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Author: James C. Garland, W8ZR

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By James C. Garland, W8ZR

The EZ-Tuner

Part 3—In the final installment of our series the author offers advice on how to build this amazing antenna tuner.

The EZ-Tuner is an advanced microprocessor-controlled legal limit antenna tuner that covers the amateur HF bands from 160 to 10 meters. The previous two articles in this series described the matching network and controller circuits. This final article describes the EZ-Tuner's construction and provides information for prospective builders. Readers interested in a more extensive discussion can download complete circuit diagrams, a fully annotated software listing, circuit board layouts and other detailed information.[11]

Building one's own equipment can be one of the most rewarding parts of the Amateur Radio experience. Devoted homebrewers love the personal satisfaction and pleasure that comes from "rolling their own." However, it is important to keep in mind that the EZ-Tuner is an advanced project for experienced builders. Readers unsure of their experience may want to hone their skills on a manual version of the tuner. Although it may not be quite so "EZ" as the automatic version, the manual EZ-Tuner is still simpler to adjust than a roller inductor tuner and is not so prone to damage caused by accidental mistuning.

The EZ-Tuner's 16 × 7-inch brushed aluminum front panel is dominated by the large RF wattmeter. Press-on letters from an art supply store were used to label the controls. After lettering was completed, two coats of satin finish clear plastic spray sealed the panel.

Construction Details

The EZ-Tuner is housed in a 17 × 7 × 16-inch cabinet manufactured by Buckeye Shapeform.[12] The internal compartment containing the RF matching components measures 16W × 11D × 4.88H inches inside dimensions and is tightly sealed with a removable cover plate, both to keep strong RF fields from disrupting the controller circuitry, and to keep digital controller "hash" from finding its way into the station receiver.

A large 16W × 14D-inch chassis plate serves as the floor of the RF compartment. The three printed circuit boards, a small "beep" speaker, and the +5 V regulated power supply are mounted on the underside of the chassis. The stepper motors, rotary solenoid and the +24 V power supply mount on the outside front wall of the RF compartment.

The chassis plate and interior metal panels are fabricated of 0.062-inch sheet aluminum. All of these panels are rectangular and are secured together with 1/2-inch aluminum angle stock, available from any hardware store. The use of angle stock greatly facilitates construction, because it eliminates the need to form lips and edges on the metal panels. Smaller metal brackets are fabricated from 0.047-inch sheet aluminum. Stainless steel hardware is used throughout to give the finished project a professional appearance.

Within the RF compartment, small blocks cut from scrap Teflon stock insulate the two variable capacitors from the chassis. (A T-network requires that both the rotors and stators of the variable capacitors be insulated from ground.) Although Plexiglas or other low-loss insulating materials can be used, it is best to avoid nylon in strong RF environments. James Millen high-voltage ceramic shaft couplers isolate the capacitor rotors from the stepper motor shafts.

The EZ-Tuner uses two air-wound coils in series to give 20.5 µH of total inductance. Inductor L1 consists of 4 turns of 3/16-inch silver-plated copper tubing (3 inches long) wound on a 1.5-inch inner diameter. The coil mounts on two ceramic standoff insulators. Inductor L2 is made of B&W 2404TL coil stock and consists of 24 turns (4 turns per inch) of #10 tinned copper wire with a 3-inch diameter.[13] Note that B&W makes two versions of this coil stock, one having polystyrene and the other Lexan spacers. Despite its greater cost, Lexan is preferred for this application, because of its higher melting point. Teflon mounting blocks support the coil.

The 10 taps from the inductor switch to L1 and L2 are made of #10 tinned copper wire. Because wire of this gauge is difficult to work with, a mockup of each tap was first fabricated out of ordinary 1/16-inch diameter solder. After bending and routing to shape, the length of solder was carefully removed from the tuner and used as a template for making the actual tap. This extra step saves wear and tear on the fragile switch contacts and leads to an orderly appearance of the completed wiring. Small B&W coil clamps secured the tap wires to the coils. Although these clamps are movable, they were permanently soldered onto the coil after the taps were positioned.

