EXHIBIT C

Modeling as an Alternative to Measurements in Determining the Extrapolation of Measurements Below 30 MHz

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Abstract

Numerical Electromagnetics Code (NEC) analysis of power lines can be used to determine the trends in the way that electric and magnetic field strength varies near power lines. NEC analysis of a complex model of an actual power line near Allentown, PA shows that it is not practical to make measurements of the way that field strength varies with distance from power lines in actual installation, and in any case absent a practical number of measurement points and frequencies. Models of this power line and more simplified line emitters show that the fields vary with distance and location in a way that makes the measurement of only four points insufficient to determine an appropriate factor to use to extrapolate measurements made at one distance from the line to other distances. The models also show that for large and small radiators, the present FCC rule specifying assumption of signal decay at 40 dB/decade of distance on frequencies below 30 MHz is inappropriate for large radiators or for small radiators outside the region bounded by the wavelength of the frequency being measured divided by 2pi ($\lambda/2\pi$).

Introduction

Although most electromagnetic compatibility (EMC) regulations and standards for permitted radiated emissions levels specify a distance from a radiating source at which a particular limit must be met, it is not always practical (or safe) to make measurements at that distance.[1] In some cases, other radiated signals present in the area (ambient signals, licensed or unlicensed) make it difficult to distinguish the signal being measured. In other cases, it is not practical to make measurements at the specified distance, due to the physical size of the test site or *in situ* location, or the inability to access the point(s) of maximum emission at the specified distance. Many regulations and standards address this issue by permitting a measurement to be made at other

[1] Regulation of emissions from BPL systems set limits for radiated emissions. These limits are established for specific distances from the equipment under test (EUT). For example, in the United States, 47 C.F.R. § 15.31 and the FCC's *Measurement Guidelines for Broadband over Power Line (BPL) Devices or Carrier Current Systems (CCS) and Certification Requirements for Access BPL Devices* sets limits based on 30 meters distance from the emitter. ITU-T K.60, sets limits for emissions from information technology devices at a distance of 3 meters.

than the required distance and correcting that measurement by application of a specified formula to obtain an estimate of what the field strength will be at the distance specified in the regulation or standard. This is a good and necessary practice if such extrapolation is done correctly, in accordance with known electromagnetic principles.

Measurement principles

The measurement of field strength can be very complex, especially *in situ*. In general, regulations and standards look to find the point of maximum emission from equipment under test (EUT), while imposing the minimum necessary test requirements to attain that goal to a reasonable degree of certainty. For example, ANSI C63.4, a U.S. standard that is incorporated into the 47 C.F.R. Part 15 regulations by reference, imposes a requirement to measure a device at 16 multiple azimuth angles around the EUT, including a height search to determine if the maximum emission is upward from the EUT rather than along the ground plane of the test site and a requirement to rotate the test antenna from horizontal to vertical.

In C63.4 and in many other standards and regulations, radiated emission testing is specified for frequencies 30 MHz and above. This is not because there is anything unique about that spectrum, but rather so as to provide a good match for most regulations. Radiated emissions are controlled and regulated above 30 MHz, and conducted emissions are controlled below 30 MHz. All of the electromagnetic theory and test principles that apply to 30.001 MHz apply equally well to a frequency of 29.999 MHz, or 1 MHz (as examples). The generic requirement to test at multiple azimuth and elevation angles is included in these standards because it is good EMC practice, not because it is a principle that applies only to frequencies above 30 MHz.

Because there are few standards that specify measurement methods below 30 MHz, good engineering practice dictates that the principles stipulated in standards that specify test methods above 30 MHz be applied to measurements below 30 MHz, scaled for frequency in cases where differences in test methods and frequency is specified in a particular standard that is serving as a reference or baseline for another standard or regulation. Most standards for measurement of emissions are limited to specifying methods for radiated emissions above 30 MHz because most regulations of emissions specify radiated emissions limits above 30 MHz (and conducted emissions limits below 30 MHz.)

Complexity of radiated fields near large and small radiators

The fields near a radiator, especially one that is large relative to the wavelength being measured, can be quite complex. Figure 1, for example, shows a bird's eye view of the field strength calculated using NEC-4[2] of a complex power-line radiator[3], modeled by the National Telecommunications Information Administration (NTIA) for use in its Phase I study of BPL.

