A Doppler Radio-Direction Finder

By Mike Kossor, WA2EBY

Part 1: A radio-direction finder (RDF) is useful in locating repeater interference (intentional or unintentional) and transmitter “fox hunting.” Join in the fun with this VHF/UHF Doppler RDF project!

Radio-direction finding has gained a lot of interest in recent years especially on the VHF and UHF bands. There are many different approaches to determining the origin of a radio transmission. Each approach has its advantages and disadvantages. An experienced RDFer learns to make use of several methods to master the art. Directional antennas with good front-to-back ratios (such as a Yagi or quad) are simple to use and very effective in obtaining bearings from a fixed location. Because of their physical size, however, such antennas are a bit awkward to use when you’re driving around in a vehicle trying to narrow the search area. Mounting a 2-meter, four-element Yagi or quad to a car window can be a safety hazard. A much more practical method of narrowing the search area uses four 1/4λ mag-mount antennas and the Doppler principle.

Theory of Operation

The classical example of the Doppler effect is that of a car approaching a stationary observer. The car’s horn sounds higher in pitch (frequency) to an observer as the car approaches. The change in frequency occurs because the motion of the car shortens the wavelength. The horn sounds lower in pitch (frequency) to the observer as the car speeds away. This occurs because the car is speeding away from the observer effectively increasing the wavelength. Fewer cycles per second, hence, lower-frequency sound. A similar effect occurs when an antenna is moved toward or away from a transmitting source. The signal received from an antenna moving toward the transmitting source appears to be at a higher frequency than that of the actual transmission. The signal received from an antenna moving away from the source of transmission appears to be lower in frequency than that of the actual transmission.

Imagine a receiving antenna moving in a circular pattern as pictured in Figure 1A. Consider the antenna at position A, nearest the source of transmission. The frequency of the received signal at point A equals that of the transmitted signal because the antenna is not moving toward or away from the source of transmission. The frequency of the received signal decreases as the antenna moves from point A to point B and from point B to point C. Maximum frequency deviation occurs as the antenna passes through point B. The frequency of

RDFing Information

If you’re looking for the how-to and why of radio-direction finding, you’ll want to read Transmitting Hunting: Radio Direction Finding Simplified, by Joseph Moell, K0OV, and Thomas Curlee, WB6UZZ. This book contains all the information you’re likely to need about equipment and techniques for HF and VHF radio-direction finding. You can order your copy of this 326-page book by requesting item#2701 from ARRL Publications by telephone: 888-277-5289 (toll free), 860-594-0355, fax 860-594-0303; e-mail pubsales@arrl.org or on the Web at http://www.arrl.org.—Ed.
the received signal at point C is the same as that of the transmitted signal (no shift) because the antenna is not moving toward or away from the source of transmission. As the antenna moves from point C to point D and from point D back to point A, the frequency of the received signal increases. Maximum frequency deviation occurs again as the antenna passes through point D. The Doppler frequency shift as a function of antenna rotation is illustrated in Figure 1B.

\[ dF = \frac{\omega r f_c}{c} \]  
(Eq 1)

where
- \( dF \) = Peak change in frequency (Doppler shift in Hertz)
- \( \omega \) = Angular velocity of rotation in radians per second \((2 \pi \times \text{frequency of rotation})\)
- \( r \) = Radius of antenna rotation (meters)
- \( f_c \) = Frequency of transmitted signal (Hertz)
- \( c \) = Speed of light

We can calculate how fast the antenna must rotate in order to produce a given Doppler frequency shift with the following equation:

\[ f_r = \frac{dF \times 1879.8}{R \times f_c} \]  
(Eq 2)

where
- \( f_r \) = The frequency of rotation in Hertz
- \( dF \) = The Doppler shift in Hertz
- \( R \) = Radius of antenna rotation in inches
- \( f_c \) = Carrier frequency of the received signal in megahertz

As an example, let’s calculate how fast the antenna must rotate in order to produce a Doppler shift of 500 Hz at 146 MHz, assuming the antenna is turning in a circle with radius 13.39 inches. The frequency of rotation is:

\[ f_r = \frac{500 \times 1879.8}{146 \times 13.39} \]  
(Eq 3)

A rotation frequency of 480 Hz translates to 480 \times 60 = 28,800 or almost 30,000 r/min, which pretty much rules out any ideas of mechanically rotating the antenna! Fortunately, Terrence Rogers, WA4BVY, proposed a clever method of electrically spinning the antenna that works very well.\(^1\) Rogers’ project, the DoppleScAnt, uses eight \( \frac{1}{4}\lambda \) vertical whips arranged in a circular pattern. Only one antenna at a time is electrically selected. By controlling the order in which the antennas are selected, the DoppleScAnt emulates a single \( \frac{1}{4}\lambda \) whip antenna moving in a circle. A clever feature in Rogers’ design is the use of a digital audio filter to extract the Doppler tone from voice, PL tones and noise. My article in QEX details the operation of such switched-capacitor filters.\(^2\)

