# Electric and Magnetic Fields Near Physically Large Radiators

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## 1. Overview

1.1 Making measurements of electric and magnetic field strength requires specialized equipment and skills. Most measurements are made by trained personnel in carefully controlled laboratory or open-area-test-site conditions. Even under these ideal conditions, uncertainty of 3-4 dB is considered to be reasonably good testing.

1.2 Carrier-current devices cannot be measured under controlled laboratory conditions because the power-line wiring they use to conduct signals is an integral part of their operation. They must be measured in-situ.

1.3 Part 15 rules require that carrier-current devices be verified by the manufacturer for compliance with the limits for intentional emitters in three "typical" locations. Even under the best of circumstances, it is difficult to determine what is "typical" for a device that can be used with the wide range of the electrical-distribution wiring types and configurations typically found in an electric-utility system. BPL systems can be deployed using residential or business wiring as conductors in a single building, or using overhead distribution medium-voltage (MV)[2] lines that may be miles long. The physical configuration of this wiring can make it very difficult to determine the point of maximum field strength to demonstrate compliance with Part 15. In many cases, it is not possible to obtain access to most of the area surrounding a BPL installation, so even the most-careful work may not measure the actual maximum emission. Some access BPL systems use *both* the MV lines and building wiring to conduct signals between BPL modems and access points, adding the uncertainties of the radiation building wiring to the already-complicated measurement site.

## 2. Radiated Patterns

2.1 The following two figures show the far-field radiated energy pattern from a simplified power-line model ARRL developed to run under EZNEC 4.0 with the NEC-4.1 calculation engine[3,4]. This model was described in another paper[5] provided to the Commission by

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[2] The FCC NOI refers to the power-line distribution lines as "medium-voltage" lines. The power-line industry usually categorizes lines as distribution equal to or less than 13 kV, sub-transmission less than 69 kV and transmission equal to or greater than 69 kV. In this paper, the term medium-voltage refers to lines that are typically 13 kV or less.

[3] EZNEC software is available from Roy Lewallen, P.E., PO Box 6658, Beaverton, OR 97007, Tel: 503-646-2885, Email: w7el@eznec.com, Web: http://www.eznec.com.

[4] NEC-4 is a licensed software distributed by the Lawrence Livermore National Laboratories, http://www.llnl.gov/.

[5] "Methods of Feeding Overhead Medium-Voltage Power Lines With BPL Signals and the Relationship of These Methods to the Radiated Emissions of the Conductors," Author: Ed Hare, ARRL Laboratory Manager.

ARRL, “Methods of Feeding Overhead Electrical Power-Line Distribution Lines With BPL Signals and the Relationship of These Methods to the Radiated Emissions of the Conductors.” A drawing of the model is reproduced in Figure 1.

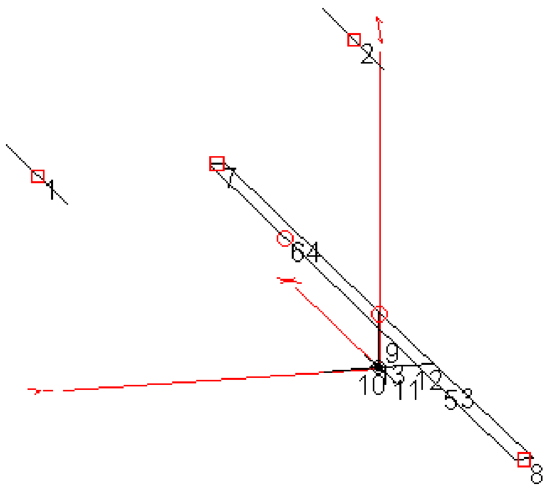


Figure 1: This is a pictorial of the model[6] used by ARRL to calculate differences in the performance of BPL systems fed in different ways.

Point 1 = Amateur half-wave dipole antenna, 10 meters high, 30 meters from line.
Point 2 = Half-wave dipole antenna, 30 meters high, 30 meters diagonally from line.
Point 6 = Single-phase differential “dipole” feed point.
Points 7 and 8 = Two phase differential feed or load, as specified in Tables.
Point 9 = Ground wire, fed where it connects to the phase.
Point 10= Earth ground radials (4).

2.2 The far-field radiated patterns from this model are shown in Figures 2 and 3. Figure 2 is modeled on 3.5 MHz and Figure 3 is modeled on 14 MHz. The near-field pattern at 30 meters distance will be closely related to the pattern in the far field, generally with more peaks and valleys in the field strength. These peaks and valleys are shown graphically in Figures 5 and 6.

