24.13 Adapting Aviation Headsets to Ham Radios

Aviation headsets are widely used for commercial and private aircraft. They have a frequency response well-suited for Amateur Radio and are comfortable when worn for long periods, even with glasses. The noise-canceling aviation microphone and the headphone earmuff's 23 dB isolation of acoustic noise are very helpful in noisy environments and contests. Adapting these headphones for amateur use requires impedance matching for the audio circuits and power for the standard electret microphone. Since aviation headsets are designed to a specific standard, other brands and models should have comparable performance.

ADAPTING THE HEADPHONE CIRCUIT

The headset earphones may be either 300 Ω stereo or 150 Ω monaural (some older sets are series connected 600 Ω). The plug fits a standard ¼ inch phone jack (two or three conductor to match). Stereo versions usually have a mono/stereo switch. If the plug is a mono version, a RadioShack 274-360 stereo-to-mono adapter can be used.

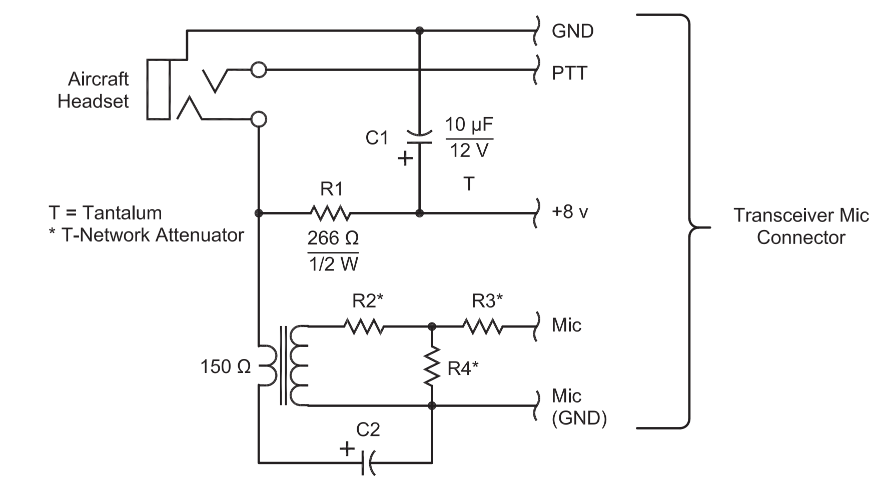
Most radios are designed for 8 Ω headphones. If your radio works with a Heil Pro Set type headset (200 Ω) no additional matching is required. To change the 8 Ω output to higher impedances, a RadioShack audio output transformer (273-1380) will do the job. Connect the low-impedance winding to the radio's headphone jack and the high-impedance winding to the headset earphones.

ADAPTING THE MICROPHONE

The microphone cannot be used with current radio models without an adapter. This project provides two different circuits — **Fig 24.54** uses a transformer-based circuit and **Fig 24.55** uses a resistive circuit with variable frequency response. **Fig 24.56** shows the relative size of a typical adapter circuit enclosure.

Aviation headsets use an electret circuit that mimics an old-style carbon microphone. The microphone amplifier requires an industry standard dc supply of 4 V at 15 mA of current. (Most headphones will tolerate higher voltages but the microphone circuit can be damaged if excess voltage is applied directly to the headset.) Current radio models can provide the needed bias voltage at the microphone jack (ICOM and Kenwood provide 8 V, Ten-Tec 9 V, Yaesu 5 V, and so on).

Nominal audio output is 400 mV into a 150-500 Ω load. A PL068 microphone plug is standard and requires a 0.210 inch three conductor jack. The tip contact is PTT (push-to-talk) and the ring contact carries the audio. A typical amateur transceiver specifies the mic input impedance at 200-10 kΩ, 600 Ω nominal.



Attenuation	R2, R3	R4
20 dB	490.9	121.2
10 dB	311.7	421.6
5 dB	168.1	986.9

Fig 24.54 — K5ALQ's transformer-based aviation-headset interface circuit. C1 is optional, but its use is considered best practice. The headset requires a 150 Ω primary; the secondary must match the load presented by the radio and use appropriate attenuation.

TRANSFORMER-BASED ADAPTER

The adapter in Figure 24.54 provides proper bias to the headset microphone, removes dc from the primary of the transformer, matches the impedance of the headset output and provides appropriate attenuation for the necessary match of level and impedance to an amateur transceiver. The value of R1 is selected for a bias voltage of 8 V. To operate properly with 9 V bias from a radio or battery, R1 should be 330 Ω, ½ W. For 5 V bias, R1 should be 68 Ω.

A Digi-Key 237-1122ND transformer is used with 600 Ω/150 Ω primary and secondary windings. Connect the 150 Ω winding to the headset microphone and the 600 Ω secondary to the radio. The 600 Ω T-network 20 dB attenuator values for R2 and R3 are 490.9 Ω each, and R4 is 121.1 Ω. Since these are not standard values, use resistors with close tolerances, handpick the resistors, and combine parallel resistors to achieve these values. An alternative is to accept the attenuation yielded by standard-value resistors. Resistor values for other amounts of attenuation are given on the schematic.

RESISTIVE-ATTENUATOR ADAPTER

A circuit that uses resistive matching is shown in Figure 24.55 (the parts list is in **Table 24.10**). R1 provides the load for the microphone. R1 plus R2 supply the dc voltage from the radio (or battery). For Yaesu radios with 5 V, eliminate R2 and C1 and connect R1 directly to the +5 V pin. C2 isolates the circuit from the microphone voltage and C3 isolates bias, if any, from the radio microphone pin (ie, ICOM radios). C5 reduces the chance of RFI via the bias supply. Aviation microphones are designed to be RFI resistant but a 0.001 µF capacitor across the circuit output to ground could be added if necessary.

R4 provides the load for the radio mic input circuit. The divider consisting of R3, R5, C4 and R4 reduces microphone audio output to an appropriate level. C4 creates a selectable "DX" rising frequency response. R5 reduces "normal" response by 2 dB to keep average

Table 24.10

Aviation Headphone Adapter Parts List

C1	100 µF, 16 V (not needed for Yaesu)
C2, C3	10 µF, 16 V
C4	See Table 24.11
C5	0.001 µF, 50 V
J1	0.210 3-conductor jack
R1	470 Ω, ¼ W
R2	390 Ω, ¼ W (not needed for Yaesu)
R3	¼ W (see Table 24.11)
R4	620, ¼ W
R5	¼ W (see Table 24.11)
P1	Plug to match radio microphone jack
S1	SPDT miniature toggle switch
T1	1000 Ω center-tapped to 8 Ω audio transformer (RadioShack 273-1380 if needed, see text

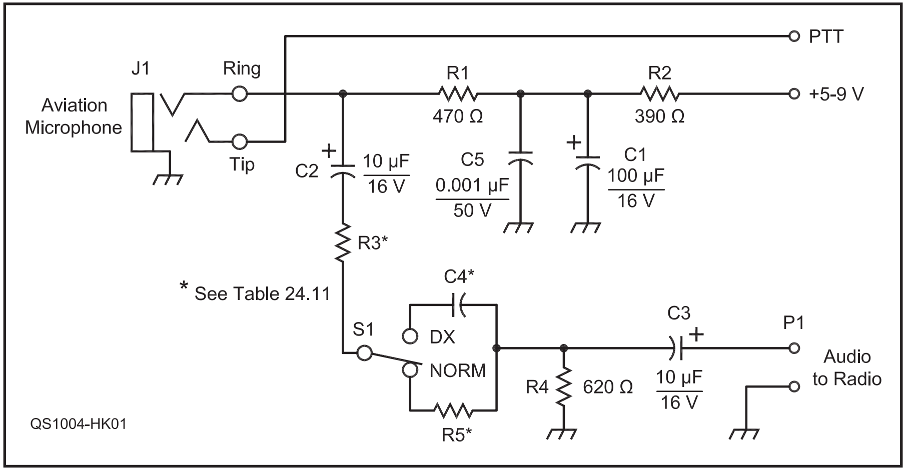


Fig 24.55 — Schematic of KØIZ's resistive-attenuator aviation headphones adapter. The parts list is given in Table 24.10.

Fig 24.56 — A completed KØIZ headset/ adapter. The black box contains the adapter circuit for the aviation headset.

Table 24.11

Aviation Headphone Adapter Microphone Equivalents

Microphone Equivalent Output	*R3*	*R5*	*C4*
Heil HC-5 (–68 dB)	18 k	3.5 k	0.01 µF
Dynamic microphone (–62 dB)	9.1 k	1.8 k	0.02 µF
Electret (–54 dB)	3.5 k	680	0.05 µF
Older ICOM radios (–46 dB)	1.5 k	300	0.12 µF

output similar to that of the "DX" response.

By selecting different values for R3 (and related R5 and C4) we can adjust the microphone output to match just about any microphone/radio combination. **Table 24.11** lists values to match a popular Heil cartridge, other dynamic and electret microphones (as used by ICOM, Yaesu, Kenwood, etc). Values are also shown for older ICOM radios such as the IC-745/751/781 and early 706s, which require even higher output. Further adjustments to these values may be required to match radios that require different input levels.

The headset microphone jack is a Switchcraft C12B or S12B. The PTT connection can be ignored if not needed. You will also need the appropriate plug for your radio's microphone jack. A RadioShack 1 × 2 × 3 inch plastic box (270-1801) will accommodate the components. If you also need to include a 9 V battery, a larger 270-1802 box will work.

A spectrum analysis of a SoftComm C-20 headset with this circuit shows the frequency response is flat through 3200 Hz, dropping off rapidly above that frequency. The "DX" frequency response is similar to Heil HC-4 cartridges.

An Arduino-based knob box for SDR

Michael A. Stott, VE3EBR

BACKGROUND

I had been out of Amateur Radio for over 25 years but I had developed a professional interest in Software Defined Radio (SDR). This led to a resurrection of interest in ham radio and the purchase of a Flex-5000 SDR as a “place to start”. The Flex-5000 works great and I got immediately hooked on the panadapter and the excellent digital filters. I set up a complete software suite including many digital modes programs such as BPSK31, JT65A and the impressive DXLab suite of programs.

I rapidly discovered that:

1) I needed lots of screen “real estate” to accommodate all of the resulting windows. This required at least two monitors for an extended desktop.

2) I needed a software equivalent of a wiring diagram to keep track of which package was talking to which and so on.

3) Software Defined Radio introduces a “latency” delay in the TX or RX paths, the amount of which depends on your CPU speed, filter sharpness settings etc. When using SSB and monitoring your own transmission in the headphones, the delayed copy of one’s own voice can reduce one to talking gibberish if the delay gets more than ~50 to 100 msec so some means of switching off the monitor would be conducive to verbal coherence.

As a result of setting up the multi-monitor display I then discovered that while I could control all of the functions of the SDR with the mouse, when I was in a hurry I could never seem to find the mouse pointer hiding in all those windows! This led to lots of frustration when trying to do something simple like changing the audio volume quickly. I wanted some knobs which would always be in the same physical location so I could access them easily.

I had purchased a companion tuning knob to go with the Flex-5000 and it had an extremely smooth and free motion.

So smooth and free in fact that the slightest accidental touch would disturb the radio tuning with bad results – especially in digital modes. I therefore wanted a tuning knob with a nice “feel” but with positive detents so I could feel how much I was tuning the radio and it wouldn’t move accidentally.

Figure 1: The exterior of the VE3EBR SDR Knob Box.

I then discovered that the DXLab suite could send a steering command to my Yaesu G-800DXA rotator based on the call sign of the station I wanted to work. However, the interface box (GS-232A/B) required to connect from the computer to the rotator control unit seemed jaw-droppingly expensive.

Thankfully, I discovered an article by K3NG which describes an Arduino-based interface/controller for the rotator and I decided to use this design as the basis for adaptation to my task.

CONSTRUCTION

Eventually I got spurred into action and I decided to build a box on a zero-cost basis, i.e., designing around parts which I already had. I rummaged around in my junkbox and discovered a die-cast aluminum box about 4¼" x 2¼" x 1" which happened to have eight ¼" holes already drilled in it.

Coincidentally, it was about the right size to house an Arduino board, provided it is the type with a mini-USB connector such as the OSEPP version.

I also found three small potentiometers, a couple of toggle switches (all with ¼" mountings) and a rotary shaft encoder with 24 detents with a nice silky “feel” to it (Panasonic EVQ-VBMF0124B/ Digikey P80685-ND).

I allocated the three potentiometers to Audio gain, RF Gain (AGC-T on my Flex 5000) and RF drive level and arranged them vertically to correspond to the control positions on the Flex-5000 “panel”.

One of the toggle switches had a centre-OFF position so I allocated it to TX/RX/Tuneup and the regular switch to monitor on/off. I allocated the mechanical shaft encoder to RF tuning frequency and I made the potentiometer knobs from 3/8 diameter aluminum rod drilled to 1/8 and with 4-40 grubscrews.

This filled six of the eight holes in my box so I decided to fill the remainder with red and green LEDs to show which direction the rotator was turning and I mounted these in the box panel using rubber grommets. The selection of type and number of controls is pretty arbitrary and one could accommodate almost any combination within the limits of the Arduino (six analog inputs, eight digital I/O, six digital I/O/PWM_analog_ output).

Photographs of the unit are shown in Figure 1 and Figure 2 and the schematic is shown in Figure 3 on the next page.

From the photographs you can see that the construction is what can politely be described as “ugly but functional”.

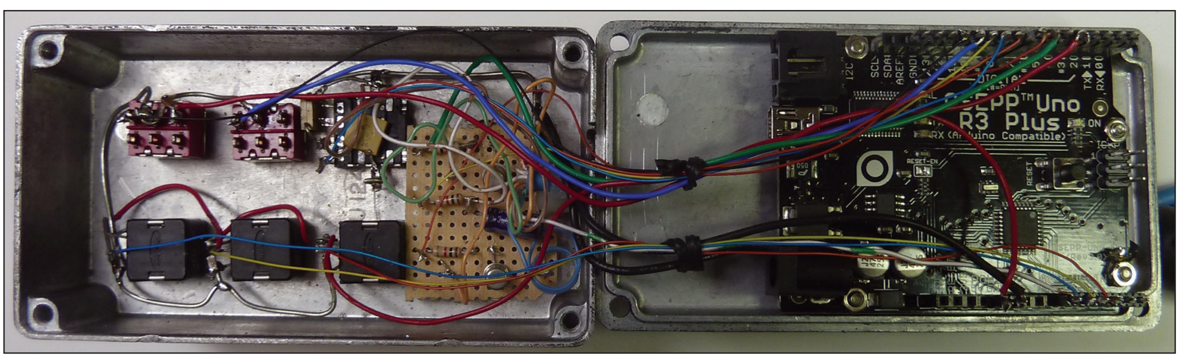


Figure 2: The interior of the VE3EBR SDR Knob Box.

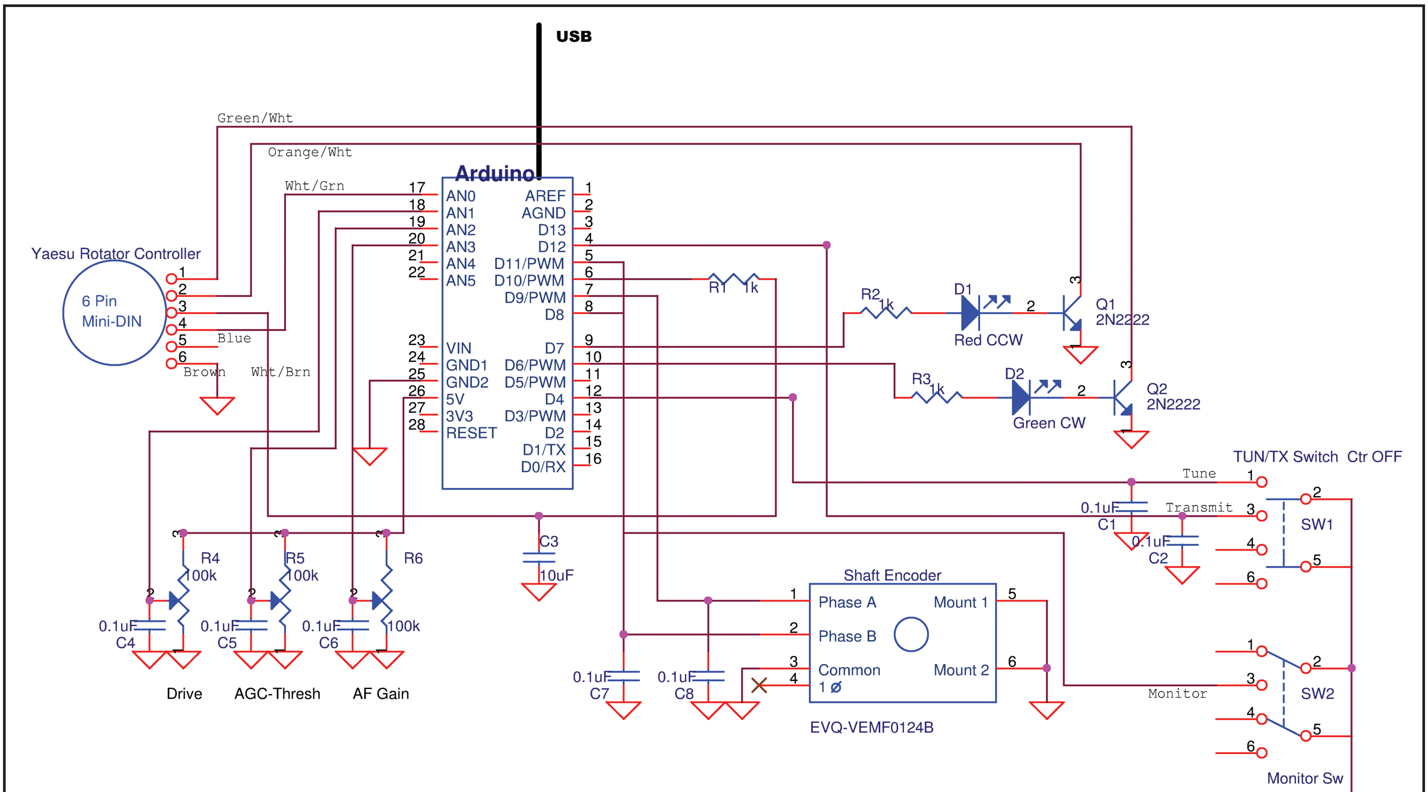


Figure 3: VE3EBR SDR Knob Box Schematic

The rotator driver transistors and other discrete parts are mounted on a scrap piece of perf-board and the wiring is just soldered in place. Loose header pins are used to connect to the Arduino. If I were doing it again I'd make a proper circuit board to mount the discrete parts and a nice wiring harness. The labels were made by laser-printing the text in a white font on top of a black surrounding box. The labels/backgrounds were then overlaid with clear scotch tape and carefully trimmed to size with sharp scissors. The trimmed labels were attached to the unit with UHU glue stick.

A few comments on the schematic are in order.

1) The rotator controller portion using 2N2222 driver transistors and variable speed control is lifted straight from the K3NG design. If you don't have a remote-enabled rotator control unit, you could instead use an Arduino relay board (or "shield" in Arduino-speak). These can be purchased on the Internet for a few dollars and will switch higher currents. This would enable an enterprising Amateur to control a slightly modified standard (i.e., local control only) rotator control box.

2) I put red and green LEDs to indicate which direction the rotator is moving. I later found I never actually looked at them so you could easily omit them but I had two holes to fill!

3) The whole unit is powered from the Arduino USB connection.

SOFTWARE

The software for the unit was created by grafting on the code for responding to the potentiometers, switches etc onto the K3NG rotator controller code. Figure 4 on the next page shows a flow diagram for the knobs portion only.

When the unit is switched on, the program stored in the onboard flash memory of the Arduino loads automatically and executes. It runs all the setup functions once and then begins a continuous looping process as shown.

The functionality is quite simple. The Arduino reads the status of the various knobs and switches and compares the most recent state to the previous state. If something changed it outputs a command to the SDR via the virtual serial link, otherwise it does nothing and continues looping around.

The "C" Language code for the knob portion of the box and the complete integrated combo unit with rotator controller can be obtained from the RAC website at http://wp.rac.ca/tca-content/. The code is compiled using the free Arduino software suite which is downloadable from arduino.cc.

Potentiometers can be a bit "scratchy" and A/D converter readings can "dither" a little around an average value. In order to compensate for these factors I found it necessary to smooth the potentiometer analog outputs by means of smoothing capacitors to ground (0.1 μF) and to put a little software "dead band" into the "has it changed" decision. In other words, the A/D converter output has to change by more than two counts in order to register as a change and the generation of a message to the SDR. Similar issues pertain to the toggle switches which I found to be occasionally scratchy while switching. Again a 0.1 μF capacitor to ground seems to do the trick.

There are many samples of Arduino code on the Internet which claim to track the output of shaft encoders. Most of them are quite susceptible to contact bounce and scratchiness as the control is rotated. I found it necessary to: (a) smooth the shaft encoder outputs with 0.1μF capacitors; and (b) utilize a state machine conversion from the shaft encoder signals to a tune up / tune down command.

The state machine code was borrowed from Buxton (http://www.buxtronix.net/2011/10/rotary-encoders-done-properly.html) which, by the way, contains a typo in the code which is corrected by a commenter ("Adrian", August 4, 2012).

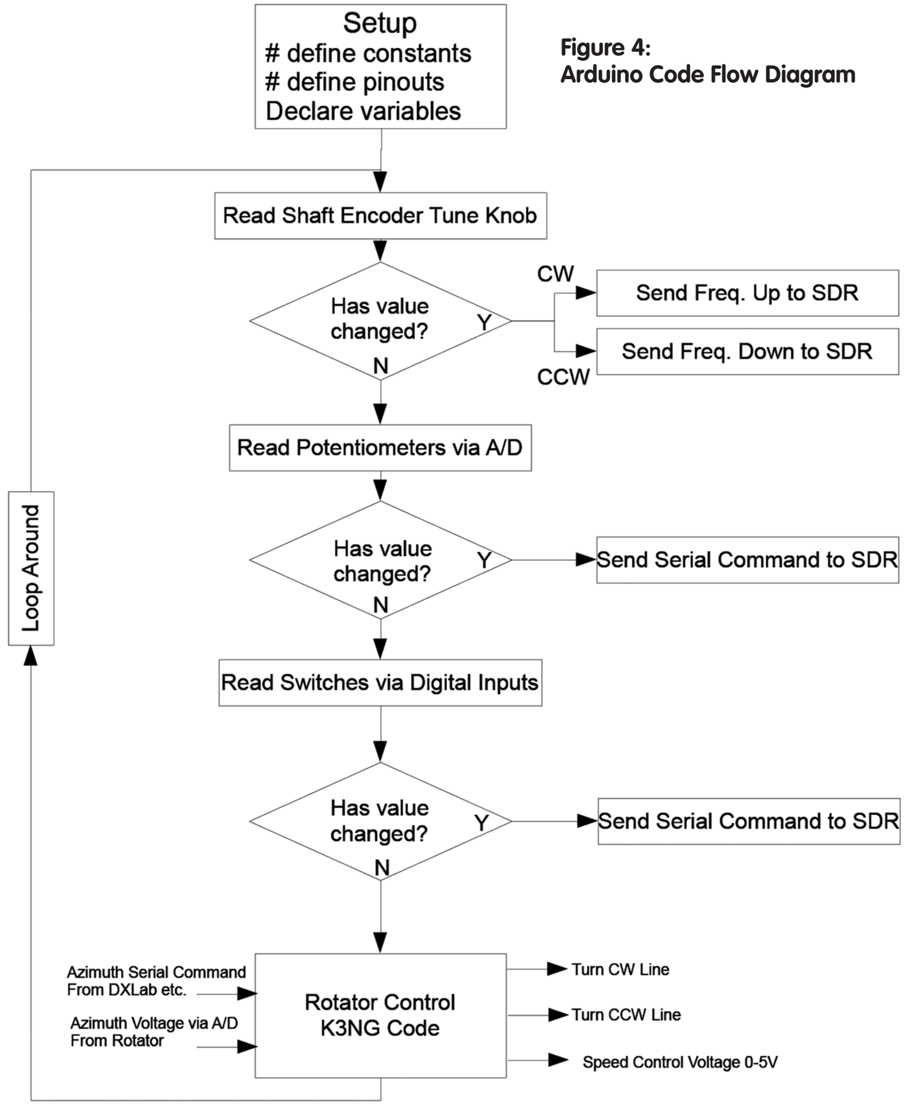


Figure 4: Arduino Code Flow Diagram

The code stored on the RAC website has had the typo corrected. One other point regarding the shaft encoder is that the state machine can be set up to track complete cycles of change (i.e., a complete detent cycle) or to produce an up/down output at the half cycle points. I preferred the half cycle mode. I output a 50Hz up/down command every half-detent and so, when the shaft encoder is at a detent point, the tune frequency is at a multiple of 100 Hz. I found this adequate for SSB and digital modes although it might be a bit coarse for very narrow-band CW.

STATION INTEGRATION

The issue of integration of the Arduino knob box with the rest of the SDR station software was surprisingly tricky. When I first started using SDR I discovered that the SDR software communicates with external programs such as BPSK31, FT65 and so on by means of virtual COM ports and Virtual Audio Cables.

I found it quite challenging to keep a mental track of what connected to what so I drew up a station software "wiring" diagram as shown in Figure 5 on page 48. When using an SDR such as the Flex-5000, a must-have piece of software is DDUtil, currently at V3.x. This free software provides a host of interfacing facilities between equipment such as Linear Amplifiers, rotators and digital modes software and the Flex-5000 CAT computer control port, Com4 (a virtual port) in my case.

The "wiring" diagram is surprisingly complex given that all the software modules shown reside in the same computer!

The connections to the Arduino knob/rotator box are shown at the lower right of Figure 5. Beam steering commands come out of the DX Lab Suite (DX_View module) and emerge via a (virtual) COM port, in my case COM14. They are created within DX_View to conform to Yaesu command set which can then be interpreted by the K3NG rotator code.

In my setup COM14 is one end of COM port Pair4 set up with Com0Com (downloadable from com0com.sourceforge.net). The other end of this pair (Com15) is connected to a companion module, hub4com which is downloadable from the same URL as Com0Com.

Hub4com acts as a kind of virtual box which houses a number of Com ports and it can be set up to pass serial data to/from just about any combination of them. Having said that, the documentation can best be described as arcane and it took quite a lot of trial and error to come up with code for the configuration shown. The beam steering commands come in on Com14 and exit on Com20.

The Arduino is connected to COM20, a virtual port at the end of its USB connection cable. This port is also used to load the Arduino software from the Arduino compiler which temporarily uses COM20 for this purpose.

In operation the Arduino generates commands destined for the SDR and these emerge from COM20, the same virtual Com port which is used to feed in the beam heading commands. This outgoing data however needs to be sent to the SDR and not to DX_View, which is where the beam heading commands came from.

The Hub4com is therefore set up so that traffic coming in on Com15 comes out on Com20, whereas traffic coming in on Com20 comes out on Com22.

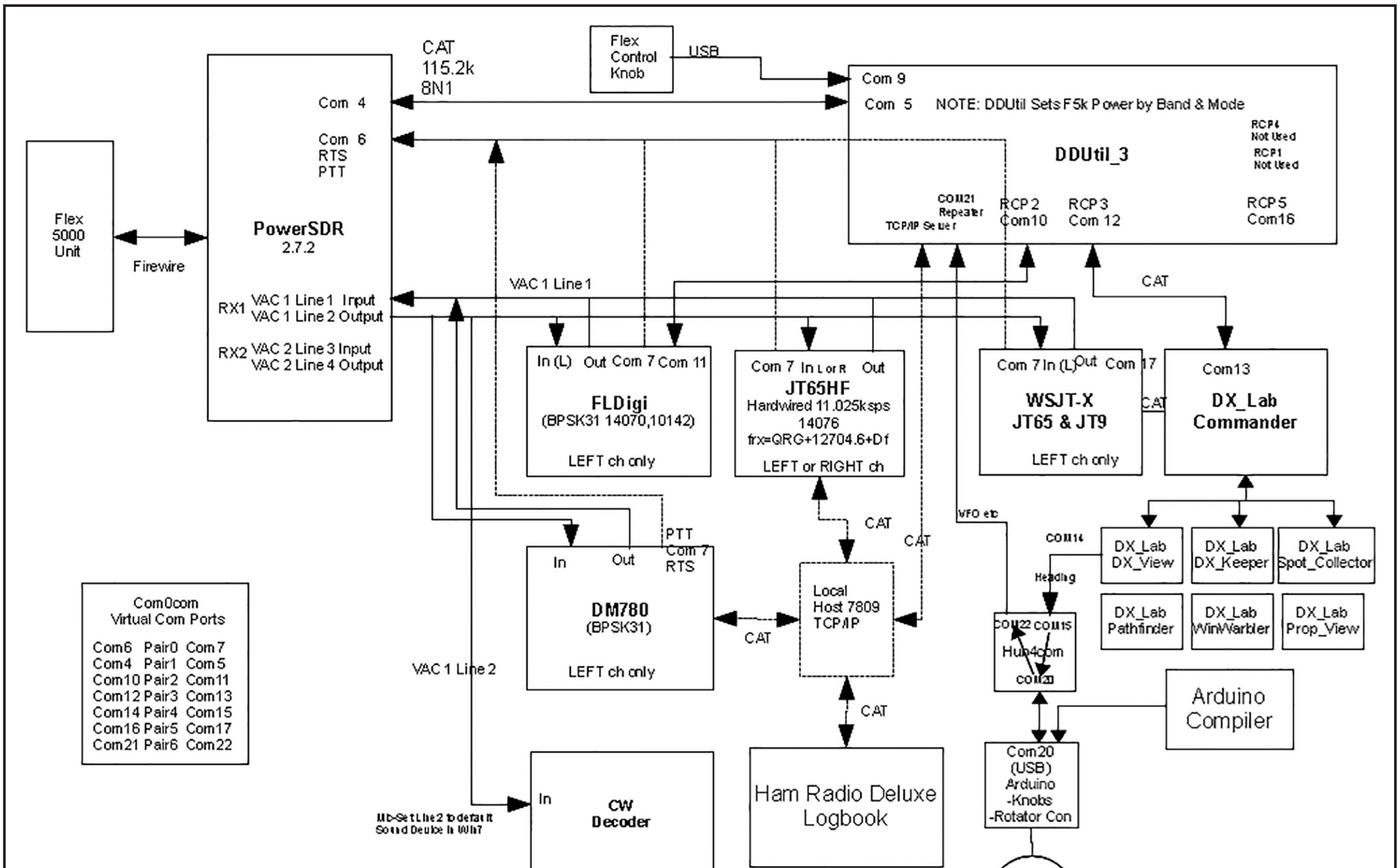


Figure 5: VE3EBR SDR/Station Software "Wiring" Diagram

A DOS batch file (hub4com.bat) is used to set this up and the batch code required is as follows:

hub4com --baud=9600 --route=1:0 --route=0:2 --octs=off \\.\COM20 \\.\COM15 \\.\COM22

The SDR commands coming from the Arduino knobs and switches therefore follow the following path:

Arduino-Com20-Hub4com-Com22-ComPair6-Com21.

