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Antenna Analyzer Pet Tricks

Discover a range of measurements you can make with your antenna analyzer.

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. Teach your antenna analyzer a few new tricks and it might become your favorite pet.

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 "go to" piece of test gear is a network analyzer. A VNA (Vector Network Analyzer) is 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.

My antenna analyzer is an inexpensive one from China, shown on the left in Figure 1. I chose it because it covers a wide frequency range, 137.5 to 2,700 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. The measurements I am about to describe 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 1,400 MHz, covering all bands from 160 meters to 1,296 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 measurements, 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.

Figure 1 — Handheld antenna analyzers.

VSWR or SWR

The obvious use for an antenna analyzer is to measure antenna VSWR or SWR ([Voltage] Standing Wave Ratio), something hams obsess over. Both analyzers can display VSWR across an entire band, as in Figure 2, rather than at a single frequency like the classic VSWR meter. A quick picture with a cell-phone 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 kilowatt amplifier.

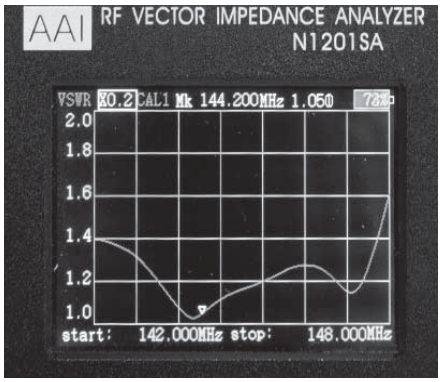
Return Loss (RL) and VSWR are both measures of relative reflected power. Return Loss is the difference between Forward and Reflected power in dB. A dead short (or an open) will reflect all of the forward power — the return loss is 0 dB, or VSWR is infinite. A good antenna might reflect only 1% of the 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 by calculation, but most antenna analyzers can display both Return Loss and VSWR. My analyzer displays |S11|, the magnitude of S-parameter S_{11}, which in decibels is the negative of Return Loss.

Antenna analyzers are sold as "antenna analyzers" but they do lots more. All the things they do are built on their ability to measure VSWR. But first, that VSWR trick is very useful. Not only can you detect degradation of an antenna in place, but you can even pre-tune a beam antenna on the ground, before putting it up, without the ground affecting our measurement. Test the antenna pointing 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 feed line — is often the first component to cause trouble. Any significant variation in swept frequency VSWR display in Figure 2 while the antenna is being rotated could indicate a broken or loose connection or water in the coax.

I found this trick 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 a coax connector.



(A)

(B)

Figure 2 — VSWR of 2-meter beam swept across entire 2-meter band on (A) the AAI N1201SA, and (B) RigExpert analyzers.

Feed-line Loss

All feed lines have some loss, and bad feed lines exhibit more loss than others. We can measure feed-line 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, then the difference between forward and reflected power — the Return Loss measured in the shack — is due to the power lost in the feed line. Since the reflected signal has traveled through the feed line twice, the cable loss is half the Return Loss in decibels.

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 3, the Return Loss plot of my 144 MHz Yagi is swept over a wider frequency range than in Figure 2. The antenna is well matched (high Return Loss) in the band, but the Return Loss outside the band is small, about 4.9 dB. The feed-line loss is half of that, or about 2.5 dB.

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 Z, 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. Alternatively, 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 4 and 5). The high impedance peaks are much sharper, so it is easier to read their frequencies. The difference in frequency ($\Delta Freq$) between any two peaks is the frequency where the cable is an electrical half-wavelength long. We can then calculate the length:

$$\text{Electrical Length} = \frac{c}{\Delta Freq \cdot 2}$$

where c is the speed of light, ~3×10^8 m/s.

In Figure 4A, we adjust the Marker (Mk) frequency at the top of the screen to find the frequency of the first peak, 251.5 MHz. Similarly, in Figure 4B, the Marker frequency is at the second peak, 378.5 MHz. The frequency difference $\Delta Freq$ is 127 MHz. Neglecting the velocity factor, we can calculate the electrical length of the cable as 1.18 meters.

