EXHIBIT B

Exhibit B

Interference Assessment of PLC Compatibility with Allocated HF Systems

Prepared by Dr. David Cohen

The ARRL has provided to me over 50 documents relating to the compatibility issue of BPL PLC operations with existing HF users in the 1-30 MHz range. They included BPL, ARRL, FCC, ITU and other miscellaneous documents.

I was asked to objectively review the documents technically. Neither the ARRL nor NTIA have influenced me in the comments I provide below.

I offer in this Exhibit B a suggested technically based approach that might serve as a basis to facilitate compatibility among the entities.

It is my conclusion based on the review of all of the supplied documents that the appropriate interference criteria is to use an I/N criteria. This calls attention to the importance of the background ambient noise level (without PLC present) as the criteria for determining whether PLC is an interference problem for other shortwave operations. The ambient background noise level is not a constant everywhere and depends upon frequency and the man-made and atmospheric noise levels (rural vs. business).

<u>1. THE PROBLEM:</u>

It is my judgment that the compatibility problem between BPL PLC and other HF radio services is best described in the soon to be published (may have already been published) Virginia Journal of Law and Technology, Tobekin, D. and Howard, N. (Reference 1) An important quote from this overview is:

"What is remarkable is the disparity between the sides as to the magnitude of interference effects with BPL technology providers contending such effects will be minimal and spectrum users contending they will be enormous."

My goal in the following comments is to try and put this in perspective as to why there can be such a difference in opinion.

The two studies I principally relied upon in developing my review are Weinmann and Dostert (Reference 3) and Kho (Reference 4).

In particular, Weinmann and Dosert's paper forms a basis for the need to utilize an I/N interference criteria and the model by Kho (which utilizes an I/N interference criteria) is my suggested technical approach for the compatibility analysis.

First, in my review I will discuss some important findings contained in the Weinmann paper and afterwards discuss the findings in the Kho paper.

2.FINDINGS FROM WEINMANN'S EMC2003 PAPER:

a. Interference from PLC:

Weinmann concludes that if all radiation sources from PLC sources comply with the German NB_{30} limits there should not be an interference problem with other shortwave sources. This limit specifies that at 3 m (from Equation 1 in his paper) at 5 MHz is 33.85 dBμV/m

b. Background noise

Weinmann in his suggestions for further work (section 6) states his "assumptions on background noise which forms the reference level for PLC". Note from this statement that Weinmann concludes that the background noise is the critical factor whether or not there is an interference condition.

From Weinmann's paper in a rural area where atmospheric noise is dominant for frequencies below 15 MHz the noise level is about 25dBμV/m while in a city where man-made noise is dominate the noise level could be significantly different and may or may not be a problem. The larger the background noise level (with PLC signals not present) the less there is a problem from PLC interference. Also the larger the regulated interference limit is the greater the potential problem from interference if it is at this limit. In this regard one needs to keep in mind the difference in the German limit (at 3m, 5 MHz) that is 33.85μV/m compared to the US limit (as extrapolated by Gephart et al) of about 65μV/m. (Reference 5)

c. Multiple Sources of Interference:

Weinmann's paper is a model of the expected field strength from a multiple number of PLC sources which cumulatively add up to give an expected (average) field.

While I was at the NTIA Les Berry of NTIA's Institute for Telecommunication Sciences (ITS) in Boulder, Colorado did a study of the cumulative effect of multiple sources with identical power and an assumed propagation law of 1/r for field strength. His conclusion was that the major contribution to the interference came from the closest interference source and that all other sources added only a small contribution to the interference. This is certainly bourn out in Weinmann's paper that shows peaks in the field strength below 50 kilometers.
Weinmann explains these peaks in the text by the comment:

…….shows peaks if the observation point is located near a radiation source (Figures 4 and 5)

d. Ground Wave
In section 3.1 Weinmann states that the field strength has a 1/r dependence. This is consistent with the modeling of Kho which I will discuss below.

3. FINDINGS FROM KHO (DEVELOPMENT OF AN EMC MODEL)

It is my conjecture that the appropriate technical analysis to solve the compatibility of PLC and HF systems is Kho's compatibility study in the Wroclaw 2002 Electromagnetic Compatibility Symposium. His paper performs an excellent technical analysis and can put the compatibility problem in perspective.

The technical parameters for HF signals, background noise and equipment characteristics vary over a wide range of values and systems efficiencies vary over large ranges. Accordingly, in these situations as an interference criteria it is appropriate to use an I/N interference criteria rather than an S/I. Kho choose as an interference criteria (Total I +N) dBm/Hz < N dBm/Hz +.5 dB. Kho was concerned with systems operating close to their sensitivity levels. There are other I/N criteria. These include I/N =-6dB. Radars utilizes an I/N of –6 dB and a suggested value for the Universal Mobile Telecommunications System (UMTS) is that the interference be permitted to be a 50% increase in noise level.

Turning now to the noise level itself this varies over a large range of values for HF systems in the 1-30 MHz. Range. Figure 1 which is Figure 6.2.1 of Kho demonstrates that the noise level varies over a wide range depending upon frequency and population situations (i.e., quiet rural to business). Kho's diagram is a calculation of the maximum interference level for PLC *but we wish to utilize it to give us a perspective on the noise level.* From the figures we can see that e.g. 5MHz the noise density can vary over about 30 dB.

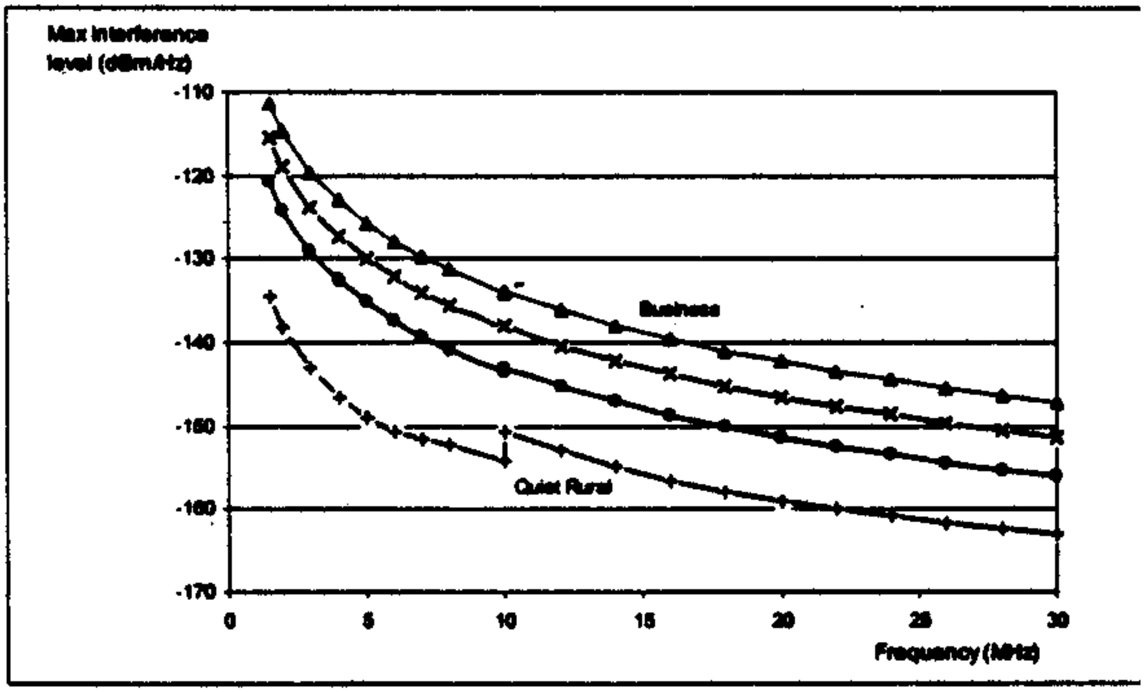

Figure 1

Exhibit A of the ARRL (Reference 6) includes a good description of data but much of it is qualitative. There is however for sites 3 and 4 the mentioning of specific measured interference levels (with BPL interference). The interference levels measured across the street from the power line source are from 28 dBµ V/m to 35 dBµ V/m. As a test of Kho's effort let's compare these measured interference values with similar distance conditions of the maximum interference permitted based on Kho's analysis. Figure 2 (extracted from Kho's study) is shown below: The various curves on the graph correspond to the same noise values found in Figure 1 above. The Figure 2 assumes that the protection distance is 10 meters and the curves are the proposed limits for the PLC field strength.

