Chapter 19

Station Layout and Accessories

Although many hams never try to build a major project, such as a transmitter, receiver or amplifier, they do have to assemble the various components into a working station. There are many benefits to be derived from assembling a safe, comfortable, easy-to-operate collection of radio gear, whether the shack is at home, in the car or in a field. This chapter, written by Wally Blackburn, AA8DX, covers the many aspects of setting up an efficient station.

This chapter will detail some of the "how tos" of setting up a station for fixed, mobile and portable operation. Such topics as station location, finding adequate power sources, station layout and cable routing are covered, along with some of the practical aspects of antenna erection and maintenance.

Regardless of the type of installation you are attempting, good planning greatly increases your chances of success. Take the time to think the project all the way through, consider alternatives, and make rough measurements and sketches during your planning and along the way. You will save headaches and time by avoiding "shortcuts." What might seem to save time now may come back to haunt you with extra work when you could be enjoying your shack.

One of the first considerations should be to determine what type of operating you intend to do. While you do not want to strictly limit your options later, you need to consider what you want to do, how much you have to spend and what room you have to work with. There is a big difference between a casual operating position and a "big gun" contest station, for example.

Fixed Stations

SELECTING A LOCATION

Selecting the right location for your station is the first and perhaps the most important step in assembling a safe, comfortable, convenient station. The exact location will depend on the type of home you have and how much space can be devoted to your station. Fortunate amateurs will have a spare room to devote to housing the station; some may even have a separate building for their exclusive use. Most must make do with a spot in the cellar or attic, or a corner of the living room is pressed into service.

Examine the possibilities from several angles. A station should be comfortable; odds are good that you'll be spending a lot of time there over the years. Some unfinished basements are damp and drafty—not an ideal environment for several hours of leisurely hamming. Attics have their drawbacks, too; they can be stifling during warmer months. If possible, locate your station away from the heavy traffic areas of your home. Operation of your station should not interfere with family life. A night of chasing DX on 80 m may be exciting to you, but the other members of your household may not share your enthusiasm.

Keep in mind that you must connect your station to the outside world. The location

Fig 19.1—Danny, KD4HQV, appreciates the simplicity that his operating position affords. (*Photo courtesy Conard Murray, WS4S*)

Fig 19.2—VE6AFO's QSL card reveals an impressive array of gear. Although many hams would appreciate having this much space to devote to a station, most of us must make do with less.

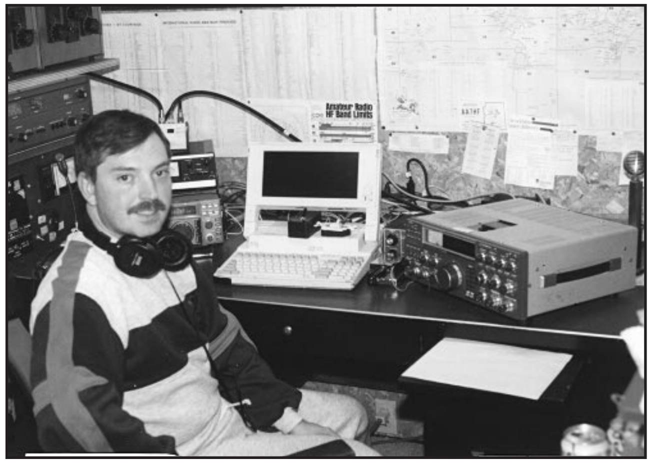


Fig 19.3—Scott, KA9FOX, operated this well laid out station, W9UP, during a recent contest. (*Photo courtesy NØBSH*)

you choose should be convenient to a good power source and an adequate ground. If you use a computer and modem, you may need access to a telephone jack. There should be a fairly direct route to the outside for running antenna feed lines, rotator control cables and the like.

Although most homes will not have an "ideal" space meeting all requirements, the right location for you will be obvious after you scout around. The amateurs whose stations are depicted in **Figs 19.1** through **19.3** all found the right spot for them. Weigh the trade-offs and decide which features you can do without and which are necessary for your style of operation. If possible pick an area large enough for future expansion.

THE STATION GROUND

Grounding is an important factor in overall station safety, as detailed in the **Safety** chapter. An effective ground system is necessary for every amateur station. The mission of the ground system is two-fold. First, it reduces the possibility of electrical shock if something in a piece of equipment should fail and the chassis or cabinet becomes "hot." If connected to a properly grounded outlet, a three-wire electrical system grounds the chassis. Much amateur equipment still uses the ungrounded two-wire system, however. A ground system to prevent shock hazards is generally referred to as *dc ground*.

The second job the ground system must perform is to provide a low-impedance path to ground for any stray RF current inside the station. Stray RF can cause equipment to malfunction and contributes to RFI problems. This low-impedance path is usually called *RF ground*. In most stations, dc ground and RF ground are provided by the same system.

Ground Noise

Noise in ground systems can affect our sensitive radio equipment. It is usually related to one of three problems:

1) Insufficient ground conductor size
2) Loose ground connections
3) Ground loops

These matters are treated in precise scientific research equipment and certain industrial instruments by attention to certain rules. The ground conductor should be at least as large as the largest conductor in the primary power circuit. Ground conductors should provide a solid connection to both ground and to the equipment being grounded. Liberal use of lock washers and star washers is highly recommended. A loose ground connection is a tremendous source of noise, particularly in a sensitive receiving system.

Ground loops should be avoided at all costs. A short discussion of what a ground loop is and how to avoid them may lead you down the proper path. A ground loop is formed when more than one ground current is flowing in a single conductor. This commonly occurs when grounds are "daisy-chained" (series linked). The correct way to ground equipment is to bring all ground conductors out radially from a common point to either a good driven earth ground or a cold-water system. If one or more earth grounds are used, they should be bonded back to the service entrance panel. Details appear in the **Safety** chapter.

Ground noise can affect transmitted and received signals. With the low audio levels required to drive amateur transmitters, and the ever-increasing sensitivity of our receivers, correct grounding is critical.

STATION POWER

Amateur Radio stations generally require a 120-V ac power source. The 120-V ac is then converted to the proper ac or dc levels required for the station equipment. Power supply theory is covered in the **Power Supplies** chapter, and safety issues are covered in the **Safety** chapter. If your station is located in a room with electrical outlets, you're in luck. If your station is located in the basement, an attic or another area without a convenient 120-V source, you will have to run a line to your operating position.

Surge Protection

Typically, the ac power lines provide an adequate, well-regulated source of electrical power for most uses. At the same time, these lines are fraught with frequent power surges that, while harmless to most household equipment, may cause damage to more sensitive devices such as computers or test equipment. A common method of protecting these devices is through the use of surge protectors. More information on these and lightning protection is in the **Safety** chapter.

STATION LAYOUT

Station layout is largely a matter of personal taste and needs. It will depend mostly on the amount of space available, the equipment involved and the types of operating to be done. With these factors in mind, some basic design considerations apply to all stations.

The Operating Table

The operating table may be an office or computer desk, a kitchen table or a custom-

Fig 19.4—The basement makes a good location if it is dry. A ready-to-assemble computer desk makes an ideal operating table at a reasonable price. This setup belongs to WK8H. (*Photo courtesy AA8DX*)

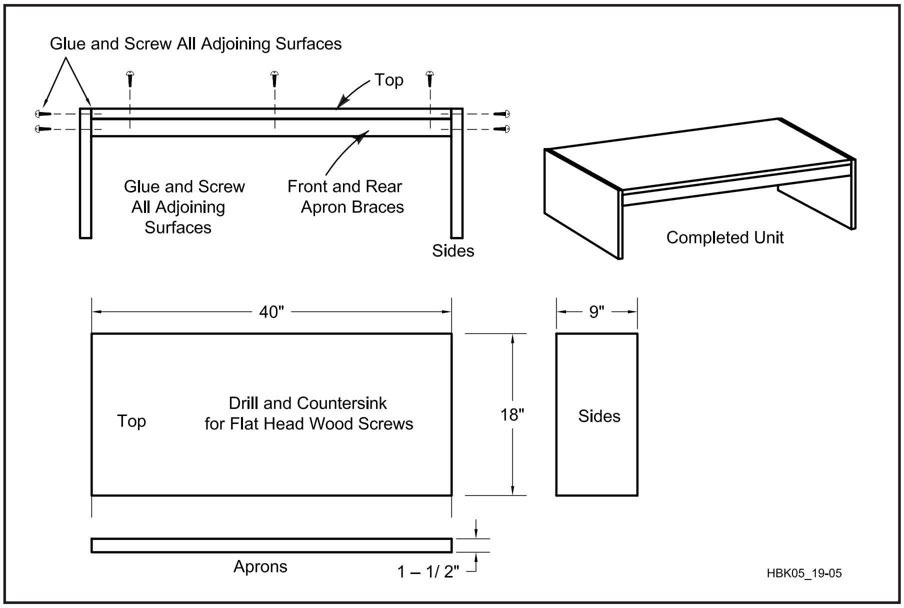


Fig 19.5—A simple but strong equipment shelf can be built from readily available materials. Use ¾-inch plywood along with glue and screws for the joints for adequate strength.

made bench. What you use will depend on space, materials at hand and cost. The two most important considerations are height and size of the top. Most commercial desks are about 29 inches above the floor. This is a comfortable height for most adults. Heights much lower or higher than this may cause an awkward operating position.

The dimensions of the top are an important consideration. A deep (36 inches or more) top will allow plenty of room for equipment interconnections along the back, equipment about midway and room for writing toward the front. The length of the top will depend on the amount of equipment being used. An office or computer desk makes a good operating table. These are often about 36 inches deep and 60 inches wide. Drawers can be used for storage of logbooks, headphones, writing materials, and so on. Desks specifically designed for computer use often have built-in shelves that can be used for equipment stacking. Desks of this type are available ready-to-assemble at most discount and home improvement stores. The low price and adaptable design of these desks make them an attractive option for an operating position. An example is shown in **Fig 19.4.**

Stacking Equipment

No matter how large your operating table, some vertical stacking of equipment may be necessary to allow you to reach everything from your chair. Stacking pieces of equipment directly on top of one another is not a good idea because most amateur equipment needs airflow around it for cooling. A shelf like that shown in **Fig 19.5** can improve equipment layout in many situations. Dimensions of the shelf can be adjusted to fit the size of your operating table.

Arranging the Equipment

When you have acquired the operating table and shelving for your station, the next task is arranging the equipment in a convenient, orderly manner. The first step is to provide power outlets and a good ground as described in a previous section. Be conservative in estimating the number of power outlets for your installation; radio equipment has a habit of multiplying with time, so plan for the future at the outset.

Fig 19.6 illustrates a sample station layout. The rear of the operating table is spaced about 1½ ft from the wall to allow easy access to the rear of the equipment. This installation incorporates two separate operating positions, one for HF and one for VHF. When the operator is seated at the HF operating position, the keyer and transceiver controls are within easy reach. The keyer, keyer paddle and transceiver are the most-often adjusted pieces of equipment in the station. The speaker is positioned right in front of the operator for the best possible reception. Accessory equipment not often adjusted, including the amplifier, antenna switch and rotator control box, is located on the shelf above the transceiver. The SWR/power meter and clock, often consulted but rarely touched, are located where the operator can view them without head movement. All HF-related equipment can be reached without moving the chair.

This layout assumes that the operator is right-handed. The keyer paddle is operated with the right hand, and the keyer speed and transceiver controls are operated with the left hand. This setup allows the operator to write or send with the right hand without having to cross hands to adjust the controls. If the operator is left-handed, some repositioning of equipment is necessary, but the idea is the same. For best results during CW operation, the paddle should be weighted to keep it from "walking" across the table. It should be oriented such that the operator's entire arm from wrist to elbow rests on the tabletop to prevent fatigue.

Some operators prefer to place the station transceiver on the shelf to leave the table top clear for writing. This arrangement leads to fatigue from having an unsupported arm in the air most of the time. If you rest your elbows on the tabletop, they will quickly become sore. If you rarely operate for prolonged periods, however, you may not be inconvenienced by having the transceiver on the shelf. The real secret to having a clear table top for logging, and so on, is to make the operating table deep enough that your entire arm from elbow to wrist rests on the table with the front panels of the equipment at your fingertips. This leaves plenty of room for paperwork, even with a microphone and keyer paddle on the table.

The VHF operating position in this sta-

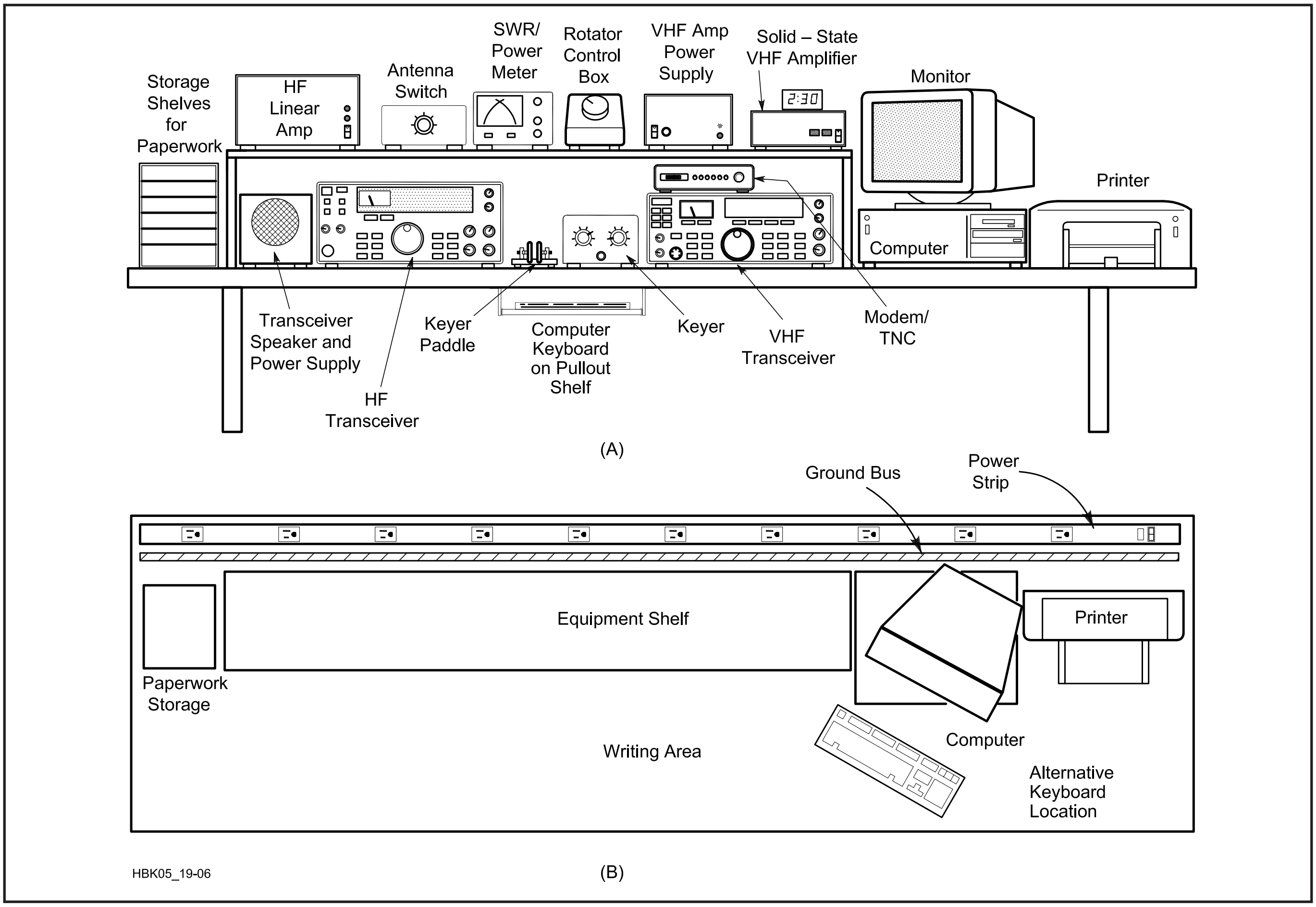


Fig 19.6—Example station layout as seen from the front (A) and the top (B). The equipment is spaced far enough apart that air circulates on all sides of each cabinet.

tion is similar to the HF position. The amplifier and power supply are located on the shelf. The station triband beam and VHF beam are on the same tower, so the rotator control box is located where it can be seen and reached from both operating positions. This operator is active on packet radio on a local VHF repeater, so the computer, printer, terminal node controller and modem are all clustered within easy reach of the VHF transceiver.

This sample layout is intended to give you ideas for designing your own station. Study the photos of station layouts presented here, in other chapters of this *Handbook* and in *QST*. Visit the shacks of amateur friends to view their ideas. Station layout is always changing as you acquire new gear, dispose of old gear, change operating habits and interests or become active on different bands. Configure the station to suit your interests, and keep thinking of ways to refine the layout. **Figs 19.7** and **19.8** show station arrangements tailored for specific purposes.

Equipment that is adjusted frequently sits on the tabletop, while equipment requiring infrequent adjustment is perched on a shelf. All equipment is positioned so the operator does not have to move the chair to reach anything at the operating position.

Fig 19.7—It was back to basics for Elias, K4IX, during a recent Field Day.

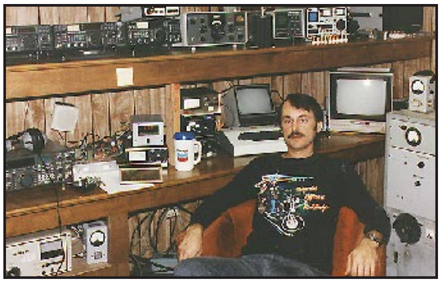


Fig 19.8—Richard, WB5DGR, uses a homebrew 1.5-kW amplifier to seek EME contacts from this nicely laid out station.

Aids for Hams with Disabilities

A station used by an amateur with physical disabilities or sensory impairments may require adapted equipment or particular layout considerations. The station may be highly customized to meet the operator's needs or just require a bit of "tweaking."

The myriad of individual needs makes describing all of the possible adaptive methods impractical. Each situation must be approached individually, with consideration to the operator's particular needs. However, many types of situations have already been encountered and worked through by others, eliminating the need to start from scratch in every case.

An excellent resource is the Courage Handi-Ham System. The Courage Handi-Ham System, a part of the Courage Center, provides a number of services to hams (and aspiring hams) with disabilities. These include study materials, equipment loans, adapted equipment, a newsletter and much more. Information needed to reach the Courage Handi-Hams is in the **Component Data and References** chapter.

INTERCONNECTING YOUR EQUIPMENT

Once you have your equipment and get it arranged, you will have to interconnect it all. No matter how simple the station, you will at least have antenna, power and microphone or key connections. Equipment such as amplifiers, computers, TNCs and so on add complexity. By keeping your equipment interconnections well organized and of high quality, you will avoid problems later on.

Often, ready-made cables will be available. But in many cases you will have to make your own cables. A big advantage of making your own cables is that you can customize the length. This allows more flexibility in arranging your equipment and avoids unsightly extra cable all over the place. Many manufacturers supply connectors with their equipment along with pinout information in the manual. This allows you to make the necessary cables in the lengths you need for your particular installation.

Always use high quality wire, cables and connectors in your shack. Take your time and make good mechanical and electrical connections on your cable ends. Sloppy cables are often a source of trouble. Often the problems they cause are intermittent and difficult to track down. You can bet that they will crop up right in the middle of a contest or during a rare DX QSO! Even worse, a poor quality connection could cause RFI or even create a fire hazard. A cable with a poor mechanical connection could come loose and short a power supply to ground or apply a voltage where it should not be. Wire and cables should have good quality insulation that is rated high enough to prevent shock hazards.

Interconnections should be neatly bundled and labeled. Wire ties, masking tape or paper labels with string work well. See **Fig 19.9**. Whatever method you use, proper labeling makes disconnecting and reconnecting equipment much easier. **Fig 19.10** illustrates the number of potential interconnections in a modern, full-featured transceiver.

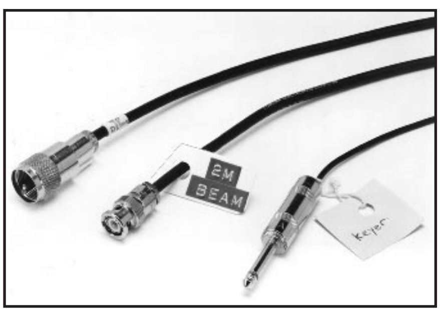


Fig 19.9—Labels on the cables make it much easier to rearrange things in the station. Labeling ideas include masking tape, card board labels attached with string and labels attached to fasteners found on plastic bags (such as bread bags).

Fig 19.10—The back of this Ten-Tec Omni VI HF transceiver shows some of the many types of connectors encountered in the amateur station. Note that this variety is found on a single piece of equipment. (*Photo courtesy AA8DX*)

Wire and Cable

The type of wire or cable to use depends on the job at hand. The wire must be of sufficient size to carry the necessary current. Use the tables in the **Component Data and References** chapter to find this information. Never use underrated wire; it will be a fire hazard. Be sure to check the insulation too. For high-voltage applications, the insulation must be rated at least a bit higher than the intended voltage. A good rule of thumb is to use a rating at least twice what is needed.

Use good quality coaxial cable of sufficient size for connecting transmitters, transceivers, antenna switches, antenna tuners and so on. RG-58 might be fine for a short patch between your transceiver and SWR bridge, but is too small to use between your legal-limit amplifier and Transmatch.

Hookup wire may be stranded or solid. Generally, stranded is a better choice since it is less prone to break under repeated flexing. Many applications require shielded wire to reduce the chances of RF getting into the equipment. RG-174 is a good choice for control, audio and some low-power applications. Shielded microphone or computer cable can be used where more conductors are necessary. For more information, see the **Transmission Lines** chapter.

Connectors

While the number of different types of connectors is mind-boggling, many manufacturers of amateur equipment use a few standard types. If you are involved in any group activities such as public service or emergency-preparedness work, check to see what kinds of connectors others in the group use and standardize connectors wherever possible. Assume connectors are not waterproof, unless you specifically buy one clearly marked for outdoor use (and assemble it correctly).

Audio, Power and Control Connectors

The simplest form of connector is found on terminal blocks. Although it is possible to strip the insulation from wire and wrap it around the screw, this method is not ideal. The wire tends to "squirm" out from under the screw when tightening, allowing strands to hang free, possibly shorting to other screws.

Terminal lugs, such as those in **Fig 19.11**, solve the problem. These lugs may be crimped (with the proper tool), soldered or both. Terminal lugs are available in different sizes. Use the appropriate size for your wire to get the best results.

Some common multipin connectors are

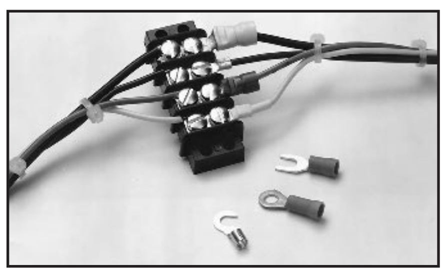
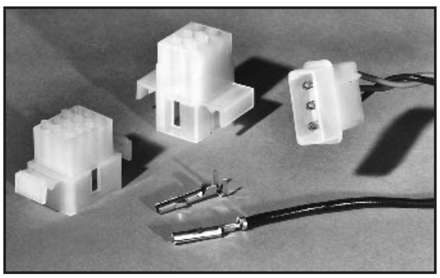


Fig 19.11—The wires on one side of this terminal block have connectors; the others do not. The connectors make it possible to secure different wire sizes to the strip and also make it much easier to change things around.

shown in **Fig 19.12**. The connector in Fig 19.12A is often referred to as a "Cinch-Jones connector." It is frequently used for connections to power supplies from various types of equipment. Supplying from two to eight conductors, these connectors are keyed so that they go together only one way. They offer good mechanical and electrical connections, and the pins are large enough to handle high current. If your cable is too small for the strain relief fitting, build up the outer jacket with a few layers of electrical tape until the strain relief clamps securely. The strain relief will keep your wires from breaking away under flexing or from a sudden tug on the cable.

(A)



(B)

(C)

Fig 19.12—The plugs shown at A are often used to connect equipment to remote power supplies. The multipin connectors at B are used for control, signal and power lines. The DIN plug at C offers shielding and is often used for connecting accessories to transceivers.

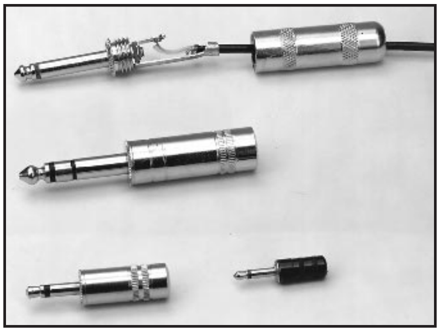


Fig 19.13—The phone-plug family. The ¼-inch type is often used for head-phone and key connections on amateur equipment. The three-circuit version is used with stereo headphones. The mini phone plug is commonly used for connecting external speakers to receivers and transceivers. A subminiphone plug is shown in the foreground for comparison. The shielded style with metal barrel is more durable than the plastic style.

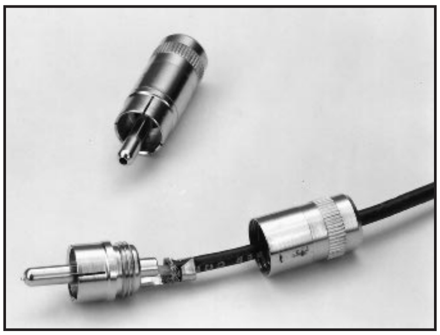


Fig 19.14—Phono plugs have countless uses around the shack. They are small and shielded; the type with the metal body is easy to grip. Be careful not to use too much heat when soldering the ground (outer) conductor—you may melt the insulation.

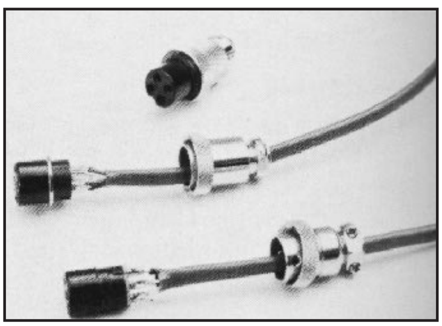


Fig 19.15—The four-pin mike connector is common on modern transmitters and receivers. More elaborate rigs use the eight-pin type. The extra conductors may be used for switches to remotely control the frequency or to power a preamplifier built into the mike case.

The plug in Fig 19.12B is usually called a "molex" connector. This plug consists of an insulated outer shell that houses the individual male or female "fingers." Each finger is individually soldered or crimped onto a conductor of the cable and inserted in the shell, locking into place. These connectors are used on many brands of amateur gear for power and accessory connections.

Fig 19.12C shows a DIN connector. Commonly having five to eight pins, these connectors are a European standard that have found favor with amateur equipment manufacturers around the world. They are generally used for accessory connections. A smaller version, the Miniature DIN, is becoming popular. It is most often used in portable gear but can be found on some full-size equipment as well.

Various types of phone plugs are shown in **Fig 19.13**. The ¼-inch (largest) is usually used on amateur equipment for headphone and Morse key connections. They are available with plastic and metal bodies. The metal is usually a better choice because it provides shielding and is more durable.

Fig 19.13 also shows the ⅛-inch phone plug. These plugs, sometimes called miniature phone plugs, are used for earphone, external speaker, key and control lines. There is also a subminiature (3/32-inch) phone plug that is not common on amateur gear.

The phono, or RCA, plug shown in **Fig 19.14** is popular among amateurs. It is used for everything from amplifier relay-control lines, to low-voltage power lines, to low-level RF lines, to antenna lines. Several styles are available, but the best choice is the shielded type with the screw-on metal body. As with the phone plugs, the metal bodies provide shielding and are very durable.

Nowhere is there more variation than among microphone connectors. Manufacturers seem to go out of their way to use incompatible connectors! The most popular types of physical connectors are the four- and eight-pin microphone connectors shown in **Fig 19.15**. The simplest connectors provide three connections: audio, ground and push-to-talk (PTT). More complex connectors allow for such things as control lines from the microphone for frequency changes or power to the microphone for a preamplifier. When connecting a microphone to your rig, especially an after-market one, consult the manual. Follow the manufacturer's recommendations for best results.

If the same microphone will be used for multiple rigs with incompatible connectors, one or more adapters will be neces-

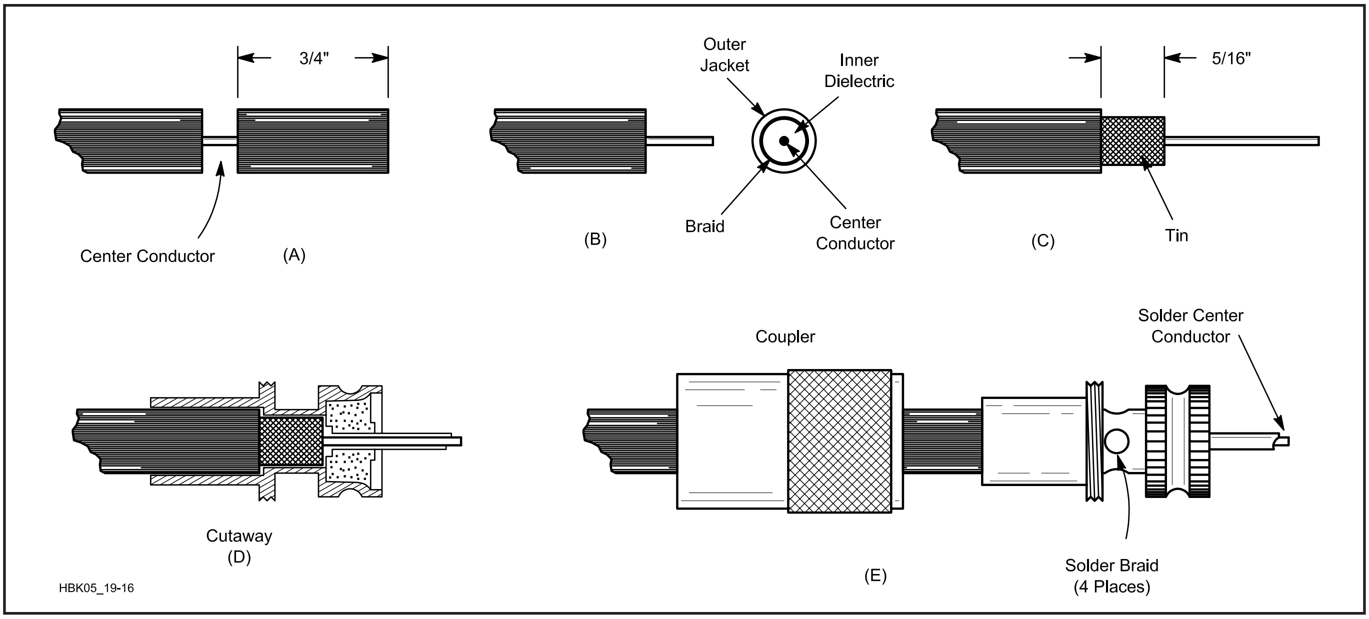


Fig 19.16—The PL-259, or UHF, connector is almost universal for amateur HF work and is popular for equipment operating in the VHF range. Steps A through E are described in detail in the text.

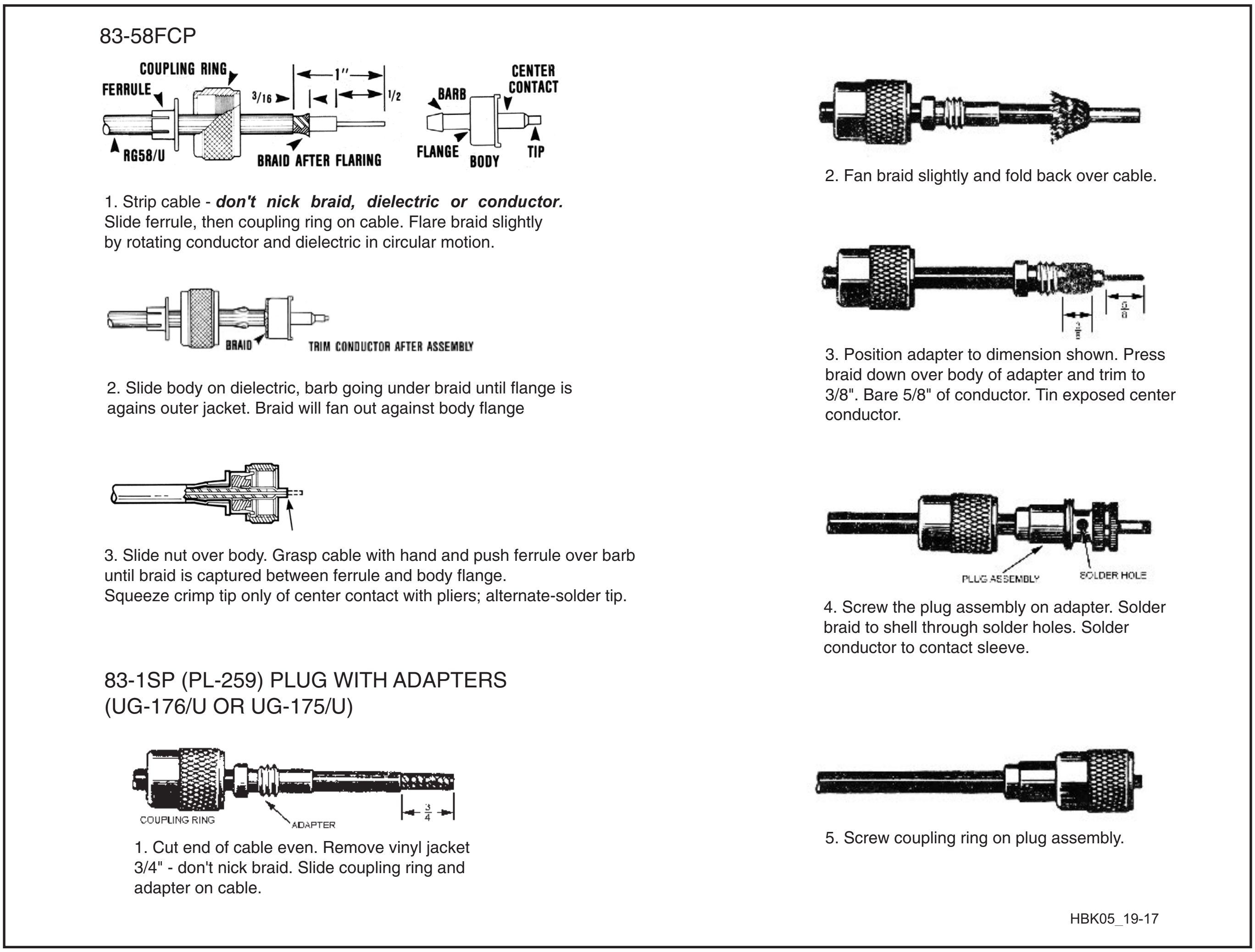


Fig 19.17—Crimp-on connectors and adapters for use with standard PL-259 connectors are popular for connecting to RG-58 and RG-59 type cable. (*Courtesy Amphenol Electronic Components, RF Division, Bunker Ramo Corp*)

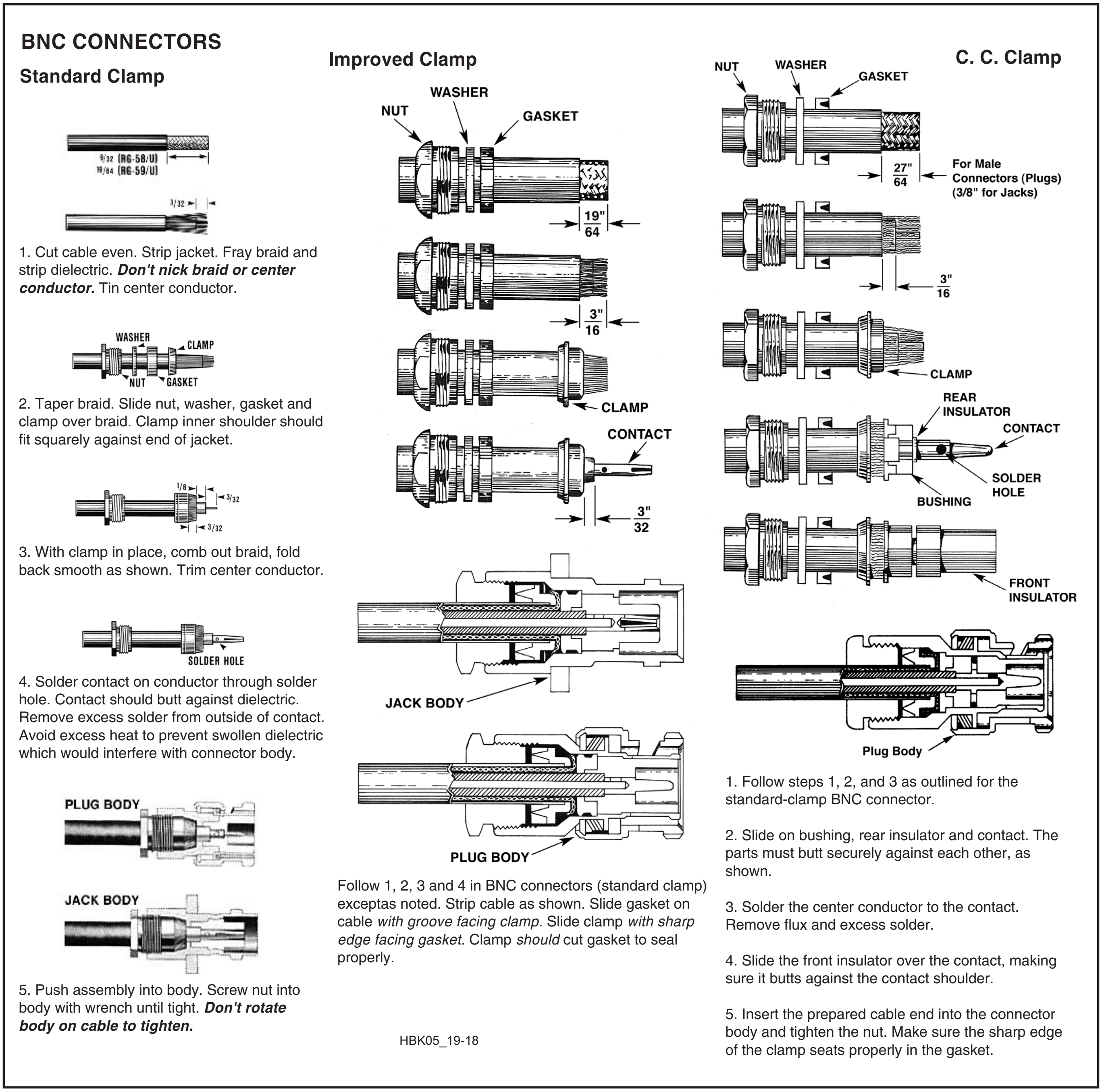


Fig 19.18—BNC connectors are common on VHF and UHF equipment at low power levels. (*Courtesy Amphenol Electronic Components, RF Division, Bunker Ramo Corp*)

sary. Adapters can be made with short pieces of cable and the necessary connectors at each end.

RF Connectors

There are many different types of RF connectors for coaxial cable, but the three most common for amateur use are the *UHF*, *Type N* and *BNC* families. The type of connector used for a specific job depends on the size of the cable, the frequency of operation and the power levels involved.

The so-called UHF connector is found on most HF and some VHF equipment. It is the only connector many hams will ever see on coaxial cable. PL-259 is another name for the UHF male, and the female is also known as the SO-239. These connectors are rated for full legal amateur power at HF. They are poor for UHF work because they do not present a constant impedance, so the UHF label is a misnomer. PL-259 connectors are designed to fit RG-8 and RG-11 size cable (0.405-inch OD). Adapters are available for use with smaller RG-58, RG-59 and RG-8X size cable. UHF connectors are not weatherproof.

Fig 19.16 shows how to install the solder type of PL-259 on RG-8 cable. Proper preparation of the cable end is the key to success. Follow these simple steps. Measure back about ¾-inch from the cable end and slightly score the outer jacket around its circumference. With a sharp knife, cut through the outer jacket, through the braid, and through the dielectric, right down to the center conductor. Be careful not to score the center conductor. Cutting

Type N assembly instructions

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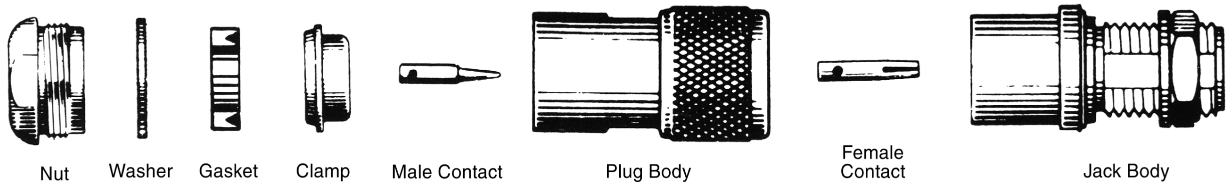
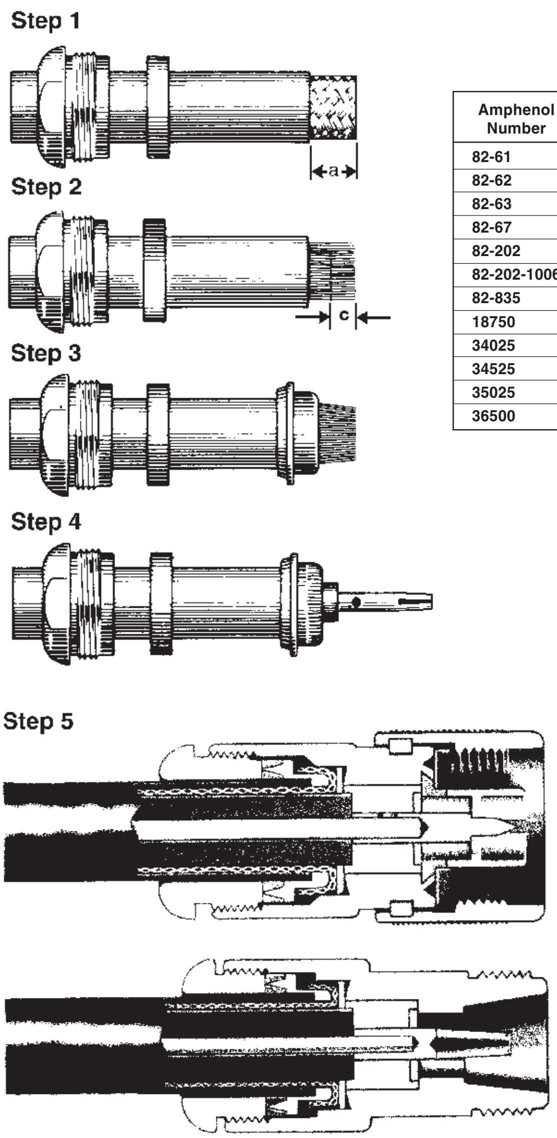
CLAMP TYPES





Amphenol Number	Connector Type	Cable RG-/U	Strip Dims., inches (mm)	
			a	c
82-61	N Plug	8, 9, 144, 165, 213, 214, 216, 225	0.359(9.1)	0.234(6.0)
82-62	N Panel Jack	8, 9, 87A, 144, 165, 213, 214, 216, 225	0.312(7.9)	0.187(4.7)
82-63	N Jack		0.281(7.1)	0.156(4.0)
82-67	N Bulkhead Jack			
82-202	N Plug	8, 9, 144, 165, 213, 214, 216, 225	0.359(9.1)	0.234(6.0)
82-202-1006	N Plug	Belden 9913	0.359(9.1)	0.234(6.0)
82-835	N Angle Plug	8, 9, 87A, 144, 165, 213, 214, 216, 225	0.281(7.1)	0.156(4.0)
18750	N Angle Plug	58, 141, 142	0.484(12.3)	0.234(5.9)
34025	N Plug		0.390(9.9)	0.203(5.2)
34525	N Plug	59, 62, 71, 140, 210	0.410(10.4)	0.230(5.8)
35025	N Jack	58, 141, 142	0.375(9.5)	0.187(4.7)
36500	N Jack	59, 62, 71, 140, 210	0.484(12.3)	0.200(5.1)

Step 1 Place nut and gasket, with "V" groove toward clamp, over cable and cut off jacket to dim. a.

