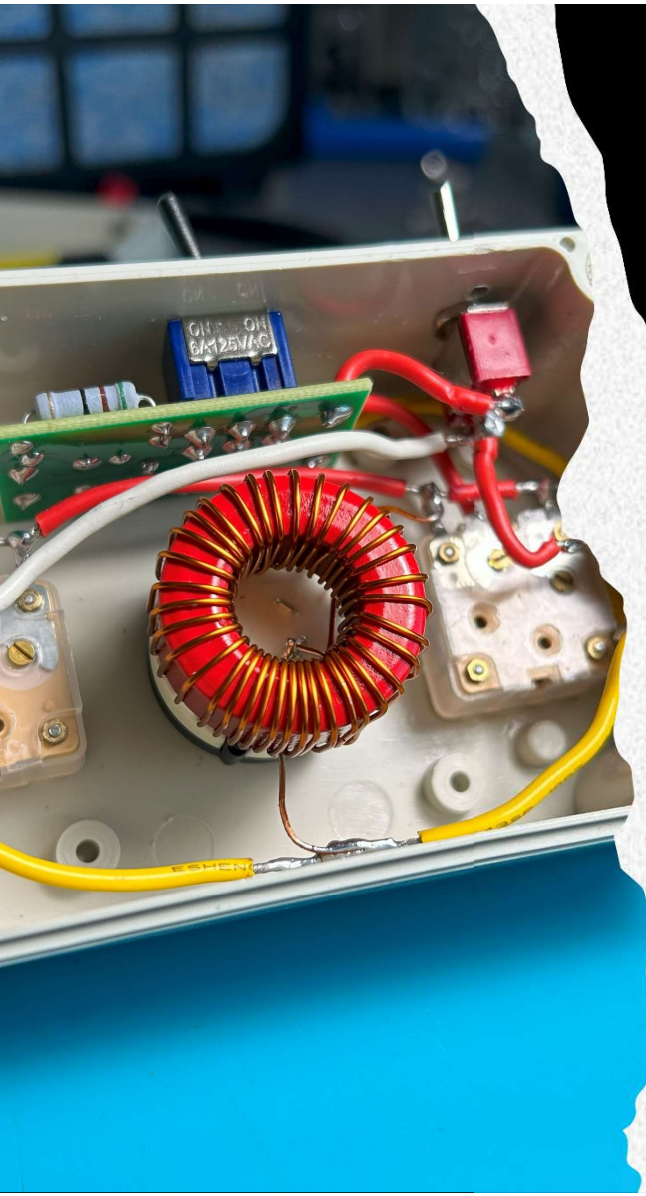


Cowtown ARC
‘Buildathon’ 2023

Project #3:

QRP – ATU

HF 10w Antenna Tuning Unit

Richard W5ARH / VK2ARH
vk2arh@att.net

Presentation - Thursday October 19th 7:00pm
Buildathon 2023 Project #3

Agenda

- ATU's
  - What is it ?
  - **Basic** Theory of Operation
  - Practical Use
  - Automatic or Manual
- Buildathon Refresh
- Project #3 – QRP ATU
  - Kit Introduction
  - Construction Process Outline
- Questions
- Kit Collection

Supported Build Program – Saturday 21st October 9:00am
Breakfast Day Break Café 8:00am for those interested

Buildathon 2023 Project #3
QRP ATU

ATU – What is it ?

An **antenna tuner** is an electronic device inserted into the feedline between a radio and its antenna.

Its purpose is to optimize power transfer by matching the impedance of the radio to the signal impedance at the end of the feedline connecting the antenna to the transmitter. Wikipedia

An antenna tuner or antenna tuning unit is a network of variable inductors and capacitors that can be altered to counterbalance the effects of the inductive and capacitive elements of the antenna with the aim of making the antenna appear as a resistive load of 50Ω.
https://www.electronics-notes.com/articles/antennas-propagation/antenna-tuning-tuner-unit/what-is-an-atu-basics.php

Their basic purpose is to ensure that the antenna system impedance matches that of the transceiver to ensure maximum transfer of power between the radio and the antenna.

The ATU does not change the radiation efficiency of the antenna, just enables more power to be transferred to it, without damaging the radio

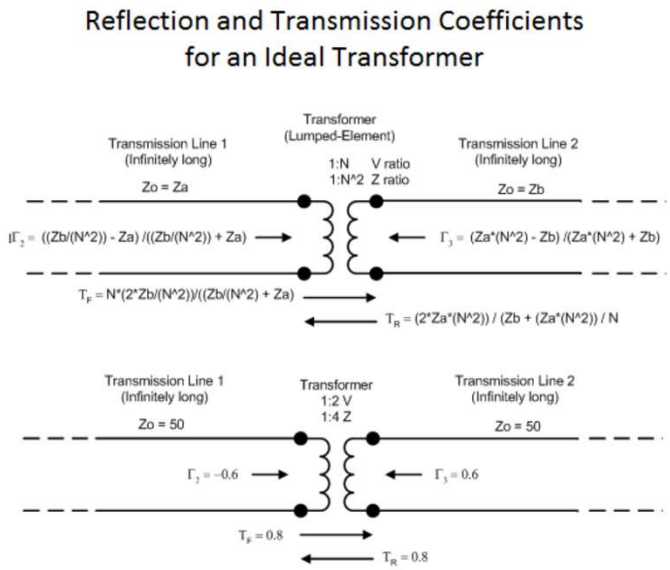
Basic Theory of Operation

An antenna tuner or antenna tuning unit is **a network of variable inductors and capacitors** that can be **altered to counterbalance the effects of the inductive and capacitive elements of the antenna** with the aim of making the antenna appear as a resistive **load of 50Ω**.

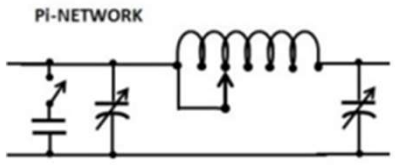
https://www.electronics-notes.com/articles/antennas-propagation/antenna-tuning-tuner-unit/what-is-an-atu-basics.php

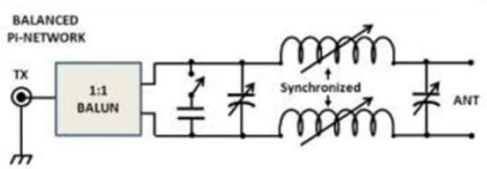
The theory is complex and 'not for the feint hearted' … BUT
We can simplify the concept

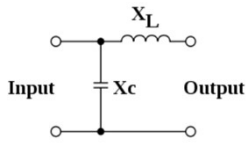
A component will exhibit a complex impedance when there a phase shift between the voltage across it and the current through it. A resistor has no phase shift between the current and voltage across it.

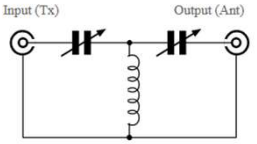


https://www.blueridgeamateurradio.com/antenna-tuner-science/how-antenna-tuners-work





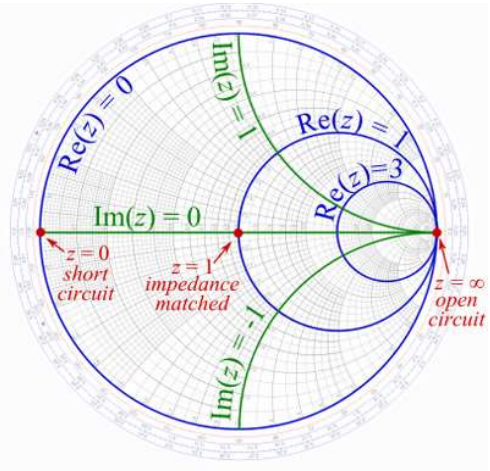


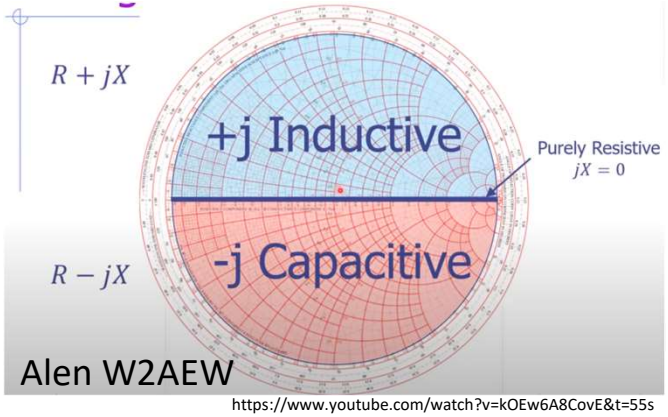


Antenna tuner - Wikipedia

Visualizing the Impact on a Smith Chart

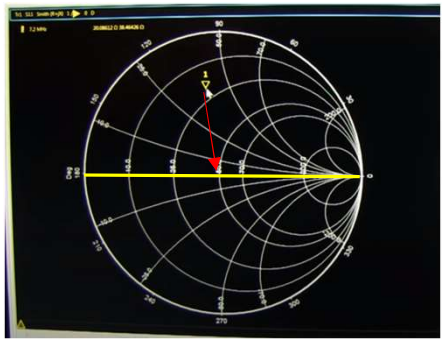
- The Smith chart is used to display the resistive and reactive portions of a **component's complex impedance** (z = ∞R + jX) versus frequency
- Complex impedance changes with frequency … a point on the chart plots a single frequency – a line plots a 'sweep'
- The **aim is to adjust the inductive and capacitive impedance of the antenna system so that we get a purely resistive 50Ω match**.