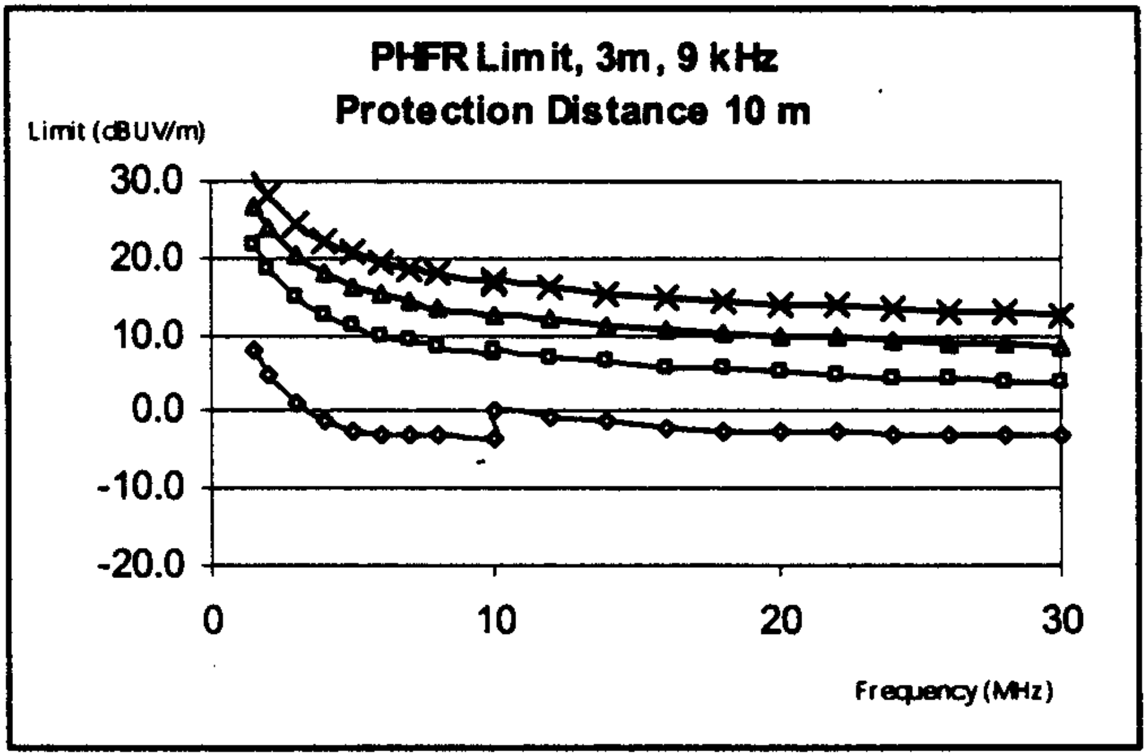

Figure 2

We can see that the calculated limits on field strength (around 10 to 30 dbµV/m) for the frequency range 0- 15 MHz (in the figure above) are in the same "ballpark" with that measured by ARRL. (28 to 35 dbµV/m)

4. RECOMMENDATION:

(1) If possible, use measured data from the NTIA forthcoming report (I have not seen any of the measurements nor know what was measured) to establish (a) a standard background noise level, (b) an appropriate I/N protection criteria
(2) Use the Kho model with the data established in Recommendation (1) to determine a Part 15 field strength limit for PLC systems (for outside antenna radiated fields only, not for in building generated fields)

References:

(1) Tobekin, D. and N Howard , The FCC's Broadband Over Power Line Inquiry:Considering Radio-Frequency Interference Rules of the Road for the Third High-Speed Communications Wire, Virginia Journal of Law and Technology Winter 2004
(2) Gebhardt, M., Weinmann, F. and Dosert, K. Physical and Regulatory Constraints for Communication over the Power Supply Grid, IEEE Communications Magazine, May 2003 Figure 6, p. 90.
(3) Weinmann, F. and K. Dosert, Modelling the Far Field Radiation of Widespread Power Line Communication Applications, EMC 2003
(4) Kho, K. S. Protection Requirements for Military HF Radio Services Based on a Generic Sharing Criteria for HF Systems EMC 2002
(5) Gebhardt, M., Weinmann, F. and Dosert, K. Physical and Regulatory Constraints for Communication over the Power Supply Grid, IEEE Communications Magazine, May 2003 Figure 6, p. 90.
(6) ARRL Reply Comments to Docket No. 03-104 Inquiry Regarding Carrier Current Systems Including Broadband over Power Line Systems

Bio Dr. David Cohen

Dr. Cohen has over 35 years experience in spectrum management and HF studies. His Ph.D. thesis modeled scattering from the D region of the ionosphere (the partial reflection experiment to determine background electron densities). His thesis was experimentally verified. While at the NTIA (1975-1996) he developed a method for the sharing of HF Broadcasting and HF Fixed services for the ITU CCIR (now ITU-R) preparatory meeting for WARC-79. Dr. Cohen was the principal technical delegate for the United States at the HF Broadcasting WARCS in 1983 and 1987. David was a past editor for the IEEE Electromagnetic Compatibility Transactions in the area of spectrum management. Also, David was a past US chairman of URSI Commission E (Spectrum Management).
Now at the University of Maryland he is the program director for Telecommunications Studies and teaches both wireless and wireline courses.

EXHIBIT C

Exhibit C

Proposed Radiated Emission Limits and Extrapolation

Paul L. Rinaldo, Chief Technology Officer, ARRL
April 28, 2004

1. Introduction

This paper examines the Part 15 rules proposed in Appendix B of the Notice of Proposed Rule Making in OET Docket 04-37 pertaining to radiated emission limits and measurement standards for Access Broadband over Power Line (Access BPL).

This paper concludes the following:

- ♦ Power lines carrying BPL are line-source, not point-source radiators.
- ♦ Measurements should be made at a single separation distance, such as 10 meters
- ♦ Loop antennas should be used for BPL measurements.
- ♦ Extrapolation should be avoided whenever possible, but where needed, an extrapolation factor of 20 dB/decade should be used.

2. Modifications to § 15.109(e) Proposed in the NPRM

Section 15.109 Radiated emission limits.

