Sooner or later most amateurs start to think in terms of antenna tuners and whether or not they should use them. Often what is not clear is why they need them and how they work. Who better to answer those questions than our own W1ICP.

How To Adjust A Transmatch Part I

BY LEW McCOY*, W1ICP

Anyone looking at the title of this article will probably figure that McCoy has lost his marbles! Why a two-part article on how to tune a transmatch, when the story could probably be told in a few paragraphs? The reason for two parts can easily be explained. I have found that many, in fact most, readers like to know the history of why things happen in amateur radio, and certainly antenna tuners and Transmatches have an important history. I hope the reader finds this subject interesting, as I enjoyed writing it.

Frankly, in all my many years of amateur radio I never thought I would be able to make the statement that nearly every amateur operating below 10 meters uses a Transmatch. I guess I still can't. However, for 160 through 10 meters the number of those who do use a Transmatch has to be over 90 percent. I find that much of my mail consists of questions about using Transmatches. And more important, no matter how much I write about the subject, there remains a strong demand for more discussion.

Before getting into actual adjustment practices (and that is what this article is suposed to be about), let's look at some history.

One of the earliest problems confronting radio amateurs was that of coupling the final stage of a transmitter to the antenna. Because the antenna was usually installed at a location relatively remote from the transmitter, it was necessary to use a feed or transmission line.

Even in the earliest times of our hobby it was possible to determine the feed characteristics of any given antenna. The properties in the feed of an antenna's impedance haven't changed. They remain the radiation resistance, ohmic resistance, and reactance. I won't go into a lengthy discussion of these properties except to state them simply.

The radiation resistance of the feed point of an antenna can be described as the useful part of the antenna impedance. While expressed in ohms ("ohms" are thought of by many newcomers as something that reduces voltages and consumes power), in this case the ohms of the radiation resistance are the "useful" part of the impedance.

Next we have the actual ohmic resistance, such as the ohmic loss in the wires, etc., and this is a pure loss in that any power used up is dissipated as heat.

When an antenna is not resonant, there is reactance present, and while it is expressed in ohms, you cannot dissipate power in a reactance. It simply stops the flow of power. Therefore, we must compensate or cancel out the reactance to get power into the antenna. A good example of what I am explaining is a half-wavelength dipole fed at the center. Such a dipole, one-half wavelength above earth, has a resonant impedance or feed point of 70 ohms—at resonance. When you QSY away from resonance, the feed point becomes reactive. The resonant dipole consists of approximately 68 ohms radiation resistance and 2 ohms, more or less, of ohmic resistance. To simplify let's assume we have 70 watts reaching this feed point. We would have 68 watts being radiated and 2 watts being lost as heat. This ratio of radiated power to lost power is very, very good. In fact, an ordinary half-wavelength dipole is probably the most "efficient" antenna you could use.

So much for the antenna end as far as the feed point is concerned. Admittedly, I have left out a lot to simplify the discussion. I might add, however, that in the early days there was a lot of mystery about feeding antennas. This is no longer true. With modern computer programs you can determine the feed impedance of practically any antenna.

The feed line used to connect the amplifier to the antenna was usually of an open-line variety—two identical conductors equally spaced using spacers to keep the two wires symmetrical. Such lines became known as "balanced" feed lines. Coaxial line also has two conductors—an inner conductor plus an outer conductor which surrounds the inner conductor, separated by dielectric material. While coax is a symmetrical line, it is commonly known by amateurs as an unbalanced feed line.

However, transmitter amplifiers of those early days were customarily designed for what was known as "link cou-

