coax and attach it to the board. Cut off the excess braid so that only 3⁄16 inch lies flat against the PC board near its attachment hole. Fasten a nylon cable tie about ½ inch below the connection point to securely anchor the coax against the board and prevent flexing.

On/Off Switch

The switch has three positions: center is off, up is for DFing, and down is for straight receiving or standby. *Don't transmit through the unit* because that could burn out the diodes, because the switching system doesn't maintain a 50-Ω impedance, and because doing so may generate harmonics.

(I must admit, however, I've often keyed a 2-W H-T even in the DFing position to bring up a repeater for demo purposes and have had no problems—yet!) If you experience diode failure, try using the PIN diodes mentioned by Geiser (see Note 3), or the ECG555 (don't confuse this identification number with that of the popular LM555 timer IC).

Resistors Versus Inductors

Although the HANDI-Finder was originally designed to help locate 2-meter-repeater interference, it operates over a much wider frequency range because the chokes traditionally used in such RF circuits are replaced by resistors (see Note 3).[8] Values in the range of 1 kΩ to 1.3 kΩ will do, but the resistors should all be of the same value. If you want to experiment with increasing the forward bias current through the switching diodes at the expense of power consumption, decrease the values of R2 and R3 toward 1 kΩ, keeping both resistor values equal to maintain symmetry.

Antennas

Because the antennas used in the PC-board version have no path to circuit ground, there's no need for dc-blocking capacitors. On the PC board, the mounting holes for C6 and C7 are shorted by traces. If you want to install C6 and C7, simply cut the traces between the mounting holes of each capacitor.

You can get the HANDI-Finder running without extensive antenna fabrication by using two simple wire antennas (having the appearance of a bow tie—see the title-page photo) attached directly to the PC board. Take two equal lengths of stiff wire about 19 inches long and bend each one into a neat **U** shape. The bottom of the **U** should be 6 inches across. Form each end of the wire ends into a hook so it can be fastened to the screw terminals on the PC board.

The wire you use should be large enough to provide desired rigidity, but thin enough to allow fastening securely beneath the screw terminals. If the wire is too large, solder on spade lugs or similar terminations. Of course, it helps if the wire is a good conductor, but coat-hanger wire (or welding rod) works satisfactorily. Better choices are brass rod or brazing rod, of 1/16- to 3/32-inch diameter.

There are three terminals along each side of the board. Using #6-32 × 3/8- or 1/2-inch machine screws, washers and nuts, fasten one end of each antenna to the top terminal on each side of the board. Similarly, attach the other ends of the antennas to the bottom terminals. Don't solder the antennas directly to the board! The heat required may cause the foil to delaminate. Also, if the antennas are bumped, the foil can be pulled off the board.

The bottom antenna terminals are merely mounting points. They are electrically isolated. *Do not ground the bottom of the loop!* If you do, you'll create a closed loop that causes a carrier null in the direction of the signal. Such a loop antenna operates on a principle other than the intended one.

The active antenna element is the vertical portion of the open loop; the horizontal sections are primarily for support. The longer the vertical element, the more signal it receives. This shows up as more carrier, better quieting, or a stronger S-meter reading. A greater separation of the vertical elements produces greater deviation and more audio.

If the vertical sections are supported farther from the PC board to increase the audio amplitude, the longer, unshielded horizontal antenna sections receive more signal as well, degrading the signal separation. You may want to experiment with the proportions of the vertical and horizontal dimensions.

The PC board accommodates connections by coax cable to other kinds of antenna arrays. Just below the top antenna mounting screw on each side of the PC board is a ground pad. This is not used with the open loop antennas, but is used for the coax shield. Thus, if you do want to make a "Double-Ducky" direction finder as described in *The ARRL Antenna Book,* you can connect the two equal-length coax cables to the HANDI-Finder circuit board. When fastening small-diameter or stranded wires to the pads, first install crimp-on spade or ring lugs to the end of the wire. If you must wrap the wire around the screw, place it beneath a flat washer and wrap it in the direction that the screw tightens (clockwise). *Be careful not to overtighten the screw.* Also, *don't use toothed lock washers on the board surface.* It's better to use slightly longer screws to accommodate flat washers and protect the board surface.

A more extravagant antenna system can be made by positioning two vertically oriented, multielement Yagis at opposite ends of a horizontal boom. Support the boom at its center on a vertical mast so it can be rotated. Use equal lengths of coax from each antenna and connect them to the HANDI-Finder board, which should be mounted in a protective enclosure (more on this later) at the center of the boom. The beams give greater forward gain and reduce the 180-degree ambiguity—but they're a little hard to use while mobile!

A Quick Handle

At the bottom of the PC board is an area for handle attachment. You can mount the board on a short handle or directly to a mast. To get going quickly, attach a piece of wood or metal to the PC board. If you use a round handle, you'll either have to make a flat cutout along one side, or cut a slot down the middle to accommodate the PC board. A round handle is best. The most utilitarian handle is described next.

