Review: The MFJ-994BRT and MFJ-998RT Remote Automatic Antenna Tuners
By Phil Salas – AD5X

Introduction

I previously reviewed the MFJ-927, CG-3000 and SG-230 remote auto-tuners specifically for use with a 43-foot vertical antenna (review is elsewhere on this website). At that time, the remote tuners were limited to about 200 watts maximum RF power. Even the SGC SG-235 (which was not reviewed) is only capable of 200 watts CW, though it is rated at 500 watts SSB. This has all changed now with the introduction of the MFJ-994BRT 600-watt and MFJ-998RT 1500-watt weatherproof remote auto-tuners.

Figure 1: MFJ-998RT on the left, MFJ-994BRT on the right.

Remote Tuner Application

A remote antenna tuner must be weatherproof, provide automatic or semi-automatic tuning, and it must be remotely powered. So for a given RF power handling and impedance matching equivalent, the remote antenna tuner will be more expensive than a desk-top tuner. So since there are many manual and automatic desk-top tuners available from numerous suppliers, why use a remote antenna tuner?

The reason is that a remote antenna tuner is an efficient way to match an antenna that has a high SWR and is fed through a relatively long length of coax cable. This is because SWR-related coax cable losses can be high when the antenna SWR is high even if an in-shack tuner provides a 1:1 SWR for your equipment. You can easily demonstrate this with EZNEC simulations and any of the several on-line coax/SWR calculators.

MFJ-994BRT and MFJ-998RT High Power Autotuner Overview

The MFJ-994BRT and MFJ-998RT are remote versions of the current MFJ-994B (600 watt) and MFJ-998 (1500 watt) switched-L desk-top auto-tuners (the MFJ-994, an earlier version of the MFJ-994B, was reviewed in the August 2006 QST). Turning these into remote auto-tuners involved mounting them in weatherproof boxes and removing some of the desk-top features such as A/B antenna switching and multiple memory banks. A comparison of the MFJ-994BRT and MFJ-998RT auto-tuners is given in Table 1.

Table 1: MFJ-994BRT and MFJ-998RT Specifications

	MFJ-994BRT	MFJ-998RT
Frequency Range	1.8-30 MHz	1.8-30MHz
RF Power Capability	600 watts CW/SSB	1500 watts CW/SSB
Resistive Matching Range	12-800 ohms	12-1600 ohms
Input Capacitor Range	0-2950pf	0-3900pf
Output Capacitor Range	0-2950pf	0-970pf
Inductor Range	0-17uHy	0-24uHy
12-15VDC current required	850ma max	1.4 amps max
Size (W/H/D approx)	14 × 3 × 10 in.	13 ¾ × 3¼ × 17 in.
Weight	3.7 lbs	9.5 lbs

Unique Features

Besides RF power ratings, the MFJ-994BRT and MFJ-998RT include some interesting features not found in other remote auto-tuners. The first is an internal BiasT for powering for those who may not have remote DC power available. A MFJ-4117 BiasT is included with both auto-tuners for injecting DC onto the coax in your shack. The MFJ-4117 BiasT includes an on/off switch for convenient power control of the auto-tuners.

The MFJ-994BRT and MFJ-998RT provide both UHF and random wire outputs (only one can be used). The UHF connector has been hi-pot tested to over 2KV to ensure there is no possibility of arcing under high SWR conditions.

These auto-tuners include an L/C limit feature which provides upper limits of inductance and capacitance according to frequency and maximum power rating which limits MFJ-994BRT maximum peak voltage to 1000 volts and maximum peak current to 10 amps across these components. For the MFJ-998RT the maximum limits are 2100 volts peak and 13 amps peak. So if a match could cause destructive voltages or currents, the auto-tuners will not permit the match.

Both auto-tuners will not tune if more than 75 watts is applied and the SWR is greater than 3:1, or if more than 125 watts is applied regardless of SWR. This effectively locks the tuner settings when high power is applied. This protects both the tuner and an in-line amplifier from damage.

Finally, both the MFJ-994BRT and the MFJ-998RT can be remotely forced to re-tune on any given frequency with the Sticky Tune™ feature. When Sticky Tune™ is enabled (default) these auto-tuners will always re-tune the first time you transmit after a power cycle. So if you want to try for a lower tuned SWR on a given frequency, simply cycle power and then transmit on that frequency. The MFJ-994BRT and MFJ-998RT will re-tune and re-store the new tuning data for that frequency only. All other previously stored memory locations will be unaffected

Tuner Loss Measurements

Resistive matching range and loss testing was performed with a precision set-up similar to that described in the February QST, 2003 (page 75) antenna tuner review. A block diagram of my set-up is shown in Figure 2 below.