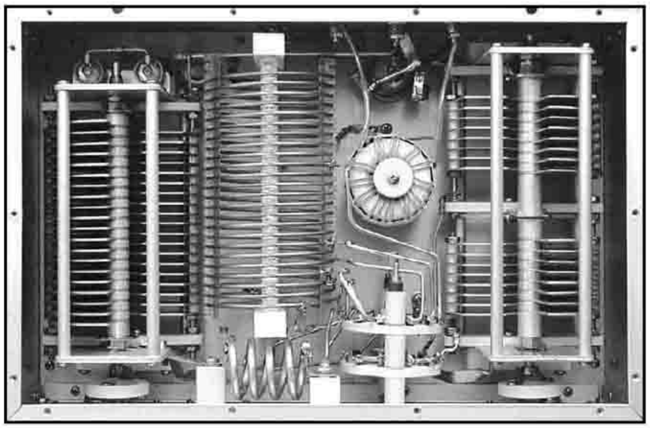
The inductor switch is a 2-pole 11-position Radio Switch model 86 ceramic high-voltage rotary switch.[14] The spring-

[11]Notes appear on page 36.

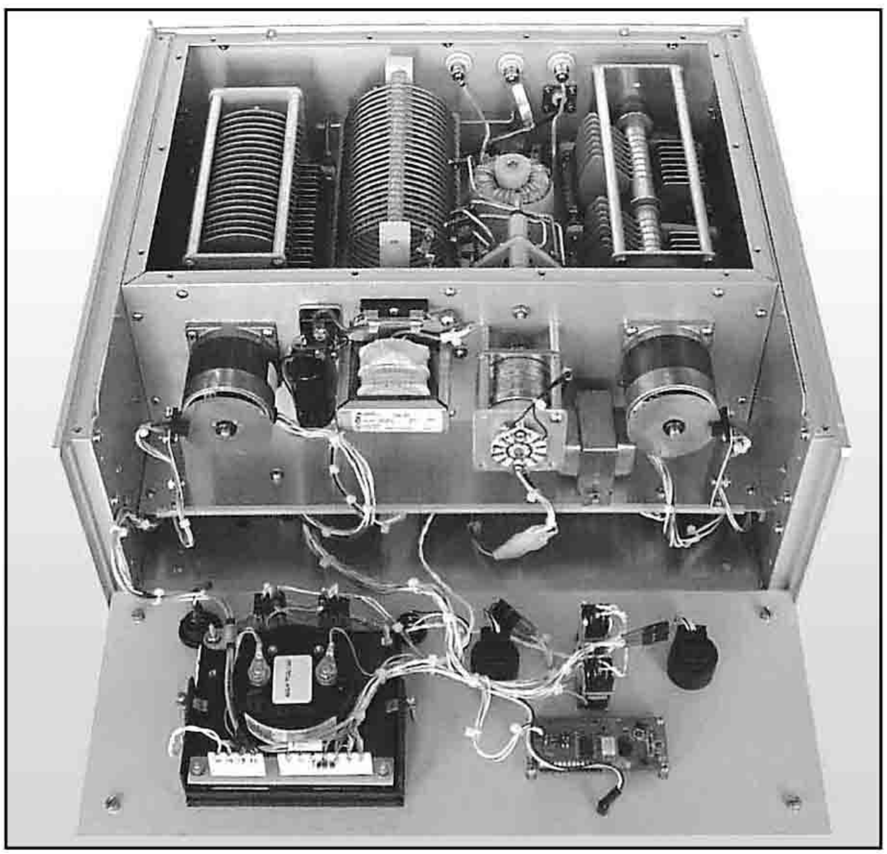
loaded detent mechanism of the switch was removed before installation, since indexing of the switch wafers is governed by the rotary solenoid.

Both relays in the RF enclosure are vacuum type and combine high current capacity with high voltage insulation in a very compact package. Although vacuum relays can frequently be found at hamfests or on-line auctions, it is certainly acceptable to use ordinary open-frame high voltage relays.

