Comparison of Measured and Calculated Current Distribution on the KinStar Low Profile MF Antenna

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ABSTRACT

The results of field measurements of current distributions on the vertical radiating wires of this new low-profile AM/MF antenna are presented and compared with predicted current values from Method of Moments (MoM) modeling. The far-field radiation characteristics are calculated from the measured current values and those derived values are then compared with the predicted radiation from the FCC formula for top-loaded radiators in 73.160 and NEC-4.1. The results show very good agreement indicating that the antenna operates as predicted. The effect of the observed slight variation in antenna geometry due to construction tolerances is shown to be insignificant in the far field, demonstrating that the antenna can be inexpensively constructed using existing utility line construction practices and still meet all operational and regulatory requirements.

KEYWORDS

AM, MF, low-profile, antenna, broadcast, current distribution, Method of Moments

INTRODUCTION

The patented KinStar Medium-Frequency transmitting antenna was first introduced to the broadcasting community in October 2002 just as field trials of a single omnidirectional antenna were starting. The fundamental characteristics of the antenna are its low height and large amount of top loading. The theory of the antenna has been presented in detail previously [1]. It relies on a combination of top-loading and current division to create a short, large-diameter cylindrical radiator whose input impedance can be efficiently matched using either an innovative transmission line system, or a more traditional lumped-element network. A schematic diagram of the antenna is shown in Figure 1.

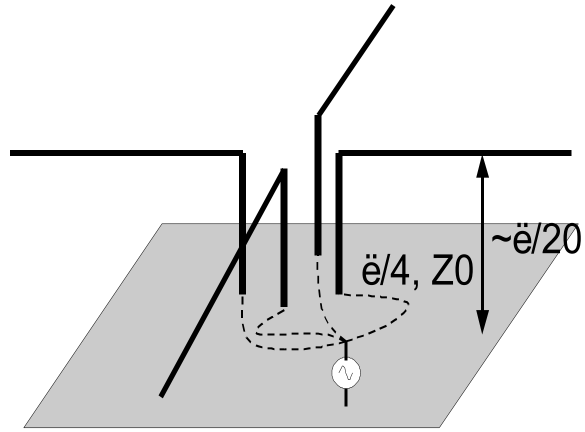


Figure 1. KinStar antenna schematic showing vertical radiators, horizontal loading wires, and transmission line matching sections

The first set of results from the field testing was aimed at demonstrating the omnidirectional azimuth characteristics of the antenna and determining its efficiency, with a goal of achieving the predicted efficiency, which met the current FCC requirements for antennas used for Class B, C, and D stations. A full 360-degree pattern proof was performed and analyzed by an independent professional engineer and showed that the efficiency of the antenna was at least 97.8% that of a standard 90 degree monopole and that it exceeded the minimum FCC efficiency requirement of 282 mV/m at 1 kilometer with 1 kilowatt of input power. The measured unattenuated field at 1 km with 1 kW was found to be at least 300 mV/m, with less than 1% variation in pattern circularity [2].

Additional testing was made to determine the current distribution on the vertical radiating wires, to be used in establishing the antenna's vertical radiating characteristics for understanding the antenna's skywave performance as necessary for gaining regulatory acceptance. The results of the current distribution measurements show that the vertical radiation ratios behave as predicted and are essentially equivalent to those for a short vertical current element with a constant current distribution. The beneficial effect of the top loading is demonstrated by the measured constant current magnitude seen on the vertical wires.

The measurements also permitted an evaluation of the effect of antenna dimension variations due to construction practices on the antenna performance. In an attempt to keep the cost of the antenna low, the demonstration antenna was constructed using standard overhead utility line techniques, with the support poles placed into holes augured into the ground and the anchors for the vertical wires screwed into the soil with the augur truck. The accuracy of placing holes and anchors depends on the consistency of the soil, the presence or rock, and the skill of the operator. As-built measurements showed a typical +/- 6 inch variation in the placing accuracy of poles and anchors, with some base wire anchors located about 1 foot farther from the center than the design specified.

The measurement data shows the current magnitudes varying by as much as 17% among the four vertical wires. Several configurations of matching network and wire connections were tried to determine the best performance. The largest variation occurred for the transmission line matched version of the antenna and resulted from the slight difference in input impedance due to the change in the wire location. No adjustment to the transmission line lengths was made; hence the impedance transformation was slightly different on each wire of the antenna, resulting in the variation in the currents. Less variation in the currents can be obtained by shunting the wires together at top and bottom and feeding the antenna through a single input from a lumped element network. Alternately, better quality control when placing the vertical wire anchors through use of engineering supervision, a template, or a fixed supporting structure would suffice. Significantly, even the 17% current variation resulted in a very small variation in the calculated far-field pattern circularity, indicating that such attention to detail may not be necessary to achieve the desired performance.

TESTING AND RESULTS

The tests were conducted in March 2003, with the antenna configurations shown in Table 1. A Nautel Ampfet 400 Watt transmitter, adjusted to an output power of 250 Watts was used for the testing. To acquire the data, Kintronics personnel built and calibrated a battery powered self-contained current measurement unit consisting of a solid-state data logger, current sensing coil, and battery power supply. This unit is shown in Figure 2. A rope and pulley system was set up to convey the measurement apparatus in trolley fashion up the vertical radiating wires of the antenna.

Each wire was measured individually, with the data logger recording a data value once every 10 seconds. In the interleaving time, the apparatus was hoisted into the next position. . Approximately 100 measurements were made on each vertical wire, providing a high level of detail in determining the current distribution.

Figure 2. Measurement unit for taking current data on vertical wire. This unit is battery powered and consists of a sensing coil, measuring circuit, and digital storage unit. Transmitter visible in cabinet to rear.

Table 1. Test Configurations

Case	Matching Method	Wires Shunted	Comments
A	Transmission Line	No	Boxes inside fence
B	Lumped Element	Bottom Only	Boxes inside fence
C	Lumped Element	Bottom and Top	Boxes inside fence
D	Lumped Element	Bottom and Top	Boxes 16ft. Outside
E	Transmission Line	No	Boxes 16ft. Outside

NEC Modeling

The original NEC-4.1 Method of Moments model of the antenna was modified to increase the segmentation of the wires and provide higher resolution of the calculated currents so that the comparison with the measured data would be more precise. The wires were segmented so that currents would be calculated for each wire in approximately one-foot increments, thus increasing the resolution of the calculated currents while not introducing modeling errors which can occur when the ratio of wire diameter to segment length becomes too large. The NEC model was simulated using average ground conditions and 120 radial wires 6 inches above the ground to make the comparison with the measured current values consistent.