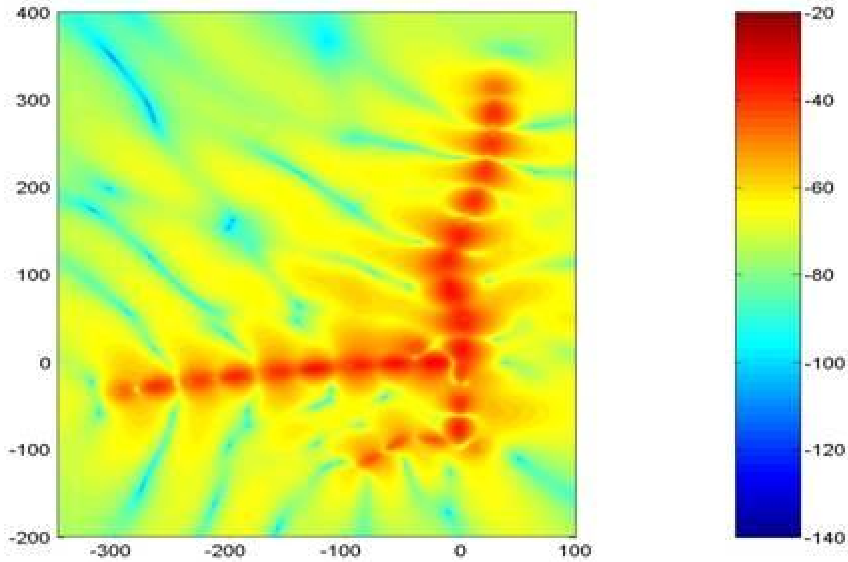

Figure 1: This is a bird's eye view of the calculated field strength near a power line model that represents a real power line that carried BPL near Allentown, PA. The impossibility of making a measurement that would represent the way that fields vary with distance is readily apparent from the radical variations in the pattern along the line and away from the line. The pattern a shows that the measurement of only four points to determine the way field strength varies with distance is unworkable. The peaks and nulls, shown in dB relative to 1 µV per meter, do not fall off cleanly with distance. A measurement made at right angles to the power line does not follow the pattern that actually occurs from the line, where the peaks and nulls are typically skewed at some other angle from the power lines. The angles of the overhead power lines used in this model can be seen, but trying to apply an extrapolation to the measurements of this system in order to reveal an accurate level at 30 meters distance from the line would be virtually impossible.

An analysis of the pattern of Figure 1 does show that fields vary with distance from a physically large emitter, but not in a smooth way that permits easy analysis, or even an easy measurement of the way these fields vary near the radiator.

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[2] NEC-4 is a method-of-moments electromagnetics program that has been used by a number of U.S. Government agencies for scientific study and for formulating various policy positions.

[3] This power line is modeled after a real power line carrying broadband over power line (BPL) near Allentown, PA.

The FCC's test method for BPL is based on the ability to locate the maximum emission along a power line. In looking at the pattern of the data in Figure 1, a number of factors can be seen in this realistic model of a power line. First, although the FCC test method does come close to determining the actual maximum if the tests are run on sufficient frequencies to ensure that the maxima correspond to the points specified based on the mid-point frequency of the emission. However, in looking at the pattern, it is obvious that a few meters along the line will make a significant difference in the way that field strength falls off with distance perpendicular to the line, making any measurement an unreliable way of determining extrapolation, even along ground level.

Other factors that impact the ability to measure in order to determine the proper extrapolation are also apparent from this graph. Looking at the standing wave along the line, it can be seen that the decrease in field strength versus distance is different for each of the peaks along the line. If one were to select one peak and make measurements (assuming that the measurements were made to a sufficient degree of detail) and obtain a result, and then make another measurement at the next peak along the line, each of the two peaks along the line would result in a different value of extrapolation. This would yield an exceptionally high degree of subjectivity, rendering the measurements useless for the purpose.

Looking at the pattern also shows that if one were to determine the actual maximum point, for most of the peaks, the decay with distance is different on one side of the power line than it is for the other. The value one obtained for a measurement would depend in part on whether the left side of the line or the right side was measured.

In looking at this real power line, with wires that don't run in a perfectly straight line, the concept of "perpendicular" is not precise. A few degrees difference in the actual angle estimated by the test engineer to be perpendicular in this complex *in situ* environment will make a significant difference in the measured result.

It is also apparent that the lobes in the pattern with increasing distance from the power line do not always run at right angles from the line, but instead are often skewed somewhat in the direction of the line. The result is that a measurement made at right angles is very likely to be measuring at least partially into a null.

Evaluating these factors in their entirety leads to the inescapable conclusion that it is not possible to accurately measure extrapolation in the complex *in situ* environment surrounding power lines, unless a large number of measurements could be made. Unfortunately, for most installations, it is not possible to make a large number of measurements, because it is not possible to gain access to many areas to be measured, due to private property, terrain obstacles or street-traffic considerations. Trying to make a measurement with only four data points, even if made at each spacing along an overhead power line as specified in the FCC measurement method, will neither reliably nor predictably measure extrapolation from any physically large radiator.

