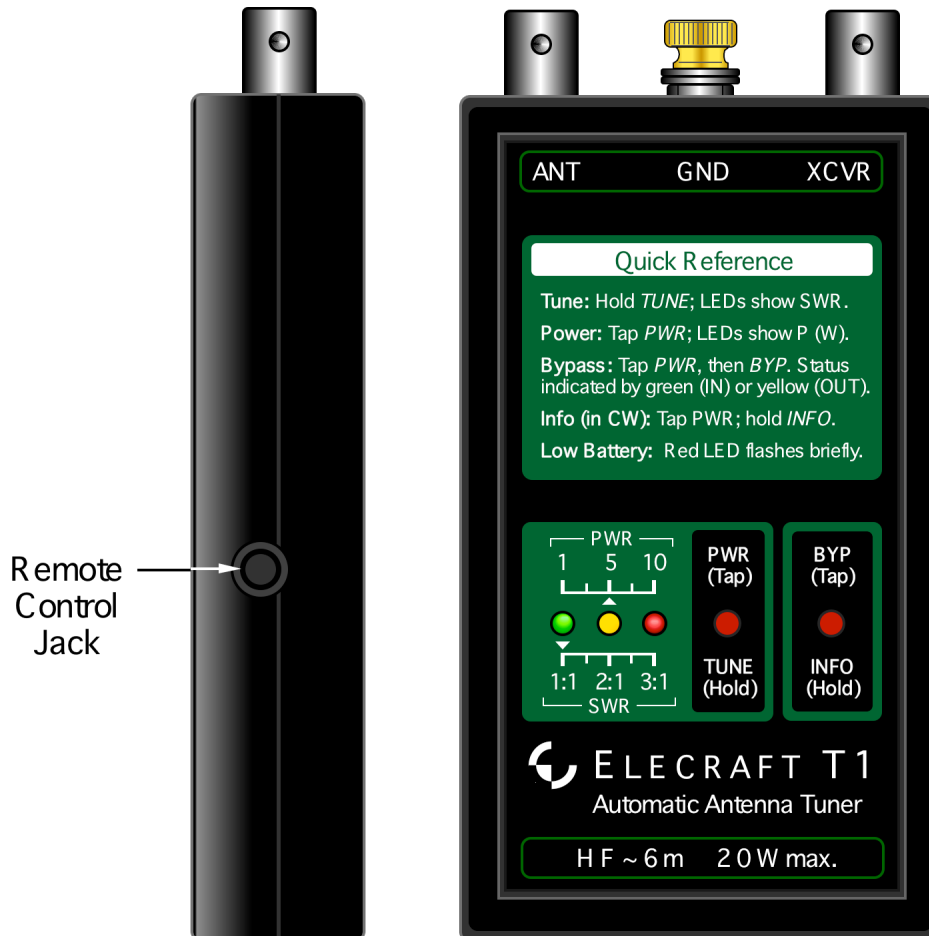


# ELECRAFT T1 AUTOMATIC ANTENNA TUNER

## Owner's Manual

Revision B, January 15, 2018. Copyright © 2018, Elecraft; All Rights Reserved



## Introduction

The T1 is a miniature, stand-alone automatic antenna tuner (ATU) that can be used with any low-power HF through 6-meter transceiver. Despite its small size, the T1 provides a wide matching range and can handle up to 20 watts SSB/CW and 10 watts FM/AM/digital. It's an ideal general-purpose ATU for home, mobile, camping, and HF Pack use.

T1 features include:

- **Rugged design** – can handle brief transmissions at more than twice its rated power
- **Tunes with a constant carrier, SSB voice, or CW keyer** – no need to change modes
- **Optional remote control adapter<sup>1</sup> provides instant recall of ATU settings when you change bands, without transmitting**
- **7 inductors, 7 capacitors, and 2 network types**, for a total of 32,768 possible combinations
- **Tries to find lowest possible SWR** – doesn't stop at 1.5:1 or 2:1
- **Works with all QRP rigs** – autotuning can be done using as little as 0.5 watts
- **Internal 9-V battery** with low-battery indication and reverse-polarity protection
- **Auto power-off and latching relays** ensure long battery life
- **SWR or Power shown on three LEDs**, with combinations of LEDs showing intermediate values
- **INFO feature reports SWR, battery voltage, etc. in CW** – uses both LED *and* RF signaling

