MFJ

RF Design Box
Model MFJ-5904

INSTRUCTION MANUAL

CAUTION: Read All Instructions Before Operating Equipment

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DISCLAIMER

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Customers using this manual should report errors or omissions, recommendations for improvements, or other comments to MFJ Enterprises, 300 Industrial Park Road, Starkville, MS 39759. Phone: (662) 323-5869; FAX: (662) 323-6551. Business hours: M-F 8-4:30 CST.

MFJ-5904 RF Network Box

Introduction

Inductors and capacitors are the fundamental building blocks for RF design, and the MFJ-5904 places both at your fingertips. With it, you can build and test almost any popular HF tuning and matching network, plus many other useful circuits in minutes -- all without plugging in a soldering iron. The MFJ-5904 is packaged for portability with a compact molded case and high-quality internal components. In fact, each component is 300-watt ATU rated so you can put your network designs to the test under actual operating conditions using a 100-Watt station transceiver.

The MFJ-5904 provides two adjustable capacitor banks, each with variable and switched components to provide any value between 12 pF to 912 pF. It also provides a switched toroid inductor assembly that is adjustable from 0.1 to 11.2 uH in 12 steps. All tunable components are RF-isolated from the aluminum front panel to ensure personal safety. Simply connect patch leads to configure the circuit -- then tune in the optimize values for peak performance. Fast setup times allow you to try different network configurations to see which one works best for your particular application. Here are examples of circuits supported by the MFJ-5904:

[ ] Single element matching, L and C

[ ] Series-L, Shunt-C (low-Z to high, low-pass)

[ ] Shunt-C, Series-L (high-Z to low, low-pass)

[ ] Shunt-L, Series-C (low-Z to high, high pass)

[ ] Series-C, Shunt-L (high-Z to low, high pass)

[ ] Pi-network (common in transmitters and amplifiers)

[ ] T-network (widely used antenna tuner circuit)

[ ] Notch (suck-out) filter, series L/C across signal path

[ ] Trap reject filter, parallel L/C in series with the signal path

[ ] Band-pass filter, parallel L/C with shunt-C, series-C input

[ ] Load converter (converts your 100-W 50-Ohm load to other values)

[ ] Selective field-strength meter

[ ] Portable antenna tuner

There's no "black magic" to RF-network design. Each one is predictable, all of which makes the RF Deign Box a tremendous learning tool. It's a great way to develop a true "feel" for how each type of RF tuned-circuit works!

Before You Begin

Prior to launching into your first project, please take time to look through the entire manual to gain familiarity with all MFJ-5904 functions and features. A few minutes spent now will help you enjoy maximum benefit from your RF Network Box right away.

MFJ-5904 Panel Layout

The RF Box is configured from left-to-right across the front panel to facilitate logical input-to-output setups. Color-coded black and red five-way binding posts help identify each junction point or circuit node. To make connections, use wire jumpers terminated with banana plugs, spade lugs, or hookup wire with stripped ends. Each binding post handles multiple connections and locks them down securely. See the panel layout below:
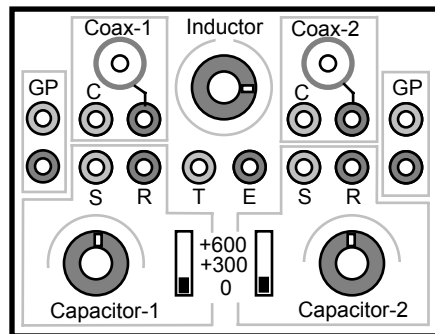

1). GP Posts: These are general-purpose binding posts. GP posts are not connected to any internal elements. Their purpose is to support external components you may wish to add.

2.) Coax Connectors: Coax-1 and Coax-2 accept standard PL-259 coaxial connectors. The shields are grounded in common with the aluminum front panel, along with the adjacent black terminal posts. Center conductors are co-terminated to the red "C" (for center) binding posts.

3.) Capacitor Bank Assembly: Capacitor-1 and Capacitor-2 are 312 pF variable capacitors, each with a scale calibrated directly in pF. Range may be extended to 612 or 912 pF by adding in the 300-pF or 600-pF fixed capacitors using the adjacent switch. Note that the variable capacitor binding posts are labeled "S" for stator and "R" for rotor.

4.) Inductor Assembly: The 11.2-uH high-Q toroid-core inductor is tapped with a 12-position selector switch in a shorted-turn configuration. "T" is the tapped terminal.

Important Warning: *When wiring network configurations, confirm all external connections are secured with no exposed conductor surfaces before applying RF power. Inadvertent contact with energized wiring can cause severe RF burns and pose an acute injury threat.*

Schematic Diagram

Internal wiring for your MFJ-5904 is shown below. Use this diagram as a reference to identify individual terminal posts when configuring jumper leads:

Internal Schematic for the MFJ-5904 Network Box
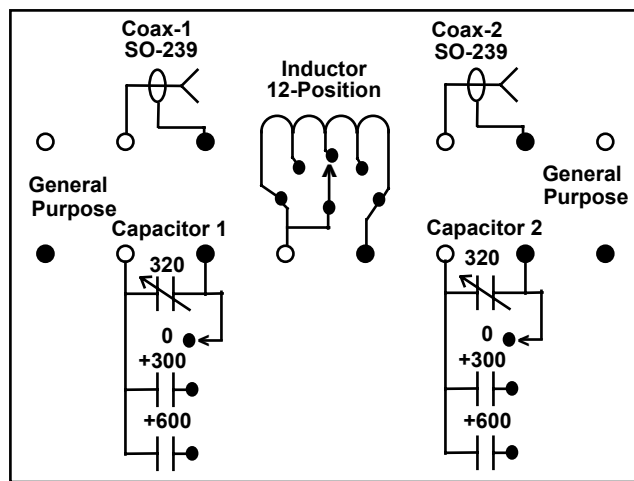
Using the MFJ-5904 with Antenna Analyzers

Hand-held antenna analyzers provide instant feedback to help you verify network wiring and dial in optimum component values. Simply connect the analyzer's antenna port to *Coax-1* and attach the antenna or device under test to *Coax-2* or the associated binding posts. *Whenever possible, use short patch cords and jumpers to minimize impedance measurement errors caused by phase rotation and stray reactance.*
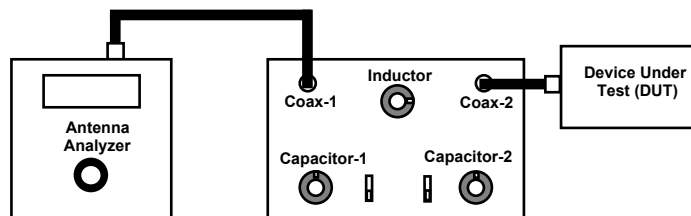
Analyzers with swept-frequency graphic capability such as the MFJ-223 or MFJ-225 provide the added advantage of picturing the network's performance over a span of frequencies. This feature is especially useful for analyzing parameters such as filter-cutoff frequencies, suppression depth, trap response, and network bandwidth. Once your setup is configured and adjusted for the best match, you can remove the analyzer (unless otherwise noted) and safely test the network using a 100-Watt station transceiver. Note that series-L networks (like the pi-network) form a dc path through the Network Box to your analyzer. When testing, always short-circuit feed-line leads to bleed off static before connecting them to the MFJ-5904.