Step 2 Comb out braid and fold out. Cut off cable dielectric to dim. c as shown.

Step 3 Pull braid wires forward and taper toward center conductor. Place clamp over braid and push back against cable jacket.

Step 4 Fold back braid wires as shown, trim braid to proper length and form over clamp as shown. Solder contact to center conductor.

Step 5 Insert cable and parts into connector body. Make sure sharp edge of clamp seats properly in gasket. Tighten nut.

Fig 19.19—Type N connectors are a must for high-power VHF and UHF operation. (*Courtesy Amphenol Electronic Components, RF Microwave Operations*)

through all outer layers at once keeps the braid from separating. Pull the severed outer jacket, braid and dielectric off the end of the cable as one piece. Inspect the area around the cut, looking for any strands of braid hanging loose and snip them off. There won't be any if your knife was sharp enough. Next, score the outer jacket about 5⁄16-inch back from the first cut. Cut through the jacket lightly; do not score the braid. This step takes practice. If you score the braid, start again. Remove the outer jacket.

Tin the exposed braid and center conductor, but apply the solder sparingly and avoid melting the dielectric. Slide the coupling ring onto the cable. Screw the connector body onto the cable. If you prepared the cable to the right dimensions, the center conductor will protrude through the center pin, the braid will show through the solder holes, and the body will actually thread onto the outer cable jacket.

Solder the braid through the solder

holes. Solder through all four holes; poor connection to the braid is the most common form of PL-259 failure. A good connection between connector and braid is just as important as that between the center conductor and connector. Use a large soldering iron for this job. With practice, you'll learn how much heat to use. If you use too little heat, the solder will bead up, not really flowing onto the connector body. If you use too much heat, the dielectric will melt, letting the braid and center conductor touch. Most PL-259s are nickel plated, but silver-plated connectors are much easier to solder and only slightly more expensive.

Solder the center conductor to the center pin. The solder should flow on the inside, not the outside, of the center pin. If you wait until the connector body cools off from soldering the braid, you'll have less trouble with the dielectric melting. Trim the center conductor to be even with the end of the center pin. Use a small file to round the end, removing any solder that built up on the outer surface of the center pin. Use a sharp knife, very fine sandpaper or steel wool to remove any solder flux from the outer surface of the center pin. Screw the coupling ring onto the body, and you're finished.

Fig 19.17 shows two options available if you want to use RG-58 or RG-59 size cable with PL-259 connectors. The crimp-on connectors manufactured specially for the smaller cable work very well if installed correctly. The alternative method involves using adapters for the smaller cable with standard RG-8 size PL-259s. Prepare the cable as shown. Once the braid is prepared, screw the adapter into the PL-259 shell and finish the job as you would a PL-259 on RG-8 cable.

The BNC connectors illustrated in **Fig 19.18** are popular for low power levels at VHF and UHF. They accept RG-58 and RG-59 cable, and are available for cable mounting in both male and female versions. Several different styles are available, so be sure to use the dimensions for the type you have. Follow the installation instructions carefully. If you prepare the cable to the wrong dimensions, the center pin will not seat properly with connectors of the opposite gender. Sharp scissors are a big help for trimming the braid evenly.

The Type N connector, illustrated in **Fig 19.19**, is a must for high-power VHF and UHF operation. N connectors are available in male and female versions for cable mounting and are designed for RG-8 size cable. Unlike UHF connectors, they are designed to maintain a constant impedance at cable joints. Like BNC connectors, it is important to prepare the cable to the right dimensions. The center pin must be positioned correctly to mate with the center pin of connectors of the opposite gender. Use the right dimensions for the connector style you have.

Computer Connectors

As if the array of connectors related to amateur gear were not enough, the prevalence of the computer in the shack has brought with it another set of connectors to consider. Most connections between computers and their peripherals are made with some form of multiconductor cable. Examples include shielded, unshielded and ribbon cable. Common connectors used are the 9- and 25-pin D-Subminiature connector, the DIN and Miniature DIN and the 36-pin Amphenol connector. Various edge-card connectors are used internally (and sometimes externally) on many computers. **Fig 19.20** shows a variety of computer connectors. See the **Component Data and References** chapter for other computer-connector pinout diagrams.

EIA-232 Serial Connections

The serial port on a computer is arguably the most used, and often most troublesome, connector encountered by the amateur. The serial port is used to connect modems, TNCs, computer mice and some printers to the computer. As the name implies, the data is transmitted serially.

The EIA-232-D (commonly referred to as RS-232) standard defines a system used to send data over relatively long distances. It is commonly used to send data anywhere from a few feet to 50 feet or more. The standard specifies the physical connection and signal lines. The serial ports on most computers comply with the EIA-232-D standard only to the degree necessary to operate with common peripherals. **Fig 19.21** shows the two most common connectors used for computer serial ports. A 9-pin connector can be adapted to a 25-pin by connecting like signals. Earth ground is not provided in the 9-pin version.

Equipment connected via EIA-232-D is usually classified in one of two ways: DTE (data terminal equipment) or DCE (data communication equipment). Terminals and computers are examples of DTE, while modems and TNCs are DCE.

The binary data is represented by specific voltage levels on the signal line. The EIA-232-D standard specifies that a binary one is represented by a voltage ranging from –3 to –25 V. A binary zero ranges from 3 to 25 V. ±12 V is a common level in many types of equipment, but anything within the specified ranges is just as valid.

The RTS (request to send), CTS (clear to send), DTR (data terminal ready) and DSR (data set ready) lines are used for handshaking signals. These signals are used to coordinate the communication between the DTE and DCE. The RTS and DTR line are used by the DTE to indicate to the DCE that it is ready to receive data from the DCE. The DCE uses the CTS/DSR lines to signal the DTE as to whether or not it is

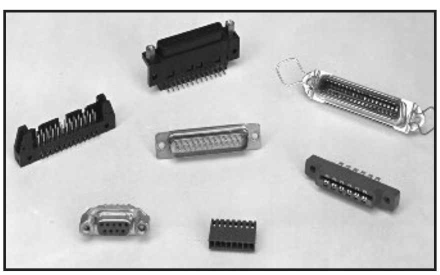
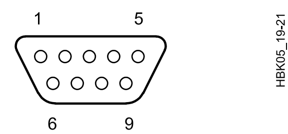
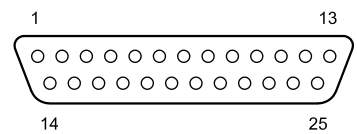


Fig 19.20—Various computer connectors.



Pin	Direction	Description
1	I	Data Carrier Detect (DCD)
2	I	Receive Data (RX)
3	O	Transmit Data (TX)
4	O	Data Terminal Ready (DTR)
5	GND	Signal Ground (GND)
6	I	Data Set Ready (DSR)
7	O	Request To Send (RTS)
8	I	Clear To Send (CTS)
9	I	Ring Indicator (RI)

(A)



Pin	Direction	Description
1	GND	Earth Ground
2	O	Transmit Data (TX)
3	I	Receive Data (RX)
4	O	Request To Send (RTS)
5	I	Clear To Send (CTS)
6	I	Data Set Ready (DSR)
7	GND	Signal Ground (GND)
8	I	Data Carrier Detect (DCD)
20	O	Data Terminal Ready (DTR)
22	I	Ring Indicator (RI)

(B)

Fig 19.21—The two most common implementations of EIA-232-D serial connections on personal computers use 9- and 25-pin connectors.

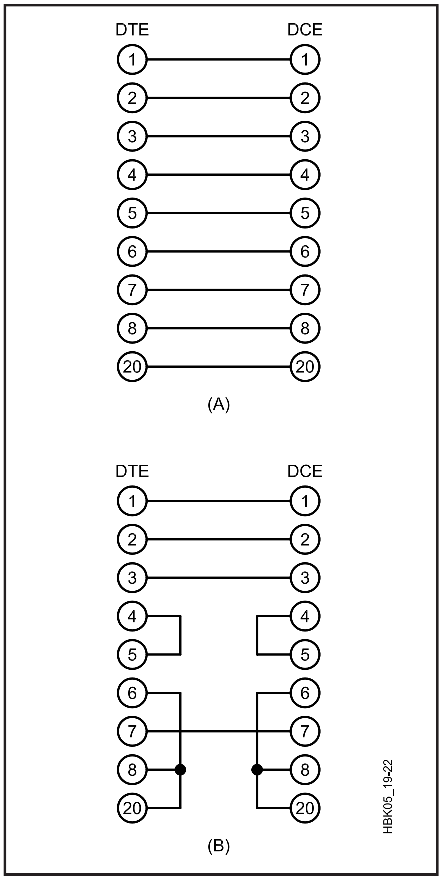


Fig 19.22—EIA-232-D serial connections for normal DTE/DCE (A) and those that ignore handshaking (B).

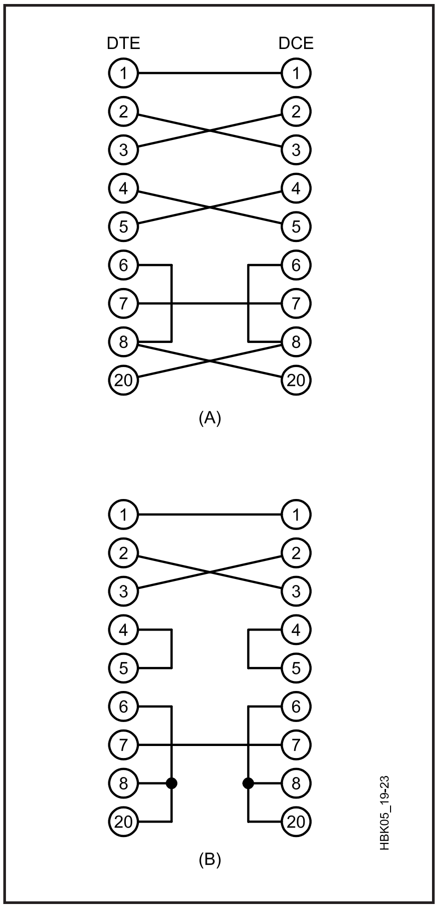


Fig 19.23—EIA-232-D null modem serial connection.

ready to accept data. DCD (data carrier detect) is also sometimes used by the DCE to signal the DTE that an active carrier is present on the communication line. A +12-V signal represents an active handshaking signal. The equipment "drops" the line to –12 V when it is unable to receive data.

You may notice that the name "ready to send" is sort of a misnomer for the DTE since it actually uses it to signal that it is ready to receive. This is a leftover from when communication was mostly one-way—DTE to DCE. Note also that the signal names really only make sense from the DTE point of view. For example, pin 2 is called TD on both sides, even though the DCE is receiving data on that pin. This is another example of this one-way terminology.

It would be much too simple if all serial devices implemented all of the EIA-232-D specifications. Some equipment ignores some or all of the handshaking signals. Other equipment expects handshaking signals to be used as specified. Connecting these two types of equipment together will result in a frustrating situation. One side will blindly send data while the other side blindly ignores all data sent to it!

Fig 19.22 shows the different possible ways to connect equipment. Fig 19.22A shows how to connect a "normal" DTE/DCE combination. This assumes both sides correctly implement all of the handshaking signals. If one or both sides ignore handshaking signals, the connections shown in Fig 19.22B will be necessary. In this scheme, each side is sending the handshaking signals to itself. This little bit of deceit will almost always work, but handshaking signals that are present will be ineffective.

Null Modem Connections

Some equipment does not fall completely in the DTE or DCE category. Some serial printers, for example, act as DCE while others act as DTE. Whenever a DTE/DTE or DCE/DCE connection is needed a special connection, known as a *null modem* connection, must be made. An example might be connecting two computers together so they can transmit data back and forth. A null modem connection simply crosses the signal and handshaking lines. **Fig 19.23** shows a normal null modem connection (A) and one for equipment that ignores handshaking (B).

Parallel Connections

Another common computer port is the parallel port. The most popular use for the parallel port by far is for printer connections. As the name implies, data is sent in a parallel fashion. There are eight data lines accompanied by a number of control and handshaking lines. A parallel printer connection typically uses a 25-pin D-Subminiature connector at the computer end and a 36-pin Amphenol connector (often called an Epson connector) on the printer.

Connecting Computers to Amateur Equipment

Most modern transceivers provide a serial connection that allows external control of the rig, typically with a computer. Commands sent over this serial control line can cause the rig to change frequency, mode and other parameters. Logging and contest software running on the computer often takes advantage of this capability.

The serial port of most radios operates with the TTL signal levels of 0 V for a binary 0 and 5 V for a binary 1. This is incompatible with the ±12 V of the serial port on the computer. For this reason, level shifting is required to connect the radio to the computer.

A couple of level shifter projects appear in the projects section at the end of this chapter. One of these two examples will work in most rig control situations, although some minor modifications may be necessary. Use the manual and technical documentation to find out what signals your radio requires and choose the circuit that fits the bill. The important factors to note are whether handshaking is implemented and what polarity the radio expects for the signals. In some cases, a 5-V level represents a logic 1 (active high) and in others a logic 0 (active low).

CSMA/CD Bus

Some equipment, notably ICOM rigs with the CI-V interface and recent Ten-Tec gear, use a CSMA/CD (carrier-sense multiple access/collision detect) bus that can interconnect a number of radios and computers simultaneously. This bus basically consists of a single wire, on which the devices transmit and receive data, and a ground wire. **Fig 19.24** illustrates the CSMA/CD scheme.

Each device connected to the bus has its own unique digital address. A radio comes from the manufacturer with a default address that can be changed if desired, usually by setting dip switches inside the

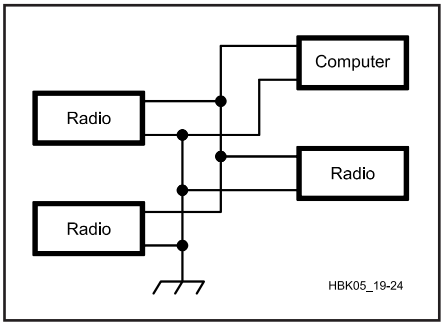


Fig 19.24—The basic two-wire bus system that ICOM and some Ten-Tec radios share among several radios and computers. In its simplest form, the network would include only one radio and one computer.

radio. Information is sent on the bus in the form of packets that include the control data and the address of the device (radio or computer) for which they are intended. A device receives every packet but only acts on the data when its address is embedded in the packet.

A device listens to the bus before transmitting to make sure it is idle. A problem occurs when both devices transmit on the bus at the same time: They both listen, hear nothing and start to send. When this happens, the packets garble each other. This is known as a collision. That is where the CSMA/CD bus collision-detection feature comes in: The devices detect the collision and each sender waits a random amount of time before resending. The sender waiting the shorter random time will get to send first.

Computer/TNC Connections

TNCs (terminal node controllers) also connect to the computer (or terminal) via the serial port. A TNC typically implements handshaking signals. Therefore, a connector like the one in Fig 19.22A will be necessary. Connectors at the TNC end vary with manufacturer. The documentation included with the TNC will provide details for hooking the TNC to the computer.

DOCUMENTING YOUR STATION

An often neglected but very important part of putting together your station is properly documenting your work. Ideally, you should diagram your entire station from the ac power lines to the antenna on paper and keep the information in a special notebook with sections for the various facets of your installation. Having the station well documented is an invaluable aid when tracking down a problem or planning a modification. Rather than having to search your memory for information on what you did a long time ago, you'll have the facts on hand.

Besides recording the interconnections and hardware around your station, you should also keep track of the performance of your equipment. Each time you install a new antenna, measure the SWR at different points in the band and make a table or plot a curve. Later, if you suspect a problem, you'll be able to look in your records and compare your SWR with the original performance.

In your shack, you can measure the power output from your transmitter(s) and amplifier(s) on each band. These measurements will be helpful if you later suspect you have a problem. If you have access to a signal generator, you can measure receiver performance for future reference.

INTERFACING HIGH-VOLTAGE EQUIPMENT TO SOLID-STATE ACCESSORIES

Many amateurs use a variety of equipment manufactured or home brewed over a considerable time period. For example, a ham might be keying a '60s-era tube rig with a recently built microcontroller-based electronic keyer. Many hams have modern solid-state radios connected to high-power vacuum-tube amplifiers.

Often, there is more involved in connecting HV (high-voltage) vacuum-tube gear to solid-state accessories than a cable and the appropriate connectors. The solid-state switching devices used in some equipment will be destroyed if used to switch the HV load of vacuum tube gear. The polarity involved is important too. Even if the voltage is low enough, a key-line might bias a solid-state device in such a way as to cause it to fail. What is needed is another form of level converter.

MOSFET Level Converters

While relays can often be rigged to interface the equipment, their noise, slow speed and external power requirement make them an unattractive solution in some cases. An alternative is to use power MOSFETs. Capable of handling substantial voltages and currents, power MOSFETs have become common design items. This has made them inexpensive and readily available.

Nearly all control signals use a common ground as one side of the control line. This leads to one of four basic level-conversion scenarios when equipment is interconnected:

1) A positive line must be actuated by a negative-only control switch.
2) A negative line must be actuated by a positive-only control switch.

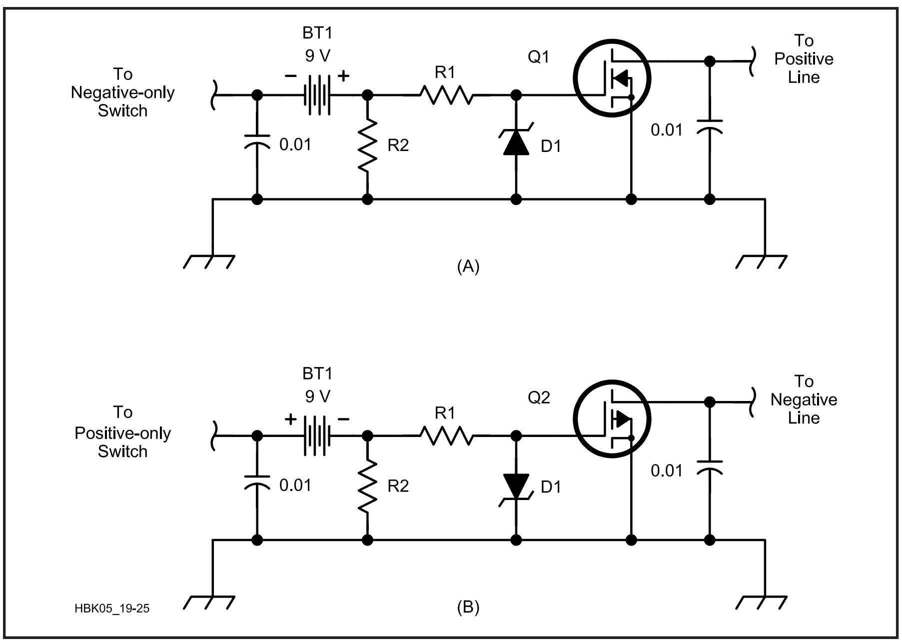


Fig 19.25—Level-shifter circuits for opposite input and output polarities. At A, from a negative-only switch to a positive line; B, from a positive-only switch to a negative line.

BT1—9-V transistor-radio battery.
D1—15-V, 1-W Zener diode (1N4744 or equiv).
Q1—IRF620.
Q2—IRF220 (see text).
R1—100 Ω, 10%, ¼ W.
R2—10 kΩ, 10%, ¼ W.

3) A positive line must be actuated by a positive-only control switch.
4) A negative line must be actuated by a negative-only control switch.

In cases 3 and 4 the polarity is not the problem. These situations become important when the control-switching device is incapable of handling the required open-circuit voltage or closed-circuit current.

Case 1 can be handled by the circuit in **Fig 19.25A**. This circuit is ideal for interfacing keyers designed for grid-block keying to positive CW key lines. A circuit suitable for case 2 is shown in Fig 19.25B. This circuit is simply the mirror image of that in Fig 19.25A with respect to circuit polarity. Here, a P-channel device is used to actuate the negative line from a positive-only control switch.

Cases 3 and 4 require the addition of an inverter, as shown in **Fig 19.26**. The inverter provides the logic reversal needed to drive the gate of the MOSFET high, activating the control line, when the control switch shorts the input to ground.

Almost any power MOSFET can be used in the level converters, provided the voltage and current ratings are sufficient to handle the signal levels to be switched. A wide variety of suitable devices is available from most large mail-order supply houses.

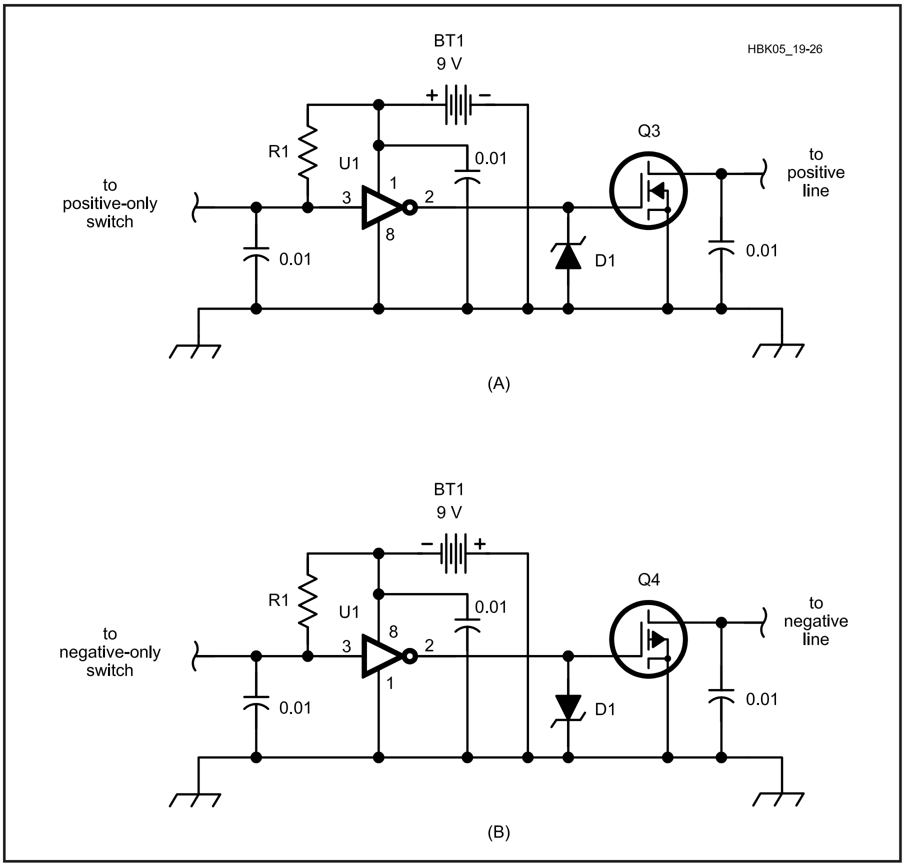


Fig 19.26—Circuits for same-polarity level shifters. At A, for positive-only switches and lines; B, for negative-only switches and lines.

BT1—9-V transistor-radio battery.
D1—15-V, 1-W Zener diode (1N4744 or equiv).
Q3—IRF620.
Q4—IRF220 (see text).
R1—10 kΩ, 10%, ¼ W.
U1—CD4049 CMOS inverting hex buffer, one section used (unused sections not shown; pins 5, 7, 9, 11 and 14 tied to ground).

Mobile and Portable Installations

Time and again, radio amateurs have been pressed into service in times of need. New developments outside of Amateur Radio (cellular phones, for example) often bring with them predictions that amateurs will no longer be needed to provide emergency communications. Just as often, a disaster proves beyond doubt the falseness of that exclamation. When the call for emergency communication is voiced by government and disaster relief organizations, mobile and portable equipment is pressed into service where needed. In addition to the occasional emergency or disaster type of communications, mobile and portable operation under normal conditions can challenge and reward the amateur operator.

Most mobile operation today is carried out by means of narrow-band repeaters. Major repeater frequencies reside in the 146 and 440-MHz bands. As these bands become increasingly congested, the 222 and 1240-MHz bands are being used for this reliable service mode as well. Many amateurs also enjoy mobile and portable HF operation because of the challenge and possibilities of worldwide communication.

MOBILE STATIONS

Installation and setup of mobile equipment can be considerably more challenging than for a fixed station. Tight quarters, limited placement options and harsher environments require innovation and attention to detail for a successful installation. The equipment should be placed so that operation will not interfere with driving. Driving safely is always the primary consideration; operating radio equipment is secondary. See **Fig 19.27** for one neat solution. If your vehicle has an airbag, be sure it can deploy unimpeded.

Mobile operation is not confined to lower power levels than in fixed stations. Many modern VHF FM transceivers are capable of 25 to 50 W of output. Compact HF rigs usually have outputs in the 100-W range and run directly from the 13.6-V supply.

If a piece of equipment will draw more than a few amps, it is best to run a heavy cable directly to the battery. Few circuits in an automobile electrical system can safely carry the more than 20 A required for a 100-W HF transceiver. Check the table in the **Component Data and References** chapter to verify the current-handling capabilities of various gauges of wire and cable. Adequate and well-placed fuses are necessary to prevent fire hazards. For maximum safety, fuse both the hot and ground lines near the battery. Automobile fires are costly and dangerous.

The limited space available makes antennas for mobile operation quite different than those for fixed stations. This is especially true for HF antennas. The **Antennas** chapter contains information for building and using mobile antennas.

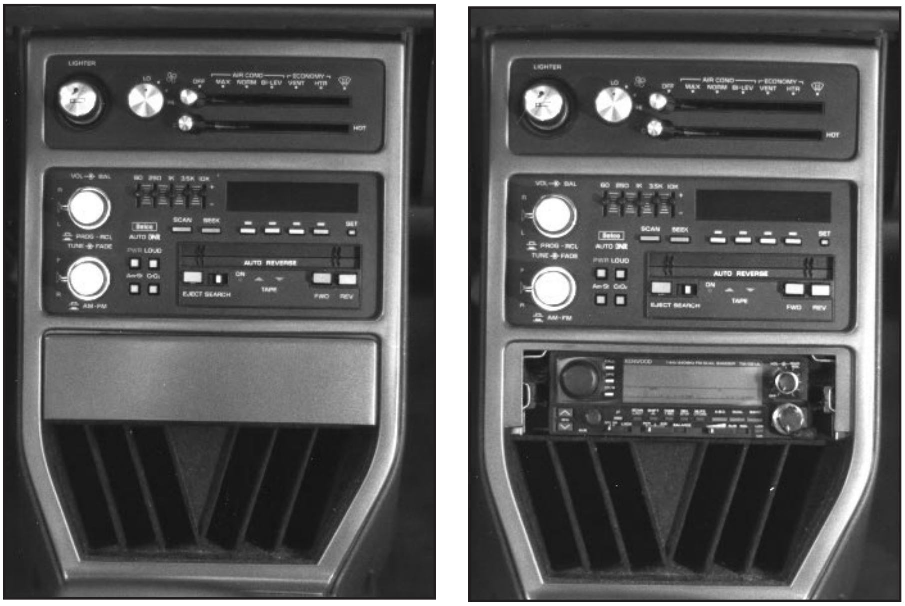


Fig 19.27—N8KDY removed the ashtray for his mobile installation. The old faceplate for the ashtray is used as a cover for the rig when not in use. This may help reduce the temptation for would-be thieves. (*Photo courtesy AA8DX*)

Interference

In the past, interference in mobile installations almost always concerned interference to the radio equipment. Examples include ignition noise and charging-system noise. Modern automobiles—packed with arrays of sensors and one or more on-board computers—have made interference a two-way street. The original type of interference (to the radio) has also increased with the proliferation of these devices. An entire chapter in the *ARRL RFI Book* is devoted to ways to prevent and cure this problem.

PORTABLE STATIONS

Many amateurs experience the joys of portable operation once each year in the annual emergency exercise known as Field Day. Setting up an effective portable station requires organization, planning and some experience. For example, some knowledge of propagation is essential to picking the right band or bands for the intended communications link(s). Portable operation is difficult enough without dragging along excess equipment and antennas that will never be used.

Some problems encountered in portable operation that are not normally experienced in fixed-station operation include finding an appropriate power source and erecting an effective antenna. The equipment used should be as compact and lightweight as possible. A good portable setup is simple. Although you may bring gobs of gear to Field Day and set it up the day before, during a real emergency speed is of the essence. The less equipment to set up, the faster it will be operational.

Portable AC Power Sources

There are two popular sources of ac power for use in the field. One is referred to as a dc-to-ac converter, or more commonly, an *inverter*. The ac output of an inverter is a square wave. Therefore, some types of equipment cannot be operated from the inverter. Certain types of motors are among those devices that require a sine-wave output. **Fig 19.28** shows a typical commercial inverter. This model delivers 120 V of ac at 175 W continuous power rating. It requires 6 or 12 V dc input.

Besides having a square-wave output, inverters have some other traits that make them less than desirable for field use. Commonly available models do not provide a great deal of power. The 175-W model shown in Fig 19.28 could barely power a few light bulbs, let alone a number of transceivers. Higher-power models are available but are quite expensive. Another problem is that the batteries supplying the inverter with primary power are discharged as power is drawn from the inverter.

Popularity and a number of competing manufacturers have caused gasoline generators to come down considerably in price. For a reliable, adequate source of ac (with sine-wave output), the gasoline-engine-driven generator is the best choice. (While still referred to as generators, practically all modern units actually use alternators to generate ac power.) Generators have become smaller and lighter as manufacturers have used aluminum and other lightweight materials in their construction. **Fig 19.29** shows the type of generator often used during Field Day.

Generators in the 3 to 5-kW range are easily handled by two people and can provide power for a relatively large mult-ioperator field site. Most generators provide 12 V dc output in addition to 120/240 V ac.

Generator Maintenance

Proper maintenance is necessary to obtain rated output and a decent service life from a gasoline generator. A number of simple measures will prolong the life of the equipment and help maintain reliability.

It is a good idea to log the dates the unit is used and the operating time in hours. Many generators have hour-meters to make this simple. Include dates of maintenance and the type of service performed. The manufacturer's manual should be the

Fig 19.28—Photograph of a commercial dc-to-ac inverter that operates from 6 to 12 V dc and delivers 120 V ac (square wave) at 175 W.

Fig 19.29—Modern gasoline engine-powered generators offer considerable ac power output in a relatively compact and lightweight package.

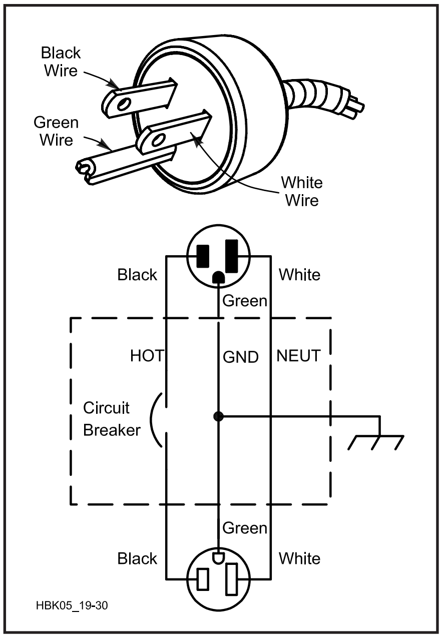


Fig 19.30—A simple accessory that provides overload protection for generators that do not have such provisions built in.

primary source of maintenance information and the final word on operating procedures and safety. The manual should be thoroughly covered by all persons who will operate and maintain the unit.

Particular attention should be paid to fuel quality and lubricating oil. A typical gasoline generator is often used at or near its rated capacity. The engine driving the alternator is under a heavy load that varies with the operation of connected electrical equipment. For these reasons, the demands on the lubricating oil are usually greater than for most gasoline-engine powered equipment such as lawn mowers, tractors and even automobiles. Only the grades and types of oil specified in the manual should be used. The oil should be changed at the specified intervals usually given as a number of operating hours.

Fuel should be clean, fresh and of good quality. Many problems with gasoline generators are caused by fuel problems. Examples include dirt or water in the fuel and old, stale fuel. Gasoline stored for any length of time changes as the more volatile components evaporate. This leaves excess amounts of varnish-like substances that will clog carburetor passages. If the generator will be stored for a long period, it is a good idea to run it until all of the fuel is burned. Another option is the use of fuel stabilizers added to the gasoline before storage.

Spark plugs should be changed as specified. Faulty spark plugs are a common cause of ignition problems. A couple of spare spark plugs should always be kept with the unit, along with tools needed to change them. Always use the type of spark plug recommended by the manufacturer.

Generator Ground

A proper ground for the generator is absolutely necessary for both safety reasons and to ensure proper operation of equipment powered from the unit. Most generators are supplied with a three-wire outlet, and the ground should connect to the plug as shown in **Fig 19.30**. Some generators require that the frame be grounded also. An adequate pipe or rod should be driven into the ground near the generator and connected to the provided clamp or lug. If no connection is provided, a clamp can be used to connect the ground lead to the frame of the generator. As always, follow the manufacturer's recommendations.

Portable Antennas

An effective antenna system is essential to all types of operation. Effective portable antennas, however, are more difficult to devise than their fixed-station counterparts. A portable antenna must be light, compact and easy to assemble. It is also important to remember that the portable antenna may be erected at a variety of sites, not all of which will offer ready-

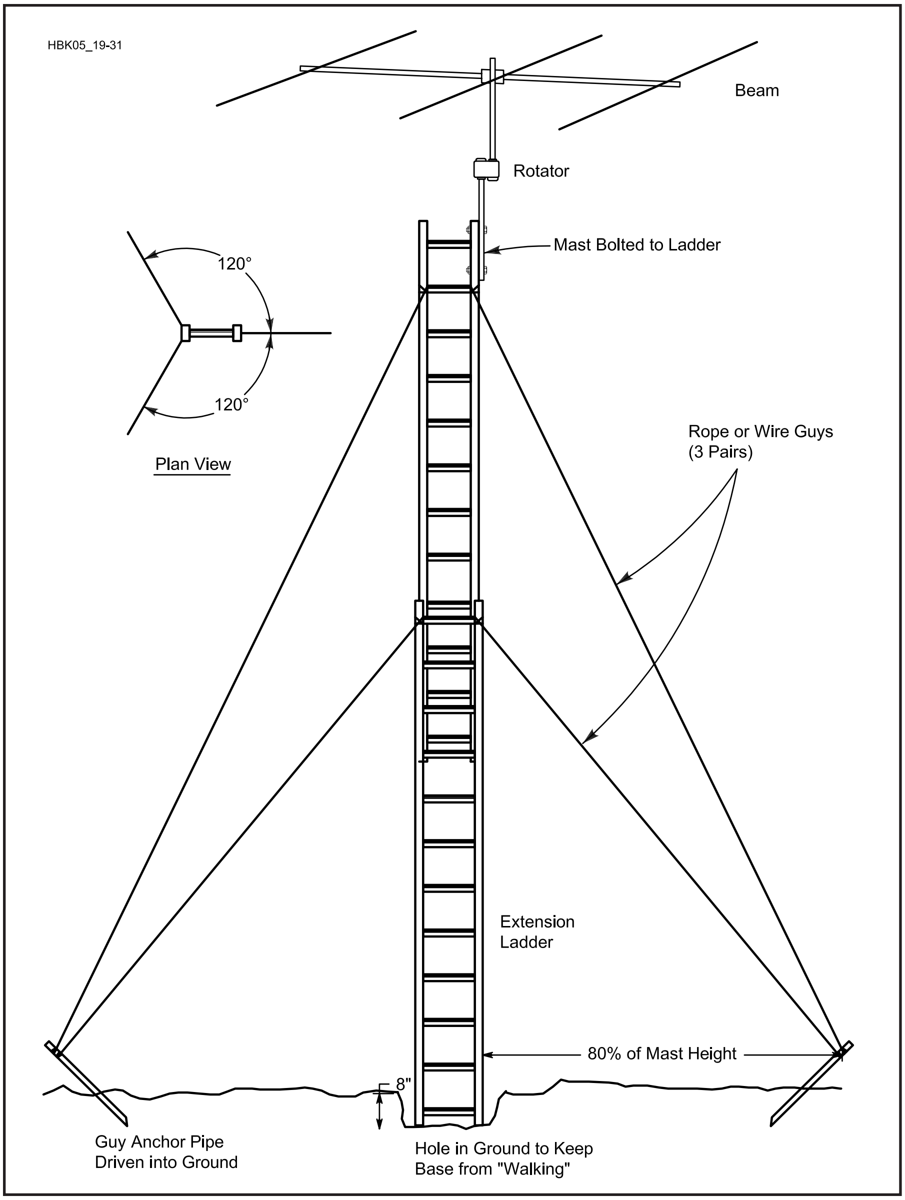


Fig 19.31—An aluminum extension ladder makes a simple but sturdy portable antenna support. Attach the antenna and feed lines to the top ladder section while it is nested and laying on the ground. Push the ladder vertical, attach the bottom guys and extend the ladder. Attach the top guys. Do not attempt to climb this type of antenna support.

made supports. Strive for the best antenna system possible because operations in the field are often restricted to low power by power supply and equipment considerations. Some antennas suitable for portable operation are described in the **Antennas** chapter.

(A)

(B)

Fig 19.32—The portable tower mounting system by WA7LYI. At A, a truck is "parked" on the homemade base plate to weigh it down. At B, the antennas, mast and rotator are mounted before the tower is pushed up. Do not attempt to climb a temporary tower installation.

Antenna Supports

While some amateurs have access to a truck or trailer with a portable tower, most are limited to what nature supplies, along with simple push-up masts. Select a portable site that is as high and clear as possible. Elevation is especially important if your operation involves VHF. Trees, buildings, flagpoles, telephone poles and the like can be pressed into service to support wire antennas. Drooping dipoles are often chosen over horizontal dipoles because they require only one support.

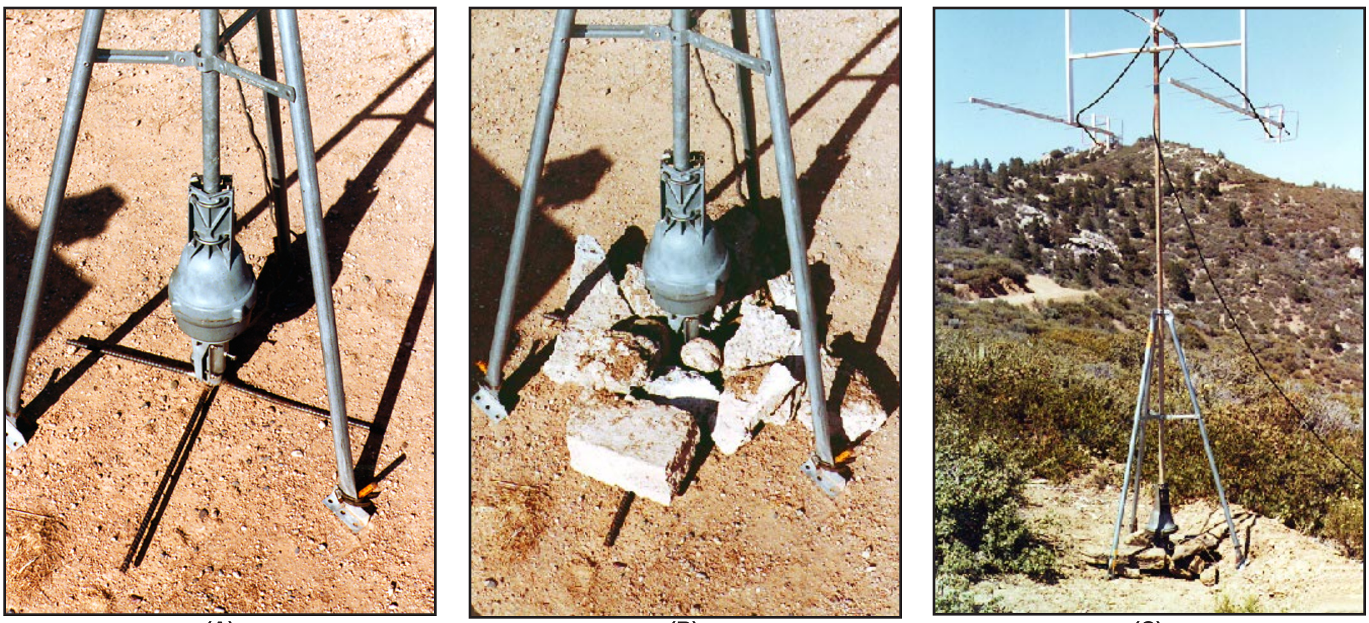
An aluminum extension ladder makes an effective antenna support, as shown in **Fig 19.31**. In this installation, a mast, rotator and beam are attached to the top of the second ladder section with the ladder near the ground. The ladder is then pushed vertical and the lower set of guy wires attached to the guy anchors. When the first set of guy wires is secured, the ladder may be extended and the top guy wires attached to the anchors. Do not attempt to climb a guyed ladder.