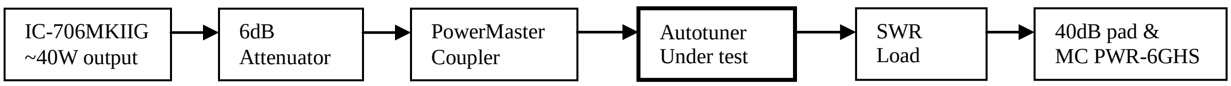

Figure 2: Tuner Loss Measurement Set-up

The Array Solutions PowerMaster and the MiniCircuits PWR-6GHS+ are both precision instruments with NIST-traceable calibration. I compared the PowerMaster to the PWR-6GHS+/attenuator without the autotuner installed and verified that the readings were identical (the measurement difference was less than 1%). The high-power 6dB pad at the output of the IC-706MKIIG helps stabilize the output power under varying load conditions, and ensures that any reflected power from a less than perfect auto-tuner match is attenuated 12dB further if re-reflected by the output circuitry of the transceiver.

To accurately measure the autotuner loss, the autotuner is inserted. After the autotuner has tuned at each SWR, the transceiver output level is adjusted so the PowerMaster reads exactly 10 watts (power display must be FWD-REFL). The resultant power is then read on the MiniCircuits PWR-6GHS+ and compared to the computed lossless power.

The SWR load box is shown in Figure 3 below. It utilizes 1% Caddock thick-film resistors to provide both high impedance and low impedance SWR loads. While close, some of the SWR selections are not even numbers as I used commonly available resistors.

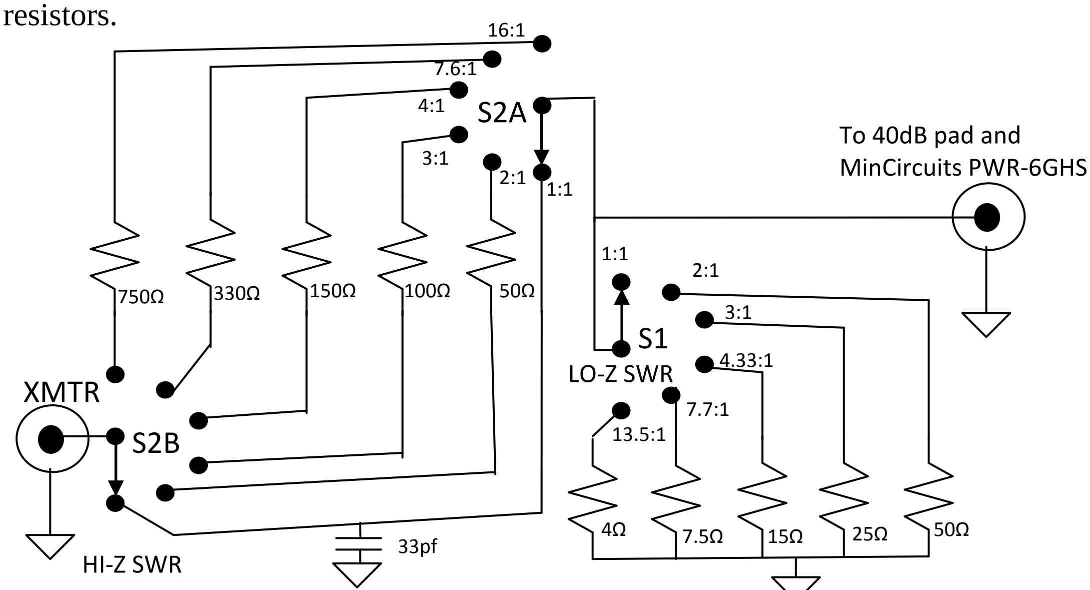

Figure 3: SWR Resistive Load Box

While resistive matching tests are great for standard antenna tuner comparison testing, remote tuners will experience maximum inductance and highest RF current with short antennas so antenna tuner losses can be higher under these conditions. As an example, a 12 ohm resistive match on 80 meters requires an auto-tuner series-L of about 0.9uHy. However a 43-foot vertical on 80 meters over perfect ground has a similar real resistance, but it has a very high capacitive reactance as well (13-j218). For this antenna the series-L needs to be about 11uHy. The higher-value matching inductance can mean higher loss due to the typically lower Q of a larger compact inductor.