A homemade 10-pF capacitor[15] samples the RF voltage at the input of the tuner for the controller's frequency counter. This capacitor is fabricated by sliding a 2.5-inch length of RG-58/U coaxial cable shield over a length of #10 Teflon-sleeved wire. The length of braid is not critical and may be made longer or shorter, depending on the desired sensitivity of the frequency counter. A 2-inch length of hookup wire soldered to the braid serves as the capacitor lead and is connected to an RCA phono jack on the chassis. A length of heat shrink tubing covers the shield and gives the capacitor a tidy appearance.



A compact, high performance, manually adjusted tuner can be made by duplicating the EZ-Tuner's RF compartment.



A tilt-down front panel provides ready access to components. A 24 V, 2 A unregulated power supply is visible on the subpanel, along with the two stepper motors and the rotary solenoid. Slotted brass disks mount on the rear stepper shafts to detect the end-of-rotation, and a rotary switch wafer on the rear shaft of the rotary solenoid serves the same purpose. The small circuit board on the rear of the front panel is the serial LCD display.

Manual Version of the EZ-Tuner

Only a few minor circuit adaptations are required to convert the EZ-Tuner's matching network to manual operation. Knobs cannot be placed directly on the variable capacitor shafts, because the rotors must be isolated from ground. Instead, builders should install panel bearings with grounded ¼-inch shafts, with connection to the capacitor rotors made using insulated shaft couplings. Inexpensive planetary reduction drives provide a convenient alternative to panel bearings and allow smooth vernier adjustment of the variable capacitors.

In addition, it is desirable to replace the two relays with switches, since a manual tuner needs no power supply. Although a heavy duty DPDT rotary switch would be a direct replacement for the bypass relay K2, builders may wish to substitute instead a five- or six-position double-pole switch to permit selection of multiple antennas or a dummy load.

The replacement of relay K1 by an SPST switch may require some ingenuity, since it is desirable that the switch be located close to capacitors C2, C3 and C4 in order to minimize stray inductance. For convenience, this switch should also be ganged to the inductor switch S1, so that it is closed only when S1 selects the two largest inductance values. For simplicity, builders may wish to delete the switch (and capacitors C3 and C4) entirely. Doing so would only affect the tuner's ability to match low impedance loads (below about 15 Ω) on 160 meters.

Parts Substitution and Design Changes

The EZ-Tuner uses costly, commercial-grade components because the expense could be spread over the many months it took to complete the project. However, with a bit of scrounging and ingenuity, builders should be able to duplicate the project for a few hundred dollars, with little or no sacrifice in performance.

Replacing the Bird wattmeter with a less expensive unit is an obvious first step in holding down costs. Any generic HF wattmeter or reflectometer from an *ARRL Handbook* will work fine, as will inexpensive commercial wattmeters. Often, RF wattmeter circuit boards and panel meters can be scavenged from old equipment.

One can find inexpensive alternatives to the EZ-Tuner's Cardwell/Johnson variable capacitors. Surplus or used variable capacitors pop up frequently at hamfests, and many can be found with suitable capacitance and voltage ratings. As a general rule, a capacitor's minimum value affects tuning on the highest frequency bands, and the maximum value mostly impacts 160-meter tuning. Depending on one's operating preferences, compromises at these limits may be acceptable.

It is not a good idea to skimp on the inductor, since most losses in an antenna tuner show up as inductor heating. Although #10 gauge is desirable, under no circumstances should wire smaller than #12 gauge be used for this application. Also, builders are encouraged to resist the temptation to use a rotary inductor, in the hope of saving construction time. Not only would the assembly time saved be lost several times over by the difficulty of modifying the software, the resulting tuner would be disappointingly slow to respond to frequency excursions.

