

Track down hidden transmitters

Build this radio direction finder

Want to find out where a radio signal is coming from? Or locate the source of an illegal transmitter? The radio direction finder described here will track it down using an electronically rotated antenna.

by GREG SWAIN

Physically, the radio direction finder consists of two separate units. One contains the control and display electronics and is located adjacent to an FM transmitter or receiver; the other is a special antenna switching unit (ASU) which is connected to the control unit via a 4-way cable.

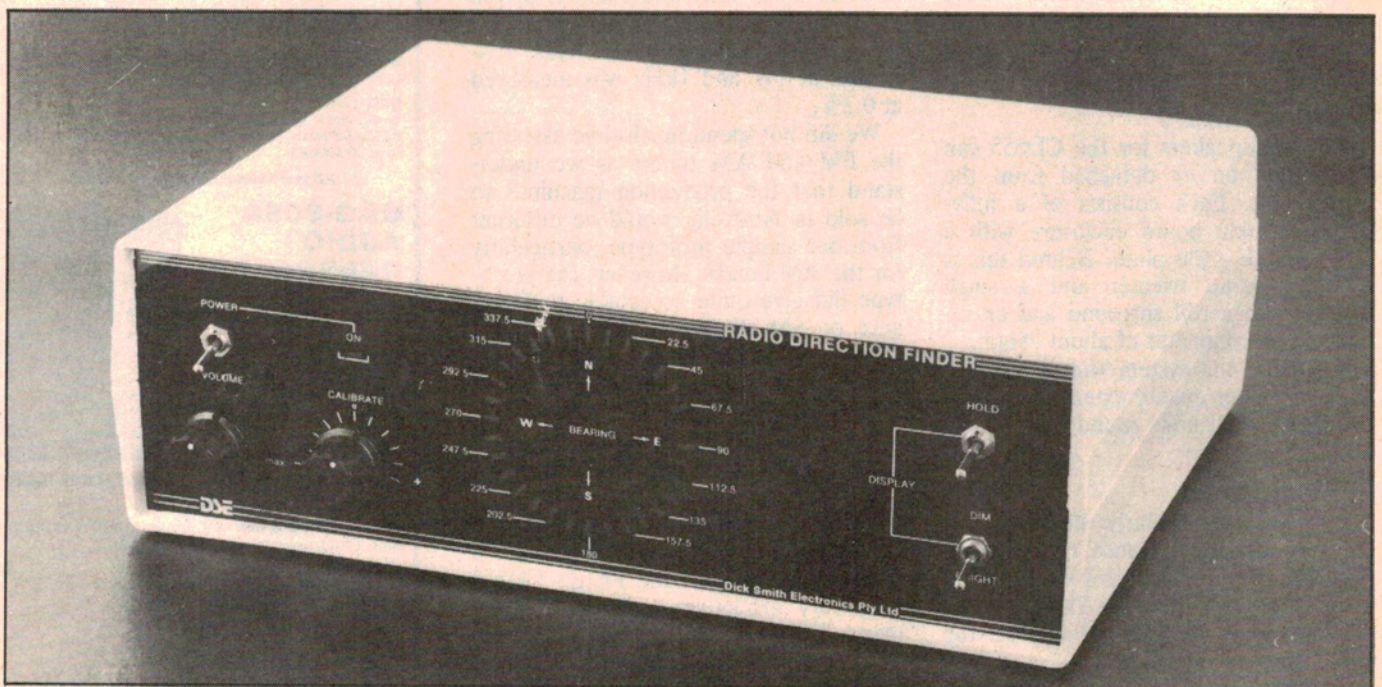
An electronic "compass" display consisting of 32 LEDs indicates the transmitter bearing. When a signal is received, its relative bearing to the antenna system is indicated by whichever of the 32 LEDs illuminates.

In fixed installations, this allows the compass bearing of the signal to be di-

rectly indicated to within ± 5.6 degrees. When installed in a car, successive readings allow you to pinpoint the exact location of the transmitter.

As such, the Dick Smith Radio Direction Finder (or RDF for short) is just the ticket for tracking down illegal transmitters and anti-social radio operators. Depending on the antenna system, it can operate on any band within the range 50-500MHz and will work with FM receivers ranging from pocket scanners to amateur radio and CB transceivers.

Radio direction finders of this type can cost around \$600 or more, but this unit can be built for just \$139. It was developed at Dick Smith Electronics and is available as a complete kit of



The relative bearing of the transmitter is indicated on a 32-LED compass rose.

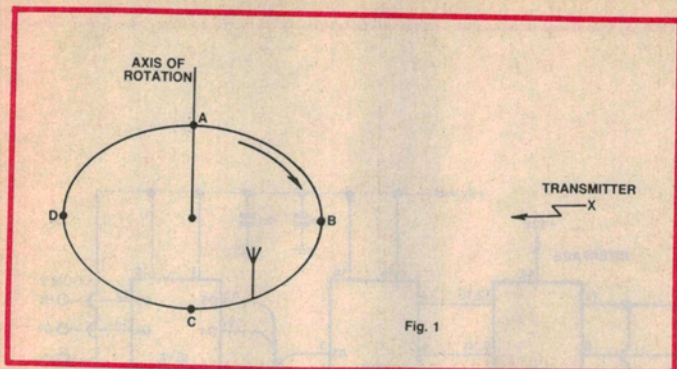


Fig. 1

Fig. 1: signals received by an antenna mounted on the edge of a rotating disc are frequency modulated due to the Doppler effect.