Figs 19.32 and **19.33** illustrate two methods for mounting portable antennas described by Terry Wilkinson, WA7LYI. Although the antennas shown are used for VHF work, the same principles can be applied to small HF beams as well.

In Fig 19.32A, a 3-ft section of Rohn 25 tower is welded to a pair of large hinges, which in turn are welded to a steel plate measuring approximately 18×30 inches. One of the rear wheels of a pickup truck is "parked" on the plate, ensuring that it will not move. In Fig 19.32B, quad array antennas for 144 and 222 MHz are mounted on a Rohn 25 top section, complete with rotator and feed lines. The tower is then pushed up into place using the hinges, and guy ropes anchored to heavy-duty stakes driven into the ground complete the installation. This method of portable tower installation offers an exceptionally easy-to-erect, yet sturdy, antenna support. Towers installed in this manner may be 30 or 40 ft high; the limiting factor is the number of "pushers" and "rope pullers" needed to get into the air. A portable station located in the bed of the pickup truck completes the installation.

The second method of mounting portable beams described by WA7LYI is shown in Fig 19.33. This support is intended for use with small or medium-sized VHF and UHF arrays. The tripod is available from any dealer selling television antennas; tripods of this type are usually mounted on the roof of a house. Open the tripod to its full size and drive a pipe into the ground at each leg. Use a hose clamp or small U-bolt to anchor each leg to its pipe.

The rotator mount is made from a 6-inch-long section of 1½-inch-diameter pipe welded to the center of an "X" made from two 2-ft-long pieces of concrete reinforcing rod (rebar). The rotator clamps onto the pipe, and the whole assembly is placed in the center of the tripod. Large rocks placed on the rebar hold the rotator in place, and the antennas are mounted on



(A) (B) (C)

Fig 19.33—The portable mast and tripod by WA7LYI. At A, the tripod is clamped to stakes driven into the ground. The rotator is attached to a homemade pipe mount. At B, rocks piled on the rotator must keep the rotator from twisting and add weight to stabilize the mast. At C, a 10-ft mast is inserted into the tripod/rotator base assembly. Four 432-MHz Quagis are mounted at the top.

a 10 or 15-ft mast section. This system is easy to make and set up.

Tips for Portable Antennas

Any of the antennas described in the **Antennas** chapter or available from commercial manufacturers may be used for portable operation. Generally, though, big or heavy antennas should be passed over in favor of smaller arrays. The couple of decibels of gain a 5-element, 20-m beam may have over a 3-element version is insignificant compared to the mechanical considerations. Stick with arrays of reasonable size that are easily assembled.

Wire antennas should be cut to size and tuned prior to their use in the field. Be careful when coiling these antennas for transport, or you may end up with a tangled mess when you need an antenna in a hurry. The coaxial cable should be attached to the center insulator with a connector for speed in assembly. Use RG-58 for the low bands and RG-8X for higher-band antennas. Although these cables exhibit higher loss than standard RG-8, they are far more compact and weigh much less for a given length.

Beam antennas should be assembled and tested before taking them afield. Break the beam into as few pieces as necessary for transportation and mark each joint for speed in reassembly. Hex nuts can be replaced with wing nuts to reduce the number of tools necessary.

Ground Rod Installation

A large sledgehammer, a small stepladder and a lot of elbow grease. That's the usual formula for driving in an 8-foot ground rod. Michael Goins, WB5YKX, reports success using fluid hydraulics to ease the task in very dense clay soil.

He suggests digging a small hole, about a foot deep, just enough to hold a few gallons of water. When the hole is complete, pour water into the hole, and then push the ground rod in as far as it will go. Next, pull it out completely. Some of the water will run into the smaller hole made by the ground rod.

Repeat the process, allowing water to run into the small hole each time you remove the rod. Continue pushing and removing until the rod is sunk as far as you want. About 6 inches of rod above the ground is usually enough to allow convenient connection of bonding clamps.

THE TICK-4 — A TINY CMOS KEYER

TiCK stands for "Tiny CMOS Keyer" and this is the fourth version of the chip. It is based on an 8-pin DIP microcontroller from Microchip Corporation, the PIC12CE674. This IC is a perfect candidate for all sorts of Amateur Radio applications because of its small size and high performance capabilities. This project originally used the TiCK-2 chip (based on the PIC12C509) and was described fully in Oct 1997 *QST* by Gary M. Diana, Sr, N2JGU, and Bradley S. Mitchell, WB8YGG. The keyer has the following features:

- Mode A and B iambic keying.
- Low current requirement to support portable use.
- Low parts count consistent with a goal for small physical size.
- Simple rig and user interfaces. The operator shouldn't need a manual and the rig interface should be paddles in, key line out.
- An audible sidetone for user-feedback functions and to support transceivers without a built-in sidetone.
- Paddle select, allowing the operator to swap the dot and dash paddles without having to rewire the keyer (or flip the paddles upside down!).
- Manual keying to permit interfacing a straight key (or external keyer) to the TiCK.

New for the TiCK-4 version are:

- Two 50-character message memories (up from one).
- Remembers operating parameters (but not message memories) when power is removed.

Design

Fig 19.34 shows the schematic for the keyer. The PIC12CE674 has 3.6 kbytes of program read-only memory (ROM) and 128 bytes of random-access memory (RAM). This means that all the keyer *functions* have

Table 19.1
TiCK-4 User Interface Description

Action	*TiCK-4 Response*	*Function*
Press pushbutton briefly	none	Memory #1 playback.
Hold pushbutton down	E (dit)	Memory #2 playback.
Hold pushbutton down	S (dit-dit-dit)	Speed adjust: Press dit to decrease, dah to increase speed.
Hold pushbutton down	T (dah)	Tune: To unkey rig, press either paddle or pushbutton.
Hold pushbutton down	A (dit-dah)	ADMIN mode: Allows access to various TiCK IC setup parameters.
Press pushbutton briefly	I (dit-dit)	Input mode: Allows the user to enter message input mode.
Hold pushbutton down	1 (dit-dah-dah-dah-dah)	Message #1 input. Send message with paddle and push button momentarily when complete.
Hold pushbutton down	2 (dit-dit-dah-dah-dah)	Message #2 input. Send message with paddle and push button momentarily when complete.
Hold pushbutton down	P (dit-dah-dah-dit)	Paddle select: Press paddle desired to designate as dit paddle.
Hold pushbutton down	A (dit-dah)	Audio select: Press dit to enable sidetone, dah to disable. Default: enabled.
Hold pushbutton down	SK (dit-dit-dit dah-dit-dah)	Straight key select: Pressing either paddle toggles the TiCK to/from straight key/keyer mode. Default: keyer mode.
Hold pushbutton down	M (dah-dah)	Mode select: Pressing the dit paddle puts the TiCK into iambic mode A; dah selects iambic mode B (the default).
Hold pushbutton down	B (dah-dit-dit-dit)	Beacon mode: Pressing either paddle toggles the TiCK to/from Beacon/No-Beacon mode. Default: No-Beacon mode.
Hold pushbutton down	K (dah-dit-dah)	Keyer mode: If pushbutton is released, the keyer returns to normal operation.
Hold pushbutton down	S (dit-dit-dit)	Cycle repeats starting with Memory playback, Speed adjust, etc.

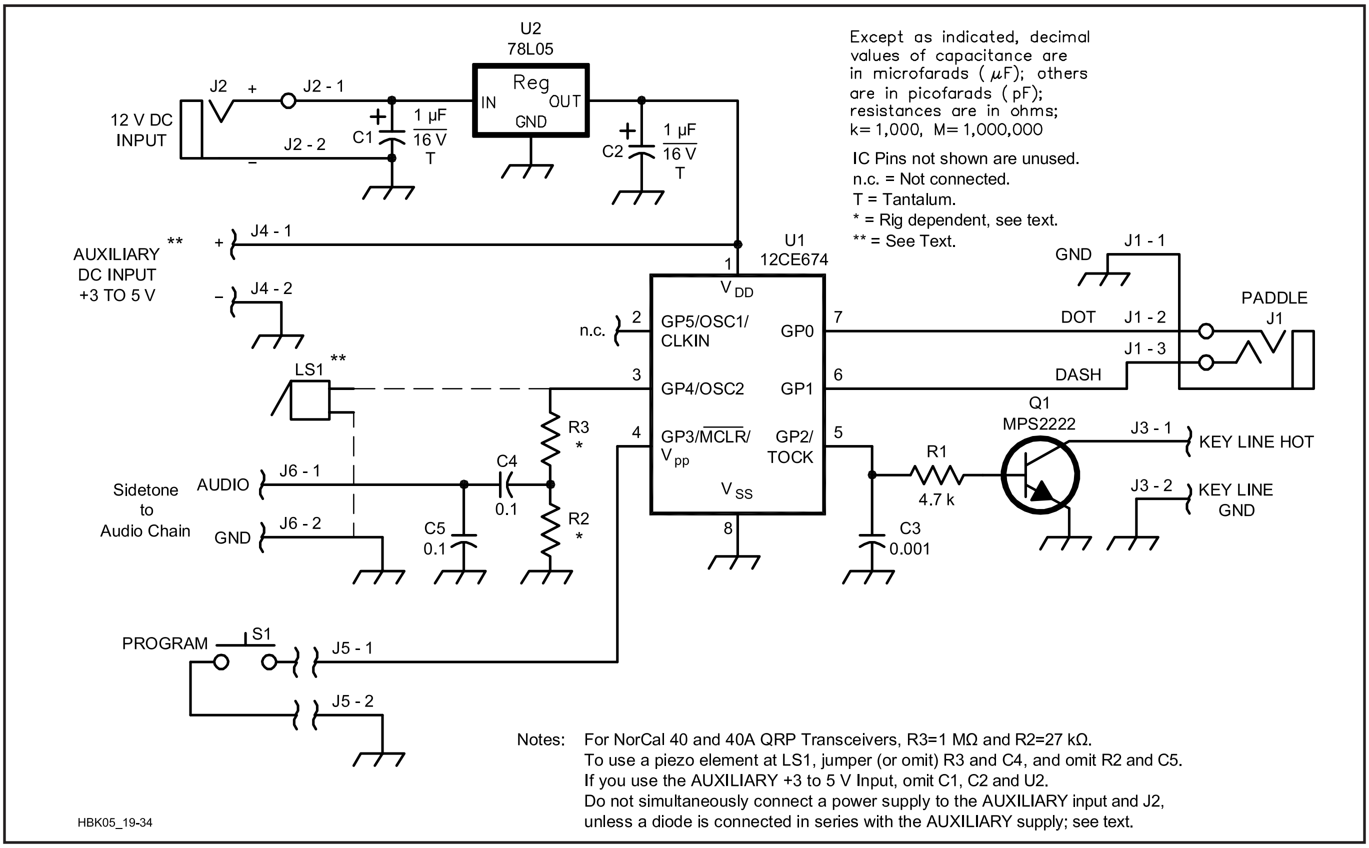


Fig 19.34 — Schematic of the TiCK-4 keyer. Equivalent parts can be substituted. Unless otherwise specified, resistors are ¼ W, 5%-tolerance carbon film units. The PIC12CE674 IC must be programmed before use; see the parts list for U1. RS part numbers in parentheses are RadioShack; M = Mouser (Mouser Electronics). Use the *TIS Find* program for address information for all suppliers mentioned. Kits are available from Kanga US (www.kangaus.com).

C1, C2 — 1 µF, 16 V (or higher) tantalum (RS 272-1434; M 581-TAP105K035SCS).
J1 — 3-circuit jack (RS 274-249; M 161-3402).
J2 — 2-circuit jack (RS 274-251) or coaxial (RS 274-1563 or 274-1576).
J3 — 2-circuit jack (RS 274-251; M 16PJ135).
LS1 — Optional piezo element (RS 273-073).
Q1 — MPS2222A, 2N2222, PN2222, NPN (RS 276-2009; M 610-PN2222A).
S1 — Normally open momentary contact pushbutton (RS 275-1571).
U1 — Programmed PIC12CE674, available from Kanga US. Programmed ICs and data sheets are available, as are kits with the PC board and other parts. Source code is not available.
U2 — 78L05 5 V, 100 mA regulator (M 512-LM78L05ACZ) or LP2950CZ-5.0 low quiescent current regulator (Digi-Key LP2950CZ-5.0NS-ND).
Misc: PC board, 8-pin DIP socket, hardware, wire (use stranded #22 to #28).

to fit within the ROM. The keyer *settings* such as speed, paddle selection, iambic mode and sidetone enable are stored in RAM. Unlike the previous TiCK keyers, this microcontroller also includes EEPROM memory that's used to store these operating parameters. So you can power the chip off, and upon power-up it will remember the last stored values for the settings.

A PIC12CE674 has eight pins. Two pins are needed for the dc input and ground connections. The IC requires a clock signal. Several clock-source options are available. You can use a crystal, RC (resistor and capacitor) circuit, resonator, or the IC's internal oscillator. The authors chose the internal 4-MHz oscillator to reduce the external parts count. Two I/O lines are used for the paddle input. One output feeds the key line, another output is required for the audio feedback (sidetone) and a third I/O line is assigned to a pushbutton.

User Interface

Using the two paddles and a pushbutton, you can access all of the TiCK's functions. Certain user-interface functions need to be more easily accessible than others; a prioritized list of functions (from most to least accessible) is presented in **Table 19.1**.

The TiCK employs a *single button interface* (SBI). This simplifies the TiCK PC board, minimizes the part count and makes for ease of use. Most other electronic keyers have multibutton user interfaces, which, if used infrequently, make it difficult to remember the commands. Here, a single button push takes you through the functions, one at a time, at a comfortable pace (based on the current speed of the keyer). Once the code for the desired function is heard, you simply let up on the button. The TiCK then executes the appropriate function, and/or waits for the appropriate input, either from the paddles or the pushbutton itself, depending on the function in question. Once the function is complete, the TiCK goes back into keyer mode, ready to send code through the key line.

The TiCK-4 IC generates a sidetone signal that can be connected to a piezoelectric element or fed to the audio chain of a transceiver. The latter option is rig-specific, but can be handled by more experienced builders.

The TiCK Likes to Sleep

To meet the low-current requirement, the authors took advantage of the PIC12CE674's ability to *sleep*. In sleep mode, the processor shuts down and waits for input from either of the two paddles. While sleeping, the TiCK consumes about 1 µA. The TiCK doesn't wait long to go to sleep either: As soon as there is no in-

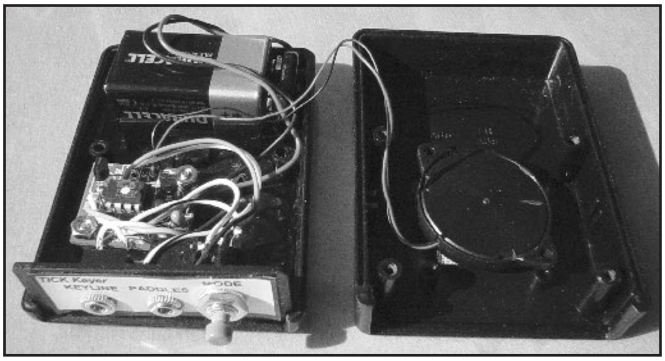


Fig 19.35A — Here's the completed TiCK-4 keyer complete with battery, mounted in a small case. (Photos courtesy Bill Kelsey, N8ET.)

Fig 19.35B — The enhanced EMB version of the TiCK-4 includes a low-current regulator, battery backup and board-mounted jacks and switches.

put from the paddles, it's snoozing! This feature should be especially attractive to amateurs who want to use the TiCK in a portable station.

Assembling the TiCK

The TiCK-4's PC board size (1×1.2 inches) supports its use as an embedded and stand-alone keyer. See **Fig 19.35A**. The PC board has two dc input ports, one at J2 for 7 to 25 V and another (J4, AUXILIARY) for 2.5 to 5.5 V. The input at J2 is routed to an on-board 5-V regulator (U2), while the AUXILIARY input feeds the TiCK directly. When making the dc connections, observe proper polarity: There is no built-in reverse-voltage protection at either dc input port.

The voltage regulator's bias current is quite high and will drain a 9 V battery quickly, even though the TiCK itself draws very little current. For this reason, the "most QRP way" to go may be to power the chip via the AUXILIARY power input and omit U2, C1 and C2. Another alternative is use of a low quiescent current 5 V regulator, such as the LP2950CZ-5.0, for U2.

When using the AUXILIARY dc input port, or if *both* dc inputs are used, connect a diode between the power source and the AUXILIARY power input pin, attaching the diode anode to the power source and the cathode to the AUXILIARY power input pin. This provides IC and battery protection and can also be used to deliver battery backup for your keyer settings.

Sidetone

A piezo audio transducer can be wired directly to the TiCK-4's audio output. Pads and board space are available for voltage-divider components. This eliminates the need to interface the TiCK with a transceiver's audio chain. Use a piezo *element*, not a piezo *buzzer*. A piezo buzzer contains an internal oscillator and requires only a dc voltage to generate the sound, whereas a piezo element requires an external oscillator signal (available at pin 3 of U1).

If you choose to embed the keyer in a rig and want to hear the keyer's sidetone instead of the rig's sidetone, you may choose to add R2, R3, C4 and C5. Typically R3 should be 1 MΩ to limit current. R2's value is dictated by the amount of drive required. A value of 27 kΩ is a good start. C4 and C5 values of 0.1 µF work quite well. C4 and C5 soften the square wave and capacitively couple J6-1 to the square-wave output of pin 3. Decreasing the value of R2 decreases the amount of drive voltage, especially below 5 kΩ. Use a 20 kΩ to 30 kΩ trimmer potentiometer at R2 when experimenting.

In Use

To avoid RF pickup, keep all leads to and from the TiCK as short as possible. The authors tested the TiCK in a variety of RF environments and found it to be relatively immune to RF. Make sure your radio gear is well grounded and avoid situations that cause an RF-hot shack.

The TiCK keys low-voltage positive lines, common in today's solid-state rigs. Don't try to directly key a tube rig because you will likely — at a minimum — ruin output transistor Q1.

To use the TiCK as a code-practice oscillator, connect a piezo element to the audio output at pin 3. If more volume is needed, use an audio amplifier, such as RadioShack's 277-1008.

The higher the power-supply voltage (within the specified limits), the greater the piezo element's volume. Use 5 V (as opposed to 3 V) if more volume is desired. Also, try experimenting with the location of the piezo element to determine the proper mounting for maximum volume.

Several Versions

The TiCK keyer has been around for more than 10 years. The TiCK-4 is a direct plug-in replacement for the TiCK-1 and TiCK-2, so if you have built a keyer with an earlier version, you can upgrade to the TiCK-4 and gain the two memories and nonvolatile parameter memory features. The TiCK-3 is a surface-mount version with limited availability. An enhanced version, the TiCK-EMB-4, includes RF/static protection, low quiescent current regulator, battery backup and board-mounted jacks and switches. See **Fig 19.35B**.

THE ID-O-MATIC

Would you rather not watch the clock when engaged in a QSO? Repeaters usually have an automatic 10-minute ID to remind you when it's time to identify your station, but on HF and simplex it's more of a problem. Dale Botkin, NØXAS, set out to design a simple 10-minute ID timer with a reminder beep and some sort of visual indicator, something along the lines of the ID timer portion of the old Heathkit SB-630. Along the way he added a few features to make the timer more useful, and as sometimes happens, things just kind of snowballed from there. The ID-O-Matic described here and shown in **Fig 19.36** is an automatic ID timer/annunciator with a rich set of features that make it useful for many applications.

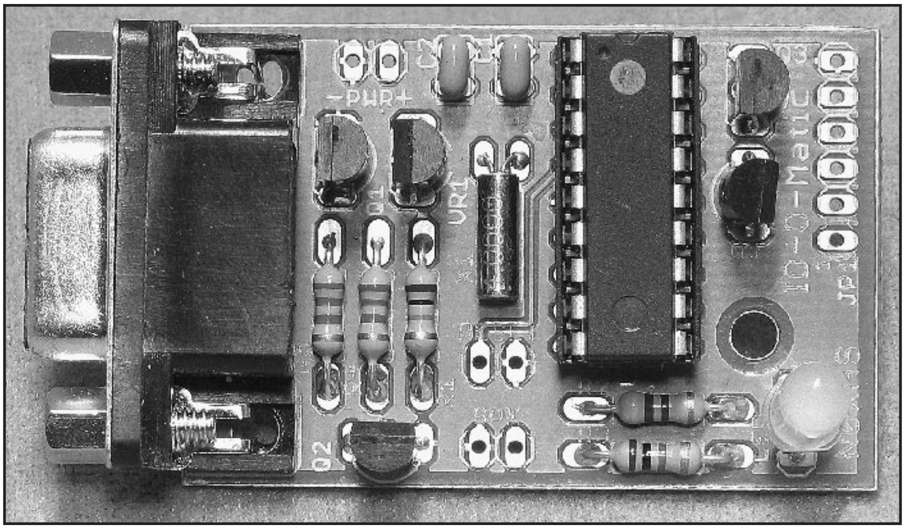


Fig 19.36 — This version of the ID-O-Matic is built from a kit offered by www.hamgadgets.com. The parts count is low, and it can easily be built on a prototype board.

FEATURE HIGHLIGHTS

There's an old saying that goes, "When all you have is a hammer, everything looks like a nail." While the author has a pretty well stocked junk box, he never liked building 555 timers and the like. He tends to use whatever is handy and can cobble together with an absolute minimum of parts, and likes to be able to make changes or add features later on. That often means writing firmware for a PIC microcontroller, and this time was no exception.

The basic device uses a single PIC 16F648A processor selected for its memory capacity, internal oscillator, hardware USART and other features. All features are implemented in program code, with just enough external hardware to provide a useful interface to the user. Audio and visual output is used to indicate the end of the time period, and one user control is all that is required other than a power switch.

Let's take a quick look first at the basic features. In its most basic timer mode, a single pushbutton is used to start the timing cycle by resetting the PIC. This starts a 10-minute timer running and lights the green section of a red-green dual color LED. The LED remains green until 60 seconds before the set period expires. With less than 60 seconds remaining, the LED turns yellow; this is accomplished by illuminating both the green and red halves. At 30 seconds the LED begins to blink, alternating between yellow and red. When the time period expires, the LED turns red and the timer starts beeping until you reset it with a pushbutton switch. Now the cycle starts again, ready to remind you in another 10 minutes.

So far so good, but using a PIC like this is a little bit of overkill. Of course no good project is complete until "feature creep" sets in! With the timing and audio portions of the program done, some other features were pretty simple to add. What if you want to ID at some other interval instead of 10 minutes, or have the device automatically ID in Morse code? What if you want to use it for a beacon or a repeater ID device? How about CW and PTT keying outputs for a fox hunt beacon?

Eventually the firmware evolved to have a fairly robust set of features. There is a serial interface for setup using a computer or terminal. You can set the timeout period anywhere from 1 to 32,767 seconds. You can set select a simple beeping alert, or set a Morse ID message with up to 60 characters. For repeater and fox hunt use, there are outputs for PTT and CW keying just in case they might be needed, as well as a couple of inputs intended for COR or squelch inputs if the chip is used in repeater mode. We'll cover all of that in a bit; first, let's look at the basic functions and the hardware design.

CIRCUIT DESIGN

As shown in **Fig 19.37**, the hardware is quite simple. In its basic form all you need is the PIC, a red and green dual-color LED, and a few other parts as seen in the schematic. Supply voltage can be 3 to 5.5 V, so you can use three AA alkaline cells. You can also add a 5 V regulator, allowing the use of a 12 V power supply. Despite their size, 9 V batteries have surprisingly low capacity and will only last a few days of continuous use in a project like this.

R1 is a pull-up resistor whose value is not critical; 10 kΩ is a good value. Its function is to hold the !RESET line high until S1 is pressed. R2 and R3 set the current for the red and green sections of the dual LED. They are different values because the red section of the LED is usually substantially brighter than the green. R4 pulls the serial RxD line high when no serial connection is present. For use in the shack to remind you to ID every 10 minutes, that's all you need.

The original prototype fits in a Pac-Tec enclosure model HMW-ET. For audio output, try a tiny Soberton GT-111P speaker. About the size of a small piezo element at 12 mm diameter and about 8 mm tall, this is actually a low current magnetic speaker that can be driven directly from the PIC's output pin. Switches can be whatever style you like. Many of the parts can be obtained at a local RadioShack, where you may also find a suitable enclosure and battery holder.

A level converter circuit allows you to connect a PC or terminal to set up some of the more advanced features. A single chip solution such as a MAX232 or similar chip could be used, but the circuit shown is effective, very low cost and easy to build. Most modern serial ports do not require full EIA-232 compliance, but will work fine without a negative voltage for the interface lines. Accordingly, the interface presented in the schematic simply inverts the polarity of the signals and also converts the ±12 V logic levels that may be present on the PC interface to levels appropriate for the PIC I/O pins. By using MOSFETs instead of the more traditional NPN and PNP transistors we can eliminate some of the parts usually seen in level shift-

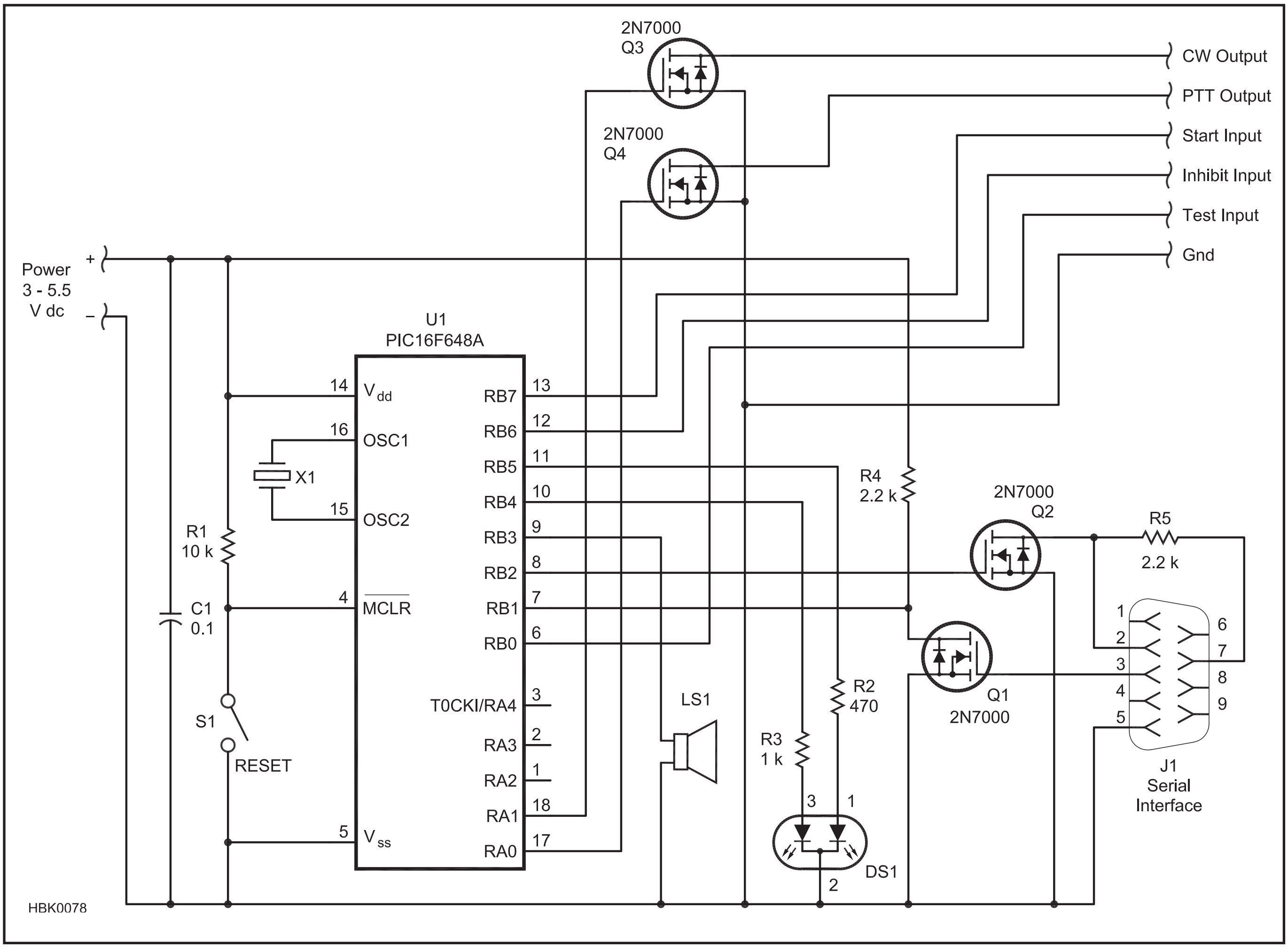


Fig 19.37 — Schematic of the ID-O-Matic. Resistors are ¼ W.

DS1 — Dual-color LED, MV5437.
J1 — DB9 female connector (Mouser 152-3409).
LS1 — Soberton GT-111P speaker or equiv (Mouser 665-AT-10Z or Digi-Key 433-1020-ND).
Q1-Q4 — 2N7000 MOSFET.
U1 — Microchip PIC16F648A. Must be programmed before use (see text). Programmed chips and parts kits are available from www.hamgadgets.com.
X1 — 4 MHz cylindrical crystal (Mouser 520-ECS-400-18-10).
Enclosure: Pac-Tec HMW-ET (Mouser 76688-510)

ing circuits like this. The only additional components are Q1, Q2 and R4, a current limiting resistor for the TxD line.

With a terminal or terminal emulator program you can set your own delay time, CW speed, ID message and select a simple beep or a CW ID. Inputs used for repeater operation (!INHIBIT and !START) are an exercise left to the builder. The thing to remember is that these inputs are active low, and the input voltage must be limited to no more than the PIC's V_{dd} supply voltage.

PUTTING THE ID-O-MATIC TO WORK

When power is applied, the PIC is set to beep at the end of a 10-minute timeout period and continue beeping until you press the reset button. To change any of the settings, simply connect a serial cable to your PC or dumb terminal set for 9600 Baud, 8 bits, no parity, no handshake and hit ENTER. The program will step through a set of prompts as shown in **Fig 19.38**. At each prompt you may either enter a new setting or simply hit ENTER to keep the existing setting, shown in parenthesis.

There are a few optional inputs and outputs that could be used to make the timer suitable for use in a "fox" transmitter or repeater.

• Pin 6 (RB0) is the !TEST input. You can momentarily ground this input to hear your ID and/or beacon messages. If no messages have been stored, the ID-O-Matic will announce its firmware version.

• Pin 12 (RB6) is the !INHIBIT input. This pin is normally held high by the PIC's internal weak pull-up resistors, and can be driven low by some external signal (squelch, for example) to delay the CW ID until the input goes high.

• Pin 13 (RB7) is the !START input, used only in repeater mode. Also pulled high internally, a LOW logic signal on this pin will start the timer. This can be handy to have your rig or repeater ID 10 minutes after a transmission, but not every 10 minutes. In repeater mode, the chip will ID a few seconds after the first low signal on the !START input. If repeated !START inputs are seen, subsequent IDs will occur at the programmed intervals.

• Pin 17 (RA0) is a PTT output. PTT goes high about 100 milliseconds before the audio starts and stays high until 100 ms after the end of the message. With the 2N7000, the PTT and CW outputs can handle up to 60 V at 200 mA.

• Pin 18 (RA1) is a CW output pin;

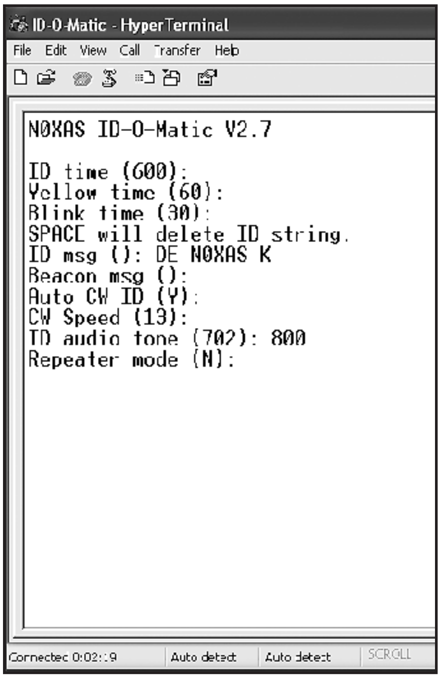


Fig 19.38 — Using *HyperTerminal* to set up the ID-O-Matic

it will output the same message as the audio output.

The original program code took several days to write and tweak, and has undergone numerous revisions since then. As with any project like this, the testing was the time consuming part. The author used the PIC C compiler from CCS, Inc. to write the program, but the logic is simple enough that porting to assembly, BASIC or a different C compiler should be pretty straightforward.

The code is relatively easy to adapt to your own equipment or requirements. For example, you may wish to move certain functions to different pins, change the polarity of various signals or change some of the timing defaults. The .LST file contains the C source with the ASM equivalents, and is a good starting point for someone wishing to understand the program logic in assembly rather than C. See the *ARRL Handbook CD* at the back of this book for these files.

The really interesting thing about this project is its versatility. Think of the ID-O-Matic as a general purpose PIC based project platform. With a serial interface, a few available inputs and outputs and a dual-color LED, the hardware can be adapted to many different uses simply by changing the PIC's program code. For example, the author built a 40 yard dash timer for his son's high school football team by substituting an infrared LED for the speaker, connecting an IR detector to one of the inputs and using another for a pushbutton switch. The serial interface is connected to a serial LCD display module. Within a couple of days he had a working device, customized with his son's team name, that can be used to time various events.

It's a good little project for beginning PIC users, and a useful station accessory that can be built in an evening and carried around in a shirt pocket.

THE UNIVERSAL KEYING ADAPTER

When Dale Botkin, NØXAS, was about to start restoring his old Heathkit HW-16, he decided it was time to explore what would be needed to key this tube rig using an electronic keyer. He also remembered — not fondly — having been "bitten" a few times when he touched metal parts of the key. There was some substantial voltage on the key, and he wanted to avoid touching it again. The key jack of this rig has a negative voltage, something like –85 V or more. Even the 2N7000 output of a solid-state keyer, rated at 60 V, would be no match for that. The Universal Keying Adapter (UKA) shown in **Fig 19.39** bridges the gap between a modern keyer and a classic tube-type transmitter, and it can also be used to key older tube-type amplifier TR switching lines with solid-state transceivers that can't handle the voltage or current requirements.

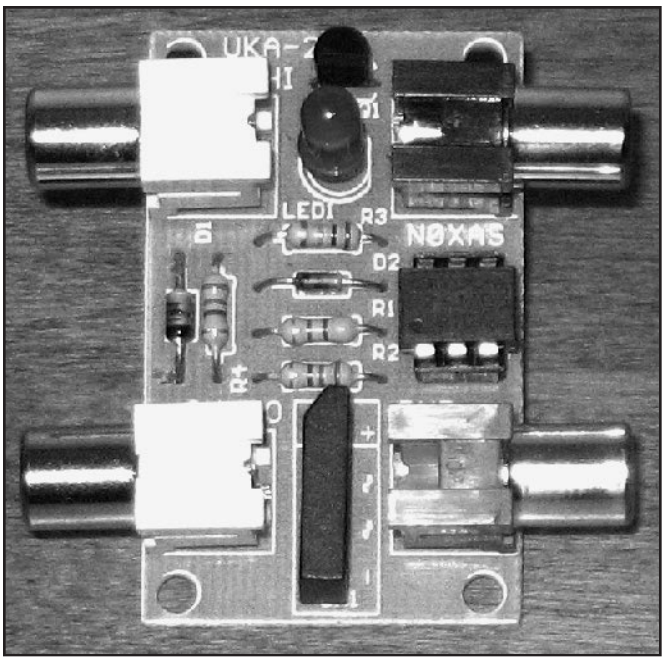


Fig 19.39 — This version of the Universal Keying Adapter 2 is available as a kit from www.hamgadgets.com. Parts count is low, and it can easily be built on a small project board.

KEYING SCHEMES

Older gear generally uses one of two keying schemes, grid-block or cathode keying. Grid-block keying requires that your key handle fairly high negative bias voltages, often in the 150 V range. Cathode keying is more demanding, with voltages up to +350 V or so. Most modern solid state keyers use a simple transistor output circuit suitable only for low-voltage, positive keying. Obviously, neither grid-block nor cathode keyed transmitters should be connected to such an output! At the very least it's going to damage the keyer.

Most grid-block keying adapters use one or two bipolar transistors and are designed specifically to key grid-block rigs. This is fine as far as it goes, but also requires that you have one setup for solid state rigs, another for grid-blocked rigs, and still another if you have a cathode keyed boat anchor as well. It's not an optimum solution. Of course one could use a relay to key just about anything, but relay contact noise would quickly get really irritating. Relays also eventually wear out, contacts get dirty and the coils can use quite a bit of current, meaning battery powered keyers will suffer from very limited battery life.

Solid-State Relays

Solid state relays exist, but they can be expensive. The author finally hit upon what seems to be an ideal solution. It's cheap, small, relatively low current, uses low voltage control and is capable of switching fairly high ac or dc voltages. Perfect! Crydom, NEC, Fairchild, Omron and other manufactures make very similar small, inexpensive MOSFET solid state relays. Suitable model numbers include the NEC PS7142 and PS7342, Fairchild HSR412, Omron G3VM-401B and others. Depending on the part selected they can handle up to a couple hundred milliamps and will switch up to 400 V ac or dc. All of this in a 6-pin DIP form factor, and for just a few bucks!

The MOSFET solid-state relay (SSR) is very similar to an optoisolator, but somewhat more versatile. Ac or dc loads can be switched, and the allowable load voltages are much higher than regular optoisolators. Driving the relay input involves supplying a few mA of current to turn on an LED inside the device. This requires about 1.4 V at a recommended forward current of 10 to 30 mA. The output is a pair of MOSFETs with common sources and a photo gate rather than a hard-wired gate. Turn on the LED and the MOSFETs conduct, turn off the LED and the MOSFETs shut off. Just like a relay, it's simple and elegant.

KEYING ADAPTER CIRCUITS

For a simple keying adapter arrangement, all that is needed is the MOSFET solid-state relay, one resistor, and a dc power source such as a battery. See **Fig 19.40**. The keying input from your hand key or electronic keyer completes the input circuit through the current limiting resistor and the input side of the SSR, turning the output on. In this example, the value of R1 is determined using Ohm's Law to give between 10 and 30 mA of current at the desired input voltage. For example, for use with two AA alkaline batteries, a range of 100 to 300 Ω is okay; 150 or 220 Ω will work reliably with NiCd or NiMH cells as well. If you plan to use a 13.8 V dc power supply, a 1 kΩ resistor should be fine for R1.

It soon became apparent that other uses existed in addition to just isolating the key or keyer from a transmitter. The addition of a simple transistor inverter allows the use of computer keying in parallel with input from a straight key, bug or keyer. This is handy, for example, to contesters using computers for keying who may need to send some information by hand from time to time. See **Fig 19.41**. The use of a 2N7000 MOSFET instead of the common NPN transistor makes it easier to accommodate both serial and parallel port use, since the gate will withstand up to 20 V positive or negative and does not need to be current limited. In this example, the value of R1 should be determined as mentioned earlier. R2's purpose is to keep the MOSFET gate from floating, so its value is not critical but 10 kΩ or 100 kΩ are good values.

The design eventually evolved to include a full-wave bridge rectifier allowing either ac or dc input, a Zener diode for voltage regulation, and an LED keying indicator. The result was the Universal Keying Adapter 2, which is also available in kit form (see **www.hamgadgets.com**). The UKA-2 can accept any dc or ac power source up to about 30 V, and is adaptable to lower power battery operation by substituting or eliminating some of the power supply parts.

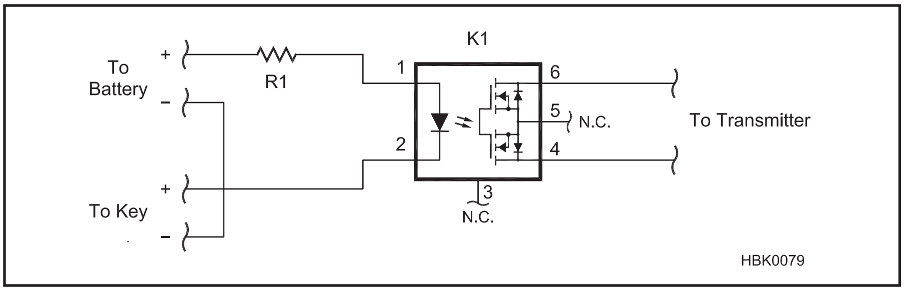


Fig 19.40 — The original Universal Keying Adapter circuit used a solid-state relay and a battery for power.

K1 — Optically coupled solid-state relay, Fairchild HSR412 or equivalent.
R1 — ¼ W resistor, varies with supply voltage (see text). Use 150 or 220 Ω for two AA cells; 1 kΩ for 13.8 V dc power source.

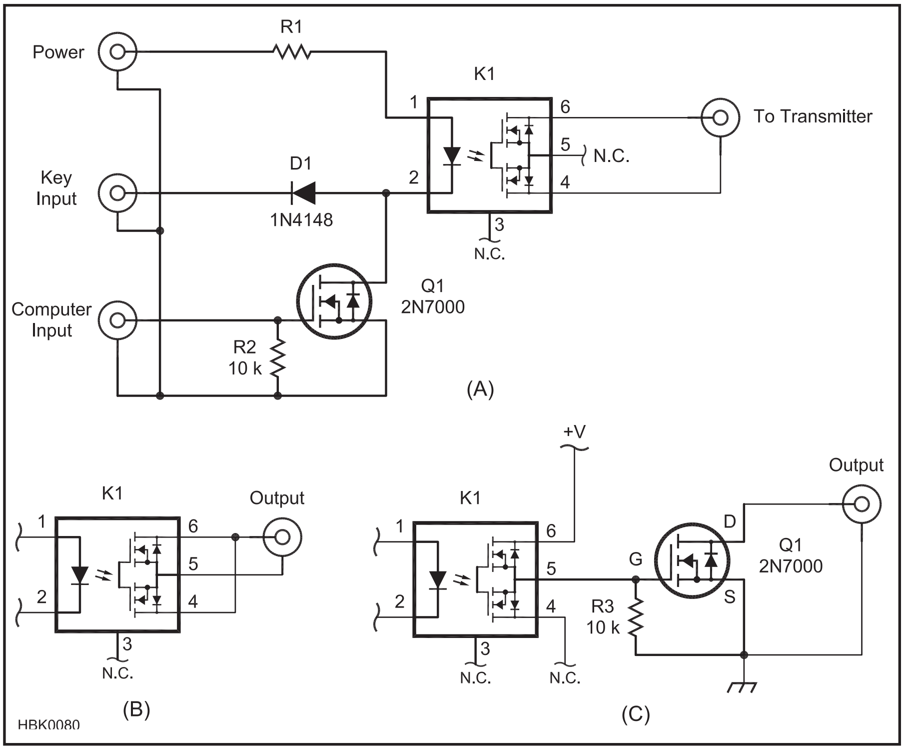


Fig 19.41 — The Universal Keying Adapter circuit with provisions for using computer keying in parallel with a hand key or keyer. Two methods of increasing the load current capacity are shown at B and C (see text for discussion).