Positioning the Inductor Taps

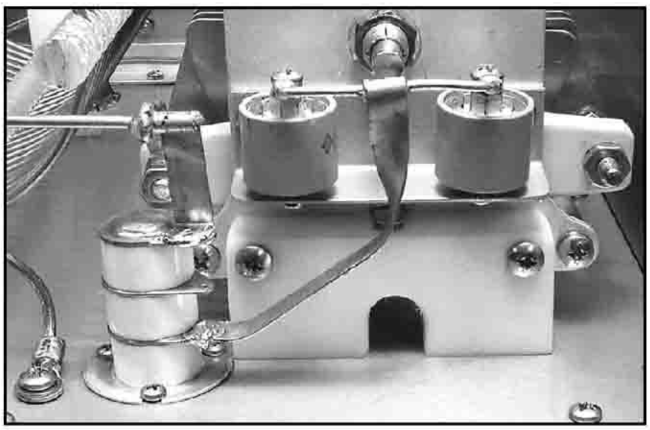
As described in Part 1, the key to the EZ-Tuner's performance is the careful choice of the 11 switch-selected inductance values. Although placing the taps on L1 and L2 is not difficult, doing so requires a systematic approach. Note that the inductances specified on the circuit diagram are approximate, nominal values. Because these inductances are small, and because of the unpredictable effects of lead lengths, parts placement, and proximity to shield partitions, one cannot position the coil taps simply by measuring the inductances with, eg, a digital LCR meter.

The preferred technique for placing taps requires the use of an impedance analyzer, such as an Autek RF-1 or an MFJ-259B. These analyzers have a built-in, low level RF generator, which can be tuned to any frequency in the HF spectrum, with a front panel indicator that shows the impedance and VSWR of a connected load. (It is also possible, although somewhat less convenient, to use a transceiver with extended frequency transmit capability and an ordinary reflected power or VSWR meter.)

The procedure is to connect a 50-Ω dummy load to the EZ-Tuner's output, and the impedance analyzer (or transceiver) to the input. A suitable dummy load is a 50-Ω, 1/4-W composition or metal film resistor, soldered to a PL-259 coaxial connector. (If a transceiver is used, both it and the (higher power) dummy load should use as short a connecting cable as possible.)

Next the input variable capacitor C1 is set to its half-meshed position (110 or 220 pF, depending on the switch position). Then, starting with Tap 1 and adjusting only the output variable capacitor C2, move the taps by trial and error until the minimum possible VSWR for each tap occurs at the frequency shown in Table 3.

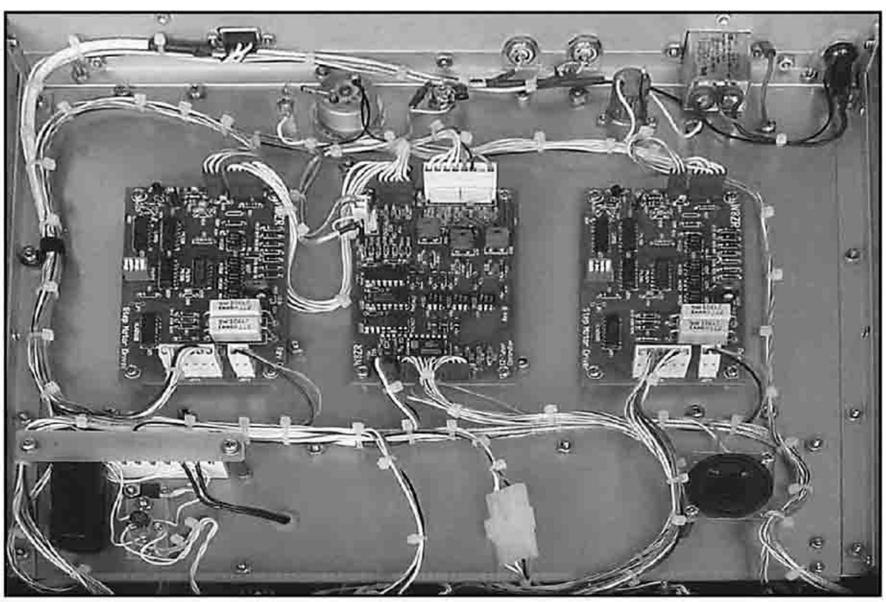
For frequencies above 10 MHz, final tap positions should be measured with the compartment cover in place. If the mechanical layout of the inductor and switch makes it difficult to position a tap at the desired spot, then try to get as close as possible. Some leeway in the positions is acceptable, especially at the larger inductance values.



