Automatic Antenna Tuner KT-005

The world's smallest QRP automatic antenna tuner
Latched relays capable of zero current operation after tuning
Ultra-compact design: 54 x 55 x 24 mm, in a lightweight and durable aluminum enclosure

Features

- The world's smallest QRP Automatic Antenna Tuner (ATU) available on the market
- ATU can works with any type of radio in any mode (CW, SSB, WSPR, PSK, FT-8,…)
- Auto Power Off function for zero current consumption when tuned
- High grade (Fujitsu) reliable mechanical latch type relay
- Durable aluminum housing: black anodised with laser-engraved symbols
- SMA female sockets for maximum miniaturization
- High efficient LED indicators for RF power level, VSWR value, battery voltage
- Low-battery detection when operating from 9 V battery
- Two control buttons for easy operation
- Reverse polarity protection

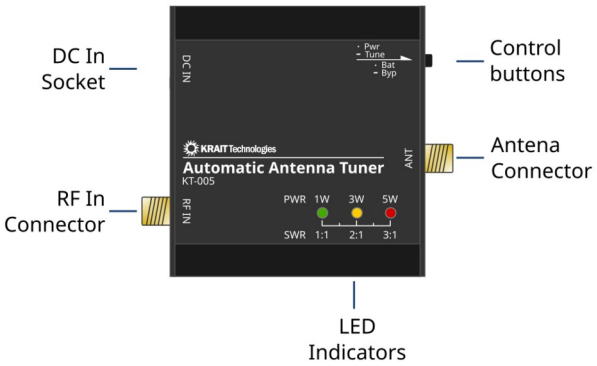

FIGURE 1. Assembled ATU KT-005

Specifications

- Matching impedance range: 16 ~ 150 R to 50 R
- Matching accuracy (VSWR): 1.5:1 or less*
- Network type: L-network with series L and shunt C
- C shunt is switched between the transmitter and antenna side
- 32 768 possible matching states due to 15 relays inside
- Minimum operating power: 0.5 W for tuning
- Maxiumum operating power: 5.0 W
- Frequency range: 1.8–30 MHz
- Input impedance: 50 R
- Tuning time: 3–5 seconds (maximum 15 seconds)
- Dimensions: 54 x 55 x 24 mm; 2.1 x 2.2 x 0.9 in (WxHxD)**
- Weight: 0.106 kg (3.74 oz)
- IP (Ingress Protection) rating: 20
- Connectors type: SMA female (50 R)
- DC input: 5.5 x 2.1 male (positive polarity)
- Power supply requirement: 8…18 VDC
- Operatable temperature: -10°C to +60°C; +14°F to +140°F

*) except for half-wavelength or multiple-half-wavelength antennas
**) without connectors

Applications

- Designed to be electrical and mechanical compatible with the QCX-mini® and QMX-mini® transceivers from QRP Labs®
- Great choice for all operators looking for the best portable equipment (POTA, SOTA and others)

Introduction

Congratulations on your purchase of a KRAIT Technologies Automatic Antenna Tuner KT-005! This manual contains information you will need for proper operation, maintenance and care of your ATU. The device is shown in **Fig. 1**.

However the impedance of any antenna normally varies, depending on the frequency and other factors, and consequently changes the signal impedance that appears at the other end of the feedline, where the line connects to the transmitter. In addition to reducing the power radiated by the antenna, an impedance mismatch can distort the signal.

Theory of Operation

An antenna tuner is a passive electronic device placed in the feed line between a radio transmitter and its antenna. Its purpose is to optimize power transfer by matching the impedance of the radio to the impedance of the signal at the end of the feed line connecting the antenna to the transmitter.

Antenna tuners are particularly important for use with transmitters. Transmitters are typically designed to feed power into a reactance-free, resistive load of a specific value (typically 50 R).

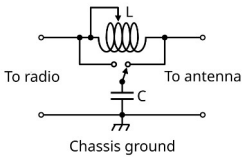

FIGURE 2. Network topology used in ATU KT-005

Thanks to switchable capacitor branch two possible topology are available (see **Fig. 2**). The variant with capacitance after series inductor helps to match in general inductive loads, while variant with capacitance before the series inductor can match capacitive loads (see **Fig. 3**). The ATU automatically selects the optimal configuration without checking all possible relay states.

