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Antenna Tuners: Setting the Record Straight

Sometimes the antenna tuner gets a bad rap and for many the antenna tuner has become a redundant relic of the past. In this article we are going to talk about what they are, what they do and answer the question, do you need one?

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Introduction

Over the winter months I started thinking about antenna tuners. There were several reasons for this. One was due to some of the discussion I had heard over the local repeater and second was the dissatisfaction I was having with my own antenna tuner. Consequently I started to really dig in and learn as much as I could about these mysterious magic boxes. What I came away with was an appreciation for what these devices do and a humility for the hams who hand built their own tuners.

Before we go further let's clarify some terms. In many ARRL publications, these devices are referred to as a transmatch, meaning to match the transmitter to the transmission line. The other popular name for the line-matching network is antenna tuner. I think the most accurately descriptive name is "*antenna tuner*" because this name is descriptive of what these devices actually do. You'll may also see the term "ATI" in foreign publications, and ATU in still other publications. In this article I will refer to these magic devices as simply "tuners."

As I think back to every HF ham station I've put together, including my mobile installations, the antenna tuner was always one of those black boxes I included. Of course when I got into ham radio in 1977 our radios didn't have built in tuners, so every ham I knew owed one and promoted their use. So it's always been a part of my ham station and I never questioned the need.

The goal of this article is to help you understand a little more about these devices so you can make an informed decision if you find yourself in a position of wanting to purchase a tuner. As I've mentioned in other articles the reviews we often see on QRZ and other Internet forums are subjective and often the reviewers lack a basic understanding of the subject matter. They think because it can tune their antenna and they were able to contact a station a few hundred miles away it's a great device. What they don't realize is there is much more to the story. I was bamboozled by some of these reviews as well and it's one of the reasons I'm writing this article. I want to set the record straight and help you not make the same mistakes I made or have some of the same misunderstanding I had and more importantly address many of the questions I often hear new hams ask.

Today almost every HF radio on the market has a built in tuner and consequently we have started to question the need for an external tuner. That will be one of the questions we are going to tackle in this article. But not just yet. I want to start by exploring some misconceptions regarding antennas and the need for a tuner.

1. An antenna operated at its resonate frequency doesn't need a tuner. *False, resonance only means the feed point is resistive and does not infer a low SWR.*

2. Resonant antennas radiate better than non-resonant antennas. *False. The pattern may change at resonance but the antenna will still need to be matched to ensure there is a maximum transfer of power to the antenna system.*

3. Most antennas are resonant at only one frequency. *False, all antennas have multiple resonate frequencies. However some of those harmonic frequencies may be outside of the ham bands.*

4. The ability to match an antenna is more important than efficiency when choosing a tuner. *True, if the antenna tuner doesn't provide a match to the antenna system not much else matters.*

5. The SWR presented by an antenna is minimum at the fundamental resonant frequency. *False, SWR may be at a minimum but it is not a requirement.*

6. A tuner placed at the antenna will result in a more efficient system than one placed in the shack. *Generally speaking this is true, by tuning in the shack you will have loss in both the tuner and the transmission line. By tuning at the antenna you will have minimal loss in the feedline and most likely only a small amount of loss in the tuner. See also 9 below.*

7. Tuners should not be cascaded? *There seems to be two different schools of thought on this and consequently no definitive answer. What I have found that seems hard to argue with is the following: "A transceiver's or amplifiers internal auto-tuner should be disengaged when using an external tuner. Cascading tuners can reflect high reactance values back into the auto-tuner and/or LPF bank. As a result, dangerously high RF voltages can appear across capacitors in these networks, leading to component failure." For my part I never cascade tuners, but then again I've never had a need to. I've found that often by adding an impedance transformer (balun or unun) at the feed-point allows my tuner to establish a match. FYI: An LPF bank is the bank of lumped value inductors and capacitors often found in many auto tuners.*

8. A tuner in a radio that is specified to match a 3:1 SWRs will be able to provide a match for all 3:1 SWRs. *False. There may be some combination of impedance and capacitance the tuner may not be able to compensate for even if the SWR is 3:1.*

9. Does Coupler Use = Incompetency? *Claims made by some would imply this is true, "I don't need a tuner since my antennas are designed properly. Tuners have too much loss." This is false! The losses in a tuner are often fairly small. But there are mitigating factors. Poorly designed tuners can exhibit a fair amount of loss at high SWR's so buyer beware.*[1], [2]

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[1] See: *"Ham Radio Basics: Jim W6LG Tests Antenna Tuners, Which One is the Most Efficient",* https://www.youtube.com/watch?v=LsAZPc65xoM. This is a short video where Jim looks at several different tuners and measures both the input and output of the tuner. What he leaves out is information regarding the SWR of the antenna he was tuning so we have no idea how big the mismatch is or how it might have changed as SWR changed. The expectation is the higher the SWR the higher the loss in the tuner.

[2] See: "*ARRL Guide to Antenna Tuners, a Radio Amateur's Guide to Antenna Matching*" Publish by the ARRL. This is one of the only books I could find on Antenna Tuners. This book is a bit thin on content but I found the

10. A tuner will improve the performance of my antenna. *False! A crappy antenna with a tuner attached is still going to be a crappy antenna. The only difference is the radio will at least be able to transfer maximum power to the crappy antenna. One should always start with the best antenna and transmission line they can deploy which will always be limited by each Amateur's unique set of constraints.*

What Does an Antenna Tuner Actually Do?

Before we get too deeply into our discussion of antenna tuners let's first define what an antenna system is. An antenna system consists of a radiator, a transmission line, and a ground. These three components are all a part of the antenna and must be dealt with as a "SYSTEM". Even with a resonant half-wave dipole or a vertical, the ground is part of the system because of the distributed capacity between the radiating element and the ground. Therefore we need to think about not just the radiating elements but the overall system and not its individual components.

Let's also look into some generalities about antennas. We understand that a resonant antenna is one in which the radiator is cut to a specific length and is resonant at a given frequency and some of its harmonic frequencies. As we move either up or down in frequency from resonance the radiator is no longer resonant and therefore, the feed-point impedance becomes a combination of resistance and reactance rather than a pure resistance.

As we go higher in frequency the radiator will appear to be too long and the radiator will show inductive reactance as a part of its feed point impedance. It follows that as we go lower in frequency the radiator will appear to be electrically shorter and will show capacitive reactance as a part of its feed point impedance. In conventional antenna theory, this condition is true regardless of the antenna type or its configuration. This does not mean the antenna stops radiating off-resonance, but it does mean the feed point impedance is no longer a pure resistance and its magnitude is now different than it was at the resonant frequency. It also means that if the transmission line were exactly matched to the radiator at its resonant frequency there would be no reflected RF energy. But we all know that using a transmission line that exactly matches an antenna's feed-point impedance is not an option if that feed-point impedance is other than 50 Ω. This is where the antenna tuner comes into the picture.

Now let's turn our attention to what an antenna tuner actually does. When the antenna tuner is properly adjusted, it tunes the "antenna system" to resonance. Resonance is reached in any Inductive/Capacitive circuit when the inductive reactance and the capacitive reactance are made equal. A properly designed and adjusted antenna tuner performs what is known as a "conjugate match." This is just another way of saying, the "system" is tuned to resonance. What this means in a broad sense is the inductive and capacitive reactance in the circuit are equal. Conjugate

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survey of tuners to be very informative and helped me to understand just how much loss can happen in a tuner especially at higher SWR.

match theory states: "In a multi-port system, if the reactance (inductive or capacitive) is tuned out at one port in the system, it is tuned out at all ports in the system," and an antenna system is certainly a multi-port system.[3],[4],[5]

For purposes of this discussion, let’s consider the typical center-fed dipole. The feed-point impedance is influenced by the radiator length, its height above real ground, the distance to and size of near-by conducting objects. In most cases but not always, our antenna tuner is located in the shack. The electrical length and natural impedance of the transmission line will also influence the magnitude of the impedance presented to the antenna tuner. Remembering conjugate match theory, the tuner must cancel out the reactance presented by the transmission line to the tuner, and it must also transform the remaining resistive component to 50 Ω, which is what all modem Amateur transmitters want to see. It does this as follows: if the reactance presented to the tuner by the transmission line is "inductive", then the tuner must present to the transmission line with an equal amount of capacitive reactance. And if the reactance presented to the tuner is capacitive then the tuner must present to the transmission line an equal amount of inductive reactance.

What that infers is that the reactance (if any) will be canceled out. This means that the radiator is now tuned to the operating frequency, regardless of its length, height above ground, or the influence of surrounding conducting objects. It does not mean the natural impedance of the transmission line has been matched to the feed point impedance of the radiator. Despite this, with a given RF power from the transmitter and since the radiator is now at resonance at the operating frequency, the same RF current will flow in the radiator that would flow in a radiator that is resonant (cut to an exact length) at that operating frequency. The key point is the tuner does NOT change the SWR between the tuner and the antenna, but it does present an exact impedance match between the transmitter output and the tuner input, which results in the maximum transfer of power from the transmitter, to the tuner, to the transmission line and to the radiating element/s.

Without a doubt these facts are what give rise to the idea that the antenna tuner only fools the transmitter into thinking it is matched to the antenna and nothing else. The point here is the fact that maximum RF current is now flowing to the radiator. Without the tuner establishing a

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[3] “*Reflection III: Transmission Lines and Antennas*”, M. Walther Maxwell, W2DU, CQ Communications. http://www.w3pga.org/Antenna%20Books/Reflections%20III.pdf This book is out of print but can be found on the used book market. It’s a book that I highly recommend if you want to understand more about Transmission lines and SWR. In his book there are a couple of chapters specific to the Antenna tuner. One is on the conjugate match and other on how the antenna tuner actually works. Be prepared for some difficult math.

[4] “*KL7AJ on the Conjugate Match Theorem*”, https://owenduffy.net/blog/?p=11618#:~:text=One%20of%20the%20most%20useful%20%28and%20sometimes%20astonishing%29,CONJUGATE%20of%20the%20load%20impedance%20%28or%20vice%20versa%29

[5] “*Conjugate Match Myths*”, Steve Stearns, K6OIK. https://www.nonstopsystems.com/radio/pdf-ant/article-6OIK-conj-mtch-mths.pdf If you decide to read this paper let me warn you in advance. Get ready for some serious physics! In spite of all of the formulas there are some nuggets to be found in this paper.

conjugate match the RF power from the transmitter would be reduced due to the fold back circuits in the transmitter.

This is also important in systems where the tuner is located at the feed point of the antenna. By minimizing the SWR on the feedline, losses in the feed-line are minimized. And given the antenna is connected directly to the tuner all the RF that makes it to the tuner is transferred directly into the antenna and is radiated into space. The bulk of the loss in such a system is only the loss in the transmission line. And given the SWR on the transmission line is minimized there will be minimal loss in the transmission line.

In a properly designed and adjusted antenna tuner, this conjugate match process will be carried out with a high degree of efficiency. Another likely point of confusion is the well-established concept that in order to obtain maximum power transfer in a system, all interfacing impedance must be matched. But, in the case of the antenna system the objective is to obtain maximum RF current flow in the radiator in order to couple maximum RF energy to space. The conjugate match does this without all interfacing impedance in the system being matched.

How Much Loss Does a Tuner Introduce?

Losses from the insertion of the antenna tuner between the radio and transmission lines seems to be the biggest objection that comes up for why folks don't want to use a tuner. This objection doesn't make much sense when you consider the benefits the antenna tuner provides. But let's look at this closer. There are two questions: how much loss can I expect and how do I minimize the loss? Both are good questions with good answers. Unfortunately, they are not simple answers. But some old material combined with some new material can make the answers easier to come by. Those who like math can focus on the equations, while those interested in operational matters can concentrate on the tables and the resulting rules of thumb to minimize losses.

Most antenna tuners today use a C-L-C network or simply a "T" network. When you see terms like C-L-C think **I**nductor, **C**apacitor. Although rarely seen anymore are the other configurations, the simple "L" (L-C), and the more complicated networks such as the "Pi", "SPC", Ultimate Transmatch, and the Z network.

The old material that contributes to determining tuner losses appears in Terman's Radio Engineers' Handbook published by McGraw-Hill in 1943, see pages 210-215. I have the 4th edition of this book published in 1955 and have read Terman's analysis of classic impedance-matching network. In that book the "T" and "Pi" matching network is introduced. The relevant term for considering tuner losses is the term, "delta", which is a simplified measure of power dissipation in networks. For any impedance matching network, the primary power dissipation culprit is the inductance.

The following material is based on work done by L.B Cebik. It will get a bit technical, but it's necessary in understanding tuner losses. To quote Dr. Cibek:

"The efficiency of these L-C networks is dependent upon the impedance transformation ratio and the phase shift. PI networks and L-C-L Tees generally exhibit a large angle of phase retardation, while the C-L-C Tee circuit shows a large angle of phase advance. In contrast, simple L-networks show small angles of phase advance or retardation. Losses increase with increasing transformation ratios and tend to be larger when the phase shift is either very large or very small. The delta-figure takes both into account. (Note, in some explanations of networks, but not in all, Terman's delta goes under the name of "working Q," "circuit Q," or "network Q.")"

At this point Dr. Cebik inserts some interesting formulas and makes some speculations regarding coil Q and losses in the capacitor but I think for the purposes of this article we will stop here and touch on the typical losses that might be found in the various tuner configurations. However we will make one general statement that plays a key role in tuner loss. Efficiency is highest with the highest coil Q and when the minimum amount of inductance is used in obtaining a match. If these rules are followed you can expect efficiencies of more than 96% for most tuning solutions. However there are some tuning solutions where efficiency will be impacted and may fall below 96%. Losses climb more rapidly with inductive loads than with capacitive loads generally speaking. **The rule of thumb for maximum efficiency is this, choose the lowest value of inductance that permits a match.**

The general guidance given above is based solely on losses in the inductor. As stated the inductor is one of the most critical components in any tuner so it's important to choose wisely. However the inductor is not the only area where loss can occur. Additional losses are possible due to poor components, poor wiring materials and low quality switches. Note that stray inductances and capacitances, and coil "suck-out" are not accounted for in the formulas. If components get warm or arc under matched conditions at 100 watts, even though the calculations indicate less than 5% losses, believe your senses. Understand that heat is lost RF. Consider the components and construction of your tuner.

The following table is from the ARRL book on antenna tuners.[2] This same information was also published in the *February 2003 issue of QST.*[6] The data is given for each tuner at an 8:1 SWR, which is considered a worst case scenario.

[6] See: "*SimSmith for Interactive RF Circuit Analysis*", http://www.ae6ty.com/Smith_Charts.html This is an extremely powerful tool for simulating and designing RF circuits such as antenna tuners as just one example.

Tuner	Type	160m	80m	40m	20m	10m
Ameritron ATR-30	T Network - Manual	20%	12%	<10%	<10%	<10%
MFJ 986 Differential	Differential T - Manual	47%	31%	21%	16%	13%
Palstar AT1500CV	T Network - Manual	*	25%	16%	12%	12%
Ten-Tec 238A	Switched L - Manual	*	<10%	<10%	<10%	<10%
Vectronics	T Network - Manual	45%	42%	16%	15%	8%
LDG RT-11 Remote	Switch L - Auto	*	17%	17%	19%	20%
LDG Z-100	Switch L - Auto	*	13%	15%	15%	20%
MFJ-991	Switch L - Auto	12%	14%	15%	24%	19%
SGC SG-237 (Remote)	Unknown - Auto	16%	18%	20%	24%	23%
SGC MAC-200	Unknown - Auto	*	16%	18%	15%	30%
LDG AT-1000	Switch L - Auto	*	*	<=10%	20%	22%
MFJ-994 Intellituner	Switch L - Auto	13%	13%	<=10%	13%	15%
Palstar AT-Auto	Differential T Auto	42%	24%	15%	12%	*
* = No Match						

Figure 1: Loss for various Tuners

There is another set of interesting tables in the ARRL Antenna Book that also looks at tuner efficiencies. In the 24th edition you can find these tables in section 24.2.6 (pages 24.10 and 24.11). A former ARRL Antenna Book editor, Dean Straw designed a high power tuner with a 1:1 balun at the input to allow the tuner to work into a balanced or unbalanced loads.[7] The tuner was designed to provide a very low SWR across an extended range. The details of this tuner are provided in the supplemental material included with the ARRL Antenna book.[8]

The tables show the measurements he took while testing the tuner against a 10:1 mismatch. In looking at the tables two things emerge, the overall efficiency of the tuner was very high rarely going below 96%. And that there were only two conditions where efficiency went below 90%. Both occurred when the tuner was configured as a high pass “T”. One occurred on 160 meters where efficiency went to 86% and another on 80 meters where efficiency went to 88%. When the tuner was configured as a low pass “T” and as a low pass “Pi” efficiencies never fell below 95% and on average were much higher than 95%.

Here again, the key takeaway is that a properly constructed tuner using quality components is extremely efficient and can be trusted to deliver maximum power to the transmission line even at high SWR values. Of course with cheaply built tuners with low quality components, all bets are off.

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[7] See: “*ARRL Antenna Book*”, 24th Edition, pages 24.10 & 24.11, tables 24.3, 24.4, 24.5

[8] See: “*High-Power ARRL Antenna Tuner*”, Supplemental Material included in the 24th edition of the ARRL Antenna Book.

The Can and Can't Do's of an Antenna Tuner

Now let's take a look at some of the significant things tuners can't do. One of the first to consider is the fact that the SWR on the transmission line has not been altered by the conjugate match. If our center-fed dipole is cut to the center of the 80 meter Amateur band and is coupled with an antenna tuner it can allow the antenna to be used across the entire 80 meter band with maximum RF current flowing in the radiator. Note however that when using an amplifier RF voltages can develop on the transmission line that exceeds several thousand volts especially in the case of a high SWR. This of course raises the possibility of "flash over" which can destroy the transmission line and other components in the antenna system. This is the reason why antenna tuner components must not only be high "Q" but they must be able to withstand the high voltage that can be produced by high SWR. If there is a broadband transformer type balun involved in the antenna system, flash over can also occur there.

Another "can't do" effect is that transmission line loss increases with high SWR, and significantly in some cases. Coaxial transmission lines in general suffer from this malady to a much greater degree than open wire line does. For example a typical RG-8 type coax using a foam dielectric is rated at 2,800 watts at 30 MHz and even less at higher frequencies. So if one were to run 1,000 watts into an antenna system with a high SWR it would be possible to exceed the power rating for a given coaxial cable and for some of the components inside the antenna tuner as well as the balun or unun. This is another reason why the power rating specification on an antenna tuner should be suspect. The power ratings assume a matched load, but understand that as SWR current increases they can potentially exceed the power handling capability of the tuner and possible other components in the antenna system.

Now that we have looked into what a tuner actually does let look under the hood and see what's inside these magic boxes and consider their matching capabilities.

Tuner Configurations

Tuners have been constructed using many different configurations. It's hard to know which is best for your particular set of requirements and constraints. Let's start by focusing on the three main circuit configurations:

- T Network
- Pi Network
- L network

After we look at these three basic configurations we will then look at some variation of these three basic configuration which include the:

- Ultimate Transmatch

- SPC
- Differential Tuner

Tuner Types (T, Pi, L, and other Matching Networks)

We will be presenting circuit diagram of each. If you're not into reading schematics don't worry we have stripped away all the extra circuitry and will focus on just the basic configuration. The key takeaway from this section will be in understanding how they are alike and how they are different and the advantages of each.

The Simple L Network (L-C Network):

The basic tuning network consists of a simple "L" design which involves the use of a single inductor and capacitor inserted to either the input or output side of the system. All other tuning topologies start with this basic circuit. The "Pi" and "T" configurations are nothing more than an extend L network. In Figure 2 are four versions of the simple "L" matching circuit. There are only two components, an inductor, represented by the squiggly line and the capacitor represented by the curved line with a straight line above. The lower horizontal line is ground which is part that is connected to the shield of your transmission line. The top horizontal line is the line connected to the center conductor of the transmission line. The left side is the input (TX) side, the right is the output (antenna) side. Because of the limitations of the L network its configuration is specific to a particular matching situation but the L network can be adapted to provide a broader matching range through the use of a switch that can move the tuning components from the input side to the output side and visa-versa.

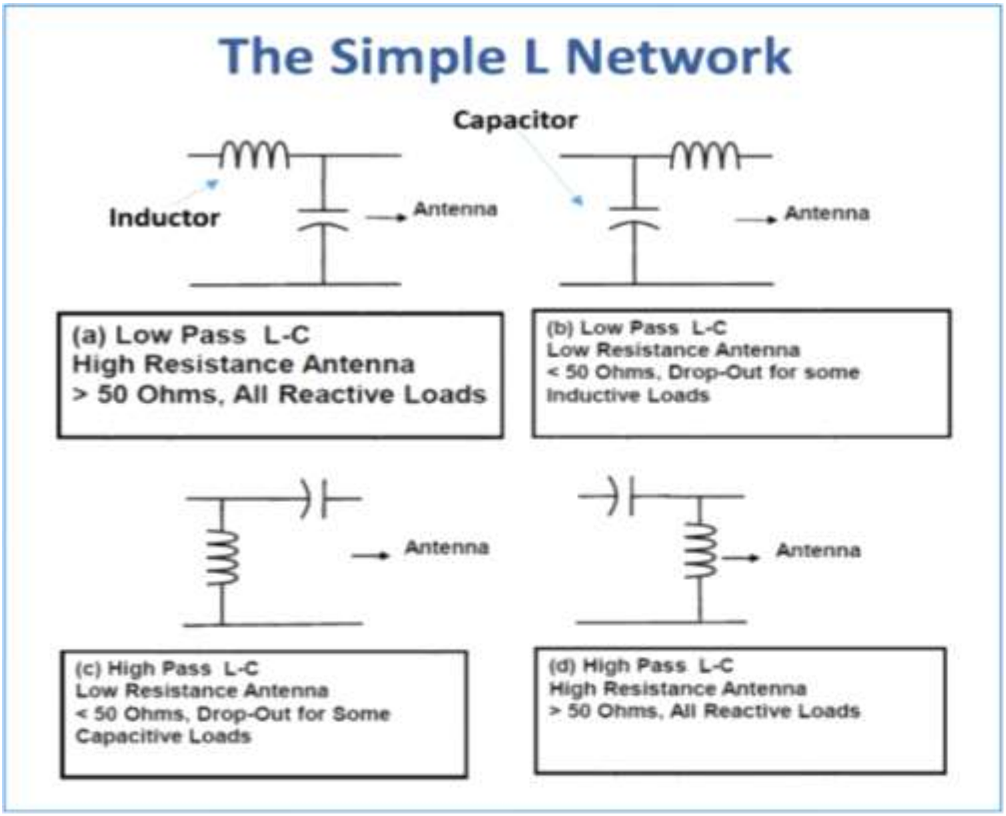

Figure 2: The Simple "L" Network. Note that in the low pass configuration the inductor is not connected directly to ground. In the high pass configuration the inductor is connected directly to ground. The placement of the inductor and capacitor is how you can tell a high pass from a low pass circuit regardless of the tuner topology.

As you can see in Figure 2 the "L" network needs to be connected to either the input side or the output side of the tuner. This infers that the "L" network has a limited matching range. However, in many tuners that use an "L" network a switch is included to allow the matching circuitry to be inserted to either the input side or the output side thereby giving the tuner an extended matching range, this configuration is referred to as a switched "L" network. The LDG AT600Pro II and the Ten-Tec 238 is an example of this kind of tuner.

Following are a set of plots created by Larry Benko in 2011. His data is some of the best I've seen in trying calculate the range of each matching network type[9]. The plots were prepared using a tool called SimSmith, you can find a reference to SimSmith at the end of this article.[6]

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[9] See: W0QF Presentation on Antenna Tuners: *http://www.w0qe.com/Papers/Antenna_Tuners.pdf* This is the source of the various SimSmith plots that I used in this article. This is an extremely good presentation. Please note that I did get permission from Larry to use his slide deck. I had a very informative email exchange with him. He is the designer of the PalStar HF Auto Tuner, which is one of the best tuners on the market today. Here's a link to his web site: *http://www.w0qe.com/index.html*

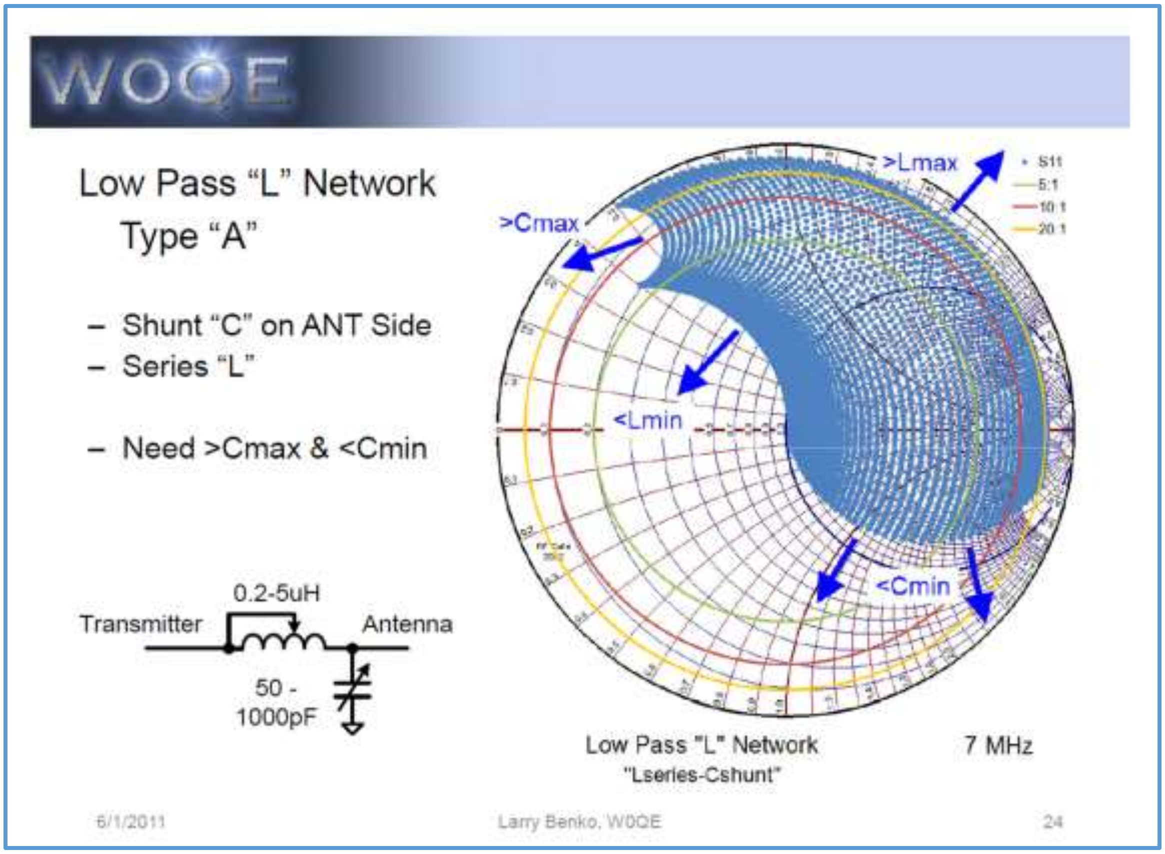

Figure 3: Low Pass "L" Network Inserted to the Input Side

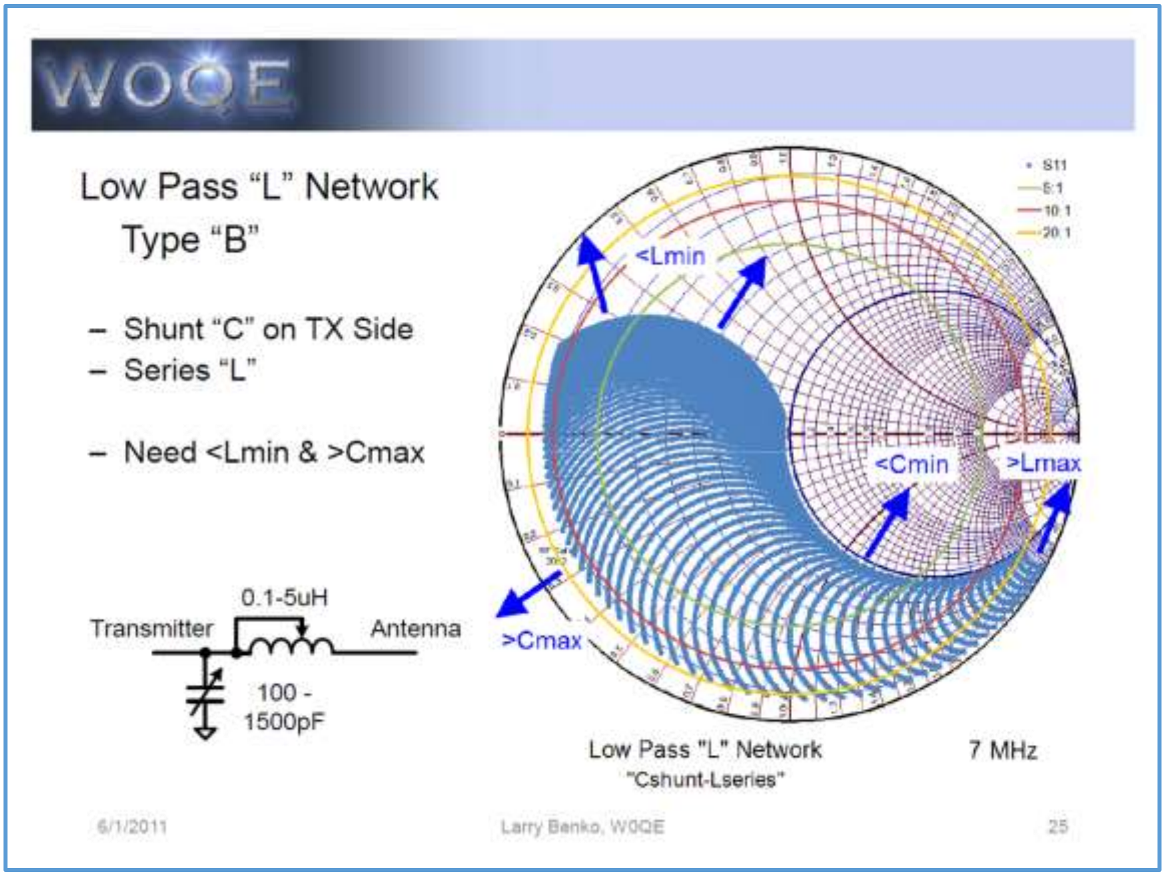

Figure 4: Low Pass "L" Network Inserted on Antenna Side

Low Pass "L" Network Results:

- Cmax ~= 8000pF & Lmax ~= 20uH on 160m
- Cmin ~= 5pF & Lmin ~= .02uH on 6m
- Pretty ugly component values.
- This happens when only two adjustable components, wide frequency, and wide matching range are wanted.
- Need some switchable offset components or variable offset components to help match especially on the higher frequencies.

There are several manufactures of the tuners using an "L" network that allow the tuning circuitry to be switch from the input side to the output side. An example of these tuners includes some of the LDG Tuners such as the LDG AT600 Pro II and the TenTec 238.

Now let's look at some High Pass "L" Network results.