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[6] The power-line model was 10 meters above ground with average conductivity and dielectric constant. The line consisted of two copper conductors, 0.12.5 mm diameter, 200 meters long. One of the conductors was grounded to simulate typical imbalance in the line. Because access BPL systems that are in development or field trial use inductive coupling to feed one line like a dipole, this is the model ARRL used for the plots in this reports. To allow this model to work on various versions of NEC, the ground connection consisted of four 10-meter radials, 5 cm above ground. This also reasonably simulates the relatively poor RF characteristics of power-line grounds. Differentially connected 50-j0 ohms loads were placed at each end of the transmission line. Two amateur antennas are also placed in the model. Antenna 1 is a half-wave dipole located 10 meters above ground, at the height of the power line, typical of many amateur tree-mounted antennas. Antenna 2 is a half-wave dipole located 30 meters above ground, 30 meters diagonally from the line. The height of this antenna is typical of many amateur tower installations. These antennas each have a 50-j0 ohm load in the center.

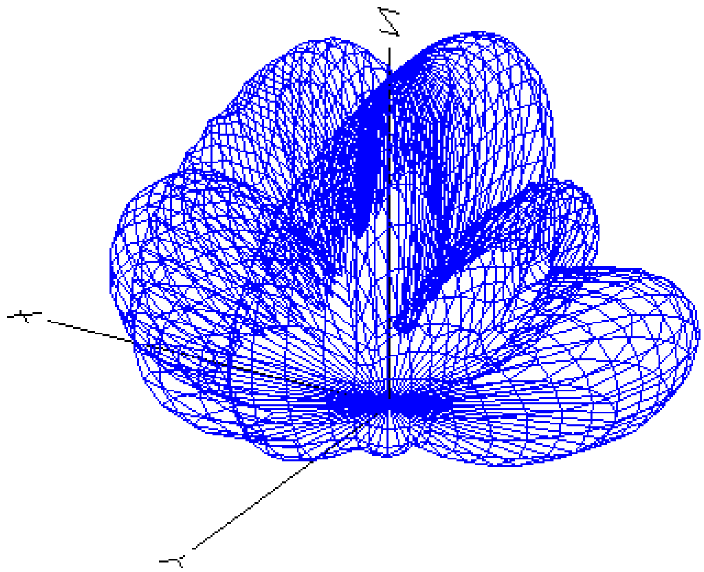


Figure 2: This complex pattern results when a 3.5 MHz signal is applied to the power-line model. (file:dip3r5.ez[7])

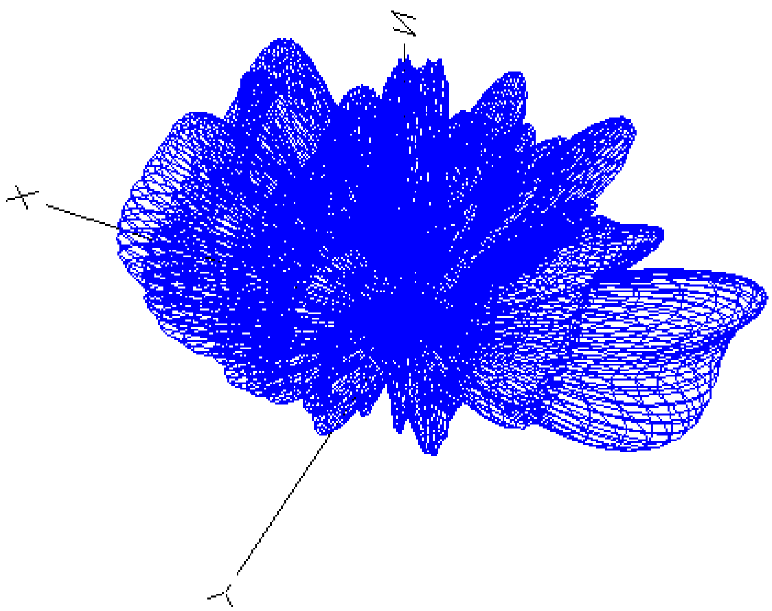


Figure 3: The pattern on 14 MHz from the same line is even more complex. (file:dip14.ez)

2.3 Even with this simple model of a single line over ground, it would be difficult to impossible to find the point of maximum field strength near this model. In the case of overhead power lines, in many cases, a test engineer wouldn't have access to all points near the wiring of an entire BPL installation, due to parking or private-property-access restrictions. If several

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[7] The EZNEC and NEC models used for the calculations in this paper are available for download at http://www.arrl.org/~ehare/rfi/bpl/antenna_models.zip

points near this model were selected on the basis of their being accessible, it is not likely that they would be at the peaks, resulting in the actual emissions being higher than tested.

