The Brown Paper and Conclusions with a Ham Focus - N6MW March 25, 2015

The famous paper "Ground Systems as a Factor In Antenna Efficiency" by Brown et al., from 1937* (http://www.k6mhe.com/BLE.html) has previously been discussed by various authors, including N6LF's July 2000 QST article, to try to extract practical ham information for lower band vertical antenna use with radials. The paper is heavily focused on AM broadcast antennas and ground waves, not sky waves so caution is needed.

For those without time and/or strength, here is a quick summary of the paper experimental methodology, mostly ignoring the theoretical discussions in the first half.

Facts:

Using 3 MHz, 100 meters wavelength, vertical antennas of 99, 88, 66,44 and 22 degree heights where used (this is over 1/4 wave to about 1/16 wave). Buried, apparently uninsulated, copper radials of lengths 135 ft (0.411 wavelength), 90 ft and 45 ft were used (never mixed). The number of radials used were one of 2, 15, 30 and 113 and then 8 just once on the ground. Burial depth was about 6 inches. The electrical properties of the ground are not specified although one might think that the conductivity was believed to be between 0.002 and 0.01 S/m based on theoretical examples used (once you unravel the units).

For the nominal 5X3X4=60 combinations, a power of 0.2 watts was fed into the vertical against the radial field and the impedance (R and X) of the system was measured at the base. The electric field strength at about 2 feet off the ground (based on a picture) as measured at 0.3 miles away. While not well described, the test field is likely fairly flat and fairly clear, based on one picture. The field strengths were translated into the equivalent value for 1000 watts input at the antenna base and also scaled to a distance of 1 mile (1609 meters). While it was not spelled out, we assume this means multiplying the raw electric field value by X 1/3.33 for distance and X sqrt (1000/0.2) for power. In addition, the local current in a single one of the radial wires was measured at a number of locations along that wire, the number and locations of these points are not specified. This measurement was made by placing a sensor near purposely exposed sections of the otherwise buried wire. These values are reported as total current in Amps for theoretical sum of all wires (by X number of radials) when converted to 1000 watts driving power.

It is contended that the earth currents (those outside wires) was also measured, including beyond the ends of the radials, although the methodology for this is referenced to another paper and so is unclear. This likely requires some of the theoretical considerations given in the first half of the paper since no description of any underground instrumentation is given. More later.

There are two lesser side experiments reported as well. One is the placement of a 9X9 foot ground screen around the base of the antenna for one case each of 113 and 15 radials, although some details are left out. The second is one time use of 8 radials of 135 ft placed on the ground (not buried) but with ground rods on the ends (outer end only?).

The results of the measurements, where presented, are shown as smooth curves, not data points, and no uncertainty levels are provided. It is not explicitly stated as to whether the current and field values are peak or rms values although equations (3) and (4) suggest the current is rms as does a check of power versus current and resistance. Theoretical I vs E suggests E is then also rms. The field strengths are always compared with that expected for the same antenna height but over a perfectly conducting infinite plane - this comparison is remarkably (some might say something stronger) close for many/long radials. These data then allow some estimate of ground losses for the various configurations.

The essential results have been given before in terms of trades of height, number and lengths of radials. Generally, not surprising, more and longer radials are better, with various qualifications and considerations. A brief version of that most relevant to hams is provided here in simple tabular form Only two heights are considered, ~1/4 and ~1/8 wavelength (88 and 44 degrees) in comparison with the stated theoretical ideal of perfect ground. Only results for radial lengths of 90 and 45 feet are provided here. They are given in dB loss (or gain if you don't like the minus sign) and might be interpreted as the ground loss as measured by the signal at a mile away but near the ground. Since the data translation from 0.3 miles to 1 mile assumed the perfect ground scaling, the loss results are really those out to 1/3 mile.

dB loss using n 45' radials

n	88deg	44deg
2	-4.17	-6.30
15	-2.29	-3.57
30	-2.18	-3.43
60	-1.95	-3.16
113	-1.84	-3.03
Ideal	0.00	0.00

dB loss using n 90' radials

n	88deg	44deg
2	-4.17	-6.02
15	-1.25	-2.29
30	-1.05	-1.71
60	-0.85	-1.12
113	-0.65	-0.81
Ideal	0.00	0.00

So more is always better but how much you are willing to pay for the next dB always becomes the question.

The side experiments are not too illuminating. The authors say that the one example of radials on the ground with end ground rods seems not obviously different from what you get by interpolating the buried radial cases. Note that the ground rods may play a helpful roll in reducing losses by collecting the outer earth currents, depending on the electrical properties of the soil.