Com21 is set up in DDUtil_3 as a simple direct repeater and it then passes the SDR commands to the SDR via the SDR CAT port, Com4.

SUMMARY

I have found the knob box to be a great operating convenience with my Flex-5000. I use it all the time.

I do coarse tuning by clicking the mouse on the panadapter display and finetuning with the knob-box tuning knob.

Similarly, I use the three gain control knobs virtually exclusively – not because I'm an oldtimer longing for a knob to twiddle but because it's easier to find them.

I could have used more shaft encoders rather than potentiometers but I preferred the "absolute" nature of the potentiometer output rather than the relative or incremental output of an encoder.

Note: *Go to http://wp.rac.ca/tca-content/ for the "C" Language Code.*

Michael Stott was first licensed in the United Kingdom as G3MJU in 1958. He came to Canada in 1969 to be involved in the early days of the Canadian space program, initially at Telesat and later as a founder of Canadian Astronautics Ltd. (CAL Corp).

He has been involved in many Canadian and World "Firsts" in space, radar, communications and radio.

He was licensed as VE3EBR in 1969 and is mainly active on the HF bands using SSB and digital modes.

Mike is an inveterate builder, developer and experimenter.

He enjoys messing with antennas, SDR and software development.

His other interests include flying his plane and sailing his boat.

TCA

Build a Legal Limit Bias T that Covers 1.8 to 230 MHz

This simple device lets you send up to 3 A dc down your coax, along with the RF.

Phil Salas, AD5X

A bias T permits the insertion and removal of a dc voltage onto the center conductor of a RF transmission line. It is used to provide dc power to remotely located RF switches, preamps and antenna tuners to avoid the need for a separate dc power cable. Figure 1 (at the bottom of this page) shows a typical application in which a pair of bias Ts power a remote antenna tuner. As you can see, the bias T orientation permits it to either insert or recover the dc operating voltage.

Design Considerations

A dc RF isolating inductor must provide high reactance across the bands of interest while carrying the required dc current. Also the Q must be high to minimize inductor dissipation and thus loss of the RF power dissipation and thus loss of the RF signal.

I measured a large number of inductors on my Array Solutions AIM*uhf* vector network analyzer and found most had either multiple resonances across the HF spectrum, or the Q was too low for the desired efficiency. I finally settled on a J. W. Miller 40 µH inductor. This inductor is rated at 3 A with a typical specified self resonant frequency of 145 MHz. Figure 2 shows the measured inductor data. R_P, the orange curve, is the finite parallel resistance of the inductor due to inductor Q. RF power will be dissipated

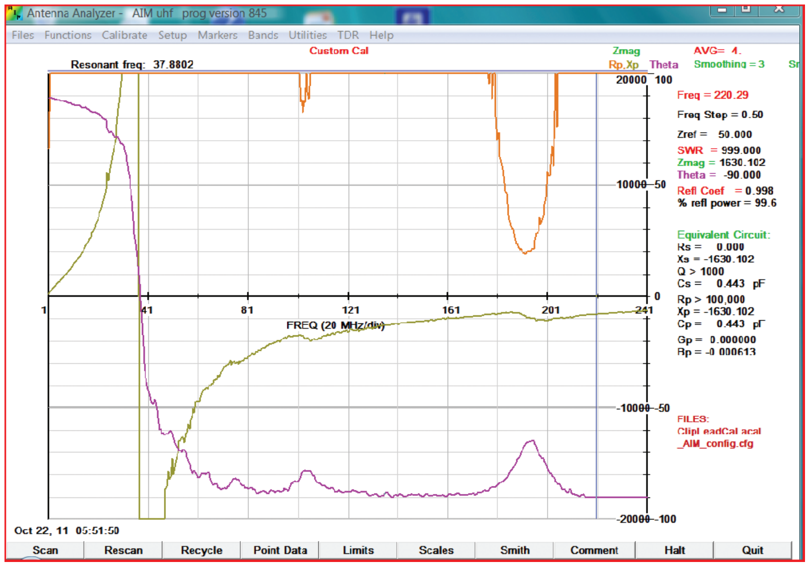


Figure 2 — AIM*uhf* data sweep of 40 µH inductor.

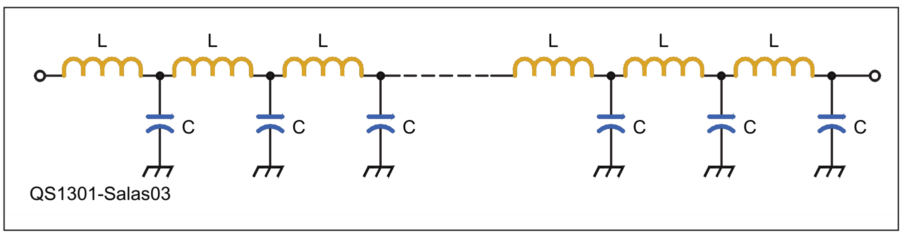


Figure 3 — Lumped element equivalent circuit of a transmission line.

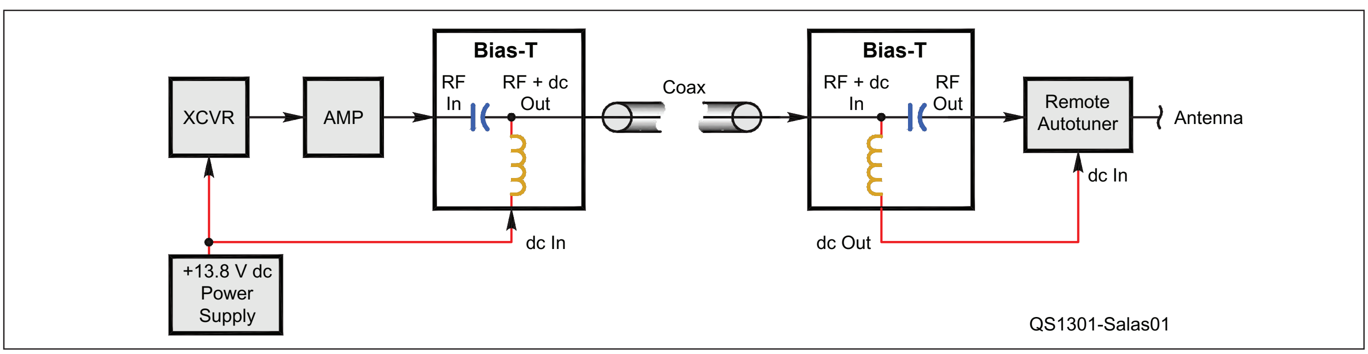


Figure 1 — Typical system connection diagram of a bias T.

Table 1
40 µH R_P and Calculated Inductor Power Dissipation (P_D) at 1500 W

Band (meters)	160	80	40	20	17	15	12	10	6	2	1¼
R_P (kΩ)	23	34	40	41	42	48	37	43	29	100	100
P_D (W)	3.3	2.2	1.9	1.8	1.8	1.6	2	1.7	2.6	0.75	0.75

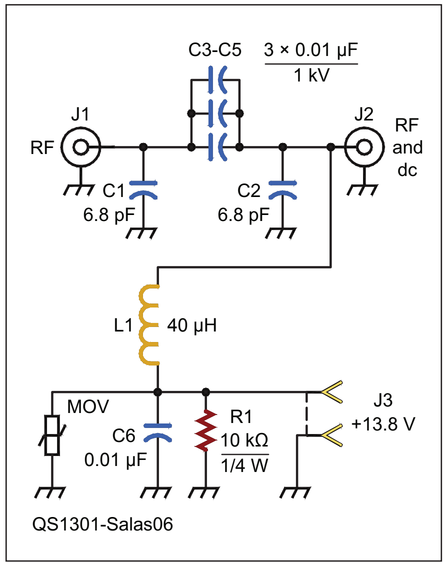


Figure 6 —Schematic diagram and parts list for the bias T. Mouser parts are available from **www.mouser.com**.

C1, C2 — 6.8 pF, 1 kV capacitor (Mouser 75-561R10TCCV68).
C3-C6 — 0.01 µF, 1 kV capacitor (Mouser 81-DEBF33A103ZA2B).
J1, J2 — SO-239 UHF coax sockets (Mouser 523-83-1R).
J3 — Chassis connector, dc power (Mouser 163-1060-EX).
L1 — 40 µH, 3 A inductor, J.W. Miller 5240-RC (Mouser 542-5240-RC).
MOV — Metal-oxide varistor, 18 V dc (Mouser 667-ERZ-V10D220).
R1 — 10 kΩ, ¼ W resistor (Mouser 660-MFS1/4LCT52R103J).
Electrical box, Reddot S100E (Lowes 71209).
Metal box cover, Reddot S340E-R (Lowes 303624).

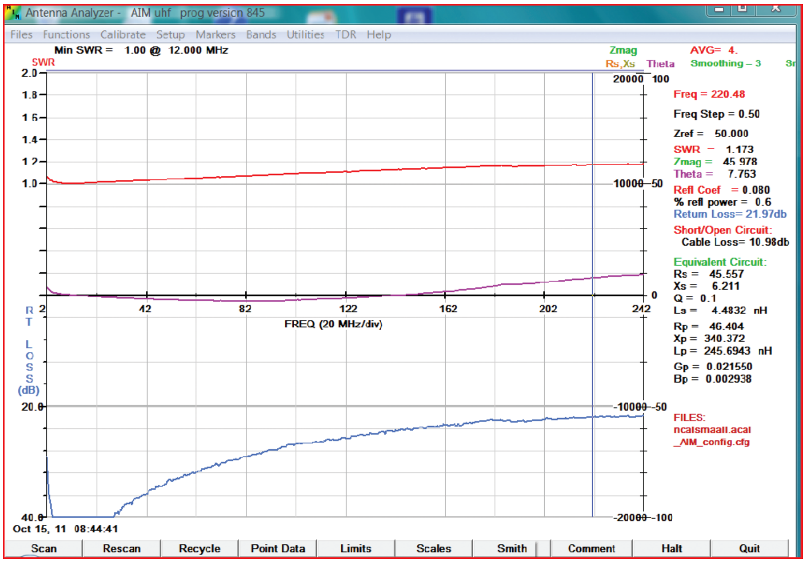


Figure 4 — AIM*uhf* data sweep of the bias T SWR with compensation.

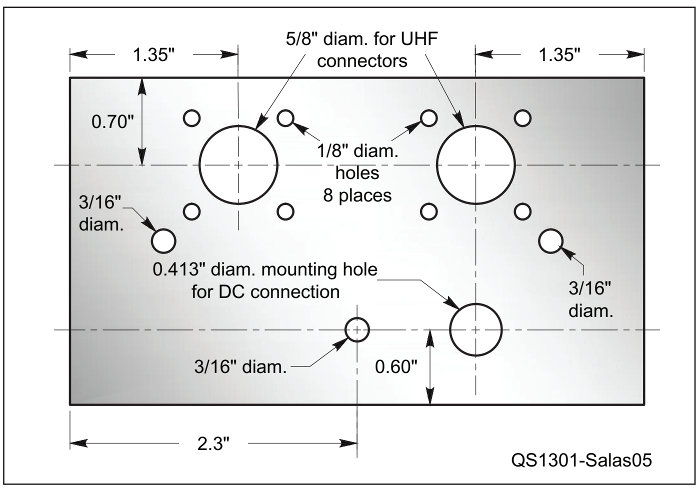


Figure 5 — Cover plate hole locations with dimensions.

in this resistance. As you can see, R_P stays high in the ham bands of interest.

I tabulated R_P for the different ham bands in Table 1. And I calculated the inductor power dissipation at 1500 W ($P_D = V^2/R_P$ where $V^2 = 75{,}000$ at 1500 W and 50 Ω). For typical low duty cycle SSB or CW operation, the power dissipation will be about 25 to 30% of that shown.

Next I built the bias T. My first bias T circuit had acceptable SWR through 6 meters (the 6 meter SWR was 1.2:1). The SWR degraded, however, to about 1.7:1 on 2 meters, so I decided to see if I could improve the performance at higher frequencies.

A lossless transmission line can be modeled as an infinite number of incrementally small series inductors and shunt capacitors (see Figure 3) with the characteristic impedance given by $Z_0 = (L/C)^{1/2}$.

A hand wired assembly such as this bias T tends to be inductive unless you use good transmission line construction practices. Sure enough, my AIM*uhf* measurement data showed that the assembly was inductive. Since $Z_0 = (L/C)^{1/2}$, increased series inductance can be compensated for by increasing the shunt capacitance. With a little experimentation I found that 6.8 pF capacitors across the input and output significantly improved performance. As you can see in Figure 4 the SWR is less than 1.05:1 up to 50 MHz, less than 1.1:1 on 2 meters, and less than 1.2:1 at 220 MHz.

Construction

I built the bias T into an inexpensive outdoor electrical cast aluminum box from a home supply store. Figure 5 shows the hole locations on the cover that ensure that the connectors and components don't interfere with the internal cover mounting brackets. I used a step drill for the dc and UHF connector holes.

After drilling the ⅝ inch diameter holes for the UHF connectors, I inserted the UHF connectors in the holes and marked the locations for the #4 (⅛ inch) mounting holes

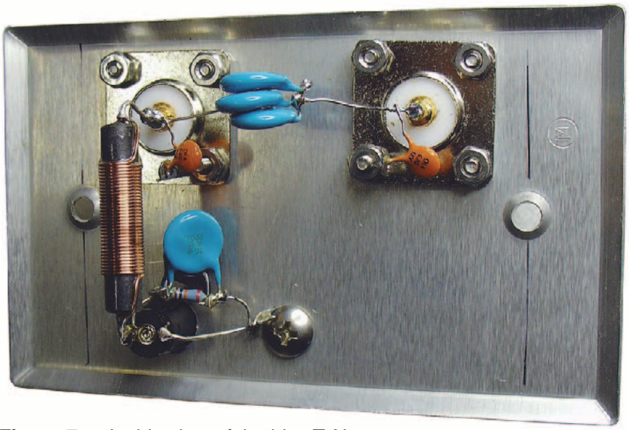


Figure 7 — Inside view of the bias T. Note the input/output compensating capacitors.

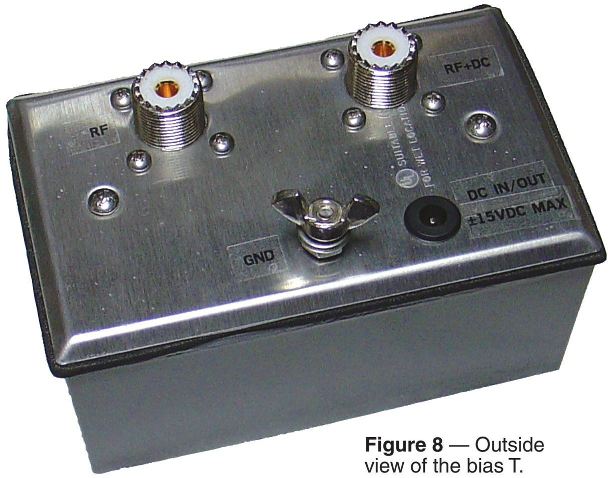


Figure 8 — Outside view of the bias T.

with an ultra fine pitch permanent marker. I then center punched and drilled these mounting holes.

The complete parts list and the schematic are shown in Figure 6. All components mount on the outlet box cover. The mounting hardware is stainless steel for outdoor use (the cover includes a weatherproof gasket). The three 0.01 µF, 1 kV paralleled capacitors were not chosen for their voltage rating, as there should be virtually no RF voltage drop across them. I did want, however, physically large capacitors that were capable of handling the power dissipation due to the approximately 5.5 A_{RMS} RF current through them under legal limit operation. On the dc in/out side, the metal oxide varistor (MOV) provides transient protection for voltages over about 18 V dc and the 0.01 µF capacitor provides RF bypassing. I included a 10 kΩ resistor to provide a constant dc path to ground.

Figure 8 is an outside view of the bias T. I used a #8-32 wing nut on the ground lug, but a standard #8-32 stainless steel nut can be substituted. Casio "Black on Clear" labeling tape sprayed with Krylon clear coat adds the text. A black permanent marking pen is a good alternative weatherproof marking method.

Conclusion

A bias T can be the ideal solution for providing dc operating voltages through your coax cable to remotely located devices. The weatherproof unit described here can provide up to 3 A of dc while simultaneously handling RF power up to 1500 W from 1.8 to 220 MHz.

ARRL Life Member and Amateur Extra licensee Phil Salas, AD5X, has been licensed continuously since 1964. Because of his interest in ham radio he obtained BSEE and MSEE degrees from Virginia Tech and SMU respectively. This led to a 33 year career in Microwave and Lightwave R&D. Now fully retired, Phil spends his time tinkering with ham related projects and relaxing with his wife and best friend Debbie, N5UPT.

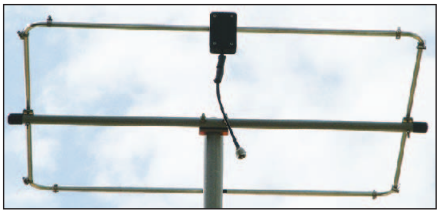
You can reach Phil at 1517 Creekside Dr, Richardson, TX 75081 or at **dpsalas@tx.rr.com**.

For updates to this article, see the *QST* Feedback page at www.arrl.org/feedback.

New Products

Cushcraft 6 Meter and HF Squalo Antennas

Cushcraft's Squalo antenna is a half-wave, horizontally polarized omnidirectional antenna offering a 360 degree pattern with no deep nulls. The square shape allows full electrical length with compact dimensions. Squalo antennas are intended for horizontally polarized mobile or fixed operation on SSB, CW or AM. Elements may be stacked for added gain. The 6 and 2 meter models are packaged with rubber suction cups and magnets for vehicle top mounting and a horizontal center support for mast or tower mounting. The 10, 15 and 20 meter models are designed for mast or tower mounting. Power rating is 100 W PEP for CW or SSB. Prices: ASQ-2, 2 meters, 10 × 10 inches, $119.95; ASQ-6, 6 meters, 30 × 30 inches, $139.95; ASQ-10, 10 meters, 50 × 50 inches, $159.95; ASQ-15, 15 meters, 65 × 65 inches, $189.95; ASQ-20, 20 meters, 100 × 100 inches, $229.95. For more information, to order, or for your nearest dealer, call 800-973-6572 or see **www.cushcraftamateur.com.**



Compact Antenna Tuner from MFJ

The MFJ-902B antenna tuner uses air variable capacitors (600 V, 322 pF) and three stacked powdered iron toroids. Rated to handle 150 W on 80 to 6 meters, the tuner is intended to be used with compact transceivers such as the ICOM IC-706MKIIG, Yaesu FT-100D, Kenwood TS-50 or any other 100 W class transceiver with a built-in SWR meter. The MFJ-902B measures 2.25 × 4.5 × 2.75 inches (HWD) and weighs less than 2 pounds. Price: $109.95. For more information, to order, or for your nearest dealer, call 800-647-1800 or see **www.mfjenterprises.com.**

ARRL Handbook CD

Template File

Title:	Interfaces
Chapter:	24
Topic:	A Trio of Transceiver/Computer Interfaces

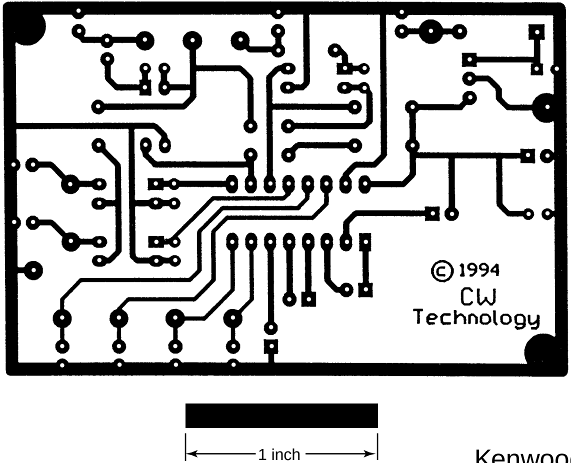
Template contains:

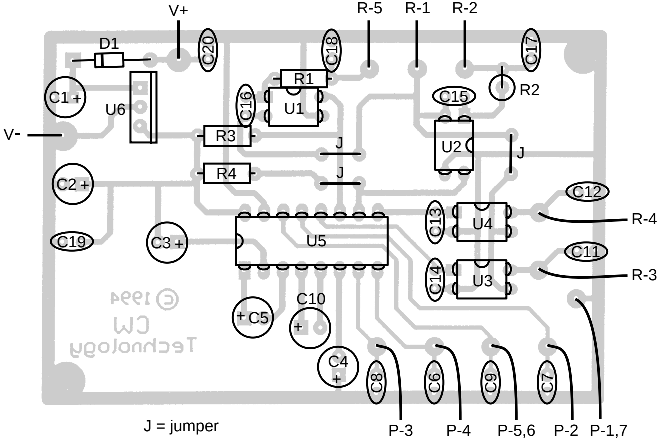
Kenwood interface PC board etching pattern.

Kenwood interface parts placement diagram.

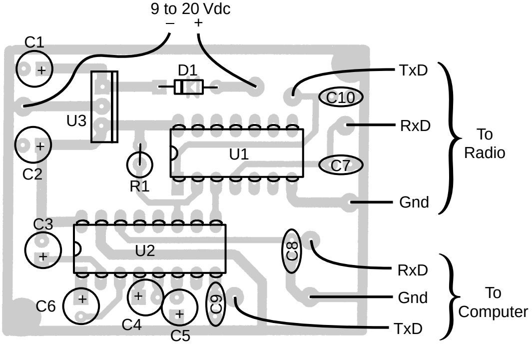
Icom/Ten-Tec/Yaesu interface PC board etching pattern.

Icom/Ten-Tec/Yaesu interface parts placement diagram.

