By Mike Kossor, WA2EBY

A Doppler Radio-Direction Finder

Part 2—In this installment, I'll discuss the antenna switcher, construction of the PC boards, calibration and checkout. Construction data is supplied for using the unit on three bands.[7]

Antenna Switcher

Figure 4 is the antenna-switcher schematic. Antenna 1 is selected when +5 V is applied to J1 pin 1. Current flows through RF choke L5, D11, D7 and RF choke L1 to ground. This current forward biases diodes D11 and D7, increasing their junction capacitance. The high junction capacitance (low reactance) allows RF signals present on antenna 1 to pass easily through D7, the 12-inch-long coaxial line, D11, C49 and on through the line to the FM receiver. C49 is a dc blocking capacitor.

J1 pins 2, 3 and 4 remain at 0 V dc while antenna 1 is selected. Without forward bias, D8, D9 and D10 exhibit very low junction capacitance and effectively isolate antennas 2, 3, and 4 from the circuit. Thus, D7 through D14 function as RF switches. They are considered closed when forwarded biased and open without forward bias. Emulating a spinning antenna in the pattern of antenna 1, 2, 3, 4, 1 is achieved simply by applying 5 V dc sequentially to pins 1, 2, 3, 4, 1.

It is absolutely essential that all unselected antennas be isolated from the circuit and circuit ground. Grounding unselected antennas has the undesired effect of adding parasitic antenna elements, which could distort the received-signal direction indication.

ECG-555 or MPN3404 PIN diodes are usually recommended for switching diodes D7 through D14. However, they are expensive compared to ordinary 1N4148 switch-

[7]Notes appear on page 40.