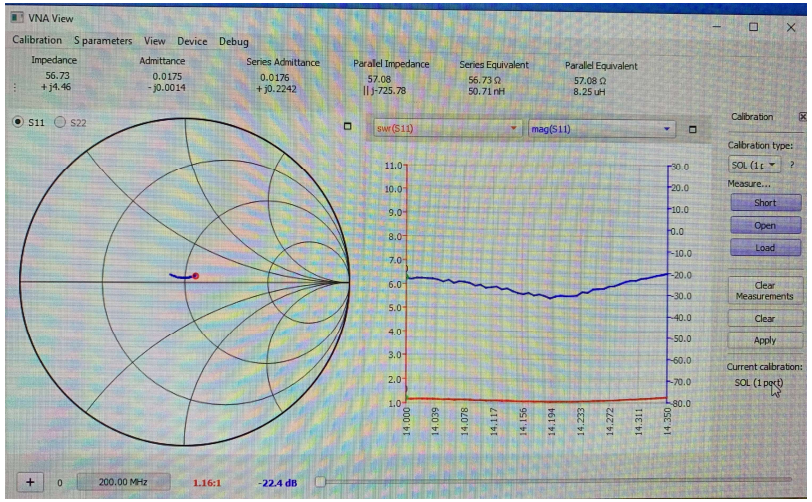




https://www.youtube.com/watch?v=kOEw6A8CovE&t=55s

https://www.youtube.com/watch?v=f8wJ0io95RE





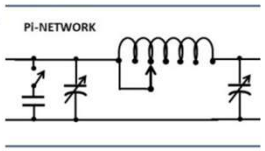
Visualizing the Impact on a Smith Chart

Great results can be achieved with the humble Nano VNA see Alen W2AEW's video

https://www.youtube.com/watch?v=xa6dqx9udcg&list=PL4ZSD4omd_AzQ7T0Dt4zTBW8sHLQHjqMQ

Tuner Types

https://www.blueridgeamateurradio.com/antenna-tuner-science/different-types-of-tuners



Tuner types

There are 4 classic antenna tuner types that are still used in all of today's modern antenna tuners. The following sections describe the pluses and minuses of each type and provides proof of efficiency for each.

A tremendous amount of additional information can be found on this very comprehensive Wikipedia page: https://en.wikipedia.org/wiki/Antenna_tuner

The PI Network

The PI-Network circuit, as depicted above, is found in both antenna tuners and as tank circuits in older tube style transmitters and linear amplifiers. The PI network is considered to be a low-pass filter and normally contains 3 tunable components. Generally the design calls for fairly large variable capacitor values and as such can be expensive to build. A concern for the Amateur Radio Operator is that the PI network, just like the T network, can produce resonance at more than one set of component values. The difference between the settings results in higher or lower efficiency and thus power lost to heating.

Component values generally range from 10-500 pf for the variable caps and 2-20uh for the roller inductor or tapped coil.

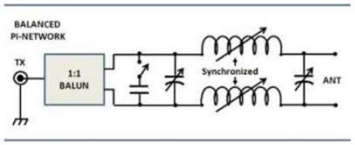
The circuit depicted above is unbalanced in that the "hot" side is treated differently than the "shield" side of the tuner. Basically it's not symmetrical and thus better suited for coax to coax antenna tuners.

Pros:

- Broad banded, able to match a wide range of impedances
- Can be modified to allow for the selection of lower value variable components by adding additional fixed components to the input side of the network
- Simple to implement

Cons:

- More knobs means more time required to find a good match
- More than one resonance point can be found using different component values
- If tuned to an incorrect resonance point, power loss due to heating of the roller inductor will result
- Power loss due to heating in this network is higher than that of the L network and significantly more than that of the symmetric PI network
- 500 pf capacitors can be large and expensive



The Symmetric PI Network

Definitely the most complicated tuner in terms of the number of components and their relationship to one another. The Symmetric PI network implementations are rare in the tuner world.

The symmetric PI-Network is definitely the most complicated design, although the fully switchable L network can be just as difficult to implement. This network topology is rare in the Amateur Radio world, due to the cost of assembling one of these units. Four separate components are required, including 2 large roller inductors and 2 variable capacitors. Additionally, this is a fully balanced network, meaning that the components are mirrored from side to side. Due to symmetric construction of this network, the entire matching section must be floated above ground (disconnected from the case) and because of this stray capacitance can play a factor in tuner performance.

Note that in this and other symmetric designs, a current balun (1:1) is required to achieve equal currents on both sides of the network and must be installed BEFORE the tuner instead of AFTER the tuner. Because the balun is installed before the tuner, the number of toroids required to provide the correct amount of common mode current impedance protection is reduced as the toroid is not subject to the wild voltages that may be encountered on the feed line side of the network.

Component values for the capacitors range from 10-300pf and the roller inductors have a value of 2-20uh. The roller inductors in this network must be linked together through a belt system, which further complicates the implementation of the device and adds to the additional expense of the unit.

Additional capacitance may be required on the output side when attempting to create a match on 160 with an antenna that is "short" for that band - i.e., less than 1/2 wavelength long. This is usually accomplished by adding switched capacitance in shunt to the output.

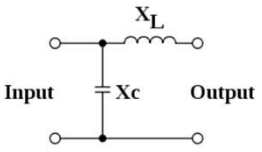
Symmetric PI network tuners can be a bit difficult to tune, but the resonant match will generally be very good. The most important fact about the symmetric tuner is that it is incredibly efficient. Where other tuners may lose up to 10% of input power due to heating, the symmetric tuner loses a fraction of that with no heating problems.

Pros:

- Provides a very good match on all frequencies where a "long" antenna is utilized -i.e., 1/2 wavelength or better
- Extremely efficient (See the section below for proof)
- Provides excellent common mode current stopping power when used in the configuration illustrated above
- Specifically designed for balanced antenna systems

Cons:

- Difficult to implement
- Requires more components and thus is more expensive
- Specifically designed for balanced antenna systems
- Improper construction can lead to stray capacitance issues



L-Network

L network tuners are very popular and can be found in all production tuners. The PI network tuner described above is really just 2 L network tuners connected back to front. The L network tuner is found in all electronic designs and is used, obviously, to convert either a low impedance to a high impedance or a high impedance into a low impedance.

TenTec 238 - 2Kw

The topology of this network must be changed to support the direction of match. Depending on whether the impedance is greater on the output or on the input side, the shunt capacitor must move from one side of the inductor to the other. There are many tuners that accomplish this task by using a set of rotary switches configured to move the capacitance from one side of the inductor to the other to further add additional capacitance to the network. Typical component values for the variable capacitors range from 20 - 500pf and up to 1000pf for fixed value capacitors. Roller inductor values range from 2uh to 20uh. In some matching conditions the larger variable components may be switched out altogether in favor of much smaller fixed value components. This is true for both the capacitors and the inductor.

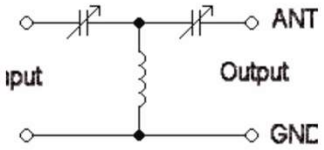
The L network depicted above is not symmetric and thus unbalanced, meaning that it is best utilized in coax to coax antenna tuners. The L network topology can be changed to be fully symmetric for better support of coax to ladder/window line transmission line.

Pros:

- Very few variable components required
- Will resolve to only one point of resonance for a given frequency and load impedance
- Inexpensive to construct if the matching requirements for the feed line and load are not particularly wild
- Lower power losses due to heating than the standard PI-network illustrated above
- Simple to implement for either hi-Z or low-z, but not both

Cons:

- In order to service both hi-Z and low-Z impedance matches, the topology of the network must be changed.
- Considerably more expensive and complicated to implement if switch gear, power and relays are required to cover both high and low Z impedances.



The T-Network

The T network configuration is found in the vast majority of commercial antenna tuners. good matching capabilities across a wide range of frequencies and can be configured wit tunable inductance (roller inductor) or a fixed switchable inductance (tapped coil).

The T network is a 3 component design that is found in the vast majority of 3 element tuners available today. Note that the T network is really just 2 L networks fixed back to back with a common inductor. This design allows for easier matching of the 50 ohm load on the input side as well as wide range matching on the load side. The network illustrated above is unbalanced and thus good for feeding a coax to coax implementation. This network has a higher loss factor than the L network described above.

Typical component values for the capacitors are 17-500pf and 2-20uh for the inductor

Note that this network topology can be implemented using a differential capacitor, meaning that the 2 capacitors are really part of the same component but with the rotors of the caps aligned 180 degrees out of phase with each other. This configuration effectively transfers capacitance from one side of the network to the other when attempting to match either high or low impedances. Additionally, by running this network using a differential capacitor, only one resonance solution will be found for any particular band.