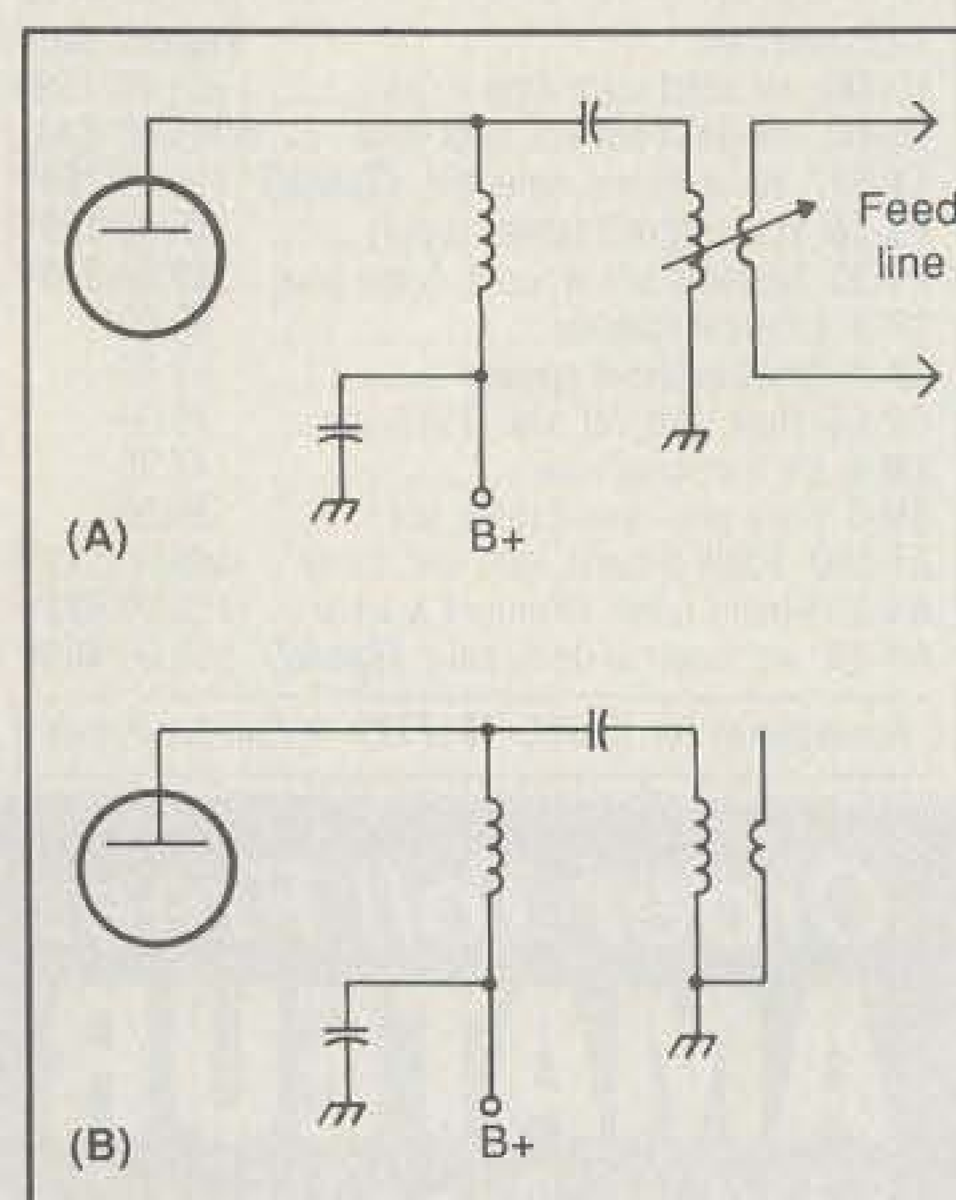

Fig. 1–At (A) is one of the common methods of using link coupling from the amplifier to the feed line. At (B) is a method used to adjust the link using a series variable capacitor for coax lines.

*Technical Editor, CQ, 200 Idaho St., Silver City, NM 88061

pling" to connect the amplifier tank circuit to the open-wire feed line (fig. 1). There were many tank-circuit designs, but believe it or not, few (if any) used the circuit that is common today. Nearly all tank circuits in current use are some form of the pi network, originally designed by Art Collins, founder of Collins Radio. The reason for the change in circuits is simple enough, but the history is not.

With early transmitters, in order to change bands you usually had to change the coils in the transmitter using plug-in coils (or have individual amplifiers for each band). When World War II came along, the groundwork was laid for many basic changes in our hobby.

Up until WW II the common type of feedline was open-wire line. This type of line was inexpensive, easy to construct, and extremely efficient. In fact, it is still the most efficient line you can use. During WW II, however, coaxial feed lines, which were difficult for amateurs to make, became extemely common, and after the war this same coax entered the surplus market, where it was readily and cheaply available. Coax was and is popular because it is a shielded line and unlike open wire it can be installed directly alongside metal objects or even buried without harmful effects. During the war, though, amateurs didn't really make a mass move towards coax simply because it meant considerable redesign of the circuits in use. One more thing was then to happen to change our methods—and I might add forevermore.

In the late 1940s television suddenly became accessible. In the beginning TV sets were terribly expensive and usually only could be seen in local bars where they were used to attract customers—and they had 5 inch screens! Whenever an amateur station was operated in the near vicinity of a TV set, the interference the amateur transmitter created either destroyed the picture or made it unusable. However, because TV sets were few in number, amateurs were not really concerned.