In order to determine auto-tuner losses in more real-world conditions, I built antenna simulator circuits based on the auto-tuner published minimum antenna length specifications for 160 meters, and for a 43-foot vertical on 80-meters since this is a popular antenna that will frequently be used with a remote auto-tuner.

Note: Most auto-tuners, the MFJ-994BRT and MFJ-998 included, do not have enough internal inductance to tune a 43-foot vertical on 160 meters. MFJ offers the MFJ-2904 external heavy-duty inductor assembly that can be manually strapped in-line at the auto-tuner output to enable 160-meter tuning capability with 43-foot verticals.

The basic Antenna Simulator schematic is shown in Figure 4. A Caddock thick-film resistor (Rp) is placed in parallel with a 50 ohm test measuring set-up to give the real resistance necessary. A series capacitor (Cs) simulates the reactive part of the hypothetical antenna and completes the physical simulation. Table 2 shows the EZNEC simulated impedances, and the actual circuit implementation components used. I included excess resistance of about 10-ohms so as to simulate real-world ground losses.

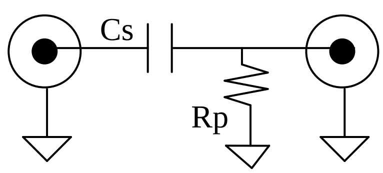

Figure 4: Antenna Simulator Circuit

Table 2: Impedances for antenna simulations

Bands	MFJ-994BRT Min. Length	EZNEC Ideal	Antenna Simulator	MFJ-998RT Min. Length	EZNEC Ideal	Antenna Simulator
160M	100 ft	18-j164	25+540pf	90 ft	14-j222	25+390pf
80M	43 ft	13-j218	22.2+200pf	43 ft	13-j218	22.2+200pf

The values of Rp necessary for the desired resistive impedances are shown in Table 3, along with the 0 dB loss power expected into the paralleled power sensor for 10-watts of RF power.

Table 3: Values of Rp selected

Rp	Rp//50	Power Expected (no loss)
40 Ω	22.2 Ω	4.4W
50 Ω	25 Ω	5.0W

I built these variations (along with additional capability for future testing) into one fixture so I could clip-in the desired simulated antenna for testing (Figure 5). The antenna simulation fixture replaces the resistive SWR test box in my loss measurement set-up.