Current Distribution Analysis

Figure 3 shows the measured currents along each of the four vertical wires for the first test case, where each wire is insulated and fed through an individual transmission line matching section. The current magnitudes vary from wire to wire as a result of slight variation in the as-built geometry of the antenna from the completely symmetrical arrangement in the ideal design case. Some of this variation is due to construction tolerances, and other is due to the topography of the test site, where there is some gentle sloping to the land, resulting in variations in the surface below the top loading wires, which affects the net amount of capacitive loading on each wire.

Table 2 shows the as-built radii of the four vertical wire anchors compared with the specified design value. The comparable NEC modeling result is shown in Figure 4, where the base positions of the vertical wires have been offset to approximate the construction variation affecting the wires in the measurement. Despite the fact that the NEC model cannot incorporate the ground elevation and other variations, the correlation between the measured and modeled current distributions are remarkably close, thus supporting our theory that the variation in observed current distributions is due to minor variations in the construction of the antenna.

Table 2. Deviation of radial spacing of vertical radiating wire anchors, from design specification

Wire	Deviation from design spacing (Feet), approximate
1	1.1
2	0.8
3	0.3
4	1.1

Concern over the seemingly large variations in the vertical wire currents resulted in an effort to eliminate possible causes for the variations. One possibility was the close proximity of the large metal enclosures for the transmitter and lumped element matching networks. These were moved as far from the antenna base as the matching cables would permit to reduce any capacitive effect they might have to the vertical wires and the measurements were repeated. It was not possible to reposition any of the wire anchors due to difficulties in getting an augur truck into the antenna location during the testing period.

Measured current distributions for the remaining cases are shown in Figures 7 though 10. These different cases were measured to develop a better understanding of those characteristics of the antenna that influence the current distribution and input impedance. The cases with wires shorted together at both top and bottom showed the best improvement in reducing the variation of currents on the antenna. For those cases using the single lumped-element matching network, a single copper tubular conductor connected the network to the approximate center of the antenna. In Case D, the matching network enclosure was moved 16 feet away from the base of the antenna; the effect of this on the input impedance of the antenna is evident in the lower current magnitudes observed due to the self-inductance of the additional 16 feet of copper tubing required.

A registered surveyor was engaged to prepare a map of the elevations throughout the section of the alfalfa field in which the antenna was constructed. Table 3 shows the average ground elevation under each of the four horizontal wires. The horizontal portion of wire 2 is the closest to the ground and thus exhibits slightly more capacitive loading effect than the others. This is felt to be the cause of the higher observed current along that wire.

Table 3. Average ground elevations under horizontal wires.

Wire	Average Elevation (Feet)	Difference from Center (Feet)
Center	100	-
1	99.33	-0.67
2	101.43	1.43
3	99.31	-0.69
4	98.79	-1.21

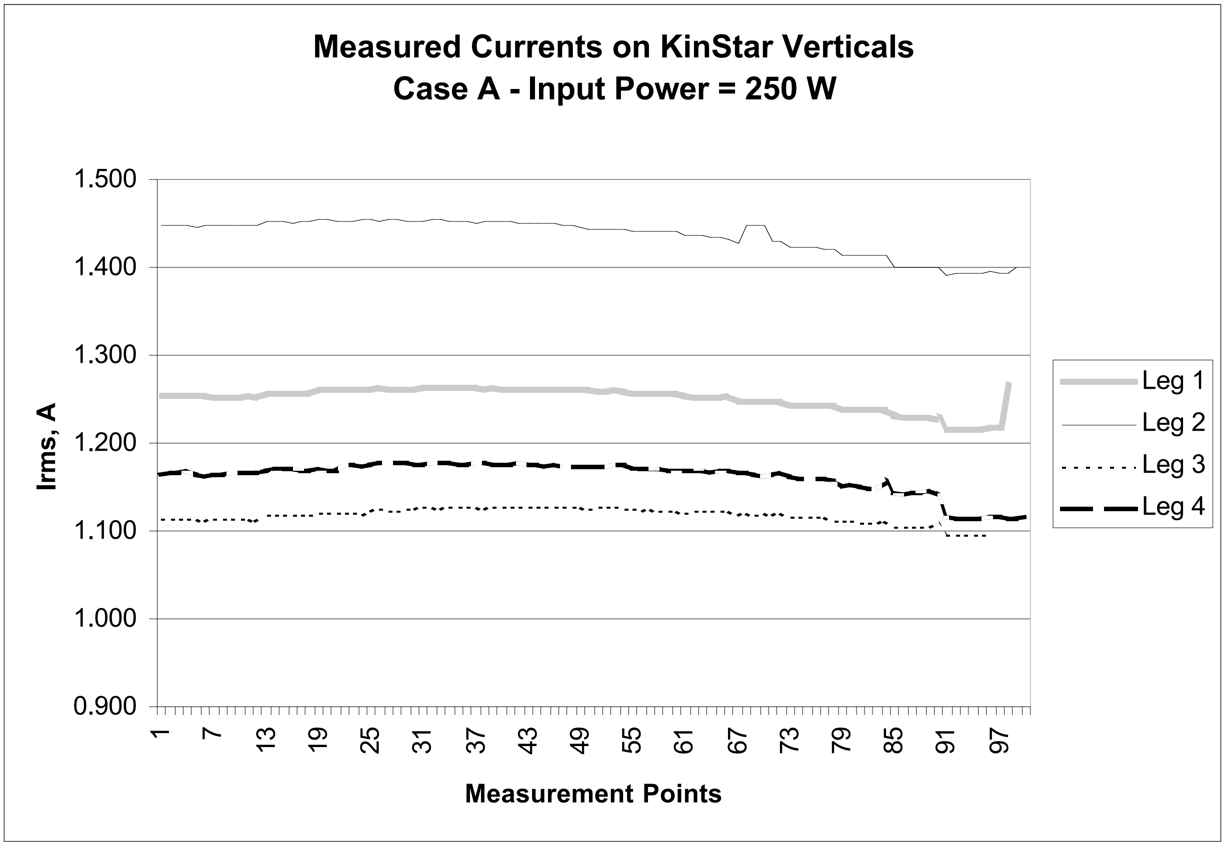


Figure 3. Measured current distribution along vertical wires of antenna from bottom (left) to top (right) for Case A, each wire insulated and fed through an individual transmission line matching section.