K1 — Optically coupled solid-state relay, Fairchild HSR412 or equivalent.
R1 — ¼ W resistor, varies with supply voltage (see text). Use 150 or 220 Ω for two AA cells; 1 kΩ for 13.8 V dc power source.

Other Configurations

It is worth noting that if only positive or only negative voltages will be used, the output current capacity can be greatly increased and the on-state resistance greatly decreased by connecting the two MOSFET drain outputs in parallel rather than serial. An example of this is shown in Fig 19.41B. For the HSR412, maximum load current increases from 140 mA for series output to 210 mA for parallel. An added feature of this arrangement is the presence of the intrinsic "body diodes" of the MOSFETS. If you are keying an amp that has an internal keying relay, this can serve to absorb some of the back EMF when the relay releases. Note that this arrangement requires that pin 5 of the IC be at a lower voltage than the other two pins — in other words, ground for positive keying, or –V for negative keying. Since the output is completely isolated from the input, the polarity of the output connector can be changed without the risk of exposing your other gear to dangerous voltages.

Although the IC solid-state relays are good for a wide range of uses, there are applications that present more of a load than the device is able to safely handle even with the outputs in parallel. For loads of more than the rated device current, an external MOSFET switch can be used. Again, the resulting output is optically isolated from the input. Resistor R3 shown in Fig 19.41C keeps the gate of the 2N7000 MOSFET low until the input is activated, so its value is not critical. The gate voltage +V needs only to be within the safe range for the device selected; in most cases 12 V will do fine.

The UKA design works well with both grid-block and cathode keyed rigs, as well as solid state. It's been tested with a TS-930SAT, Heath HW-16, FT-817, Rock-Mites, FT-480R and more. It has also been used with cathode keyed rigs such as the Heath DX-40, and many more examples of this circuit are in use keying various "boat anchor" rigs and amps. It works quite well to key older tube power amplifiers with solid-state transceivers that are not equipped with suitable keying relays or circuits. The input works well with any rig, key, electronic keyer, serial or parallel port tried so far.

THE TANDEM MATCH—AN ACCURATE DIRECTIONAL WATTMETER

Most SWR meters are not very accurate at low power levels because the detector diodes do not respond to low voltage in a linear fashion. This design uses a compensating circuit to cancel diode nonlinearity. It also provides peak detection for SSB operation and direct SWR readout that does not vary with power level. **Fig 19.42** is a photo of the completed project. The following information is condensed from an article by John Grebenkemper, KI6WX, in January 1987 *QST*. Some modifications by KI6WX were detailed in the "Technical Correspondence" column of July 1993 *QST*. A PC Board is available from FAR Circuits.[1]

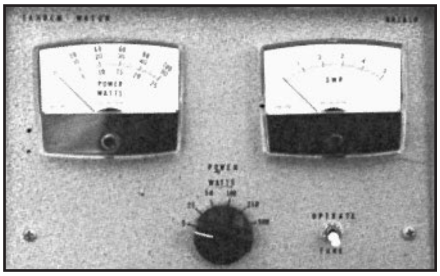


Fig 19.42—The Tandem Match uses a pair of meters to display net forward power and true SWR simultaneously.

Circuit Description

A directional coupler consists of an input port, an output port and a coupled port. Ideally, a portion of the power flowing from the input to the output appears at the coupled port, but *none* of the power flowing from the output to the input appears at the coupled port.

The coupler used in the Tandem Match consists of a pair of toroidal transformers connected in tandem. The configuration was patented by Carl G. Sontheimer and Raymond E. Fredrick (US Patent no. 3,426,298, issued February 4, 1969). It has been described by Perras, Spaudling and others. With coupling factors of 20 dB greater, this coupler is suitable to sample both forward and reflected power.

The configuration used in the Tandem Match works well over the frequency range of 1.8 to 54 MHz, with a nominal coupling factor of 30 dB. Over this range, insertion loss is less than 0.1 dB. The coupling factor is flat to within ±0.1 dB from 1.8 to 30 MHz, and increases to only ±0.3 dB at 50 MHz. Directivity exceeds 35 dB from 1.8 to 30 MHz and exceeds 26 dB at 50 MHz.

The low-frequency limit of this directional coupler is determined by the inductance of the transformer secondary windings. The inductive reactance should be greater than 150 Ω (three times the line characteristic impedance) to reduce insertion loss. The high-frequency limit of this directional coupler is determined by the length of the transformer windings. When the winding length approaches a significant fraction of a wavelength, coupler performance deteriorates.

The coupler described here may overheat at 1500 W on 160 m (because of the high circulating current in the secondary of T2). The problem could be corrected by using a larger core or one with greater permeability. A larger core would require longer windings; that option would decrease the high-frequency limit.

Most amateur directional wattmeters use a germanium-diode detector to minimize the forward voltage drop. Detector voltage drop is still significant, however, and an uncompensated diode detector does not respond to small signals in a linear fashion. Many directional wattmeters compensate for diode nonlinearity by adjusting the meter scale.

The effect of underestimating detected power worsens at low power levels. Under these conditions, the ratio of the forward power to the reflected power is overestimated because the reflected power is always less than the forward power. This results in an instrument that underestimates SWR, particularly as power is educed. A directional wattmeter can be checked for this effect by measuring SWR at several power levels. The SWR should be independent of power level.

The Tandem Match uses a feedback circuit to compensate for diode nonlinearity. Transmission-line SWR is displayed on a linear scale. Since the displayed SWR is not affected by changes in transmitter power, a matching network can be simply adjusted to minimize SWR. Transmatch adjustment requires only a few watts.

Construction

The schematic diagram for the Tandem Match is shown in **Fig 19.43**. The circuit is designed to operate from batteries and draws very little power. Much of the circuitry is of high impedance, so take care to isolate it from RF fields. House the circuit in a metal case. Most problems in the prototype were caused by stray RF in the op-amp circuitry.

The schematic shows two construction options. Connect jumpers W1, W2 and W3 to use the circuit as it was originally designed (with two 9-V batteries and TLC27L4 or TLC27M4 op amps). By omitting these jumpers, any quad FET-input op amps can be used instead of the TLC27x4s. Possible substitutes include the TL064, TL074, TL084, LF347 and LF444. In that case you should also omit the 9-V batteries and the automatic turn-on circuitry of Q1, Q2 and Q3 (everything to the left of the jumpers on the top row of the diagram). Now you will have to connect an external + 15 V supply between the + V line and chassis ground and a –15 V supply to the –V line.

The FAR Circuits Tandem Match circuit board is double sided, but does not have plated-through holes. The component side is mainly the chassis and circuit ground planes, although there are a few signal traces. You will have to install "jumper posts" in a few locations, and solder them to both sides of the board to connect these traces. Carefully follow the schematic diagram and parts-placement diagram supplied with the board to identify these "posts." Check the board carefully to ensure that none of the ground traces pass too close to a circuit lead. You may have to scrape a bit of foil away from a few places around the component holes. This is easy with an X-ACTO knife.

The trimmer pots must be square multi-turn units with top adjustment screws for use with the FAR Circuits board. Mount the ferrite beads so they don't touch any board trace; the beads have sufficient leakage to cause problems in the high impedance parts of the circuit. Before mounting the SO-239 connectors to the circuit board, enlarge the center location holes to ⅝-inch diameter to accept the connector body. The components connected to the SO-239 are soldered directly between the center pin and the board traces.

Directional Coupler

The directional coupler is constructed in its own small (2¾×2¾×2¼-inch) aluminum box (see **Fig 19.44**). Two pairs of SO-239 connectors are mounted on opposite sides of the box. A piece of PC board is run diagonally across the box to improve coupler directivity. The pieces of RG-8X coaxial cable pass through holes in the PC board. (Note: Some brands of "mini 8" cable have extremely low breakdown voltage ratings and are unsuitable to carry even 100 W when the SWR exceeds 1:1. See "High-Power Operation" for details of a coupler made with RG-8 cable.)

Begin by constructing T1 and T2, which are identical except for their end connections. (Refer to Fig 19.44.) The primary for each transformer is the center conductor of a length of RG-8X coaxial cable. Cut

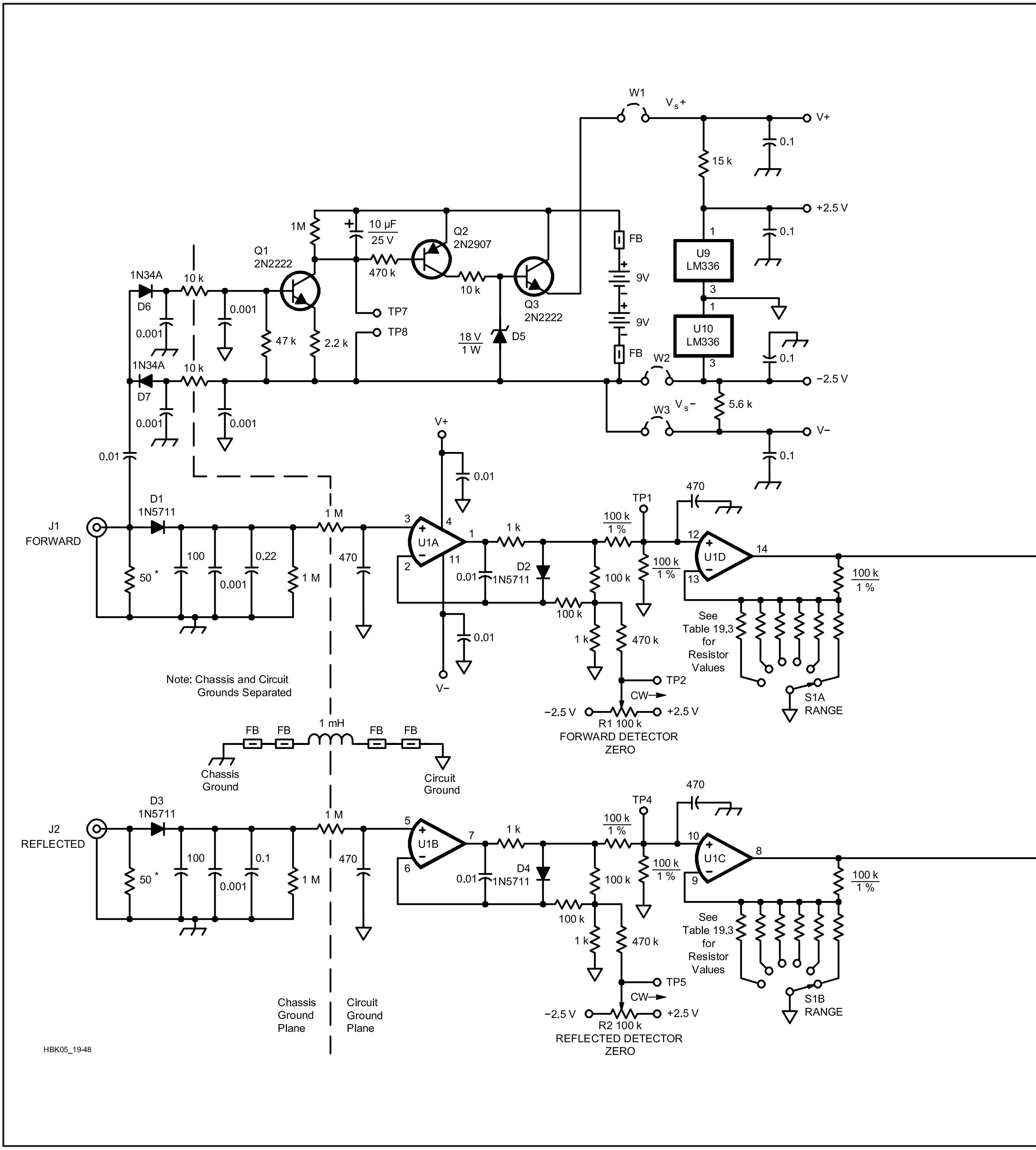
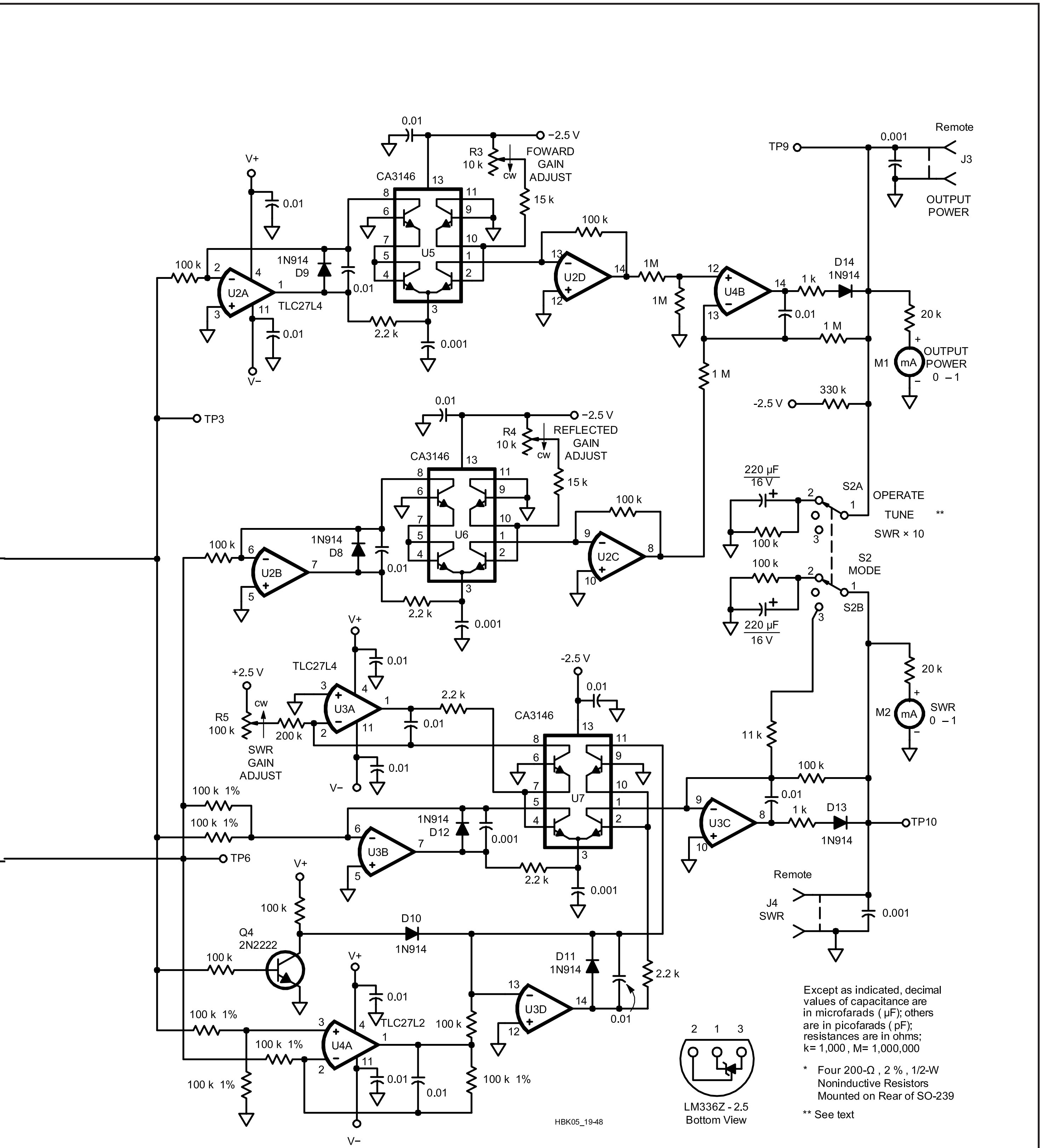


Fig 19.43—Schematic diagram of the Tandem Match directional wattmeter. Parts identified as RS are from RadioShack. Contact information for parts suppliers can be found using the *TIS Find* program.

D1-D4—1N5711.
D6, D7—1N34A or 1N271.
D8-D14-1N914.
FB-Ferrite bead, Amidon FB-73-101 or equiv.
J1, J2—SO-239 connector.
J3, J4—Open-circuit jack.
M1, M2—1 mA panel meter.
Q1, Q3, Q4—2N2222 metal case only.
Q2—2N2907 metal case or equiv.
R1, R2, R5—100-kΩ, 10-turn cermet Trimpot.
R3, R4—10-kΩ, 10-turn, cermet Trimpot.
U1-U3—TLC27M4 op amp.
U4—TLC27L2 or TLC27M2.
U5-U7—CA3146.
U9, U10—LM336.



two cable lengths sufficient for mounting as shown in the figure. Strip the cable jacket, braid and dielectric as shown. The cable braid is used as a Faraday shield between the transformer windings, so it is only grounded at one end. *Important—connect the braid only at one end or the directional-coupler circuit will not work properly!* Wind two transformer secondaries, each 31 turns of #24 enameled wire on a T-50-3 iron-powder core. Slip each core over one of the prepared cable pieces (including both the shield and the outer insulation). Mount and connect the transformers as shown in Fig 19.43, with the wires running through separate holes in the copper-clad PC board.

The directional coupler can be mounted

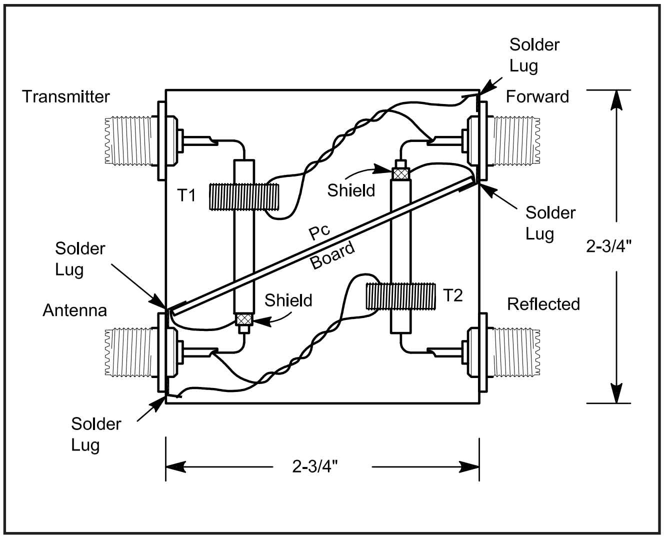


Fig 19.44—Construction details for the directional coupler. A metal case is required.

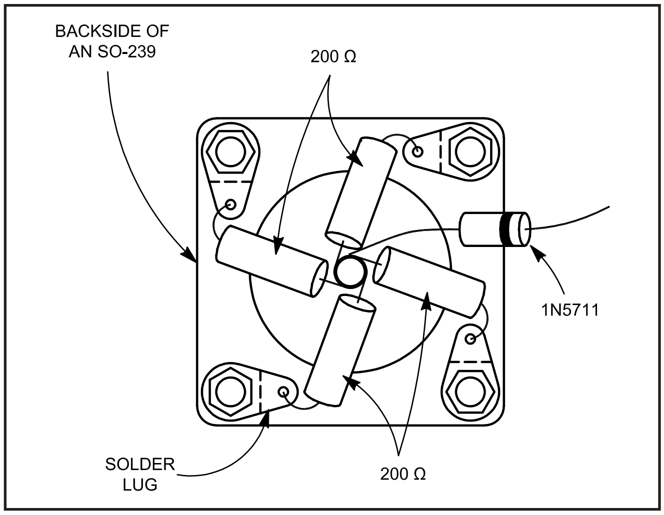


Fig 19.45—The parallel load resistors mounted on an SO-239 connector. Four 200-Ω resistors are mounted in parallel to provide a 50-Ω detector load.

separately from the rest of the circuitry if desired. If so, use two coaxial cables to carry the forward- and reflected-power signals from the directional coupler to the detector inputs. Be aware, however, that any losses in the cables will affect power readings.

This directional coupler has not been used at power levels in excess of 100 W. For more information about using Tandem Match at high power levels, see "High-Power Operation."

Detector and Signal-processing Circuits

The detector and signal-processing circuits were constructed on a perforated, copper-clad circuit board. These circuits use two separate grounds—*it is extremely important to isolate the grounds as shown in the circuit diagram*. Failure to do so may result in faulty circuit operation. Separate grounds prevent RF currents on the cable shield from affecting the op-amp circuitry.

The directional coupler requires good 50-Ω loads. They are constructed on the back of the female UHF chassis connectors where the cables from the directional coupler enter the wattmeter housing. Each load consists of four 200-Ω resistors connected from the center conductor of the UHF connector to the four holes on the mounting flange, as shown in **Fig 19.45**. The detector diode is then mounted from the center conductor of the connector to the 100-pF and 1000-pF bypass capacitors, which are located next to the connector. The response of this load and detector combination measures flat to beyond 500 MHz.

Schottky-barrier diodes (type 1N5711) were used in this design because they were readily available. Any RF-detector diode with a low forward voltage drop (less than 300 mV) and reverse breakdown voltage greater than 30 V could be used. (Germanium diodes could be used in this circuit, but performance will suffer. If germanium diodes are used, reduce the values of the detector-diode and feedback-diode load resistors by a factor of 10.)

The rest of the circuit layout is not critical, but keep the lead lengths of 0.001- and 0.01-µF bypass capacitors short. The capacitors provide additional bypass paths for the op-amp circuitry.

D6 and D7 form a voltage doubler to detect the presence of a carrier. When the forward power exceeds 1.5 W, Q3 switches on and stays on until about 10 seconds after the carrier drops. (A connection from TP7 to TP9 forces the unit on, even with no carrier present.) The regulated references of +2.5 V and –2.5 V generated by the LM334 and LM336 are critical. Zener-diode substitutes would significantly degrade performance.

The four op amps in U1 compensate for nonlinearity of the detector diodes. D1-D2 and D3-D4 are the matched diode pairs discussed above. A RANGE switch selects the meter range. (A six-position switch was used here because it was handy.) The resistor values for the RANGE switch are shown in **Table 19.2**. Full-scale input power gives an output at U1C or U1D of 7.07 V. The forward- and reflected-power detectors are zeroed with R1 and R2.

The forward- and reflected-detector voltages are squared by U2, U5 and U6 so that the output voltages are proportional to forward and reflected power. The gain constants are adjusted using R3 and R4 so that an input of 7.07 V to the squaring circuit gives an output of 5 V. The difference between these two voltages is used by U4B to yield an output that is proportional to the power delivered to the transmission line. This voltage is peak detected (by an RC circuit connected to the OPERATE position of the MODE switch) to indicate and hold the maximum power measurement during CW or SSB transmissions.

SWR is computed from the forward and reflected voltages by U3, U4 and U7. When no carrier is present, Q4 forces the

Table 19.2
Performance Specifications for the Tandem Match

Power range: 1.5 to 1500 W
Frequency range: 1.8 to 54 MHz
Power accuracy: Better than ±10% (±0.4 dB)
SWR accuracy: Better than ±5%
Minimum SWR: Less than 1.05:1
Power display: Linear, suitable for use with either analog or digital meters
SWR display: Linear, suitable for use with either analog or digital meters
Calibration: Requires only an accurate voltmeter

SWR reading to be zero (that is, when the forward power is less than 2% of the full-scale setting of the RANGE switch). The SWR computation circuit gain is adjusted by R5. The output is peak detected in the OPERATE mode to steady the SWR reading during CW or SSB transmissions.

Transistor arrays (U5, U6 and U7) are used for the log and antilog circuits to guarantee that the transistors will be well matched. Discrete transistors may be used, but accuracy may suffer.

A three-position toggle switch selects the three operating modes. In the OPERATE mode, the power and SWR outputs are peak detected and held for a few seconds to allow meter reading during actual transmissions. In the TUNE mode, the meters display instantaneous output power and SWR.

A digital voltmeter is used to obtain more precise readings than are possible with analog meters. The output power range is 0 to 5 V (0 V = 0 W and 5 V = full scale). SWR output varies from 1 V (SWR = 1:1) to 5 V (SWR = 5:1). Voltages above 5 V are unreliable because of voltage limiting in some of the op amp circuits.

Calibration

The directional wattmeter can be calibrated with an accurate voltmeter. All calibration is done with dc voltages. The directional-coupler and detector circuits are inherently accurate if correctly built. To calibrate the wattmeter, use the following procedure:

1) Set the MODE switch to TUNE and the RANGE switch to 100 W or less.
2) Jumper TP7 to TP8. This turns the unit on.
3) Jumper TP1 to TP2. Adjust R1 for 0 V at TP3.
4) Jumper TP4 to TP5. Adjust R2 for 0 V at TP6.
5) Adjust R1 for 7.07 V at TP3.
6) Adjust R3 for 5.00 V at TP9, or a full-scale reading on M1.
7) Adjust R2 for 7.07 V at TP6.
8) Adjust R4 for 0 V at TP9, or a zero reading on M1.
9) Adjust R2 for 4.71 V at TP6.
10) Adjust R5 for 5.00 V at TP10, or a full-scale reading on M2.
11) Set the RANGE switch to its most sensitive scale.
12) Remove jumpers from TP1 to TP2 and TP4 to TP5.
13) Adjust R1 for 0 V at TP3.
14) Adjust R2 for 0 V at TP6.
15) Remove jumper from TP7 to TP8.

This completes the calibration procedure. This procedure has been found to equal calibration with expensive laboratory equipment. The directional wattmeter should now be ready for use.

Table 19.3
Range-Switch Resistor Values

Full-Scale Power Level (W)	*Range Resistor (1% Precision) (kΩ)*
1	2.32
2	3.24
3	4.02
5	5.23
10	7.68
15	9.53
20	11.0
25	12.7
30	15.0
50	18.7
100	28.7
150	37.4
200	46.4
250	54.9
300	63.4
500	100.0
1000	237.0
1500	649.0
2000	open

Accuracy

Performance of the Tandem Match has been compared to other well-known directional couplers and laboratory test equipment, and it equals any amateur directional wattmeter tested. Power measurement accuracy of the Tandem Match compares well to a Hewlett-Packard HP-436A power meter. The HP meter has a specified measurement error of less than ±0.05 dB. The Tandem Match tracked the 436A within ±0.5 dB from 10 mW to 100 W and within ±0.1 dB from 1 W to 100 W. The unit was not tested above 1200 W because a transmitter with a higher power rating was not available.

SWR performance was equally good when compared to the SWR calculated from measurements made with 436A and a calibrated directional coupler. The Tandem Match tracked the calculated SWR within ±5% for SWR values from 1:1 to 5:1. SWR measurements were made at 8 W and 100 W.

Operation

Connect the Tandem Match in the 50-Ω line between the transmitter and the antenna-matching network (or antenna if no matching network is used). Set the RANGE switch to a range greater than the transmitter output rating and the MODE switch to TUNE. When the transmitter is keyed, the Tandem Match automatically switches on and indicates both power delivered to the antenna and SWR on the transmission line. When no carrier is present, the output power and SWR meters indicate zero.

The OPERATE mode includes RC circuitry to momentarily hold the peak-power and SWR readings during CW or SSB transmissions. The peak detectors are not ideal, so there could be about 10% variation from the actual power peaks and the SWR reading. The SWR×10 mode increases the maximum readable SWR to 50:1. This range should be sufficient to cover any SWR value that occurs in amateur use. (A 50-ft open stub of RG-8 yields a measured SWR of only 43:1, or less, at 2.4 MHz because of cable loss. Higher frequencies and longer cables exhibit a smaller maximum SWR.)

It is easy to use the Tandem Match to adjust an antenna-matching network. Adjust the transmitter for minimum output power (at least 1.5 W). With the carrier on and the MODE switch set to TUNE or SWR×10, adjust the matching network for minimum SWR. Once minimum SWR is obtained, set the transmitter to the proper operating mode and output power. Place the Tandem Match in the OPERATE mode.

Parts

Few parts suppliers carry all the components needed for these couplers. Each may stock different parts. Good sources include Digi-Key, Surplus Sales of Nebraska, Newark Electronics and Anchor Electronics. Use the *TIS Find* program for latest address information.

High-power Operation

This material was condensed from a letter by Frank Van Zant, KL7IBA, that appears in July 1989 *QST* (pp 42-43). In April 1988, Zack Lau, W1VT, described a directional-coupler circuit (based on the same principle as Grebenkemper's circuit) for a QRP transceiver. The main advantage of Lau's circuit is very low parts count.

Grebenkemper uses complex log-antilog amplifiers to provide good measurement accuracy. This application gets away from complex circuitry, but retains reasonable measurement accuracy over the 1 to 1500-W range. It also forfeits the SWR-computation feature.

Lau's coupler uses ferrite toroids. It works great at low power levels, but the ferrite toroids heat excessively with high power, causing erratic meter readings and the potential for burned parts.

The Revised Design

Powdered-iron toroids are used for the transformers in this version of Lau's basic circuit. The number of turns on the secondaries was increased to compensate for the lower permeability of powdered iron.

Two meters display reflected and forward power (see **Fig 19.46**). The germanium

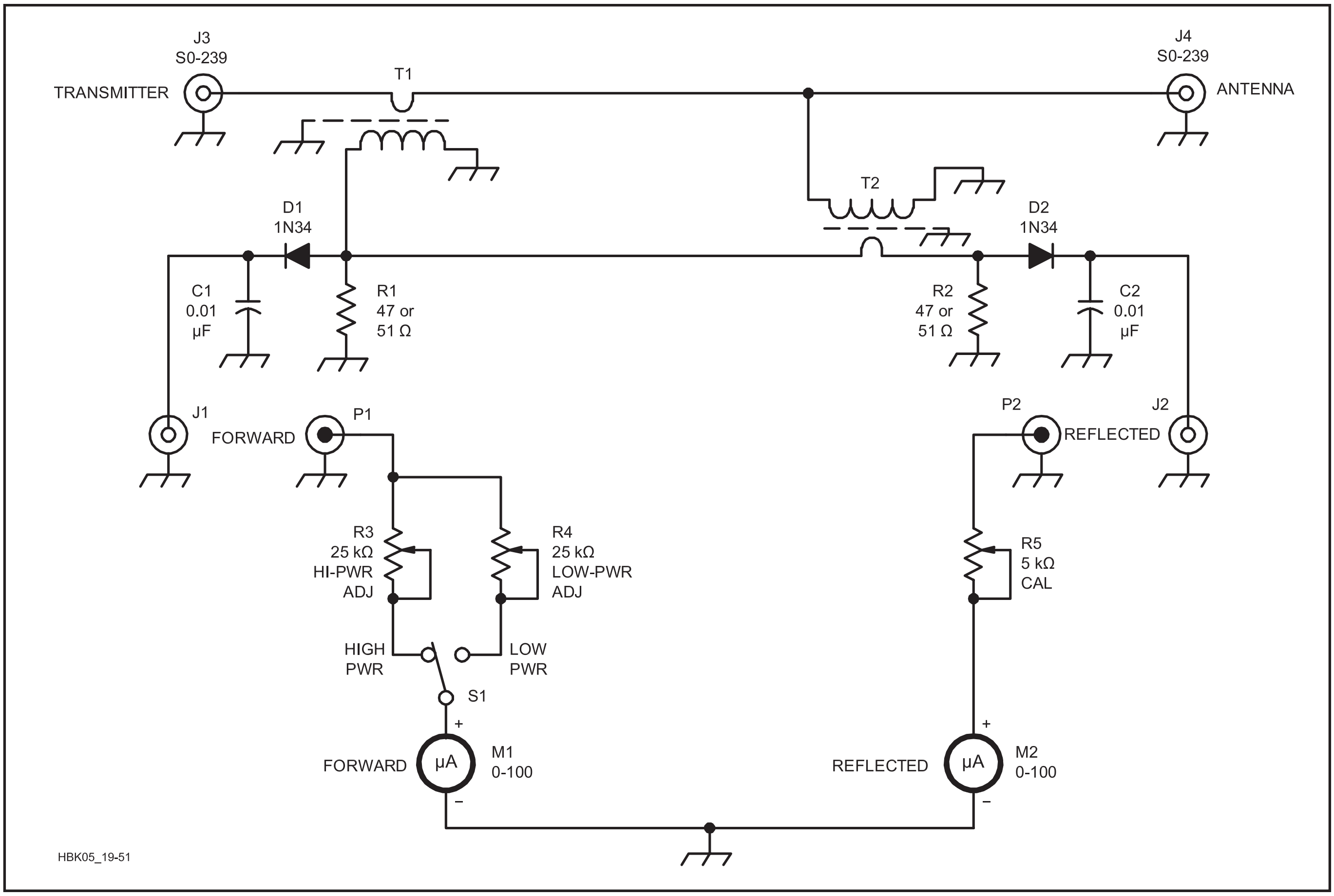


Fig 19.46—Schematic diagram of the high-power directional coupler. D1 and D2 are germanium diodes (1N34 or equiv). R1 and R2 are 47- or 51-Ω ½-W resistors. C1 and C2 have 500-V ratings. The secondary windings of T1 and T2 each consist of 40 turns of #26 to 30 enameled wire on T-68-2 powdered-iron toroid cores. If the coupler is built into an existing antenna tuner, the primary of T1 can be part of the tuner coaxial output line. The remotely located meters (M1 and M2) are connected to the coupler box at J1 and J2 via P1 and P2.

detector diodes (D1 and D2—1N34) provide fairly accurate meter readings particularly if the meter is calibrated (using R3, R4 and R5) to place the normal transmitter output at midscale. If the winding sense of the transformers is reversed, the meters are transposed (the forward-power meter becomes the reflected-power meter, and vice versa).

Construction

Fig 19.47 shows the physical layout of this coupler. The pickup unit is mounted in a 3½×3½×4-inch box. The meters, PC-mount potentiometers and HIGH/LOW power switch are mounted in a separate box or a compartment in an antenna tuner.

The primary windings of T1 and T2 are constructed much as Grebenkemper described, but use RG-8 with its jacket removed so that the core and secondary winding may fit over the cable. The braid is wrapped with fiberglass tape to insulate it from the secondary winding. An excellent alternative to fiberglass tape—with even

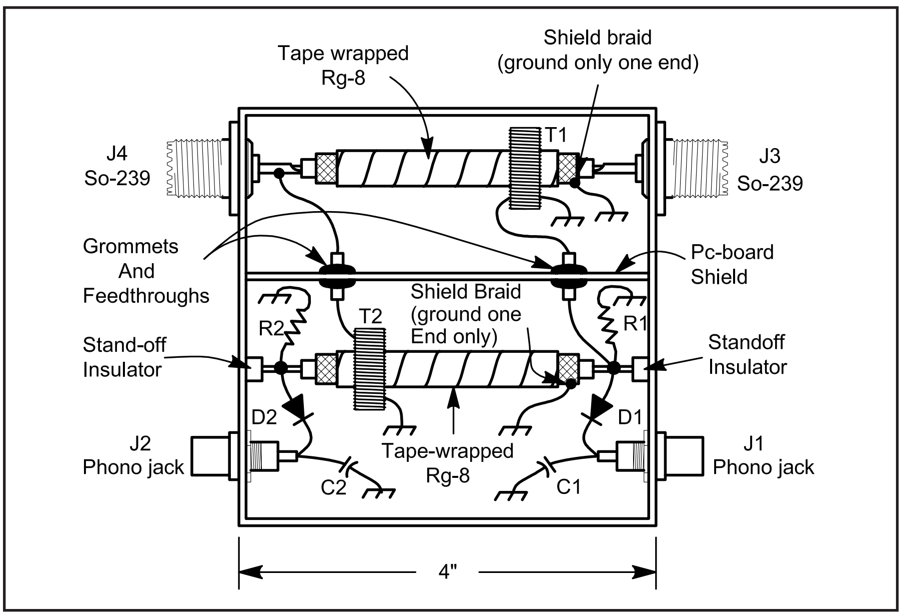


Fig 19.47—Directional-coupler construction details. Grommets or standoff insulators can be used to route the secondary windings of T1 and T2 through the PC-board shield. A 3½×3½×4-inch metal box serves as the enclosure.

higher RF voltage-breakdown characteristics—is ordinary plumber's Teflon pipe tape, available at most hardware stores.

The transformer secondaries are wound on T-68-2 powdered-iron toroid cores. They are 40 turns of #26 to 30 enameled wire spread evenly around each core. By using #26 to 30 wire on the cores, the cores slip over the tape-wrapped RG-8 lines. With #26 wire on the toroids, a single layer of tape (slightly more with Teflon tape) over the braid provides an extremely snug fit for the core. Use care when fitting the cores onto the RG-8 assemblies. After the toroids are mounted on the RG-8 sections, coat the assembly with General Cement Corp Polystyrene Q Dope, or use a spot or two of RTV sealant to hold the windings in place and fix the transformers on the RG-8 primary windings.

Mount a PC-board shield in the center of the box, between T1 and T2, to minimize coupling between transformers. Suspend T1 between SO-239 connectors and T2 between two standoff insulators. The detector circuits (C1, C2, D1, D2, R1 and R2) are mounted inside the coupler box as shown.

Calibration, Tune up and Operation

The coupler has excellent directivity. Calibrate the meters for various power levels with an RF ammeter and a 50-Ω dummy load. Calculate I^2R for each power level, and mark the meter faces accordingly. Use R3, R4 and R5 to adjust the meter readings within the ranges. Diode nonlinearities are thus taken into account, and Grebenkemper's signal-processing circuits are not needed for relatively accurate power readings.

Start the tune-up process using about 10 W, adjust the antenna tuner for minimum reflected power, and increase power while adjusting the tuner to minimize reflected power.

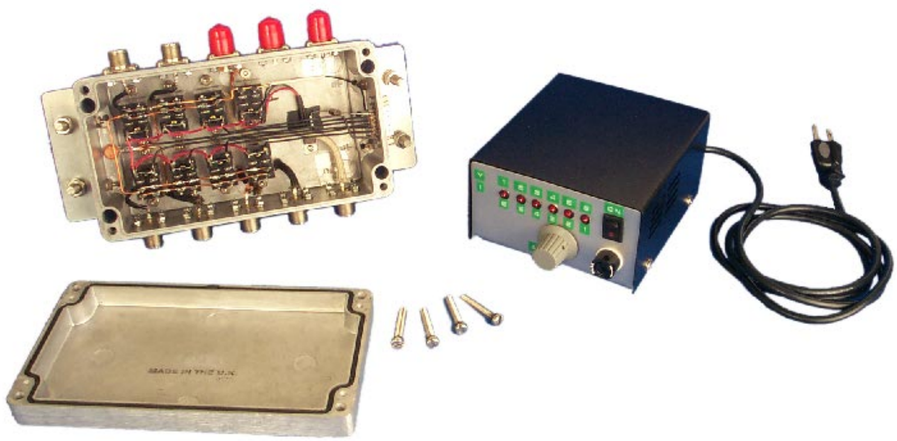
This circuit has been built into several antenna tuners with good success. The bridge worked well at 1.5-kW output on 1.8 MHz. It also worked fine from 3.5 to 30 MHz with 1.2- and 1.5-kW output. The antenna is easily tuned for a 1:1 SWR using the null indication provided.

Amplifier settings for a matched antenna, as indicated with the wattmeter, closely agreed with those for a 50-Ω dummy load. Checks with a Palomar noise bridge and a Heath Antenna Scope also verified these findings. This circuit should handle more than 1.5 kW, *as long as the SWR on the feed line through the wattmeter is kept at or near 1:1*. (On one occasion high power was applied while the antenna tuner was not coupled to a load. Naturally the SWR was extremely high, and the output transformer secondary winding opened like a fuse. This resulted from the excessively high voltage across the secondary. The damage was easily and quickly repaired.)

Notes

[1]Use *TIS Find* program for latest address information.

AN EXTERNAL AUTOMATIC ANTENNA SWITCH FOR USE WITH YAESU OR ICOM RADIOS



This antenna-switching-control project involves a combination of ideas from several earlier published articles.[1,2,3] This system was designed to mount the antenna relay box outside the shack, such as on a tower. With this arrangement, only a single antenna feed line needs to be brought into the shack. The lead photo shows the control unit and relay box, designed and built by Joe Carcia, NJ1Q. As the W1AW chief operator, Joe has plans for the switch at W1AW. Either an ICOM or Yaesu HF radio will automatically select the proper antenna. In addition, a manual switch can override the ICOM automatic selection. That feature also provides a way to use the antenna with other radios. The antenna switch is not a two-radio switch, though. It will only work with one radio at a time.

Many builders may want to use only the ICOM or only the Yaesu portion of the interface circuitry, depending on the brand of radio they own. The project is a "hacker's dream." It can be built in a variety of forms, with the only limitations being the builder's imagination.

Circuit Description

Fig 19.48 is a block diagram of the complete system. An ICOM or Yaesu HF radio connects to the appropriate decoder via the accessory connector on the back of

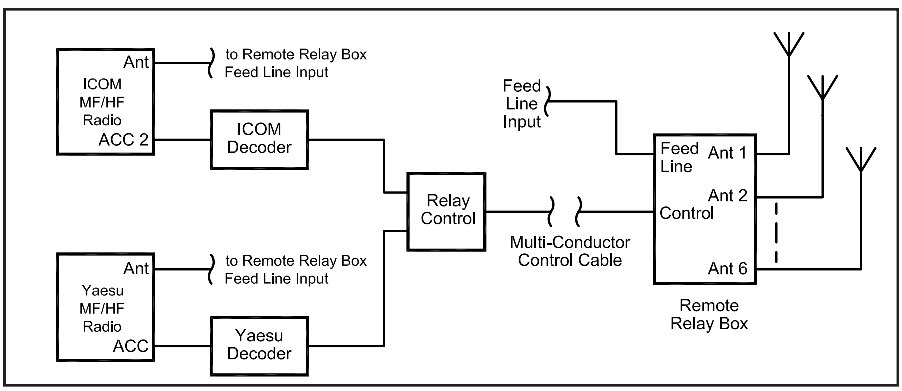


Fig 19.48—Block diagram of the remotely controlled automatic antenna switch.