## Specifications

Network Type	L-network (series L, shunt C); C switchable to transmitter or antenna side
L and C Ranges	L (inductance): 0-7.5 $\mu$ H in 128 steps; C (capacitance): 0-1300 pF in 128 steps
Frequency Range	1.8 to 54 MHz
SWR Range	10:1 or better (reduced range on 160 and 6 meters)
Min. Power	0.5 watts minimum required for autotuning (2 to 5 watts recommended)
Max. Power	20 watts SSB/CW, 10 watts FM/AM/digital modes
Tuning Time	5 sec. average for initial tunes; 1 to 2 sec. for retunes
SWR/Power Display	1:1 to 3:1 and 0.5 to 10 watts on three LEDs (5 gradations)
Battery Voltage	8 to 10 V (9-volt <i>Ultralife</i> lithium or alkaline battery recommended)
Current Drain	20 mA average during TUNE, 0 mA when inactive (automatic power-off)
Size	4.4" (L) x 2.5" (W) x 0.9" (H) (11.2 x 6.3 x 2.3 cm)
Weight	Approx. 5 oz. (0.14 kg) including battery

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<sup>1</sup>Adapters for specific transceivers can be found on our web site. You can also build your own T1 remote-control interface as explained on page 8.

## Customer Service Information

### *Technical Assistance*

If you have any difficulty with an Elecraft product, we're here to help. You may be able to save time by first consulting our web site, [www.elecraft.com](http://www.elecraft.com), or by posting your question on the Elecraft e-mail forum, [elecraft@mailman.qth.net](mailto:elecraft@mailman.qth.net). You'll need to subscribe to the forum first; instructions are on our web site.

Telephone assistance is available from 9 A.M. to 5 P.M. Pacific time (weekdays only) at 831-763-4211. You can e-mail assistance requests to [support@elecraft.com](mailto:support@elecraft.com), and parts requests to [parts@elecraft.com](mailto:parts@elecraft.com). *Please use e-mail when possible since this gives us a written record of the details of your problem.*

### *Repair Service*

If necessary, you may return the unit (completed, if purchased as a kit) to us for repair. **Contact Elecraft before mailing the unit to obtain the repair shipping address, as well as information on repair fees.** (Kits that have been soldered using acid core solder, water-soluble flux solder, or other corrosive or conductive fluxes or solvents cannot be accepted for repair—see Warranty below.)

**The following should be provided to expedite repair:** your name, address, and phone number; your e-mail address (if applicable); and a complete description of the problem.

**Shipping:** First, seal the unit in a plastic bag to protect the finish from dust and abrasion. Use a sturdy packing carton with 3" or more of foam or shredded paper on all sides. Seal the package with reinforced tape. (Neither Elecraft nor the carrier will accept liability for damage due to improper packaging.) Cover the "to" address label with clear tape.

### **Elecraft's 1-Year Limited Warranty**

This warranty is effective as of the date of first consumer purchase. Before requesting warranty service on kits, you should complete the assembly, carefully following all instructions in the manual.

What is covered: During the first year after date of purchase, Elecraft will replace defective parts free of charge (post-paid). We will also correct any malfunction caused by defective parts and materials. You must send the unit at your expense to Elecraft, but we will pay return shipping.

What is not covered: This warranty does not cover damage due to electrostatic discharge (ESD), correction of kit assembly errors or misalignment; repair of damage caused by misuse, negligence, or builder modifications; or any performance malfunctions involving non-Elecraft accessory equipment. *The use of acid-core solder, water-soluble flux solder, or any corrosive or conductive flux or solvent will void this warranty in its entirety.* Also not covered is reimbursement for loss of use, inconvenience, customer assembly or alignment time, or cost of unauthorized service.

Limitation of incidental or consequential damages: This warranty does not extend to non-Elecraft equipment or components used in conjunction with our products. *Any such repair or replacement is the responsibility of the customer. Elecraft will not be liable for any special, indirect, incidental or consequential damages, including but not limited to any loss of business or profits.*

## Inside the T1



If you need to open the T1 to do testing or replace parts, use an anti-static mat or touch a grounded metal surface occasionally. This will help prevent ESD damage to sensitive components.

