

By Tom Wheeler, NØGSG

# The NØGSG DSP Radio Direction Finder

This easy-to-build, dual-microprocessor direction-finder provides a convenient LED bearing display and eliminates cumbersome setup and calibration procedures. Lay in a course, Mr Sulu!

**F**ox hunting is the increasingly popular art of finding hidden transmitters. Although a lot of hams enjoy the thrill of the hunt, there's more to it than just having fun. Repeater operators often use direction-finding (DF) to locate sources of interference. Amateurs use DF to assist in the search for lost hikers and downed aircraft, saving lives in an emergency.

## Direction Finding Methods

A common method is simple enough; attach a directional antenna to a receiver, tune to the fox's frequency, and rotate the antenna until the signal level indicated by the receiver either peaks or nulls. This gives the bearing either away from (toward a null) or toward the transmitter. The hunter then moves in the indicated direction and repeats the process until the transmitter has been found. A popular variation is to place a hand-held transceiver against the body and turn slowly, listening for a null in the signal. The body absorbs most of the RF energy from behind, thus providing a crude but effective way of determining the rough bearing to the RF source.

These methods are simple but have three limitations. First, they are difficult or impossible to apply in a moving vehicle. Second, because these methods are best applied from a fixed position, multipath reception can cause serious errors. Last, using signal strength as an indicator of bearing becomes very difficult when close to the fox, where the field strengths tend to saturate receivers (resulting in little or no change in signal level regardless of the direction the directional receive antenna is aimed).

The NØGSG radio direction finder (RDF) is based on Doppler frequency

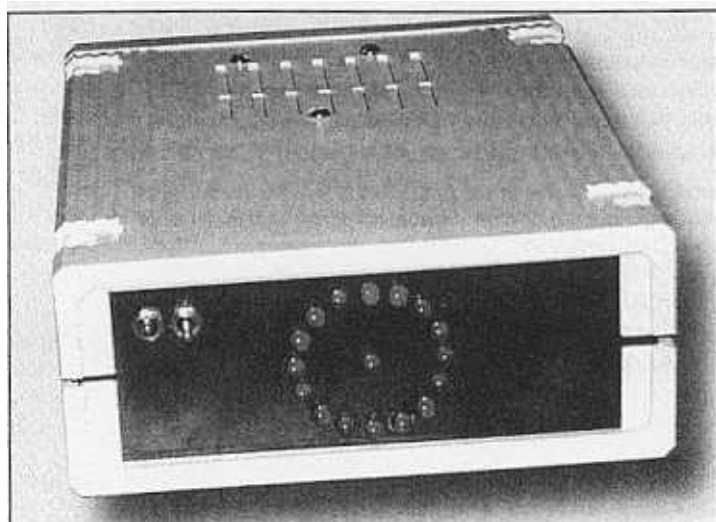
shift, which is independent of the signal strength of the transmitter. Doppler is the apparent increase or decrease in the frequency of a signal as an observer travels toward or away from the signal source. You've experienced this before; a train's whistle or car horn sounds higher in pitch as it approaches, lowering as it passes by. The amount of change of pitch is determined by the relative velocity of the source and the observer.

This effect can be used for determining direction at radio frequencies by rotating the receiver's antenna electrically at a high rate. The NØGSG RDF uses a rate of 800 rotations per second. When the antenna is moving toward the RF source, the apparent carrier frequency of the source will increase. Likewise, when the receiver antenna is moving away from the source, the carrier frequency will decrease. An FM receiver will convert these shifts into changing voltages (positive and negative) at its audio output. By cor-

relating frequency shifts of the received signal with the position of the antenna, a bearing to the source can be computed.

This article describes a modern implementation of an RDF using the Doppler shift. The circuit uses two microprocessors—one as a timing and sequence controller, and the other as a digital signal processor.<sup>1</sup> Although the circuit has a low parts count (there are only four active ICs!), it has several advantages over existing amateur DF units. First, there are no potentiometers to adjust. All calibration is independent of frequency, performed by software and the configuration permanently stored in nonvolatile memory (EEPROM). The result is a "one touch" calibration that can be easily updated for different vehicles, with the antenna mounted in the most convenient fashion.

Second, the circuit is quite insensitive to audio signal level. There are no critical adjustments of signal volume or indicators of "over and under level." The



<sup>1</sup>Notes appear on page 33

software will automatically alert the user if there isn't sufficient signal to obtain a good fix.

