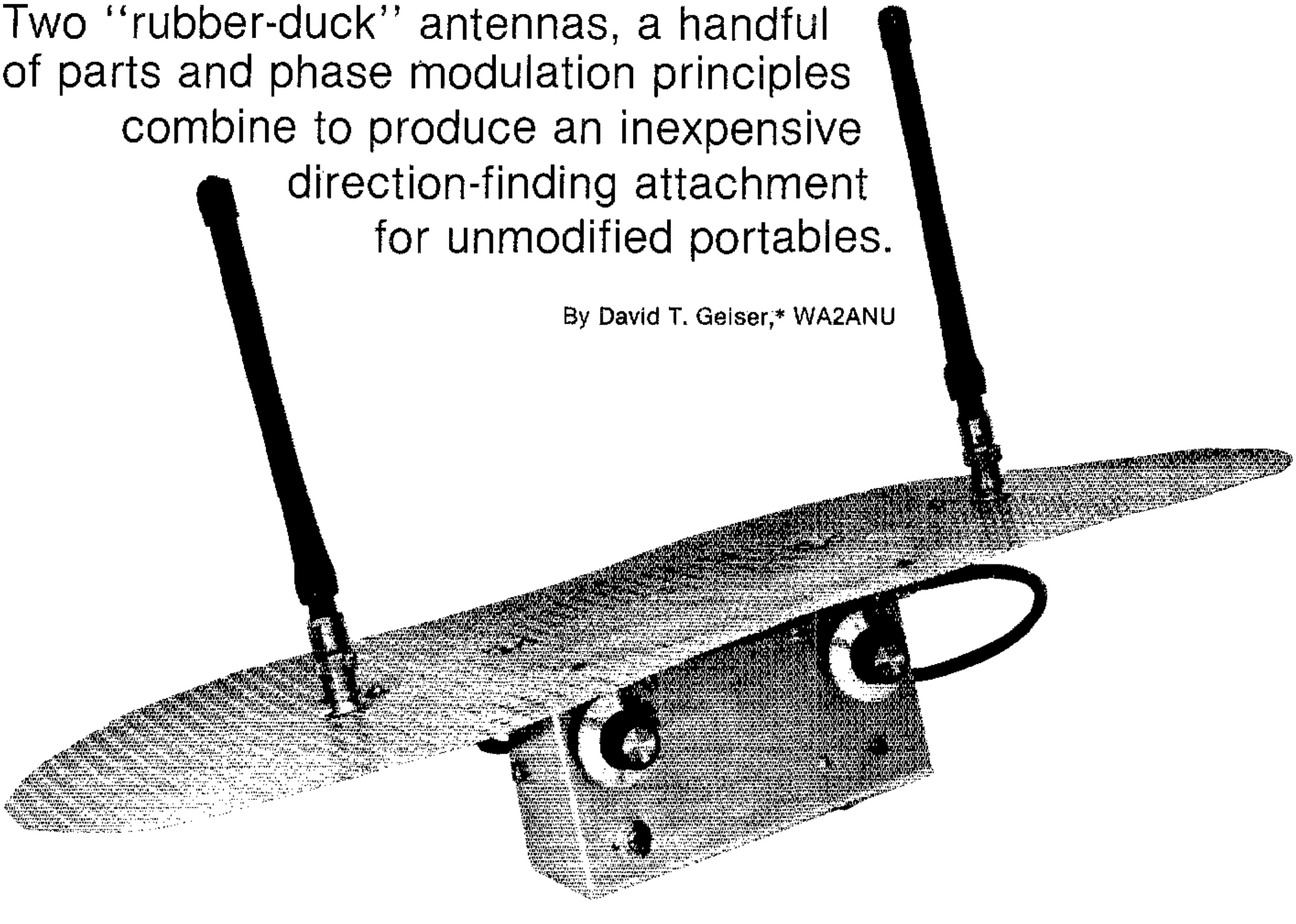
Double-Ducky Direction Finder

Two "rubber-duck" antennas, a handful of parts and phase modulation principles combine to produce an inexpensive direction-finding attachment for unmodified portables.