I cannot help but add an aside here about my personal life that was to affect my future. At the time, 1947, I was W9FHZ (Fanny's Hand Zipper!) and was living south of Chicago. I was also happily chasing DX. I had seen TV in the taverns (where I rarely went!), but no one had a set anywhere near where I lived. That fall I went east to Boston to visit my wife's family and two weeks later when I returned I noted a strange antenna on my *nextdoor* neighbor's house. You guessed it! He was the first one in a very wide area to purchase a TV set. He was a good friend and neighbor, but I have to state, not for long. I can probably safely say that shortly after that time I knew as much about TVI, public relations, etc., as any ham alive. I wound up selling my home and moving to Missouri, becoming WØICP and living in the Ozark Mountains. There was no TV and little of anything else. Strangely, though, all these problems were probably for the best. After starving for a year in the Missouri Ozarks, a job opened up at ARRL Headquarters in Connecticut.

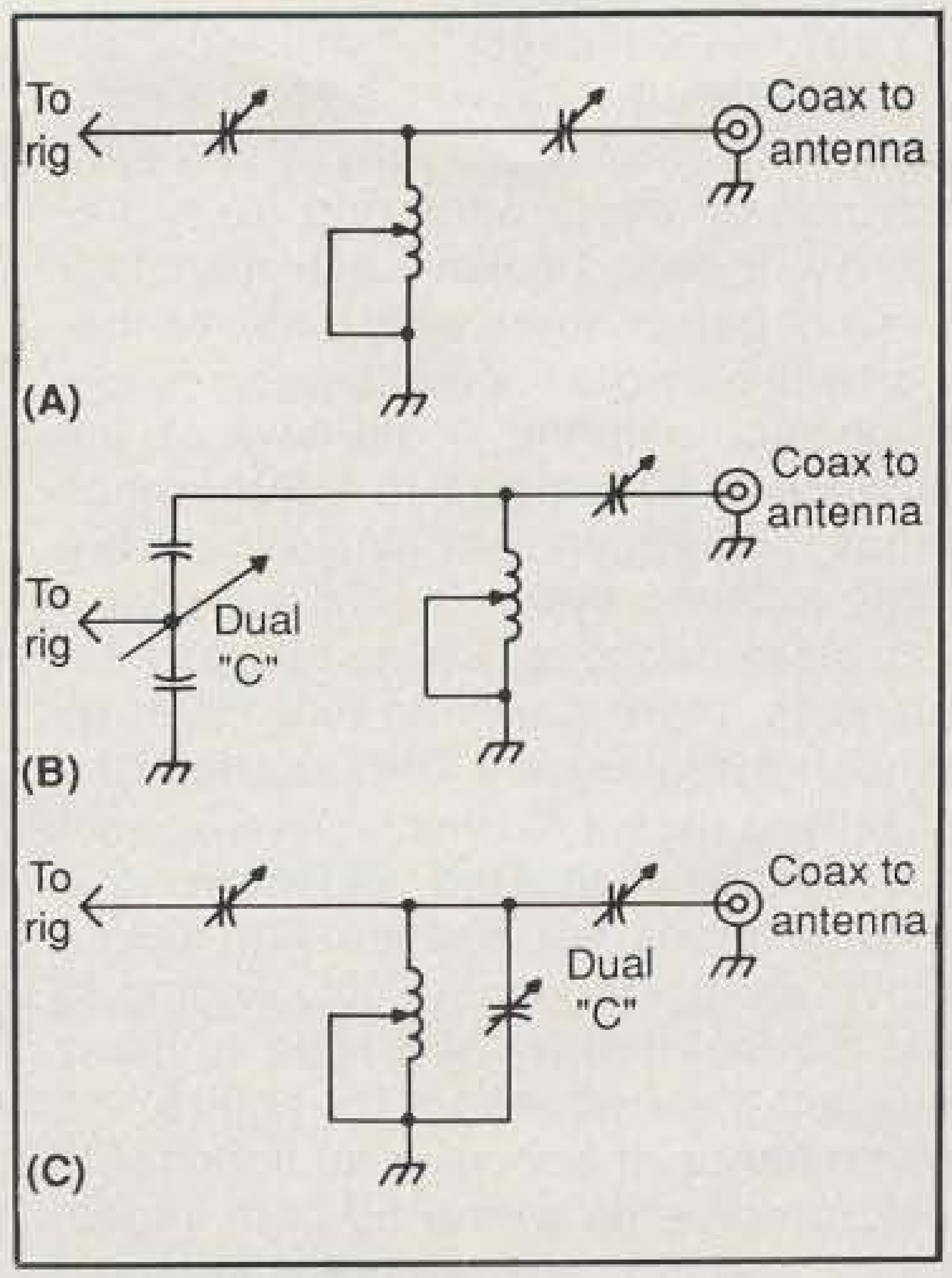

Fig. 2– At (A) is the more popular of the current types of Transmatches. This consists of two variable capacitors and a variable inductor. Shown at (B) is the Ultimate Transmatch and at (C) the SPC. As I mentioned in the text, any of these three, using the proper value variables, will match any *load an amateur is likely to encounter. The circuit at (A) is preferred because of its simplicity.*

At that time George Grammer, W1DF, Technical Editor of *QST*, and Phil Rand, W1DBM, were working very hard to find methods whereby amateurs could coexist with TV. I applied for a job in the Technical Department, and I will always remember my first interview with George Grammer when he asked me if I had had any experience with TVI!

My first job in the Technical Department was traveling around the then 48 states and Canada lecturing on the causes and cures of TVI. I visited and lectured in well over 150 cities. I transported two TV sets, transmitters, TVI-causing devices, and so on. I guess I knew about TVI.

Meanwhile, back to the subject at hand, George Grammer and Phil Rand and others had determined the only answer to TVI was complete RF tight shielding of a transmitter and the use of low-pass filters on the transmitter and high-pass filters on the TV sets. No longer was it possible to use plug-in coils for band-switching, because you lost the shielding integrity or effective shielding became

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almost impossible to sustain. It was important that the generated RF be contained so that the output could be fed through a low-pass filter to effectively kill any TVI causing harmonics. It was much simpler to design the amplifier tank circuits for bandswitching using a pi network to work into the low-impedance filter designs. This meant coax feed lines, at first 70 ohm line and then 50 ohm line, simply because 50 was more readily available.

