Tuning up a 160M full sized vertical with strong AM broadcast RF on the antenna. – Jay Terleski, WX0B

I often get asked about how to match a ¼ WL vertical to a 50 ohm transmission line and what to do about lightning protection and even how to make RF measurements in the presence of strong AM broadcast RF on the antenna. I have seen solutions from just attach the coax to the antenna and live with it, to adding a capacitor in series to allow tuning the antenna over the band. Even the use of L networks to match the 30+ ohms to 50 ohms. Let's look at a very simple solution that I think is the most useful and most elegant solution to use.

First let's look at my ¼ WL 160m vertical. It is sort of an inverted L. Rising up from ground level to 50 feet as a free standing aluminum tube vertical, at this point I attach a #12 wire that slopes upwards at a 45 degree angle to my 150 foot tower. The system has 64 buried radials, and fortunately we have excellent ground here. Due to the sloping wire the antenna has a feed impedance less than the theoretical 36 ohms. What we will attempt to do is tune this antenna for a 50 + j0 ohm resonance at 1.830 using an LC network. For a capacitor we will just shorten the antenna length a small amount to create the capacitance we need, and then a single inductor across the feed point is all we will need to match the antenna to the transmission line. I don't like to use series capacitors since they are prone to failure at high currents and lightning events. The "gimmick" capacitor technique is a great way to do this kind of matching network.

There are many AM broadcasters in the area, and one is even at 1710 KHz. These stations place 10V peak to peak of RF onto my antenna during the day, and even more at night. Fig 1 shows how to attach a scope probe to the coax stub going to the heliax. Fig 2 shows the scope reading at the end of 150 feet of 50 ohm ½ inch heliax. Trying to make an accurate measurement with any of the impedance meters available to hams is impossible. They overload, and some will even blow their diode bridges and will require a trip to the factory to fix them. The AIM 4170B analyzer that we produce will not blow up, but it will fail to make this measurement due to the strong RF if you just hook it up to the feedline. But, it has a neat software tool that can be used to make this measurement accurately, and we will use it to help us tune up this antenna.

10V of peak to peak RF is 0.25 watt of power into 50 ohms. The AIM 4170B puts out micro-watts of RF power to make its measurement. So how can this device over-ride the power in the antenna?