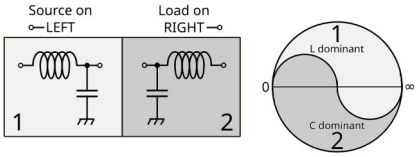

FIGURE 3. Available ATU topologies and their corresponding Smith Chart coverage

Operation Modes

The ATU is equipped with two buttons on the right side. Each button allows you to activate two functionalities. Three-LED display (see **Fig. 4**) shows the selected mode in Morse code (see **Tab. 4**) and then the measured value for the activated operating mode.

Top button:
1. **PWR** (▪) – short click to measure RF output power
2. **TUNE** (–) – long click to start tuning process

Bottom button:
3. **BAT** (▪) – short click to check battery voltage
4. **BYP** (–) – long click to bypass antenna tuner

FIGURE 4. Three LED indicators: RF power and SWR meter

The ATU remains active for three minutes (180 seconds) after the last mode activation. After this time, it goes into full sleep mode: zero current consumption from the power supply. Thanks to the use of latching relays, the last selected configuration remains active.

► Please note that the top button only wakes the ATU from sleep mode. To start tuning immediately, press and hold the top button.The ATU will then start working in TUNE mode.

1. PWR mode

A short click on the top button activates the RF forward power measurement function. First, all LEDs will light up to indicate the “P” mode (see **Tab. 4**). Then the current value of RF forward power is displayed by three LEDs (**Tab. 1**). Power is measured 30 times per second.

► If the measured output power exceeds 7.5W, all LEDs will light up, indicating that the ATU is overloaded.

Table 1. PWR mode - LED status as a function of RF forward power

Power range [W]	LED status
0.0…0.5	I – I – I – I
0.5...1.5	I O I – I – I
2.0…4.0	I – I O I – I
4.0…6.0	I – I – I O I
> 7.5 (OVLD)	I O I O I O I

'–' – LED off, 'O' – LED on

2. TUNE mode

To activate the tuning function immediately, press the top button for more than 1/3 second. A good practice is to start transmitting (CW) on the selected frequency and then long press the top button to start the tuning process. First, all LEDs will light up to indicate the “T” mode (see **Tab. 4**). Maintain carrier transmission until tuning is complete. Depending on the tuning result, the message will be returned: “S” for successful tuning or “E E E E” for no match. After that the LEDs indicator shows the current VSWR value (see **Tab. 2**).

If the match is better than 1.5 then the system doesn't even start the tuning procedure. In typical conditions the ATU considers the match acceptable if the VSWR is below 1.5:1 (96% of the transmitted power goes to the antenna). If ATU does not find a good match within 15 seconds, it stops the search procedure at the best match found so far. If the match is worse than 3.5:1, then the tuner signals this with three diodes.

The algorithm selects some rough matches, then evaluates which ones are the best and performs fine-tuning on them. Each fine-tuning matching process follows a slightly different pattern to avoid local SWR minima if necessary.

To minimize the interference level, it is best to limit the transmiter power to 1.0 W when tuning.

► Before starting tuning, the ATU checks the actual RF power level. If the measured RF forwared power exceeds 6.0 W, tuning will not start to avoid overloading the relays during switching! This will be shown by flashing all LEDs (“V” code as overload).

Table 2. TUNE mode - LED status as a function of VSWR coefficient

SWR value	LED status
1.5 <	I O I – I – I
1.5…2.5	I – I O I – I
2.5…3.5	I – I – I O I
> 3.5	I O I O I O I

'–' – LED off, 'O' – LED on

3. BAT mode

This mode allows you to verify the voltage value of the power source. The system is calibrated for precise operation with a 9V battery (i.e. 6F22).

The voltage indicator uses three LEDs and distinguishes six states (see **Tab. 3**).

► Please note that BAT mode can only be activated if PWR mode has been pressed to wake up the ATU or the device has already been in this mode.