Important Warning: *Never connect your handheld analyzer to a strong RF source such as a transmitter, high-level signal generator, etc. Also, avoid dc sources such as a bias-tap or static-charged antenna line. When connecting large arrays to the Design Box, discharge the conductors first to protect the analyzer installed at the opposite end of the network.*

Building and Testing a Practical Test Circuit

In order to gain a feel for how the MFJ-5904 operates, we recommend taking a few minutes to build the simple L-network presented below. The network's "job" is to transform a 500-Ohm load installed at R2 down to the 50-Ohm source connected at R1. You'll begin by connecting your handheld antenna analyzer to Coax-1, setting it up for 10 MHz, and using it to monitor your results.
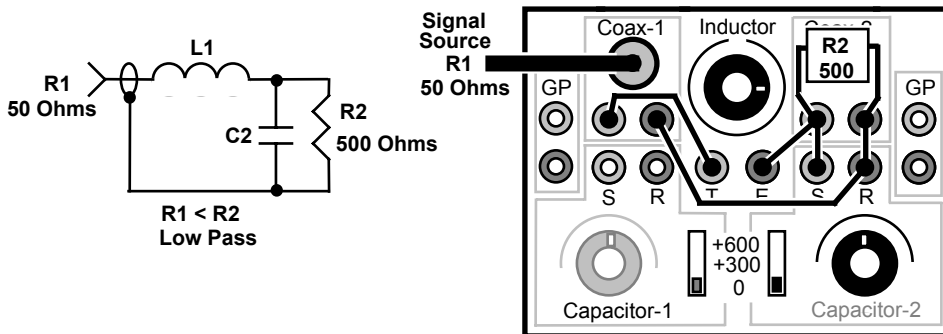
When configuring a shunt-C network, note that the shunt capacitor (C2) is always installed at the high-impedance end of the network (R2). Follow these steps to set up your test:

[ ] Using a short patch cable, connect your analyzer to Coax-1
[ ] Set the analyzer frequency to 10 MHz
[ ] Using short jumpers, connect leads to the terminal posts shown.
[ ] Connect a 500Ω load across R2 (single 470Ω resistor or two 1K in parallel).

This manual provides several similar setup diagrams for most popular network configurations, along with a thumbnail description of each. Note that *Capacitor-2* is wired in for this test. To find functional L/C values, use the same tuning procedure you might for matching an unknown load with a antenna tuner.

[ ] Start by setting *Inductance* at minimum (0.1 uH).
[ ] Sweep C2 across its range (12-312 pF).
[ ] If no SWR response, step to the next inductance value (0.4) and sweep C2.
[ ] Continue advancing Inductance until sweeping C2 provides a response.
[ ] If two adjacent Inductor settings yield a dip, choose the one with lowest SWR

You may not obtain a "flat" 1.0:1 SWR reading, but it should fall well under 2:1 and be usable with any solid-state transceiver. The capacitance reading you obtain at minimum SWR is the *optimum value for the inductance provided by the coil's switch setting.* Different values of inductance would yield different capacitor settings, and if the inductor were infinitely adjustable, one of them would present a perfect 1:1 match.

For users who are mathematically inclined, the numerical solution for this network is presented in the "Doing The Math" section the manual, along with other formulas required for calculating network solutions.


Sample Network Solutions

The next portion of the manual present a collection of commonly used L/C network configurations you can build using the MFJ-5904 RF Design Box. Each network example includes a non-technical explanation of how it functions, schematic diagrams, pictorial wiring setups for the MFJ-5904, and suggested applications. However, before we begin, here are a few basic definitions for some of the terminology you'll see used in the text:

Resistance: Opposition to the flow of electric current, as measured in Ohms. Resistance absorbs power and performs work.

Reactance: The opposition to a change in voltage (ac) due to capacitance (capacitive *reactance*) or in current due to inductance (inductive reactance). Reactance is measured in Ohms, but unlike pure resistance, it doesn't absorb and dissipate power. Instead, it stores and returns it.

Impedance: The combination of resistance and reactance (Z = R ±jX) presented by a load.

Resonance: The frequency when inductive reactance (+jX) and capacitive reactance (-jX) cancel each other to leave only the resistive component of the load impedance.
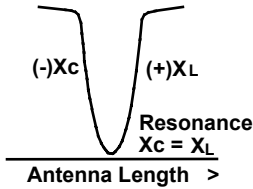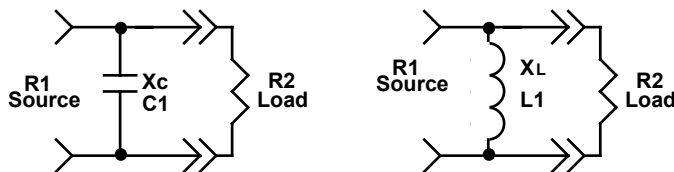

Reactance Formulas:

$$X_L = \omega L \quad \text{and} \quad X_c = \frac{1}{\omega C} \qquad (\omega = 2\pi f L)$$

Reactance and Frequency: The reactance in Ohms a component contributes to a circuit depends on both its electrical value (pF, uH, etc.) *and on the frequency of the RF energy being applied.*

Series Reactance: Series *inductors* become more reactive as frequency increases. When inserted in the signal path (see below), *inductors* act as *low-pass filters*. Series *capacitors* become more reactive as frequency decreases, so they act as *high-pass filters*.
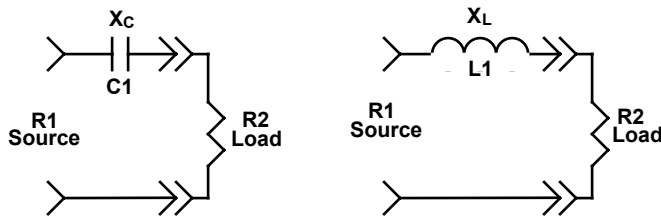
Shunt Reactance: When shunted across the signal path, *capacitors* function as *low-pass filters* while *inductors* act as *high-pass filters*.

Matching Element: An individual inductor or capacitor installed along a signal path to add or subtract reactance for the purpose of implementing an impedance match. Also sometimes called a "lumped" matching element.

Network Circuit Example 1: Single-Element Match

This first MFJ-5904 setup uses a single component (C1 or L) to find a matching solution for a ¼-wave vertical. The antenna's driving resistance is typically well below 50 Ohms, especially if the radiator has been physically shortened by a loading coil, capacitive hat, or both.

To shunt-match this antenna for a 50-Ohm feed, you must first intentionally tune it off-resonance to generate some reactance. If planning to use a shunt inductance, shorten the radiator -- tuning it higher in frequency. Doing so causes it to exhibit capacitive reactance. Alternatively, if you plan to use a shunt capacitance, lengthen the antenna -- tuning it to a lower frequency. Doing so causes it to exhibit inductive reactance.

Next, introduce an opposing reactance at the feed point -- using the Network box to re-resonate it on frequency. With the right combination of de-tuning and re-tuning with shunt reactance, it's possible to force the feed point to present a non-reactive (resonant) 50-Ohm load.
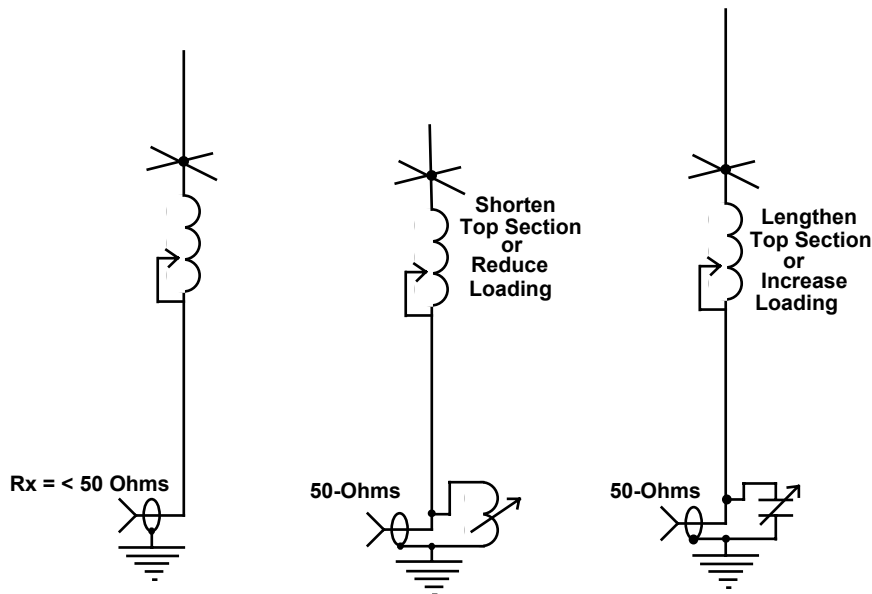
It may take a few trials to obtain the best match because you are working with two variables: (1.) The "detuned" antenna's reactance and (2.) The shunt reactance provided by the network box.