By David T. Geiser,* WA2ANU



Most amateurs use antennas having pronounced directional effects, either a null or a peak in signal strength, for direction finding. Fm receivers are designed to try to eliminate the effects of amplitude variations and are difficult to use for direction finding without looking at an S meter. Most modern portable transceivers do not have S meters.

This "Double-Ducky" direction finder (DDDF) is different in that it switches between two nondirectional antennas, creating phase modulation on the incoming signal that is heard easily on the fm receiver (Fig. 1). When the two antennas are exactly the same distance (phase) from the transmitter (Fig. 2), the tone disappears.

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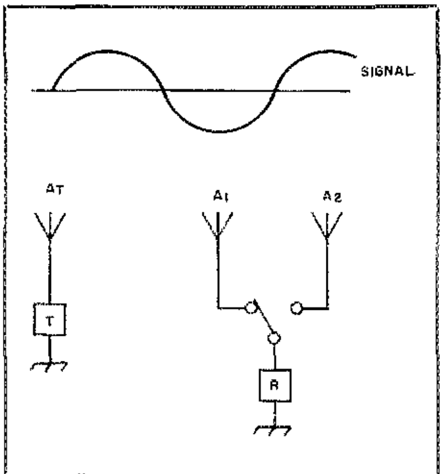


Fig. 1 — Rapid switching between antennas samples the phase at each antenna creating a pseudo-Doppler effect, which an fm detector will detect as phase modulation.

Fm receiver detectors usually fall into either the "discriminator" or "phase-detector" categories. The phase-detector will convert audio-rate changes in phase to an audio tone. Discriminators look upon changes in phase as if they were

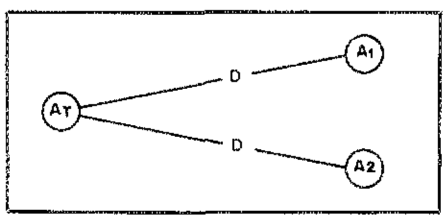


Fig. 2 — If both receiving antennas are an equal distance (D) from the transmitting antenna, there will be no difference in the phase angles of the signals in the receiving antennas; therefore, the detector will not detect any phase modulation, and the audio tone will disappear from the output of the detector.

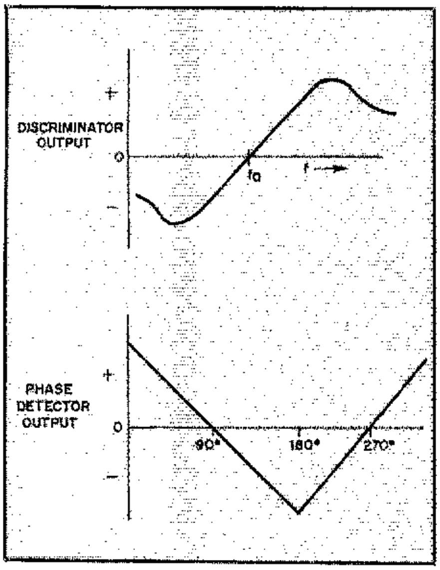


Fig. 3 — Typical discriminator and phase detector response curves.

