Rainbow Tuner

Assembly & Operator's Manual

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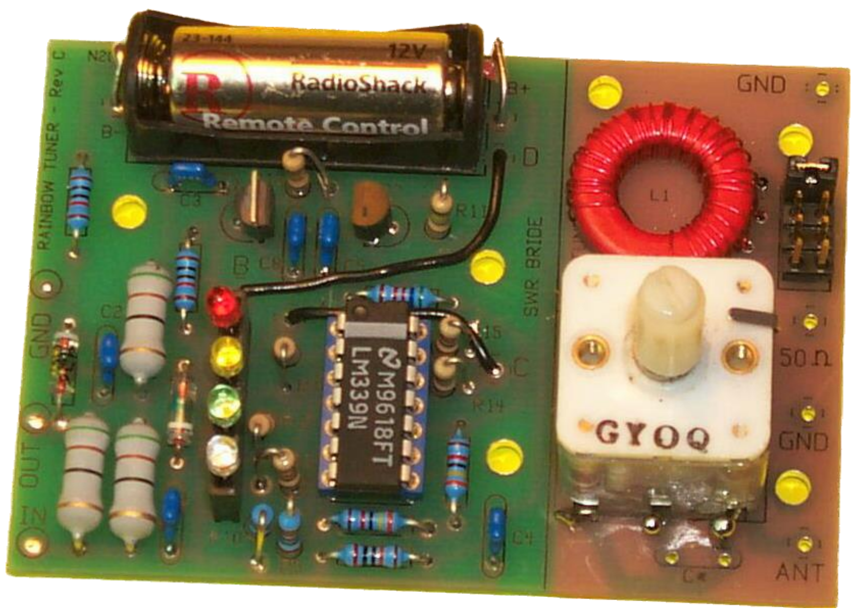
with enhanced Build, Test & Operating sections!



Back in 1996 the NJQRP Club unleashed the Rainbow Tuner, designed then by RF engineer, homebrewer and critically acclaimed humorist Joe Everhart, N2CX. This was the club's vanguard kit into the QRP community, soon to be followed by a long string of additional designs and projects stemming from N2CX. ***Rainbow Tuner kits*** *were an instant success with hams all over the world using them as stand-alone QRP antenna tuners and building them into other equipment and rigs. App notes were written, add-on projects were created, and novel circuit adaptations were made. Kitting ended in 1998 as we moved on to other club projects, but many have been asking for the rebirth of the Rainbow Tuner Kit ... so here we go again!*

(This is an updated of the original N2CX and NJQRP documentation … n2apb)

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BACKGROUND

This circuit really doesn't tune rainbows, but it does use a rainbow of sorts. It embodies the Spartan design philosophy exemplified by the 40-9er, the Pixie, the Fireball 40, the MRX-40, and other simple QRP "rigs". It combines a very special antenna tuner with a simple-to-use and accurate SWR meter. Intended to fit in the popular Altoids mint tin, it can be built for under $30. The heart of the Rainbow Tuner is a user-friendly SWR indicator that can be used by itself or in other homebrew projects.

The kit consists of a printed circuit card and all parts needed to make a QRP SWR Bridge and a simple tuner intended for use with an end-fed half-wave antenna. Not included are antenna connectors, a DC display power source or an enclosure.

The Rainbow Bridge is an absorptive-type resistive bridge that can be used with transmitter powers from: 200 mW to about 5W. The resistive bridge ensures that SWR reflected to the transmitter used with it is no greater than 2:1. The Bridge uses a multi-color LED bargraph display that features both relative and absolute SWR readings. Automatic RF sensing turns the display on when RF power is present and off when the signal is removed. The bridge uses integrated circuit comparators to automatically calculate SWR from forward and return RF power readings. The tuner section is a tapped parallel resonant tuned circuit that will match a simple end-fed half-wave antenna to 50-ohm coaxial cable. SWR can be adjusted to less than 1.5:1 on either 30 or 40 meters with an antenna of proper length.

CIRCUIT DESCRIPTION & OPERATION

Referring to the schematic, the antenna tuning function is performed by L1 and C7. In this configuration they are connected as a parallel-tuned resonant circuit with a tapped output, intended for use with a half-wave end-fed wire. The high impedance presented by the half-wave wire is transformed to 50 ohms by taps on the toroidal coil. The variable polyvaricon (PVC) tuning capacitor C7 is used to cancel any reactance presented by the antenna, and inductor taps are selectable to give a close match to a 50-Ohm feedline.

A novel SWR bridge was presented in the June 1995 issue of QST by K1KP. It used the familiar toroid type SWR bridge and replaced the meter with LEDs. It had no means of displaying actual SWR but merely a relative indication via brilliance of its LEDs.

The Rainbow SWR indicator uses a bridge circuit more suited to QRP operation and a self-adjusting LED indicator that is only slightly more complex than K1KP's but providing relative indications for tuning and exact final SWR reading.

The SWR bridge consists of resistors R1, R2 and R3. R1 and R2 for a voltage divider with exactly half the input voltage present at their junction. This is rectified by D1 to produce a DC voltage proportional to forward RF power. The other half of the bridge is comprised of R3 and the output load – either an antenna or the tuner circuit, whichever is connected. When the load is 50 ohms, the voltage at the junction of R3 and the load is the same as the R1-R2 junction. This corresponds to a 1:1 SWR and the voltage difference across the bridge arms is zero. When the load is not 50 ohms, the difference voltage is proportional to the SWR. D2 rectifies the difference voltage to provide the reflected voltage.

Using resistors for the SWR bridge provides a real advantage when using the Rainbow Tuner with simple QRP rigs. Most SWR indicators pass their output SWR right on through to the rigs driving them. Transmitters like the one used in the 40-9er and other misbehave with high SWR loads. At best they become unstable and may oscillate, generating off-frequency spurious signals. At worst, a high SWR load may destroy the final transistor. The **absorptive bridge** in the Rainbow tuner limits the SWR that the transmitter sees to at most 2:1.

Most SWR measurement devices require the operator to adjust for full-scale meter reading on forward power and then switch to a reverse power reading to read the reflected energy. The Rainbow tuner eliminates this complication. It uses the fact that in an SWR bridge the reflected voltage is a fixed fraction of the forward voltage. For example, with a 3:1 SWR, the reflected voltage is *always* half the forward voltage, no matter what power level is used. As shown in the schematic, the forward sample is connected to a voltage divider RX through RZ. The resistors are chosen to set a fraction of the forward voltage at comparator U1 inputs to correspond to 5:1, 3:1, 2:1 and 1.5:1. The other comparator inputs are fed directly by the reflected voltage. LEDs at the outputs of the comparators indicate SWR by lighting in response to the compared forward and reflected voltages.

The multi-colored LEDs form the rainbow display. As shown in FIG 4, only the green LED is on when SWR is less than 1.5:1, both the green and yellow LEDs are on with SWR between 1.5:1 and 2:1, and so on. Two levels of intensity are provided on the red LED for the highest SWR because I ran out of colors for inexpensive LEDs! No voltage regulator is needed by the comparator since it relies only on the resistive divider for accuracy.

The SWR indicator is switched in or out of the circuit by DPDT toggle switch S1. It is not connected at all times for two reasons. First, the tuner has a 6 dB loss, even with a good match to the antenna. Secondly, power is required for illuminating the LEDs when the indicator is being used.

The tuner SWR indicator senses RF and turns itself on with less than 150 mW of RF. Q1 is a special MOSFET with a very low turn-on voltage. I’ve measured a number, and all have turned on with less than 1.5 volts.

Recommended battery B1 has a rated capacity of only 33 mAH and the indicators draw from 10 to 50 ma, depending on how many are illuminated. Battery life is prolonged by using the indicator only when needed. Even longer life can be achieved with a 9-volts alkaline battery, but it won’t fit into the mint tin along with the Rainbow pc board.

The tuner is sized to fit in an Altoids mint tin with room for the SWR bridge selection switch and some small connectors. I used RCA phono jacks because of their small size. The bridge has its own input and output jacks which can be connected to the tuner section with a small coax jumper. This way the tuner and SWR bridge can be used separately, if desired. One could alternatively use a small switch between the bridge and tuner sections to eliminate the extra connector and jumper lead.