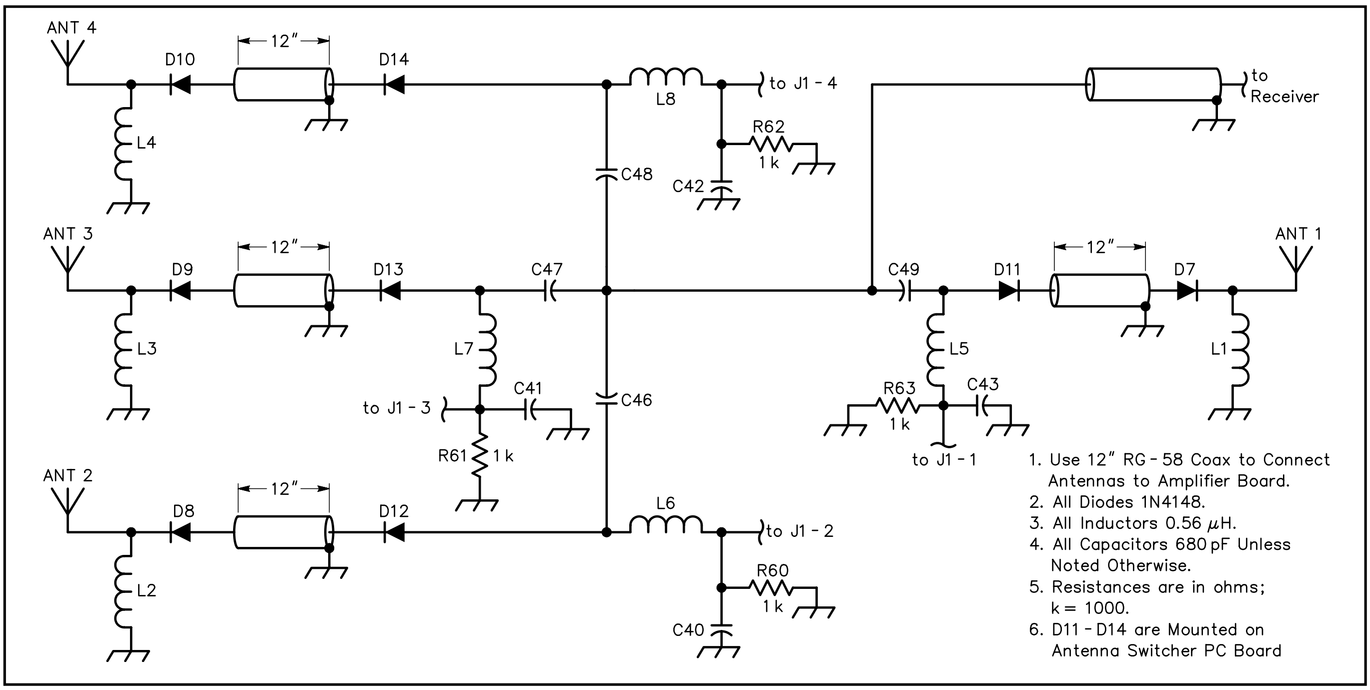

Figure 4—Antenna switcher schematic. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Part numbers in parentheses are Mouser (Mouser Electronics, 958 N Main St, Mansfield, TX 76063-4827; tel 800-346-6873, 817-483-4422, fax 817-483-0931; sales@mouser.com; http://www.mouser.com. Equivalent parts can be substituted; n.c. indicates no connection. Switcher PC boards only (371-SWITCHERPCB); includes switcher PC board and four mag-mount antenna PC boards.

C40-43, C46-49—680 pF, 25 V chip capacitors (140-CC502B681K)
D7-D14—1N4148 silicon diode (583-1N4148)
L1-L8—Surface-mount inductor, 0.56 µH (434-07-R56K)
R60-R63—1 kΩ chip resistors (71-CRCW1206-1.0K)

Miscellaneous
4—1/2 inch brass hex spacers (534-1450C)
1—6-pin DIN plug (171-0276)
4—#4-40 × 1 inch flat-head screws
12—#4-40 star lock washers
12—#4-40 nuts
4—1/16 diam × 36-inch-long copper welding rod (Lincoln R45)
5—Magnet strips 3 1/2×3 1/2 inches
4—Soda bottle caps (pop tops) for antenna bases
10 feet of RG-58 coax, 95% shield
10 feet of 6-conductor #24 AWG shielded wire

ing diodes. I decided to compare the difference between expensive PIN diodes costing as much as $10 each with common 1N4148 switching diodes costing as little as four cents each. I tested a pair of each diode type in the same test circuit using a network analyzer to measure the insertion loss through both diodes and return loss. (Return loss is a measure of how close the input impedance is to the ideal 50 Ω.) A 0 dB return loss corresponds to an infinite SWR (open or short circuit) while a –20 dB return loss corresponds to a good SWR of 1.2:1. The diodes were turned off by not applying any forward bias and turned on with 15 mA of forward current. The test results are presented in Table 1.

Not surprisingly, the most expensive PIN diode performed the best. I was a little surprised, however, to find that the popular ECG-555 has very poor isolation (4.5 dB) at UHF. This makes it totally unacceptable for use on 446 MHz. The ECG-553 is a better choice for VHF and UHF applications, but it costs considerably more than the switching diodes without providing a significant improvement in performance. I chose to use the Rectron 583-1N4148 and obtained excellent results with it.