2.4 In most cases, for radiators at the height of typical distribution lines, especially on MF and HF, the point at which the maximum field strength will be found is higher than the radiator. To actually measure this energy would require placing a test antenna higher than the line, at a vertical or diagonal distance of 30 meters. For compliance, however, it is necessary that this point of maximum radiation be determined. Many antennas, such as amateur towers greater than 10 meters in height; antennas with stations operating from airplanes or other antennas located on terrain higher than the power lines will be at points higher than the lines. Although individual BPL modems will not generally propagate at levels strong enough to be heard by skywave, the aggregate of many such devices in a major metropolitan area can have enough total power to do so. Carefully controlling the radiated field strength upwards is important.

## 3. A More Complicated Model With Additional Distribution Legs

3.1 Real-world power lines are more complicated than the simple model ARRL used, so the variations and deviations from the above patterns will be significant. In most cases, the pattern will be even more complex.

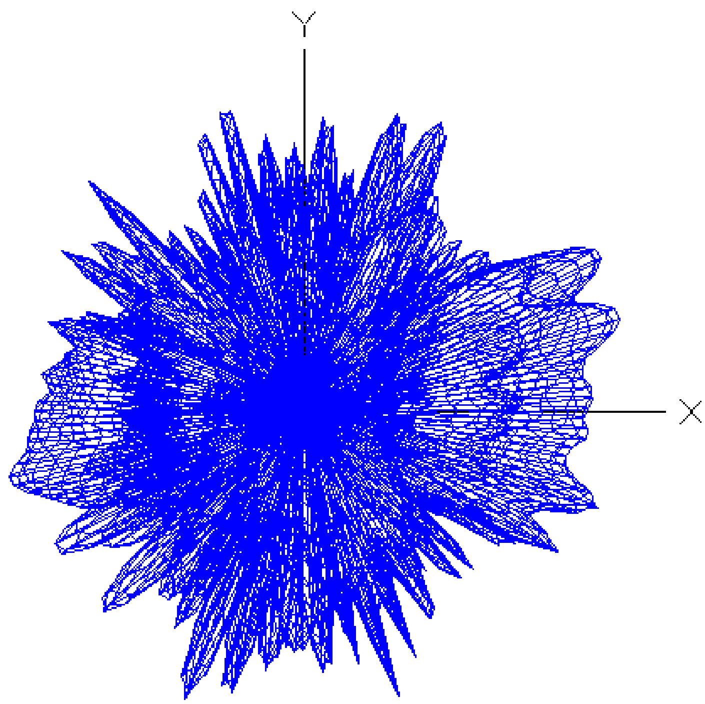


Figure 4: This bird's-eye-view of the pattern from a power-line model with only two additional legs has become impossibly complex. Making measurements at a few points around this pattern would probably not find the peak field strength. When additional loads and conductors, such as would be found in the electrical wiring in a single building, are connected to the model, the pattern would generally become even more complex and asymmetrical. (file:comp20m.ez.)

## 4. Near-field Considerations

4.1 § 15.31(f)(1) and (2) state that it is best to make measurements at the distances specified in the regulations, but the rules do permit measurements to be made at other distances if it is not practicable to measure at the required distance. Below 30 MHz, if measurements are made at other distances, the test engineer is permitted to either measure the fields at two points to determine the correct extrapolation factor or to use 40 dB/distance decade to estimate the field at the specified distance.

4.2 This technique may work reasonably well for very small radiators, but for physically large systems, all such points are in the reactive or radiating near-field region of the radiating conductors. In the near-field region of large, complex radiators, the fields vary in very complex ways and a "proper extrapolation" factor simply does not exist. This can be seen in the preceding antenna patterns and the following graphs. For a large radiator, 40 dB/decade is exactly backwards – in the near field region, electric or magnetic field strength can actually increase with distance, although if the peaks can be found (an uncertain assumption at best), they generally do decrease with distance, although not always in a linear or easily predicted fashion.