Figure 5 shows a measurement of a longer cable. The frequency difference between 149.4 MHz in Figure 5A and 171 MHz in

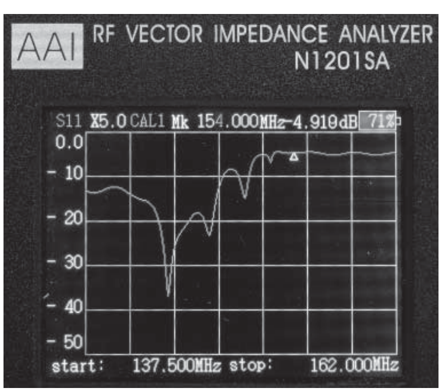
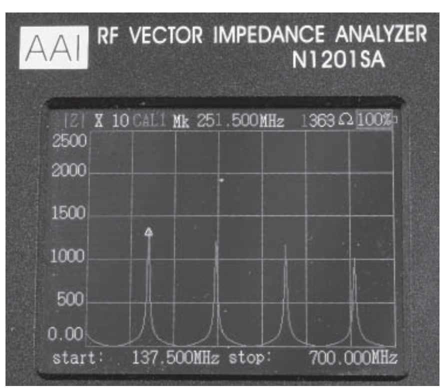
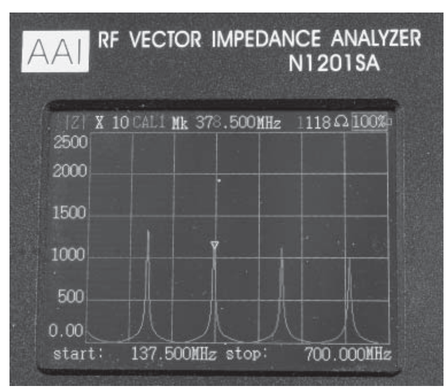


Figure 3 — VSWR sweep over wider frequency range to find cable loss.



(A)



(B)

Figure 4 — Using Markers to find frequencies of impedance peaks for estimating cable length. The marker is set at (A) to 251.500 MHz, and at (B) to 378.500 MHz.

Figure 5B is 21.6 MHz, for an electrical length of 6.94 meters.

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 V_f if we know the physical length:

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

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:

$$\text{Physical Length} = V_f \cdot \text{Electrical Length}$$

For the cable in Figure 4, 0.66 × 1.18 meters = 0.78 meters — my tape measure says 0.79 meters — and about 4.9 meters for the cable in Figure 5.

Cable Characteristic Impedance

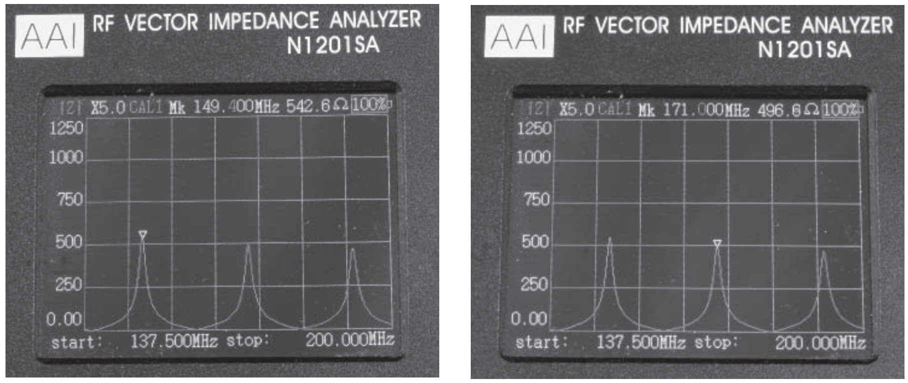
I bought a bag of nice jumper cables at a ham fest, but when I used them, results were sometimes strange. So I tested one with the antenna analyzer, with a 50 Ω termination on the end, resulting in the plot shown in Figure 6. The plot of *R*, the resistive part of the impedance, for a standard 50 Ω cable would be 50 Ω at all frequencies, so this cable has a different characteristic impedance Z_0. The *R* plot shows a repeating pattern — it repeats every half-wavelength, like the cable length measurement. At frequencies where the cable is ½ λ long, the impedance Z_{in} seen at the input is the same as at the load at the far end: $Z_{in} = Z_{load} = 50\ \Omega$. Halfway between the 50 Ω frequencies, the impedance is much higher: $Z_{in} = 108.7\ \Omega$ at the marker. At these ¼ λ frequencies, the impedance Z_{in} is resistive, so the calculation for the impedance transformer is simple:

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

then,

$$Z_0 = \sqrt{Z_{in} \cdot Z_{load}} = \sqrt{50 \cdot 108.7} = 73.7\ \Omega$$

and the cable characteristic impedance Z_0 is calculated as 73.7 Ω. This is obviously a 75 Ω cable, another common cable impedance.



(A) (B)

Figure 5 — Impedance peaks for a longer cable; (A) at 149.400 MHz, and (B) at 171.000 MHz.

Figure 6 — Swept frequency plot of R, for calculating cable characteristic impedance.

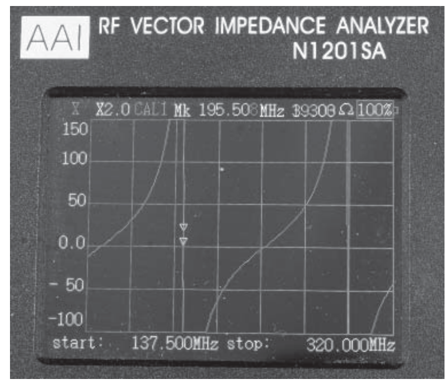


Figure 7 — Use the frequency where reactance X changes abruptly to match cable lengths.