Table 3. BAT mode - LED status as a function of supply voltage

Voltage range [V]	LED status
< 8.1	I – I – I – I
8.1…8.7	I O I – I – I
8.7…9.3	I – I O I – I
9.3…9.9	I – I – I O I
9.9…10.5	I – I O I O I
> 10.5	I O I O I O I

'–' – LED off, 'O' – LED on

4. BYP mode

In bypass mode the ATU does not perform any impedance transformation.

If you call the bypass function again, you will return to the previously set configuration without re-tuning. This enables quick control of the transciver operation bypassing the ATU.

In this mode, the VSWR value is indicated, but only when the transferred power is at least 500 mW. For lower RF powers the LED indicator is off. The scale the same as in TUNE mode.

Power Off function

The ATU enters sleep mode three minutes after being turned on or changing the operating mode. A short message („O”) is displayed on LEDs just before going into Power Off mode. The system then goes into full sleep mode and draws no power at all. There is no need to disconnect the ATU from the battery power source. The relays remain in the last set state.

Absolute Maximum Ratings

Maximum Input Voltage:	18.0 VDC
Current consuption @ 9 Vin DC:	up to 45.0 mA (tuning)
Current consuption @ 9 Vin DC:	15 mA (ON, no LED)
Current consuption @ 9 Vin DC:	0.0 uA (Power Off)
Operating Temperature Range:	-25...+60°C
Maximum RF Power:	5.0 W (+37 dBm)
Ingress Protection (IP) rating:	20

LED Codes

Each selected operating mode is confirmed by LEDs (three at a time) using Morse code as shown in **Tab. 4**. This is a visual confirmation of the selected operating mode. Then the LED indicator switches to the power, voltage or VSWR indication mode according to the selected operating mode.

Table 4. LED Codes – description

Letter	Morse code	Description
P	•––•	ATU works in PWR meter mode
V	•••–	ATU is overloaded (Pi >7.5 W)
T	–	ATU started tuning in TUN mode
S	•••	ATU succesfully matched antenna
E E E E	• • • •	ATU matching was unsuccesfull
Y	–•––	ATU is bypassed
R	•–•	ATU returned to the last known match
N	–•	Too low RF power during tuning
B	–•••	ATU works in BAT meter mode
O	–––	ATU goes into sleep mode (OFF)

Circuit Description

▪ The main goals of the design process were:

- the smallest possible form factor,
- covering the Smith Chart, as in other projects of this type,
- due to maximum miniaturization, this version does not include additional circuitry such as phase and impedance measurement circuits or an internal attenuator; they will be available in the ATU PRO version,
- for the reasons mentioned above, it is not the fastest ATU available, although equally effective.

▪ The main part of ATU are latched relays. When set they do not consume any electric power.

▪ The ATmega8A microcontroller is used to control the whole circuit. It controls directly relays, convert voltage from SWR bridge (Pi and Pr values), control LED indicators, sense buttons and control self-power-off circuit.

▪ The ATU is equipped with a voltage regulator (78L05) preceded by a protection diode. This makes the ATU protected against reverse polarity and accepts standard power sources: 9.0 V from a 6F22 battery, 11.1 V from a Li-Pol or typical 13.8 V DC from a car battery.

▪ The KT-005 ATU source code is not public. Actual firmware uses about 90% from 8 kB program memory and 38% from 1 kB RAM.

Technical Characteristics

▪ Maximum installed inductance: 7.48 uH
▪ Maximum installed capacity: 1.301 nF

Using ATU with QCX®/QMX® TRX

► The KT-005 ATU is based on the mechanical relays. Tuning process is based on an algorithm for searching for the lowest reflected power in the fewest steps by switching relays under RF power conditions.

► During teh tuning process, the transmitter stage is subjected to various load condition: from a nearly short circuit condition to open state.

► Since the tuning process took a few seconds there is no risk of overloading the power stage based on BS170 transistors because of too much power losses.

► The only risk is the possibility of damaging the power stage by too high voltage during tuning. When Class E transmitter is not nominally loaded this will cause higher voltage spikes on the MOSFETs (maximum voltage for BS170 is 60 V).