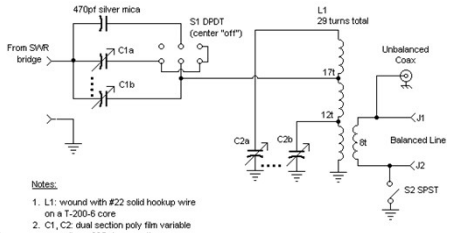
Pros:

- Widely used by the Amateur Radio community
- Very simple construction
- Components easily acquired as new or at swap meets
- Can be implemented with a differential capacitor

Cons:

- Higher power loss than the L network
- Differential capacitors are scarce and expensive
- When used with 2 independent capacitors, multiple resonance points can be found for a specific frequency

Z-Match Tuner

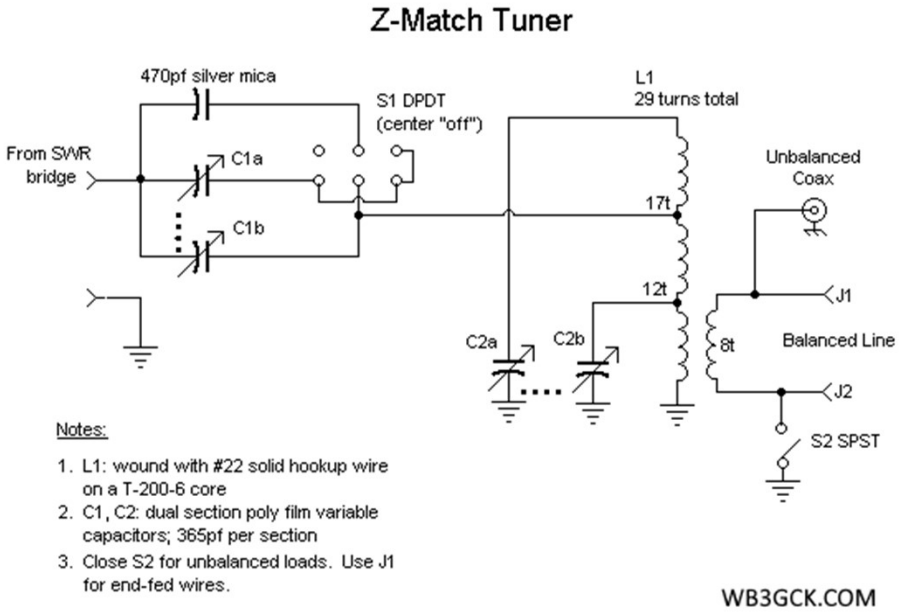


Notes:

1. L1: wound with #22 solid hookup wire on a T-200-6 core
2. C1, C2: dual section poly film variable capacitors; 365pf per section
3. Close S2 for unbalanced loads. Use J1 for end-fed wires.

WB3GCK.COM

Z Match – Popular QRP ATU



Advantages

- Matches balanced loads without the use of lossy baluns.
- Being a parallel resonant circuit, the Z-match can provide some band-pass filtering for your receiver and harmonic attenuation for your transmitter.
- A well-designed Z-match tuner has a high Q and is more efficient (less lossy) than other types of tuners.
- The fixed inductor simplifies construction (no taps or rollers needed).
- Using a toroid inductor and some small poly-film variable capacitors, the Z-match can be built into a very compact package. Appeals to QRPers.

Disadvantages:

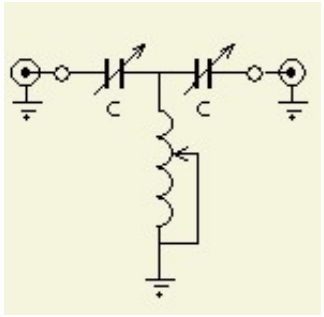
- Tuning is usually very narrow and can be a bit touchy
- The range of impedances that can be matched is not as great as in other designs, such as the “T” configuration.

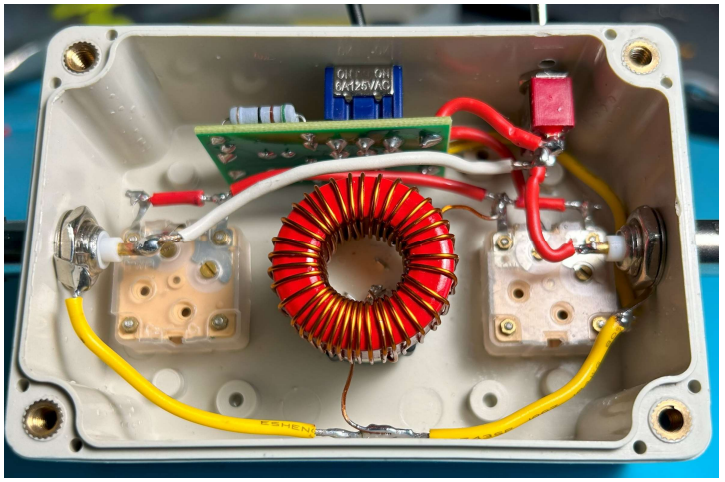
https://wb3gck.com/2020/04/18/a-homebrew-z-match-transmatch/#:~:text=Being%20a%20parallel%20resonant%20circuit,than%20other%20types%20of%20tuners.

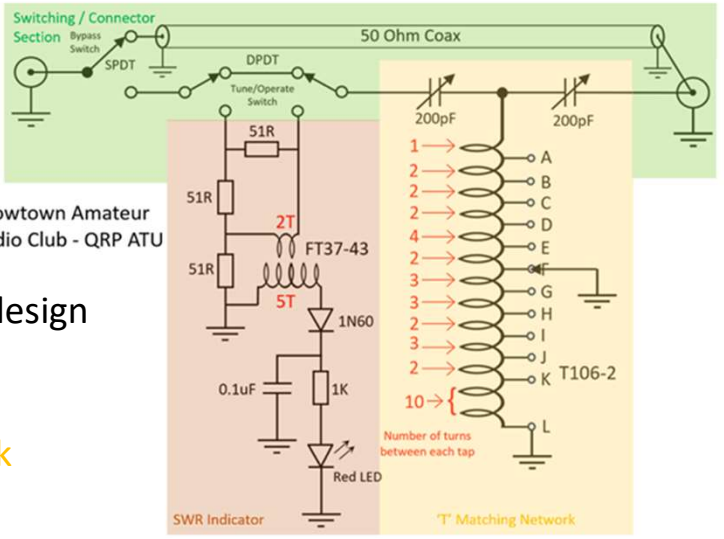
The Cowtown ATU uses the T Network

The T network configuration is found in the vast majority of commercial antenna tuners.

- It provides **good matching capabilities across a wide range of frequencies** and can be configured with either a tunable inductance (roller inductor) or a fixed switchable inductance (tapped coil).
- T network is really just 2 L networks fixed back to back with a common inductor.
- This **design allows for easier matching of the 50Ω load on the input side as well as wide range matching on the load side**.
- The network illustrated above is unbalanced and works well in a coax to coax implementation.







Cowtown Amateur Radio Club - QRP ATU

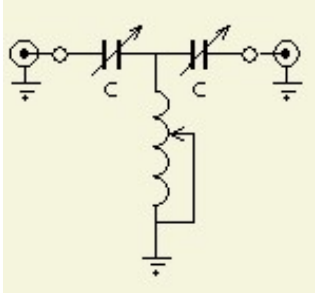
3 Components to the design

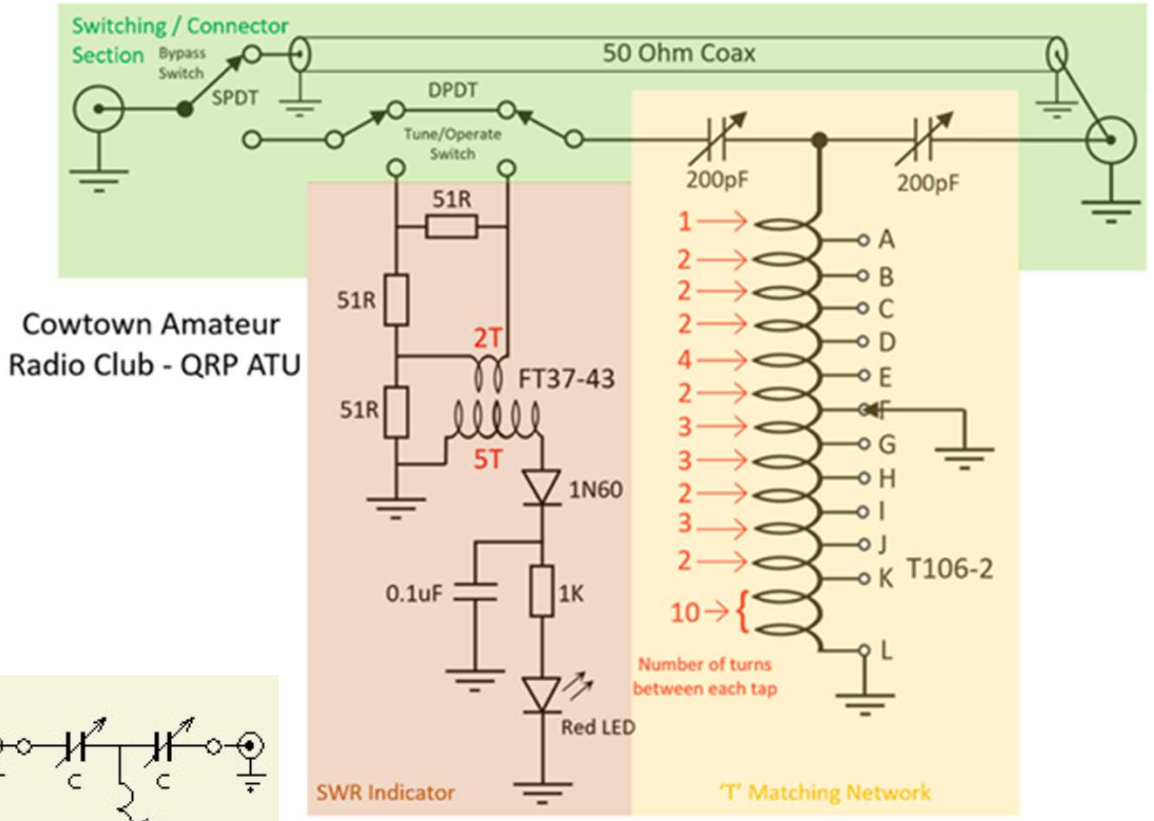
- Switches
- SWR Indicator
- T Matching Network

