Building an Antenna Tuning Stub

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Why Have an Antenna Tuning Stub

Radio antennas are designed and manufactured for specified purposes. The primary purpose is to resonate optimally at a named frequency. However, there are manufacturing tolerances and consequently, no two model number antennas will precisely match those original specifications. They will come close enough but can benefit from optimization.

An antenna tuning stub is a custom designed solution for any one antenna. The object is to precisely center the bandwidth of any one antenna on the center of the band that it is designed for.

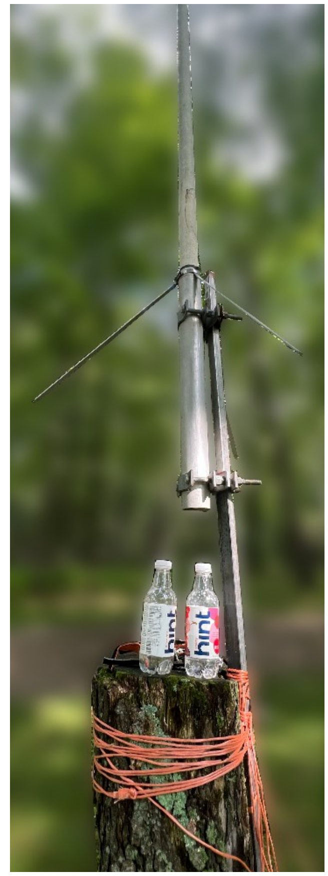

Figure 1 Our antenna set up on a tree stump so that measurements can be obtained.

What about This Antenna

The subject antenna will be utilized for base 2-meter operations. The antenna will ultimately be mounted atop a tower but is shown in Figure 1 mounted temporarily to a tree stump so that measurements could be conveniently made.[1] Its vector impedance was measured under varying conditions as outlined in the table below.

The vector impedance using the 89 cm jumper was selected from the set to base our design upon.

What the Antenna Parameters Represent

Z is a vector impedance of the series set: Z = R + jX. This is ALL THAT IS IMPORTANT! The other parameters can be calculated from these. The impedance meter merely is solving for them for you.

Discussion on Antenna Vector Impedances

Understanding what these impedances are all about is revealing. Let us start with an understanding that fundamentally, there is a real component and an imaginary.[2]

$$Z_a = R_a + jX_a \qquad (1)$$

In equation (1, R_a is the component of the vector impedance that has an appearance of being "real" in that it dissipates heat. The jX_a represents the imaginary component. The "j" identifies the component as existing on the imaginary plane distinguishing it from the real.

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[1] The presence of the Hint water may seem odd. Its presence is only to guarantee an immediate sense of the antenna size.
[2] The terminology "imaginary" does not mean that we are playing pretending game. The only reason that we have that terminology is because in the sixteenth century when these mathematics were being invented, mathematicians found that by adding the square root of negative one (-1) to an equation, it became solvable and in the process, the square root of negative 1 fell out of the equation.

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Experimental Measurements.

f_o = 147.403 MHz at +/- 585 Hz

Cable Len (cm)	SWR	RL (dB)	|Z|	R	X	L (nH)	C (pF)	R||	X||	L||	C|| (pf)
152	1.16	22.4	55.1	54.7	6.4	6.9	-	55.5	477	515	-
152+89	1.26	18.7	62.7	62.6	3.7	4.0	-	62.8	1058	1143	-
89	1.04	34.8	48.9	48.9	-1.4	-	752	48.9	-1669	-	0.6

f_o = 146.000 MHz +/-585 Hz

Cable Len (cm)	SWR	RL (dB)	|Z|	R	X	L (nH)	C (pF)	R||	X||	L||	C|| (pf)
89	1.39	-	69.1	**69.0**	**-3.7**	-	291	-	-	-	-
89+152	1.24	-	55.0	54.0	-10.5	-	104	-	-	-	-
152	1.43	-	67	65.7	-13.2	-	83	-	-	-	-

The Vector Impedance Interpreted within SimSmith

Reference *Figure 2*. Within the Smith Chart exists the Holy Grail located in the exact center of the Smith Chart itself. Our vector impedance measurement is marked by the blue circle which is slightly below the equator and to the right of the Holy Grail.