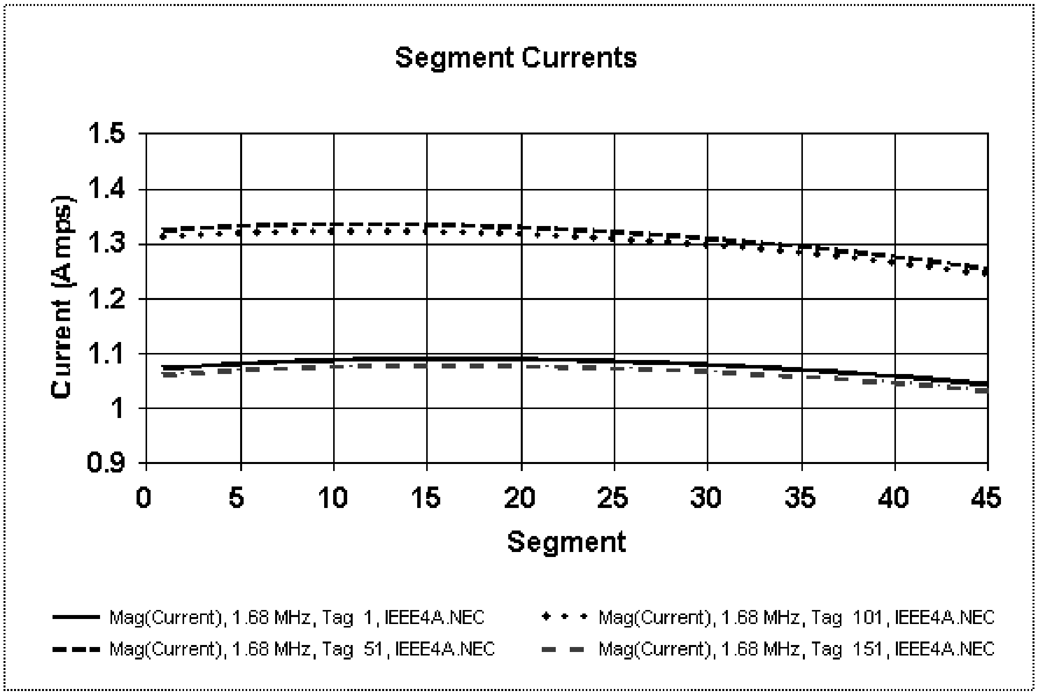


Figure 4. NEC modeled currents for Case A, using 1-foot offsets in wire anchor positions.

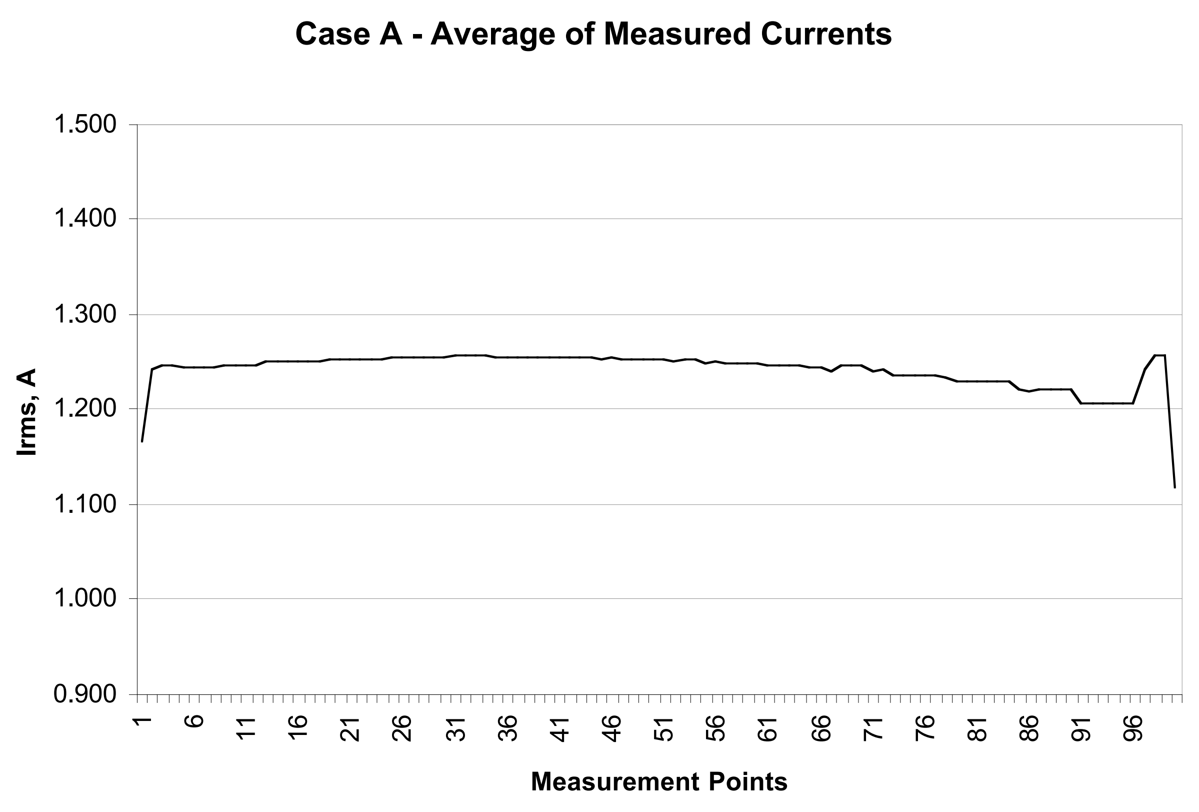


Figure 5 Average of measured currents along all four vertical wires from Case A.