Paint-Roller Handle

Buy an inexpensive paint roller equipped with a handle that's threaded for use with an extension pole. Most of the handles available are plastic, force-fit directly to the metal roller rod. Clamp the rod securely in a vise and pull off the handle. Hacksaw a slot in the handle, slide the PC board into the slot and fasten it with a machine screw.

Next, get a wood or metal paint-roller extension pole, preferably one made of three screw-together sections. Now, you have a flexible system. You can use the HANDI-Finder with the paint-roller handle alone, or screw on up to three lengths of additional "mast." You may even want to use a second extension for a longer mast. Some extension handles have different threads between the sections than they have at the roller end.

The HANDI-Finder works best when the first 1/4 wavelength of feed line to the receiver is kept vertical, parallel to the center line of the PC board. (Measure the 1/4 wavelength from the bottom antenna terminal.) If the coax moves, it can throw off the bearing. When using the unit with a short handle, make sure to hold it straight and high so that the cable hangs straight down. When using the unit with a long handle, use tape or cable ties to attach the coax to the mast for the first 1/4 wavelength.

Is an Enclosure Really Needed?

The HANDI-Finder can be used without an enclosure. Its long, narrow profile is designed to minimize wind resistance for the benefit of a mobile unit whose DFer may be trying to hold onto the unit mounted on a narrow mast protruding through a window. An enclosure increases drag. With only minimal care, unenclosed units have rattled around in many trunks and back seats without damage.

To fit the PC board into a case, you must cut off the bottom end (an irreversible procedure) and discard the battery holder in favor of a simple pigtail battery connector. I suggest you first become familiar with the HANDI-Finder's operation without a case. After that, you may not want to bother housing it.

If you decide to enclose the PC board, two Radio Shack boxes are good candidates: #270-257, and #270-293. The former is tall and thin and offers the least wind resistance; the latter is shorter and wider, and has a separate cover for battery access.

Mount the PC board with the component side against the inside wall of the case so that the slide switch handle protrudes through a slot. If you're careful to keep the components below the level of the slide-switch body, you can mount the board closely enough (using 5/16-inch long × 1/4-inch diameter spacers) so that the slide-switch handle is accessible from the outside. Use #6-32 screws through the existing antenna connection holes in the circuit board that are long enough to feed straight through to the outside of the case where the antenna wires can be attached.

Trial Run

It's best to start off with a test situation in which you know the location of the source, and experiment with getting a feel for the null. Hold the unit above your head and position it for the best null. The null is fairly sharp, but doesn't always manifest itself as a *total* null of the audio tone. If a jump in tone one octave upward is observed, or a buzz or a "twiddle" is observed, it indicates the reception of multipath signals. Change your location by a few feet and try again until a clean null is obtained. It's usually not possible to observe a null while moving.

If there's a strong transmitter in the area (such as a paging system a few megahertz from the DFing frequency), the receiver appears to desense when the HANDI-Finder is switched to the DFing mode. The sharp edges of the diode-switching waveform cause it to be rich in harmonics, all of which modulate that strong RF source and broaden its spectrum at the receiver input. (This is the same problem that bothers the more complex DoppleScAnt units that switch 4 or 8 antennas; see Note 3.)

Using the unit with a synthesized scanner or one of the new extended-coverage H-Ts allows you to work the ham bands, and other frequencies as well. Prototypes were evaluated over the range of 49 to 470 MHz with good results. As you get considerably above the 150-MHz design frequency, you may find that your unit nulls signals that aren't perpendicular to the PC-board plane. This is caused by minor differences between the two antenna circuits that can produce a significant phase shift as the frequency increases. Therefore, try to make your antenna structures as symmetrical as possible. However, a nonperpendicular null sometimes occurs in high-reflection areas (especially indoors) because of multipath reception. (Don't try to do any meaningful DFing indoors!) In any event, don't jump to conclusions. Take several measurements at different locations a few feet apart, and consider your findings carefully before deciding whether the problem is caused by location or is characteristic of the way you set up your HANDI-Finder.

Checking Direction Calibration

Once you have a good feel for how the unit operates, you can check the direction calibration. A round handle allows you to make a calibration mark at any angle. Test your unit outdoors in an open field by walking in a circle around a central signal source. A person keying an H-T held at arm's reach is the most expedient, but the rig must be held still. The null should always occur perpendicular to the plane of the antennas, but your radio or other factors may introduce phase shift. If the error is consistent as you walk around the circle, mark the true direction on the handle. If you do this, expect this calibration to change at different frequencies, and possibly if you change the CD4047 oscillator frequency.

If the error is not consistent, and changes as you walk around the source, you are experiencing multipath reflections from the surroundings. Try reducing the power of the source. For example, if a 100-mW H-T is too strong, remove its antenna and use a 51-Ω dummy antenna (such as an inexpensive 2-watt carbon resistor or a Radio Shack #21-506 dummy load). If you still get erratic readings, you'll have to try another location.

Once you've established the calibration mark, fasten the cable along the side of the handle or mast so it runs over the mark. That way, you can feel it in the dark. Now you're ready to do some serious DFing or fox hunting!