Table 19.4
ICOM Accessory Connector Output Voltages By Band

Band (MHz)	*Output Voltage*
1.8	7 – 8.0
3.5	6 – 6.5
7	5 – 5.5
14	4 – 4.5
18, 21	3 – 3.5
24, 28	2 – 2.5
10	0 – 1.2

Note: The voltage step between bands is not constant, but close to 1.0 V, and the 10-MHz band is not in sequence with the others.

Table 19.5
Yaesu Band Data Voltage Output (BCD)

Band	*A (1)*	*B (2)*	*C (4)*	*D (8)*	*(BCD Equiv.)*
1.8	5V	0V	0V	0V	1
3.5	0V	5V	0V	0V	2
7.0	5V	5V	0V	0V	3
10.1	0V	0V	5V	0V	4
14	5V	0V	5V	0V	5
18.068	0V	5V	5V	0V	6
21	5V	5V	5V	0V	7
24.89	0V	0V	0V	5V	8
28	5V	0V	0V	5V	9

the radio. Some other modern rigs have an accessory connector used for automatic bandswitching of amplifiers, tuners and other equipment. For example, Ten-Tec radios apply a 10 to 14-V dc signal to pins on the DB-25 interface connector for the various bands. Other radios use particular voltages on one of the accessory-connector pins to indicate the selected band. Check the owner's manual of your radio for specific information, or contact the manufacturer's service department for more details. You may be able to adapt the ideas presented in this project for use with other radios.

A single length of coax and a multiconductor control cable run from the rig and decoder/control box to the remotely located switch unit. The remote relay box is equipped with SO-239 connectors for the input as well as the output to each antenna. You can use any type of connectors, though.

ICOM radios use an 8-V reference and a voltage divider system to provide a stepped band-data output voltage. **Table 19.4** shows the output voltage at the accessory socket when the radio is switched to the various bands. Notice that seven voltage steps can be used to select different antennas. The ICOM accessory connector pin assignments needed for this project are:

Pin 1 +8 V reference
Pin 2 Ground
Pin 4 Band signal voltage
Pin 7 +12 (13.8) V supply

Yaesu radios provide the band information as binary coded decimal (BCD) data on four lines. Nine different BCD values allow you to select a different antenna for each of the MF/HF bands. **Table 19.5** shows the BCD data from Yaesu radios for the various bands. The Yaesu 8-pin DIN accessory connector pin assignments needed for this project are:

Pin 1 +12 (13.8) V supply
Pin 3 Ground
Pin 4 Band Data A
Pin 5 Band Data B
Pin 6 Band Data C
Pin 7 Band Data D

Fig 19.49 is the schematic diagram for the control box. We will discuss each part of the control circuit later in this description. First, let's turn our attention to the external antenna box.

EXTERNAL ANTENNA BOX

Only the number of control lines going out to the relay box limits the number of antennas this relay box will switch. The unit shown in the lead photo has ten SO-239 connectors, to switch the common feed line to any of nine antennas. Many hams will use an eight-conductor rotator cable (such as *Belden 9405*) to the relay box. Using eight wires, we can control seven relays (six for antennas and one to ground the feed line for lightning protection) with the relay coil B+ supply, as well as a ground lead. The lead photo in Fig 19.48 shows eight relays, and I plan to add two additional relays so I can select between all nine antennas when I install the unit at W1AW. The box contains a 12 V dc voltage regulator (LM7812 or equivalent), which I bolted to the aluminum box. I used an insulating spacer (TO-220 mounting hardware) between the back of the regulator and the box, and applied a layer of heat-sink compound on both sides of the insulating wafer. There is also a connector for power and control lines. I used a DB-15 connector because I plan to add more relays and control lines later, so I can switch between 9 antennas. A DB-9 connector would be suitable for use with the eight-conductor control cable, or you may wish to use a weatherproof connector. **Fig 19.50** shows the relay box schematic diagram.

Since the box will be located outside, I used a weatherproof metal box—a *Hammond Manufacturing*, type 1590Z150, watertight aluminum box. It's about 8½×4¼×3⅛ inches. This is a rather hefty box, meant to be exposed to years of various weather conditions. You can, however, use almost anything.

The coax connectors are mounted so each particular antenna connector is close to the relay, without too much crowding. I used flange-mount SO-239s (although the single hole type will also work). For added weather protection (and conductivity), I applied Penetrox® to the connector flange mount, including the threads of the mounting screws. On the power/control line connector, I used Coax Seal®.

I attached aluminum angle stock on either side of the box to mount it on a tower leg. The U-bolts should be of the proper size to fit the tower leg. They should also be galvanized or made of stainless steel.

Antenna Relays

One of the more difficult parts of this project was the modification of the relays (DPDT Omron LY2F-DC12). To improve isolation, the moveable contacts (armature) are wired in parallel and the connecting wire is routed through a hole in the relay case.

Remove the relay from its plastic case. Unsolder and remove the small wires from the armatures. Carefully solder a jumper across the armature lugs. I used #20 solid copper. Then solder a piece of very flexible wire (such as braid from RG-58 cable) to either armature lug. Obviously, the location of the wire depends on which side you wish to connect the SO-239. You will also need to make a hole in the plastic case that is large enough to accommodate the armature wire without placing any strain on the free movement of the armature. I slipped a length of insulating tubing over this wire to prevent it from shorting to the aluminum box.

The normally open and normally closed contacts are also wired in parallel. This can be done on the lugs themselves. For this, I used #12 solid copper wire.

I mounted the relays in the aluminum box, oriented so they could be wired together without difficulty. (See **Fig 19.51**.) With the exception of the wire used for the relay coils (#22 solid wire), I used #12 solid copper wire for the rest of the connections.

To eliminate the possibility of spikes or "back emf," a 1N4007 diode is soldered across the coil contacts of each relay. In addition, 0.01-µF capacitors across the diodes will reduce the possibility of stray RF causing problems with the relay operation.

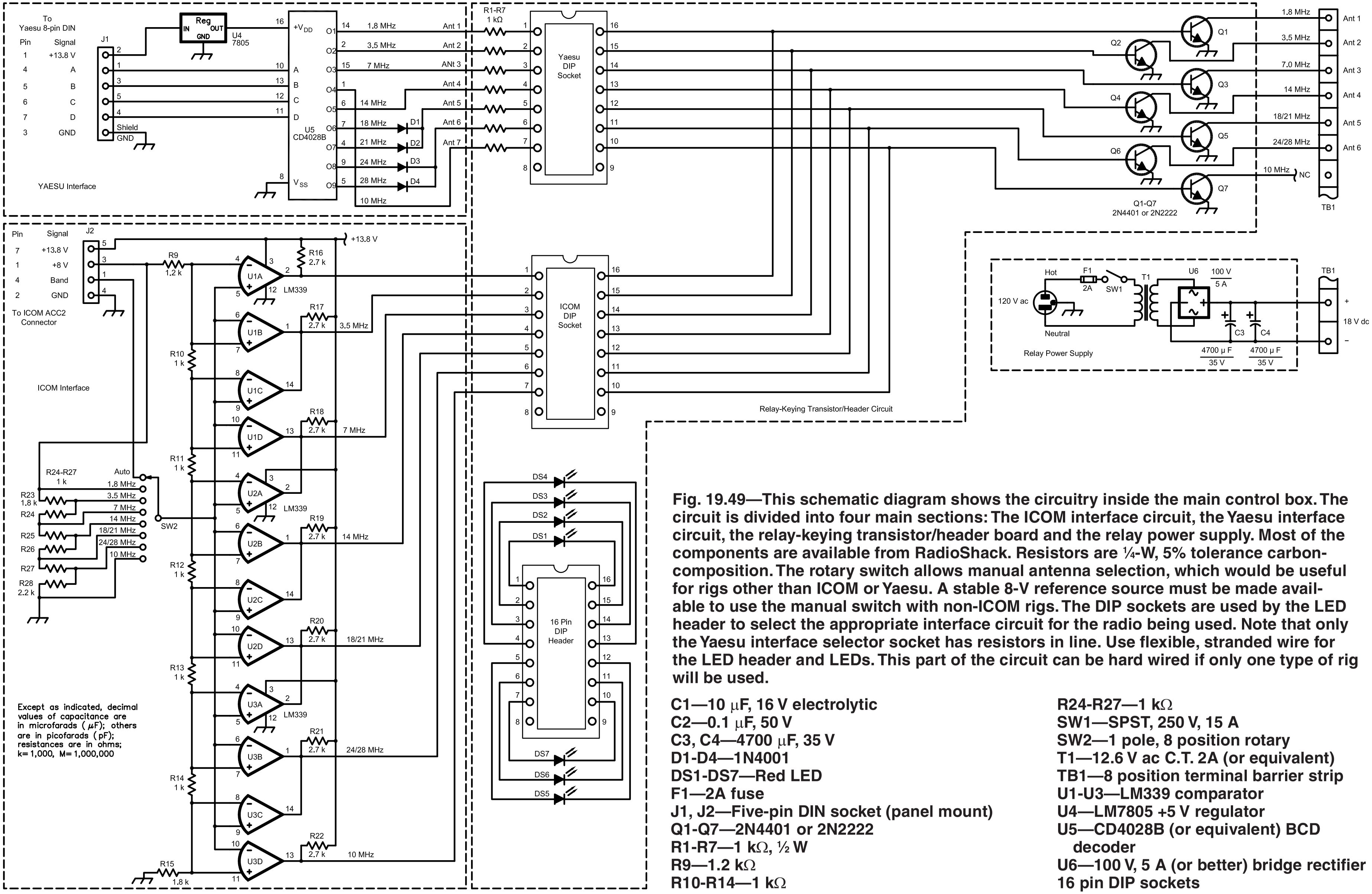


Fig. 19.49—This schematic diagram shows the circuitry inside the main control box. The circuit is divided into four main sections: The ICOM interface circuit, the Yaesu interface circuit, the relay-keying transistor/header board and the relay power supply. Most of the components are available from RadioShack. Resistors are ¼-W, 5% tolerance carbon-composition. The rotary switch allows manual antenna selection, which would be useful for rigs other than ICOM or Yaesu. A stable 8-V reference source must be made available to use the manual switch with non-ICOM rigs. The DIP sockets are used by the LED header to select the appropriate interface circuit for the radio being used. Note that only the Yaesu interface selector socket has resistors in line. Use flexible, stranded wire for the LED header and LEDs. This part of the circuit can be hard wired if only one type of rig will be used.

C1—10 μF, 16 V electrolytic
C2—0.1 μF, 50 V
C3, C4—4700 μF, 35 V
D1-D4—1N4001
DS1-DS7—Red LED
F1—2A fuse
J1, J2—Five-pin DIN socket (panel mount)
Q1-Q7—2N4401 or 2N2222
R1-R7—1 kΩ, ½ W
R9—1.2 kΩ
R10-R14—1 kΩ
R15, R23—1.8 kΩ
R16-R22, R28—2.7 kΩ
R24-R27—1 kΩ
SW1—SPST, 250 V, 15 A
SW2—1 pole, 8 position rotary
T1—12.6 V ac C.T. 2A (or equivalent)
TB1—8 position terminal barrier strip
U1-U3—LM339 comparator
U4—LM7805 +5 V regulator
U5—CD4028B (or equivalent) BCD decoder
U6—100 V, 5 A (or better) bridge rectifier
16 pin DIP sockets
16 pin DIP header

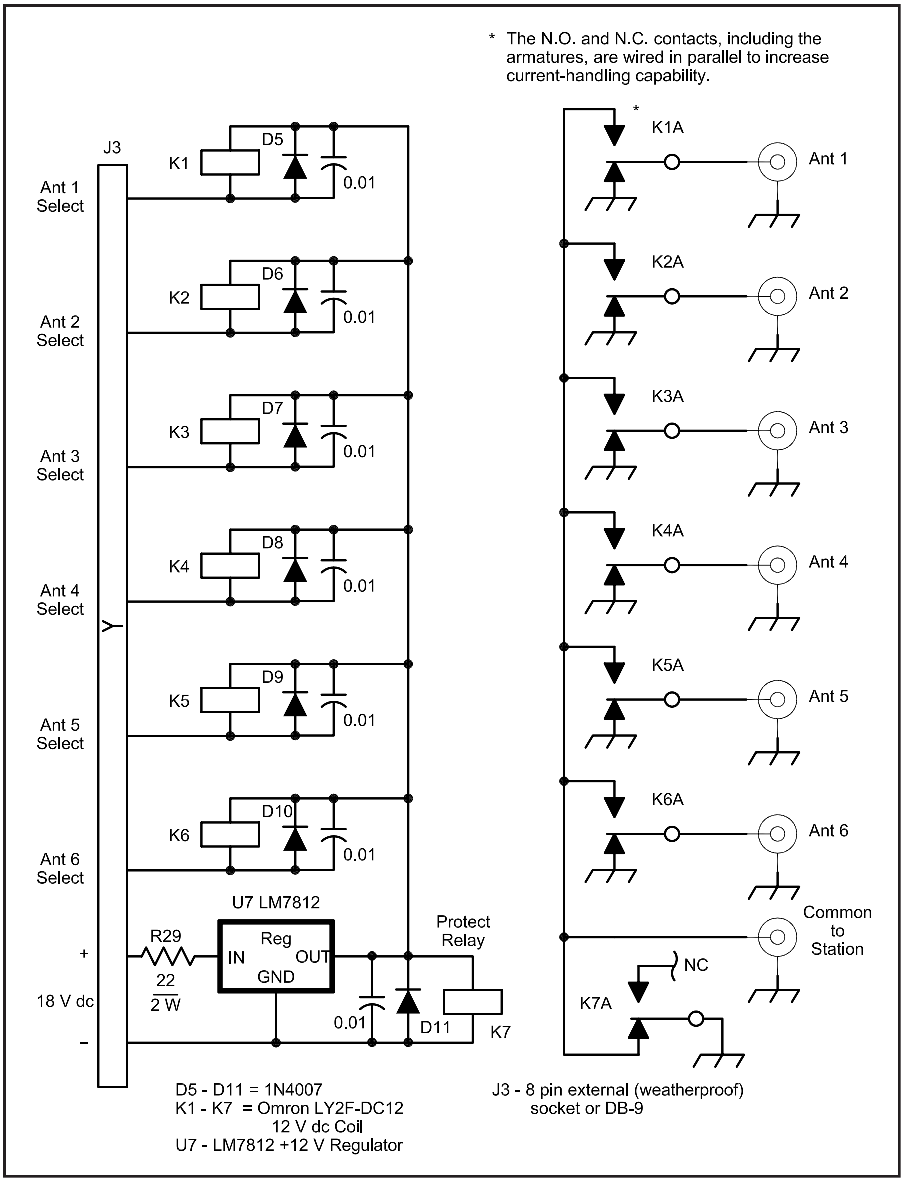


Fig 19.50—The schematic diagram for the external antenna relay box. All relays are DPDT, 250 V ac, 15 A contacts. R29 is used to limit the regulator current. Mount the regulator using TO-220 mounting hardware, with heatsink compound. With the exception of the normally closed and normally open contacts, all wiring is #22 solid copper wire.

D5-D11—1N4007
J3—8 pin external weatherproof connector (or DB-9 with appropriate weather sealant)
K1-K7—Omron LY2F-DC12 with 12 V coil (Allied Electronics Stock number 821-2019)
U7—LM7812 +12 V regulator

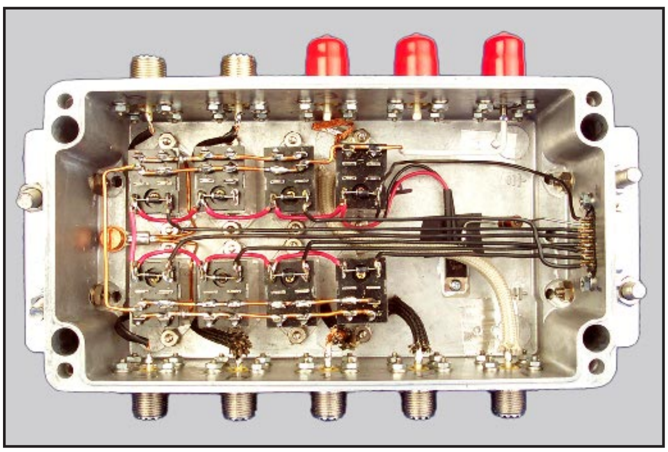


Fig 19.51—This photo shows the external relay box. The LM7812 regulator is mounted to the bottom of the box. The relay normally open and normally closed contacts are wired in parallel using #12 solid copper. Joe Carcia plans to install two additional relays to use this project at W1AW, so he included the extra flange-mount SO-239 connectors when he was drilling holes in the box. Unused SO-239s can be capped off.

Fig 19.52 (below)—This photo shows the inside of the control box. A RadioShack aluminum enclosure holds all of the components. The ICOM interface is built on a two-section RadioShack Universal Project Board (276-159B) and another single section of the same board. The bottom board in the enclosure as well as the right half of the middle section hold the ICOM circuit. The Yaesu interface is built on another section of the Universal Project Board, and is on the left side of the middle section. The top circuit board is a RadioShack Universal Project Board (276-150), which holds the DIP sockets and relay-selection transistors. The circuit boards use point-to-point wiring. All high voltage leads are insulated. The LEDs are mounted in holders on the front panel. The 7805 5-V regulator is mounted on the back panel using TO-220 mounting hardware, with heatsink compound.

Since the cable run from the shack to the tower can be quite long, consideration has to be given to the voltage drop that may occur. The relays require 12 V dc. As such, I installed a 12 V dc regulator in the box, and fed it with 18 V dc (at 2 amps) from the control box. If the cable run is not that long, however, you could just use a 12-V supply.

One of the relays is used for lightning protection. When not in use, the relay grounds the line coming in from the shack. When the control box is activated, it applies power to this relay, thus removing the ground on the station feed line. All the antenna lines are grounded through the normally closed relay contacts. They remain grounded until the relay receives power from the control box.

CONTROL BOX

This is the heart of the system. The 18 V dc power supply for the relays is located in this box, in addition to the Yaesu and ICOM decoder circuits and the relay-control circuitry. All connections to the relay box are made via an 8-position terminal barrier strip mounted on the back of the control box.

The front of the box has LEDs that indicate the selected antenna. A rotary switch can be used for manual antenna selection. The power switch and fuse are also located on the front panel.

The wiring schemes on the Yaesu and ICOM ACC sockets are so different, I opted to have a 5-pin DIN connector for each rig on the control box. Since there is only one set of LEDs, I used an 8-pin DIP header to select the appropriate control circuit for each radio. See **Fig 19.52**.

ICOM CIRCUITRY

This circuit originally appeared in April 1993 *QST*.[2] I've modified the circuit slightly to fit my application. The original circuit allowed for switching between seven antennas (from 160 to 10 meters). The Band Data signal from the ICOM radios goes to a string of LM339 comparators. Resistors R9 through R15 divide the 8-V reference signal from the rig to provide midpoint references between the band signal levels. The LM339 comparators decide which band the radio is on. A single comparator selects the 1.8 or 10 MHz band because those bands are at opposite ends of the range. The other bands each use two comparators. One determines if the band signal is above the band level and the other determines if it is below the band level. If the signal is between those two levels, the appropriate LED and relay-selection transistor switch is turned on.

I used point-to-point wiring on Radio Shack Universal Project Boards to build the various circuit sections. The ICOM interface uses both sections of a 276-159B project board shown at the bottom of the stack in Photo B for U1 and U2. Another section of project board holds U3, located on the right side of the middle section.

The ICOM circuit allows for manual antenna selection. The 8-V reference is normally taken directly from the ICOM ACC socket. If this circuit is to be used with other equipment, then a regulated 8-V source should be provided.

YAESU CIRCUITRY

The neat thing about Yaesu band data is that it's in a binary format. This means you can use a simple BCD decoder for band switching. The BCD output ranges from 1 to 9. In essence, you can switch between 9 antennas (or bands). Since the relay box switches just six antennas, I incorporated steering diodes (D1 through D4 in Fig 19.49) so I can use one antenna connection for multiple bands. In this regard, I opted to use one antenna connection for 17 and 15 meters, and another connection for 12 and 10 meters because the ICOM band data combines those bands. I did not include the control line or relay for a 30-meter antenna with this version of the project.

One section of the RadioShack 276-159B project board holds the Yaesu interface circuit. That board is shown on the left side of the middle layer of the stack shown in Fig 19.52.

DIP Sockets and Header

A RadioShack Universal Project Board, 276-150 holds the DIP sockets along with the relay keying transistors. This board is shown as the top layer in Photo B. The Yaesu socket has 1-kΩ resistors wired in series with each input pin. The other header connects directly to the ICOM circuitry.

The DIP header is used to switch the keying transistors between the ICOM and Yaesu circuitry. The LEDs are used to indicate antenna number. Use stranded wire (for its flexibility) when connecting to the LEDs.

Relay Keying Transistors

Both circuits use the same transistor-keying scheme, so I only needed one set of transistors. Each transistor collector connects to the terminal barrier strip. The emitters are grounded, and the bases are wired in parallel to the two 16-pin DIP sockets. The band data turns on one of the transistors, effectively grounding that relay-control lead. Current flows through the selected relay coil, switching that relay to the normally open position and connecting the station feed line to the proper antenna.

Power supply

The power supply is used strictly for the relays. Other power requirements are taken from the rig used. There is room here for variations on the power supply theme. In this case, I used a 12.6 V, center-tapped, 2 A power transformer. I feed the output to a bridge rectifier, and two 4700 µF, 35-V electrolytics. (I happened to have these parts on hand.)

Notes

[1]"An Antenna Switching System for Multi-Two and Single-Multi Contesting," by Tony Brock-Fisher, K1KP, January 1995 *NCJ*.

[2]"A Remotely Controlled Antenna Switch," by Nigel Thompson, April 1993 *QST*.

[3]"*NA* Logging Program© Section 11"

A TRIO OF TRANSCEIVER/COMPUTER INTERFACES

Virtually all modern Amateur Radio transceivers (and many general-coverage receivers) have provisions for external computer control. Most hams take advantage of this feature using software specifically developed for control, or primarily intended for some other purpose (such as contest logging), with rig control as a secondary function.

Unfortunately, the serial port on most radios cannot be directly connected to the serial port on most computers. The problem is that most radios use TTL signal levels while most computers use RS-232-D.

The interfaces described here simply convert the TTL levels used by the radio to the RS-232-D levels used by the computer, and vice versa. Interfaces of this type are often referred to as level shifters. Two basic designs, one having a couple of variations, cover the popular brands of radios. This article, by Wally Blackburn, AA8DX, first appeared in February 1993 *QST*.

TYPE ONE: ICOM CI-V

The simplest interface is the one used for the ICOM CI-V system. This interface

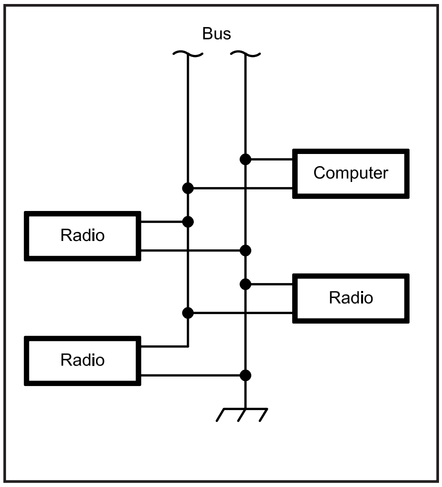


Fig 19.53—The basic two-wire bus system that ICOM and newer Ten-Tec radios share among several radios and computers. In its simplest form, the bus would include only one radio and one computer.

works with newer ICOM and Ten-Tec rigs. **Fig 19.53** shows the two-wire bus system used in these radios.

This arrangement uses a CSMA/CD (carrier-sense multiple access/collision detect) bus. This refers to a bus that a number of stations share to transmit and receive data. In effect, the bus is a single wire and common ground that interconnect a number of radios and computers.

The single wire is used for transmitting and receiving data. Each device has its own unique digital address. Information is transferred on the bus in the form of packets that include the data and the address of the intended receiving device.

The schematic for the ICOM/Ten-Tec interface is shown in **Fig 19.54**. It is also the Yaesu interface. The only difference is that the transmit data (TxD) and receive data (RxD) are jumpered together for the ICOM/Ten-Tec version.

The signal lines are active-high TTL. This means that a logical one is represented by a binary one (+5 V). To shift this to RS-232-D it must converted to –12 V while a binary zero (0 V) must be converted to +12 V. In the other direction, the opposites are needed: –12 V to +5 V and +12 V to 0 V.

U1 is used as a buffer to meet the interface specifications of the radio's circuitry and provide some isolation. U2 is a 5-V-powered RS-232-D transceiver chip that translates between TTL and RS-232-D levels. This chip uses charge pumps to obtain ±10 V from a single +5-V supply. This device is used in all three interfaces.

A DB25 female (DB25F) is typically used at the computer end. Refer to the discussion of RS-232-D earlier in the chapter for 9-pin connector information. The interface connects to the radio via a 1/8-inch phone plug. The sleeve is ground

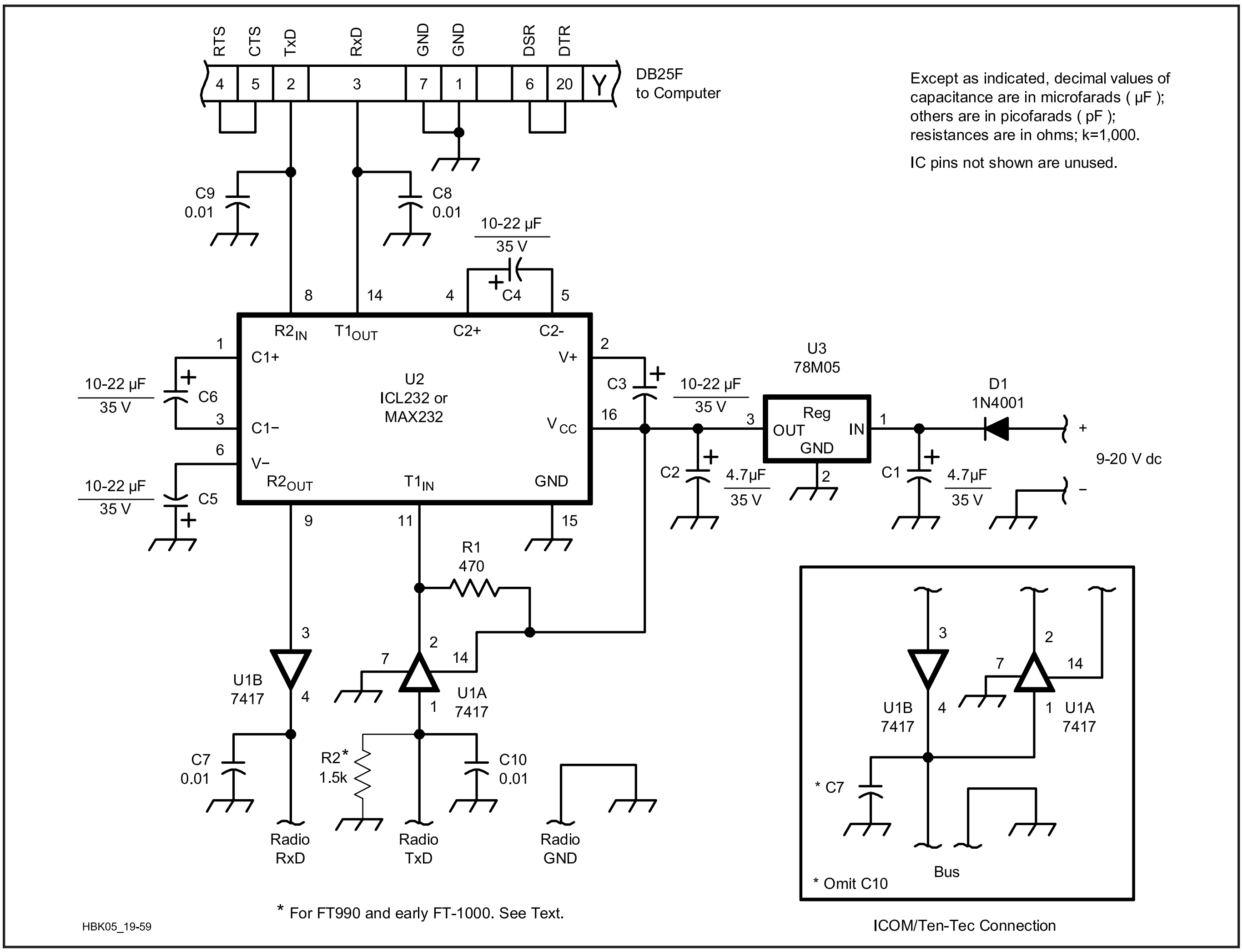


Fig 19.54—ICOM/Ten-Tec/Yaesu interface schematic. The insert shows the ICOM/Ten-Tec bus connection, which simply involves tying two pins together and eliminating a bypass capacitor.

C7-C10—0.01-μF ceramic disc.

U1—7417 hex buffer/driver.

U2—Harris ICL232 or Maxim MAX232.

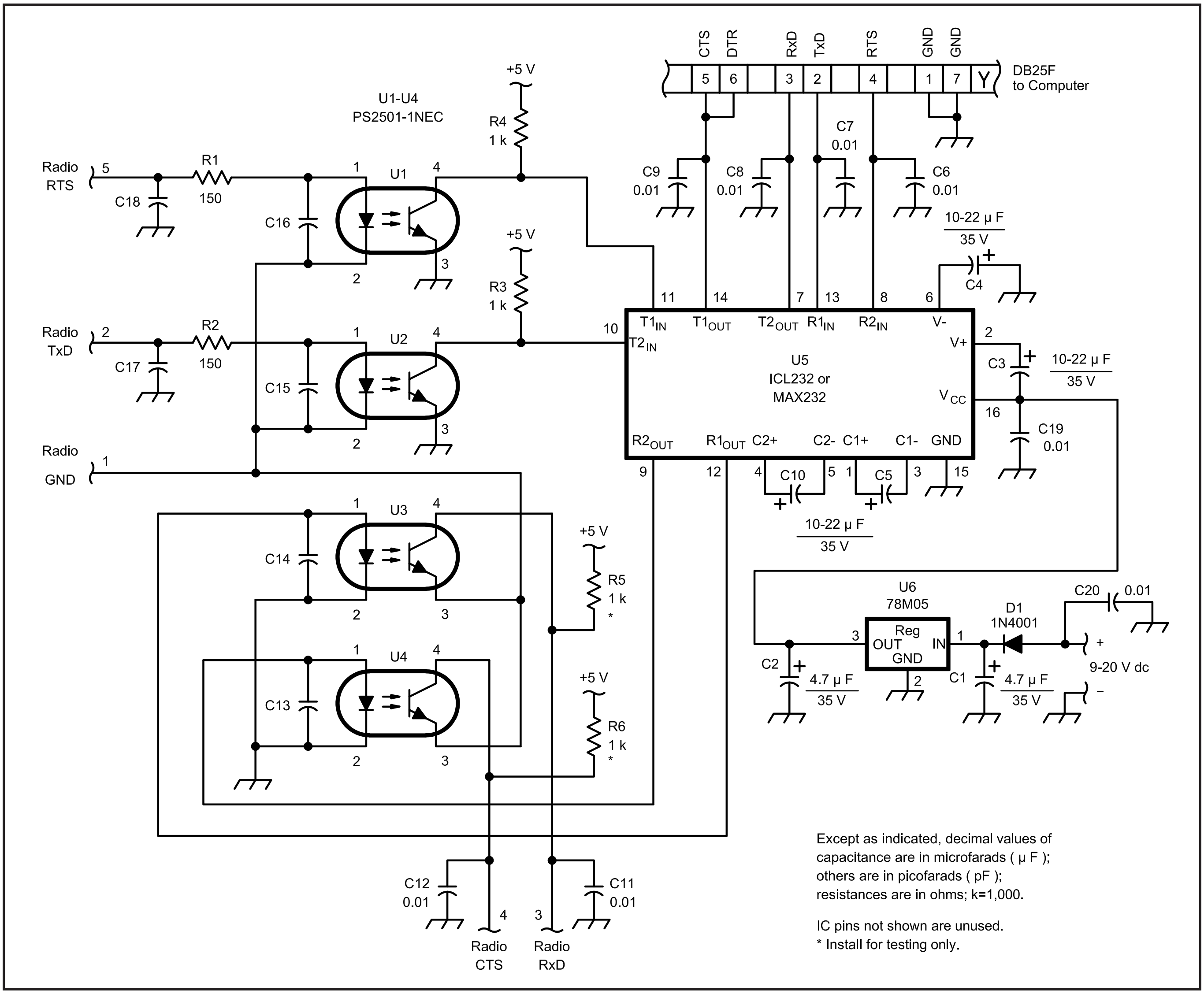


Fig 19.55—Kenwood interface schematic.
C6-C9, C11, C12, C17, C18—0.01-µF ceramic disc.
C13-C16, C19-C21—0.01 µF ceramic disc.
U1-U4—PS2501-1NEC (available from Digi-Key).
U5—Harris ICL232 or Maxim MAX232.

and the tip is the bus connection.

It is worth noting that the ICOM and Ten-Tec radios use identical basic command sets (although the Ten-Tec includes additional commands). Thus, driver software is compatible. The manufacturers are to be commended for working toward standardizing these interfaces somewhat. This allows Ten-Tec radios to be used with all popular software that supports the ICOM CI-V interface. When configuring the software, simply indicate that an ICOM radio (such as the IC-735) is connected.

TYPE TWO: YAESU INTERFACE

The interface used for Yaesu rigs is identical to the one described for the ICOM/Ten-Tec, except that RxD and TxD are not jumpered together. Refer to Fig 19.54. This arrangement uses only the RxD and TxD lines; no flow control is used.

The FT-990 and FT-1000/FT-1000D use an emitter follower as the TTL output. If the input impedance of the interface is not low enough to pull the input below threshold with nothing connected, the FT-990/FT-1000 (and perhaps other radios) will not work reliably. This can be corrected by installing a 1.5 kΩ resistor from the serial out line to ground (R2 on pin 1 of U1A in Fig 19.54.) Later FT-1000D units have a 1.5 kΩ pulldown resistor incorporated in the radio from the TxD line to ground and may work reliably without R2.

The same computer connector is used, but the radio connector varies with model. Refer to the manual for your particular rig to determine the connector type and pin arrangement.

TYPE THREE: KENWOOD

The interface setup used with Kenwood radios is different in two ways from the previous two: Request-to-Send (RTS) and Clear-to-Send (CTS) handshaking is implemented and the polarity is reversed on the data lines. The signals used on the Kenwood system are active-low. This means that 0 V represents a logic one and +5 V represents a logic zero. This characteristic makes it easy to fully isolate the radio and the computer since a signal line only has to be grounded to assert it. Optoisolators can be used to simply switch the line to ground.

The schematic in **Fig 19.55** shows the

Table 19.6
Kenwood Interface Testing

Apply	*Result*
GND to Radio-5	–8 to –12 V at PC-5
+5 V to Radio-5	+8 to +12 V at PC-5
+9 V to PC-4	+5 V at Radio-4
–9 V to PC-4	0 V at Radio-4
GND to Radio-2	–8 to –12 at PC-3
+5 V to Radio-2	+8 to +12 V at PC-3
+9 V to PC-2	+5 V to Radio-3
–9 V to PC-2	0 V at Radio-3

Table 19.7
ICOM/Ten-Tec Interface Testing

Apply	*Result*
GND to Bus	+8 to +12 V at PC-3
+5 V to Bus	–8 to –12 V at PC-3
–9 V to PC-2	+5 V on Bus
+9 V to PC-2	0 V on Bus

Table 19.8
Yaesu Interface Testing

Apply	*Result*
GND to Radio TxD	+8 to +12 V at PC-3
+5 V to Radio TxD	–8 to –12 V at PC-3
+9 V to PC-2	0 V at Radio RxD
–9 V to PC-2	+5 V at Radio RxD

Kenwood interface circuit. Note the different grounds for the computer and the radio. This, in conjunction with a separate power supply for the interface, provides excellent isolation.

The radio connector is a 6-pin DIN plug. The manual for the rig details this connector and the pin assignments.

Some of the earlier Kenwood radios require additional parts before their serial connection can be used. The TS-440S and R-5000 require installation of a chipset and some others, such as the TS-940S require an internal circuit board.

Construction and Testing

The interfaces can be built using a PC board, breadboarding, or point-to-point wiring. PC boards and MAX232 ICs are available from FAR Circuits. Use the *TIS Find* program for the latest address information. The PC board template is available on the CD-ROM.

It is a good idea to enclose the interface in a metal case and ground it well. Use of a separate power supply is also a good idea. You may be tempted to take 13.8 V from your radio—and it works well in many cases: but you sacrifice some isolation and may have noise problems. Since these interfaces draw only 10 to 20 mA, a wall transformer is an easy option.

The interface can be tested using the data in **Tables 19.6, 7** and **8**. Remember, all you are doing is shifting voltage levels. You will need a 5-V supply, a 9-V battery and a voltmeter. Simply supply the voltages as described in the corresponding table for your interface and check for the correct voltage on the other side. When an input of –9 V is called for, simply connect the positive terminal of the battery to ground.

During normal operation, the input signals to the radio float to 5 V because of pullup resistors inside the radio. These include RxD on the Yaesu interface, the bus on the ICOM/Ten-Tec version, and RxD and CTS on the Kenwood interface. To simulate this during testing, these lines must be tied to a 5-V supply through 1-kΩ resistors. Connecting these to the supply without current-limiting resistors will damage the interface circuitry. R5 and R6 in the Kenwood schematic illustrate this. They are not shown (but are still needed) in the ICOM/Ten-Tec/Yaesu schematic. Also, be sure to note the separate grounds on the Kenwood interface during testing.

Another subject worth discussing is the radio's communication configuration. The serial ports of both the radio and the computer must be set to the same baud rate, parity, and number of start and stop bits. Check your radio's documentation and configure your software or use the PC-DOS/MS-DOS MODE command as described in the computer manual.

A SIMPLE SERIAL INTERFACE

A number of possibilities exist for building an RS-232-to-TTL interface level converter to connect a transceiver to a computer serial port. The interface described here by Dale Botkin, NØXAS, is extremely simple, requiring only a few common parts.

Most published serial interface circuits fall into one of the following categories:

- Single chip, MAX232 type. These are relatively expensive, require several capacitors, take up lots of board space and usually require ordering parts.
- Single chip, MAX233 type. This version doesn't need capacitors. Otherwise it shares most of the characteristics of the MAX232 type device, but is even more expensive.
- Transistors. Usually transistor designs use a mix of NPN and PNP devices, four to eight or more resistors, and usually capacitors and diodes. This is just too many parts!
- Other methods. Some designs use series resistors, or TTL logic inverters with resistors. The idea is that the voltages may be out of specification for the chip, but if the current is low enough it won't damage the device. This is not always safe for the TTL/CMOS device. With just a series resistor the serial data doesn't get inverted, so it requires the use of a software USART. It can work, but it's far from ideal.

A SIMPLER APPROACH

The EIA-232 specification specifies a signal level between ±3 V and ±12 V for data. The author looked at data sheets for devices ranging from the decades-old 1489 line receiver to the latest single-chip solutions. Not a single device found actually required a negative input voltage! In fact, the equivalent schematic shown for the old parts clearly shows a diode that holds the input to the first inverter stage at or near ground when a negative voltage is applied. The data sheets show that a reasonable TTL-level input will drive these devices perfectly well.

Relieved of the burden of exactly replicating the PC-side serial port voltages, the interface shown in **Fig 19.56** is designed for minimum parts count and low cost — under $1.

Why use MOSFETs for Q1 and Q2? In switching application such as this, there are several advantages to using small signal MOSFETs over the usual bipolar choices like the 2N2222 or 2N3904. First, they need no base current limiting resistors — the MOSFET is a voltage operated device, and the gate is isolated from the source

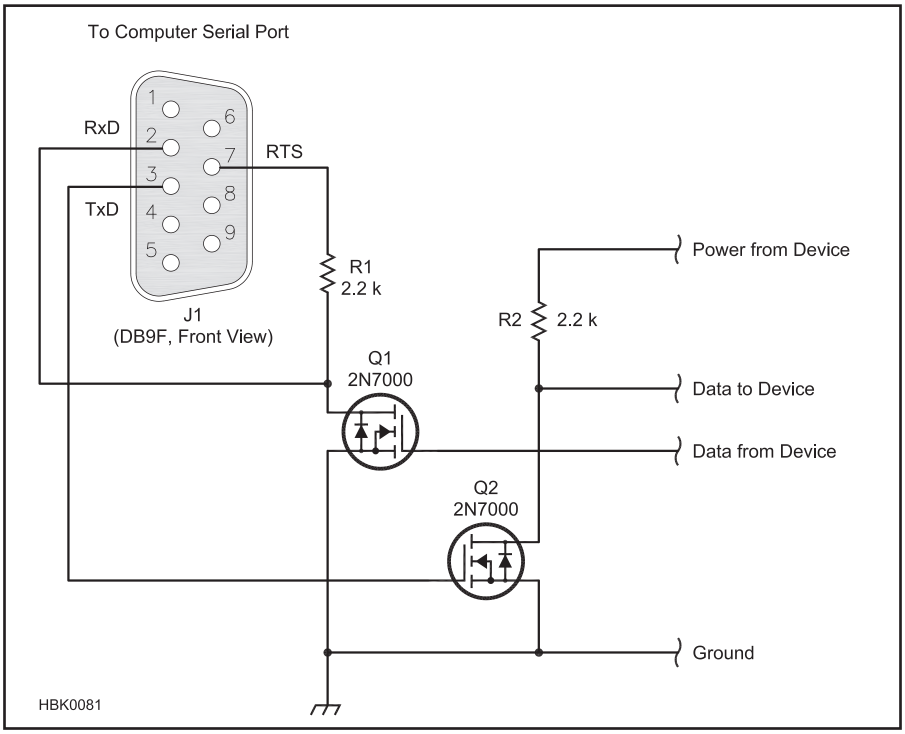


Fig 19.56 — Schematic for the simple serial interface.

J1 — DB9F or connector to fit device serial port. Note that pin assignments for RxD, TxD and RTS are different on DB25 connectors.

Q1, Q2 — Small signal MOSFET, 2N7000 or equiv.

and drain. The gate on a 2N7000 is rated for ±20 V, so you don't need a clamping diode to prevent negative voltages from reaching the gate. They can also be had just as cheaply as their common bipolar cousins. (If sourcing 2N7000s is a challenge in Europe, the BS170 is basically identical except for the pins being reversed.) Now all that is needed is a drain limiting resistor, since the gate current is as close to zero as we are likely to care about.