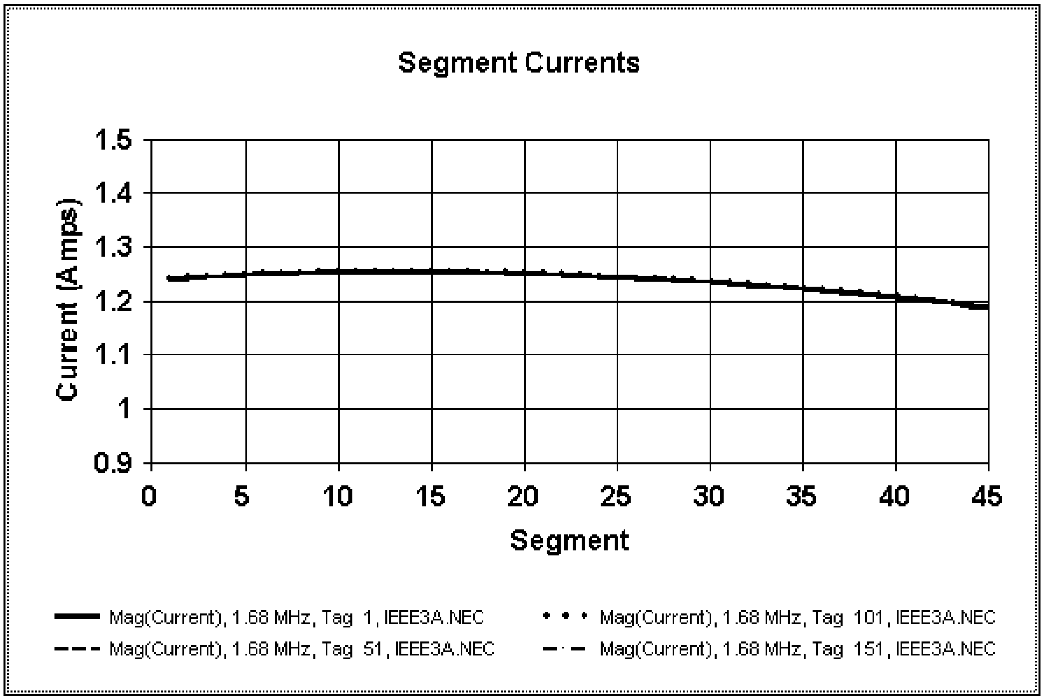


Figure 6. NEC predicted currents along vertical wires for the ideal design-case KinStar. Values agree remarkably well with the measured current magnitudes.

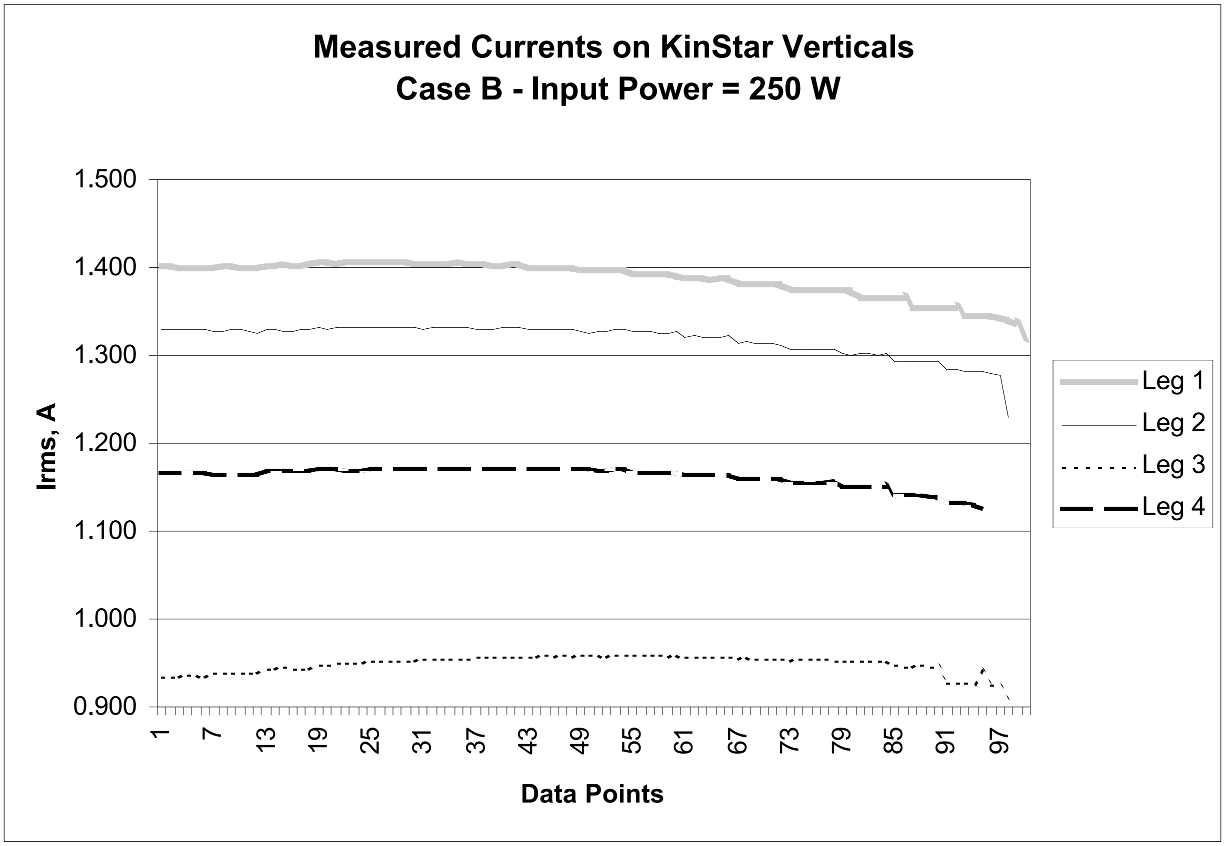


Figure 7. Measured current distribution along vertical wires of antenna from bottom (left) to top (right) for Case B, with all four vertical wires shunted together at bottom and connected to a single

lumped element matching network. There is a slight change in the current magnitudes as the input impedance of the antenna is modified, however the large variation between the wires remains.