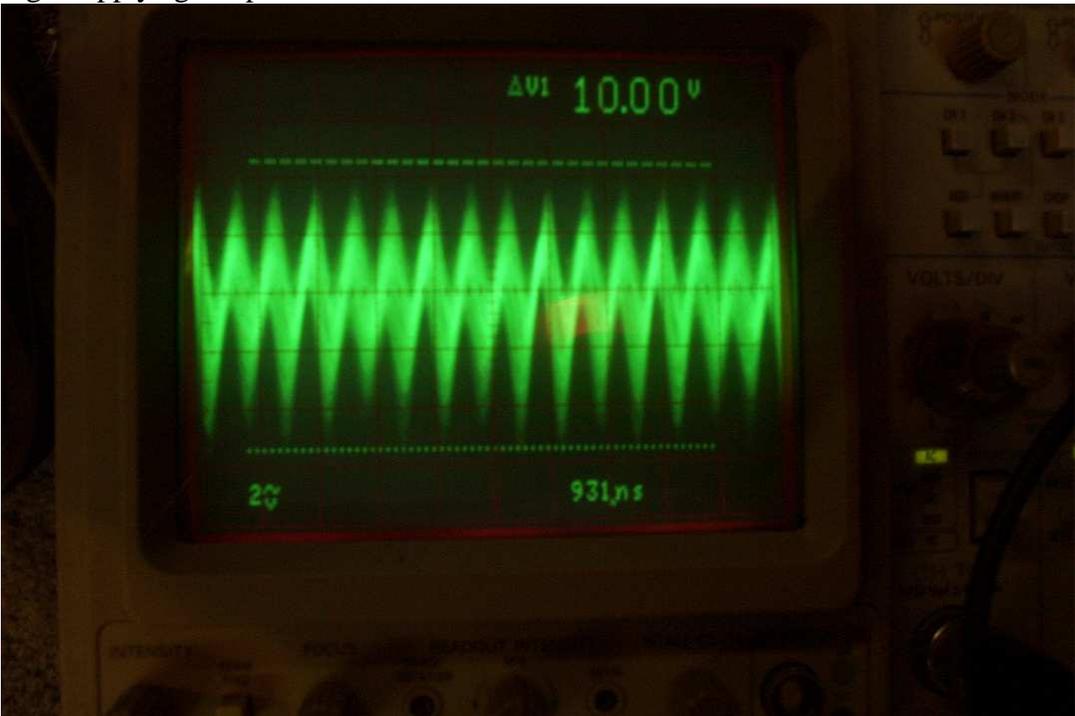Fig 1 Applying the probe to the coax

Fig 2 10V Peak to Peak RF

When we attach the AIM 4170B to this antenna and coax, we see the following plot (fig.3) when we do a scan from 1.5 to 2.5 MHz. The plot is color coded and the parameter plotted can be read from the associated colors on the plot.
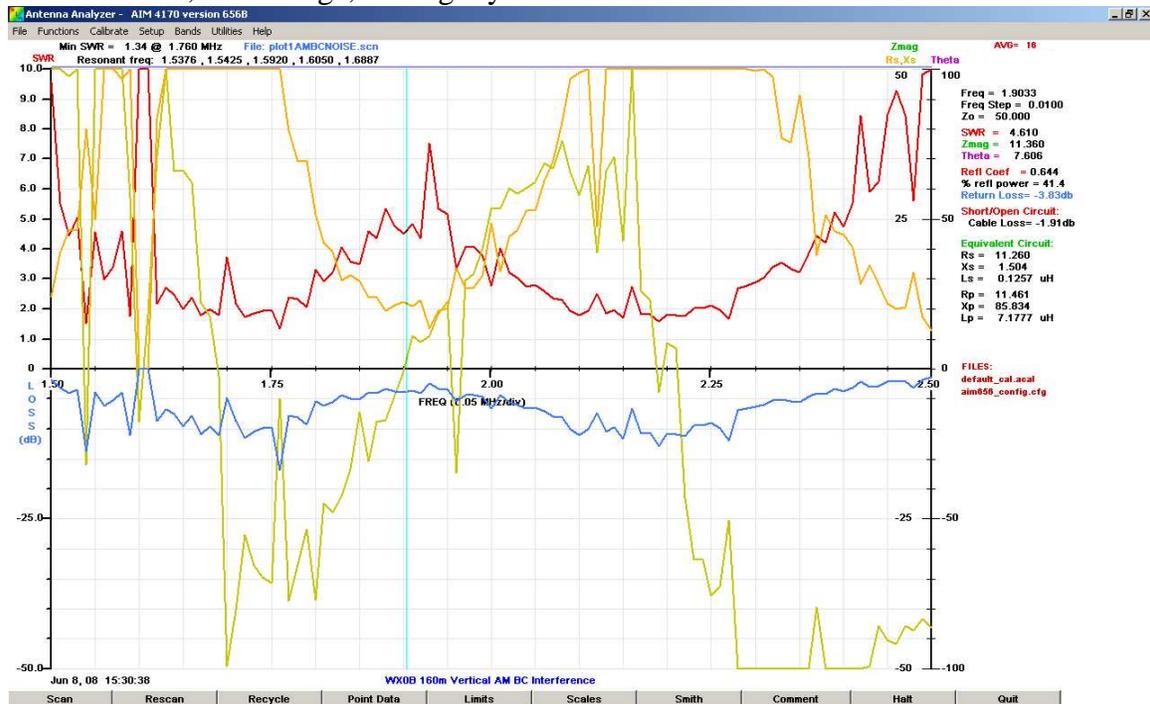Red is VSWR, R is orange, X is light yellow.

Fig 3 – plot of antenna from 1.5 to 2.5 MHz, AM broadcast is making the measurement useless.

The plot is not very useful and we need to adjust our measurement technique if we are to get good information to allow us to adjust this antenna. Hence we need to utilize a good broadcast band high pass filter. W3NQN makes a superb BCB HP filter and I have attached it to the RF connector of the AIM 4170B analyzer. But before we just use it, we need to null out its transfer function so the measurements we make are not affected by it.

These high order filters have phase shifts, and other linear parameters due to the design. We must normalize them out, and to do this we have developed a "custom calibration" software tool for the AIM 4170B. What you do is a "super" calibration using the short, open, and load technique through the filter over a limited frequency range. And you do this with, say, 500 or more points of measurement. The software will create a very detailed calibration table that will essentially move the measurement point from the analyzer's RF connector to the input connector of the BCB HP filter.