Q1 gets its input from the TTL-level device. Q1 and R1 form a simple inverter circuit, with the inverted output going to pin 2 (RxD) of the serial connector. The pull-up voltage for RxD comes from pin 7 (RTS) of the serial connector, so the voltage will be correct for whatever device is connected — be it a PC or whatever else you have. Q2 and R2 are another inverter, driven by TxD from pin 3 of the serial connector. The pull-up voltage for R2 should be supplied by the low-voltage device — your radio or microcontroller project.

There you go. Two cheap little MOSFETs, two resistors. The 2.2 kΩ, ¼ W resistors, seem to work with every serial port tried so far. The author has sold several hundred kits using this exact circuit for the serial interface without issues from any users. It's been tested with laptops, desktops, USB-to serial-converters, a serial LCD display and even a Palm-III with an RS-232 serial cable. It's also been used with very slight modifications in computer interfaces for VX-7R and FT-817 transceivers. It's simple, cheap and works great — what more could you ask?

USB INTERFACES FOR YOUR HAM GEAR

Over the past several years, serial ports have been slowly disappearing from computers. The once-ubiquitous serial port, along with other interfaces that were once a basic part of every computer system, has largely been replaced by Universal Serial Bus (USB) ports. This presents problems to the amateur community because serial ports have been and continue to be the means by which we connect radios to computers for control, programming, backing up stored memory settings, contest logging and other applications. Radios equipped with USB ports are rare indeed, and many of the optional computer interface products sold by ham manufacturers are serial-only. The project described here by Dale Botkin, NØXAS, offers a solution.

THE UNIVERSAL SERIAL BUS

So what is USB, and how can it be used in the ham shack? The USB standard came about during the early 1990s as a replacement for the often inconvenient and frustrating array of serial, parallel, keyboard, mouse and various other interfaces commonly used in personal computer systems. The idea is to use a single interface that can handle multiple devices sending and receiving different types of data, at different rates, over a common bus. In practice, it works quite well because of the very well defined industry specification for signal levels, data formats, software drivers and so forth.

At least two and sometimes as many as six or more USB ports are now found as standard equipment on nearly all new computer systems. Support for USB ports and generic USB devices is built into most operating systems including *Windows*, *Linux*, *Solaris*, *Mac OS* and *BSD* to name a few. USB use has spread beyond computers, and the standard USB "B" or the tiny 4-conductor "Mini B" connectors are now found on all manner of electronic devices including cameras, cell phones, PDAs, TVs, CD and DVD recorders, external data storage drives and even digital picture frames. USB is indeed becoming *universal*, as its name implies — everywhere, it seems, except for Amateur Radio gear!

The EIA-232 serial interface specification we have used for decades is just that — an electrical interface specification that defines voltage levels used for signaling. The asynchronous serial format most commonly used with serial ports defines how data is sent over whatever interface is being used. Any two devices using the same protocol and format can talk to each other, whether they are both computers, both peripheral devices (like printers, terminals or TNCs) or any combination. All that is required is the proper cable and the selection of matching parameters (speed, data bits, handshaking) on each end of the connection.

This is not the case with USB devices. USB uses a tiered-star architecture, with well defined roles for the host controller (your computer) and devices. Devices cannot communicate directly with each other, only with a host.

See **Fig 19.57**. At the top of the stack is the *host controller device* (HCD), usually your computer, which controls all communication within the USB network. The computer may have several host controllers, each with one or more ports. The host controller discovers, identifies and talks to up to 127 devices using a complex protocol. No device can communicate directly with another device; all communication is initiated and controlled by the host controller. As a result, you cannot simply connect two USB devices together and expect them to communicate. (Some USB printers will talk directly to digital cameras because the printer also has a host controller built in.)

As you have probably already figured out, moving from serial to USB is not a simple matter of converting voltage levels or even data formats. USB devices all need some embedded "smarts," usually in the form of either a dedicated USB interface chip or a microcontroller using firmware to talk to the USB host. Where we could once use simple transistor circuits to adapt RS-232 serial to the TTL voltage levels used by many radios, we now must add the complete USB interface into the picture.

The USB specification is freely available and well documented, and there are books dealing with designing the software to use the interface. If you're starting from scratch it is a very daunting task to even understand exactly how USB works, let alone design and build your own USB-equipped device. If you're willing and dedicated enough, you can implement your own USB device using a fairly broad range of available microcontrollers. There are also dedicated function chips that implement a complete USB interface — or parts of it — in one or two devices.

Fortunately, several manufacturers have stepped up to make using USB relatively easy for the experimenter. One of the most commonly used solutions is from Future Technology Devices International (FTDI). FTDI manufactures a line of USB interface chips that plug into the Universal Serial Bus on one side and present a serial or parallel interface on the other side. The chips are quite versatile and are commonly used to add USB functionality to a wide range of devices ranging from cell phones to USB-to-serial cables. They are also available in several forms such as plug-in modules with a USB connector and the interface logic, all on a small PC board with pins that can be plugged into a standard IC socket.

CONSTRUCTION

This project uses an FT232R series chip from FTDI to bridge the USB interface from your computer to a TTL-level serial interface that can be adapted to use with many different ham rigs. The chip has built-in logic to handle the USB interface, respond to queries and commands from the computer, and send and receive serial data. By using special drivers available from FTDI (and built into *Windows* and many other systems), it can appear to your programs as a standard serial COM port.

Once the conversion to serial data is done, all that remains is to adapt the signals to the particular interface used by your equipment. In many cases, this serial data can simply be connected directly to the rig using the appropriate connector. In others it may require some extra circuitry to accommodate various interface schemes used by manufacturers. The most common is an open-collector bus type interface, which is easily accommodated using a few inexpensive parts.

Construction of this project can be handled in a couple of different ways. The FT232R series chips are available from various suppliers at low cost. Unfortunately they are only available in SSOP and QFLP surface mount packages that can be difficult to work with unless you use a custom printed circuit board. (An additional letter is tacked onto the part number to identify the package. For example, the FT232RL uses a 28-pin SSOP package.) There are SSOP-to-through-hole adapter boards available, but they are relatively expensive and still require some fine soldering.

Fig 19.58 — The FTDI TTL-232R cable simplifies construction.

Fortunately FTDI also sells a solution in the form of the TTL-232R (**Fig 19.58**). It incorporates a USB "A" connector, an FT232RQ chip and the required power conditioning on a tiny PCB encapsulated in plastic, all about the size of a normal USB connector. A 6-ft long cable terminates in a 6-position inline header that provides ground, +5 V, and TTL level TxD, RxD, RTS and CTS signals.

You can connect these signals directly to your own microprocessor projects and have an "instant" USB connection. You can also build a variety of interface cables or boards for use with different radios. This arrangement is ideal for the experimenter and the person who might need several different interfaces for use with several different rigs — like many of us! The cost of the TTL-232R cable is quite reasonable, in fact lower than the cost of having a prototype PCB made to build your own equivalent device. Of course that option is still available to those who need more flexibility.

USING USB IN THE SHACK

With the USB-to-serial conversion handled so easily, the only remaining task is to adapt the TTL-level serial interface of the FT232R to the interface used by your particular radio. In the case of some rigs, such as the Yaesu FT-817, Kenwood TM-G707A and many others, it's simply a matter of wiring up the right connector, as shown in **Fig 19.59**.

For communicating with individual ICOM and Ten-Tec rigs, one simple solu-

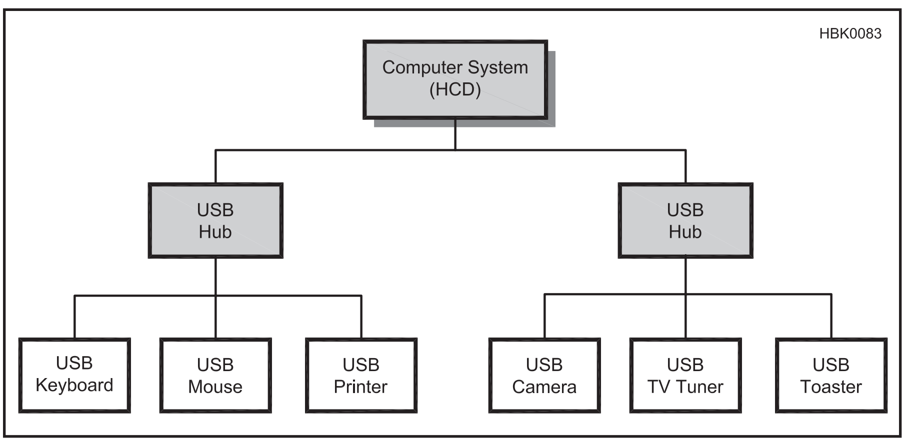


Fig 19.57 — Typical USB architecture.

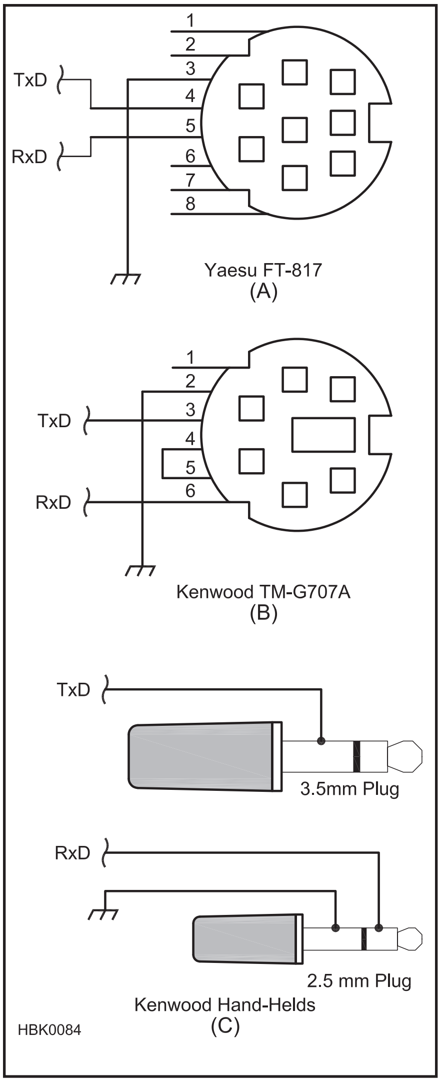


Fig 19.59 — Using the FTDI USB-to-serial interface with radios some radios is as simple as wiring up a connector. Connections for the Yaesu FT-817 are shown at A, the Kenwood TM-G707A (PG-4 type) at B, and Kenwood hand-helds (PG-5 type) at C. Ground, RxD and TxD connections are made to the 6-pin connector on the TTL-232R cable.

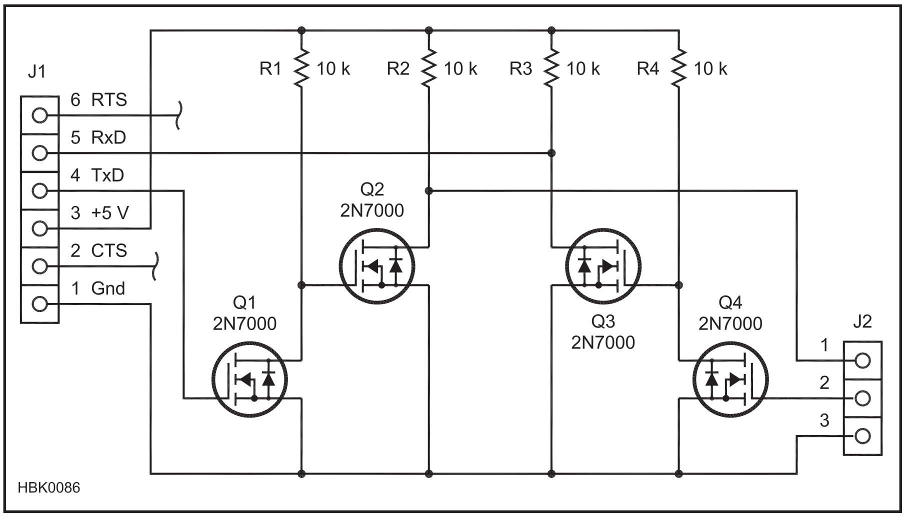


Fig 19.61 — Schematic of the basic interface buffer board.

J1 — 6-pin, 0.1-inch pitch header to match TTL-232R cable.
J2 — 3-pin header to match radio cable.
Q1-Q4 — Small-signal MOSFET, 2N7000, BS-170 or equiv.
R1-R4 — 10 kΩ, ¼ W resistor.

tion is to simply connect the transmit and receive data signals together and wire up a ⅛-inch stereo plug an shown in **Fig 19.60**. This will work with a single device connected, but lacks the open-collector drivers needed to be compatible with attaching multiple devices to the CI-V bus.

A Little More Versatility

Many hand-held transceivers use a single data line for both transmit and receive. This method is very similar to CI-V, but requires an open-collector or open-drain configuration for a single device. Some additional buffering is required to provide an interface to the rig.

Fig 19.61 shows the design of the general-purpose buffer board for use with various radios. This circuit simply provides a noninverting, open-drain buffer for data in each direction. Adapters for various rigs can be plugged into J2 with no further changes needed. Use of MOSFETs instead of their bipolar counterparts simply reduces the parts count. No additional resistors are needed to limit base current, as you would need when using 2N2222 or similar transistors. Parts can be mounted on a small project board as shown in **Fig 19.62**.

This arrangement turns out to be extremely versatile and will work with CI-V, FT-817, Yaesu VX-series handhelds, and the other rigs the author was able to test as well. All that is required is the proper adapter cable from the base interface board to the rig. Some examples are shown in **Fig 19.63**.

Adding PTT

Handling PTT is quite simple, and it can be done either with or without isolation

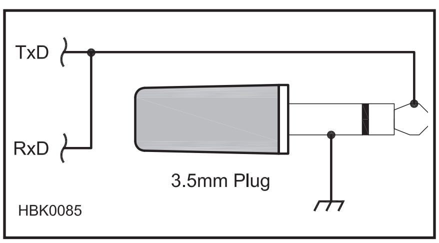


Fig 19.60 — The transmit and receive data signals can be connected together for use with a single Ten-Tec or ICOM CI-V device.

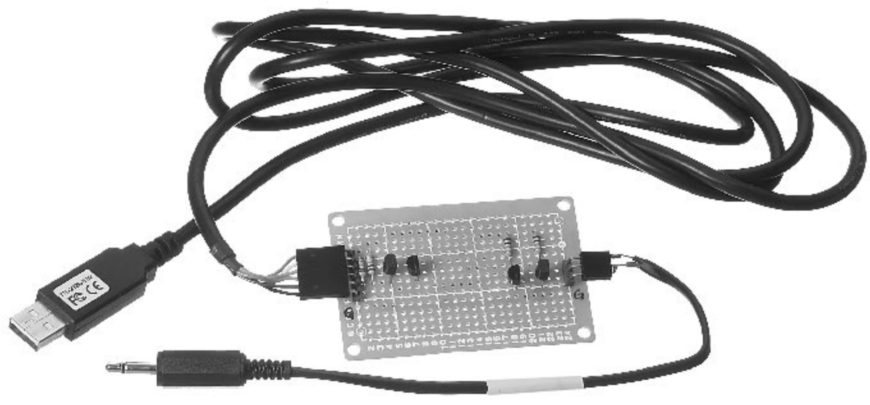


Fig 19.62 — The completed buffer board. Adapter cables for various radios plug into the header on the right edge of the board.

as shown in **Fig 19.64**. For a non-isolated PTT line, we can simply drive the gate of a 2N7000 or similar MOSFET from the FT232RL's RTS output. If you prefer an optically isolated PTT output, all you need to add is one resistor and an optocoupler such as a 4N27. Note that the TTL-232R provides a 100 Ω resistor in series with the RTS signal (the same is true for TxD), so a smaller value resistor (R1) can be used for the optocoupler's input than you would normally use.

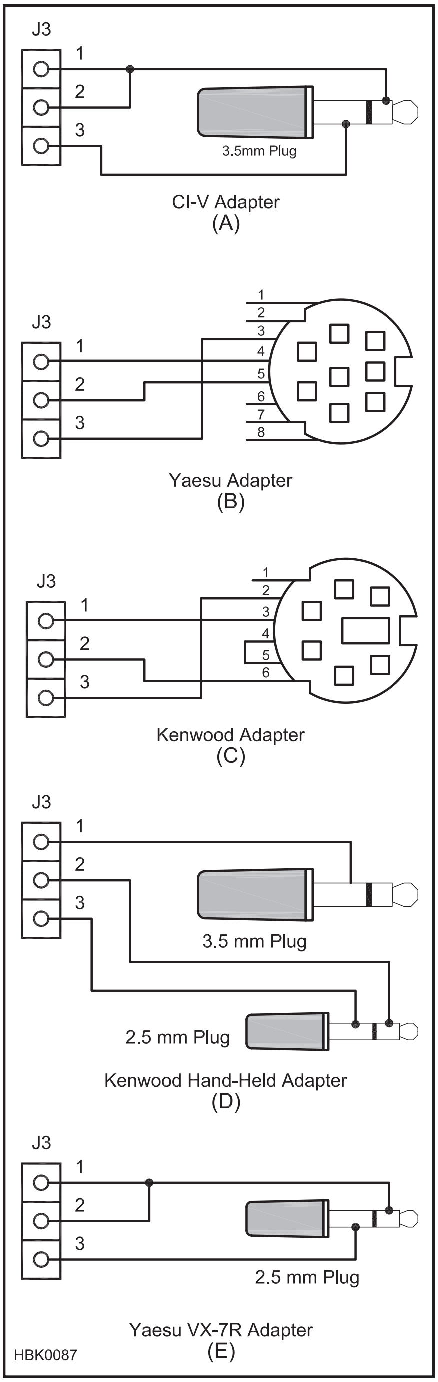


Fig 19.63 — Adapters for using the buffer board with various radios. J3 matches the adapter used on the buffer board.

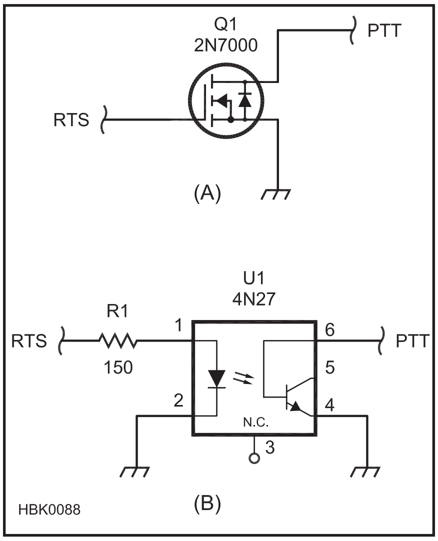


Fig 19.64 — PTT can be added either without isolation (A) or with an optoisolator (B).

While connecting the data lines directly to the rig is a suitable solution for many applications, some Kenwood HF rigs require a different approach. They require inverted TTL-level data, and may experience "hash" noise from the computer when not using an isolated interface. **Fig 19.65** shows an optically isolated method of connecting to a Kenwood rig such as the TS-850S. Note that this has not been tested but the design is similar to numerous examples of serial interfaces for the TS-850S and similar radios.

It's probably only a matter of time before we start seeing the tiny USB "Mini B" connector appear on new ham gear. It has become inexpensive and easy to add USB to pretty much any product, and as serial ports become more and more rare the manufacturers will eventually face overwhelming consumer demand to switch. In the meantime, you can do a little homebrewing and use your new, serial port free computer to talk to all of your ham gear for very little cost.

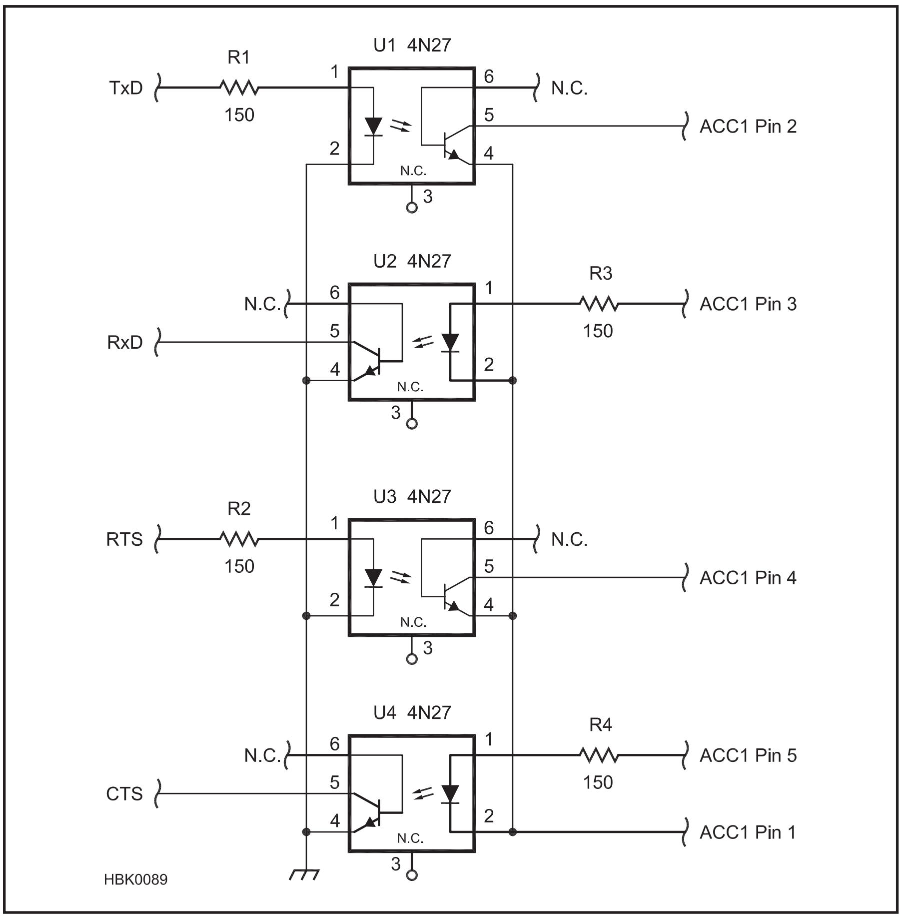


Fig 19.65 — Isolated Kenwood interface for the TS-850S and similar HF transceivers requiring inverted TTL-level data and isolated lines.

A QRP T-MATCH ATU

An antenna tuning unit (ATU) is very useful if you are a licensed radio amateur or a short-wave listener. The purpose of an ATU is to adjust the antenna feed impedance so that it is very close to the 50-Ω impedance of the receiver or transmitter, a process known as *matching*.

When used with a receiver, an ATU can dramatically improve the signal-to-noise ratio of the received signal. On transmit, the antenna must be matched to the transmitter so that the power amplifier operates efficiently. The QRP tuner shown in **Fig 19.66** is also presented from *Practical Projects*, courtesy of the RSGB.

DESIGN

The basic ATU design is called a *T-Match*; you can see the basic shape of the letter 'T' reflected in the layout formed by the components C1, C2 and L1 in **Fig 19.67**. The circuit will match the coaxial output of the transceiver to an end-fed antenna or to a coaxial cable feed to the antenna. This design also uses a BALUN (BALanced to *un*balanced) transformer for use with antennas using twin-wire balanced feeder. This unit will handle up to 5 W and operates over the frequency range of 1.8 to 30 MHz.

CONSTRUCTION

Inductor L1 is wound on a T-130-2 powdered-iron toroid. The inductor is tapped and fixed to the tags (terminals, in American English—*Ed.*) of a 12-way rotary switch. Taps are formed by making a loop about 1 cm long in the wire and twisting it tightly. The loops are scraped clean of enamel and tinned with solder ready to be soldered onto the tags of the 12-way rotary switch. If the loops are about 1 cm long, it is just possible to bend them to fit the tabs of the switch without having to extend them with short wires.

The balun is wound with two wires twisted together; known as BIFILAR WINDING. These two wires can be twisted together (before winding on to the toroid) by fixing one pair of ends in a vice, the other ends in a small hand drill. The drill is then slowly rotated so that the two

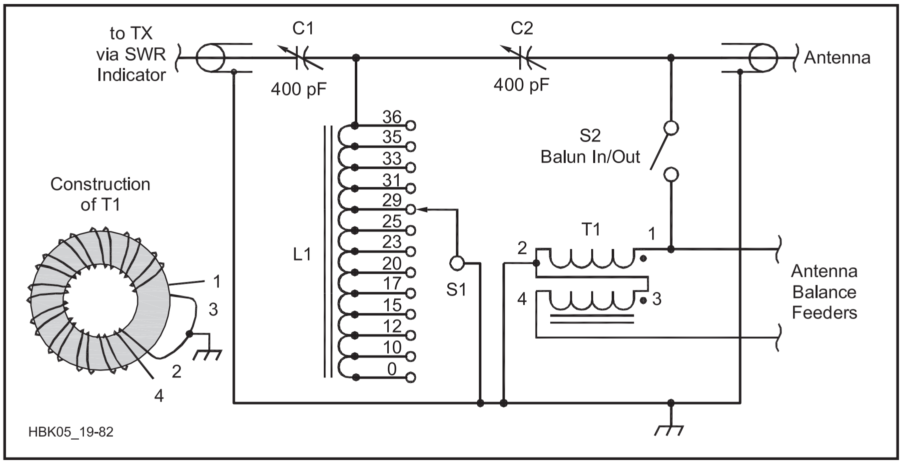


Fig 19.67—Basic circuit of the T-Match ATU.

Table 19.9
Components list

Capacitors

C1, 2 200 - 200 pF

Inductors

L1 T-130-2 powdered iron toroid with total 36 turns of #22 SWG enameled copper wire, tapped at 10, 12, 15, 17, 20, 23, 26, 29, 31, 33 and 35 turns from the earth end

T1 12 bifilar turns of #26 SWG enameled copper on FT-50-43 toroid

Additional items

S1 1-pole 12-way rotary switch

S2 SPST toggle switch

RF connectors, SO239 sockets or similar (see text)

Aluminium or die-cast metal box

Three plastic knobs for capacitors and switch

Two 4mm sockets for balanced antenna connection

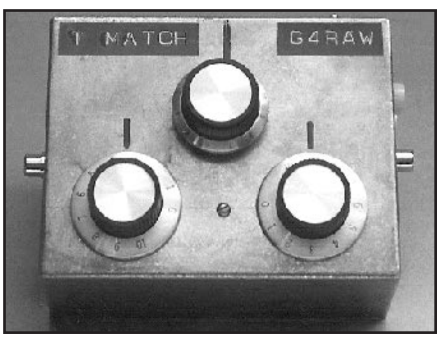


Fig 19.66—The completed T-Match ATU.

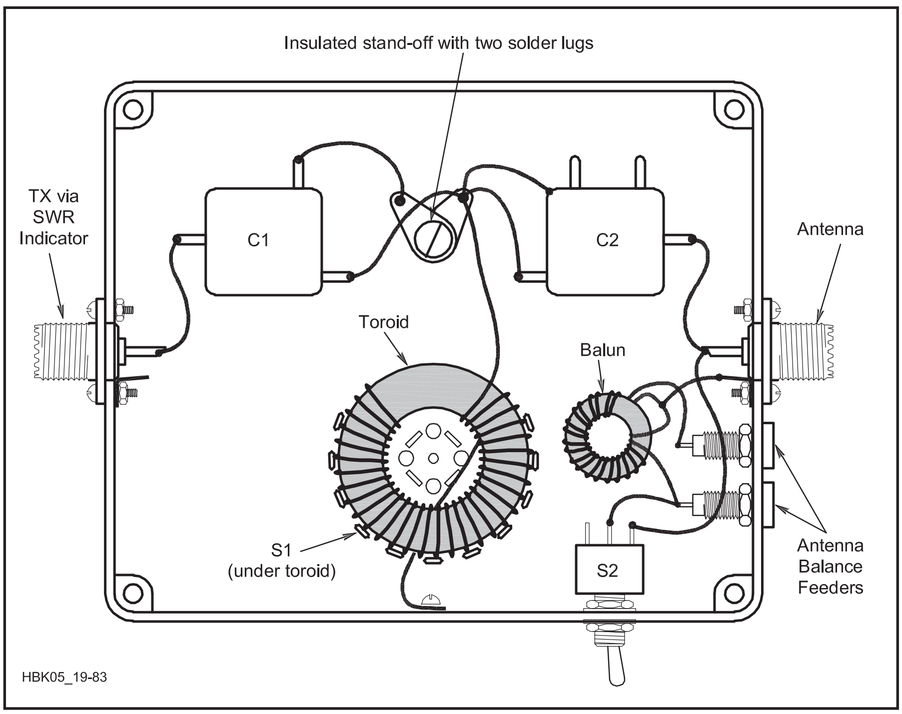


Fig 19.68—Internal view of the ATU. A small metal box makes a suitable housing.

wires are twisted together neatly. Identify the start and finish of each winding with a buzzer and battery or an ohmmeter. The finish of the first winding is joined to the start of the second, as shown in Fig 19.67.

The two capacitors are twin 200-pF polyvaricon capacitors with both gangs connected in parallel to give 400 pF max. You have to drill holes in the box for the control shafts of the capacitors and the switch and the RF sockets. The switch is fixed using a nut on the control shaft and the two capacitors are fixed using adhesive (hot melt glue is preferred). Take care not to let any tags from the capacitors touch the box as both sides of both capacitors are not earthed.

An appropriate RF socket, such as a SO-239, BNC or phono socket may be used—the choice is yours and should suit your existing equipment. 2-4 mm sockets may be used for the balanced output. See **Fig 19.68** for layout. It is a good idea to make a graduated dial for each of the three control knobs. An alternative is to use calibrated knobs. You can then calibrate the settings of the three controls so that they can rapidly be reset when you change frequency bands.

OPERATION

The best indication of optimum matching can be achieved using an SWR bridge; the ATU controls are adjusted sequentially and several times for minimum SWR. If used for receive only, the best antenna-to-receiver match can be achieved by adjusting the controls for maximum signal.

A SWITCHED ATTENUATOR

How many times has a signal been too strong for the experiment you wish to carry out? It could be from an oscillator on the bench or from signals from an antenna overpowering a mixer. This attenuator will solve those problems and is presented from *Practical Projects*, courtesy of the RSGB.

ATTENUATORS

When designing the attenuators, we must take into account the possibility of poor shielding. There is hardly any point in designing a 20-dB attenuator when the leakage around the circuit is approaching this value. It is also important to decide on the accuracy required. If it is intended to do very accurate measurements, the construction has to be impeccable, but for comparisons between signals such precision is not essential.

The most useful attenuator is a switched unit covering 0 to 60 dB (or more) in 1-dB steps. This is not as difficult as it first seems because, by summing different attenuators, we can obtain the value we need. It takes only seven switches to cover 65 dB. The seven values of attenuation are 1, 2, 4, 8 and 10 dB, and two at 20 dB; these can be switched in or out at will. As an example, for 47 dB, switch on the two 20-dB pads plus the 4, 2 and 1-dB pads.

Construction

The resistor values shown in **Fig 19.69** determine the attenuator's accuracy at around 5%. This is done for practical reasons, to make use of available ¼ W, 1% resistor values. For example, if we wanted to make the attenuation value of the 4-dB section exactly 4 dB, the resistor values would have to be 220.97 and 23.85 Ω. The values used are 220 and 24 Ω, giving an attenuation value of 4.02 dB. The switches must have low capacitance between the contacts, and simple slide switches are the best selection. J1 and J2 must be coaxial jacks (builder's choice).

The attenuator is housed in a box made from epoxy PCB material. The top and sides are cut to size and soldered into a box. It is easier to cut the switch holes prior to making the box. After the box has been constructed, screens made from thin brass shim should be cut and soldered between the switch holes to shield each section. Next, the switches are fitted and the unit wired up. When this is done, the unit is checked and a back cover, securely earthed to the box, is fitted.

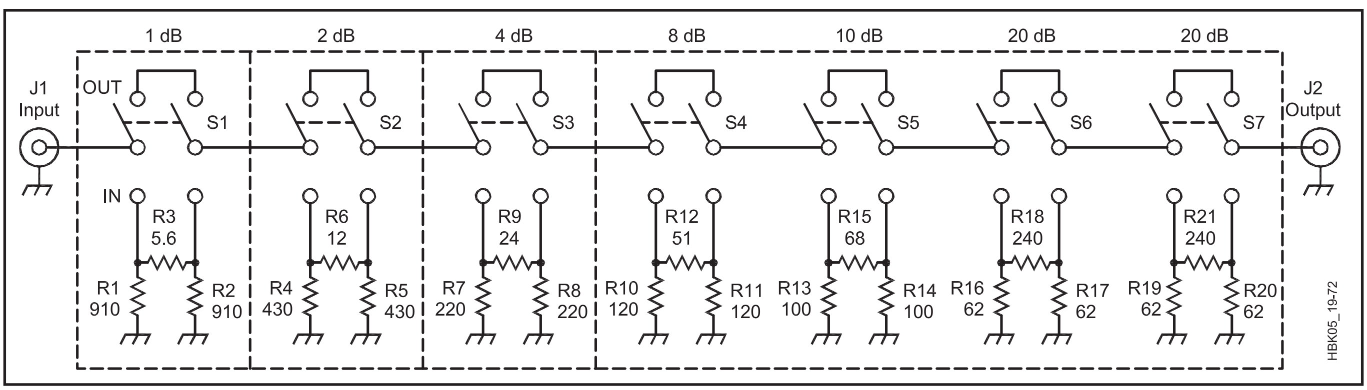


Fig 19.69 — The attenuator consists of seven pi network sections, so-called because each pad (eg, R1, R3 and R2) resembles the Greek letter pi (π). Input and output impedances are 50 Ω.

AN AUDIO INTERFACE UNIT FOR FIELD DAY AND CONTESTING

For Field Day and multioperator contest operation, it's sometimes desirable for a logger or observer to listen to a transceiver in addition to the main operator. The project shown in **Fig 19.70**, originally described in June 2008 *QST* by John Raydo, KØIZ, makes two person operation more efficient. Dual stereo headphone jacks, volume controls and external speaker jack are provided, as well as jacks for both dynamic and electret microphones and an intercom feature for operator and logger to more easily communicate via headset mics.

Fig 19.70 — Front view of the audio interface box. Operator controls are on the left and logger controls are on the right.

There are times when the operator and logger need to talk, for example to resolve a call-sign ambiguity. With this unit the operator can initiate two-way intercom communication by pressing an intercom switch. The logger, however, can only initiate one-way intercom to the operator. This is so that the logger can't inadvertently cut off the operator during a contact. To respond, the operator presses his intercom switch. In both instances radio volume is reduced for "talk-over" during intercom use.

Both operator and logger need headsets with microphones. The unit has two intercom switches plus jacks for optional foot switches for hands-free operation. Here's how it works:

Operator communicating with logger: Operator presses and holds INTERCOM switch (on unit or foot switch). This disconnects the operator mic from radio. Both mics are connected via internal amplifier to both earphones. Radio volume is reduced (adjustable using the RADIO VOL control). Operator and logger can talk.

Logger communicating with operator: Logger presses and holds INTERCOM switch (on unit or foot switch). Logger mic is connected via internal amplifier to both earphones. Operator mic remains connected to radio and can still transmit on the radio. Radio volume is reduced. The operator can respond to the logger by pressing the operator INTERCOM switch.

Circuit Description

The circuit diagram shown in **Fig 19.71** is designed for use with dynamic microphones such as the HC4 and HC5 elements used in various Heil headsets, or for Heil iC type headsets that use an electret element. The electret mic jacks supply the required dc for that type microphone. Mic bias current is limited to less than 1 mA to avoid damage if a dynamic mic is accidentally plugged into the wrong jack. The higher electret output is reduced by resistors R11 and R28.

Both mics have preamplifiers with 34 dB gain set by the ratio of the resistors R4/R3 and R9/R8. The VOLUME controls, R14 and R15, allow operator and logger to individually adjust their intercom volumes. The preamps feed a single 2 W intercom amplifier.

Pressing the operator INTERCOM switch transfers the operator mic from radio to intercom preamp and amplifier via relay K1 and then to the headphones via relay K2. Pressing the logger INTERCOM switch will also activate K2 (but not K1). During intercom use audio from the radio passes through control R20 (RADIO VOL) at reduced volume. Switch S2 allows selection of both left and right sides of the headphones or only the right side, for the intercom. The operator and logger each have individual headphone VOLUME controls R24 and R25 (the operator control also has POWER switch S1).

Construction

The unit shown is built in a PacTec plastic box. Front panel controls include two headphone volume controls, two intercom volume controls, radio volume and L+R / R switch and two intercom switches.

The back panel (**Fig 19.72**) has ¼ inch stereo jacks for two pair of headphones, two 3.5 mm mono jacks for headset microphones, 3.5 mm stereo and mono jacks for connection to the radio's headphone and mic jacks, one stereo 3.5 mm jack for a speaker, two 3.5 mm mono jacks for foot switches and a jack for a 9 V power supply (a wall wart is okay). A 12 V dc supply can be substituted if K1 and K2 are changed to 12 V type and the LED series resistors R22 and R23 are changed to 1 kΩ.

Other than controls and jacks most components are mounted on a RadioShack prototype circuit board attached with four ½ inch spacers and shown in the box in **Fig 19.73**. A suggested parts layout is shown in **Fig 19.74**. Point to point wiring is used between circuit board pads and is not particularly critical.

Connections to both mic jacks and radio mic jack use shielded cable to reduce hum and risk of interference pickup. Connect the shields on the operator and radio mic cables to a common ground point on the circuit board near U1. Bypass capacitors C8, C9 and C16 and resistor R6 are mounted at their respective jacks. Rub-on lettering, followed by a couple light coats of clear plastic spray, helps give a professional appearance.

Connecting an external speaker in addition to two headphones might be too much of a load for some radios and cause reduced volume and/or distortion. Try an inexpensive amplified computer speaker plugged into the audio interface external speaker jack to reduce the load.

You will need two cables to connect the unit to your radio. A 3.5 mm mono plug-to-plug shielded cable for the mic circuit is compatible with a Heil headset mic. A 3.5 mm stereo plug-to-plug cable (RadioShack 42-2387 plus 274-367 adapter) works for the earphones.

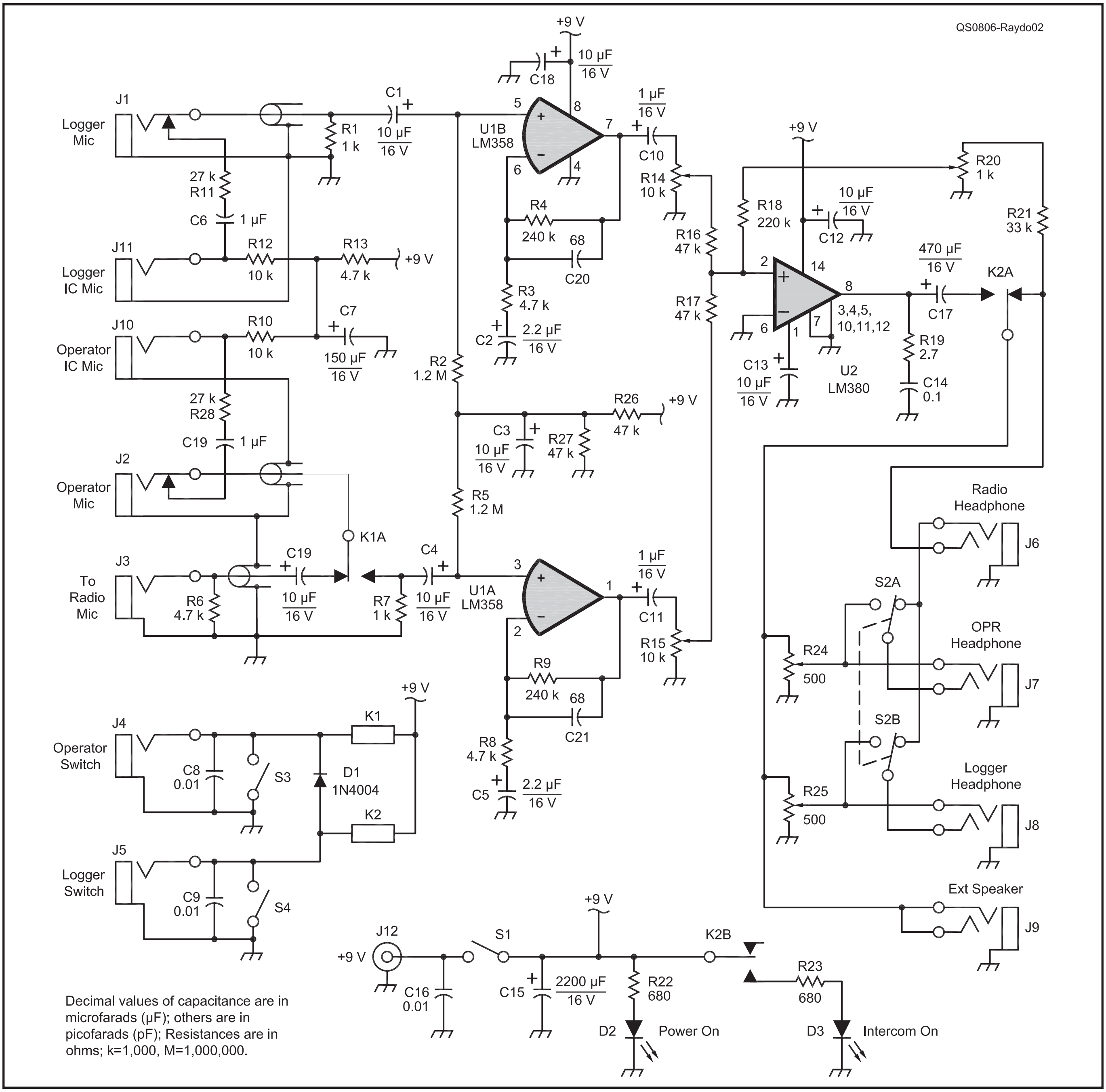


Fig 19.71 — Schematic diagram and parts list for the audio interface unit. Mouser parts are available at www.mouser.com, RadioShack parts at www.radioshack.com.