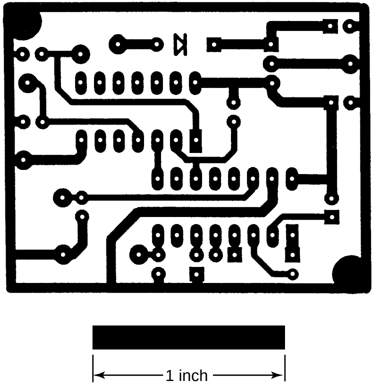




Kenwood Interface



ICOM / Ten-Tec / Yaesu Interface



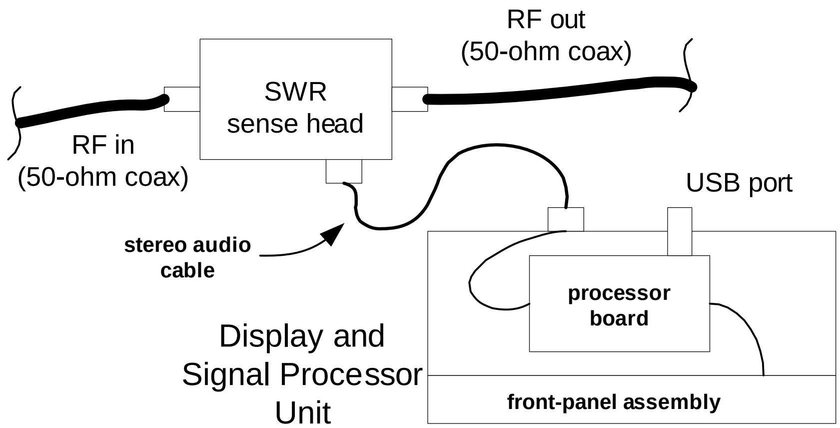


Figure 1. - Block diagram

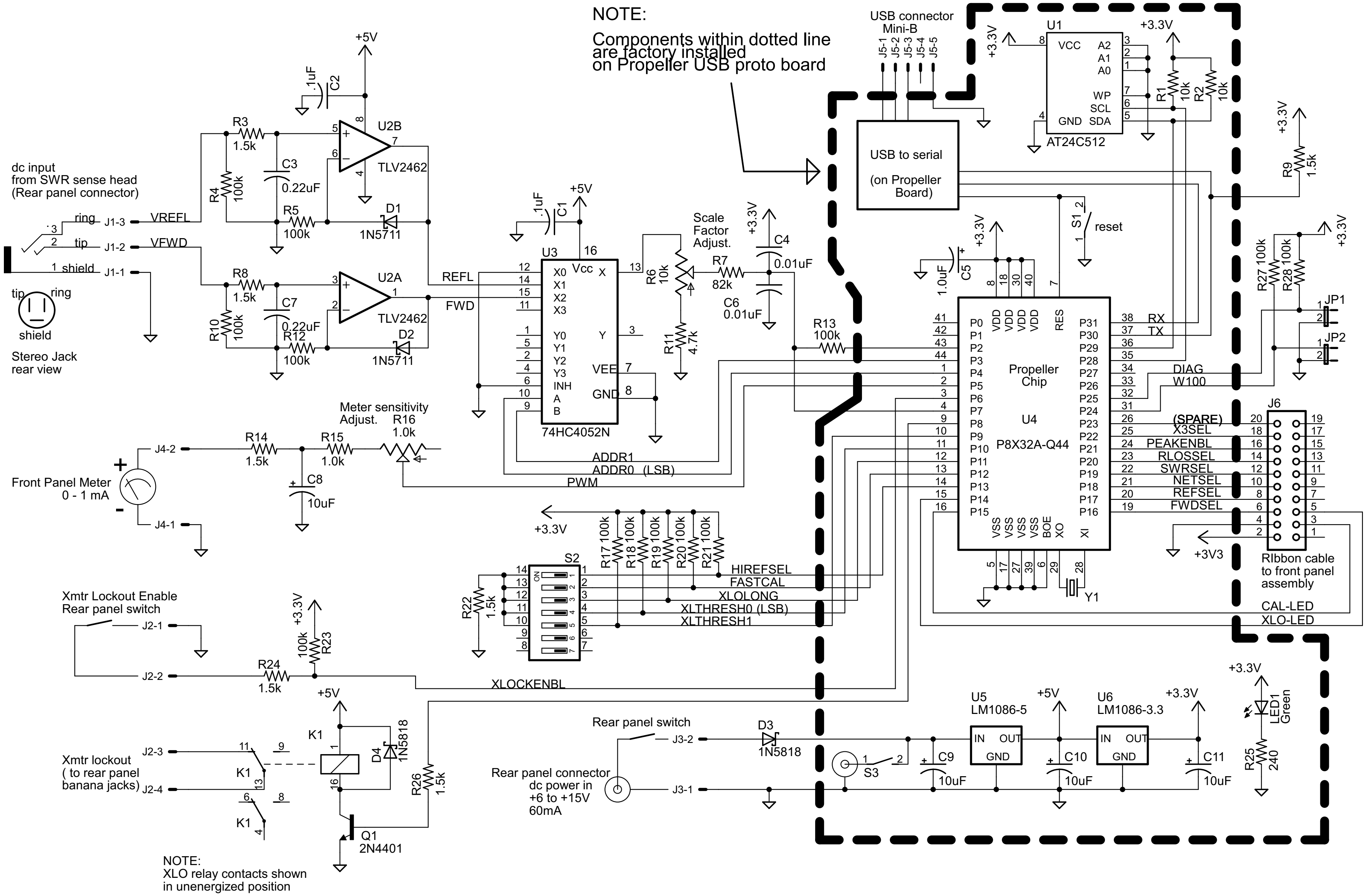


Figure 4 -- Processor Board

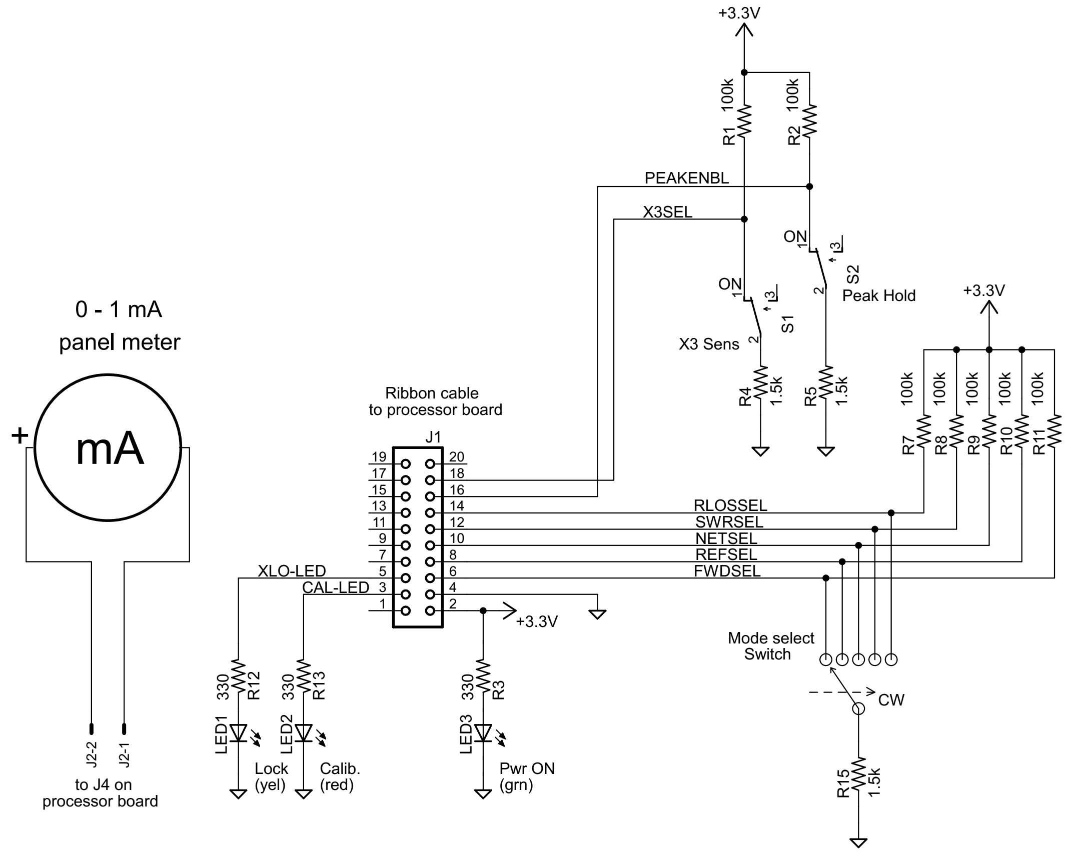


Figure 5 -- Front panel components

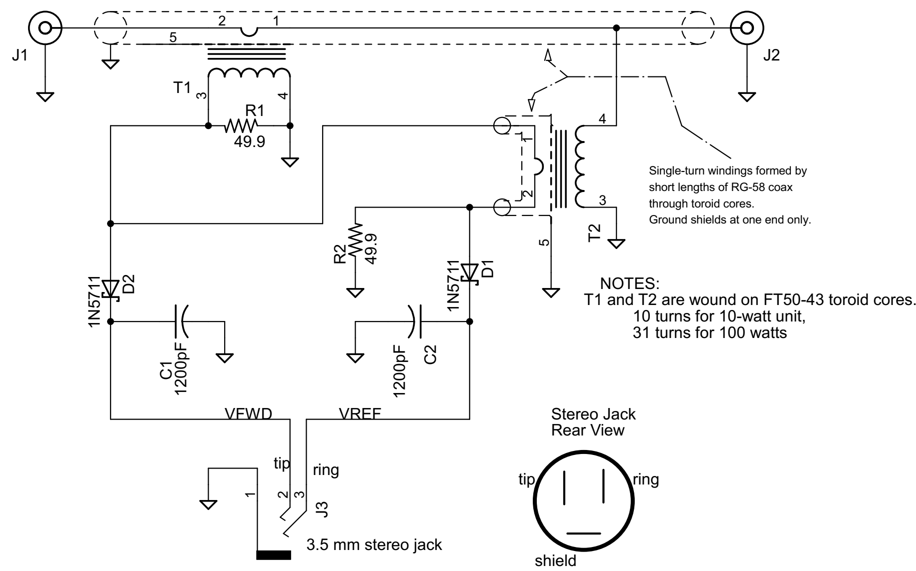
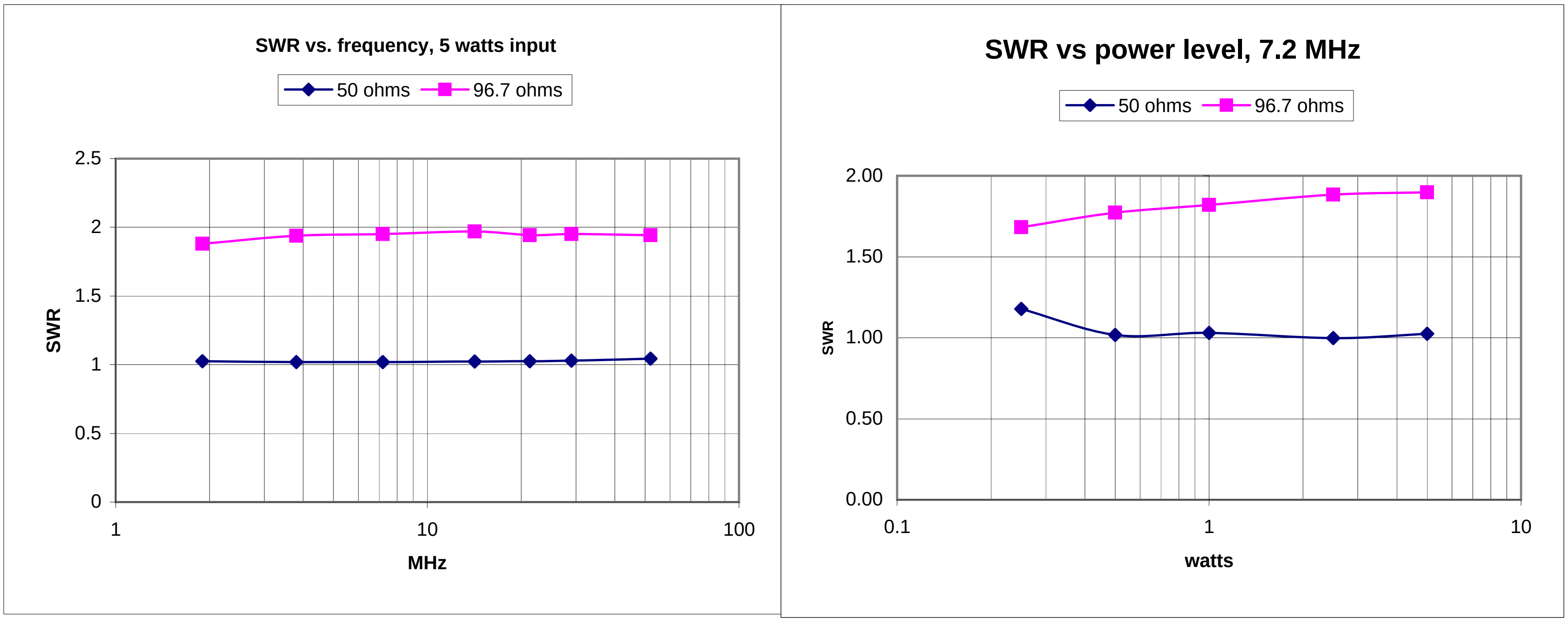


Figure 9. SWR Sense Head



(A) (B)

Figure 11 -- SWR vs. frequency and power level

24.13 The ID-O-Matic Station Identification Timer

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 24.54** is an automatic ID timer/annunciator with a rich set of features that make it useful for many applications.

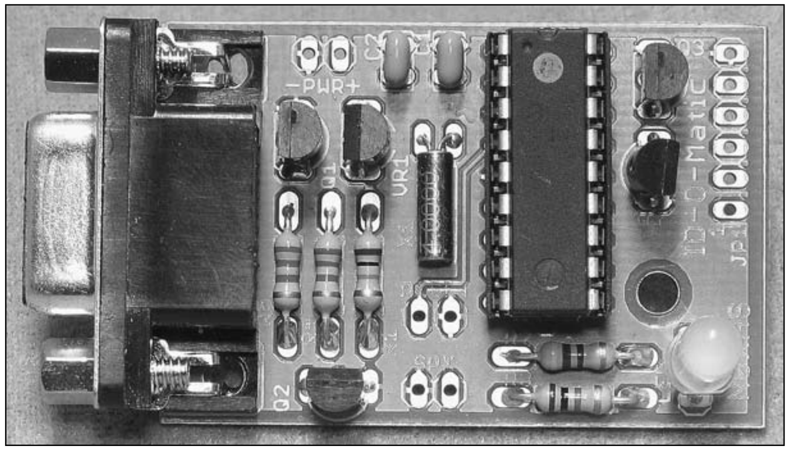


Fig 24.54 — This version of the ID-O-Matic is built from a kit offered by www.hamgadgets.com. The parts count is low, and it can easily be built on a prototype board.

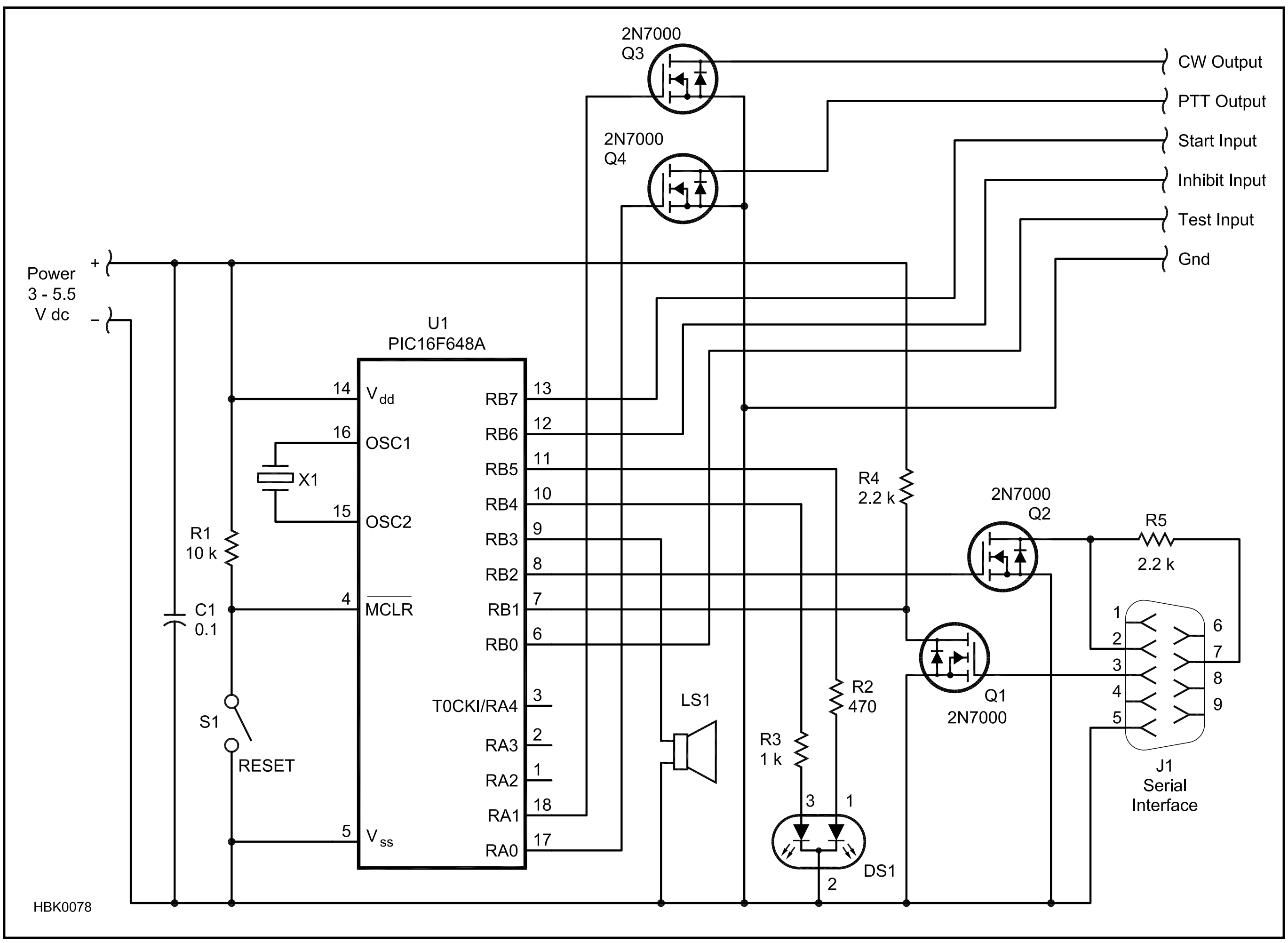


Fig 24.55 — Schematic of the ID-O-Matic. Resistors are ¼ W.

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. (ARRL now publishes a book about PIC Programming for beginners.)
X1 — 4 MHz cylindrical crystal (Mouser 520-ECS-400-18-10).
Enclosure: Pac-Tec HMW-ET (Mouser 76688-510).

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 24.55**, 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 pinch 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 shifting 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 time-out period. After a series of reminder beeps, it will automatically reset and begin a new timing cycle. To change any of the settings, simply connect a serial cable to your PC or a dumb terminal and the ID-O-Matic. Any serial communication program such as *PuTTY*, *HyperTerminal* or *Minicom* can be used. The communication settings are 9600 baud, 8 bits, no parity and no handshaking. Hit the ENTER key twice to view and edit the configuration. The program will step through a series of prompts as shown in **Fig 24.56**. 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. During normal operation, this pin will select the alternate ID message. This may be useful to indicate, for example, if a repeater site has switched to battery power, or if a "fox" transmitter has been located.

• 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

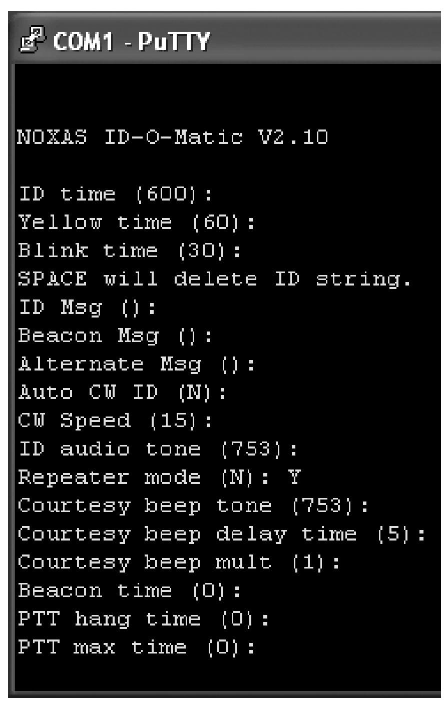


Fig 24.56 — Using *HyperTerminal* to set up the ID-O-Matic

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; it will output the same message as the audio output.

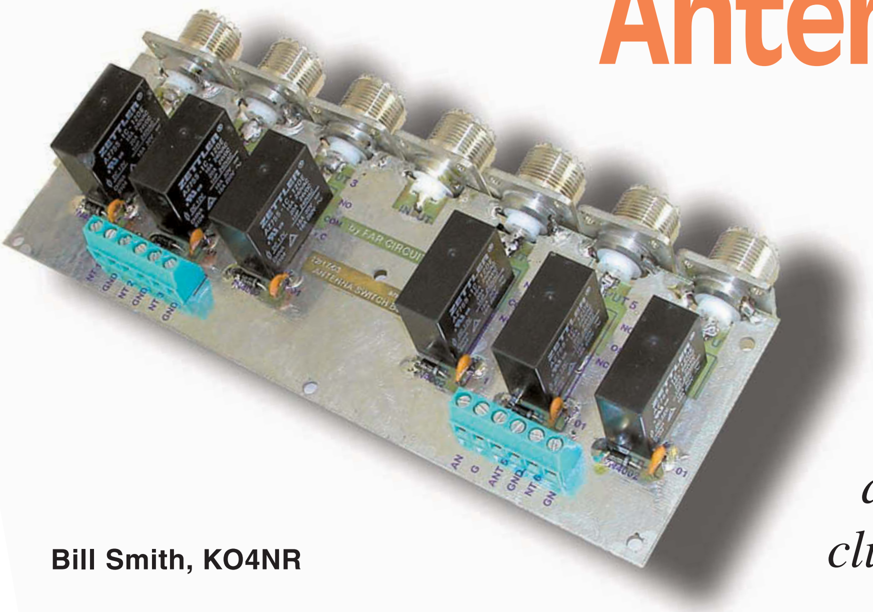
The original program code took several days to write and tweak, and has undergone numerous revisions since then. As with any project like this, the testing was the time consuming part. The author used the PIC C compiler from CCS, Inc. to write the program, but the logic is simple enough that porting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

A Low-Cost Remote Antenna Switch



Here's an easy and inexpensive way to reduce the number of antenna feed lines cluttering up your shack.

Bill Smith, KO4NR

How many of us have struggled with getting multiple antenna feed lines into our shacks? I believe it is a common problem that can be easily solved with a suitable remote antenna switch.

My shack is in the basement on the opposite end of the house from the antenna feed lines. My antenna farm consists of a 2 meter beam, an end-fed half-wave sloper and a modified Zepp by NB6Z. I pondered the problem of getting the feed lines for all the antennas into the shack for several days without coming up with a good plan. My dilemma was finding a path to run three or more coaxial feed lines across the top of the basement's suspended ceiling. In addition I would have to win the approval of my wife.

I cautiously began the easement negotiations knowing it would take some time. Negotiations were complicated by the fact that a hole large enough for three or more coaxial feed lines would have to be cut in the house's wood siding. In the end, my wife agreed to a plan that included a small hole in the wood siding and a single coax run across the top of the basement's suspended ceiling. Switching antennas meant frequent trips outside to connect the right feed line to the coax running into the house. I operated this way for over four years, all the while longing for a better way to switch my antennas.

Remote antenna switches were the answer, but they can be expensive. I had seriously considered purchasing one of the many remote antenna switches on the market, but I couldn't decide which one to go with. As if struck by lightning, it came to me: Why not build a switch using one of the many printed circuit board (PCB) power relays on the market? Surely one of the hundreds of PCB power relays available would be suitable for switching antennas.

Relay Selection

The solution to my antenna switching problem presented itself while I was experimenting with PCB relays for use in a linear amplifier's tuned input circuit. The search for a suitable PCB relay for the amplifier revealed interesting innovations in PCB relay design. They now come in small packages, exhibit high dielectric strength and can carry impressive amounts of current.

Although not factory tested for RF use, I found the American Zettler AZ755 series PCB relays to work very well.[1] 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. I used American Zettler 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 single-pole double-throw (SPDT). The E suffix indicates that the relay is epoxy sealed. I thought the epoxy seal would provide better protection from dirt and moisture contamination. If you prefer relays that are not epoxy sealed, drop the E from the part number.

American Zettler relays are readily available on-line from **RelayCenter.com**.[2]

Circuit Design and Board

Figure 1 shows the final circuit. I settled on a switch that would handle up to six antennas, enough for my current antenna farm and possible future expansion. 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.

[1]Notes appear on page 41.

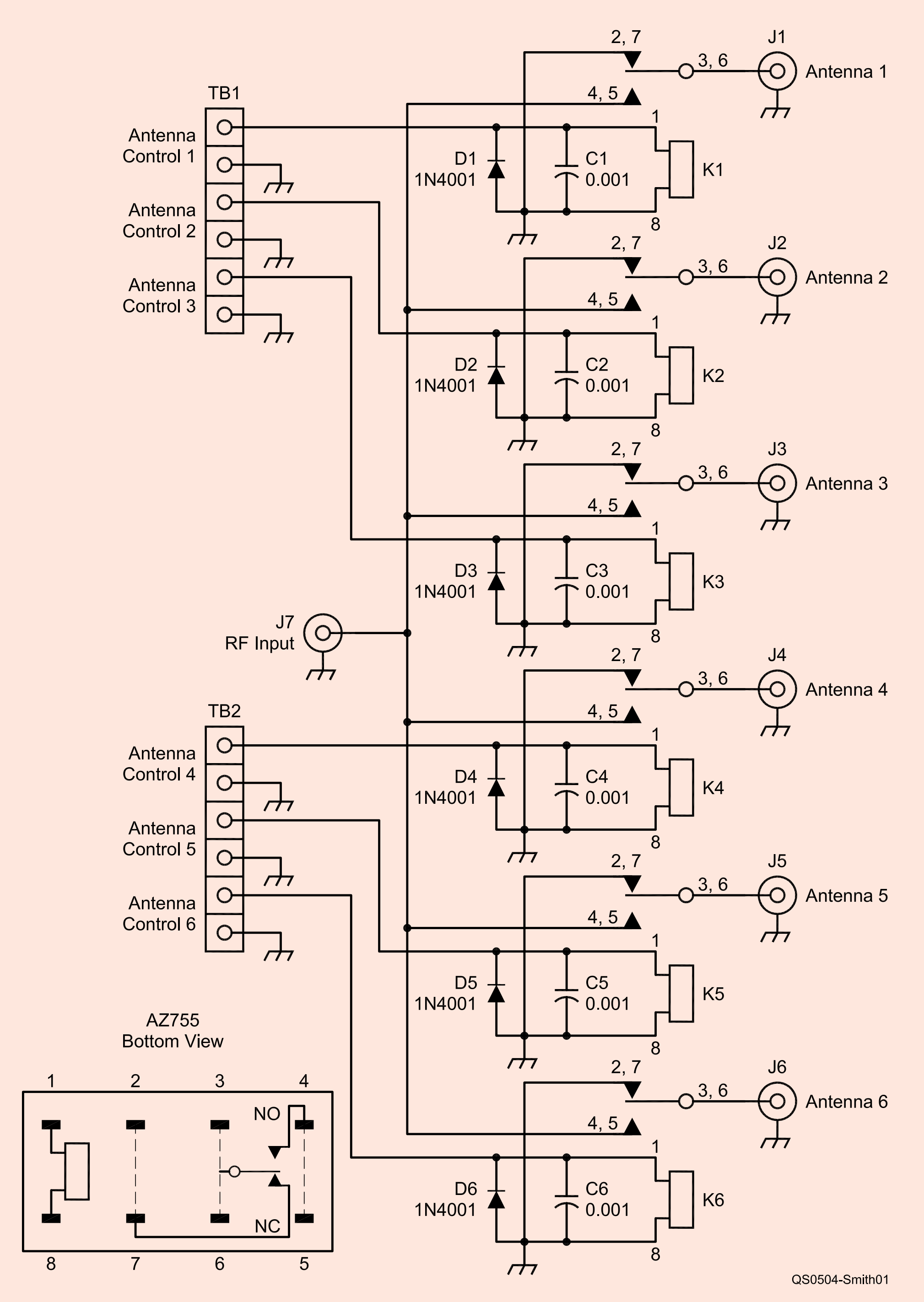


Figure 1—Schematic and parts list for the remote antenna switch. All parts except the PC board and relays K1-K6 are available from Mouser Electronics, 1000 N Main St, Mansfield, TX 76065; 800-346-6873; www.mouser.com.

C1-C6—0.001 µF, 50 V disc ceramic capacitor (Mouser 140-50P5-102K-TB).
D1-D6—1N4001 diode (Mouser 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). See text.
TB1, TB2—PC board terminal block with 6 contacts (Mouser 651-1729050).

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.

To keep stray RF out, 0.001 µF ceramic disc capacitors (C1-C6) are installed across the relay coils. In addition, 1N4001 diodes (D1-D6) are installed across the coils to prevent voltage spikes when the power is removed from the coil.

Once I located a relay that might work and had a circuit in mind, I contacted FAR Circuits to see if an inexpensive circuit board could be produced. FAR Circuits has built several boards for my linear amplifier projects and has a proven history of supplying high quality circuit boards. Fred at FAR Circuits agreed to design the board[3] for me using the AZ755 relays with SO-239 input and output connectors. He suggested mounting the SO-239s directly to the board to eliminate wiring and minimize SWR problems. The finished board with all components mounted is shown in the title photo. The RF INPUT connector is in the center, with three ANTENNA connectors on each side. The control cable connects to the two terminal blocks.

Assembly Notes

The design is simple and assembly doesn't require special tools. Far too often, projects require sophisticated test equipment and a degree of expertise I don't possess. This project can easily be completed by anyone with basic soldering skills.

In addition to the PC board and parts, you'll need a suitable enclosure to keep

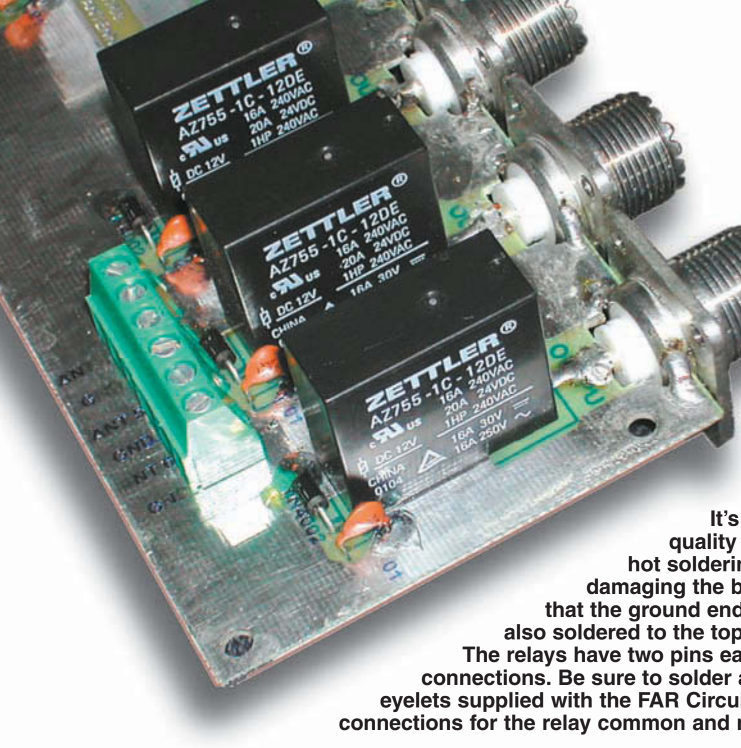


Figure 2—The connector flanges are soldered to the board's ground plane top and bottom. It's important to use good quality SO-239 connectors and a hot soldering iron to avoid damaging the board or connectors. Note that the ground ends of D1-D6 and C1-C6 are also soldered to the top and bottom of the board. The relays have two pins each for the contact connections. Be sure to solder all pins and to install eyelets supplied with the FAR Circuits board to ensure good connections for the relay common and normally closed pins.

the board dry and pests away. I installed mine in a plastic children's lunch box that hangs under my deck. Initially this enclosure was just for testing purposes, but it has worked out so well that I may not change it.

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 location 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. Of course you can use other SO-239 connectors, but you may have to modify the board 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 Figure 2. I used a Sears Craftsman Dual 230/150 W iron

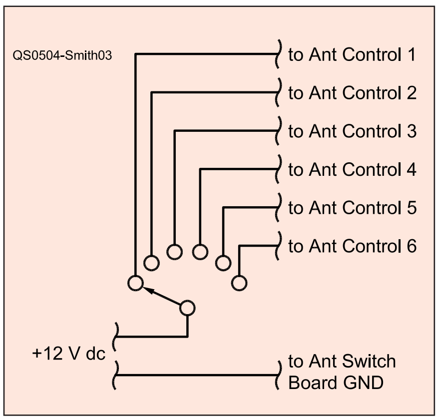


Figure 3—I used a simple 12 V supply and rotary switch in my shack to select antennas.

and it worked great. 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 no. 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.

Powering It Up

To control the switch, I use a 12 V dc power supply in the shack and a small ceramic rotary switch as shown in Figure 3. 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 your outside lightning protection ground system.

I ran an 8-conductor control cable into the shack using the same route taken when I installed the coax. My wife agreed to it when I explained the cable would eliminate the need to run additional coax into the house. My control cable has #16 conductors and is something I had in my parts collection. There is a chart at **www.altronix.com/html/an101.htm** that you can use to help you determine the right wire size for your installation. Long runs of wire may require larger 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.

Test Results

Once the switch was completed, I performed several tests to see how it worked. The testing was done with my Kenwood TS-850S transceiver, RadioShack MTA-20 digital power meter and Swan Mark 1 linear amplifier. The board was not installed in an enclosure for the initial testing. It was lying on top of a plastic box.

Test 1. For the initial test, I connected the TS-850S (with internal antenna tuner off) to the RF INPUT jack on the antenna switch board. Then I connected one of the antenna jacks on the switch board to the RadioShack power meter and then to a dummy antenna. From 160-10 meters, the internal meter in the TS-850S indicated that the SWR was about 1.2:1, and the external power meter indicated no loss of power through the relay board. My TS-850S is sensitive to SWR and has always folded the power back when transmitting into a high SWR. That didn't happen, so I concluded the SWR with the board in the line must be low.

Test 2. Next I added the Swan Mark 1 amplifier between the transceiver and antenna switch. I measured the power with the digital power meter before and after the antenna switch board and could detect no difference. I operated the amplifier in the CW mode at 1-1.3 kW. The relay got a little warm but no more than I would expect from an energized coil, and it seemed to handle the power just fine. SWR with the switch in line remained low on all bands.

Test 3. For the final test, I borrowed a friend's MFJ-259B antenna analyzer to use as a reality check. For this test, I placed the board under my deck where it would be in normal use, connected it to a dummy antenna, and ran about 70 feet of RG-8X to the antenna analyzer. I then used the MFJ-259B to measure the SWR, reactance (X_s) and resistance (R_s) on each band from 1.8-144 MHz. The results are shown in Table 1.

ARRL Lab Testing. The ARRL Lab had an opportunity to test the completed antenna switch board as well. 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.

The various tests showed that although they are not designed for RF, the relays seem to perform well. The board exhibits low SWR, low insertion loss and good isolation over a wide frequency range. It handles 1-1.3 kW during normal intermittent SSB and CW operation (I did not try it with a key-down mode like RTTY).

Summary

This project offers a rewarding solution to managing the number of feed lines snaking through your house. Parts are readily available, and the FAR Circuits PC board makes construction straightforward. If homebrewing is not your cup of tea, don't despair. There are several good commercial antenna switches available from the advertisers in *QST*.

Table 1
MFJ-259B Test Results

Freq (MHz)	*SWR*	*X_s (Ω)*	*R_s (Ω)*
1.8	1.1:1	0	63
2.0	1.1:1	0	61
3.5	1.1:1	5	53
4.0	1.0:1	0	56
7.0	1.0:1	0	57
7.3	1.0:1	0	58
10.1	1.2:1	9	51
10.15	1.1:1	7	49
14.0	1.1:1	7	50
14.35	1.1:1	4	53
18.068	1.1:1	2	50
18.168	1.0:1	0	55
21.0	1.2:1	9	48
21.45	1.1:1	8	52
24.89	1.4:1	5	53
24.99	1.1:1	3	53
28.0	1.1:1	6	50
29.7	1.0:1	0	61
50	1.0:1	0	57
54	1.0:1	0	61
144	1.2:1	11	47
148	1.2:1	9	47

Notes

[1]You can find more information at American Zettler's Web site, **www.americanzettler.com**. A data sheet for the AZ755 series relays may be downloaded from **www.azettler.com/pdfs/az755.pdf**.