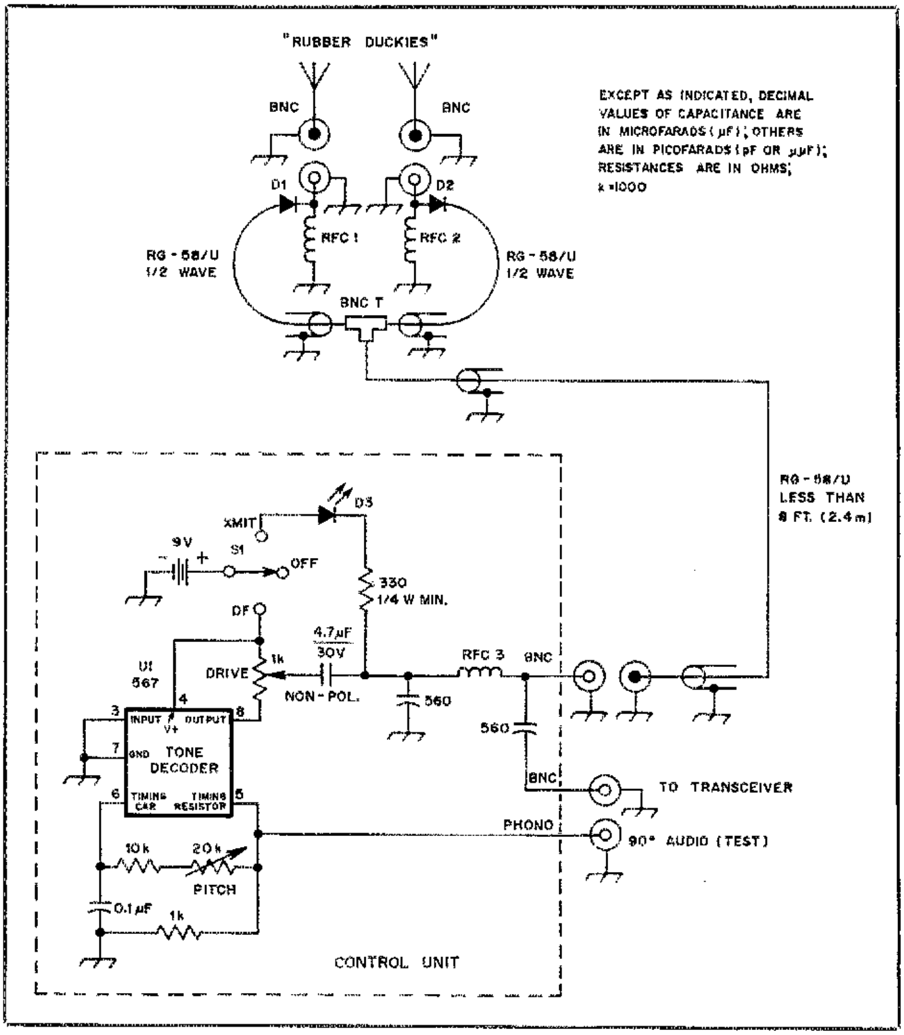


Fig. 4 — Schematic diagram of the DDDF circuit. Construction and layout are not critical. Components inside broken lines should be housed inside a shielded enclosure. Most of the components are available from Radio Shack, except D1, D2, the antennas and RFC1-RFC-3, which are discussed in the text. S1 — See text.

changes in frequency and, if the phase changes happen at an audio rate, will give alternately reversed pulses at that same rate. Both detectors give audio output from the speaker that disappears only when the phase doesn't change as a result of the switching (Fig. 3).

In theory the antennas may be very close to each other, but in practice the amount of phase modulation increases directly with the spacing, up to spacings of a half wavelength. While a half-wavelength separation on 2 meters (40 inches or 1020 mm) is pretty large for a mobile array, a quarter wavelength in my experience gives entirely satisfactory results, and even a one-eighth wavelength (10 inches or 250 mm) is acceptable.

I think in terms of a fixed spacing between the antennas, mount them on a ground plane and rotate that ground plane. The ground plane held above the hiker's head or car roof reduces the needed height of the array and the directional-distorting effects of the searcher's body or other conducting objects.

Direct pickup of the signal by the receiver does not have much effect. Such pickup with minimum/maximum systems (S meters) smears nulls and peaks, but only provides a convenient beat for the phase modulation in this system.

The basic principle is not new, though I have seen only one Amateur Radio article on the topic.[1] Commercial direction finders similar to the DoppleScAnt are offered (usually costing upwards of $1000) giving directional indication to a fraction of a degree. (The DoppleScAnt gives unidirectional indication and is an interesting "post-graduate" course in this principle.)