The pi-network circuit lent itself to simple bandswitching, plus it had a great deal of flexibility in dealing with wide ranges of reactance and impedance mismatches. Probably the best of those early commercial rigs was the Johnson Viking Ranger, which had the ability to match some really crazy loads. Gradually, however, the commercial manufacturers started to eliminate tank circuit flexibility and require that the amateur have an antenna load that was very close to 50 ohms impedance. With the advent of solid-state amplifiers, the manufacturers built in devices to actually limit the mismatch to protect the solid-state devices. Solid-state amplifiers have the nasty habit of burning out if operated into a large mismatch. We all are fairly familiar with standing-wave ratios, and what we are faced with now is maintaining an SWR of less than 2 to 1 or the transmitter will shut itself off.

You must realize at this point that practically every amateur wanted an antenna system that would be exactly 50 ohms impedance on every band and every frequency. In fact, I believe that manufacturers of transmitters really believed that such a thing would come to pass, where an all-band antenna would have an impedance of 50 ohms (1 to 1 SWR on all bands, all frequencies). While there are some antenna systems that will give a very close match for a wide range of frequencies, there are none that cover all bands, all frequencies. They just don't exist in the amateur market.

Keep in mind that the feed impedance of an antenna will change with height above earth, frequency, etc. Adding to that the fact that we now have so many different low-frequency (10 meters and lower) bands, it becomes an impossible task to come up with a 50 ohm impedance, all-band, all-frequency antenna. There are a few such antennas for military use, but they are huge, cost fantastic sums, and require a large amount of real estate. Keep that point in mind, because if you desire a perfect 1 to 1, 50 ohm load on all frequencies, then a Transmatch is required no matter what you read or hear.

Under certain fixed environments, and accepting certain losses, we can come up with antennas that will cover a wide range of frequencies. However, remember what I said: The cutoff point where the amplifier power is automatically reduced with modern transceivers is a mismatch of 2 to 1, or very close to that figure.

At this point I would like to add a word in defense of antenna manufacturers and SWR figures. To repeat what I said earlier, you should keep in mind that the impedance, and hence the SWR, of an antenna can vary widely for different installations, and these factors include height above ground, type of ground, nearby objects or other antennas, and on and on.