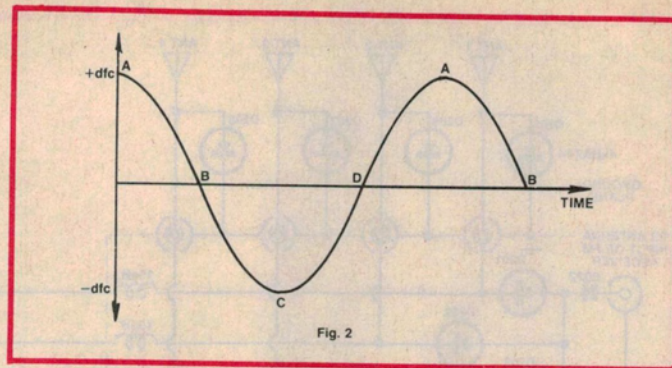


Fig. 2

Fig. 2: this graph illustrates the frequency shift as the antenna moves towards and away from the transmitter.

parts. We think it will be especially popular with amateur radio operators.

How it works

The theory of operation is reasonably simple. Radio signals received on a rapidly moving antenna undergo a frequency shift due to the Doppler effect, an effect well known to anyone who has observed a moving car with its horn blowing.

Consider a single antenna mounted on the edge of a rapidly spinning disc. As the antenna moves towards the source of the RF carrier, the apparent frequency will increase due to the Doppler effect. Conversely, as the antenna moves away, the frequency will decrease.

Thus, the rotating antenna causes frequency modulation of the received carrier. When this type of antenna is connected to an FM receiver (the type most often used on 2 metres), a tone is heard.

By analysing the phase of this tone, the direction of the transmitter can be determined.

To avoid the obvious drawback of a mechanically rotated system, the Dick Smith RDF simulates a rotating antenna electronically. Four vertical whip antennas are arranged around a circle of diameter .07-0.4 wavelengths. These are electronically switched clockwise in sequence such that all four antennas are scanned once every 1/1250th of a second.

This situation is equivalent to one vertical antenna mounted on the perimeter of a disc spinning at 1250 revolutions per second. For a diameter of say 800mm (for the 2-metre band), this results in a tangential velocity of 3140 metres per second.

The deviation of the received carrier is determined as follows. For $V \ll C$, we can neglect relativistic effects and write:

$$\begin{aligned} F_r/F_t &= 1 - V/C \\ \text{also } dF &= |F_r - F_t| \\ \text{therefore } dF &= F_t \times V/C \end{aligned}$$

where F_r is the received frequency, F_t is the transmitter frequency, dF is the frequency shift, C is the velocity of light (3×10^8 m/s) and V is the antenna velocity.

For $V = 3140$ m/s and $F_t = 144$ MHz, the carrier will deviate 1.5 kHz at a rate of 1250 Hz. For lower carrier frequencies, the deviation will be proportionally lower.

Note, however, that the 1250 Hz modulating tone remains constant as it is a function of the antenna switching rate only.

The output from the FM receiver is applied to the signal input of the RDF adapter and compared with an internal reference phase. The resultant phase angle appears as a 5-bit binary code and this is decoded to a one-of-32 output to drive the appropriate indicator LED.

In addition, the detected audio tone can be monitored on an internal loudspeaker. This provides audible indication that the receiver is correctly tuned to the transmitter frequency.

The circuit

Antenna switching is accomplished by first deriving a 2-bit binary code from a 1 MHz master oscillator. Here's how it's done:

Inverter stages IC2a, b & c (4069) form the 1 MHz oscillator with buffering provided by IC2d. This clocks decade

counters IC4 and IC7, both of which divide by five to produce a 40 kHz signal on pin 1 (CK) of IC10.

IC10 is a 4024 7-stage binary counter. Its Q1-Q5 outputs directly drive the D1-D5 inputs of IC12, a 40174 hex latch, while Q4 and Q5 also drive IC9 which is a 4555 one-of-four decoder.

What happens is that IC9 accepts a 2-bit binary code from IC10 and provides the quadrature antenna switching signals. These signals are interfaced by a 1488 line driver (IC6). The outputs of IC6 swing positive and negative in sequence to provide bias for the matrix diodes (D201-D208) in the antenna switching unit (ASU).

The diode matrix is arranged so that, at any given instant, three of the antennas are effectively shorted and only one is coupled to the receiver. For example, when pin 11 of IC6 is low (-9V), D205-D207 are forward biased and short out antennas 2 to 4.

At the same time, D201 will also be forward biased while D202-D204 are turned off. Antenna 1 will thus be connected to the receiver.

The detected audio tone from the FM receiver is applied to the input of the RDF adapter, limited by D1 and D2, and filtered by a single-pole active low-pass filter stage (IC5). This chip is described by National Semiconductor as an MF5 Universal Monolithic Switched Capacitor Filter. Basically, it is a general purpose active filter building block.