Lets Take a Closer Look at the ATU Circuit

3 Sections to the design

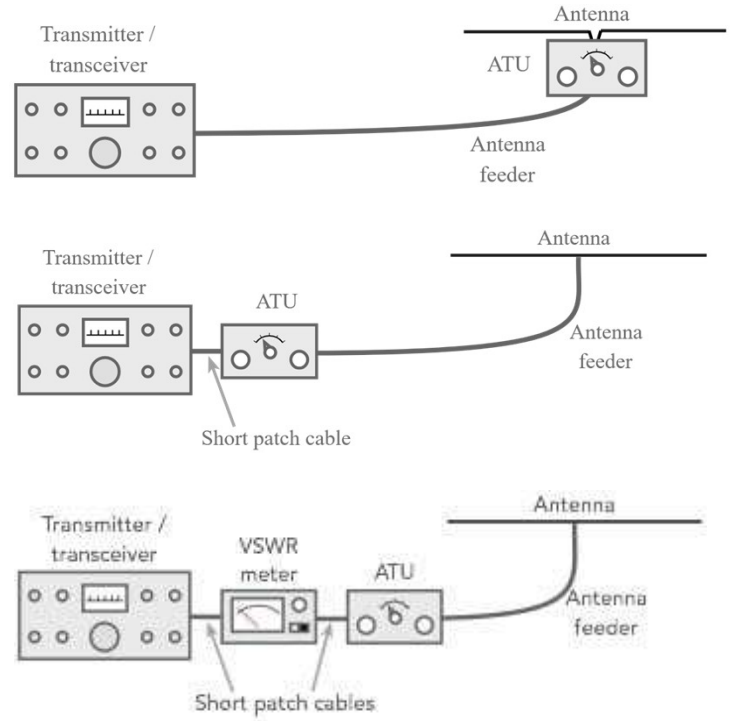
- Switches
  - Bypass
  - Tune / Operate
- SWR Indicator
  - Resistive Wheatstone Bridge SWR Sensor
    - When the antenna impedance is 50Ω the bridge is in balance and no voltage appears across the primary of the toroid.
    - As the impedance departs from 50Ω a proportional voltage appears across the transformer and lights the LED.
    - The SWR Bridge introduces a 6dB loss when in use, so is switched out for operation.
- T Matching Network
  - Utilizes two 200pF Polyvaricon capacitors
  - 12 Tap (variable in steps) inductor





Where to Locate the ATU

- The ideal position for the location of the antenna tuner is at the point where the antenna is fed by the feeder. In this way, the antenna can be matched to the feedline and all the way through the system there are good matches, and low SWR levels.
- BUT …. Not very practical – so more practical to locate next to the radio.
    - It is a common misconception that a high standing wave ratio itself causes loss. This is not true… When a high standing wave ratio exists, this results from power being reflected back along the feeder as a result of a mismatch. When it enters the antenna tuner, it is reflected back along the feeder to the antenna where a proportion is radiated and some reflected back along the feeder again.
    - With an SWR of 2:1, 11% of power is reflected and 89% is radiated. **If you can transfer more power to the antenna, you get 89% of the extra power radiated.**
- It is worth placing a VSWR meter in the line to monitor the actual level of standing waves seen by the transmitter. Note: a separate meter may not be required if one is incorporated into the transmitter or the ATU, unless it is more convenient to monitor the level separately.



https://www.electronics-notes.com/articles/antennas-propagation/antenna-tuning-tuner-unit/what-is-an-atu-basics.php

Types of ATU – Automatic / Manual

Prices Shown US$ Oct 23 pre-Tax & Shipping

~ $215

~ $120

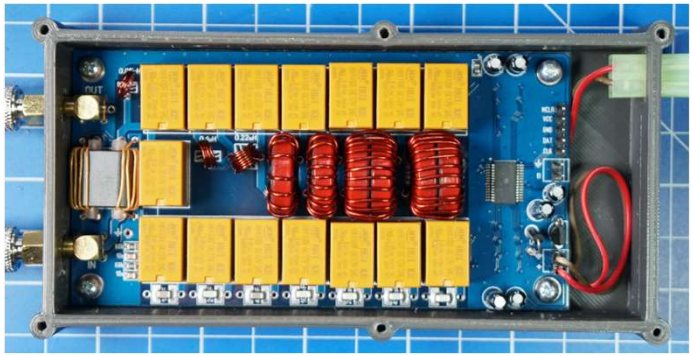
QRP – 10w

~ $285

~ $30

QRP – 5W

~ $310



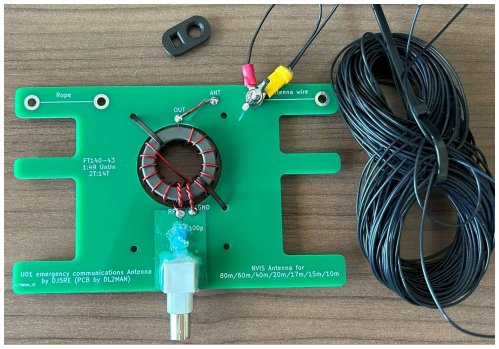
~ $60

100W

‘Buildathon’ 2023

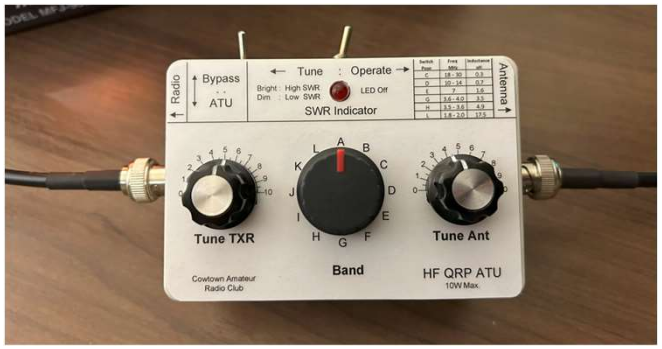
The Buildathon set out to provide three practical kits this year:

- Project #1:
  EFWH Antenna



Project #2:
QRP Digital Mode HF Transceiver (ADX)

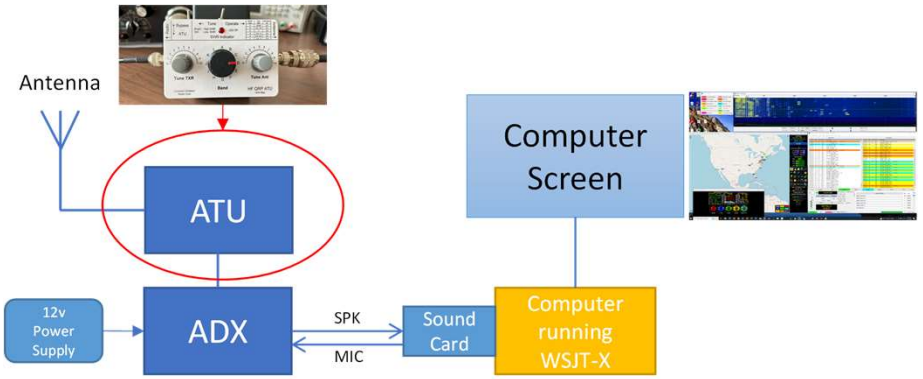
Project #3:
QRP Manual ATU



The ATU project complements the previous 2 projects and provides a working QRP capability for shack and field operations