FIG 5 shows sketches and photos of the tuner as installed in the tin. The pc board fits into the tin and is insulated from the metal box by a piece of cardboard beneath it. The battery is installed in a holder for a type-N cell. Access to the tuner’s variable capacitor is made via a hole punched in the mint tin’s lid. Size 6-32 screws and knurled nuts are used for antenna wire and counterpoise connections. Shoulder washers insulate the “hot” antenna wire hardware.

The display LEDs are plugged into a single inline socket strip cut down to 8 pins. The LED leads are bent at right angles so that the socket can be glued inside the mint tin with the LEDs being visible through holes in the tin lid. A short piece of ribbon cable connects the inline socket to the respective pins on the pc board. I prefer to use pins in pc boards to connect external wires – pins like the Vector T-44 types are soldered to the pc board and wires going off-board are soldered to them.

Operation is very simple. To use just the SWR bridge, attach the rig and antenna cables to the proper connectors and set the switch to the “in-line” position. As soon as you transmit, the circuit will turn on and you can read the SWR using the LEDs. When the RF disappears, the tuner shuts off the DC power. When not in use, like during a QSO, set the switch to “bypass”.

The antenna tuner is intended for a half-wave end-fed wire. An antenna of this type presents an impedance of 1,000 to 10,000 ohms or so. To check out the tuner and learn how it works, connect a non-inductive resistor in that range across the antenna and ground terminals and a coaxial jumper from the tuner phono jack to the SWR bridge ANTENNA jack. Use a 40-meter rig with an output of 150 mW to 1 Watt to feed the RIG jack. Set the tuner tap jumper between the LOW Z taps.

Set the switch to the “in-line” position and key the transmitter while monitoring the LEDs. Adjust the tuner’s variable capacitor for the lowest SWR, using a non-metallic tuning tool. If it isn’t below 1.5:1, try the next higher tap and repeat the tuning. You should be able to find a tap and tuning setting that illuminates only the green LED.

Tuning with an antenna is done the same way. Use a single wire about 67 feet long and at least one 33-foot wire as a counterpoise. Try to get the antenna wire about 15-20 feet off the ground. Key the transmitter and tune as done with the resistor load. Due to the tuner’s limited adjustment range you may find it necessary to trim the antenna slightly to get minimum SWR. It is recommended that once you have found a wire length that tunes up well, always use that wire and counterpoise.

The parts indicated in the schematic were selected for maximum accuracy and performance. Some substitutions can be made, however, with more available components. R1, R2 and R3 directly affect bridge accuracy and the unit’s power handling capability. One can use 47-ohm 5% values with only a slight effect on accuracy. Half-watt values will be adequate for intermittent use with transmitter power levels up to 2 watts. Smaller wattage resistors will burn up at that power level. One-watt values will handle up to 4W input, and 2W resistors theoretically can handle up to 8W input power. Prolonged transmit periods will cause excessive component heating. Precision resistors are shown for R6 through R10 and R18 in the comparator circuit. 5% values can be substituted but will result in degraded SWR accuracy.

ASSEMBLY

There is no special order to assembling parts to the Rainbow Tuner pcb, other than …

1) **Component Orientation** – Pay careful attention to the orientation of polarized parts (transistors, diodes, integrated circuit)
2) **Q1 is Static Sensitive!** – The VN10KM device (Q1) is extremely static sensitive, so be sure to handle it with appropriate care, ensuring that your wrist (ideally) is grounded while handling it.
3) **Measure the Precision Resistors** – Values of the precision resistors R6-through-R10 should be verified using a multimeter before soldering to the pcb. Doing so will ensure that the correct resistive voltage divider chain is established for the comparator IC (U1) inputs and that SWR will correctly indicate out via the LEDs.
4) **Polyvaricon (PVC) Tuning Capacitor: C7**
    a. Carefully study the pins on the tuning C7 using the diagrams provided below. And once it is attached to the board, screw the 2x7mm screw (through the plastic standoff) into the shaft of C7 for use as a shaft to which the knob may be attached.
    b. The leads of C7 have been prep'd (when necessary) to remove tarnish and allow for easy soldering to the pcb.
    c. A mix of tan and white PVC caps are being provided in kits for C7, so don't worry if yours looks different from one that is pictured in this manual.
    d. As you will notice later herein and/or in one of the Rainbow App Notes, some mods can be done to use the tuning section of the Rainbow on different bands. To this end, the following information is provided …
        i. With the "white" PVC caps, the sections are connected in series to create a variable 6-70 pF range.
        ii. With the "tan" PVC caps, the sections are connected in series to create a variable 2-134 pF range.
5) **Winding L1** – Use the L1 Diagram below as a guide for winding the correct number of turns around the toroid to form the antenna matching transformer.
6) **"R6"** – Below Q2 on the pc board is a resistor noted as R9 … **but it is really R6**.
7) **R4 & R5** – The 1-watt resistors provided for R4 and R5 are slightly larger than what the PC board provides, so carefully bend the resistor leads to fit neatly into the holes.
8) **Block Diagram Shows External Wiring** – Use the Block Diagram below for interconnecting the "inputs" and "outputs" of the Rainbow Tuner with the external (user supplied) switches and connectors, as desired. The schematic alone may seem confusing without the Block Diagram as a guide to understanding.

SCHEMATIC

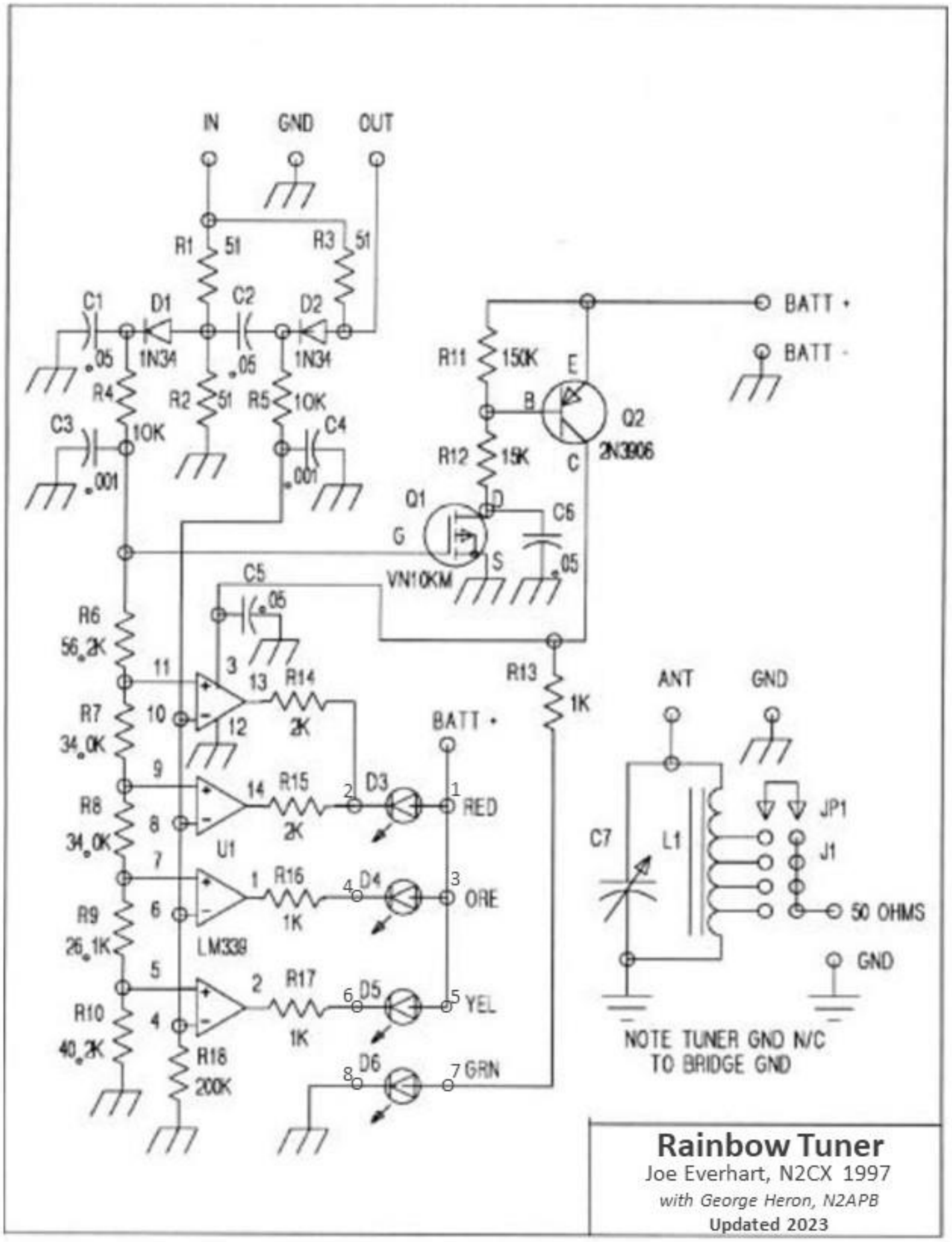
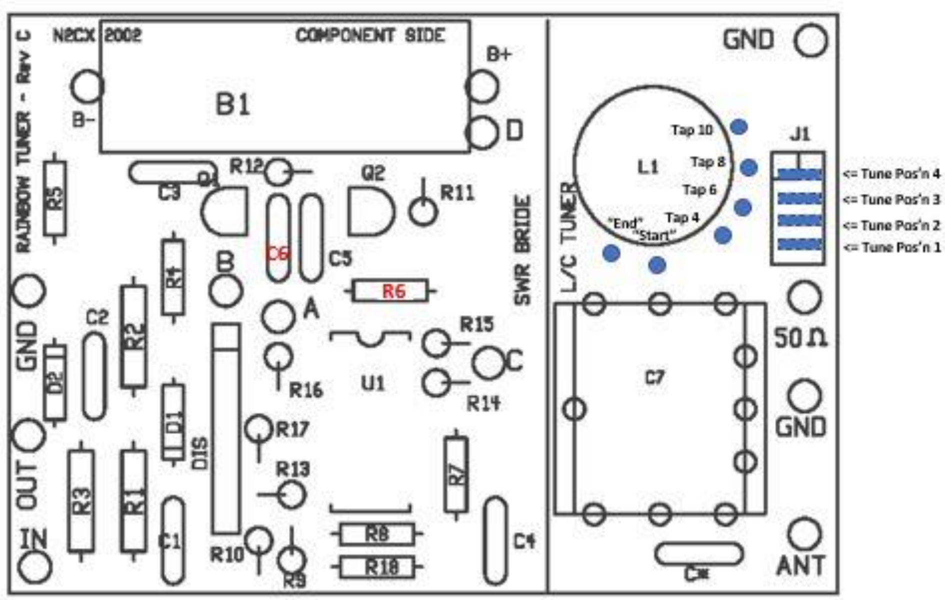