The DDDF is bidirectional and, as described, its tone null points both to and away from the signal origin. An L-shaped search path would be needed to resolve the ambiguity. Probably a reflector could be added, putting some asymmetry into the pattern and giving a sense indication.

Specific Design

It is not possible to find a long-life mechanical switch operable at a fairly high audio rate, such as 1000 Hz. Yet we want an audible tone, and the 400- to 1000-Hz range is perhaps most suitable considering audio amplifiers and average hearing. Also, if we wish to use the transmit function of a transceiver, we need a switch that will carry perhaps 10 watts without much problem.

A solid-state switch, the PIN (positive-intrinsic-negative) diode, has been developed within the last few years. The intrinsic region of this type of diode is ordinarily bare of current carriers and, with a bit of reverse bias, looks like a low-capacitance open space. A bit of forward bias (20 to 50 mA) will load the intrinsic region with current carriers that are happy to dance back and forth at a 148-MHz rate, looking like a resistance of an ohm or so. In a 10-watt circuit, little enough power is dissipated in the diode for it to survive.

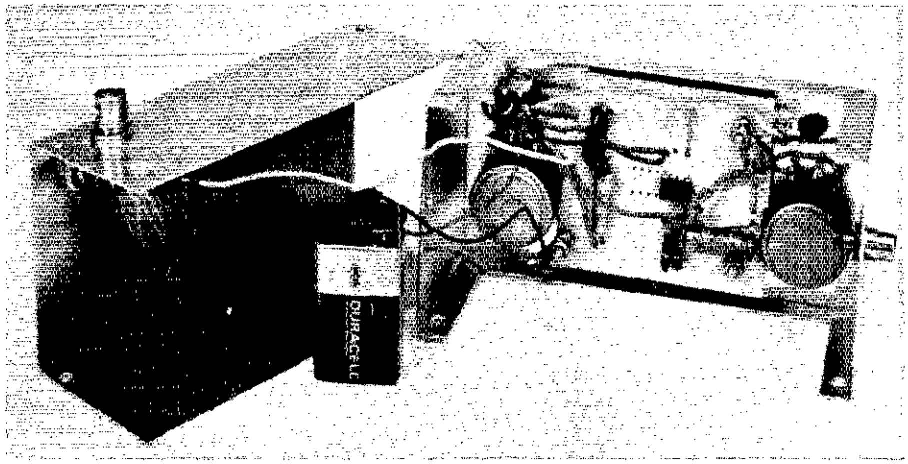
Because I intended to use only two antennas, the obvious approach (Fig. 4) was to connect one diode "forward" to one antenna, to connect the other "reverse" to the second antenna and to drive the pair with square-wave audio frequency ac. Rf chokes (Ohmite Z144, J. W. Miller RFC-144 or similar vhf units) were used to let the audio through to bias the diodes while blocking rf. Of course, the reverse bias on one diode is only equal to the forward bias on the other, but in practice this seems sufficient.

A number of PIN diodes were tried in the particular setup built. These were the Hewlett-Packard HP5082-3077, the

[1] T. Rogers, "A DoppleScAnt," *QST*, May 1978, p. 24. [There are a number of errors in the DoppleScAnt diagram, Fig. 4. A corrected diagram is available upon request from ARRL Hq.]

Alpha LE-5407-4, the KSW KS-3542 and the Microwave Associates M/A-COM 47120. All worked well, but I left the HP diodes in the finished equipment because they provided a slightly lower SWR (about 3:1) during my testing. Rigs accustomed to working with "rubber duckies" will not be dismayed with such an SWR.

The square-wave generator should put out good square waves — each diode should be equally (or nearly equally) biased. The generator should be tunable with a variable resistor, and the bias should be adjustable. After some survey of various ways to do this, I settled on the 567 IC as the best compromise. The output does have a dc bias that had to be removed with a nonpolarized coupling capacitor. This minor inconvenience was more than rewarded by the ability of the IC to work well with between 7 and 15 volts (a nominal 9-V minimum is recommended).