Table 1

On and Off Performance of Various Diode Types

Diode Number And Type		*146 MHz Return Loss (dB)*	*146 MHz Insertion Loss (dB)*	*446 MHz Return Loss (dB)*	*446 MHz Insertion Loss (dB)*	*Cost (Each)*
HP3077-745	Off	0.16	66.00	0.03	49.50	$10
PIN	On	23.00	0.44	15.10	0.79	
NSMP-3820	Off	0.10	47.30	0.10	27.00	$1
PIN	On	25.20	0.21	18.20	0.44	
ECG-553	Off	0.10	48.00	0.05	27.60	$2
PIN	On	21.40	0.76	19.10	1.00	
ECG-555	Off	0.10	29.10	2.80	4.50	$2
PIN	On	25.30	0.23	16.40	0.51	
MPN-3404	Off	0.10	42.70	0.30	20.30	$1.25
PIN	On	24.20	0.23	14.40	0.57	
1N914A	Off	0.10	56.30	0.20	37.10	$0.12
Switching	On	16.70	1.82	17.80	2.42	
1N4454	Off	0.06	49.00	0.28	29.50	$0.05
Switching	On	24.50	0.76	22.90	1.15	
1N4537	Off	0.05	48.00	0.27	30.80	$0.05
Switching	On	25.50	0.66	22.70	1.24	
333-1N4148	Off	0.10	50.50	0.37	33.40	$0.04
Switching	On	24.10	0.93	24.40	1.40	
583-1N4148	Off	0.04	47.10	0.27	29.00	$0.04
Switching	On	26.70	0.62	22.30	1.09	

Construction

Main Board

I used PC board construction for the main Doppler RDF board because of the large number of interconnections. Point-to-point wiring can be used if you have the patience and are a stickler for detail. Part placement is not critical, but use care to isolate digital and analog grounds. The main PC board fits nicely inside a 2 × 8 × 6.25-inch (HWD) plastic Pac-Tec enclosure. The **CALIBRATE**, **DAMPING** and **AUDIO LEVEL** controls and the **ON/OFF** and **SCAN STOP** switches are mounted on the front panel for easy access. Dc power input, Doppler tone **PHASE INVERT** switch S3 and the audio inputs and outputs are located on the rear panel. I mounted the external speaker inside the enclosure and drilled speaker holes in the top.

Display Board

A PC board simplifies construction and provides a uniform circular pattern for the LED display. Point-to-point wiring can be used if desired; part placement is not critical. I made my own LED standoffs from #20 wire insulation. Strip the wire, removing a single tube of plastic insulation six inches long. Then cut 16 equal-length pieces, 0.20 inch long. Install the standoff on each LED's anode (longer) lead. The PC-board hole spacing varies to facilitate layout. Keep the anode lead straight at all times, and bend the cathode lead as necessary to reach the wide-spaced mounting holes. The standoffs ensure all display LEDs are the same distance from the board. Repeat the same procedure for LEDs D3, D4 and green **CENTER** LED, D16.

Antenna Switcher

Double-sided PC board construction with plated through holes is used for the antenna switcher circuit. Microstrip transmission lines are employed to minimize impedance discontinuities and route signals to the summing point. Double-sided PC boards are also used to make each of the four 1/4-λ antennas (see Figure 5). Each 2.5 × 2.5-inch antenna PC board contains an antenna-mounting stud, one switching diode and an RF choke connected to a microstrip line. A thin, flexible magnet attached to the bottom surface of each board makes it a mag-mount antenna. Business-card size magnetic material is available from office-supply stores. This material has an adhesive backing. It also helps make an excellent, low-cost mag-mount antenna! To add support to the antenna-mounting stud, I use plastic soda-bottle caps (pop tops). Drill a hole in the center of a cap for the whip-mounting screw and notch one side of the cap to pass the coax, as illustrated in Figure 5. For this reason, I dubbed my homemade mag-mount antenna the Pop Top Mag-Mount. A 12-inch length of RG-58 coax connects each antenna to the antenna switcher PC board. take care to make the lengths of all four coax lines exactly equal: This ensures the accuracy of the RDF bearing indication. Use hot-melt glue or epoxy to secure the RG-58 to the antenna-switcher PC board and each Pop Top Mag-Mount PC board. Larger fruit and sports drink caps work well to protect the antenna switcher electronics.