Figure 1 shows the interior of the T1. It is accessed by opening the battery compartment, then removing four screws on the bottom of the unit. The LEDs and switches are on the Control board, which plugs into the Main board at J4 and J5. U1, the microcontroller (MCU), is located beneath the Control board.

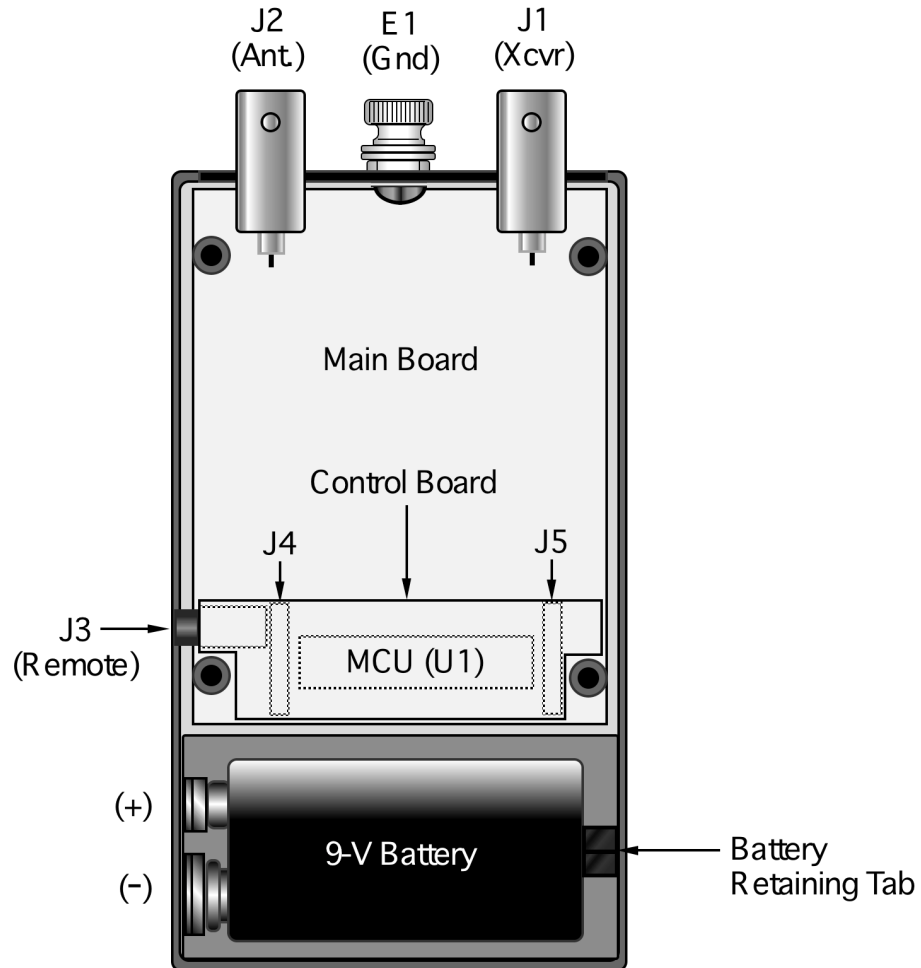


Figure 1

## Battery Installation

Slide open the battery compartment cover on the bottom of the T1. Align the 9-V battery's (-) terminal with the *wider* of the two contacts (**Figure 1**). Note: The T1 includes reverse-polarity protection.

## Storing the Battery for Transport

When packing the T1 for travel, remove the battery and re-install it flipped left-to-right, with the battery terminals away from the contacts. This takes just a couple of seconds, and will prevent the T1 from getting turned on inside a pack or suitcase. (Even if it does get turned on, it will turn itself off after a few seconds.)

## Connections

Connect the T1 to your transceiver, antenna, and ground as shown in **Figure 2**. (Also see **Antenna Considerations** on page 9.) If you have a T1 remote control adapter, connect its 3.5 mm phone plug to J3 on the left side of the T1, and plug the other end into your transceiver's accessory jack. (Further information can be found in the instruction sheet for your adapter.)