Internal "workings" of the DDDF. Simplicity of design, along with a minimum of components, makes this a simple one- or two-evening project.

The nonpolarized capacitor also proved useful for blocking dc when the function switch was set to XMIT. I placed D3, a light-emitting diode (LED), in series with the transmit bias to indicate I had selected its high battery current drain (20 mA or so).

I originally chose an ordinary center-off toggle switch for S1, but am now of mixed mind whether I should have used a locking type. Certainly the ordinary switch is more convenient if rapid transmit/receive is desired, but the batteries I have worn out by accidentally leaving the switch on would have paid for the more expensive locking type.

"Rubber duckies" are not very efficient antennas, but they were chosen for two reasons. Full quarter-wave whips were used in one of the early models, but they whipped and were too tall. The whipping confuses the null (even on a relatively small excursion), but rubber damps vibration. Better pickup results from better antennas; I have done 60-mile (96-km) DFing with the 1/4-wave whips.

Cables going from the antenna to the coaxial T connector were cut to an electrical 1/2 wavelength (about 2/3 of a free-space half wave) to help the open circuit, represented by the reverse-biased diode, look open at the coaxial T. (The length of the line within the T was included in the calculation.)

The length of the line from the T to the control unit is not particularly critical. I, however, like to keep the total of the cable length from the T to the control unit to the transceiver under 8 feet (2.4 m) because the capacitance of the cable does shunt the square-wave generator output. (I have a prejudice in favor of square waves having square edges.)

My choice for the size and shape of the ground plane (Fig. 5) was arbitrary, guided by instinct and the size of scrap metal in the junk box. The metal really should extend away from the base of the antennas a distance at least equal to their height, 8 inches (200 mm), but thoughts of wind resistance and spending more money argued for the smaller size.

The size and shape of the control box are unimportant; all that matters is the shielding. The 5-1/4 × 3 × 2-1/8 inch (133 × 76 × 54 mm) standard Minibox is convenient and widely available. I powered the unit with a common 9-volt, transistor-radio battery mounted in the box.

Other Variations

The first model used shunt PIN diodes to short out the antenna (Fig. 6). This is good for receiving and eliminates the need for two rf chokes, but the power-handling capability on transmit is only about 2.5 watts. Quarter-wave coax lines are run from the antennas to the T so that the shorted antenna will appear like an open

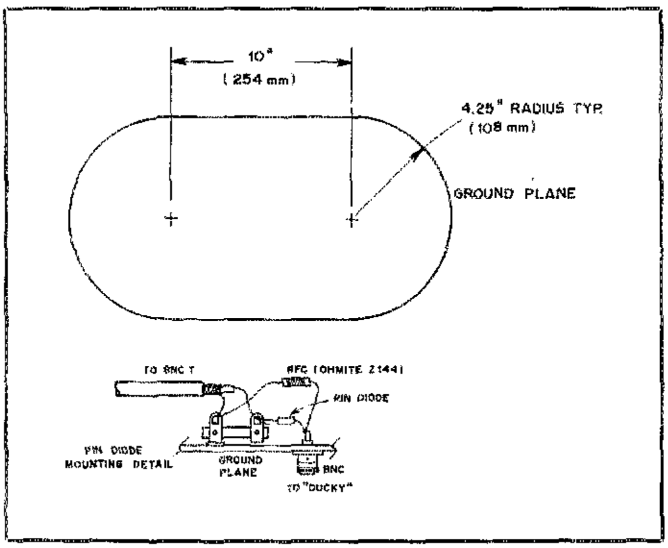


Fig. 5 — Ground-plane layout and detail of parts at the antenna connectors.