Antenna switcher close-up

Detachable antenna whips are made from 1/6-inch-diameter copper-plated-steel welding rods (Lincoln R45) and available from welding supply stores. The rod is easily soldered halfway into the zinc-plated #4-40 × 1/2-inch hex standoffs. Install a #4-40 × 1/2-inch screw in one end of the standoff to prevent solder from flowing more than halfway into the standoff. Insert the antenna whip into the other end and solder it in place. Remove the screw when the solder has cooled. Caution: All plastic pop tops are not created equal. Because their height varies, screw the antenna whip into the pop-top mag-mount base *before* cutting it to length. Table 2 provides the whip lengths for 146, 223 and 446 MHz operation. The whip length is measured from the top surface of the Pop Top Mag-Mount base to the whip tip. You'll notice that the whip lengths are somewhat longer than that calculated using the formula $l = 234/f$. The extra length is required to compensate for the capacitive coupling between the mag-mount base and the car top.

Check Out

Basic Testing

It is wise to review your workmanship, looking for circuit shorts or opens prior to applying power. Use an ohmmeter to measure the resistance between power and ground; the value should be greater than 2 kΩ. Apply 12 V dc to the RDF unit with the power-supply current limited to 150 mA to prevent damage in the event of a problem (normal current drain is 100 mA). Verify the presence of the following supply voltages: +5 V on the output of U10, pin 16 of U8, pin 8 of U4, pin 8 of U6, pin 16 of U7, pin 24 of U11, pin 16 of U5. Verify +2.5 V on pin 14 of U3, verify +12 V on pin 4 of U1 and U2. This completes the basic testing of the Doppler RDF circuit. The following tests are recommended to identify and troubleshoot problems, but don't worry if you don't have all the necessary test equipment. Satisfactory performance can usually be achieved without performing these tests.

Functional Testing

Before connecting the antenna switcher, verify the operation of clock oscillator U4 by connecting an oscilloscope to pin 3. The output should be a square wave with an amplitude of 5 V and a period of 125 µs (8 kHz). Use a frequency counter to verify the clock frequency is 8 kHz ±250 Hz for best performance. If necessary, the values of R27 and R28 can be changed to adjust the clock frequency. Verify that closing switch S2 disables the clock. Open S2 (**SCAN STOP**) and verify the operation of BCD counter U7 by connecting the oscilloscope sequentially to pins 14, 13, 12 and 11. The signal frequency on these outputs should be approximately 4, 2, 1 and 0.5 kHz, respectively. Verify the presence of a square wave signal on pins 2, 4, 6 and 8 of buffer U12.

Signal-Level Indicators

The following test uses an audio-signal generator to simulate the presence of the Doppler tone. Disconnect the speaker from **AUDIO LEVEL** control potentiometer R50 to prevent loading the signal generator. Connect an audio-signal generator to the receiver audio-input terminal. Set the generator to apply a 500 Hz sine wave with amplitude 1 V P-P. Rotate R50 until the **AUDIO OVERLOAD** LED D3 illuminates. Then, adjust R50 until **LOW SIGNAL LEVEL** LED D4 lights. Adjust R50 so that LEDs D3 and D4 are off, set **CALIBRATE** control R36 to the center of its range and adjust **DAMPING** control R19 for minimum damping (fully CCW).

Direction Indicator

Adjust the frequency of the audio generator very slowly around 500 Hz while observing the LED display. You should see the direction-indicating LEDs around the green center LED illuminating. The LED illumination should rotate *clockwise* when the frequency of the generator is set slightly *lower* than the antenna rotation frequency. (Only one LED will be on when the frequency of the generator equals the antenna-rotation frequency.) The display should rotate *counterclockwise* when the frequency of the generator is slightly *higher* that the antenna-rotation frequency. Because the digital filter is sharp, the transition between clockwise, stationary and counterclockwise directions is very abrupt. The audio generator must be capable of very fine frequency adjustment in order to observe the transition. All LEDs in the display may appear to be on if the signal generator frequency is just 10 Hz different from that of the antenna-rotation frequency determined by U4. It is interesting to observe the sharpness of the digital filter on pin 1 of U2 on the oscilloscope as the display makes the transition from clockwise to counterclockwise. You can see the simulated Doppler tone of the generator come out of the noise, peak and return into the noise as the transition takes place.