Last, the RF switching circuitry is designed to handle a wide variety of conditions. The antenna switching pulses are shaped to concentrate as much of the received energy as possible within the bandwidth of a typical VHF/UHF FM receiver. This enhances receive sensitivity and reduces spurious responses. The switching circuitry will work over a wide frequency range. Antenna tuning is only needed if maximum sensitivity is required.

### Circuit Description—Main Unit

Figure 1 is the schematic diagram of the main unit. U101, an Atmel AT90S1200A microprocessor, performs all control activity and switches the four receiving antennas from its port B pins (12-19). Two differential signals switch each antenna. For example, +ANT1 and -ANT1 are the signals that control antenna 1. To turn on antenna 1, +ANT1 is set high (+5 V) and -ANT1 low (0 V). All the other antennas are turned off at this time with opposite logic levels on their control signals. Each antenna control signal is shaped by an RC network comprised of R103 (the DIP resistor array) and C106-C113. These lengthen the rise and fall time of the switching pulses, which reduces the amount of spurious products in the antenna unit RF output. This concentrates the received signal within the passband of the receiver (instead of spreading it out), maximizing sensitivity. Figure 2 shows the timing pattern of the antenna signals.

The electrically rotating antenna superimposes an 800 Hz tone caused by the Doppler shift on the received audio. U104a and U105a extract the 800 Hz tone and prepare it for processing by U103. U104a, an MF10 switched capacitor filter, is configured as a band-pass filter with a Q of approximately 150 and a center frequency of 800 Hz. The band-pass filter removes almost all information from the incoming audio signal except for the Doppler tone.

U104a is clocked at 80 kHz by U101. Since there is a fixed 100:1 relationship of the 80 kHz clock signal to the recovered 800 Hz Doppler tone, there are exactly 100 clock ticks of the 80 kHz signal for a 360 degree phase shift. This causes the center frequency of the band-pass filter formed by U104a to be exactly synchronized with antenna rotation.

The filtered audio tone is input to the Schmitt trigger comparator U105a, an LM339. U105a converts the audio sine wave into an 800 Hz square wave while carefully preserving the zero-crossing timing information. The square wave

The N0GSG Hunt Team and antenna unit. Left to right: John, N0TFW (SK); Joyce, KC8PHD; Tom, N0GSG, and Mary, KC0MEM.



from U105a drives input pin PD1 (3) of U103, the second microprocessor. U103 measures the phase of the square wave against that of the reference antenna pulse (+ANT1) using the 80 kHz signal from U101. The phase of the square wave with respect to the antenna's rotation determines the bearing to the RF source.

U103 also performs calibration and stores the data in its on-chip EEPROM when switch S102 is closed for more than 3 seconds. U103 also drives the multiplexed 16-LED array (D103-D118) to provide a bearing display for the user. The software for U103 also performs validation, filtering and averaging of the incoming Doppler tone in order to provide a stable display in the presence of changing RF signal conditions. The display is updated approximately four times per second. Closing switch S103 during power-on disables the filtering and averaging features, resulting in a raw (unfiltered) data display.

### Circuit Description—Antenna Unit

The antenna unit consists of five sub-assemblies—four antennas and their switching circuits and the center combiner circuit. The antennas are four identical quarter-wave whips mounted on SO-239 connectors laid out in a square on a ground plane. The switching circuit for each antenna routes the antenna's output signal to a central combiner circuit.

In the switching circuit for antenna 1, PIN diode D7 switches the antenna on and off the feed line, while in the combiner, D8 switches the antenna signal on and off the main RF output. C11 provides dc isolation between the RF output and the switching circuits. R8 and R7 provide RF isolation and set forward PIN diode current. L8 and L7 provide additional RF isolation and improve the SWR of the

switching circuit to the antenna. Since the coaxial cable (RG-174 is recommended) from the combiner to the switching circuit also carries the dc control voltage for switching diodes D7 and D8, C12 and C16 are needed to keep the shield at RF ground potential. The selected signal at the RF output is passed to the receiver through jack J5.