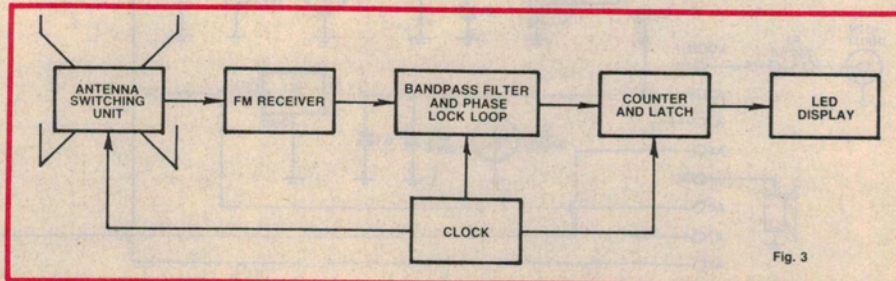
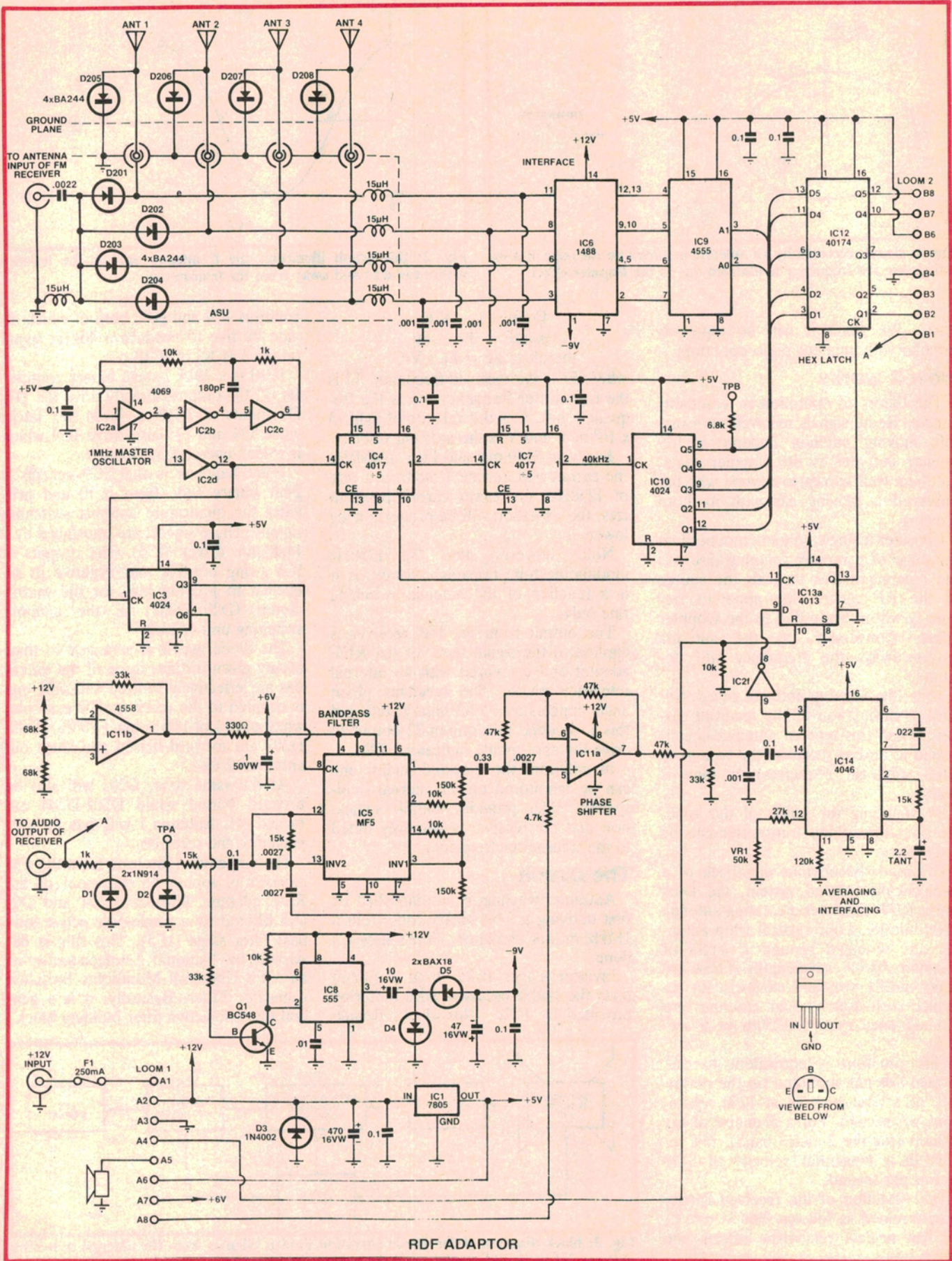
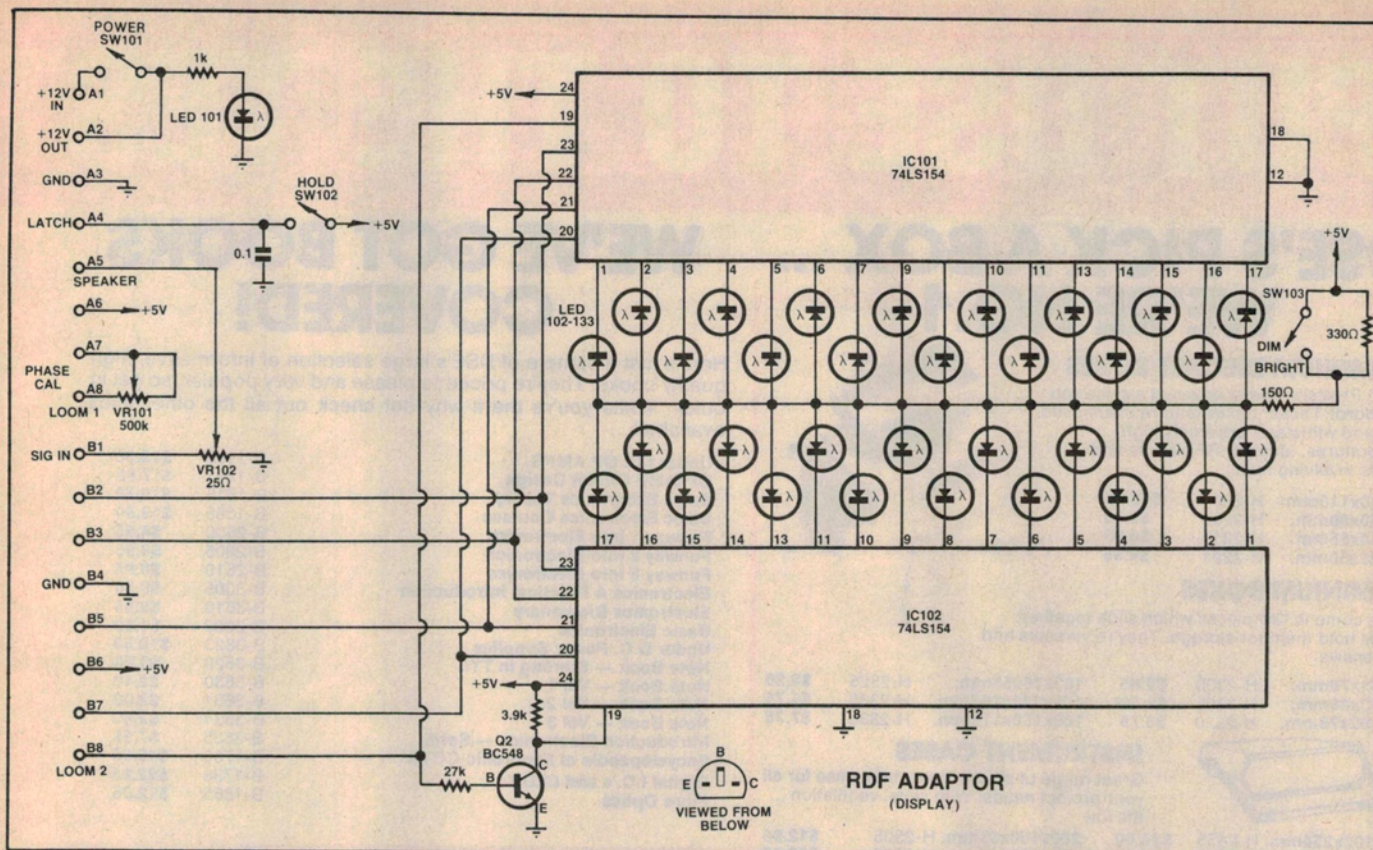


