Antenna Analyzer Pet Tricks

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Antenna analyzers have become a very popular accessory, and many hams have acquired one. Since most of us don't change antennas weekly, the antenna analyzer may not see frequent use. But these instruments can do many other useful things that might have you reaching for one more often.

An antenna analyzer is really a one-port network analyzer, a powerful RF measurement tool. When professionals need to characterize an RF component, whether it is an antenna, transmission line, or filter, the "goto" piece of test gear is a network analyzer. These are expensive, complex, heavy, and delicate. While not as versatile as an expensive network analyzer, the inexpensive antenna analyzers that have recently appeared on the market can be very useful in characterizing transmission lines, filters, and RF components as well as antennas. Let's look at some measurements that can be made with an antenna analyzer that a microwave engineer would do with an expensive network analyzer.

Figure 1- Handheld Antenna Analyzers

My antenna analyzer, shown on the left in Figure 1, is an inexpensive one from China – see Figure 2. I chose it because it covers a wide frequency range, 137.5 to 2700 MHz, including six VHF, UHF, and microwave bands. The user interface can be charitably described as execrable, but can be decoded by referring to the manual. The major advantage is that it is cheap – cheap enough to drop off a tower without crying – see Figure 2. But these measurements may be made with any antenna analyzer.

I borrowed another antenna analyzer from my neighbor, Chip Taylor, W1AIM. This one, from the Ukraine, is on the right in Figure 1. The frequency range is from 1 to 1400 MHz, covering all bands from 160 meters to 1296 MHz; important since Chip also operates HF. The user interface is better, since the package is larger with more buttons, but the price is much higher – dropping this one would be painful.

When operated at a single frequency, as in Figure 1, both analyzers display several different quantities: **VSWR** or **SWR**, **Z**, **R**, **X**, **RL** or **|S11|,** and **C**.

All of them are **variations on impedance measurement, and most are useful in different contexts, as we shall see. But the single frequency quantities** don't provide a lot of insight, and if we are just looking at **VSWR** at a single frequency, an inexpensive meter will often suffice.

VSWR or **SWR**, (Voltage) Standing Wave Ratio is a measure of relative reflected power, and another is Return Loss (**RL**), the difference between Forward and Reflected power in dB. A dead short (or an open) will reflect all of the forward power – the return loss is 0dB. A good antenna might reflect power only 1% of the power, so the Return Loss is 20 dB. **VSWR** and return loss are related: a low return loss (lots of reflected power) indicates a high **VSWR**. The conversion may be done be by calculation, but most antenna analyzers can display both Return Loss and **VSWR**. My analyzer displays **|S11|**, the magnitude of S-parameter **S11**, which is the negative of Return Loss.