Once the custom calibration is run, it can be saved as a file for future use. Now that we have the Analyzer and filter fully calibrated, we can retest the antenna and coax system. Fig 4 shows the plot obtained scanning through the filter. Note I added "averaging" of 8x to the measurement to get rid of any residual noise on the measurement. AM broadcast stations have side band power that can be eliminated using the averaging function since they are always changing. You can see the "AVG=8" in the upper right corner of the trace. We have other tools that can be used including "trend" and "smoothing" but they were not needed since we have a clean plot now.

Fig 4 – Very clean plot, Marker (blue vertical line) at X zero crossing, R = 31.4 ohms, VSWR = 1.59   The little glitch is the second harmonic of KRLD.

Just to check, I looked at the antenna through the filter with the scope, fig 5 shows we have about 125 mv of RF still getting through the filter. This is still pretty high and probably most analyzers under $500 will not be able to make an accurate measurement.

The AIM can make the measurement since it has RF immunity up to 125 mv. See our website for more detailed information about the AIM 4170B architecture.
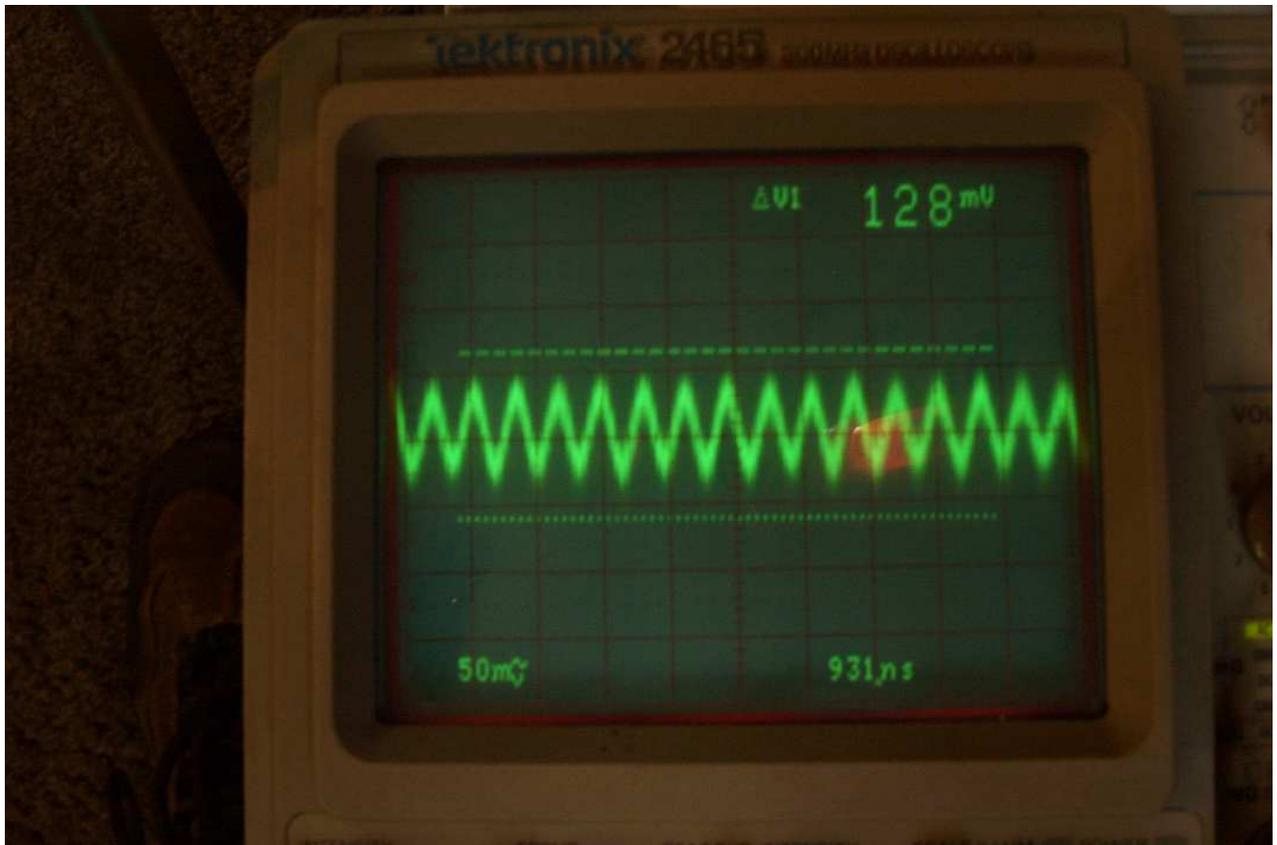
Fig 5 – sidebands show about 125 mv of RF still getting through the filter.