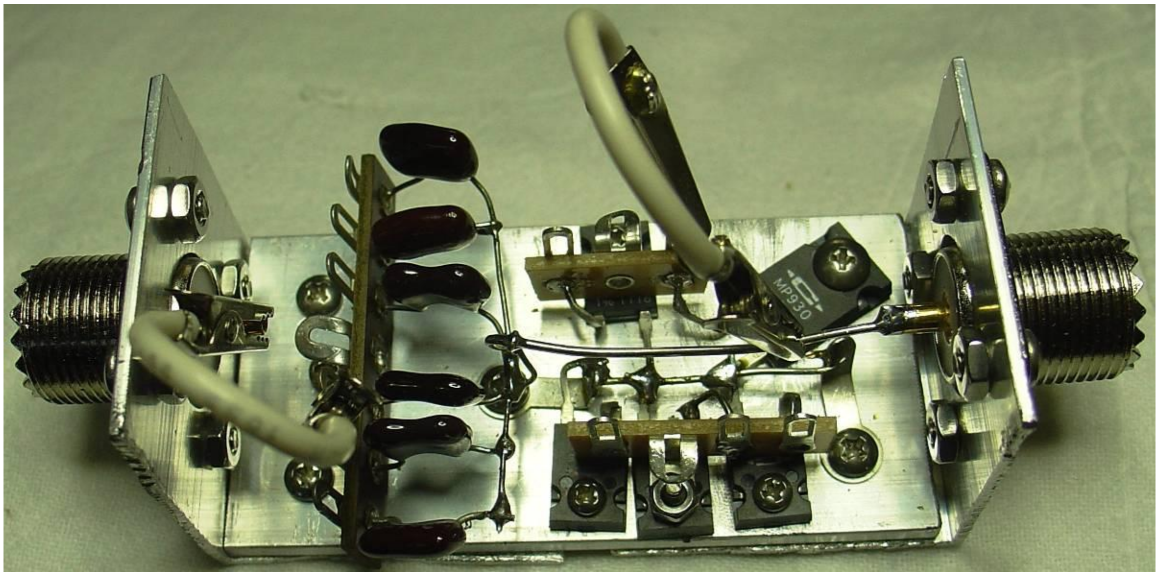

Figure 5: Author's Antenna Simulator test fixture

For final testing, each auto-tuner was connected to the base of my 43-foot vertical and the tuned SWR was recorded on the different bands. The SWR was measured in my shack with an Array Solutions PowerMaster. Seventy feet of Andrews FSJ4-50B ½" heliax connects my transceiver and amplifier in the shack to the auto-tuners at the base of the 43-foot vertical. Three ground rods and approximately 20 radials provide RF and DC grounding at the antenna – certainly not a perfect ground, but probably not atypical. As a reference, I measured the resonant impedance of my 43-foot vertical on 60 meters as 48-j0, which implies my ground loss is 12 ohms on that band.

The MFJ-994BRT Remote Auto-tuner

The MFJ-994BRT is the smaller auto-tuner. With a 600-watt capability, it is perfect for the many medium power amplifiers on the market. Figure 6 shows the outside of the unit, and Figure 7 shows the internal circuitry. Note that the inductors consist of a mix of toroidal- and wide-spaced air-wound inductors.

Figure 6: MFJ-994BRT interfaces

Figure 7: Internal view of the MFJ-994BRT

My resistive load tuning range and loss measurements are given in Table 4. The lossless computed RF power is in parenthesis for each load, and is based on a 10-watt driving source. As you can see, the MFJ-994BRT matched all resistive loads presented to it. And while there were a few cases where the SWR didn't reach the 1.5:1 target, in most cases the 1.5:1 target specification was met.

Table 4: MFJ-994BRT Resistive load and loss testing

Measured Current usage: 2.4 A peak during tuning, 214 mA idle.
Tuning Sensitivity: 10 watts and higher: 2:1 SWR starts a retune.
Matching Range: 4:1 for <50 Ω, 16:1 for >50 Ω. Tuning Power 5-20 W.
Target SWR: 1.5:1. Tuning Threshold: 2:1 SWR.

SWR	Load Ω (Ideal pwr)		160m	80m	40m	20m	10m
4.33:1	11.5 (2.31W)	Power Meas	2.26(2%)	2.26(2%)	2.24(3%)	2.3(0%)	2.3(0%)
		SWR	1.51	1.31	1.47	1.6	1.42
3:1	16.7 (3.33W)	Power Meas	3.32(0%)	3.28(2%)	3.29(1%)	3.25(2%)	3.17(5%)
		SWR	1.53	1.59	1.59	1.43	1.1
2:1	25 (5W)	Power Meas	4.96(1%)	4.96(1%)	4.9(2%)	4.87(3%)	4.68(6%)
		SWR	1.54	1.06	1.54	1.66	1.53
1:1	50 (10W)	Power Meas	9.91(1%)	9.91(1%)	9.83(2%)	9.74(3%)	9.27(7%)
		SWR	1.02	1.04	1.15	1.34	1.58
2:1	100 (5W)	Power Meas	4.85(3%)	4.78(4%)	4.8(4%)	4.77(5%)	4.57(9%)
		SWR	1.33	1.55	1.01	1.32	1.24
3:1	150 (3.33W)	Power Meas	3.2(4%)	3.2(4%)	3.2(4%)	3.14(6%)	2.94(12%)
		SWR	1.43	1.49	1.48	1.33	1.44
4:1	200 (2.5W)	Power Meas	2.4(4%)	2.39(4%)	2.36(6%)	2.33(7%)	2.18(13%)
		SWR	1.49	1.18	1.42	1.44	1.72
7.6:1	380 (1.32W)	Power Meas	1.24(6%)	1.22(8%)	1.22(8%)	1.2(9%)	1.03(22%)
		SWR	1.07	1.51	1.55	1.27	1.71
16:1	800 (0.625W)	Power Meas	.59(6%)	.57(9%)	.56(10%)	.54(14%)	.42(33%)
		SWR	1.4	1.45	1.13	2.12	1.58

Next I measured the MFJ-994BRT tuner losses into the 160-meter spec-limit antenna simulator and the 43-foot vertical simulator as described earlier. Again, transmit power into the MFJ-994BRT was 10 watts. Approximately 10 ohms of real resistance was added to simulate ground losses. The results are shown in Table 5.