The antenna manufacturer sets up (adjusts his matching system) for a given height under given conditions. Normally his tests would be made using an antenna in an area all by itself—no wires or metal or other antennas in the near vicinity. His conditions (SWR curves and so on) are set for that location and height. The amateur buys this antenna and usually puts it up among other antennas and in an environment completely different from what the manufacturer used. The amateur then gets upset when his antenna doesn't meet the SWR curves of the manufacturer. The buyer must understand that we are dealing with two *different* installations which will produce different SWR results. Keep that in mind.

In Part II I will get into the actual mechanics of installing and using/tuning/adjusting a Transmatch. CQ

(To Be Continued)

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How, why, when, and where are answered in this installment on how to adjust a Transmatch. W1ICP describes the process in clear, simple language.

How To Adjust A Transmatch Part II

BY LEW McCOY*, W1ICP

The logical answer to all the problems discussed in Part I of this article *(see the March issue)* is the use of a Transmatch. Exactly what is a Transmatch? The name was coined by George Grammer and myself in my article "The 50-Ohmer Transmatch."

The problem with the name *antenna tuner* is that it is not appropriate. You don't tune an antenna. In practice, tne antenna *system*, which combines the antenna *and feed line*, is tuned from an unknown load to one which matches the transmitter output impedance.

One of the most difficult technical points for a newcomer to understand is the one of the load at the end of the feed line that is attached to the transmitter. Many amateurs think that when a 50 ohm impedance line is attached to the rig the load is going to be 50 ohms. About the *only* time such a condition can exist is when the antenna impedance is exactly 50 ohms and nonreactive. In truth, the load can vary from as low as a fraction of an ohm to several thousand ohms! Therefore, our problem becomes one of converting this unknown load to a pure 50 ohm load.

Essentially, a Transmatch could be called an adjustable RF transformer and reactance "tuner-outer." It takes the unknown load at the transmitter end of the coaxial line and transforms that load to 50 ohms—the desired output impedance of the transmitter. Note that I said "unknown load." The value of the load could be measured with the proper equipment, but that isn't necessary. What is necessary is that we can cancel any reactance present and step up or step down the mismatch as needed.

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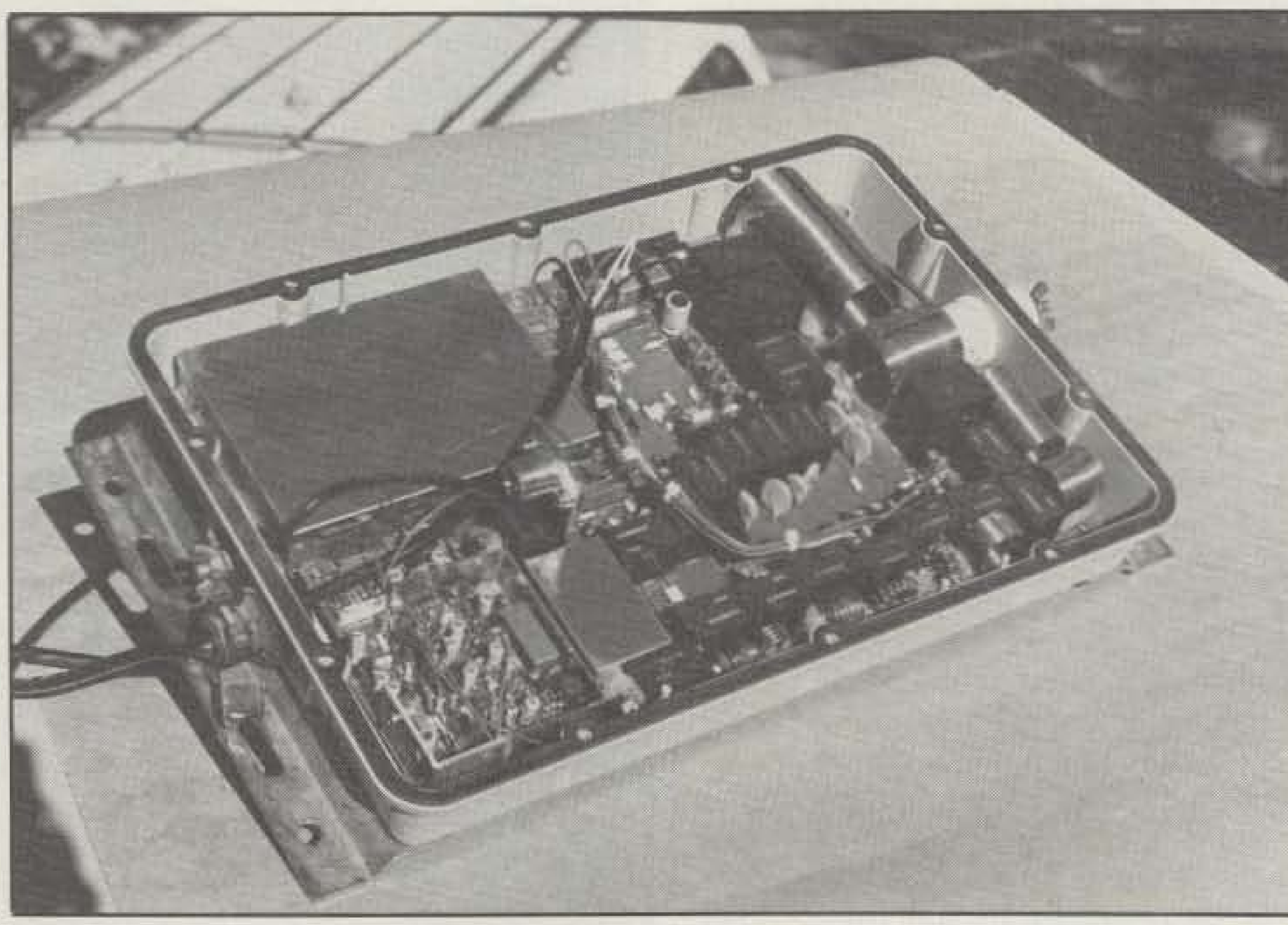

