Have Fun Building This Inexpensive 2 M Mobile Antenna While Learning to Use The Smith Chart

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I wanted to install a 2 meter antenna on my Mitsubishi that would look like a factory installed antenna. The car radio antenna is on the rear driver's side and I considered using it for 2 meters, but I decided that wasn't feasible. A stainless steel 32 inches long replacement car antenna, costing about $12 could be mounted on the opposite side of the vehicle, but how is such an antenna impedance-matched for the 2 meter band?

An antenna length of about 100°, or 0.28 λ, provides high efficiency, a resistive input component of about 52 Ω[1], and an inductance reactance of about 80 Ω[2]. Using 146 MHz for calculations, EZNEC[3] showed that the impedance of a 0.28 λ (21.7 inches) vertical antenna over a perfect ground is Z = 52.7 +j58.6 Ω, agreeing very well with the above values from the ARRL Antenna Book[1,2]. Using an antenna length greater than 0.25 λ is also desirable in that the inductive reactance can easily be canceled "tuned out" with a series capacitor (capacitive matching generally has lower loss and is more easily adjustable than inductive matching.) Given the contours of the car body, this was unlikely to be the exact impedance, but it provides a place to start. Ideally, a series variable capacitor would be placed at the antenna base. However, given the internals of the vehicle, that isn't invariably an easy thing to do. Impedance repeats along a transmission line at electrical distances of nλ/2 (where n = 1, 2,3, …). So another option was placing the capacitor in the feed line at a convenient distance of nλ/2 from the antenna base. If the impedance is very far from Z = 50 +jxx, it will be necessary to add a transmission line section of length L (0<L<λ/2) to your convenience length of nλ/2 (where n = 1, 2,3, …) to convert the resistive component of the load to 50 Ω.

After mounting the antenna, measure the impedance of the full length antenna (32 inches.) If it is any where close to 50 Ω , approximately 20 Ω to 150 Ω, you can forgo the trimming and let the transmission line section do the resistance conversion. If not, or if you want to try for a closer value, trim the antenna as needed in 1/4" increments for the best value, keeping in mind not to shorten it below about 22 inches. If you are close to 22 inches and the resistance is 20 to 150 Ω, stop trimming and let the transmission line section do the resistance conversion. The goals are to (1) lower the SWR (to minimize feed line losses) while (2) being sure that the reactive component remains inductive (permitting matching with a series capacitor.) If you can get Z = 50 +jxx Ω, great, otherwise at least try to obtain a resistance value between approximately 20 to 150 Ω (this keeps the losses close to a minimum value.) I used a MFJ-259B antenna analyzer for the impedance measurements. The little safety ball on the end of the antenna can be removed from the cut off piece of antenna and placed on the final trimmed antenna for safety.

My Mitsubishi antenna measured 122 + j211 Ω and my Corvette antenna measured Z = 26 + j9 Ω, with an antenna length of approximately 22.25 inches.

As the impedance of the antenna depends upon the vehicle contours, your results more than likely will differ from mine, and will likewise require a matching transmission line section. Assuming this is the case, I will illustrate two methods of calculating a matching network that requires only a transmission line section and capacitor to convert the antenna impedance to 50 Ω. The example that I describe is one of my mobile antenna installations. One method uses the Smith Chart[4] to determine the transmission line matching section length. The other method uses the TLW (Transmission Line for Windows) program packaged with the ARRL Handbook. The Smith Chart provides a graphical solution with minimal calculations. TLW does all the calculations internally, and additionally incorporates line losses.

Smith Chart

In my case, after trimming the antenna to approximately 22 inches, the measured impedance was $Z = 26 + j9\ \Omega$, DP1 (Data Point 1.) First DP1 is plotted on the Smith Chart (Figure 1), then move clockwise around the SWR = 2 circle to the 50 Ω circle, DP2. My value DP2 from the chart is $Z = 50 + j35.5\ \Omega$. The angle formed by DP1, the center of the chart, and DP2 (82°) gives the length of the the transmission line, in electrical degrees, necessary to convert the resistance portion of the impedance to 50 Ω, keeping in mind that one rotation (360°) around the Smith Chart is 180 electrical degrees or $\lambda/2$ ($(82°/360°)*(\lambda/2) = 0.114\ \lambda$.) From DP2, adding a capacitive reactance in series to cancel the inductive reactance will move the impedance counter clockwise on the 50 Ω circle to $Z = 50 + j0\ \Omega$.

The Smith Chart shown in Figure 1 has a 0 to $\lambda/2$ graduated outer scale for one rotation around the chart for easy determination of the feed line length required. The matching transmission line length can be read directly from the chart by drawing lines from the center of the chart through DP1 and DP2 to the outer scale. The feed line length given by moving clockwise (wavelength toward generator) around the Smith Chart from the DP1 to the DP2 line-scale intersections, $0.151\ \lambda - 0.037\ \lambda = 0.114\ \lambda$, is the transmission line section electrical length needed to transform the real part of the impedance from 26 to 50 Ω. Using this scale eliminates the need for the manual calculation in the preceding paragraph.

