Mag Mount Antenna Tune

Wesley Cardone, N8QM, July 2021

The mag mount antenna may possibly be categorized as a commodity in both amateur radio and all hobbyist communications. Its installation is pretty much plug-and-chug except for a slight positioning of the transmitting element by means of a set screw. The user of the mag mount antenna typically uses an SWR meter to position the transmitting element rod optimally for a minimum SWR. It's really quite simple. This simplified approach works for the commercially available, pre-fabricated mag mount antennas since it is designed for a specified operating band, whether CB, aviation, business, or amateur radio. This will become vividly apparent as we study from this point what it takes to fine tune a pre-fab mag mount antenna.

But anyone who has tuned a mag mount antenna for minimum SWR has likely wondered why he or she was likely unable to tune the antenna for an ideal 1-to-1 SWR match, that is, no reflected waves. The reason is manufacturing tolerances as we shall see within this presentation. But if you set your mind to it and are willing to spend some elbow grease cutting coax, crimping PL-259s, and getting your thumbs sore, you can optimize your mag mount antenna.

In this presentation we will examine what many would consider to be the behind-the-scenes workings to the mag mount antenna. We will look at an analytic approach on how a much more ideal SWR match might possibly be made during installation. Be warned, however… maximum elbow grease will be required as well as your thinking cap.

Let's start with the measurements of a mag mount antenna intended for 2-meter amateur radio use as pictured to the right in its destination environment. While this sample antenna (purchased from Amazon.com) has already been tuned for optimal SWR in its operating environment, that is irrelevant. What is important is that feedline length contributes to optimal operation and therefore, the vector impedance measurements need to be taken with the antenna placed in its destination location. In this case the operating environment was mobile on the roof of a 2018 Ford Escape. We must also note the coax type used (Belden 8259, RG-58) and its length—350cm. Its velocity factor is specified by cable type at 66% but we took the time to measure its actual velocity factor--63%.

As we proceed from this point we will retain both velocity factors which will enable this paper to document a contribution of manufacturing tolerances.

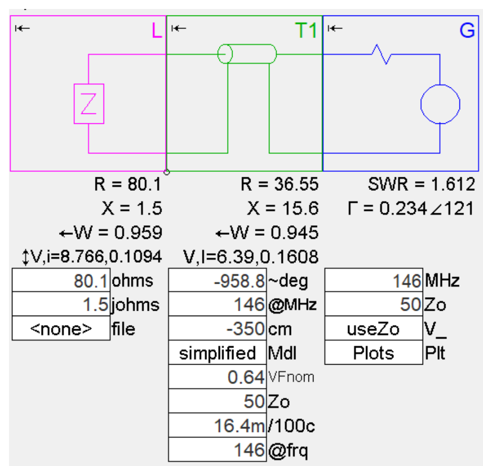
But let's inquire about that length of 350cm. Is there logic behind that length or is it merely a random value that was cut for the antenna at the factory?

Consider that the intended resonance frequency is 146 MHz, wavelength = 2.0534m. 350cm of 0.63 velocity factor cable will hold 1.0738 wavelengths for a 146 MHz signal. 1.0738 may also be represented by double its value as half-wavelengths—2.1477 component half-wavelengths. In the same fashion as 370^o is the same thing as 10^o, so also the Smith Chart repeats every half-wavelength. Therefore, the only relevant part of 2.1477 half-wavelengths is 0.1477 half-wavelengths. We have not forgotten about the same set of calculations for 66% velocity factor cable.

350cm of cable will cause 2 revolutions representing no change at all in a vector impedance except for a slight attenuation. What counts is the remaining 0.1477 half-wavelengths' effect on the vector impedance.

The first step is to measure its vector impedance at 146 MHz as illustrated at the right. The measured vector impedance is:

80.1 + j 1.5 Ohms



We are seeing 80.1 Ohms real and 1.5 Ohms (inductive) imaginary. This is for practical purposes ideal given the experimental hardware error. While the indication is still 1.5 Ohms (nearly zero), it may be for practical purposes zero.

Because the reactance is zero, the impedance magnitude (Z) is the same as the real impedance—80.1 Ohms. Here we see that this antenna is resonating nearly perfectly at 146 MHz. Its SWR is coming in at 1.6 to 1 which is perfectly acceptable and even quite nice.

But there is one step backward that we must take, and this is a CRITICAL step in a feedline analytic process. There is 350cm of RG-58 coax between the measurement location and the antenna. We need to account for this in our analytics effectively subtracting out the phase difference (our 0.1477 half-wavelengths) introduced by the coax cable. In this way we are able to "see" the vector impedance at the antenna input which is not directly accessible. This is a fancy way of saying that we need to pull a trick.