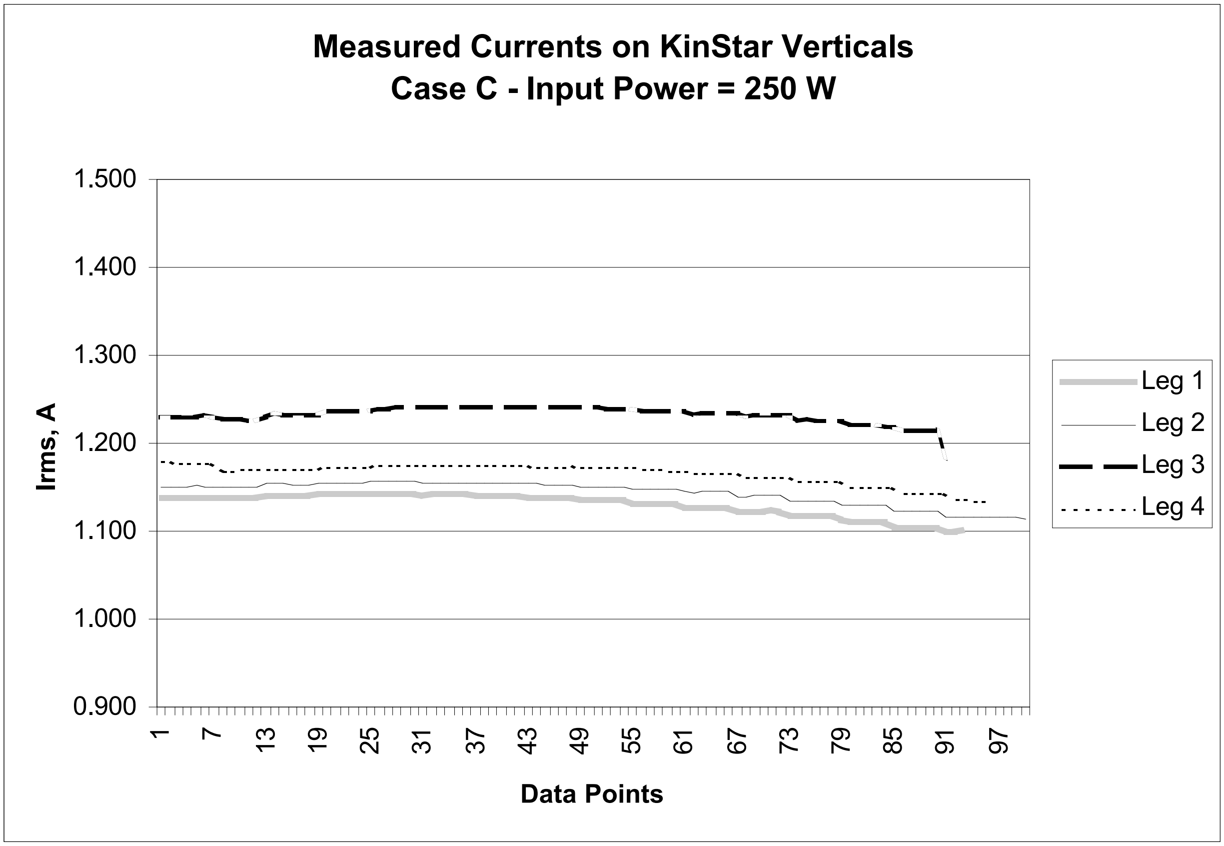


Figure 8. Measured current distribution along vertical wires of antenna from bottom (left) to top (right) for Case C, with all four vertical wires shunted together at top and bottom and connected to a single lumped element matching network. The additional connections between the wires reduces the current variation between them and brings the current magnitudes closer to the NEC predicted value.