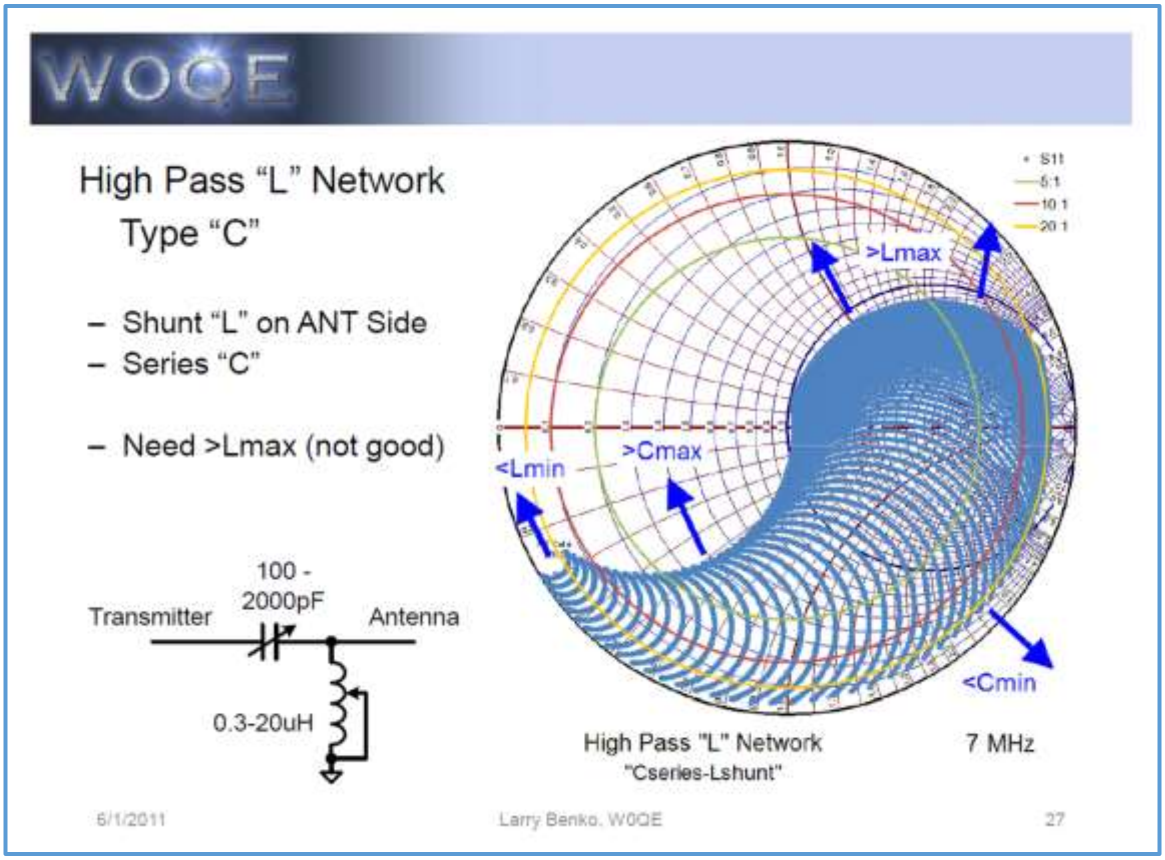

Figure 5: High Pass "L" Network inserted On the Input Side

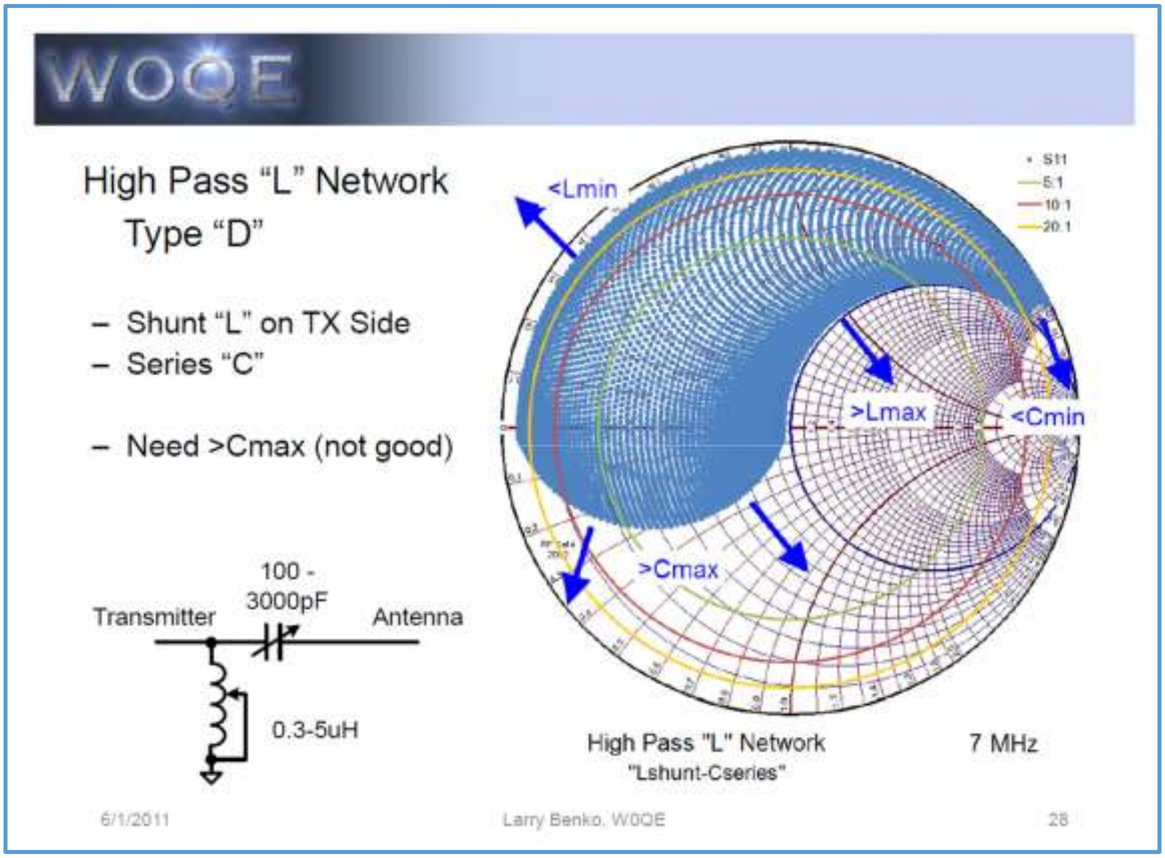

Figure 6: High Pass "L" Network Inserted On the Output Side

High Pass "L" Network Results:

- Worse component values than Low Pass "L".
- Variable component "L" networks are not commonly used for wide range matching on the lower frequencies for good reason.
- Low Pass "L" networks are used in most switched component tuners with reduced 160m and 80m matching range.
- Often good choice if match impedance is known as would be found in a mono-band antenna.

The "Pi" (C-L-C) Network:

The "Pi" network is nothing more than two "L" networks sharing a single inductor. Its name is due to the resemblance to Pi symbol (π). The "Pi" network eliminates the need for a switch and allows for tuning of both the input and output side of the system and provides for a fairly broad matching range depending on the values of the variable capacitors and variable inductor.

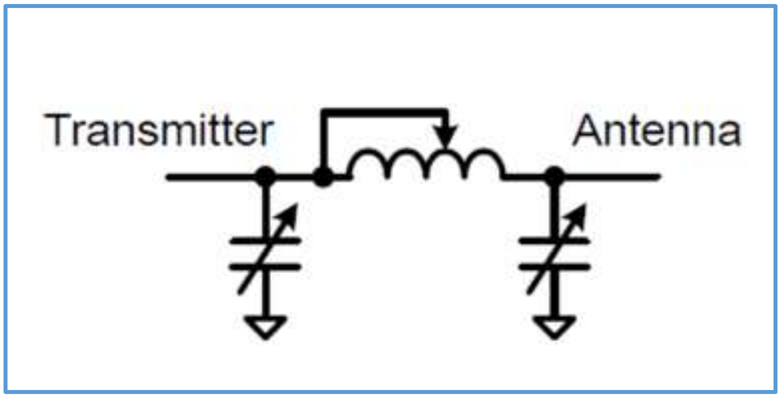

Figure 7: The "Pi" Network. Note the resemblance to the Greek lowercase letter π

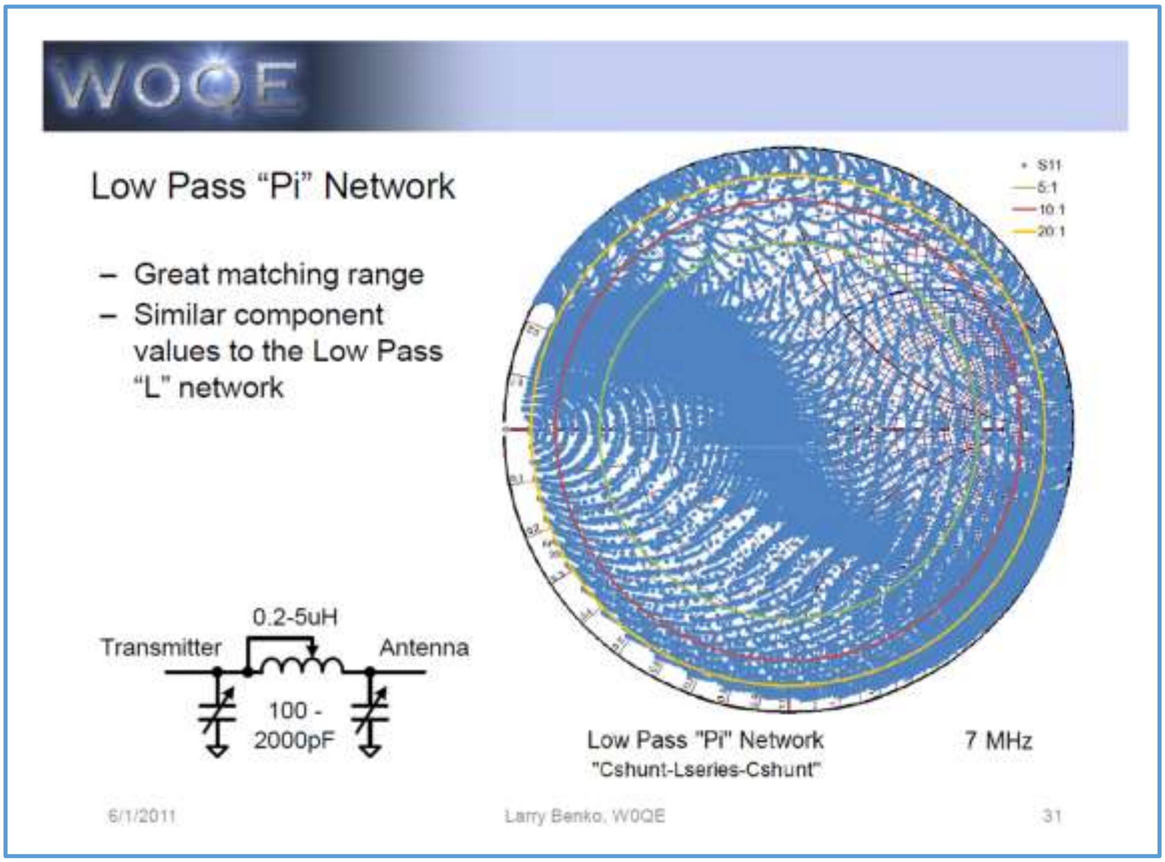

Figure 8: The Low Pass "Pi" Network

As you can see from the above diagram the "Pi" network provides one of the widest matching ranges possible. There are several variations of the "Pi" network. Some have even broader matching capabilities but I suspect have slightly more loss due to the additional inductors that can be inserted to the topology through the use of switches. The Nye Viking MB-V-A 3KW is an example of this type of tuner. However, in the case of the Nye Viking tuner, additional capacitance can be inserted into the circuit, but the inductance is limited to the just the one variable inductor. You can read about the **Nye Viking MB-V-A 3KW Antenna Tuner** on page 57.

It should be noted that the tests for both the "L" network and the "Pi" network was limited to 40 meters. So the question to ask, "is the "L" or "Pi" tuner the best solution for a multiband tuner capable for use across all the HF Amateur bands from 160 meters to 10 meters?" The data suggest that they aren't. Of course of you can turn the simple "L" match into a switch "L" network then it could make a good multiband tuner. In the case of the "Pi" network, that without additional switchable capacitors or inductors the "Pi" network would be somewhat limited. However it would be possible to extend its tuning range through the use of non-standard components with extended ranges of capacitance and inductance. But here again by using an inductor with an extending range might result in a tuner with even more loss than a conventional "T" network.

I'm aware of only one vendor today that sells a PI style tuner however it is specifically designed for antennas fed with a balance transmission line. It is referred to as a "*Symmetric (balanced) Pi-Network antenna tuner*", See https://www.blueridgeamateurradio.com/antenna-tuners.

The "T" (C-L-C) Network:

Since the mid 70's the "T" network has by far been the dominate tuner configuration. Today you will rarely find tuners using any other configuration. The key reason for this is the "T" network provides the broadest matching capability, the components are readily available and the tuner is easy to build.

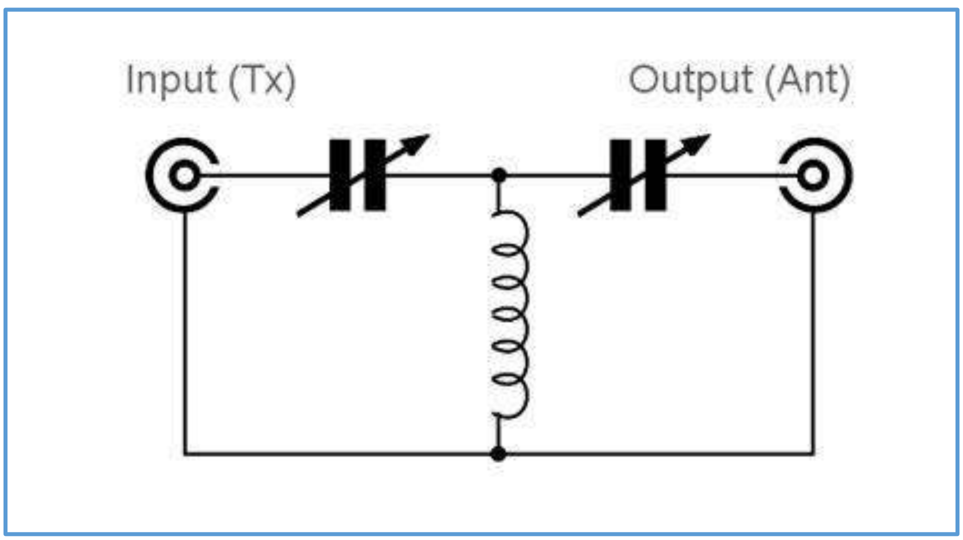

Figure 9: The "T" Network

As you can see in Figure 9 the “T” tuner is a very simple circuit consisting of two variable capacitors and a variable or tapped inductor.   Below are examples of the components that you will find in most tuners today. Refer to Figure 10. **A.** Roller Inductor, **B.** Variable Capacitor, **C.** Tapped Inductor. In the typical “T” Tuner you will find at least one inductor and two variable capacitors.

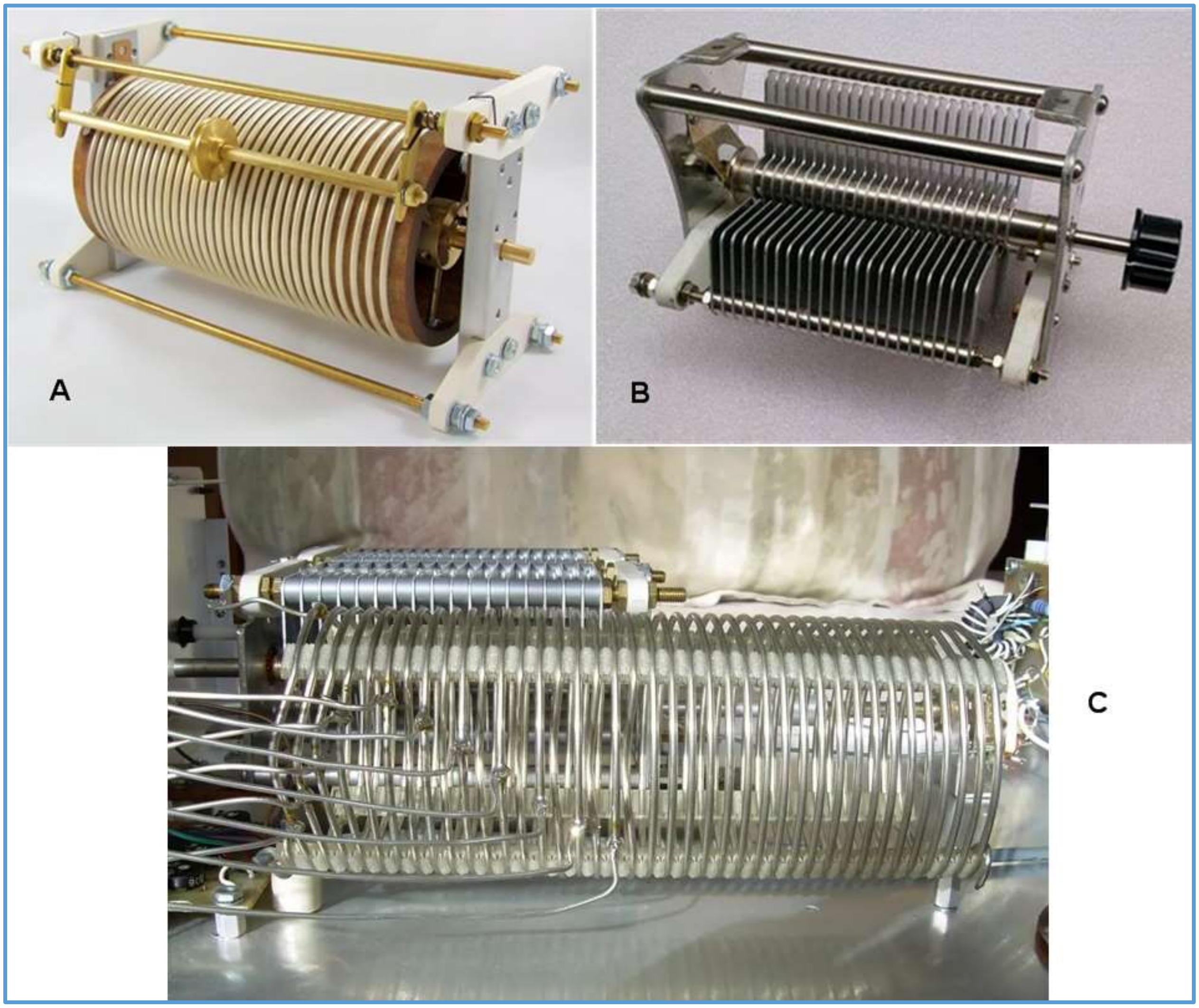

Figure 10: Antenna Tuner Components

It’s in the inductor where 80 to 90% of the loss occurs. For this reason you should be selective about which tuner you buy. Inductors using smaller gauge wire and having longer and/or smaller diameter coils exhibit larger amounts of loss when compared to inductors with larger conductors and larger diameter coils. Although these tuners may have a broader matching range due to their longer inductors they will have much larger losses in the inductor at frequencies where a large portion of the inductor is needed to tune the antenna system.

In the "*ARRL Guide to Antenna Tuners*" measurements were taken on a number of antenna tuners comparing loss values at various SWR ranges and frequencies.[2] As an example the MFJ-986 surrendered 47% of the power in a system with an 8:1 SWR at 160 meters. By comparison, the Ameritron ATR-30 only lost 20% of its power under the same test conditions. When you compare the inductors it's easy to understand why.

You will also see other components in today's tuners. There will be circuitry related to SWR/power meter, an antenna switch for selecting different antennas and often a balun for connecting the tuner to an end fed wire or a balanced feed line. But the key components that allows the tuner to find a match is the inductor and the capacitors.

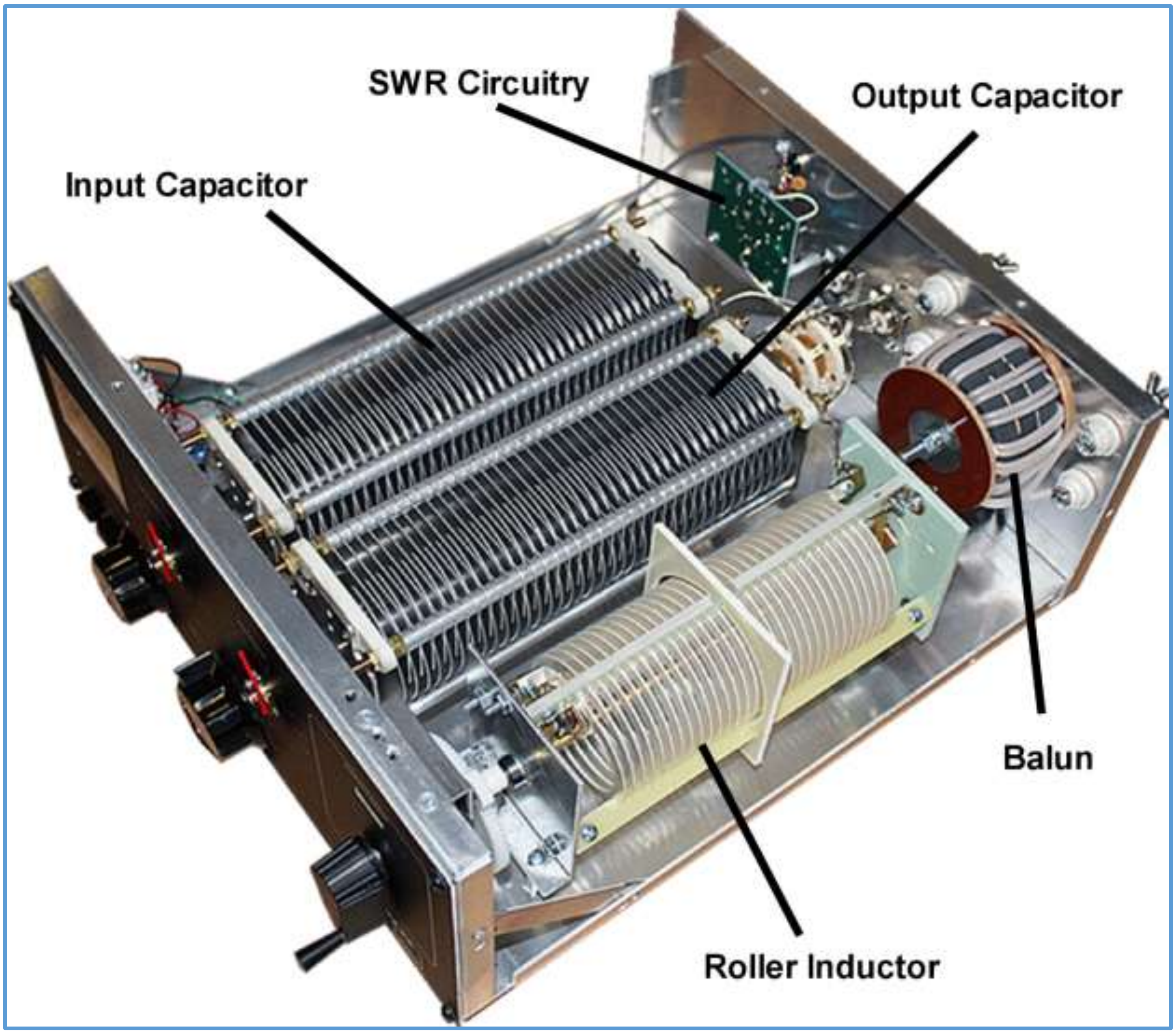

Figure 11: Ameritron ATR-30X. Note the use of the flat conductor in the roller inductor. In theory this inductor will have less loss than an inductor using a smaller gauge round wire. Note also that inductor length may also be a factor in inductor loss. This is the key reason why you want to always tune for minimum inductance.

Tapped Inductors Versus Roller Inductors: *The key difference between the two different styles is that the roller inductor is infinitely adjustable across its entire range. Whereas the tapped inductor isn't. Given this difference it's possible in many cases to get a perfect 1:1 match with the roller inductor whereas with the tapped inductor it might not be. In most cases there will be little difference in efficiency between a perfect 1:1 match and a match of 2:1. However, many of today's solid state amplifies require a low SWR. So for the amateur using a solid state amplifier a tuner with a roller inductor may be the better choice. For auto tuners that use lumped inductors and capacitors such as the LDG AT600Pro II an appropriate match may not be possible with some antennas. In those cases an auto tuner using a roller inductor and variable capacitors would be the better option. An example would be the PalStar HF-Auto Tuner.*

Now that we have had a good look inside the "T" network lets looks at its matching abilities.

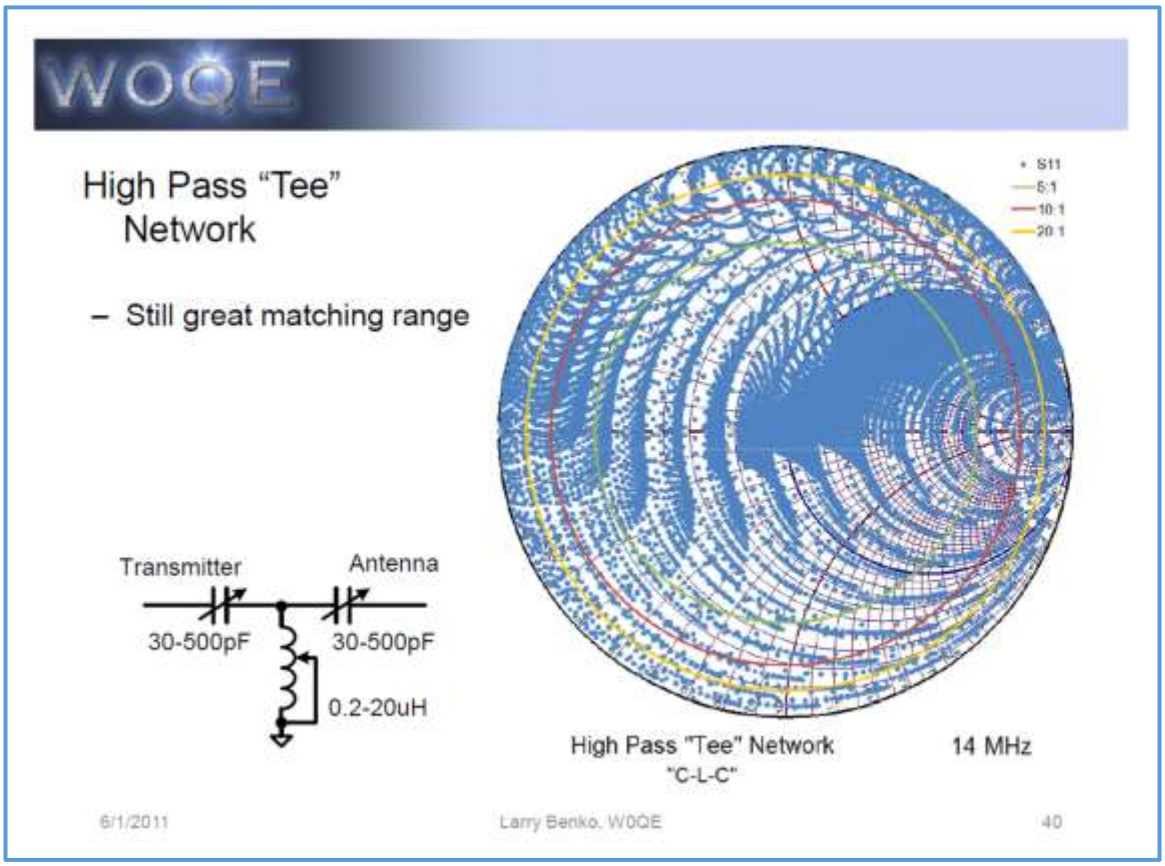

Figure 12: The High Pass "T" Network for 20 Meters

As you can see from the above graphic the "T" network provides a very broad range of matching capabilities. In Figure 13 we see the same tuner on 160 meters. As you can see from the two graphics the "T" tuner is an extremely versatile tuner and one of the reasons it's the tuner of choice for most of the antenna tuner manufactures.

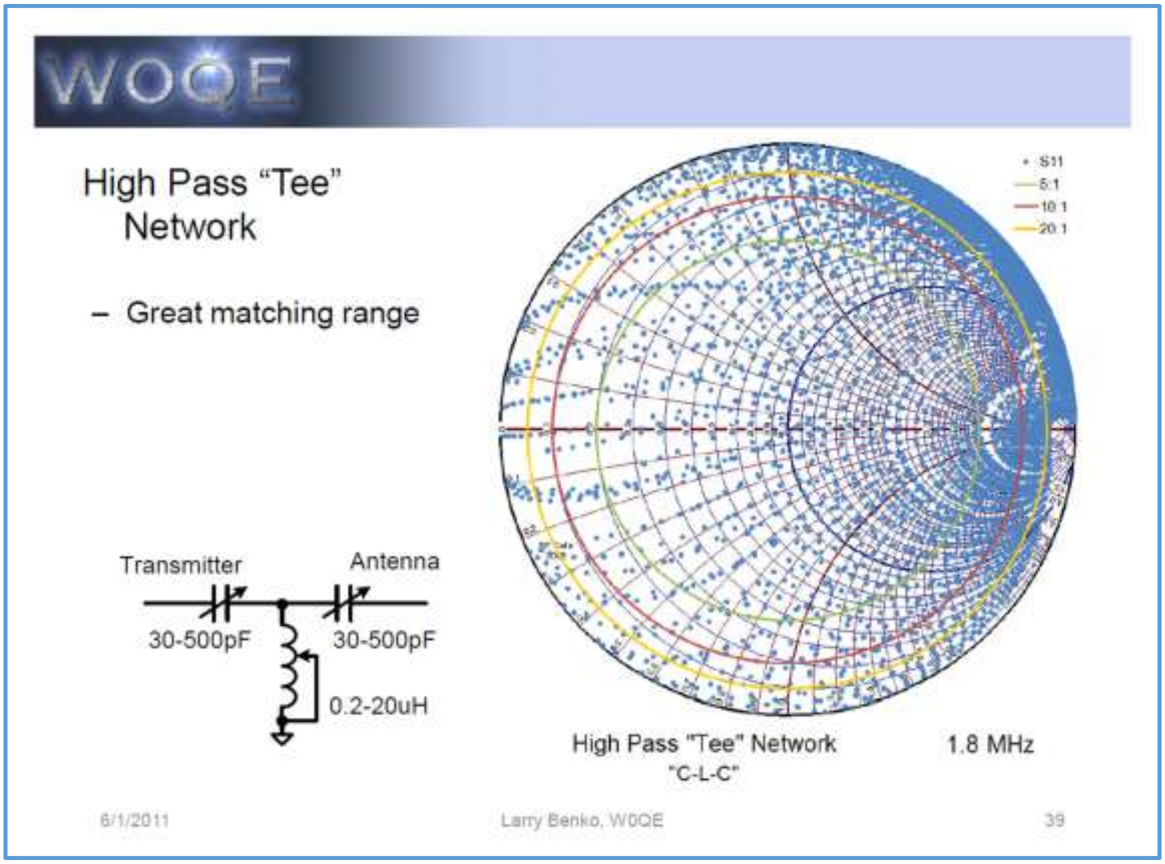

Figure 13: The High Pass "T" Network for 160 Meters

Virtually all makers of tuners today use the "T" topology. There are three key reasons for this, 1. They are very easy to build, 2. Parts are readily available, 3. They have a very broad tuning range. The down side is that losses in the inductors used in these tuners can vary considerably due largely to characteristics of the inductor. Long inductors using a small diameter coil, made with smaller gauge wire with very broad tuning ranges generally speaking will have higher losses. This is one of the biggest issues with some of the low cost tuners on the market today. For example any of the MFJ tuners using the 404-1052 roller inductor should be suspect.

Other Matching Networks: We've have had a good look at the three most popular matching networks but in fairness we can't stop there. There are several other topologies. Following is a brief look at some of the other approaches to antenna matching.

The Ultimate Transmatch:

In the July 1970 issue of QST Lewis McCoy publish a description of a turner he referred to as the Ultimate Transmatch.[10] I happen to be one of the lucky owners of one of these fine tuners and was able to put it on the air for a couple of months. Overall I was extremely pleased with it. Especially after using a particular commercial tuner. The build quality of the home-brew tuner I bought was some of the finest examples of quality workmanship I had ever seen in an antenna tuner. I also found it was able to tune all of my antennas to within 1.5:1 on all bands except 17 meters. Refer to Figure 14 for the circuit diagram and Figure 17 for a peek under the hood. This tuner is also described in the Supplement to this article, *see the KB0ES Ultimate Transmatch Tuner* on page 45.

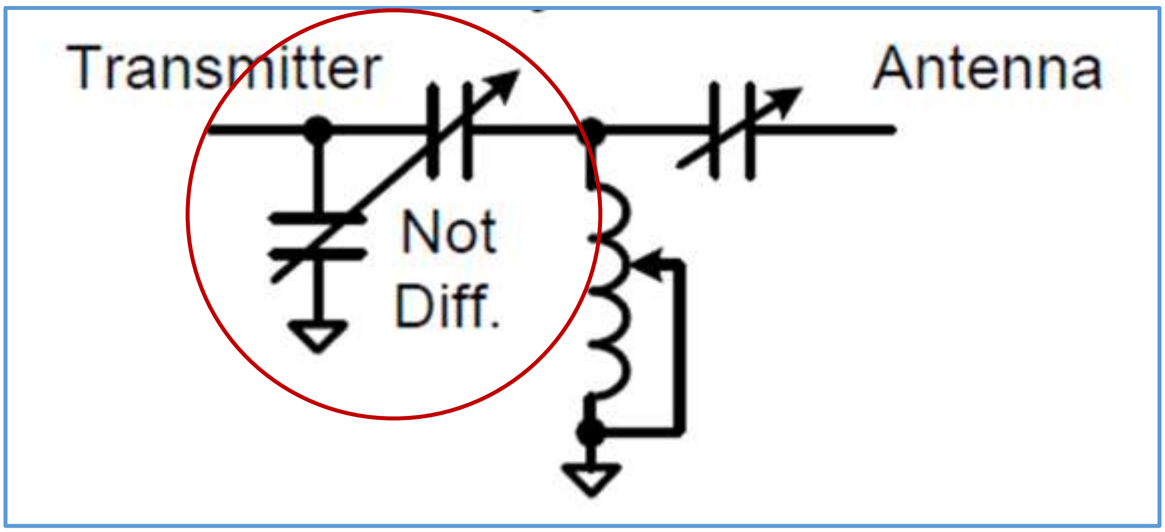

Figure 14: Lew McCoy W1ICP, Ultimate Transmatch (1970). Note the Split-Stator circled in red.

One of the unique features of the Ultimate Transmatch is the use of a split-stator. On the surface this circuit looks like a cross between a T match with a pi circuit on the input side. The split-stator capacitor is one in which two variable capacitors are mounted on the same shaft. The split-stator capacitor normally uses a pair of identical capacitors, each the same value, rotated by the same shaft. The shaft is common to both capacitors. As the shaft is rotated the capacitance value changes, refer to Figure 15 and Figure 16. The device can be wired as two separate capacitors or as one capacitor in series. You will find the split stator in the Ultimate Transmatch, the SPC Tuner and in the Johnson Matchbox.

[10] See: "*The Ultimate Transmatch*", Lewis G. McCoy W1ICP, Nov. 1970, page 24. https://www.arrl.org/files/file/Technology/tis/info/pdf/7007024.pdf

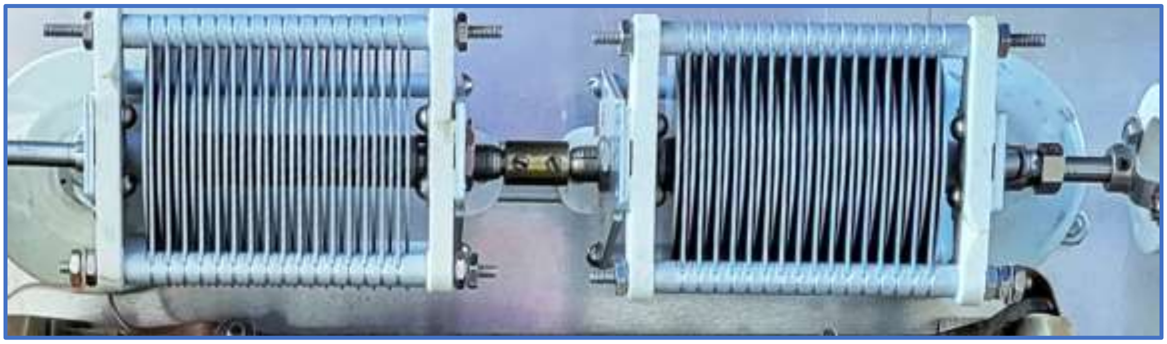

Figure 15: Variable Split Stator - Basically a split stator is two capacitors sharing a single shaft. You can wire the device to be two independent devices or connect the two capacitors together in series to increase the range of the device.