Phasing Line Matching

Phasing lines with matched electrical length are often needed for antenna arrays. 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 from inductive to capacitive. We can see this by switching the display to show reactance *X* as in Figure 7 — 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.

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 by a ¼ λ stub.

The stub is connected to a T-connector at the antenna analyzer with a 50 Ω termination on the other leg, as shown in Figure 8. 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, by the frequency range with very high VSWR, and see whether the stub has any effect on VSWR at operating frequencies.

Several stubs can be used to reduce multiple harmonics, with the stubs separated by lengths of transmission line or, at lower frequencies, by inductors[1]. The whole assembly can 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 Ω 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 home brewer had a Grid Dip Meter. This is a tunable oscillator with an external coil.

Figure 8 — Measuring resonant frequency of a stub

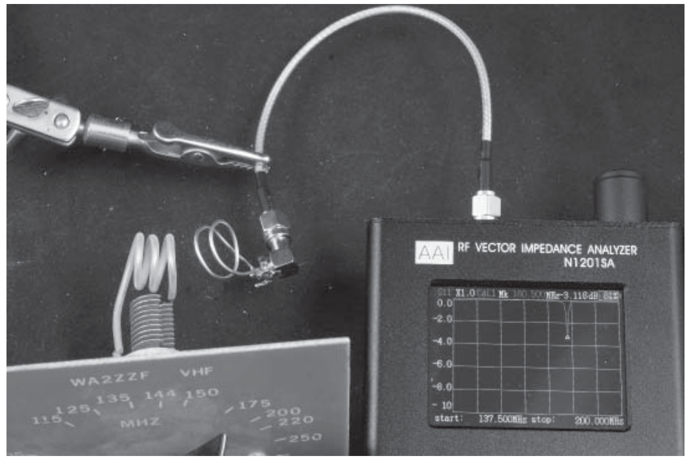


Figure 9 — Using the Antenna Analyzer as a Grid Dip Meter to find the resonant frequency of a tuned circuit. The alligator clip is for mechanical support.

Figure 10 — Schematic diagram of a 432 MHz low-pass filter.

When the coil is held near a resonant circuit, some of the oscillator energy is sucked out of the coil when the Grid Dip Meter 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 it is 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 all these instruments seem to have gone out of favor. Mine is more than 50 years old, and is 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 9. 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.

While the photo shows an isolated tuned circuit, this technique will often work with components in-place in 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.

Inductance Measurement

It is very difficult to measure the small inductances we use at VHF and higher frequencies with a meter — the inductance of test leads is greater than the desired inductance. I recently needed a low-pass filter for a small power amplifier module at 432 MHz to remove harmonics from the output. Using free software, I designed one that provides the desired performance, but the inductor values, shown in the schematic diagram in Figure 10, are quite small.

I guessed that a small 3-turn inductor might be in the ballpark for the small inductances. I wound one around a Q-tip and soldered it to a scrap of printed-circuit board in parallel with an 18 pF chip capacitor to form a resonant circuit, and added an SMA connector to connect the Antenna Analyzer.

The inductor and capacitor form a parallel-resonant circuit, which has high impedance at the resonant frequency and lower impedance at other frequencies. Figure 11 shows the impedance plot *Z* on the antenna analyzer, with the marker at the resonant frequency, 226 MHz. The resonant frequency calculation is

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

Turning this around, inductance is

$$L = \frac{1}{C \cdot (2\pi f)^2}$$

The inductance to resonate with 18 pF at 226 MHz is 28 nH, close to the desired value for the center inductor — inductance can be adjusted a bit by squeezing the turns together or stretching them apart.

Figure 11 — Measuring resonant frequency of a parallel-resonant circuit to determine the value of a small inductance.

Removing one turn and re-soldering changed the resonant frequency to 289 MHz, for an inductance of 17 nH, which is in the ballpark for the smaller values.

Filter Measurement

I assembled the low-pass filter on the amplifier printed-circuit board with temporary SMA connectors to measure the VSWR that the amplifier module will see with a 50 Ω termination at the filter output. A low-pass filter should act like a transmission line below the cutoff frequency, but have a high VSWR at frequencies above the cutoff frequency so that those frequencies are reflected rather than passing through.

The VSWR plot in Figure 12 for the low-pass filter shows a low VSWR, like a transmission line, below 432 MHz, and very high VSWR above 432 MHz, with a 50 Ω termination at the filter output. Note that I designed the filter for optimum performance at the operating frequency at the expense of a slightly higher VSWR at lower frequencies — a very good 432 MHz filter rather than a good low-pass filter. Also, for each 10 pF capacitor, I used two 5 pF chip capacitors in parallel for lower loss.