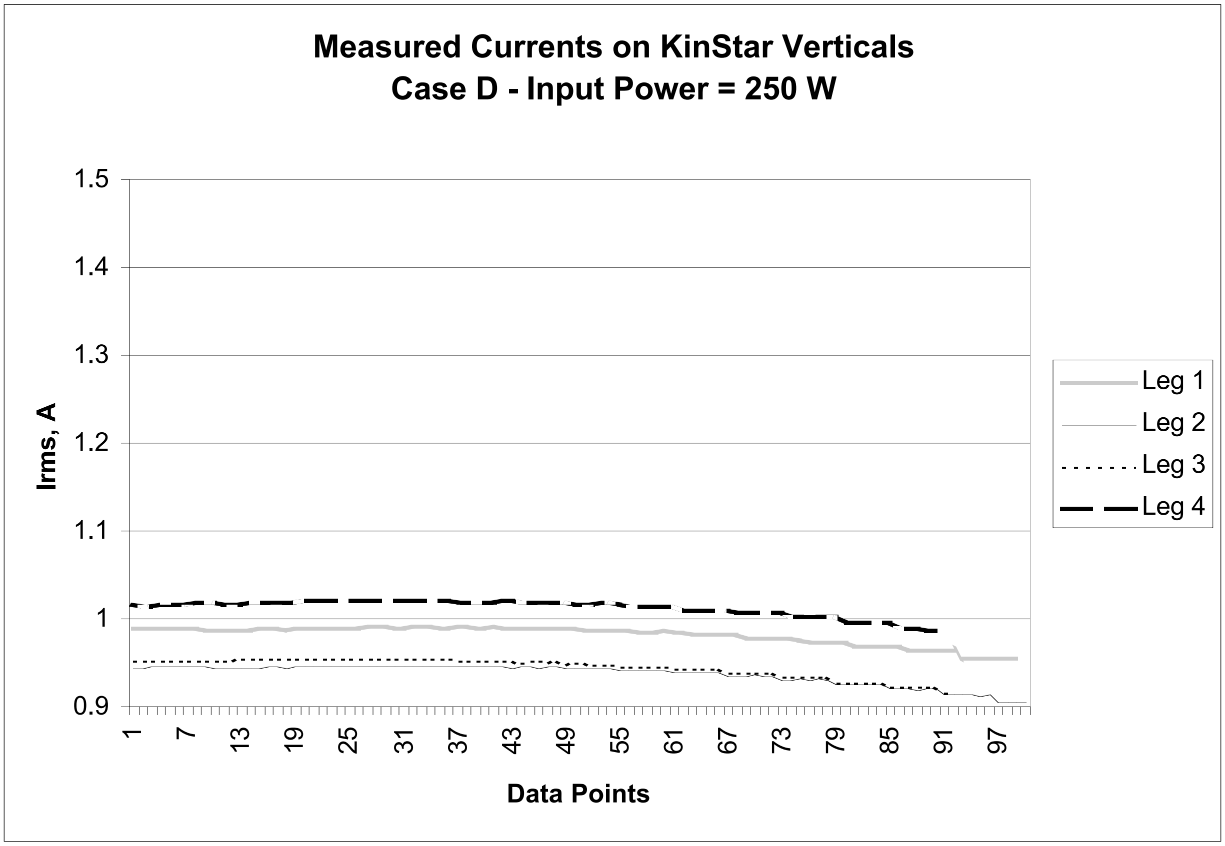


Figure 9. Measured current distribution along vertical wires of antenna from bottom (left) to top (right) for Case D, with all four vertical wires shunted together at top and bottom and connected to a single lumped element matching network now located farther from the antenna base. The additional length of single copper feed conductor to the shunt point from modifies the impedance enough to reduce the current magnitudes significantly.

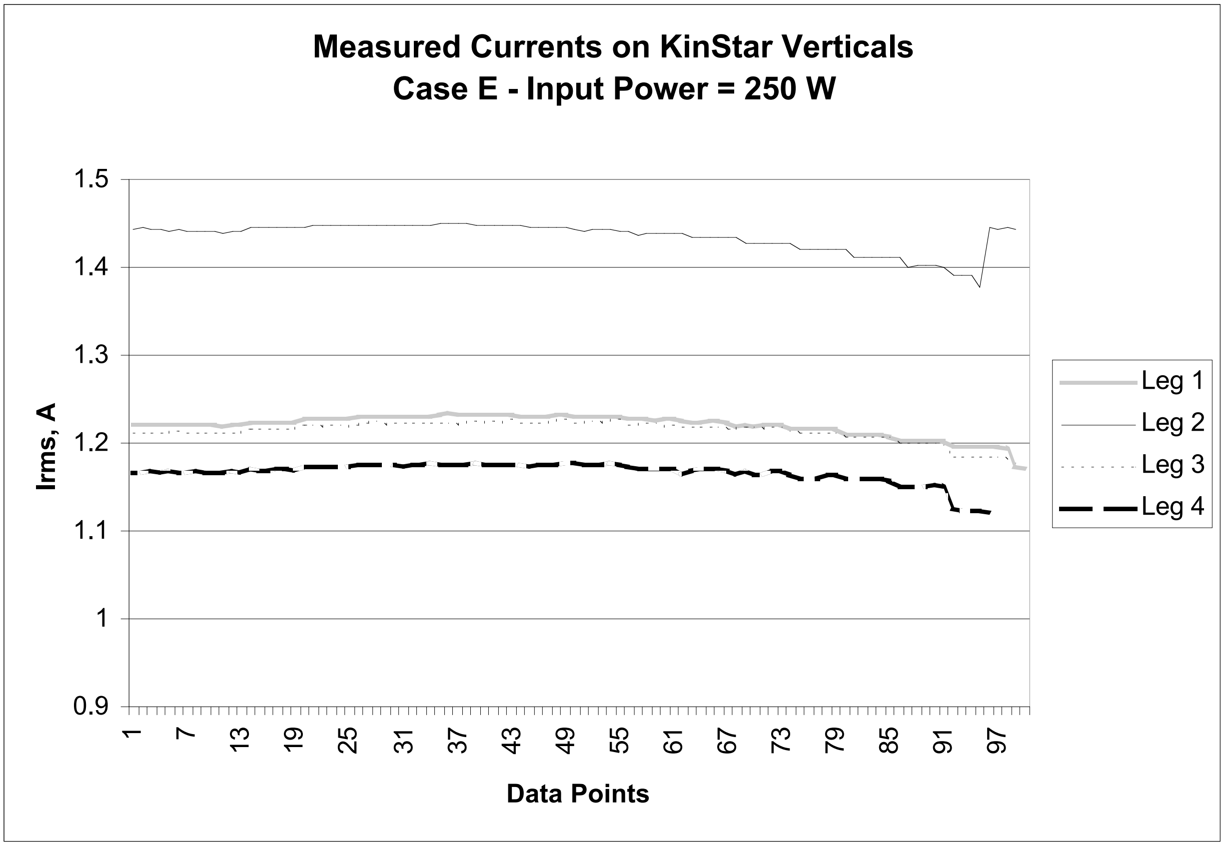


Figure 10. Measured current distribution along vertical wires of antenna from bottom (left) to top (right) for Case E, each wire insulated and fed through an individual transmission line matching section from the junction in the lumped element matching network enclosure now located farther from the antenna base. The current variations remain, indicating that they are due to the geometry of the antenna and not due to the proximity of the metal enclosure boxes. Since the transmission line matching sections are of the same length as in Case A, the input impedance is not significantly changed and the current magnitudes remain essentially unchanged.

Far-Field Radiation Characteristics

The far-field radiation can be readily calculated using the superposition of fields from each measured current element. It has been shown [3] that for an infinitesimal dipole located above a perfectly conducting ground plane that the radiation can be approximated by:

$$E_{\theta} \cong j\eta \frac{kI_0 le^{-jkR}}{4\pi R} \sin\theta\left[2\cos\left(kh\cos\theta\right)\right]$$

where η = Characteristic Impedance of Free Space, k is the wave number, I_0 is the current on the element, R is the distance from the center of the current element to the observation point, h is the height of the current element above the ground plane, l is the length of the current element, and θ is the angle from the zenith (90 – Elevation Angle above horizon). This expression considers the field contributions from both the actual current element and its image formed at an equal distance below the ground plane.

We can calculate the positions and lengths of each current element along each wire and use this along with the measured current value to then calculate the far-field radiation. An Excel routine was written to make this calculation automatically for each set of current data. The routine calculated the 1 km radiation field for each 10-degree increment of elevation angle from 0 to 90 degrees. The azimuth for calculation could be set by the user to make comparisons.