******
(e) Carrier current systems, including BPL systems, used as unintentional radiators or other unintentional radiators that are designed to conduct their radio frequency emissions via connecting wires or cables and that operate in the frequency range of 9 kHz to 30 MHz, including devices that deliver the radio frequency energy to transducers, such as ultrasonic devices not covered under Part 18 of this Chapter, shall comply with the radiated emission limits for intentional radiators provided in Section 15.209 for the frequency range of 9 kHz to 30 MHz. As an alternative, carrier current systems used as unintentional radiators and operating in the frequency range of 525 kHz to 1705 kHz may comply with the radiated emission limits provided in Section 15.22(a). At frequencies above 30 MHz, the limits in paragraph (a), (b) or (i) of this Section, as appropriate, continue to apply. For all BPL systems, the requirements of this paragraph and paragraph (a) of this section shall also apply to the emissions from all low-voltage lines from the distribution transformer to all in-building wiring.

3. Applicable Elements of §15.209

(a) Except as provided elsewhere in this subpart, the emissions from an intentional radiator shall not exceed the field strength levels specified in the following table:

Frequency (MHz)	Field strength (microvolts/meter)	Measurement distance (meters)
***	***	***
1.705-30.0	30	30
30-88	100 **	3
***	***	***

** Except as provided in paragraph (g), fundamental emissions from intentional radiators operating under this section shall not be located in the frequency bands 54-72 MHz, 76-88 MHz, 174-216 MHz or 470-806 MHz. However, operation within these frequency bands is permitted under other sections of this part, e.g., Secs. 15.231 and 15.241.

(b) In the emission table above, the tighter limit applies at the band edges.

(c) The level of any unwanted emissions from an intentional radiator operating under these general provisions shall not exceed the level of the fundamental emission. For intentional radiators which operate under the provisions of other sections within this part and which are required to reduce their unwanted emissions to the limits specified in this table, the limits in this table are based on the frequency of the unwanted emission and not the fundamental frequency. However, the level of any unwanted emissions shall not exceed the level of the fundamental frequency.

(d) The emission limits shown in the above table are based on measurements employing a CISPR quasi-peak detector except for the frequency bands 9-90 kHz, 110-490 kHz and above 1000 MHz. Radiated emission limits in these three bands are based on measurements employing an average detector.

(e) The provisions in Secs. 15.31, 15.33, and 15.35 for measuring emissions at distances other than the distances specified in the above table, determining the frequency range over which radiated emissions are to be measured, and limiting peak emissions apply to all devices operated under this part.

(f) In accordance with Sec. 15.33(a), in some cases the emissions from an intentional radiator must be measured to beyond the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator because of the incorporation of a digital device. If measurements above the tenth harmonic are so required, the radiated emissions above the tenth harmonic shall comply with the general radiated emission limits applicable to the incorporated digital device, as shown in Sec. 15.109 and as based on the frequency of the emission being measured, or, except for emissions contained in the restricted frequency bands shown in Sec. 15.205, the limit on spurious emissions specified for the intentional radiator, whichever is the higher limit. Emissions which must be measured above the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator and which fall within the restricted bands shall comply with the general radiated emission limits in Sec. 15.109 that are applicable to the incorporated digital device.

(g) Perimeter protection systems may operate in the 54-72 MHz and 76-88 MHz bands under the provisions of this section. The use of such perimeter protection systems is limited to industrial, business and commercial applications.

4. § 15.31(f) Provisions

(f) To the extent practicable, the device under test shall be measured at the distance specified in the appropriate rule section. The distance specified corresponds to the horizontal distance between the measurement antenna and the closest point of the equipment under test, support equipment or interconnecting cables as determined by the boundary defined by an imaginary straight line periphery describing a simple geometric configuration enclosing the system containing the equipment under test. The equipment under test, support equipment and any interconnecting cables shall be included within this boundary.

(1) At frequencies at or above 30 MHz, measurements may be performed at a distance other than what is specified provided: measurements are not made in the near field except where it can be shown that near field measurements are appropriate due to the characteristics of the device; and it can be demonstrated that the signal levels needed to be measured at the distance employed can be detected by the measurement equipment. Measurements shall not be performed at a distance greater than 30 meters unless it can be further demonstrated that measurements at a distance of 30 meters or less are impractical. When performing measurements at a distance other than that specified, the results shall be extrapolated to the specified distance using an extrapolation factor of 20 dB/decade (inverse linear-distance for field strength measurements; inverse-linear-distance-squared for power density measurements).

(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. Pending the development of an appropriate measurement procedure for measurements performed below 30 MHz, 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).

(3) The applicant for a grant of certification shall specify the extrapolation method used in the application filed with the Commission. For equipment subject to Declaration of Conformity or verification, this information shall be retained with the measurement data.

(4) When measurement distances of 30 meters or less are specified in the regulations, the Commission will test the equipment at the distance specified unless measurement at that distance results in measurements being performed in the near field. When measurement distances of greater than 30 meters are specified in the regulations, the Commission will test the equipment at a closer distance, usually 30 meters, extrapolating the measured field strength to the specified distance using the methods shown in this section.

> (5) Measurements shall be performed at a sufficient number of radials around the equipment under test to determine the radial at which the field strength values of the radiated emissions are maximized. The maximum field strength at the frequency being measured shall be reported in an application for certification.

5. Modifications to § 15.109(e) Proposed in Appendix B:

Compared to the existing § 15.109(e), the modifications introduced above are to intended clarify that § 15.209 emission limits for 9 kHz to 30 MHz and § 15.109(a), (b) or (i) for above 30 MHz continue to apply to BPL systems. In effect, there is no change from the current § 15.109(e) with respect to treating BPL systems as intentional emitters.

6. Field Strength and Measurement Distances in § 15.31(f):

Typically, amateur stations at fixed locations are situated such that their receiving antennas are well within 30 meters of a power line. A distance separation between power lines carrying BPL and a receiving antenna at a distance of 10 meters is more representative for suburban residential properties. This is consistent with § 2.b of Appendix C of the NPRM, which states:

> b. <u>Radiated Emissions Measurement Principles for Overhead Line Installations</u>
>
> 1) Measurements should normally be performed at a horizontal separation distance of 10 meters from the overhead line. If necessary, due to ambient emissions, measurements may be performed at a distance of 3 meters.

It is puzzling why the NPRM proposes that measurements be made at a separation distance of 10 meters, then specifies the field strength limit at 30 meters, then specifies an extrapolation formula for the user to derive the field strength limit at 10 meters. It would be simpler to specify that measurements be made at 10 (or alternatively 3) meters separation distance and the field strength limit applicable to that distance.

7. Extrapolation Specified in § 15.31(f):

Restating § 15.31(f)(2),

> (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. Pending the development of an appropriate measurement procedure for measurements performed below 30 MHz, 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).

For simplicity and consistency of results, it would be desirable to standardize on a measurement separation distance of 10 meters and eliminate the provision for measurements at a distance of 3 meters. Based on observations of residential situations during actual field measurements, of the two distances, 10 meters is a more practical measurement distance for most residential situations.