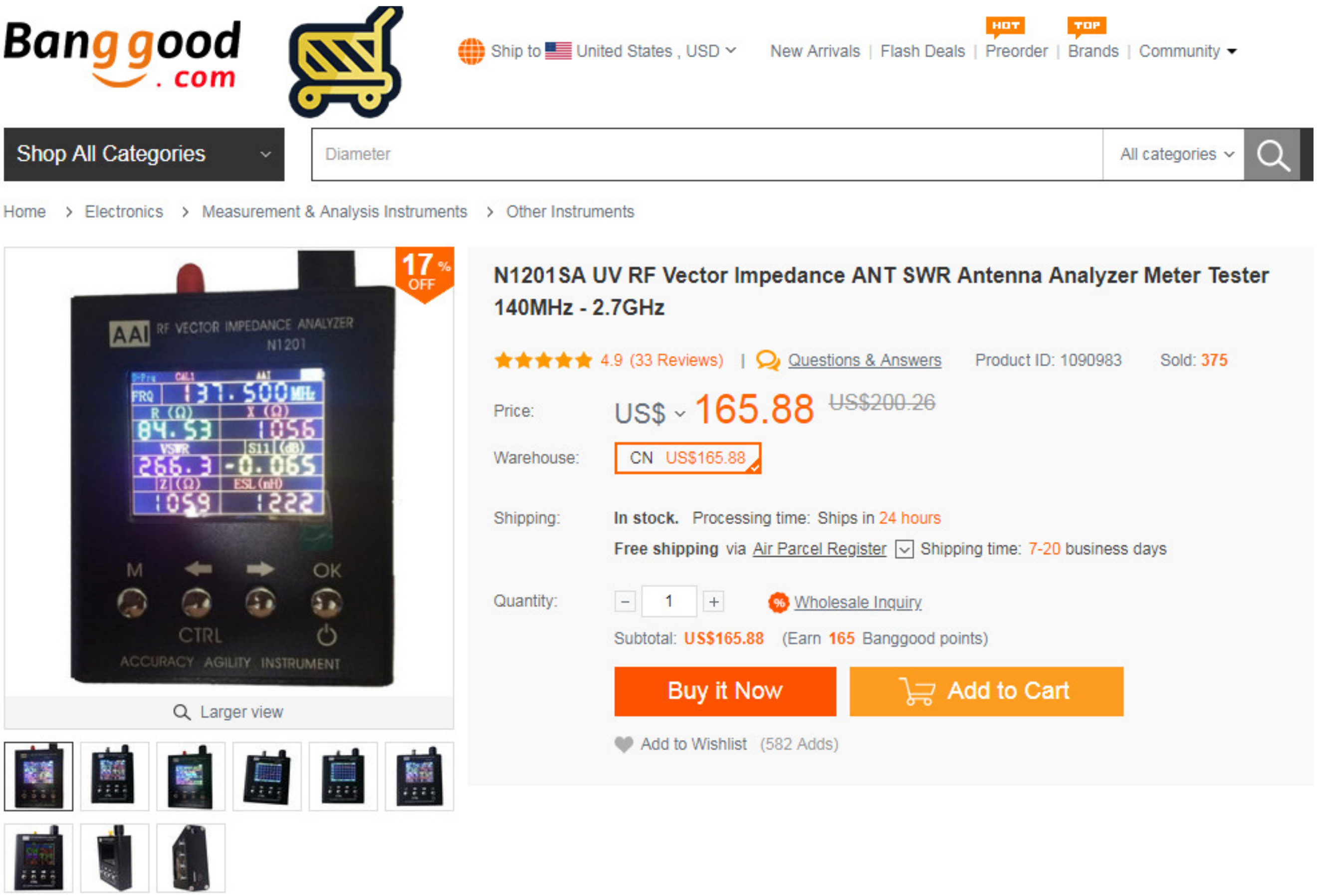

Figure 2- ebay listing for inexpensive Antenna Analyzer

VSWR or SWR

The obvious use for an antenna analyzer is to measure antenna **VSWR**, something hams obsess over. Both analyzers can display **VSWR** across an entire band, as in Figure 3, rather than at a single frequency like the classic VSWR meter. A quick picture with a cellphone camera can record the plot for later reference, to be sure the antenna hasn't changed. In New England, rain, ice, and snow can detune an antenna, so we can check the effect. I neglected to check one winter and blew up a solid-state KW amplifier.

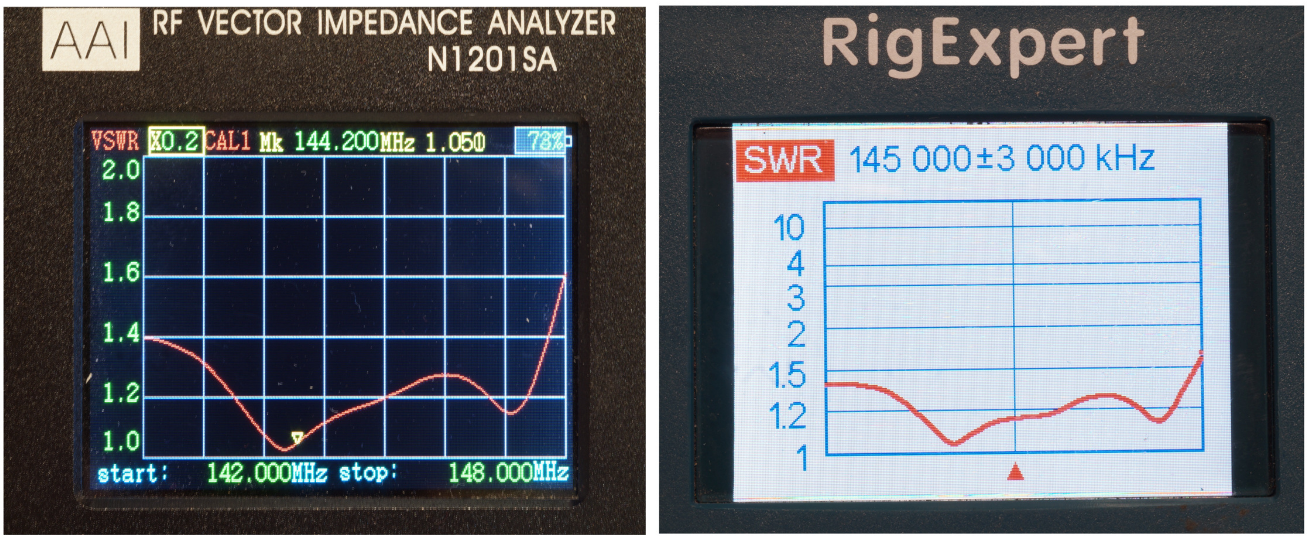

Figure 3 – VSWR swept across entire 2-Meter band

How can we test a beam antenna on the ground, before putting it up, without the ground affecting our measurement? By pointing the antenna straight up, with the reflector a few feet above the ground. This might involve a wooden ladder and some ropes for temporary support, and is obviously easier with a VHF or UHF antenna than a 40 meter beam.

Rotor Loop Test

Once an antenna is up in the air, its cables start to degrade. For a rotatable antenna, the rotor loop, the flexible part of the feedline, is often the first component to cause trouble. If we monitor the swept **VSWR** display in Figure 3 while the antenna is rotated, any significant variation could indicate a broken or loose connection, or water in the coax.

I found this tricks some years ago, before convenient portable antenna analyzers. I managed to connect a large network analyzer, too heavy to lift, to a misbehaving antenna. On the swept **VSWR** or Return Loss display, the hills and valleys moved around as the antenna rotated. I had used coax with air cavities for the rotor loop, and water drained out after I removed it.