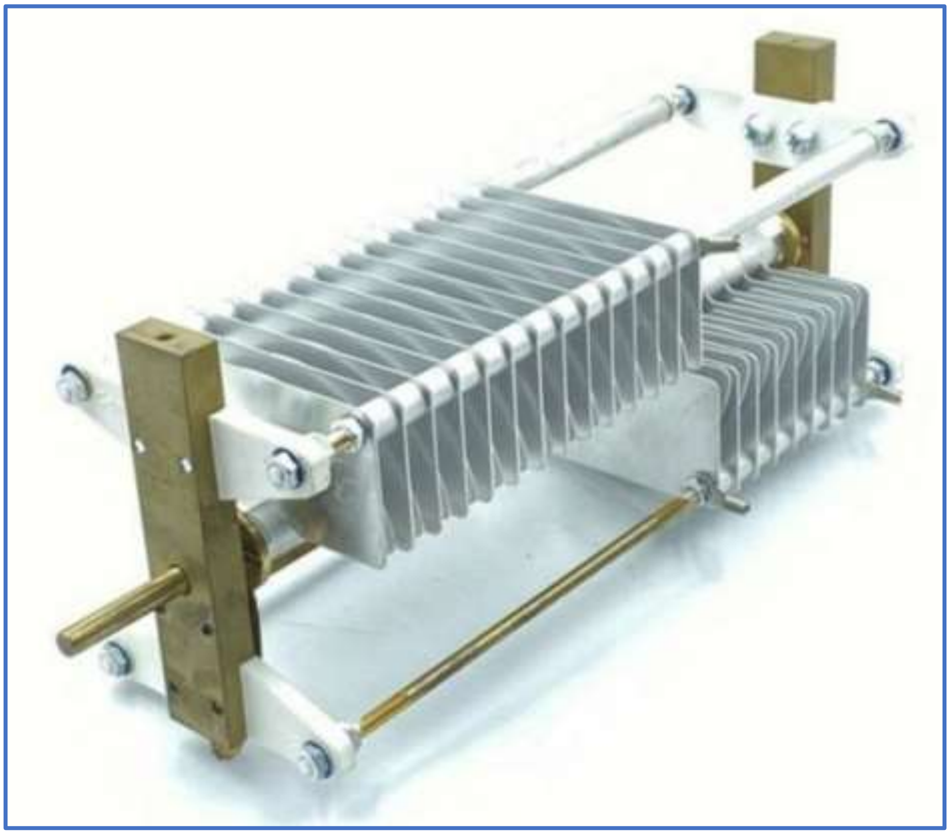

Figure 16: Another example of a split-stator variable capacitor

Like other series-capacitance designs, the Ultimate Transmatch appears most effective with purely resistive and inductive loads. Although the loss values are higher than with some other designs, efficiency remains very high at around 96%. In fact, the efficiency of the Ultimate Transmatch appears to increase (at least to some limit) with increases in the ratio of output-to-input impedance.

Figure 17: Homebrew Ultimate Transmatch built by John Burger KB0ES. This tuner was built in 1977. Note the use of the interconnecting copper straps and the high quality rotary switch.

Tuners using this circuit are no longer sold commercially as far as I know. They do at times become available on the used market but usually command a fairly high price. More tragically many times they are disassemble and sold for parts as was almost the fate of the tuner pictured in Figure 17. After I saw the craftsmanship that went into this tuner I didn't have the heart to tear it apart for parts. The roller inductors that were used in these tuners are extremely hard to get and when you can find them are expensive.

My Antenna Farm: *Because I made a reference to my personal experience in regard to my antennas I felt it only fair to describe my antennas. Let me start by saying my antenna farm may not be the best for assessing a tuners tuning range. I have three antennas, a 190' end fed wire I use exclusively for 160 and 80 meters, a 40/30/10 meter ¼ wave vertical used for 40, 30, 10 and once in a while 20 meters. The 10 meter element is a ¾ wave vertical. I also have a 10 meter two element quad I use exclusively on 10 meters although it will tune on 12 and 15 meters as well.*

Link Coupled Tuners (The Johnson Matchbox):

This tuner is considered one of the classic tuners used exclusively for systems using twin lead to feed the antenna. I have read that it could be used to match an unbalanced system but it required one of the output post to be grounded. Note that I have not been able to confirm this.

The unique thing about this tuner is the use of inductive coupling of the inductors. Below is a copy of its circuitry. It may be a bit hard to follow for those not akin to reading schematics. It is never the less and interesting design.

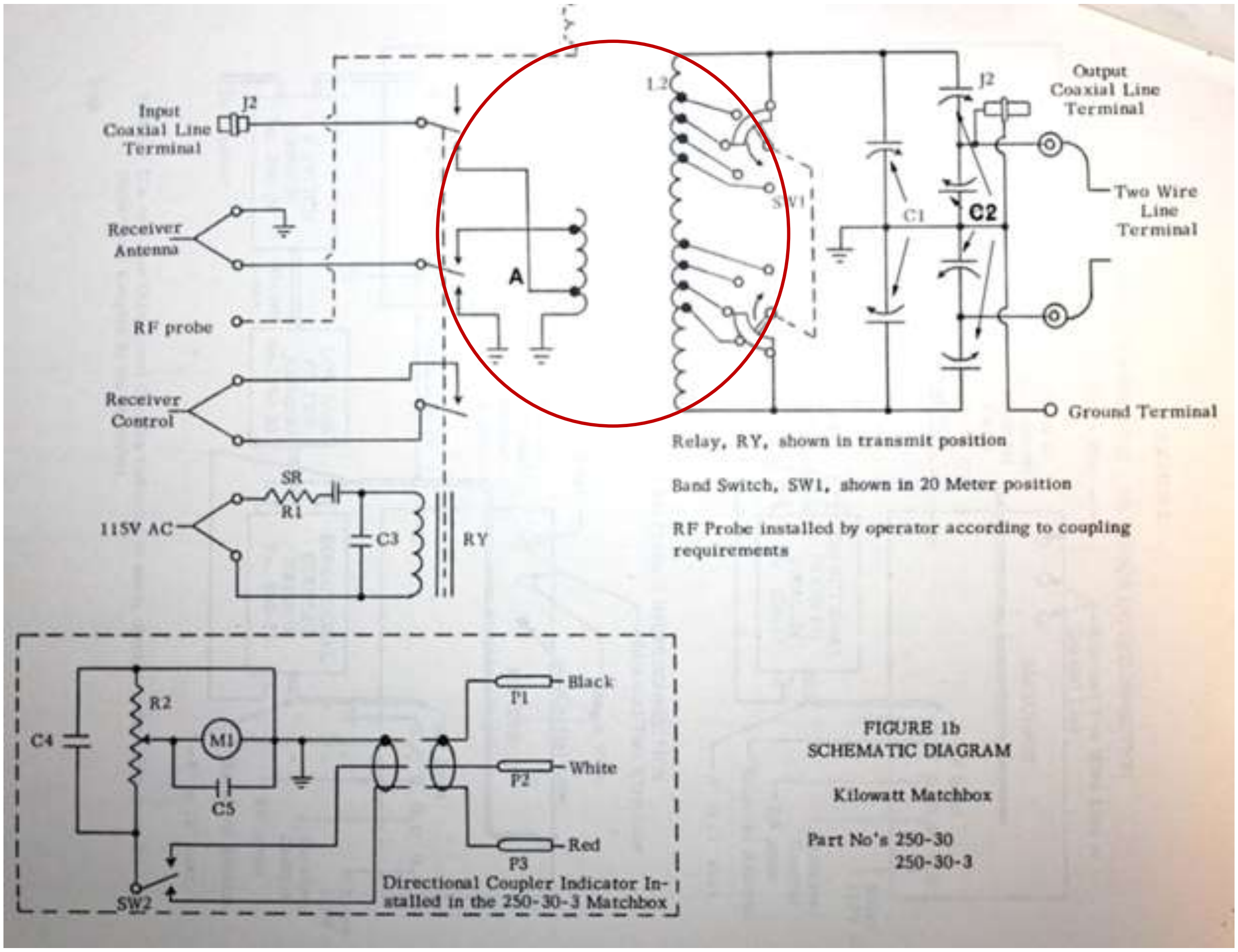

Figure 18: Johnson Matchbox. Note the linked inductors circled in red

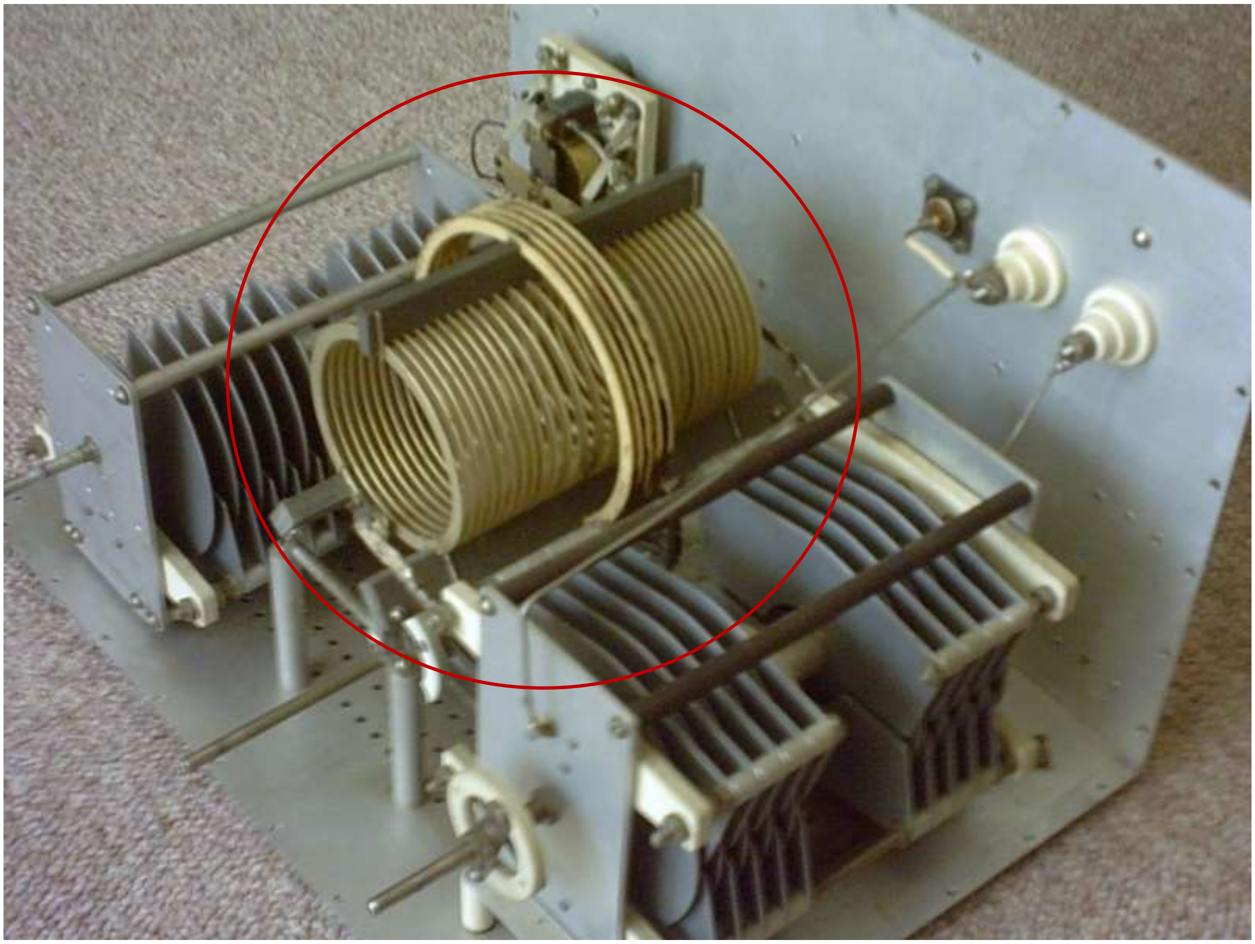

Figure 19: The Inside of the Johnson Matchbox with the face plate removed. Note the linked inductor circled in red

You can find out more about this classic tuner on the internet. Today the Johnson Matchbox Balance Line Tuners is one of the most sought after tuners. If you find one you can bet they will be asking a premium price. I was able to pick up the dual stator capacitor with knob as shown in the bottom right of Figure 19 at a recent swap meet for $5. I'm aware of where there are two of these tuners, the kilowatt version and the 275 watt version but neither are for sale at this time. I'm hoping that will change as both are doing nothing but collecting dust.

Editor's Note: *There are a lot of these old school tuners out there just collecting dust, which is a tragedy. The high quality components and the hand built craftsmanship of these classic old tuners is nothing like the offshore assembly line low quality tuners we see today. The possible exception is the Palstar tuners, which are handcrafted and built in the US but command a higher price than those built offshore. (Note: I'm not getting any compensation from Palstar, I'm simply stating what I see and my experience with their products in comparison to other tuners I have owned.)*

SPC Transmatch (Series-Parallel-Capacitor) (1980):

In spite of a fair amount of investigation I was not able to find out much about this tuner configuration. It's based largely on the Ultimate Transmatch created by Lew McCoy. The key difference is the split stator is placed on the output side of the circuit rather than the input side of the circuit. The claim is that the SPC design had better harmonic suppression than the Ultimate Transmatch, the inventor of the SPC design, Doug DeMaw, W1FB, claimed that it provided an estimated 20 dB of harmonic suppression assuming that a high circuit Q could be maintained.[12] I should note that I have not been able to confirm this claim. If you're interested in this tuner there are two very good articles describing the construction of the SPC Tuner.[11],[12] There are no commercial versions of this tuner available on the market today that I'm aware of. You will find an example of this kind of tuner in the supplement included with this article.

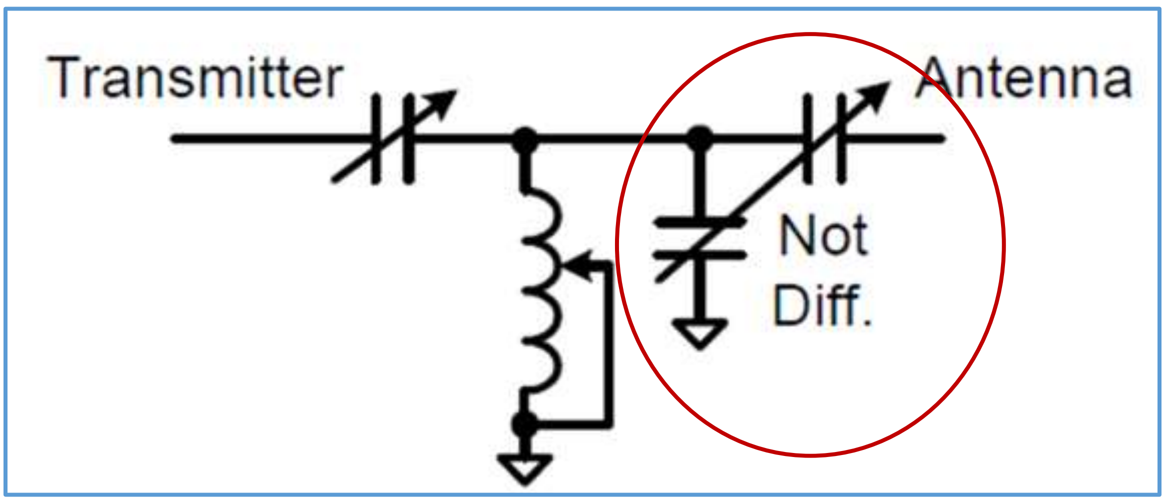

Figure 20: Doug DeMaw W1FB, SPC Transmatch (1980). This design uses a split stator, circled in red on the antenna side of the tuner. The designer also makes clear this is not a differential capacitor but is a split stator capacitor.

High Pass Differential "T":

This tuner is rather unique when compared to the other tuners in that there are only two adjustment knobs and only one solution for each matching condition. The other tuner types by comparison will often have more than one tuning solution. This dual knob feature makes this tuner rather unique and easy to use. The down side is this tuner seems to exhibit higher losses than the other tuner types.

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[11] "*Gotta Match*", https://www.qsl.net/n4dfp/transmat.html This article is about the SPC Transmatch written by David Hammack, N4DFP.

[12] See: "*The SPC Transmatch: Improved Performance For 20-10 Meters*", L.B. Cebik W4RNL, pages 22-25

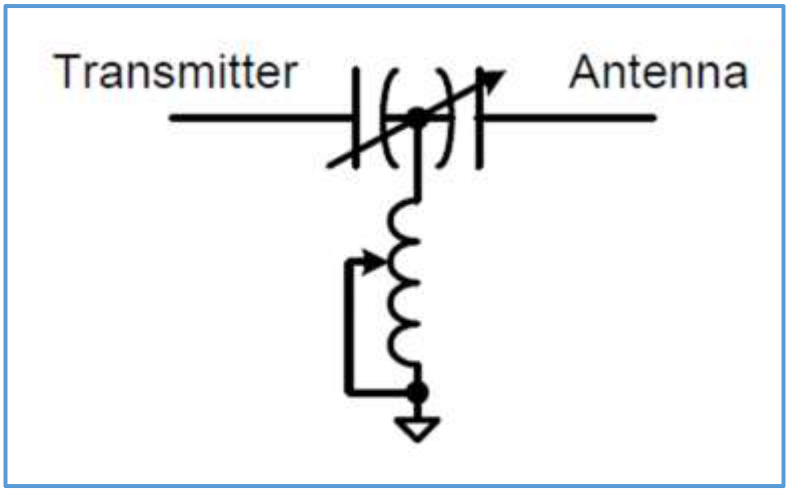

Figure 21: High Pass Differential Tee (MFJ & later Palstar). Note the symbol for a differential capacitor in this schematic as compared to the symbol for a split stator capacitor as shown in Figure 20.

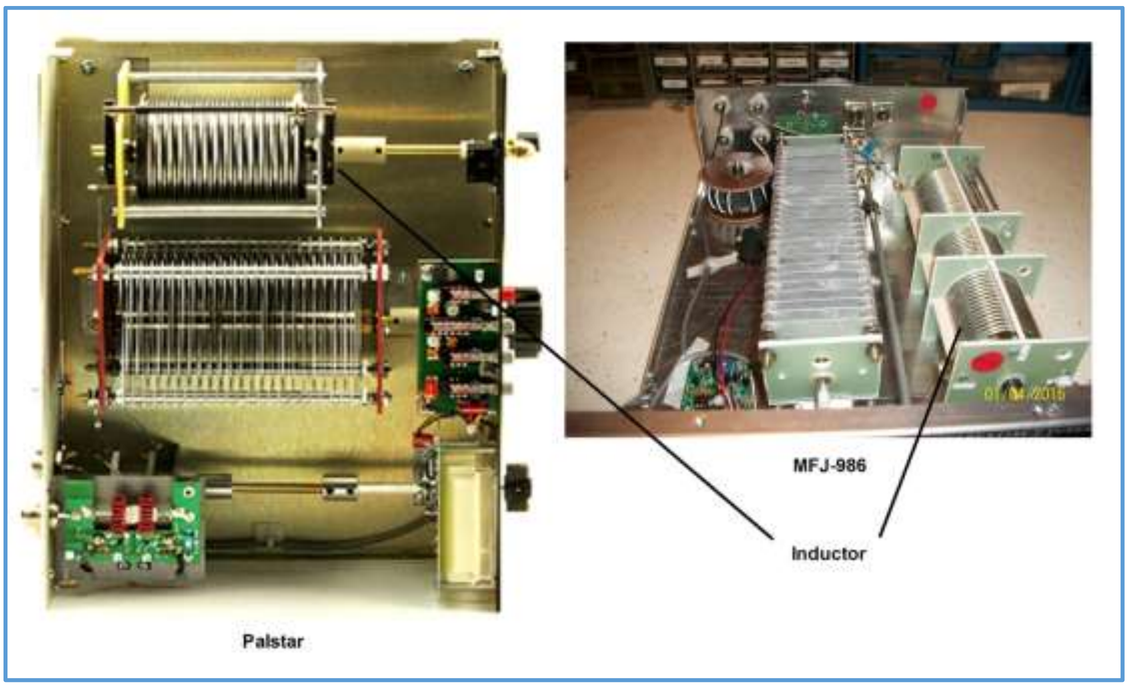

Figure 22: The PalStar and MFJ Differential Tuners. Note the differences in the Roller Inductor. The PalStar will have lower loss than the MFJ.

