A “T” MATCH TUNING PECULIARITY

by Dick Knadle, K2RIW edited 8/12/06

It is a common misconception that adjusting the arm lengths of a T match will change only the Resistive portion of the impedance match to the Driven Element of a Yagi. This is almost untrue.

As you extend the T match adjusting clips, the main thing you are doing is adding capacitance to the ends of the driven element, which lowers its resonant frequency. This does raise the resistive component slightly, but more importantly it makes the Driven element more Inductive. Only on rare occasions will this adjustment alone, accomplish a good impedance match.

You will almost always require a second method of adjustment to remove the reactive component. And, a VSWR of 1.1:1 (or better) is worth seeking if you want to get full performance from that Low Noise Amplifier (LNA) that you so carefully tuned while it was connected to a nearly perfect 50 ohm Automatic Noise Figure Indicator (ANFI).

I have submitted an article on this subject to a number of publications who have all turned it down. They seem to believe the subject is boring, and that everyone knows how to get a great match to the Driven Element of any Yagi. The stories I hear tell me this is not so, particularly when someone makes any change in the materials used to construct the Yagi.

Enclosed is a copy of the article that no one wants to publish, “Perfect Impedance Matching of a Yagi”, that explains how to fix the problem. It also tries to de-mystify the crazy rumor that a Yagi can not give full performance if the Driven Element is as long (or longer) than the Reflector.

73 es Good VHF/UHF/EME DX,
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PERFECT IMPEDANCE MATCHING OF A YAGI

by K2RIW 09/12/05, edited 8/06/06 & 8/12/06.

INTRODUCTION -- Most Low Noise Amplifiers (LNA) only achieve top performance if they see a particular input impedance. This fact should motivate EME operators to achieve a "perfect match" at the Driven Element of their Yagi antennas. There are often-used impedance matching procedures that disturb the Pattern and Gain performance of the Yagi; the procedure described here does not do that. This article describes an impedance matching subtlety that has been overlooked, and it describes the peculiar relationship between the length of the Driven Element and the Reflector.

It is amazing how unknown this impedance matching procedure is. You can understand the concept by viewing the Graphs (that are included), or by memorizing two rules about a Dipole:
(1) Longer makes the R higher
(2) Longer makes the X more Inductive.

GRAPHICALLY – The graphs are included here. When you are away from home you will also find them in any edition of the McGraw-Hill "Antenna Engineering Handbook" by Jasik (1st ed. 1961), Jasik & Johnson (2nd ed. 1984), or Johnson (3rd ed. 1993), on pages 3-7 and 3-8 of the first edition, and on pages 4-7 and 4-8 of the last two editions. These Graphs tell you the Impedance of essentially all Monopole Antennas, for all reasonable Lengths and Diameters.

A DIPOLE IS TWO MONOPOLES -- First, remember that a Dipole is simply two Monopoles back-to-back. Therefore, all Impedances and Lengths (in degrees) that you read from the Graphs should be doubled when considering a Dipole. Figure 4-3 tells you the Resistive Component of the Impedance versus the Length (in degrees). Figure 4-4 tells you the Reactive Component of the Impedance versus the Length (in degrees).

THE GRAPHS SAY IT ALL -- When you study Figure 4-3, you will notice something very interesting. The Resistive Component of the Impedance always gets Larger, as the antenna is made Longer, up to 180 degrees for a Monopole, which is equal to 360 Degrees (One Wavelength) for a Dipole. Therefore, you do not need any fancy Impedance Matching Networks in order to get a perfect Resistive Match for your particular Dipole; and it doesn't matter if you are using a 35, 50, 70, 200, 300, or 600 ohm transmission line. Choose the correct Length of the Dipole, and you will achieve that exact Resistive Component, anywhere from 1 ohm to over 1,000 ohms.