Feedline Loss

All feedlines have some loss, and bad feedlines exhibit more loss than others. We can measure feedline loss between the shack and an antenna without climbing the tower. Most antennas will reflect nearly all of the power at some out-of-band frequencies. If all the power is reflected at the antenna, the difference between forward and reflected power, the Return Loss measured in the shack, is the power lost in the feedline. Since the reflected signal has traveled through the feedline twice, the cable loss is half the Return Loss.

We find the cable loss by widening the frequency range until we find frequencies with very high **VSWR**, or low Return Loss. Then we can estimate the cable loss as half the Return Loss. In Figure 4, the Return Loss plot of my 144 MHz Yagi is swept over a wider frequency range than in Figure 3. The antenna is well matched (high Return Loss) in the band, but the Return Loss outside the band is small, about 4.9 dB at 154 MHz, marked by the small triangle below the trace. The feedline loss is half of 4.9 dB, or about 2.5 dB.

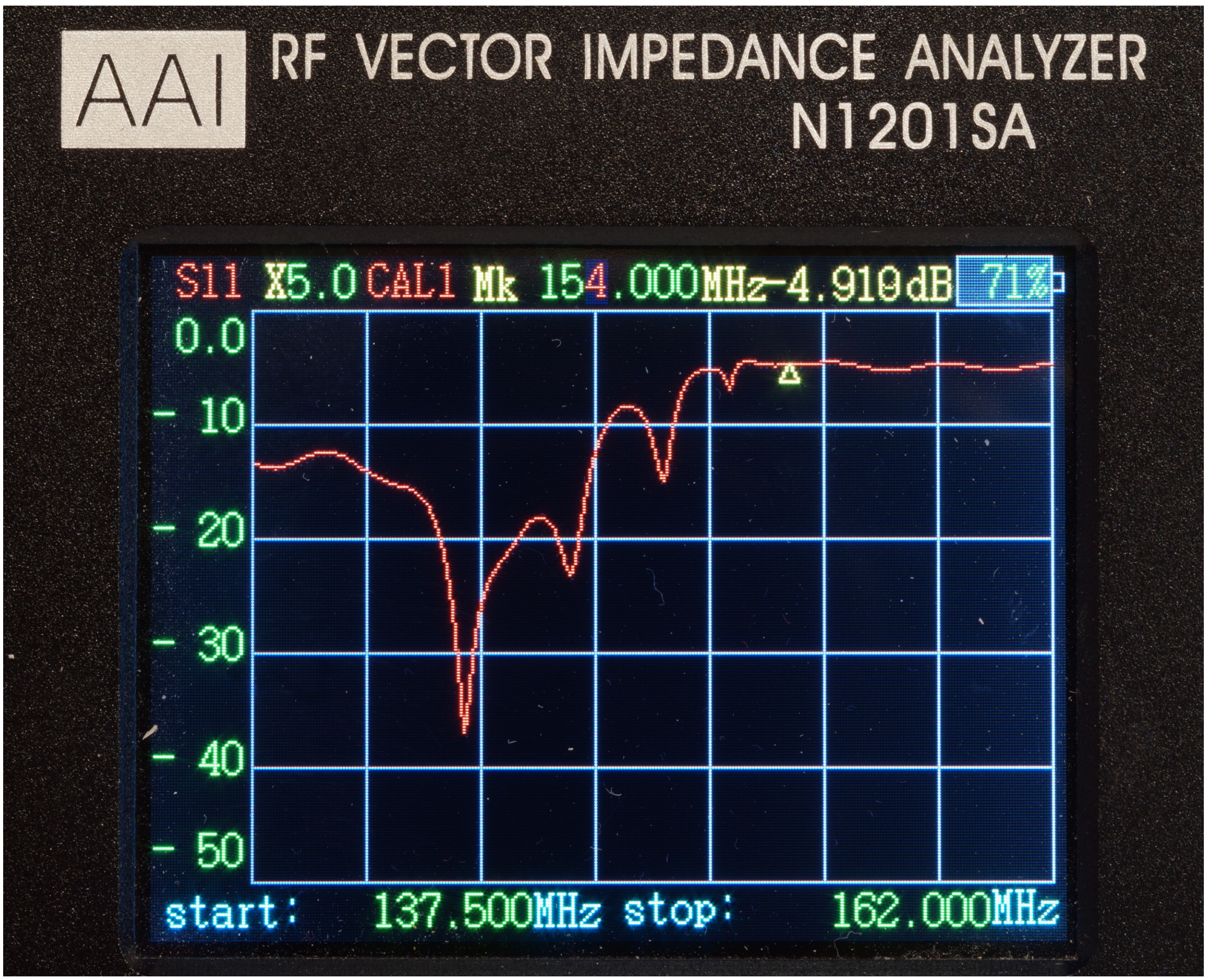

Figure 4 – VSWR sweep over wider frequency range to find cable loss

Cable Length or Distance to Fault

Some cables are worse than lossy: they are broken, shorted, kinked, or disconnected. A large discontinuity in a cable, like an open or short, causes a large reflection. Transmission lines are also impedance transformers – a quarter-wavelength of transmission line inverts the impedance, so that a short circuit (**Z = 0**) at one end appears as an open circuit (**Z=infinite**) at the other end. A second quarter-wavelength inverts the impedance again, back to the original impedance. A third quarter-wavelength inverts again, so ¾ λ is the same as ¼ λ. Additional quarter-wavelengths repeat the pattern, so that every half-wavelength produces an identical impedance. Alternately, we can look at frequency – a half-wavelength at one frequency is two half-wavelengths at twice the frequency, three half-wavelengths at three times the frequency, and so on.