FIGURE 1

PARTS LIST & PCB LAYOUT

Parts List

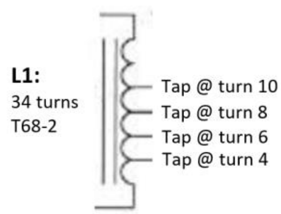
QTY ea kit	Ref Designator	Description
4	C1,2,5,6	.047 uF mono cap
2	C3,4	1000 pF mono cxap (102K)
1	C7	Polyvaricon variable capacitor
2	D1,2	1N34 germanium diode
1	D3	LED, red, 3mm
1	D4	LED, orange, 3mm
1	D5	LED, yellow, 3mm
1	D6	LED, green, 3mm
1	DS1	SIP socket for LEDs, 8-position
1	J1	pin header, 4-position, dual row,.1" spacing
1	L1	Toroid core, T68-2 (red, .68" dia.)
1	Q1	transistor, VN10K
1	Q2	transistor, 2N3906
4	R1,2,3,X	resistor, 51 ohm, 5%, 1W (GRN,BRN,BLK,GLD)
2	R4,5	resistor, 10K, 1%, 1W (BRN-BLK-BLK-RED-BRN)
1	R6	resistor, 56.2K, 1%, 1/4W (GRN-BLU-RED-RED-BRN)
2	R7,8	resistor, 34K, 1%, 1/4W (OR-YEL-BLK-RED-BRN)
1	R9	resistor, 26.1K, 1%, 1/4W (RED-BLU-BRN-RED-BRN)
1	R10	resistor, 40.2K, 1%, 1/4W (YEL-BLK-RED-RED-BRN
1	R18	resistor, 200K, 1%, 1/4W (RED-BLK-BLK-OR-BRN)
1	R11	resistor, 150K, 1%, 1/4W (BRN-GRN-YEL-GLD)
1	R12	resistor, 15K, 1%, 1/4W (BRN-GRN-OR-GLD)
3	R13,16,17	resistor, 1K, 5%, 1/4W (BRN-BLK-RED-GLD)
2	R14,15	resistor, 2K, 5%, 1/4W (RED-BLK-RED-GLD)
1	RY*	resistor, 2K, 5%, 1W (RED-BLK-RED-GLD)
1	U1	IC, LM339 comparator
1	L1	Tuner inductor, T68-2 toroid, 34 turns, taps: 4, 6, 8 and 10
80"		magnet wire, 28 ga
6"		hookup wire, solid, 24 ga.
1		jumper, 0.1" shorting plug
1		pc board



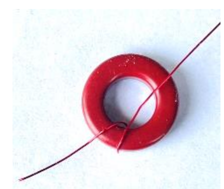
TOROID WINDING

In this section we'll guide you through creating the toroid transformer L1 used in the matching section of the Rainbow Tuner. In short, you'll be winding 34 turns of #28 magnet wire around the T68-2 toroid and putting "taps" at the turns indicated in the schematic representation of L1 below.

NOTE: We've supplied "Strip-Eeze" magnet wire to allow for easy lead preparation of the toroid leads once prepared. Once L1 has been fully wound, snip off excess lead lengths leaving about ¾" for each lead. Then we need to get the enamel off the wire. One technique is to gently scrape enamel from as many sides as possible of each lead using a sharp razor knife and then hold the tip of the soldering iron to the wire while applying solder (and its flux!) until the remaining enamel burns off.



Step 1: Begin winding L1 as shown. Remember that in the nomenclature of toroidal inductors, each time the wire passes through the center of the toroid counts as 1 turn.

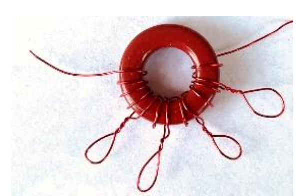


Step 2: Wind 4 turns then make a loop between the 4^{th} and 5^{th} turns. This is for the 4-turn tap. Twist loop to keep things tight.

Step 3: Similarly, wind 2 more times to the 6^{th} turn then make another loop between the 6^{th} and 7^{th} turns. This is for the 6-turn tap.

Step 4: Once again, wind up to the 8^{th} turn then make another loop between the 8^{th} and 9^{th} turns. This is for the 8-turn tap.

Step 5: And for the last tap, wind up to the 10^{th} turn then make another loop between the 10^{th} and 11^{th} turns. This is for the 10-turn tap.