Two 50-pF, 5000-V capacitors are fixed to the back plate of the output variable capacitor with a small bracket and are switched into the circuit by a surplus Jennings RF3A vacuum relay. Teflon blocks insulate the variable capacitors from the chassis.

Uploading the Control Program

Loading the control software into the EZ-Tuner takes but a few minutes and requires only a personal computer. The procedure is first to download the control program which is a text file written in P-BASIC, and which contains descriptive comments on each line. This control program is not loaded into the BS2sx, but

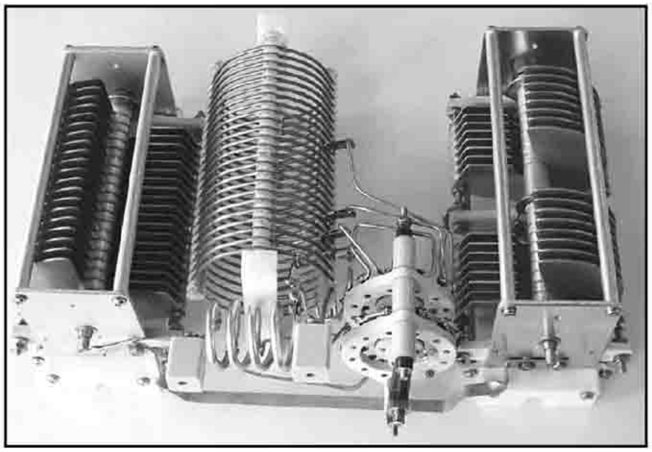


The 3 × 5-inch controller circuit board, center, is shown flanked by two stepper motor driver boards in this underchassis view. A 5-V, 1-A power supply is visible on the front left of the chassis, and a small "beep" speaker on the front right. The wiring harnesses use Teflon insulated wire secured with nylon fasteners. A combination 120 V ac receptacle/power line filter is visible at the right rear.

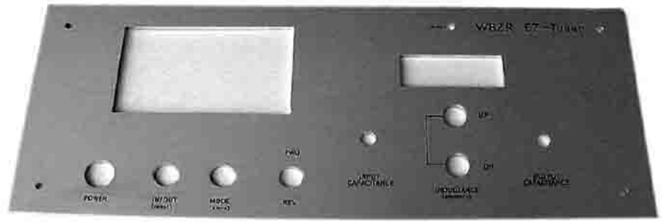
Table 3
Tap Position Test Frequencies

Note: Table assumes 50-Ω resistive load and half-meshed input capacitor (110 or 220 pF). The tap is adjusted to give best possible match at indicated frequency.

Tap	*Frequency (MHz)*
1	25.51
2	20.71
3	14.25
4	11.90
5	10.06
6	6.34
7	5.33
8	4.60
9	3.73
10	2.48
11	1.73



Details of the inductor switch wiring and coil taps.



Careful filing and attention to detail will ensure an attractive and unscratched front panel.

W8ZR's Homebrewing Hints

- Be a tortoise and not a hare: Builder impatience leads to as many failed projects as inexperience. Rushing your work never saves time, because haste creates compounding problems. Take your time to do it right.
- Don't attempt projects you can't fix: Unless it's a tried-and-tested kit or circuit board, most homebrew projects aren't "plug and play." It's good to stretch yourself, but stay clear of projects too far above your skill level.
- Don't be penny-wise and pound-foolish: You owe it to yourself to use quality parts. Saving a dime on an unmarked transistor isn't good value if it leads to hours of troubleshooting. And, please, invest an extra buck in some nice hardware. That tin can of rusty screws and nuts belongs in the garage, not on your workbench.
- Make your projects look good: Spend time drawing an attractive panel layout, and use matching knobs and coordinated colors. Don't use leftover pink spray paint on your new front panel, just to save yourself a trip to the hardware store.
- Measure twice and cut once; the old carpenter's adage is good advice when doing metalwork and laying out components. "Planning, planning, planning" is to homebrewing as "location, location, location" is to real estate.

rather is used as the basis for generating the "tokenized" object code, which is a second file that contains the microcontroller's actual instructions and data.