We use this property to find cable length with an open circuit or short on the far end, or the distance to a fault on a transmission line. Displaying impedance **Z** on the analyzer over a wide frequency range will show a series of high impedance points and low impedance points (Figures 5 and 6). The high impedance peaks are much sharper, so it is easier to read their frequencies. The difference in frequency ΔFreq between any two peaks is the frequency where the cable is an electrical half-wavelength long. Then we can calculate the length:

$$\boldsymbol{Electrical\ Length} = \frac{\boldsymbol{c}}{\boldsymbol{\Delta Freq * 2}}$$

where **c** = the speed of light, 3 x 10^8 meters per second.

In Figure 5a, we use the Marker (Mk) frequency at the top of the screen to find the frequency of the first peak, 251.5 MHz. Similarly, in Figure 5b, the Marker frequency is at the second peak, 378.5 MHz. The difference, ΔFreq, is 127 MHz. Neglecting the velocity factor, we can calculate the electrical length of the cable as 1.18 meters.

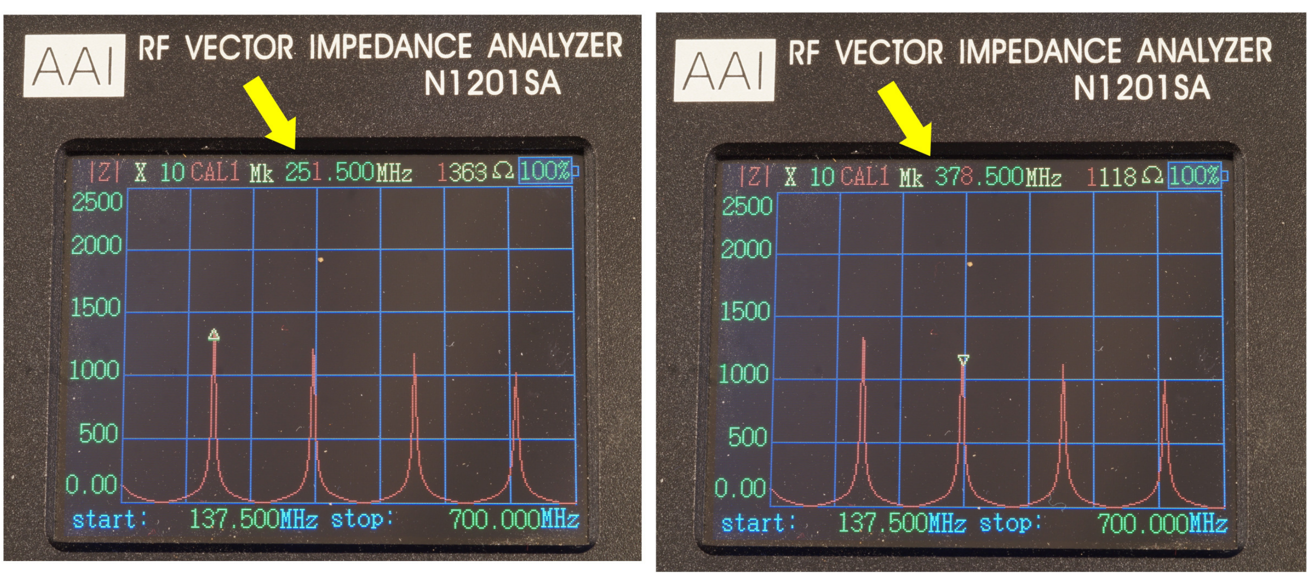

Figure 5 – Using Markers to find frequencies of impedance peaks for estimating cable length.

Figure 6 shows a longer cable: the frequency difference between 149.4 MHz in Figure 5a and 171 MHz in Figure 5b is 21.6 MHz, for an electrical length of 13.9 meters.