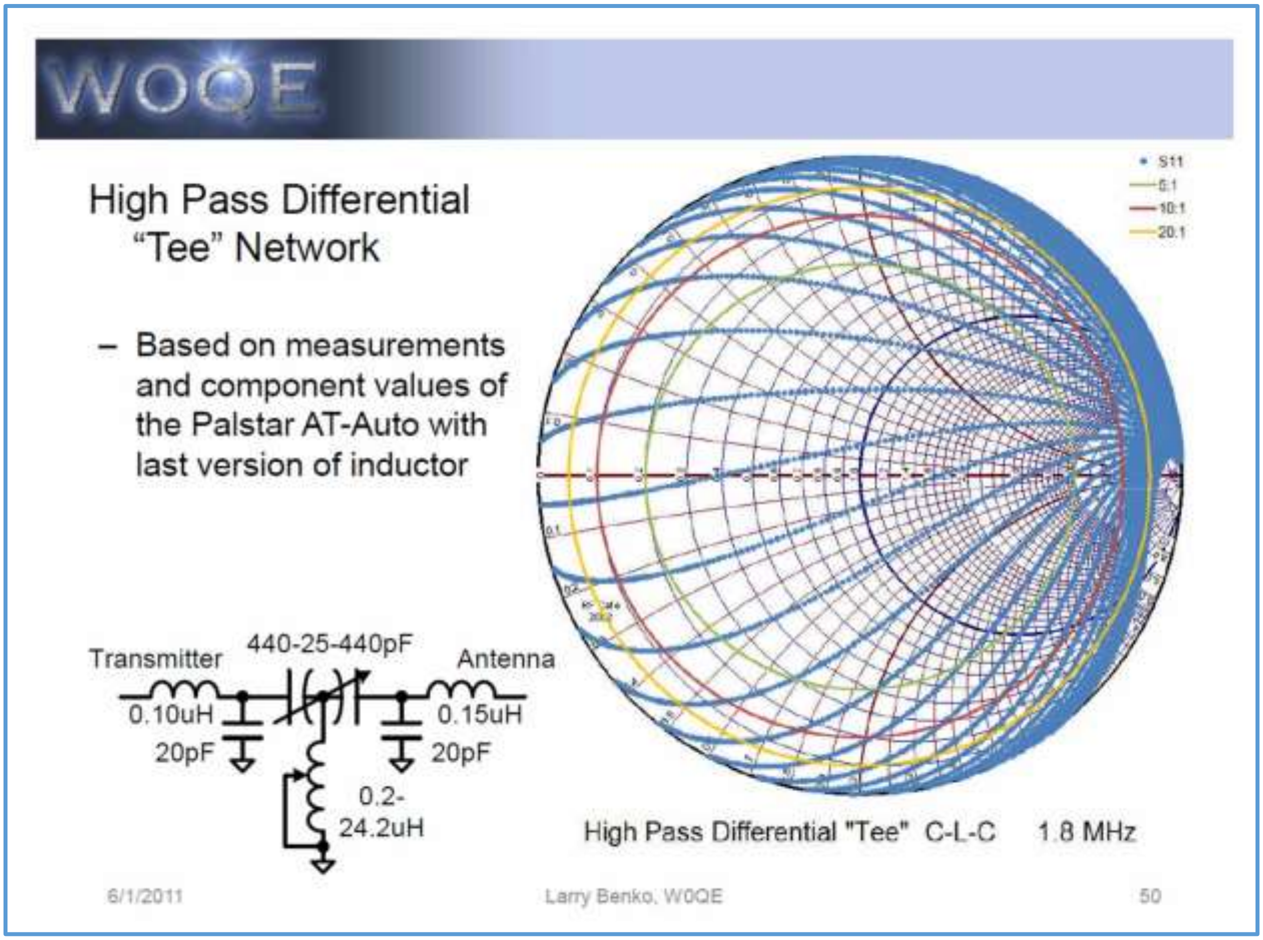

Figure 23: Palstar Differential Tuner on 160 Meters

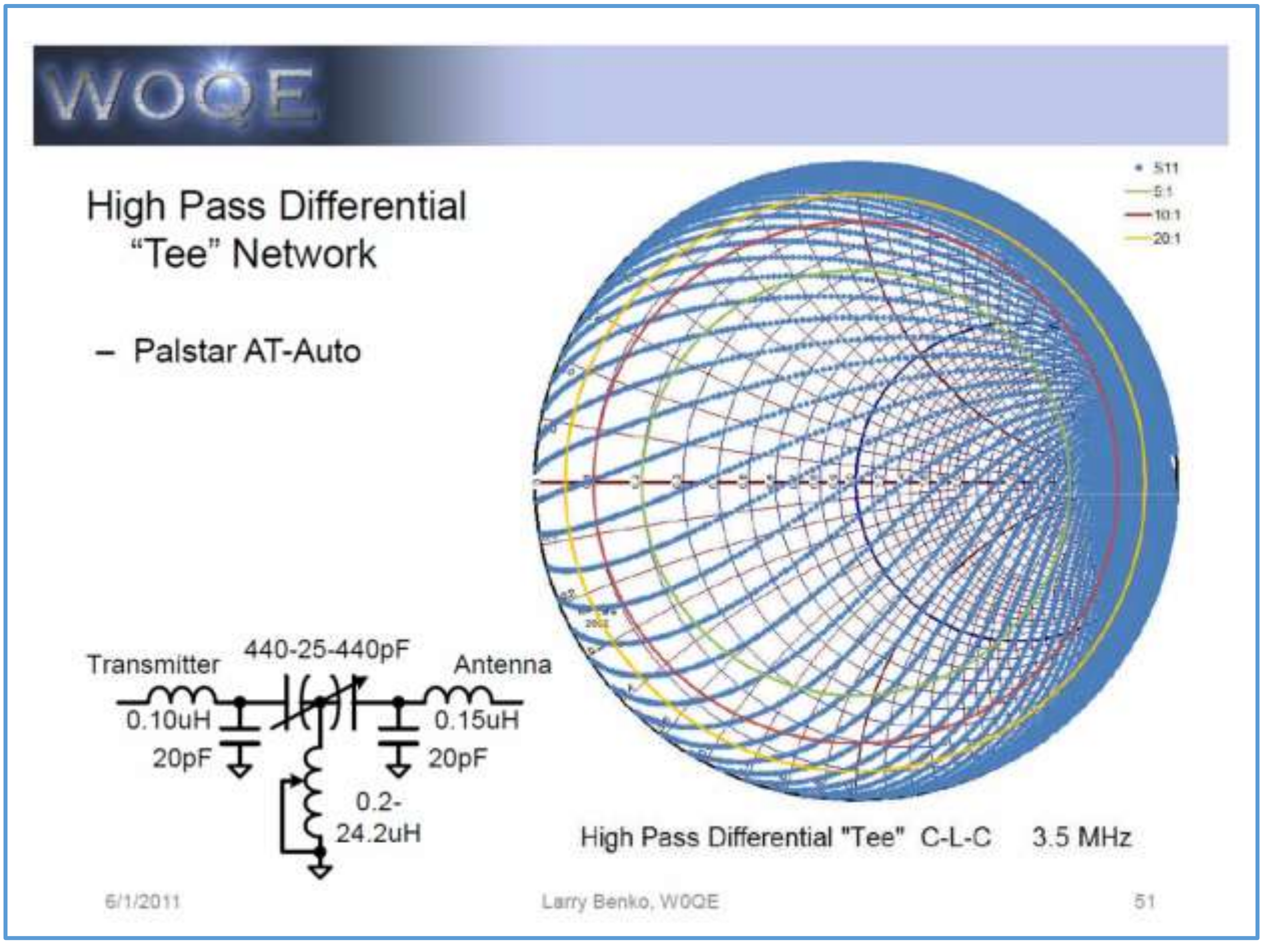

Figure 24: Palstar Differential Tuner on 80 Meters

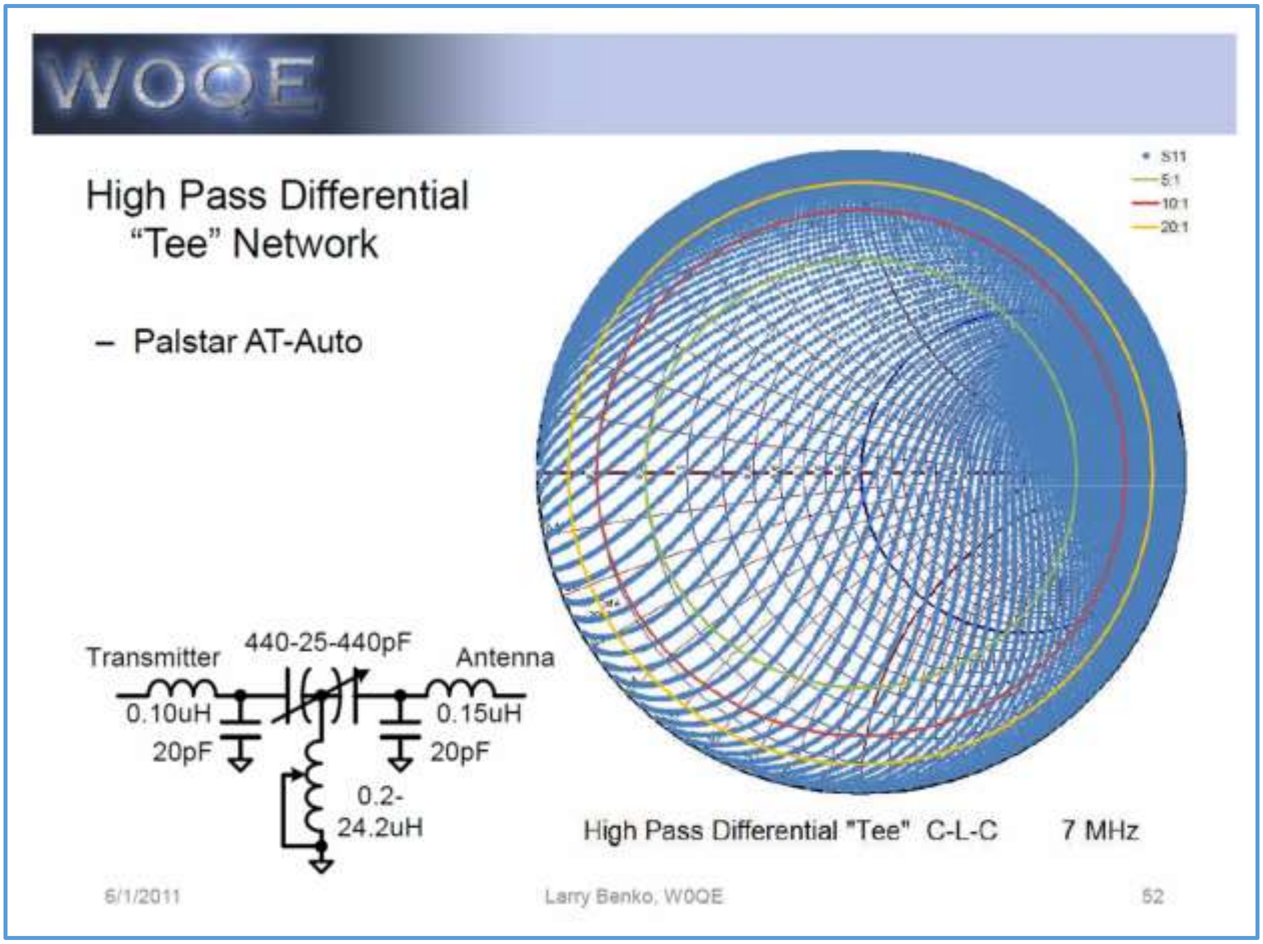

Figure 25: Palstar Differential Tuner on 40 Meters

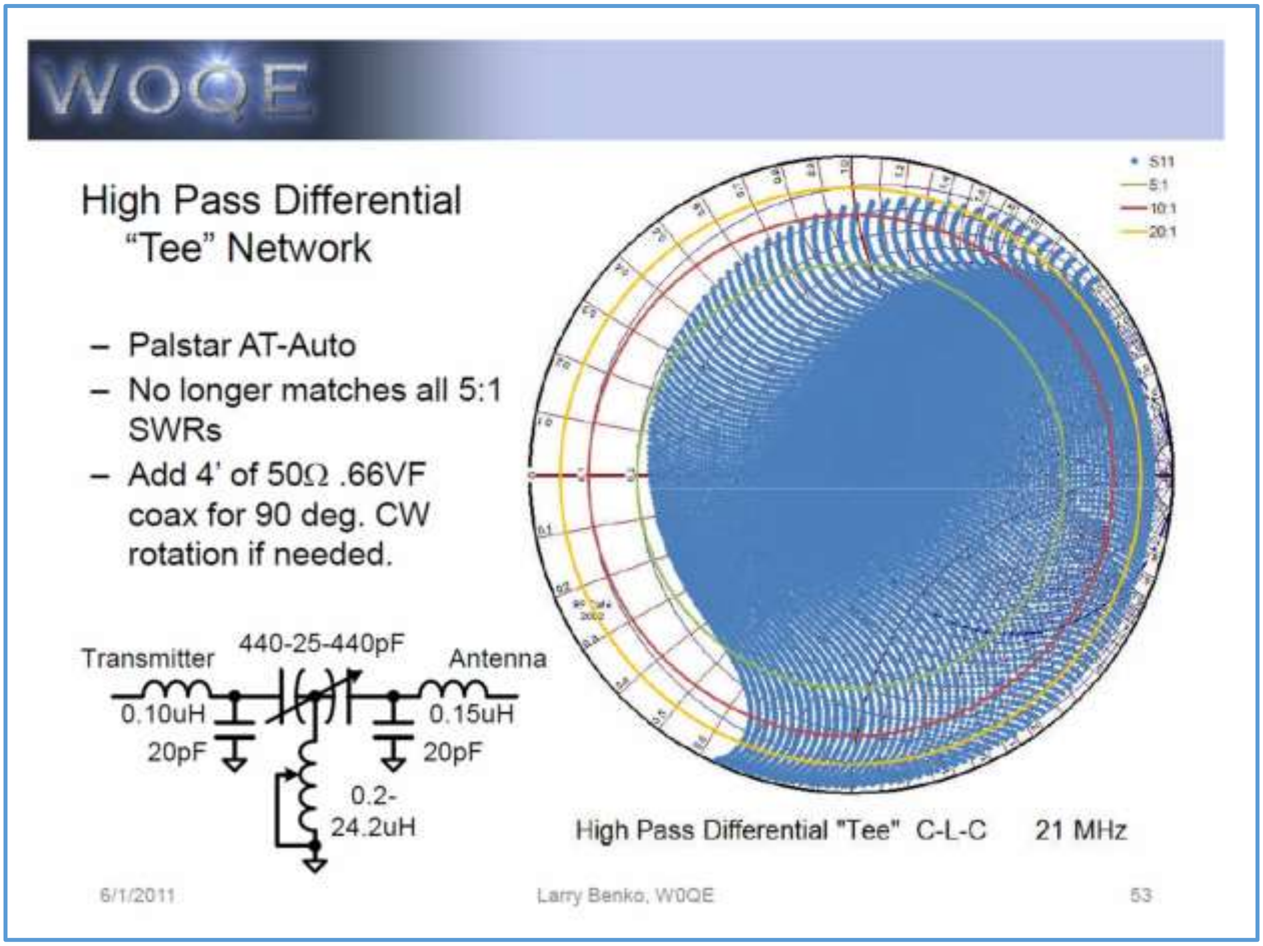

Figure 26: Palstar Differential Tuner on 15 Meters

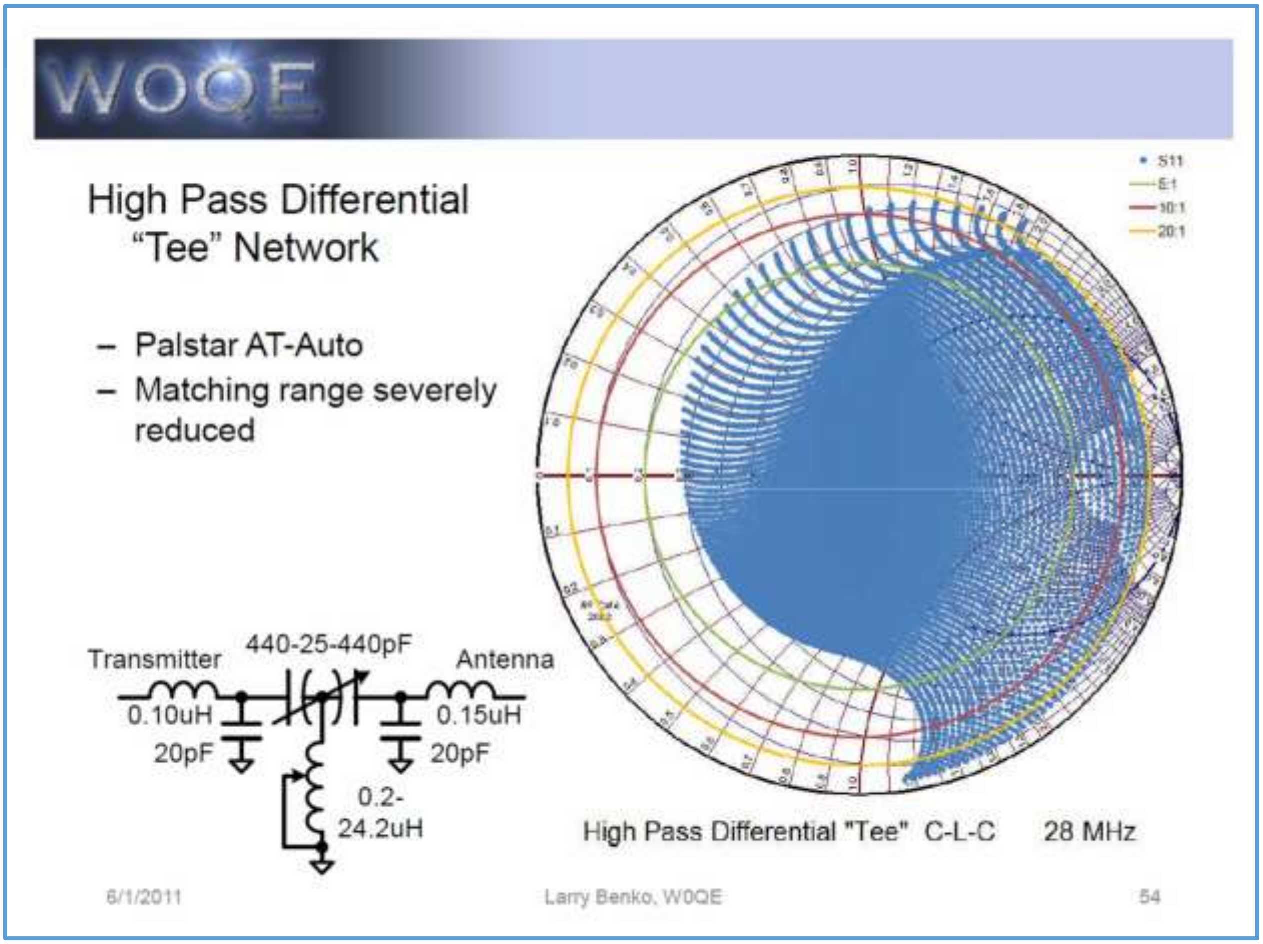

Figure 27: Palstar Differential tuner on 10 Meters

Tuner Power Specification and Tuning Ranges – The Fine Print

In the manuals that comes with most antenna tuners you will often find a paragraph or two on power ratings and they usually start off saying there is no standardize power rating system for tuners. That is a true statement. This infers that the manufactures can claim almost any power rating they want. A quick review of the ads in magazines and on the Internet prove my claim. But when you dig into the fine print you realize that the 1500 watt tuner you thought you bought can't handle more than 600 watts on CW and even less in the digital modes such as FT8. That 100 watt mobile tuner you purchased can't handle more than about 30 watts on FT8. So Buyer beware. Before buying a tuner you might download the manual and take a look at the fine print. Unfortunately the manual will often not give you the full story.

To understand what's really going on we need to talk about SWR for a moment. Let's take a quick look at one of the SWR formulas:

$$SWR = \frac{Max\, Voltage\, of\ Combined\, Wave}{Min\, Voltage\, of\ Combined\, Wave}$$

The term "combined wave" refers to the combined wave of the forward power and reflected power. What happens is at points along the transmission line where the two waves are in phase their voltages combine. What that means is if you are sending 100 watts to the antenna and 25 watts is being reflected (3:1 SWR) at those points where the voltages combine if you were to measure the voltage you would see peeks of 125 volts. As you can see from the formula the higher the SWR the greater the peak voltages. To take this to the extreme consider the case of an open or a short at the end of the transmission line. This would result in an infinite SWR and a peak voltage of 200 volts on the transmission line and the tuner components. If the combined voltage exceeds the specification for the components in the tuner the tuner could be damaged unless the output power was reduced to an acceptable level.

Also note that on the input side of the tuner, if adjusted correctly, everything is fine, the radio sees a 50Ω load and transfers all of its power into the tuner. But remember the tuner does not change the SWR on the output side of the tuner. If there is a 3:1 mismatch then the combined forward and reflected waves will result in a peak voltage 25% greater than the output of the tuner. So in our example 100 watts goes out, 125 watts bounces back.

There's one more factor to be considered. Load conditions and control settings greatly affect the power handling capability of the tuner. The worst operating condition for a tuner are low impedance capacitive reactance loads. What this means is you need to be especially careful when operating at the lower end of the HF spectrum where antennas tend to be short in relation to the wavelength and are often also low to the ground in comparison to actual wave length. Antennas that tend to be too short and low to the ground will result in low impedance capacitive reactive loads. For example a typical inverted L on 160 meters can have an input impedance as low as 22 Ω.

In a worst case scenario what can happen is on transmit you might hear a flash over in the variable capacitor or worse yet smell smoke coming from the tuner as happened in my commercial tuner. I was on 10 meters running 100 watts into my tuner, which was rated for 1500 watts. I was feeding into an antenna with a fairly low SWR when I started smelling smoke. When I opened the tuner it was pretty obvious the inductor had got so hot that it melted the fiberglass trigger on the "*self-resonance-killer*" mechanism. When I looked into this problem further I found out this was a common problem with this particular tuner.

The key takeaway is always be aware that your tuners power rating can be affected by both the amount of power you are sending to the antenna and the SWR in the transmission line especially when operating in a condition where the antenna has a low impedance capacitive reactive load.

Now that we have had a close look at antenna tuners we should now consider if you should add an antenna tuner to your station.

Tuner Options

Now that we have looked at the various circuit configurations lets now consider tuner options. What do I mean by tuner options, well let's list a few:

- Auto Tuners, Semi Automatic tuners and Manual Tuners.
- Tuners with and without SWR meters
- Multiple Antenna ports, single wire feed and parallel wire feed.
- Balun or No Balun.

Auto Tuners, Semi-Automatic Tuners, and Manual Tuners: Auto tuners are tuners that can automatically tune the antenna. Basically what that means is when you transmit the tuner can look in memory to see if it has stored setting for that frequency and will set the tuner configuration using the stored values. If the frequency has not been previously stored it will adjust the components for a match that is within a specified range and then store those settings. It can also over write those memory setting if it finds the stored settings are no longer correct.

This is perhaps the simplest tuner you can buy in terms of use, however there are two key disadvantages with this kind of tuner, namely cost and more importantly it does not necessarily find the best match. Let me explain how this works. Every auto tuner has a setting that represents the threshold match. Often this threshold match can be set by the user however you may not be able to set it where you want it. For example on the LDG auto tuner the lowest threshold you can set is 1.7:1. For other manufactures that threshold can be slightly lower.

The way this works is the tuner is only looking for a match that is at or below a specified threshold. That does not mean that it's looking for the lowest possible SWR, only a match that is good enough. With a **semi-automatic tuner** the user can manually tweak the settings in order to establish the best match and then can save those setting manually to the tuners memory. The PalStar Auto Tuner is just one example of this kind of tuner.

One other point about auto tuners we should point out. Auto tuners come in two flavors. Some tuners use infinitely variable capacitors and inductors. Other tuners use what we call lumped value components. In other words they use a bank of capacitors and inductors and switch in and out capacitors and inductors until an acceptable match is found. Setting aside the threshold setting, a tuner that uses lumped value components may be able to get close to the best possible match whereas a tuner with components that are infinitely adjustable within their respective ranges may be able to actually establish a perfect 1:1 match. We will talk about this a bit more in the section on which tuner you should buy.

In practicable application the difference between the threshold SWR and the lowest SWR may be undetectable to a station 800 miles away or even 3000 miles away. However some solid state amplifiers require a low SWR and the difference between the amplifier's acceptable SWR and the tuners threshold SWR may be out of range.

Manual Tuners: With the manual tuner the user has to manually adjust the tuner settings for an acceptable match. The disadvantage is of course it can take longer every time you have to change frequencies. The advantage is you can zero in on the best match rather than just an acceptable match. Also manual tuners tend to be less expensive than their auto-tuner counterparts.

SWR Meter: Nearly all tuners on the market today have a built in SWR meter. The only down side is these meters are usually not very accurate. I strongly recommend that you have an SWR meter, regardless if it's built into the tuner or external to the tuner. Even if it's not the most accurate meter it's far better than no meter. The reason for my recommendation is by having an SWR meter that you can see while transmitting will help you quickly see if there is an unexpected issue with the antenna system. For example if you are accidently using the wrong antenna or if something has happened to the antenna or transmission line. This is also why I recommend that if your only SWR meter is the one in your radio that you still purchase a separate SWR meter. So often the meters in our radios are set to show power or ALC. If something was wrong with the antenna system you would have no way of knowing until it was too late. I also recommend an SWR meter for your VHF and UHF antenna systems even though we rarely see antenna tuners used for VHF and UHF systems. Again the reason for this is an SWR meter can be the first sign of a problem with the antenna system.

Multi Antenna Ports: Of course this depends on you installation. If you only have one HF antenna and never plan on having more than one HF antenna then having multiple ports would be of no value. If however you plan on having more than one HF antenna then having multiple ports would be an advantage in most situation. We talk about this more in the section on configuring your station.

What about having ports for a balanced line or end fed wire antenna? Here again it depends. So few hams these days bring the balance line or single line antenna all the way into the shack. The reason for this is you are bring the radiating portion of the antenna all the way into the shack. This has a couple of disadvantages. The first is the balance transmission line and single line antenna tend to be detuned by any metallic materials in the area such as windows seals, metal rain gutters or aluminum siding. Second you will be flooding your shack with all kinds of RF which can have the same effect as common mode current which is typically erratic behavior of electronic devices such as computers, routers, computer mice, TV's, even washers and dryers.

Of course this problem is easily solved by running coaxial cable out of the shack and then connecting the coaxial cable to the end fed wire or a balance transmission line with an appropriate unun or balun. For that reason having balanced feed port or single wire feed on your tuner isn't really needed anymore. In fact some manufactures have stopped including these ports in their tuners.

How about a built in balun? Typically the inclusion of a balun is associated with the inclusion of balance line ports on the tuner. If you don't use the balance line connections on the tuner then obviously there is no reason for a built in balun.

In very rare situation you will find some homebrew tuners have a tapped balun that sits between the input port of the tuner and the capacitor or inductor on the "radio" side of the tuner. There is also a switch that allows for switching between the different taps on the balun. As I said this is an extremely rare configuration. For the purposes of this article I'll not go into this further other than to say it can give the tuner a bit more tuning range.

Should You Buy an Antenna Tuner?

Should you purchase a tuner? Here's where all the confusion and misinformation regarding antenna tuners starts to really show. I've written on this before and some of what you are about to read you may recognize. In this day and age given the radios on the market the real question is, "should I buy an external antenna tuner?"

Here's a simple rule of thumb: If you don't have an amplifier and your internal tuner allows you to operate on the bands and frequencies you want then the answer is simple, no you don't need to add a tuner to your station. But if you're internal antenna tuner is not able to match your antenna and limits your options or if you are using an amplifier then the answer is yes, you should invest in an external antenna tuner. This assumes of course that you want all the power your radio can deliver to be transferred to the transmission line and you want to avoid the fold back circuitry from reducing output.

If you have decided that you should add an antenna tuner to your station then you should read the next two sections.

If I have decided to buy a tuner what kind should I buy? Great question! Given all the options that can be a hard question to answer. Let me share a couple of perspectives. If you are purchasing a tuner because you have a solid state amplifier then I would not get an automatic tuner unless it's one that uses a motor driven roller inductor and motor driven capacitors and can be manually adjusted. And I would avoid any tuner that uses lumped value components. Remote tuners might be an exception to this rule.

What I found is that with most automatic tuners their software is set to not look for the best match but a match below a certain threshold. Often that threshold can be set by the user but even then that threshold may not be satisfactory to your solid state amplifier. For example my LDG-600 Pro II's minimum threshold is 1.7:1 and won't allow me to set it lower. There is another factor that plays into this as well. Some auto tuners have infinitely variable controls others use what I call lumped value components.

A tuner that is infinitely variable within the range of the components can usually be adjusted to get the lowest SWR possible. These tuners will use roller inductors and variable capacitors. Lumped value tuners have an array of fixed inductors and fixed capacitors. The software tries to get the best combination of inductance and capacitance that will get the SWR below a preset threshold which again may not always be the lowest SWR possible. This problem is further exacerbated by the fact that you can't fine tune the settings in that you are limited to the lumped values of the components. It's like having a radio with fixed channels rather than a VFO and you're trying to tune in a station that is right between channel x and channel y. This leads to the challenge of finding the best match versus finding a match that is good enough.

If you decided to go with a manual tuner I would go with one that uses a roller inductor rather than a tapped inductor. Of course in most cases it's okay to go with a "close enough" match as long as you can get a match close enough to prevent the fold-back circuit from throttling back the output of your transmitter. However if you're the perfectionist and like to find the best match possible then a tuner with a roller inductor is the better way to go.

As to the type of tuner, "T" or Differential, either works very well. The advantage of the differential tuner is there are only two controls and one matching solution. Whereas there are three controls on a "T" style tuner and often more than one matching solution. But as has been stated, the solution with the lowest amount of inductance is the right solution. The disadvantage of the differential tuner is they generally have more loss than a "T" style. So if you go with a differential tuner don't let budget be your final arbitrator. Spend a little more and get the best one you can afford.

Finally a word about tuning ranges. Most built in tuners have a matching range around 3:1. Yes there are exceptions, some of the built in tuners do have a broader range. But the tuners in the Icom 7300 and the Yaesu 991A are examples of tuners with a somewhat limited tuning range. Whereas the Xiegu G90 and some of the more expensive Yaesu, Icom, and Kenwood radios seem to have a much broader tuning range.

A word on tuning ranges: There seems to be two categories of external tuners, tuners with ranges in the 800 Ω (10:1) range and tuners with a range of 1600 Ω (16:1). When shopping for your tuner try to determine what the matching range of the tuners you are considering. Of course it only needs to be good enough to tune your antenna. Before buying a tuner consider arranging to have someone with an antenna analyzer evaluate your antenna and see what the SWR range is for the bands and frequencies you want to operate on.

Should I add a tuner to my mobile HF Station? Adding a tuner to a mobile installation I believe is a good idea. Mobile antennas generally speaking are usually fairly short for the wavelength they support. For example most mobiles antennas are not going to be more than 8' long and most are much shorter than that. The smallest HF frequency in terms of wavelength is the 10 meter band, which has a quarter wavelength of around 102 inches. For 10 meters an 8' length will work fine. But consider the 20 meters band, a quarter wave on 20 meters is going to be around 16 feet long. The net effect of using antennas that are far shorter than a quarter wave for their respective frequency is they tend to be fairly narrow banded due to the use of coils and traps. By adding a tuner you can extend the frequency range of your mobile antenna. This does not infer extending the actual geographic coverage range of your antenna, it only extends the operational frequency range of your antenna.

Over the years I've used a number of mobile antennas, the Hustler with its many different resonators, hams sticks, as well as a couple of others whose names I no longer remember. To all of these I found my tuner was a welcome addition because it allowed me to operate across a wider portion of each band than I otherwise would have been able to. Ultimately I ended up with the good old 102" whip, which I can use from 10 to 40 meters without having to change antennas, resonators, or jumpers.

Of course if you're using an antenna that can adjust itself, such a screwdriver antenna then of course a tuner is not needed. However, remember coils tend to be RF wasters as they can turn a good portion of your RF into heat. Understand that coils and traps are technically speaking nothing but large inductors.

What About Relying on Reviews? If you have read any of my other articles you know that I tend to consider the reviews you find on the Internet too subjective to be trusted. There's also the human nature aspect. When we spend what we consider to be a lot of money or time on a piece of gear we are naturally reluctant to admit that our purchase or efforts was perhaps not the best choice we could have made. The other problem is the person writing the review often has limited understanding of the technology and is therefore commenting on something they know little about.   So should one trust the reviews or even bother reading them? It's my opinion that you should consider reviews but you need to know what to look for and what to ignore.

To begin, looking at the five star reviews is generally speaking a waste of time, unless that's all there is. I always begin by looking at the negative reviews. Reviews that complain about non-technical aspects I usually ignore. Complaints about slow shipping, poor technical support, or poor documentation I usually don't pay much attention to. What I do focus on are technical issues. We should recognize that every manufacture will on occasion ship product that may not be up to their standard so you will often find at least one or two technically focused bad reviews. If I don't then I suspect the sample is small. But when there are repeated reviews citing the same technical issue, those I pay attention to. I'll give a specific example that happened to me.

I had purchased a tuner that I unfortunately did not research very well. I had it on the air for a month or so when I started to notice the SWR would slowly start to rise on 10 meters, regardless of how much power I was running. So one day I decided I was going to try and track down the root cause of the issue. Using the full output of my radio, about 90 watts on CW, I started transmitting on 10 meters. As the SWR kept rising I kept retuning and transmitting. After a few minutes I notice a burning smell. I had suspected something was getting hot and that was the reason for the change in SWR. At that point I opened up the tuner and noticed the fiberglass trigger on the "*self-resonance-killer*" had been burned away. It was clear the variable inductor was getting hot, so hot as to melt fiberglass. This led me to start doing more research on the issue and what I found was this was not an uncommon problem on this particular tuner. Had I done my research in the beginning I would not have purchased this brand of tuner. But I had to own up to it. I decided to not pursue a warranty claim for a number of reasons. The biggest of which was I knew it would fail again, the issue was simply a poorly designed inductor. I knew manufacturer would simply replace the inductor with the same flaw component and that it would only be a matter of time before it failed again.

What I ended up doing was pulling the differential capacitor out of my commercial tuner and putting it in a tuner with a properly designed roller inductor. I used that homebrew tuner with the differential capacitor from my old commercial tuner and have had not one issue, even running 200+ watts on 160 meters.

There is another group of reviews that I always take seriously when they are available and they are the technical reviews done by QST, QEX and CQ magazine. In those reviews they often include technical data, data that can be quantified numerically, reproduced and verified. They are not subjective but are instead objective. I find those reviews can be trusted and I consider them to be reliable. An example are the reviews you find in the ARRL book on antenna tuners.[13],[2] In that review it quantified a number of relevant aspects of each tuner, what I call a true apples to apples comparison. Had I seen that review before I purchased my tuner I would have never purchased the one I did.

The key takeaway from my story is do your research. You may see 100 five star reviews, but if you see ten reviews all describing the same technical or mechanical issue then you should take note and perhaps consider other options, or at the very least dig deeper.

The Proper Way to Adjust Your Manual Tuner

Now that you have purchased or built a tuner let's spend a few paragraphs on how to actually use it. Let me begin by saying, consult your manual! I know, real men don't read manuals. But I'll counter that by saying, real hams do. Understand that there is a right way and a wrong way to adjust your tuner. The wrong way is to just start keying your rig and blindly twisting knobs looking for the lowest SWR. Using that method you have a 50 50 chance of getting it right if your using a traditional three knob tuner.

Step 1: Set you radio to the desired frequency. If the frequency is in use try to find a frequency that is not in use but close to the frequency that you will ultimately want to transmit on.

Step 2: Set the radio in CW or AM mode. The reason for this is you need a carrier. Of course you can use the old CB trick of whistling into your mic but know that if you do that you will be forever labeled a "lid". Without whistling into your mic key the rig and adjust the RF output power to 10 watts or so. Check your manual for the recommended power levels for tuning but generally speaking you are going to be safe with 10% of your radio's maximum output capability.

Step 3: Without keying the rig adjust the input and output capacitance knobs on the tuner to 50%

Step 4: Without keying the rig adjust the inductance knob while watching the S-Meter on your radio and listing to the audio. Adjust for maximum signal strength. This is usually where the noise is the loudest and the signals the strongest.

Step 5: Now adjust the capacitance knobs while listening for the loudest noise or watching for the strongest signal on the S-Meter.

[13] "*QST Reviews Five High-Power Antenna Tuners*", QST, Feb 2003, pages 69-74.

Step 6: Make sure that when you transmit that you won't be interfering with anyone. You want to be on a clear frequency. Key your radio and start tweaking the three knobs starting with either of the capacitance knobs. **No whistling into the mic!** Watch the SWR meter, you want to adjust for maximum forward power and minimum reflected power. If you need to tweak the inductance knob do so but remember you want minimum inductance.

Step 7: Once you have tuned for the lowest SWR (minimum reflected power) and lowest inductance, you are now ready to get on the air. Tune to the frequency you want to transmit on assuming it's within a few kilohertz of where you tuned up. Set your radio to the desired mode, SSB, CW or other mode. And finally turn the RF power back up to the desired level.

Whenever you are transmitting be sure to keep an eye on your SWR meter. If something unexpected should happen the SWR meter and sometimes your nose will be the first place where you will notice that things have gone wonky.

One of the questions that often comes up is, "*When do I need to readjust the tuner?*" Answer: Whenever you notice the SWR has gone past about 1.7:1. This can happen if you QSY (change frequencies) several kilohertz and whenever you change bands. On some bands your antenna may be fairly broad banded and may not require any adjustment when you change frequencies. This is typical on the higher HF frequencies like 10 and 12 meters. But on the lower frequencies antennas tend to be narrow banded and may require tweaking after changing your frequency by only a few kilohertz. This is especially true on 160 meters.

Configuring You're Station: Where should I Place the Tuner?

One of the questions I often get asked by new hams is where to put the tuner? The short answer, between the radio and the antenna. If you have an amplifier, between the antenna and the amplifier.

Arguments for placing the Tuner at the Antenna: In some installations it's possible to place a tuner at the feed-point of the antenna. This does require that you run 12 volts to the tuner but that can be easily done using what they call a "Bias Tee DC Power Injector." Although the name makes them sound complicated and expensive they usually aren't, generally they sell for around $40. They allow you to put 12 volts on the coax in the shack which can be pulled off at the tuner. The MFJ remote tuners all come with a bias Tee and work very well. In my installation I can deliver 12 volts across 150' of coax to my MFJ-994BRT tuner for my 160 meter antenna.

The advantage of tuning at the antenna is you minimize loss on the coaxial cable. As you may recall from previous discussion the greater the SWR the greater the loss in the transmission line. Loss due to SWR happens in the transmission line due to the transmission line's attenuation properties. With a remote tuner the SWR is minimized on the transmission line which results in minimum loss due to SWR and maximized power going to and coming from the antenna.

Of course it's not always possible or practical to place a tuner at the feed-point of the antenna which means the antenna tuner usually sits proudly next to the radio.

The Typical Station: Almost every station that uses an antenna tuner will place the tuner in the ham station. Of course this is the easiest and most convenient location for the antenna tuner. From that position it is easy to adjust the tuner. Figure 28 shows a typical station. The tuner should always be placed between the radio and the antenna. And because we want to monitor the SWR between the radio and the tuner the SWR meter should go between the radio and the tuner if you are using an external SWR meter.

Nearly all antenna tuners have a built in SWR/Power meter so an external SWR meter may not be necessary. The thing to note about many built in SWR meters is they are not very accurate but they are generally speaking good enough.

Figure 28: Typical Station Using an External Tuner

In Figure 29 we show another configuration, this time of a station with an amplifier. Here again because the radio and the amplifier need to see a 50 Ω load the antenna tuner must sit between the antenna and the last output device, in this case the amplifier.

Multiple Antennas, What if you have more than one HF antenna? Many of today's radios have multiple antenna ports. This is also true for most antenna tuners. So what should you do, connected the other antenna to the radio or to the tuner? The simple answer to that question depends on if you need to use the external tuner to tune the other antenna. If yes then you need to connect the other antenna to the antenna tuner and use the antenna switch built into the tuner to switch antennas.

Q: But what if you're using an amplifier? In that case you should purchase an external antenna switch and place the switch between the tuner and the other antennas. That will allow you to use both the tuner and the amplifier on any antenna connected to the switch.

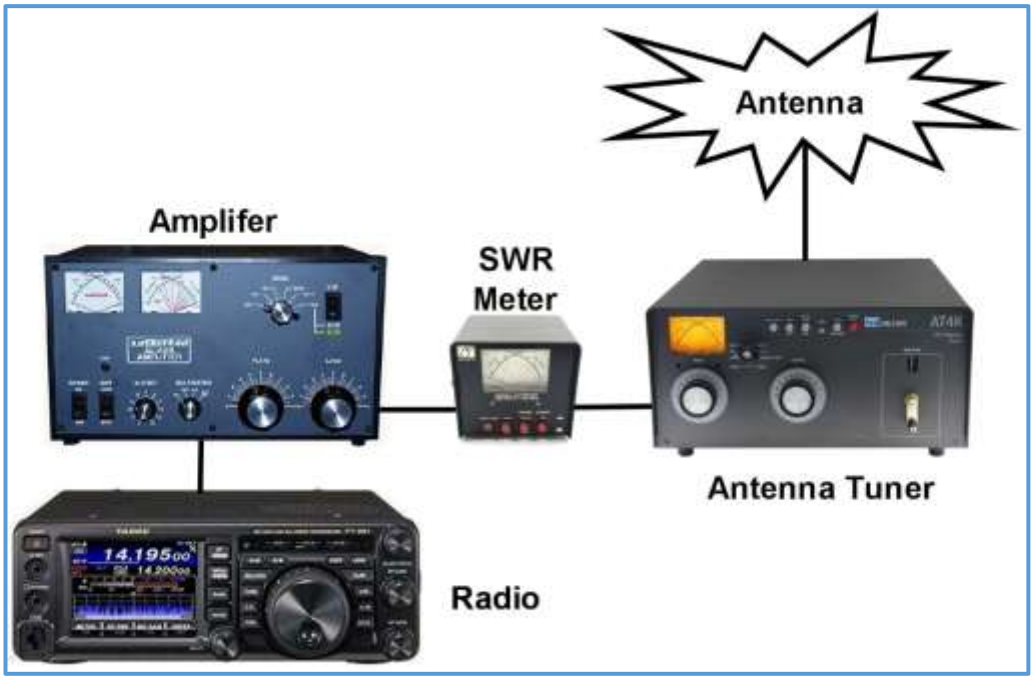

Figure 29: Typical Station with Amplifier

External SWR Meters: Practically all antenna tuners and amplifies sold today have a built in SWR meter. It the configurations depicted in Figure 28 and Figure 29 the external SWR meter is redundant. However as was already stated the built in meters are generally speaking not very accurate.

If you are looking for accuracy the LP-100A or one of the other products available from TelePost (http://www.telepostinc.com/n8lp.html#top) is considered to be one of the most accurate meters on the market. The other reason you might want an external meter is you might prefer a digital SWR meter (MFJ-826B), or you simply want a bigger meter that you can see easier (MFJ-868B). In those cases you will want to add an external SWR meter. The correct placement for this device is between the last output device and the tuner.

Note that the LP-100A can be purchased with two sensors, one can be placed in front of the tuner and the other between the tuner and the antenna. This is handy if you want to monitor the SWR and the power at both the input and output of the tuner, although that would make you a member of the overly obsessive group ;-).

Conclusion

In this article we have taken an in depth look at the antenna tuner. We have learned that there's more than one way to skin a cat as they say. We looked at the various matching topologies and to some degree been able to understand their strengths and weakness. We have looked at the Ultimate Transmatch and its close relative the SPC Tuner. Both are a type of "T" match as well as the "Pi". All three suffer from the same weakness, their matching ranges can be limited. To extend their matching range beyond 10:1 requires the use of components with values that are out of the main stream and are consequently hard to get or expensive. They also tend to exhibit more loss than the conventional "T" match. However if one uses quality components losses can be minimized such that they can outperform many of the commercially available "T" tuners on the market today. Unfortunately in the case of the Ultimate, the SPC and the "Pi" there are no commercially available options today. If you want one of these tuners you're either going to have to build it yourself or search the used market. And if you happen to find one on the used market you can bet that it will have a premium price tag.

We also looked at the "L" match which has the lowest loss of any of the tuner topologies generally speaking, however the matching range of the standard "L" network is also somewhat limited but can be extended by using the switched "L" configuration. Unfortunately the only switched "L" devices on the market today are all auto tuners using lumped value components. The net effect is losses can be higher than the conventional "T" network and establishing the "perfect" match or even the best match is not always possible.

I'm not aware of any L, SPC, Pi, or Ultimate Transmatch like tuners in a manual or automatic configuration using a roller inductor and variable capacitors on the market today. If you are aware of one please let me know.

So we are left with the conventional "T" tuner. Overall it's proven to be a good tuner, it has a wide matching range using mainstreamed components and is very efficient and in many cases more so than any of the other tuner configurations with the possible exception of the "L" match. In extreme matching situations the "T" tuner has been shown to be more efficient than its counterparts. Of course its biggest advantage is it's widely available in the market place and in a wide variety configurations and tuning ranges. If you're looking to be able to get the perfect match using either a manual or automatic tuner, get one with a roller inductor rather than a tapped or lumped inductor. If you're looking for inexpensive go with one that has a tapped inductor, roller inductors are expensive. But if you're looking for simple then our next tuner is a good choice.

The differential "T" tuner has a very broad matching range but is less efficient than the conventional "T" tuner generally speaking. Its big advantage is that of all the tuners it's the easiest to use given that it only has two adjustment controls and which results in one solution for any given matching condition. Although there are not a lot of differential tuners on the market today there are models available from both MFJ and Palstar.

Although this is the end of the main article I have included information on many of the interesting and unique tuners I looked at while preparing this article. I would invite you to take a look at some of these tuners. I found it fascinating looking at the insides at the build quality and different components they used. On some I have included what Information I could find out about their construction. I came away thinking about a popular saying I often hear when looking at older technology, “they sure don’t build’em like they used to.”

To that point, one of the key takeaways from this article is if you are considering an antenna tuner don’t let money be your final arbitrator, especially if it’s going to be a key component in your station. What that means is if you are going to rely on your tuner to allow you access to portions of the radio spectrum you want to operate in that you otherwise couldn’t, or if it’s going to allow you to avoid pushing the boundaries with your HOA, your property manager, or your spouse, then choose wisely. Look under the covers. Do your research. There’s a big difference in the quality and capability of antenna tuners and I hope this article has been helpful in giving you some insights into what those differences are and in understanding the difference between high quality and low quality.

That pretty much brings us to the close. If you have read to this point I hope you felt the investment in time you made reading this article was worthwhile. If you have any comments, questions or additional information please contact me. I will be sure to add it to the online version of this article.