Follow the pictorials below to use the MFJ-5904 as a shunt matching element:
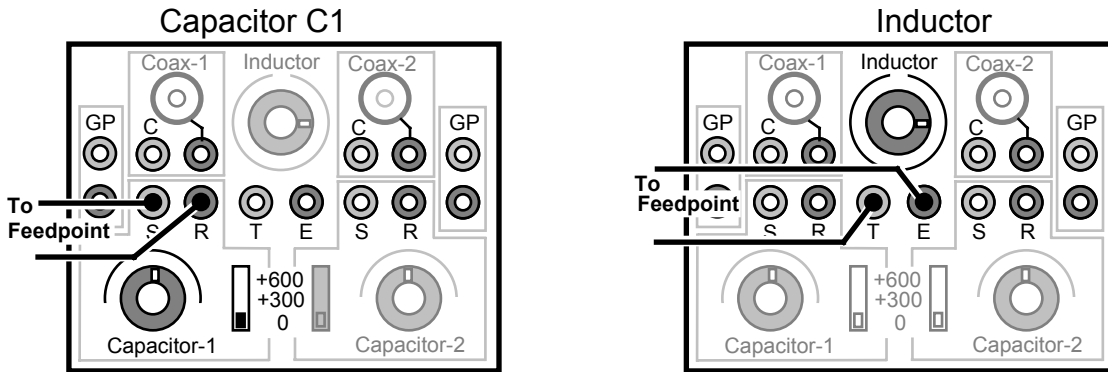
Shunt Capacitance: To find a suitable value, adjust C1 for minimum SWR. If necessary, add in additional capacitance using the slide switch. At lower HF frequencies, it's possible the value of C may exceed 312 pF.

Shunt Inductance: To adjust L (Inductor), try each different switch position to find a dip in SWR. Note that the capacitor offers continuous tuning whereas the inductor offers fewer (switched) options. If you can't find a workable match using the inductor, retune the antenna (make it longer) and try a capacitive shunt.

Even though only one component is used for the match, this example is really a two-element matching solution. The second element consists of the reactance you created by mistuning the antenna. The next section covers L-networks, where we'll carry the concept of the two-element match much further.

L-Networks

The family of L-networks are named for their "L" shape -- where one element is connected in series with the signal path and the other is shunted across to ground. L-network configurations may transition from low to high impedance, or from high impedance to low. Both types are used widely for inter-stage coupling in transmitters and receivers, and for many other RF applications, as well.

Circuits like the L-network use reactance to create a condition where the source "sees" a load termination equal in value to itself (even though the actual load may be quite different). According to theory, when the source and load are matched up to each other in this manner, maximum power transfer can take place across the signal path. This condition is called a *conjugate match*.

When properly designed, L networks have little loss. However, the matching range is somewhat limited because the network's Q will depend on the impedance ratio between the source and the load. If the matching ratio is high,

then Q will also be high (and vice versa). L-networks with very low Q may lack enough selectivity for their intended application. Networks with very high Q may be touchy to adjust, have more loss, and be prone to high-voltage breakdown.

L-networks are also widely used as filters -- both for low-pass and high-pass applications. *Series-L* networks are *low-pass filters* that find use for both matching and suppressing harmonics. They are also used to selectively route low-frequency signals to a particular load destination in a wideband network. *Series-C* networks are *high-pass filters* -- they don't suppress harmonics, but are still used for matching and signal routing when harmonic suppression is achieved in other ways.

If you're an audio buff, the L-network schematics probably look familiar because they are widely used for passive crossover networks. A *series-L* circuit routes bass to the woofer while attenuating highs, and a *series-C* circuit routes highs to the tweeter while attenuating lower-frequencies that could cause damage. You can build up four L/C L-network configurations using the MFJ-5904.

When installing patch leads on the MFJ-5904, note that the shield side of the SO-239 connectors (*Coax-1* and *Coax-2*) are tied to together via the aluminum chassis. The terminal posts assigned to these shields are also tied together, so there's no need to install a patch lead to establish a ground path between the source and load side of the unit.

Once your L-network circuit is patched in, if you are unsure of the approximate part values to dial in, you can usually find the solution off-hand using trial and error. Simply rotate the *capacitive element* through its full tuning range at each setting of the *Inductor* switch (same procedure you'd use with an antenna tuner connected to an unknown load). At some combination of L and C, the circuit should become responsive, causing SWR to drop and power transfer to increase.

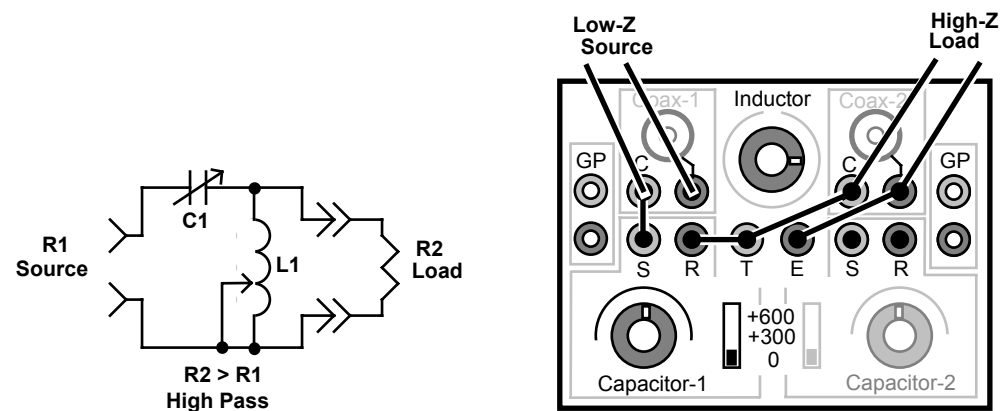## Matching Network Example-2: Setting Up A *Series-L Shunt-C Circuit*
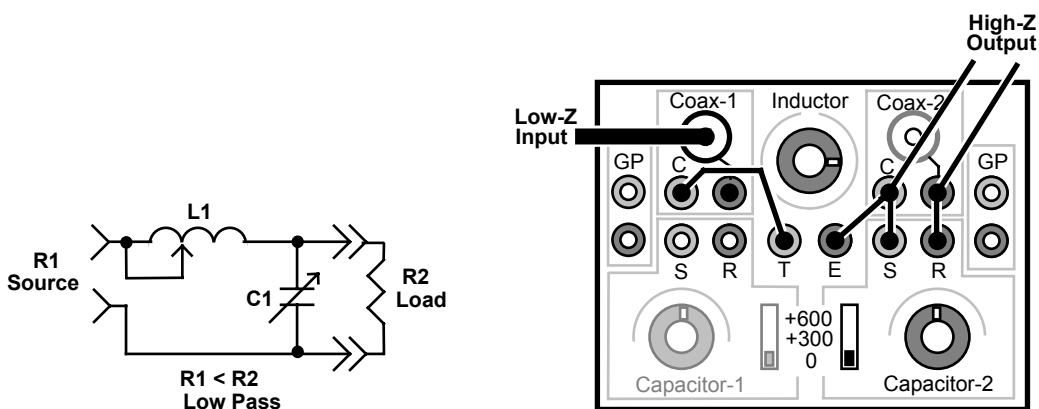
The *Series-L, Shunt-C* network uses a *series inductor* and *shunt capacitor* to transform a *lower-impedance source to a higher-impedance load*. Note that the shunt capacitor is always installed on the high-impedance side of the network. This network also functions as a low-pass filter to suppress transmitter harmonics.