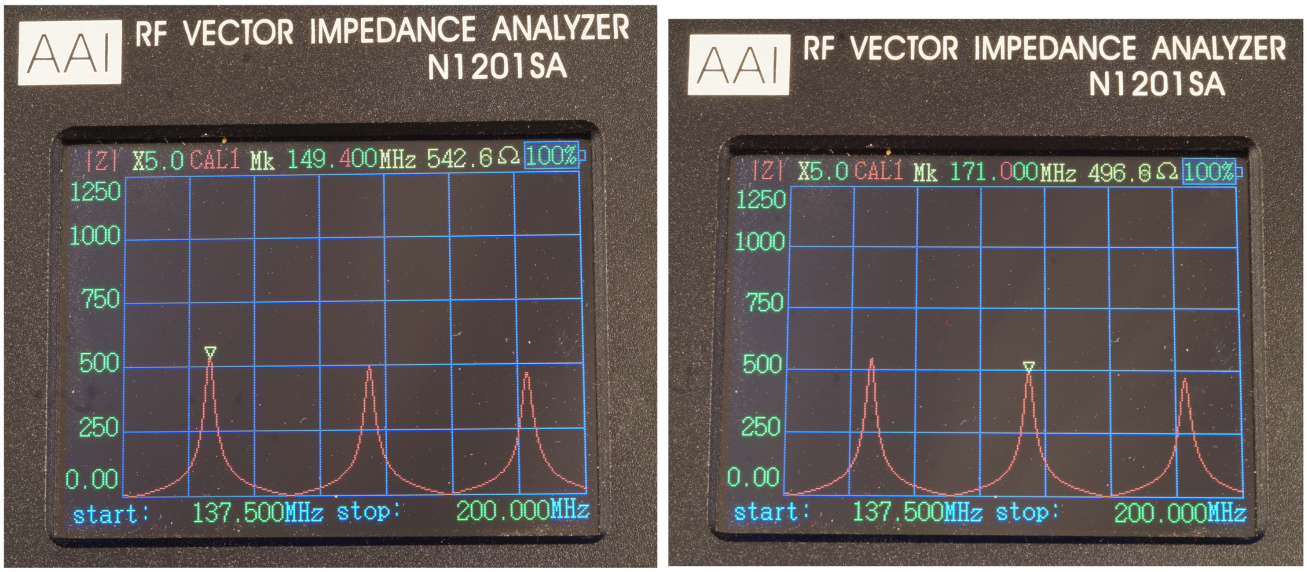

Figure 6 – Impedance peaks for a longer cable

Velocity factor

Common coaxial cable is constructed with a plastic dielectric, which slows down the RF, so it does not travel at the speed of light through the coax, but at a slightly slower speed, typically about 2/3 of the speed of light, so the velocity factor would be 0.66 or 66%. Cables with foam dielectric have less plastic and more air in the foam, so they have a velocity factor that is a bit higher. For an unknown cable, we can estimate the velocity factor $\mathbf{V_f}$ if we know the physical length.

$$V_f = \frac{Physical\ Length}{Electrical\ Length}$$

But if we don't know either, say a roll of cable too big to unwind, a good guess for the velocity factor would be 66%, a common value for ordinary coaxial cable. Then we can roughly estimate the length:

$$Physical\ Length = V_f \cdot Electrical\ Length$$

For the cable in Figure 5, 0.66 **x** 1.18 meters = 0.78 meters – my tape measure says 0.79 meters – and about 9.2 meters for the cable in Figure 6.

Cable Characteristic Impedance

I bought a bag of nice jumper cables at a hamfest, but when I used them, results were sometimes strange. So I tested one with the antenna analyzer, with a 50-ohm termination on the end, resulting in the plot shown in Figure 7. The plot of **R**, the resistive part of the impedance, for a standard 50-ohm cable would be 50 ohms at all frequencies, so this cable has a different characteristic impedance, $\mathbf{Z_0}$.