Table 5: MFJ-994BRT Theoretical Antenna Loss Measurements

Rp	C Selected	Rp//50 Z tested	Power (ideal)	Power Meas/SWR	Loss
40 Ω	200pf	22.2 Ω 43ft 80M	4.4W	4.18W/1.33:1	5%
50 Ω	540pf	25 Ω 100ft 160M	5.0W	4.80W/1.74:1	4%

The MFJ-998RT Remote Auto-tuner

The MFJ-998RT handles a full 1500 watts. Figure 8 shows the interface side of the unit, and Figure 9 shows the internal circuitry. Like the MFJ-994BRT, the inductors consist of a mix of toroidal- and wide-spaced air-wound inductors.

Figure 8: MFJ-998RT External Interfaces

Figure 9: Internal view of the MFJ-998RT

Next came my resistive load tuning range and loss measurements. As you can see in Table 6 below, in most cases the 1.5:1 target specification was met.   The notable tuning problem is the low impedance 4.33:1 SWR on 20 meters, where the MFJ-998RT could not do better than a 2.15:1 SWR. Technically, the MFJ-998RT low impedance spec limit for tuning is for a 4:1 SWR, and the 4.33:1 SWR is very close to the L/C limit current spec of the MFJ-998RT.

Table 6: MFJ-998RT Resistive load and loss testing

Measured Current usage: 2.8 A peak during tuning, 277 mA idle.
MFJ-998RT measured loss (%) into resistive loads.
Matching Range: 4:1 for <50 Ω, 32:1 for >50 Ω. Tuning Power 5-20 W.
Target SWR: 1:1-to-2:1 selectable, 1.5:1 default. Tuning Threshold: 0.5 to 1.5 above target SWR, 0.5 default.

SWR	Load Ω (Ideal pwr)		160m	80m	40m	20m	10m
4.33:1	11.5 (2.31W)	Power Meas	2.27(2%)	2.23(3%)	2.2(5%)	2.28(1%)	2.3(0%)
		SWR	1.2	1.31	1.2	2.15	1.37
3:1	16.7 (3.33W)	Power Meas	3.31(1%)	3.25(2%)	3.25(2%)	3.32(0%)	3.25(2%)
		SWR	1.26	1.22	1.30	1.69	1.47
2:1	25 (5W)	Power Meas	5.0(0%)	4.94(1%)	4.88(2%)	4.93(1%)	4.83(3%)
		SWR	1.2	1.23	1.22	1.54	1.41
1:1	50 (10W)	Power Meas	9.95(0%)	9.86(1%)	9.83(2%)	9.82(2%)	9.60(4%)
		SWR	1.01	1.15	1.11	1.22	1.49
2:1	100 (5W)	Power Meas	4.85(3%)	4.83(3%)	4.79(4%)	4.81(4%)	4.60(8%)
		SWR	1.36	1.20	1.49	1.44	1.65
3:1	150 (3.33W)	Power Meas	3.30(1%)	3.19(4%)	3.20(4%)	3.13(6%)	3.04(9%)
		SWR	1.2	1.31	1.46	1.38	1.31
4:1	200 (2.5W)	Power Meas	2.37(5%)	2.38(5%)	2.37(5%)	2.34(6%)	2.16(14%)
		SWR	1.28	1.37	1.4	1.47	1.21
7.6:1	380 (1.32W)	Power Meas	1.25(5%)	1.24(6%)	1.23(7%)	1.20(9%)	1.10(17%)
		SWR	1.15	1.59	1.5	1.34	1.18
16:1	800 (0.625W)	Power Meas	0.60(5%)	0.58(7%)	0.57(8%)	0.54(13%)	0.44(30%)
		SWR	1.16	1.46	1.25	1.41	1.50

Next I measured the MFJ-998RT tuner losses into the 160-meter spec-limit antenna simulator and the 43-foot vertical simulator as described earlier. Again, approximately 10 ohms of real resistance is added to simulate ground losses. The results are shown in Table 7.