The introduction of an extrapolation factor raises the question of which is the correct one to use. The core of the question is whether a BPL power line is a point-source or a line-source radiator. The controversy is introduced in §§ 22 and 23 of the NPRM, as follows (footnotes omitted):

> 22. A number of BPL proponents argue that the technical assumptions used by opponents of Access BPL to predict interference are incorrect. They dispute claims that the electric power lines will act like an efficient antenna and that signals from Access BPL devices will aggregate to raise the noise floor. Southern states that there is a high degree of variability in the ability of power lines to radiate BPL signals and that signals on power lines will tend to cancel each other out. It argues that its research to date would suggest that a BPL signal injection point can appear like a point-source radiator, with the power line having characteristics somewhere between a waveguide and an antenna. Thus, Southern contends that ARRL erred in depicting the power line as an efficient antenna for a single, discrete frequency.
>
> 23. Current Technologies submits that its data indicate that BPL emissions drop off very rapidly away from the BPL source and that emissions fall off in point-source fashion. Ameren Energy Communications Inc. (AEC) states that the notion that the power lines will act as efficient antennas and pollute their surroundings with harmful interference is not supported by scientific measurements. AEC asserts that because of impedance

> mismatch in real-world power lines, a single power line is expected to be a rather inefficient radiator.

As a basis for discussion, it is useful to consider whether power lines are antennas. The *IEEE Standard Dictionary of Electrical and Electronics Terms* provides the following definition:

> **antenna (1) (general).** That part of a transmitting or receiving system which is designed to radiate or to receive electromagnetic waves. **(2) (data transmission).** A means for radiating or receiving radio waves.

According to the above definition, power lines do not qualify as antennas because they were not "designed to radiate or receive electromagnetic waves." Instead, they are transmission lines designed for carriage of electrical power at a frequency of 60 Hz. Power lines are not designed to carry radio-frequency signals, but they act as radiating (leaky) transmission lines in the band 1.7-80 MHz. Electric lines are not terminated in their characteristic impedance at RF and the loads change dynamically as they are connected and disconnected or active and inactive. Many BPL systems excite a single line in a common-mode (asymmetric-mode) configuration rather than using a balanced line having some reduction of unintended radiation. Nevertheless, BPL transmission lines have radiation characteristics of antennas.

In the ET Docket No. 98-80 Notice of Inquiry regarding conducted emission limits below 30 MHz for equipment regulated under Parts 15 and 18 of the Commission's rules, the FCC recognized that power lines act as antennas, as follows (footnote omitted):

> 3. Many radio frequency devices obtain their electrical energy from the AC power line (i.e., 110 volt household electrical line). Such devices include personal computers, personal computer peripherals, TV and FM receivers, video cassette recorders, cordless telephone base stations, wireless security alarm systems, RF lighting devices, microwave ovens, induction cooking ranges and ultrasonic equipment. The radio frequency energy

> that these devices generate can be conducted back onto the AC power line. The conducted radio frequency energy can cause interference to radio communications via two possible paths. First, the radio frequency energy may be carried along the electrical wiring to another device that is also connected to the electrical wiring. Second; the AC electrical wiring can act as an antenna to radiate signals over the airwaves. At frequencies below 30 MHz, where wavelengths are greater than 10 meters, the long stretches of electrical wiring can act as very efficient antennas. Further, the signals radiating onto the airwaves can cause interference to operations at considerable distances because propagation losses are low at these frequencies.

Having clarified that power lines carrying BPL "can act as very efficient antennas," in order to understand how the field strength increases and decreases with distance, thus determining the extrapolation factor, it is necessary to establish whether the power line is a point-source or a line-source radiator.

The *IEEE Standard Dictionary of Electrical and Electronics Terms* provides the following definitions:

> **point source (laser-maser).** A source of radiation whose dimensions are small enough compared with the distance between source and receptor for them to be neglected in calculations.
>
> **line source (1) (antennas).** A continuous distribution of sources of electromagnetic radiation, lying along a line segment. *Note:* Most often in practice the line segment is straight.

Note that the above "point source" definition is provided in a laser-maser context but appears to fit the antenna case as well.

A point-source signal radiation spreads as an expanding sphere.

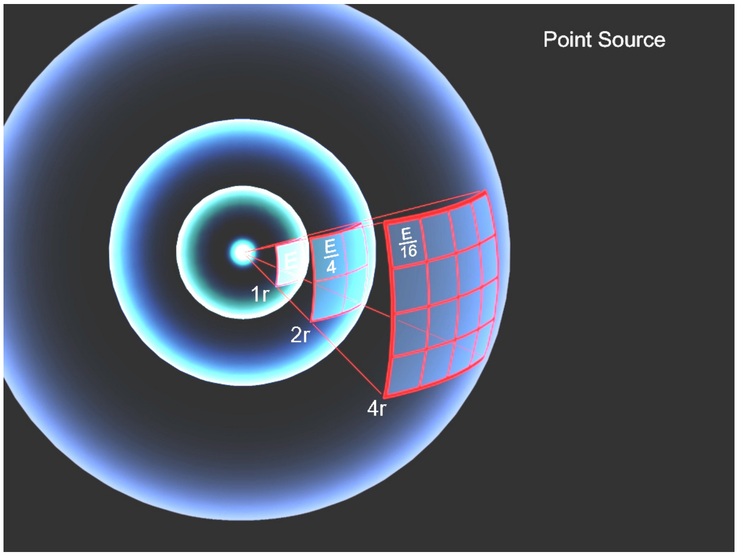

Figure 1– Inverse square radiation from point source.

By contrast, the signal from a line source spreads as an expanding cylinder.

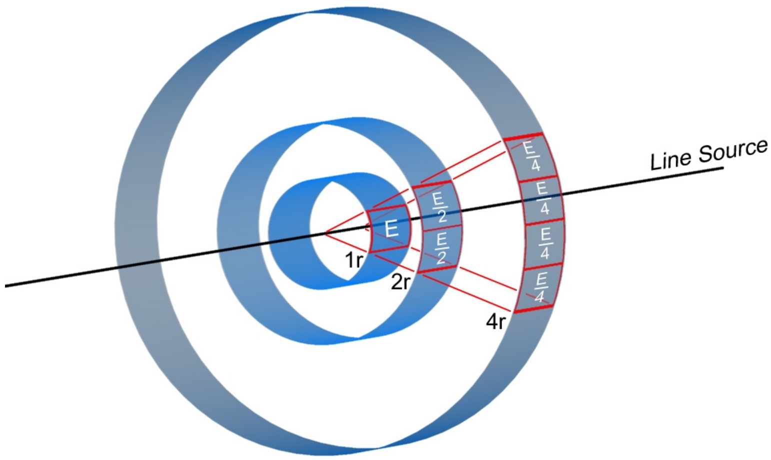

Figure 2 – Inverse distance radiation from line source.

The dispersion will be less over distance with a line source than with a point source.

The following is a comparison of several types of sources as one approaches the sources (footnotes omitted):

> In the radiating near-field region of a square broadside aperture, the on-axis power density |*E x H*| oscillates with distance about a fixed value which depends upon the aperture taper. A line source, however, behaves differently: the power density oscillates with distance, but about an inverse slope (1/*R*) line…[1]

Comparisons of power densities with increasing separation distance from the source are shown in Figure 3, below:

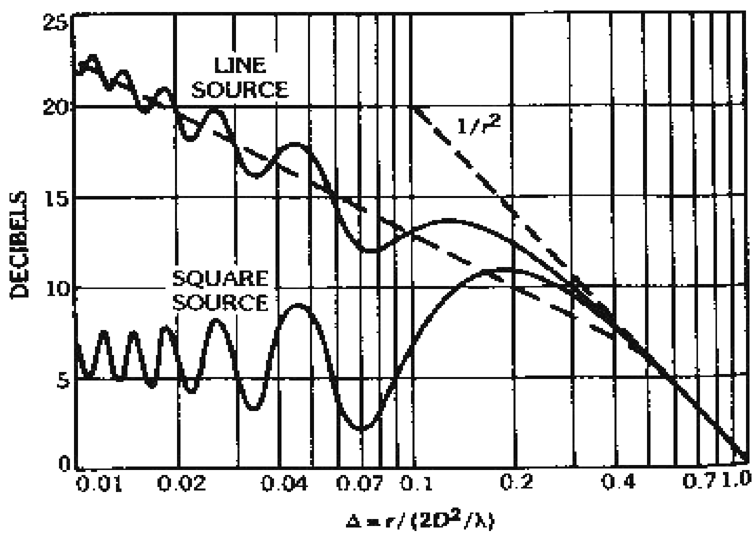

Figure 3 – On-axis power density.