73,

Gene (WB7RLX)

EE_morgan@outlook.com

A Look at Some Select Antenna Tuners

Following are pictures of many different tuners. There are some beautiful examples of what a well-made tuner should look like. They may not be very pretty on the outside, but at the end of the day, it's what's on the inside that matters. The thing to remember, with every one of these tuners there is a history and a story to go with it. I only wish I could have found out more. Before considering building or buying a tuner you might look at some of the tuners presented here.

KB0ES Home Brew Ultimate Transmatch

Figure 30: KB0ES Home Brew Ultimate Transmatch - Front

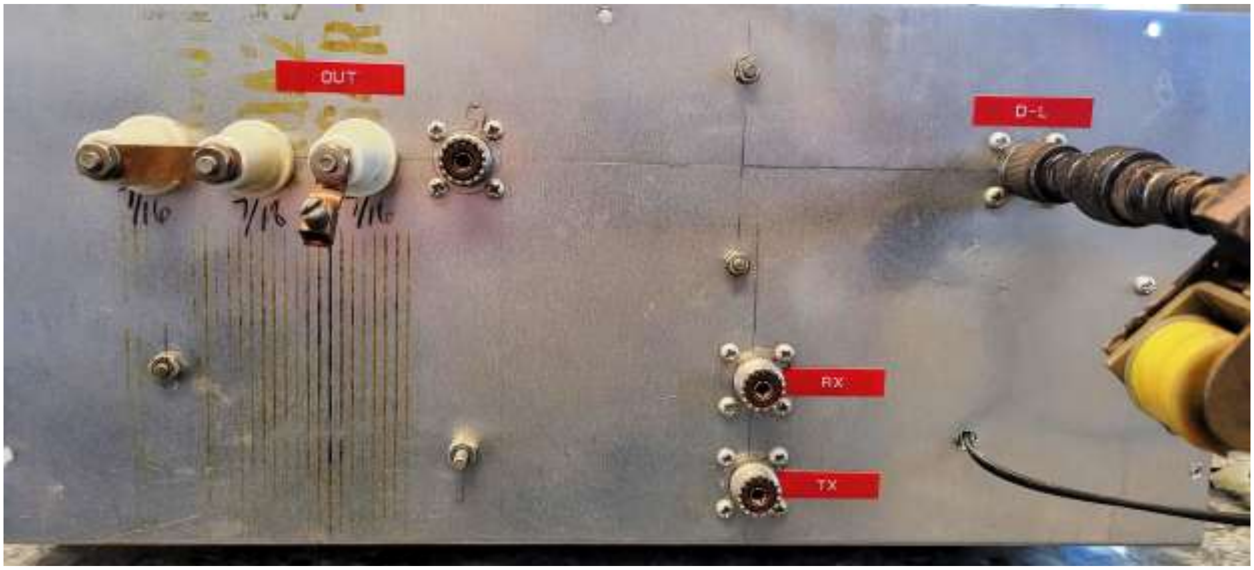

Figure 31: KB0ES Home Brew Ultimate Transmatch - Rear

Figure 32: KB0ES Home Brew Ultimate Transmatch. Note the massive inductor and the use of copper strips rather than round copper wire. This is a very well made tuner, one of the best I have seen.

Written by the builder, John Burger, KB0ES.

"I wanted to build it without taking short cuts and using the best components and construction practices I could. I was stationed at Korat Royal Thai Air Force Base in 1975. On my off duty time I worked as a volunteer radio operator at the MARS station on base. We ran phone patches back to the states for the personnel stationed there. The station call sign was AIA8KO. We had two complete Collins stations, KWM-2 transceivers and 30L-1 amplifiers. We used to run primarily with a station in California and Senator Barry Goldwater's station in Arizona. There was a lot of older equipment in the building that wasn't used. The roller inductor came from there.

The tuner was built in late 1977 or early 1978 when I was stationed at Ellsworth AFB in Rapid City SD. I had the best part already, the roller inductor. The rest of the parts were either bought new or were surplus gotten from other Hams in the area. The coax connectors, ceramic feed through insulators, the ceramic stand offs, the rubber feet and the Vernier dials were bought new. The toroid core was bought new but I wound it. I made the case."

Editor's Note: After I purchased this tuner and got it home and opened it up, I was amazed at the quality of the workmanship. Note the use of the copper strips between the components. Once I saw the craftsmanship I didn't have the heart to disassemble it for parts. I did however remove the SWR circuitry and the TR/TX relay circuitry. Other than that it remain as it was. I put it on the air and was very pleased with its performance. With it I was able to complete WAS on 160 and 80 meters. It sits proudly on my shelf today.

KZ7O Pi Tuner

Figure 33: KZ7O Pi Tuner - Front

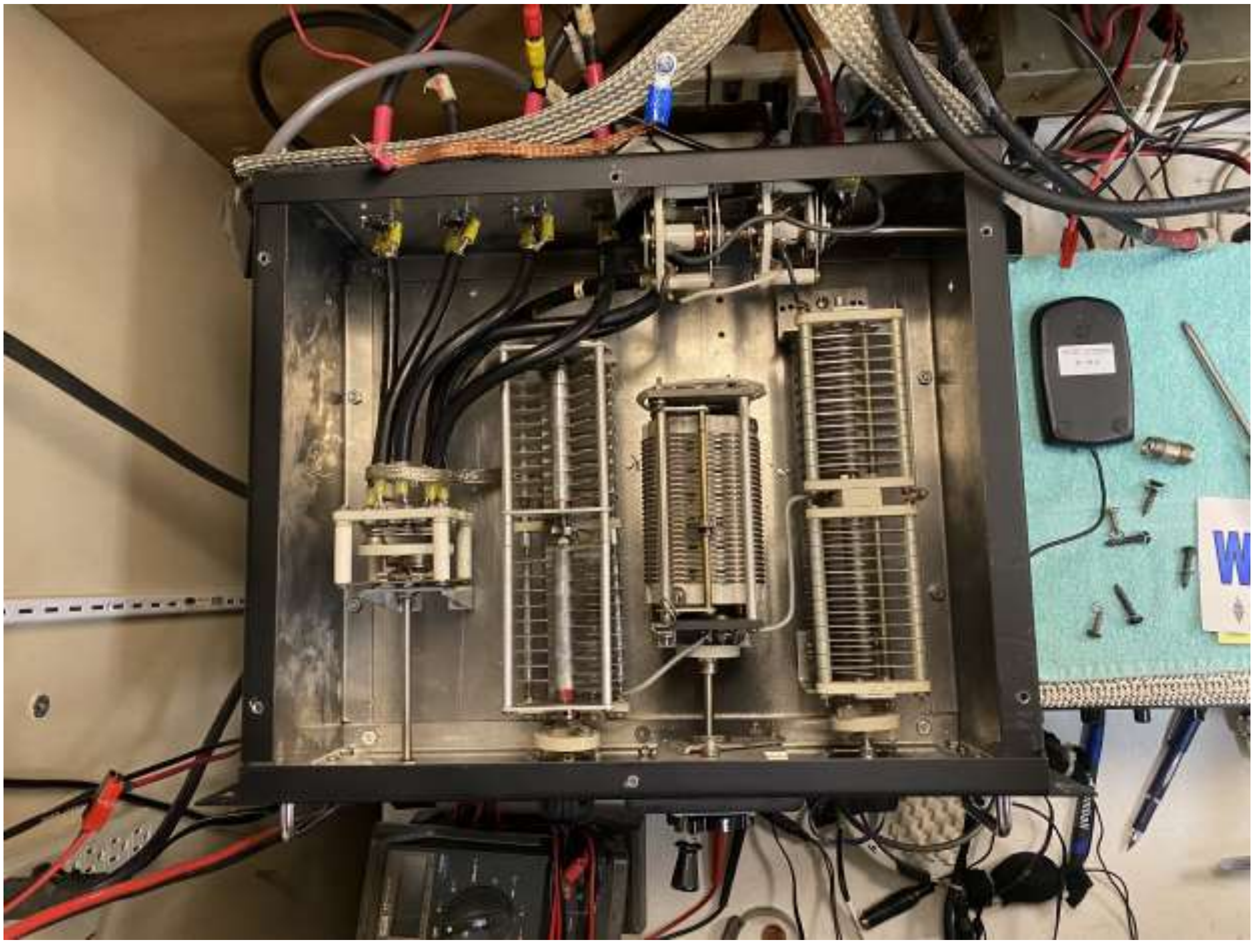

Figure 34: KZ7O Pi Tuner - Inside

This tuner was built by Mike Fullmer KZ7O. Another high quality build. Note the use of the RG-8 style coaxial cable. Also note that the split stator has been wired together to increase the capacitance range. Also note the size and quality of the ceramic rotary switches. The following was written by Mike in answer to my questions about the use of the coax and the capacitor configuration and the rotary switches.

"I needed more capacitance so I ganged the shafts together. This allowed me to get to lower frequencies. The coax is to try and reduce the losses as much as possible for the upper bands. I really do not know if it helps or not. These switches are hard to come by any more. This was the typical military switch. They have two wipers per contact. They are practically indestructible. The whole tuner is rather large, but it works great. I cleaned the roller inductor 3 months ago because the silver was tarnishing on the wires which are silver coated. It was fun to build but took a while."

D.F. Hammack SPC Tuner

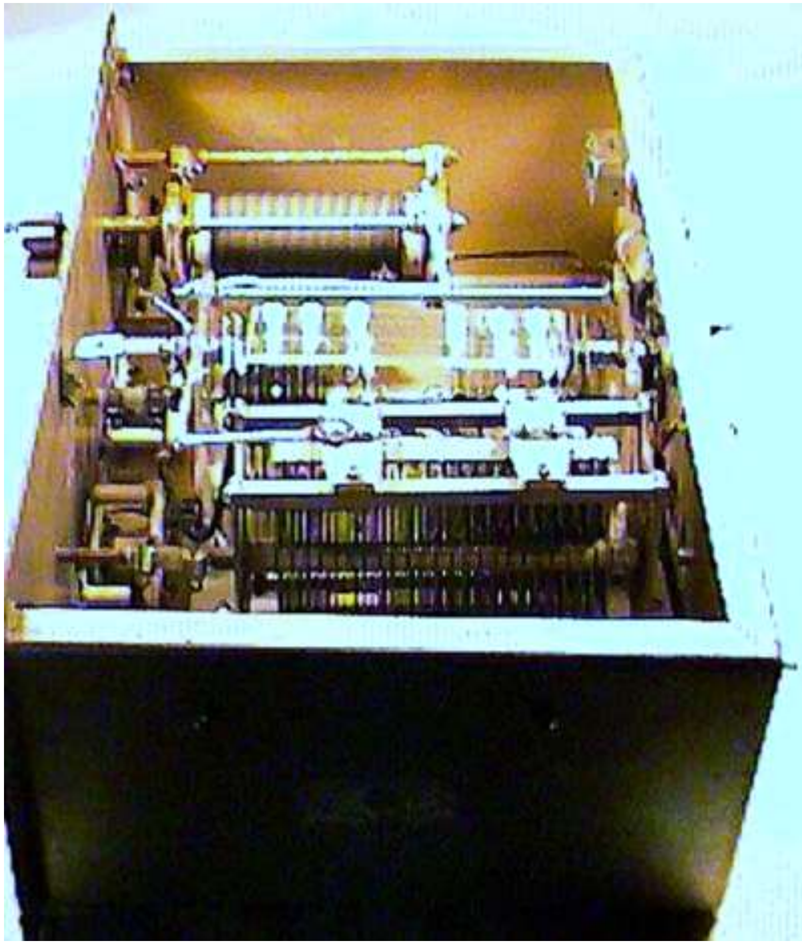

Figure 35: Hammack SPC Tuner – Interior view

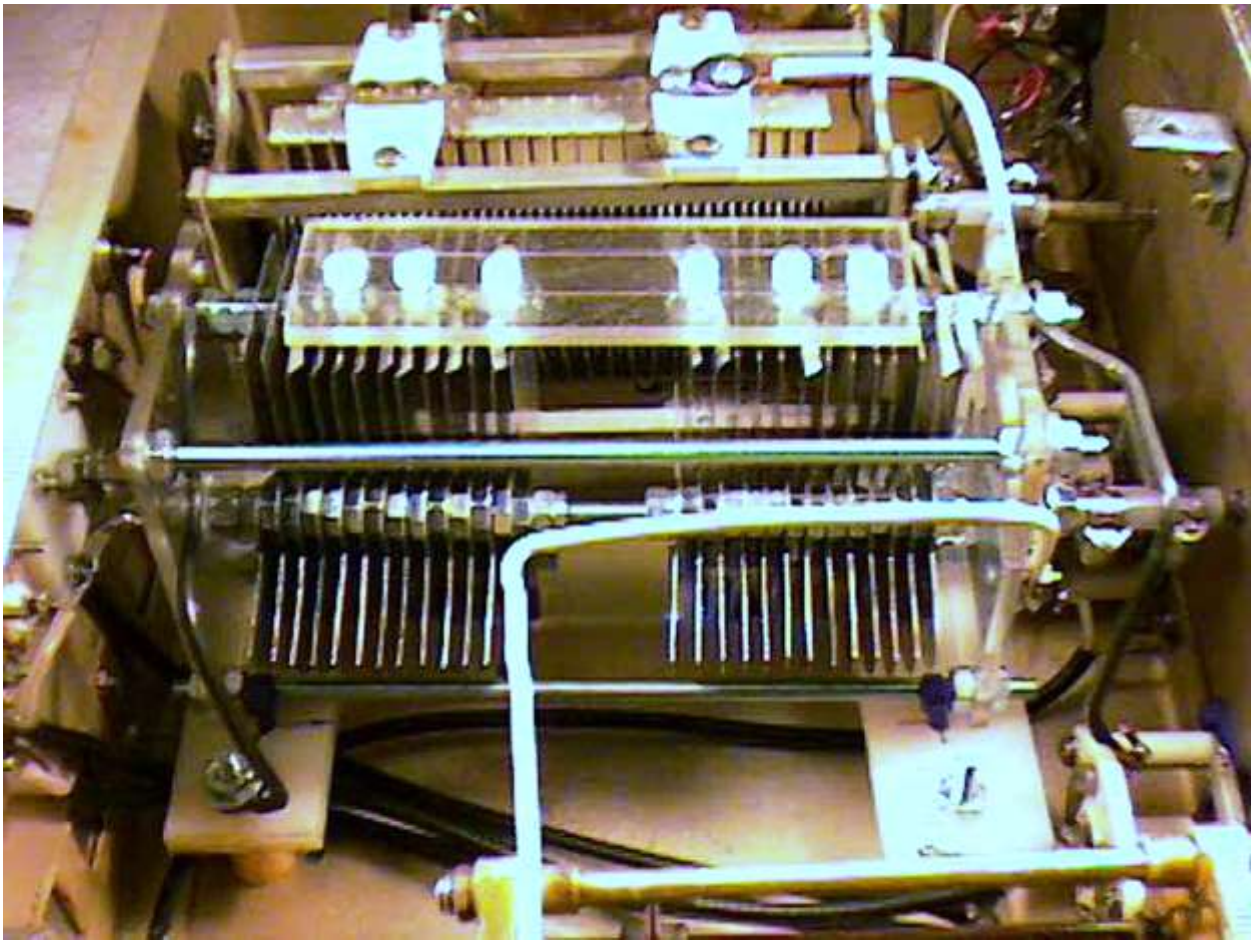

Figure 36: Hammack SPC Tuner – Homemade Variable Capacitor

Figure 37: Hammack SPC Tuner - Front View

Written by the Builder, D.F. Hammack N4DFP:

“Way back when I was a new, young Ham, I was eager to work all the HF I could. Problem was, I had limited usable antenna space. I priced a Transmatch and found them to be beyond my meager means. Well as a new, young Ham, I scrounged everywhere and had put together a respectable [Junque] Box... it filled the garage. I looked through my treasure and found a couple of dandy high power air variable capacitors and a roller inductor with a turns counter. I had also acquired a transportable rackmount cabinet with chassis. To me this looked like the perfect Transmatch. I built it as an Ultimate Transmatch, and it tuned my 80m Dipole to any frequency I chose. I built it, I used it, I loved it, and I lost it. Somehow it didn't make the trip in a move. I hope whoever found it can appreciate its beauty. After that move, work didn't permit a lot of time for HF operations so HF fell by the wayside. Now, years later, the HF bug has bitten again, and again I have limited usable antenna space. After many moves and years of maturity, my [junque] box no longer fills a garage, but I did find the makings of another transmatch; not as nice as my first beauty, but workable.”

(I purposely left some of the misspelling in as I thought it gave the reader a feel for the personality of the writer.)

You can read more about this tuner here: https://www.qsl.net/n4dfp/transmat.html

Update: I did exchange a couple of emails with David. Below is one of his emails. I hold these old timers in ah when I read their stories and get insights into their lives. David is one of those hams that I’m inspired by. His email follows:

“Hi Gene, Thanks for writing, and I am glad you found my article interesting and inspirational. I am sorry I cannot tell you much about writing the article. I wrote that article almost 20 years ago while building from my original plan, of about 40 years ago. Since my stroke I am not very active as a Ham anymore, neither on the air, nor as a homebrewer. My stroke occurred shortly after I upgraded to Extra, and changed my call.

I am pretty sure my info all came from W1FB's article in "The Radio Amateur Handbook" I do not remember which volume, but the good news it that means it was published in QST. So, if you are an ARRL member, you can search it in the QST database. I may also have supplemented it from Bill Orr's (W6SAI SK) "Radio Handbook", various editions of which are available to download on the internet, and a must have for any homebrewer. If you look for this book in print, you will pay a fortune for it, and it is that valuable. Good luck with you hobby, and there still are a few homebrewers out here, so do not give up! Thank's for the note, and very sorry I could not be more help.

TNX & 73,

DE David F Hammack”

Dentron MT-2000A

The Dentron MT-2000A is another classic antenna tuner from the 70's and 80's. The story has it that Dentron was going use the Ultimate Transmatch design but change their minds after Walter Maxwell wrote an article inferring that the Ultimate Transmatch design was inferior to the standard "T" topology. The Ultimate Transmatch required the use of a split stator which was far more expensive than the standard variable capacitor. Consequently Dentron change their design in favor of the standard "T" network. Dr. Maxwell's article spelled the downfall of the Ultimate Transmatch and made the "T" network the industry standard to this day.

The Dentron, like a lot of tuners from that era were built to last and they have. You can still find them on the used market but like a lot of the old tuners they command a fairly high price. The only complaint was the tuner used a tapped inductor rather than the more expensive roller inductor. But it was as they say, "Built like a tank" with high quality components and hand crafted workmanship. And did what it was meant to do year after year after year.

FYI: The tuner feature here is one of the very first pieces of gear I bought back in 1977. I still have this tuner and used up until about four years ago. This is another one of those items that will become an air loom that my kids will have to dispose of. I hope it ends up in a good place.

Dentron, located in Twinsburg, Ohio, closed production in 1980 and later Ameriton emerged from what was left.

Figure 38: Dentron MT-2000A

Figure 39: Dentron MT-2000A - Rear view

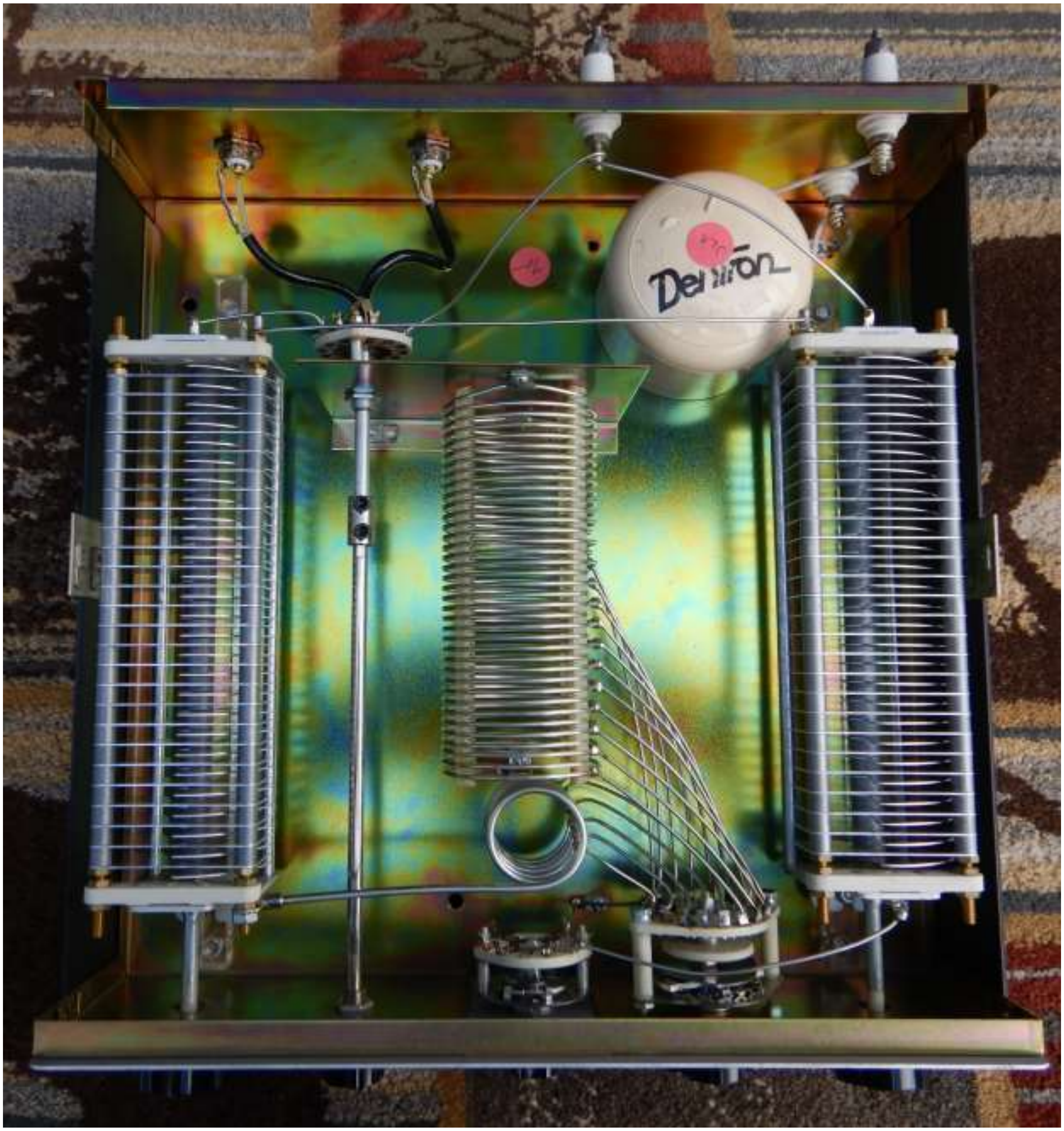

Figure 40: Dentron MT-2000A. Interior View

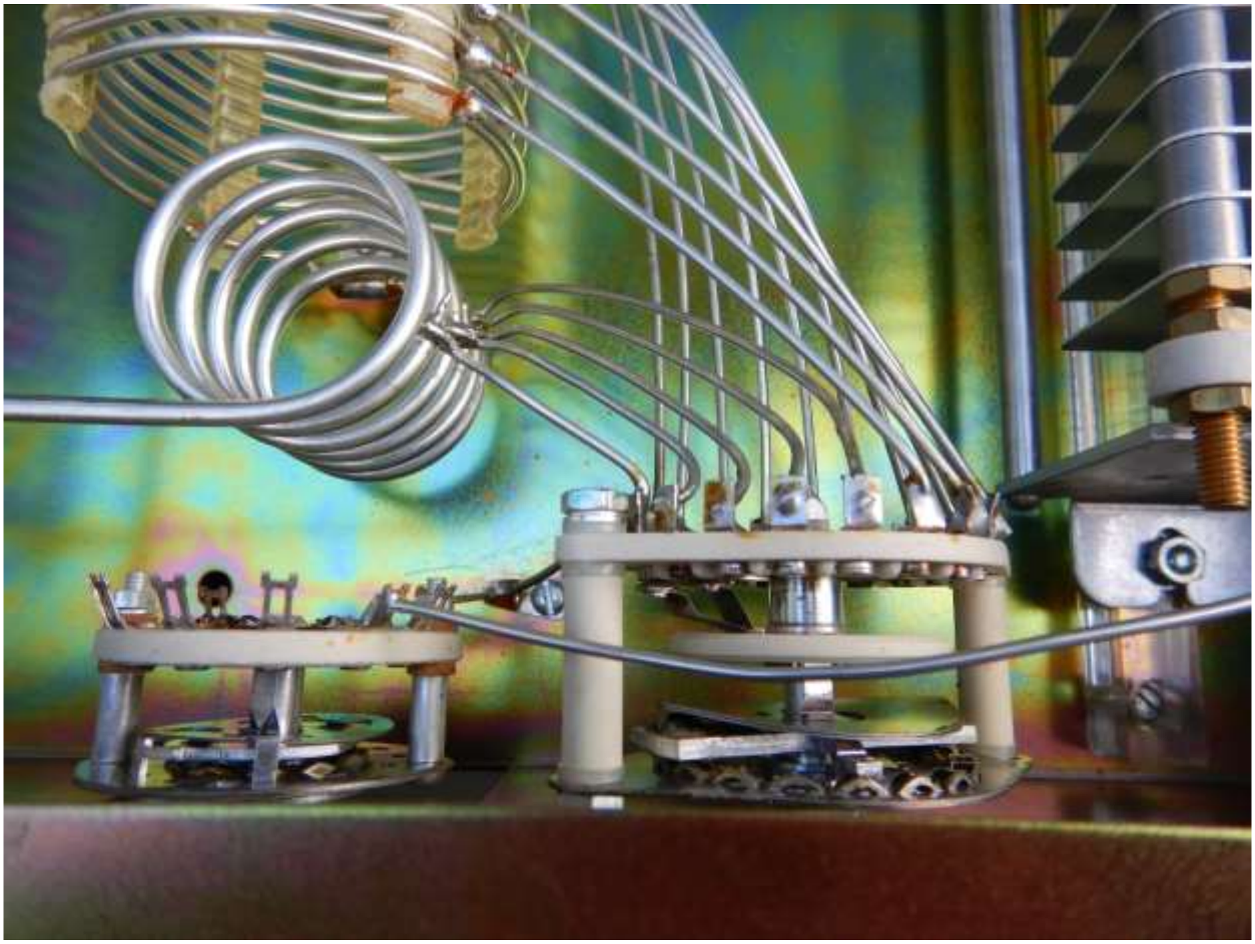

Figure 41: Dentron MT-2000A. A close look at the robust rotary switch.

Nye Viking MB-V-A 3KW Antenna Tuner

The Nye Viking Tuner was a very successful tuner designed by Mr. Nye. It was one of the only commercially available tuners using a Low Pass Pi Network tuning 1.8 to 30MHz. Heavy duty, silver-plated continuously variable inductor with 25:1 Vernier dial, 7000-volt variable capacitor and 15,000V switch selected fixed capacitors on output side. Tunes 40 to 2000 ohm antennas. Also provides harmonic suppression. It also included a 3KW Balun. Trifler-wound, triple core toroid that had a matching rang of from 200 to 1000 ohms and unbalanced output down to 20 ohms.

The lower push buttons on the face of the MB-V-A add capacitance and when all are un-engaged, only the variable capacitor was active. When you push button 2 then the variable & one padding cap is engaged. When you push button 3 then two caps are engaged & the rotor & so on up to button 5 which has all four padding caps engaged and the variable capacitor. Note the size of the variable capacitor. It's hard to judge its size by looking at the picture but it is without a doubt the biggest capacitor I've ever seen in a tuner built for the Amateur market.

Note also the switch in the back of the unit. This switch was invented by Mr. Nye. There were a number of custom built components, note the capacitor plates that sit underneath the pushbutton assembly. These capacitors were found only in Mr. Nye's tuner and were designed and built specifically for this tuner.

The components used it this tuner along with the build quality makes this tuner one of the finest commercial tuners ever produced for the Amateur market. The only complaint I've read about this tuner was in regard to its difficulty in matching antennas for 160 meters. But it's only fair to note that 160 meters is difficult for a lot of tuners to match.

For more on this tuner see: http://doctorgary.net/Nye%20Viking%20MB-V-A.htm

The tuner featured here was owned by Alan Parks N7SHA until his passing in December of 2022.

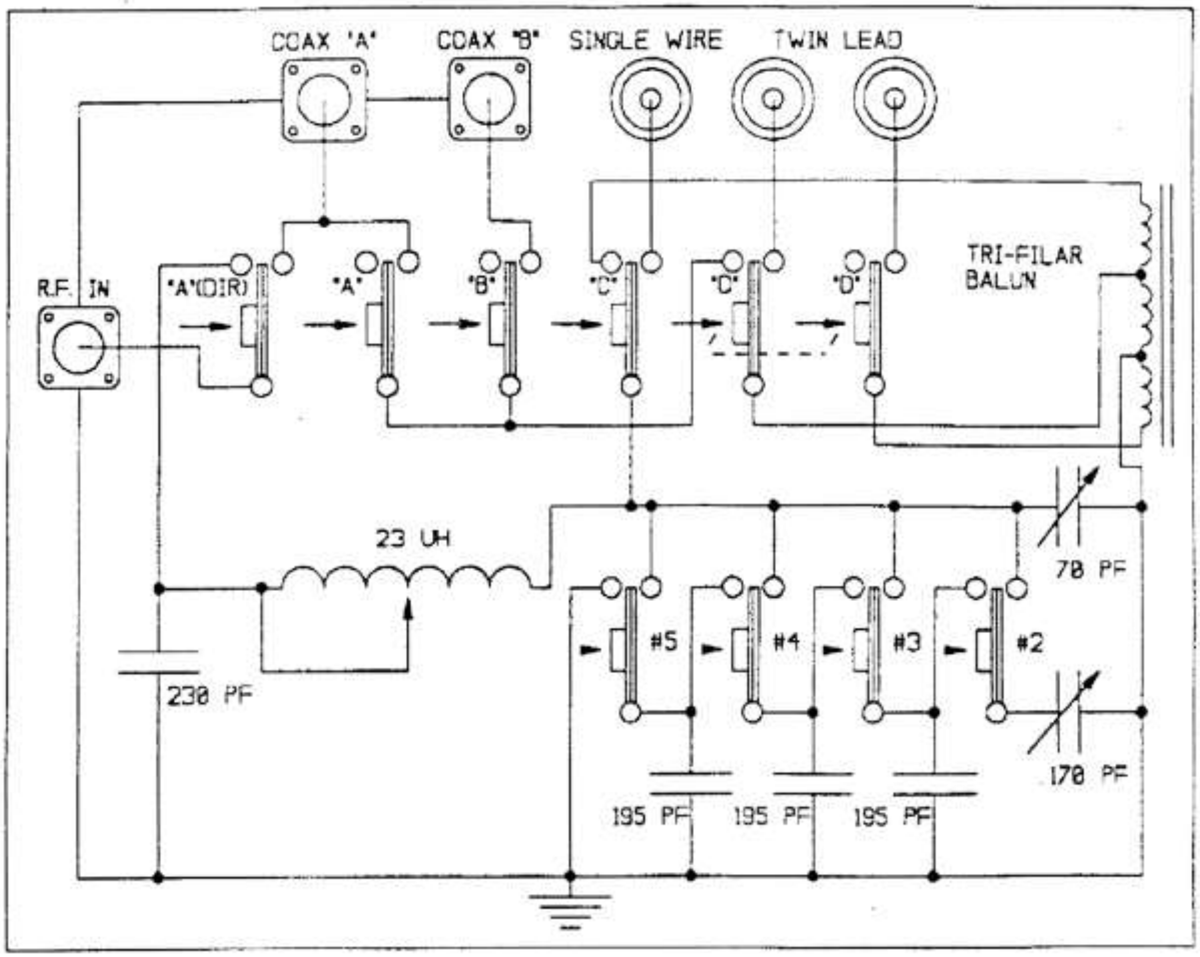

Figure 42: Schematic of the Nye Viking MB-V-A-3KW Tuner

Figure 43: Nye Viking 3KW Tuner - Front view

Figure 44: Nye Viking 3KW Tuner - Rear view

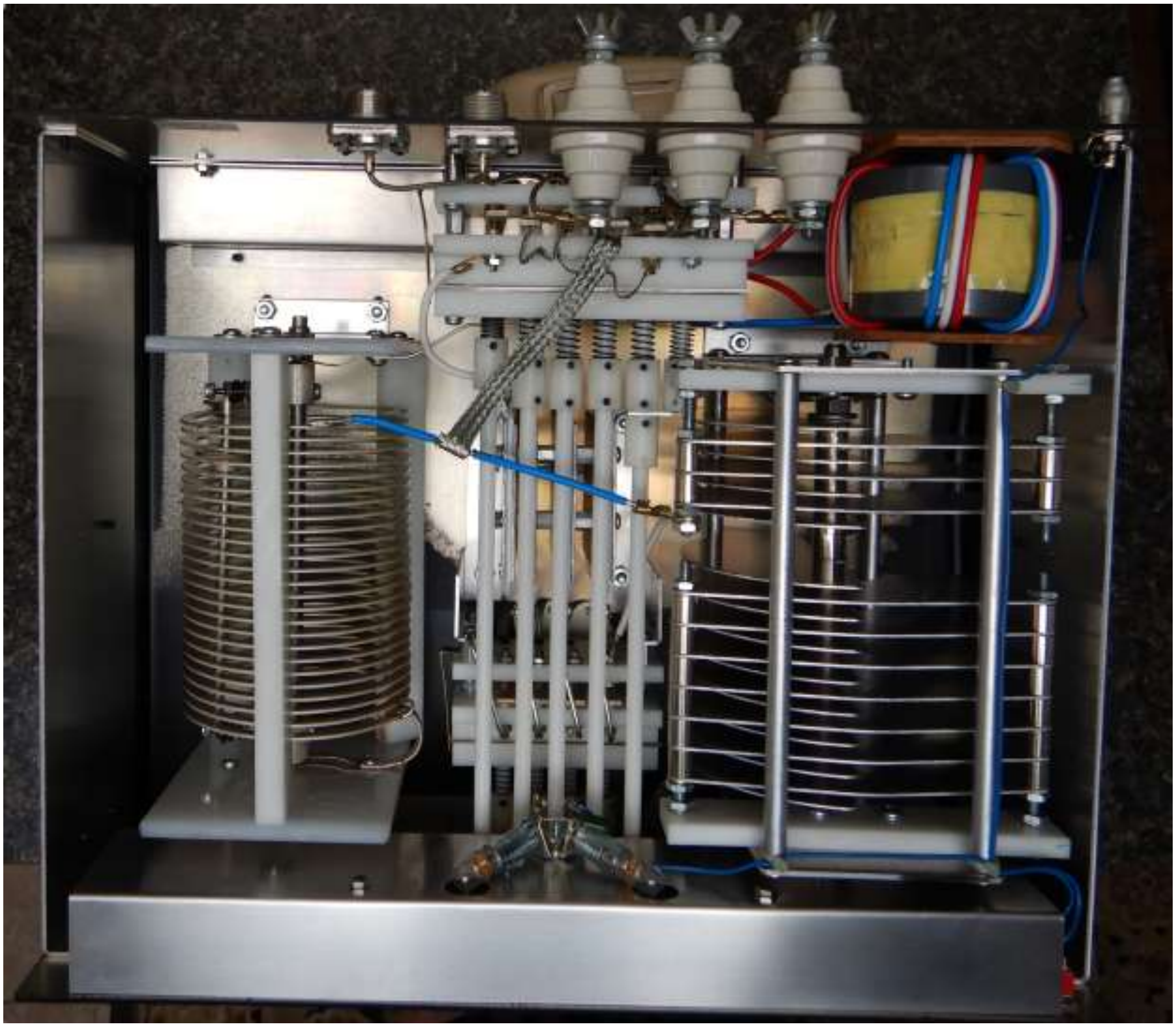

Figure 45: Nye Viking 3KW Tuner - Note the variable capacitor. It's huge! This one of the biggest capacitors I've seen in a tuner. The only other capacitor that is possibly bigger is the one in the Johnson Match Box.