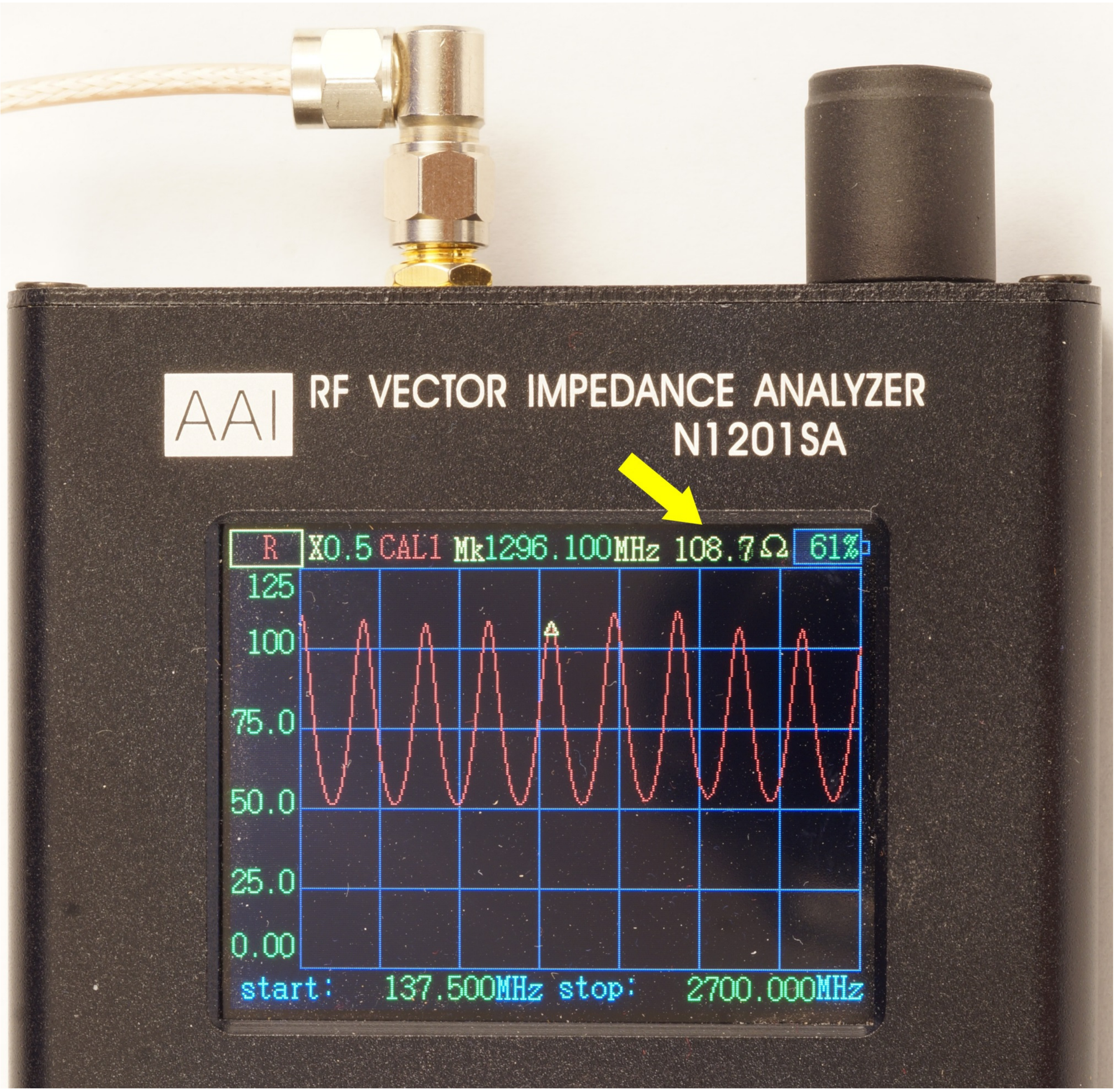

Figure 7 – Swept plot of R, for calculating cable Characteristic Impedance

We can see that the pattern is repeating every half-wavelength, like the cable length measurement. At frequencies where the cable is ½ λ long, the impedance $\mathbf{Z_{in}}$ seen at the input is the same as at the load at the far end: $\mathbf{Z_{in} = Z_{load}}$ = 50 ohms. Halfway between the 50 ohm frequencies, we see a much higher impedance, $\mathbf{Z_{in}}$ = 108.7 ohms at the marker. At these ¼ λ frequencies, the impedance $\mathbf{Z_{in}}$ is resistive, so the calculation for the impedance transformer is simple:

$$Z_{in} = \frac{Z_0{}^2}{Z_{load}}$$

Then $$Z_0 = \sqrt{Z_{in} * Z_{load}} = \sqrt{50 * 108.7}$$

and the cable characteristic impedance $\mathbf{Z_0}$ is calculated as 73.7 ohms. This is obviously a 75-ohm cable, another common cable impedance.

Phasing Line Matching

For many antenna arrays, phasing lines with matched electrical length are needed. We can calculate lengths as we did above, but it is possible to match the lengths more accurately. At the frequencies where the impedance peaks, the reactance changes abruptly from inductive to capacitive. We can see this by switching the display to show reactance **X** like Figure 8 – the reactance changes abruptly from positive (inductive) to negative (capacitive). We can measure the frequency of the abrupt change in sign accurately, and trim each cable to the same frequency and have identical electrical lengths. The exact frequency doesn't matter.