## Matching Network Example-3: Setting Up The *Shunt-C Series-L Circuit*
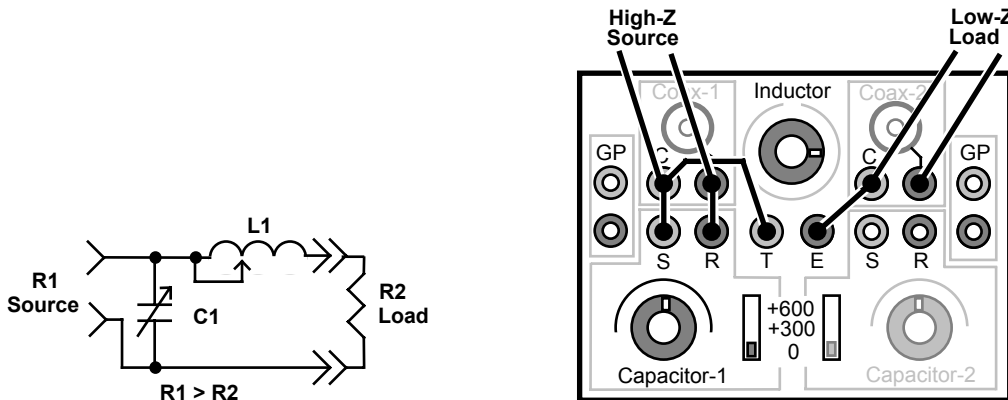
The *Shunt-C, Series-L* network flips the position of the shunt capacitor to the source end of the inductor. It is used to match a *higher impedance source to a lower impedance load*. The source may be 50 Ohms (or typically some higher value), but R2 must have lower impedance than R1 for the network to yield a match. This network also functions as a low-pass filter to suppress harmonics.

Matching Network Example-4: Setting Up The *Series-C, Shunt-L Circuit*

The *Series-C, Shunt-L* network uses a series capacitor and a shunt inductor to transform a lower-impedance source to a higher-impedance load. It also functions as a high-pass filter, suppressing low frequency signals and routing only higher-frequency signals to a load. Unlike the series-L networks, series-C configurations do not suppress transmitter harmonics.

Matching Network Example-5: Setting Up The *Shunt-L, Series-C Circuit*
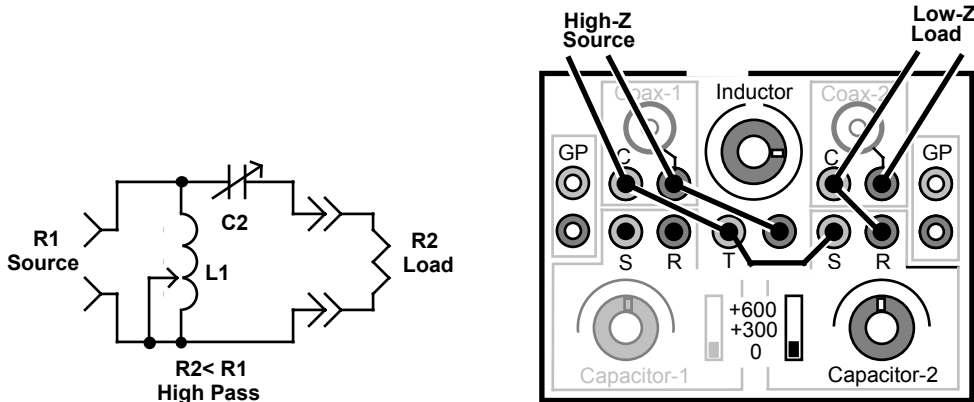

The *Shunt-L, Series-C* configuration transforms a higher-impedance source to a lower-impedance load. Note that inductor L1 is now located on the source side of the network. Being a *Series-C* circuit, it doesn't suppress transmitter harmonics.

The Pi-Network

The *Pi-network* derives its name from the Greek letter π. As shown below, it has three components – an inductor in series with the signal path and a capacitor shunting the inductor at both ends:
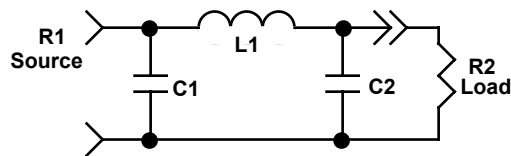
Being a *Series-L* configuration, the Pi-network is a low-pass design that suppresses transmitter harmonics. Although the Pi-network has only three physical components, it really consists of two back-to-back L-networks connected together. L1 represents the *total inductance required to make up both networks* when they are added together in series (see below):
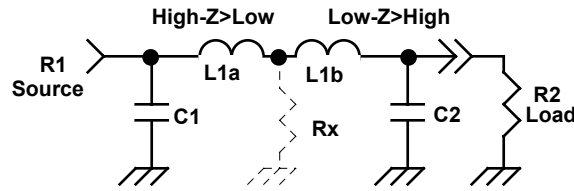
From the positioning of C1, we know the L-network at the source end of the signal path is configured to transform a high impedance to low impedance. Recall the capacitor end of the network is always the high-impedance end. At the same time, the L-network at the load end is configured to transform low impedance to high (C2). In the middle, then, we find an imaginary resistance (Rx) that is *lower in value than either the source or the load.*

When designing a Pi-network, the impedance value assigned to Rx can be almost anything you wish it to be -- as long as it is less than R1 and R2. However, the value you choose will establish the network Q. Recall that, for L-networks, *the matching ratio determines Q.* So, when designing a Pi-network, you can use the value of Rx to define the matching ratio and set the network Q.

Choosing the optimum value of Q for a network can be an arbitrary exercise -- and it is a topic beyond the scope of this primer. However, your choice will likely depend on design considerations such as the need for harmonic suppression, reactance cancellation, and the voltage or current limitations of your components. The equation below provides a good approximation of network Q.

$$Q = \sqrt{\frac{R_H}{R_x} - 1} \qquad R_H = \text{the higher value of R1 or R2}$$

Matching Network Example-6: Setting Up a Pi-Network
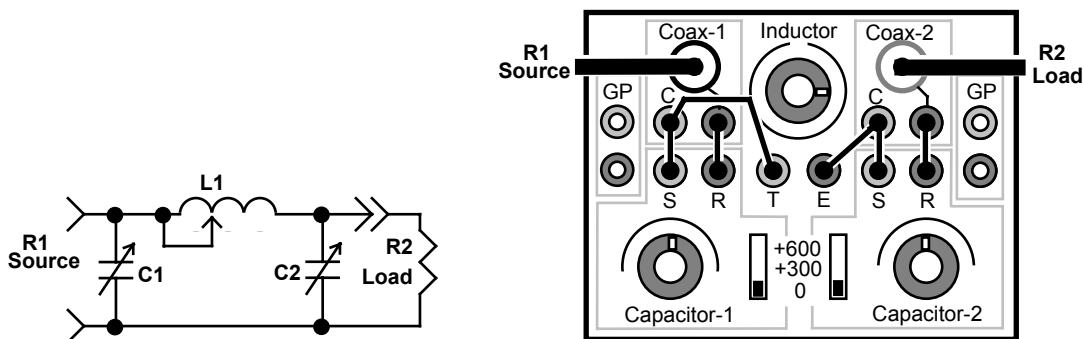
The MFJ-5904 Pi-network set up is similar to the series-L network setups, but with both capacitors patched into the signal path (C1 *and* C2).

R1, the source, may represent a higher or lower resistance than R2, but *both values must be greater than Rx*. If you don't know actual component values for your particular match, you can often find them by trial and error. In fact, if you own a tube-type amplifier or transceiver, the procedure should be familiar.

Treat *C1* like the amplifier *Tune* control, *C2* like the *Load* control, and *Inductor* like your *Band Switch*. However, note that the *maximum component values on the MFJ-5904 are at the clockwise end of the dial scale*. Transceivers, amplifiers, and antenna tuners typically reverse this order so dial scales advance from low-frequency to high-frequency rather than low component value to high component value.

[ ] Set the Inductor to some arbitrary setting (your best guess).
[ ] Set C2 fully clockwise and sweep C1 across its range.
[ ] Now, slowly reduce C2 while continuing to sweep with C1.

If you've chosen a good *Inductor* setting, at some point, the circuit will become responsive, causing SWR to drop and power transfer to increase. If not, change the inductor setting and repeat the procedure until you find a response.