The calculated field at 1 km for the 250-Watt transmitter was found to be 152.6 mV/m, which compares closely with the effective antenna efficiency of 153 mV/m calculated from the field proof measurement conducted in the Fall of 2002 [4]. Figure 11 compares the field elevation ratios as calculated from the measured currents with the predicted field ratios from NEC and the FCC formula for top-loaded radiators:

$$f(\theta) = \frac{\cos B\cos\left(A\sin\theta\right) - \sin\theta\sin B\sin\left(A\sin\theta\right) - \cos\left(A+B\right)}{\cos\theta\left(\cos B - \cos\left(A+B\right)\right)}$$

as found in Section 73.160 of the FCC Regulations. From the far-field radiation equation above, the expected elevation field from any small radiator close to ground is expected to follow approximately a sine(θ) distribution. The calculated measured current KinStar values agree with this despite the current variations with height and among the four vertical radiators.

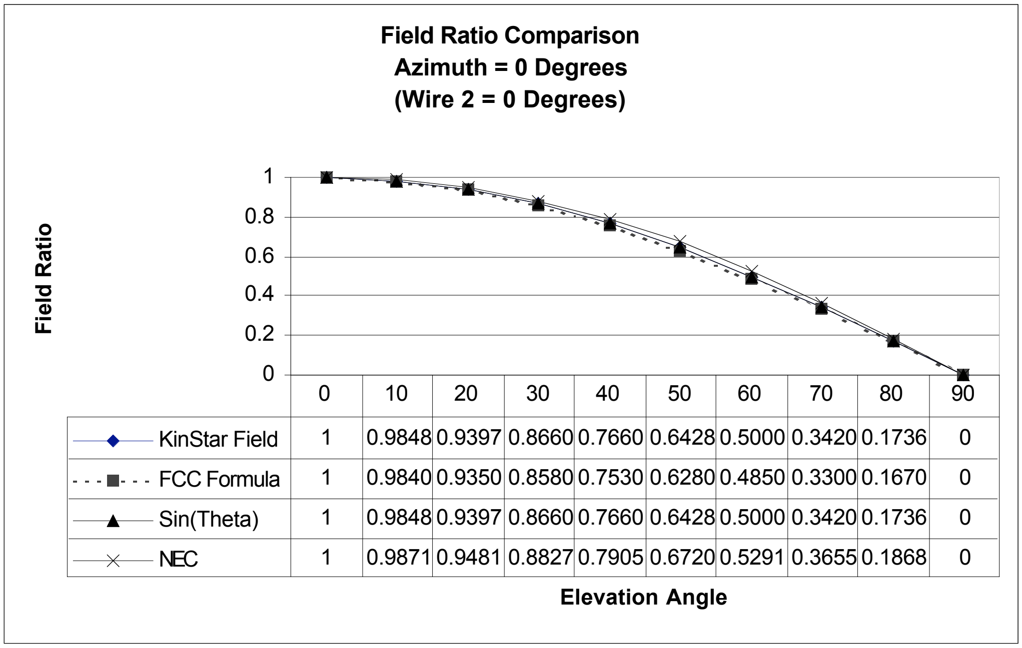
Calculations with the FCC formula were based on using an electrical height of 28 degrees with 76 degrees of effective top loading. The amount of top loading was found by inspection of the shape of the current distribution compared with the current distribution expected according to the transmission line model of antenna currents.

Elevation pattern calculations made using NEC-4.1 finds slightly greater field ratios at higher elevation angles than either the FCC formula or calculated field values. The maximum variation occurs at an elevation of 80 degrees where NEC predicts a field ratio approximately 11.8% (0.97 dB) higher than the FCC formula. This has been observed in other cases where differences between NEC and the FCC formula of over 1 dB have been observed. Additional analysis work is being done to ensure that the vertical radiation characteristics are correctly understood to allow accurate calculation of skywave radiation for licensing for nighttime operation of the antenna.

Pattern circularity is also calculated from the Case A currents as a worst-case situation where the antenna environment or degradation or modification due to wear or weather results in a situation where the currents on the vertical wires become asymmetrical. Despite the observed current variation of up to 0.3 Amperes on the vertical wires, the phase difference due to the spacing of the wires is sufficiently small as to keep the pattern circularity (of the unattenuated field) at 1 km under 0.6%. The vertical radiators of the KinStar thus are seen to effectively operate as one single thick radiator rather than as four separate radiators, with the small phase difference due to their close spacing ensuring that any non-ideal current situation on the wires is averaged out in the course of the formation of the far radiation field.

NEC modeling suggests that sag of the wires will have minimal effect on the radiation pattern, and construction showed that sufficient tension to hold the wires almost perfectly horizontal was easily achieved using common overhead utility line industry practices. When installing the antenna it is best to choose as level a site as possible so that the current magnitudes on opposite wires remain as close as possible. This ensures cancellation of the horizontal radiation components.

Even with the non-ideal as-built current distribution, NEC modeling showed that all horizontal components were at least 30 dB below the maximum vertically polarized field. If constructed perfectly according to the design, the KinStar horizontally polarized components are essentially zero. Since this may not be practical, the NEC model used to generate the current values seen in Figure 4 was modified by connecting together the top ends of all the vertical wires. This significantly reduced the disparities in the currents on the vertical and horizontal wires, as shown in Figure 13. This simple precaution will even out the currents among the four legs of the antenna and minimize the effects of any influences which would tend to cause uneven currents and any degradation of the radiation pattern.



	0	10	20	30	40	50	60	70	80	90
◆ KinStar Field	1	0.9848	0.9397	0.8660	0.7660	0.6428	0.5000	0.3420	0.1736	0
■ FCC Formula	1	0.9840	0.9350	0.8580	0.7530	0.6280	0.4850	0.3300	0.1670	0
▲ Sin(Theta)	1	0.9848	0.9397	0.8660	0.7660	0.6428	0.5000	0.3420	0.1736	0
× NEC	1	0.9871	0.9481	0.8827	0.7905	0.6720	0.5291	0.3655	0.1868	0

Figure 11. Elevation field ratio comparison between NEC-4.1, theoretical sine(□), FCC formula calculation, and calculated fields from measured vertical current distribution on wires. FCC formula values were taken for a physical height of 28 degrees with 76 degrees of top loading. All presume perfect ground.