[2]**www.relaycenter.com**. At publication time, the AZ755-1C-12DE relays used in this project were $2.25 each plus shipping and handling, with a minimum order of $25.

[3]The circuit board is available from FAR Circuits, 18N640 Field Ct, Dundee, IL 60118 for $11 plus $2 shipping and handling. For ordering information, see the FAR Circuits Web site at **www.farcircuits.net** and look under the Repeater Controller & Station Accessory heading.

Bill Smith, KO4NR, enjoys repairing and modifying vintage linear amplifiers, including a Swan Mark 1 and Heath Warrior. He usually operates 17 and 40 meter SSB, and especially likes chatting with other hams who share his passion for building and working on equipment. Employed as maintenance manager at a gas fired energy plant, Bill can be reached at 244 Cameron St, Manchester, NH 03103, or by e-mail at **ko4nrbs@yahoo.com**.

New Products

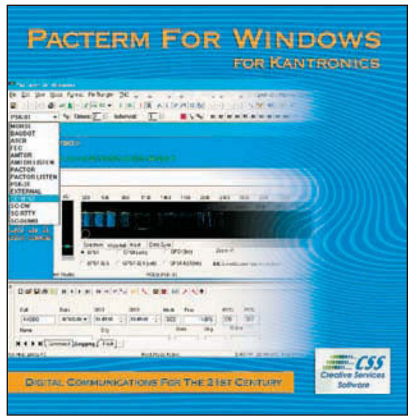
QRP PROTOTYPING KIT

◊ The QRP Prototyping Kit has been added to the Alden McDuffie kit product line. This kit is designed to save time for those constructing a project. The kit includes case, printed circuit board (PCB) with "dead bug" construction area and pads with layout for SO-239 coaxial connectors, two 3.5 mm audio jacks and two alternate-action switches. All those parts are included. The printed circuit board is designed to fit in their 3.2×4×1.25 inch project case.

A step-by-step manual is designed to assist in building the kit and planning the project. Included are the case, mechanical drawings, schematic and parts list for the PCB kit. Price: fully assembled with case, $54.95; full kit, $42.95; PCB kit without case, $29.95. For more information, contact Alden McDuffie, PO Box 3636, Lawrence, KS 66046; tel 785-766-0404; **www.aldenmcduffie.com**.

PACKET TERMINAL SOFTWARE

◊ *PacTerm 3 for Windows* and *PkTerm 3 for Windows* are offered in preview version by Creative Services Software.



This new release includes a new user interface in a single window, a built-in generic logging program, the MT63 soundcard mode, PSK 62.5 mode, TCP/IP support and more.

New sound card modes just plug in. This means a ham can create a dynamic linked library (DLL) file for any mode, put that DLL into the *PacTerm* or *PkTerm* folder and that new mode appears on the HF mode menu of *PacTerm* or *PkTerm 3*.

The software includes sample skeleton source code to allow a user to create their own modem (HH_DUMB.DLL and source code). Also included is the source code for the HH_MT63.DLL.

Neither program requires a TNC. There is a soundcard only mode that will work with the RIGblaster, MFJ units, Timewave's soon to be released Hamhub and homebrew interfaces.

Price: *PacTerm for Windows and PkTerm for Windows*, $99.95; upgrades from earlier versions, $49.95. Both programs include a 30 day full featured demo version, so hams and MARS users can try them out before purchase. For more information or to order, see **www.cssincorp.com**.

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Title: Multiband Tuning Circuits
Author: R.W. Johnson, W6MUR

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Multiband Tuning Circuits

Some Considerations in the Design of Single-Ended Networks

BY R. W. JOHNSON,* W6MUR

• In recent months, we have been hearing more and more about multiband tuning circuits — circuits that cover 3.5 Mc. to 30 Mc., for instance, without switching or changing coils. This article covers the design of the single-ended type, and considers some possible variations from the popular version of the circuit.

A multiband tuning circuit was introduced by King[1] of the National Company in 1948. The circuit has been used in a recent transmitter by Chambers,[2] and is commercially available as the National Company Type MB-150 and MB-40L. There appears to have been only scant design data[3] presented on this circuit, to permit the average amateur to design his own circuit. There also has been overlooked a possible modification of the circuit using but one tapped coil instead of the two coils usually used. In this article, both of these subjects will be discussed.

Circuit Description

The basic circuit of King is shown in Fig. 1, in single-ended form. Equal capacitors are used

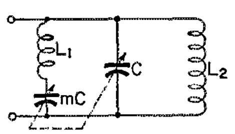


Fig. 1 — Basic circuit of a single-ended multiband tuner.

in the National circuits, but we will not restrict this discussion to equal capacitors. The capacitors are ganged together, and the coils (in the simplest case) have no mutual inductance between them. This circuit, properly designed, is capable of tuning ratios equal to the capacity ratio (C_{max}/C_{min}) instead of the square root of this capacity ratio as in ordinary circuits. Thus a continuous 8:1 or 9:1 frequency range is possible with this circuit, without coil switching.

Calibration

There are simultaneously always two parallel-resonant frequencies for the circuit of Fig. 1, as well as one series-resonant frequency. The two parallel-resonant frequencies may or may not be harmonically related, depending on design. The series-resonant frequency always lies between the parallel-resonant frequencies, and can even be used to advantage in suppression of certain harmonics.

If f_o is defined as the resonant frequency of L_2C taken alone, then the parallel-resonant frequencies of the total circuit are

$$f_{r_1} = K_1 f_o \qquad (1)$$

and

$$f_{r_2} = K_2 f_o \qquad (2)$$

where K_1 and K_2 are constant for all settings of C, and depend on L_1, L_2 and m of Fig. 1. If, as C is tuned through its range, f_o changes from f_{o_1} (the lowest frequency) to f_{o_2} (the highest frequency), frequencies f_{r_1} and f_{r_2} change from $K_1 f_{o_1}$ to $K_1 f_{o_2}$, and from $K_2 f_{o_1}$ to $K_2 f_{o_2}$, respectively.

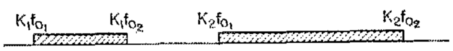


Fig. 2 — Frequency-scale representation of tuning range.

This situation is depicted in Fig. 2 on a frequency scale (not tuning scale). The two bands occupy the same positions on the capacitor tuning dial even though they are separated in frequency.

Since K_1 and K_2 depend only on L_1, L_2 and m of Fig. 1, they can be chosen arbitrarily, within limits. K_1 is a number less than unity, and K_2 is a number greater than unity, for realizable cases. The ratio K_2/K_1 can be almost anything desired, which means that the two bands of Fig. 2 can (a) overlap, (b) be adjacent, or (c) be separated, on the frequency scale. The maximum possible *continuous* (all frequencies covered) tuning range occurs in case (b), or when $K_1 f_{o_2} = K_2 f_{o_1}$, or $K_2/K_1 = f_{o_2}/f_{o_1}$. The tuning ratio for this case is $K_2 f_{o_2}/K_1 f_{o_1} = (f_{o_2}/f_{o_1})^2 = C_{max}/C_{min}$.

Selection of parameters is thus determined by the desired tuning ratios, or in other words, by K_2 and K_1. The design must be such that K_2/K_1 is about midway between integers, if harmonic response is to be minimized. We therefore need the relation between the Ks and the circuit parameters.

Relation for K

Input admittance of the circuit of Fig. 1 can be written in the usual fashion and set equal to zero. A fourth-degree quadratic frequency equation results, giving the parallel-resonant fre-

* % The Ralph Parsons Company, Pasadena 8, Calif.

[1] King, "No Turrets — Just Tune!" *QST*, March, 1948.

[2] Chambers, "Three-Control Six-Band 813 Transmitter," *QST*, Jan., 1954.

[3] DiMarco, "Circuitos de Resonancia Multiple y Su Apicacion en los transmisiores para Aficionades," *Revista Telgrafica Electronica* (Argentina), March, 1954.

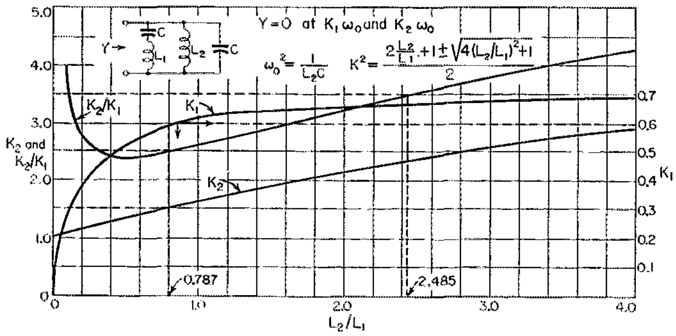


Fig. 3 — Curves of K_2, K_1, and the ratio K_2/K_1 *vs.* L_2/L_1, for equal capacitors ($m = 1$).

quencies (and hence K) when solved. The relation for K is

$$\left.\begin{aligned} K_1^2 &= \frac{S - \sqrt{S^2 - 4\,\dfrac{L_2}{mL_1}}}{2} = (f_{r_1}/f_o)^2 \\ K_2^2 &= \frac{S + \sqrt{S^2 - 4\,\dfrac{L_2}{mL_1}}}{2} = (f_{r_2}/f_o)^2, \end{aligned}\right\} \quad (3)$$

where $S = \frac{L_2}{L_1}\frac{1+m}{m} + 1$, and $f_o = \frac{1}{2\pi\sqrt{L_2C}}$

Since L_2/L_1 is usually desired when given m and K, *Eq.* (3) can be rearranged to give this result. Thus,

$$L_2/L_1 = mK^2\,\frac{K^2 - 1}{(1+m)K^2 - 1} \qquad (4)$$

which is valid for either K_1 or K_2. For the usual case of equal capacitors, $m = 1$ and *Eqs.* (3) and (4) become

$$K^2 = \frac{2L_2/L_1 + 1 \pm \sqrt{4(L_2/L_1)^2 + 1}}{2} \qquad (3a)$$

and

$$L_2/L_1 = K^2\left(\frac{K^2 - 1}{2K^2 - 1}\right) \qquad (4a)$$

In *Eq.* (3a), the plus signs is used in solving for K_2 and the minus sign for K_1.

Curves of K_2, K_1 and the ratio K_2/K_1 *vs.* L_2/L_1 are shown in Figs. 3 and 4. Fig. 3 is for equal capacitors ($m = 1$), and Fig. 4 is for $m = 0.5$. Preferred operating points, to avoid harmonic responses, are shown on the curves.

If unequal but ganged capacitors are used, then $m \neq 1$. As can be seen from Fig. 4, the preferred operating point, $K_2/K_1 = 2.5$, falls at $L_2/L_1 = 1.06$ when $m = 0.5$. Thus, if it is more convenient to use identical coils for L_1 and L_2, m can be chosen accordingly. The value $m = 0.789$ gives $L_1 = L_2$ and $K_2/K_1 = 2.5$.

Example

As a design example, suppose we desire to tune all amateur bands in the range 3.5–21.5 Mc. Assume that equal ganged capacitors are used, and that the available capacitor ratio is at least 6.25:1 (corresponding to, say, 150 $\mu\mu$f. maximum and 24 $\mu\mu$f. minimum). If we want continuous frequency scale coverage, we would choose $K_2/K_1 = (6.25)^{1/2} = 2.5$. This value is a preferred operating point in Fig. 3, at which $L_2/L_1 = 0.8$, $K_2 = 1.5$ and $K_1 = 0.6$. The lowest desired frequency, 3.5 Mc., is $K_1 f_{o_1}$, so that f_{o_1} (the resonant frequency of L_2C_{max} is 3.5/0.6 = 5.83 Mc. For a given capacitor, coil L_2 is determined from this frequency of 5.83 Mc. Coil $L_1 = L_2/0.8 = 1.25L_2$. At minimum capacity, the resonant frequency of L_2, C_{min} is $5.83 \times 2.5 = 14.6$ Mc. Thus, the two bands A and B of Fig. 2 extend from $0.6 \times 5.83 = 3.5$ Mc. to $0.6 \times 14.6 = 8.75$ Mc., and from $1.5 \times 5.83 = 8.75$ Mc. to $1.5 \times 14.6 = 21.9$ Mc. These two bands are of course coincident across the dial, and are covered simultaneously in 180° of capacitor rotation.

Coupled Impedance

Output coupling can be to coil L_2 only. In this case, parallel-resonant impedance is about K^2 times what it would be for a normal L_2C circuit. This means that in the lowest band, where K_1 (< 1) is used, capacitor C can be smaller than that which would otherwise be

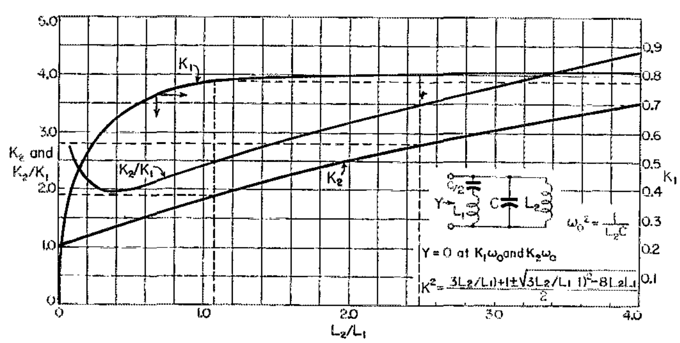


Fig. 4 — Curves of K_2, K_1, and the ratio K_2/K_1 *vs.* L_2L_1 for $m = 0.5$.

necessary; and in the higher band, where K_2 (> 1) is used, C can be larger than would otherwise be necessary. L/C ratio and ease of coupling thus tend to remain more constant with this circuit than with an ordinary resonant circuit. This was pointed out by King.[1]

Coupled Coils

The general case, where mutual inductance exists between L_2 and L_1, has been worked out, but the results will not be presented here, except for one special case that is extremely useful. This case is that of a center-tapped coil, connected as shown in Fig. 5 with a split-stator capacitor C.

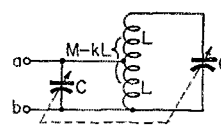


Fig. 5 — Multiband-tuner circuit using a center-tapped coil.

Connection to the tank circuit is made at terminals a and b in Fig. 5. The impedance between a and b is parallel-resonant at $K_1 f_o$ and $K_2 f_o$ as before, where K is now given by the relations

$$K_1^2 = \frac{3 + 2k - \sqrt{(3 + 2k)^2 - 4(1 - k^2)}}{2(1 - k^2)}, \tag{5}$$

$$\text{and } K_2^2 = \frac{3 + 2k + \sqrt{(3 + 2k)^2 - 4(1 - k^2)}}{2(1 - k^2)},$$

where k is the coupling coefficient between the two halves of the coil. (k is negative for this case, but this has already been considerated in *Eq.* (5), to avoid errors in using the relations.) Frequency f_o for use with *Eq.* (5) is given by

$$f_o = \frac{1}{2\pi\sqrt{LC}},$$

and is the resonant frequency of half the total coil taken alone with C. A curve of *Eq.* (5), showing K_1, K_2 and K_2/K_1 *vs.* coupling coefficient k is shown in Fig. 6. Preferred operating points, to avoid harmonic response, are also indicated in Fig. 6.

Estimation of Coupling Coefficient

To use the curves of Fig. 6 or the relations of *Eq.* (5), a relation between coupling coefficient and coil dimensions is needed. Fortunately, this relation is not complex for a center-tapped coil. As shown in Fig. 7, a center-tapped coil can be replaced by a T equivalent. Looking into terminals *a-b* or *b-c* we see merely L, but looking into terminals *a-c* we see $2L(1 + k)$. One can apply the Wheeler formula[4] for the inductance of a single-layer solenoid that is not too short (length at least equal to 0.8 times diameter) to solve for coupling coefficient k. This is done by first calculating the inductance between *a-b* (or *b-c*) for a coil of half the total length and half the total turns, and then the inductance between *a-c* for a coil of the total length and total turns. These two relations when solved simultaneously give coupling coefficient as

$$k = \frac{9}{9 + 20(l/d)} \tag{6}$$

where k is of the correct sign for substitution into *Eq.* (5). (l/d) is the ratio of length to diameter of the coil, in the same units of measurement. *Eq.* (6) holds only for values of (l/d) of about 0.8 or greater. A curve of k *vs.* (l/d) is shown in Fig. 8. The portion much below $(l/d) = 0.8$ has been obtained by another more exact inductance formula, but with the same approach.

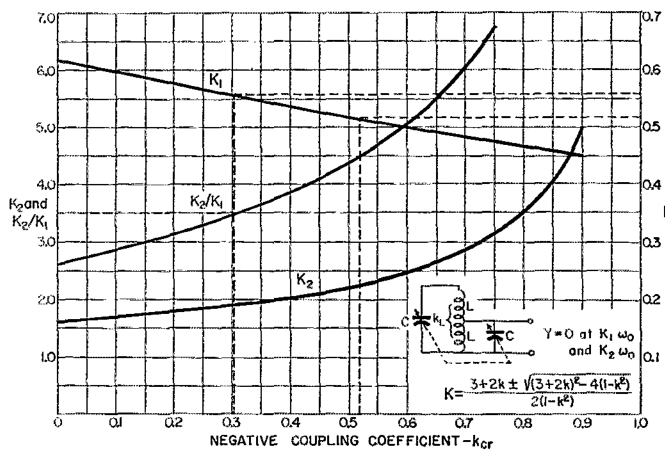


Fig. 6 — Curve of *Eq.* (4), showing K_1, K_2, and K_2/K_1 *vs.* coupling coefficient k.

Example

Suppose we wish to cover the range 3.5–30 Mc., such as to tune all amateur bands. For a given capacitor and capacitor tuning ratio, what must be the size and proportions of a single, center-tapped inductance?

We first observe that the total tuning ratio is

[4] Terman, *Radio Engineer's Handbook*, 1st ed., 1943, McGraw-Hill, p. 55.

30/3.5 = 8.58. If we were to insist on continuous frequency scale coverage of the entire range, ratio K_2/K_1 must be $(8.58)^{1/2} = 2.93$. This is dangerously close to 3, so that third harmonic response would be appreciable if this ratio were used. We therefore choose the nearest value of K_2/K_1 that is a preferred operating point, or $K_2/K_1 = 3.5$, realizing that in so doing we must allow a gap to exist in the frequency coverage, if we must still tune 3.5–30 Mc. (Continuous coverage with $K_2/K_1 = 3.5$ requires a capacity tuning ratio of $(3.5)^2 = 12.25$, which is impracticably high.)

From Fig. 6 at $K_2/K_1 = 3.5$, we find $K_2 = 1.92$, $K_1 = 0.55$ and $k = 0.3$. From Fig. 7 at $k = 0.3$ we find l/d of the coil to be 1.05. Arbitrarily setting the lower band limit at 3.4 Mc. to insure coverage at 3.5 Mc., resonant frequency f_{o_1} is $3.4/K_1 = 3.4/0.55 = 6.19$ Mc. With a capacitor tuning ratio of 9:1, $f_{o_2} = 3 \times 6.19 = 18.55$ Mc. Thus the two bands are

$6.19 \times 0.55 = 3.4$ Mc. to $1855 \times 0.55 = 10.2$ Mc., and

$6.19 \times 1.92 = 11.9$ Mc. to $18.55 \times 1.92 = 35.6$ Mc.

No coverage is obtained between 10.2 Mc. and 11.9 Mc., but this is unimportant for amateur applications.

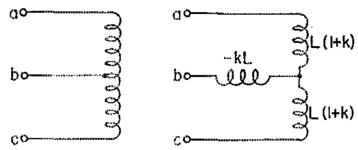


Fig. 7 — T equivalent of a center-tapped coil.

The design is therefore complete. One selects a coil such that *one half of the coil* has a length-to-diameter ratio of 0.525, and for a given maximum value of capacitor C, finds the number of turns this half-coil must have to resonate at 6.19 Mc. The final coil has just twice the number of turns and twice the length of the half-coil. The capacitor must be at least 9 times the minimum value expected, which minimum includes strays and tube capacitances. Thus a capacitor of maximum value about 200 $\mu\mu$f. per section is necessary if a 9:1 capacity tuning ratio is required.

The circuit can be tested by first tuning only half of the coil by C, with the remainder of the circuit disconnected. A grid-dip meter can be used to indicate resonance in the usual way. Connecting the remainder of the circuit as in Fig. 5, a grid-dip meter coupled to the coil will show the desired resonance points. Depending on coupling to the grid-dip meter, *three* dips may be noted as the grid-dip meter is tuned, for any setting of C. These will be at a low, medium and high frequency. The one at medium frequency may be disregarded: it is the series-resonant frequency of the circuit. Only the lowest and highest dip need be considered, and these should be close to the calculated values.

Experimental Verification

A Barker & Williamson Type 3015 coil (1-inch diameter, 16 turns per inch) was used in a test circuit. The coil used had 34 turns total, and was center-tapped and connected with ganged 150-$\mu\mu$f. capacitors in the circuit of Fig. 5. Resonant frequencies were measured with a grid-dip meter, using the calibration of the meter (which is not highly accurate). The following results were obtained:

	Measured	*Calculated*
Band A	3.45 — 11.4 Mc.	3.41 — 11.15 Mc.
Band B	10.4 — 35.9 Mc.	10.4 — 34.0 Mc.

Summary

This article has given essential design relations for the two-coil and center-tapped single-coil cases of wide-range tuning circuits. Application of these circuits, especially the latter (Fig. 5), to transmitters can result in much more compact equipment than has been possible with band-switching circuits, with resultant saving in cost, complexity and efficiency.

(Continued on page 122)

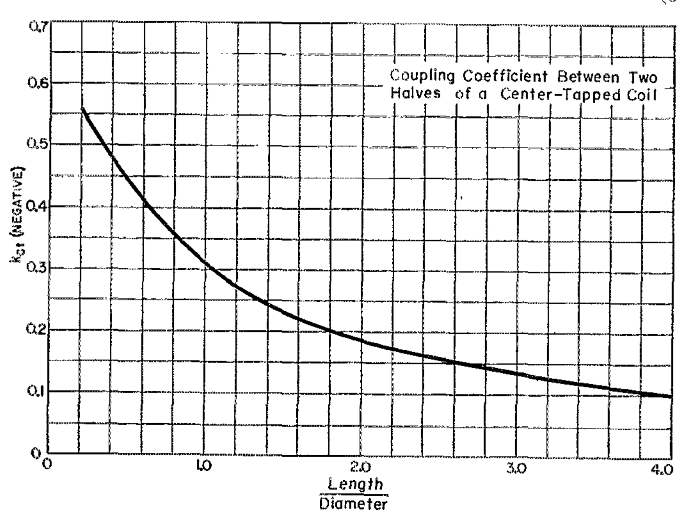


Fig. 8 — Curve of k *vs.* l/d for center-tapped coil.

Multiband Tuning Circuits

(*Continued from page 28*)

It is also felt that these circuits can be applied to receivers, when it is *desired* to have simultaneous coverage of two bands. Using a harmonic relation (such as 2.0) for ratio K_2/K_1, one can have r.f. circuits (and hence a receiver) with eventually simultaneous coverage of two bands. Such a receiver has some obvious applications for contest work where one may operate on two bands at once or in close sequence. Tuning rates are in the ratio K_2/K_1 (in this case 2, 3 or 4), so identification of signals as to band is possible.

This article has not been intended to cover other important factors, such as resonant impedance under various coupling situations, bandwidth, loaded Q, etc. Further experimental work will undoubtedly bring forth improvements and further modifications of the circuit, as well as actual data on factors omitted from this article.

Never-Never Land

(*Continued from page 30*)

ably to the mechanical strength of the chassis.

It is easy to get into trouble in the circuit layout if you have one tube performing too many jobs, or if you use regeneration or other shortcuts in the hope of getting good performance with too few tubes. The best way is to use plenty of stages at low gain and separate tubes for each job. The usual precautions about short grid and plate leads have to be taken also, and the old rule about keeping an i.f. amplifier strip (for any one frequency) in a straight line is a good one. If you put the power supply, last audio stage and speaker in a separate cabinet, you will keep your receiver cabinet cool and away from the mechanical vibrations of the speaker.

Dials

Don't overlook the importance of a good dial mechanism. You can build your own by using one of the popular planetary-drive units and making a dial bezel of thin metal or plastic. A dial scale can be made of cardboard, with dial lights added for a de luxe job. This type of dial allows a half-circle scale length.

If you have some gears from surplus equipment, you can make a dial that will go around about 330 degrees while the condenser rotates 180 degrees. Naturally, such a dial will give nearly twice the scale length of the half circle. An example is shown in Figs. 3 and 6.

Remember to keep the dial simple. A direct-reading single dial is easier to read than a two-dial system or one that requires interpolation. There are many types — slide rule, drum, semicircle and others — but the one that gives the most dial length in a given space is the circular dial. Above all, the most important thing is to have a dial with plenty of bandspread and no backlash.

(*Continued on page 124*)

A Raspberry Pi Net Server/Client for Antenna Rotor

Tom Doyle • W9KE

Net Server

A net server is a device used to create a network connection to an antenna rotor system. A net server can be especially useful when operating portable or from a remote location. While there are many different ways to do this, such as running GPredict software on a Raspberry Pi computer, the particular solution presented here is designed to use the Raspberry Pi with as much of your existing hardware and software as possible.

In the solution described here, the Yaesu G-5500 serves as the rotor and an LVB Tracker (USB interface) as the controller. The Raspberry Pi Net Server (Net Server) optionally can control four relays using a very high quality board currently available for about $10 on Amazon. These relays can control things like antenna polarity switches and amplifiers, or they can be used to turn equipment on and off remotely. The relay board is not required and could easily be added later. If you are interested in only the remote control relays, the programs will run without an LVB Tracker connected.

The hardware is a Raspberry Pi 2 shown in Figure 1, along with the relay board for controlling other devices. Three cables are connected to the Raspi: an RJ-45 network cable, a USB cable from the LVB Tracker, and a power cable that goes to a common USB charger. Five wires connect the Raspi to the optional relay board.

If you do not already own a Raspberry Pi, the Raspberry Pi 2 Model B (Raspi) is an excellent choice. If you purchase a Raspi, select the default Raspbian version of UNIX while doing the initial setup. For more information, see **www.raspberrypi.org/help/quick-start-guide/**.

The initial setup of the Raspi requires that a keyboard, mouse and monitor be connected to the device. After the initial setup, the keyboard, mouse and monitor may be removed and the device operated using what is referred to as a remote desktop connection. Since the Raspi uses a multi-tasking operating system, it can run the Net Server program and another server program to allow access from a remote device at the same time. This means that you do not need a monitor, keyboard or mouse connected to the Raspi after the initial setup. It also means the little two line LCD monitor we often see on these devices is not required. A Raspi operated this way is often referred to as "headless."

There are two parts to a remote desktop connection. The first part is a program named "xrdp" that runs on the Raspi. This program can easily be installed by entering the following command into a terminal window after the initial setup: sudo apt-get install xrdp. Once xrdp is installed and you have rebooted your Raspi, you can forget about xrdp. It will start automatically every time your Raspi boots up.

The other part of the system is the remote desktop client that runs on your device. The device can be a PC, Mac, or even an iPad.

Windows includes a remote desktop client called Remote Desktop Connection. When you run this program on your device, you should see a screen like that depicted in Figure 2.

Enter the address for your Net Server in the Computer text box and click on the Connect button. Note you do not have to enter a port number; the default RDC port number is selected automatically. When the connection is made, you should see a screen that looks like the depiction in Figure 3. Leave the Xvnc Module selected, enter your Net Server username (defaults to pi) and password (defaults to raspberry), then click on the OK button. You will then be taken to a standard Raspi GUI window.

For the iPad, you will first need to download a free app from the Apple app store called Microsoft Remote Desktop (Figure 4). This is an excellent app and, in some ways, is easier to use than the PC version.

After you have downloaded and run the app, create a connection to your Net Server by tapping on the little + in the upper right corner of the app screen. This will be stored, so you only have to do it once. Tap on the connection that you created and you will see a screen that looks like Figure 5. Enter the user name and password as usual and tap on Done. This will take you directly to the Net Server GUI.

You may not realize how powerful the Net Server remote desktop connection is. Figure 6 shows a partial screen shot of the iPad running Microsoft Remote Desktop connected to the Net Server, which is currently running GPredict. This also can be done from a PC using Remote Desktop Connection. It is a bit easier on a PC than the iPad because you can use a mouse on the PC, but both work fine.