► Please note that the QCX transceiver is not equipped with an over-voltage protection.

► If you are not sure about the actual load impedance (i.e. field antenna) or you are runing TRX at Pi = 5 W it is good practice to add a 50 R attenuator in series (before the ATU) and then start tuning. If the ATU match correctly, remove the attenator and connect the TRX directly to ATU for maximum RF power.

► Another approach is to lower TRX input voltage to e.g. 9 VDC to reduce the output power and then perform tuning. The lower voltage will reduce voltage spikes on BS170 transistors during the matching process.

Safety Considerations

Do not overload the ATU! The maximum RF power provided to the RF input is 5.0 W (+37 dBm).

The ATU is built on **discrete relays**. This means that it switches different loads during tuning. Be sure that your transmitter can handle such load spikes.

Do not use ATU for frequencies higher than 30 MHz! Despite the apparent operation, the system may not adjust properly. Power losses in components may permanently damage the device!

Remember that the tuner **cannot** tune all possible load impedances. Some antenna lengths cannot be tuned and this is due to physical reasons, not the tuner design.

Never touch the antenna element while tuning or transmitting! Despite the low QRP transmitter power, the ATU can increase the output voltage several times

Do not reverse the ATU in connection! RF IN connector must always be connected to the transceiver output (50 R).

This product was **NOT** designed for use in wet/damp locations and should **NOT** be used near water or exposed to rain.

ATU Operational Hints

1. ATU is a kind of impedance transformer. Due to some physical limitations it is not possible to efficently match all possible load conditions.

2. Note that for specific load conditions (e.g. R > 1000 R) the ATU has to transform the voltage several times. For Pi = 5 W at 50 R it is 15.8 Vrms, but for 1000 R (i.e. long wire anntenna connected directly to the ATU) the reqired voltage is 50 Vrms (70.5 Vpeak !) to achieve matching. It is strongly advised not to use ATU in such conditions!

3. The ATU is not design to directly tune i.e. a long-wire antenna, which is 450 R (nominal). In this case the 1:9 Unun is recommended for rough impedance matching, then the ATU will correctly match the impedance to the transmitter (50 R).

4. Running the ATU without any load (with open connector), should be avoided as this may generate excessive voltage inside the ATU and can lead to an internal arc.

5. If you are not sure about the load impedance connected to the ATU, it is a good practise to add a series attenuator (50 R) before the ATU and then tune the antenna. In case of high mismatch the TRX stage will not see the high mismatch conditition.

6. Changing frequency or the band require re-tuning the ATU. This ATU does not have a built-in frequency counter measurement circuit, therefore changing the operating frequency may increase the level of mismatch.

7. Retuning may be necessary within a given band if the frequency has been changed only slightly and the antenna is narrowband. Monitor the current VSWR value. Click short PWR to wake up the ATU. Then long click twice BYP button (–) to activate real time VSWR measurement mode for three minutes.

8. If you have trouble tuning your antenna, change its configuration slightly. This may help the ATU find the correct tuning.

9. A small random component has been added to the search algorithm. This causes the search path to be slightly different each time. For antenna with very ultra-narrow charactersitics, this ATU feature allows to override suboptimum matching.

10. There are no “peak & hold” circuits in SWR measurement circuit. This means that CW operation is the only appropriate mode for tuning procedure.

11. Make sure the TRX does not reduce output power (ALC circuit) when a large mismatch condition occurs during the tuning process. However most portable QRP TRXs use a simple Class-E amplifier without advanced protection circuitry, which is the best choice for this ATU.

12. The ATU’s internal algorithm calculates the actual VSWR, rather than only monitoring the Pr value. In case of ALC circuit response it may return false feedback for the ATU. This ATU is therefore insensitive to ALC effects.

13. The ATU uses latching type relays. If you do not use the tuning for a long time and the ATU experiences mechanical shocks, the previously set relays layout may not be maintained. In this case, retuning is required. The algorithm initializes all relays at the beginning of the tuning procedure.

14. The ATU has internal EEPROM memory which is used to store last succesfull matching configuration. If you turn on the device again (PWR mode) and then click BYP twice, the device will return to the previous relay configuration.