Calculation and modeling

Because it is often not practical or safe to measure at heights above the power lines, and not practical to make thousands of measurements, antenna-modeling techniques can be used to analyze the way that field strength varies with distance from various emitters at various frequencies. In theory, such modeling could be used to help determine compliance. Although the various electromagnetic modeling calculation engines can and do provide accurate results of the modeled system, and are generally well accepted as providing scientifically valid results, a model is only as good as the parameters entered into it. In the real-world environment, systems including power lines contain too many variables, many of which are unknown, to permit modeling to be used instead of measurements to determine specific compliance.

This does not diminish the usefulness of models to determine the best factors to apply to extrapolation, however, as modeling shows clearly how electromagnetic theory applies to a wide range of radiator types. Modeling can, therefore, be used to show trends that are useful to setting test methods and extrapolation, especially of those trends are shown to be consistent across a number of different modeled assumptions.

In its earlier filings in this proceeding, ARRL has used NEC-2 or NEC-4 based method-of -moments EM modeling to predict field-strength trends near radiating structures. (The NEC-2 engine, more common and affordable, provides essentially the same results as NEC-4 for most applications. NEC-4 includes refinements such as allowing modeling of buried radiating elements.)

Determining the Appropriate Extrapolation Rate

If *in situ* measurements are not practical in determining the appropriate extrapolation of measurements made at one distance to a different distance, then one must analyze what electromagnetic modeling shows about various radiators in order to obtain an appropriate extrapolation factor.

In many cases, it is best to start from first principles. For that reason, the first analysis should start with well-known models. In this case, this will include a small dipole, to approximate an infinitesimally small dipole, a half-wave dipole, a simple line radiator and a terminated transmission line with a modeled source similar to the way that most BPL emitters are fed.

To analyze the emissions from "point sources," a 1-meter dipole was selected. For reasons described above, this was modeled in free space. Figure 5.1 below shows how the H field and E field vary with distance from this antenna at frequencies of 1 and 10 MHz. For reference, a 20 dB/distance decade line is also included.

A physically large line radiator is also analyzed. Although its radiated field structure is more complex than the physically small radiator, both large and small radiators show the same general principles, supported by electromagnetic theory.

It goes without saying that the phenomena that are demonstrated to apply to fundamental, small and large models have applicability to all radiators, with variations from the simple models seen in the more complex radiators, but with those variations being in both directions (greater and lesser) from the mean established by the more fundamental models. An overhead power line, or radiating electrical wiring in a building, as two examples, must have characteristics somewhere between a very small radiator and a large radiating line. Applying the principles demonstrated in both the small- and large-line models will yield a result that, on average, will best represent the actual decay of distance from radiating elements of all sizes.

FCC Rules and Distance Extrapolation

FCC's rules on measurement of radiated emissions specify the distance extrapolation to be applied if measurements cannot be made at the distance in the rules for which limits are set. [4] Above 30 MHz, FCC regulations specify that extrapolation shall be done using a 20 dB/decade extrapolation factor. Below 30 MHz, a 40 dB/decade extrapolation is specified.

The presumption is that above 30 MHz, measurements are being made in the far-field region of the radiating element and that below 30 MHz the measurement is being made in the near field. In the near field region, the regulations presume that the field strength will decrease rapidly with distance.

Fallacy in the Present FCC Rules

There are significant differences between the way fields vary in the reactive and radiating near field regions. In the reactive near-field region, field strength decays at a 40 dB/decade rate. In the radiating near-field region, fields generally develop a standing-wave pattern, but one that, on the whole, decays at a 20 dB/decade rate.

This reveals the fundamental error in the present FCC rules, which treat all areas below 30 MHz as if they are in the "near field" region, without differentiating properly between reactive and radiating near-field phenomena; and they treat all areas above 30 MHz as being in the far field.

As cited earlier in this paper, the reactive near-field boundary is generally taken to be $\lambda/2\pi$. At the distances generally used to measure BPL signals, typically 10 meters distance from the radiating source, the measurement point and the distance being extrapolated to (30 meters) are all outside the $\lambda/2\pi$ boundary for any frequency greater than 4.78 MHz. As shown in this paper, outside of the $\lambda/2\pi$ region, field strength does <u>not</u> decay at a 40 dB/decade rate.

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[4] 47 C.F.R. § 15.31 (f)(1)

If the premise is that below 30 MHz, measurements are in the radiating near-field region, that premise is flawed above 30 MHz. The generally accepted boundary beyond which points are not considered as being in the radiating near field is:

Far field boundary = 2 D * D / λ (Where D is the largest physical dimension of the radiating element).

FCC measurements made of the Ambient BPL system in Briarcliff Manor, NY show that power lines carrying BPL signals radiate for a distance of more than 1000 meters *along* the line. If it is conservatively assumed that D is 1000 meters, at a frequency of 3.5 MHz, where the wavelength is 85.7 meters, applying the radiating near-field boundary formula, the radiating near-field region extends to 23,330 meter from the radiating source.