The tokenized file is created by the free BASIC Stamp Editor, which can also be downloaded from the Internet, and which has the "feel" of a very simple text editor.[16] Using the editor, one simply opens the EZ-Tuner's control program and clicks on "RUN." The editor then automatically creates the tokenized code and uploads it to the EZ-Tuner, via an ordinary serial port. (Note that because the EZ-Tuner shares its programming port with the LCD display, the display will flash random characters while the program is uploading. If the display freezes, it will be necessary to reset it by cycling the ac power.)

Because the BASIC Stamp editor program also contains commands for editing and debugging, it is very easy to update or modify the control program. Program changes are ready to test in the blink of an eye, and if the revised code doesn't work, or even causes the EZ-Tuner to lock up, then the original code can be restored in seconds. This versatility means that one shouldn't hesitate to try out new ideas.

Checkout and Calibration

Once assembly has been completed, the EZ-Tuner requires very little alignment. When the EZ-Tuner first powers up, you will be greeted by the display's opening message and the sound of the stepper motors and rotary solenoid going through their initialization routine. Once the movement ceases, you can be assured the motor limit-detect circuitry is working normally. At this point, adjust the variable capacitors with the rotary encoders until the LCD display shows zero for each capacitor. Then loosen the setscrews from the shaft couplers, manually rotate the capacitor to their fully meshed positions and retighten the setscrews.

At this point, you are ready to check out the frequency tracking circuits. Toggle the tuner into the automatic mode and, with a dummy load connected, gradually apply RF power to the input. When a power level increases to several watts (the threshold will vary somewhat from band to band), the display should jump to the correct band segment and the inductor and capacitors should move to their preset 50-Ω settings. If the capacitors are aligned properly, the RF wattmeter will show no reflected power.

If the tuner does not track the transmit frequency accurately, then the internal frequency counter must be calibrated to compensate for inaccuracy in the BS2sx internal clock. This correction requires changing the value of a calibration constant in the control program. The procedure takes but a minute and is described in the program listing.

The EZ-Tuner is now working properly and is ready to use, and all that remains is to hook up your antennas and store the matched settings. One final hint: after you reach this point it is highly recommended that you take your spouse out to a nice restaurant, as a reward for being patient during all those evenings and weekends you disappeared into your workshop. It is the author's long experience that such small investments reap large dividends.

Notes

[11] **www.w8zr.net/eztuner/**.

[12] Model DII-70-4-16/black vinyl. Buckeye Shapeform, 555 Marion Rd, Columbus, OH 43207; tel 800-728-0776; **www.buckeye-shapeform.com**.

[13] Barker & Williamson, 603 Cidco Rd, Cocoa, FL 32926; tel 321-639-1510; **www.bwantennas.com/**.

[14] *Multi-Tech Industries, Inc.* PO Box 159, 64 South Main St, Marlboro, NJ 07746; tel 800-431-3223; **multi-tech-industries.com/**.

[15] This capacitor is C5 in the schematic diagram (Figure 5 of Part 2).

[16] The BASIC Stamp Windows Editor v.1.3 (3.3 MB) and programming reference manual (413 kB) can be downloaded from **www.parallaxinc.com/**.

James C. Garland, W8ZR, has been a licensed amateur for 47 years, having been first licensed in 1955 as WN0ZKE at age 12. He upgraded to W0ZKE (General class) within the year. In 1969, he operated in England as G5APG, and then moved to Ohio in 1970. He passed his Extra exam that same year, and was licensed as W8KFL. He acquired his present call, W8ZR, that same year. Over the years, Jim has been interested in HF DXing and contesting, but his primary interest has been in homebrewing. He's built numerous rigs, amplifiers and other projects over the years. You can contact the author at 310 E High St, Oxford, OH 45056; **w8zr@arrl.net**.