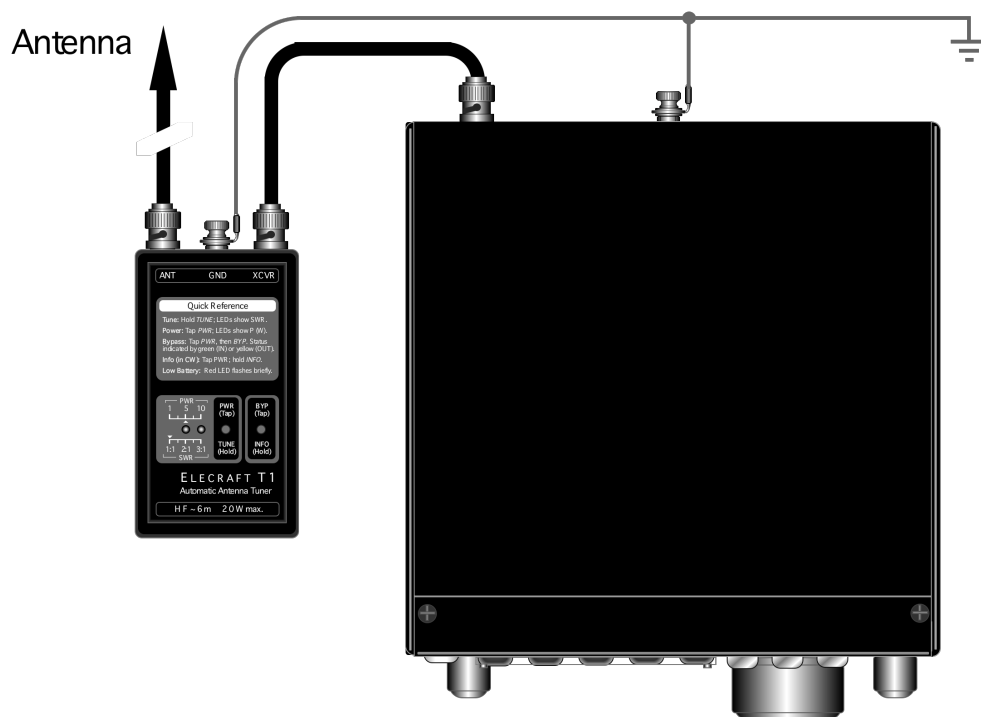


Figure 2

## Basic Operation

The switch on the left (S1) turns on the T1 and activates the PWR and TUNE functions, described below. The battery is checked on each power-up. If it's getting low, the red LED will flash twice, and the battery should be replaced. (Actual battery voltage can be checked as part of the INFO report; see page 7.)



### IMPORTANT – PLEASE READ BEFORE USING THE T1:

- **If your transceiver is not protected against high SWR, or if you're not sure, use no more than half its rated power during antenna matching. This reduces stress on the final stage.**
- **Do not use the T1 on bands above 54 MHz.** Even though the T1 may appear to achieve a low-SWR match on these bands, most of the power will be dissipated in the tuner itself.
- **When the T1 is turned on, it may generate signals that are audible in your receiver.** Once the operation is complete and the T1 turns itself back off, it will not generate signals of any kind.

#### *Autotuning and SWR Display*

- Hold the PWR/TUNE switch until the green LED turns on, then release. The LED will flash.
- To start tuning, transmit while the green LED is flashing (about 3 seconds). If you use SSB voice or a CW keyer, relay switching will start and stop. Keep transmitting until all LEDs turn off.
- The three LEDs will show approximate SWR as labeled on the SWR bar graph. Intermediate values are indicated by combinations (**Green+Yellow**, about 1.5:1; **Yellow+Red**, about 2.5:1). If desired, a more accurate SWR reading can be obtained using the INFO feature (page 7).
- Initial tune-ups average 5 seconds. Settings are saved in memories, so retuning is much faster.
- The T1 will turn itself off after tuning, preserving the present settings due to its latching relays.