### Constructing the Main Unit

Construction of the main unit is not critical. See the schematic diagram in Figure 3. All components can be mounted on experimenter's perforated board with point-to-point wiring and good grounding practice. All ICs (with the exception of the voltage regulator, U102) should be in sockets. Keep the wiring of U101 as far as possible from U104A to prevent leakage of 800 Hz pulses into the audio processing chain, which will reduce the unit's useful sensitivity.

Pay close attention to the polarity of the display LEDs (D103-118) as shown in the schematic—the microprocessor switches port PD6 and PB0-7 from sourcing to sinking current in order to "double up" on the number of LEDs that can be driven without an external decoder.

In general, mechanically robust construction is recommended—remember that this unit must operate reliably in the field and while mobile. You don't want anything to break in the middle of a hunt! See Figure 4.

### Constructing the Antenna Unit

Care must be taken in the construction of the antenna unit. The antenna unit should be built on a metal base, which will act as a ground plane for the antennas and an RF shield for the electronics. All electronics must be shielded for good strong-signal performance and isolation. Keep all

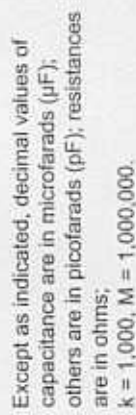


Figure 1—The schematic diagram of the main unit of the Doppler Direction Finder. Note: C102, C105, C114 and C115 should be as close as possible to their respective ICs.

C101—470  $\mu$ F / 25 V electrolytic.  
 C102, C104-C113, C115, C117—0.1  $\mu$ F / 50 V ceramic or mylar.  
 C103, C119—22  $\mu$ F / 25 V electrolytic.  
 C114—47  $\mu$ F / 25 V electrolytic.  
 C116—0.47  $\mu$ F / 50 V ceramic or mylar.  
 C118—47 pF / 50 V ceramic.  
 C120—0.01  $\mu$ F / 50 V ceramic or mylar.  
 D101—1N4001.  
 D102—Green panel-mount LED (Digi-Key L10005-ND).  
 D103-D118, incl—Red panel mount LED (Digi-Key L10001-ND).  
 J1—Power connector, coaxial chassis, 2.5 mm (Mouser 163-4026).  
 J2—Audio connector, chassis mount phono jack (Mouser 161-1052).  
 LS1—Loudspeaker, 3", 16-32  $\Omega$ .  
 P1—Connector, DB9F solder cup (Digi-Key A2047-ND).  
 R101—220  $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R102, R108—10 k $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R103—Resistor pack, 100  $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R104, R105, R115—100  $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R106—10  $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R107—1 M $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R109—1.5 k $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R110, R114—220 k $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R111—22 k $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 R112, R113—2.2 k $\Omega$ ,  $\frac{1}{8}$  W, 5%.  
 S101—SPST switch, panel, power (Mouser 10TF105).  
 S102, S103—Push-button switch, momentary (Mouser 103-1012).  
 U101, U103—Atmel AT90S1200A microcontroller (Digi-Key AT90S1200A-12PC-ND).  
 U102—78L05 low power regulator (Digi-Key LM78L05ACZ-ND).  
 U104—National MF-10 monolithic switched capacitor filter (Digi-Key MF10CCN-ND).  
 U105—National LM339 quad comparator (Digi-Key LM339AN-ND).

component leads as short as practically possible, since VHF and UHF signals are being switched. The four antennas can be constructed by soldering copper-clad welding wire into PL-259 connectors.

The author used a 36 x 48 inch sheet of galvanized tin over a  $\frac{1}{4}$  inch sheet of plywood. Circles were cut from the plywood underneath each antenna to allow access to the antenna terminals. Surplus brass boxes were soldered in place over each circuit assembly for shielding. Figures 5 and 6 show the prototype antenna unit as seen from the bottom.