For another view, Figure 4, below, has the results of a series of NEC-4 near-field calculations of a 2000-meter long center-fed antenna in free space. A frequency of 14 MHz was used. These data are for the magnetic field, normalized to a value of +29.5 dBµV/m at 30 meters. The near-field function was used to find the point of maximum magnetic field 3 meters from the radiator, along its length. From that point a near-field calculation was made perpendicular from a point 3 meters from the radiator to a point 100 meters away.

[1] Ricardi, L.J. and Hansen, R.C., "Comparison of Line and Square Source Near Fields," *IEEE Trans. on Antennas and Propagation*, pp. 711-712, November 1963.

Figure 4 – Magnetic Field Strength Close to a Long Dipole

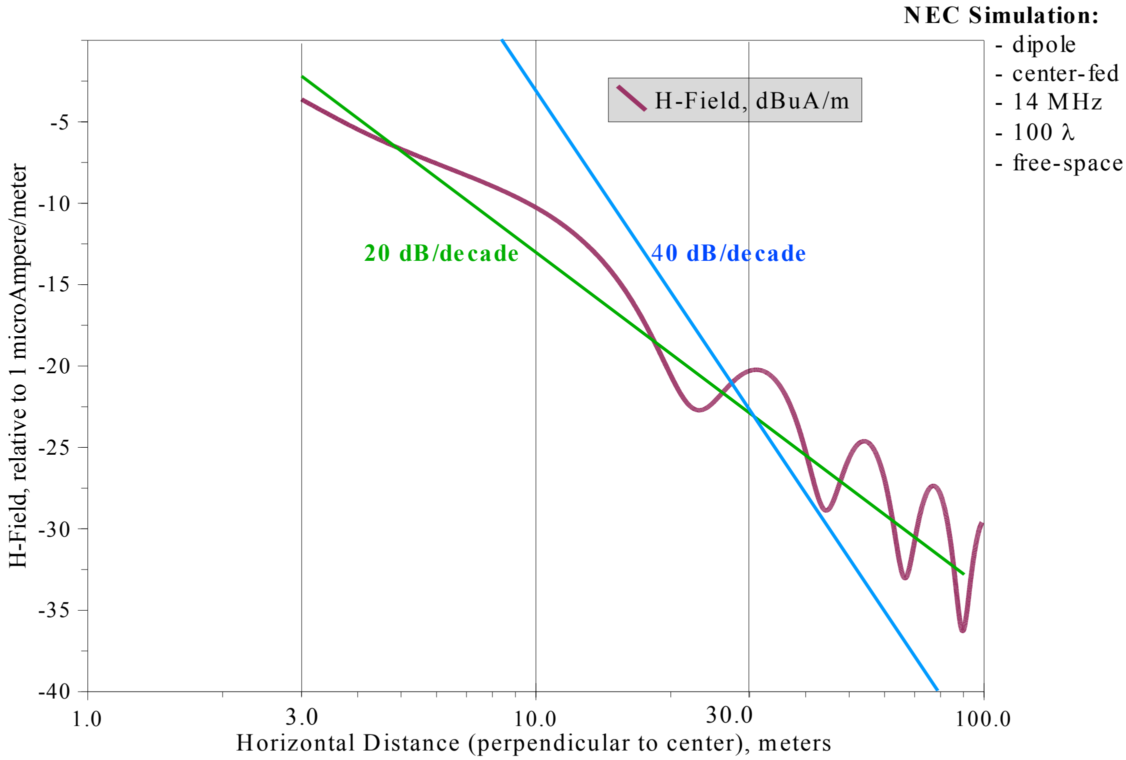

Figure 4 shows the result of examinations of the near-field region with NEC computer simulation of a long, center-fed dipole antenna in free space. The length is 100 wavelengths at 14 MHz. Lines of field-strength decay at 20 dB/decade-distance and 40 dB/decade-distance are added to show that the trend of decay along the perpendicular axis of this long line is approximated by the 20 dB rate over the range of distances from 3 meters to 100 meters.

From Figures 3 and 4, the field strengths are significantly non-monotonic. Thus, selecting a single measurement point from which to extrapolate the position and character of the entire curve will yield questionable results.

8. Extent and Relevance of Avoiding Measurements in the Near-Field Region

§ 15.31(f) states:

> * * * *
>
> (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….

The caution that an attempt should be made to avoid making measurements in the near field is not only vague but is an impractical requirement. It interesting to quote standard definitions for these regions:

> **near-field region (1) (antennas).** That part of space between the antenna and far-field region. *Note:* In lossless media, the near-field may be further subdivided into reactive and radiating near-field regions. [*IEEE Standard Dictionary of Electrical and Electronics Terms*]
>
> **far-field region (1) (antennas).** That region of the field of an antenna where the angular field distribution is essentially independent of the distance from a specified point in the antenna region… [*IEEE Standard Dictionary of Electrical and Electronics Terms*]

Part 15 appears to assume a point source for which distances under □ / 2 □ are considered to be within the near-field region. However, over the amateur service allocations in the 1.7-54 MHz range at points accessible for measurements, some frequencies will be within the near-field region and others will be in the far-field region. Whether the measurement point is within the near- or far-field region is only academic, as the practical matter is the field strength measured at that point. To a victim receiver, the region does not matter.

Kraus observes:

> Based on Huygen's principle it does not matter, where the sampling of the field takes place provided enough information is obtained on some surface surrounding the AUT [antenna under test].[2]

Practical experience substantiates that in the near-field region, the coupling to antennas is primarily magnetic. This is why BPL measurements should be done with small loop antennas without regard to near-field or far-field regions.

The magnetic field of a line radiator decreases as 1/r at all distances.[3] [4] There is no near/far field boundary, as is the case for a point source. Thus in measuring magnetic fields of large radiators, such as power lines, with a loop antenna, and have to extrapolate due to physical constraints, it would be appropriate to use a 20-dB/decade scaling factor bearing in mind the oscillations of up to several dB about the 20-dB/decade line.

Because of the occurrence of oscillations of several dB about the flat 20 dB/decade line, this would still be an approximation, but is one that would provide a reasonable means of extrapolation and permit the use of magnetic loop antennas to obtain accurate and repeatable measurements in the high-frequency band.

9. Conclusion

Power lines carrying BPL are line-source, not point-source radiators. For compliance purposes, measurements should be made at a single separation distance, such as 10 meters, which should be the true range between the power line radiating elements under test and the measurement antenna. Loop antennas should be used for BPL measurements.

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[2] Kraus, J. D. and Marhefka, R.J., *Antennas for All Applications*, Third Ed., McGraw-Hill, p. 830.

[3] Smith, A. A., *Radio Frequency Principles and Applications*, 1998, IEEE Press, p.8.