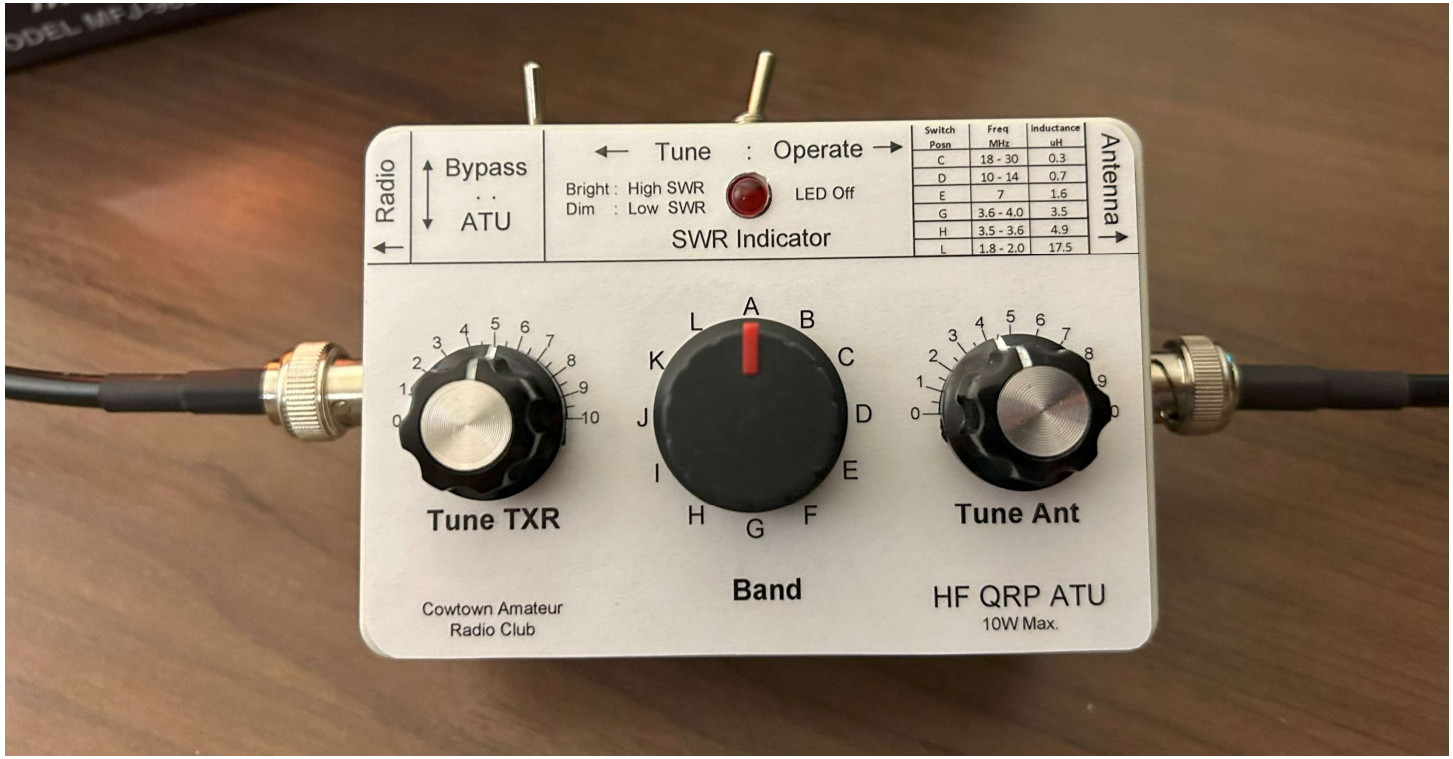
The project introduces the following Elements:

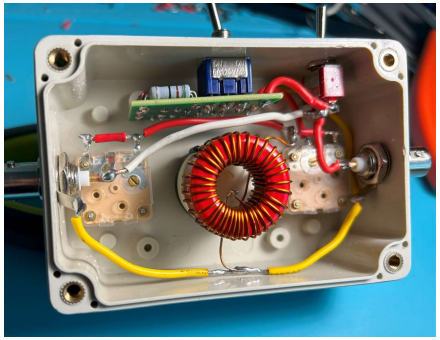
- Hardware Mounting and Integration
- Tapped Inductors
- Emphasis on mechanical as well as electrical construction
- New theory and operating concepts

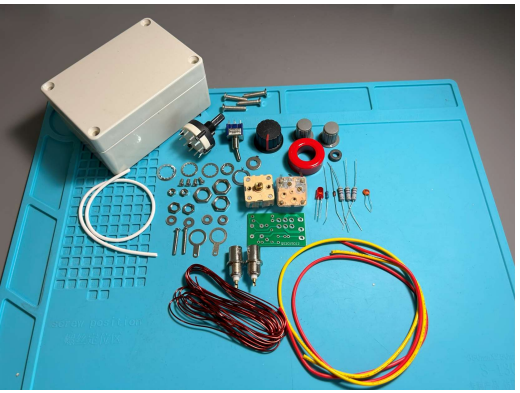


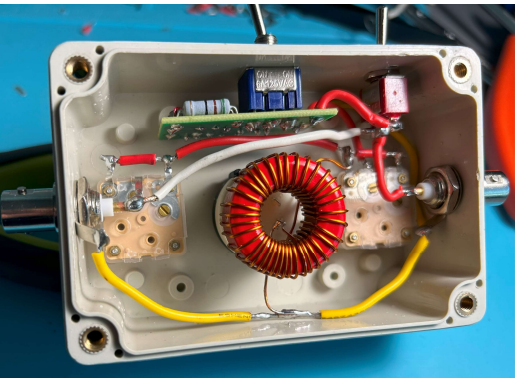
‘Buildathon’ 2023

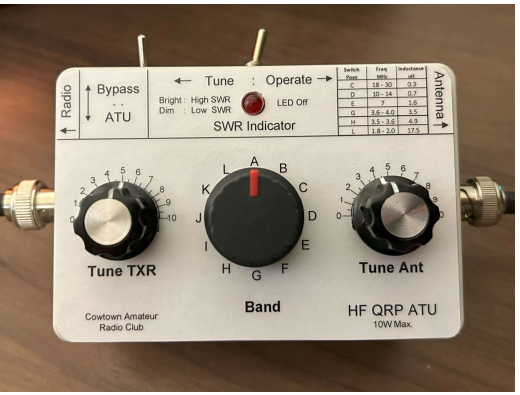
- Project #3: HF QRP Antenna Tuning Unit – Lets take a closer look at the build process





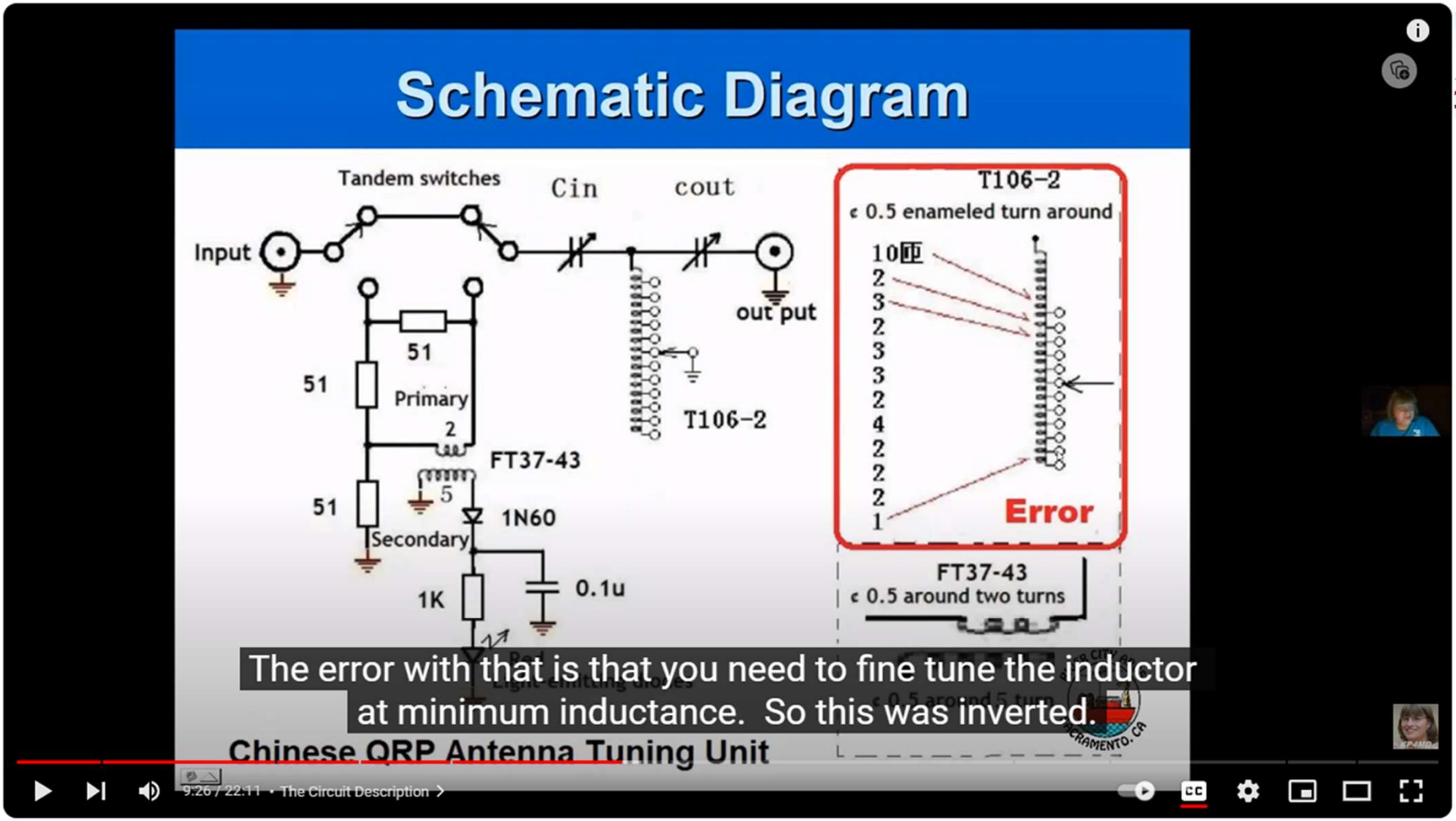






Buildathon Project #3 - QRP ATU

- Provides a HF Antenna Tuning Unit (ATU) capable of supporting QRP radio's – up to 10w$_{max\ (SSB)}$, and is a great little pocket sized and 'fit for purpose' ATU – It works well
- Is utilizes a 'T' matching network consisting or a switched inductance and two variable capacitor – matches across a wide range of frequencies
- Has built in SWR indicator which can be used when tuning the antenna with the ATU
- Cowtown Kit incorporates:
  - ATU bypass switch
  - Templates to facilitate the correct drilling and placement of components, and a high-quality panel overlay
  - Detailed construction manual (similar in detail to the Cowtown ADX manual) see: https://github.com/VK2ARH/Cowtown-ADX-Project
  - Corrected all the errors with the original 'Chinese kit'
    - Identified by Carol KP4MD in her excellent video on the topic → https://youtu.be/JceLhTV28oI?si=10w3uxhJedoQut1m