Table 7: MFJ-998RT Losses with simulated short antennas simulations

MFJ-998RT Theoretical Antenna Loss Measurements

Rp	C Selected	Rp//50 Z tested	Power (ideal)	Power Meas./SWR	Loss
40 Ω	200pf	22.2 Ω 43ft 80M	4.4W	4.10W/1.2:1	7%
50 Ω	390pf	25 Ω *90ft 160M	5.0W	4.72W/(1.59:1	6%

Open/Short Circuit Testing

The last bench tests were to see how the autotuners would do when trying to match an open- or short-circuit load. Ideally a tuner should not be able to match an open or short. If it does, this means that it is tuning into its own internal losses. However, no antenna tuner is lossless due to finite-Q components. From past experience I've found that most antenna tuners – both manual and automatic – can find a match on one or more frequencies when connected to an open or a short. However even if a match is found, if the SWR is greater than 2:1 the user should check his antenna system as solid-state amplifiers are generally not tolerant of a 2:1 or greater SWR. My data on the MFJ-994BRT and MFJ-998RT is shown in Table 8.

Table 8: Open- and Short-Circuit testing of the MFJ-994BRT and MFJ-998RT.

	MFJ-994BRT		MFJ-998RT	
Band	Open	Short	Open	Short

160M	NT	NT	NT	NT
80M	NT	NT	NT	NT
40M	NT	8.4:1 SWR	NT	NT
30M	NT	9.2:1 SWR	NT	2.43:1 SWR
20M	NT	1.74:1 SWR	NT	1.38:1 SWR
17M	NT	NT	NT	NT
15M	NT	NT	NT	2.25:1 SWR
12M	NT	4:1 SWR	NT	8.3:1 SWR
10M	NT	6.2:1 SWR	NT	NT

As you can see in the above table, neither tuner could find a match into an open-circuit. However, there are some short circuit match occurrences that are noteworthy. These occur on both the MFJ-994BRT and MFJ-998RT on 20 meters where a less-than-2:1 SWR was found. If you have a shorted antenna feed on 20 meters and the tuners find a match, all your power will be dissipated within the tuner. You will probably damage the autotuner if you transmit into it with full power. So if you don't hear any signals on 20 meters either before or after a tune-up, you might want to check your antenna system before you start transmitting. It is probably a good idea to record your antenna's untuned SWR in your shack on your bands of interest so you can check that nothing changes over time. This is easily done by turning off autotuner power, which bypasses the tuner.

<u>43-foot Vertical Antenna Testing</u>

My final tests involved connecting both the MFJ-994BRT and MFJ-998RT antenna tuners to the base of my 43-foot vertical. Tuning was very fast, with initial tuning typically occurring in less than 2-seconds and tuning from memory essentially instantaneous. The results are shown in Table 8. I have two solid-state amplifiers – an Ameritron ALS-600 and an Elecraft KPA500. Both amplifiers put out full power into the tuned antenna system on all bands from 80-10 meters (I did, of course, limit power to 200 watts on 30 meters).

Figure 10: MFJ-994BRT & 43-foot vertical

Figure 11: MFJ-998RT & 43-foot vertical

<u>Table 8: 43-foot vertical testing</u>

	MFJ-994BRT	MFJ-998RT

Band	Shack SWR no tuning	Shack SWR w/tuning	Shack SWR w/tuning
160M	>20:1	NT (expected)	NT (expected)
80M	11:1	1.53:1	1.12:1
60M	2:1	1.38:1	1.14:1
40M	3.8:1	1.21:1	1.32:1
30M	6.7:1	1.47:1	1.61:1
20M	5.4:1	1.59:1	1.55:1
17M	2.5:1	1.39:1	1.42:1
15M	4.3:1	1.35:1	1.64:1
12M	3.1:1	1.32:1	1.35:1
10M	2.3:1	1.06:1	1.27:1

As pointed out in both manuals, I did find occurrences where both autotuners would not tune when changing bands. This can occur if the tuning solution for the previous band results in a very high SWR on the new band, and more often happens when going from a lower frequency band to a higher frequency band especially when using a highly reactive antenna. This very high SWR can reflect all input power from your transceiver, so the autotuner cannot sense RF input power. The solution is to simply cycle power to the autotuner when changing bands. This drops the autotuner to bypass prior to tuning so some forward power is sensed thus permitting a tune to occur.