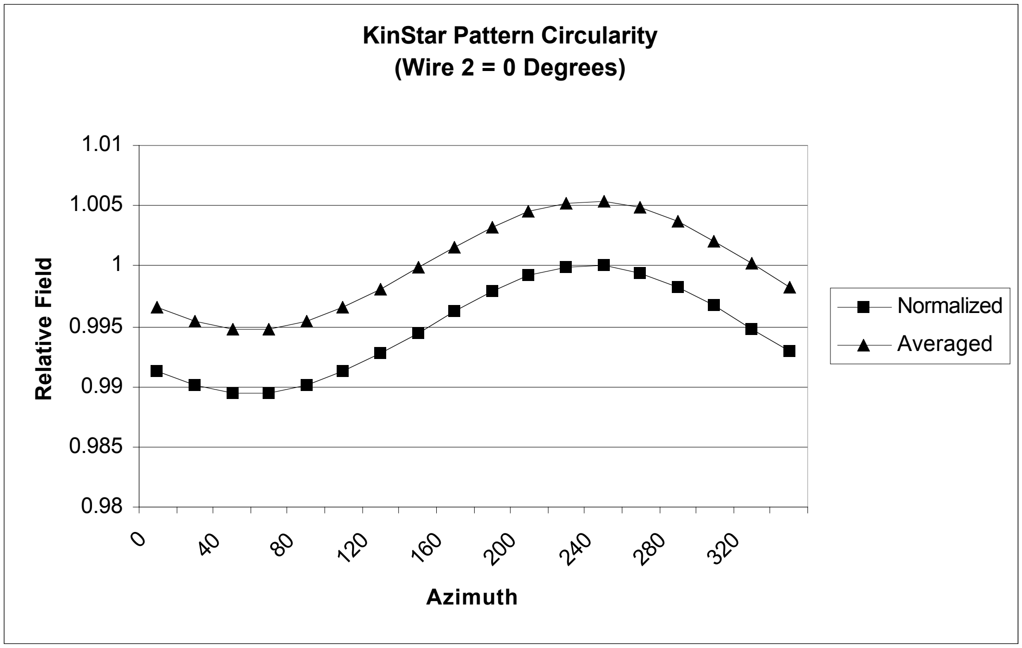


Figure 12. Pattern circularity of calculated field from measured currents from Case A. This shows even with worst-case current distributions on the vertical wires, there is less than 0.6% variation in the pattern circularity.

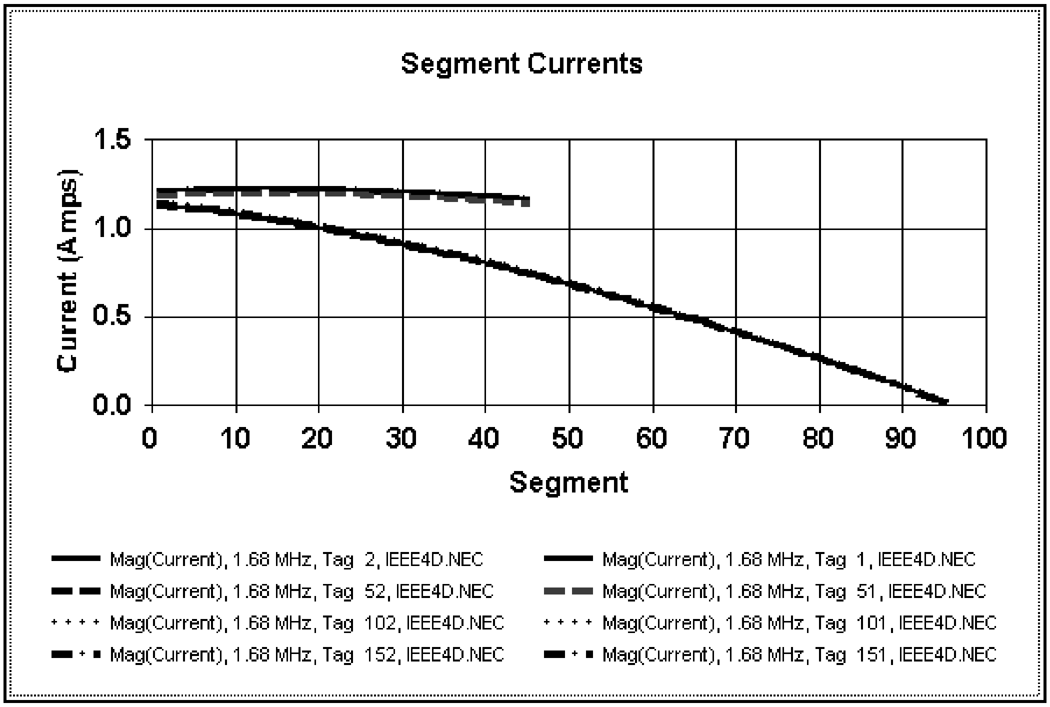


Figure 13. NEC model currents showing smoothing effect on unequal currents from shorting tops of vertical wires together. This compares with Figure 4 where the model is identical except for lacking the top shorting wires. The horizontal radiation component is reduced by 6 dB to at least 36 dB below the maximum vertical field. Upper traces are currents on the vertical radiating wires, lower traces are for the horizontal loading wires.

CONCLUSION

The results of full-scale field test measurements of the vertical radiating wire currents for the KinStar low-profile medium frequency transmitting antenna were presented for several configurations. The antenna as-built suffered from some minor differences from the design specifications as a result of difficulties in accurately placing poles and screw-in anchors used to support the radiating wires. The test site also was not perfectly level and ground height variations were shown to slightly affect the characteristics of the antenna.

Analysis of the data shows that even with the non-ideal real-world construction of the antenna, the far-field radiation characteristics remain essentially unaffected. The elevation and azimuth patterns are predictable and correspond well with established methods of modeling and describing top-loaded antennas.

It is suggested that in future installations of this antenna that care be taken to ensure a reasonably level area within the area of the quarterwave ground screen, the tops of the vertical wires be electrically connected together, and that the support structures for the antenna be accurately placed so as to ensure maximum symmetry among the currents on the antenna. Even with the observed variations, however, acceptable antenna performance is achieved, suggesting that a well-installed antenna will continue to perform as required despite minor normal changes due to weather and aging effects. The skywave performance of the antenna fits closely to accepted FCC methodology for describing top-loaded broadcasting antennas.

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