Fig. 3

Fig. 3: block diagram of the Radio Direction Finder. Signals from the antenna switching unit are fed to an FM receiver and the output compared to a reference phase.



RDF ADAPTOR



The control and antenna switching circuitry is at left while above is the display circuit.

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The rest of IC5 is configured as a second-order bandpass filter to remove unwanted audio modulation from the 1250Hz tone. The centre frequency of the filter is set to 1250Hz by the clock signal applied to pin 8. This clock signal is derived via IC3 which divides the 1MHz master oscillator signal by eight.

Note that the clock for the bandpass filter is derived from the same source as that used to switch the antennas. This means that the filter is automatically centred on the scanning tone, even when there is some frequency drift.

The output of IC5 (pin 1) is a sine wave with a nominal frequency of 1250Hz. This signal is applied to op amp IC11a which functions as a phase shifter. Adjustment of the phase shifter is by means of VR1.

The job of the phase shifter is to allow calibration of the circuit and to compensate for any audio phase shifts in the receiver.

From there, the signal is further processed by a 4046 phase lock loop (PLL). The function of this stage is to average out any modulation present in the pass-band of IC5 and to produce a 1250Hz square wave which is essentially free of

noise and jitter.

It is this signal that is used to latch IC12. The output of the PLL (pins 3 & 4) is first inverted by IC2f and applied to D-type flipflop IC13a. Subsequently, when D goes high, IC13a latches IC12 on the first positive-going clock pulse from pin 10 of IC4.

The result of all this is that IC12 is latched with a 5-bit code which is directly related to the transmitter direction. A phase comparator function is thus performed.

Note that IC13a is necessary to pre-

vent the latching signal from coinciding with a change of data on IC12's inputs.

A pair of 74LS154 one-of-16 decoders (IC101 and IC102) on the display board converts the 5-bit code to a one-of-32 output. These decoders directly drive the 32 display LEDs to indicate the transmitter position.

Switch SW102 allows the display to be held or "frozen" by resetting IC13a. SW101 serves as a power on/off switch, while SW103 allows the display to be dimmed by switching a 330Ω resistor into the common anode circuit of the LED display.

To make the unit as easy as possible to use, the audio output from the FM receiver is also fed to an internal loud-

Where to buy the kit

The Radio Direction Finder described here was developed by the Research and Development Department at Dick Smith Electronics Pty Ltd. It is available as a complete kit of parts by mail order or from your nearest Dick Smith Electronics store.

The kit comes complete and includes a perspex front panel, screen-printed fibreglass PC boards, antenna bases, plugs and sockets, and a detailed construction manual. The cost is \$139 plus postage and packing charges where applicable.

Mail orders should be sent to: Dick Smith Electronics Pty Ltd, PO Box 321, North Ryde, NSW 2113. Phone (02) 888-2105.

Note: all PC artworks for this project are copyright Dick Smith Electronics Pty Ltd.

Radio direction finder

Antennas and Operation

For mobile operation, four $\frac{1}{4}$ -wave vertical whip antennas attached to a roof-rack assembly would be the best approach. The ASU could then be conveniently located between the antennas. It should be weather-proofed using a silicone sealant.

In most cases, a separate ground plane will have to be provided adjacent to the antenna bases. A suggested method is to secure a sheet of aluminium to the roof-rack. Make sure that the assembly cannot come adrift.

A hand-held transceiver can be used to aid the initial setting-up procedure. Depending on the set-up, it may be necessary to "rotate" the antenna array until the compass rose reads true relative to the direction of the vehicle.

The calibrate control can be used to make the final adjustment. A walk around the antenna array with the hand-held transceiver will then reveal if the installation is functioning correctly. This should take place in an open area to avoid strong signal reflections.

In the case of a fixed installation, four ground plane antennas should be mounted symmetrically on a vertical mast, together with the ASU. The array can then be adjusted so that the compass rose displays the true bearing with the calibrate control set to mid-position.

Note that, in either case, the distance between opposing antennas should be between .07 and 0.4 wavelengths.

speaker. The volume is adjusted by means of potentiometer VR102 which is mounted on the front panel.

Power supply

Power for the RDF unit is derived from an external 12V source which connects to a 2-pole socket on the rear panel. This supplies +12V direct to several ICs and to the input of 3-terminal regulator IC1. IC1, in turn, supplies a regulated +5V rail to the remaining ICs.

Op amp IC11b provides a buffered +6V rail to IC5 and also to the phase calibration control (VR101).

Finally, a -9V supply rail is required for the 1488 line driver IC. This is generated by a DC-DC converter circuit based on 555 timer IC8. It buffers a 16kHz square wave derived from IC3 and drives a diode charge pump based on D4 and D5 to produce the required -9V rail.