THE REACTIVE COMPONENT -- Then from Figure 4-4 you will notice that for your chosen length, the Dipole Impedance usually has a Reactive Component left over. You will also notice that for almost all Diameters of the antenna, the Reactive Component goes through zero at about 85 degrees of Length (for a Monopole), which equals 170 degrees for a Dipole (about 0.472 wavelength). For shorter Lengths the Reactive Component is (-) [Capacitive], and for longer Lengths the Reactive Component is (+) [Inductive].

LOW R IS BETTER -- I find that it is easier to live with the Inductive Dipole case. Therefore, any method that lowers the natural Resistive Component of the antenna's Impedance (relative to the transmission line) is desirable. This can come about by using a fat Dipole, a higher impedance transmission line, an impedance-lowering device (such as a Delta March or a T Match), or choosing one of the Yagi designs that creates a Low Impedance Driven Element -- most of the good designs do this automatically.

LONGER IS INDUCTIVE -- Once the feed point of the Driven Element has a lower Resistive component than your transmission line Impedance, that will force you to lengthen the Dipole so as to raise it's Resistive component. This, in turn, will cause the Dipole's feed point to become Inductive. Then, all you have to do is to create a small Shunt Capacitor at the feed point, and you have a perfect match (a 1.0:1 VSWR), or a Reflection Coefficient (S11) of -30 dB, if that's what you desire.

AN EASY PROCEDURE -- The first time this is explained to you, it may seem complicated. Once you have perform the procedure once or twice, you will say, "why hasn't someone told me this sooner?" A skilled operator who is watching the Reflected Power on a Bird Watt Meter, a Directional Coupler, or the screen of Network Analyzer, can perform the procedure in about 3 minutes. Be sure your instrumentation has High Directivity, or else the "perfect tuning" will be a "false perfection".

TUNING TRICKS -- Here are some additional tricks. You can always electrically lengthen your Dipole by placing small pieces of Copper Tape on the tips of the Dipole (these are capacitive Top Hats), or by placing sliding pieces of tubing in that area. You can create a Shunt Capacitor at the antenna's Feed Point by placing a piece of Copper Tape across the terminals of the feed point, after first insulating one of them with some paper tape. Your intention here is to prove that you can achieve a perfect impedance match to your Dipole. Once achieved, it is a simple matter to convert your "gimmick capacitors" into permanent fixtures that are mounted to the antenna in a weatherproof manner.

INDUCTIVE Z IS BETTER -- I like the Shunt Capacitor approach because it is very easy to create a variable capacitor by way of Copper Tape. The capacitor can be easily tuned under working conditions by poking an overlapping piece of Copper Tape with a thin diameter wooden stick, as you stand out of the way of the antenna's field. This also is the way to tune the pieces of Copper Tape that are placed on the tips of the Dipole (by bending them). The Dipole Tip-Tuning and the Feed Point Shunt Capacitor Tuning will display some interaction. But, after a couple of tuning cycles, you will have a 1:1 VSWR within a few minutes.

CAPACITIVE Z IS HARDER -- If you have to make the Dipole electrically shorter than 170 degrees (to match the antenna's Resistive Component for a transmission line that has a lower Impedance), that will force the antenna's Reactive Component to be Capacitive, and this will require a shunt or series Inductor to be placed at the Feed Point. I find that it is more difficult to make a variable Inductor gimmick tuning device. But, maybe some of the smarter EME'ers and Microwavers will also solve that problem.

YAGI TUNING -- Here are some notes concerning Yagi antennas. Many amateurs worry that gimmicky devices placed on the Driven Element will decrease the Gain, or change the Pattern of an otherwise well-designed Yagi. As long as lossless devices are used, this is not a problem. For a Yagi to work well, all that is required is for the Driven Element to:

(1) Radiate in a Linear-Polarized, Dipole-like manner.
(2) Present a good impedance match to the transmission line.
(3) Present no Common Mode Currents that flow on the outside of the coaxial transmission line (use a good Balun, like a 1/2 wave coax Balun).
(4) And for all of the Yagi's Parasitic Elements to be the right electrical lengths, and be in the right positions.