This is the heart of the ICOM AH-2, an automatic tuner. It is capable of handling 200 watts under widely varying loads. It is primarily designed for remotely tuning a multiband whip such as in a mobile or TV installation. I thoroughly tested and reviewed this unit a while back and rated it very highly.

When Is A Transmatch Needed?

This is a good and frequently asked question. Naturally, if your transmitter is in a shut-down condition because of an SWR of 2 to 1 or more, you'll need to either match the antenna to the line or use a Transmatch. Matching the antenna to the line can be an impossible situation in many cases, particularly when we QSY, etc. Therefore, in this case a Transmatch is the answer.

Also, don't be misled by claims from makers of multiband trap dipoles that

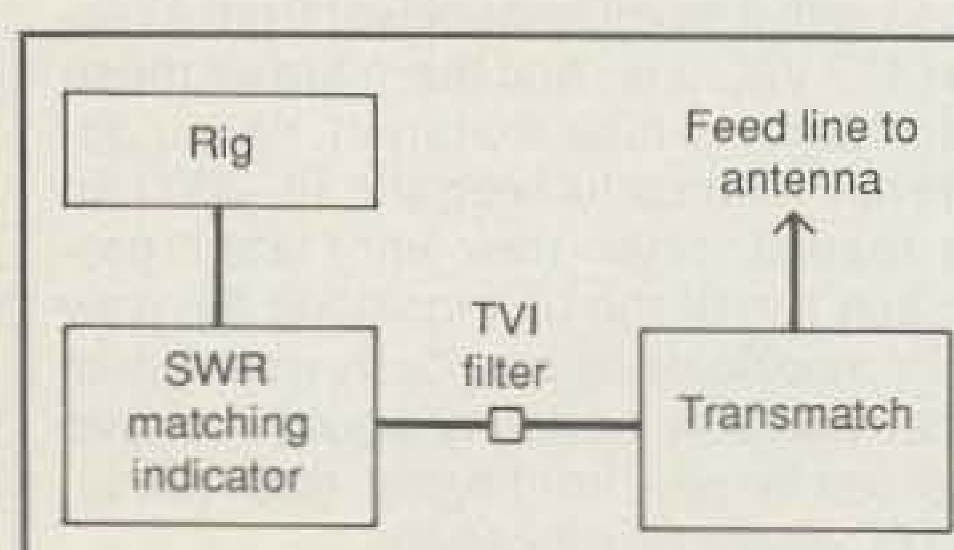

Fig. 1– The correct arrangement for a station setup using a Transmatch. Note the position of the low-pass filter. This is only important in weak TV signal areas.