4.3 The following graphs and discussion are based on the power-line model shown in Figure 1.

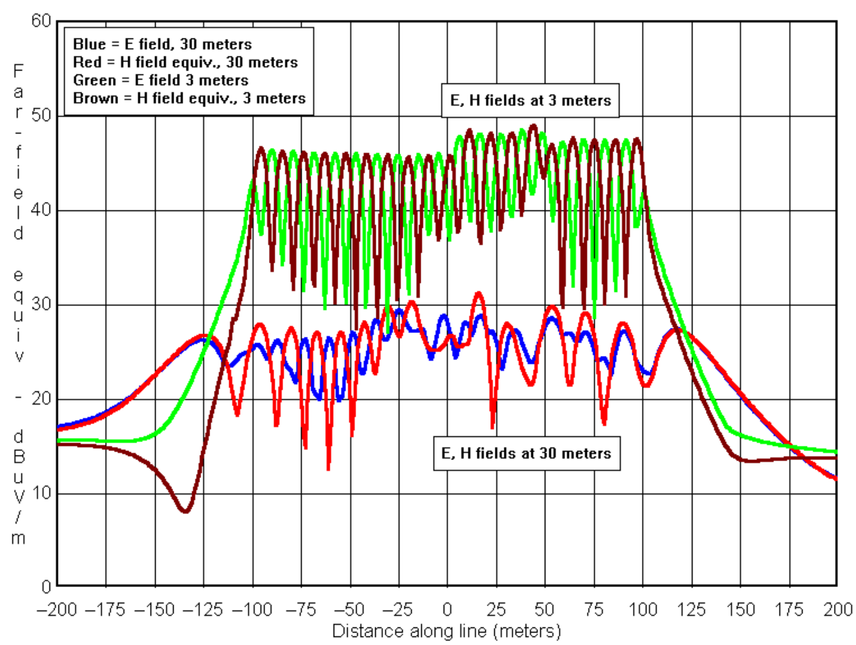


Figure 5: This graph shows the calculated electric and magnetic fields on 14 MHz at points 3 and 30 meters from the line, parallel to the line at a height of 10 meters. (files: dip14e30.ez, dip14h30.ez, dip14e3.ez, dip14h3.ez, dip14-1.txt, dip14-1.tif)

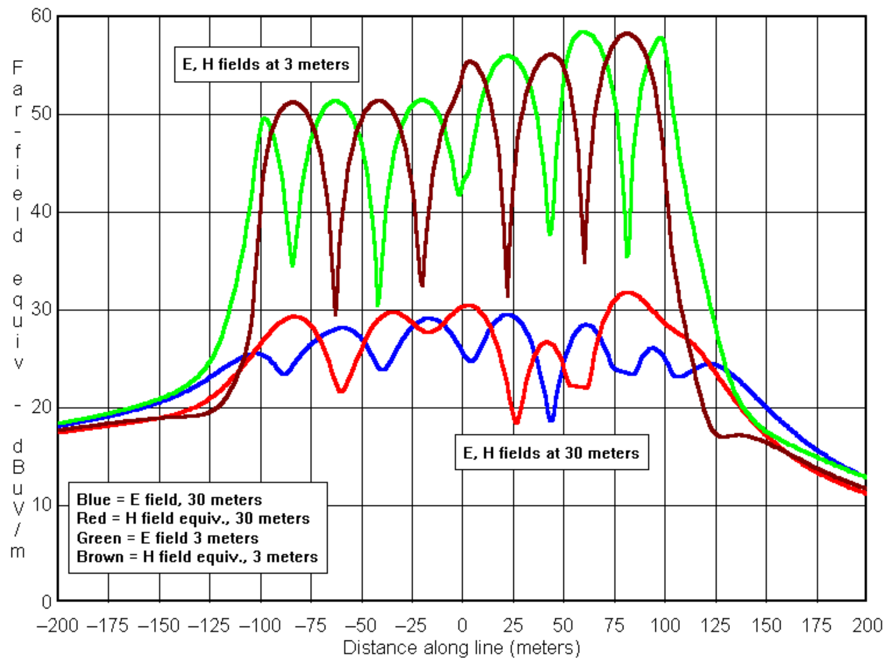


Figure 6: This graph shows the calculated electric and magnetic fields on 3.5 MHz at points 3 and 30 meters from the line, parallel to the line, at a height of 10 meters. (files: dip3r5e30.ez, dip3r5h30.ez, dip3r5e3.ez, dip3r5h3.ez, dip3-1.txt, dip3-1.tif)

4.4 In environments near complex radiating conductors, it would be very difficult to find the peaks associated with these varying fields. There is no "actual extrapolation factor" associated with the way the field strength pattern varies wildly around this power-line radiator. Certainly, it is not likely that even an approximation of the relationship between the peak field at 3 meters and the peak field at 30 meters could be established with just the two measurements stipulated in Part 15. A careful inspection of the graphs shows that the peaks and valleys are not always perpendicular with each other, with the differences in the valleys resulting in changes of ten dB or more by moving horizontally a few meters.