Fixing a Chinese "QRP Manual Days" Antenna Tuner Kit

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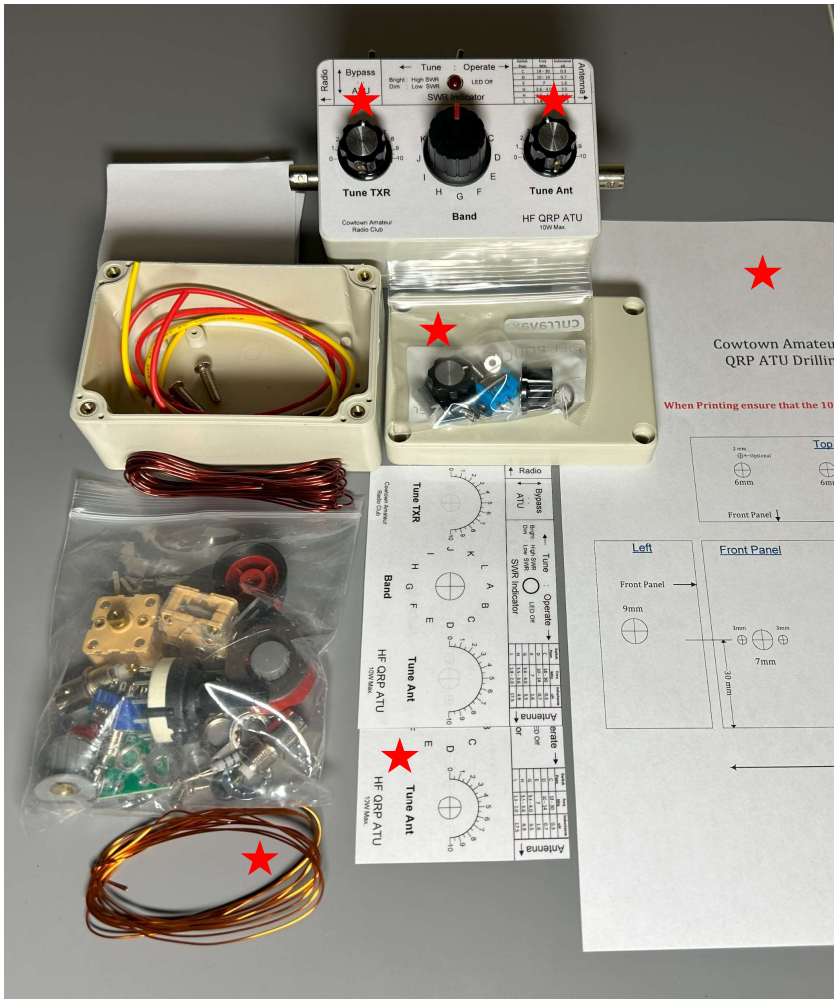
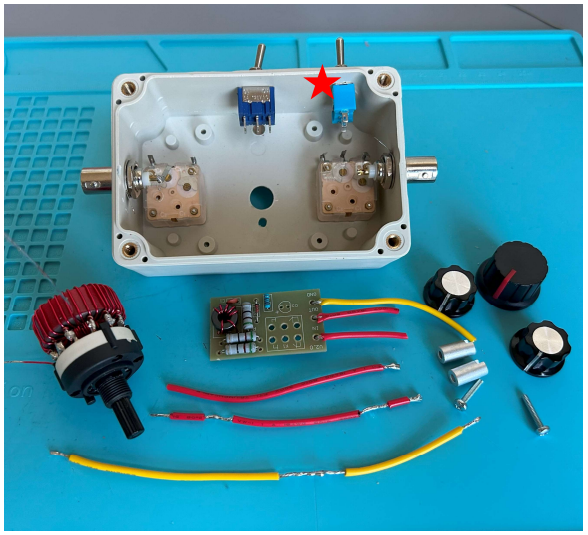
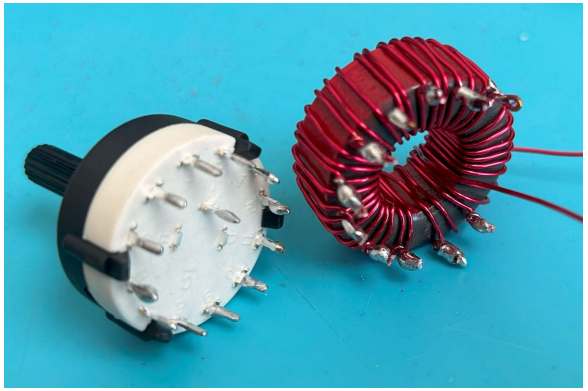
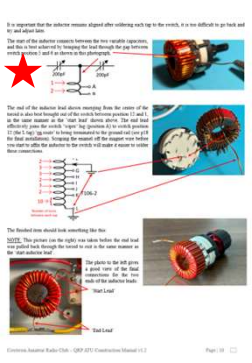
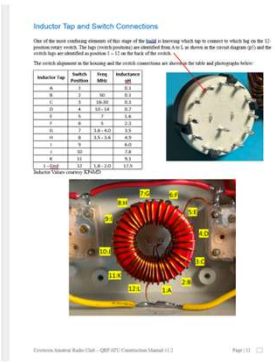
The Cowtown Kit – Differences from the Original Chinese ‘Manual Day’ Kit

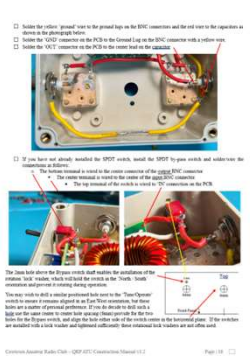


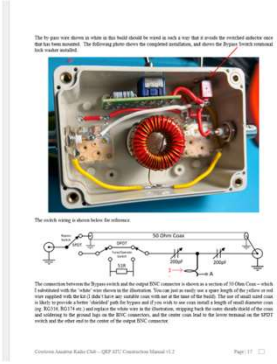












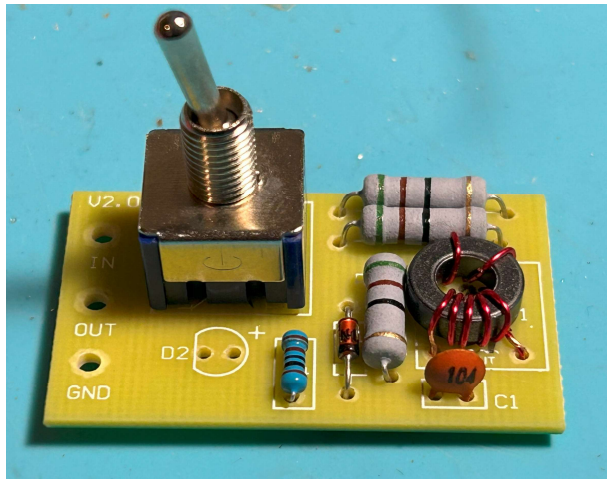
23 Page Construction Manual

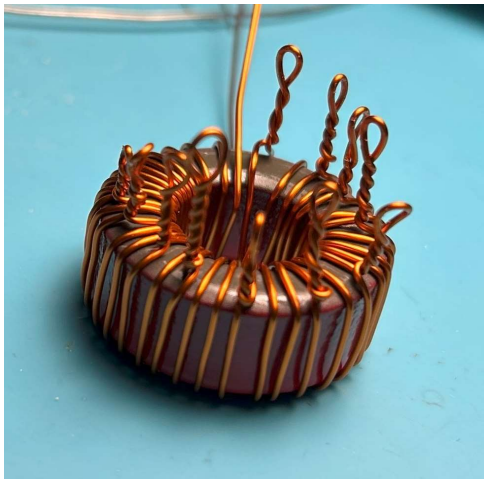
Corrected all the errors with the original kit

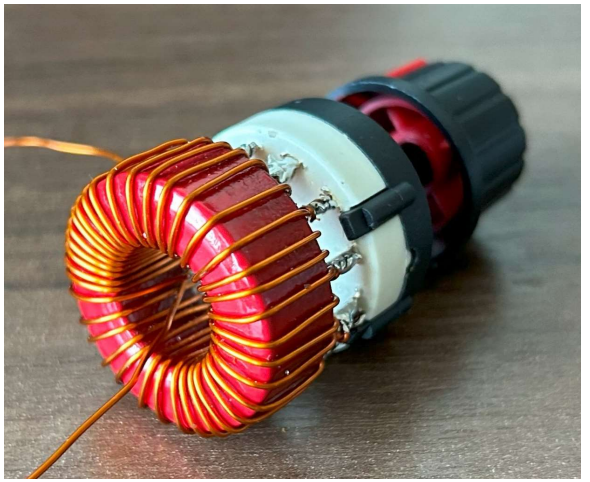
https://github.com/VK2ARH/Cowtown-ATU-Project