At 30 MHz, where the wavelength is smaller, the radiating near field region of this 1000-meter long radiator is 200,000 meters.

This does not mysteriously change at 30 MHz. To the contrary, as the frequency increases, the wavelength continues to decrease. At a frequency of 80 MHz, the radiating near-field region is an incredible 533,000 meters from the radiating source.

Although the 2D*D/λ formula is only an approximation, clearly at distances of 10 meters from the radiating source, it is completely inappropriate to apply a 40 dB/decade extrapolation below 30 MHz for any frequency above 4.78 MHz. Even below 4.78 MHz, the fields vary at 40 dB/decade *only* within the λ/2π region.

There is no reasonable rationale for applying a 40 dB/decade factor in the radiating near-field region below 30 MHz, and then stop applying it above 30 MHz, where the physical size of the radiating near field region continues to increase with frequency. A 40 dB/decade extrapolation beyond the reactive near-field region is flawed on its face and at distances of 10 meters or more, all points are outside of the reactive near-field boundary for all frequencies at and above 4.78 MHz.

The FCC rules recognize this lack of rationale, stating: (emphasis added)

> Sec. 15.31(f)(2): At frequencies below 30 MHz, measurements may be performed at a distance closer than that specified in the regulations; however, an attempt should be made to avoid making measurements in the near field. <u>Pending the development of an appropriate measurement procedure for measurements performed below 30 MHz,</u> when performing measurements at a closer distance than specified, the results shall be extrapolated to the specified distance by either making measurements at a minimum of two distances on at least one radial to determine the

proper extrapolation factor or by using the square of an inverse linear distance extrapolation factor (40 dB/decade).

Large and Small Radiators and the Near-Field Regions

Reactive and radiating near-field regions

The premise for the extrapolation factors specified in the present FCC rules is only partially correct at best. The electromagnetic theory that field strength changes rapidly with distance in the near field is correct, but *only* in the reactive near-field region of the radiator. In general, the reactive near-field region is the distance from the radiator represented by λ(wavelength) / 2π. *Within the distance up to λ / 2π,* field strength generally falls off at a rate of the inverse of distance squared (40 dB/decade).