Transistor Q1 simply functions as a switch. Its job is to interface the +5V CMOS circuit to the +12V 555 circuit.

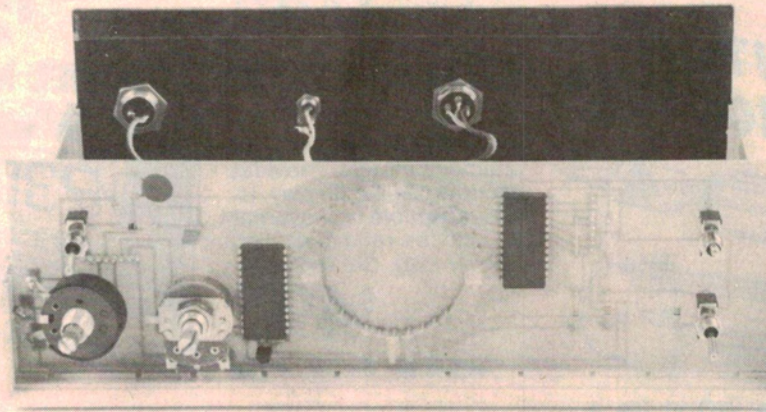
Construction

Construction is straightforward with most of the parts mounted on three PC boards, two in the main unit and one in the ASU. These boards are coded ZA-1543a, ZA-1543b and ZA1543c.

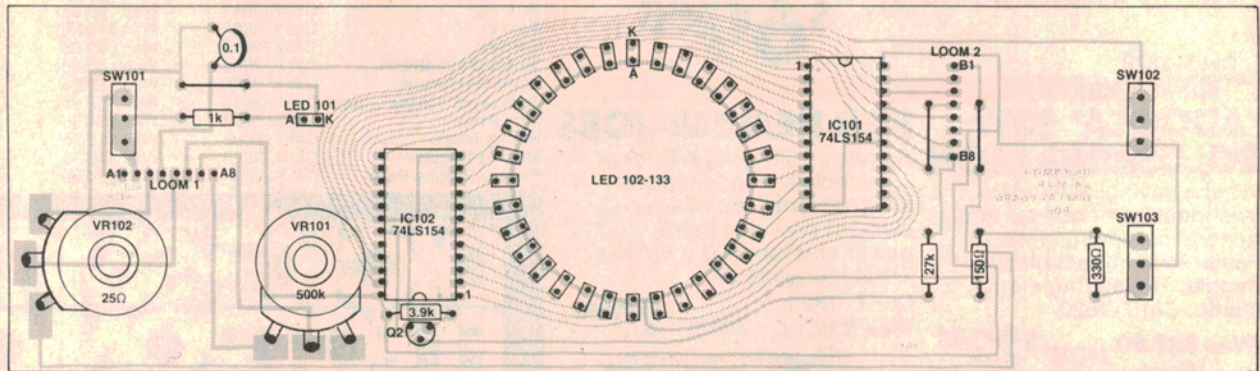
A plastic instrument case fitted with a perspex front panel houses the control electronics, while the ASU board is housed in a plastic zippy case.

Begin by constructing the main PC board (ZA-1543a). No special procedure need be followed when assembling the board although we suggest that the larger components be left till last. Note carefully the orientation of the semiconductors and electrolytic capacitors when they are being installed.