#### *Faster Retuning with Difficult Loads*

- Normally, the T1 retunes from memory only if it finds an SWR of under 1.5:1. You can select a save/retune SWR threshold of 2:1 to speed retuning of often-used, yet hard-to-match antennas.
- To select a 2:1 threshold for a given initial tune or retune, hold PWR/TUNE until the green LED turns *on and then off*, then release. Start transmitting while the LED is flashing, as above.

#### *Autotuning using Remote Control (requires optional adapter)*

- Change bands at the transceiver; the T1 will recall the last settings used on the new band.
- To retune, transmit while the green LED is flashing (about 3 sec.). The LEDs will show SWR.

#### *Power Display*

- Tap the PWR/TUNE switch (a tap is a press shorter than 1/2 sec.). The yellow LED will flash.
- Begin transmitting within 3 seconds. Approximate power output will be shown on the LEDs: **Green** 0.5-1.5 W, **Green+Yellow** 1.5-3 W, **Yellow** 3-5 W, **Yellow+Red** 5-8 W, **Red** over 8 W.
- If power drops below 0.5 W for 3 seconds, the T1 will turn itself off.

## Additional Operating Features

The switch on the right (S2) provides access to three additional functions. These are described below.

### *Bypassing the ATU (L and C set to 0)*

- Tap PWR/TUNE; the yellow LED will flash.
- Tap BYP/INFO to alternate between ATU in-line (green LED on) and bypassed (yellow LED on).
- When bypassed, the T1 can still show SWR; activate TUNE mode, then key the transmitter. This is especially useful when adjusting backpacking or mobile antennas to resonance.

### *INFO Report*

The last SWR reading, battery voltage, and other information can be obtained using the INFO feature.

- Tap PWR/TUNE; the yellow LED will flash. Hold BYP/INFO for about 1 second, then release.
- The T1 will send several parameters in slow Morse code on both the yellow LED and via a weak RF signal (see page 11). “R” (radix) is used in lieu of decimal points. Parameters sent include:

<b>Sx</b>	SWR (e.g., S1R0 = 1.0:1)
<b>Vx</b>	Battery voltage (e.g., V9R0 = 9 volts)
<b>Lx</b>	Inductance in $\mu\text{H}$ (e.g., L1R45 = 1.45 $\mu\text{H}$ )
<b>Cx</b>	Capacitance in pF (e.g., C330 = 330 pF)
<b>Nx</b>	Network configuration (NT = K8 set to “TX”, NA = K8 set to “ANT”)
<b>Bx</b>	Band ID: B0, no band data; B1-B11, 160-6 m; B12, over 6 m (L & C set to 0)
<b>Fx</b>	Firmware revision (e.g., F1R06 = revision 1.06)

- The report can be cancelled by holding PWR/TUNE for about 1 second.

### *L-Network Testing*

The T1 includes a test mode that’s useful for troubleshooting relays and L-network components (also see page 10). To use test mode:

- Tap or hold PWR/TUNE. The yellow or green LED will flash.
- Hold BYP/INFO for over 4 seconds, then release. “L0” will be sent in slow CW on the yellow LED, showing that L = 0 (C is also set to 0). A test-mode “heartbeat” will flash on the red LED.
- Tap BYP/INFO to select L1; “1” will be sent on the yellow LED. Further taps select L2, L3...L7.
- Hold BYP/INFO to switch to C; “C0” will be sent. Tapping BYP/INFO selects C1, C2...C7.
- Hold BYP/INFO to select N (net relay); “NT” will be sent (C TX). Tap to select “NA” (C ANT).
- Relays can also be controlled by sending binary data via J3. Use the TUNE and DATA timing shown in **Figure 3**. Send 0000 to reset all relays, and 0001-1111 to set K1-K15 respectively. Once any relay data is sent via J3, you’ll need to use only this method, not manual selection.
- Connect a sensitive SWR bridge between the T1 and transmitter to test components (page 10). Tap PWR/TUNE to exit. (Note: In TEST mode, the T1 turns off after 60 seconds of no activity.)