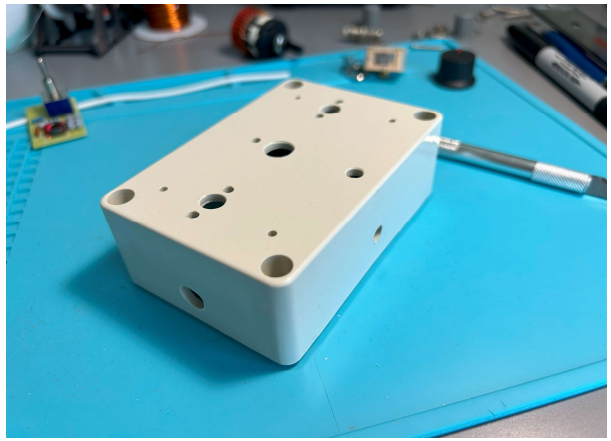
‘Buildathon’ 2023

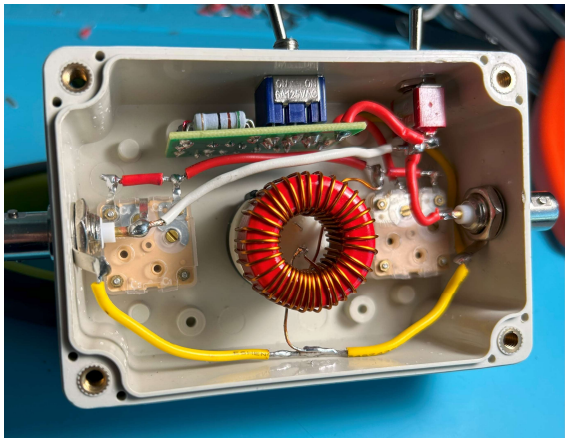
- Project #3: HF QRP Antenna Tuning Unit – Stages of the Build



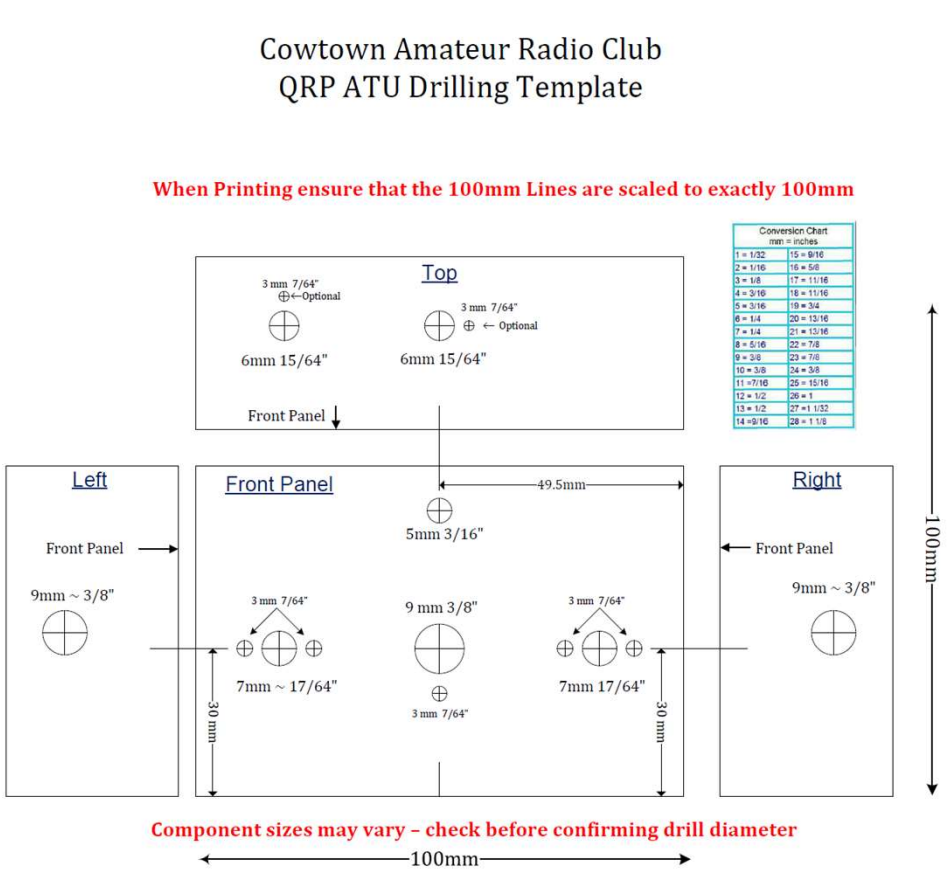


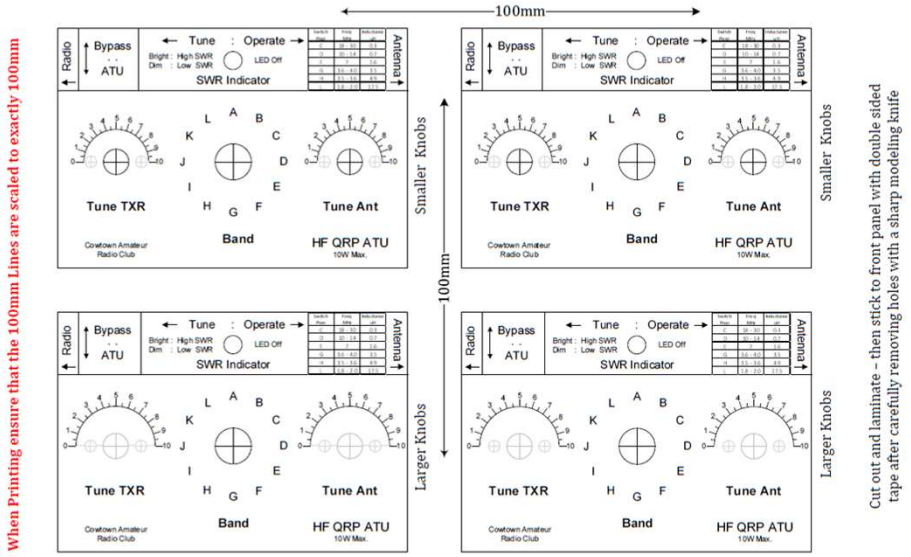




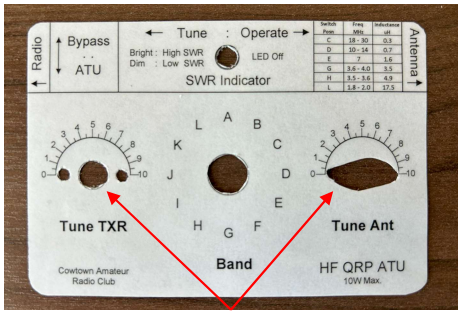


Drilling Template and Panel Overlay



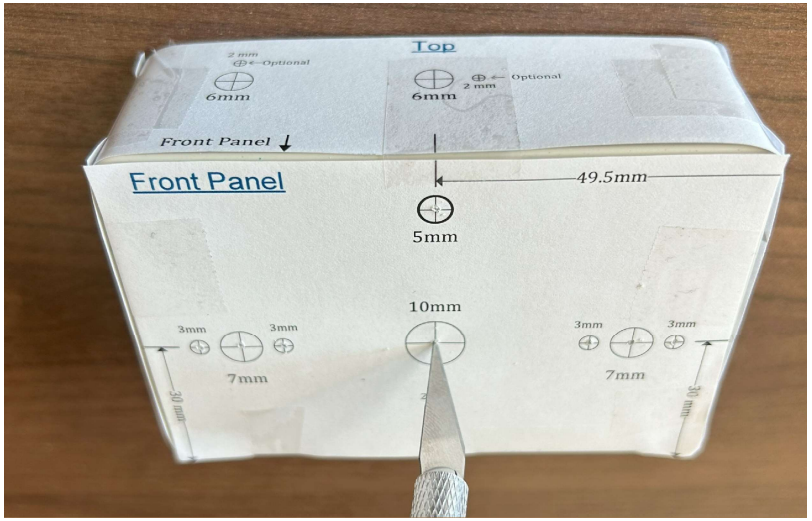


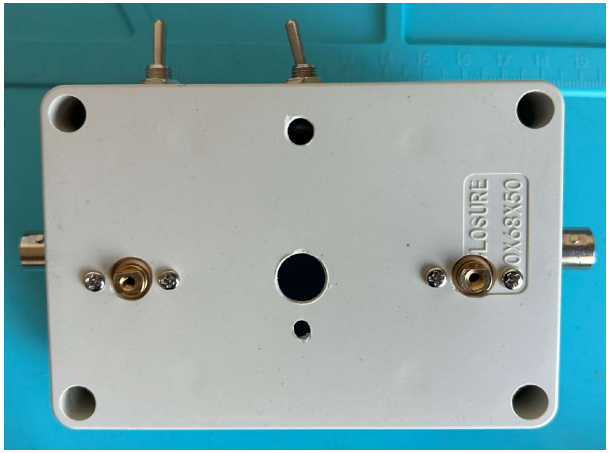
Two Sizes of Scale provides for different sized tuning knobs