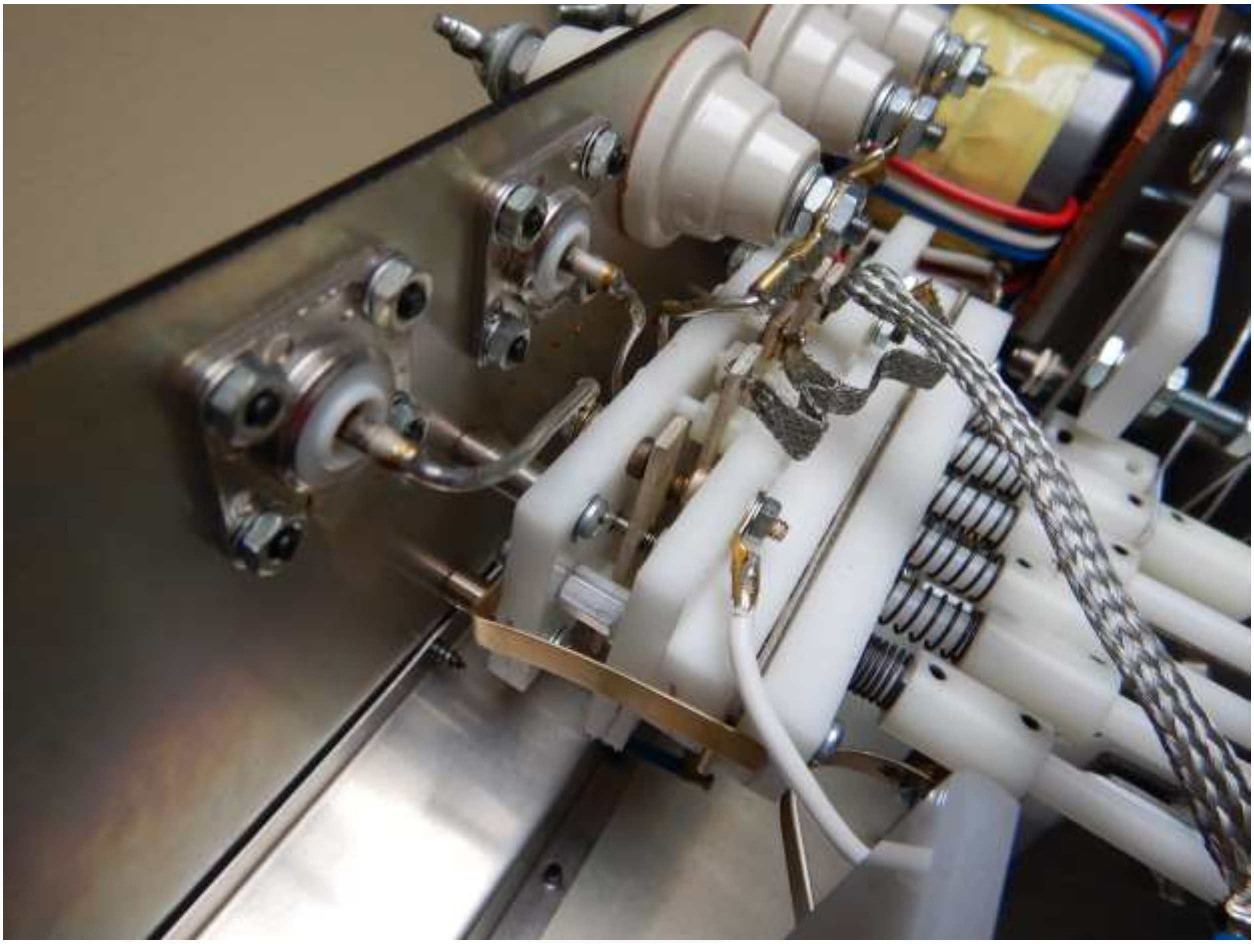

Figure 46: Nye Viking 3KW Tuner - A close look at the custom designed push-button switch.

Ten Tec Model 238

The following was copied from the manual: "The matching circuit used in the model 238C is basically an "L" network. The "L" network has several advantages over other circuit configurations. It has only two adjustable parts; one inductor and one capacitor; most other networks use three. Because there are no internal nodes in the network, the maximum circuit voltages and currents which occur are never more than those present at the input or output terminals.

Because there are only two variable components, there is only one setting of each which will provide a perfect match to a given load impedance, and this unique setting automatically provides the lowest network Q possible. Low Q means low circulating currents, hence low loss, and it also provides the widest frequency bandwidth of operation before retuning is necessary. Finally, since the inductor is always series, the network always provides a two-pole low pass response to provide harmonic rejection.

There are, however, some disadvantages which have prevented wider use of the "L" network in the past. First, to match all possible antenna loads, two configurations are required. One, for impedances greater than 50 ohms (i.e. the antenna has a fairly low SWR already) the values of L and C in the network required for a perfect match become very small, smaller than the stray or minimum values of the components used.

To circumvent this problem, a small fixed compensating capacitor or inductor is placed into the circuit depending upon whether the network is configured for low or high impedance respectively (HI Z or LO Z on the center tuner switch). At low frequencies, the value of network capacity needed to match some loads is quite large, requiring a large and expensive capacitor. To provide for this, fixed capacitors are placed in parallel with the variable capacitor to obtain the value needed. This function is performed by the center switch; further rotation from the center position increases the value of capacitance in the circuit.

There are five tuner configurations that are possible depending on the position of the center switch."

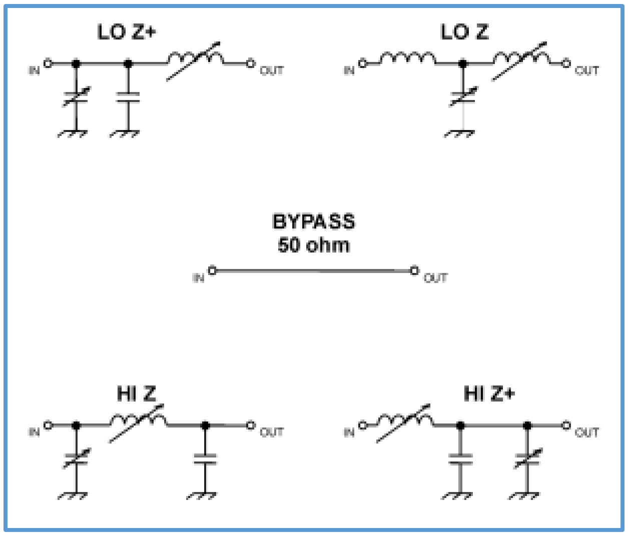

Figure 47: Ten Tec Model 238 tuner configuration options

It does appear that Ten Tec is still in business and still sells the Model 238C. I was not able to find it offered through HRO, DX Engineering, GigaParts or Universal Radio Inc. All the reviews I read were positive and practically all said the 238 was one of the best tuners they had ever used. Again I must state these are subjective claims without any base line for making comparisons so one needs to view such reviews with some skepticism. However based on actually looking inside one of these tuners and understanding the properties of the "L" network this does appear to be one of the best tuners on the market today assuming that it actually is still commercially available. I did check on eBay and found just one of these tuners for a moderate price of $210.50. The pictures below are of the tuner I found on eBay. Someone is going to get a very nice tuner for not a lot of money.

Figure 48: Ten Tec Model 238 - Front view

Figure 49: Ten Tec Model 238 - Rear view

Figure 50: Ten Tec Model 238 - Interior view

Figure 51: Ten Tec Model 238 - A close look at the rotary switch

WanZer Antenna Tuner

This was an unusual antenna tuner built in the 70's and early 80's by the Wanzer Co located in Spokane, Washington. He also had a ham store at his "factory" at 25 S. Girard which is in the Spokane Valley. The actual designer and builder was Cliff Wanzer, WB7DFD. Mr. Wanzer passed away on October 22, 2005[14]. Of all the tuners I research this is one of the more obscure tuners. Most of the information I was able to find out about this tuner came from the e_Ham site which the following was copied from:

"Cliff devoted considerable effort to minimizing parasitic resonances in his tuners, of which there were several models. The tuner was designed as a" legal limit" tuner, using reasonable quality components and without "bells & whistles", so as to be sold for an affordable price. Cliff manufactured all or most of his components, including the enclosure. Models with metering of course used commercial meters. There were several iterations. One version used a "glass" coil form for the roller inductor. Cliff's Z-match business was scaled back in the mid-eighties, owing to his operation of a ham radio store in Spokane that required much of his time. MFJ was beginning to make inroads in the tuner business and Cliff subsequently sold his rights to the design and manufacture of his "Z-match" to a gentleman from Idaho. There was a "low profile" version of the "Z-Match" that Cliff had made that looked like an MFJ 969. It was this version that the buyer of Cliff's business intended to promote. A "Z-Match" that is mechanically & electrically sound is a very good buy when they can be found on the used market. The components were reported to be good quality and the unit itself was robust. The range of impedances is unknown. Front panel toggle switches were provided for altering the internal component arrangement electrically."

This tuner had the option of running in the normal "T" mode but at the flip of a switch could be run in the "Pi" mode. This is the only tuner I was able to find that was capable of both, a very unique configuration to say the least. There are some references that infer that it used a "Z" match configuration but it appears this was not the case after reviewing the schematic.

It came it two models, one with meters (Z-4M) and one without meters (Z-4). Top of the line model included a relative fwd/ref output meter. Had an "in-out" switch and a switch to change from a "PI" configuration to a "T" configuration. It utilizes two 750pf heavy duty variable capacitors and a 28uh plated roller inductor with a turn counter. The WaZer Match covered 1.8 to 30 MHz and could handle full legal limit. Physically it was a fairly small at 9x8x5.

All the reviews I was able to find all sung the praises of this tuner stating that the build quality was excellent and the components used in the tuner were of high quality. The only complaints were about the glass "glass inductor."

I was only able to find one of these on eBay being offered out of Canada. It appear to be in very poor condition and was listed as "not working", "parts only". I did put in a bid for the tuner for

[14] See: https://columbiabasinherald.com/news/2005/oct/25/clifford-l-wanzer-2/

what I thought was a reasonable offer. My offer was rejected. This same tuner has come up for auction several times and when last I checked had not been sold (3/13/22). I believe the seller is simply asking too much for a non-functional very rare tuner that few people even understand what it is. I would love to acquire it so I could study it but for $300 ($237 US + $67, shipping) I think it' still over-priced. FYI: The pictures used in this article are of a different tuner and not the one being offered on eBay.

Figure 52: WanZer Tuner

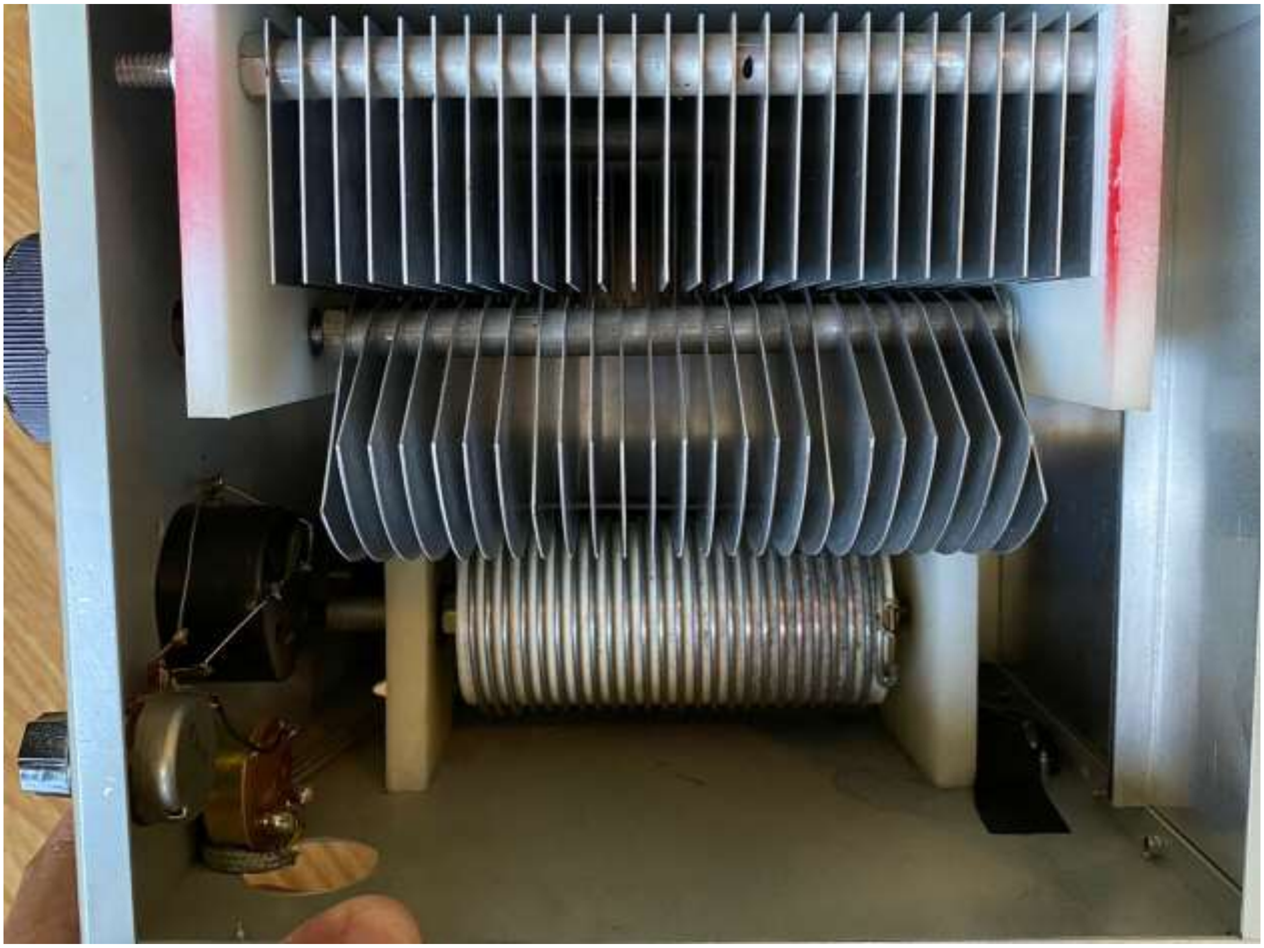

Figure 53: WanZer Tuner - Interior view

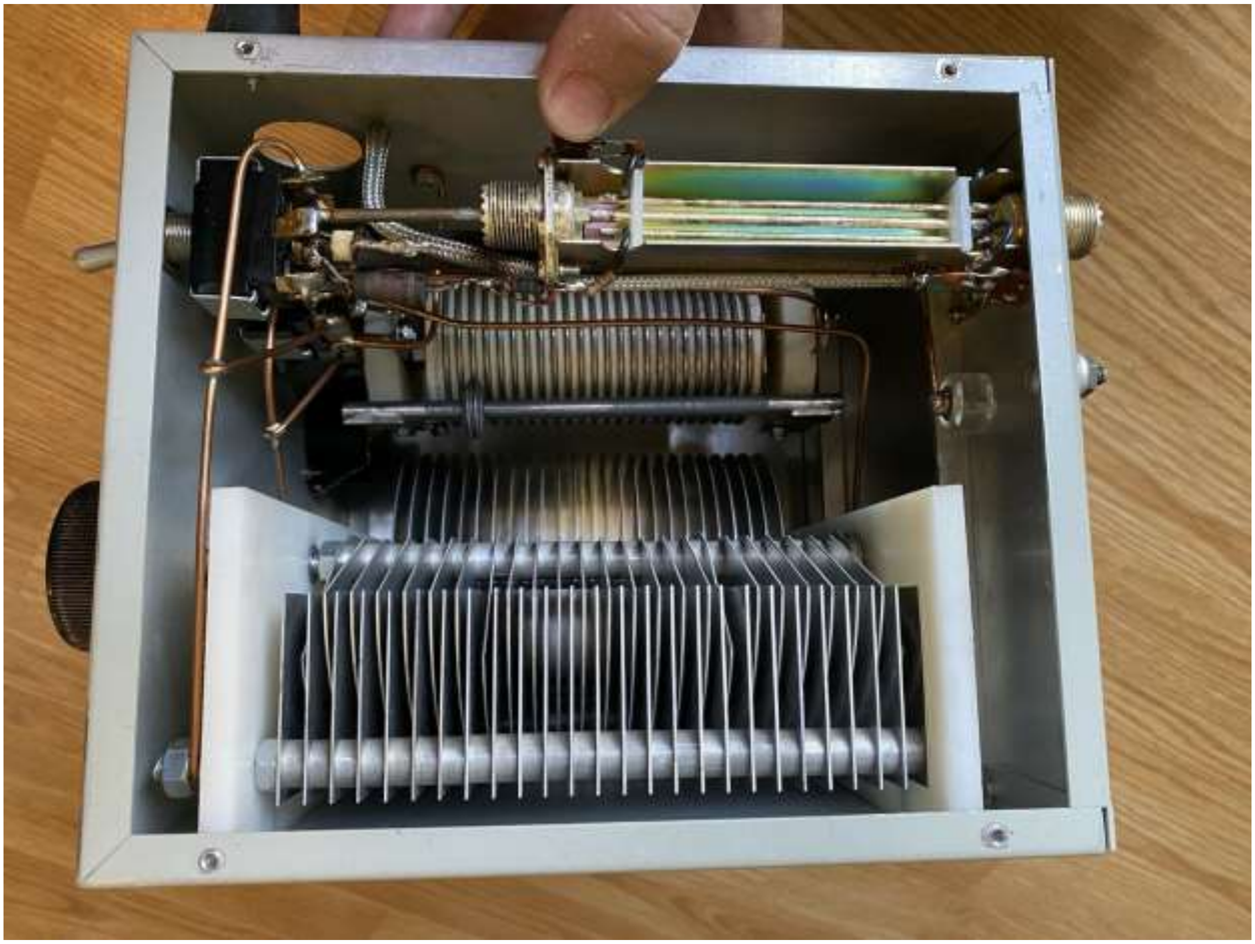

Figure 54: WanZer Tuner - Interior view

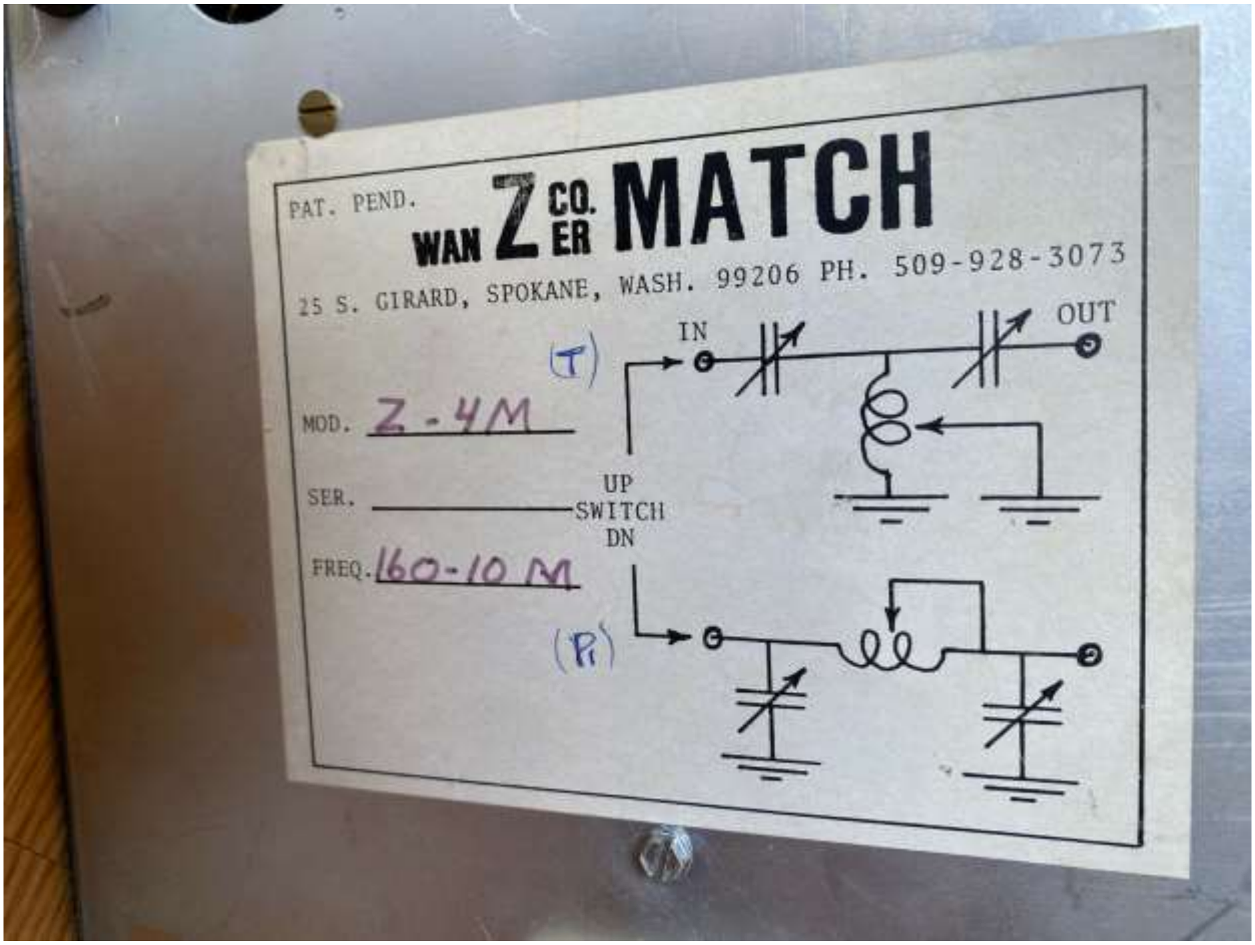

Figure 55: The WanZer Tuner could be configured as either a T or Pi match at the flip of a switch. A pretty innovative idea.

In February of 2023 I was able to acquire a Z-4M. I plan on opening it up and taking a look inside and put it on the air and see how it does with my antenna farm. I will include my results in a later revision of this article.

Johnson Match Box

I'm not sure when the Johnson Matchbox came onto the market. The earliest reference I can find is in the manual dated February 1958 although it could have been available sooner. The tuner came in four variations, two capable of handling 1,000 watts, one with an SWR meter and one without. It also was available in a 275 watt version, one with an SWR meter and one without.

The Matchbox is capable of matching the 52 ohm coaxial output of a transmitter into loads ranging from approximately 50 ohms to 1200 ohms for balanced lines, and 50 to 2000 ohms for unbalanced lines. Large amounts of reactance can be compensated for by the tuner, the amount depends on the frequency, the transmission line and the antenna properties.

The coupler circuit consists of a parallel resonant network, utilizing an inductor with a coaxial wound coupling link, a dual tuning capacitor, and a dual differential matching capacitor. Impedance matching for balanced or unbalanced transmission lines and antennas is accomplished by the front panel controls of the two dual capacitors without resorting to the customary coil taps or link adjustments. The Matchbox tuned circuit provides additional harmonic attenuation of the transmitter output by at least 15 db. The 52 ohm coaxial line between the transmitter and coupler provides for the insertion of a low pass (TVI) filter for improved harmonic attenuation.

The Kilowatt Matchboxes have a switching relay system designed for "fast make-slow break" operation allowing the final amplifier plate voltage to be cut off before the transmitter load is removed. The time of delay is fixed between .15 and .25 of a second which is ample to allow the relay contacts to break without any arcing.

In its day the Johnson Matchbox was perhaps one of the best tuners on the market. Unfortunately the single biggest problem with the Johnson Viking Matchbox is its age. When the Matchbox first appeared on the market we only had five HF bands: 80, 40, 20, 15 and 10m. The WARC bands would not come into being until 1980. The addition of these bands really pushed the limits of the Matchbox as well as other tuners built before the 80's. Additionally, most of our radios built back then had tubes and could easily match and deliver power efficiently to a 5:1 SWR load. As technology progressed our radios started using solid state components which were not as flexible as the older tube technology. This lead to another innovation that is commonplace today, our radios included a tuner as a part of their internal circuitry. There was also one other significant change. From the start of ham radio until well into the 60's the preferred transmission line was balanced transmission lines, aka twin lead, window line, and ladder line. These various balances transmission lines had a high impedance starting at 300 Ω all the way up to over 600 Ω. These balance transmission lines also exhibited very low loss even at high SWR values. Its biggest flaw was it like to couple with any metal that it came in contact with which is one of the biggest reasons the US military adopted coaxial cable in WWII. As the price of coax started coming down and the quality of the cable started improving more and more hams started to abandon the preferred transmission line of their predecessors to the transmission line that is now common place today, coaxial cable.

Don’t misunderstand, the Johnson Matchbox is still consider to be one of the best tuners ever built with a significant tuning range.

While researching the Johnson Matchbox I came across the following on an email forum. This was written by Walter Maxwell, W2DU who you will recognize as the author of the book “*Reflections III*”: I found the thread to be fascinating and full of good information and worth taking the time to read.[15]

“However, because the designer(s) didn’t fully understand the function of the inner two sections of the four-section capacitor, they misled the users concerning the function of those two sections. The instruction manual for the Matchbox tells us that the four-section capacitor is a voltage divider, and thus performs as an impedance divider, which is why they included it in the design. Big mistake, because it in no way performs as an impedance divider. The inner two sections are unnecessary, perform no useful function, and are in fact superfluous, and can be disconnected with no harmful results.”[16]

The following pictures are of the kilowatt Johnson Matchbox I tracked down in Idaho. Admittedly it was in pretty rough shape and had been altered. But I think these pictures will give you a good idea of how this tuner was built.

[15] See: Examining the Johnson Matchbox ATU (amfone.net).
[16] See: “*Examining the Johnson Matchbox ATU*”, Walter Maxwell - W2DU. This is a very interesting and critical evaluation of the Johnson Matchbox. He goes into detail describing exactly how the tuner actually works. http://www.amfone.net/Amforum/index.php?topic=26452.0

Figure 56: The KW Johnson Match Box - Front view

Figure 57: KW Johnson Matchbox - Right Side

Figure 58: KW Johnson Matchbox - Left Side

Figure 59: KW Johnson Matchbox - Rear view. Note the extra hole that someone added for an SO-239 socket. The small hole in the top right was for the SWR wire that attached to an external directional coupler.

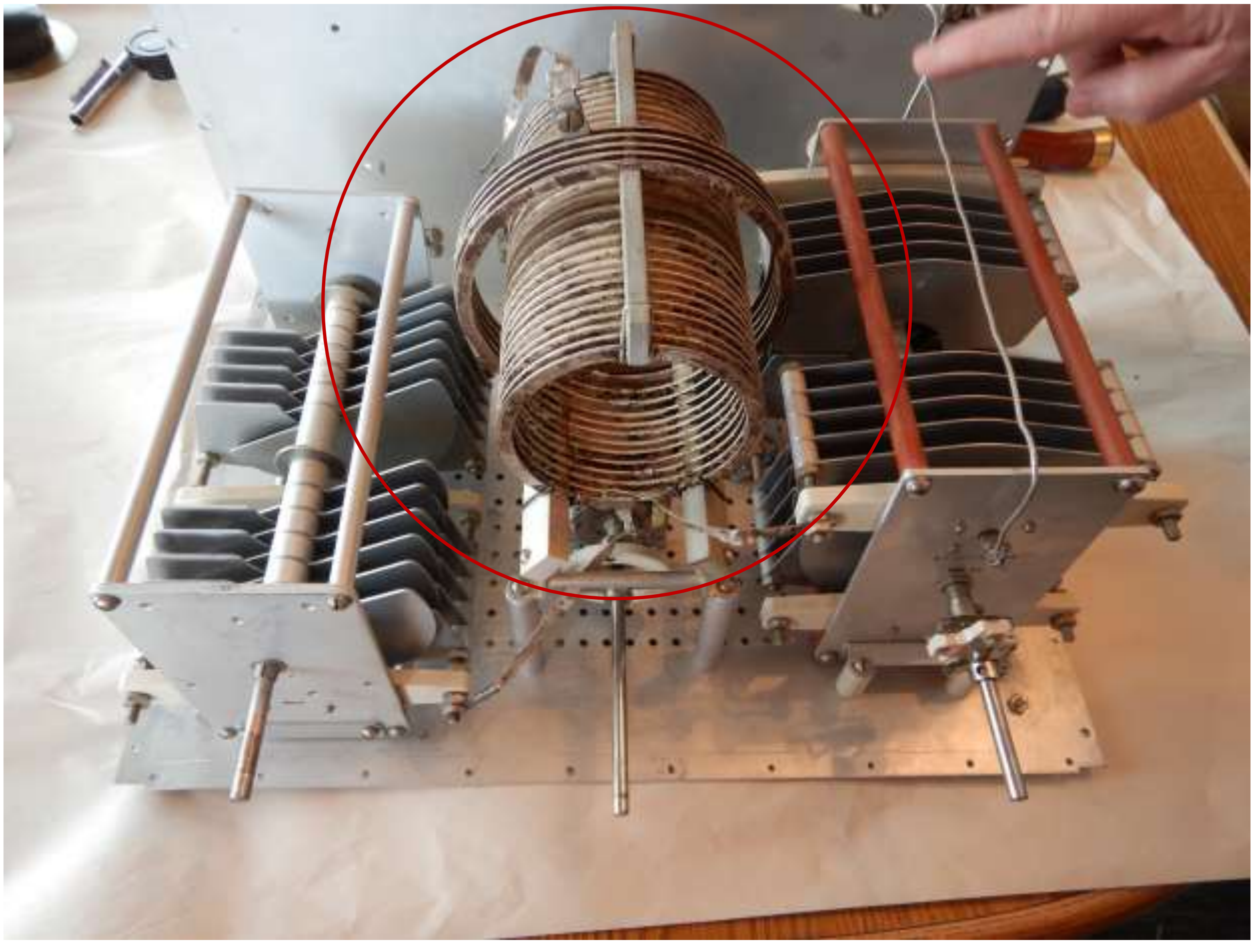

Figure 60: The inductors are tarnished due to the fact they were silver plated. No expense was spared in the building of these fine old tuners. Also note the inductor in an inductor. This is why this tuner is referred as inductor coupled.