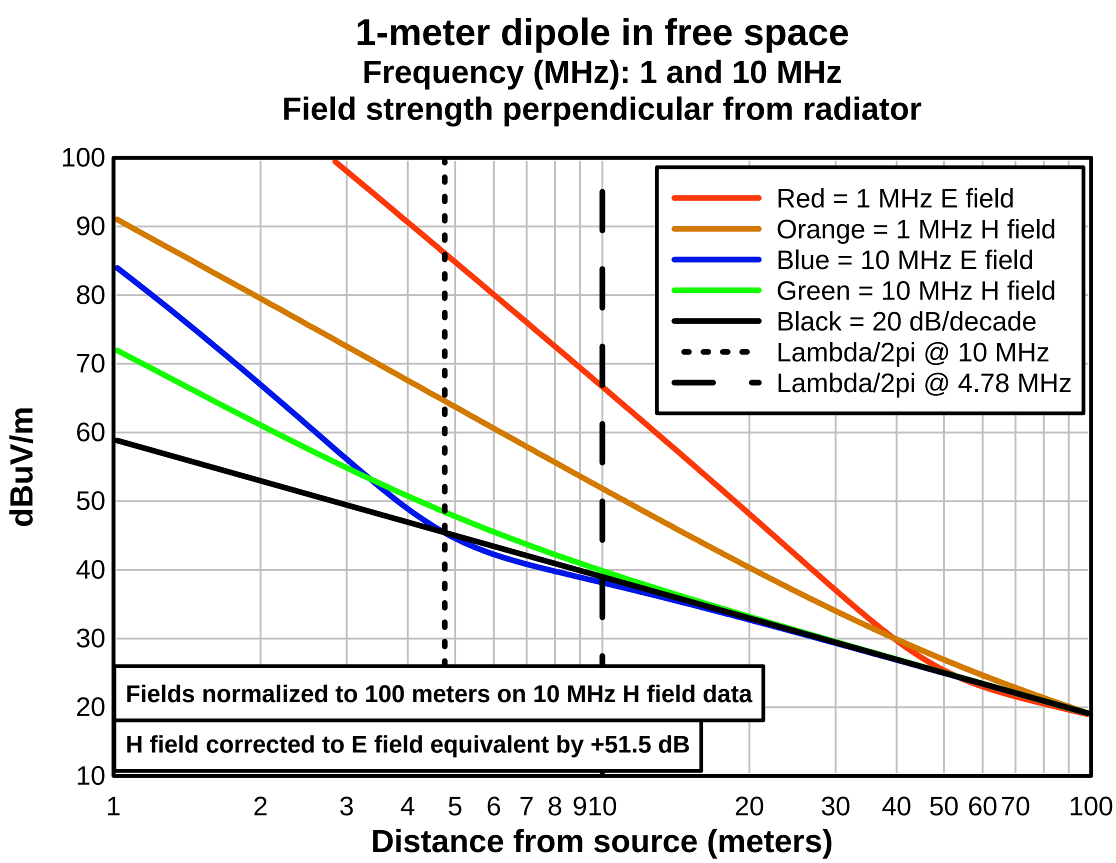

Figure 2 – This shows how E and H fields vary with distance from a dipole with dimensions that are small in comparison to the wavelength of the radiated signal (electric-field source). The delineation of the reactive near-field and far-field regions is most apparent in the E field, as would be expected from a small dipole, whose near field region is dominated by electric fields. This region is delineated by the classic $\lambda/2\pi$ definition.

Figure 2 shows the way that electric and magnetic field strengths vary near a physically small radiator. The relationship shown by this figure has appeared in numerous articles and other literature related to electromagnetic theory. This model is of a small dipole, which is primarily an electric field (E) source. The model shows that within the λ / 2π region, the E field varies at a 40 dB/decade rate and beyond that distance from the source, the field strength decays at a 20 dB/decade rate. A small loop would primarily be a magnetic-field (H) source, so the H field would decay at a 40 dB/decade rate within the reactive near-field region and decay at a 20 dB/decade in the far field region.

There are a number of things that can be learned from analyzing this simple model. For point sources, the near-field region is clearly defined by $\lambda/2\pi$. In this case, a small dipole was used, in which the E field dominates within the near-field region. If a small loop source were used for the model instead, within the near-field region, the H field would dominate. However, for physically small sources, most extrapolations will be made from a distance of approximately 10 meters to a 30 meter or 3 meter distance. Above 4.78 MHz, 10 meters and 30 meters are both in the far field region, where a 20 dB/decade extrapolation would be correct. Thus, for physically small sources, such as pad mounted transformers, for example, (and to some extent, radiating premise wiring)if measurements are made at 10 meters distance, over most of the frequency range, an extrapolation of 20 dB/decade would be exact.

From Figure 2, one can determine that at 1 MHz, distances of 10 and 30 meters are both within the near-field region. In this area, the E field is varying more rapidly than 40 dB/decade. However, at 1 MHz the H field is varying by just slightly less than 40 dB/decade.

It is apparent that for small radiators, 40 dB/decade is NOT supportable to extrapolate from 10 meters to 30 meters above 4.78 MHz.

Radiating Near-Field Region

A radiating source is probably not going to act completely like a short dipole or small loop, however. For larger sources, for some distance from the source, any particular point is outside the reactive near-field region, but close enough to the radiator that it is not equidistant from different parts of the radiator. The geometric region near a radiator bound by these conditions is known as the radiating near-field region.

Line emitters

Modeling of physically small radiators shows that beyond the reactive near-field region, field-strength decays at a 20 dB/decade rate. For large radiators, as seen in Figure 1, as an example, it is a lot more complex. However, a simple line radiator is a good model to use to predict what will happen for overhead power lines, which are also physical lines in dimension and radiating characteristics.

The following figures and Figure 1 show that near a radiating line, standing waves develop, both along the line, but also radiating away from it. Along the line, at any distance (10 meters, for example) there is a standing wave of electric field and a standing wave of magnetic field seen along the line. The maxima for these two fields are not at the same physical distance along the line, but the maxima are spaced approximately 0.25 λ along the line. (Interestingly, the relationship between the maximum value of the E field and the maximum value of the H field along the line is such that E/H = 377Ω, approximately, providing good support for the use of a magnetic loop to measure field strengths with a specified limit expressed in microvolts/meter.)

The following Figures all show the field strength going away perpendicularly from the radiating line, in free space, starting at the point along the line that is the maximum H field. For these physically large radiators, what is seen in these data is that within the region of λ/2π, the fields do not decay at 40 dB/decade as they do for physically small radiators, but generally decay even up close at approximately 20 dB/decade (This is in line with electromagnetic theory for line emitters, discussed in several of the earlier ARRL filings in Docket 04-37). Beyond the reactive near-field region, the calculated field strength shows a standing wave, but the peaks of that standing wave, or the average of the square of the fields of the standing wave, decay at a 20 dB/decade rate.