Try to get a visual image of what is going on here. We have a transmitter connecting to a coax feed line which connects to the antenna. The transmitter impedance is specified by the manufacturer to be 50 + j0 Ohms. The manufacturer specified characteristic impedance of RG-58 coax matches that so we are off to a good start. In a perfect world, the antenna would also have a vector impedance of 50 + j0 Ohms but we are not so fortunate in this case. All that we know at this point is that the impedance that any transmitter will see with this mag mount antenna in its destination environment through the factory feedline would be 80.1 + j1.5 Ohms. In order to do our analytics it will be necessary to subtract out the phase difference introduced by the 350cm of coax. We need to know what the vector impedance is at the antenna input, not the feedline input.

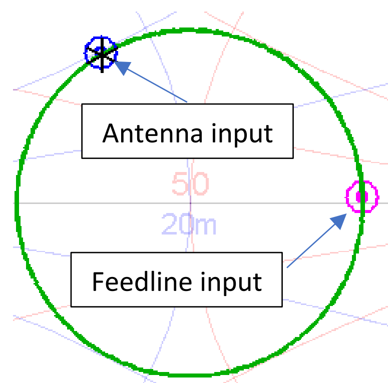
Belden 8259 RG-58 coax is specified by the manufacturer to have a velocity factor (vf) of 0.66 but we measured this mag mount coax to have a vf=0.63. The speed of electrical transmission from end to end of 350cm of this cable would therefore be 7.3551nSec. Electricity will travel down this coax at nearly the speed of light but by a factor less of 63%.

Transmission line length affects a vector impedance in that it contributes a phase difference as a function of the speed of electricity it conducts. Consider that a 360° circle repeats every 360°. Therefore, 370° is the same as 10°. The same is true with electricity except that for electromagnetic purposes, only absolute values are relevant. Therefore, units of wavelengths are treated as half-wavelengths. A full wave has two halves: a positive half and a negative half. Since absolute values are all that can be recognized, it is more convenient to talk and analyze in terms of half-wavelengths. An antenna feedline signal repeats every half-wavelength. Consequently, the only relevant portion of a feedline's length is the left-over fractional half-wavelength.

But why are wavelengths significant in this discussion? We know that the cable introduces a time delay or phase difference but how much phase is only relevant with respect to half-wavelengths. What counts is the left-over half-wavelength.

To answer the earlier question of what wavelengths are represented in 350cm, let's rephrase the constituents. Instead of 146 MHz, let's call it 146e6 cycles per second. Consider that one cycle is one wavelength. 7.3551nSec times 146e6 wavelengths per second cancels the seconds and leaves wavelengths—1.0738 wavelengths. Our interest is in the fractional or left-over wavelength of 0.1477.

Let's use SimSmith to take the drudgery out of our calculations that must follow. In the schematic illustration above, we have our generator (the transmitter) at **which we measured 80.1+j1.5 Ohms—feedline input**. We then have 350cm of RG-58 coax except that we have inserted the length as a <u>negative value</u>. The pink dot in the chart shown at the right represents the vector impedance reading that we took—80.1 + j1.5 Ohms. The green dotted line circle travels from the pink dot counter-clockwise to the starting point except for some slight attenuation which adds some slight copper resistance. The blue dot marks the termination of the green dotted line which has circled 360° to its starting point counter-clockwise plus some.



SimSmith tells us (via the blue dot) that the impedance at the mag mount base (which is not directly accessible for measurement) has a vector impedance of 36.5 + j15.6 Ohms.

Antenna Input Impedance: 36.5 + j15.6 Ohms

The next step is to find a path on the Smith Chart to the Holy Grail—the dead center of the chart which represents 50 + j0 Ohms. Finding that path is a two step process. We have to add or subtract coax feed line such that a resulting phase difference will place the blue dot on a 50 Ohm resistive path line. Smith Chart resistive path lines are the lines bowing to the left (red in this case). Conductive path lines are those bowing to the right (blue). Resistive path lines are more favorable to us in this case because the step that follows that is made easy—lengthen or shorten the radiating element of the antenna.

We could consider removing 8cm of existing factory coax putting us on a resistive path to 50 Ohms.