4.5 These data also show that a distance extrapolation factor of 40 dB/decade would not be appropriate for large radiators such as overhead power lines. ARRL has run a number of EZNEC models and in no case has it seen anything approaching 40 dB/distance decade for large radiators. The data in this report are representative of the results found over years of antenna modeling of large structures. In using the FCC-recommended method of extrapolating the electric field from the strongest magnetic field, on 14 MHz, the "actual" extrapolation factor is 15 dB between 3 and 30 meters. On 3.5 MHz, the factor is 24 dB. At other distances, 10 meters vs 30 meters, perhaps, even this simple model shows a still-different extrapolation factor.

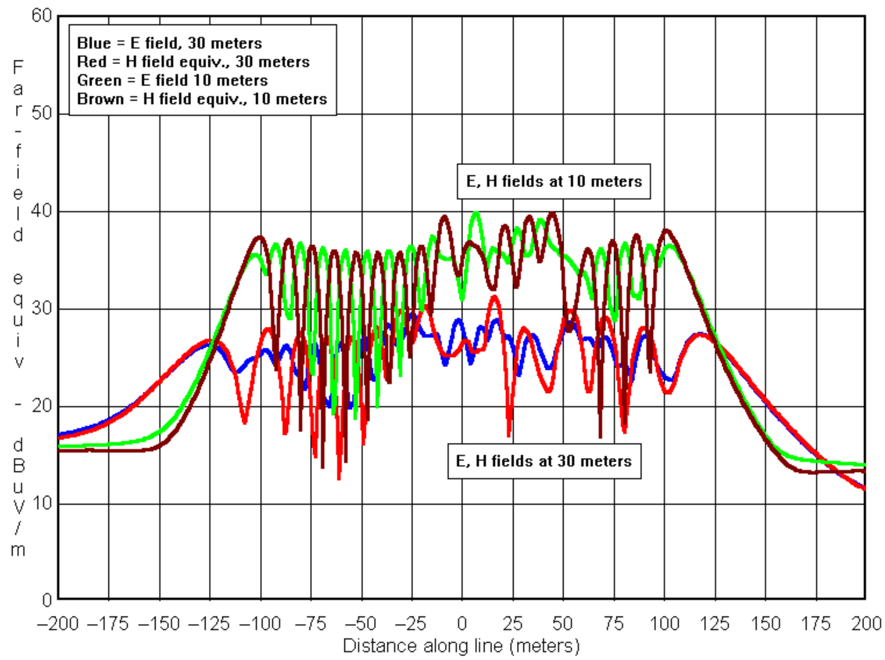


Figure 7: When the fields at 30 meters are compared to the fields at 10 meters on 14 MHz, the whole extrapolation premise falls apart altogether! (files: dip14e30.ez, dip14h30.ez, dip14e10.ez, dip14h10.ez, dip14-2.txt, dip14-2.tif)

4.6 This can be seen dramatically in Figure 7. Note that in at least one case, the magnetic field at 30 meters is slightly higher than it is at 10 meters distance. Not only does the 40 dB/decade rule fail badly in this case, the whole concept of “extrapolation factor” simply does not exist in near-field regions around large radiators.

## 5. Field vs Patterns

5.1 The rules permit specified maximum field strength at specific distances from the radiator. As can be seen from Figures 2 and 3, much of the energy radiated by power lines is radiated upward. To accurately know the field strength created by a particular radiator, it may be necessary to measure the fields above the radiator. It is unlikely that anyone testing a power line will place a test antenna at a height of 30 meters above the lines. It would be quite convenient for inexperienced test engineers to make measurements near ground level, using the short tripods and masts that come with most EMC antennas. Figure 8 shows the way that the calculate electric fields vary with height above ground for 3 points along the line, at a horizontal distance of 10 meters from the line. This model was run on 14 MHz.