## Remote Control

J3 on the T1 has two signals: DATA (tip) and TUNE (ring). This section explains how to use them to control the T1 from a transceiver, computer, or other device. **Note:** If you place the tuner where you can't see its LEDs or hear its relays, you'll need an SWR bridge to verify the T1's matching progress. During tuning, SWR will vary rapidly. Once SWR has stabilized for a few seconds, you can stop transmitting.

### Using the TUNE Signal

An external PWR/TUNE switch (or a low-going signal from an open-collector or open-drain driver) can be connected to J3-ring. Pulling this line to ground for about 1/2 second will enable auto-tuning just as if you pressed the T1's TUNE switch. The cable supplying the TUNE signal to the T1 should be well-shielded; small coax such as RG-174 can be used in most cases. If you use also use the DATA line (see below), you'll need cable with two conductors as well as a shield, such as Belden type 1508A.

### Using the DATA Signal

DATA (J3-tip) is a *bidirectional* logic input. After the T1 is activated by the TUNE signal, it will request band information via the DATA line. If valid band data is received, the tuner will store and recall network settings on a per-band basis. This is very convenient since the tuner will then track band changes at the rig without the need to transmit. If the tuner sees a TUNE signal but does not receive band data, it will revert to default operation, i.e. no per-band storage. (Band IDs for 160-6 meters are 1-11. An ID of 0 is ignored, and an ID of 12 sets L and C to 0. You can verify the band ID received by the T1 using INFO; see page 7.)

**Figure 3** shows the protocol. First, the T1 sends a band request pulse on the DATA line, which is initially an *input* at the control device. When the control device sees the end of the request pulse, it sets up DATA as an *output*, and after a 10-ms delay, sends a band ID to the T1 (band 6 in this example, or "0110" in binary). The ID is sent most-significant-bit (MSB) first, each bit having a high and low period. The high period is 4 ms for a "1" and 1.5 ms for a "0". The low period is always 1.5 ms, except for that of the LSB (least-significant-bit), which can be extended indefinitely. Timing values should be held to +/- 15%.

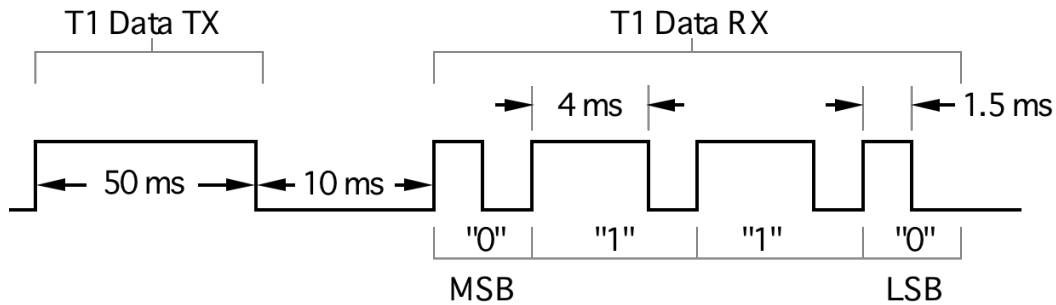


Figure 3



## Antenna Considerations

The T1 can be used with nearly any antenna—dipoles, verticals, whips, beams, and random-length wires. In general, the longer an antenna is, and the higher it is, the better it will work. If you're planning operation in the field, test your chosen antenna system with the T1 ahead of time if possible.



**Never connect a whip directly to the T1. This may damage the antenna jack or PC board.**

**Ground system:** *A good ground counterpoise is a necessity for efficient transmit operation with verticals, whips, and end-fed random-wire antennas.* With a poor ground, the receiver may still sound “hot,” and the indicated SWR may be low when you transmit, but your effective transmit power will be much lower – often by 10 to 20 dB or more. Use at least one ground radial, cut to about 1/4th wavelength on the lowest band. When possible, use two or more radials, with at least one cut to 1/4 wavelength on each band used.

**Coax-fed antennas:** The T1 will extend the frequency range of most coax-fed antennas. For example, the tuner might allow you to use a somewhat narrow-banded 40- or 80-meter antenna across the full band. In many cases it will also match single-band antennas on multiple bands.