What'll You Hear?

When driving through our neighborhoods, it was interesting to scan the bands and see which frequencies are in use. One of our experimenters found several homes with 49-MHz baby monitors. You may also hear cordless-phone conversations. Another application is to locate interference on 145.250 MHz, pinpointing leakage from pole and lawn boxes used for CATV distribution.

If you're a radio-controlled model-airplane enthusiast, consider putting a low-power transmitter and "crash switch" in your plane. Then, if it gets away and crashes in the woods, you can track it down!

Some areas have rather extensive parks, reserves or other areas where naturalists tag wild animals with radio transmitters to track their migration. Naturalists are quite interested in reports on these animals, and may disclose the frequencies to individuals with a genuine interest in helping. Invite your local naturalist to speak to your club and demonstrate how you can help. But keep in mind they don't put radio transmitters on deer and fowl just to make it easy for game hunters to track and kill them!

Acknowledgments

My thanks to Rich, N8FIL, for his nagging; Russ, W8SQY; and Paul, N8HHG, for testing out the prototypes; Jim, WB8WTS; Dave, AD8Y; and Gary, KB3LP; for their encouragement and help with the manuscript.

Notes

1 "DOP-SCAN" refers to a more complex direction finder called the DoppleScAnt. See T. Rogers, "A DoppleScAnt," *QST*, May 1978, pp 24-28. A multipage template package for this project is available for $1 from the ARRL. Address your request for the DOPPLESCANT CIRCUIT BOARD TEMPLATE to: Technical Department Secretary, ARRL, 225 Main St, Newington, CT 06111. The two PC boards are available from FAR Circuits, 18N640 Field Ct, Dundee, IL 60118-9269; price $30.

2 Inspiration for this project is based on a design credited to Tom Feierabend, SO/CM 03N18, circa 1979, which appeared in a newsletter published in May, 1980 by Van Field, DCP XVIII, entitled *VHF Radio Direction Finding Manual for Coast Guard Auxiliary Use.* (No longer in print.)

3 A similar circuit, referred to as the "Double-Ducky" direction finder (DDDF) designed by David Geiser, WA2ANU, is described in July 1981 *QST*, and reprinted in the 14th and 15th Editions of *The ARRL Antenna Book.*

4 The spelling and form of HANDI-Finder as used throughout this text, and in all references to this design constitutes a trademark pending official registration with the US Patent Office.

5 A HANDI-Finder kit is available for $27.95. It contains all the parts necessary to build the control circuit and includes an extensive instruction manual. You supply the 9-V battery, coax cable and connector(s) and appropriate antennas. Quantity discounts are available for the kits as well as for bare boards for club projects. Contact Rick Wells, K8SCI, at North Olmsted Amateur Radio Depot, 29462 Lorain Road, North Olmsted, OH 44070, tel 216-777-9460; MasterCard, VISA, Discover charge cards are accepted.

A PC-board template package is available free from the ARRL. Address your request for the LESKOVEC HANDI-FINDER TEMPLATE to: Technical Department Secretary, ARRL, 225 Main St, Newington, CT 06111. Please be sure to enclose a business-size SASE.

6 Ideally, the amplitude should increase linearly from 0 to 180 degrees of wavelength, then decrease linearly from 180 to 360 degrees, etc.

7 J. Moell and T. Curlee, *Transmitter Hunting: Radio Direction Finding Simplified* (Blue Ridge Summit: TAB/McGraw-Hill), 1987, page 137, Fig 9-15. Price: $19. This book is available from your local dealer or directly from ARRL. See the ARRL Publications Catalog elsewhere in this issue for ordering information.

8 If you want to experiment with inductors, you can make them by close-winding one layer of #28 enameled wire on a 1-MΩ, ½-watt carbon-composition resistor. (The resistor value isn't important: It's the *physical size and shape* we're concerned with. The intent is to ensure that the shunt resistance is at least 100 times greater than the inductive reactance. Therefore, any resistor value above 100 kΩ is acceptable. Mouser Electronics carries a line of quality subminiature RF chokes (the 43LQ series) that are reasonably priced (38 cents each). The 1-µH value is part number 43LQ106.

Bob Leskovec has been licensed since 1957 when he got his Novice call sign, KN8DTS, at age 15. In 1958, he upgraded to General; he currently holds the Advanced class license. Also in 1958, Bob obtained a Second-Class Radiotelephone Certificate and the First-Class Radiotelephone Certificate with Radar Endorsement in 1960.

Bob is Director of Electronic Services at Case Western Reserve University, where he designs special electronic instrumentation for research, and consults in electronic product development. He serves as Staff Advisor and Facilities Manager for the Case Amateur Radio Club (CARC), W8EDU.

Bob holds five patents and has earned BS and MS degrees in Physics from John Carroll University. He spent several years as Chief Engineer of WCLV-FM in Cleveland and worked as a consultant in other areas of radio broadcasting. He has also worked with land-mobile, marine, aircraft, RF navigation and communications.