Mechanical Details

ATU dimensions: 54 x 55 x 24 mm W x D x H (measured without RF connectors)

PCBs specification: FR 4, 35 um layers, HAL, two-layer, 1.5 mm

At the top there are:
- three LED indicators (green, yellow, red)

At the bottom there are:
- four rubber foots

On the left side there are:
- DC input connector
- RF input connector (SMA female)

On the right side there are:
- Two TACT buttons
- RF output connector (SMA female)

FIGURE 5. Voltage polarity on the power cable

Connecting the Power Supply to ATU

To achieve the smallest possible size, the ATU does not have a built-in power source. Power is needed for a short time during tuning, so it makes sense to use the power source that powers the TRX.

The ATU can be powered by any voltage in the range of 8...18 VDC. Remember that when the ATU goes into sleep mode it does not consume any power at all. There is no need to disconnect it.

The device is protected against reverse polarity.

To connect everything easily, use a special power splitter as shown in **Fig. 6** (available for purchase separately). The adapter is supplied with angled DC plugs. This allows you to directly connect the QCX to the ATU using an adapter, as shown in **Fig. 11**.

FIGURE 6. Power distribution cable

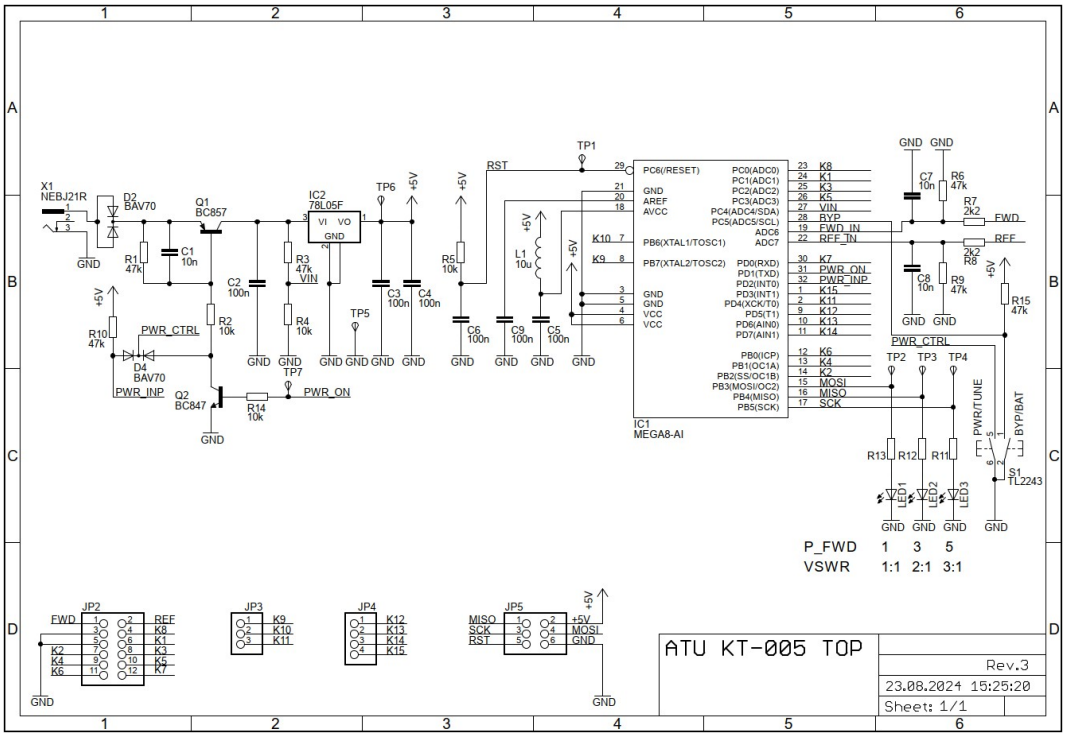

FIGURE 7. KT-005 – Automatic Antenna Tuner schematic diagram – top board

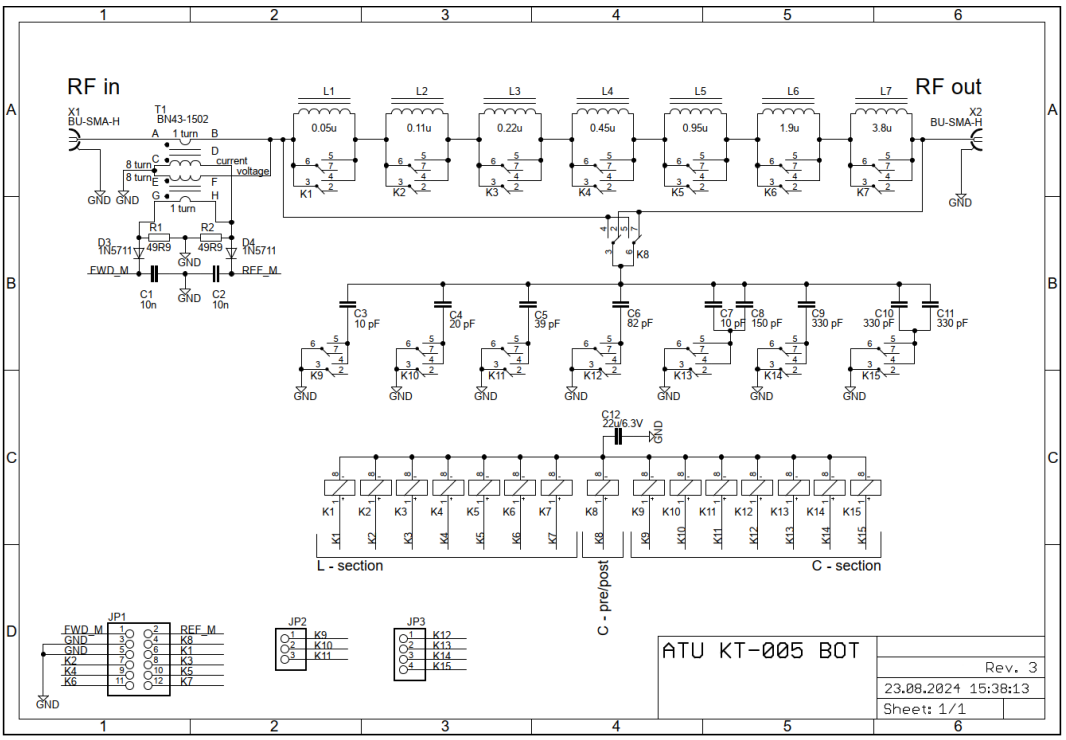

FIGURE 8. KT-005 – Automatic Antenna Tuner schematic diagram – bottom board

Printed Circuit Boards

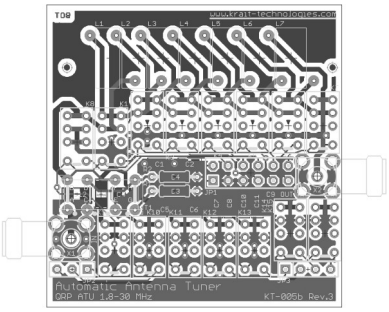

FIGURE 9. KT-005 PCB bottom board

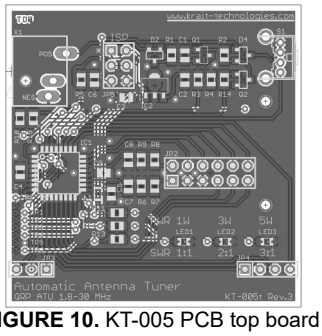

FIGURE 10. KT-005 PCB top board

ATU Size Comparison

FIGURE 11. QCX-mini® and ATU (KT-005) size comparison

Ordering Information

Table 5. Ordering information

Description	Version	Ordering Code	QTY
Assembled ATU in black aluminum enclosure ready to use	Assembled	KT-005A	1
Kit for self assembly (SMT components populated) with programmed microcontroller with aluminum enclosure	Kit	KT-005KE	1
Kit for self assembly (SMT components populated) with programmed microcontroller without enclosure	Kit	KT-005K	1
Enclosure for KT-005	-	KT-005E	1

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