[4] Kraus, J.K., *Antennas*, Second Ed., McGraw-Hill, p. 212.

Extrapolation should be avoided whenever possible, but where needed, an extrapolation factor of 20 dB/decade should be used.

EXHIBIT D

Exhibit D

Proposed Test Methods

Ed Hare, ARRL Laboratory Manager

April 28, 2004

1. Introduction

This paper presents the results of NEC-4 antenna modeling ARRL has done to answer some of the questions posed and to support most of the FCC test-method recommendations. These results do indicate that some changes to the test method would make them a more reliable predictor of the actual field-strength levels near power lines carrying BPL.

This paper supports the following:

- Testing should be done at the maximum power settings over the frequency range and data rates.
- Below 30 MHz measurements should be performed with loop antennas in all three axes.
- Electric-field measurements should be made above 30 MHz, at heights from 1 to 4 meters.
- The requirement to test each device is reasonable.
- ARRL supports the use of 10 meters as the standard measurement distance.
- ARRL agrees with the test methods proposed for in-house BPL and carrier-current devices.

2. The Notice of Proposed Rulemaking

In the NPRM text, the FCC states:

> In addition, we specifically solicit comments on the height of receive antennas used for radiated emissions measurements for Access BPL systems operating on overhead power lines and on the possible use of correction factors to account for antenna height. The proposed guidelines in Appendix C recommend a fixed loop antenna height at 1 meter and scanning the height of electric field sensing antennas from 1 to 4 meters. While these recommendations correspond to standard practice for other types of devices (especially when measured on a test site), these heights may not capture the maximum emissions from an overhead power line. In Appendix C, we address this issue by specifying that distance extrapolation for emission measurements on overhead lines be based on slant-range distance from the Access BPL location on the pole to the measuring antenna, rather than on horizontal distance.[5] However, this technique does not account for field strength reductions caused by ground effects. We seek comment on the following:
>
> (a) Is it necessary to require that emission measurements be conducted at antenna heights greater than those proposed in Appendix C?
>
> (b) Is it practical and safe to make in-situ emission measurements at antenna heights up to the height of an overhead medium voltage power line (typically 11 meters) when operating 10 meters from the power line? As an alternative to requiring higher antenna heights, should we specify that measurements that are performed at heights significantly lower than the power line be subjected to a correction factor to estimate the maximum field strength that would have been observed at a higher measurement height? How should such a correction factor be determined?

Appendix C of the NPRM contains additional discussion of measurement height:

> <u>General Measurement Principles for Access BPL, In-House BPL and CCS</u>
>
> * * *
>
> 5. For frequencies above 30 MHz, an electric field sensing antenna, such as a biconical antenna is used. The signal shall be maximized for antenna heights from 1 to 4 meters, for both horizontal and vertical polarizations, in accordance to ANSI C63.4-2001 procedures.

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5 *See* 47 C.F.R. § 15.31(f)(1) & (2). The extrapolation factor is used to address the difficulty of making measurements at large distances. "Decade", a 10:1 range, refers to the ratio of the specified measurement distance to the actual measurement distance. For example, in the 1.705-30 MHz band, measurements are specified at a distance of 30 meters. If however, actual measurements were made at a distance of 3 meters, the ratio of the distances is a decade (30/3=10) and the field strength result must be corrected by subtracting 40 dB.

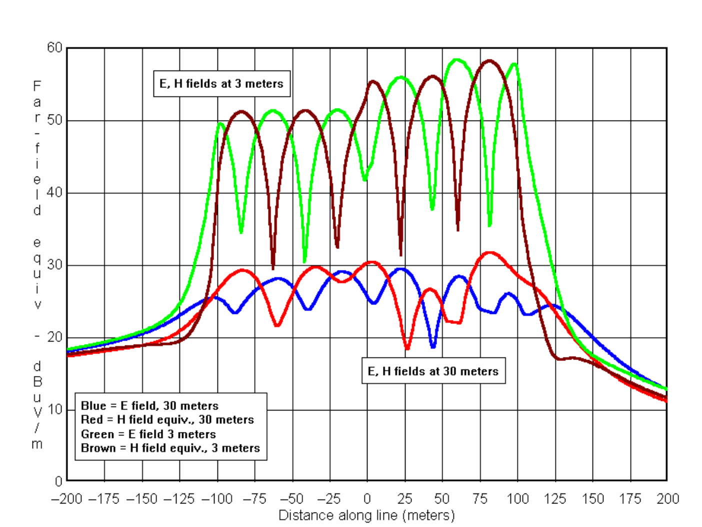
6. For frequencies below 30 MHz, an active or passive magnetic loop is used. The magnetic loop antenna should be at 1 meter height with its plane oriented vertically and the emission maximized by rotating the antenna 180 degrees about its vertical axis.

* * *

2. Measurement Antennas

ARRL supports the use only of loop antennas of necessary sensitivity to make field-strength measurements below 30 MHz. Further, ARRL recommends that magnetic-field testing be made by making measurements in three orthogonal axes and combining the results to determine the total field strength at the measurement point.

ARRL responded to the BPL Notice of Inquiry with a paper, "Electric and Magnetic Fields Near Physically Large Radiators."[6] This paper included the results of near-field calculations of a number of antenna models. Figures 5 to 7, below, show the calculated electric and magnetic fields at a height of 10 meters, and separation distances of 3 and 30 meters from the radiating power line. Figure 6 from that paper is reproduced here as Figure 1.



6 http://www.arrl.org/announce/regulatory/et03-104/Fields_near_large_radiators.doc

Figure 1: 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. The upper set of curves shows the fields 3 meters horizontally from the line and the lower set shows the field strength 30 meters from the line.

Figure 2, below, uses a slightly different antenna model to show the calculations of the electric and magnetic fields along the length of the power line. The fields were calculated at a distance 10 meters horizontal spacing from the overhead power line, at a height of 1 meter.

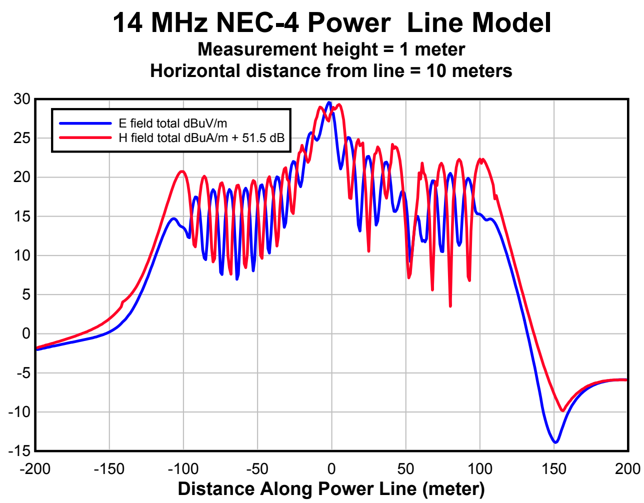


Figure 2. This example on 14 MHz shows the calculated electric and magnetic fields at a measurement height of 1 meter at a horizontal separation of 10 meters perpendicular from the radiating line. This model represents a two-wire transmission line, 10 meters in height, 200 meters long. One phase is fed with a BPL coupler, 25% from one end. The other phase is grounded in the middle, simulating the imbalance caused by grounded phases and transformer connections. Resistive loads of 50 ohms were connected to the end of each line[7].