One would assume, though it is not stated, that the ground screen used was electrically connected to the common ends of the radials at the antenna base. The numbers for the ground screen tests provided in the unnumbered table in the text seem odd. They compare 113 and 15 radials with and without the 9X9 foot ground screen. We presume these are all for the 135 foot radial case for all, although it doesn't exactly say. Their quoted large ratio of resistances can only be found in the plots for very short verticals (Fig 25) so they must have used the 22 degree height case. However if you compare the fields for 15 and 113, the field ratio from the plot is about 120/177 = 0.68 at 22 degrees (where it is smallest), while the table value given is 0.56. They imply that adding the screen to the 15 radial case gets a 3 dB improvement (field ratio .78/.56) which seems like a big deal, if true. However, this is (apparently) only for the 22 degree height which will diminish ham interest. It seems likely that the authors had actual data points, rather than the hand smoothed curves, to generate the numbers in their table which may account for our difference here. But if the points are that far off the curve, you have to wonder about other stuff. Just because you have a PhD doesn't mean . . .

We need to keep in mind that the actual electrical soil properties are not known and it is assured that the results are dependent on those properties (as in the theory section), so this is just a fuzzy piece of the puzzle. R. Fry suggests the conductivity is likely ~ 5mS/meter which is "average" soil to some.

(Informed?) Opinion:

Aside from the evident feature that the Brown paper's summary at the beginning tends to overstate some aspects a bit, there are several considerations that we might keep in mind.

The measured "Total Earth Currents" are provided only for the 113, 135' radial case but not for the 88 degree antenna. Interpolating to estimate the 88 degree case, current near the base appears to be about 5 Amps. The 22 degree case goes off scale close in but at 2.5 m from the base it is about 25 Amps. Measured "Total Current in Buried Wires" is provided for the 135' radials in 88 degree and 22 degree cases. For the 88 deg 113 radial case, they get ~ 5.3 Amps near the base and about 23 Amps for the 22 deg case.

So it appears likely that the Total Earth Currents must include the effects (i.e., the currents) of any buried wire currents - but due to the technology-limited nature of the plots without data points, it is hard to know for certain. The <u>theory</u> result of Fig (6) shows the "total current in the earth" sometimes called "actual current in the earth" goes to zero near the antenna agreeing with my statement above. This all might be clarified if one knew the technique for measuring Total Earth Currents which seems to hinted at as the use of above ground electric fields again. Where possible to compare, the two experimental results (Total vs. Wire) seem quite similar, at least not too far from the antenna base.

No experimental effort is made to separate the currents into a portion what is purely in the ground. However they do claim that the theoretical earth currents are 90 deg out of phase with wire currents. The basis for this not intuitive (to me) statement is not source referenced although it is well known that the <u>displacement</u> currents in the ground (that do not give losses) are 90 degrees out of phase with the conductive in-ground currents – a possible source of confusion. They also implicitly assume displacement currents in the earth can be ignored for the theory work. This is certainly not always true. For a conductivity of 5mS/m at 3 MHz the ratio of conduction to displacement current is about 30/Ke where Ke is the relative dielectric constant - this ratio is proportional to the conductivity. Some versions of conventional soil properties wisdom (http://www.technik.dhbw-ravensburg.de/~lau/groundconductivity.html) say "pastoral" land has conductivity of ~5mS/m and Ke ~20 at 3 MHz so displacement current in the earth would not be small. The importance of this is not so clear.

And on a further side note, since the radials were apparently bare wire, no information is gained, or suggested, about the bare versus insulated buried wire ham dust up. However, Brown et al. do indicate in the theoretical discussion that the earth conductive currents flow into the wires more and more as you come toward the base. So if the wires were insulated that flow would have to be by displacement current across any insulation jacket and it is not clear that this would be the same, but maybe it would. Displacement "currents" essentially mean that electrical charges build up the the region, like charging a capacitor.

No claims at all are made for sky wave performance so your best information is a possible measure of relevant ground loss near-ish the antenna (really within 0.3 miles) which is probably dominated by near field losses close to the antenna. Variation of these losses with height, length and number of buried radials is then available. In addition, there are antenna impedance data provided that seem to pretty well conform to ham NEC type expectations and conventional wisdom. Again, what all this might mean in terms of low angle sky wave radiation is certainly not addressed.

It might be noted that the low resistances of short antennas are not a deterrent to their use as far as Brown et al. are concerned – it is all about the losses. For others, say hams, this may not be so true since matching small impedances to 50 ohms often means high currents, voltages and losses in non-radiating portions of the matching unit. At some level, mere $ can overcome such issues - but how many?

Also, it is also not clear that a top loaded vertical with the some impedance will give the same losses as the equivalent number of degrees pure vertical, especially if done by the inverted L route.

Thanks to R. Fry for comments on a preliminary version of this note.

* Brown, Lewis and Epstein, "Ground Systems as a Factor In Antenna Efficiency", IRE Proceedings v25 no 6, 1937.