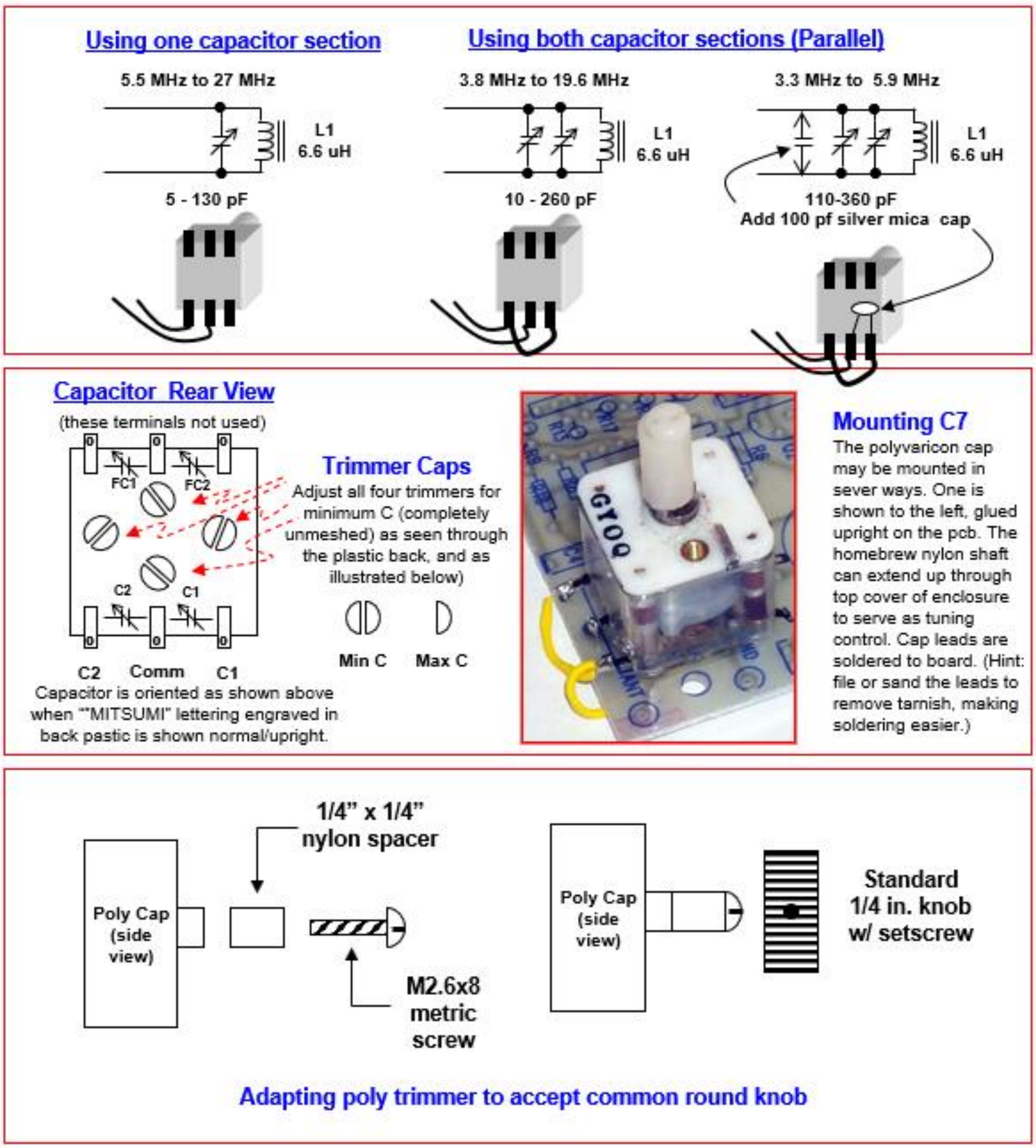


Step 6: Continue onward to wind the remaining turns to complete the total of 34 turns.

Step 7: Now with a pair of pliers, you can squeeze each of the loops into a sharp point and snip off the ends such that it is easy to fit through the holes at the 4, 6, 8 and 10 taps (see the PCB Layout).

Step 8: Insert all the wires in their correct holes and apply high heat (longtime-applied) when soldering to ensure thorough attachment of the wires to the pads.