In addition to the data in Figures 1 and 2, ARRL has made similar calculations on a number of antenna designs. At distances typically used for measurements of radiated emissions on HF, all of these models show consistency between the point of maximum electric field and the *nearby* point of maximum magnetic field

[7] ARRL has measured the RF impedance of several models of step-down transformers used by the electric-utility industry. A 50-ohm resistive load is a reasonable representation of some of those measured values.

In the Notice of Inquiry, several commenters noted that the correlation between the electric and magnetic fields is not good in the near-field region of an antenna. For *a particular point in space*, NEC modeling demonstrates this to be true, but if a magnetic-loop antenna is used to find the point of maximum magnetic field emissions, reasonable correlation exists between that value and the corresponding value of the nearby point of maximum electric field. If the FCC-recommended measurement guidelines can be revised slightly to find that point of maximum emission, ARRL supports the FCC's recommendation that measurements below 30 MHz be made only with a magnetic loop antenna. It is widely recognized in the EMC engineering community that below 30 MHz, magnetic loop measurements generally give more accurate and repeatable results than measurements made with electric-field antennas.

3. Measurement Antenna Height

ARRL supports measurements being made at a height of 1 meter above ground.

In ARRL's paper, "Electric and Magnetic Fields Near Physically Large Radiators," presented to the FCC in the BPL NOI, a NEC-4 near-field calculation was made showing how the calculated electric fields varied considerably with height. Figure 8 from that paper is reproduced here as Figure 3.

Higher impedance loads at the end would not have substantially affected the way that the field strength varies with height for the other models.

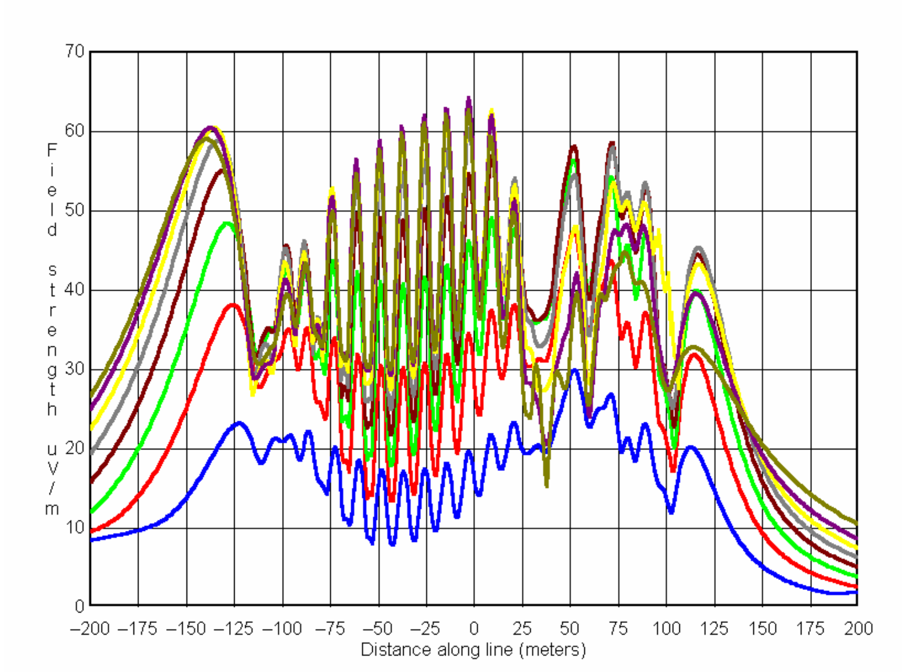


Figure 3. The calculated results obtained can increase or decrease depending on the height above ground of the simulated measurement point. These 14-MHz electric-field levels were calculated at 5 through 40 meters above ground, along the length of the line, at an absolute distance of 30 meters from the 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. At other heights, the maximum field strength at one height would be near a minimum field strength point if measured at a lower height along the same Y

The FCC has asked whether it is possible and reasonable to make measurements at a lower height and then extrapolate from that measurement to obtain the point of maximum emissions from the radiating system. ARRL understands and accepts the safety reasons that it is not practical to make measurements in-situ at heights typical of power lines.

The FCC has proposed a measurement height of one meter. The FCC correctly notes that the presence of earth ground will have an effect on the field-strength levels near a power-line radiator. The exact nature of that effect is determined by the height above ground and the conductivity and dielectric constant of the ground. The specific ground characteristics are unknown and unknowable since they vary widely by location. The ground characteristics will also vary significantly with soil moisture and temperature, changing from season to season.

ARRL's earlier modeling showed that the *electric* field can vary by typically 10 dB with height above ground. However, ARRL has recently done antenna modeling that shows that the *magnetic* field varies much less with height. The following graphs demonstrate that the modeled variation in magnetic field between measurements made at 1 meter in height and the point of maximum emission will typically be approximately 3 dB, although the exact amount of variation and the ultimate field strength depend on frequency, the point of the measurement along the line and ground conductivity and dielectric constant.

Two examples that show the variation are included as Figures 4 and 5, below. NEC-4 was first used to find the point of maximum H-field emissions along the line, at a height of 1 meter and a horizontal separation of 10 meters from the line. The program was then used to calculate the magnetic fields vertically from that point, in increments of 1 meter, to a height of 20 meters. The data were corrected at each point for the true (slant-range) distance to the line and the graph and normalized to 0 dB□V/m at its maximum point.

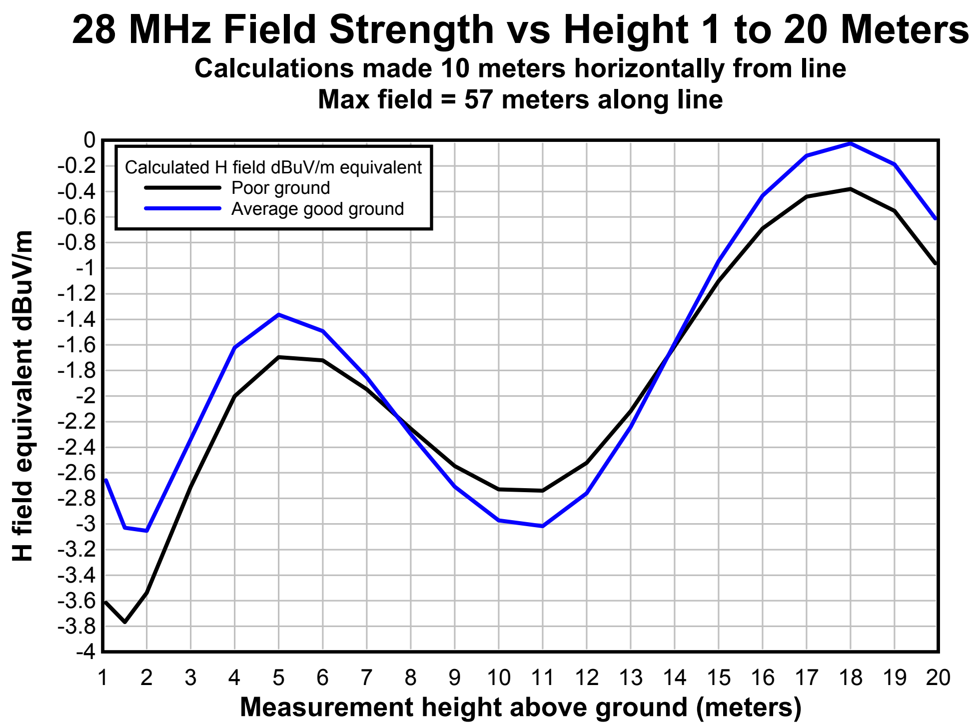


Figure 4. This shows the power-line model[8] operated at 28 MHz. Calculations have been made at measurements heights from 1 to 20 meters, over ground with poor conductivity and dielectric constant (1.0 mS/m, dielectric constant = 5) and average conductivity and dielectric constant (5.0 mS/m and a dielectric constant of 13). These data have been individually corrected for the slant range distance to the radiator.