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Here is the Ten-Tec fully automatic tuner capable of matching virtually any load, covering both coax and open-wire or single-feed lines. It covers 160 through 10 meters. Power-handling capability is the full legal amateur limit (1500 watts). It has 21 memories that can be preset, so band changing is fully automatic to a 1 to 1 matched condition in seconds. This is an amazing product, and it will be reviewed fully in an upcoming issue of CQ.

state the antenna will stay below 2 to 1 on all amateur HF bands, 160 or 80 through 10. This cannot happen unless very lossy resistors are used. To reiterate, you don't need a Transmatch if your SWR stays below 2 to 1 (but frankly I prefer to use one anyway because my amplifier will always be working into a matched condition). On the other hand, I might add that the multiband trap dipoles and other antennas such as the off-center-fed models will present a "reasonable" antenna-system load for a coax-fed antenna to work *with* a Transmatch. (You will still need a Transmatch to use all frequencies.) In other words, you don't want to use coax as a "tuned" line if the SWR is really high, as it can be with some antenna impedances. By using multiband coax-fed dipoles you can expect the SWR to be a reasonable figure with coax feed. You also should keep in mind that antenna efficiency will always suffer to some degree if traps are used.

This brings up a point that bears mentioning. Without using a Transmatch, what is an "ideal" SWR? An SWR of 2 to 1 is almost the limit simply because that is what the transceiver manufacturers set for their limits. Any losses in the transmission line from a match of 1 to 1 up to 2 to 1 are insignificant and not worth considering as important. I would say then that if your antenna-system feed stays below 2 to 1 on the bands and frequencies you operate, you may not need a Transmatch. Because of the transceiver 2 to 1 limit, you do need a Transmatch if this figure is exceeded.

Another bonus when using a Transmatch is that it will offer a certain degree of selectivity to your station. For example, amateurs living close to broadcast stations or other high-power RF installations can get a lot of interference from cross-modulation generated by the overloading of your receiver by these high-power signals. In many instances a Transmatch will eliminate this problem. Because of the Transmatch selectivity, there is a certain amount of harmonic rejection. However, I don't intend to get into a discussion of harmonic suppression and which of the common Transmatch circuits—the "T," the "SPC," or the "Ultimate"—is best for harmonic reduction (see fig. 2 in Part I). Each has its advantages, and in any case, the argument about harmonics is academic simply because the FCC rules state you must have your harmonics down at least 40 dB from the final stage of your *transmitter* for the 160 through 10 meter bands, and as far as I know, all commercial-built rigs meet this standard.

Regardless of which of the above-mentioned circuits you use, *all* have the infinite beauty of matching any kind of antenna system you use. Think about that statement for a second. I said *any kind of antenna system* you use. This means random-length wires, rain gutters, guy lines on towers, or towers themselves. In fact, anything that is metal can be matched to a 1 to 1 ratio with the circuits mentioned above. I guess I should add that most of the commercial units using the above-mentioned circuits are usually for 80 through 10 meters (some include 160). To satisfy the statement of matching "anything" does mean having the three main components—input capacitor, inductor, and output capacitor—all variable. Many of the commercial circuits use a switched tapped inductor. While this is okay in most matching cases, there are some loads that are impossible to get to a perfect match. Usually, however, you can achieve a better than 2 to 1 match for any system.

Some amateurs are concerned that using a Transmatch introduces loss into the system. Some years back I made extensive tests and found that when using good RF connections on all components in a Transmatch, plus reasonable power-handling components, the average power lost was on the order of 3 to 5 percent, depending on the load being matched. On the other hand, this loss can be more than compensated for by using the Trans-

MFJ's differential capacitor Transmatch. This legal-limit unit does an outstanding job with both coax or tuned feeders.

match so that your rig is always working into its design load. You have everything running cooler, with better efficiency, and so on.

Now I will get to what this article is supposed to be about—how to tune Transmatch. I know there are several methods available, and each of the commercial units give details for their units in their manuals. The system I used is one I developed over the years, and it works fine for me.

Before going into that, let's see where we should place the Transmatch. See fig. 1 for the basic setup of *where* a Transmatch should go in the station. If you are using a low-pass filter, it should be installed between the rig and the Transmatch, and also between the SWR bridge and the Transmatch. In extreme fringe areas of television reception there are diodes used in bridges. The diodes can generate harmonics, so the low-pass filter should have a chance to "kill" such harmonics. The SWR-bridge placement is not important to cable-TV areas or in strong-signal locations—just in fringe or weak-signal spots. Filters are designed to work into 50 ohms, and that point in your station setup is where you will have a 50 ohm impedance.

I should also point out that there are many "automatic" Transmatches available commercially. Many modern transceivers have the option of providing a built-in automatic Transmatch. I cannot get excited about most of these units simply because the matching range is limited. Amateurs purchase such transceivers expecting them to match any antenna load and are then disappointed when they don't. On the other hand, there are some automatic tuners that will handle practically any load. In the photographs are shown two of the units that will handle just about any load an amateur will encounter. To be fair, there are other commercial units available, so study the ads in *CQ*. The question you should ask is simple enough: "What is the matching range of impedances and what is the power level they will handle?" But again, this article is about manually adjusted devices, and that is what I intend to discuss.