A PROBLEM: YAGI TUNING WITH THE DIRECTOR OR REFLECTOR – You may have been told you can use the First Director (or two), or the Reflector, for adjusting the Impedance Match of the Driven Element. However, when you do this you are simultaneously changing the Yagi's Pattern, and it's Front-to-Back Ratio.

Tuning the Yagi, and adjusting the Impedance Match of the Driven Element, really are two separate operations. A good number of experienced Yagi builders believe that the Gain and Pattern are not significantly impacted when tuning the First Director (only) as a means of improving the Impedance match. For some particular Yagi designs, where the First Director is very close, this may be true. I say, if you are smart enough, one operation doesn't have to contaminate the other; why take the chance when independently correcting the VSWR is so easy?

LENGTH OF THE DRIVEN ELEMENT VERSUS THE REFLECTOR -- When you follow this impedance matching procedure you will often find that the Driven Element ends up almost as long, or even longer, than the Reflector. This greatly disturbs many Yagi users, because they have come to believe that the Reflector most be longer for proper Yagi operation -- this is an incorrect belief.

THE EXPLODING YAGI? -- I have seen some very respected EME operators lengthen the Driven element, the Impedance match was getting better, the measured pattern did not change, but they would stop at the instant the length approached that of the Reflector -- they seemed to believe the antenna pattern would EXPLODE if they went any further. Their mistaken belief in this area was that strong.

The Yagi will perform correctly if each of the Parasitic Elements has the correct Electrical Length, and each is in the correct position. The Driven Element only needs to radiate in a broadside manner to supply the signal that sets that process in motion; it's physical length does not matter, as long as it is in the vicinity of one half wavelength long (for a conventional Yagi).

ONE WAVELENGTH DRIVEN ELEMENT? -- Here is an exaggerated example to demonstrate some principles: if the Driven Element was made a full wavelength long, only then the Dipole might have a broadside null in it's Radiation Pattern (depending on how it was fed), and it might not properly excite the Parasitic Elements. However, with the proper feeding technique, a one wavelength Dipole will supply the proper Yagi excitation pattern (and a more narrow excitation beam width), and that pattern might be an improvement that could increase the performance. This is a hole new area that has not been investigated.

USE DUAL INSTRUMENTATION WHILE TUNING A YAGI -- If you are designing your own "Super Yagi", here is a procedure I recommend. A really smart technologist will use two pieces of instrumentation, or he will set up his Network Analyzer so there are two traces on the screen (in different colors). Then he can simultaneously display the Gain and the Impedance Match, as he does the tuning of the individual Yagi elements. You will be amazed how often an adjustment of a Director will make the Gain jump up 1 dB, at the same time that the Driven Element VSWR goes from a 1.0 to a 1.5 (a loss of 0.18 dB). The smart technologist will leave the Director tuning at the High Gain position, and then he will INDEPENDENTLY work on the Driven Element to bring the VSWR back down. At the end of this tuning procedure he will have a Yagi that has Maximum Gain, and the Best VSWR, without allowing one operation to contaminate the other.

LOSS TEST -- If you have any doubt that there may be lossy components within an antenna, a simple test will reveal that fact very fast. Simply put 100 watts into the antenna for 5 minutes. Then turn off the RF and quickly go over and touch the components of the antenna. The heat radiated by the lossy components will be revealed to you very quickly with that test.

LOSS TEST SENSITIVITY -- Here is an example of how sensitive that test is:
(1) Your hand can easily detect the temperature increase of a component that is dissipating one watt for 5 minutes.
(2) One watt of loss out of 100 watts represents 99% efficiency, or a loss of 0.04 dB.

CONCLUSION -- I hope you find this information to be useful. I think I have earned a small fortune over the years by using these techniques to tune the antennas for my consulting clients. They were amazed that I could achieve a 1.05 VSWR (and better), sometimes over a considerable bandwidth -- but that's another story. There are modern sophisticated receiver circuits that will only perform well when an extremely low VSWR is present.

73 es Good VHF/UHF/EME es YAGI DX,
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<http://www.consult-li.com/listings/DKnadle.htm>