Figure 1

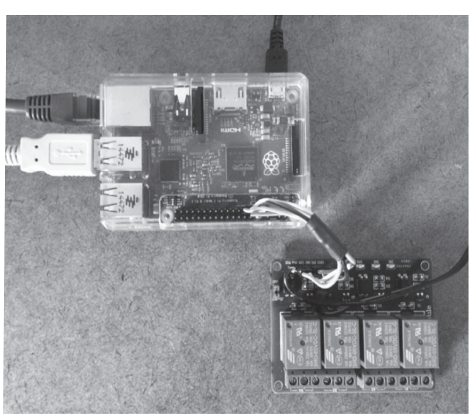
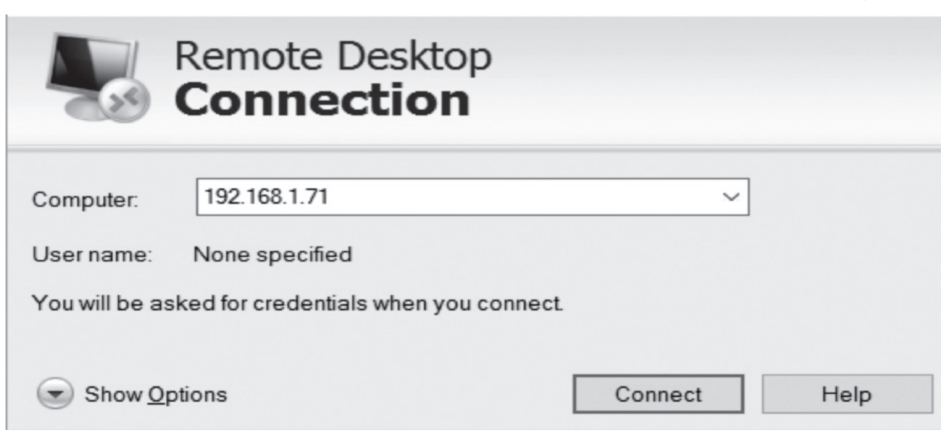


Figure 2



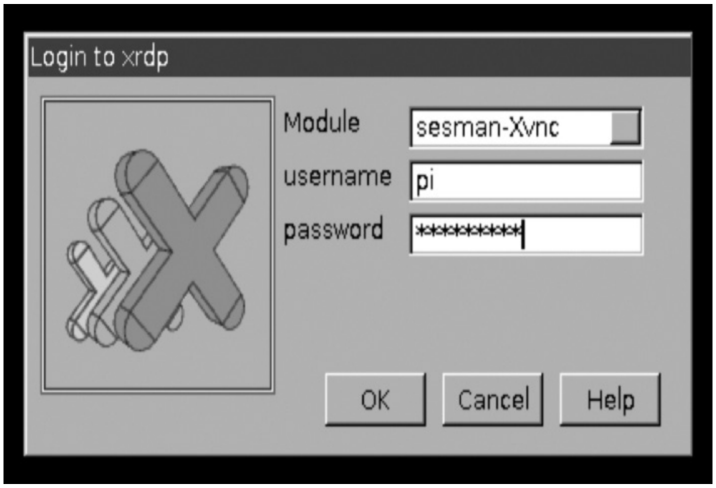


Figure 3

Figure 4

You also can use the remote desktop connection software on a PC or an iPad to connect to standard PCs. If you are using a "Pro" version of Windows, the server side software is built in. Figure 7 shows a partial screen shot from the iPad running Microsoft Remote Desktop connected to a Windows 7 Pro desktop running SatPC32. If you are not using Windows Pro, other third party remote desktop servers are available.

We have come a long way thanks to the great work done by Erich, DK1TB, with SatPC32 on the PC, Mark, N8MH, with SAEBRTrack on the Basic Stamp, and Howard, G6LVB, with LVBTracker on the PIC. As they say, "the only reason we can see so far is we stand on the shoulders of giants."

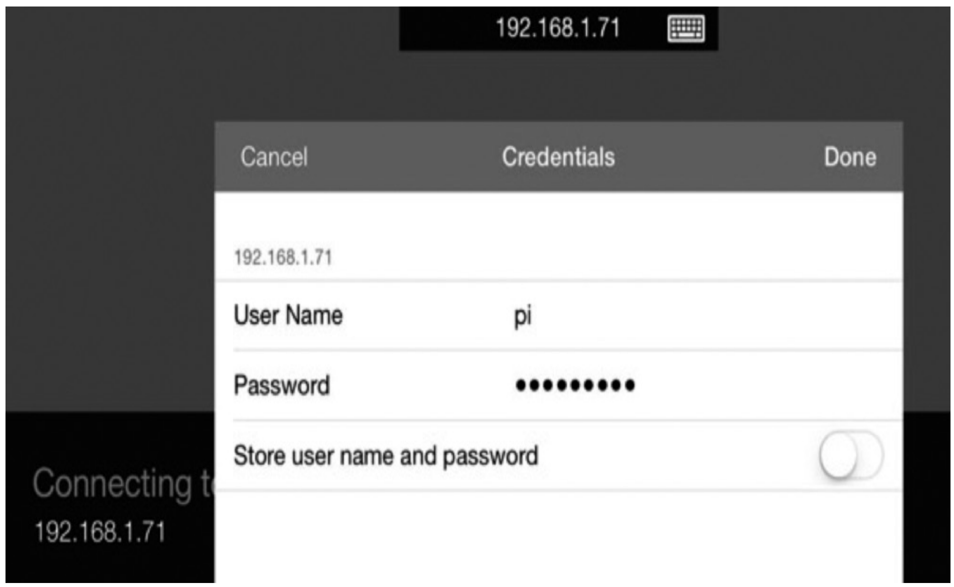


Figure 5

After you have established the remote desktop connection, you can operate your Raspi from your device the same way you would operate if you were using a keyboard, mouse and monitor connected directly to the Raspi. This helps reduce clutter in the shack and also reduces the cost of the system. It is also a very important advantage when operating portable.

When Raspi is up and running, create a directory under your home directory for the Net Server program. The directory name is not critical. I used "net_server" for the directory name. You can use the Raspi GUI or a terminal window.

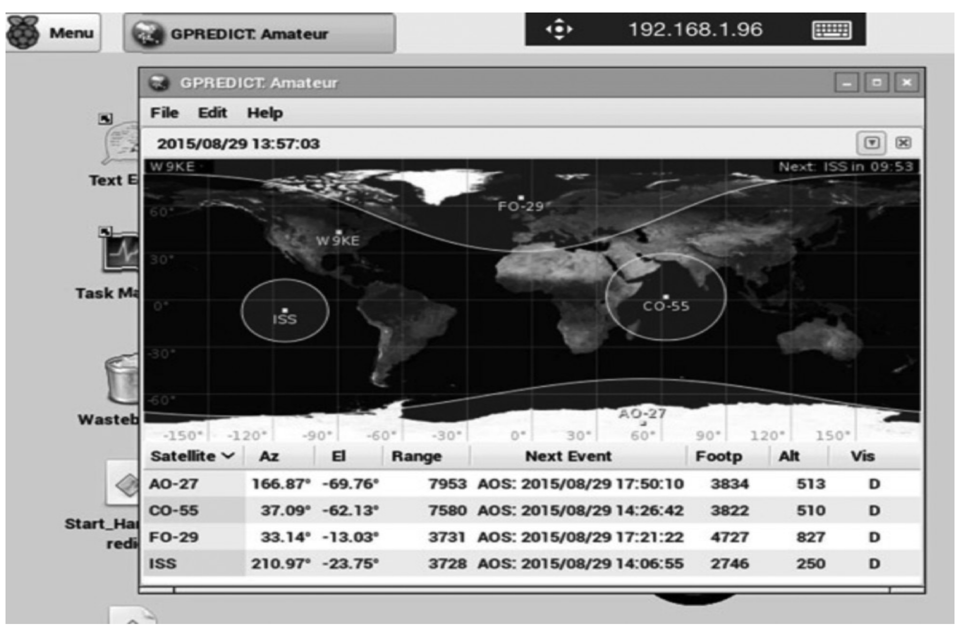


Figure 6

Download and install the Wiring Pi interface library. This library provides access to the input/output pins on the Raspi GPIO connector. For more, see **wiringpi.com/download-and-install/**.

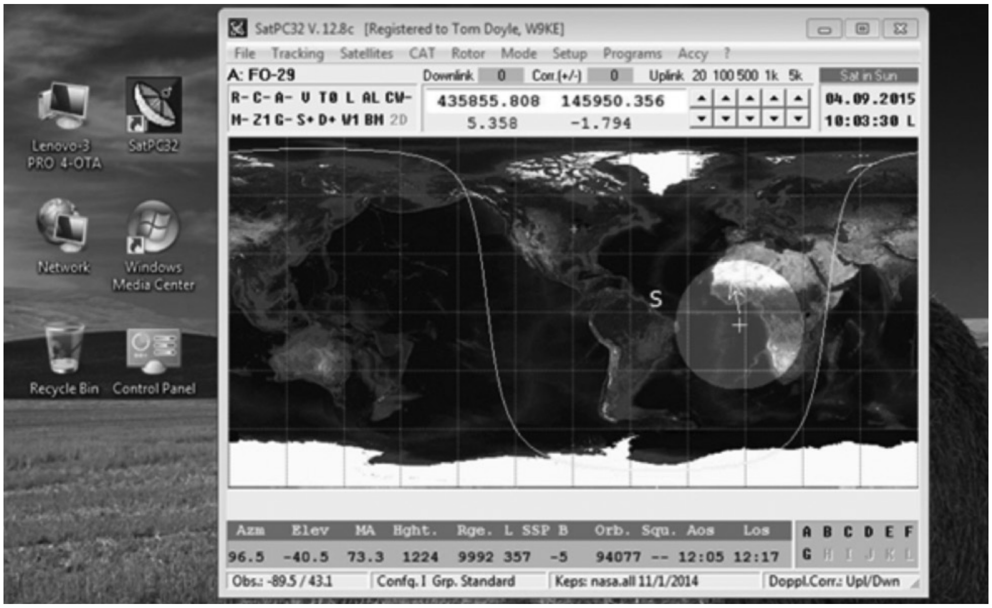


Figure 7

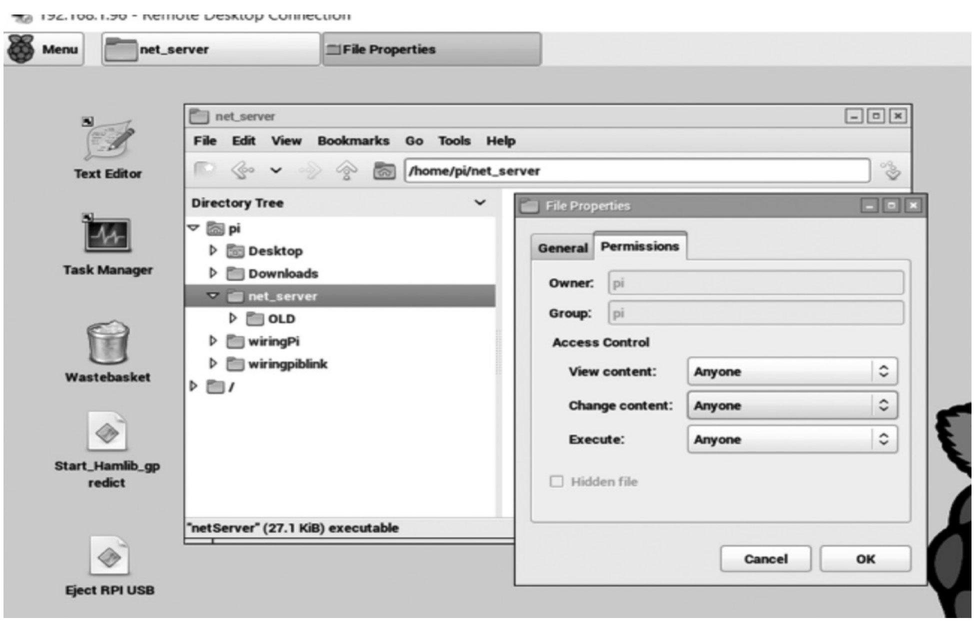


Figure 8

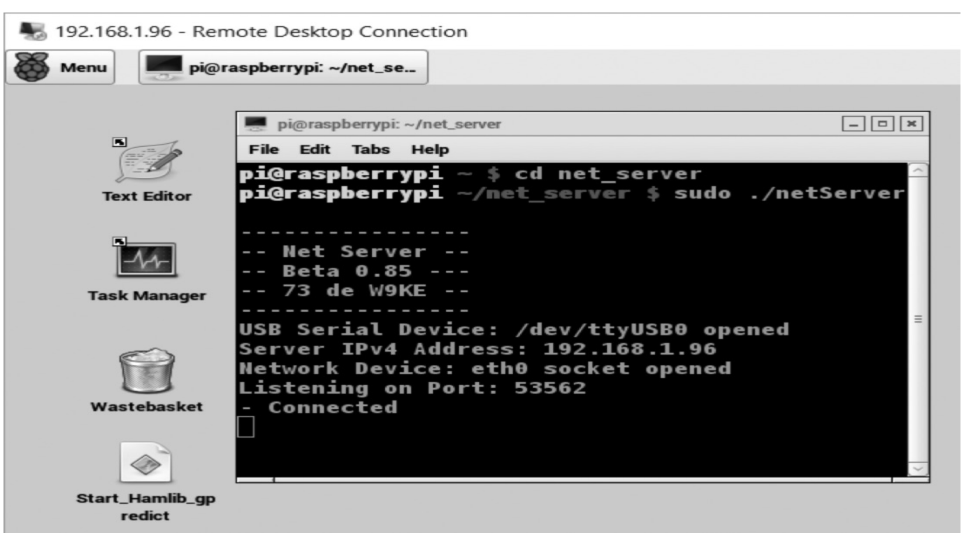


Figure 9

When you are ready to try out the program on your Raspi, send me an email, and I will send the program to you. It is a compiled binary named netServer designed to run on the Raspi, not X86 boxes.

Copy the program into the directory you created earlier. UNIX security probably will not permit you to run the program until you change the access rights. You can do this with "chmod" in a terminal window, but I find it easier to use the File Manager program available in the Raspi GUI. Note in Figure 8 that all the permissions for the netServer file have been set to "anyone."

You should now be able to run the netServer program. This is a console program designed to run from a terminal window. For this example, I opened a terminal window in the GUI. When you open a terminal window, it defaults to your home directory. The default user name is "pi," so I left it as-is for this example.

In the terminal window image (Figure 9), you can see the two commands necessary to start the program:

- 'cd net_Server' moves you into the directory we created earlier that contains the netServer program, and
- 'sudo ./netServer' causes the program to run.

The "USB Serial Device" is the USB connection to the LVB Tracker. If you do not have the LVB Tracker plugged in, it will complain. That is fine. Just shutdown and, if you have one, plug the tracker into the Raspi and start the Raspi back up (you probably could do a hot swap but just to be safe, power down and reboot). You can continue even if you do not have the LVB Tracker connected.

The "Network Device" is the Ethernet connection to your network through the RJ-45 connector. You will need the IP address and the port number later, so write them down.

When the program runs, a configuration file will be created in the same directory as the program named NetServerConfig.txt (Figure 10). You can see it opened in the Raspi GUI Text Editor. This editor is very nice. Having been stuck with VI for many years back in the day, it is a real treat to use this editor. If you need to change the port, network device, or USB device, you can do it here. Do not change any of this unless you are sure you know what you are doing.

Net Client Beta

The Net Client program, a Windows program, communicates over the network with the Net Server. When you run it, you should see something similar to what is shown in Figure 11. Ignore any message about the Serial Port not being configured; we do not need the serial port at this time. Enter the IP address and Port number you saw in the terminal window for the Raspi when you ran the netServer program. After you have entered the correct IP Address and Port, click on the Save/Restart button at the bottom of the window (the button should have turned yellow when you changed a value to remind you to save it). When you do this, updated values will be saved and the program will restart. The little button to the right of the Network label should turn green if you have a good network connection (it was most likely red when you first ran the program).

If you have an LVB Tracker connected to the Raspi, you should see the current AZ and EL for your rotor in the lower left part of the window in the section labeled "Rotor." This value is updated at an interval shown in the "Interval ms" box. Unless you have some really old slow hardware, you should not have to change it. If you make the value too low, you will have an unsatisfactory user experience.

The group of four buttons and indicators in the bottom right of the window (S1-S4) control the four relays you saw in the images of the Raspi Net Server system. For example, if you click on the S1 button, a message will be sent to the Net Server telling it to activate relay 1. When this is done, the Net Server will send back a message indicating that relay 1 is activated, and the little button indicator to the left of the S1 button will turn from red to green. This means that the indicator button will not turn green immediately after you click on the button, or it may not change at all if you do not have a network connection and a working Net Server. This system is smart in that it waits to see if the message was received by the Net Server. However, it is not brilliant because it cannot tell if you have a relay board installed.

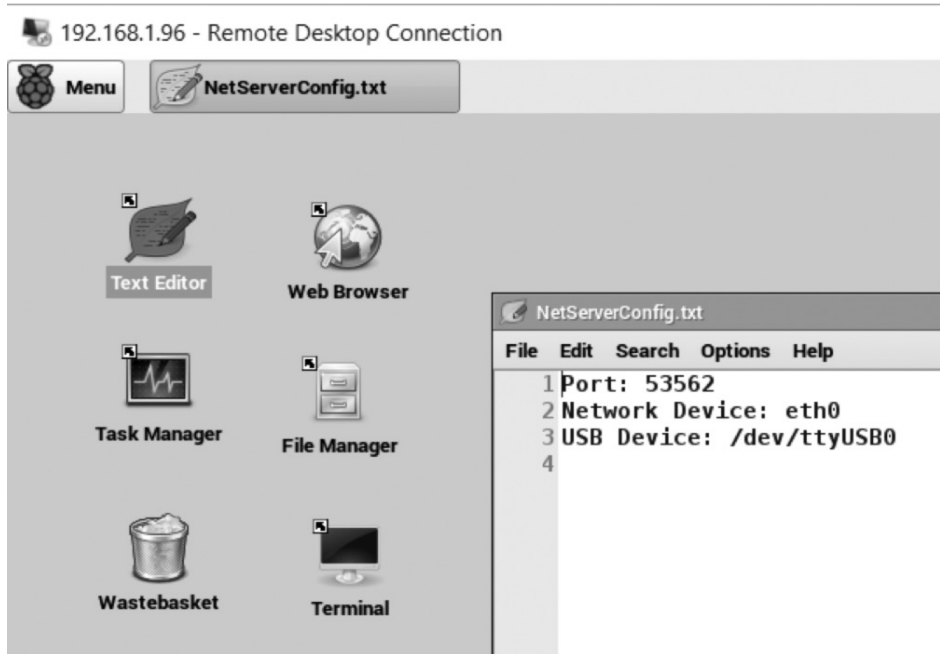


Figure 10

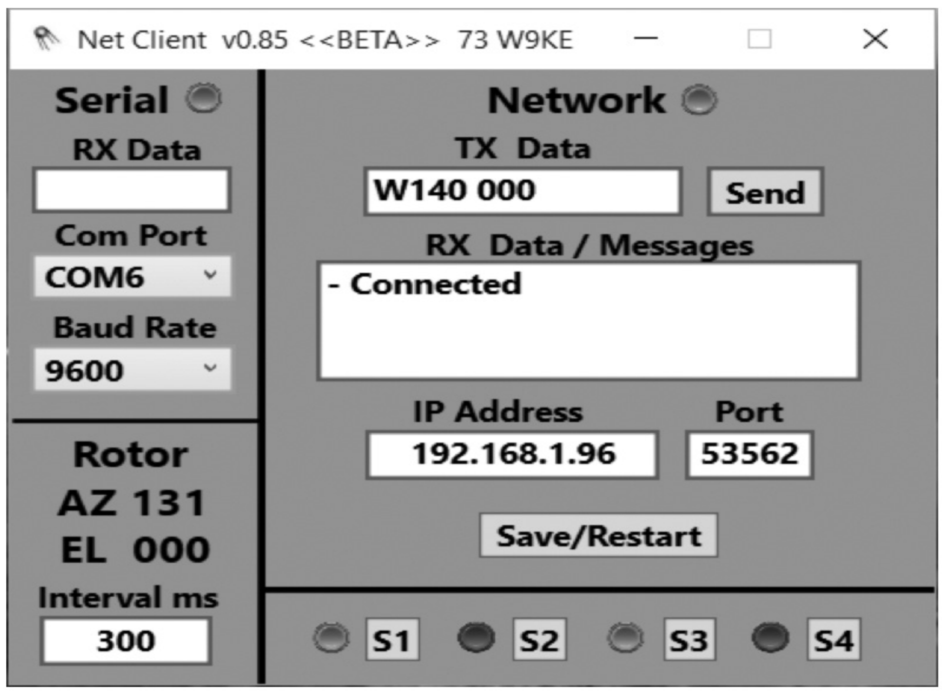


Figure 11

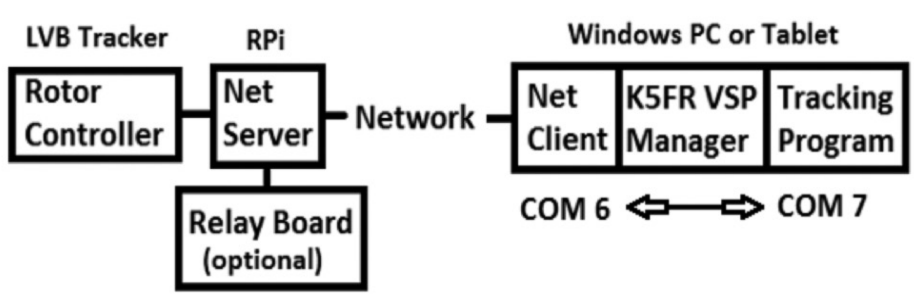


Figure 12

If you enter a valid LVB Tracker/Yaesu GS-232 command to move rotors, like "W140 000," as shown in Figure 11, and then click on the Send button, the rotor should move to the new position. The position information shown in the Rotor portion of the display will track the move with updates at an interval specified in the "Interval ms" text box.

If you make any changes to the values in the window other than the "TX Data" text box, the Save/Restart button will turn yellow to remind you to save your changes. When you click on the Save/Restart button, the values will be saved and the program will automatically restart. When deciding what to hook up to the relays, remember that the relays will all be turned to the off state whenever the Net Server starts up.

The Serial portion of the screen shows the controls used to configure the serial port that is used to connect Net Server to satellite tracker programs that have a serial interface. Use the K5FR VSP Manager program to set up a pair of virtual serial ports. Connect one of the ports to your tracker program and the other port to Net Client using the boxes in the Serial part of the Net Client window.

When the serial port connection is made, the indicator button to the right of the word Serial will turn green. For this example, I have Net Client connected to virtual port COM6 at 9600 Baud and the other virtual port of the pair COM7 connected to the tracking program. This way the tracking program can control the rotor. Figure 12 shows the path from the tracking program to the rotor controller and relay board. It is not quite as complicated as it looks.

When you are ready to try the Net Client program, send me an email at tomdoyle1948 at gmail dot com, and I will send you the program.

The only supported platform is the Raspberry Pi model 2 B with the default raspbian wheezy installed. This does not mean it will not work on other platforms; it just means if you use something else and it does not work, I probably will not be able to help.

Michael Dzado, ACØHB

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An Eight Channel Remote Control Antenna Selector

Select between eight antennas or feed one antenna to any of up to eight radios. With better than 70 dB of port-to-port isolation, you can be sure the signal is going where you want it to.

A few years ago, my friend Joe Spinks, AAØKW, and I started building and experimenting with Double Bazooka antennas. I decided to build two 20 m and two 40 m antennas for my antenna farm. My plan was to deploy a 20 and 40 m Double Bazooka facing East-West and a 20 and 40 m Double Bazooka facing North-South. These, along with a vertical antenna and two G5RV antennas I already had mounted, quickly gave me a cabling and switching problem. Also, Joe pointed out that my wife may not appreciate me punching seven more holes in our house and running a sizable bundle of coax across my basement to my station. Even if I could do all that, manual switching wasn't practical between that many antennas. I would be constantly connecting and disconnecting antennas when I wanted to change directions or bands.

That's when I decided to design a remote control antenna selector to select between eight antennas. I am currently a Systems Engineer but have degrees in both Electrical Engineering and Software Engineering. In addition, I have electronic circuit design and printed circuit board layout experience. Joe is also an electrical engineer, and has designed automatic antenna tuners for our company and has extensive RF circuit design experience. So creating and testing a viable design was not a technical concern. The main question then became, what improvements could be made over the existing products. The answer came quickly: Isolation between the selected and other antennas! Wouldn't it be nice to select one antenna and not get interference from another antenna?

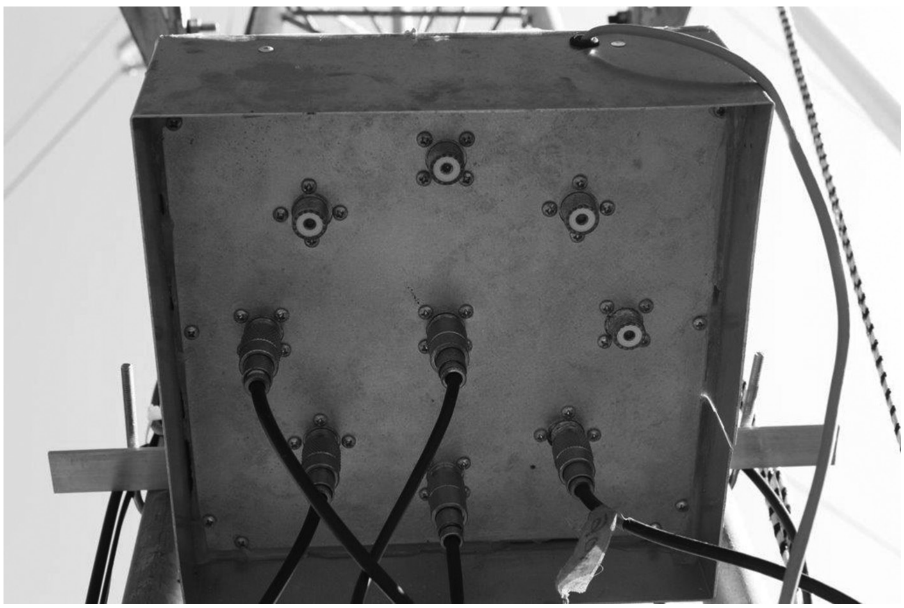


Figure 1 — The remote antenna selector board is mounted on the side of my tower. As shown here, it is selecting between four antennas.

We achieved greater than 70 dB of isolation between antenna ports, as shown in the test plots included with this article. There are several design techniques that helped us achieve this kind of isolation: Two relays were used in each signal path to double isolate the antenna from the radio input. The traces that make up the RF path were designed as a coplanar waveguide. The RF connector placement on the circuit board was tightly controlled to be symmetrical to make the RF electrical paths identical. RF trace routing followed good design practices by limiting angles to 45°. Control traces were routed on the bottom of the circuit board to maximize ground plane continuity. For our switch, we selected control trace widths of 15 mils for better current capacity.

Implementing the Design

I mounted a switch assembly on my tower and connected four antennas to the assembly as shown in Figure 1. My home station consists of an Icom IC-706 MKIIG rig, with an LDG tuner and our remote control antenna selector, as shown in Figure 2. The remote controller is shown in the lower left. Switching between eight antennas is just a matter of twisting the rotary switch. The real story is the isolation between antennas. Figure 3 shows the IC-706 S meter displaying S6 when an antenna is selected. Figure 4 shows the IC-706 S meter displaying blank when an unused port is selected.

One evening in my "Lab," Gregg Lind, KCØSKM, noticed my design and board layout. Gregg and I have been collaborating on a remotely deployable solar powered Weak Signal Propagation Reporting (WSPR) station using a Netduino. Gregg immediately saw multiple applications for our project and had me present it to both of our local clubs, Cedar Valley Amateur Radio Club (CVARC) and Collins Amateur Radio Club (CARC) here in Cedar Rapids Iowa. He quickly took orders from 20 hams that were interested in purchasing our project if we offered it as kit. The kit was then featured during one of our club's annual kit build nights.

The project was a big hit with both clubs. It turns out that I was not the only one grappling with antenna management. Besides, many amateurs like to build kits. Gregg used this success to convince me to write this article to invite collaboration from other Amateur Radio enthusiasts throughout the ham community.

Later, Gregg used our switch to solve a radio and antenna management problem in our club's shack. Our club has multiple radios and multiple antenna options, which require an operator to trace cables behind a huge rack and make the connection manually. Automatic selection of radios and antennas would make the station much more user friendly. The application required two remote controlled antenna selectors, one to select a radio connected to another antenna selector that picks the desired antenna. Since the installation, our station usage has increased dramatically. The first switch selects one of eight radios, the second switch selects one of eight antennas. Figure 5 shows the two RF switch assemblies used in the CARC (NØCXX) station. Currently the assembly is managing the selection of four radios to six antennas.

Design Details

The remote control antenna selector consists of a switch assembly and an optional remote controller assembly.

The switch assembly contains the relays and relay drive circuitry to select between position 0 to 7. The assembly only requires a 13.8 V dc supply and a 3-bit TTL signal to input for the switch selection. This interface allows for a variety of remote control solutions. Figures 6 and 7 show the bottom and top views of the RF switch assembly.

A remote controller assembly was designed as a simple solution for my station. The remote controller assembly consists of an eight position rotary switch and an 8-to-3 digital encoder connected to 2N2222A transistors to drive the switch assembly via a standard CAT-5 eight wire cable. The remote controller Assembly is shown in Figure 8.

As mentioned earlier, one major design consideration was to minimize RF coupling between antenna channels. Therefore, it was essential to follow the rules and principals of good basic RF/Microwave design.

The switch assembly features a coplanar

Figure 2 — This photo of my operating position shows my power supply, LDG Autotuner, and Icom IC-706 MKIIG radio. The antenna selector control panel is mounted behind a block of wood to match the operating position shelf. You can see the selector shaft, with the first of eight LEDs illuminated to show which antenna has been selected. I still have to add labels below the LEDs to help identify the antennas.

Figure 3 — Here is a close-up of the Icom radio display. Notice that with a 40 m antenna connected, the S meter is showing an S6 signal.

Figure 4 — In this close-up of the Icom radio display, there is no antenna connected. In this case, the S meter is showing no signal.

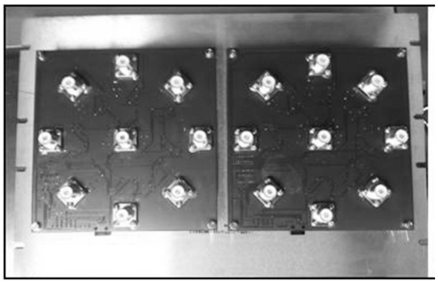


Figure 5 — This photo shows the two RF switch assemblies used in the Collins Amateur Radio Club (NØCXX) station. The assembly is managing the selection of four radios to six antennas in the club station.