C1, C3, C4, C12, C13, C18, C19 — 10 µF, 16 V electrolytic capacitor.
C2, C5 — 2.2 µF, 16 V electrolytic capacitor.
C6, C10, C11, C19 — 1 µF, 16 V electrolytic capacitor.
C7 — 150 µF, 16 V electrolytic capacitor.
C8, C9, C16 — 0.01 µF, 50 V ceramic capacitor.
C14 — 0.1 µF, 50 V ceramic capacitor.
C15 — 2200 pF,16 V electrolytic capacitor.
C17 — 470 µF, 18 V electrolytic capacitor.
C20, C21—68 pF ceramic capacitor.
D1 — Diode, 1N4001 or 1N4004.
D2 — Red LED.
D3 — Yellow LED.
J1-J5, J10, J11 — 3.5 mm mono jack, Mouser 16PJ135.
J6, J9 — 3.5 mm stereo jack, Mouser 161-3402E..
J7, J8 — Three conductor ¼ inch jack, Mouser 502-12B.
J12 — 2.5 mm jack for dc input, Mouser 502-712A.
K1, K2 — DPDT relay, 9 V coil, Mouser 653-G6A-274P40-DC9.
R1, R7 — 1 kΩ, ⅛ W resistor.
R2, R5 — 1.2 MΩ, ⅛ W resistor.
R3, R6, R8 — 4.7 kΩ, ⅛ W resistor.
R4, R9 — 240 kΩ, ⅛ W resistor.
R10, R12 — 10 kΩ, ⅛ W resistor.
R11, R28 — 27 kΩ, ⅛ W resistor.
R13 — 4.7 kΩ, ⅛ W resistor.
R14, R15 — 10 kΩ potentiometer, Mouser 31JA401-F.
R16, R17, R26, R27 — 47 kΩ, ⅛ W resistor.
R18 — 220 kΩ, ⅛ W resistor.
R19 — 2.7 Ω, ⅛ W resistor.
R20 — 1 kΩ potentiometer, Mouser 31JN301-F.
R21 — 33 kΩ, ⅛ W resistor.
R22, R23 — 680 kΩ, ⅛ W resistor.
R24, S1 — 500 kΩ potentiometer with SPST switch, Mouser 31VM205-F.
R25 — 500 Ω, potentiometer, Mouser 31VA205-F.
S2 — DPDT toggle switch, Mouser 10TC260.
S3, S4 — SPDT long handle, center off, momentary contact switch, Mouser 10TA445.
U1 — Dual op amp IC, LM358, Mouser 595-LM358P
U2 — Audio amplifier IC, LM380 or NTE740A, Mouser 526-NTE740A.
Project box, 8 × 4.25 × 2.25, Mouser 616-72004-510-000
Circuit board, RadioShack 276-158.

Fig 19.72 — Rear view of the audio interface box. Operator jacks are on the right, logger on the left. Connections to the radio are in the center.

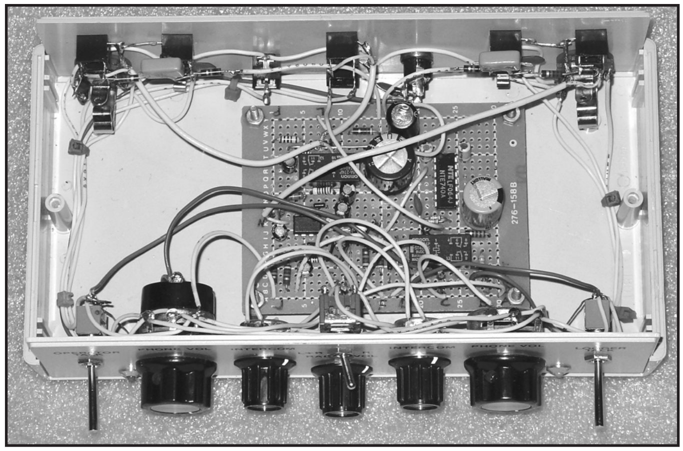


Fig 19.73 — Inside view of the audio interface box. A RadioShack project board is used for most components.

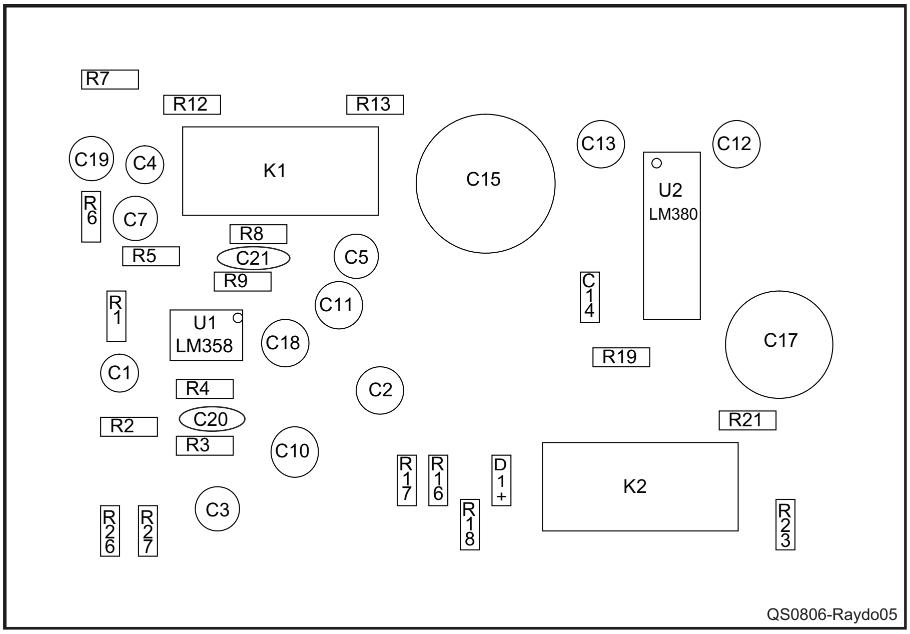


Fig 19.74 — Suggested parts layout for audio interface box.

A REMOTE POWER CONTROLLER

Some older solid-state transceivers such as the Ten-Tec Triton IV will run from battery power but lack a switch to turn the radio on or off from the front panel. You have to either unplug the power cord or remove the cables from the battery. As designed, the power switch for the Triton IV controls the 120 V ac supply primary circuit in the matching model 262 power supply. The power switch does not, and cannot, handle the more than 20 A at 13.8 V dc the transceiver requires.

Mike Bryce, WB8VGE, developed the remote power controller shown in **Fig 19.75** to solve the problem. It was originally described in September 2007 *QST*. The front power switch on the radio operates normally, but it now controls a large power relay. This relay sends +13.8 V dc to the radio from any source, be it a battery or an ordinary dc power supply.

What Makes it Tick

The relay, K1, is controlled by power MOSFET Q1. The MOSFET is controlled by turning on the radio's power switch, which sends 13 V to the gate of Q1 through R3, a current limiter. Resistor R2 discharges the gate of Q1 when the power switch is turned off. Resistor R4 keeps the gate low, preventing Q1 from turning on from noise or stray voltage. Resistor R4 serves another purpose too. It allows about 2 mA of current to flow through the radio's power switch. This is enough to clean the contacts of the power switch.

Capacitor C1 charges via K1's coil, causing closure of the relay contacts. Once K1 has pulled in, however, it doesn't require the same amount of current to keep the contacts closed. Resistor R1 provides just enough current to hold the contacts in after C1 charges. The result is a savings of over half the required holding current. For the Omron relay specified, the nominal coil current is 90 mA. With R1 in series, the current drops to a battery saving 40 mA. While it does not sound like a lot, of savings, over the course of several hours or days this adds up to quite a few ampere-hour savings.

DS1 lights up when the relay pulls in. (If minimum power consumption is your goal you can leave out R5 and the LED.) Diode D1 clamps the EMF produced when K1's coil drops.

Filter capacitors C2, C3 and C4 keep

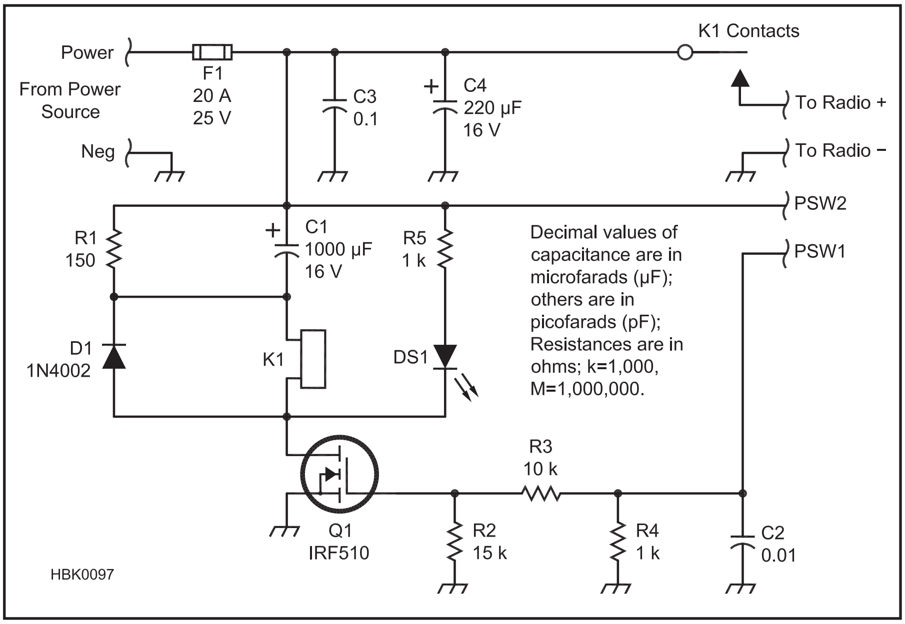


Fig 19.75 — Schematic of the remote power controller.

C1 — 1000 µF, 16 V electrolytic.
C2 — 0.01 µF.
C3 — 0.1 µF.
C4 — 220 µF, 16 V electrolytic.
D1 — 1N4002 rectifier.
DS1 — LED.
F1 — 20 A automotive blade-type fuse.
K1 — T-90 Omron relay, Mouser 653-G8P1A4TP-DC12.
Q1 — IRF510 power FET.
R1 — 150 Ω, 1 W.
R2 — 15 kΩ, ¼ W.
R3 — 10 kΩ, ¼ W.
R4, R5 — 1 kΩ, ¼ W.

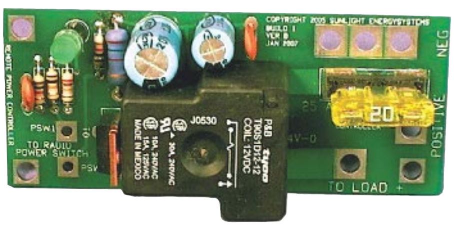


Fig 19.76 — The completed PCB for the remote power controller.

stray RF and other noise out of the circuit. F1 is a 20 A ATC "blade" type fuse for safety. Every high current dc line should be fused, but in the case of the old Triton IV an additional magnetic circuit breaker should be installed as well.[1]

Building Your Own RPC

The remote power controller shown in **Fig 19.76** is built on a double sided, plated through printed circuit board. A kit of parts and PC board are available.[2] You could easily build one using perf board or even "dead bug" style.

There is nothing fancy or special required. You can change the values of most of the parts without any problems, although the value of R1 should be left alone. Too much resistance and K1's coil won't stay in. Too low and you'll eat up battery power in the coil. I found that 150 Ω was about right for the relay specified.

You could substitute a Potter & Brumfield T90 relay for the one specified (Mouser 655-T90S1D12-12). To save some money, an open frame version will work too (Mouser 655-T90N1D12-12).

The power MOSFET is sensitive to damage from static discharge, so handle carefully. Once installed in the PCB it's quite robust.

After assembly, make a few simple tests to make sure the circuit is working correctly. You'll need a 13 V dc power supply with current limiting. Don't start out trying to use a large battery (like a car battery), because if you have a wiring error such a battery can supply enough current to burn copper traces right off the board!

Apply power to the circuit. Nothing should happen. Now, short the PSW1 and PSW2 pads. The relay should click in and the LED should light. A quick check on the output pad labeled TO RADIO with your VOM should show +13 V dc referenced to ground. Remove the short between PSW1 and PSW2 and the relay should drop out and the LED should go dark.

To ensure that the current saving function created by R1 and C1 is working, temporarily unsolder one end of R1 and remove this lead from the PCB. Now short PSW1 and PSW2. The relay will click in and then drop out. This shows that C1 has been charged via the relay initially, but with R1 out of the circuit there's no holding current available. Solder the loose end of R1 back in the circuit.

The assembly fits in a small plastic project box from RadioShack. Finish up with your favorite dc connector.

Anytime you need to control a high current, low voltage load from a distance, the remote power controller can do it. For example, you might use one to control dc fans, low voltage emergency lighting, or a VHF "brick" amplifier.

Notes

[1]Older Ten-Tec transceivers did not have SWR foldback circuitry. These transceivers relied on the matching power supply to protect the finals. When the SWR is high the finals draw more current than they should, tripping the power supply. Ten-Tec required a fast acting magnetic circuit breaker (AIR PAK T11-1-20.0A recommended) to protect the finals while running from a battery or any non Ten-Tec power source.

[2]A complete kit of parts for the RPC with the printed circuit board, or just the PC board, are available from SunLight Energy Systems. See **www.theheathkitshop.com**.

AUDIBLE ANTENNA BRIDGE

The audible antenna bridge (AAB) shown in **Fig 19.77** was designed by Rod Kreuter, WA3ENK. Originally described in June 2007 *QST*, this project would help a visually impaired ham, but sighted hams will also find it very useful. (For example, tuning a mobile screwdriver antenna while you're driving.) The AAB is rugged and easy to use, both in the harsh light of day and in the dark of night. It's also inexpensive to build, and a kit is available.[1]

An absorptive type of SWR meter, the AAB is used to indicate how close the match is between your transmitter and your antenna. Its output is a tone whose pitch is proportional to SWR. It also sends the SWR value in Morse code.

Unlike most SWR meters on the market, this one actually absorbs power from your transmitter while you're tuning, helping to protect your transmitter during tune-up. Many transmitters have SWR foldback capability and will decrease the output power if the antenna match is poor, but some do not.

By absorbing power in the AAB, no matter what you do at the antenna port, the transmitter never sees an SWR greater than 2:1. The trade-off is that 75% of your transmitter power ends up as heat in the bridge, so you need to switch out the AAB after you have tuned your antenna.

Theory of Operation

The AAB works on a principle taken right from the *ARRL Antenna Book*. The bridge consists of four impedances, or arms. See **Fig 19.78**. If three of the arms are 50 Ω resistors and the fourth is an antenna (or an antenna and tuner combination), then the bridge will be balanced when the antenna port is also 50 Ω. Diodes D1 and D2 sample the forward and reverse voltages, respectively. A peripheral interface controller (PIC) with a 10 bit analog to digital converter (A/D) digitizes these voltages and calculates the SWR.

The SWR is used to control a hardware pulse width modulator that produces the output tone. It's also used by the Morse code routine to send the actual value of SWR, at 15 WPM with 5 WPM spacing.

The power that the AAB can handle during tune-up is a function of the resistors used in the three reference arms of the bridge. The 30 W noninductive resistors, R1-R3, are made by a number of companies but are not cheap. The bridge resistors must be noninductive. Don't use wire wound resistors!

Antenna tuning should be done with minimal power, and the AAB will work down to about 1 W. The 30 W resistors will handle tune-ups with about 60 W or perhaps 100 W for a short time. If you always remember to turn down your transmitter power, and you tune up quickly, the bridge resistors could be perhaps 5 W for normal rigs and 1 W for QRP rigs.

Building the AAB

A PC board is a nice way to build the AAB, but you could easily construct such a simple circuit using ugly construction. Keep the wires short in the RF section. See **Fig 19.79**.

Use a heat sink for the noninductive resistors. Like many power devices, the power rating depends on getting the heat out! These resistors get really hot running at 10 or 20 W. See **Fig 19.80**. Use a big heat sink with heat sink compound, give yourself plenty of room in the cabinet and drill some holes to let the heat escape.

Switch S1 chooses TUNE/OPERATE and S2, the INQUIRE button, is used to report on various conditions, such as the SWR value in Morse code. You can eliminate the TUNE/OPERATE switch, but remember to remove the AAB from your feed line after tuning up.

To use the AAB in a QRP station, you may want to reduce resistors R4 and R5. They are sized so that a 25 W transmitter will not saturate the analog to digital converter (ADC) on the PIC when using fresh batteries (more on this later). A good value for a 5 W transmitter would be about 20 kΩ. So long as the voltages at pin 12 and pin 13 of U1 are below the battery voltage, the system will work fine.

Powering the AAB

To save power the AAB uses a sleep mode. If you haven't pushed the INQUIRE button for about 5 minutes, the AAB will go to sleep after sending the letter N for "night night." During sleep the current draw is about 2 μA. Pushing the switch while it's sleeping will wake up the AAB and it will send the letter U ("up").

The first four prototypes used four AAA batteries and a low-dropout 4.7 V regulator. This made for a nice stiff supply and very good battery life, with only one problem. Even though the PIC uses less than 2 μA during sleep, the regulator uses 500 μA. Battery data says that alkaline AA batteries will last 6 months at this level and AAA batteries about half that long. Consider adding an ON/OFF switch if you go this route.

The other option is to use batteries without a regulator. Normally you couldn't get away with this without providing a separate voltage reference for the ADC in the PIC. In this case it doesn't matter as much because SWR is a ratio of two voltages.

What does matter is the battery voltage with respect to the voltage produced by the RF signal. Diodes D1 and D2 rectify the RF and produce a dc voltage proportional to RF power. This voltage is divided by resistors R4, R6 and R5, R7. The voltage at the ADC inputs of the PIC, pins 12 and 13, must be less than the power supply voltage. With a regulated supply this isn't much of a problem and if you're careful it can also work with unregulated batteries.

Microchip recommends that these parts be run on 2.5 to 5.5 V if you need the 10 bit ADC to be accurate. Many battery combinations will provide this, but consider lithium batteries instead of alkaline. The voltage from an alkaline battery begins to fall very early in its life and continues at a downward slope until it is exhausted. A lithium battery, on the other hand, provides a nearly constant voltage throughout its useful life. A 3.6 V AA size lithium should last a few years, but with the lower output voltage you may want to reduce R4 and R5. The final prototype used three AAA lithium batteries (each about 1.7 V when new), with no regulator or ON/OFF switch, which should last at least two years.

Fig 19.77 — Front view of the audible antenna bridge.

U1's ADC converter will saturate at some level. With new batteries, let's say this level is 25 W when the power supply is 4.5 V. When the power supply has fallen to 3.5 V, the RF level that will saturate the converter will be 15 W. So if you find that the output of your rig, which used to be fine, is now saturating the ADC, it's time to change batteries.

Using the AAB

Connect your transmitter to the INPUT and your antenna/tuner to the OUTPUT. Turn your transmit power down to 5 or 10 W and put S1 in the TUNE position. Wake the AAB up by pushing the INQUIRE button. Key your transmitter in a mode with some carrier power. The AAB should start to produce a steady tone. Adjust your tuner or antenna for the lowest tone pitch. Press the INQUIRE button for the numeric SWR value.

When the AAB is operating normally, it produces a tone proportional to SWR. The tone ranges from 250 Hz at an SWR of 1.0:1, rising to 4450 Hz at an SWR of about 15:1. Errors can occur and at times the AAB can't make a measurement. If an error occurs, either a high pitched tone or no tone is produced. Pushing the INQUIRE button will give you more information. Five different conditions can occur:

Normal operation. A tone proportional to SWR is produced. Press INQUIRE and a two digit SWR value is sent separated by

[1]A kit of parts including a printed circuit board is available from Q-Sat, 319 McBath St, State College, PA 16801. The price is currently $30, postpaid. PC boards are available for $7 postpaid and a programmed PIC is available for $6 postpaid. Source code for an unprogrammed PIC is available on the ARRL Web site as *aabpic2.hex* at **www.arrl.org/files/qst-binaries/kreuter0607.hex**.

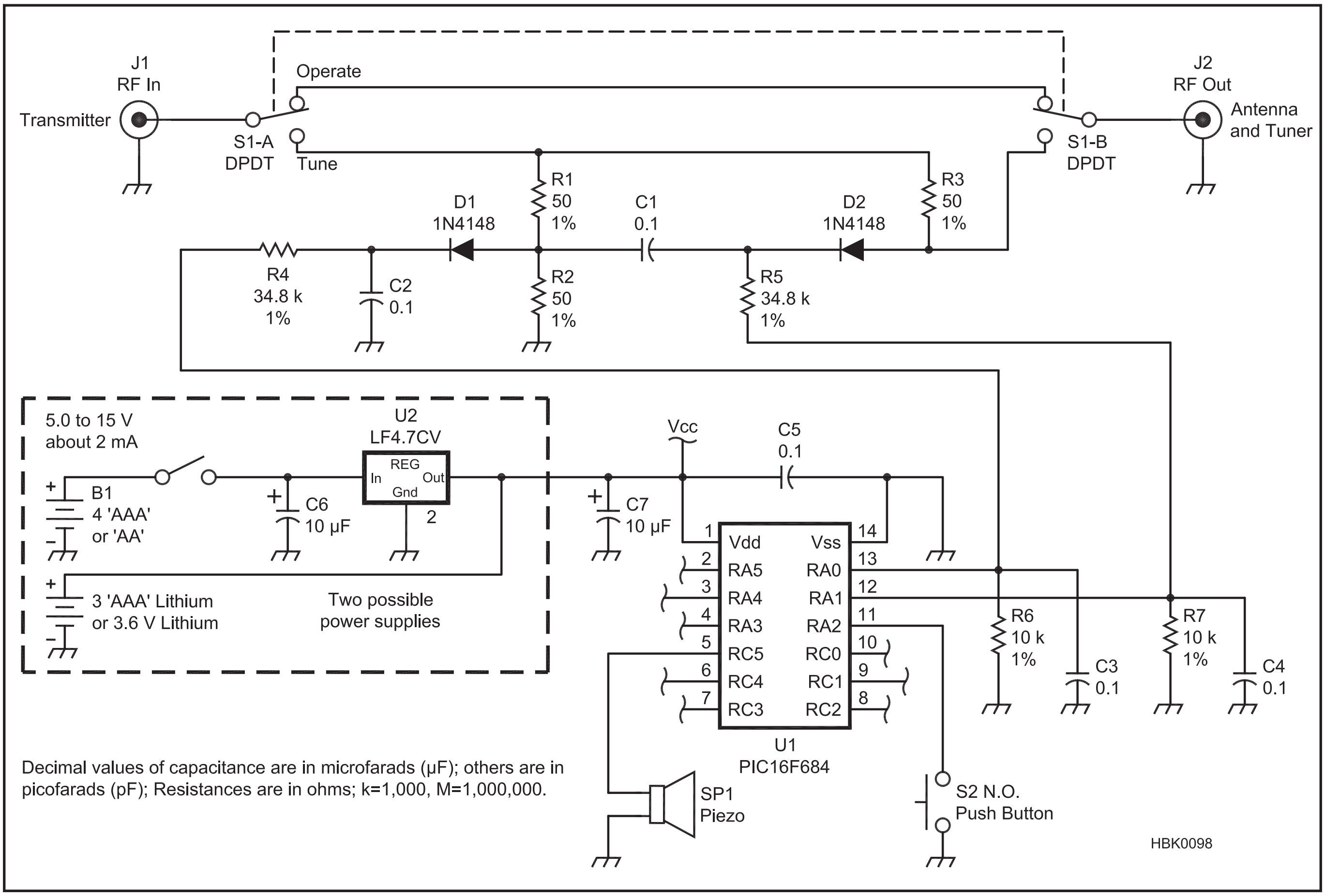


Fig 19.78 — Schematic and parts list of the AAB.

C1-C5 — Capacitor, ceramic 0.1 µF.
C6, C7 — Capacitor, electrolytic, 10 µF, 25 V.
D1, D2 — Diode, 1N4148.
J1, J2 — SO-239 UHF coaxial jack.
R1 -R3 — Resistor, 50 Ω, 1%, 30 W Caddock noninductive (Mouser 684-MP930-50).
R4, R5 — Resistor, 34.8 kΩ, 1%.
R6, R7 — Resistor, 10 kΩ, 1%.
S1 — Switch, DPDT (Digi-Key SW333-ND).
S2 — Switch, momentary contact (Mouser 612-TL1105LF250Q).
SP1 — Piezoelectric buzzer EFB-RD24C411 (Digi-Key P9924-ND).
U1 — PIC16F684 (Digi-Key PIC16F684-1/P-ND). Must be programmed before use. See Note 1.
U2 — Regulator, LF4.7CV (Mouser 511-LF47CV).

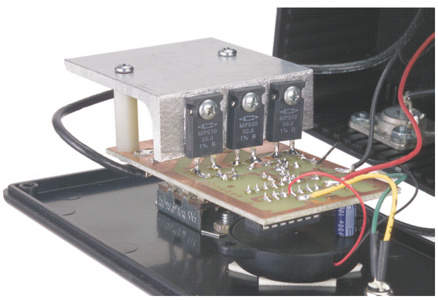


Fig 19.79 — Close-up view of three CaddockTO-220 style bridge resistors mounted on the heat sink.

Fig 19.80 — Interior view of the AAB, showing the battery pack at the bottom of the enclosure.

the letter R (Morse for the decimal point character).

Error 1. The forward power is too low for a reliable measurement. No tone is produced. INQUIRE button sends letter L (low).

Error 2. Forward power is too high (almost saturating the ADC). A pulsing tone proportional to SWR is produced. However, if the ADC is saturated this value might be meaningless. INQUIRE button sends letter S (saturated).

Error 3. SWR is greater than 9.9:1. A tone proportional to SWR is produced. INQUIRE button sends letter H (high).

Error 4. The reverse voltage is greater than the forward voltage. Two things can cause this error. You might be near a high power transmitter, or you connected the transmitter to the output port. No tone is produced. INQUIRE button sends letter F (fault).

The PIC used in this design could be used in a more standard SWR meter, such as those with a transformer type sensor. As long as the meter produces a forward and reverse voltage that you can scale to be from 0 to 3 up to 5 V (depending on your power supply choice), it will work just fine. However, the driving impedance of the voltage must be 10 kΩ or less.

The author thanks the Ham Radio Committee of the National Federation of the Blind for inspiration, and Tom Fowle, WA6IVG, and Bill Gerrey, WA6NPC, of the Smith-Kettlewell Research Institute for testing prototypes.

A LOW-COST REMOTE ANTENNA SWITCH

Getting multiple antenna feed lines into the shack is a common problem that can be easily solved with a suitable remote antenna switch. The project described here by Bill Smith, KO4NR, provides an easy and inexpensive solution. It originally appeared in April 2005 *QST*.

Relay Selection

Interesting innovations in printed circuit board (PCB) power relay design have produced a number of compact units that exhibit high dielectric strength and can carry impressive amounts of current.

Although not factory tested for RF use, the American Zettler AZ755 series PCB relays work very well in this application. (See **www.americanzettler.com** for datasheets and information.) The AZ755 is rated for 480 W switched power with a resistive load and a maximum switched current of 20 A. Despite the relay's small physical size, the dielectric strength between the contacts and coil is 5 kV RMS, with an impressive 1 kV RMS between the open contacts. This means that the relay is resistant to a flashover that could damage the coil or pit the contacts.

The AZ755 series relays are offered in a wide variety of configurations. This project uses part number AZ755-1C-12DE. This model has a 12 V dc coil, but you can use any of the available coil voltages in the series. The contact style is Form C, which is SPDT. The E suffix indicates that the relay epoxy is sealed for better protection from dirt and moisture. For relays that are not epoxy sealed, drop the E from the part number.

Circuit Design

Fig 19.81 shows the circuit, which handles up to six antennas. The common contacts of the relays (K1-K6) are connected to SO-239 connectors (J1-J6) for the antenna feed lines. The normally open (NO) contacts are all connected to the RF INPUT connector, J7. The normally closed (NC) contacts are all connected to ground so that the antennas are grounded when not in use. To select an antenna, apply 12 V dc to the appropriate ANTENNA CONTROL terminal to energize the relay and connect the ANTENNA to the RF INPUT.

C1-C6 help to keep stray RF out. In addition, D1-D6 are installed across the coils to prevent voltage spikes when the power is removed from the coil. The finished board (available from FAR Circuits) with all components mounted is shown in **Fig 19.82**.

Assembly Notes

The design is simple and assembly doesn't require special tools. In addition to the PC board and parts, you'll need a suitable enclosure to keep the board dry and pests away. The author used a plastic children's lunch box that hangs under his deck.

The most difficult part of the project is drilling the holes in the enclosure for the SO-239 connectors and getting everything to line up. You may find it easier to install the connectors in the enclosure first, and then solder them to the board. (Use the board to mark the center line and loca-

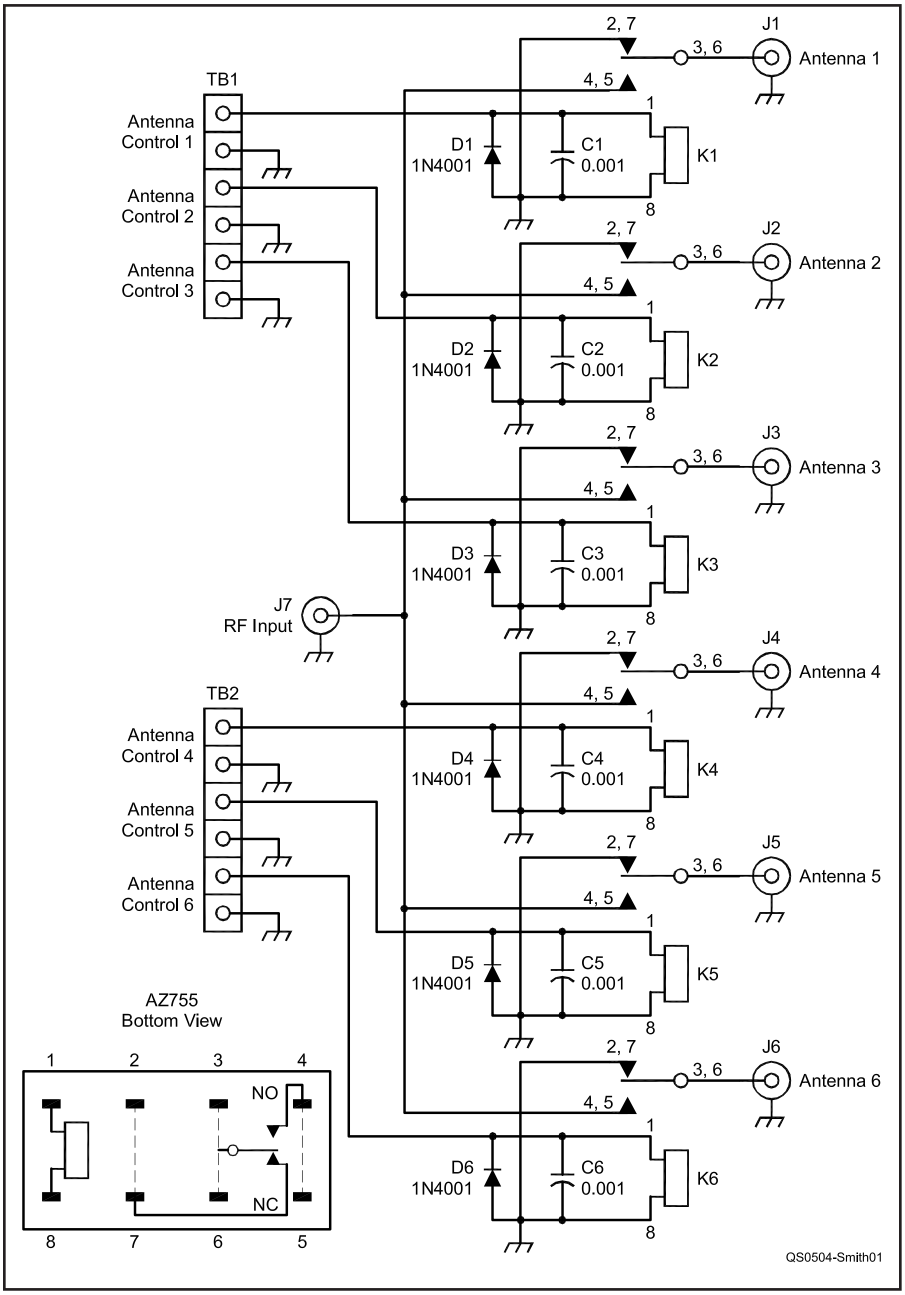


Fig 19.81 — Schematic and parts list for the remote antenna switch. Part numbers indicated with an M are available from Mouser Electronics (www.mouser.com). PC boards are available from FAR Circuits (www.farcir.net). See the *TISFind* database (www.arrl.org/tis) for more contact information.

C1-C6 — 0.001 µF, 50 V disc ceramic capacitor (M 140-50P5-102K-TB).
D1-D6 — 1N4001 diode (M 512-1N4001).
J1-J7 — SO-239A chassis mount coaxial connector with silver-plated 4-hole square flange and Teflon insulation (Amphenol 83-798 available as Mouser 523-83-798).
K1-K6 — SPDT PC board power relay with 12 V dc coil (American Zettler AZ755-1C-12DE). Available from www.relaycenter.com. See text.
TB1, TB2 — PC board terminal block with 6 contacts (M 651-1729050).

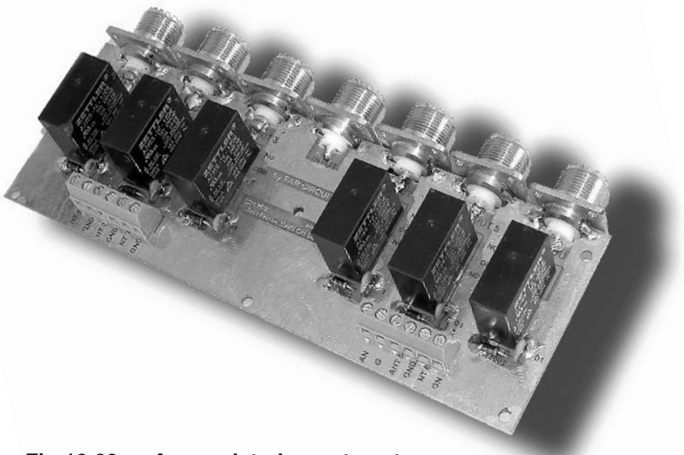


Fig 19.82 — A completed remote antenna switch. The RF INPUT connector is in the center, with three ANTENNA connectors on each side. The control cable connects to the two terminal blocks.

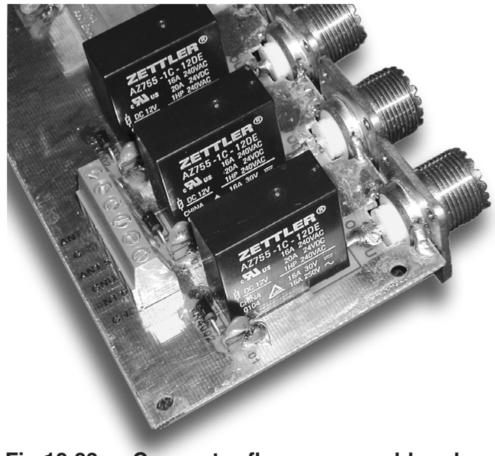


Fig 19.83 — Connector flanges are soldered to the board's ground plane top and bottom. The ground ends of D1-D6 and C1-C6 are also soldered top and bottom. The relays have two pins each for the contact connections. Solder all pins and install eyelets supplied with the FAR Circuits board to ensure good connections for the relay common and normally closed pins.

tion of the connectors on the enclosure.) After the connectors are tacked in place, remove the screws holding the SO-239s to the enclosure and remove the total assembly. This ensures a perfect fit when reassembling.

Make sure the SO-239s are all the same type and brand to ensure a uniform fit. The board was designed around the Amphenol connectors recommended in the parts list. They have silver-plated center pins and flanges, and Teflon insulation. The silver plating makes the connectors easier to solder than nickel-plated connectors, and the Teflon insulation is much less prone to melting than the plastic often found on inexpensive connectors. Other SO-239 connectors may fit with possible modification for a good fit.

Use a *hot* soldering iron when soldering the flange of the SO-239 to the board's ground plane as shown in **Fig 19.83**. Be sure to solder top and bottom.

The PC board is double-sided, and FAR Circuits supplies eyelets with the board to use in the larger holes for the common and normally closed relay pins. They provide for a better connection to the component side of the board. In addition, soldering a short length of #14 bare copper wire into the center pin of each SO-239 will give you a better connection to the circuit trace on the board. Be sure to solder the ground ends of C1-C6 and D1-D6 on both the top and bottom sides of the board.

Powering It Up

The switch is controlled with a 12-V dc power supply and small ceramic rotary switch as shown in **Fig 19.84**. The switch simply sends 12 V to energize one of the relay coils and select the desired antenna. When 12 V is removed, the normally closed relay contacts connect all feed lines to ground. Connect the PC board's ground plane to a ground rod for lightning protection and as a means of eliminating static.

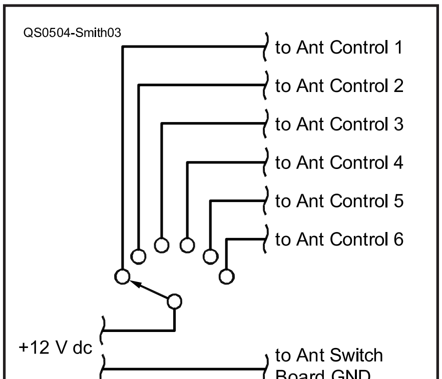


Fig 19.84 — Antennas are selected with a simple 12-V supply and rotary switch.

The control cable can be the 8-conductor variety usually used for rotators. Long runs of wire may require large conductors to prevent unacceptable voltage drops at the relay coils, but the relays will work over a fairly wide range of coil voltages so it's not critical.

Testing

Initial testing should be conducted on the bench with an antenna analyzer or a transceiver (internal antenna tuner off) and power/SWR meter connected to the RF INPUT jack. Connect a 50 Ω load to one of the antenna jacks on the switch board. Apply a small of RF power. The SWR should be close to 1:1 (similar to readings without the switch in the line.

If everything looks okay, increase the power and check the SWR through the switch on all bands that you plan to use it on. Next, move the wattmeter to the switch output and verify that the power on that side is about the same as the power at the input. There should be little or no measurable loss through the switch. Repeat these tests for all of the switch positions.

If you run an amplifier, test the switch at high power. The author used the switch at 1-1.3 kW during normal intermittent operation (SSB and CW) with no problems.

Although they are not designed for RF, the relays perform well. The board exhibits low SWR, low insertion loss and good isolation over a wide frequency range. The ARRL Lab tested the completed antenna switch board. Insertion loss measured <0.1 dB for 2-50 MHz (for all ports to common). SWR measured 1.1:1 or less from 2-28 MHz, 1.2:1 or less on 50 MHz. Isolation was >60 dB for 2-28 MHz, except for the two innermost ports, which were 50 dB at 28 MHz. Worst-case isolation on 50 MHz was 45 dB.

A PIC-BASED HF/VHF POWER METER

The Analog Devices AD8307 logarithmic amplifier (log amp) can be used to build a power meter capable of measurements from –80 dBm to +7 dBm from 1 to 500 MHz, and the measurement range can be expanded to about 50 W with the use of a 40 dB coupler. Wes Hayward, W7ZOI, and Bob Larkin, W7PUA, presented an AD8307-based power meter in *QST*.[1] Building on the Hayward/Larkin project, Roger Hayward, KA7EXM, added an LCD display and a versatile PIC processor for controlling the system. The resulting project, shown in **Fig 19.85**, was originally described in May/Jun 2005 *QEX*.

Use of a microprocessor makes significant additional features possible. In this power meter, calibration points are stored in memory; power measurements are displayed in dBm or W; software accounts for on-screen offset for high power measurements with an external coupler; and a high-accuracy differential measurement mode allows measurement of insertion loss, amplifier gain, return loss and VSWR with resolution better than 0.1 dB.

For those interested in replicating the power meter, kits are available from Kanga US.[2] The source code is available for those interested in developing other projects based on the PIC and LCD module presented in this article.

As with most power meters, an accurate calibration step is required. This is performed by using a signal of known level, or by comparing an unknown signal level against another calibrated measurement device. Bob Kopski, K3NHI, described a way for the home experimenter to calibrate the meter. He translated the output of the log amplifier into a 1 mV/dB range, such that the measurements could be displayed by a digital voltmeter (DVM) module without the need to convert measurement levels through a lookup chart.[3] In a later paper, he presented a simple RF signal source that can be calibrated with an oscilloscope or RMS voltmeter.[4]

Fig 19.85 — Exterior view of the PIC power meter.

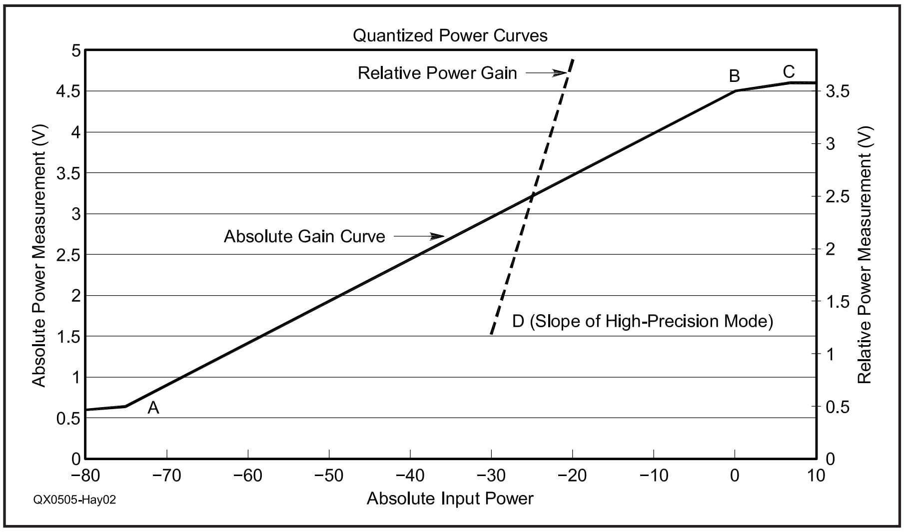


Fig 19.86 — Log amplifier voltage output is interpreted between three calibration points, A, B and C. For relative measurements, an absolute reference is determined and a higher-gain slope output is used to determine the relative change.

Theory of Operation

Low-level RF in the 1-500 MHz range is terminated in 50 Ω in the power meter. The AD8307 log amp accepts the RF input and converts it to a voltage on a logarithmic scale. The output voltage increases 25 mV for every dB change in input power. The output voltage is then scaled by an op amp to roughly 50 mV/dB, such that the entire –80 to +7 dBm range spans from 0 to just under 5 V. This range may be easily captured by an A/D converter and converted from V to dBm through a lookup and interpolation step.