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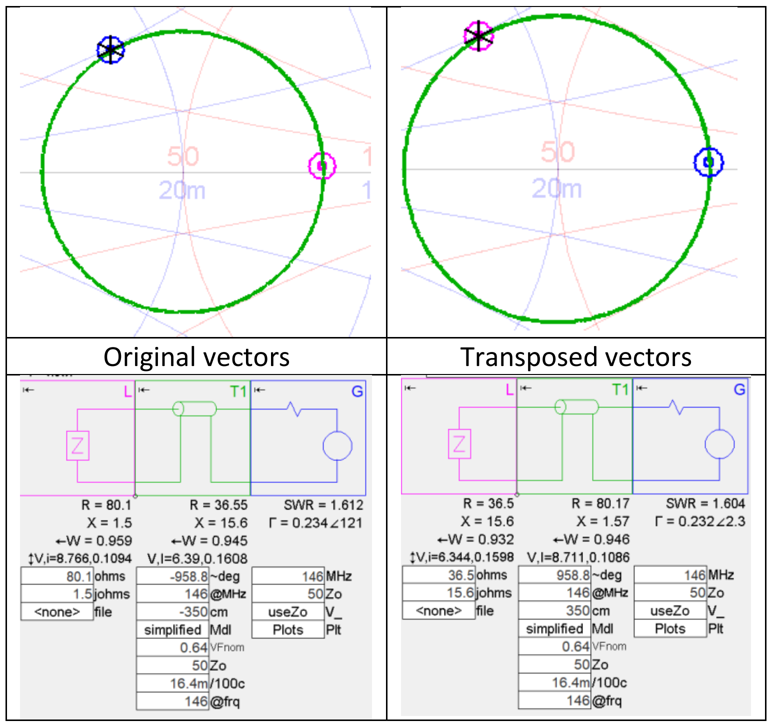
At this point we will consider manufacturing tolerances. Suppose that the coax of this antenna had the velocity factor specified of 0.66. Inserting a velocity factor of 0.66 into earlier calculations will change things considerably. In the earlier paragraph we determined that shortening the coax by 8cm would put us on a target path. With a velocity factor of 0.66 we could do the same thing by adding 2.5cm to the cable. ***That's one inch, folks!*** It is clear at this point that everything about this mag mount antenna was designed to give optimum performance at 146 MHz out of the box.

Let's now consider ADDING coax. If we add 19cm of vf=0.787 coax, we find ourselves smack dab on the 50 Ohms resistive line. The subsequent move to home plate will then be a matter of shortening the radiation element.

The intended resonance frequency is 146 MHz which wavelength is 2.0534m. 350cm of 0.63 velocity factor cable will hold 1.0738 wavelengths for a 146 MHz signal. 1.0738 may also be represented by double its value as half-wavelengths—2.1477 component half-wavelengths. In the same fashion as 370^{o} is the same thing as 10^{o}, so also the Smith Chart repeats every half-wavelength. Therefore, the only relevant part of 2.1477 half-wavelengths is 0.1477 half-wavelengths.



Original vectors | Transposed vectors

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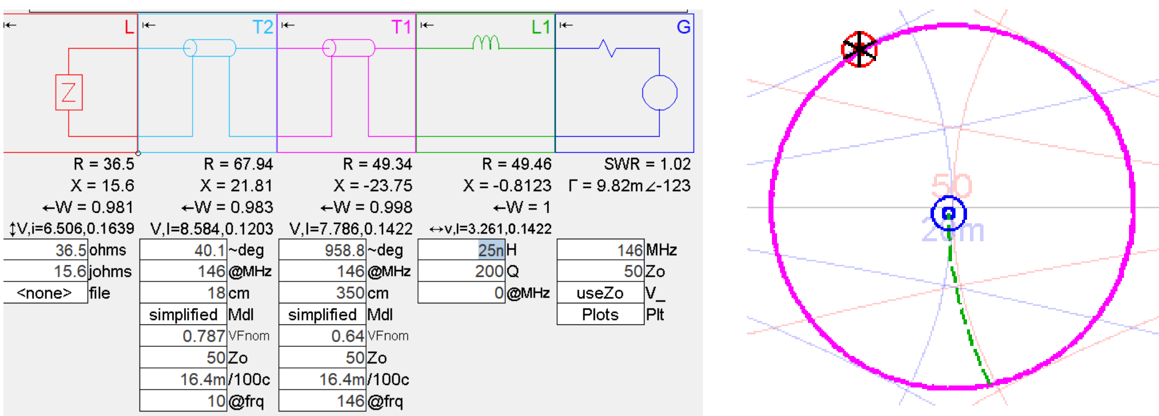
To make this a little simpler to comprehend, we will first adjust our SimSmith representation of the antenna. To this point we put in the measured vector impedance for the generator and added a negative length coax. We will now switch things around since we know from SimSmith what the antenna actual impedance is — 36.5 + j15.6 Ohms. The generator (transmitter) impedance will now be set for that vector impedance, 36.5 + j15.6 Ohms, and we will add a positive value of 350cm feed line going to the antenna. We then add a second transmission line. Our supply coax for this is DXE RG-8X specified to have a velocity factor of 0.78 but we measured 0.787. This second transmission line will add phase causing a CLOCKWISE rotation around the Smith Chart. We find that if we make this second transmission line 18cm that the blue dot falls on the 50 Ohm resistive line in capacitive reactance territory (the lower hemisphere of the Smith Chart). After adding the new coax there will be a lengthening of the radiating element which will bring us towards the Holy Grail—50 + j0 which is a 1:1 SWR. To confirm, we can simulate a lengthening of the radiation element by adding an inductance to the radiating element of 25nH. The result is illustrated below by the green dotted line which leads to home plate—the Holy Grail!



So, now that everything is said and done the reader may be asking, “Is it worth all the work?” Probably not since the antenna was working just fine before coming in with a SWR better than 1.6 to one. But now we are seeing one-to-one and we therefore have certainty that our output EM signature is improved.