I must admit that the plot in Figure 12 wasn't the first try. The first one, with the inductors from Figure 11, was slightly high in frequency even after squeezing the inductors — I hadn't allowed for the stray capacitance of the PC board. Winding new inductors with a slightly larger diameter got it right.

A band-pass filter may also be measured with the Antenna Analyzer. With a 50 Ω termination at the filter output, the VSWR should be low in the passband, where the filter is acting as a transmission line, and high at other frequencies. Figure 13 shows the VSWR plot of a band-pass filter for 432 MHz.

This simple filter measurement is also useful for unknown filters at ham fests. I occasionally see a box of filters with cryptic markings. A quick test with the Antenna Analyzer might find a useful one, or one at a frequency close enough to retune.

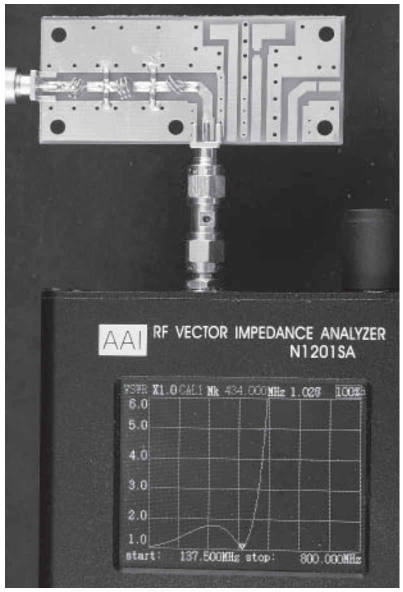


Figure 12 — Input VSWR of low-pass filter with 50 Ω termination on the output.

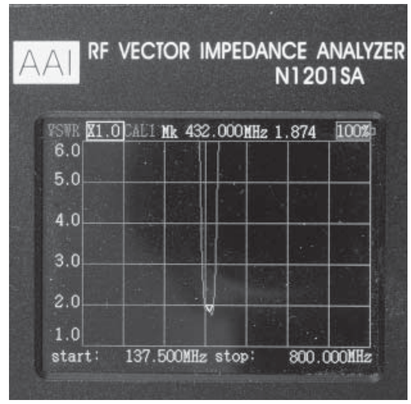


Figure 13 — Input VSWR of a band-pass filter with 50 Ω termination on the output showing the filter frequency range.

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[2].

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. 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, like Figure 9, at the filter center frequency. Then connect the analyzer to the other end of the filter and again tune for a dip; if there are only two resonators, there may be a double dip. Next, connect a 50 Ω termination to the far end of the filter, and the Return Loss should improve significantly for a filter with two resonators. Filters with a third resonator in the center should now be tuned for best Return Loss. This filter tuning should be close enough to fine tune for maximum signal in the system.

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, which can be put together as a complex impedance. Then the complex impedance can be plotted on a Smith Chart or entered into a software simulator to do impedance matching. For instance, in *QST* "Microwavelengths" for July 2016, I used a network analyzer to do simple impedance matching using transmission lines and stubs — an antenna analyzer would do just as well.

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 uses 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 a 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.

Acknowledgements

Thanks to Don Twombly, W1FKF; Chip Taylor, W1AIM; and Matt Reilly, KB1VC; for help with this project.

Paul Wade, W1GHZ, previously N1BWT and WA2ZZF, has been licensed since 1962 and has never made a contact below 50 MHz. He has been a microwave experimenter for years and has published numerous articles as well as the "Microwavelengths" column in QST. He is active in the Vermont 10 GHz group and is past president of the North East Weak Signal Group. An ongoing project is the "W1GHZ Microwave Antenna Book", online at ***www.w1ghz.org****.*

In 1997, he was honored by the Central States VHF Society as the recipient of the Chambers Award. He has been honored by the ARRL with the 2000 Microwave Development Award, in 2001 with the Thomas Kirby Eastern VHF/UHF Society Award, and in 2009 by Microwave Update and the North Texas Microwave Society with The Don Hilliard Award for Technical Contributions to the Microwave Community.

After a long career in electrical engineering, he and Beth, N1SAI, are now happily retired in Vermont with a new puppy named Hannah. Paul was also a ski instructor for a time, and now enjoys skiing on a new bionic knee, and skijoring with Hannah.

Notes

[1]John Regnault, G4SWX, "Coaxial Stub Filters," **www.ifwtech.co.uk/g3sek/swxfiltr/swxfiltr.htm**.

[2]Peter Martin and John Ness, "Coupling Bandwidth and Reflected Group Delay Characterization of Microwave Bandpass Filters," **www.rfshop.co.uk/Martin.pdf**.