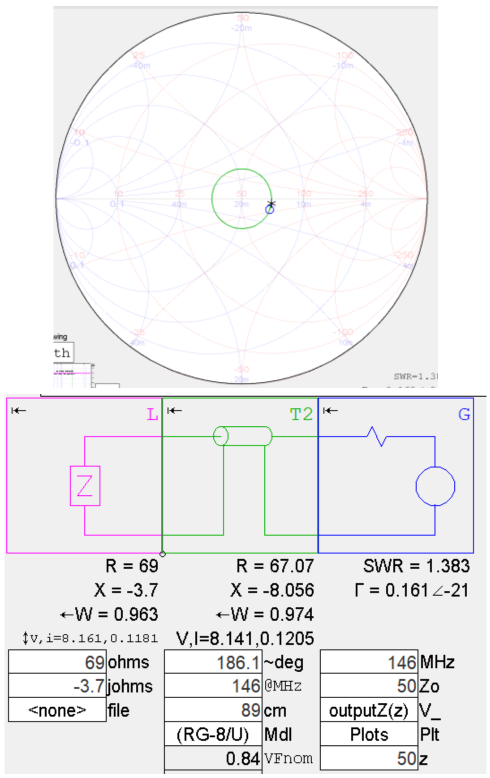

Figure 2 Starting point with the Smith Chart

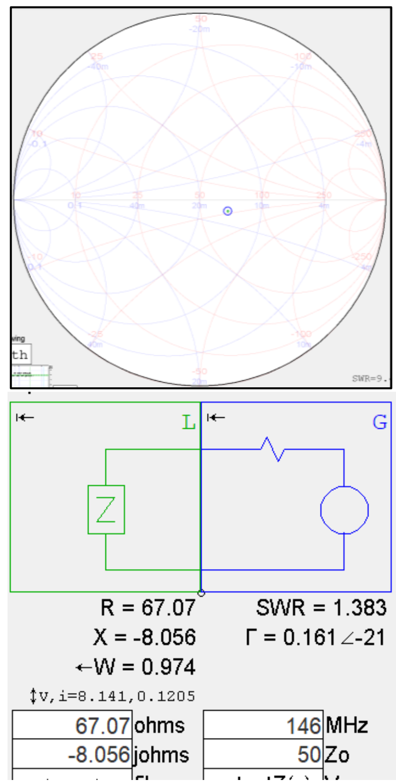

Figure 3 This is our starting point calculated antenna impedance at 146 MHz

Beneath the Smith Chart in *Figure 2* is a circuit represen-tation of what our vector impedance measurement was measuring. Z is the vector impedance meter or nanoVNA. The meter was reading 69 – j3.7 Ohms.

To the right of the jumper cable is the antenna itself. In theory, it is supposed to be 50 Ohms at an input frequency of 146 MHz and is thus indicated.

The jumper cable tells us “where the vector impedance came from.” What is impossible to miss in *Figure 2* is the “green circle.” To better understand the nature of this green circle, consider what fractional wavelength the 89 cm jumper cable represents at 146 MHz.

A half-wavelength at 146 MHz is 102.668 cm. Assuming a velocity factor of 0.84, an effective half-wavelength is 86.24 cm. This tells us that the jumper cable is longer than a half-wavelength at the subject frequency. The green line tells us where the vector impedance came from so that *we can now see what is on its other side* of the cable. We can simplify what we are now by deleting the jumper cable and adopting the indicated vector impedance as the antenna vector impedance at 146 MHz. The other end of the jumper cable is therefore calculated to have a vector impedance of

67.07 – j8.056 Ohms at 146 MHz

which becomes our starting point in this tuning stub design. This is illustrated in *Figure 3*.

Key Point of Understanding

At this point we recognize a key concept in understanding all this stuff. When the stored magnetic and electrical energy are equal in magnitude, it leads to a resonance condition in the antenna. At resonance, the antenna reactance is null or zero. The only reason that I offer the two terms null and zero in this article is to emphasize that we are talking about a *net* reactance. There will be both capacitive and inductive reactances but they will be equal to each other and cancel or “null” the reactance.