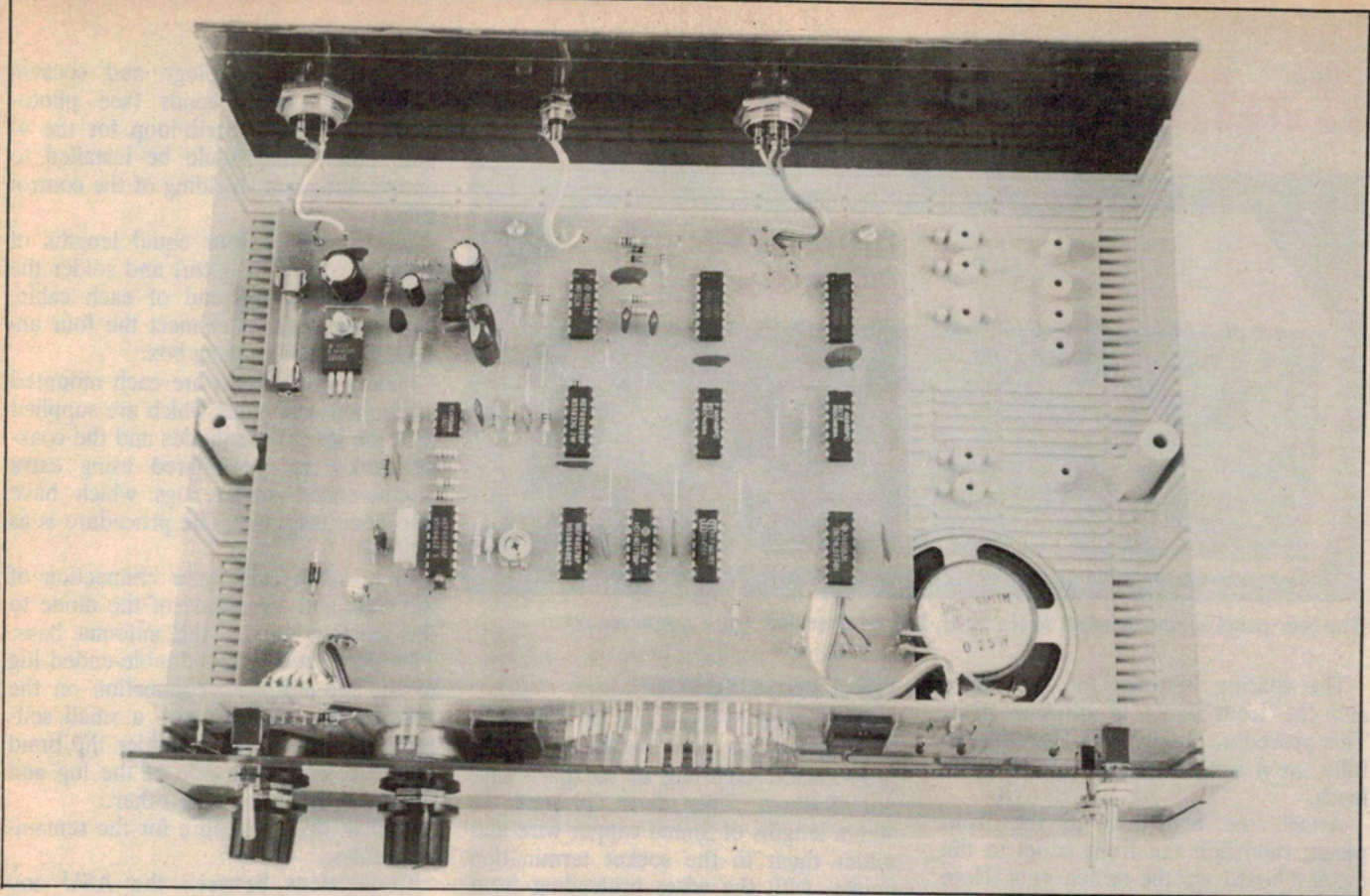
The 7805 regulator is installed so that



This view shows the completed display board. The pot leads are soldered to PC stakes.



Parts layout for the display PC board. Note that the two ICs face in opposite directions.



View inside the assembled RDF adaptor. Note mounting details for the front panel and the display board.

its metal tab lies flat against the board. It is then secured using a machine screw and nut. Note that PC pins are used to terminate all external wiring connections.

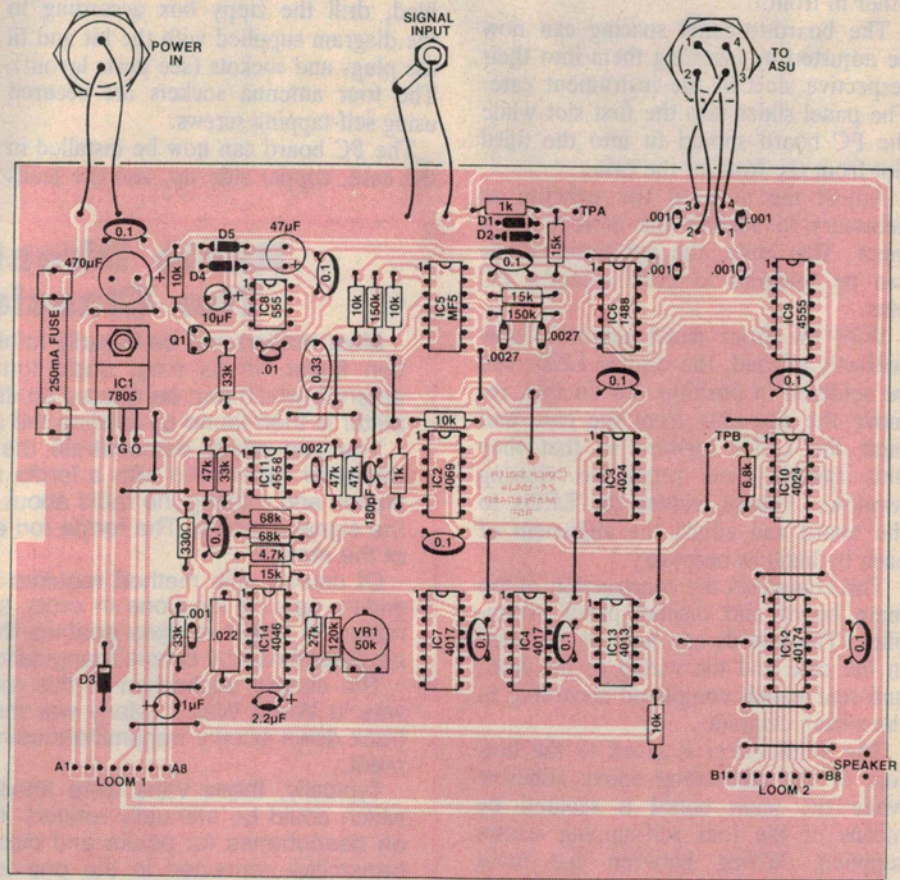
The display board (ZA-1543b) is constructed next. Begin by mounting all parts except for the two potentiometers and the 33 LEDs. Be careful with the orientation of the two LS154 decoder ICs as they face in opposite directions.

PC pins are used to terminate the wiring connections to the main board and to terminate the pot terminals. With the exception of the pot terminals, these should all be mounted on the copper side of the board.

Next, press all the LEDs into the board, noting that the yellow LEDs should be used for the quadrant markers and the red LED for power indication. Make sure that all the LEDs are correctly oriented — the anode lead is the longer of the two.

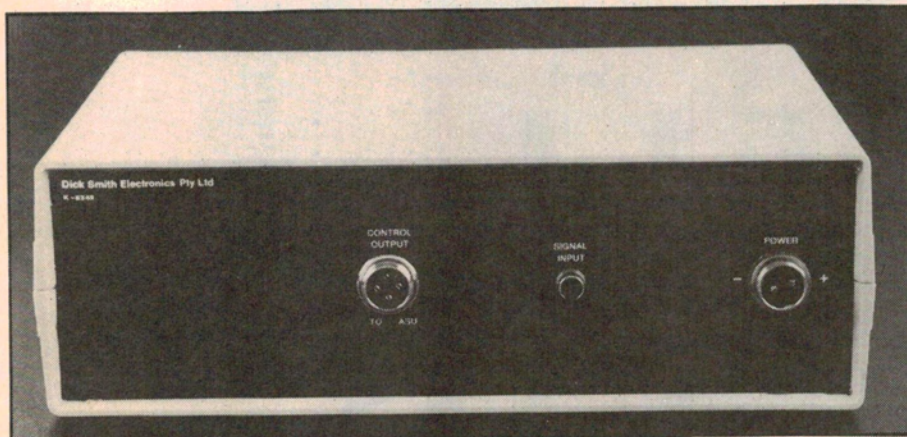
Do not solder them in at this stage as they must be aligned with the front panel later on.