C1 and C2 interact, so normally you'll tune them alternately for best power transfer or lowest SWR. However, changing the relationship between C1 and C2 can impact on imaginary resistance Rx, altering network Q. Generally, choosing a higher capacitance value at C2 (heavier loading) lowers Q and reduces peak voltages. Lower values of C result in lighter loading, higher network Q, and (in some cases) greater risk of arcing.

Note that the SO-239 connectors are used for this particular example, but you may also use terminal posts at your option.
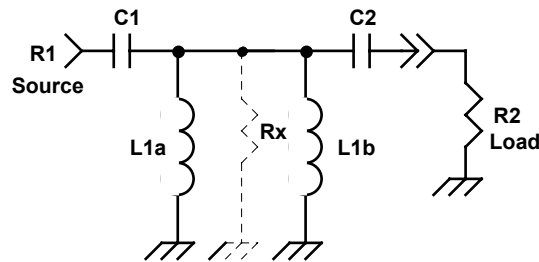
The T-Network

The T-network is a three-component configuration that looks like the letter "T". It consists of an inductor shunted across the signal path with a capacitor connected in series on either side (see below):
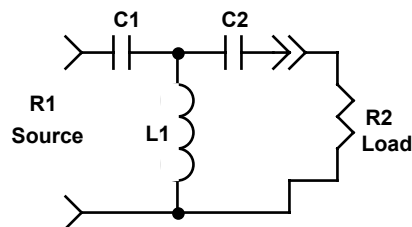
Being a *Series-C, Shunt-L* configuration, the T-network is a high-pass design that does not suppress harmonics. However, it is still very widely used for amateur radio and commercial antenna tuners because of its ability to match an exceptionally wide range of complex loads (especially low-impedance loads). All manufactured transmitting equipment must already meet FCC suppression requirements, so additional harmonic rejection is not a requirement for tuners.

Although the T-network uses only three components, it is composed of two back-to-back L-networks (like the Pi-Network). The difference is, the two inductors are shunted across the signal path rather than connected in series. As a result, L1 is the product of two inductances connected in parallel (see below). When two inductors are connected in parallel, the combined inductance will always be less than for either one individually. Consequently, the coil inductances used in T-networks are typically smaller than for a comparable Pi-network, a factor that often means lower network losses (consider starting with lower *Inductor* switch settings when you set up the MFJ-5904 for a T configuration).

Like the pi-network, the T-network gives designers control over network Q by manipulating the value of resistance Rx. However, in this case, the resistance of Rx must be *larger* than the value of R1 or R2 in order to yield a match. The formula commonly used to estimate T-network Q is:

$$Q = \sqrt{\frac{R_x}{R_L} - 1}$$ R_L = the lower value of R1 or R2

**Matching Network Example-7: Setting Up a T-Network**

- 15 -
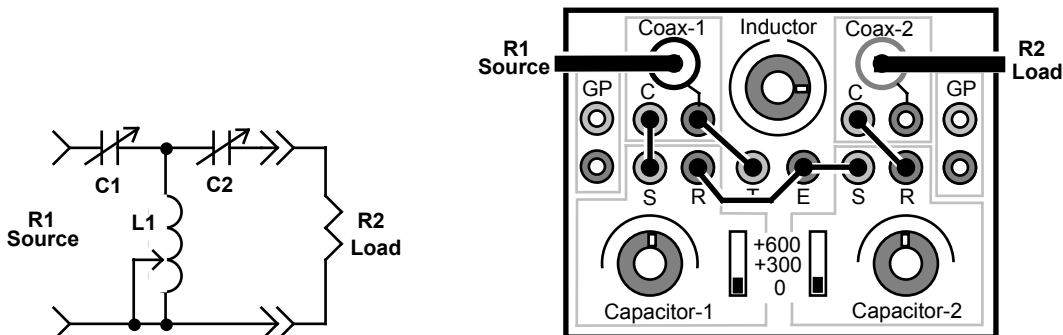
The MFJ-5904 L-network setup is similar to a *Series-C setup*, but with the added capacitor (C1 and C2). Note that the tapped end of the inductor (T) is grounded. The source impedance at R1 could be higher or lower than R2, *but both values must be less than Rx.* If you don't know the approximate network values for your setup, trial and error will usually yield results.

[ ] Set the Inductor to the lowest inductance setting.
[ ] Slowly adjust C2 across its range while rapidly sweeping C1.
[ ] If no response, advance *Inductor* and repeat the procedure.
[ ] Continue until the circuit becomes responsive.

SWR will drop and power transfer will increase when you're in the ballpark. As with the pi-network, C1 and C2 interact, so tune alternately for optimum values. Again, a higher component value at C2 (heavier loading) typically results in lower network Q with broader tuning and lower peak voltages.

**Example-8: The T-Network as a Portable Antenna Tuner:**

When configured as a T-network (see Example-7), the MFJ-5904 becomes a handy 100-Watt HF antenna tuner. As explained earlier, the one difference is that *the rotational direction of the two capacitors and the inductance switch is reversed from most ATUs* (see below)*.*
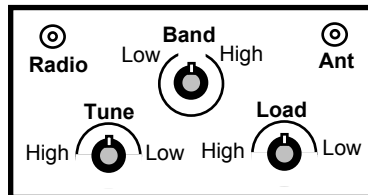
Tuners normally provide maximum component values at the counter-clockwise knob settings to coincide with lower operating frequency. However, the *MFJ-5904 follows the electronics industry convention for component substitution boxes by scaling values from low to high in a clockwise direction.* Therefore, the lowest frequency tuner setting will be with controls fully clockwise.

The Parallel L/C Circuit

This network consists of a capacitor and inductor connected in parallel across the signal path.
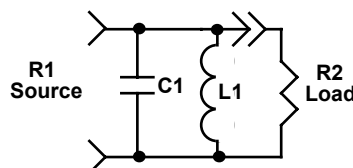
At resonance, the shunt L/C circuit exhibits high resistance across the signal path, allowing signals to pass without attenuation. However, when loaded properly, it has the ability to attenuate signals sharply on either side of resonance, making it desirable for band-pass filter applications. Also, multiple sections may be connected in series to build tighter selectivity, or sections may be stagger-tuned to create a pass-band filter with sharp skirts and flat response.

Being a high-impedance circuit, the shunt-L/C circuit meshes well with high-impedance devices such as tubes, FETs, etc. However, when used in lower-impedance circuits (bipolar transistors, 50-Ohm networks, etc), a coupling circuit is usually needed in order to admit power. The finer points of L/C filter design could fill several volumes, so we'll simply focus in on a couple simple ham-radio applications that use the MFJ-5904.

Antenna Matching Using the Parallel L/C Circuit

Parallel L/C circuits are often used to feed high-impedance antennas such as end-fed half-wave whips or long wire. The impedance presented by the end-fed half-wave radiator is theoretically infinite, but realistically falls in the K-Ohm region where a shunt L/C tuned circuit can couple to it directly. However, something additional is needed to admit power from a 50-Ohm source. In this application, that transition is made using a *capacitive tap* -- also called a *shunt-C, series-C* L-network (see below):
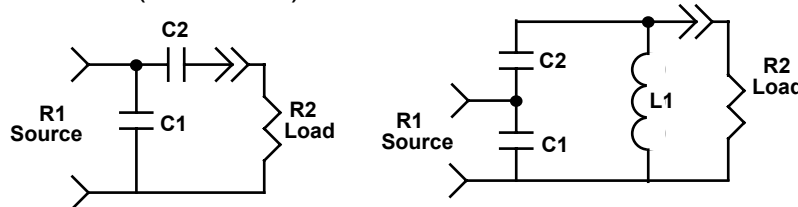

 The *capacitive tap* functions like a coil tap (or inductive tap), except the ratio of C1 to C2 determines the source resistance instead of the position of a tap.

$$\frac{C2}{C1} = \sqrt{\frac{RL}{RS}} - 1$$

RL = Larger (Load) Resistance
RS = Smaller (Source) Resistance

Because the matching ratio is very large, shunt capacitor C1 will always be many times larger in value than series capacitor C2. In fact, it is usually only slighter larger than the value needed to resonate the circuit using just a single capacitor.