For a specified frequency, the magnitude of antenna impedance is a maximum. There exists a bandwidth. That is, the range of frequency is considered resonant. At resonance the magnitude is a maximum but falls off as the frequency deviates from the precise value of resonant frequency. The frequency at which the magnitude of antenna impedance falls to half of its resonant value is called a 3 dB point.

Normalizing: Why Bother?

For those well acquainted with the Smith Chart it will appear confusing in that for this presentation I am going to treat the Smith Chart as a 50 Ohm entity. The standard practice with the Smith Chart is to

1. normalize a 50 Ohm based initial vector impedance to unity
2. solve for what is needed at a unity impedance
3. and then unnormalize to a standard 50 Ohm impedance.

The standard practice thus presented is itself likely confusing to the vast majority of amateur radio readers. So, for this presentation we will assume that the Smith Chart is itself 50 Ohms. In doing so we can completely ignore any need for normalization.

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The Nuts and Bolts of the Smith Chart

Conductance: Notice the blue and red circles within the Smith Chart. First look to the extreme left of the chart along the equator. Note that blue circles start here and grow bigger with the edge of each larger circle touching the left end of the chart. The blue circles keep getting larger and larger until the last one actually becomes or merges with the outer circle. These are circles of "conductance." The circle of conductance that passes through the Holy Grail has a value of 1/50 or 0.02 Siemens.

Notice, also, the blue number values appearing on the lower side of the equator. These name the value of conductance for a corresponding circle. Thus, at the Holy Grail we see the blue number 20m representing 0.02 Siemens (the equivalent of 50 Ohms).

Key concept, folks: What happens as the blue circles go beyond the Holy Grail? The denominator value keeps getting larger and larger until reaching the outer circle at the right end of the equator where it reaches infinity (1/infinity) or nearly zero.

Resistance: With an understanding the nature of the blue circles comes an understanding of the red circles. These are circles of "resistance." The circle of resistance that passes through the Holy Grail marks out values of 50 Ohms.

Conductance/Resistance? What's the diff? It's all the same stuff when it comes out of the cleaners, Right? It may seem as if when we specify a resistance in terms of a conductance that we are unnecessarily complicating matters. But in this case we shall see that it simplifies things considerably.

Key concept: What is an infinite resistance? An infinite resistance is also a zero conductance. What is a zero resistance? A zero resistance is also an infinite conductance.

$$Infinite\ Siemens\ Conductance = 0\ Ohms\ Resistance$$

Note where the circles of resistance and of conductance touch but do not intersect each other at the Holy Grail. Why is that? It is because the two are equal in substance. 50 Ohms is another way of saying 0.02 Siemens. You are probably thinking that this is unnecessarily confusing but we will get there.

Phase: Next note the outer circle. This is the circle that the other circles are within. This is the big guy. This is the circle that holds the entire Smith Chart. This circle represents time itself. For convenience we call it phase. One complete trip around the outer circle is a half-wave length. This is where it might begin to seem complicated in that 360° represents a half-wavelength or 180°. That

sounds complicated but another even more complicated way to express it is in seconds and thus tradition calls it "phase" for simplicity. This circle represents the relative time it takes electrons to travel through a specified length of a fractional wavelength. The complication begins to unravel when you then recognize that the longer a coax or feedline is, the longer it takes electrons to travel along its path. Thus, adding or subtracting feedline length changes the degree of wavelength covered. 180° is a half-wavelength. One complete trip around the Smith Chart is also a half-wavelength. Moving clockwise around the Smith Chart adds feedline while moving counter-clockwise is subtracting feedline length.

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Our Cool Trick Allowing SimSmith Do the Work

In school we learn to use a compass and strait-edge to mark out impedances on the Smith Chart in solving for the values needed for a tuning stub. But we are going to put the free computer application SimSmith[3] to work for us in making the solution intuitive.

We start with a measured vector impedance Z (R +/- jX) as derived from the topology shown in *Figure 2* the meter, a jumper coax, and the antenna itself. When we measured that vector impedance, we had to use a jumper coax in order to connect the vector impedance meter (usually a nanoVNA). It was otherwise not possible to connect the meter directly to the antenna. We are going to use smoke and mirrors.