The Microchip 18F452 PIC processor[5] has a built-in A/D converter with a resolution of 10 bits or 1024 unique values. Assume for a moment that the RF range of 87 dB spans 0.5 V to 4.5 V to the A/D converter. This uses 80% of the 1024 points in the A/D converter. With 80 dB relating to 800 points, the highest resolution available is roughly 0.1 dB per step from the converter. This limits measurements to a ±0.1 dB resolution.

For some applications, power measurements accurate to ±0.1 dB are probably sufficient. If you are measuring the output power of a transmitter, 0.1 dB variations in output level are minor. However, if you are checking insertion loss of a filter, or trying to measure the loss in a piece of coax, an error of 0.1 dB may be large.

One simple way of improving the resolution without moving to a higher cost A/D converter is to add even more gain after the log amp output. Additional dc gain (for example, another 5×) can be added after the log amp to generate greater sensitivity, on the order of 250 mV/dB. Although this exceeds the specified absolute accuracy of the AD8307, it is not significant for difference measurements.

From this, the concept of relative power measurement is introduced. For a given input power level, remember this value and establish a reference voltage. The power meter then measures the difference from

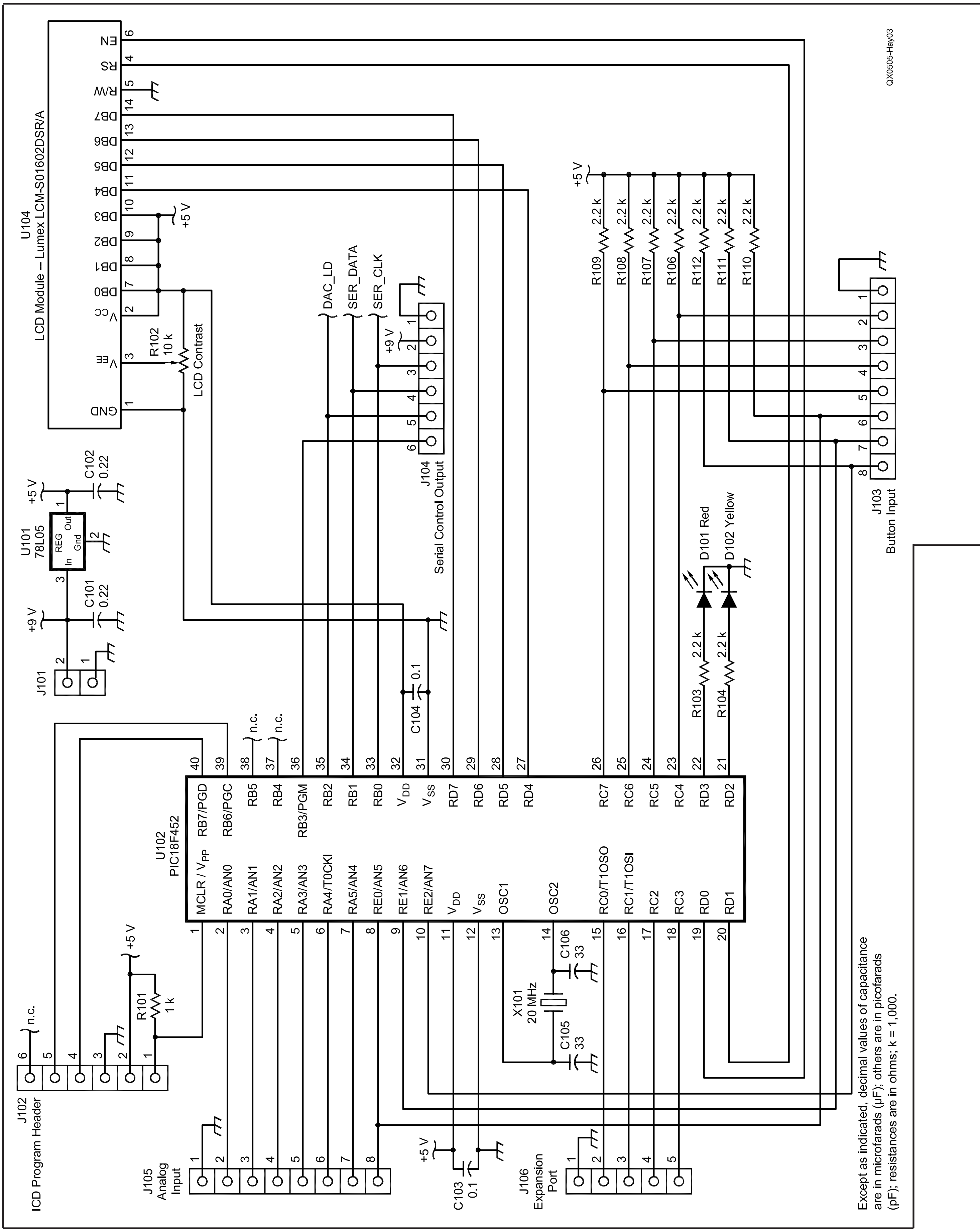

U104
LCD Module -- Lumex LCM-S01602DSR/A
R102
10 k
LCD Contrast
U101
78L05
C101
0.22
C102
0.22
J101
J102
ICD Program Header
R101
1 k
U102
PIC18F452
J104
Serial Control Output
DAC_LD
SER_DATA
SER_CLK
C104
0.1
J103
Button Input
D101 Red
D102 Yellow
X101
20 MHz
C105
33
C106
33
J105
Analog
Input
C103
0.1
J106
Expansion
Port
Except as indicated, decimal values of capacitance
are in microfarads (µF); others are in picofarads
(pF); resistances are in ohms; k = 1,000.
QX0505-Hay03

Fig 19.87 — PIC and display module schematic diagram. DigiKey part numbers are shown in parentheses. A parts kit is available from Kanga US (see Note 2) and source code is available from the author's Web site (see Note 6).
C101, 102 — 0.22 µF, 50 V, X7R 1206 (399-1251-1-ND).
C103, 104 — 0.1 µF, X7R 1206 (399-1248-1-ND).
C105, 106 — 33 pF, 50 V, NP0 1206 (399-1199-1-ND).
D101 — Red, LED (small) (67-1069-ND or equiv).
D102 — Yellow, LED (small) (67-1078-ND or equiv).
R101 — 1 kΩ, 5%, SMT 1206 (P1.0KECT-ND).
R102 — 10 kΩ, variable (3329H-103-ND).
R103, 104, 106-112 — 2.2 kΩ, 5%, SMT 1206 (P2.2KECT-ND).
U101 — 78L05-SOT89 (497-1183-1-ND).
U102 — PIC18F452 (requires programming, see text) (PIC18F452-I/P-ND).
U104 — LCM-S01602DSR/A (67-1768-ND).
X101 — 20 MHz, CA-301 (SE3438-ND).

this point, and places a high gain in the signal, allowing the A/D converter to see far more resolution than during the absolute power measurement mode. See **Fig 19.86**. The absolute gain curve depicts the expected output voltage for a given input level. The relative power gain curve depicts the output voltage, once a reference point has been established.

A D/A converter is required to set up a reference signal. The Analog Devices AD7391 is a low-cost 8-bit DAC that operates from a single +5 V supply and has a serial interface that is easily controlled via the PIC processor. With this and a differential op amp (with gain), a higher-resolution measurement may be performed.

The reference signal is set up to provide a 2.5 V output from the differential amplifier upon initial setup. With a feedback gain of approximately 5 in the op-amp circuit, changes in power level on the order of 0.02 dB relate to a single bit of resolution in the 10-bit A/D converter. Although a change of 0.02 dB is probably nonsense on the workbench, it provides assurance that measured values on the order of 0.1 dB are believable.

The bulk of this system is controlled through software inside the PIC processor. Since the PIC has multiple A/D converter inputs, the absolute (RF_ABS) and relative (RF_DIFF) power measurements are captured separately. If the operator wishes to measure insertion loss, or antenna return loss, the software will automatically keep track of what measurement mode the meter should be running in. When relative measurements exceed the range of the higher-gain differential amplifier, the program will automatically shift to using the absolute power measurement value to determine the difference. The resolution of the measurement will change on the display, depending upon which internal measurement mode is being utilized.

Consider the example shown in Fig 19.86. If the input signal level is at –28 dBm, then the absolute power measurement A/D measures approximately 3.2 V (as seen on the left axis). If a relative measurement needs to be taken from this point, the circuitry will set up a reference value such that the relative power measurement A/D input is 2.5 V (as seen on the right axis). Any change in the power level from this point on will result in a greater change on the relative slope than on the absolute slope.

By setting the initial reference point at half of the supply voltage, the high-resolution system can measure gain as well as loss.

Three calibration points may be stored within the PIC processor's flash memory. Any measurements between these three data points are interpolated automatically. In addition, the relative power measurement mode may be calibrated with any 3-10 dB attenuator and any RF signal source as input.

CPU Module

Fig 19.87 shows the CPU module circuit. A crystal provides the CPU clock and an on-board voltage regulator allows operation from a 9 V battery. Various header pins are exposed on the top and bottom edges of the board. Analog input is on J105. J103 provides room for the four function buttons. J104 controls the D/A converter through a 3-wire serial interface. U104 is a Lumex 2 line by 16 character LCD. It is mounted on the back side of the PCB with 4-40 standoffs.

There are two LEDs on the CPU module. Although these are for debug purposes, it's a good idea to include them. The CPU's most-common event is watching the four user-interface buttons. Within this routine, the two diodes are toggled and they should occasionally flicker during normal operation. A stall indicates that the CPU is doing something more important, such as performing a calculation. It is a great way to verify that the PIC is alive and well, even before the LCD is connected.

J102 on the CPU board is a header that matches Microchip's ICD header. This allows the developer to program the PIC in place. Although the header is not required for normal power-meter operation, R101 must still be inserted on the board, in order to keep the part running the stored program.

A large bank of 2.2 kΩ pull-up resistors for the push buttons is present, along with a number of headers surrounding the PIC, for off-board interaction. The board has an empty SO-16 footing, along with a few landings for electrolytic capacitors. These will accommodate an RS-232 interface for a future project.

RF Module

Fig 19.88 shows the RF module circuit. Because of the low-level signals to be measured, the RF module was designed from the start to be on its own RF-shielded board. The RF module uses surface mount technology throughout. With no pitches tighter than 0.05 inch, it is still practical to hand-solder these parts to the printed circuit board.

The RF input stage is virtually identical to the previous design of Hayward and Larkin, including slight equalization to level the measurement accuracy at higher frequencies. The absolute RF output is sent to a quad op amp. An AD7391 DAC provides the reference voltage for the high-precision circuitry.

While studying the schematic, you may see some components in places where you might not expect them. In an effort to resolve some noise issues with the AD7391 DAC in an earlier prototype, extra decoupling and bypass stages were added. Separate voltage regulators provide a clean supply to each of the two 5 V devices. Series resistors, along with the 0.1 µF capacitors, in and out of the regulators act as a low pass filter designed to stop stray noise from working its way through these stages. Series resistors near the inputs of op-amps also isolate noise. The LM324 quad op-amp allows further isolation of potential noise by adding two pass-thru stages between the DAC and the differential amplifier.

The RF module must be enclosed in its own RF-tight enclosure. A limited number of interface wires should all be fed to the board via 1000 pF feedthrough capacitors, soldered on the wall of the RF enclosure. See **Fig 19.89** for interconnection details.

Assembly Notes

As is often the case, this project is best constructed in stages. The Hammond 1590J case is large enough to hold the circuitry

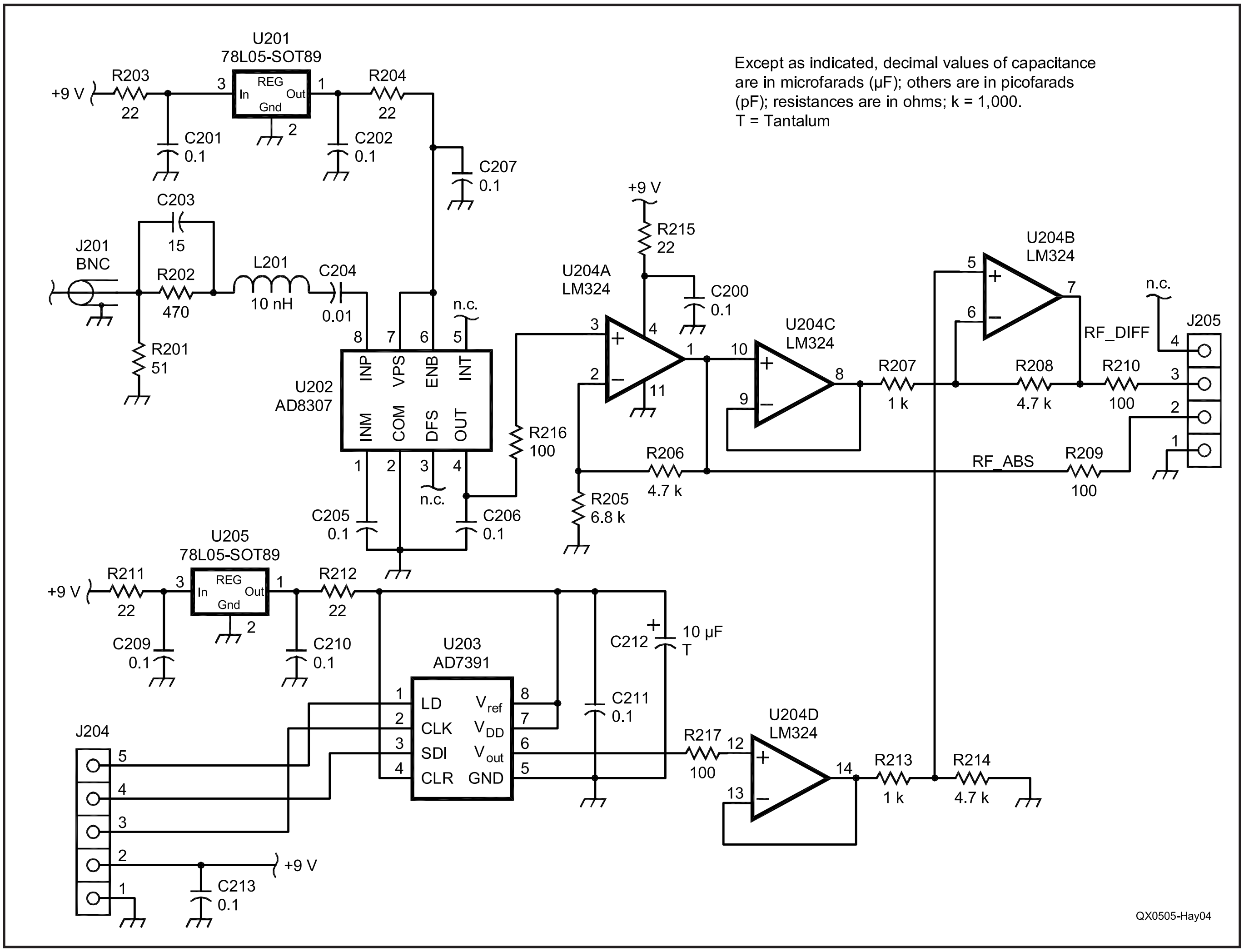


Fig 19.88 — RF measurement module schematic diagram. DigiKey part numbers are shown in parentheses.

C201, 202, 205-211, 213 — 0.1 µF X7R 1206 (399-1248-1-ND).
C203 — 15 pF, 50 V, NP0 1206 (399-1194-1-ND).
C204 — 0.01 µF, 50 V, X7R 1206 (399-1234-1-ND).
C212 — 10 µF tantalum (478-1762-1-ND).
L201 — 10 nH, 10%, SMD 0805 (PCD1160CT-ND).
R201 — 51 Ω, 5%, SMT 1206 (P51ECT-ND).
R202 — 470 Ω, 5%, SMT 1206 (P470ECT-ND).
R203, 204, 211, 212, 215 — 22 Ω, 5%, SMT 1206 (P22ECT-ND).
R205 — 6.8 kΩ, 5%, SMT 1206 (P6.8KECT-ND).
R206, 208, 214 — 4.7 kΩ, 5%, SMT 1206 (P4.7KECT-ND).
R207 — 1 kΩ, 5%, SMT 1206 (P1.0KECT-ND).
R209, 210, 216, 217 — 100 Ω, 5%, SMT 1206 (P100ECT-ND).
R213 — 1 kΩ, 5%, SMT 1206 (P1.0KECT-ND).
U201, 205 — 78L05-SOT89 (497-1183-1-ND).
U202 — AD8307AR, log amplifier, SO-8 (AD8307ARZ-ND or direct from Analog Devices).
U203 — AD7391AR 8-bit DAC, SO-8 (AD7391AR-ND or direct from Analog Devices).
U204 — LM324 quad op amp, SO-14 (296-9540-5-ND)

and a 9 V battery (**Fig 19.90**). If you plan to use the meter often, it may be better to choose an enclosure that can hold six to eight AA batteries.

Start by cutting a hole for the LCD display, then finding the right locations for the four mounting holes. Dry-fit the LCD bezel until it fits snugly on the front panel. After this, mount the bare PCB in place and locate positions for the four push buttons. Space the A, B, and C buttons equally across the bottom of the display. The F key can be located anywhere you choose.

The CPU module board can be booted without the need to connect the RF module. Start by soldering all resistors and capacitors on the back side of the board, followed by the front-side components, including the crystal oscillator section (X101) and capacitors. Finally, solder in the socket for U102, the PIC processor.

After verifying that the 5 V regulator is supplying voltage to the board, it is time to confirm that the pre-programmed PIC processor springs to life. Install the processor into the socket and verify the board is operational by applying power and viewing the LEDs D101 and D102 on the circuit board. (It may take up to 10 seconds after power is applied to see the LEDs begin to flash.) Once this is verified, mount the LCD on to the back of the board, and mount all 16 wires from the LCD to the CPU board. These pads line up with one-another such that only a 0.25 inch piece of bare wire, such as the lead from a ¼ W resistor, is needed for each.

Apply power again and watch the display for the banner. Adjust the LCD contrast by varying R102 — the display may appear blank until this has been adjusted. Next, wire in the push buttons to make

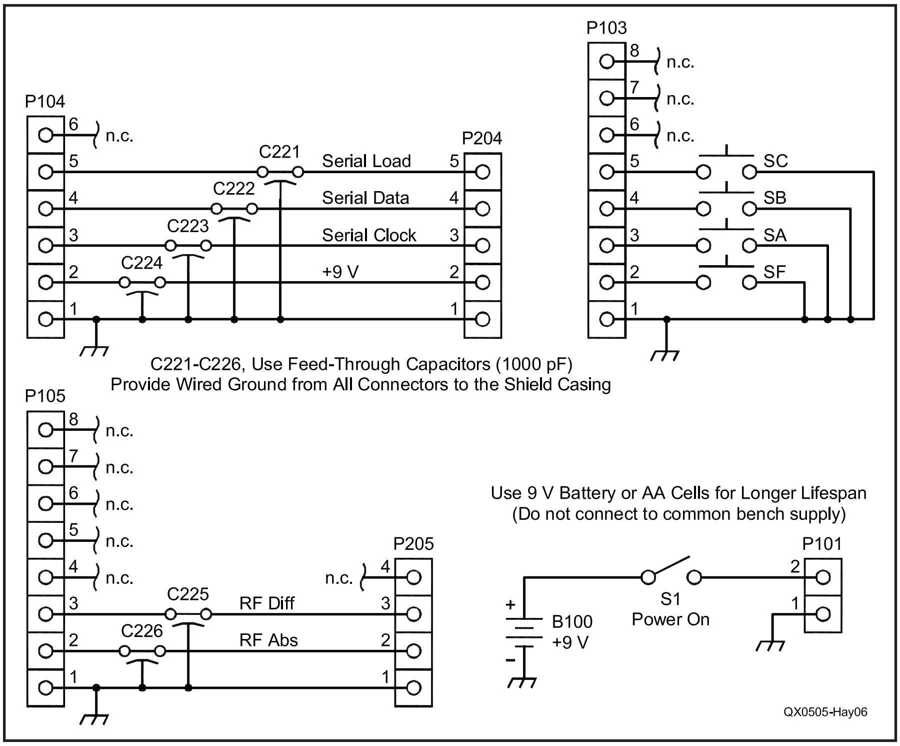


Fig 19.89 — Interconnection details.
C221-226 — 1000 pF feed-thru capacitor (one source is www.emifilterco.com).
S-A, B, C — Normally open push-button, black cap (DigiKey EG2011-ND or equiv).
S-F — Normally open push button, red cap (Digi Key EG2015-ND or equiv).

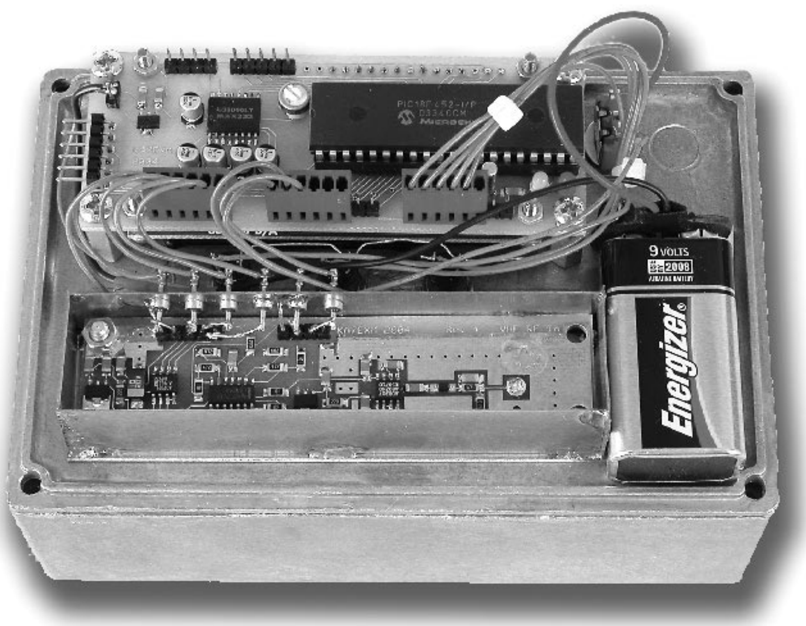


Fig 19.90 — Inside view of the meter. The CPU module is on the top, the RF measurement section is on the bottom. The LCD is mounted under the CPU module.

sure the F, A, B, and C buttons behave as expected.

With the remaining space in the chassis, it is time to construct an RF-tight box for the measurement module. The RF PCB was designed to rest right onto the pin of a BNC connector. See **Fig 19.91** for a detailed side-cutout diagram of the RF module.

Cut a piece of copper-clad material approximately 0.1 inch wider on all edges than the RF module circuit board. Plan on having it rest up against the back-side of the front panel. Drill a hole for the BNC connector, centered over J201 on the RF module. Include a ground lug while bolting on the BNC. Drill another hole at the opposite side of the board, such that the printed circuit board will have mechanical stability. Plan on using a short 6-32 spacer to hold the RF module away from the copper material.

Using soft 0.75 inch strips of brass, cut a wall for the back side of the RF module. Pre-drill six holes for the feedthrough capacitors in this wall, add the capacitors, and solder the wall on to the copper-clad material. This needs to be done before mounting the RF module in place, as it will be nearly impossible to get a hot soldering iron to it afterwards.

Verify RF module operation before mounting it into the chassis. Apply +9 V to pins 2 and 1 of J204. Verify each of the two 5 V regulators, U201 and U205, are functioning properly. With a DVM, measure the dc voltage out of the log amplifier and from the output of the op amp U204. Remember that even with no RF input to the log amplifier, a small residual output will still be measured. Early prototypes, when shielded properly, measured approximately 0.65 V at RF_ABS.

To mount the RF module, slip the center pin of J201 directly onto the center pin of the BNC connector. To provide a solid RF ground to the board, bend the ground lug of the BNC until the end of the lug is pushing up against the back-side of the RF module's ground plane. You may need to scrape off additional solder mask in the location where the ground lug touches the ground plane. Using a *hot* soldering iron, solder the lug directly to the backside of the PC board. (Do not omit this step. A solid ground-return is required for accurate measurements.)

Solder the center pin of J201 to the BNC connector. Mount a 6-32 screw to your spacer on the other end of the board.

Now that the board is in place, build and mount the other three sides of the RF box using brass material. Seal the container with a lid made of copper or brass. Although it is recommended that this box be as RF tight as possible, remember that you may want to get back in to the box at some point in time, so don't seal it so tight that you can't get the lid back off again!

After mechanical assembly, complete wiring the interface to the CPU. When running in ZERO mode, the DAC should present a 2.5 V output to the A/D converter on the RF_DIFF net.

Software

The source code is available from the author's Web site.[6] It could also serve as a good springboard for the development

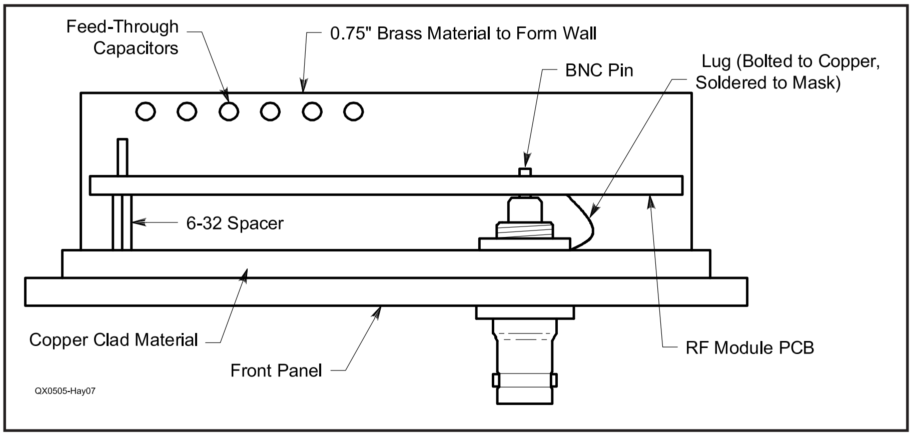


Fig 19.91 — Side cutout details of RF module and enclosure.

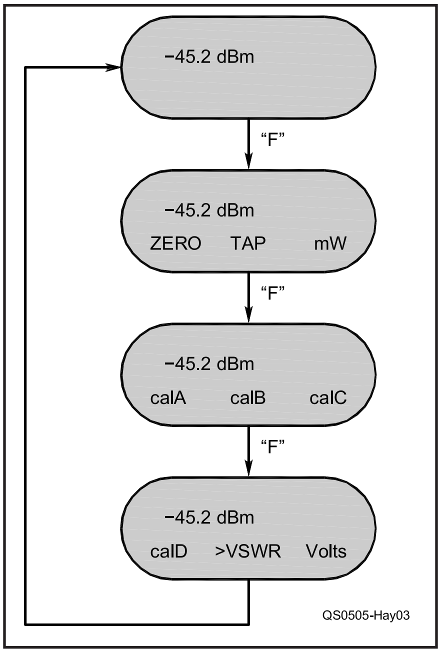


Fig 19.92 — Accessing all menu functions is easy with the function key.

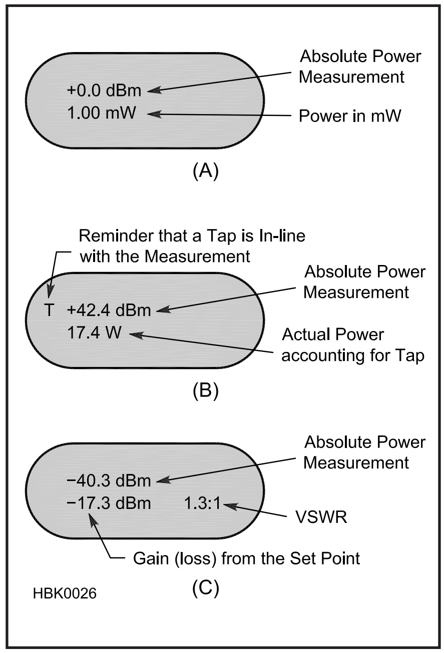


Fig 19.93 — At A, the display with the PIC power meter set up to measure power. At B, using a coupler (tap) to measure higher power levels. At C, measuring differences in power level. This includes return-loss and VSWR.

of other projects, since the LCD driver code, flash memory and interactive menu have already been written. Since all of the RF measurement hardware is on its own sub-assembly, the CPU/LCD could be used for other projects.

The program is written in C, and CCS provides not only the compiler, but many useful tools to ease the development of any project.[7] Test code, interrupt handlers, and functions for manipulating the flash memory are all available as part of the standard CCS compiler package. This allows the developer to concentrate more on the application at hand, and less on the inner workings of the PIC.

Programming the PIC processor was accomplished with the Microchip USB ICD-2 module. With the addition of the header J102, the PIC may be programmed and re-programmed countless times without the need to remove the part from the board. This was vital to the development of the project, as new ideas could be coded and tested easily.

Operating the Meter

With the advent of newer miniature "appliances" from the major vendors, most Amateur Radio operators have become accustomed to driving their radios by way of some menu-driven interface. Often, the bottom of the LCD display is lined with push buttons. The buttons perform different features, depending upon what the radio is doing. The operator can shift to another bank of features by pressing an F button, or perhaps scrolling an optical shaft encoder until the desired selection is found.

The power meter uses a similar approach. The top line of the display always shows absolute power level measured. To invoke an advanced function, press the F key, and selections appear on the bottom line. Subsequent presses of the F button advances to the next set of features. **Fig 19.92** shows the sequence. These selections may be chosen by pushing the button immediately below the function label. Typically after choosing a setting, the bottom menu line returns to blank.

Calibrating Absolute Power Measurements

Upon first power-up, the meter will move *factory* settings from ROM to flash memory. You will want to calibrate your meter before taking any serious measurements. For our discussion, assume for a moment that you have a signal generator capable of output at –70 dBm to +7 dBm.

Three calibration points need to be stored within the meter. It is important to make sure that $P_a < P_b < P_c$, as the interpolation code assumes this. The strongest level, P_c, will be +7 dBm, as an overload warning will trigger when any level exceeding this value is detected.

You may set the calibration points in any order you choose. Let's begin with point A on the absolute power curve shown in Fig 19.86.

The push button under the power switch (see Fig 19.85), acts as the F or function key. Press F until the display reveals the prompt CALA. Press CALA. Apply a very weak signal to the meter, such as –70 dBm. To tell the meter that this is –70.0 dBm, select the SET_ DB button. Use the UP and DOWN buttons to set the display to the exact value that you are applying to the meter, such as –70.0 dBm. The calibration point will move in 0.1 dB steps. If you press-and-*hold* the UP or DOWN button, the meter will scroll in 1.0 dB steps to speed up the process. Once the display matches the known signal level, press SAVE. This point has been calibrated and stored in to the flash memory of the PIC processor.

To back out of the calibration process, press the F key and the display will return to normal operation.

Repeat the procedure again for a +0 dBm signal (or so). This is CALB. After setting the B point, carefully apply a +7 dBm signal source and calibrate for point C.

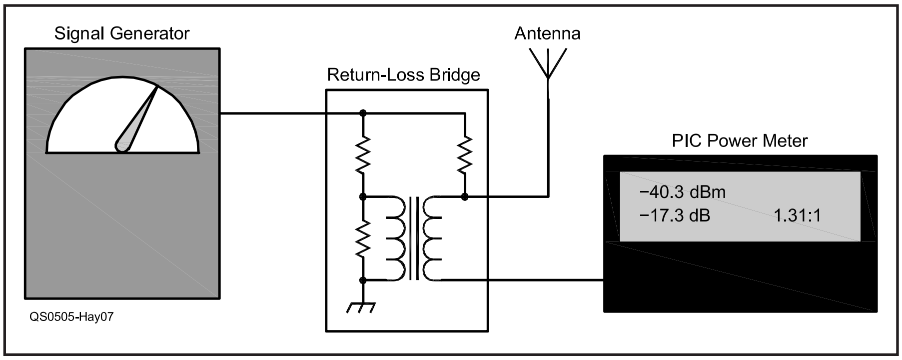


Fig 19.94 — Representative power difference display used to measure VSWR.

Note that the CALC point of calibration should be set near the strongest acceptable power level for the log amp. Signal levels in excess of +10 dBm may harm or destroy the log amp. To alert the operator of an overload, the meter will flash the measured value on the display, an indication that the input signal level needs to be reduced to a safer level.

At this point, your meter is calibrated against your signal source. Vary the amplitude of the input signal level to see how well things track. The meter should reflect changes across the span over which

A 40 dB Tap for Higher Power Measurements

Transmitter powers are rarely as low as the maximum that can be measured with this power meter. Several circuits can be used to extend the range including the familiar attenuator. Perhaps the simplest is a resistive tap, shown in **Fig 19.95**. This circuit consists of a flat piece of metal, L1, soldered between coaxial connectors J1 and J2, allowing a transmitter to drive a 50-Ω termination. A resistor, R1, taps the path to route a sample of the signal to J3, which connects to the power meter. R2 shunts J3, guaranteeing a 50-Ω output impedance. Selecting the values that comprise R1 establishes the attenuation level.

The tap extends the nominal +7 dBm power meter maximum level to +47 dBm, or 50 W. Power dissipation becomes an issue at this level, so R1 is built from three series-connected half-watt, carbon-film resistors.

The tap is built with the J1 to J2 connection configured as a 50-Ω transmission line as shown in **Fig 19.96**. Adjustments were performed with an HP-8714B network analyzer. The analyzer was used to adjust the value of C for an attenuated path to J3 that is flat within 0.1 dB up to 500 MHz. The tap can then be used with a spectrum analyzer or laboratory grade power meter.

It is not realistic to achieve 0.1-dB accuracy through UHF without a network analyzer for adjustment. However, if the tap is duplicated using the mechanical arrangement of Fig 19.96, you can expect the tap to be flat within about 1 dB through 500 MHz. The low-frequency attenuation is determined merely by the resistors, so can be guaranteed with DVM measurements. If the primary interest is in measurements below 150 MHz, you can replace the N connectors with BNC connectors. The tap is housed in a Hammond 1590A box. *— Wes Hayward, W7ZOI, and Bob Larkin, W7PUA, from June 2001* QST

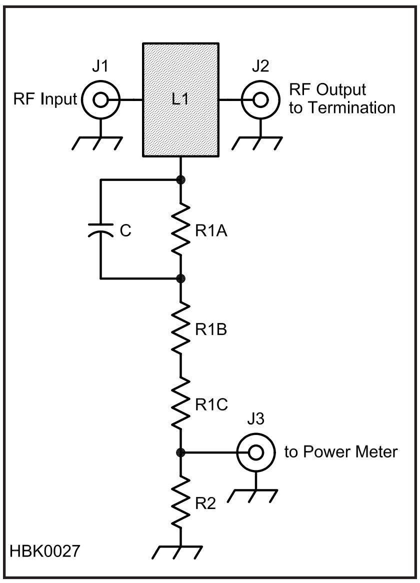


Fig 19.95 — A tap that attenuates a high power signal for use with the power meter. See the text and Fig 19.96 for discussion of the capacitor, C.
J1, J2 — N or BNC connectors (see text).
J3 — BNC connector
L1 — 1 × 1.5 inch piece of sheet brass (see text).
R1A-R1C — Three series-connected, 820 Ω, ½ W carbon film
R2 — 51 Ω, ¼ W carbon film

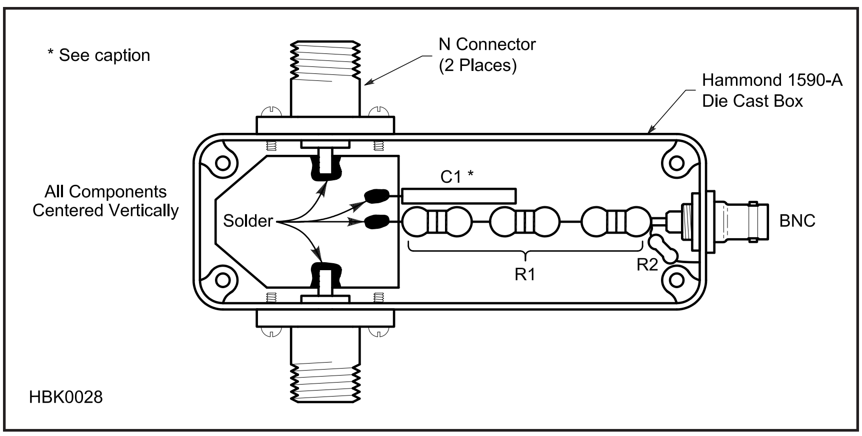


Fig 19.96 — Drawing of the 40-dB power tap assembly shown schematically in Fig 19.95. The center conductors of the two N connectors (RF INPUT and RF OUTPUT) are connected by a 1 × 1.5-inch piece of sheet brass with its corners removed to clear the pillars in the Hammond 1590A die-cast aluminum enclosure. C1 is made from a piece of #22 AWG insulated hook-up wire; it extends 0.6 inch beyond the edge of the tinned metal piece and almost rests against the two resistor bodies.

it was calibrated.

When setting calibration points, note that a voltage is present on the display as well. This is the actual measured voltage presented to the A/D converter (RF_ABS). Write the dBm and voltage pair down for each of three calibration points into your notebook. If you ever need to recalibrate the meter in the future without a wide-range signal generator, the meter allows you to enter the calibration points without a signal source. With no signal source required at the input, simply calibrate the dBm value first, then enter the voltage by selecting the ADJ_V button in the calibration menu.

Calibrating the Differential-Mode Measurement System

To calibrate the absolute power measurement points, we input a known power level to the system and ask it to remember the value. To calibrate the relative measurement system, we have to provide a known relative change in power. The easiest way to do this is with an RF carrier and an attenuator of known value.

Apply a signal source to the meter, somewhere in the 0 to –10 dBm range (it is not critical, as long as it is stable). Press F, then ZERO, and wait for the meter to converge on this signal. The second line should show +0.00 dB, or something very close to zero. Now insert an attenuator, such as 10 dB, between the signal source and the meter. The relative measurement should show something near –10.00 dB. To calibrate this value, press F until you see the CALD (short notation for Calibrate-Differential) button. Select it. The values you see reveal the gain of the op amp. As you did with the absolute power measurement system, all you have to do is press SET_ DB, and enter the amount of attenuation you have applied to the signal (such as 10.0 dB), then press SAVE. From this point on, differential power measurements are calibrated against your attenuator. Again, you may want to write this value down for future reference.

Calibrating the Tap Offset

A coupler or tap like the one shown in the sidebar, "A 40 dB Tap for Higher Power Measurements," is very handy. The power meter can be shifted into TAP mode, in which the signal level on the screen will reflect the fact that the tap is being used. To toggle this feature, press F, then TAP. The letter T will show up to the left of the absolute power level, to remind you that you are reading a shifted value on the display.

If you wish to read or set the tap calibration point, simply press F then press and hold the TAP button until the calibration is revealed on the display. To change this value, press SET_ DB. Use the UP and DOWN buttons to step in 0.1 dB steps (press and hold to step in 1 dB steps). When you have the value of your tap, press SAVE. Although the TAP position is generally thought to correspond to the tap described in the sidebar, it could also be another circuit such as a power attenuator, fixed-gain amplifier or directional coupler.

General Operation

Once the calibration points are set, the meter is very easy to operate. To measure absolute power, simply turn it on! The display is shown in **Fig 19.93A**. To make a relative power measurement, such as the insertion loss of a filter, start by applying your reference signal to the meter. Press F, then ZERO. Future measurements will show the power level relative to this reference.

If you are using a 40 dB coupler, press F, then TAP to shift the measurement on the display automatically. VSWR may be shown during return-loss measurements. To turn this off, press F until you get to the third menu, and then press VSWR. The > character indicates whether the mode is enabled or not.

Measuring Power

Remember that the meter's input terminates your signal in 50 Ω, and you should not exceed +7 dBm (about 5 mW) input to the meter. If you do exceed +7 dBm, the display will flash the absolute power value to alert you to lower the input power as soon as possible.

If your power level does exceed the upper limit of the log amplifier, use an external coupler and the meter's TAP mode. Press F and then TAP. The letter T will show on the display next to the absolute power value as shown in **Fig 19.93B**.

Measuring Insertion Loss or VSWR

To measure the insertion loss of a filter, apply a reference signal to the power meter. Press F, then ZERO. The meter will store this value in its memory and establish a reference voltage that is representative of this signal. From there, a filter, or gain stage can be inserted. The difference in signal level will be shown on the second line of the display as shown in **Fig 19.93C**.

By adding a return loss bridge to the system, as shown in **Fig 19.94**, return loss or VSWR of your antenna may be measured. Apply a signal at the frequency of interest to the load to be tested through the return loss bridge. The DETECT port of the bridge is then terminated at the power meter. Apply power without the load connected and press F then ZERO to store the reference value at full reflection. Then connect the load to be measured to the return loss bridge. The return loss, and optionally, the VSWR, will be shown on the display.

This is especially useful for tuning smaller VHF antennas. Once a calibrated RF value is established at the meter, the antenna can be adjusted and results are seen immediately on the screen.

It is extremely handy to monitor the values measured by the A/D converter during debug and test. This may be toggled by pressing the VOLTS button under the menu.

If for any reason you want to restore the meter back to its default settings, a back door has been provided. With the meter shut off, press and hold the B and C buttons together, and turn the meter on. You will see the display begin with RESETTING FACTORY SETTINGS. From there, you will want to recalibrate, or enter your calibration points again.

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Notes

[1]W. Hayward, W7ZOI, and R. Larkin, W7PUA, "Simple RF-Power Measurement," *QST*, Jun 2001, pp 38-43.

[2]Parts, kits and preprogrammed PIC CPUs are available from Kanga US. See **www.kangaus.com** for details.

[3]R. Kopski, K3NHI, "An Advanced VHF Wattmeter," *QEX*, May/June 2002, pp 3-8.

[4]R. Kopski, K3NHI, "A Simple RF Power Calibrator," *QEX*, Jan/Feb 2004, pp 51- 54.

[5]The Microchip PIC-18F452 is pin-compatible with the more popular 16F877. See **www.microchip.com**.

[6]Source code, PC board artwork and more construction notes are available from the author's Web site, **www.ka7exm.net**. A discussion group for builders of this project is available on the Web at **groups.yahoo.com**. Search for the "picpower" group.

[7]Custom Computer Services offers a C compiler for most of the PIC processor families. See **www.ccsinfo.com** for more details. The PCH module was used to compile the code for the 18F452 target.