Calibration Control

Verify the function of the **CALIBRATE** control by adjusting the audio generator equal to the antenna rotation frequency. At this point, only a single LED will illuminate. Rotate the **CALIBRATE** control through out its range and observe the direction-indicating LED "move" around the display. The range of movement should be more than 360°. The direction-indicating LED may move slightly if the generator frequency drifts. It is very difficult to keep the generator frequency synchronized exactly, but that's not necessary in this test. Disconnect the signal generator and reconnect the speaker to the receiver audio-input terminal.

Antenna Switcher

Verifying proper operation of the antenna-switcher sequencing circuit requires only a dc voltmeter. Connect the antenna switcher to the Doppler RDF unit and position the four mag-mount antennas on a table. Do *not* install any of the whip antennas for this test.

It is essential that the antennas be turned on in sequence to emulate an antenna spinning in a circular pattern for the Doppler RDF

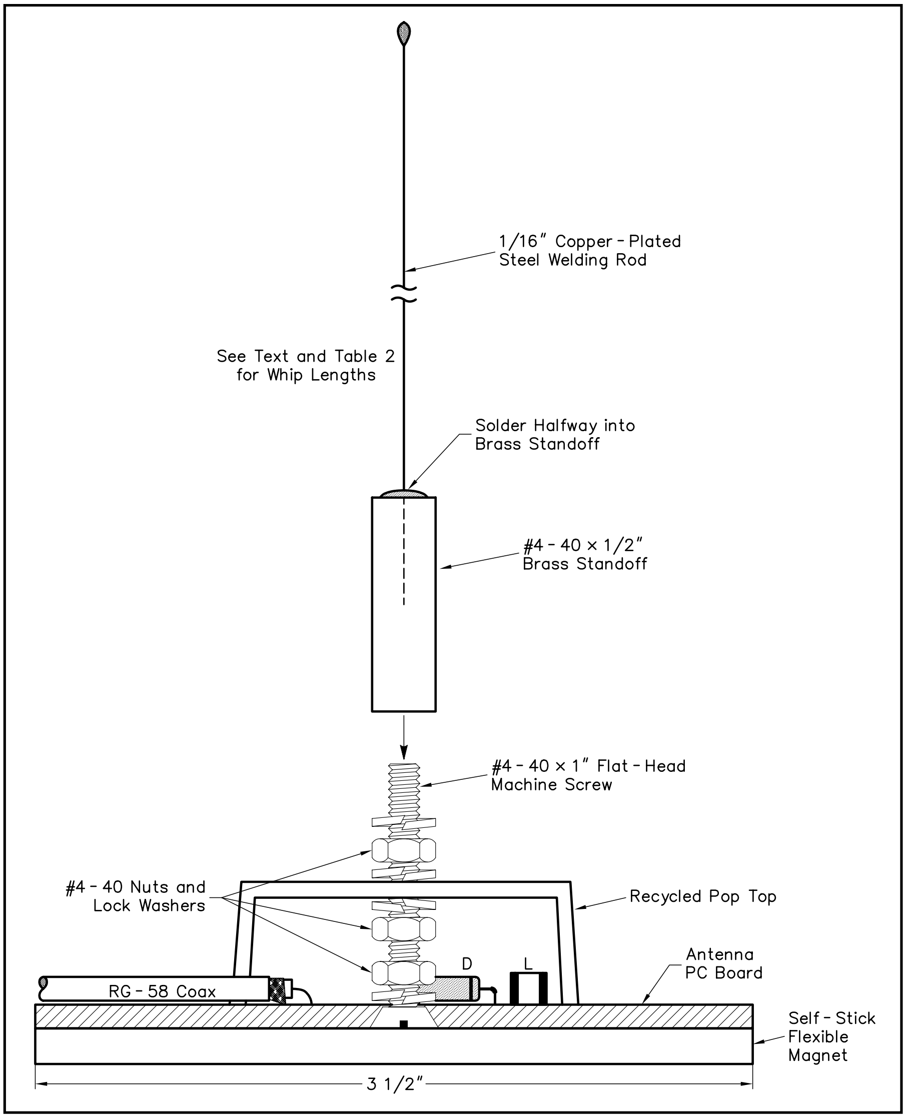

Figure 5—Assembly drawing of one of the four Pop Top Mag-Mount antennas. Dimensions for the whip lengths for three bands are given in Table 2.