Adjusting the Antenna to create the virtual capacitor

What we need to do is adjust the resonant frequency, instead of 1830 KHz, to be 1900 KHz or above. Since I don't care about working above 1875 KHz, I used 1900 KHz as my target frequency to create a capacitive X at 1830 KHz. Using an LC network program like the Network program we sell, it is easy to create a match for this antenna. First we need to find the impedance at our desired frequency. Fig 6 shows a plot with the marker at 1830 KHz and the corresponding R and X are shown at the right of the plot. R = 41.6 ohms and X = -41.5 ohms. This is at the end of the transmission line. To obtain the exact reactance at the antenna we could take the AIM to the antenna and measure the input terminals, or we can just use the "Refer to Antenna" function in the software, describe the 150 feet of 50 ohm heliax, the loss of the heliax (which is a lookup table), and the velocity factor of the coax (also a lookup table). Putting these numbers into the software prompts, and doing a new scan will now give us the measurement as if we were at the feedpoint. All from the comfort of my air conditioned shack! The numbers R and X numbers turn out to be almost exactly the same as at the transmitter end of my cable. At 160m this is probable, but don't assume they will be the same at higher frequencies. They could be drastically different. The LC network software calculates that we need a shunt coil of about 5.8 uH to match this impedance to 50 ohms. I built an inductor on a 3 inch PVC pipe form and placed 12 turns on it per the network software's coil design program.

You might want to make the inductor larger, then tap it down for best match. Fig 7 shows the inductor at the base of the antenna.
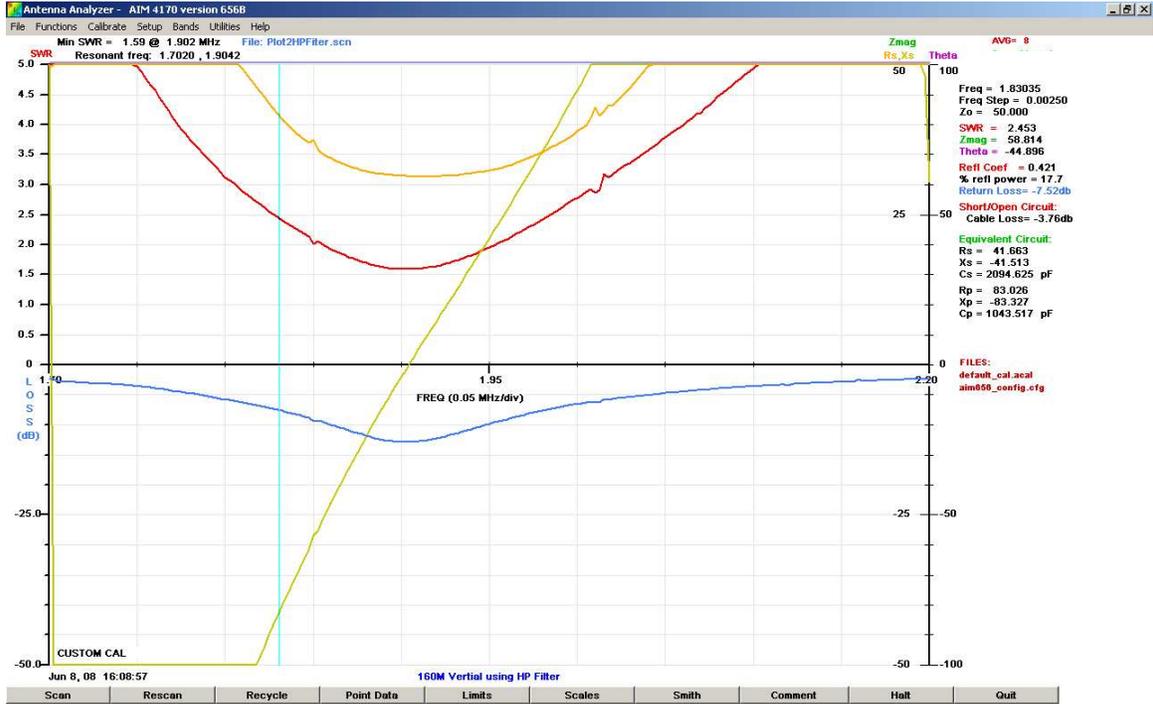

Fig 6 – Marker at 1830 KHz, R= 41.6 ohms and X = -41.5 capacitive ohms.

