Rudy Severns, N6LF

PO Box 589, Cottage Grove, OR 97424; **n6lf@arrl.net**

Conductivity of Trees at HF

N6LF publishes his measurements of tree dielectric parameters.

The effect of trees on HF antennas has been a very long running discussion in the amateur community with little resolution or hard data. During the 1960s and 1970s much work was done for the military on propagation through jungle forests, but much of this work was for frequencies above 50 MHz, so it didn't really answer the questions. In the February 2018 edition[1] of *QST* Kai Siwiak, KE4PT, and Richard Quick, W4RQ, took a serious look at this using NEC modeling [as well as infinite cylinder analytical modeling — *Ed.*] to quantify the impact of trees on vertical radiators, which it turns out can be significant. The article is a real step forward.

Electrical Parameters of Trees

A critical part of the analysis is a determination of the electrical characteristics of trees, that is, their conductivity (S/m) and relative permittivity ε_r. After reading their article I realized that I had already performed measurements on both coniferous (Douglas fir) and deciduous (big leaf western maple) trees, which might help. In 2007 I had a 3-element vertical array[2] on 160 m located in a dense fir forest where the trees were conveniently approximately $\lambda/4$ high and close to the antenna, within 50 ft, well within the near-field. While the array seemed to work okay I wondered just how much I was losing to the forest so I made some measurements on actual trees.

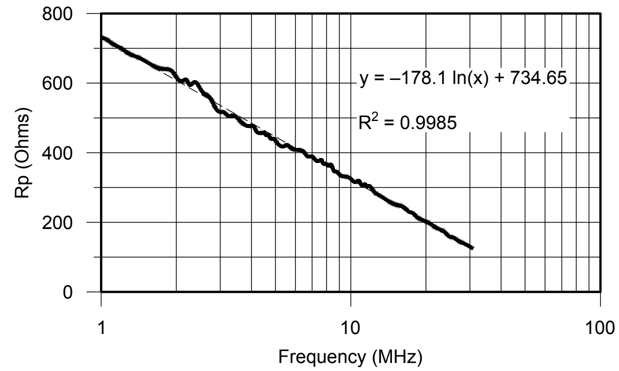
I assumed that the primary loss would be from the longitudinal E-field, that is, the vertical polarization, and that a tree could be viewed as a cylindrical vertical impedance which could be measured experimentally. For the experiments I drove a series of nails approximately 2 inches long, connected with a wire to form two rings about one foot apart as shown in Figure 1. The impedance between the two rings was measured using a vector network analyzer (an N2PK VNA). Measurements were made on Douglas fir — diameter at the inner bark of 10 inches — and big leaf maple — 8 inch diameter — trees in late March when the sap was up.

One problem when using a VNA is the need to properly calibrate out the effect of the cable and leads to the two rings, to isolate the impedance of the tree between the two rings. For the open-circuit, short-circuit, load calibration procedure I used a plastic trash can as shown in Figure 2.

The trash can diameter was about the same as the trees being measured. The interconnected nails in each ring were inserted into holes. The open-circuit calibration is shown in Figure 2, for the short-circuit calibration I used 6 parallel wires distributed symmetrically around the trash can each end

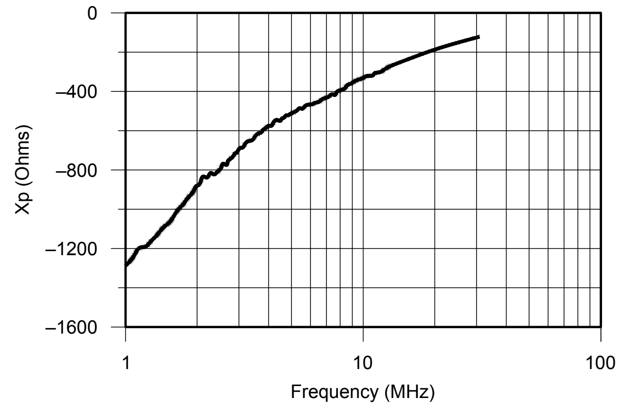
Figure 1 — Impedance measurement on a Douglas fir tree.

Figure 2 — Calibration test fixture shows the AIM4170 as the VNA, but the same fixture was used to calibrate the N2PK vector network analyzer that was used for the actual measurements.



QX1805-Severns03

Figure 3 — Fir tree equivalent parallel resistance, *Rp*, second run, 25 Mar. 2007.



QX1805-Severns04

Figure 4 — Equivalent parallel impedance, *Xp*, second run, 25 Mar. 2007.

connected to the ring. For the load calibration I inserted resistors in series with these wires with a total parallel resistance of 50 ohms.