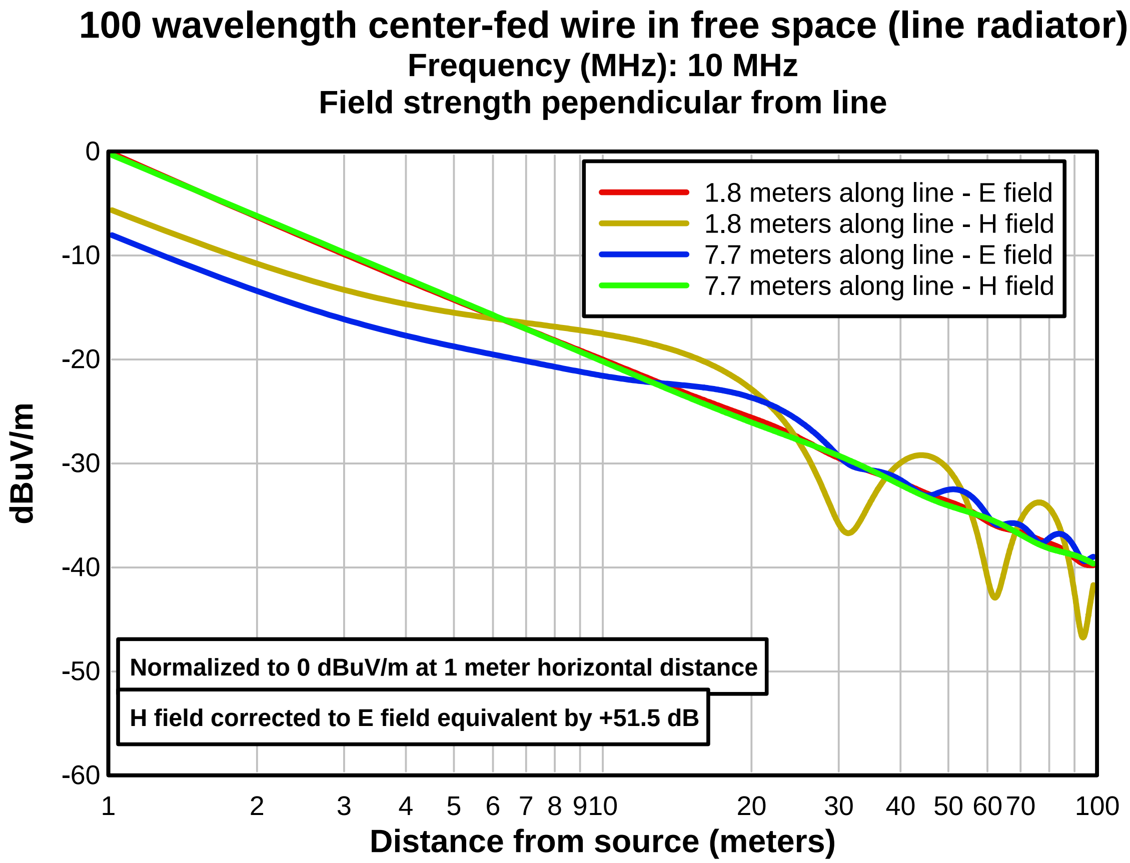

Figure 3 -- This shows how E and H fields at a frequency of 10 MHz decay with distance perpendicularly from a radiating 100-wavelength line, center fed in free space. The graph shows the E and H fields, starting at the point that is the maximum along the line a horizontal distance of 1 meter.