Table 2
Antenna Whip Lengths and Antenna Spacings for Use on Three Bands

Frequency (MHz)	*Whip Length (inches)*	*Antenna Spacing per Side (inches)*
146	20 1/16	18.25
223	13	11.5
446	6 11/16	5.75

unit to operate correctly. A single antenna turned on out of sequence is enough to produce a bogus RDF reading. It does not matter if the antenna spins clockwise or counterclockwise. For this test, we'll assume the antenna spin is clockwise.

SCAN STOP switch S2 stops the antenna from spinning. Close and open S2 until the voltage on terminal J1 pin 1 of Figure 3 reads +5 V. Pins 2, 3, and 4 should all read 0 V. Pin 1 is the antenna-enable signal for antenna 1. Label the corresponding magmount antenna on the table as antenna 1. Close and open S2 until the voltage on terminal J1 pin 2 reads +5 V. Pins 1, 3, and 4 should all read 0 V. Pin 2 is the antenna enable signal for antenna 2 and should be positioned to the right of antenna 1 as viewed from the center of the antennas for a clockwise spin. Close and open S2 until the voltage on terminal J1 pin 3 reads +5 V. Pins 1, 2, and 4 should all read 0 V. Pin 3 is the antenna-enable signal for antenna 3 and should be positioned to the right of antenna 2 as viewed from the center of the antennas. Close and open S2 until the voltage on terminal J1 pin 4 reads +5 V. Pins 1, 2, and 3 should all read 0 V. Pin 4 is the antenna enable signal for antenna 4 and should be positioned to the right of antenna 3 as viewed from the center of the antennas.

Testing the RF operation of the antennas is quite simple. Place all four mag-mount antennas around the center of the car roof, placing each antenna at the corner of an 18.25-inch-square pattern for operation on 146 MHz. Do *not* install any of the whip antennas yet. Connect the RF output of the antenna switcher to an FM receiver or transceiver tuned to a strong NOAA weather broadcast signal. *Caution*: Make sure you disable transmit mode if you are using a transceiver!

Apply power to the RDF unit and open S2 to stop the spinning process. Take one whip antenna and touch it to the mounting screw on each of the mag-mount antennas. Only one antenna should provide a signal strength reading similar to it being connected directly to the FM receiver. Remove the whip from the selected antenna and touch it to each of the other three antennas. The NOAA signal should be weak or nonexistent. Close and open S2 until another antenna is selected and repeat the same test. Continue the process until you have verified each antenna can be turned on while the other three remain off.

Operation

Checking performance of the RDF unit is best done in a large, empty area away from tall buildings; a parking lot will do. Use caution at all times during open-road operation of the RDF unit. Use a minimum of two people for all testing and operation of the RDF unit: one to operate the vehicle and the other to operate the RDF unit. As a safety measure, secure each Pop Top Mag-Mount with 20-pound fishing line when operating the vehicle at highway speeds.

Attach all four whip antennas to the mag-mount antenna bases placed about the center of the car top. Connect the RF output of the

Single antenna base

antenna switcher to a FM receiver or transceiver tuned to a strong NOAA weather broadcast signal. *Caution*: Again, make sure you disable transmit mode if you are using a transceiver!