USING THE POLYVARICON TUNING CAPACITOR C7



BLOCK DIAGRAM

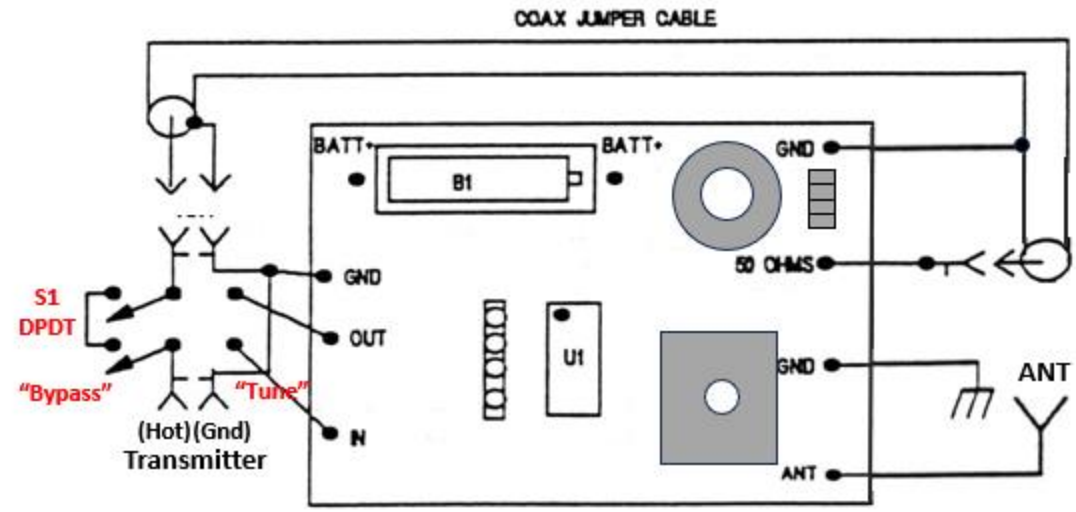


FIGURE 3

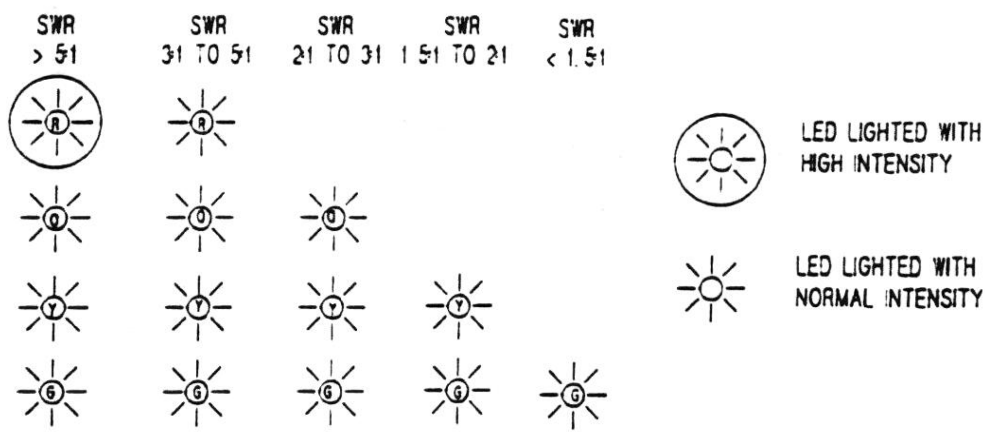


FIGURE 4

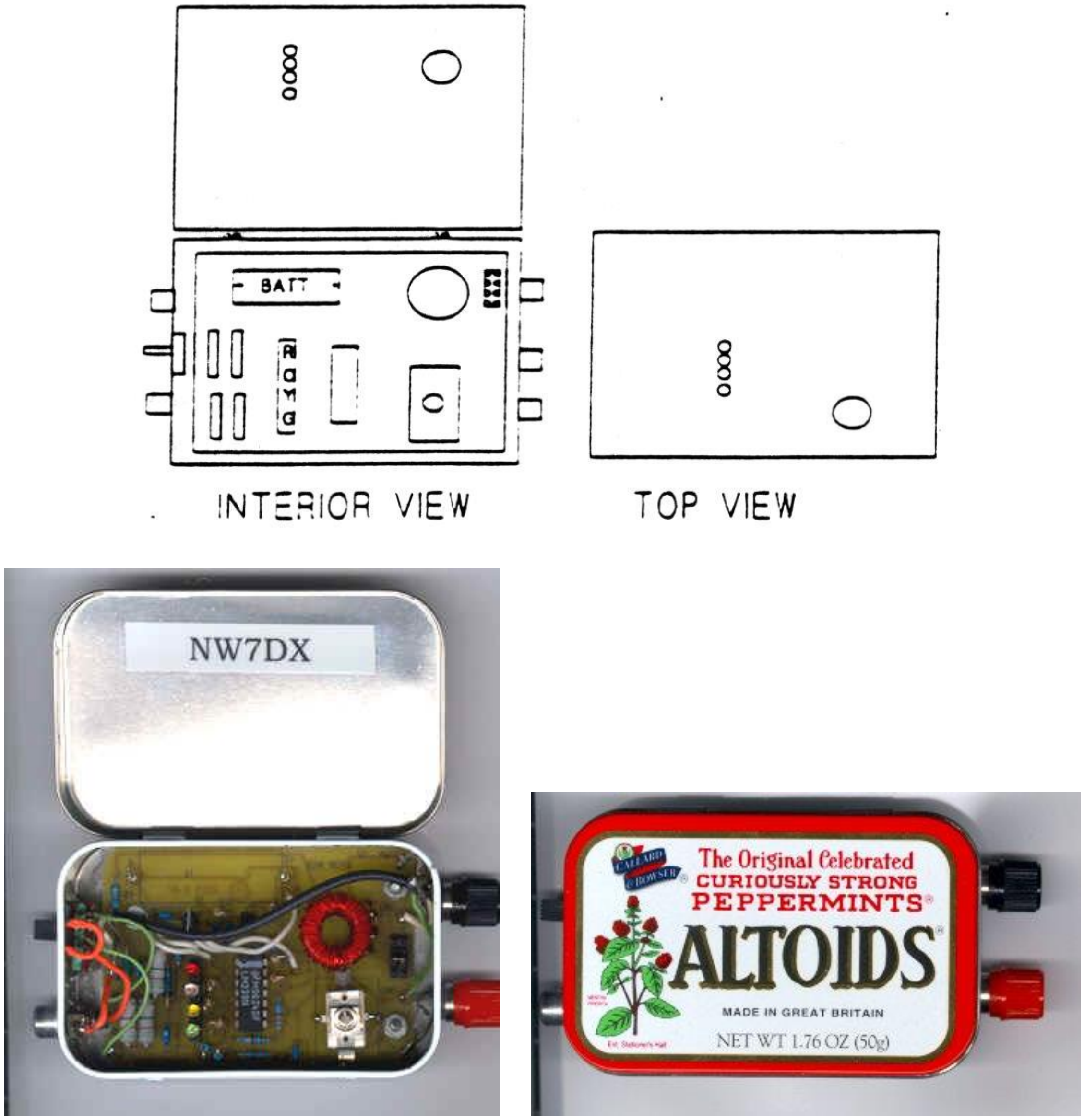
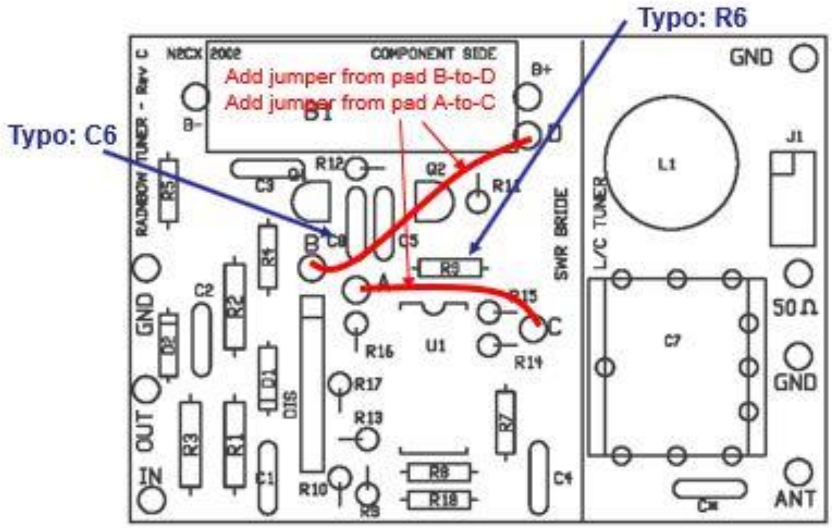
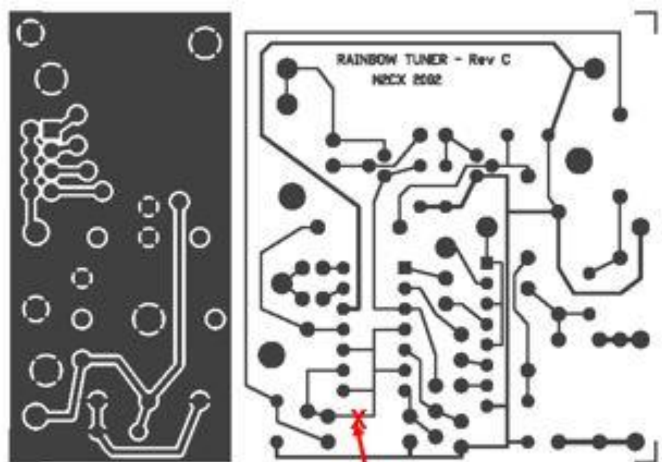

BATT
INTERIOR VIEW
TOP VIEW
NW7DX
The Original Celebrated
CURIOUSLY STRONG
PEPPERMINTS
ALTOIDS
MADE IN GREAT BRITAIN
NET WT 1.76 OZ (50g)

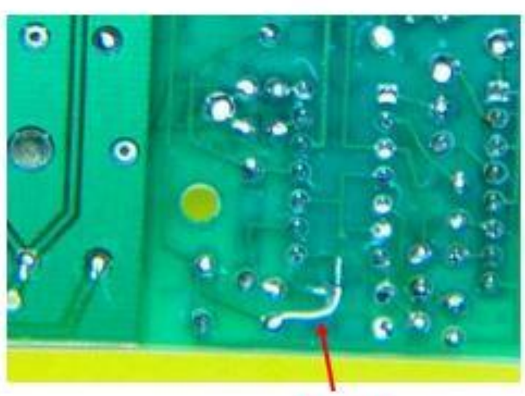
FIGURE 5

PCB ERRATA





Cut trace at X above



Add jumper as shown

TESTING THE FINISHED BOARD

Inspection

After assembling your Rainbow, it is very important to carefully examine it before firing it up (literally and figuratively). A few minutes of preparation can help avoid hours of troubleshooting. Here is a short checklist. By the way, don't be shy to use a good strong light and a magnifier (I like the kind used for stamps) so that you can see everything as well as a sharp-eyed teenager!

- Are all parts installed? Double check using the parts list. Remember that there are "extra" 1W resistors, one 51 ohms and the other 2K ohms, that are not mounted on the board. They will be used for checkout later on.

- Are all parts oriented correctly? Use the Pans Layout figure to verify that everything is mounted the right way. Pay particular attention to diodes, transistors, LEDs, and the tuning components Ll and C8.

- Are all component leads soldered? Are all of the solder joints smooth, bright and shiny? "Cold" solder joints, ones that are misshapen or dull and grainy, can mean that there is not a good electrical and mechanical connection.

- Are you sure that there are no solder shorts between close-spaced pc pads or traces? Check with an ohmmeter if you are not sure.

Initial Bench Tests

It is recommended that you check out the Rainbow Tuner before mounting it permanently. To do this, temporarily wire up the display, connectors and coax connectors as shown in FIG 3. The switch shown is really not needed at this time. Follow the steps below to make sure that everything is working as it should. Start off by temporarily connecting the "extra" 2K resistor across terminals ANT and GND of the tuner section in place of an antenna.

Checkout With Antenna Analyzer

If you have a Micro908 Antenna Analyst, an MFJ SWR Analyzer, a noise bridge or other "non-transmitter" type SWR indicator, proceed with this section. If not go to the **DC Power Test** and **Checkout with Transmitter** sections.

- Connect the analyzer to the connector on the 50 OHM and GND terminals and tune it to either the 40- or 30-meter bands at the frequency you intend to operate on. Slowly adjust the compression trimmer for the lowest SWR indication. You may find that the setting is rather sharp. If this value is larger than 1.5:1, try the next tap setting on the jumper block by moving the shorting plug. Retune the capacitor after changing taps for lowest SWR. Repeat the above until an SWR reading of less than 1.5:1 is reached. You may also want to tune off the best reading and retune several times to get the feel of the tuning process.

- You may also want to try out tuning an end-fed half-wave antenna by the Antenna Analyzer method before using the Rainbow with a transmitter. To do this, simply remove the 2K resistor and connect a half-wavelength wire to tuner ANT terminal and a suitable counterpoise to the matching GND terminal. Tune up as in the preceding paragraph. If you cannot tune within the adjustment range of the trimmer capacitor, the antenna may be too short or too long. See the section entitled **When Things Don't Work** for troubleshooting hints.