C1 many times larger than C2

**C2 only slightly larger than if one cap used**
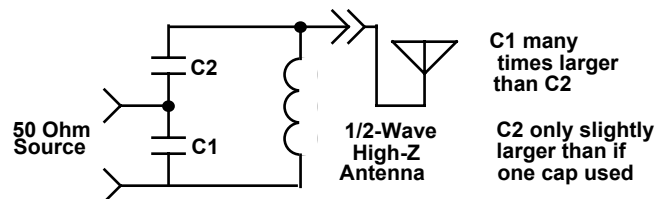
As a point of information, if an inductive tap were used in place of the capacitive tap, the transition circuit would technically be a *Series-L Shunt-L* L network. We've used the capacitive tap for this exercise because the MFJ-5904's inductor isn't conveniently accessible for installing inductive taps. The same restriction is also true for most inductors used in lower-power RF stages.

Shunt-L Series-L Network (Coil Tap)
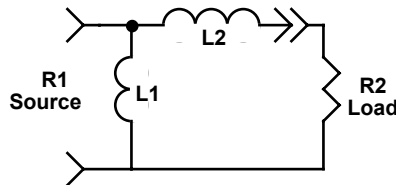
Matching Network Example-9: The Shunt L/C Circuit
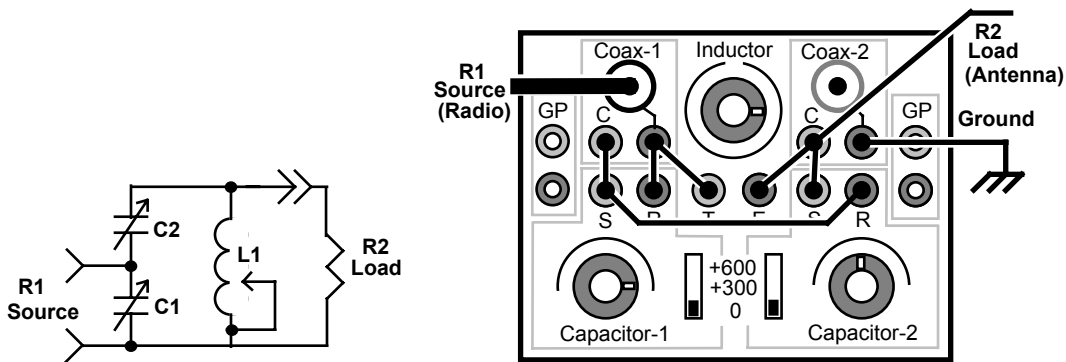
For this setup, keep in mind that *C1* will always be many times larger than *C2*. Also, RF voltages will be very high at the top of L1, so use caution to avoid exposed wiring -- and only use low power when adjusting circuit components.

[ ] Set *C1* fully clockwise at 310 pF, set *C2* at minimum. Set *Inductor* to 11.2 uH.
[ ] Sweep C2 across its range. If no response, move to next inductor setting.
[ ] Sweep C2 at progressively lower inductor setting until a response is found.
[ ] To further reduce SWR, *reduce or increase* C1 while continuing to sweep C2.

Sweep slowly -- the first response you find may be very sharp with high SWR. To increase C1 over 310 pF, switch in +300-pF.

This circuit may also be used as a passive pre-selector when using short whips or wires receiving antennas. Once the network becomes responsive, received signals and background noise may be all you'll need for a tuning aid.

Warning, Potential RF Burn Hazard: *Because of high RF potentials, we suggest limiting RF power to 20 Watts or less when transmitting. Also, be sure to connect a good RF ground and tune using very low power. Keep hands clear of wires and terminal posts. If arcing occurs, reduce power immediately.*

Setup Example 10: A Frequency-Selective Field-Strength Meter

You may also use the parallel L/C network in conjunction with any broadband (diode-detector) field strength meter to markedly improve its measurement performance (Example-9). The network will attenuate out-of-band signals that may otherwise elevate base-line readings -- and reduce usable measurement range. It will also match your pickup antenna impedance to the meter's diode detector for increased power transfer and better sensitivity.

To optimize, set up a signal generator (or antenna analyzer) nearby to generate a strong signal on the frequency where you plan to test. Then, tune the MFJ-5904 for maximum signal response on the field strength meter. Once signals are peaked up, you're ready to test.
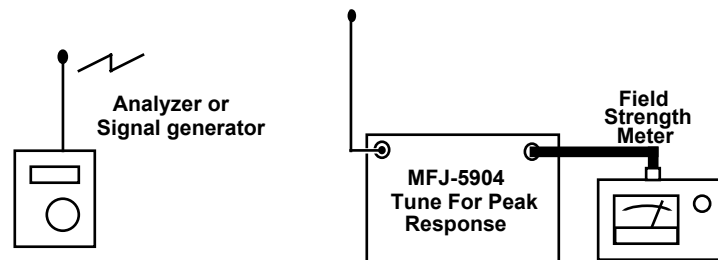
Important Note: This circuit *should not be used in conjunction with antenna analyzers* for the purpose of pre-selection when making SWR measurements on antennas. Connecting a parallel L/C circuit between a test antenna and the SWR analyzer could introduce large errors, resulting in highly inaccurate SWR readings.

Notch Filters

We use notch filters attenuate unwanted signals over a very narrow band of frequencies. Also called suck-out or reject filters, they consist of a series-connected inductor and capacitor shunted across the signal path. At resonance, L1 and C1 form a very low resistance path to ground that blocks signals by taking on the properties of a frequency selective short circuit (see below).
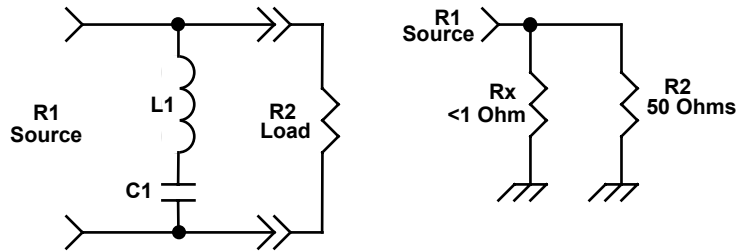
Passive notch filters may be used to null out interfering spurious signals, harmonics, or even powerful off-frequency broadcast signals that leak into a receiver in via the antenna line. Unwanted signals may be attenuated by 50 dB or more, depending on the circuit, while signals falling outside of the notch zone pass from source to load with minimal attenuation. Off resonance, the reactance of L1 and C1 tend to offset each other, holding the value of Rx high enough to prevent large attenuation losses.

Network Example-11: Setting Up a Notch Reject Filter
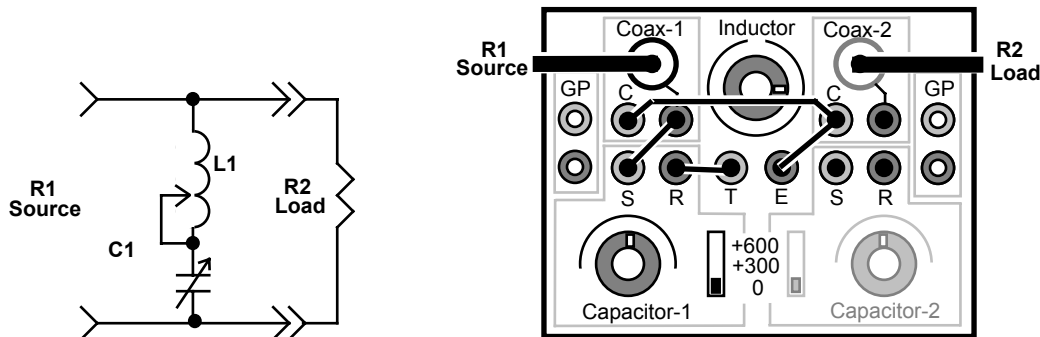
Unlike matching networks, we tune reject filters for *maximum SWR or minimum power transfer*. Because unwanted signals are shunted directly to ground, never apply transmitter power at the filter's resonant frequency -- the low-resistance load could easily damage the transmitter or the network-box inductor switch.