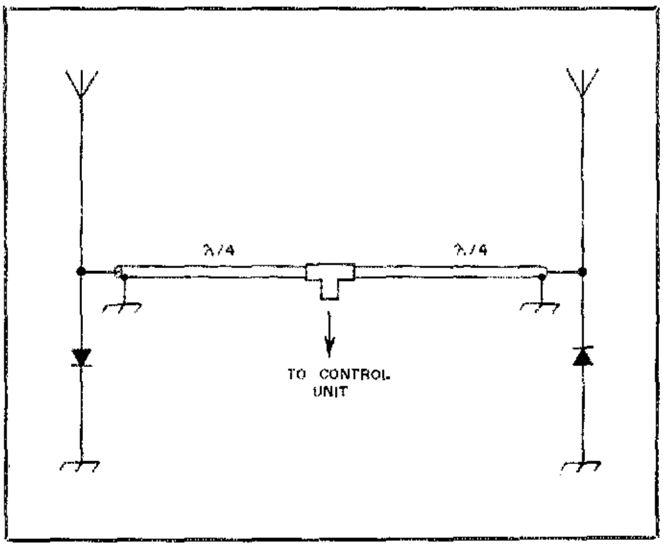


Fig. 6 — This variation of the basic design uses PIN diodes to shunt the antennas.

circuit at the junction of the T.

A shorted quarter-wave line may be used in place of the antenna rf chokes in the present design. This will look like a fairly high reactance (capacitive or inductive) over most, if not all, of the band, while still looking like a short circuit to the square wave (Fig. 7).

Increasing the spacing between the pickup antennas will give the greatest improvement. Every doubling (up to a half wavelength) will cut the width of the null in half. A 20-inch (500-mm) spacing has given me nulls about 1° wide.

I succumbed to temptation and mounted an automobile compass between the two antennas so I would have a true direction finder! The idea didn't work out because the magnetic material in my "rubber duckies" made the compass always indicate north, regardless of which way was north! (The compensators didn't have enough range.)

Perhaps the most interesting variation is to add right/left indication. The receiver audio output is put through a phase shifter (if necessary) and run to a balanced modulator that uses the quadrature output of the square-wave generator as a reference. As the dc polarity output changes when the antenna swings through the null, a dc microammeter on the mixer output can be used to give a right/left indication (Fig. 8). (For reasons discussed later, the indication is good only in the region of linear operation of the detector in the receiver.)

Usage Instructions

Switch the control unit to DF and advance the drive potentiometer until a tone is heard on the desired signal. Do not advance the drive high enough to distort or "hash up" the voice. Rotate the antenna for a null in the fundamental tone. Note that a tone an octave higher may appear. The cause of the effect is shown in Fig. 9. At A an oscilloscope synchronized to the "90° Audio" shows the receiver output with the antenna aimed to one side of the null (on a well-tuned receiver.) Fig. 9B shows the null condition and a twice-frequency (one octave higher) set of pips, while C shows the output with the antenna aimed to the other side of the null.

If, on the other hand (Fig. 10), the incoming signal is quite out of the receiver linear region (10 kHz or so off frequency), the off-null antenna aim may present a fairly symmetrical af output to one side (A). It may also show a near null with instability (indicated by the broken line on the display) at a sharp null position (B) and, aimed to the other side, give a greatly increased af output (C). This is caused by the different parts of the receiver fm detector curve used. The sudden tone change is the tip-off that the antenna null position is being passed.

Even in difficult nulling situations where a lot of second-harmonic af exists, rotating the antenna through the null position causes a very distinctive tone change. With the same frequencies and amplitudes present, the quality of the tone (timbre) changes. It is as if a note were first played by a violin, and then the same note played by a trumpet. (A good part of this is the change of phase of the fundamental and odd harmonics with respect to the even harmonics.) The listener can recognize differences (passing through the null) that would give an electronic analyzer indigestion.

The user should practice with the DDDF to become acquainted with how it behaves under known situations of signal direction, power and frequency. Some will want to tune the signal with the function switch in XMIT position and then switch to DF. In an unknown situation I like to use the tone to tell me a signal is present — my transceiver (IC-211) will both whine and DF on signals more than 10 kHz off frequency. Use of the 5-kHz synthesizer step then helps keep the tone spectrum less complicated.