Rainbow Bridge DC Power Test

The DC power source can be any DC supply or battery capable of supplying 50 mA at 9 to 12 V DC. Do not energize the DC source yet. Also wire connectors to Bridge terminals GND, IN and OUT for later testing. Refer to the Figure 3 and the Schematic diagram, Figure 1, for reference:

Make a last check of the display and power wiring, then energize the DC source. The display LEDs may flicker momentarily, but then they should remain dark.
If not, refer to the **When Things Don't Work** section for help.

If the Rainbow display remains dark with power applied, proceed with next the section.

Testing with a Transmitter

Rainbow testing with a transmitter proceeds step by step:

Step 1: Checking the Bridge
First we will make sure that the Bridge turns on and shows both high and low SWR properly. Connect a transmitter to Bridge input J1 capable of delivering a CW signal of 200 mW to 4W at the desired operating frequency. Make sure that there is nothing connected to the OUT terminal (except perhaps a connector). This gives the Bridge a very high SWR. Key the transmitter for no more than a few seconds while matching the Rainbow display. All four of the LEDS should light up, as shown in FIG 4. This means that the SWR indication is more than 5:1. When you unkey the transmitter, the LEDs should all go out. If these indications are not achieved check the section **When Things Don't Work** for troubleshooting hints.

Now either connect a good 50-ohm dummy load to the connector on the OUT terminal or temporarily solder the "extra” 51-ohm resistor between the OUT and GND terminals. This gives the bridge a load with nearly a 1:1 SWR.

Again, key the transmitter briefly while watching the display. This time only the green LED should light up. This means that the SWR is less than 1.5:1. The LED should go dark when the transmitter is unkeyed. As before, refer to **When Things Don't Work** if things don't work!

Step 2: Checking the tuner with the bridge

If you have gotten this far, the bridge should be working correctly, so it's time to check out the tuner with the bridge. First remove the dummy load or “extra” 51-ohm resistor. Connect a coax jumper between bridge output J2 and the 50 OHM input to the tuner J3 (refer to Figure 3). Don't just use a piece of wire between the OUT terminal and the 50 OHM terminal because the grounds of the bridge and tuner are isolated. Make sure that the "extra" 2 K resistor is connected between the tuner ANT and GND terminals and that the shorting plug is installed between two terminals on the tap selection jumper strip.

Keyup the transmitter briefly while watching the display. At this point, don't keyup for more than 10 seconds or so. Depending on how well adjusted the Tuner is, all or some of the L E D s should illuminate.

The LEDs should all go dark when the transmitter is unkeyed.

The green L E D should ALWAYS illuminate whenever RF power is applied. If only the green LED is lit, the indicated SWR is below approximately 1.5:1. If only the green and yellow ones are lit, the SWR is above 1.5:1 and below 2:1. The green, yellow and orange LEDs light for SWR between 2:1 and 3:1. With an SWR of 3:1 to 5:1 all four LEDs are lighted. And (as is often the case) with an SWR of greater than 5:1, all four LEDs are lighted and the red one is at a high intensity.

If the tuner was not adjusted previously probably all LEDs will light up.

Now briefly key up the transmitter again while watching the display and slowly adjusting the Tuner capacitor C7. A point should be reached where the LEDs cycle from all being lighted down through the above sequence until only the green LED lights. If you cannot get down to where only the green one is lit, try another coil tap by moving the jumper on the jumper block to a new position. You should be able to select a tap and find a capacitor setting where you can get an indicated SWR of 1.5:1. If not, check the troubleshooting steps in the **When Things Don't Work** section.

The final step is to repeat the transmitter tuning steps above with an antenna connected to E9. The antenna should be an end-fed wire that’s a half wave at the desired operating frequency. A ground or quarterwave counterpoise must also be connected to E10. The counterpoise length is not critical. A water pipe or radiator ground is probably acceptable.

Once the tuner is properly adjusted, the bridge section can be disconnected by connecting the transmitter directly to J3. Keying the transmitter now should not result in any of the LEDs lighting. The tuner is now ready for operation.

When Things Don't Work

Troubleshooting consists of making a series of two- way decisions about what does and doesn't work so that you can isolate where the problem lies. This section will give you a few hints about how to track down problems if your Rainbow doesn't work. The first and most important step is to study the circuit description so that you understand how the Rainbow Tuner should work!

When any electronic project doesn't work after initial turn on, the most likely problem is in the construction. So first double-check that all components are properly installed and that all solder joints are proper.

Review the **Inspection** section of the manual for a checklist. In addition to the items provided there, be sure to check for hairline solder shorts between traces and very fine gaps in the printed-circuit foil pattern. Occasional flaws of these types are inherent in printed circuit boards and are usually difficult to detect except by very careful inspection.

The very first troubleshooting decision to make is whether the problem is in the bridge or the tuner circuitry. If you are not sure, test each independently to see which one is working and which isn't.

Below is a table of typical dc voltage readings made on a Rainbow bridge fed by a 200-mW, 40-meter transmitter.

	XMTR OFF	**50-ohm load**	**No load**
SWR		**(1:I SWR)**	**(HI SWR)**
BATT +	12.2 V	11.2 V	10.3 V
QI-G	0	1.8	2.3
QI-D	12.2	0.02	0.01
Q2-B	12.2	10.4	9.7
UI-1	11	9.7	0.3
UI -2	11	9.7	0.3
UI-3	0	11. 1	10.2
Ul -4	0	0.06	2.3
UI-5	0	0.4	0.5
U1-6	0	0.06	2.3
U1-7	0	0.6	0.8
UI-8	0	0.06	2.3
U1-9	0	0.95	1.2
U1-10	0	0.06	2.3
Ul-11	0	1.3	1.65
U1-12	0	0	0
UI-13	11	9.7	0.2
UI-14	11	9.7	0.2

The first column shows the measurement point and the others are voltages under different operating conditions. The second is with the transmitter off. With no RF present, the bridge should be quiescent with no LEDs lighted.

The third column shows readings with the transmitter on and the bridge output loaded with a good 50-ohm dummy load (actually 51 Ohms) so that the SWR is below 1.5:1. In this condition, only the green LED should be lighted.

The fourth column is for the condition where the transmitter is on and there is no bridge output load. The SWR here is very high and all four LEDs are lighted. Voltages applied to the comparator sections by the SWR bridge are usually proportionately higher with more RF power.

There are a couple of significant readings:

1. The rectified forward RF sample from the bridge is used to turn on Q1 to energize the rest of the circuitry. A positive voltage here turns on Ql and Q2, applying the battery voltage to IC, U1 (pin 3) and to the green LED. It also is fed to the (-) inputs of comparator U1 through a resistive voltage divider.

2. The rectified reverse sample is applied directly to the (+) inputs of U1 to be compared with divided- down samples of the forward voltage.

3. When the (+) input of a comparator section is more positive than the (-) input, the output is an open circuit, so the corresponding LED does not light. When the (+) input is less than the (-) input, the output goes low, turning on the LED connected to that comparator section.

The tuner section is much less complicated. It is simply a parallel tuned circuit with a variable capacitor to tune it and taps on the inductor to match the antenna impedance to 50 ohms. For troubleshooting, first verify that the tuner works by itself with the "extra" 2K resistor.

An antenna or SWR analyzer or RF noise bridge is recommended to be sure that the tuner can be adjusted to resonance and will provide an output SWR of less than 1.5:1.

The tuner should be adjustable to resonance on both 30 and 40 meters, as indicated by a discernible dip in SWR. In extreme cases, here may not be enough tuning range due to defective components or a problem with the toroidal coil. Be certain that the solder joints at the coil taps are good so that there is not a poor connection between the two wires of the coil at that point (been there, done that with two prototypes!) Verify end-to-end continuity of L1 with an ohmmeter. You should see a reading of less than 1 ohm.

If the tuning capacitor is all the way loose on 30 meters to achieve resonance, carefully remove a few turns from the toroid at the hot end (the end away from the taps). If the tuning capacitor must be tightened fully on 40 meters, you may need to add a couple of turns. However, if you must adjust the number of turns to get proper operation on one band, the other may be affected, too.

Problems with the tuner when it is connected to an antenna can be more difficult to troubleshoot. Here are a few things to look for:

1. Are you sure that the antenna is the right length? For 30 meters and end-fed half wave antenna is about 46 feet and for 40 meters it is about 66 feet. The antenna length is measured from the antenna connector on the tuner to the end of the antenna. A short ground connection or counterpoise is needed for the ground return. The recommended counterpoise is a quarter-wave wire. It can be merely stretched out on the ground or out of the way, but it should not be coiled up.