Adjust the receiver's audio to a comfortable level in the external speaker. Apply 12 V to the RDF unit and spin the antenna by closing switch S2. As soon as S2 is closed, you should hear a 500 Hz tone imposed on the receiver audio. Rotate **AUDIO LEVEL ADJUST** control R50 so that **LOW SIGNAL LEVEL** LED D4 and **AUDIO OVERLOAD** LED D4 are extinguished. *Never trust bearing indications if D3 and/or D4 are illuminated.* The direction-indicating display should be relatively constant with a single LED lit, or one or two adjacent LEDs alternately illuminating. Adjust **CALIBRATE** control R36 so that the direction-indicating LED is consistent with the general direction of the NOAA transmission with respect to your location and the position of the car.

Have the driver slowly circle while you observe the display. You should see the direction-indicating LED move in the opposite direction as the car is turning in a circle. The position changes relative to the changing direction of the car; however, the direction indicated from the center of the circle the car is driving around should remain fixed. If the display turns in the same direction as the car, flip **PHASE INVERT** switch S3 to the opposite position to correct the 180° phasing offset. This completes the rough calibration procedure.

Final Calibration

A more accurate calibration can be achieved while the car is in motion. Position a volunteer with an H-T in a safe spot on the side of a long, straight and vacant roadway about 1/4 to 1/2 mile away. Have them transmit on low power (0.5 W) while traveling towards them. The RDF operator should calibrate the RDF display to indicate 0° as straight ahead. The display should change to 180° indicating the signal is coming from directly behind the car as the vehicle passes the transmitter. The moving calibration procedure functions to average out false reflected signals caused by multipath propagation.

You may notice that the Doppler tone changes as the car moves about. The Doppler tone will sound like a pure, undistorted 500 Hz sine wave in the absence of reflected or multipath interference. Direction indications are most reliable under these conditions. When reflected or multipath signals are present, the Doppler tone will sound raspy and distorted. These signal components may arrive from different directions causing false bearing indications. The LED display tends to jump around randomly under these conditions. Avoid taking bearing information when the Doppler tone sounds raspy for this reason. You can minimize display jitter by slowing the response time of the digital filter. This is accomplished by increasing **DAMPING** control R19. With a little time, you can master the art of Doppler RDFing.

RDFing on Other Bands

The wide-bandwidth antenna switcher can be used for DFing on other bands, provided the proper antenna whip lengths and antenna spacings are used. Arrange the antennas in a square pattern. Typical antenna spacing is $0.22\,\lambda$ per side. Table 2 provides the whip lengths for use of the DFer on 146, 223 and 446 MHz. Whip lengths are measured from the top surface of the mag-mount PC-board base to the tip of the antenna.

Other band-limiting components associated with the antenna switcher are the inductors L1-L8. The recommended inductor for the antenna switcher in the parts list is a 0.56 µH unit with a self-resonant frequency of 440 MHz. This inductor presents an impedance of more than 500 Ω from 146 MHz to 446 MHz. Part substitution is permissible, providing the inductor has a inductive reactance of at least 500 Ω and a self-resonant frequency greater than the highest frequency at which the antenna switcher will be used.

Summary

This project incorporates several useful features developed over the years into a single, compact design. The wide bandwidth antenna-switcher design introduced here can be built using commonly available components, significantly reducing the overall cost of the project. In constructing this project, you have the opportunity to learn about analog, digital and RF circuits—and have a great deal of fun organizing and participating in "fox hunting."

Acknowledgments

I want to thank Harry Randel, WD2AID, for capturing the schematic and parts layout of this project, and my brother, Dave, KC2BDL, for assisting with field testing. My thanks also to these members of the Tri-County Radio Club (TCRA): Gerry Miller, AA2ZJ, Bob Grassmann, KB2BBD, Ed Grassman, N2TDM, and Dick Montgomery, N3DV, for providing the opportunity to hone my RDFing skills with many memorable hours of fox-hunting.

[7]Part 1 of this series appears in *QST*, May 1999, 35-40.

Note: In Part 1, Figure 3, page 38, the input pin of U12A shjould be shown as pin 9, not pin 4. Also, the author's mailing address is 244 N 17th St, Kenilworth, NJ 07033.

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See Feedback in July 1999 *QST*.