**Random-wire antennas:** Random-wire results will vary depending on the wire length, height, type of support, and ground system. Avoid lengths close to a multiple of 1/2-wavelength on any band you plan to use. If you use an end-fed wire with no feedline and/or a poor ground, you may need to reduce power to avoid RFI problems with the transceiver, tuner, nearby computers, portable phones, etc. For portable antennas, we recommend #26 stranded copperclad steel wire, such as Wireman #534 (also available from Davis RF as #WM534). It's strong, lightweight, and easy to keep straight. (When antenna wire is not in use, wind it in a figure-8 pattern to keep it from tangling.)

**Backpacking verticals and other short antennas:** The T1 can extend the range of loaded antennas, often allowing full-band operation without readjustment of coils or elements. It will typically match an unloaded 8' whip on 40 meters and higher. On 80 and 160 meters, a loaded antenna or supplemental series inductance will be required. Center loading is preferable to base-loading; capacitive top-hats often beat both.

With loaded antennas, you should manually resonate the antenna at the desired center frequency before using the T1 for matching. First, put the T1 into bypass mode as described on page 7. Next, go into TUNE mode and transmit. The T1 will show approximate SWR, allowing you to adjust the coil tap or element length. Then exit bypass mode. Finally, use the T1's TUNE function to fine-tune the match.

**Do I need a really low SWR?** Not necessarily. For example, if the SWR is 2:1, the loss in transmitted signal strength will only be about 0.5 dB. However, a low SWR may prevent power “roll-back,” and can protect simpler QRP transmitters that are unstable with some reactive loads. The T1 always tries to reach 1.0:1, and with most antennas it will find an SWR below 1.5:1 on bands within its matching range.

**Using a balun:** A balun can do as many as three things at once: (1) improve the match to very high-impedance antennas; (2) allow the T1 to be used with antennas that have balanced feedlines; (3) help isolate the antenna from the rig and ATU to reduce RF pickup. A low-loss, broad-band, 4:1 balun such as the Elecraft BL1 is a good choice (it's also quite small—just 1.5 x 3”).

## Troubleshooting



**If you need to open the T1 to do testing or replace parts, use an anti-static mat or touch a grounded metal surface occasionally. This will help prevent ESD damage to sensitive components.**

**T1 doesn't turn on:** Make sure you're using a fresh 9-V battery. Verify that the MCU is installed in the correct orientation and is plugged into its socket as far as it will go. Also check for proper mating of the connectors on the Control board. Try unplugging the remote control cable (if applicable).

**Intermittent failures:** If the T1 suddenly stops working, it may be because the transceiver's supply voltage is being pulled too low during transmit. This is especially likely if you're using a battery and maximum power output. Try reducing power, recharging the battery, or disconnecting the remote-control cable.

**T1 fails to find a match, stops tuning, or turns on by itself:** Such problems can be caused by RFI due to a poor ground, an end-fed antenna (especially if it's close to 1/2-wavelength long), or an antenna placed close to the transmitter. Try improving your ground system, moving the antenna farther away, altering its length, or using a balun (see page 9). Using high power will worsen RFI, especially on the highest bands; try 2-5 W for initial tune-ups. Typically the T1 will reset itself and recover from excessive RFI after a few seconds. If it continues to be unresponsive, remove and reinstall the battery. If problems only occur with a remote control cable connected, try a shorter cable and/or better shielding. Also make sure the T1 is not in bypass mode.

**T1 causes interference on receive:** You may hear harmonics of the T1's MCU clock or other odd sound effects while the ATU is turned on. These should cease when the ATU turns itself off. If not, the MCU may be in an unknown state due to excessive RFI during a previous transmission. Remove and replace the battery if this occurs. If that doesn't fix the problem, try re-seating the MCU and the Control PC board.

**SWR indication on the transceiver doesn't match the T1's:** SWR bridges vary in sensitivity and accuracy, if calibrated at all, especially at frequency extremes. Some rigs also roll back power at high SWR. This can make SWR read lower than reality during auto-tunes, making it appear that the T1 has not selected the best match. In any case, such discrepancies rarely matter (see SWR discussion on page 9).

**PWR indication is always about 0 watts:** The windings of transformer T1 or T2 may be reversed, or one or more leads of T1, T2, or L1-L7 may not be properly stripped. Also look for a short in the L-network.