2. Are you sure that you are using the correct ground connection for the tuner? To prevent interaction, there is no ground connection on the Rainbow pc board between the bridge and tuner circuits.

3. Do you have enough tuning range on the variable capacitor to compensate for end-fed half- wave wires that are within a couple of feet of the desired length? If not, you can adjust the antenna length slightly. If the tuning capacitor is adjusted too tight, the antenna may be too short, so increase its length by a foot or so. It the tuning capacitor is too loose, try removing a foot from the antenna.

USING THE RAINBOW TUNER

DC Power Needs

The Rainbow circuitry gives good performance over a wide range of supply voltages. Its self-adjusting SWR comparator eliminates the need to use any power supply regulators. However, the power supply voltage used must be high enough to enable the comparators to accept the highest sampled voltages from the resistive SWR sensor. For power levels up to 2W, a 9-V transistor radio battery (alkaline) is fine. But for powers approaching be QRP limit of 5W, a 12-V or higher source should be used. Of course 12V is fine for any power level from 200 mW on up to 5W.

The Rainbow pc board was laid out to accept a very small 12V battery that is widely available. The Synergy Digital Energizer A23 12V battery is very handy for the Rainbow. No on-off power switch is needed because the Rainbow turns itself on and off in response to applied transmitter power.

Mounting and Enclosure Ideas

Numerous small homebrew projects have been installed in Altoids mint tins. The Rainbow was designed with this mounting in mind. The ARTIST'S DECEPTION in Figure 5 shows how this can be accomplished. The pc board is only about 2.25 x 3.25 inches in size so it may be a tight fit. Nipping off the pc board's comers will help fit it into the mint tin with its rounded corners. Holes punched in the tin's lid allow viewing the Rainbow display and give access to the tuner variable capacitor. Typical connections are shown in FIG 3.

For those who want to mount the Rainbow in a more conventional case, three mounting holes are provided in the pc board. The holes are sized to clear #4 hardware. Two holes are at the tuner end of the board, between the 50 OHMS/GND and ANT/GND terminals. A third hole is on the other end of the board, below the B- power terminal. To prevent short- circuiting to components and circuitry on the board, it might be a good idea to use plastic standoffs and hardware.

When you lay out an enclosure for the Rainbow, be sure to take into account access to the display, the tuning capacitor and the toroid tap mounting jumper block. If you want to, you can remove the LEDs from the board-mounted SIP socket and use the socket to accept a SIP plug and cable connected to a remote display. And there is no reason why a panel-mount l5Hpf variable capacitor could not be used to replace C7, the mica trimmer.

The Rainbow is so small that it can be mounted right inside a QRP rig cabinet for a compact portable unit. Don't forget to provide yourself with convenient access to the display and the tuning cap.

Another option is to use the Rainbow bridge without the tuner section. It could easily be mounted in a case with a small QRP rig and used without a tuner for antennas that don't need one or with an external tuner as a simple hands-free SWR bridge.

Antenna Tuning Notes

The tuner in the Rainbow Bridge is intended for use with an end-fed half-wavelength single wire and a ground connection. This makes for a very simple and effective antenna system well suited for portable operation. Using an end-fed half-wave wire means that the antenna impedance is on the order of several thousand ohms. So, unlike quarter-wave or shorter wires often used for portable setups, little power is lost in a poor ground connection. Not only that, using a half-wave wire lets you put the high current portion of the antenna high in the air, and that's the part that does the radiating. Another benefit is that any antenna length that is a multiple of a half wavelength (one wave, 1-1/2 waves. 2 waves etc,) has the same impedance characteristics.

A potentially interesting antenna is a wire that is a half-wavelength long on 40 meters. If it is put up as shown in FIG 6, it will behave like a half-square antenna on 20 meters and an ordinary half-wavelength wire on 40 meters. This gives you a good low-angle radiator on 20 meters for long distance communication and a high angle radiator on 40 meters for close-in contacts. Ideas for extending the tuner to 20 meters will be described in the **Modification Ideas** section. Although not tunable with the Rainbow, the same antenna could be used (with a good ground system) as a quarter-wave Marconi antenna on 80 meters.

The tuner uses a parallel resonant tuned circuit that inherently operates at a high impedance. Making the tuned circuit variable with C7 lets you tune up to an antenna that is not exactly the right length, so that you can effectively transfer power to it. And the taps on toroid L1 transform the high impedance down to the commonly used coaxial-cable value of 50 ohms.

Several antenna configurations are shown in FIG 6. Depending on available supports, the antenna can be set up as an inverted-L, a sloper, a vertical or, if used from above the ground (such as from a motel or other building), a horizontal wire. While a ground of some sort is needed, it can be very simple. Probably the most repeatable type of ground is a quarter-wavelength wire used as a counterpoise. It can be stretched out under the antenna or simply laid out in almost any convenient fashion. Just don't coil it up, or it won't be much good. In a building, a radiator or water pipe ground may work, but may need to be augmented with a wire counterpoise. For portable operation in a camping situation, the metal frame of a camper, motorhome or car has proven effective.

It is strongly recommended that you check out whatever antenna you want to use *before* you depend on it. For portable use, temporarily string up your half-wave wire and counterpoise at home and make sure it tunes up and works as expected and then carefully store it away ahead of time.

Bridge and Tuner Operation

The Rainbow Bridge is simple to use. All you have to do is hook it up to an antenna or RF load and a transmitter. As soon as you try the transmitter, the RF signal turns on the active circuitry, which then computes the SWR and indicates it via the Rainbow display. As shown in Figure 4, the number of LEDs lighted depends on the SWR:

With an SWR below 1.5:1 only the green LED lights;

- for 1.5:1 to 2:1, both the green and yellow LEDs light up;
- for 2:1 to 3:1 the green, yellow and orange LEDs light up;
- for 3:1 to 5:1, all four light up; and
- for SWR greater than 5:l, all light up and the red one is at a higher intensity.

When the RF is removed, the circuit turns off and all LEDs go out. The bridge should be switched out of the circuit or disconnected after SWR measurement since it has a 6 dB loss when in use. The switch shown in the EXTERNAL COMPONENT WIRING diagram, FIG 3, serves this purpose.

The tuner section has only two controls: a tuning capacitor and an inductor tap. In use, the tuner is connected to a half-wavelength wire and an SWR inductor (like the Rainbow bridge!) Tuning capacitor C7 is then adjust for lowest SWR. If the SWR is greater than 1.5:1, the tap can be changed (with RF power removed, of course) and tuning retried until the lowest value is obtained.

Modification Ideas

Stand-alone Bridge

The Rainbow tuner and SWR bridge are intended for QRP applications. However, the indicator portion of the Rainbow can be used with other SWR bridges rather than the internal resistive bridge. The primary factor limiting the high end of the power rating for the Rainbow is its resistive bridge. While beyond the scope of this manual, the same type of bridge has been used in other configurations for a wide range of power levels. However, previous SWR meters using this technique have used analog meters.

The SWR indicator itself can be used with Bruene- type (or other) reflectometers for almost any power level. The requirements to do so are:

1. Simultaneous access to DC rectified forward and return samples;
2. Balance between those samples so that they are equal for infinite SWR and track proportionately for lower values; and
3. A minimum of 1.8 VDC for the infinite SWR sample values.

Adapting for the Band of Your Choice

Because it is based on a frequency insensitive resistive bridge and because lead lengths are kept to a minimum, the Rainbow bridge should operate with good accuracy on any of the amateur bands. The only additional precaution needed is to keep external leads short or to use coaxial cable instead of wire leads.

The tuner portion of the Rainbow Tuner is optimized for operation on 30 or 40 meters. The primary limiting factor is the limited tuning range of the PVC tuning capacitor. Inductor LI has an inductance of approximately 6 microhenries so it resonates on 40 meters with a capacitance of about 85 pf. At 30 meters, it needs about 40 pf.

If desired, C7 could possibly be replaced with a variable capacitor with a smaller minimum capacitance to tune as high as 20 meters. Alternatively, if a coil equal in inductance to LI were placed in parallel with it (via the ANT and GND terminals), the existing tuning capacitor would be well within range.