Over the past 20 years, many modifications to Rogers’ original design have evolved. A popular version introduced by Chuck Tavaris, N4FQ, is dubbed the Roanoke Doppler direction finder named for the Roanoke, Virginia, location where it was built and used. Modifications were later proposed to prevent false readings when the Doppler tone was too weak or too strong.\(^3\) Experimentation revealed that only four antennas are needed to provide good performance. Antenna switching methods were proposed that allow the same antenna switching circuit to be used on VHF or UHF.\(^4\) I set out to build a Doppler DF that has several of the improved features. A careful review of the Roanoke design revealed use of somewhat obsolete 4000 series CMOS logic circuits that require CMOS-to-LED display drivers to operate the LEDs. These IC drivers are still available, but are a bit expensive ($15 for the three). Another costly aspect of the project is the use of four \( \frac{1}{4}\lambda \) mag-mount antennas for the array. The cheapest mag-mount antenna I could find cost $15 each. Multiply that times four, and you have spent $60 before you add any electronics! My design offers slightly improved audio filtering, 74HC-series logic circuits capable of driving the LED display directly and a wideband VHF/UHF antenna switcher that you can make for about $40—including the four \( \frac{1}{4}\lambda \) mag-mount antennas! High-quality PC boards and parts kits are available that make building this project simple and economical.\(^5\) Total project cost is about one-third the cost of purchasing a commercial RDF unit—and building the project is a lot more educational!

**How it Works**

To understand the operation of the Doppler RDF circuit, see the block diagram of Figure 2. An 8 kHz clock oscillator drives a binary counter. The output of the counter performs three synchronized functions: “spin” the antenna, drive the LED display and run the digital filter. The counter output drives a 1-of-4 multiplexer that spins the antennas by sequentially selecting (turning on) one at a time in the

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\(^1\)Notes appear on page 40.

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order A, B, C, D, A, etc., at 500 times per second. The counter output also drives a 1-of-16 multiplexer used to drive the LED display in sync with the spinning antenna. The RF signal received from the spinning antenna is connected to the antenna input of a VHF or UHF FM receiver.

The spinning antenna imposes a ±500 Hz frequency deviation on a 146 MHz received signal. A 146 MHz FM receiver connected to the spinning antenna’s RF output demodulates the ±500 Hz frequency deviation and sounds like a 500 Hz tone with loudness set by the 500 Hz frequency deviation. The receiver audio, including 500 Hz Doppler tone, is processed by a series of audio filters. A high-pass filter rejects PL tones and audio frequencies below the 500 Hz Doppler tone. A low-pass filter rejects all audio frequencies above the 500 Hz Doppler tone, and a very narrow bandwidth digital filter extracts only the 500 Hz Doppler tone.

The output of the digital filter represents the actual Doppler frequency shift described in Figure 1B. Zero crossings of the Doppler frequency shift pattern correspond to the antenna position located directly toward the source of transmission (position A) or directly opposite the source of transmission (position C). The zero-crossing signal passes through an adjustable delay before it latches the direction-indicating LED. The adjustable delay is used to calibrate the LED direction indicator with the actual direction of the transmission.

Circuit Description

Figure 3 is a schematic of the WA2EBY Doppler RDF. The heart of the system is an 8 kHz clock oscillator built around a 555 timer. U4, configured as an astable multivibrator. C26 and R27, and R28 and R29 determine the multivibrator’s oscillation frequency. R28 and R29 are series connected to allow fine-tuning the oscillation frequency to 8 kHz. It’s not critical that the clock frequency be exactly 8 kHz, but I recommend that it be adjusted to ±250 Hz of that frequency for reasons that I’ll discuss shortly. The 8-kHz output of U4 provides the clock for a 4-bit binary counter U7. The 3-bit binary coded decimal (BCD) output of U7 is used to operate three synchronized functions.

Three Synchronized Functions

The first function derived from binary counter U7 is antenna array spinning. This is accomplished by using the two most-significant bits of counter U7 to select 1-of-16 data outputs of U11. The selected output of U11 goes low, allowing current to flow through the output of a digital filter consisting of analog multiplexer U5, R18, R19 and C10 through C17. (Readers interested in the detailed operation and analysis of this fascinating digital filter are encouraged to review my QEX paper; see Note 2.)