You are going to need an SWR-indicator bridge, and it must be placed between the rig and the Transmatch as shown. This is important because the bridge provides the visual indication of when one is correctly tuned. Many commercial units have an SWR bridge built in, so please note what I said about weak TV signal areas. Keep notes as you do your adjusting, because once you find the correct settings you will want to make a record of them so you can quickly return to the proper settings.

First, *and most important*, you must always adjust a Transmatch using the minimum amount of power that provides you with indications. If your SWR indicator has different power levels, use the lowest one for your adjustments. I am going to assume you are using a multiband Transmatch, 80 through 10 meters. Let's talk about 80 and 40 first. Before applying power, set the variable capacitors to maximum capacitance—plates fully meshed. In fact, you probably will find several different Transmatch settings which provide a perfect match. This is not unusual, but always use the match that provides the most capacitance in the circuit. I could go into the whys, but that would be a whole article in itself. Just take my word for it: Maximum capacitance is always best.

Next switch your bridge to read **Forward**, turn on your rig, and adjust your drive or gain control to put out enough power for a reading. Usually for me this is about 10 to 20 watts with a 100 watt rig. This level of power could be used all day without hurting anything. If you have a roller inductor for your inductance, start at minimum inductance and run the roller out, increasing the inductance while observing the bridge meter. At some point you likely will get an indication of more power output. Now you must switch to the **Reflected** reading and adjust both capacitors, looking for a drop toward zero. When you find those settings, you are starting to close in on a 50 ohm match. Carefully adjust the inductor and the capacitors looking for a zero reading on the meter. Once you achieve that setting, you have matched the antenna system—an unknown load—to 50 ohms, the design factor of your transmitter.

You now can bring up your power to the rated transmitter level. You may have to gently touch up your reflected reading with the Transmatch controls. If you are operating on 80, write down your frequency and then try QSYing to see how far you can move and still stay less than 2 to 1. Usually, with an 80 meter half-wave dipole fed with open-wire line you will only be able to go about 100 kHz without resetting the Transmatch.

The procedure for 20 through 10 meters is similar, except in this case set your capacitors at about half mesh or even one-quarter mesh. Also, you will find that you only need a few turns of inductance on these bands. In fact, on 10 meters matching some loads will be touchy, but it can be done. With switched, tapped inductor Transmatches you will have to try different switch settings. With some loads you may find that you cannot get 1 to 1, but usually you can get very close to a good match. Personally, I would accept a match of 1.5 to 1 or better.

By using a Transmatch here you now have a "tuned system." It is important to know that you *have not changed* the SWR on the transmission line nor the pattern of the antenna. You have taken the antenna and feed line, with its unknown load and reactances, and converted the load to one which the transmitter and receiver see as a "pure" 50 ohm load. Admittedly, this is over-simplifying, but it gets the job done. Also, and this is very important, any dipole of any overall length, fed with the twin lead or open-wire line, is a true multiband system—no trap, no baluns, just the feed line and the dipole. If you like, you can make the dipole portion 102 feet long, center fed, and tell everyone you are using a G5RV, because that essentially is what G5RV antenna is. Or if you have more room, you can make the dipole 150 feet long, or longer, and you will have an antenna with more gain than the G5RV.

You will often hear hams say they are using a "McCoy" antenna system. Frankly, such systems have been around longer than I have, but I try to emphasize the simplicity of such system. Any combination of a reasonable-length dipole fed with open-wire line and a Transmatch is this kind of system. How short should the dipole be? If you only have 60 feet or so, the dipole will still tune and work on all the bands the Transmatch will reach. A question frequently asked is "What is the minimum useful length of a center-fed dipole or inverted Vee?" *Any* short dipole will work, but I prefer a dipole that is at least ¼ wavelength long on the lowest band used—in other words, 60 feet or so on 80 meters, *but* this doesn't mean the antenna won't work if it is shorter. It just won't be as good a performer. With antennas the old saying "Make the antenna as big and as high as possible." Certainly is a sound statement. But also don't forget rain gutters, roof flashing, back stays on boats, or the barbed-wire fence. If they are metal or a conductor, they are also multiband antennas, and a Transmatch will make them that. Good luck! CQ

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