Since the impedance repeats along the line at $\lambda/2$ intervals, a convenient length of feed line from the antenna to the tuning capacitor, $n\lambda/2 + 0.114\ \lambda$ (n = 1, 2,...), can be chosen. For flexibility I used an additional $\lambda/2$ electrical length of feed line from the in line capacitor assembly (Figure 2) to the radio so I did not have to place the capacitor assembly box right at the radio, although any length could have been chosen from the capacitor. A 31pf capacitor provides the 35.5 capacitive reactance (X_C) to cancel the inductive reactance (X_L.) A 7-45 pf variable capacitor works well in this application.

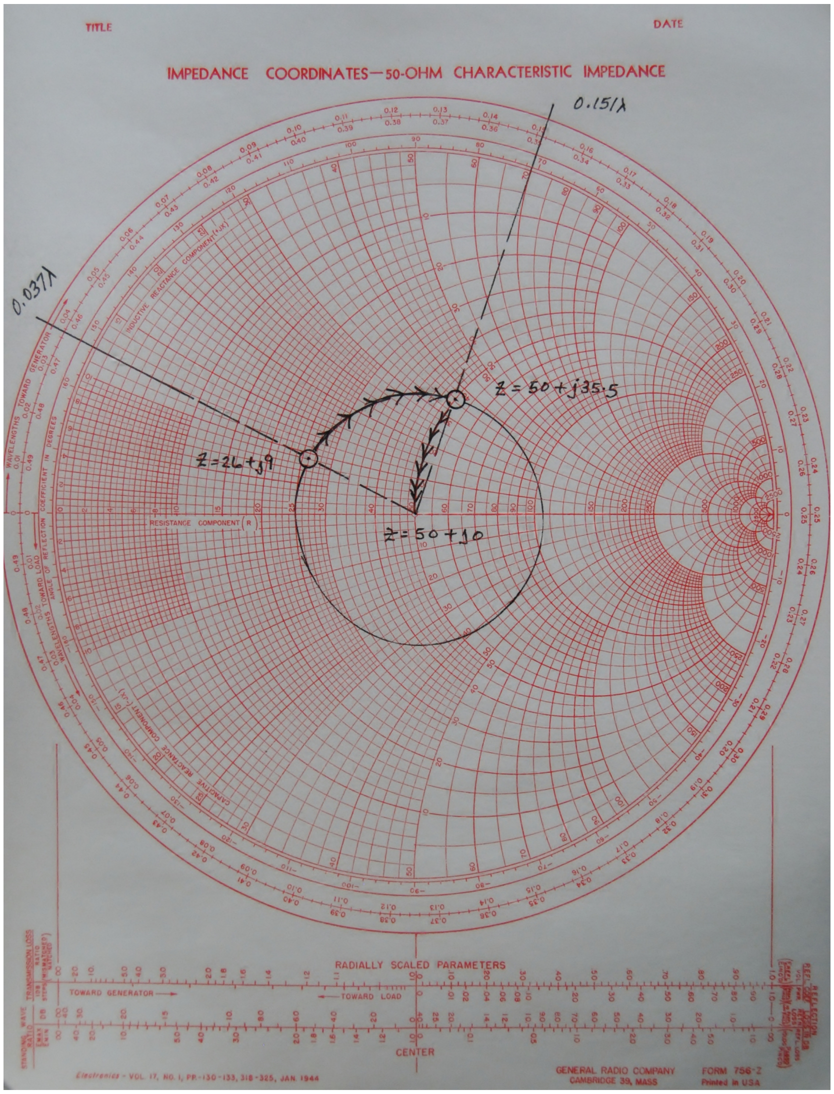

Figure 1. Smith Chart – Graphical solution to matching the antenna Z to Z = 50 Ω.

Figure 2 – Altoids tiny tin tuning capacitor housing.

Figure 3 – Open Altoids tiny tin showing tuning capacitor assembly.

The Smith Chart easily provided a good solution − the way these problems were solved before computers were prevalent.

TLW

TLW, given the coaxial cable type and length, the frequency, and the impedance at either the load or source will calculate the impedance respectively at the source or load, SWR, and cable loses.

I chose RG-58A. This cable is small and convenient for the application. It has higher losses than some others, however, with a short feed line, that was not a problem.

Run TLW and enter your data.