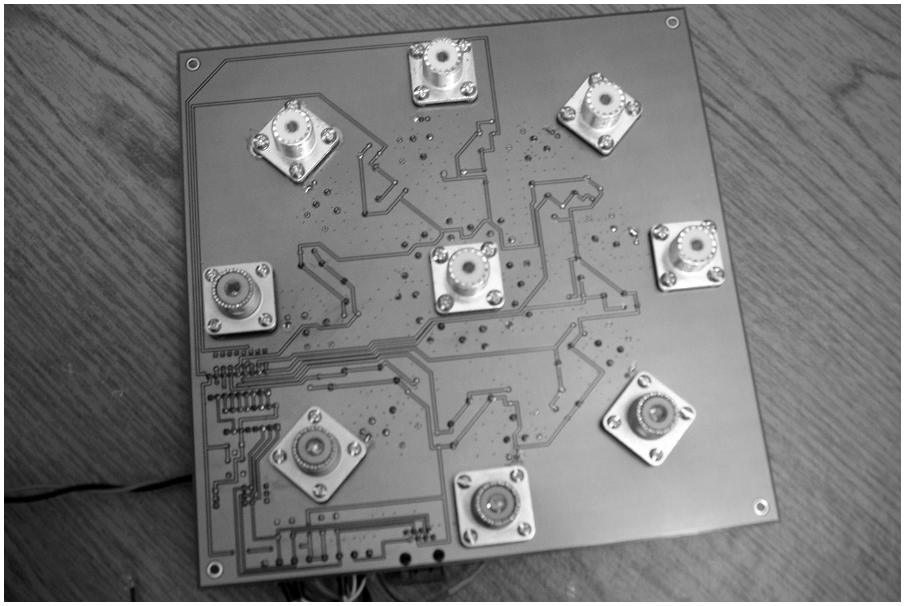


Figure 6 — Here is a close-up of the SO-239 connector side of the antenna selector circuit board.

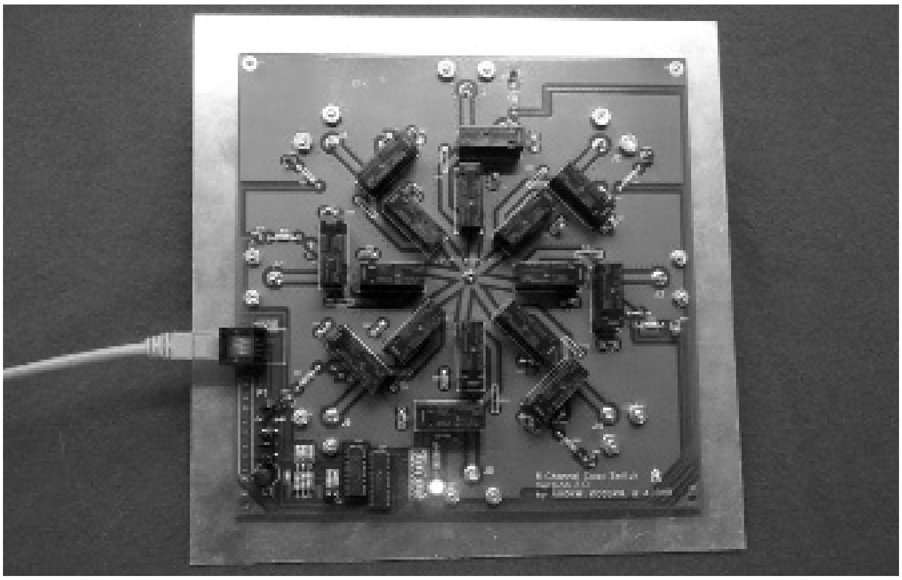


Figure 7 — This photo shows the relays and the circuit board traces that form the coplanar waveguide.

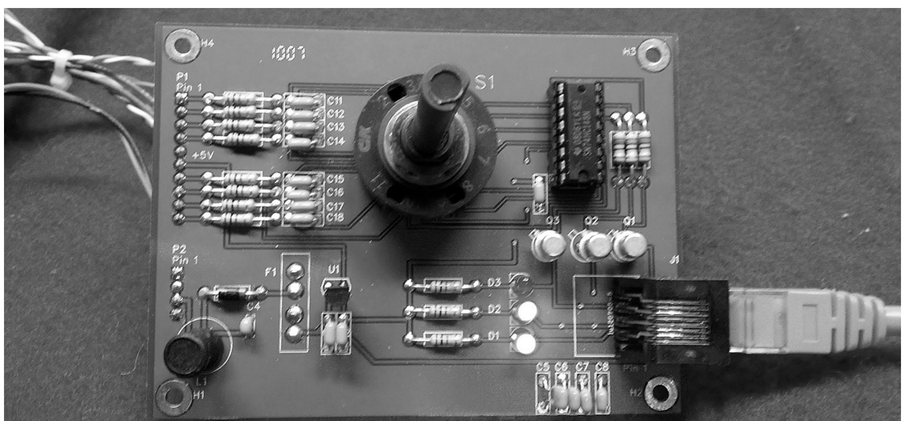


Figure 8 — This photo shows the antenna selector control board.

waveguide design for all RF traces, tuned to a 50 Ω impedance with ground plane stitching that ensures maximum isolation between ports.

Complete impedance (Z_0) matching (50 Ω in to 50 Ω line to 50 Ω out) minimizes return loss and SWR. A coplanar waveguide design was chosen so that the trace impedance on the circuit board could be matched to the input and output impedances. In a coplanar waveguide design, Z_0 is a function of signal conductor width & thickness and a function of the dielectric constant (ε_r) of the material surrounding the signal conductors.

Signal return currents follow the path of least impedance. In high frequency circuits this equates to the path of least inductance. Stitching the ground planes with vias every 0.1 inches or so around each RF trace helps minimize the inductance in the signal return path by virtually creating a waveguide on the circuit board.

The RF connectors were placed symmetrically around the output connector (located in the center of the assembly) to ensure an equal electrical length for each RF path. Typical isolation measured between ports is greater than 70 dB.

Extensive RF decoupling on the power and control lines was added to provide maximum RF decoupling from the control signals. I added transient-voltage-suppression diodes (Transorbs) on all input control lines for good surge protection.

The project begins with a schematic program to capture the logical design. I chose *TinyCAD* for my schematic capture and *Free PCB* for the circuit board layout and trace routing. Both tools are easy to use and use the same net list format.[1, 2]

The switching relay is the heart of this design. We chose an Omron Electronics Inc G6RN-1-DC12, which is a sealed double pole double throw (DPDT) relay with 8 A silver

[1]Notes appear on page 17.

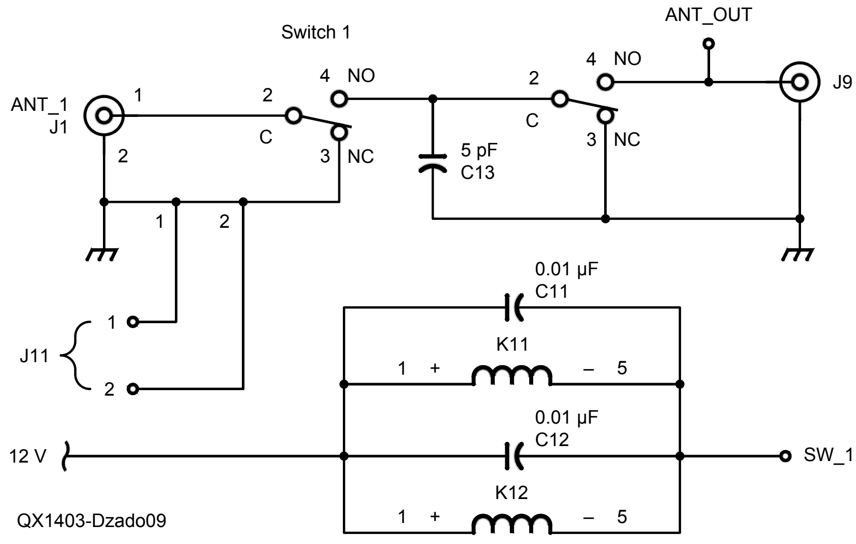


Figure 9 — The schematic of the basic selector switch operation. The normally closed side of the relay grounds the antenna when it is not selected. The second relay serves to isolate that antenna port from the output signal on a selected antenna.

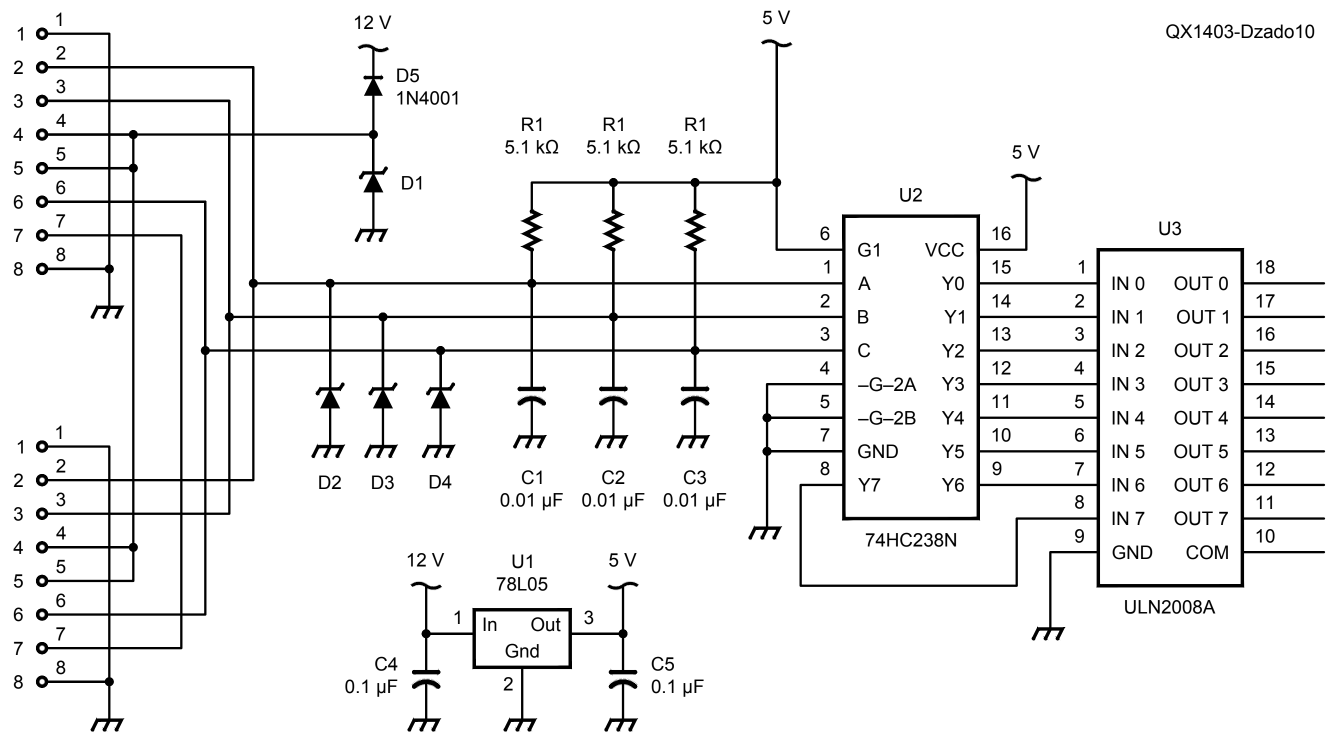


Figure 10 — The schematic of the antenna selector control logic. U2 is a 74HC238 3-to-8 decoder IC and U3 is a ULM2008A high current, 8 pair Darlington transistor array to provide the relay drive current.

over gold contacts. The contact capacity is more than adequate for our design. We chose to double isolate each RF port by using two relays in each path. As shown in Figure 9, the first relay will ground the antenna input when de-energized. The second relay simply isolates the RF port from the output.

The switch control logic incorporates a simple 3-to-8 decoder (74HC238) and a high current, eight-pair Darlington transistor array (ULM2008A) to provide the relay drive current, as seen in Figure 10.

Topologically speaking, a coplanar waveguide design offers better isolation between signals versus a microstrip design. Even though a microstrip design is easier to layout, Joe and I opted for maximum isolation between antennas.

The RF path design starts with the basic power equation to determine the trace width to handle the transmit current.

$$P = I^2 Z_0 \qquad \text{[Eq 1]}$$

then solving for I:

$$I = \sqrt{\frac{P}{Z_0}} \qquad \text{[Eq 2]}$$

Then for a 100 W transmitter into a 50 Ω load we have:

$$I = \sqrt{\frac{100\ \text{W}}{50\ \Omega}} = \sqrt{2}\ \text{A} = 1.4\ \text{A}$$

Using the *AppCAD Coplanar Waveguide Calculator* by Avago Technologies, I set the known dimensions of the circuit board and adjusted the trace width, W, and gap, G, until Z_0 = 50 Ω, or there about, as shown in Figure 11.[3] I chose the trace width of 115 mils and a gap of 100 mils as a good combination for the 100 W circuit boards. Note that other combinations of trace width and gap will also result in a Z_0 of 50 Ω. For example, a trace width of 125 mils and a gap of 250 mils would also work, but that requires quite a bit more space on the circuit board.

Referring to Table 1 for the circuit board trace current capacity, a 115 mil trace is adequate for this design. You can see that at 100 W, the trace temperature rise will be considerably less than 10°C. In fact, with a power of 1000 W into a 50 Ω load, the current would be 4.47 A, so these traces can handle that power with only about a 10°C temperature rise.

Figure 12 shows the printed circuit board component placement and trace routing.

I used an HP-8753D Network Analyzer to test the completed circuit board. Measurements were taken between all eight channels for port-to-port isolation, insertion loss, and SWR.

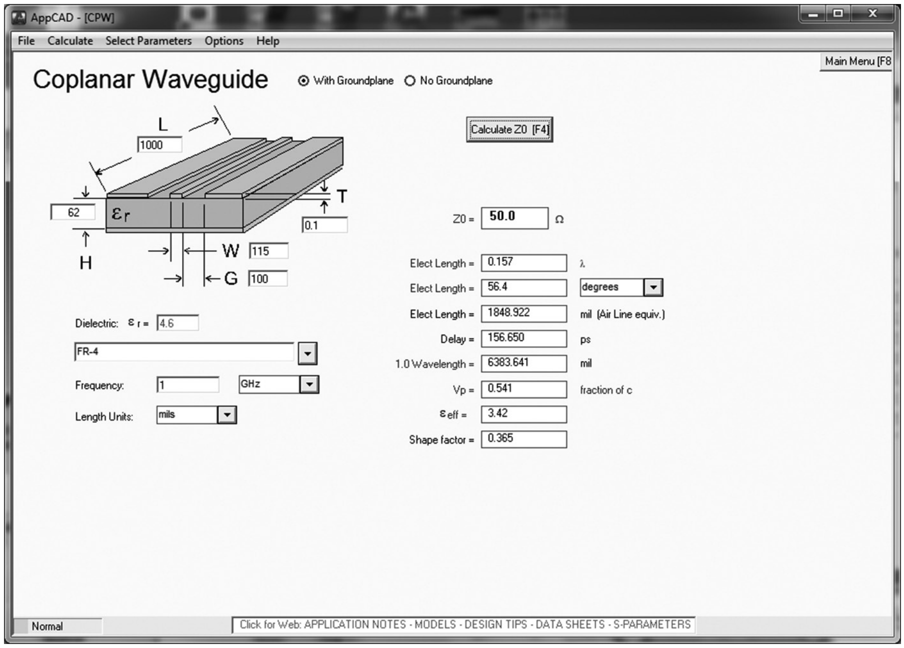


Figure 11 —This is a screen shot of the *AppCAD Coplanar Waveguide Calculator.* I set the following parameters: Circuit Board Material = FR-4, W (Trace Width) = 125 mils, H (Circuit Board Thickness) = 62 mils. Then I adjusted the trace width (W) and the gap between the traces (G) until the calculated Z_0 came to 50 Ω. A width of 115 mils and a gap of 100 mils gave the desired impedance. Other combinations of those dimensions may also result in a 50 Ω impedance, but this combination gave a reasonable trace width for the power handling capability that I wanted.

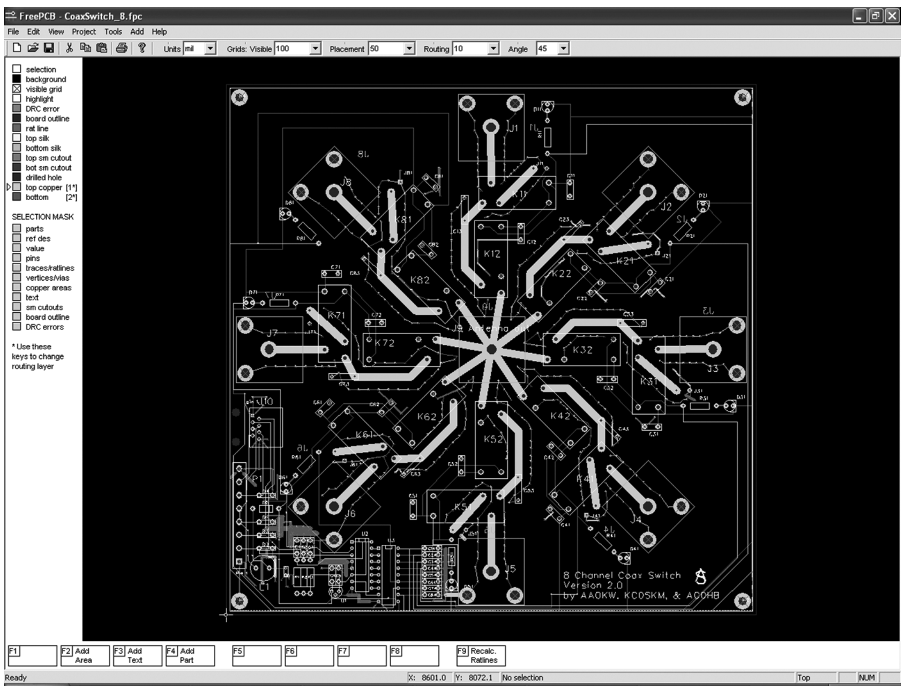


Figure 12 — This is the parts-placement view of the antenna selector circuit board. It also illustrates the coplanar waveguide traces.

Figure 13 shows the test results for port to port isolation between channels 1 and 2. Figure 14 shows the insertion loss for port 1 and Figure 15 shows the SWR for port 1.

The test plots for the remaining ports are almost identical to the port 1 test results. This is due to the coplanar waveguide topology for the RF traces and the symmetrical RF component placement.

Specifications

- **Power Requirements:** 13.8 V dc single power supply at less than 75 mA.
- **Control Line:**
  - Minimum 5-wire connection (2 power, 3 control lines) or
  - Standard CAT-5 cable (8 wire) interconnect between RF Switch and Remote Controller.
- **Switches:** Sealed RF Relays, Contacts are silver over gold for an 8 A contact rating.
- **Status LED indicators:** on both the switch and remote control assemblies.
- **Impedance:** 50 Ω.
- **Connectors:** SO-239 Silver plated Teflon connectors.
- **RF Power:** 1000 W over 2:1 SWR.
- **SWR:**
  - At 30 MHz, < 1.12:1
  - At 50 MHz, < 1.23:1
- **Port to Port Isolation:**
  - At 30 MHz, < –75 dB
  - At 50 MHz, < –70 dB
- **Insertion Loss:**
  - At 30 MHz, < 0.10 dB
  - At 50 MHz, < 0.16 dB
- **Dimensions:**
  - Switch Circuit Board: 8 × 8 inches.
  - Enclosure: 9.5 × 9.5 × 2 inches.
  - Remote Controller: 3 × 4 inches.

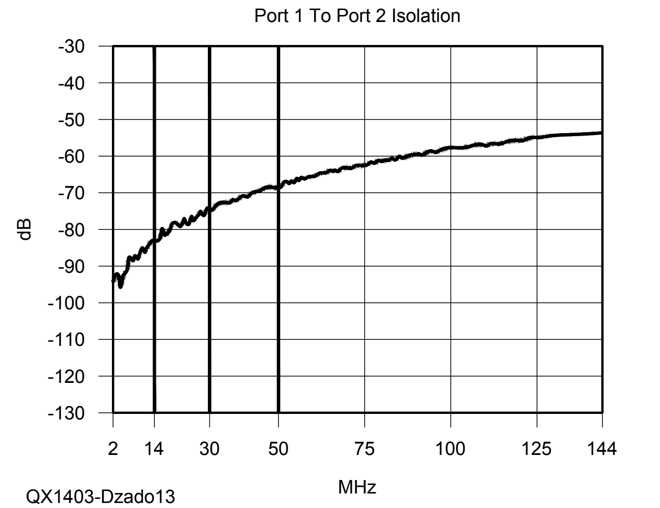


Figure 13 — This graph shows the port-to-port isolation between positions 1 and 2 versus frequency. The test plots for the remaining ports are virtually identical.

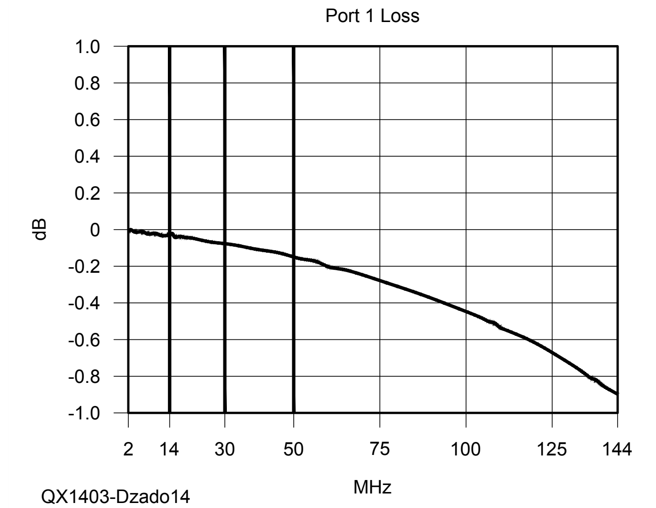


Figure 14 — This graph shows the signal response (S_{11} parameter) versus frequency for port 1. The responses for the other ports are virtually identical.

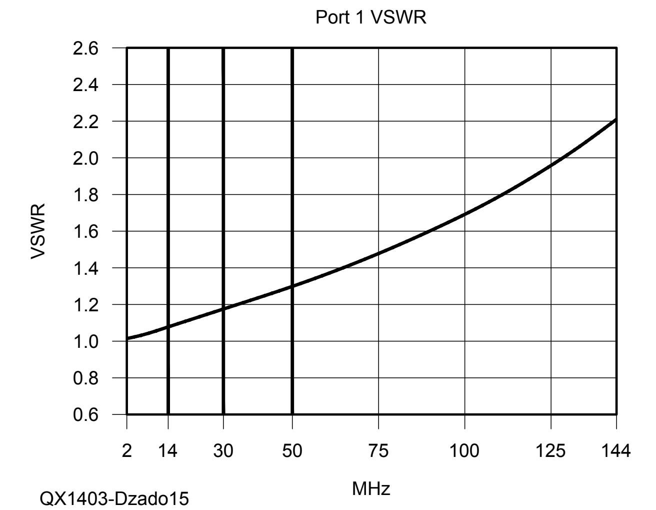
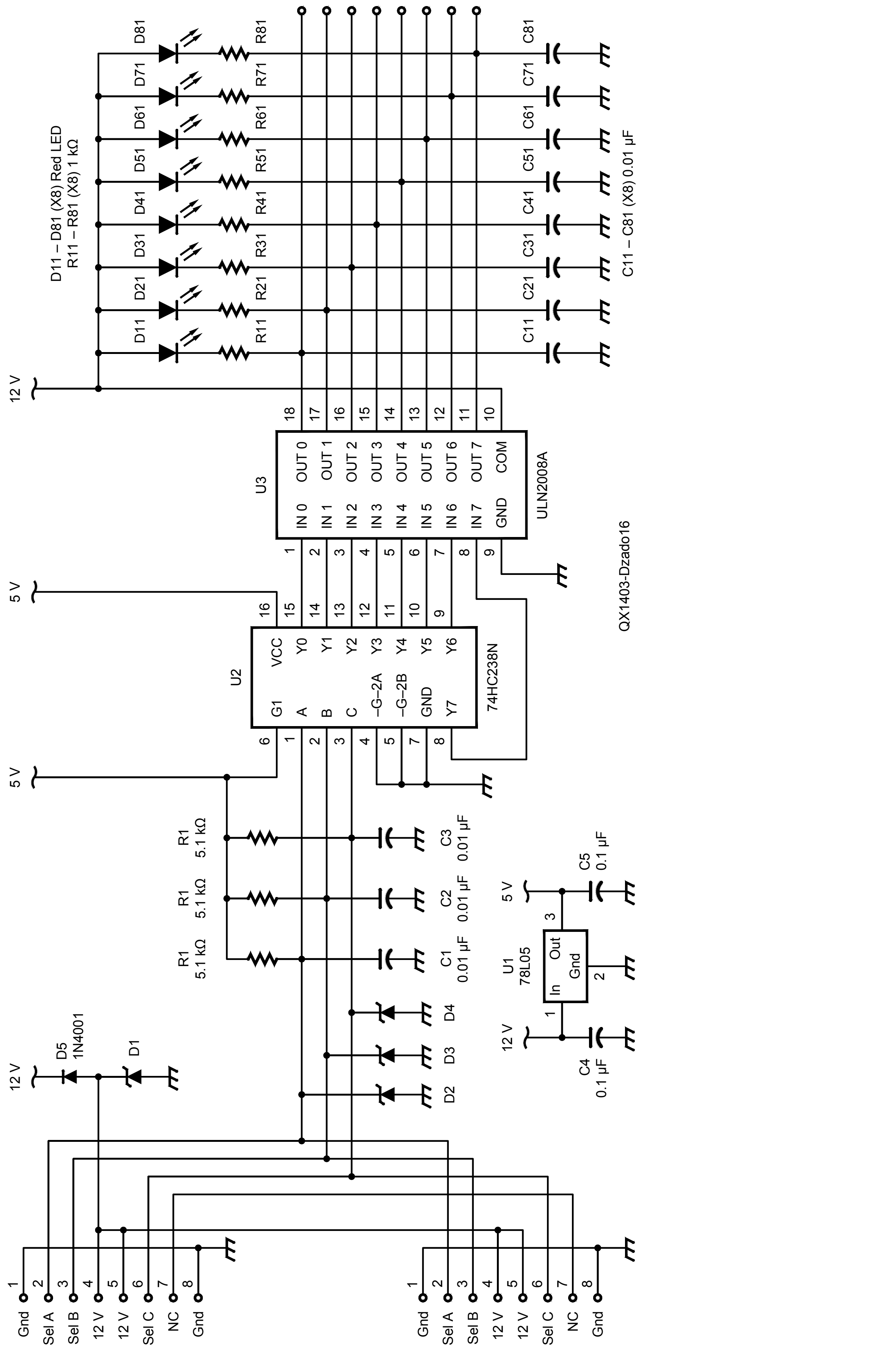


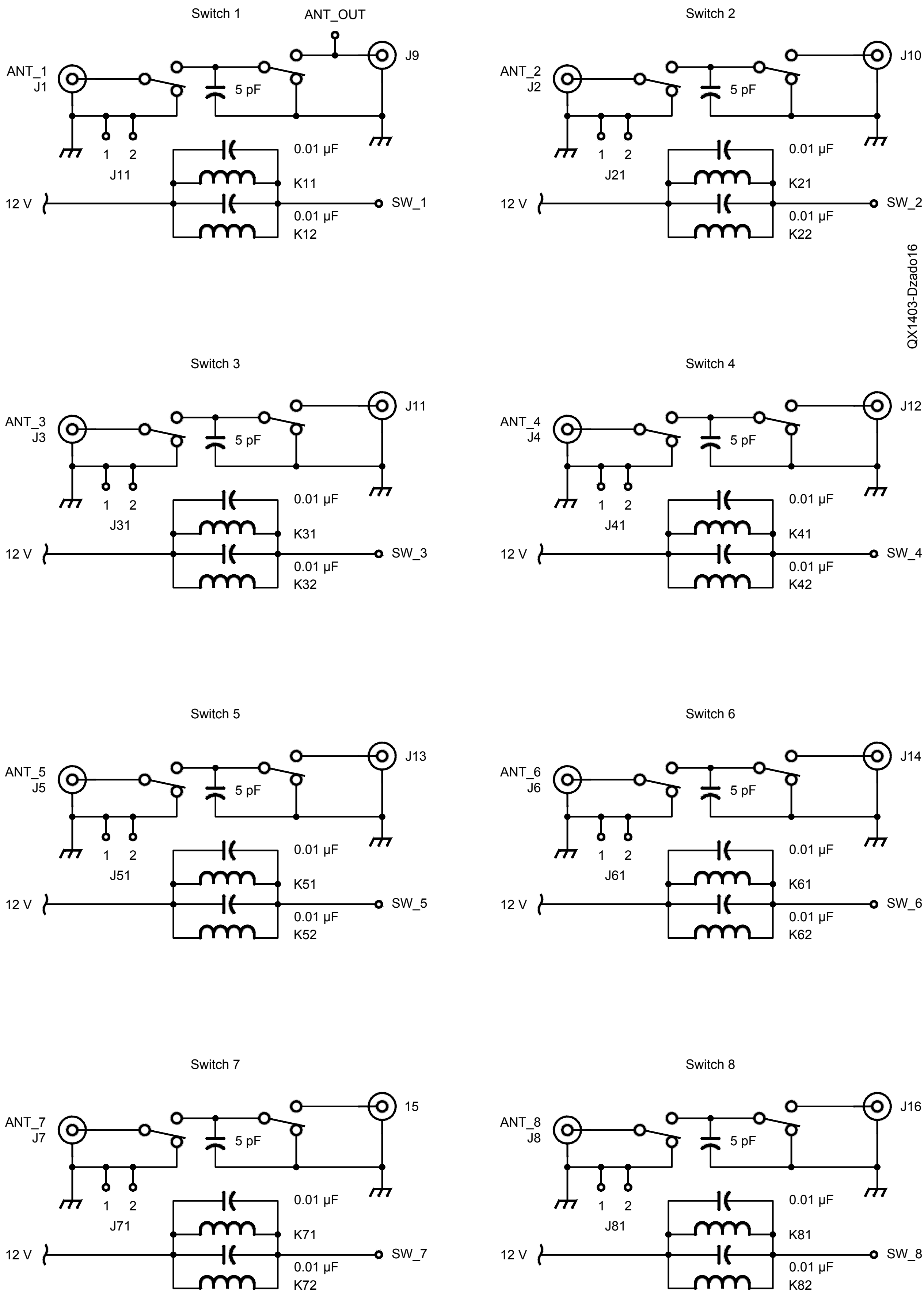
Figure 15 — Here is the SWR response versus frequency as measured for port 1. The other ports have the same response.