I find that the whine (or tone) the DDDF adds to a carrier gives an unexpected dividend — I can receive cw telegraphy with its help on any fm receiver. When I hear the tone (and I can recognize it below the fm threshold) I turn the antennas for maximum volume and start copying. It's fun. Try *that* with your S meter!

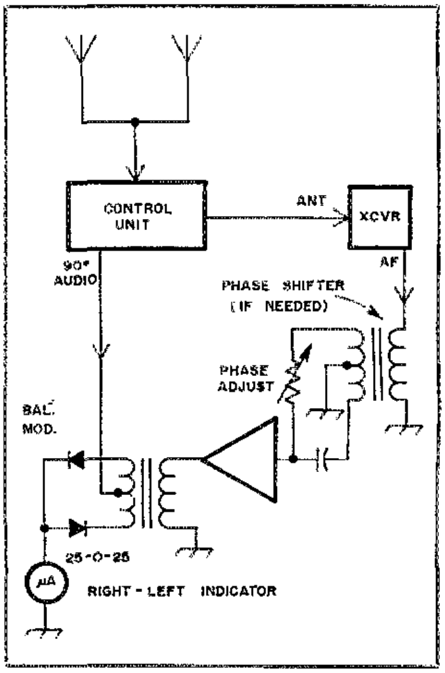


Fig. 8 — Block diagram of a simple right/left indicator. Depending on the setting of the potentiometer, the phase shift may range from 0° to near 180°. In general, one half the full value of resistance of the potentiometer should equal the capacitive reactance of the capacitor at the audio frequency used. Readers with questions should send an s.a.s.e. directly to the author.

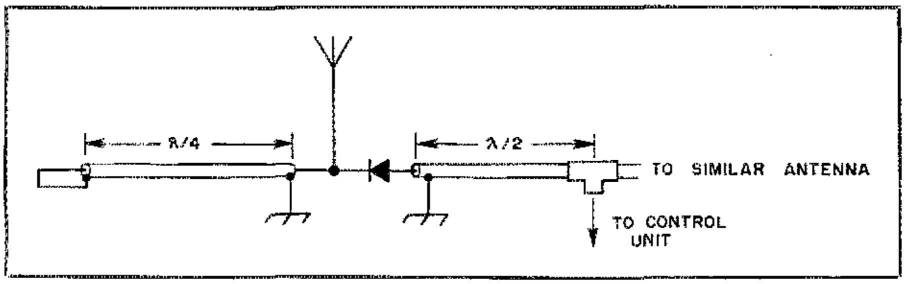


Fig. 7 — Another variation of the basic design. Here, a shorted quarter-wavelength section of coaxial cable replaces the rf choke at the antenna.

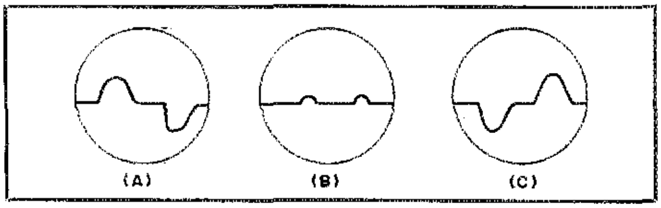


Fig. 9 — Typical on-channel responses. See text for discussion of the meaning of the patterns.

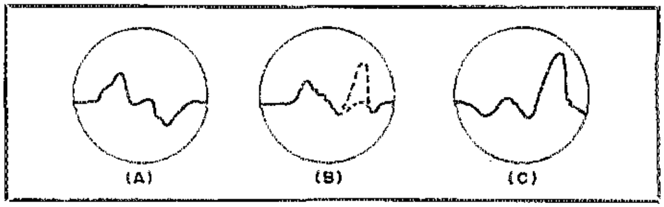


Fig. 10 — Representative off-channel responses. See text for discussion of the meaning of the patterns.