**SWR indication is higher than 1.0:1 with a 50-ohm load:** An antenna tuner can usually tune out its own stray reactance. However, if the T1's SWR is higher than 1.5:1 into 50 ohms on some bands in bypass mode, check the relays and L/C network components using TEST mode (see procedure below).

**T1 is unable to achieve a low SWR on some bands:** Make sure the tuner is not in bypass mode (see page 7). You could also have a defective relay, inductor, or capacitor; use test mode (page 7) to test each L and C by noting their effect on SWR. Insert a sensitive SWR bridge between the transceiver and the ATU, and connect a 50-ohm load to the antenna jack. Start on the highest band. Select L0, key the rig, and note the SWR. Then select L1 and key again; the SWR should change by a small amount. L2 should have a larger effect, etc. If the SWR goes above the meter's scale, switch to a lower band to test the other inductors. Similarly, check C0-C7. Look for a part that has a disproportional effect on SWR in relation to others.

## Using Your HF Transceiver to Listen to the INFO Report

The INFO report is sent via both the yellow LED and a weak RF signal. To find the best signal, disconnect the antenna from the T1 to reduce background noise, switch in a wide receive filter, then tune your transceiver's VFO across any band while the T1 sends data (see page 7). Some frequency ranges to try include 1.8-1.9, 3.8-3.9, 7.0-7.2, and 14.0-14.2 MHz. **Note:** The reason the signal frequency varies from one T1 to the next (and drifts a bit) is that its MCU runs from a ceramic resonator rather than a crystal.

### Circuit Details

**(Please refer to the schematic, next page.)** The ATU uses seven inductors and seven capacitors in an L-network. The capacitance can be placed at the transmitter or antenna end of the network via relay K8. Each inductor and capacitor has its own DPDT relay, with the individual sections of each relay placed in parallel for reliability. The relays are selected under control of the ATU's microcontroller, U1. Latching relays are used so that they will not consume any power except when the operator is actually tuning.

The T1 uses a comprehensive, three-stage tuning algorithm to ensure selection of the best of its 32,768 relay combinations. The coarse phase takes the longest because the impedance is an unknown (using band data via remote control can reduce this time by eliminating some L and C values based on the operating band). High SWR "subtrees" of L/C possibilities are also "pruned" during this phase. Fine and very fine matching stages try successively narrower L/C groups. Once a match has been found, it is saved in EEPROM for later consideration when retuning. A number of such matches are saved, so the tuner will rarely need to tune completely from scratch. If band data is available, it is used to load the last-used network values on each band. Further details on using band-data appear on page 8.

T1, T2, D1, D2 (etc.) form a directional coupler for SWR and power measurements. This type of bridge is inherently balanced over a wide frequency range and requires no adjustment. The bridge outputs are connected to A-to-D inputs on U1. U1 measures these voltages and converts them to SWR or power readings, using averaging and linearization techniques to improve accuracy. Before matching starts, the T1 determines the peak power of the transmitted signal, then uses a large fraction of this value as a qualifier for SWR readings. In this way, SSB voice as well as any other modulation method can be used for antenna tuning, with little loss of accuracy compared to the use of a constant carrier.

The Control board provides the user interface (LEDs D6-D8 and switches S1-S2) as well as the interface between the remote jack (J3) and the microcontroller (U1 on the main board). Since the Control board is a plug-in module, future variations can be accommodated. D3 is a reverse-polarity protection diode for Q1 and U2. Q1 is turned on whenever the user presses the PWR/TUNE switch, providing about 9 volts to U2, the 5-volt regulator. This wakes up the microcontroller, which loads the present settings from EEPROM and verifies proper relay configuration. R10 and R11 form a voltage divider for battery voltage checks. DATA is a bidirectional logic line used by the T1 to request band data from remote-control adapters.

The INFO report RF output is generated by placing a digital pulse train on the VREFL line during "ON" code elements. This modulates the 4-MHz oscillator and its subharmonics, providing audible CW signals throughout the HF and VHF range. The signal is coupled to the transceiver via leakage paths in the SWR bridge and L-C network.