The Digital Filter

Using the three most-significant bits of U7 to drive the digital filter divides the 8 kHz clock by two, making the digital-filter clock rate 4 kHz. The center frequency of the digital filter is determined solely by the clock frequency divided by the order of the filter. This is an 8th-order filter, which makes the center frequency of the filter 4 kHz / 8 = 500 Hz. This is the exact frequency at which the antenna spins, hence, the same frequency of the Doppler tone produced on the receiver audio connected to the spinning antenna. This is truly an elegant feature of the Doppler RDF design. Using the same clock oscillator to spin the antenna and clock the digital filter ensures the Doppler tone produced by the spinning process is precisely the center frequency of the digital filter. Even if the clock oscillator frequency drifts, the Doppler tone drifts accordingly, but the center frequency of the digital filter follows it precisely because the same clock runs it. Excessive drift in the 8 kHz clock should be avoided, however, because the analog high and low-pass filters that precede the digital filter have fixed passband centers of 500 Hz. A drift of ±250 Hz on the 8 kHz clock corresponds to ±62.5 Hz (250 / 4) drift in the Doppler tone produced. This value is acceptable because of the relatively low Q of the analog band-pass filter.

Digital filter Q is calculated by dividing
Figure 3—Schematic of the WA2EBY Doppler RDF system main circuit board. Unless otherwise specified, resistors are \( \frac{1}{4} \) 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. To accommodate existing PC-board overlays, we deviate from QST style here in identifying LEDs with a D designator instead of the standard DS prefix. Because of changes during development, some component IDs are not used: C27, C28, C34, R40, R41, R44 and U9.

C1-C6, C18, C19, C38—0.01 µF, 25 V (581-10NJ63)
C7, C9-C17, C21, C31, C51-C54—0.1 µF, 25 V (581-100NJ63)
C8, C25, C32—1 µF, 35 V tantalum (540-1.0M35)
C20—0.47 µF, 25 V (581-470NK63)
C22, C24, C26—0.001 µF, 25 V, NPO

D1, D2, D5—1N4148 (583-1N4148)
D3, D4, D17-32—T1 red LED (351-3102)
D6—1N4002 (592-1N4002A)
D16—T1 green LED (351-3003)
Q1, Q2—2N3904 (592-2N3904)
R1-R3, R5-R7, R9-R11, R20, R26, R30, R31, R34, R35, R38, R43, R45—33 kΩ (29SJ250-33K)
the filter’s center frequency by its bandwidth (Q = f / BW) or 500 Hz / 4 Hz = 125. It’s very difficult to realize such a high-Q filter with active or passive analog filters — and even more difficult to maintain a precise center frequency. The slightest change in temperature or component tolerance would easily de-Q or detune such filters from the desired 500 Hz Doppler tone frequency. The digital filter makes the high Q possible and does so without the need for precision-tolerance components. By varying damping pot R19, the response time of the digital filter is changed. This digital filter damping helps average rapid Doppler-tone changes caused by multipath-reflected signals, noise or high audio peaks associated with speech.

A digitized representation of the Doppler tone is provided at the digital filter output. A two-pole Sallen-Key low-pass filter built around U2B filters out the digital steps in the waveform providing a near sinusoidal output corresponding to the Doppler shift illustrated in Figure 1B. The zero crossings of this signal indicate exactly when the Doppler effect is zero. Zero crossings are detected by U2C and used to fire a monostable multivibrator (U6) built around a 555 timer. U6’s output latches the red LED in the display corresponding to the direction of transmission with respect to the green CENTER LED, D16. Calibration between the actual source of transmission and the red direction-indicating LED latched in the display is easily accomplished by changing the delay between the Doppler-tone zero crossing (firing of U6) and the generation of the latch pulse to U11. C23, R36 and R37 determine this delay. Increasing or decreasing the delay is achieved by increasing or decreasing the value of the calibrate potentiometer R36.