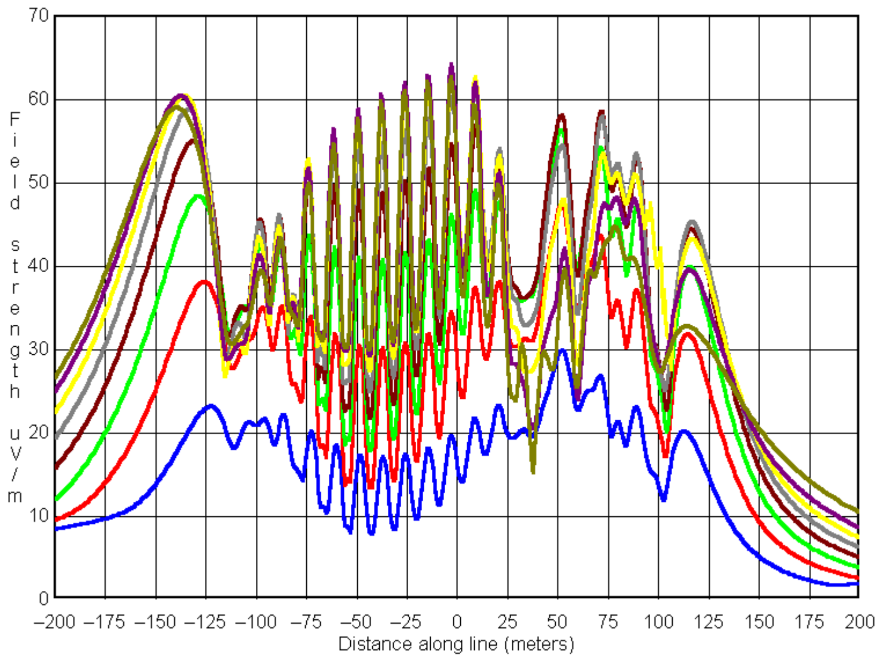


Figure 8. The calculated results obtained can increase or decrease depending on the height above ground of the simulated measurement point. These 14-MHz data were calculated at 5 through 40 meters above ground, along the length of the line, at an absolute distance of 30 meters from the line radially. The blue line, calculated at the lowest height, is the lowest electric field strength shown on the graph. The field strength was normalized to 30 uV/m for this line, and the other field strengths were scaled to the 5-meter height level. The maximum field strength increases with height for this model. The power-line model extends from –100 to +100 meters along the X axis. This calculation extends past the line by another 100 meters in each direction. Note that not only is the field strength higher above the line than at lower heights, at some heights, the point of maximum field strength is some 35 meters past the end of the line. At other heights, the maximum field strength at one height would be near a minimum field strength if measured at a lower height along the same Y axis. (files: dip14e30.ez , all.txt, all.tif)

5.2 As seen in the graph in Figure 8, the maximum radiated fields are often found above the power lines. If the fields were measured below the lines and thus underestimated the actual radiated emissions, the resultant radiated emissions would have significant implications for any aeronautical operation (amateur, commercial or military) and for any receive antennas higher than the lines. This would also increase the level of aggregate signals propagated by skywave as compared to the level if those same signals were radiated at the present Part 15 limits.

## 6. Conclusions

6.1 The model used by ARRL is much less complex than real world installations, yet even in this simplified model, it would be hard to predict just where to make measurements to obtain the actual maximum value of the electric field at 30 meters distance. These peaks occur at only specific places and it is likely that practical measurements would be made at points that will underestimate this peak, sometimes by tens of dB. Determination of an extrapolation factor for distance is not possible, yet if the extrapolation factor of 40 dB/decade were used, in one of these models, the error would be as much as an additional 25 dB underestimation of the electric field at 30 meters. Making measurements at the height of the line or lower adds several more dB of uncertainty. If the true peak is not found, this adds several more dB. If all of these factors add up in the wrong direction, the total error in the measurement could be greater than 40 dB.

6.2 The only way these measurements can be made accurately in-situ is to make measurements at the specified distances at closely spaced intervals above, below and to the sides of the installation. Electrical distribution systems often vary considerably in their physical characteristics at different points in the system, with significantly different potential to radiate. Antenna modeling of simple changes in this structure shows significant differences in the antenna gain of the radiating conductors, indicating a corresponding difference in the radiate near electric and magnetic fields. If measurements are to be used to demonstrate compliance, they must be made at more than "3 typical" parts of a system because with all of the variables, there are a lot more than 3 possible permutations of the factors involved and no such "typical" configuration can be representative of the wide variation in the emissions potential from such a large and diversely configured system.