Table 1
Circuit Board Trace Widths

Temp Rise	*10°C*	*20°C*	*30°C*
Width (mils)	*Max Current (A)*		
10	1	1.2	1.5
15	1.2	1.3	1.6
20	1.3	1.7	2.4
25	1.7	2.2	2.8
30	1.9	2.5	3.2
50	2.6	3.6	4.4
75	3.5	4.5	6
100	4.2	6	7.5
200	7	10	13
250	8.3	12.3	15

Figure 16 — This schematic shows the control wiring and the antenna selector wiring for all eight antenna positions.




Switch 1
ANT_OUT
ANT_1
J1
J9
5 pF
1 2
J11
0.01 µF
K11
12 V
SW_1
0.01 µF
K12
Switch 2
ANT_2
J2
J10
5 pF
1 2
J21
0.01 µF
K21
12 V
SW_2
0.01 µF
K22
QX1403-Dzado16
Switch 3
ANT_3
J3
J11
5 pF
1 2
J31
0.01 µF
K31
12 V
SW_3
0.01 µF
K32
Switch 4
ANT_4
J4
J12
5 pF
1 2
J41
0.01 µF
K41
12 V
SW_4
0.01 µF
K42
Switch 5
ANT_5
J5
J13
5 pF
1 2
J51
0.01 µF
K51
12 V
SW_5
0.01 µF
K52
Switch 6
ANT_6
J6
J14
5 pF
1 2
J61
0.01 µF
K61
12 V
SW_6
0.01 µF
K62
Switch 7
ANT_7
J7
15
5 pF
1 2
J71
0.01 µF
K71
12 V
SW_7
0.01 µF
K72
Switch 8
ANT_8
J8
J16
5 pF
1 2
J81
0.01 µF
K81
12 V
SW_8
0.01 µF
K82

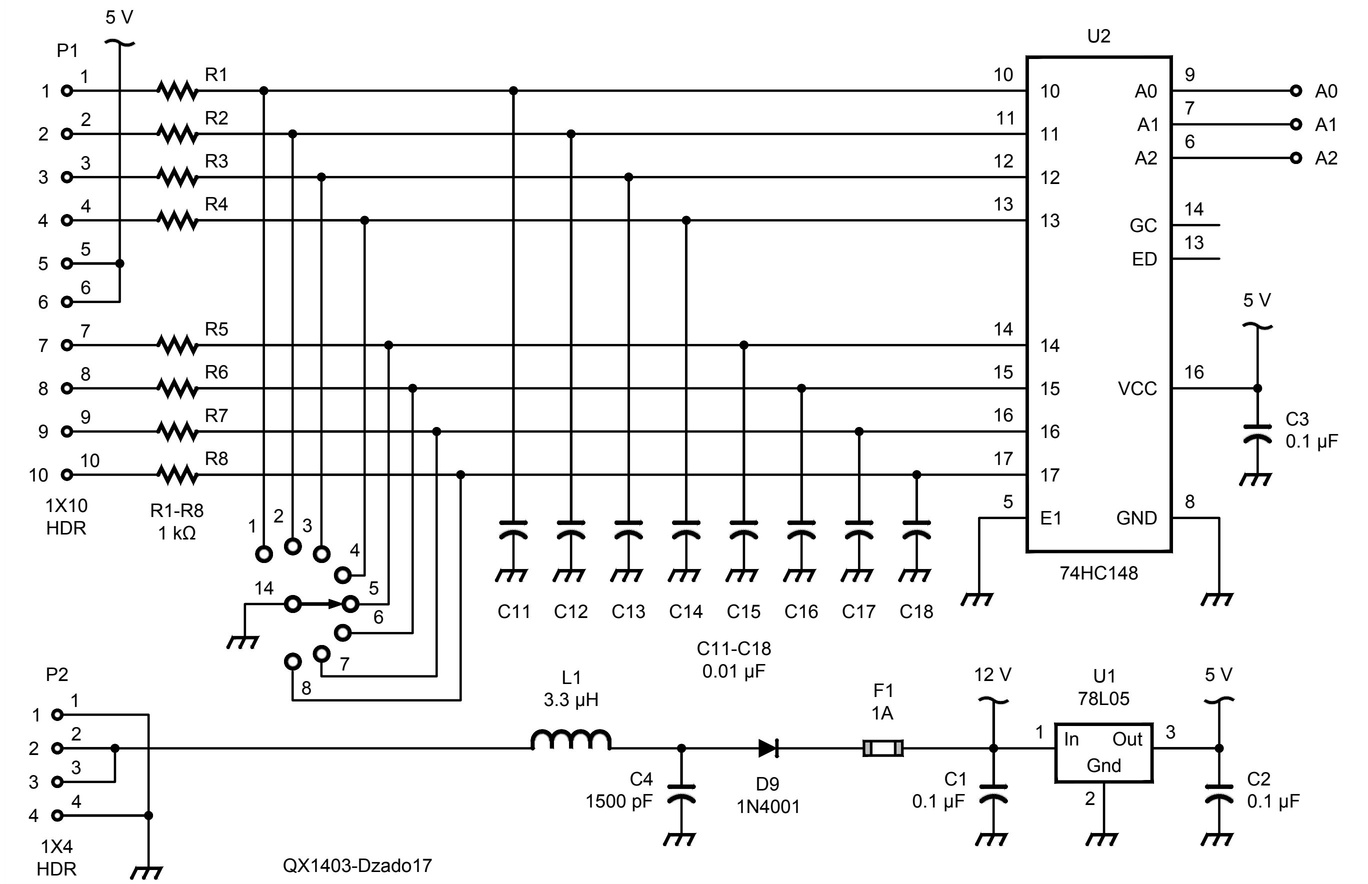


Figure 17 — Here is the antenna selector switch remote control wiring.

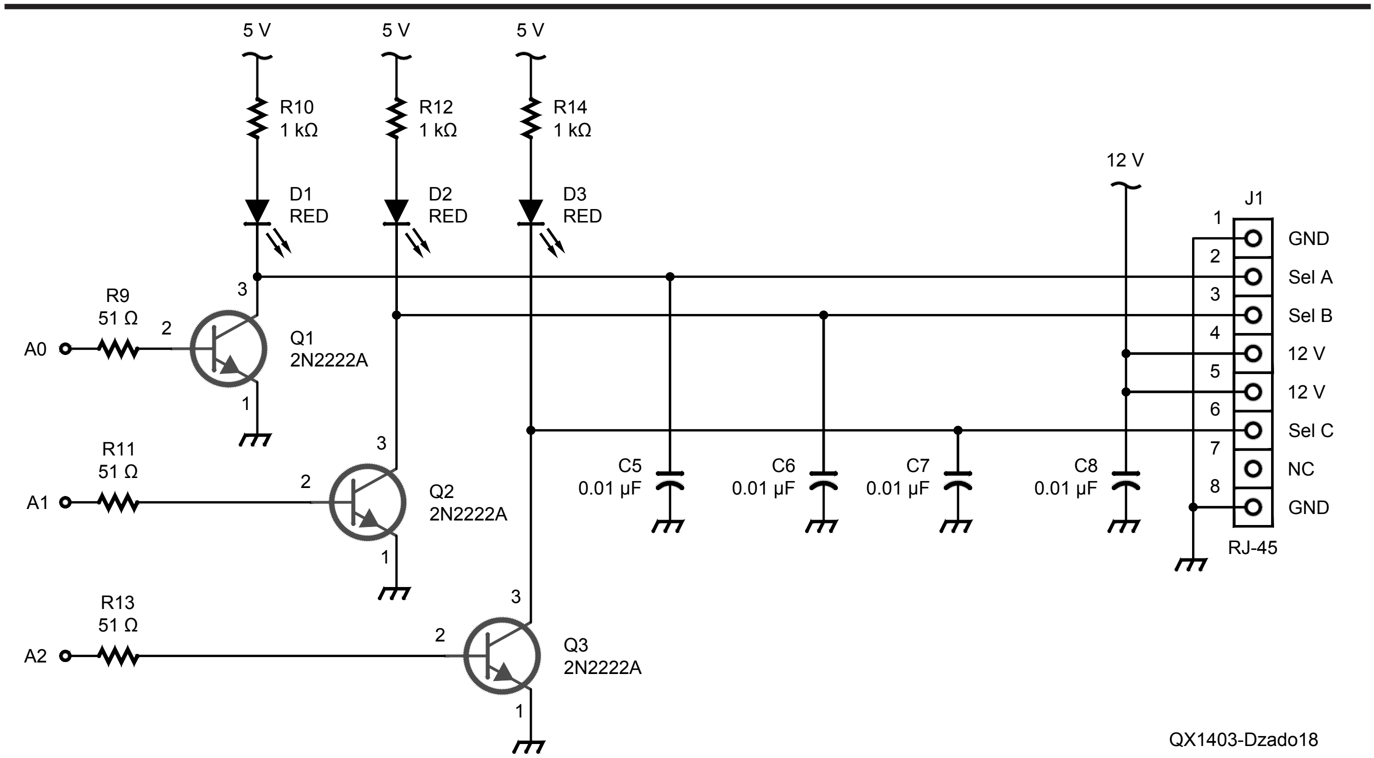


Figure 18 — This schematic diagram shows the remote control wiring output to the antenna selector switch.

Mike Dzado, ACØHB, obtained his Amateur Extra Class License in 2007. Mike has over 35 years combined experience as an Electrical and Software Engineer, which includes CAE/CAD experience. Mike started his career as an Electronic Technician with the USAF and currently is a Senior Systems Engineer for Rockwell Collins Air Transport Large Display Systems. Mike holds an Associate Degree in Meteorological Equipment from the Community College of the Air Force (1978), Bachelor of Science in Electronic Systems Management from Southern Illinois University (1980), Bachelor of Science in Electrical Engineering from the University of Utah (1984), and a Master of Science in Software Engineering from the National Technological University (1994). Mike's career experience includes Power Supply Design, Communications Protocol Software Development, Computer Aided Engineering Design and Analysis Tool development, and Software Defined Radio development.

Mike's other hobbies include weather spotting, and designing and building electronic kits for fellow club members. He is a member of the Cedar Valley Amateur Radio Club (CVARC) and Collins Amateur Radio Club (CARC) See his website, **www.AC0HB.com** *for some of his current projects.*

Notes

[1]Learn more about *TinyCAD* and download the program free at: **tinycad.en.softonic.com**/.

[2]For more information about the *Free PCB* program and to download the installation files, go to: **www.freepcb.com/**.

[3]You can download the *AppCAD* design software free from the Avago Technologies website. Go to **www.avagotech.com/pages/appcad**.

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

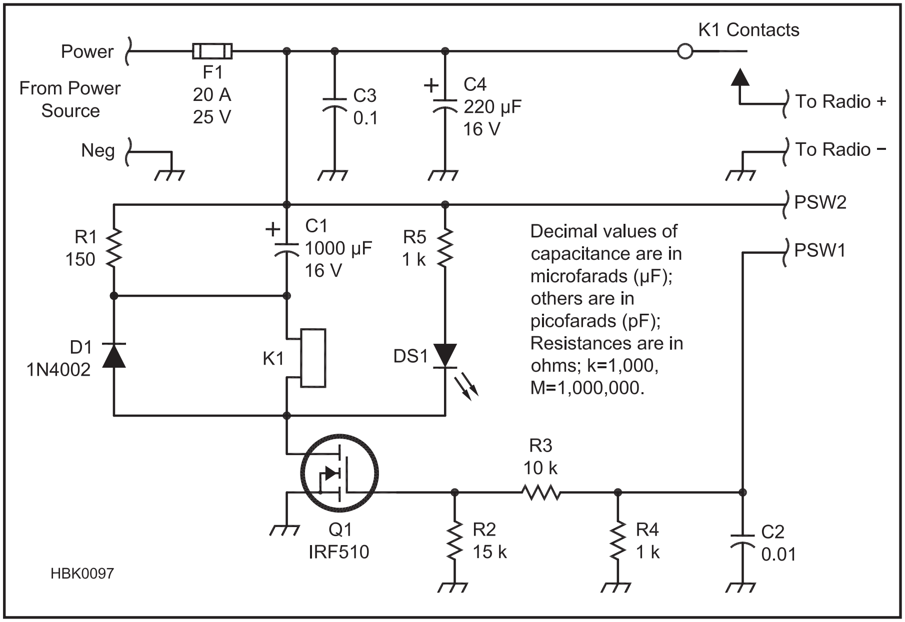


Fig 19.75 — Schematic of the remote power controller.

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.

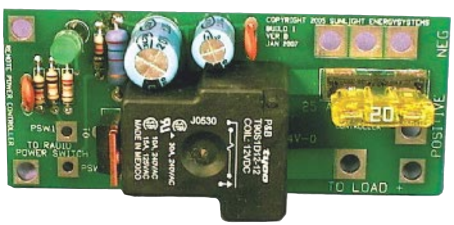


Fig 19.76 — The completed PCB for the remote power controller.

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**.

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.

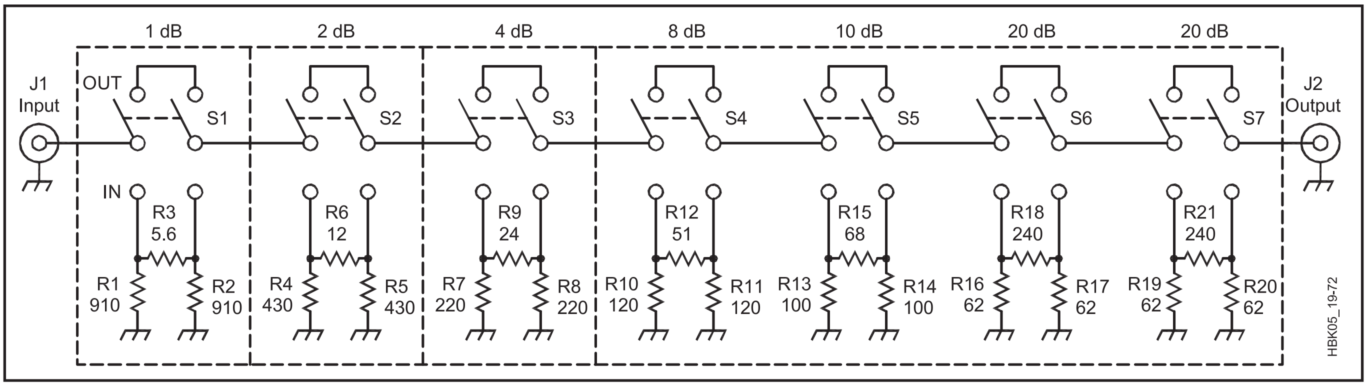


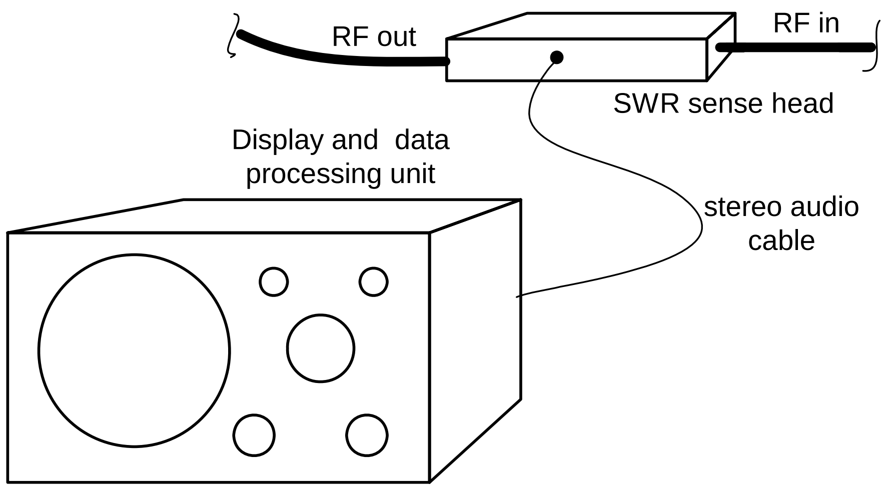
Fig 19.69 — The attenuator consists of seven pi network sections, so-called because each pad (eg, R1, R3 and R2) resembles the Greek letter pi (π). Input and output impedances are 50 Ω.

Operating instructions for the SWR/Power/Return Loss monitor and a summary of features.

Description

The VSWR/Return Loss monitor consists of a sense head and a separate display and data processing unit. The sense head is designed for use in a 50-ohm system and contains a Stockton Standing Wave Ratio (SWR) bridge with Schottky diode detectors. The diodes convert forward and reflected RF voltages to dc levels which are passed to the main data display and processing unit via a 3-conductor stereo audio cable.

The sense head is small and may be located any reasonable distance from the display.



There are two separate sense heads for use with the display unit. One can handle RF power levels up to 10 watts, the other up to 100 watts. Both cover the frequency range 1.8 to 54 MHz..

Based on the forward and reflected voltage readings, a microprocessor in the data display module calculates

- Relative forward power
- Percent reflected power
- Net power delivered to the load
- Standing Wave Ratio (SWR)
- Return loss (in db)

Accuracy of the SWR reading is better than 5% over a range from 1.0 to 10.0 when used in a 50-ohm system.

The return loss scale covers a range of 0 to 33 db.

Measurements are displayed on an analog panel meter and are also available as ASCII character strings for display on a computer terminal.

Auto-calibration

When the instrument is first powered on, the instrument goes through an initial calibration and zero adjustment sequence and the front panel LED labeled *Calibrating* remains lit for about three seconds before starting its normal cycle. Occasionally, the initial calibration sequence may be repeated two or three times at power-up. This is normal.

After it is up and running, the system goes through a zero-adjustment cycle approximately every six seconds. The *Calibrating* LED flashes very briefly when this occurs. The normal flashing of this LED can be thought of as a “heart beat” indicating that the main portion of the software is running as it should.

Transmitter Lockout

There is a *Transmitter Lockout* (XLO) feature which is enabled by a slide switch on the rear panel. When enabled, this feature opens a set of relay contacts when the SWR exceeds a pre-determined level. By this means, the transmitter can be automatically turned off in the event of high SWR, possibly protecting the output RF amplifier from a damaging condition. A LED on the front panel is also lit when the XLO is in effect.

Adjustments and Controls

The meter display mode is controlled by a front panel rotary switch. The user can select among Forward power, Percent Reflected power, Net Power, VSWR or Return Loss modes.

Internal to the monitor, mounted on the circuit board, there is a multi-section dual-inline package (DIP) switch which enables and controls several setup and operating functions of the VSWR meter. (See the illustration below.)

Five sections of the DIP switch are used:

DIP switch section 1 overrides all operating modes and simply puts out a full-scale level to the meter. When this switch is on, the meter sensitivity trimmer resistor R15 is adjusted so that the meter reads full scale. This switch is turned on only during the initial setup of the meter and must be turned off for normal operation.

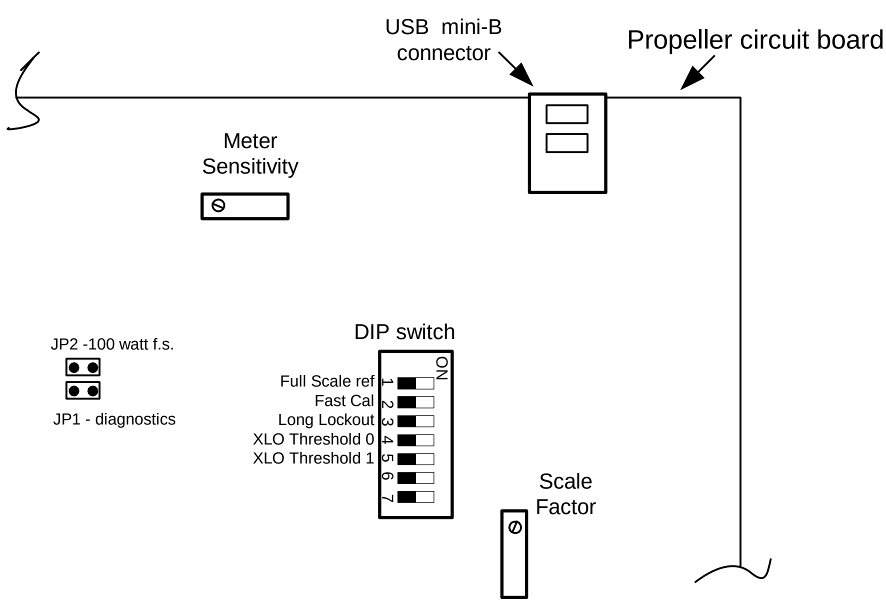
Trimmer resistor R6 controls the scale factor of the meter. This adjustment allows setting the forward power as displayed on the meter to agree with some known level of input. When setting the sensitivity in this manner, it is convenient to have the meter respond more quickly than normal. Accordingly, section 2 of the DIP switch bypasses much of the averaging which is built into the signal processing firmware, thereby speeding up the response of the meter. This switch also should be off for normal operation

DIP switch sections 4 and 5 set the SWR threshold level at which the Xmtr Lockout relay is energized as shown in the following table.

DIP SWITCH SECTION 5 XLOTHRESH1	**DIP SWITCH SECTION 4 XLOTHRESH0**	**VSWR THRESHOLD**
OFF	OFF	1.5:1
OFF	ON	2:1
ON	OFF	3:1
ON	ON	4:1

Normally, the relay remains energized and the LED on the front panel remains lit for three seconds after the SWR drops back below the threshold. This can be extended to approximately 9 seconds by turning on DIP switch section 3.

The sketch below shows the location of the internal switches, jumpers and trimmers.



A convenience feature is a toggle switch on the front panel which increases the meter sensitivity by a factor of three for ease in reading low-power sources. This switch affects the sensitivity of the forward, % reflected, SWR and net power readings only. Return Loss meter readings are not affected by the position of this switch.

A second front-panel toggle switch enables a peak capture and hold function so that power and SWR can be monitored during CW or SSB operation.

Terminal display and keyboard commands

The USB port located on the top panel of the data display unit can be connected to a computer running terminal emulation software, such as MS Windows HyperTerminal. The terminal should be set for 19200 baud, 8 data bits, no parity and one stop bit. All five data channels can then be displayed as a single data record for monitoring or logging purposes.

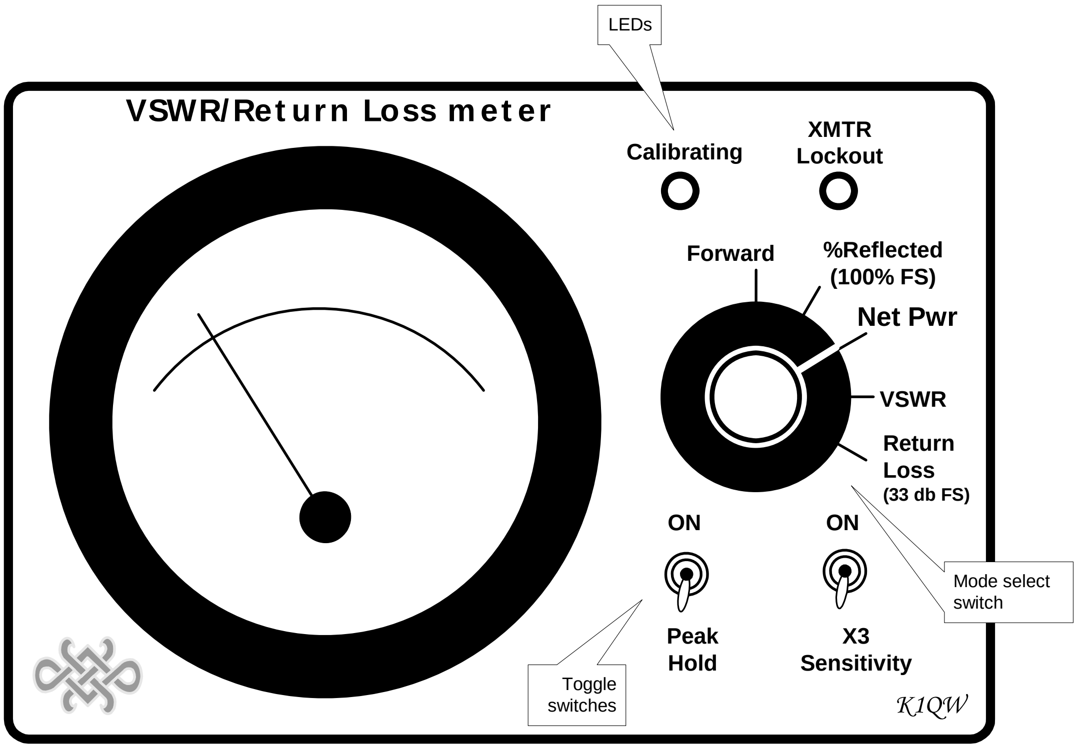
A rudimentary set of commands from the terminal control the collection of data.

- Pressing the “Enter” key at the terminal will display a single line of data.
- Holding down the “Control” key while pressing “L” (Ctrl-L) will initiate periodic logging of data records. A message is shown prompting the user to enter a logging interval from 1 to 99 seconds. Then, pressing the “Enter” key will begin logging data records to the terminal.
- Logging is ended by sending Ctrl-Q from the terminal.

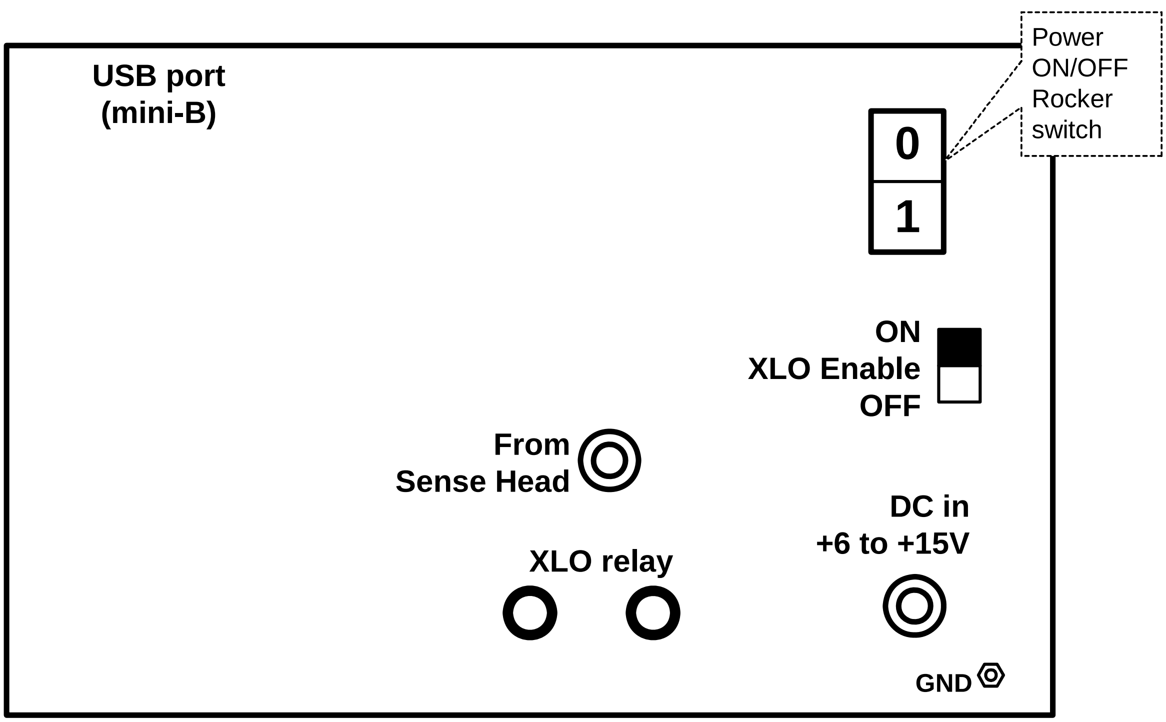
The logged data may be captured in a file and easily entered into a spread sheet for further processing and/or graphical display.

JP2 (“100 watts”) should be installed whenever the 100 watt sense head is in use. This jumper allows the terminal display to read forward and net power correctly in watts. It affects the terminal display only and has no affect on the meter reading.

If jumper JP1 (“diagnostics”) is in place, the display on the terminal changes to show “raw” data conversions of forward voltage, reflected voltage and dc zero offset voltage. These data are displayed in the range 0 – 4096 counts as converted by the ADC before any filtering or corrections are made. This jumper must be removed for a normal terminal display.



Front Panel Controls



Rear Panel Layout

SWR/Power/Return Loss monitor – Some additional software details

All of the code for this project was written to run on the Propeller chip, a product of Parallax, Inc. using the free development tools available from Parallax. This chip is designed around a unique architecture using eight independent, identical processors in a single package. These peripheral processors are known as “cogs” and are capable of executing tasks either independently or cooperatively. All cogs are driven from the same clock source and a central “hub” processor cycles through all cogs and synchronizes their actions.

The code for the SWR monitor is written entirely in the Propeller's SPIN language, a high-level language similar to BASIC. Parallax supplies a complete software development package called Propeller Tools, free for the downloading from their web site, www.parallax.com. Also available at this web site is a library of useful self-contained software objects. From this library, the floating point math package, *Float32.spin;* floating point to string conversion utility, *FloatString.spin;* and the serial communication utility, *FullDuplexSerial.spin.* are also used in the code for this instrument.