Attention can now be turned to the perspex front panel. Using a smooth file, carefully file a radius on each corner. This is to prevent the right-angled corners of the panel from biting into the instrument case when it is eventually assembled.



Parts layout for the main PC board. Take care with component orientation.

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The rear panel sockets connect to the ASU, FM receiver and +12V power supply.

The spacing between the PC board and the front panel is adjusted next. This procedure should be followed carefully, as it sets the length of the LED leads.

Attach the two pots to the front panel, then bolt the front panel to the display board via the switch nuts. Note that there should be two nuts on each switch — one behind the panel and the other in front.

The board-to-panel spacing can now be adjusted by inserting them into their respective slots in the instrument case. The panel slides into the first slot while the PC board should fit into the third slot from the front of the case.

Adjust the nuts on the switches as necessary to achieve the correct alignment. This done, the pot terminations can be soldered to their adjacent PC pins.

With the front panel assembly now correctly aligned, the display LEDs can be soldered in position. To do this, remove the assembly from the case and push the LEDs forward so that they butt against their respective viewing windows. Finally, solder the LEDs to the board and adjust the alignment of each by hand as necessary.

This completes the construction of the main board and display panel assemblies. The boards can now be installed in the case and the wiring to the front and rear panels completed according to the wiring diagram.

The loudspeaker is glued to the bottom of the case using epoxy adhesive while the main board is secured by means of the four self-tapping screws supplied. Wiring between the main board and the front and rear panels can be run using rainbow cable.

ASU construction

Commence construction of the ASU by installing the parts on the PC board (ZA-1543c) according to the parts layout diagram. This done, prepare 11 40mm lengths of tinned copper wire and solder them to the socket termination points, with the wires protruding from the copper side of the board.

Once the PC board has been assembled, drill the zippy box according to the diagram supplied with the kit and fit the plugs and sockets (see parts layout). The four antenna sockets are secured using self-tapping screws.

The PC board can now be installed in the case, copper side up, and the leads

connected to the plugs and sockets using right angle bends (see photograph). Note the earth-loop for the 4-pole plug. This should be installed to ensure adequate shielding of the control cable.

Next, prepare four equal lengths of coaxial cable (70-100cm) and solder the line plugs to one end of each cable. These are used to connect the four antennas to the switching box.

Diodes D205-D208 are each mounted on the antenna bases which are supplied with the kit. These diodes and the coaxial cables are terminated using extra double-ended solder lugs which have also been included. The procedure is as follows:

First, solder the inner connection of the coax and the anode of the diode to the existing lug on the antenna base. This done, secure the double-ended lug to the ground-plane connection on the base of the antenna with a small self-tapping screw. Finally, solder the braid of the coax to one side of the lug and the diode cathode to the other.

Repeat this procedure for the remaining cables.

Connections between the ASU and the control unit should be run using 4-core cable, while the connection to the FM receiver should be run using coaxial cable. All you have to do is trim the cables to the desired lengths and terminate them with the appropriate plugs.

Note that the wiring connections to the plugs at both ends of the control

Radio Direction Finding: The Classic Technique

Most readers will be broadly familiar with the concept of a radio direction finder. In its most basic form, it consists of a receiver and an antenna which can be rotated on its own axis. The direction of the transmitter is then found by rotating the antenna for a signal peak or null.

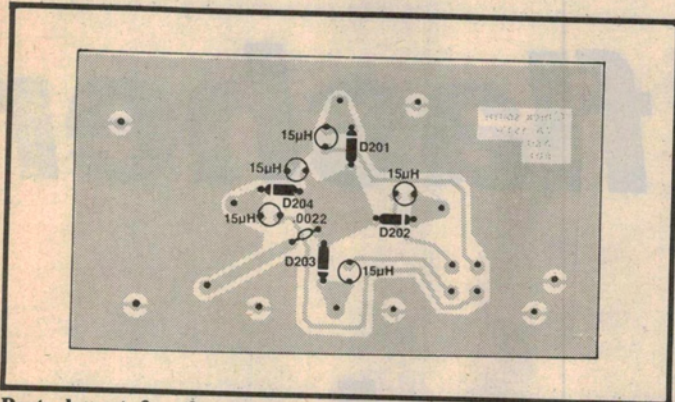
You can easily demonstrate the effect for yourself using a portable transistor radio fitted with a ferrite rod antenna. By tuning the radio to a station and rotating the radio about its vertical axis, a null will be found in the signal strength. The ferrite rod antenna will then point in the direction of the station.

Of course, this method requires that "fixes" be taken at two or more widely spaced locations in order to find the true direction of the transmitter. In fact, two fixes enables the exact location of the transmitter to be determined by simple triangulation.

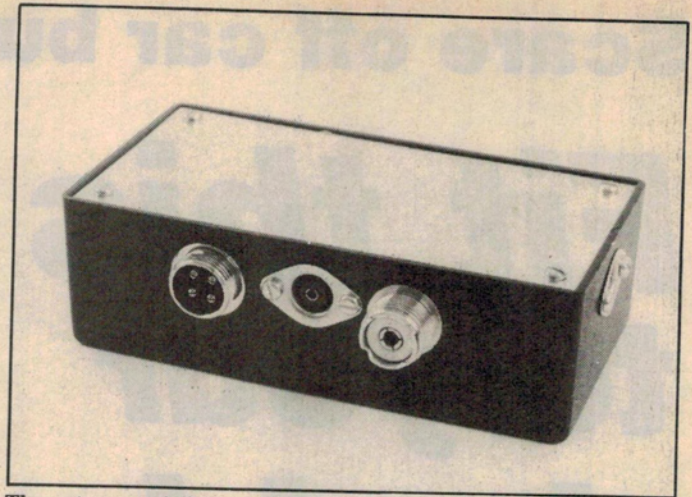
The classic application of this radio direction finding (RDF) technique was in World War II. Many war movies showed how it was possible to track down enemy transmitters using special vans fitted with RDF equipment.