For my example I entered the following:

Input Data:
Cable type: RG-59A
Length: 13.840 feet
Frequency: 146MHz
Load Z: 26 +j9 Ω
Input Z: to be calculated

Output:
Input Z:52 + j28 Ω
Length: 3.113 λ

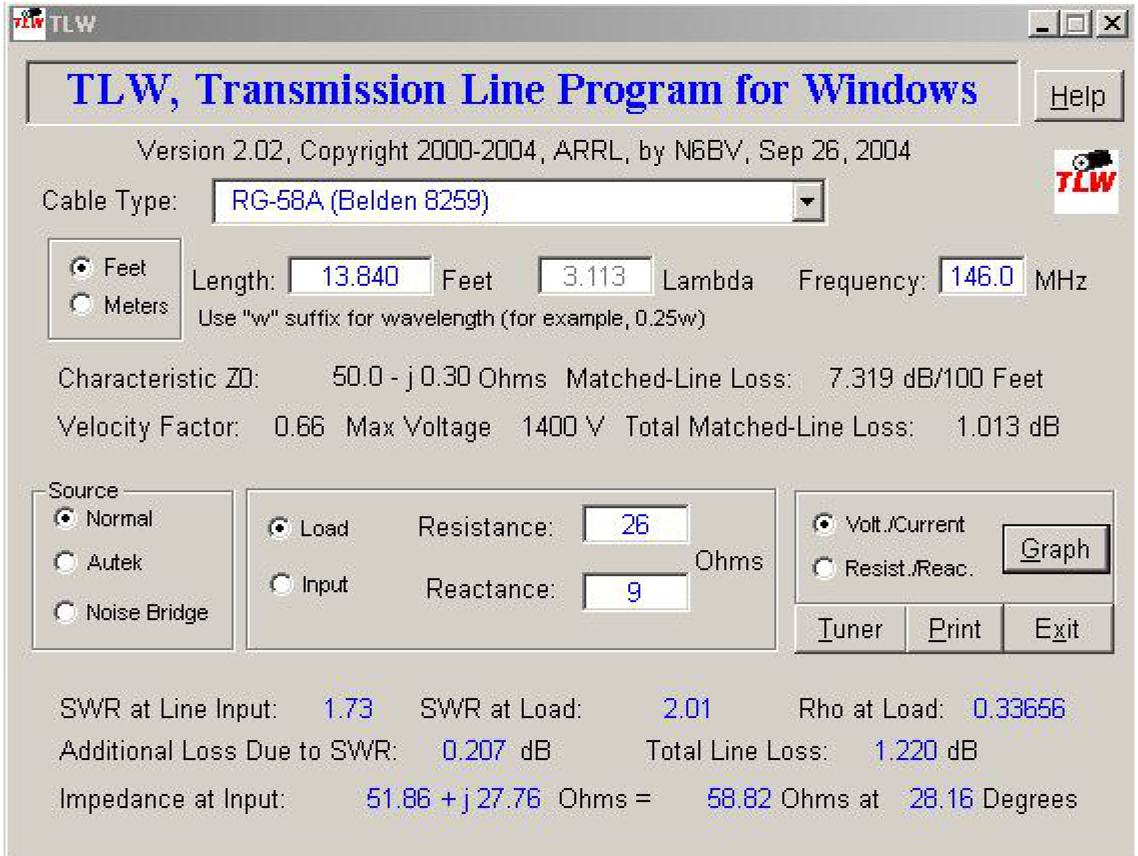

Figure 4 – TLW program window showing the transmission line parameters.

The length is 6 λ/2 +0.113 λ (3.113 λ) which agrees well with the graphical Smith Chart solution. The 0.113 λ is the transmission line section that changes the real part of the impedance from 26 to 52 Ω, the 6λ /2 repeats the input impedance. The length, 6λ/2 +0.113 λ, was chosen because it provided a convenient length for my installation.

The input is now 52 Ω and the capacitor assembly (adjusted to 39 pF) will cancel X_L (28 Ω) resulting in Z = 52 + j0 Ω. The 7 – 45 pF variable capacitor has enough tuning range to adjust for a wide variation of X_L.

The TLW program provides the line loss, additional line loss due to SWR, and SWR at load and input. If you measured the input impedance, TLW will calculate the load impedance. You can play with the various parameters to see how they interact.

I installed replacement antennas on my Mitsubishi and Corvette using this method of design (Figures 5 & 6). Due to lack of perfect models for the antenna and and vehicle, measurements and calculated results will likely differ a bit (so expect to do a little cable trimming), but this approach should get you close and provide insight to enable final tuning. Both antennas worked out well for me and go from a SWR of 1.5:1 (144 MHz) to 1.1:1 (146 MHz) to 1.6:1 (148 MHz). All for about $12 each and a little fun.

Figure 5 – The near antenna is the replacement
antenna designed for 2M.

Figure 6 – The Corvette 2M replacement antenna is mounted on a 1.25" x 1/8" piece of steel bolted to the spare tire housing.

[1]The ARRL Antenna Book, 10th Ed., 1964, Chapter 3, pp 124-125.

[2]The ARRL Antenna Book, 10th Ed., 1964, Chapter 2, pp 61.

[3]The ARRL Antenna Book, 20th Ed., 2004, Chapter 4.

[4]The ARRL Antenna Book, 20th Ed., 2004, Chapter 28.