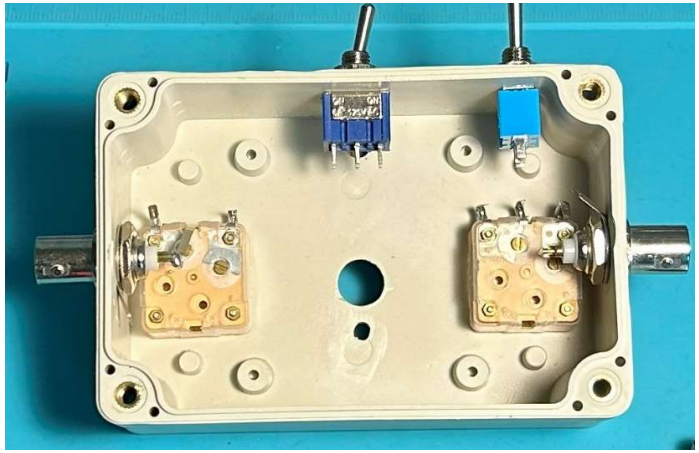


Tuning Knobs cover the holes so either option OK

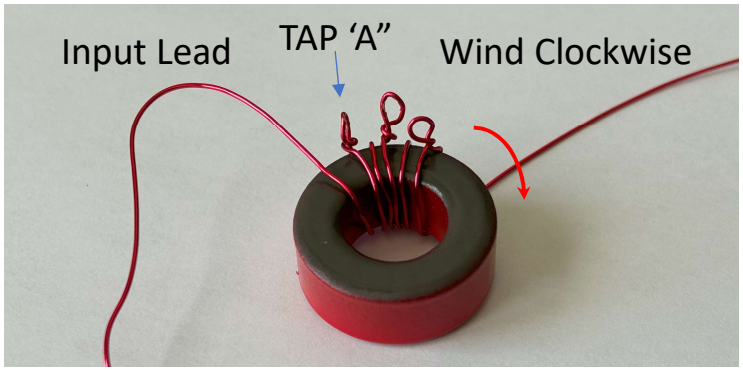
Preparing the Enclosure



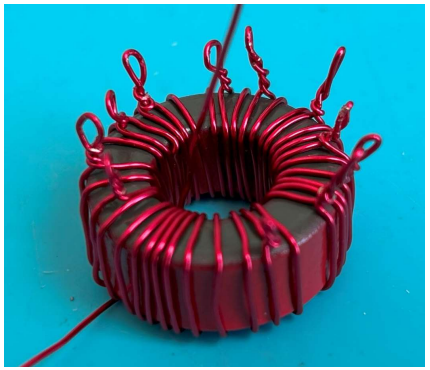




Building the Tapped Inductor

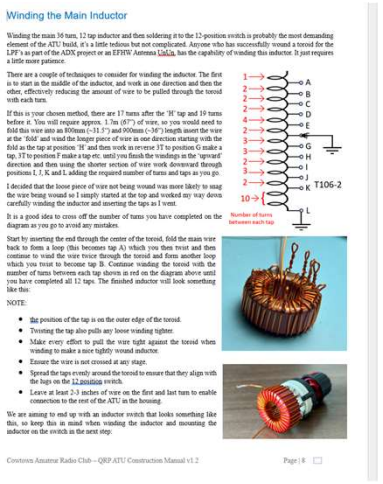


Starting the Wind



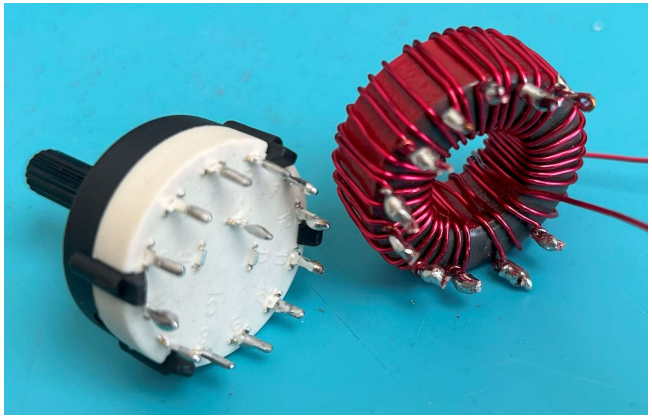
The finished Inductor

Keep it tight – twisting the taps helps

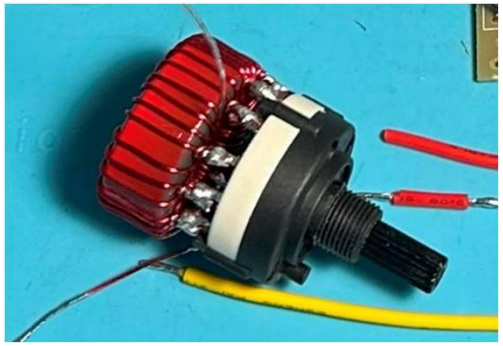


Read and follow the manual

Take your time and count / mark off the turns between the taps as you go.

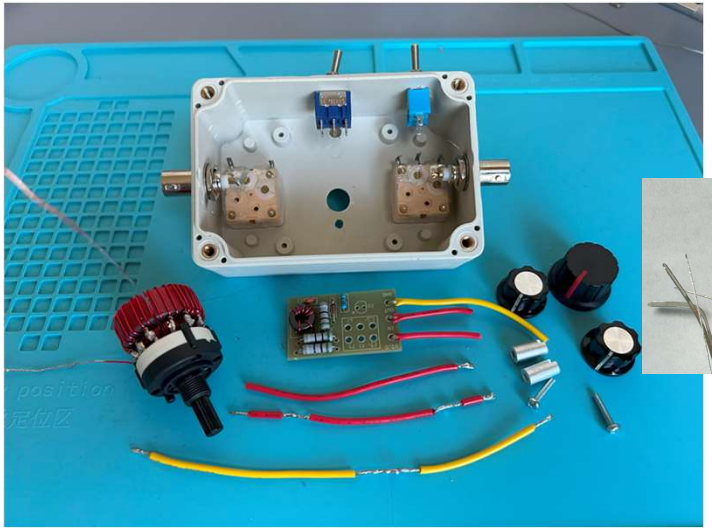


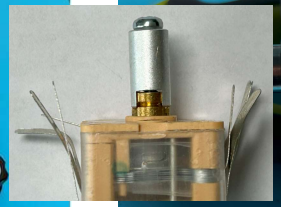
Scrape and 'Tin' the Taps and the switch lugs

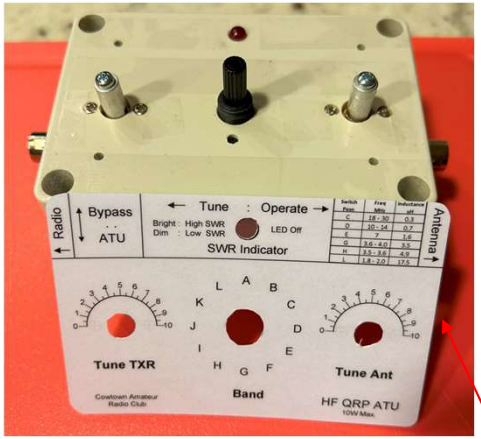


Spread the Taps to Align with the lugs on the switch and progressively solder to the switch

Final Assembly







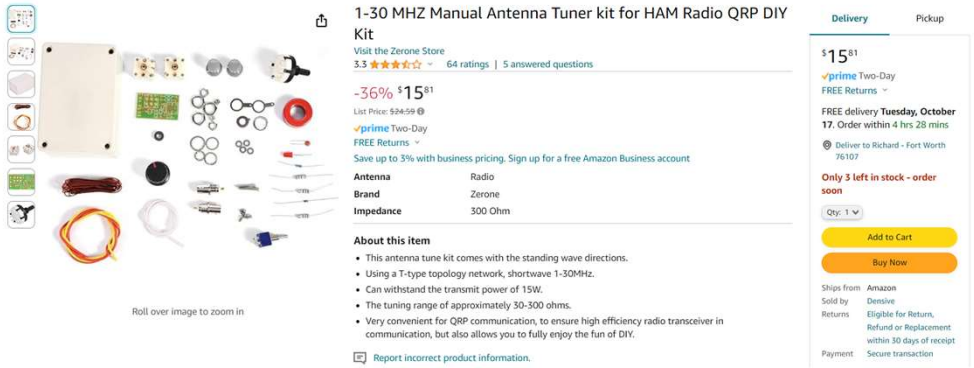
Cut to ensure no overlap of edge of enclosure

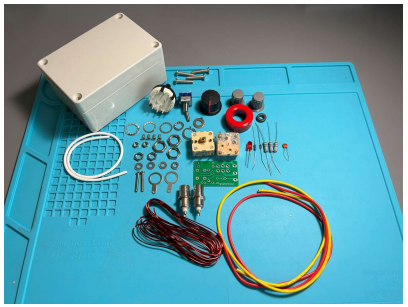
- This is a mechanically challenging project
- You'll learn a lot if you haven't done this sort of project before
- Take your time
- Build in stages
- Check your work at each stage
- It's not a race
- Take pride in your work
- Enjoy the results

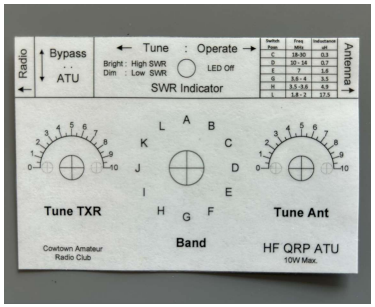
The ATU Project
'Buildathon' Event #3

Logistics and Details:

- **Cost of the kits is $15** - now available for collection
- 20 Kits were reserved – additional Chinese kits can be sourced from Amazon, but these kits don't have the Cowtown Extra's.
- I have a small number of extra tuning capacitor 'knobs and shafts' if anyone needs them. $3 per set of 2. I also have spare panel overlays and drilling templates







- All documentation can be downloaded and printed from:
  - https://github.com/VK2ARH/Cowtown-ATU-Project
  - Club Groups.io site – Buildathon Project Files

Supported build session on Saturday October 21st commencing with breakfast next door to the club at 8.00am

QRP – ATU Manual Antenna Tuning Unit

Documentation from the Cowtown Amateur Radio Club (Fort Worth, Tx) ATU Project and can be found here:

https://github.com/VK2ARH/Cowtown-ATU-Project

Contacts for the Cowtown Amateur Radio Club:

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https://www.cowtownarc.org/home