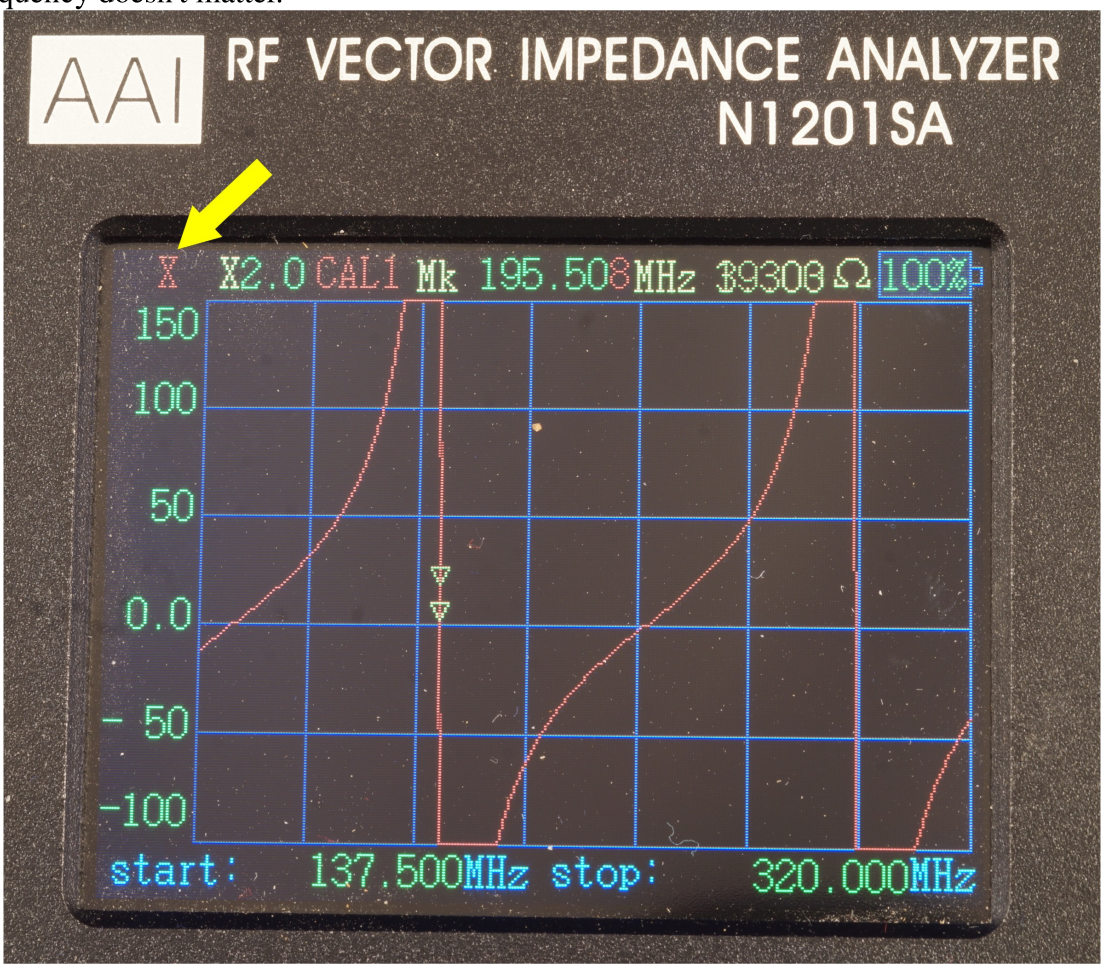

Figure 8 – Trimming length using frequency where reactance X changes abruptly

Tuning Stubs

Quarter-wavelength stubs are often used as filters for harmonic reduction or as traps for removing a specific unwanted frequency. As we saw when measuring cable length, quarter-wavelength of transmission line with a short circuit on the far end looks like a very high impedance at the input. But at twice the frequency, it is a half-wavelength long, so the input also looks like a short circuit – the second harmonic is shorted out.

To measure the resonant frequency of a stub, it is connected with a T-connector, with a 50-ohm termination on the other leg, as shown in Figure 9. Then the stub can be tuned for maximum **VSWR** at the desired frequency, and the display switched to show **X** for fine tuning. We can also estimate how sharp the stub response is, and whether it has any effect at operating frequencies.

Figure 9 – Measuring resonant frequency of a stub

Several stubs can be used to reduce multiple harmonics, with the stubs separated by lengths of transmission line or at lower frequencies by inductors[2]. The whole assembly may be tested just like a single stub, to see that the VSWR is low at the desired frequency and high at the harmonic frequencies. A final test would be to replace the 50-ohm termination with the antenna.

Grid Dip Meter Replacement

RF equipment is full of tuned circuits, and it is important to know the resonant frequency. Back in the Dark Ages, every homebrewer had a Grid Dip Meter. This is a tunable oscillator with an external coil. When the coil is held near a resonant circuit, some of the oscillator energy is sucked out of the coil when it is tuned to the resonant frequency, and the grid current would decrease (dip). Thus we could find the resonant frequency of a tuned circuit, even when in equipment. The trick is to couple loosely; otherwise the oscillator circuit and tuned circuit detune each other and produce an erroneous frequency reading.

Solid-state versions lack grids, so they used diode detectors to detect oscillator energy in the coil. But these instruments seem to have gone out of favor – mine is more than 50 year old, and getting finicky (like its owner).

An antenna analyzer can work as a dip meter – it has an oscillator and a detector. We attach a small coil to the analyzer, with a short cable for convenience, and place the coil near a tuned circuit to couple some energy. The maximum amount of energy is coupled to the tuned circuit at its resonant frequency, producing the dip in the **|S11|** or Return Loss trace in Figure 10. Tuning the circuit moves the dip, allowing us to tune the circuit to the desired frequency. Moving the coil closer or farther away can demonstrate detuning changing the resonant frequency.