## Bench Checkout of the Main Unit

### DC Checkout

Remove all ICs from their sockets and apply power. Using a voltmeter, verify proper voltage (5 V  $\pm$  0.1 V) at U101 pin 20 and U103 pin 20. Verify proper voltage at U104a pins 6, 7, 8 (12 V unregulated) and U105a pin 3 (12 V unregulated). Verify bias at U104a pin 15

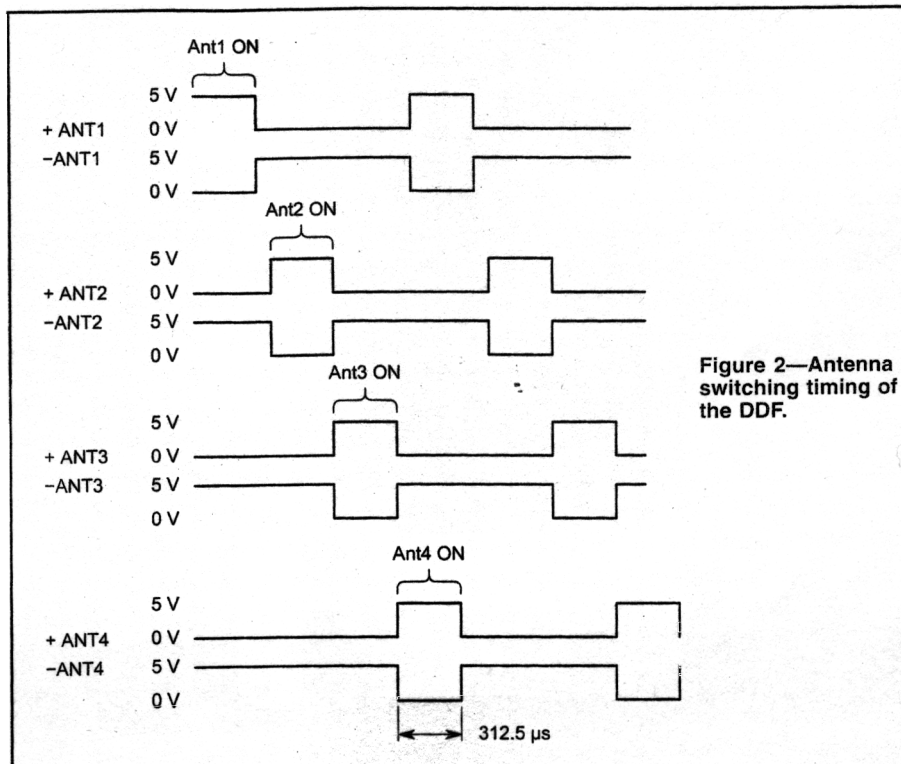


Figure 2—Antenna switching timing of the DDF.

(6 V—half of the unregulated 12 V power supply). If all checks out okay, remove power and install the ICs.

### Operational Checkout

Disconnect the main unit from the antenna unit. With all ICs in place, close the CALIBRATE switch as you apply power and keep it closed for a second or two. You should see all LEDs flash twice, followed by one clockwise circle tracing of the LEDs, followed by a counterclockwise circle. If this occurs, U101 and U103 (the microprocessors) are working correctly and the display is okay. The display should continue to flash all LEDs after the power-on sequence. This is the "no signal acquired" indication.

Closing the CALIBRATE switch during a power-on cycle forces all EEPROM data to its default value and is recommended when the unit is first built. All previous calibration data is erased by this procedure.

+ANT1 through +ANT4 serve as built-in test signals on the main unit. Carefully jumper the audio input to the +ANT1 signal on P1 pin 1. You should hear an 800 Hz tone on the built-in speaker, and the bearing display should light one LED continuously. Close the CALIBRATE switch for three seconds to force the unit to display a bearing of zero degrees. The 0-degree LED should now be lit.

Remove the jumper. The 0-degree LED should now be flashing. When the signal is lost, the unit displays the last good bearing and flashes the LED to in-