Fig 7 – Inductor attached to the insulated vertical element and grounded at far end (not shown in picture).

Rerunning the plot (Fig 8) we can see we now have matched the antenna.
The inductor acts just like a hairpin match on a Yagi. And the loss in the inductor is only about 5 watts at 2,000 Watts input. The inductor also works as a static bleed choke and will definitely help save equipment if the antenna has a lightning hit or nearby hit. This is a pretty elegant solution for a matching device, a static bleed choke, and a surge arrestor all in one single component!

How accurate is the measurement?
Fig 9 shows a wide band sweep from 1 to 2.2 MHz. Note the BC band stations are perturbing the measurements below the 160m band but the filter's attenuation allows the AIM to make the measurement in the 160m band. But how accurate is it considering there is such turmoil of RF nearby?

Let's use a NIST calibrated watt / VSWR meter and my IC781 to verify the readings of the AIM 4170B. The AIM plot fig 8, shows the VSWR is 1.029 at about 1832 KHz. Tuning the IC781 to 1832 KHz (fig 9) and sending out some RF we see the calibrated VSWR meter (fig 10) has 1.03 VSWR. That's pretty darn close and well within the margin of error of these measurements. And we have some other components in line that could affect the reading such as the amplifier, coax cables, wattmeter coupler, etc.

Now let's check the bandwidth of the antenna with the VSWR meter and compare it with the plot of fig 12.   I moved the VFO to both of these frequencies and tested the VSWR with the rig and meter. The VSWR meter shows almost the exact same VSWR readings and the bandwidth is exactly the same. Matter of fact even at higher VSWR numbers they are the same.
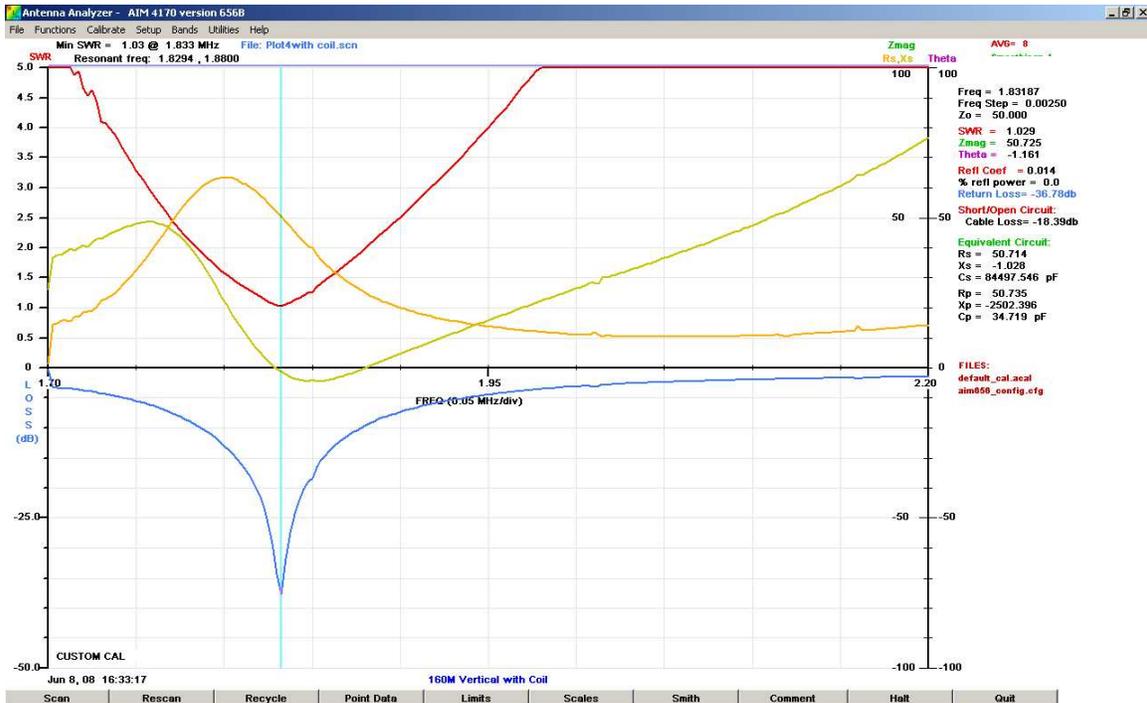