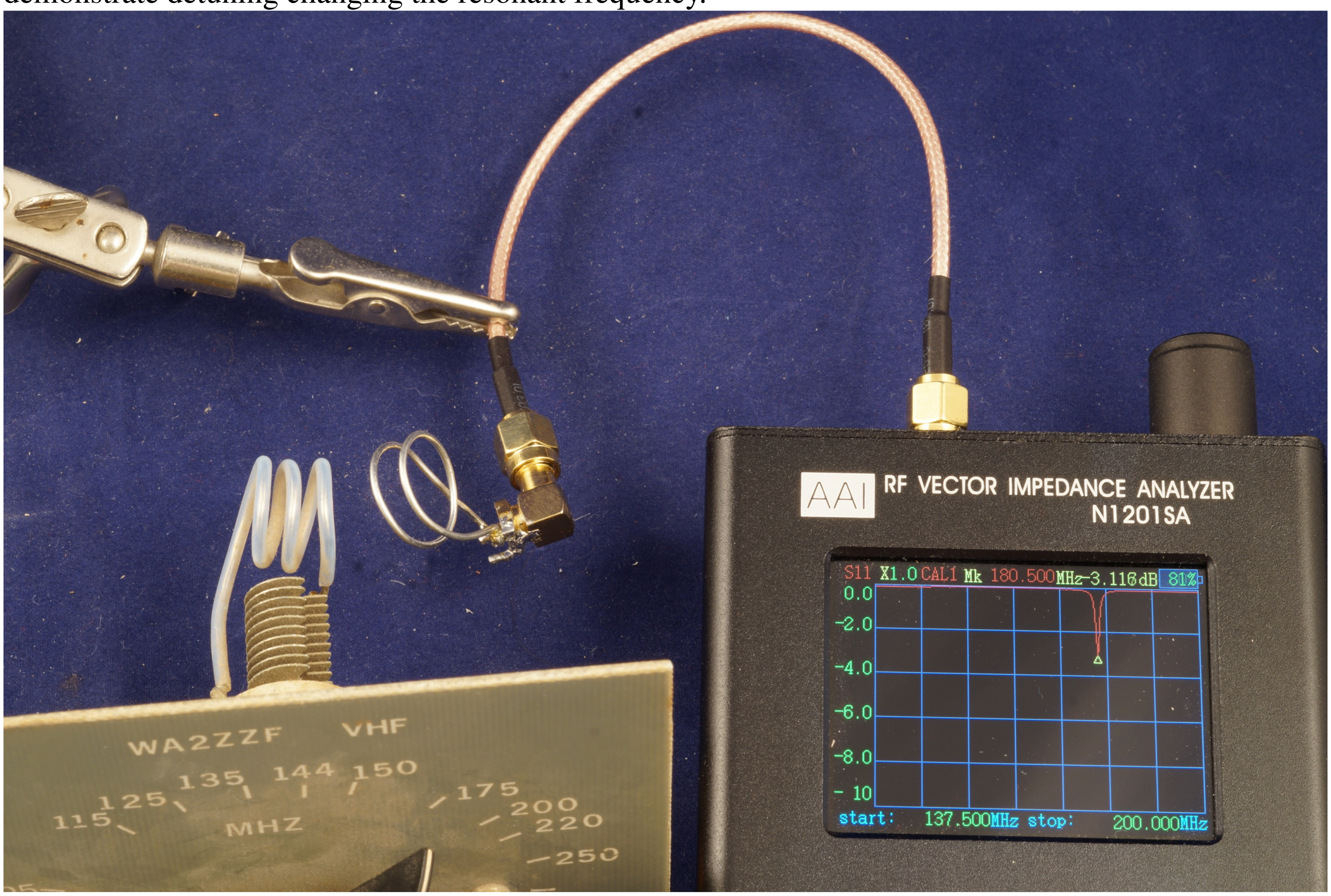

Figure 10 – Using Antenna Analyzer as a Grid Dip Meter to find resonant frequency

While the photo shows an isolated tuned circuit, this technique will often work in complete equipment. Vacuum tubes have high impedances, especially with no voltages applied, but solid-state equipment usually has lower impedances so the dip is much less pronounced.

Filter Tuning

Filters with multiple resonators are valuable for removing undesired signals, either coming through the antenna or generated by our equipment. They can be devilishly hard to tune without good test equipment. But we do have good test equipment – the antenna analyzer. If the antenna analyzer has a Polar or Smith Chart display, which mine does not, we can try a method described by Martin and Ness[1].

Most of the filters I have built, and many used by hams, have only two or three coupled resonators. These relatively simple filters can be approximately tuned with the antenna analyzer. We start by detuning all the resonators, then connect the analyzer to one end and tune the nearest resonator for a dip in the **|S11|** or Return Loss trace, just as we did in Figure 10. Then connect the analyzer to the other end of the filter and again tune for a dip; if there are only two resonators, you may see a double dip. Next, connect a 50-ohm termination to the far end of the filter, and the Return Loss should improve significantly for a filter with two resonators. If there is a third resonator in the center, it should now be tuned for best Return Loss. This filter tuning should be close enough to fine tune for maximum signal in the system.

We can also estimate the operating frequency of an unknown surplus filter by looking at the Return Loss with the far end terminated. If the frequency isn't useful but is not too far from a ham band, we can adjust the end resonator to see if it might be tunable to that band.

Vector Network Analyzer

Since the antenna analyzer is really a network analyzer, why not use it as one? The Vector term implies complex impedance, R + jX; our analyzer provides both R and X, so we can put them together as a complex impedance. Then we can plot them on a Smith Chart or use a software simulator to do impedance matching. For instance, in QST Microwavelengths for July 2016, I used an analyzer to do simple impedance matching using transmission lines and stubs.

Please note that I have said "about" or "approximately" quite frequently. A laboratory Vector Network Analyzer requires a careful calibration procedure to be performed often, and then used to calculate computer corrections for high accuracy. With an antenna analyzer, accuracy to even one decimal place is optimistic, but is quite adequate for ham use.

Summary

An antenna analyzer is too useful a piece of test equipment to be limited to antenna measurements. As a network analyzer, it can do much more, and is far more convenient, portable, and affordable than commercial network analyzer. These are a few of the things you can do with one, but hams are resourceful and can probably come up with others. So teach your analyzer some new tricks.

Notes

1. Peter Martin & John Ness, "Coupling Bandwidth and Reflected Group Delay Characterization of Microwave Bandpass Filters," www.rfshop.co.uk/Martin.pdf
2. John Regnault, G4SWX, "Coaxial Stub Filters," http://www.ifwtech.co.uk/g3sek/swxfiltr/swxfiltr.htm