Typically, these vans were fitted with a large external loop antenna which could be manually rotated. An operator inside the van listened in on headphones for peaks and dips in the signal strength. Provided the transmitter remained in the one location for long enough, its location could eventually be pinpointed.

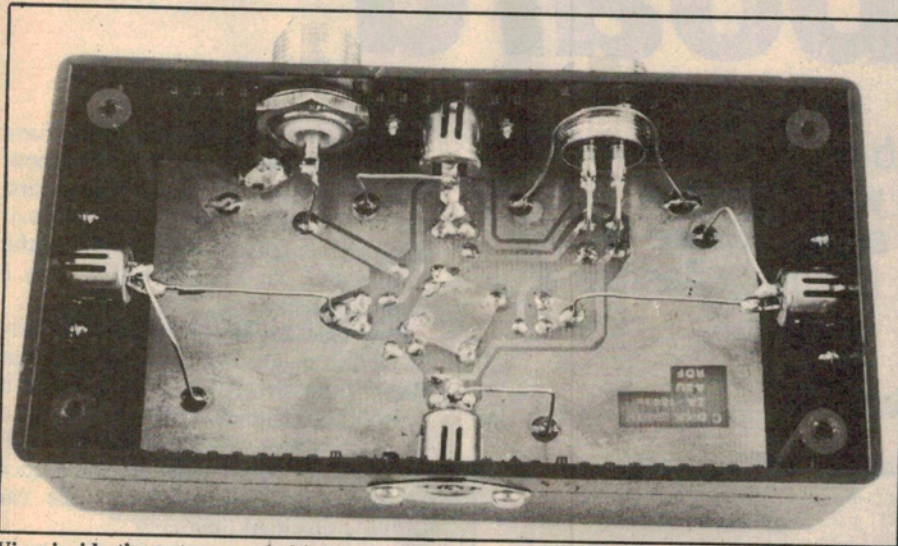
Direction finder



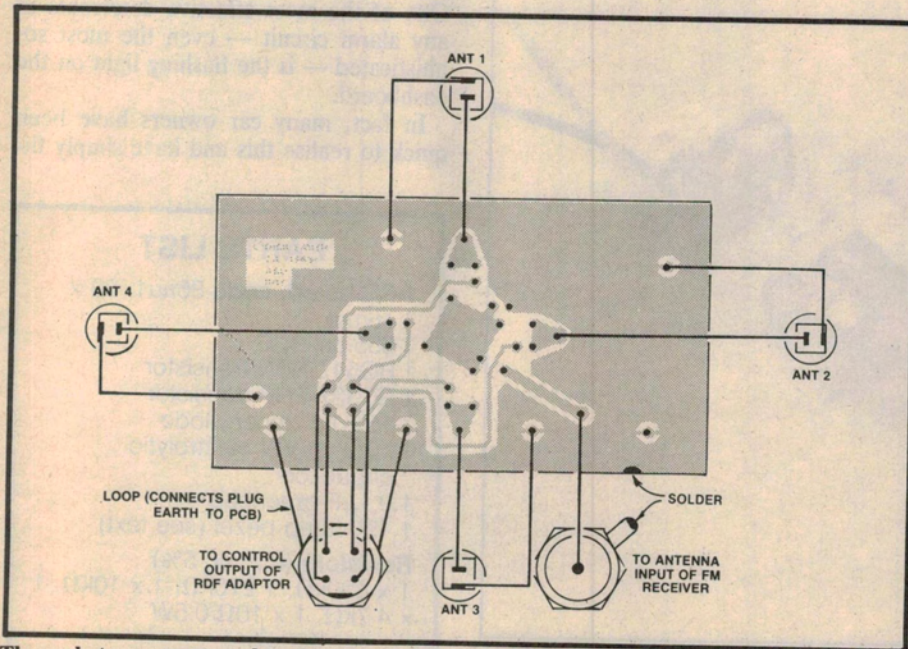
Parts layout for the antenna switching unit. The diodes are all BA244 types.



The antenna switching unit is housed in a plastic zippy case. It can be weatherproofed using silicone sealant.



View inside the antenna switching unit. Note the earth loop for the 4-way socket.



The sockets are connected to the copper side of the PC board using tinned copper wire.

cable must be made on a one-to-one basis, otherwise the antennas will not rotate in the correct sequence.

Setting up

An alligator clip lead and a small screwdriver are all that are necessary to adjust the unit.

Connect up a 12V supply (be careful of polarity!) and switch on with the hold off and the ASU disconnected. All the LEDs in the display should rapidly flicker on and off as the display is scanned.

Assuming all is well, connect the two test points (TPA and TPB) together using the clip lead and adjust VR1 until a single LED is latched. Confirm this adjustment by unhooking and reconnecting the clip lead.

If the display does not latch when the test lead is reconnected, repeat the above procedure. This adjustment brings the VCO to within the capture range of the PLL.

Note that, with the calibrate control at mid-position, the latched LED should be at the top of the circle.

If a dual-trace oscilloscope is available, VR1 can be adjusted for a 90° phase angle between the signal input (pin 14, IC14) and the PLL comparator input (pin 3, IC14).

Finally, the control unit can be checked out by connecting outputs 1, 2, 3 & 4 (to the ASU) in sequence to test point TPA. First, connect output 1 to TPA and adjust the calibrate control so that the latched LED is at 0°. The 90° LED should now light when output 2 is shorted, the 180° LED when output 3 is shorted, and the 270° LED when output 4 is shorted.

That completes the construction. Your Radio Direction Finder is now ready for use.

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