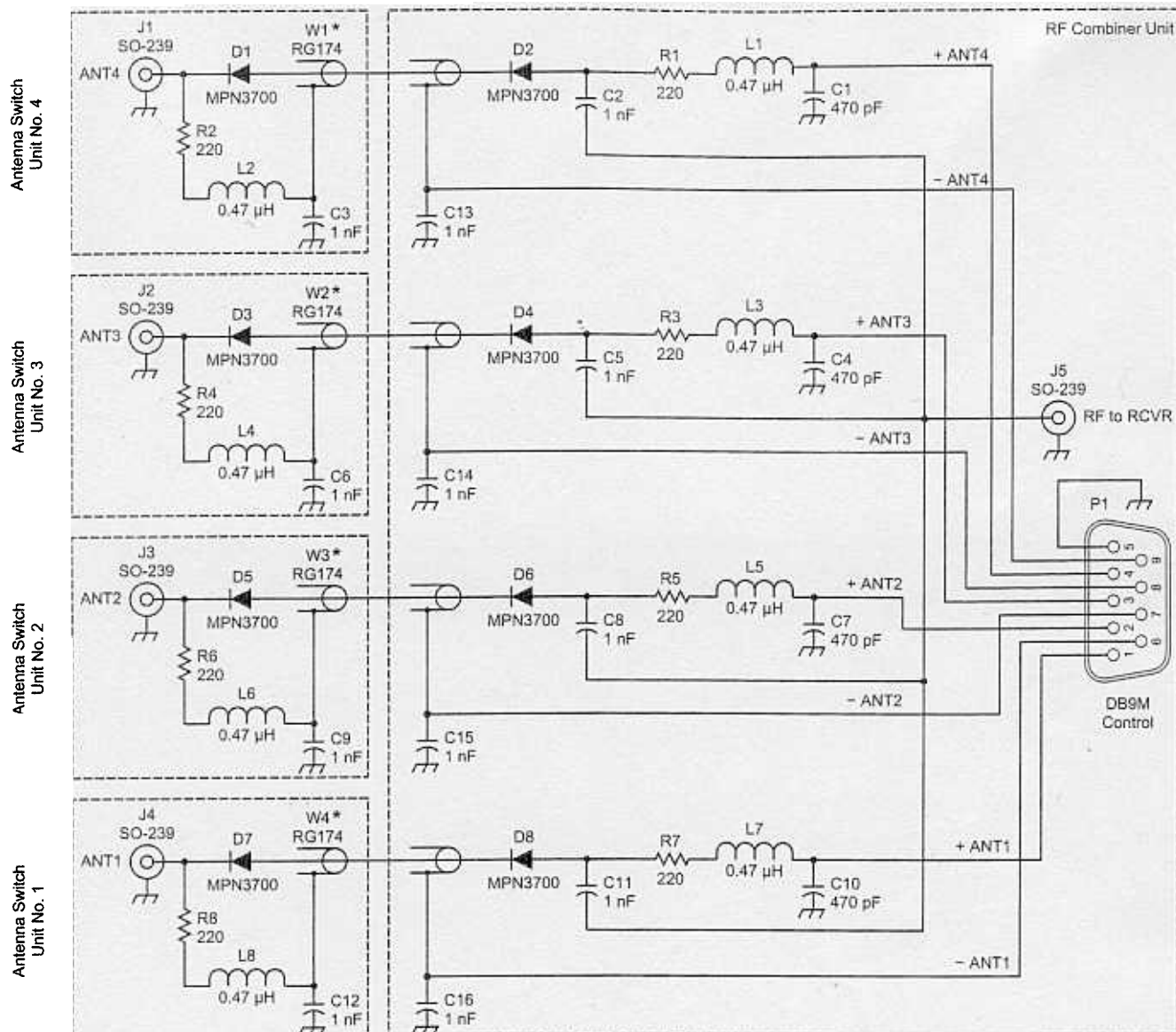
dicate that there is no input signal.

Finally, move the jumper to the +ANT2 through +ANT4 signals (pins 2, 3 and 4 of P1). The bearing should show 90 degrees for +ANT2, 180 degrees for +ANT3 and 270 degrees for +ANT4. If those bearings are displayed correctly, the main unit is working correctly.

### Installation and Initial Calibration

Mount the antenna unit on top of the hunt vehicle in the manner most convenient for you, making sure that no other antennas are nearby (which might distort the pattern of the array). Marking the front antenna will simplify recalibration each time you use the direction finder. The RF output from the antenna unit connects to the FM receiver, and the audio output from the speaker jack of the receiver connects to the audio input of the direction finder main unit. Use the best receiver available, preferably one with good band-pass filtering in the front end. The better the receiver, the better results you'll get—especially when the fox is weak!

In an open area, have a buddy stand directly ahead and north of the vehicle at least 100 feet away while transmitting an unmodulated carrier. If your buddy is using an HT, make sure that it is held vertically overhead to provide a cleaner pattern. Close the CALIBRATE switch for several seconds to fix the signal at "dead ahead" (North). That's all you need to do! You may feel better if you have your buddy walk around the vehicle and verify that the DF bearing follows them.<sup>2</sup>



\* Do not ground shield of W1 - W4.