The complete code for the SWR monitor instrument, ready to be programmed into the Parallax USB Development Board, can be found in the file SWRMON_090816.SPIN . The source code is heavily commented, and is reasonably self-explanatory.

Programming the Propeller Development Board

The USB port and logic-level converter built in to the Propeller USB Development Board makes it easy to load programs using the Propeller Tools. No additional hardware is required other than a USB cable with a mini-B connector. With the USB cable in place, it's only necessary to load the Propeller Tool suite into the host computer and call up the file containing the program to be installed – in this case the SWRMON_090816.SPIN file. Make sure that copies of the three library utilities *FloatString.spin, Float32.spin* and *FullDuplexSerial.spin* have been loaded into the same directory as the SPIN file.

Pressing the F10 key loads the software into the RAM area of the Propeller chip on the board and then executes it. Key F11 does the same thing, but also loads the same software into EEPROM for non-volatile storage. When stored in the EEPROM the program will run automatically whenever the board is powered up or the chip is reset.

Program Flow Diagram

The software for the SWR/Power/Return Loss monitor is made up of a number of software objects housed in several independent cogs. The accompanying software flow chart shows their interaction. Details of the primary software objects are given below, in pseudo-code form.

The MAIN object

The MAIN program object runs first, in its own cog, and starts three other cogs: ADC3CH, PWM and MONITOR. ADC3CH, in turn, starts a new cog, ADC, and MONITOR starts a new cog, PCMON. MAIN also uses library objects FullDuplexSerial.spin and Float32.spin. These last two objects also run in cogs of their own, so that all eight cogs are in use.

Pseudo-code listing – MAIN

```
Set up pin directions
Check out a lock
Start objects in separate cogs:
        AD3CH, PWM, MONITOR, FP (floating-point library)
Enter endless loop:
        Wait until lock is set by the ADC object
        Read data block from AD3CH object:
                forward power, % reflected power, net power and SWR
        Clear lock
        Convert power and SWR data to floating point numbers
        Calculate return loss (db)
        Get state of the DIP switches
        If XLO is enabled and SWR exceeds programmed threshold
                Energize XLO relay and front panel LED
        Get state of the front panel switches
        Write selected data channel to the PWM object
```

The AD3CH object

Pseudo-code – AD3CH

```
Set up multiplexer and LED pin directions
Start A-to-D converter in a new cog
Get initial analog zero level (MUX channel 0)
```

Enter endless loop:

    Wait until lock has been cleared by the MAIN program, then set lock
    Sample forward and reflected voltage amplitudes (MUX channels 1 and 2)
    Correct for zero offset
    Call PEAKHOLD object
    Call LPFILTER object
    At intervals of 10 seconds, take another zero reading and flash LED
    Clear lock

The PEAKHOLD object

This object looks for a peak in the forward power reading and, when it finds one, stores it in memory and starts a software timer. PEAKHOLD is called on each pass of the AD3CH loop, and each time through, the stored peak value is decreased by a small amount, until its value is less than the newest value of forward power. Net power is treated in the same way. If the “Peak Hold” switch on the front panel is ON, these values are used by the MAIN program for display on the panel meter.

The rate of decay is controlled by a program constant (accel) stored in the CON block.

Pseudo-code – PEAKHOLD

IF the newest sample of forward power is less than the value stored in hpkfwd

    Decrease hpkfwd by a fractional amount determined by the constant accel
    and by the contents of the timer.

ELSE update hpkfwd with newest sample of forward power and start a timer.

The LPFILTER object

This software object implements a single-stage low-pass IIR filter which operates on the data stream generated by the Analog-to-Digital Converter (ADC) running in AD3CH.

The PWM object

The data channel selected by the front-panel rotary switch is converted to analog in the form of a pulse-width modulated (PWM) waveform. The pulse repetition rate is 100 Hz and the duty cycle ranges from 0 to 100%, corresponding to a digital input value of 0 to 4096. The PWM waveform is transmitted from port P5 and is smoothed by a resistor-capacitor low-pass passive filter, which provides dc to drive the analog meter mounted on the front panel.

The MONITOR object

This object handles the interface to an external computer running a terminal display program, similar to HyperTerminal. The same USB port used for programming the Propeller Development Board is also used to communicate with the terminal program. All five channels of data (forward power, Percent reflected power, net power, SWR and Return Loss) are converted to ASCII strings and written out the USB port for display on the terminal. Depending on the command received from the keyboard, this object sends out data records either singly, when the Enter key is pressed, or at regular intervals for logging purposes.

For proper operation, the terminal must be set up for 19200 baud, 8 bits, no parity, and one stop bit. Further details of the data display and the keyboard commands can be found in the accompanying document “Operation and Features”.

SWR monitor test procedure

Connect either the 10 watt or 100 watt SWR sense head to the display module via a stereo audio cable.

Connect the USB cable to the computer

Set up terminal program (HyperTerminal or something similar) on computer (19200 baud, 8 bits, no parity, 1 stop bit)

Open the case of the display and data processing unit. Set all DIP switches OFF. Remove jumper JP1. Insert jumper JP2 only if the 100 watt SWR sense head will be used. (See the Operating Instructions document for the location on the circuit board of the DIP switch and jumpers). Turn rear panel *XLO Enable* switch OFF.

Set front panel *Peak Hold* and *X3 Sensitivity* toggle switches OFF.

Turn on power to meter and check that the green LED on the front panel comes on. Verify *Calibrating* LED comes on steadily for 3 sec (this may happen 2-3 times), and then starts flashing briefly every 6 seconds, indicating normal activity. Sequence the front panel rotary switch through all display modes. Meter should read near zero in all modes. *XMTR Lockout* LED should remain OFF.

Start the computer terminal program.

Press the “Enter” key. This should generate a one-line display of data from the SWR monitor. Verify zero reading on all five channels.

Turn DIP-1 ON. Observe *Calibrating* LED steady ON. Adjust the meter sensitivity pot R16 for full-scale reading on the meter. Turn DIP-1 OFF. Verify *Calibrating* LED is OFF, flashing very briefly about every ten seconds.

Connect the transmitter output to the sense head input with a short length of 50-ohm coax.

Attach a 50 ohm dummy load to the sense head output.

Turn DIP-2 ON. Verify fast flash rate on *Calibrating* LED (2-3 times per second). Set the *Mode* switch to Forward. Run the transmitter in CW mode. Apply a known level of medium RF power from xmtr (i.e., about 5 watts if the 10-watt sense head is in use, or about 50 watts for the 100-watt head). Adjust scale factor pot R6 for correct reading of power level. Turn DIP-2 switch OFF. Turn the transmitter OFF.

Sequence through all five positions of front panel *Mode* switch: Forward, %Reflected, Net Power, SWR, and Return Loss. Verify that %Reflected is near 0%, Net Power is about the same as Forward, SWR is about 1.0 and Return Loss is near full scale on the meter.

Press “Enter” on computer terminal keyboard to display one line of data. Verify all five channels.

Temporarily install internal jumper JP1. Press “Enter” on the computer terminal keyboard and verify that the terminal now displays three raw data channels: Zero, Forward and Reflected.

Remove JP1.

Reduce xmtr power to less than one-third full scale. Verify operation of *X3 Sensitivity* switch on Forward, Net Power and SWR displays. Turn *X3 Sensitivity* switch OFF.

Change xmtr to SSB mode. With *Peak Hold* switch ON and forward power mode selected, speak into the microphone and verify the peak hold function. Or, just send a single “dit” in CW mode. Turn *Peak Hold* switch OFF.

Change xmtr to CW mode. Increase xmtr forward power to near full scale on meter. Turn xmtr OFF and change load on the sense head output connector to 100 ohms.

Turn transmitter ON. Verify that SWR reads about 2.0, % Reflected power shows about 25 % and Return Loss is about 6 db.

With transmitter running and supplying power to the sense head, test data logging:

- Press “Enter” to display one data record on terminal, and verify readings.
- Press CTRL-L. After the prompt, enter “2”. Press “Enter”
- Verify data records log at 2-second intervals
- Press CTRL-Q to end logging and display “End Log” message.

Turn ON the rear panel *XLO Enable* switch. Make sure DIP-3 (long lockout time) is OFF.

With DIP-4 and DIP-5 both OFF, briefly (less than 1 second) cycle the transmitter on and then off. The *XMTR Lockout* LED on the front panel should come ON for about 3 seconds and then turn OFF. At the same time the XLO relay should open as observed with an ohmmeter across the rear panel banana jacks.

Move DIP-3 switch to ON. Again apply a brief burst of power from the transmitter. The *XMTR Lockout* LED should come ON for about 9 seconds and then turn OFF. The XLO relay should open for the same length of time.

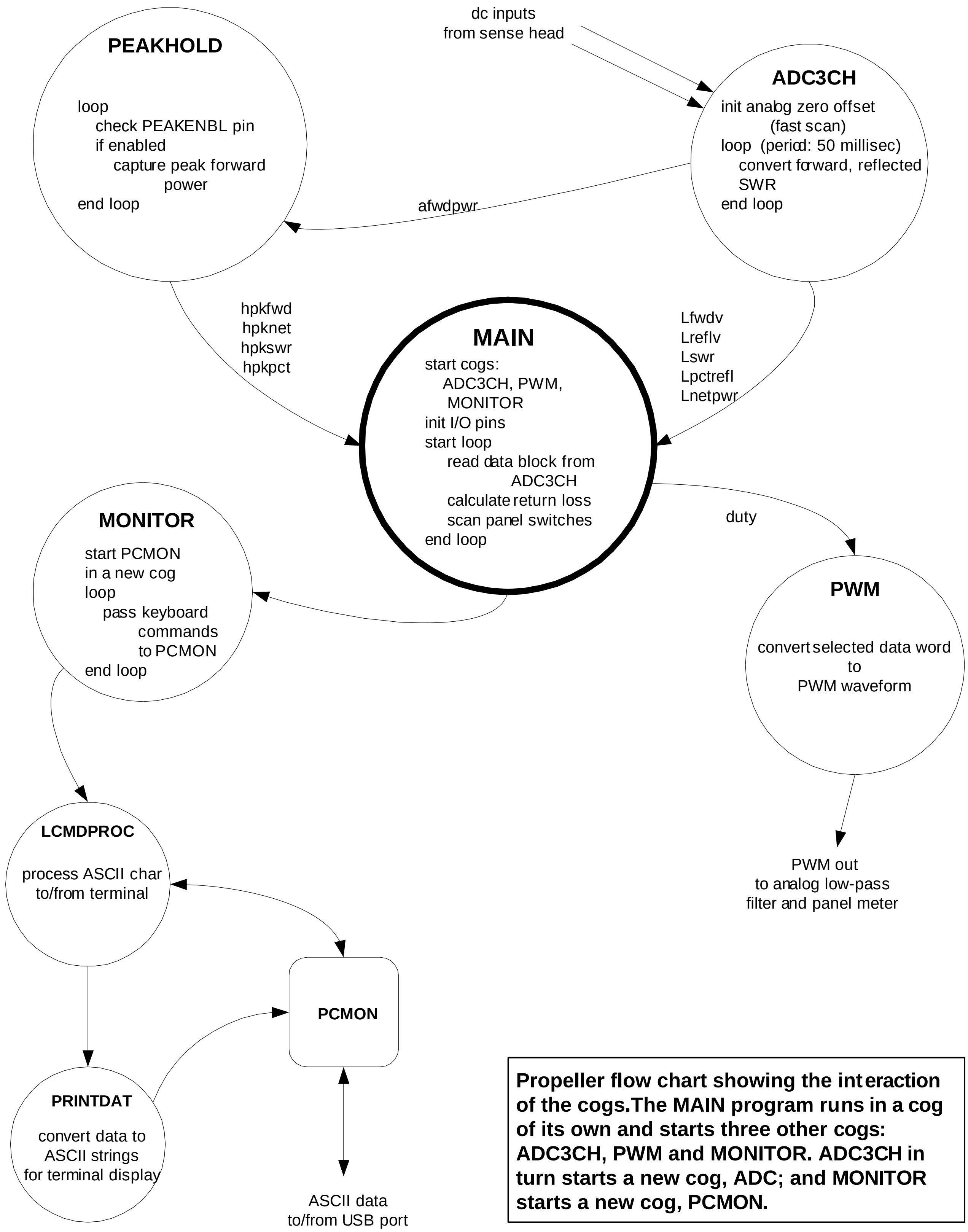
Turn both DIP-4 and DIP-5 ON (selects XLO Enable threshold at SWR = 4.0). Briefly turn ON the transmitter. Verify that the *XMTR Lockout* LED does not turn ON and that the XLO relay contacts remain closed..

Turn OFF the rear panel *XLO Enable* switch. Turn all DIP switches OFF.

SWR/Power/Return Loss monitor

Propeller program flow diagram

30 Apr 2009



Propeller flow chart showing the interaction of the cogs.The MAIN program runs in a cog of its own and starts three other cogs: ADC3CH, PWM and MONITOR. ADC3CH in turn starts a new cog, ADC; and MONITOR starts a new cog, PCMON.

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]

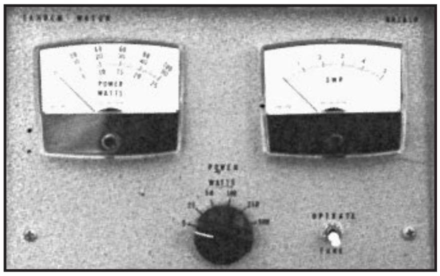


Fig 19.42—The Tandem Match uses a pair of meters to display net forward power and true SWR simultaneously.

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 multiturn 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

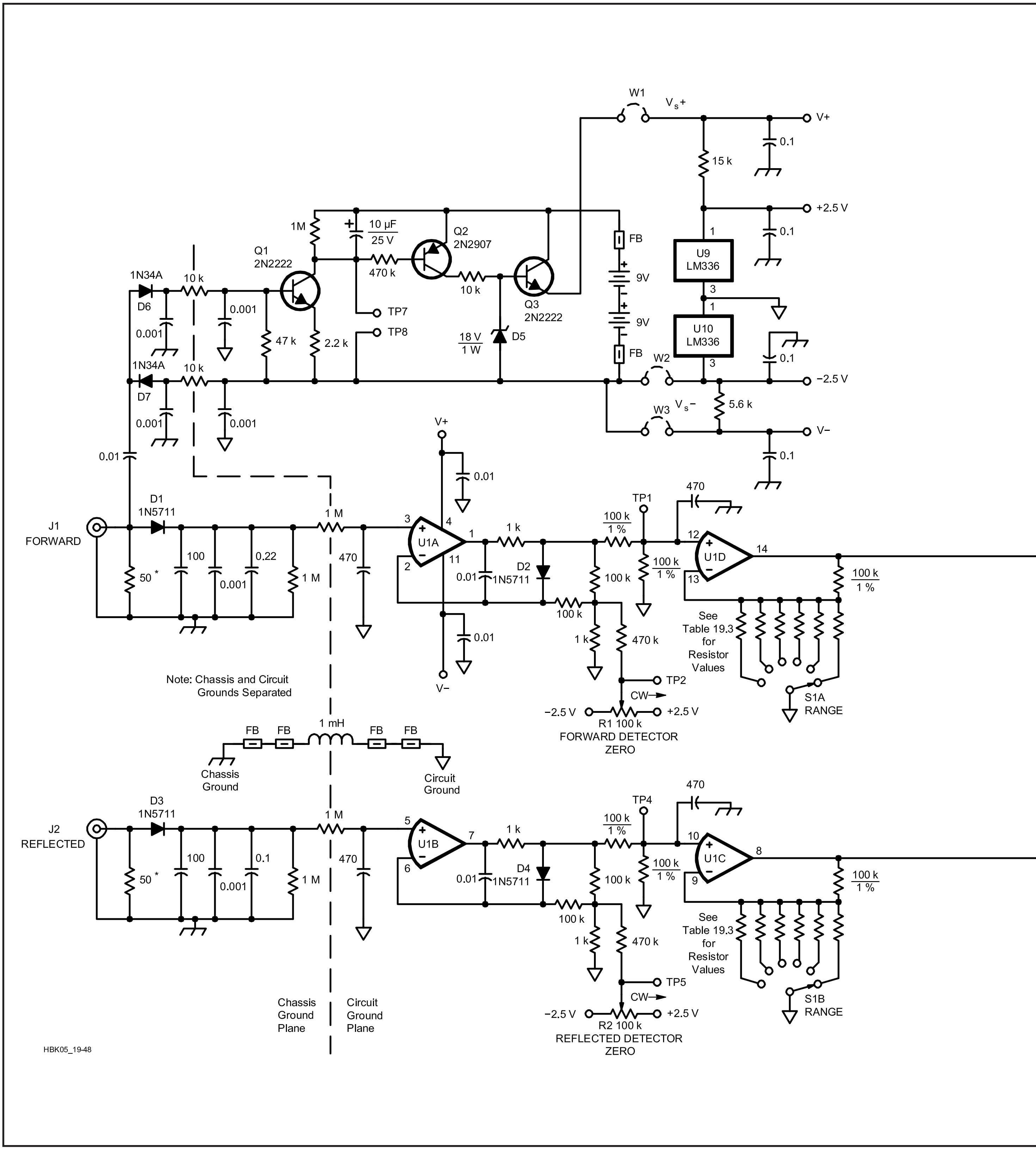
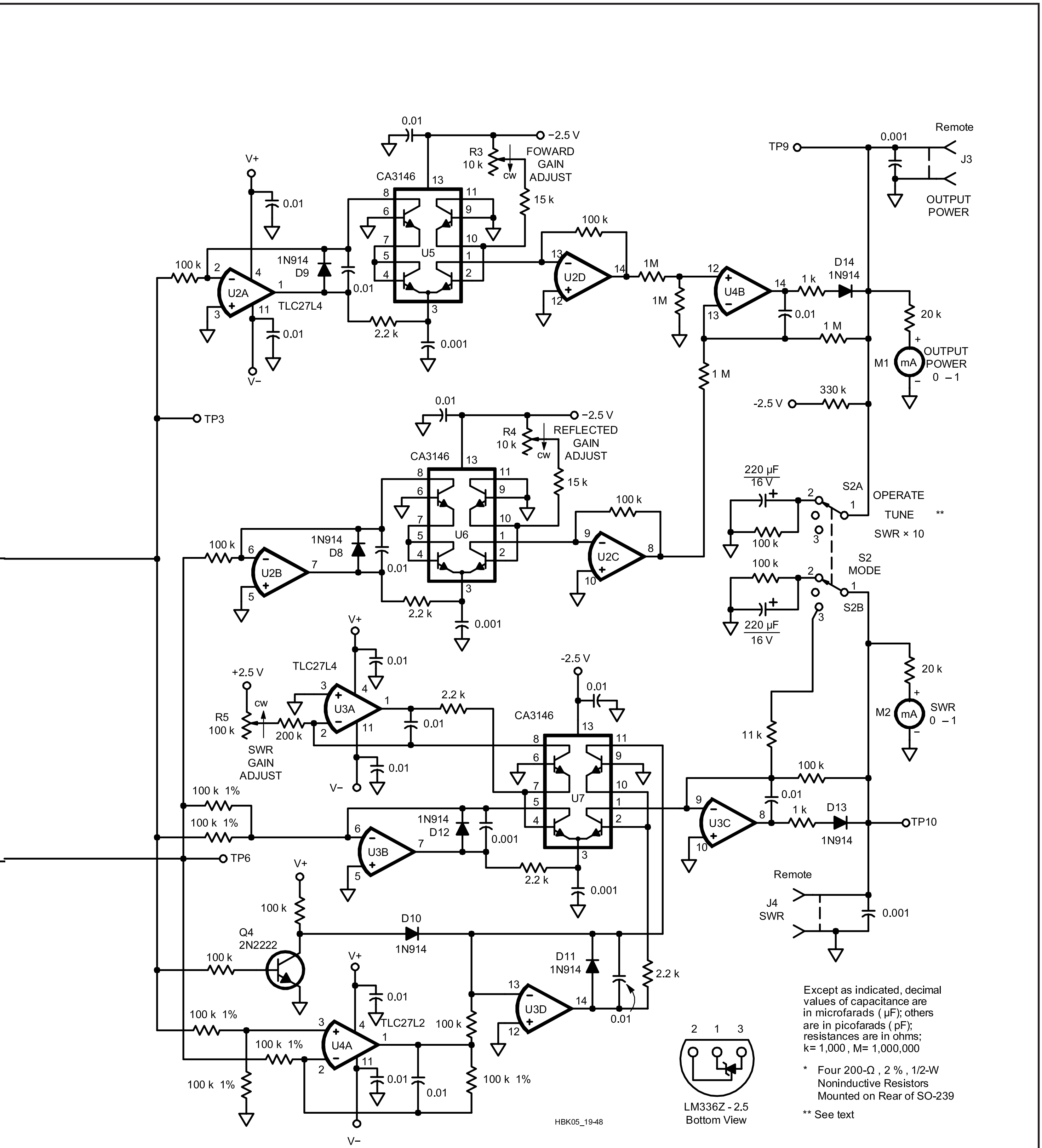


Fig 19.43—Schematic diagram of the Tandem Match directional wattmeter. Parts identified as RS are from RadioShack. Contact information for parts suppliers can be found using the *TIS Find* program.

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

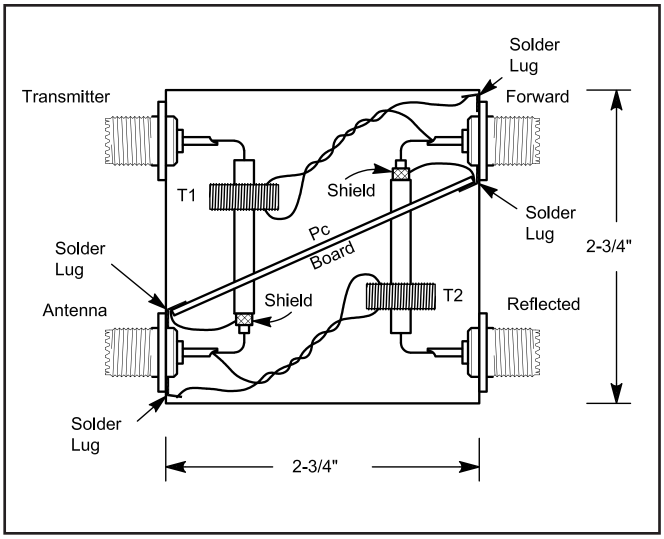


Fig 19.44—Construction details for the directional coupler. A metal case is required.

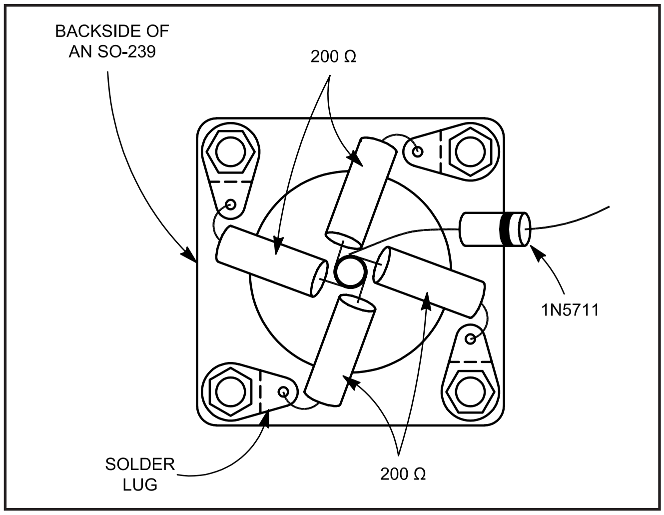


Fig 19.45—The parallel load resistors mounted on an SO-239 connector. Four 200-Ω resistors are mounted in parallel to provide a 50-Ω detector load.

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

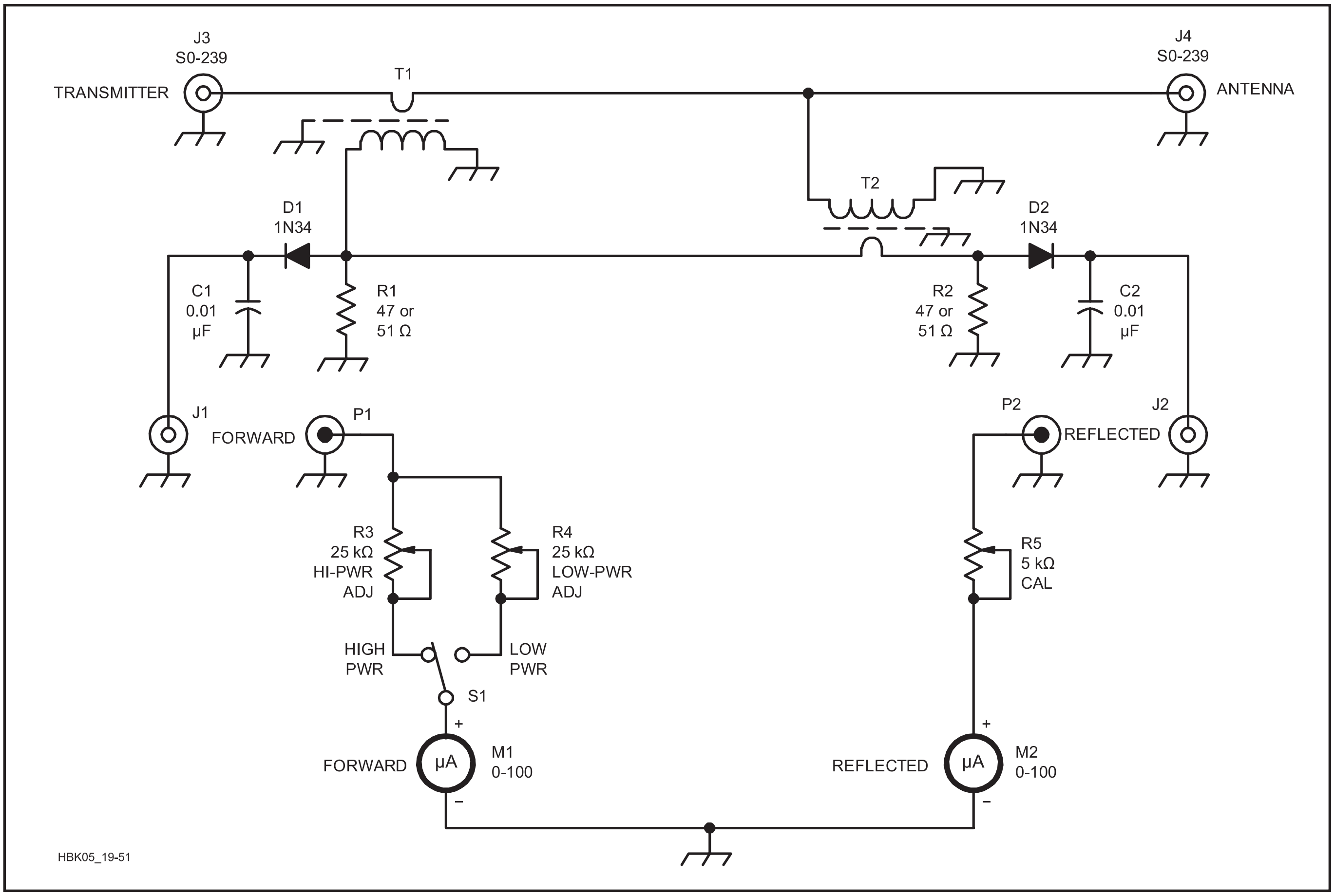


Fig 19.46—Schematic diagram of the high-power directional coupler. D1 and D2 are germanium diodes (1N34 or equiv). R1 and R2 are 47- or 51-Ω ½-W resistors. C1 and C2 have 500-V ratings. The secondary windings of T1 and T2 each consist of 40 turns of #26 to 30 enameled wire on T-68-2 powdered-iron toroid 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

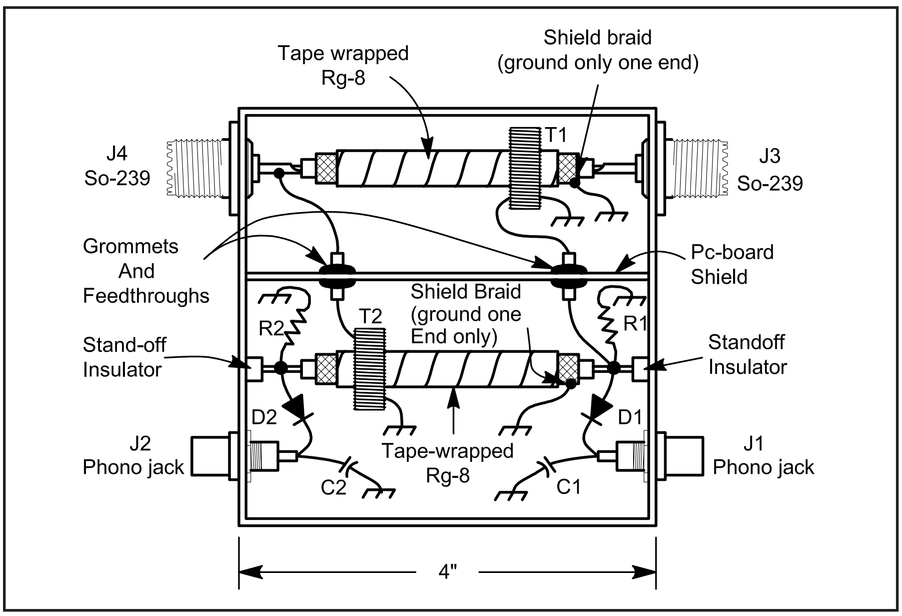


Fig 19.47—Directional-coupler construction details. Grommets or standoff insulators can be used to route the secondary windings of T1 and T2 through the PC-board shield. A 3½×3½×4-inch metal box serves as the enclosure.

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.