Fig 8 – 1832 KHz, R= 50.7, X = -1, and VSWR = 1.029

Fig 9 – wide band sweep of the antenna from 1 to 2.2 MHz, Note all the noise below 1.7 MHz. This is caused by the huge amount of attenuation in the filter at these frequencies. The calibration data is not valid in the attenuation band, but that is outside of the region of interest anyway. Everything above 1.7MHz is valid and the 160m band is not affected

Fig 10 – IC781 set to 1832 KHz
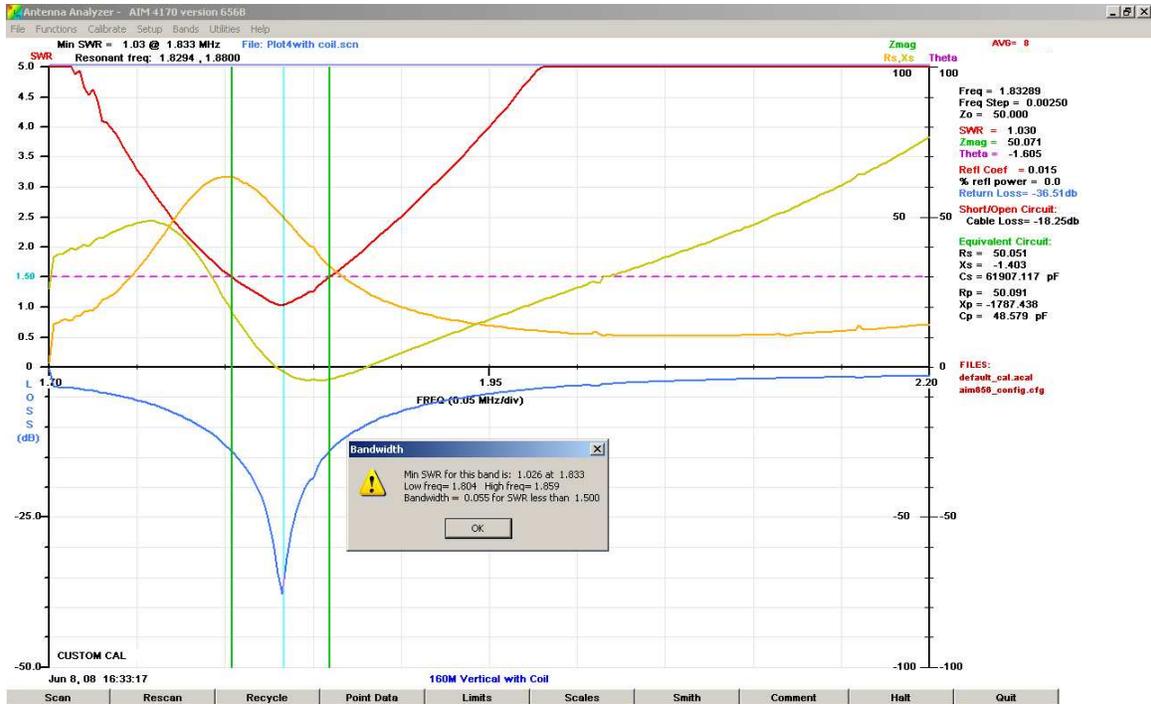

Fig 11-VSWR 1.03 at 1832 KHz

Fig 12 – Using the Antenna Bandwidth tool, and setting the VSWR ruler at 1.5
Bandwidth is 55KHz, low end at 1804 KHz and high end at 1859 KHz.

Summary

I have shown how to make a very simple but elegant matching device for a ¼ WL
vertical, which also operates as a static bleed device and a surge arrestor. To measure the
antenna and get the data needed to make the matching device and to tune the antenna
correctly an AIM 4170B analyzer was used in the presence of strong RF from AM
broadcast stations nearby. Using the custom calibration tool, and a BCB high pass filter
we were able to make accurate measurements of VSWR, R, and X. This enabled us to
design the matching network, and verify its characteristics.