Figure 3—The schematic diagram of the antenna unit.

C1, C4, C7, C10—470 pF ceramic disk, 50 V.  
 C2, C3, C5, C6, C8, C9, C11-16, incl—1 nF ceramic disk, 50 V.  
 D1-D8, incl—Motorola MPN3700 PIN diode, Allied Electronics MPN-3700.  
 J1-J5, incl—SO-239 chassis female connector, Mouser 523-83-1R.  
 L1-L8, incl—0.47  $\mu$ H solenoid inductor, Mouser 542-9230-12 (Note: This component must be self resonant above 200 MHz for 2 meter operation and 500 MHz for 70 cm operation. For operation on 70 cm, reduce L1-L8 to 0.22  $\mu$ H, Mouser 542-9230-04.)  
 P1—DB9M male panel-mount receptacle, solder cup (Digi-Key A2043-ND).  
 R1-R8, incl—220  $\Omega$ ,  $\frac{1}{8}$  W 5%.  
 W1-W4, incl—RG-174 jumper, 10" long.

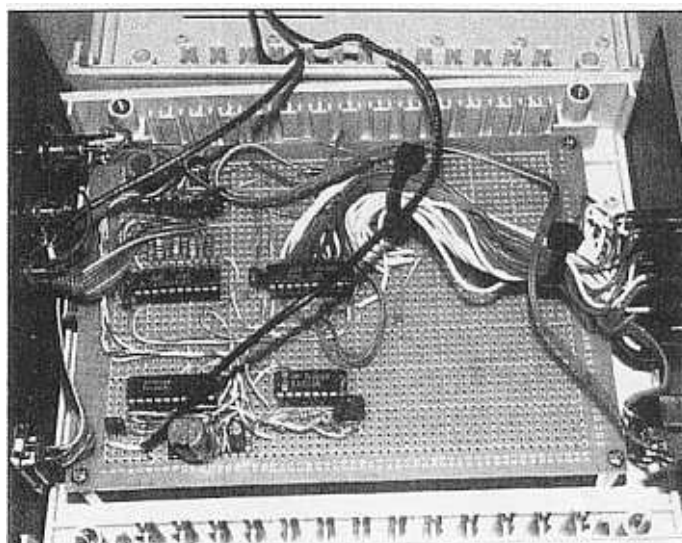


Figure 4—Inside view of the prototype main unit.



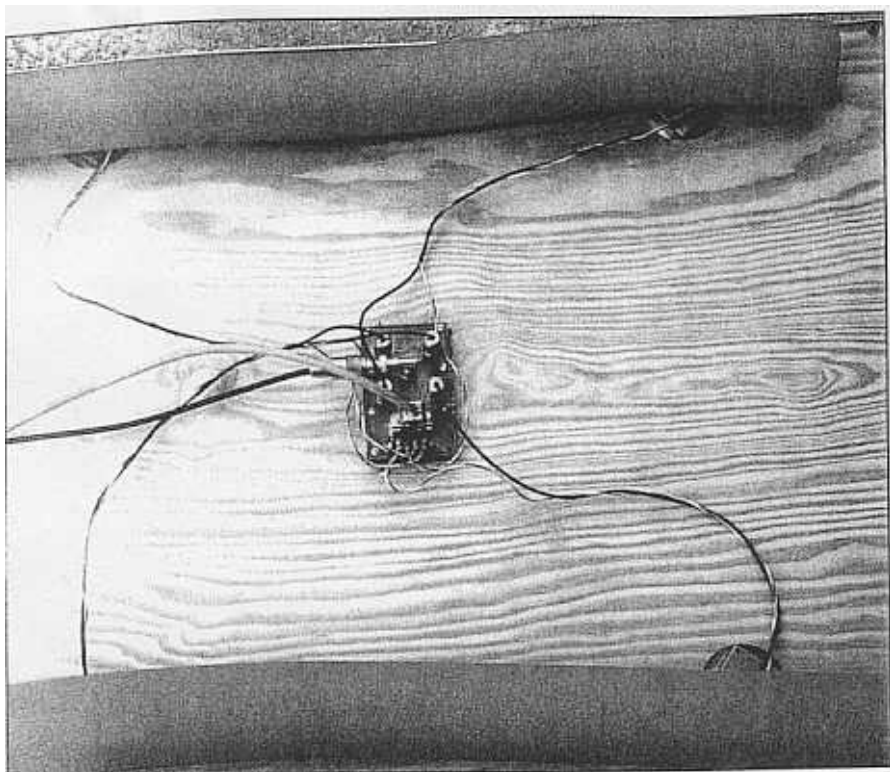


Figure 5—Bottom view of the prototype antenna unit.