Low-Signal-Level and Audio-Overload Indicators

Two useful modifications included in this design are the LOW SIGNAL LEVEL lockout and AUDIO OVERLOAD indicators. U2D continuously monitors the amplitude of the Doppler tone at the input to the zero-crossing detector. U2D’s output goes low whenever the Doppler tone amplitude drops below 0.11 V peak. This is done by referencing the negative input of U2D to 2.39 V, 0.11 V below the nominal 2.5 V dc reference level output of U2B by means of voltage divider, R21 and R22. U2D’s output remains high when the Doppler tone is present and above 0.11 V peak. C9 discharges via D2 whenever U2D goes low, causing U3A’s output (pin 7) to go high, turning on Q1 via R16 and illuminating LOW SIGNAL LEVEL LED, D4. D4 remains on until the Doppler tone returns with amplitude above 0.11 V peak and C9 recharges via R23. The LED display remains locked by disabling U11’s strobe input whenever the Doppler tone is too low for an accurate bearing. This is done by pulling pin 1 of U11 low via D5 when Q2 is turned on. AUDIO OVERLOAD indicator D3 tells you that audio clipping of the Doppler tone is occurring. Clipping results if the signal level from the digital filter is too high and can produce an erroneous bearing indication. The output of U1D goes low whenever the output of the digital filter drops below 0.6 V as the amplitude of the Doppler tone approaches the 0 V supply rail. C7 discharges via D1 and causes the output of U3C to go high, turning on Q1 via R16 and illuminating AUDIO OVERLOAD LED D3. I elected not to lock the LED display on audio overload; doing so, however, only requires connecting a diode between the collector of Q1 and pin 1 of U11, similar to the low-level lock-out function.

Phase Correction

If the audio output of the Doppler RDF FM receiver is incorrectly phased, S3, PHASE INVERT, can fix that. (If phasing is incorrect, LED direction indications are 180° opposite that of the actual signal source.) Moving S3 to the opposite position corrects the problem by letting U2C sense the trailing edge. This is particularly useful when switching between different receivers. S2 disables the 8 kHz clock to disable the antenna spinning. This helps when you’re trying to listen to the received signal. Presence of the Doppler tone in the received audio makes it difficult to understand what is being said, especially with weak signals.

Power Supply

Power is delivered via a 1/2 A fuse (F1) and ON/OFF switch S1. D6 provides supply voltage reverse-polarity protection by limiting the reverse voltage to 0.7 V and allowing sufficient current to flow to blow fuse F1. U10 provides a regulated 5 V dc to all digital ICs. C29 through C33 are bypass filters. U10’s 5 V dc output is dropped 2.5 V by resistive divider R43 and R45. Noninverting voltage follower U3B buffers the 2.5 V source to provide a virtual ground reference for all analog filters and the digital filter. Using a virtual ground 2.5 V above circuit ground allows op amps to process analog signals without the need of a negative power-supply voltage. Analog voltages swing from near 0 V to near +5 V with the virtual ground level right in the middle, 2.5 V.

Next Month

In Part 2, I’ll discuss the antenna switcher, construction and calibration.

Notes
5 PC boards and parts kits are available from Mouser (Mouser Electronics, 958 N Main St, Mansfield, TX 76603-4827; tel 800-346-6873, 817-483-4422, fax 817-483-0931; sales@mouser.com; http://www.mouser.com): main PC board and PC board components kit (371-2771CF), $50; display PC board and board components kit (371-2771D1), $20; main PC board only (371-MAINPCB), $15; display board only (371-DISPLAYPCB), $6; switcher PC board and components kit (371-2771-D1), $32; switcher PC board and four mag-mount PC boards (371-SWITCHERPCB), $15. Add shipping to all prices.
You can contact Mike Kossor, WA2EBY, at 244 N 12th St, Kenilworth, NJ 07033; mkossor@lucent.com. See Feedback in July 1999 QST.
A Doppler Radio-Direction Finder

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 switches.

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 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.
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 446 MHz. The ECG-555 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.

**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 magnet 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.

Detachable antenna whips are made from 1/2-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 × 1/4-inch hex standoffs. Install a #4-40 × 1/4-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

\[ l = \frac{234 f}{c} \]

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 Dop-
pler 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 than 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 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 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 circuit.

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**Table 2**

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Whip Length (inches)</th>
<th>Antenna Spacing per Side (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>146</td>
<td>20 7/16</td>
<td>18.25</td>
</tr>
<tr>
<td>223</td>
<td>13</td>
<td>11.5</td>
</tr>
<tr>
<td>446</td>
<td>6 11/16</td>
<td>5.75</td>
</tr>
</tbody>
</table>
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.

**Operation**

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 mag-mount 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. 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 of each of the mag-mount antennas. Only one antenna should provide a signal strong enough to be read by the RDF and should be the one selected by the switcher. 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. With a little time, you may notice that 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 λ 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 and RF circuits—and have a great deal of fun organizing and participating in “fox-hunting.”

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2. Note: In Part 1, Figure 3, page 38, the input pin of U12A should be shown as pin 9, not pin 4. Also, the author’s mailing address is 244 N 17th St, Kenilworth, NJ 07033.
3. You can contact Mike Kossor, W2AEBY, at 244 N 17th St, Kenilworth, NJ 07033: mkkossor@lucent.com.
4. See Feedback in July 1999 QST.