On The Air with the Remote Autotuners

Each autotuner was installed on my 43-foot vertical for about one week. During this 2-week period of time I enjoyed numerous QSOs on 80-15 meters primarily using my KPA500 amplifier. In all cases I would start anew on each band by pressing the TUNE button on my K3 (my K3 TUNE output is set for 15 watts) with the amplifier off-line. It was interesting to watch the PowerMaster SWR readout in the shack as the remote tuners would do their thing. Once tuning stopped, usually less than 5-seconds on an initial tune, or instantaneously for a previously memorized tune, I would enable the amplifier and operate with no worries. Changing bands or large frequency changes within a band was a trivial effort. And I never had an occurrence of either autotuner trying to tune while operating at high power. A very pleasant experience indeed!

Summary

There are definite benefits in using a remote auto-tuner with an un-tuned antenna. First, of course, is operating convenience. And second, the remote autotuner will reduce SWR-related coax losses. In the past, we have been limited to barefoot operation with the remote auto-tuners available. But now with the introduction of the MFJ-994BRT and MFJ-998RT high power remote auto-tuners, we can realize these benefits when using a high power amplifier. The MFJ-994BRT works well with medium-power HF amplifiers feeding less than perfect antenna systems. But if you are running more than 600 watts or plan to do so in the future, the MFJ-998RT is the way to go.

Product Update

Since these review units were received, MFJ has improved the design by adding static and lightning protection to both the MFJ-994BRT and MFJ-998RT outputs, and an external DC jack for powering the units directly from a DC source if desired. If you have an early MFJ-994BRT or MFJ-998RT and wish these improvements, contact MFJ for pricing and availability of an upgrade kit.

Addendum: Impact of a non-perfect transmission system on in-shack measured SWR
Phil Salas – AD5X

In this review of the MFJ-994BRT and MFJ-998RT remote auto-tuners my bench tests showed, both auto-tuners did a good job of meeting the tuned input SWR spec of 1.5:1. And when I measured the in-shack SWR with these tuners connected to my 43-foot vertical, I used a very clean transmission system consisting of a single coax patch panel, one coax jumper and 70-feet of ½" Heliax with N-connectors – resulting in in-shack SWR measurements of about 1.5:1 or better. However, when I connected everything normally used in my system (70 feet of 1/2-inch heliax, ICE arrestor, five coax jumpers, wall patch panel, two UHF elbows, and a MFJ-4726 switch) I found the in-shack SWR exceeded 1.5:1 in a few cases. This is not entirely unexpected, as a transmission system with a finite intrinsic SWR can change the far-end SWR as seen in the shack. Note that this is not an issue when using an in-shack tuner, as an in-shack tuner will tune out all anomalies in the entire transmission system whereas a remote tuner only tunes the remote antenna system.

The expected in-shack SWR variation of two finite-SWR series-connected systems can be calculated as follows: Given two cascaded SWR systems where SWRa is the system with the highest SWR, and SWRb is the system with the lowest SWR, then:

SWRmax = SWRa X SWRb, and
SWRmin = SWRa/SWRb

For example, a remote tuned 1.5:1 SWR cascaded with a transmission system that has a 1.3:1 SWR can result in an in-shack measured SWR range of 1.95:1 maximum to 1.15:1 minimum.

To determine the intrinsic SWR of my transmission system, I placed a good dummy load (return loss >40dB from 160-10 meters) at the remote tuner location. Then I substituted the MFJ-998RT/43-foot vertical for the dummy load and measured the in-shack SWR after the remote tuner had tuned. Finally, I calculated the worst-case theoretical SWR that could occur assuming the MFJ-998RT did no better than its target SWR of 1.5:1. My measurements and calculations are shown follows:

Band	In-shack SWR with Dummy Load	In-shack SWR with MFJ-998RT tuned	Theoretical maximum In-shack SWR for Tuner SWR of 1.5:1
80M	1.10:1	1.37:1	1.65:1
40M	1.13:1	1.26:1	1.70:1
30M	1.26:1	1.64:1	1.89:1
20M	1.35:1	1.25:1	2.03:1
17M	1.32:1	1.41:1	1.98:1
15M	1.42:1	1.38:1	2.13:1
12M	1.71:1	1.37:1	2.57:1
10M	1.68:1	1.81:1	2.52:1

As you can see, all in-shack SWR measurements are below the theoretical worst-case SWR that can occur with a remote tuned SWR of 1.5:1.

So an in-shack SWR higher than desired on some band or bands may require you to clean-up your transmission system – or possibly just add some transmission line length to change the frequency of maximum in-shack SWR.