Beginning the Solution

It was not possible to hook the vector impedance meter directly to the antenna so we used an 89 cm RG-8 coax jumper cable and assumed a velocity factor of 0.84 for it. We measured 69 – j3.7 Ohms at the generator side of the jumper at

146 MHz. Using SimSmith we saw therefore that the other end of the coax jumper was

67.08 – j8.056 Ohms 2

representing the actual impedance of the antenna directly at its input. That value from this point became our starting point in the process of solving for an antenna tuning stub.

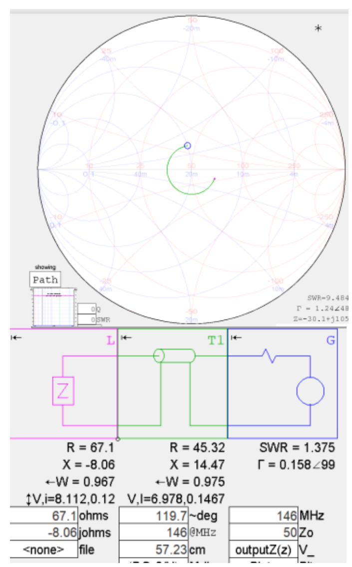

Figure 4 Phase added bringing the impedance point to a Holy Grail conductance line. The parallel open-stub length is set to zero in this illustration.

Finding a Path to the Holy Grail

Reference Figure 4 where we have added 57.23 cm of RG-8X coax which brings the impedance point on the side of the antenna to a Holy Grail conductance line. We then added a parallel open-stub coax length to 8.5 cm (Figure 5) which brought the impedance at the interface of the open-stub and antenna to the Holy Grail of 50 + j0 Ohms. But the job is ONLY HALF DONE!

Smoke and Mirrors

The trick now is to flip the combination pair of coax wires over so as to mirror them and thus place the Holy Grail at the transmitter. This has been done as illustrated in Figure 6. We flipped the tuning stub combination over horizontally, right-to-left, in attempt to move

[3] SimSmith is a free computer application that brings the Smith Chart out of the shadows and into the useful domain of the typical amateur radio operator.

the Holy Grail impedance point to the generator. We then set the generator impedance to 50 + j0 Ohms recognizing the movement (smoke and mirrors).

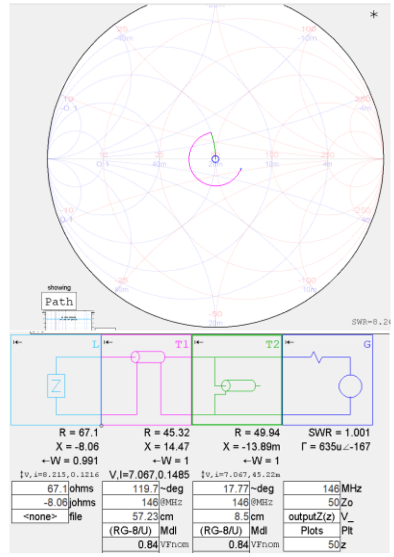

Figure 5 Parallel open-end stub added.

But Something is Wrong

The reader will observe an apparent incongruency in that the impedance indicated for the antenna input is not what the generator was seeing. The object was to flip the tuning stub pair over horizontally and thereby flip the impedance points. The antenna impedance (50 Ohms) should now be seen by the generator and the antenna should be seeing what the generator had been seeing. That did not happen. The indicated impedance at the antenna node is 66.65 + j7.60 Ohms where we wanted to see that shown for equation 2.

The problem is that SimSmith only allows for a real component vector impedance at the antenna which is 50 Ohms. To correct this in our smoke and mirrors game, we need to add another 7.1 cm of coax (see Figure 6). This brings the antenna node impedance to 68.26 – j3.334 Ohms (see Figure 7). For the actual build of the tuning stub we will of course sum these two jumpers together.