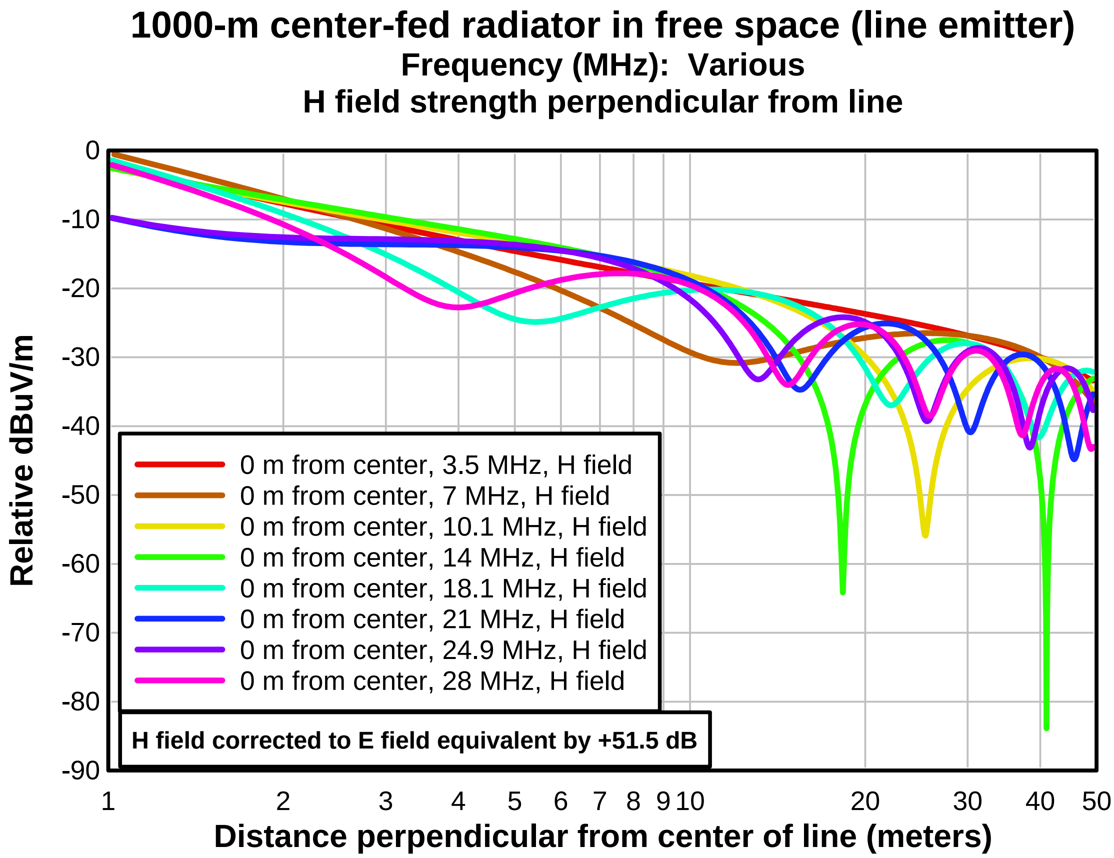

Figure 3 -- This shows how E and H fields at various frequencies from 3.5 to 28 MHz decay with distance perpendicular to a radiating 1000-wavelength line, center fed in free space. The graph shows the E and H fields, starting at the point that is the maximum along the line a horizontal distance of 1 meter. These data show that for any frequency, the maxima and minima may be at different points, but on the whole, the peaks or the average of the decay is at 20 dB/decade. It can also be seen that if one were to measure four points to determine the "real" extrapolation, if any of those points were not on the peaks, the measurement would be made, to one degree or another, into a null and the determined value of extrapolation would be higher than it actually is.

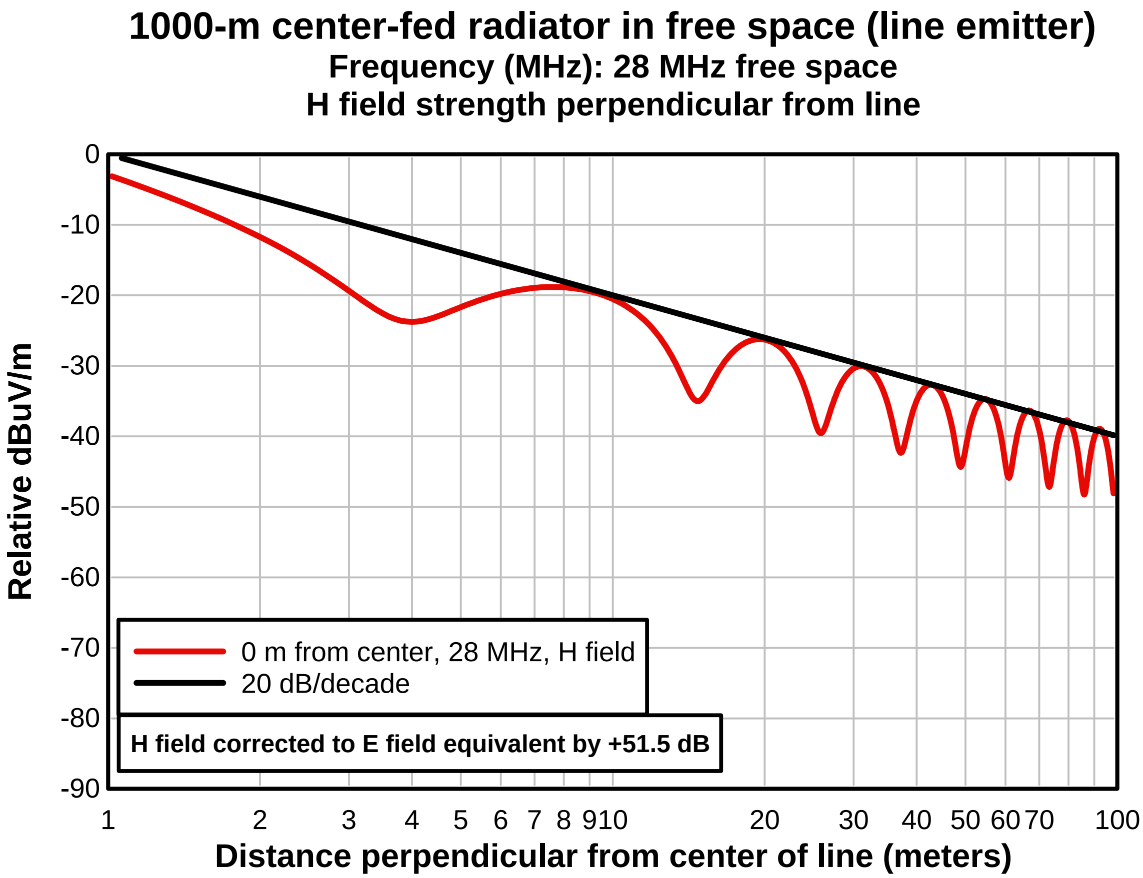

Figure 4 -- This shows the same data, but only for the 28 MHz signal, to allow the trend of decay with distance to be more apparent.