The direction finder will retain this calibration setting, even after the power has been turned off. No further adjustments are needed.

### Operation

For safety, it is strongly suggested that the equipment be operated by a team of at least two persons. One person should have only the task of driving.

After calibrating the unit, you only need power up the receiver and main unit to begin hunting. Each time the unit is turned on, it will spin the LEDs clockwise then counterclockwise to test the display. Adjust the volume of the receiver to a comfortable level; the level is not critical. If the fox is weak, you may want to increase the volume as high as possible in order to get an initial bearing. The direction finder will warn you with a flashing display should the volume level be set too low. The volume level does not affect the bearing display.

If all LEDs flash, no bearing has been found. A valid and current bearing is indicated by a steady LED display. Keep in mind that if the display is flashing, the bearing is not current, or the quality of the signal is too low to provide a consistent bearing.

It is normal to see fluctuations in bearing as you drive. This is due to reflections from multiple signal paths. When the tone in the loudspeaker is clean and pure, the bearing to the RF source is likely to be primarily direct.

### Foxhunting Hints

There are several ways to increase your chances of being first in a foxhunt. First, you should form a team and train thoroughly. The author worked as part of a team of four persons. In the team exercises, one person acted as the fox and hid in a location unknown to the others. Each person rotated through the various team functions (driver, map reader, DF operator, fox). In this way, each team member learned to operate the equipment and work with the other team members. Having at least two persons on hand to interpret display readings is very important! See the photo.

Another way of improving your technique is to develop a consistent search method. For example, many hunters start by simply driving one of the main roads forming the boundaries of the search area while watching the display. When the display passes through 90 (or 270 degrees), the hunter knows to turn right or left at the next opportunity. After making this first turn, the hunter repeats the process until they reach the fox. In locations with streets on a grid this is a very effective method. Develop your own methods and practice them!

Finally, certain equipment can really be of help when you get close to the fox. A portable direction finder<sup>3</sup> can be of great assistance when you're on foot. Many fox hunters use HTs or other portable receivers for the last phase of a fox hunt—try tuning to the third harmonic of

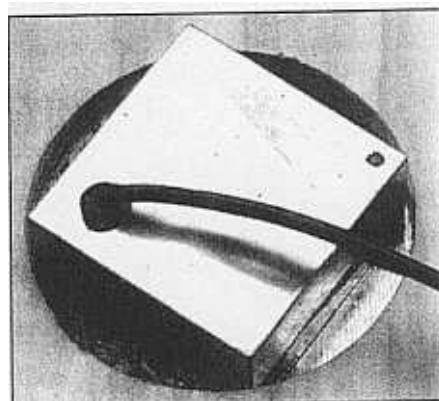


Figure 6—The detail underneath each antenna.

that strong 2 meter signal. Flashlights are a necessity for night and evening hunts.

### Summary

The direction finder described in this article can easily be built in a few evenings, and provides state-of-the-art performance. It is rugged, reliable and easy to operate. You'll find it to be an indispensable part of your DF arsenal for many years to come. Happy hunting!

### Notes

<sup>1</sup>Preprogrammed ICs for U101 and U103 are available. Send \$20 (check or money order) to Tom Wheeler, 11224 Holmes Rd, Room 208, Kansas City, MO 64131. Make sure to specify that you need the ICs for the mobile direction finder. For those that wish to program their own Atmel microprocessors, the object code for both is available for download at [faculty.kc.devry.edu/twheeler/projects](http://faculty.kc.devry.edu/twheeler/projects).

<sup>2</sup>The best calibration can be made by driving directly toward a known RF source (such as a repeater) across an open area free of reflections. This is difficult to achieve in practice, and the simpler method described in the article works just fine if done with care. If the unit is going to be used on several different vehicles, check to make sure that calibration is consistent on each one or recalibrate when switching vehicles.

<sup>3</sup>"The NØGSG Portable DF," *CQ Magazine*, Jun 2002.

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