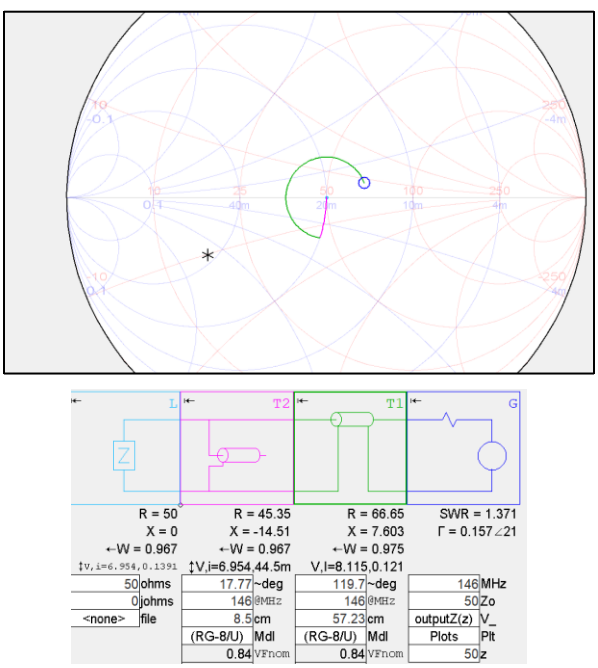

Figure 6 Presented here is our first attempt for a mirror image where we have effectively flipped the tuning stub combination over right-to-left, setting the effective generator observed impedance to 50 Ohms.

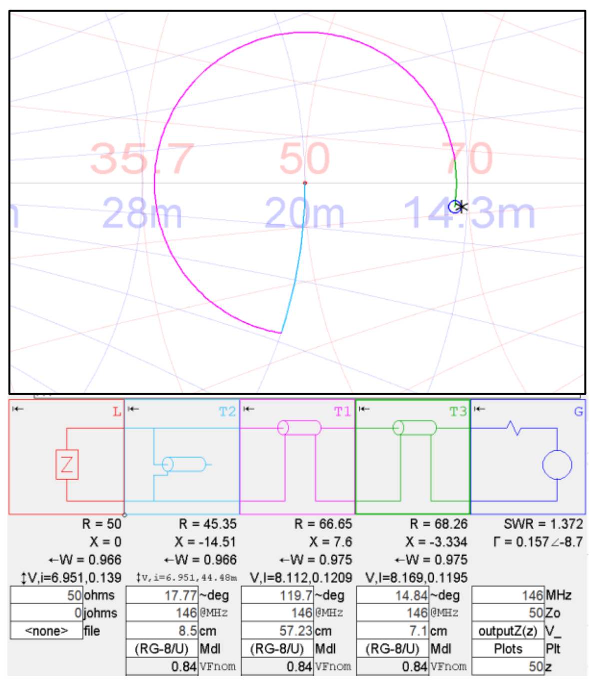

Figure 7 ***THE FINAL SOLUTION*** *-- We have added 4.2 cm of coax in attempt to complete the mirroring exercise. This now represents a tuning stub solution for our project.*

But notice that there is still not a precise duplication of the equation 2 impedance. Instead of **68.8 – j3.51 Ohms**, we are seeing 68.0 – j3.42 Ohms. The difference is small and even challenges the precision of our measurement instrumentation. In practice, this is not enough difference to care about.

The completed antenna tuning stub design is illustrated in Figure 8. Please look for a soon coming follow-up blog post documenting the building of this tuning stub.

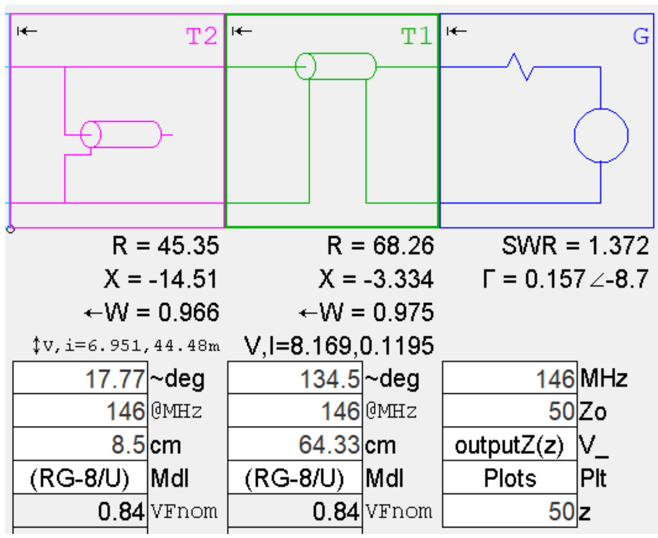

Figure 8 A tuning stub design making an antenna vector impedance of 67.1 – j8.056 Ohms to 50 + j0 Ohms