[ ] Connect analyzer to R1 (source) and tune it to the desired notch frequency.
[ ] Connect a 50-Ohm load to R2.
[ ] Set *Inductor* to an arbitrary setting, depending on the frequency of interest.
[ ] Sweep C1 across its range until SWR *increases.*
[ ] If no response is found, repeat using other *Inductor* settings.
[ ] Once a response is found, carefully peak C1 for *maximum* SWR.
[ ] Connect antenna to R1, radio to R2.
[ ] The radio S-meter may be used to further attenuate the unwanted signal.

Important Warning: Never transmit with high power on a notch filter's resonant frequency, or damage may result.

Series Trap Circuit

Like the notch filter, this classic "trap" circuit also suppresses signals over a narrow band of frequencies. However, in this case, the trap is a parallel-configured capacitor and inductor installed in series with the signal path. At resonance, it presents a very high series resistance that blocks signals by taking on the properties of an open circuit.
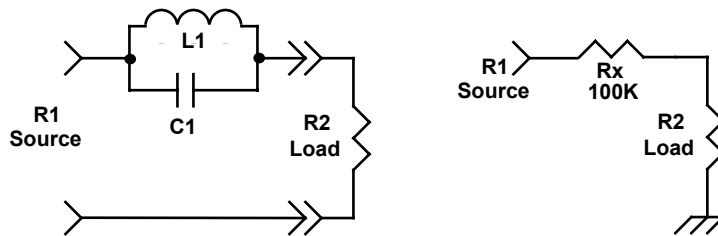
"Traps" are commonly used for band-switching antennas, where they are installed directly on the element. When stimulated by RF (either received or transmitted) at the resonant frequency, L1 and C1 act like a high-impedance switch that cuts off and isolates lower-frequency segments of the element. Traps are also used in other applications such as frequency-selective interference filters, common-mode current chokes, and RF switches.

Network Example-12: Setting Up a Trap Filter
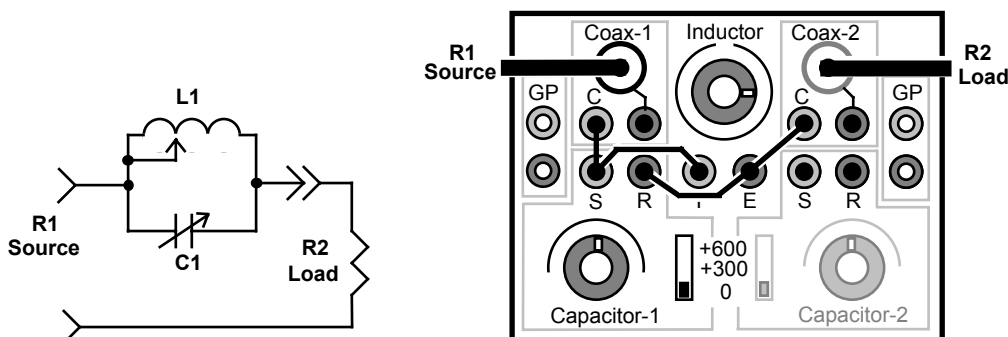
Like notch filters, traps are tuned for *maximum SWR (or minimum power transfer) at the desired operating frequency.* At resonance, impedance at the source is nearly infinite, so applying transmitter power at the reject frequency

could easily damage your transmitter or cause arcing inside the network box. To tune the filter:

[ ] Connect an antenna analyzer to R1 and set it to the desired trap frequency.
[ ] Connect a 50 Ohm load to L2.
[ ] Set *Inductor* to an arbitrary setting, depending on the frequency of interest.
[ ] Sweep C1 across its range until SWR *increases.*
[ ] If no response found, repeat using other *Inductor* settings.
[ ] When a response is found, carefully peak C1 for *maximum* SWR.
[ ] Connect the antenna to R1.
[ ] Connect radio to R1.

Important Note: Although signal attenuation is minimal either side of resonance, SWR on other frequencies may be altered. Below resonance, the trap will contribute inductive reactance to the signal path, and above resonance, it will contribute capacitive reactance.

Important Warning: Never transmit on the trap's resonant frequency unless a suitable load is connected in parallel on the source side of the network. The high impedance presented by the trap could damage your amplifier and cause unwanted arcing inside the network Box.


Network Example-13: A Resistive Load Converter

Most of us own a 50-Ohm dummy load capable of handling 100 Watts or more, but what about having access to a 25, 75, 100, or 200-Ohm dummy load capable of handling 100 Watts? The MFJ-5904 can provide a wide range of high-power load options using the T-match tuner configuration in conjunction with your station load.

The procedure involves using the MFJ-5904's T-match circuit plus an antenna analyzer connected to R1 to match a low-wattage resister of the desired load value connected to R2. Then, a 50-Ohm dummy load is connected in place of the analyzer at R1 (50-Ohm port) -- and the device under test (R2) is connected to the opposite end of the network at R2 (see below):
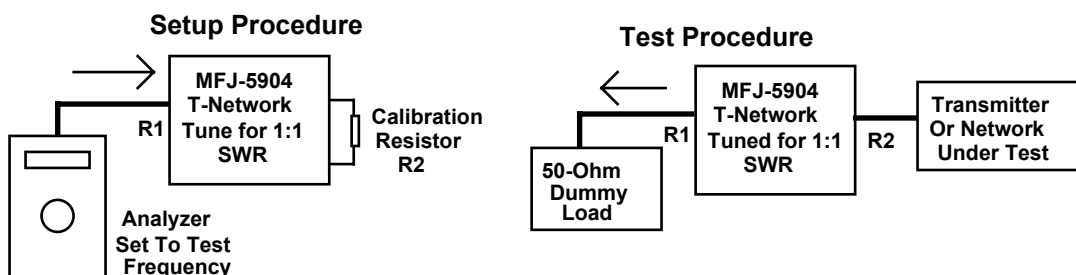
For reference, here is the T-network Setup for the MFJ-5904:
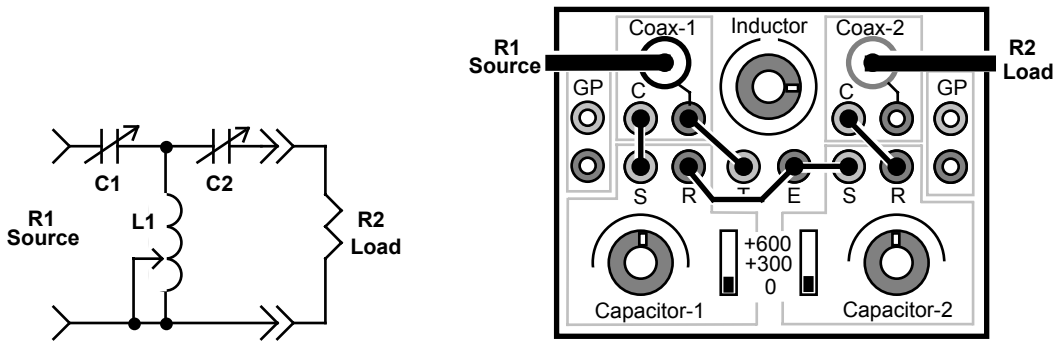
[ ] Connect an antenna analyzer at R1 set up for the frequency of interest.
[ ] Connect a low-wattage resistor of the desired calibration value at R2
[ ] Following the T-network procedure, match the resistor to the 50-Ohm source.
[ ] Disconnect the analyzer and connect a 50-Ohm dummy load at R1
[ ] Disconnect the calibration resistor and connect the device under test at R2.
[ ] Apply power – the 50-Ohm load will be transformed to the desired value.

Doing The Math

This last section of the manual begins with the step-by-step process for solving the practical L-network setup described earlier. Other useful formulas are also presented.