To extend operation to 80 meters, a tuning capacitance of about 340 pf is needed. There are no guarantees but adding an external capacitor of about 270 pf might allow be tuner to resonate an 80-meter half-wave wire.

Experimentation for other bands can be done with both different toroid inductors and variable capacitors. Just be sure that the LC circuit resonates on the band you want with the tuning cap ideally at mid-range. And scale the taps in the same ratio as the "stock" tuner so that there is enough impedance adjustment range available.

Other Tuner Configurations

The parallel tuned circuit tuner configuration was selected for the Rainbow to give the most bang for the buck. Inductance matching range is limited in a simple circuit, because the reactive elements need to be widely variable to cover a large adjustment range for antennas with unknown impedance and reactance. Using a half-wave, end-fed antenna limits the range of adjustability needed. This is not to say, however, that other configurations are not possible, even on a small pc board like the Rainbow if one is willing to experiment. The pc patterns are not set up for other networks, However, so trace cutting will be needed.

Other configurations possible with only two tuning components are the "L" network and the series-resonant circuit See FIG 7.

The "L" has the advantage of being able to either step up or down in impedance from the feed value (50 ohms). The ARRL Antenna book and other amateur handbooks can be consulted for formulas to calculate the values needed. But don't expect to be able to tune random-length antennas without a lot of cut-and-try effort.

The series-resonant circuit is analogous to the parallel- resonant circuit except that it watches the low impedance of a quarter-wavelength antenna to a feedline. It can be used without coil taps to simply resonate the antenna, or with taps to perform impedance matching as well. For best results, the coil taps should be at the ground end of the inductor, which means that, unlike the Rainbow tuner, this setup has both sides of the tuning capacitor above ground.

Of course, other configurations such as "T" and "PI" networks and Z-match configurations can be used as well, but space is tight on the Rainbow pc board.

TYPICAL 1/2-WAVE ANTENNAS

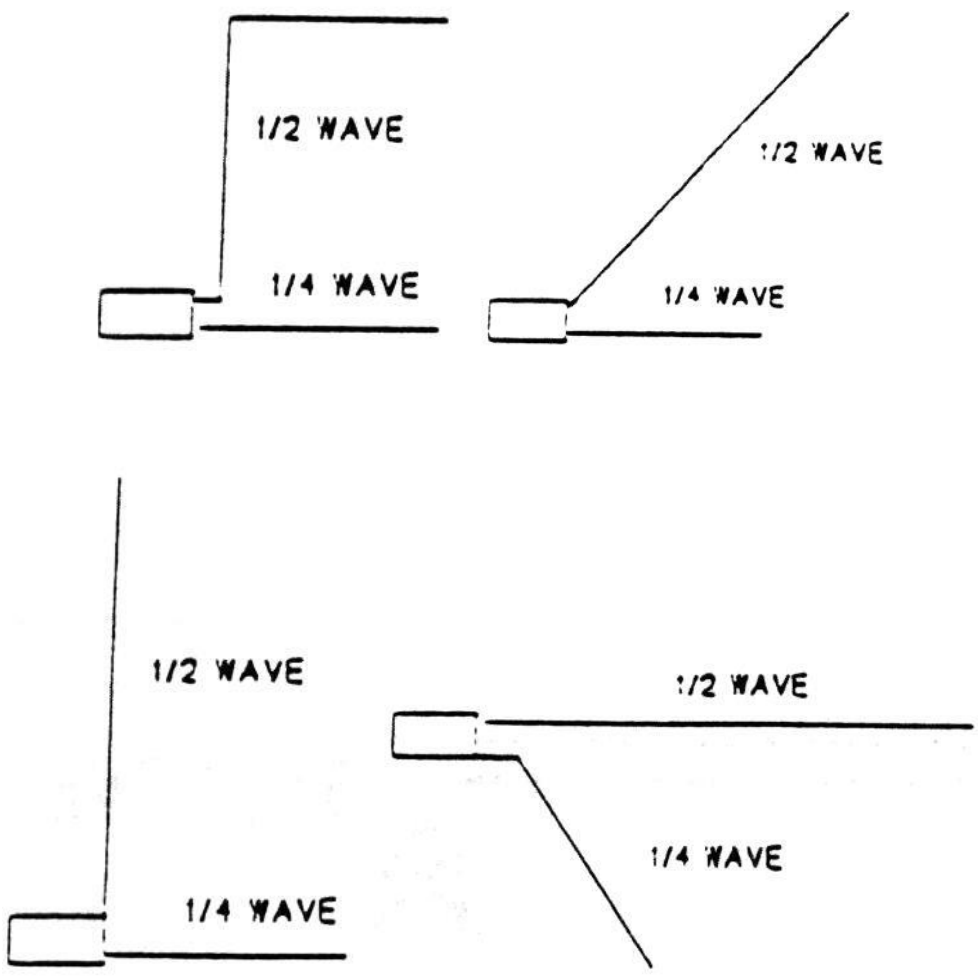


FIGURE 6

TYPICAL 1/4-WAVE ANTENNAS

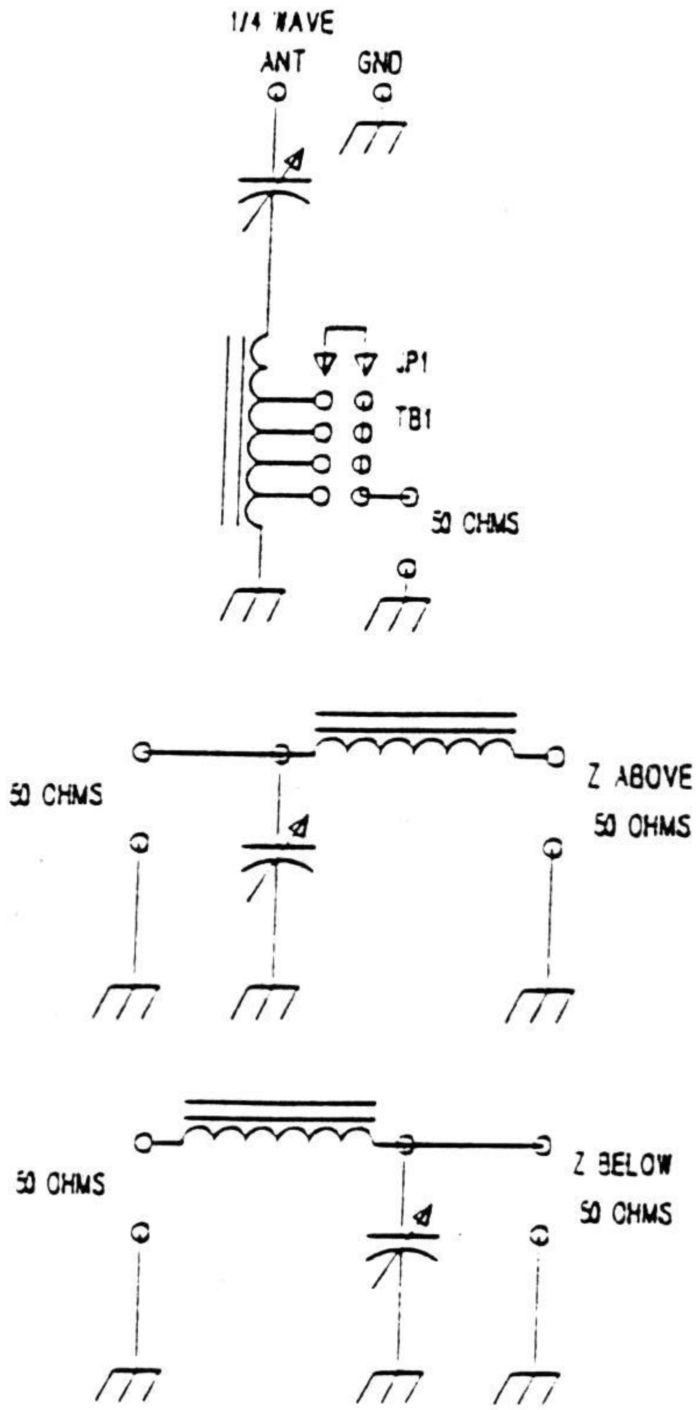


FIGURE 7