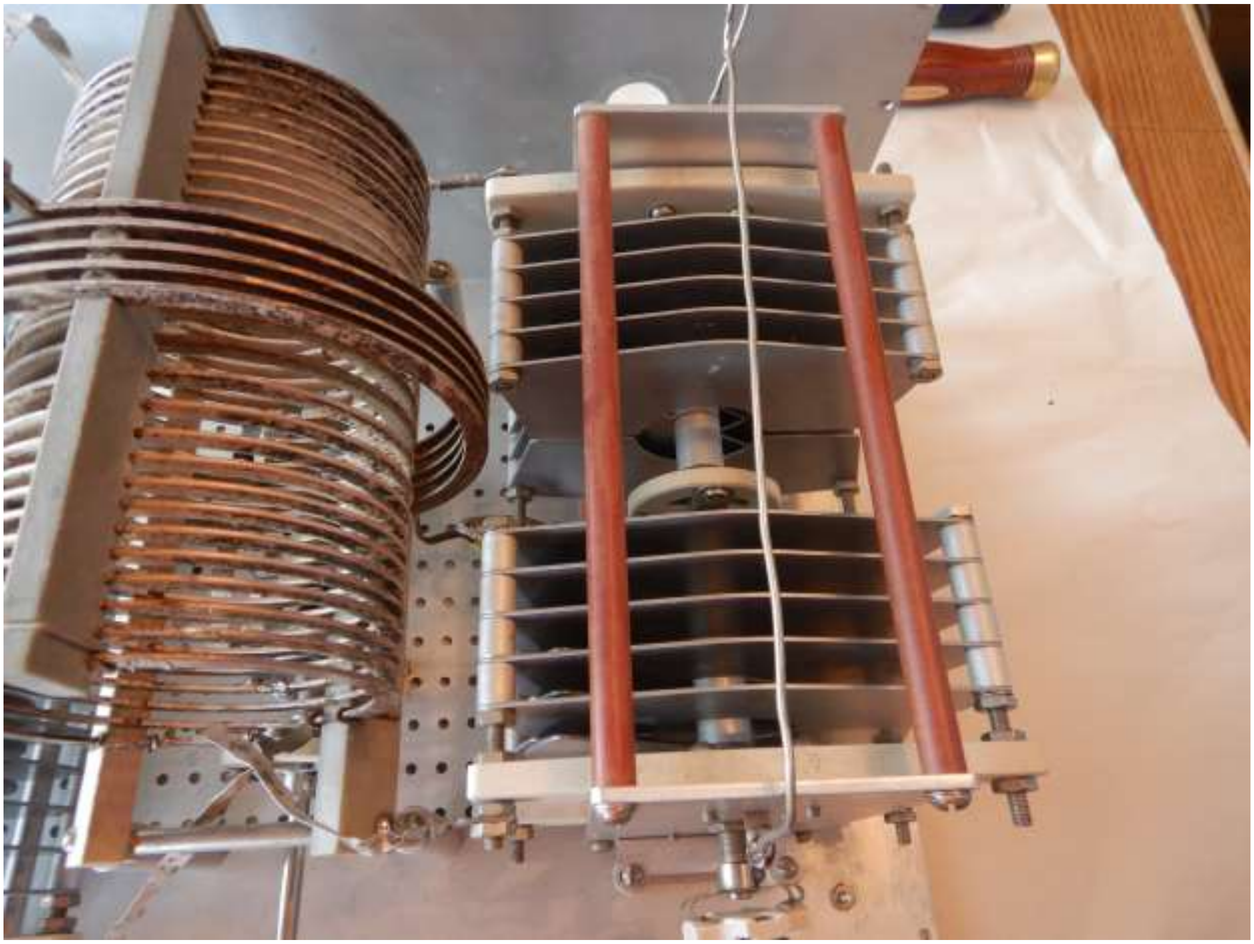

Figure 61: KW Johnson Matchbox - This is the biggest variable capacitor I've seen in an antenna tuner - it's HUGE!

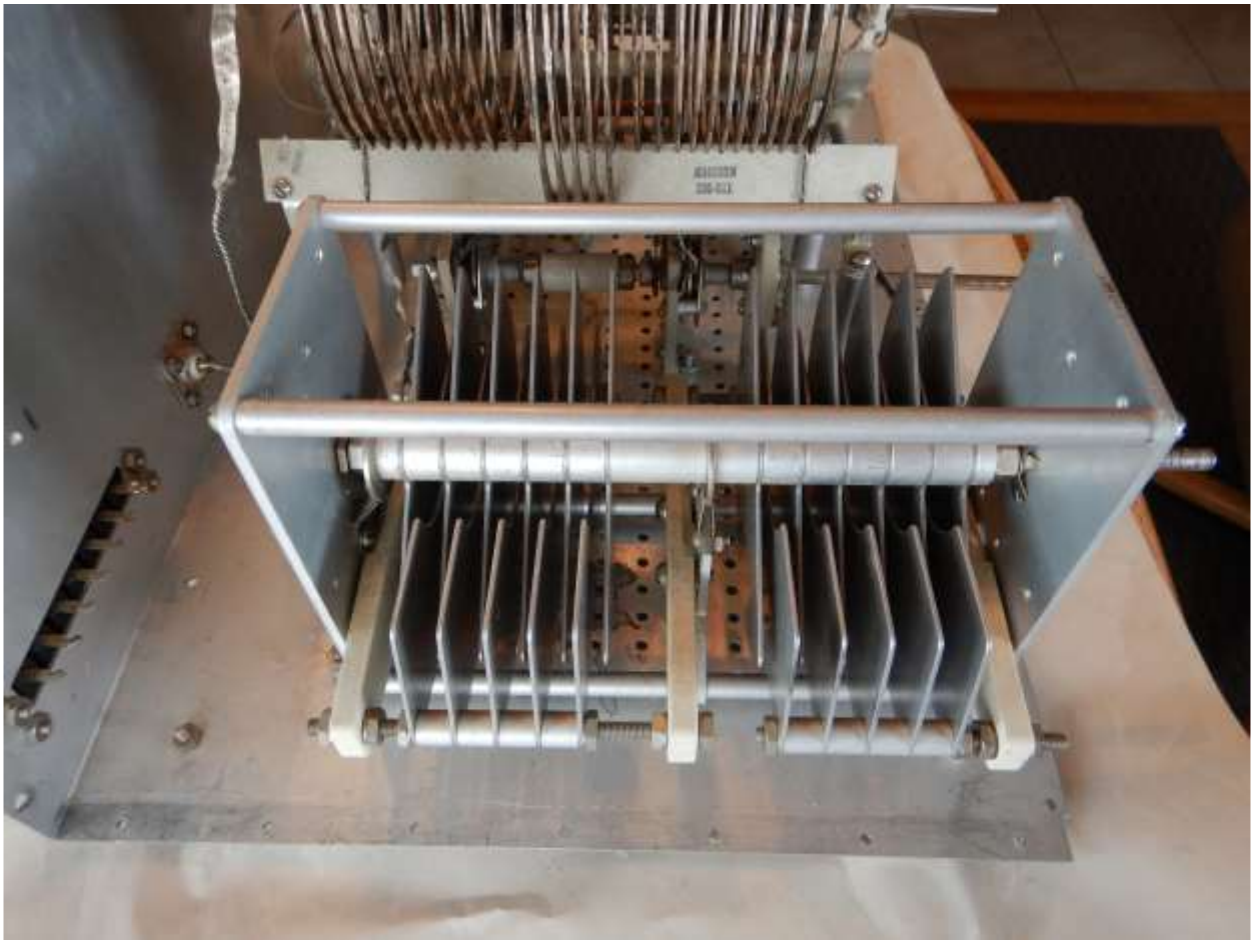

Figure 62: KW Johnson Matchbox - The other variable capacitor

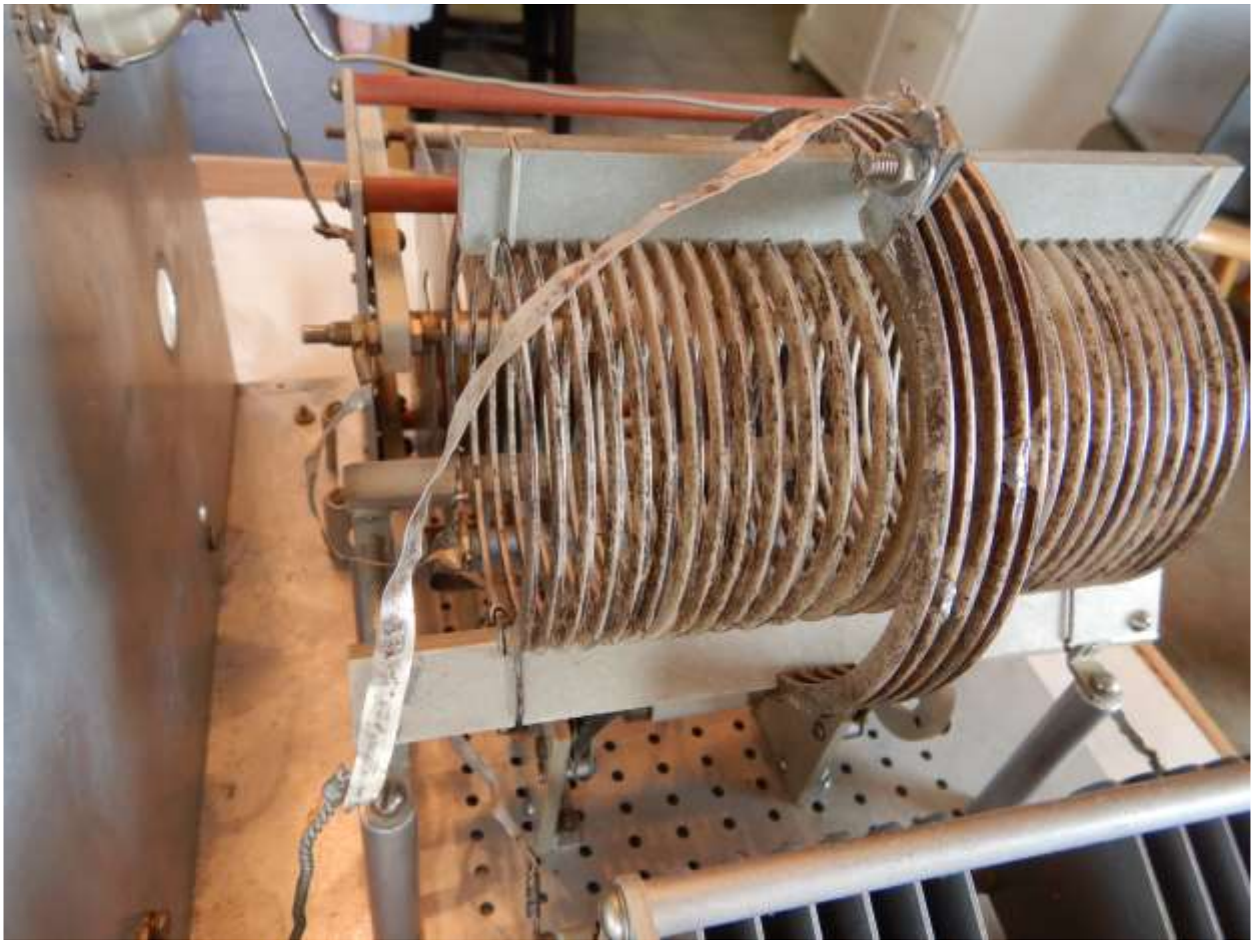

Figure 63: KW Johnson Matchbox - The inductor coils. Note the silver tarnish.

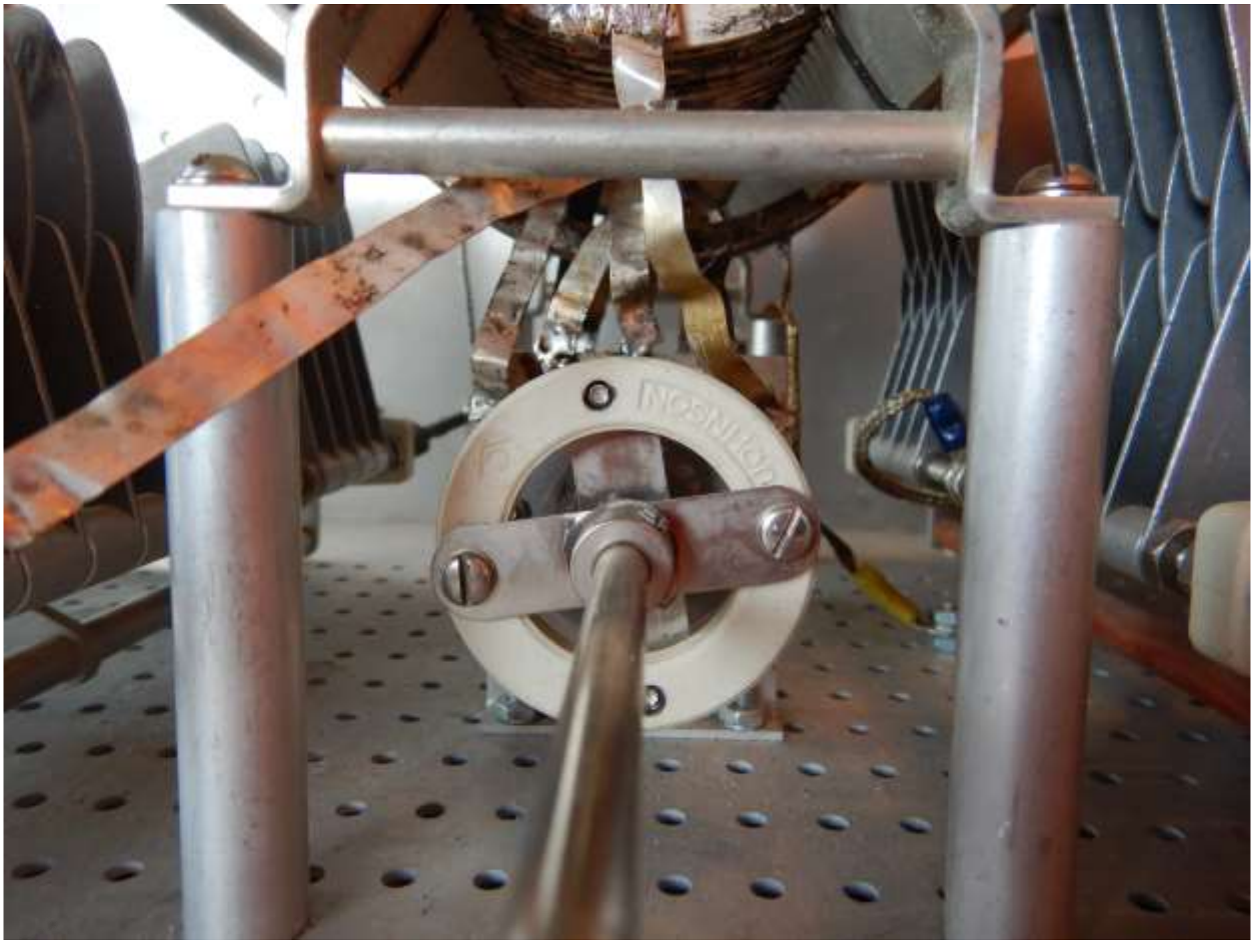

Figure 64: KW Johnson Matchbox - Note various taps between the rotary switch and the inductor.

Figure 65: KW Johnson Matchbox - this was for connecting the tuner to the Johnson kilowatt amplifier

WB7RLX Homebrew Tuner

The next tuner I wanted to include was a tuner I built out of a homebrew tuner that I acquired that didn't work. I thought this would make a good addition to the article because it demonstrates what you can do with a bunch of leftover parts.

For over a year I have been using an MFJ-986 Differential tuner. I was intrigued by the idea of a differential tuner given that it only had two adjustments and consequently only one solution for any given tuning situation. However the 986 suffer one serious drawback. The roller inductor was improperly sized for the tuner. The problem would manifest by a slow rise in SWR on the 10 meter band regardless of how much power one was running. As I researched the issue I found out this was a known issue with this tuner. So I was faced with sending it back to MFJ to be repaired under warranty or just scrapping the tuner altogether. I assumed that if I sent it back they would just replace the roller inductor with the same model of inductor. So I decided to scrap it for parts.

After I got the used homebrew tuner that didn't work I decided that I'd take the differential capacitor out of the MFJ tuner and mount in inside the homebrew tuner I had acquired. While I was in the process of dismantling the old tuner I figured out why it didn't work. At some point someone had rewired it to change it from a Lew McCoy Ultimate Transmatch design to a standard "T" match. Unfortunately they cocked it up. I was able to successfully rewire it to be a differential tuner.

After I had completed the work and tested the tuner I decided to customize it for my station. It already had three outputs, one for each of my antennas but it only had one input and I needed two. Fortunately there was a lot of extra space in the tuner as well so adding a switch was not going to be a problem. I decided to install a two port antenna switch inside the tuner so I could have an input for the FT-950 and one for the FT-3000. There was a concern that if I used a standard rotary switch there might be an issue with isolation between the two ports. So I decided to install a commercial antenna switch inside the tuner. That appears to have been a good decision, there is over 60 DB of isolation between the two input ports.

Figure 66: WB7RLX Differential Tuner – Note the unused hole in the front. I'm going to mount a propagation compensator in the unit and locate the control switch there. A note on the six position antenna selector switch: When the switch is pointing above horzontial, as it is in the picture, the tuner is engaged. If the arrow is pointing below the horzontial then the tuner is disengaged.

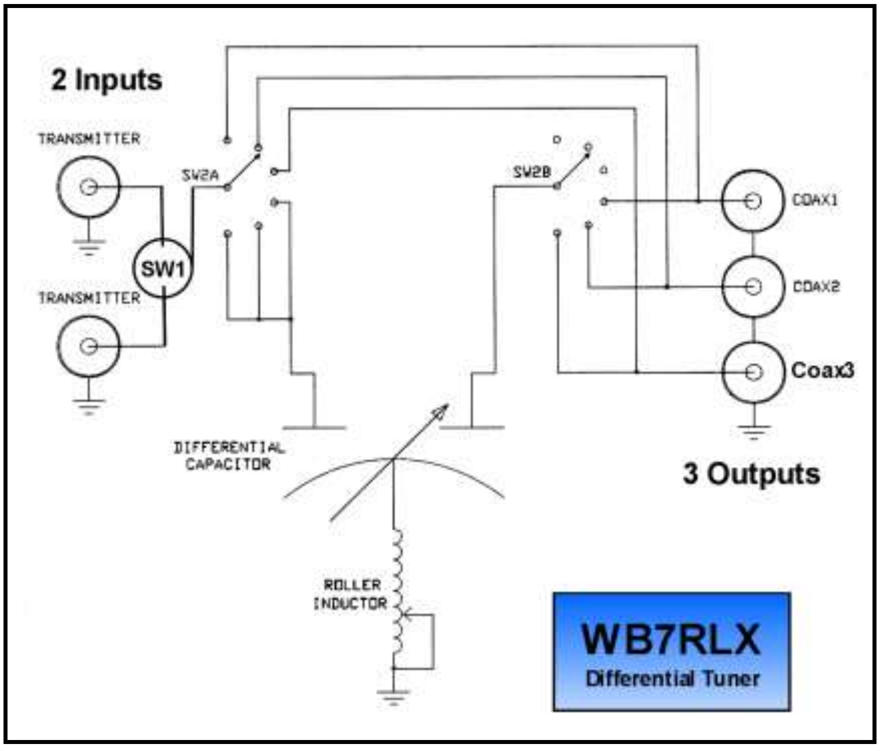

Figure 67: Differential Tuner Diagram

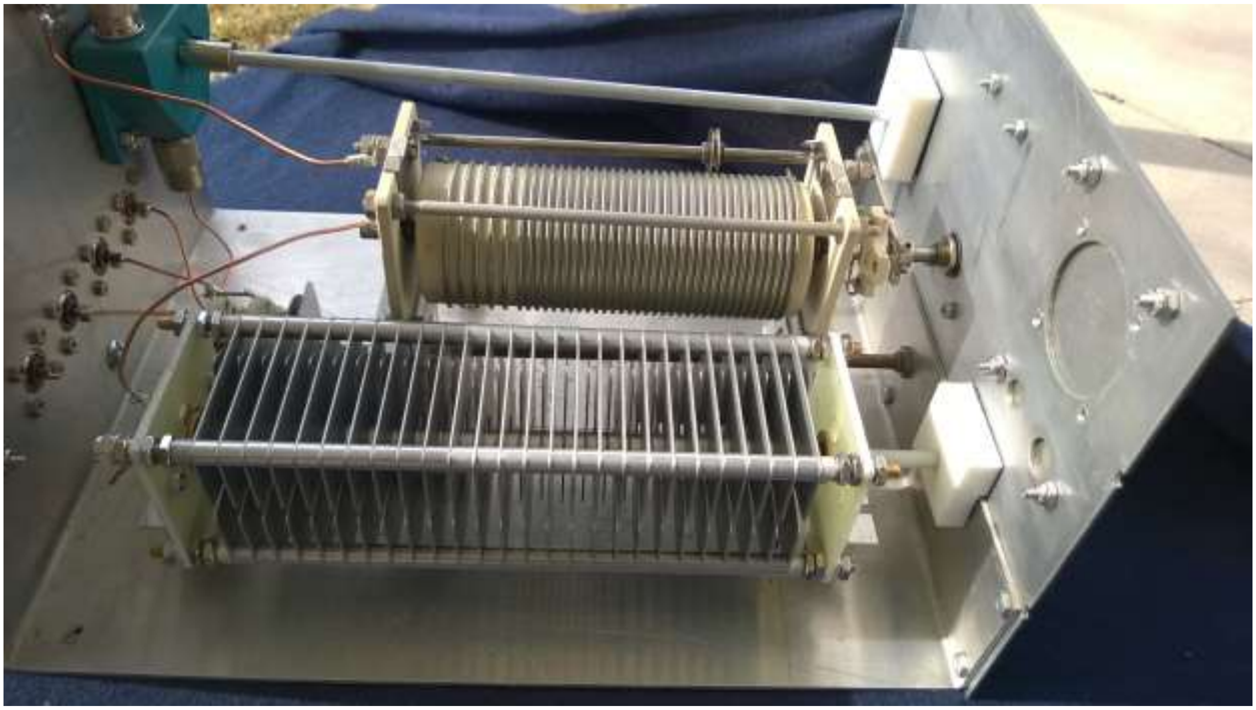

Figure 68: WB7RLX Differential Tuner – This is a good view of the differential capacitor that originally was in the MFJ-986 tuner. It does appear to be of good quality. It should also be fine for use with 600 watts or less. I'm afraid that if I were to put 1000 watts into the tuner with a high SWR I would get flash-over in the capacitor. Note also that the capacitor and inductor are isolated from the front panel.

Figure 69: WB7RLX Differential Tuner – Inside. This is a good view of the roller inductor. Note also that I replaced the brass shaft going to the rotary switch and the aluminum shaft going to the input switch with fiberglass rods. I wanted to minimize any potential for stray capacitance.

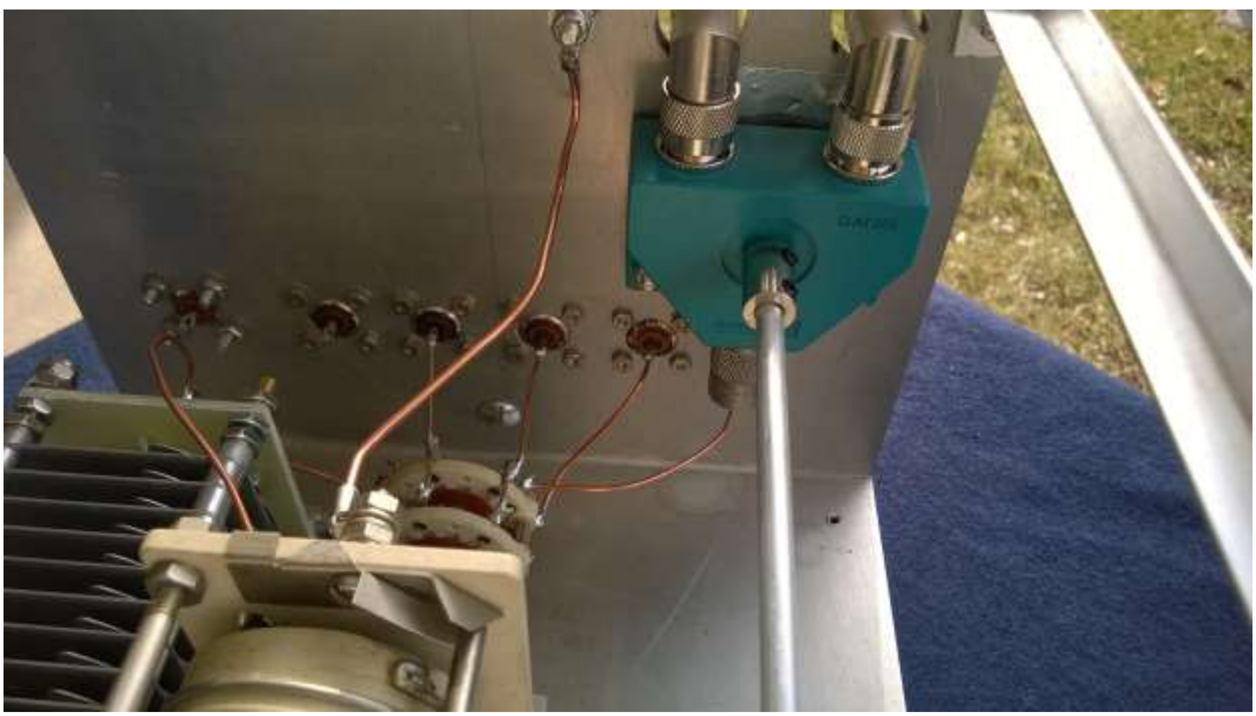

Figure 70: WB7RLX Differential Tuner - looking toward the antenna switch. Note the two ports on the left are not used.

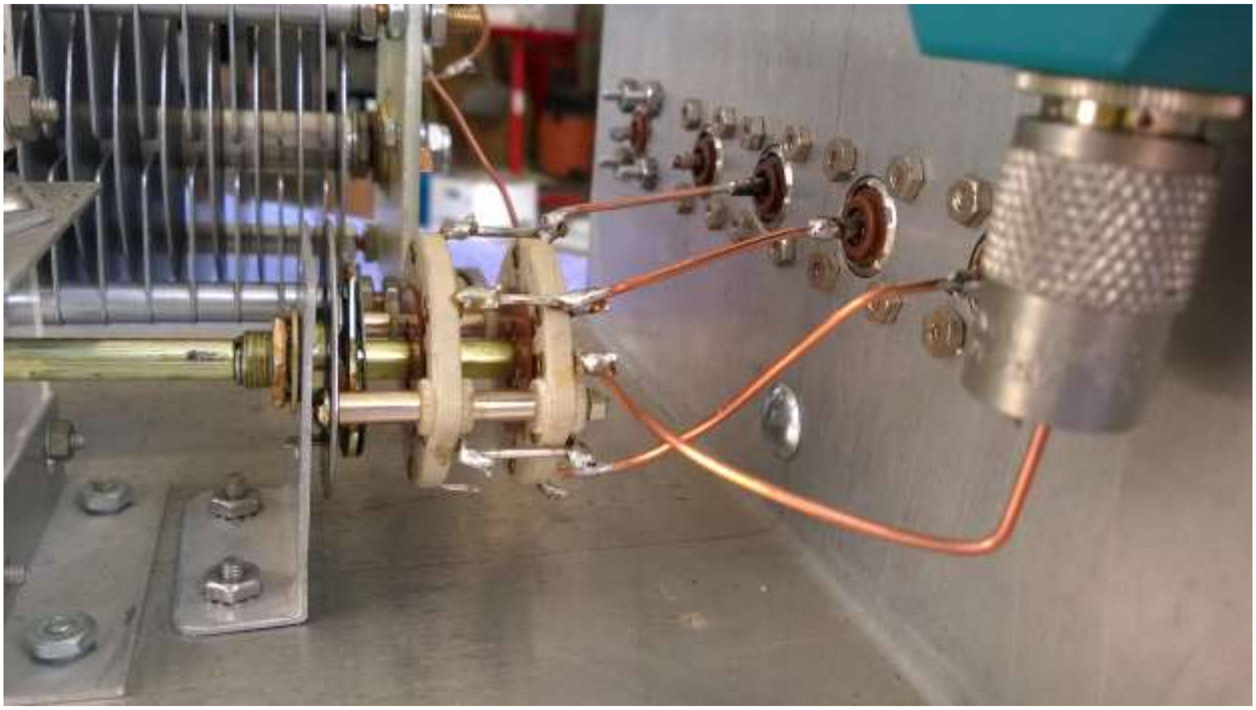

Figure 71: WB7RLX Differential Tuner - Rotary Switch. My key goal in wiring the components was to keep the leads as short as possible in an effort to minimize loss and stray capacitance. I will eventually replace the rotary switch with a higher quality switch. This switch is out of the MFJ-986 Tuner. The contact surface area is pretty small when compared to higher quality switches.

The Millen 92200 2KW Transmatch

This tuner was first described by Lewis McCoy in the July 1961 issue of QST. This tuner used the Ultimate Transmatch design with the split-stator on the input side (TX) and a variable capacitor on the output side. However, the tuner described by Lew McCoy in the 1961 QST article used a variable inductor. The Millen Transmatch uses a tapped inductor. *Refer to Figure 72*.

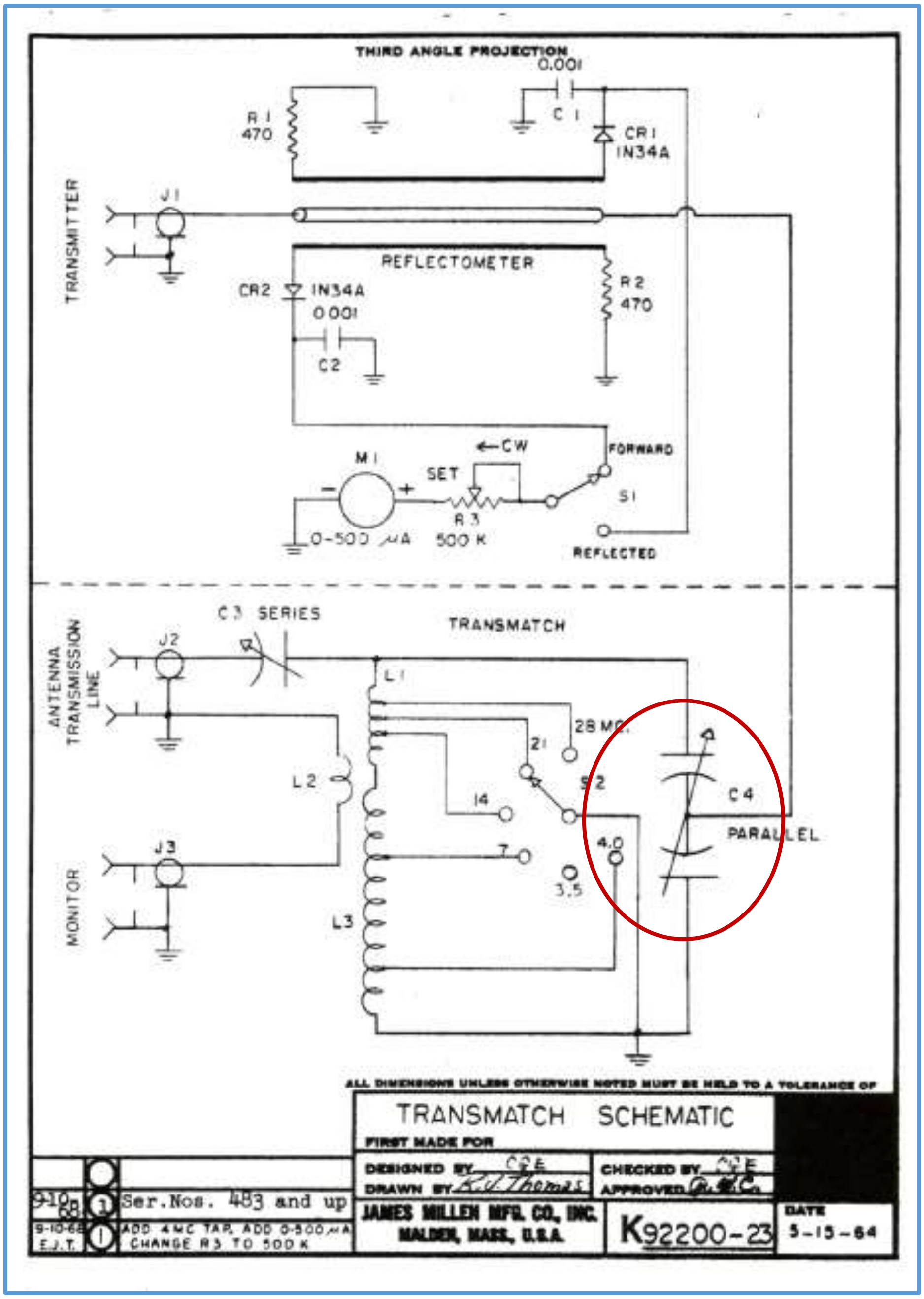

Figure 72: Millen 92200 Transmatch. Note the location of the split stator in the input side of the circuit.

One of the unique features of the Millen tuner was its copper lined cabinet which is also one of the reasons I included in the article beside the fact that is also considered to be a classic antenna tuner built to last for generations. In the CQ Magazine review the tuner was tested with 1,300 watts and it performed flawlessly. It was able to provide matches ranging from 10-1300 Ω on all five Amateur bands from 80 meters to up through 29.7 MHz. It was not tested on 160 meters but in fairness it was not rated for use on 160 meters. The one negative that I spotted in the review was the tuner did not have a bypass switch. The review also gave the tuner high marks for its heavy duty components and made special note of the “heavy-duty solid-silver contacts and silver plated conducting elements." After reading the review and examining the tuner first hand I have to agree. This is another example of the old saying, "they sure don't build'em like they used to."

In 1969 the tuner sold new for a whopping $147. In a recent search of eBay I was not able to find any of these tuners for sale, but I did find plenty of parts. I did however find one that had sold on eBay for $228.50 in February of this year. This is another of those vintage tuners that if you can find one for under $300, I'd snatch it up. However, remember it does not have a bypass switch.

Figure 73: James Millen 92200 Ultimate Transmatch – Front view

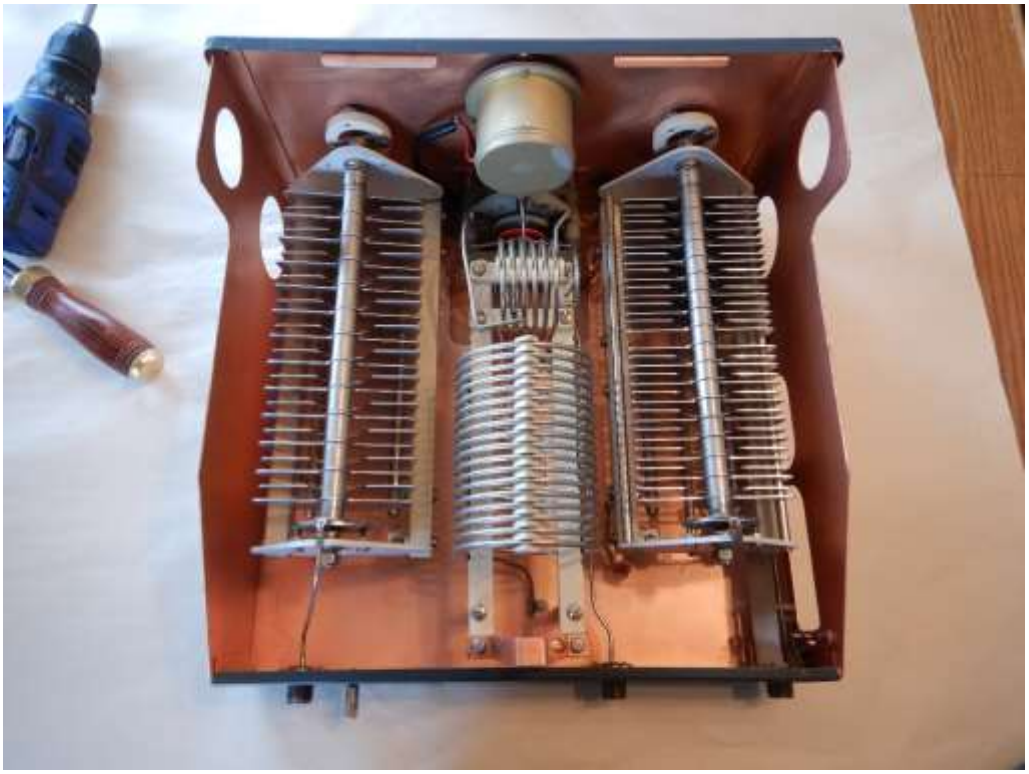

Figure 74: James Millen 92200 Ultimate Transmatch - The case is made completely of copper!