Mathematical Analysis of a L Network:

Problem: You want to design a *series-L shunt-C* type *L-network* to match your 50-Ohm transmitter into a 500-Ohm load at 10 MHz. Note that the shunt component (the capacitor) is connected on the high-impedance side of the network.
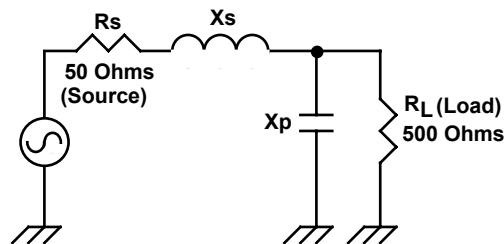
The solution for this type of network has three steps. First, calculate *network Q*, which is determined by the size (or magnitude) of the impedance transformation. The larger the impedance transformation ratio, the higher the Q requirement.

$$Q = \sqrt{\frac{R_L}{R_S} - 1} \ = \sqrt{\frac{500}{50} - 1} \ = \sqrt{9} \ = 3$$

Next, use the calculated "Q" to determine how much *reactance* the series inductor and parallel capacitor must contribute to the circuit in order to make the 500-Ohm load "look like" 50 Ohms at the network's input end. Note that Qs (series-Q) and Qp (parallel-Q) are of equal value.

$$Xs = Qs \cdot Rs = 3x50 = 150 \ \ (or \ j+150)$$

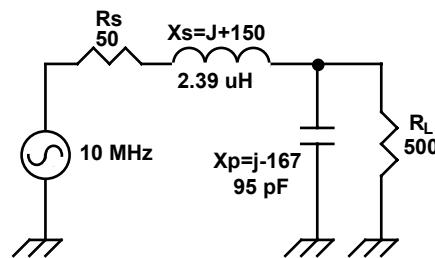$$Xp = \frac{Rs}{Qp} = \frac{500}{3} = 167 \ \ (or \ j-167)$$

Finally, calculate the actual *component values* it will take to develop the required amount of reactance *at the 10-MHz operating frequency*.

$$Note: \ \omega \ = 2\pi \cdot f \ (Hz) \ or \ 6.283 \cdot (10x10^6 \ )$$

$$L = \frac{Xs}{\omega} \ = \ \frac{150}{\omega} = 2.39 \ uH$$

$$C = \frac{1}{\omega \cdot Xp} = \frac{1}{\omega \cdot 167} \ = 95 \ pF$$

See diagrammed results below:

Tip: Should your math be a little rusty, you may find the conversions from Hz, Henries, and Farads to MHz, pF, and uH can lead to a misplaced decimal point. To reality-check your calculations, try using a Reactance Nomograph. Nomographs are also available online and in several ARRL publications, including the annual Handbook. They will also help you make quick L and C approximations for setups using the MFJ-5904. In fact, it's often possible to skip exact L and C reactance calculations altogether and obtain "ballpark" values using only the Nomograph. Reactance-vs-frequency solutions are also available using one of several online calculators. Use your browser to find what's currently available, pick one, and plug in your data. The program will do the math for you. Not all "reactance calculators" are created equal, so you may wish to try a selection and choose the one that works best for you.

Pi-Network Design Formulas

This set of formulas is commonly used to solve for Pi-Network values.
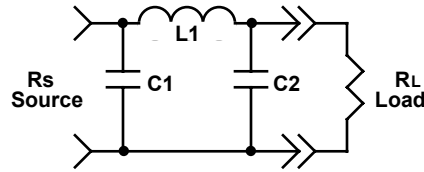
Where $R_S \geq R_L$

Choose a value for Q

$$X_{C1} = \frac{R_S}{Q}$$

$$X_{C2} = R_L \sqrt{\frac{R_S / R_L}{Q^2 + 1 \; - R_S / R_L}}$$

$$X_{L1} = \frac{Q R_S + R_S R_L / X_{C2}}{Q^2 + 1}$$

Convert Reactance to Part Values

$$C = \frac{1}{\omega X_C} \qquad L = \frac{X_L}{\omega}$$

Conclusion

The purpose of this primer has been to provide a basic introduction to help you put your MFJ-5904 to work. The on-line version of this manual will be expanded from time to time to include more data and more applications for your RF Design Box. For a deeper understanding of networks and network theory, several good primers are available, including the ever-popular "ARRL Handbook" and "ARRL Antenna Book". In addition, we highly recommend "RF-Circuit Design", a SAMS publication authored by Chris Bowick, and "Experimental Methods in RF Design" by Hayward, Campbell, and Larkin (ARRL Publications).

Many other resources are also available. However, we urge you to seek out credible peer-reviewed sources when delving more deeply into the fine points of network theory. Not everything you read on the internet, see in product ads, or overhear on the ham bands will be accurate.

TECHNICAL ASSISTANCE

If you have any problem with this unit first check the appropriate section of this manual. If the manual does not reference your problem or reading the manual does not solve your problem, you may call *MFJ Technical Service* at **662-323-0549** or the *MFJ Factory* at **662-323-5869**. You will be best helped if you have your unit, manual and all information on your station handy so you can answer any questions the technicians may ask.

You can also send questions by mail to MFJ Enterprises, Inc., 300 Industrial Park Road, Starkville, MS 39759; by Facsimile (FAX) to 662-323-6551; or by email to techinfo@mfjenterprises.com. Send a complete description of your problem, an explanation of exactly how you are using your unit, and a complete description of your station.

NOTES

LIMITED 12 MONTH WARRANTY

MFJ Enterprises, Inc. warrants to the original owner of this product, if manufactured by MFJ Enterprises, Inc. and purchased from an authorized dealer or directly from MFJ Enterprises, Inc. to be free from defects in material and workmanship for a period of 12 months from date of purchase provided the following terms of this warranty are satisfied.

1. The purchaser must retain the dated proof-of-purchase (bill of sale, canceled check, credit card or money order receipt, etc.) describing the product to establish the validity of the warranty claim and submit the original or machine reproduction of such proof of purchase to MFJ Enterprises, Inc. at the time of warranty service. MFJ Enterprises, Inc. shall have the discretion to deny warranty without dated proof-of-purchase. Any evidence of alteration, erasure, or forgery shall be cause to void any and all warranty terms immediately.

2. MFJ Enterprises, Inc. agrees to repair or replace at MFJ's option without charge to the original owner any defective product under warrantee provided the product is returned postage prepaid to MFJ Enterprises, Inc. with a personal check, cashiers check, or money order for **$7.00** covering postage and handling.

3. This warranty is **NOT** void for owners who attempt to repair defective units. Technical consultation is available by calling the Service Department at 662-323-0549 or the MFJ Factory at 662-323-5869.

4. This warranty does not apply to kits sold by or manufactured by MFJ Enterprises, Inc.

5. Wired and tested PC board products are covered by this warranty provided **only the wired and tested PC board product is returned.** Wired and tested PC boards installed in the owner's cabinet or connected to switches, jacks, or cables, etc. sent to MFJ Enterprises, Inc. will be returned at the owner's expense unrepaired.

6. Under no circumstances is MFJ Enterprises, Inc. liable for consequential damages to person or property by the use of any MFJ products.

7. **Out-of-Warranty Service:** MFJ Enterprises, Inc. will repair any out-of-warranty product provided the unit is shipped prepaid. All repaired units will be shipped COD to the owner. Repair charges will be added to the COD fee unless other arrangements are made.

8. This warranty is given in lieu of any other warranty expressed or implied.

9. MFJ Enterprises, Inc. reserves the right to make changes or improvements in design or manufacture without incurring any obligation to install such changes upon any of the products previously manufactured.

10. All MFJ products to be serviced in-warranty or out-of-warranty should be addressed to:

    MFJ Enterprises, Inc.,
    300 Industrial Park Road
    Starkville, Mississippi 39759 USA

    and must be accompanied by a letter describing the problem in detail along with a copy of your dated proof-of-purchase.

11. This warranty gives you specific rights, and you may also have other rights which vary from state to state.