Test Results

In the first test I connected a dc ohmmeter between the rings. What I noticed immediately was the resistance changing slowly over time much like what you see when checking an electrolytic capacitor for leakage current. The sap of the tree is an electrolyte so that behavior was not a surprise. For the impedance measurements I assumed a parallel *Rp Cp* equivalent circuit. Samples of typical measurements are given in Figures 3, 4, and 5. The general behavior was much the same for both the fir and the maple trees.

The conductivity and permittivity, as a function of frequency, appear to behave very much like soil[3]; conductivity (σ) goes up with increasing frequency — *Rp* goes down — and ε_r goes down with increasing frequency to a point where it flattens out (*Cp* is a function of ε_r).

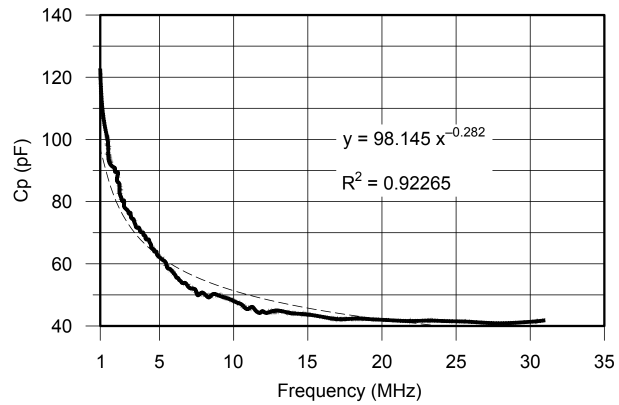
I made an estimate of σ from the equation for a resistor:

$$\sigma = \frac{L}{(Rp)(A)}$$

where *L* is the 12 inch (0.3048 m) distance between rings; *A* is the effective cross sectional area in square meters.

Determining the cross sectional area, *A*, is a bit tricky. If you assume the conduction is limited to the cambium, a thickness of about 0.125 inches (0.003175 m), and the diameter is 10 inches (0.254 m), then $A = 0.00253$ m^2. From Figure 3, *Rp* is about 325 Ω at 10 MHz. This gives $\sigma = 0.37$ S/m, which seemed pretty high! However, that number is based on a 1/8" conduction layer. Kai, KE4PT, sent me an extract from a book on wood characterization by Bucur[4], which indicates that the characteristics across the entire diameter do not vary greatly, at least for the case of young trees with little or no heartwood. If the wood across the diameter also conducts, then the calculated conductivity is lower. For example, for a diameter *d* of 10 inches (0.254 m), $A = 0.016$ m^2, $\sigma = 0.059$ S/m. This gives a range of conductivity at 10 MHz of about 0.06 to 0.4 S/m. The actual average conductivity is likely somewhere in between.

At this point in my 2007 experiments I found it hard to believe such high values for tree conductivity. Because I did not have any backup from other sources for my measurements I have been reluctant to publish this work. However, in the February 2018 *QST* article the authors assume[5] $\sigma = 0.17$ S/m, which lies within the range of my measurements. Their value was derived from extensive earlier



QX1805-Severns05

Figure 5 — Equivalent parallel capacitance, *Cp*, second run, 25 Mar. 2007.

work in the professional literature so I now have some faith in my measurements. The only additional comment I would add is that the values of conductivity used in the NEC model should include the variation with frequency (dispersion) so clearly shown in my measurements.

I think at this point we can use NEC modeling with some confidence to estimate the effect of trees on HF antennas. Unfortunately that effect appears to be substantial and not a good thing!

Rudy Severns, N6LF, was first licensed as WN7AWG in 1954. He is a retired electrical engineer, an IEEE Fellow and ARRL Life Member.

Notes

[1] K. Siwiak, KE4PT, and R. Quick, W4RQ, "Live Trees Affect Antenna Performance", *QST* Feb. 2018, pp. 33-37.

[2] Rudy Severns, N6LF, "A 3-Element 160 Meter Vertical Array", NCJ May/June 2009, pp. 12-13.

[3] Rudy Severns, N6LF, "Measurement of Soil Electrical Characteristics at HF", *QEX* Nov/Dec 2006, pp. 3-9.

[4] Voichita Bucur, **Nondestructive Characterization and Imaging of Wood**, Springer Series in Wood Science, Chapter 7.

[5] Tree data; D. Tomasanis, "Effective Dielectric Constants of Foliage Media," RADC-TR-90-157, Interim Report AD-A226 269, Jul. 1990.