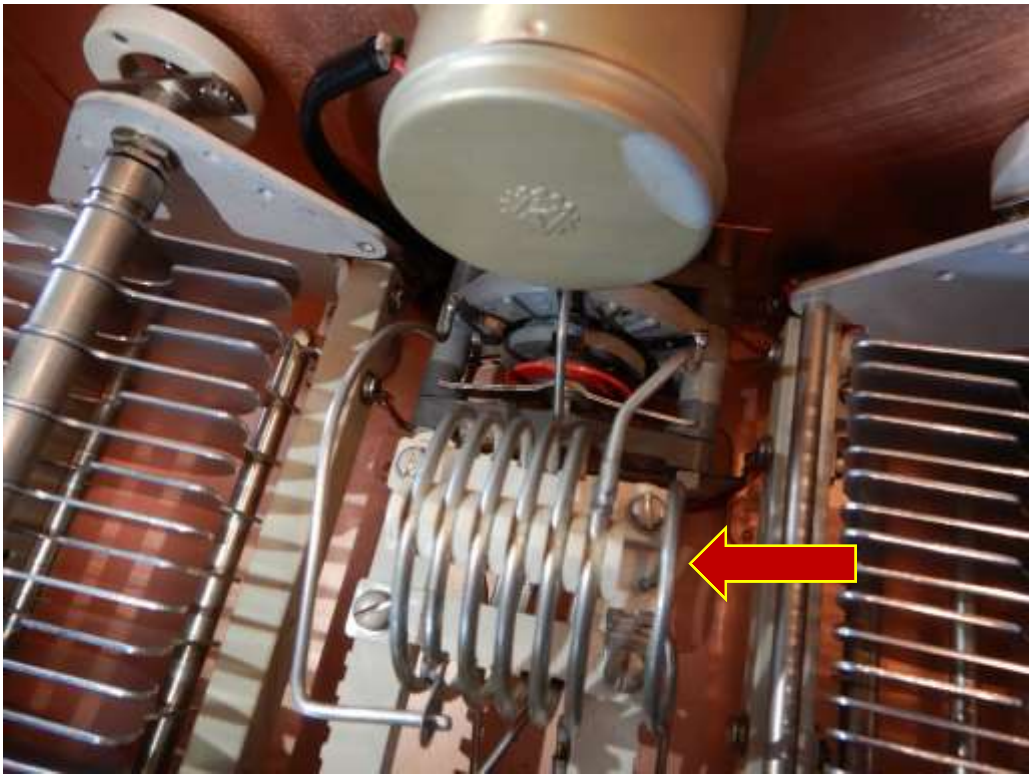

Figure 75: James Millen 92200 Ultimate Transmatch - Note the small loop to the right of the small induction coil. That coil is the sensor for an oscilloscope. The socket for the oscilloscope is on the rear panel.

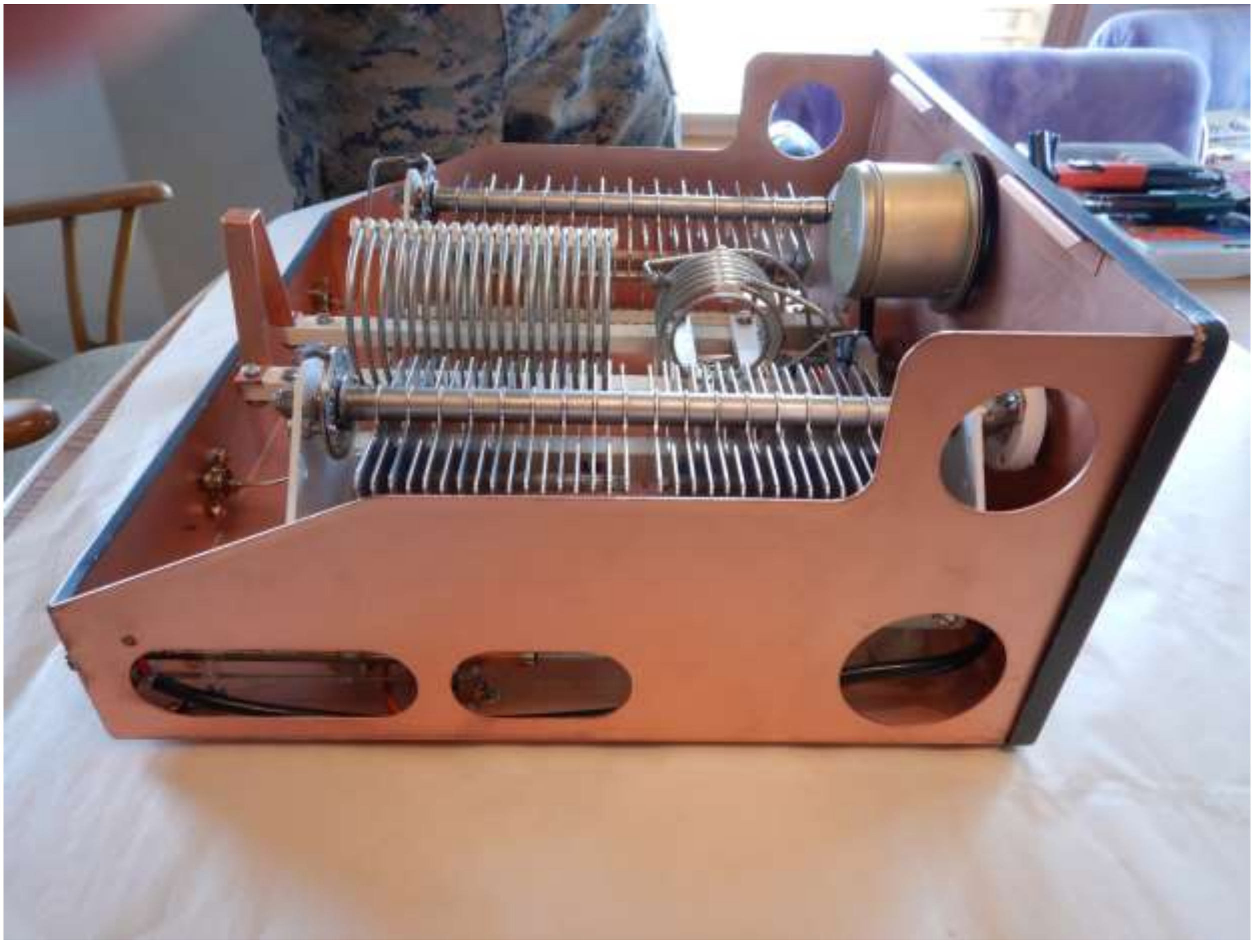

Figure 76: James Millen 92200 Ultimate Transmatch - Another view of the copper case.

Figure 77: James Millen 92200 Ultimate Transmatch

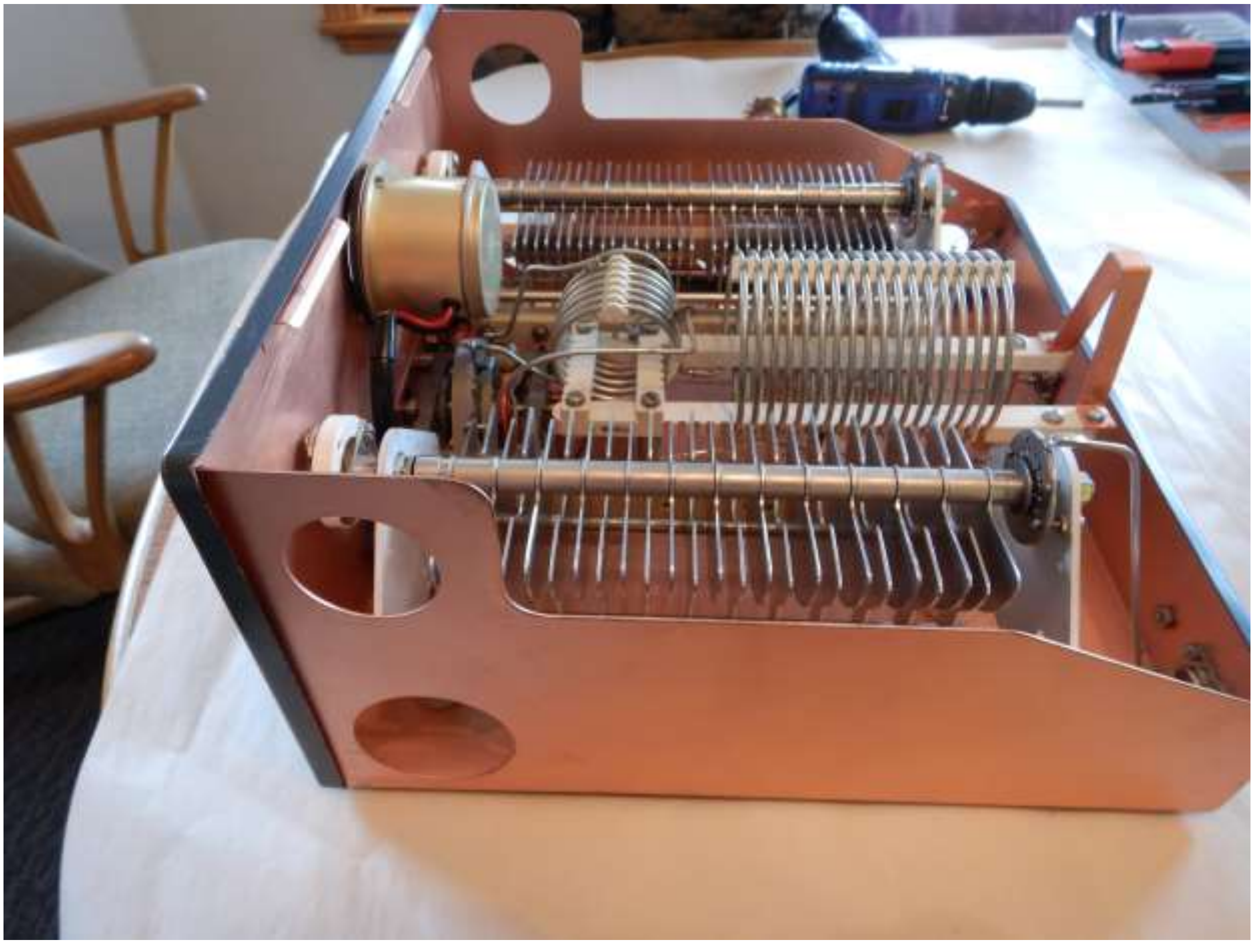

Figure 78 James Millen 92200 Ultimate Transmatch

Figure 79: James Millen 92200 Ultimate Transmatch – Power (SWR) Meter. A front panel switch was used to select forward or reflected power.

Figure 80: James Millen 92200 Ultimate Transmatch - Front left side. Note the copper where the paint has been chipped

Figure 81: James Millen 92200 Ultimate Transmatch Rear view

We come almost to the end of our story but we have one more tuner I want to feature, but we'll get to that in a minute. I know there are not many that will understand or see the beauty of these old boxes. However if you enjoyed looking at these old tuners and if they brought back fond memories of your Elmer or of your first experiences as a ham then know this work, this effort was done for you. There is a lot of history wrapped up in every tuner featured in this article. If each of these tuners could talk what stories they would tell. Many of these fine old tuners are gone now, turned into scrap, or sitting somewhere forgotten, and others have been disassemble and tragically parted out. These tuners to me represent a golden age of ham radio and a time when American workers took pride in what they built and what they built was built to last.

The last tuner we are going to look at represents the state of the art today in tuner technology. As you look at it you will see in its construction and design evidence of its heritage. It too is an American made hand built tuner. We are going to close by looking at the Palstar AT2K tuner.

Palstar AT2K

The Palstar is the latest in manual tuner technology. I wanted to include it in the discussion of tuners as an example of how the technology has evolved. The curious thing is if you look at the schematic, at least at the heart of it where the tuning actually occurs it looks exactly like a "T" match from the 50's with the same basic component layout. It includes a variable capacitor on the input and output side and a variable inductor that goes to ground in the middle. Even the values of the components are in line with tuners of the past.

You will note however there is no balun in this tuner. I believe that is due in large part because we no longer see much use of twin lead. The biggest change is of course the SWR circuitry which is now automatic and no longer requires the user to calibrate the meter before taking a reading. You do however need to select the power level which I find interesting because that was addressed in the Nye Viking 3KW tuner decades ago. In the Nye-Viking tuner the meter would automatically switch to the appropriate power level.

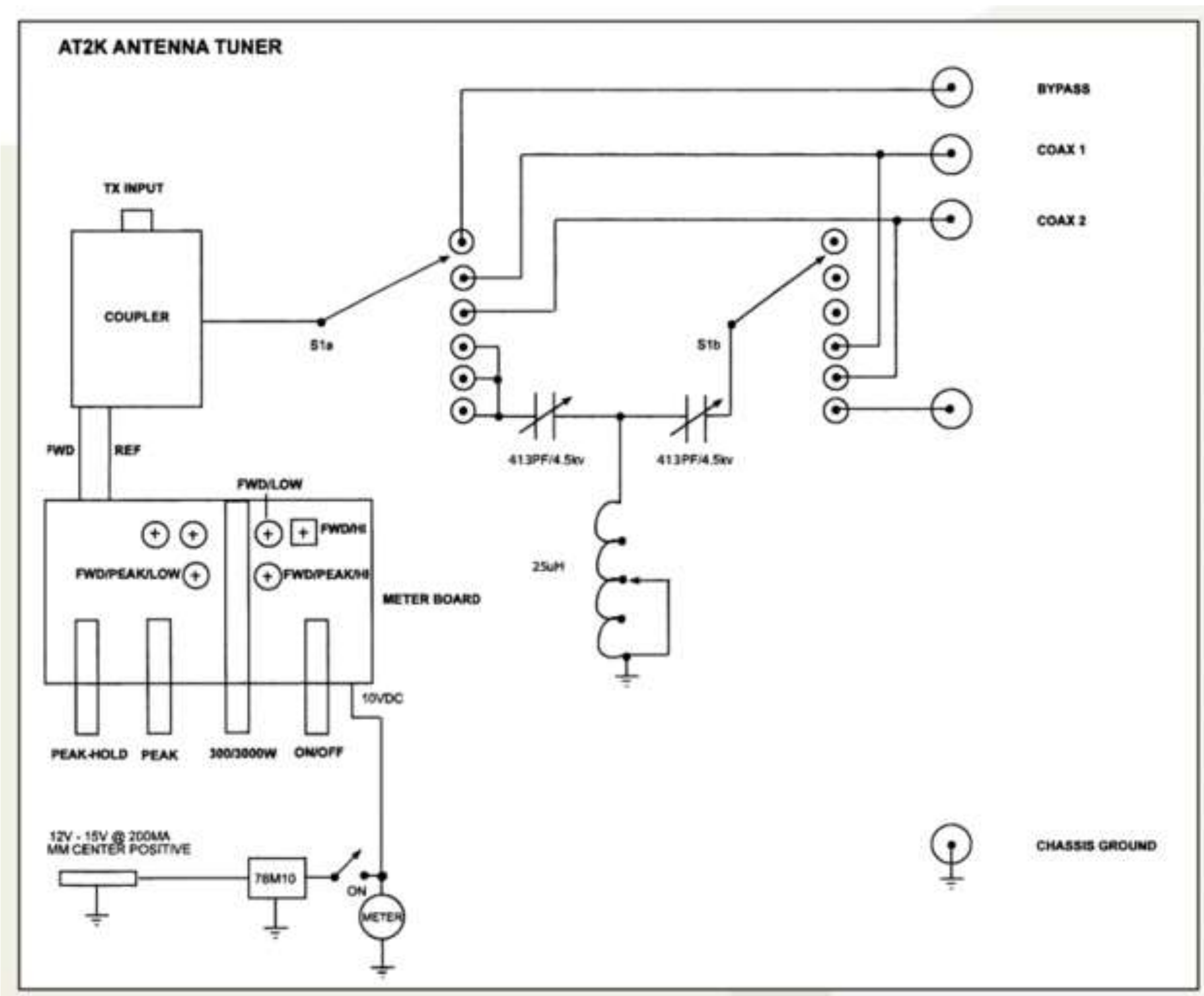

Figure 82:Palstar AT2K Schematic

Figure 83:AT2K Front Panel

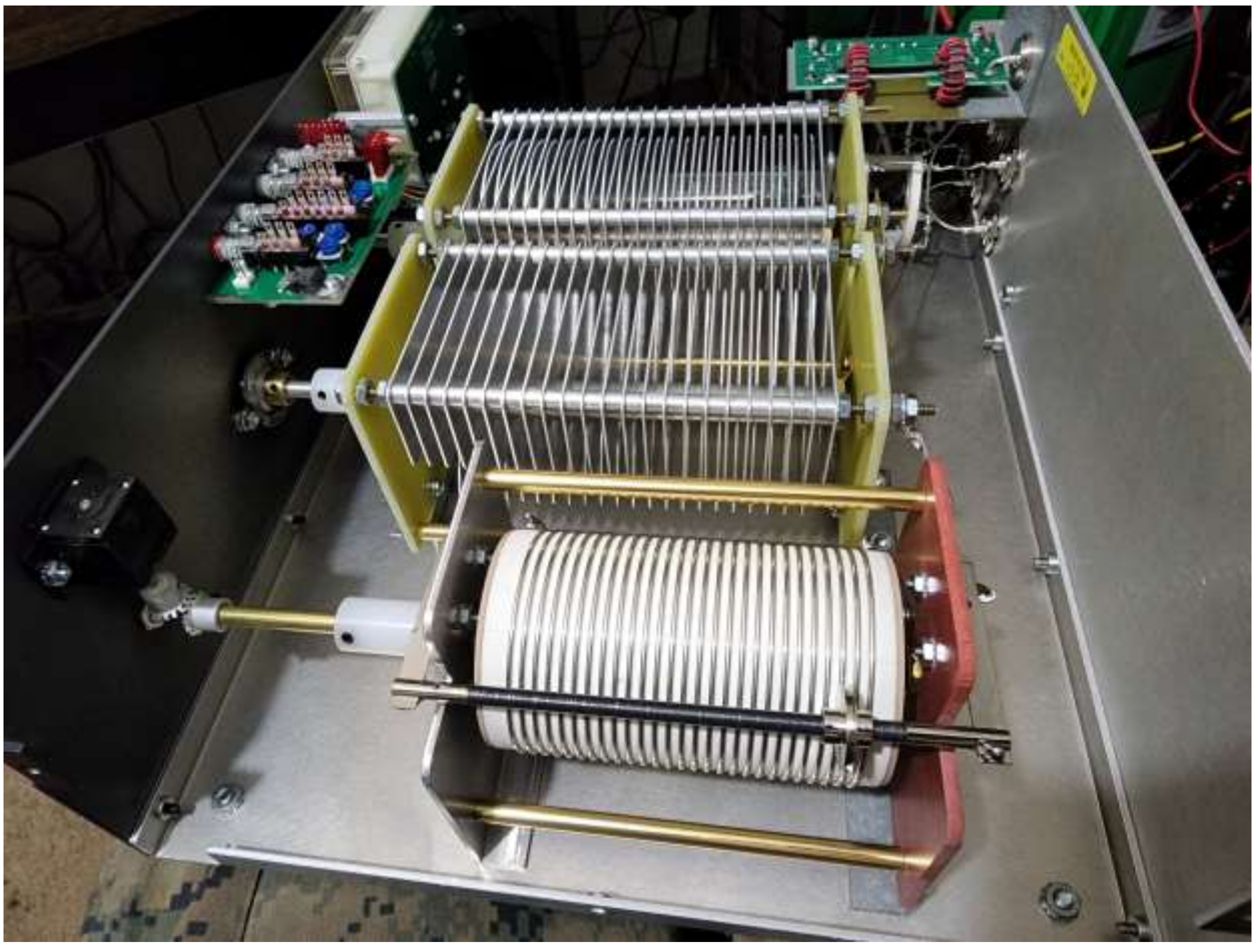

Figure 84: Palstar AT2K: Interior. Note the size of the components. Makes for an interesting comparison when compared to low cost tuners. This is the extra value you get with a premium tuner. Note also that the capacitors and inductor are electrically

isolated from the adjustment knobs. In tuners where this is not the case just touching the knob can affect the SWR reading. Isolating the components from ground is considered a best practice.

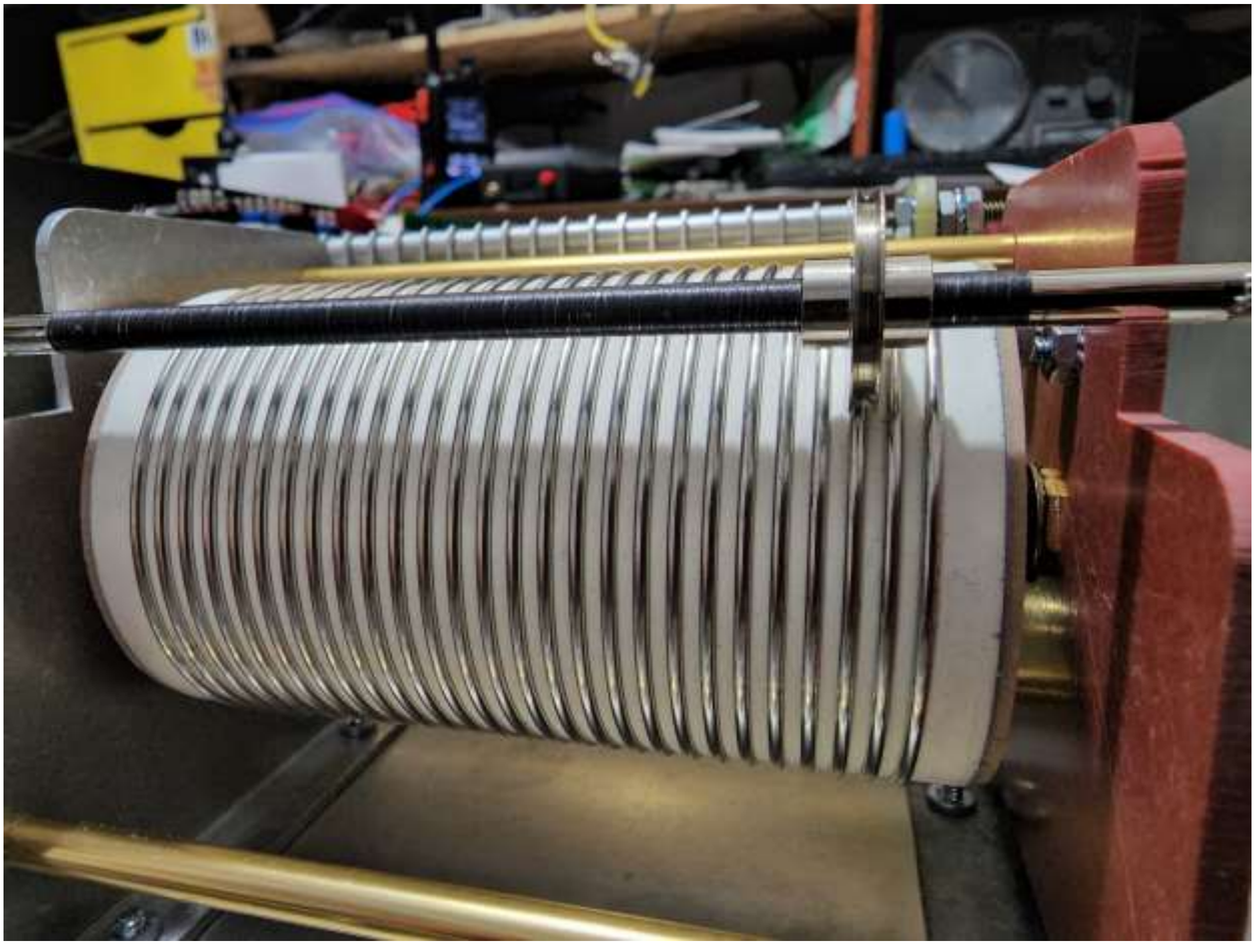

Figure 85: Palstar AT2K - Roller inductor – This is what high quality looks like.

Figure 86: Palstar AT2K variable capacitors

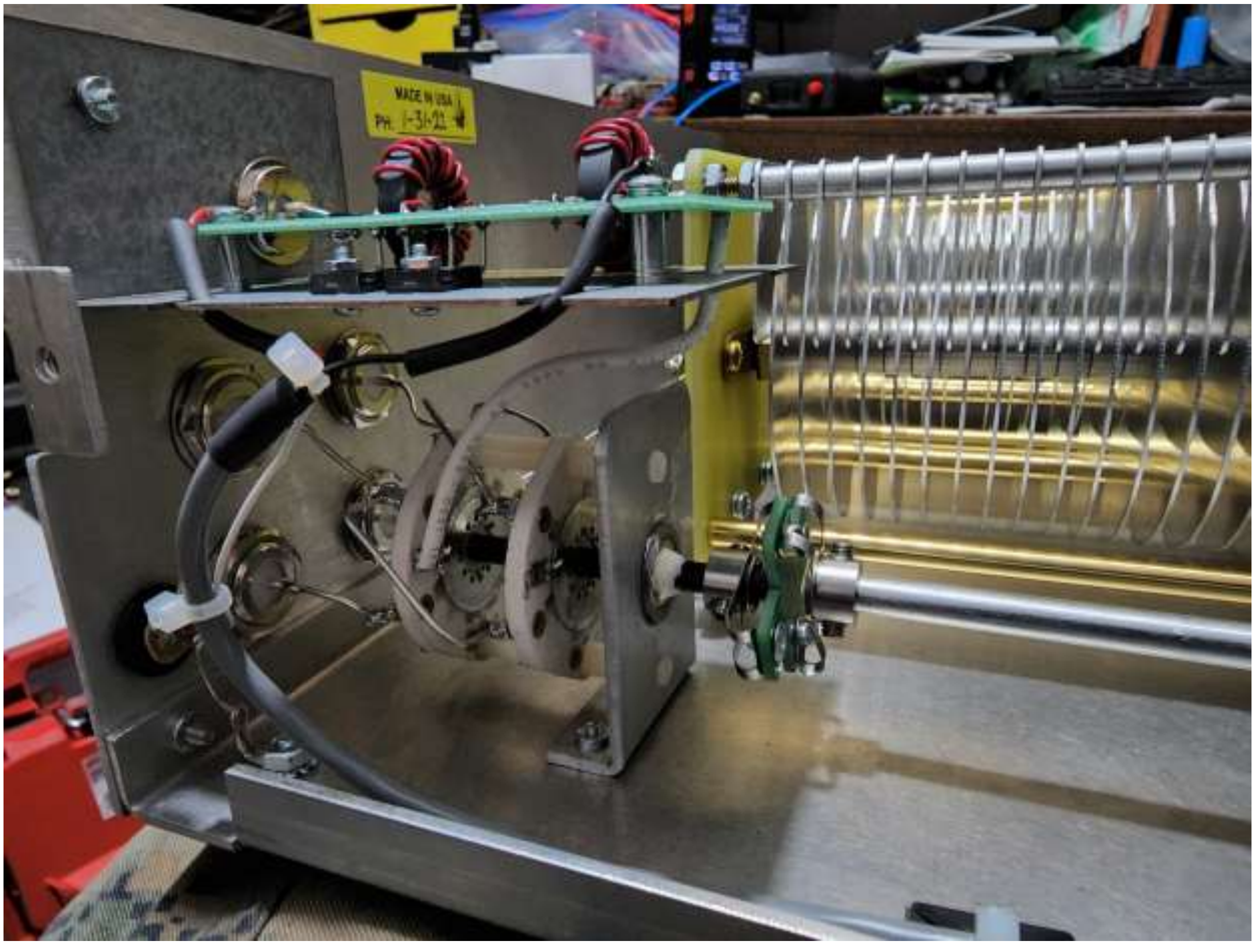

Figure 87: Palstar AT2K Rotary Switch

Figure 88: Palstar AT2K, rear view. If I could add just one feature it would be to allow for multiple inputs.

We are at the end – finally! If there are any tuners out there that you would like me to research please send me what information you have and I'll do my best to research it. Also if you have a homebrew tuner that you would like me to include in this supplement please send me pictures and a story about building it.

Keep the iron hot, the solder flowing, and the wire singing!

73,

Gene (WB7RLX)

Acknowledgements

As you may have noticed there were a number of SimSmith plots that I borrowed from a presentation delivered by **Larry Benko, W0QE** that he delivered to the Boulder Amateur Radio Club in Jun. 2011. I wrote Mr. Benko for permission to use portions of his presentation which he graciously gave. Through our email exchanges I found out he was the principle designer of the Palstar HF Auto Tuner. I owned one of these fine tuners for several years. It was without a doubt one of the best tuners I ever used. I ended up selling it because I felt like I no longer needed an auto tuner capable of 1500 watts and wanted to downsize my station. In the references I have provided a link to his site and his presentation. If you found this article interesting I would recommend you review his article. He also has a couple of other videos that I found to be very informative, his video on transmission lines especially so. I would also like to add that Larry has a YouTube channel with a lot of very good content. I have enjoyed his excellent series on SimSmith Basics.

Larry if you are reading this I want to express my heartfelt thanks and appreciation for letting me use portions your presentation. It added immeasurably to my article. Thank You!

Here's a link to his channel:
https://www.youtube.com/channel/UCKSyLSu4fm_1RHoO3Jvk4YQ.

I'd also like to express my thanks to my friend in Idaho, **John Wilson, K0IP**. John is the man behind the Yellow Pages Yellow Sheets SWAP (pocatelloarc.org) If you're looking for used and especially vintage gear this is the place to go. I really enjoy going up to see John. Wandering around his home looking at all the gear is always mind blowing, even if you've been there before. And I always look forward to going to lunch with him to the Café Tuscano. I've spent several afternoons enjoying a cold beverage or two and listening to his many stories and being entertained by his experiences in faraway places and distant times and talking about ham radio both then and now. How the world has changed.

Besides the great stories and being able to wandering around his house, (museum? warehouse? horde? All of the above?) I have two reasons to thank John. The first, he let me photograph his Johnson Match Box Tuner which are featured in this article and his James Millan antenna tuner. The other reason is he sold me his Nye Viking MB-V-A 3KW Antenna Tuner. These fine old Pi tuners are getting very hard to find. If you do fine one, snatch it up. The Nye Viking 3KW tuner is one of the best examples of tuner innovations from the past there is. It's a perfect example of the saying, "They sure don't build'em like they used to." The Nye Viking tuner is considered by many to be one of the best antenna tuners ever sold commercially. Some would argue it was the best. I have to admit that I'm a member of that group. John, if you're reading this, "Thanks!"

I also need to give a shout out to Scott Willis (KD7EKO) who did the final proof of the article. Scott also provided pictures of his Palstar AT2K tuner for this article. Scott I really appreciate

the time and effort you put into doing the final proof. Given the length of this article that was no small task. You were able to see things that I was not able to see. Thank You!

Finally To My Readers: Thank you for your time. I know this was a long article. When I started I had only intended it for the clubs newsletter. I would have not thought it possible to end up with over 100 pages on the topic of antenna tuners. But as I got deeper and deeper into the subject matter I became more fascinated with each new discovery. Writing this article was an educational experience for me to say the least. My sincere hope is that it was for you as well.

Thank You!

Additional References

1. "*Using a Manual Antenna Tuner: Ask Dave Episode 5*", https://www.youtube.com/watch?v=RRkbdTadmUU This is a good video on how to use a manual tuner.

2. "*Best Manual ATU Tuning Method*", https://www.youtube.com/watch?v=QlgkOICas5Y Short video on the proper way to tune an antenna using a manual tuner.

3. "*Reflection III: Transmission Lines and Antennas*", M. Walther Maxwell, W2DU, CQ Communications. http://www.w3pga.org/Antenna%20Books/Reflections%20III.pdf This book is out of print but can be found on the used book market. It's a book that I highly recommend if you want to understand more about Transmission lines and SWR. In his book there are a couple of chapters specific to the Antenna tuner. One is on the conjugate match and other on how the antenna tuner actually works. Be prepared for some difficult math.

4. "*How To Use A Ham Radio Manual Antenna Tuner*", https://www.youtube.com/watch?v=ScHrZ_cwt-Q Josh does a good job explaining the proper way to adjust your manual antenna tuner.

5. "*The Johnson Kilowatt Matchbox Revisited*", John Le Vasseur – W2WDX. https://www.qsl.net/w2wdx/articles/a4.html#:~:text=The%20Kilowatt%20Matchbox%20was%20originally%20designed%20as%20an,line%20systems%2C%20it%20was%20designed%20for%20this%20specifically.

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10. "*The 50-Ohmer Transmatch*", Lewis McCoy – W1ICP, QST, July 1961, pages 30,31, cont. 136. This article is the first known description of what would later be known as the Millen 92200 Transmatch.