Measurements along ground level vs emissions at angles upward from an emitter

In most cases, measurements are made at ground level. FCC Part 15, for example, specifies that measurements should be made at 1 meter height. Few, if any, radiocommunications antennas are located at 1 meter height. For that reason, the methods for extrapolation specified in this standard should be directed toward determining what the emissions from a system would be at compliance-distance points that are related to the location of radiocommunications systems.

In many cases, on HF (3-30 MHz), antennas of nearby radiocommunications systems are located at heights greater than overhead power lines. Any extrapolation based on measurements made at ground level must correlate well to emissions at upward angles if the limits specified are to offer any protection to those licensed stations.

At these upward angles, the compliance distance of 30 meters, for example, the necessary measurement points would be at locations that are likely to be impractical and unsafe to actually measure. For that reason, this standard is on the right track in stipulating measurements to be made at ground level.

Several of the papers ARRL filed in the record in this proceeding correlate ground-level measurements to upward angles. This generally involves adding a height correction to the measurements made at ground level. To simplify that, and to provide conservative results, this paper does not generally do so, but instead uses free space models to show the underlying trends involving extrapolation vs distance at various frequencies for large and small emitters. The earlier papers filed by ARRL show that field strength does increase with height. These papers also show good correlation between measurements made at 1 meter in height at 10 meters horizontal distance from the radiator and the emissions at 30 meters distance from a radiating overhead wire at angles upward from the line emitter.

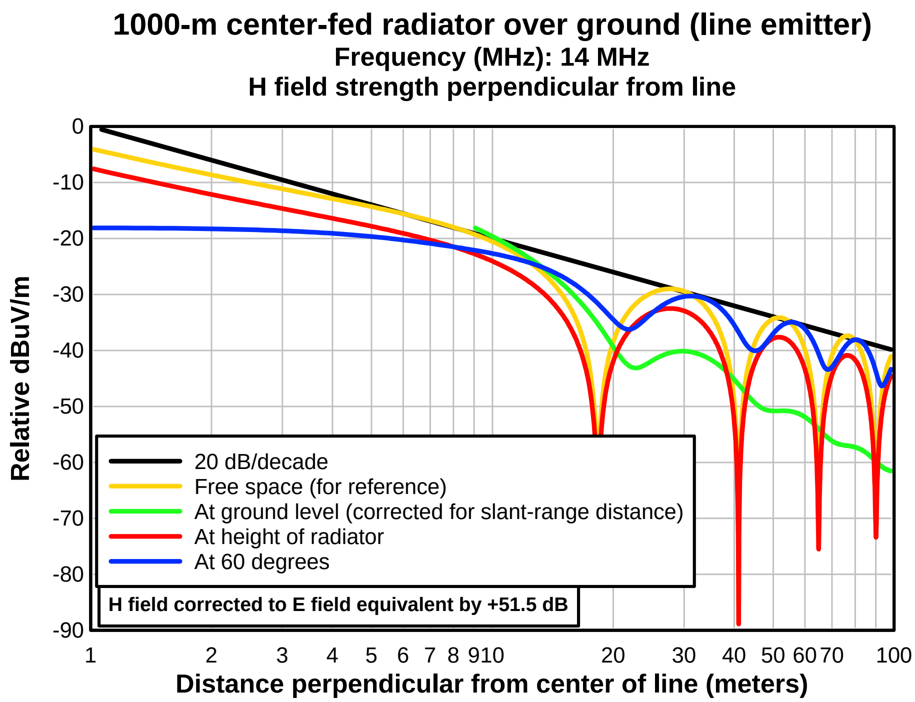

Figure 5 -- This shows the decay with perpendicular distance on a frequency of 14 MHz from a 1000-meter long power line, at various heights, modeled over real ground. . The upward angle of 60 degrees shown represents the angle of the maximum emissions for a horizontal radiator at a height of approximately 10 meters. The ground-level calculation is made at a height of 1 meter above ground. It is clearly seen that at the height of the radiator or at upward angles -- the locations where HF antennas are apt to be located -- the fields decay at 20 dB/decade. At ground level, losses from the ground do increase the decay rate. At angles that represent the location of HF antennas and at the angles for which the aggregate of noise from multiple devices could propagate by skywave, the decay rate is not the same as what would be measured along the ground.