[8] This model represents a two-wire transmission line, 10 meters in height, 200 meters long. One phase is fed with a BPL coupler, 25% from one end. The line is not grounded. Resistive loads of 50 ohms were connected to the end of each line.

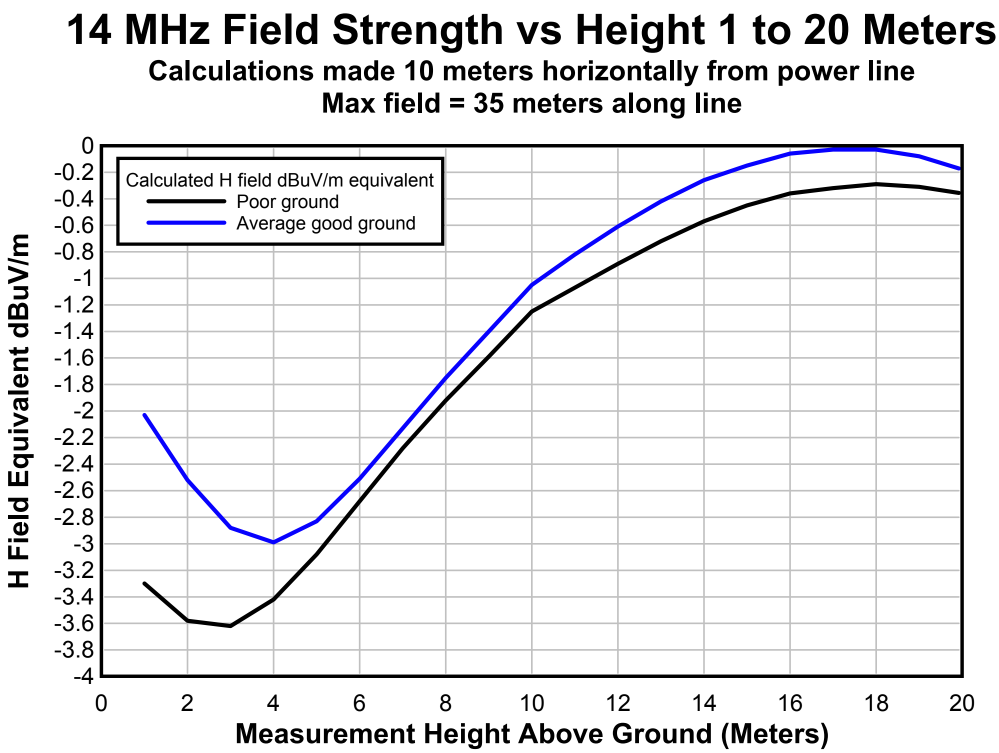


Figure 5. This shows the power-line model[9] operated at 14 MHz. Calculations have been made at measurements heights from 1 to 20 meters, over ground with poor conductivity and dielectric constant (1.0 mS/m, dielectric constant = 5) and average conductivity and dielectric constant (5.0 mS/m and a dielectric constant of 13). These data have been individually corrected for the true (slant range) distance to the radiator.

4. Testing in Three Orthogonal Axes

ARRL recommends that magnetic-field testing be made by making measurements in three orthogonal axes and combining the results to determine the total field strength at the measurement point.

At any point in space, the total field strength is a combination of fields in multiple axes. NEC-4 calculates the field strength in the X, Y and Z planes separately, and then calculates the square root of the sum of the squares of the fields in these three axes to obtain the total field. This is considered the best practice for EMC testing.

NEC-4 predicts that in the radiating near-field region of typical power-line radiators, fields with polarization in all three axes will be present. The FCC test procedure requires the test engineer to orient the magnetic loop antenna in a vertical position and rotate it through 180 degrees. This will not fully capture the fields present near a power-line radiator, sometimes somewhat underestimating the fields.

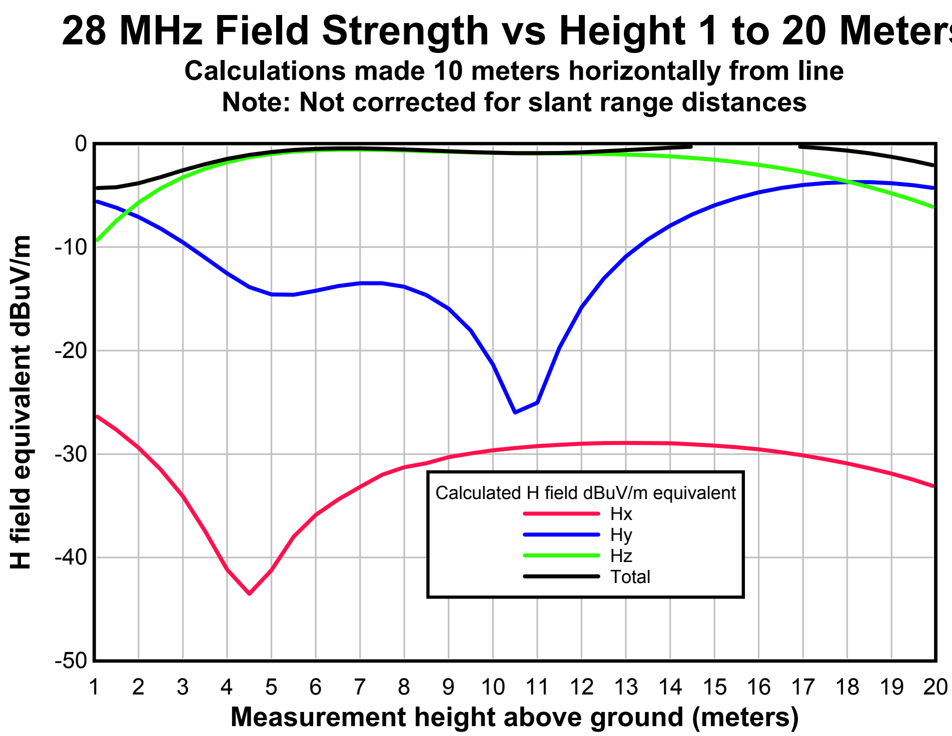


Figure 6. This shows an example of how the field components in 3 axes, Hx, Hy and Hz, vary with height near a power-line radiator[10]. These data were calculated at the point of maximum emissions from an overhead power line model[11], over ground with a conductivity of 5 mS/m and a

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[9] This model represents a two-wire transmission line, 10 meters in height, 200 meters long. One phase is fed with a BPL coupler, 25% from one end. The line is not grounded. Loads of 50-j0 ohms were connected to the end of each line.

[10] The electric and magnetic fields are approximately at right angles to each other in radiated fields, so the magnetic field is at right angles to the polarization of the electric wave.

[11] This model represents a two-wire transmission line, 10 meters in height, 200 meters long. One phase is fed with a BPL coupler, 25% from one end. The line is not grounded. Resistive loads of 50 ohms were connected to the end of each line.

dielectric constant of 13. At some measurement heights, it is necessary to include both Hy and Hz in the calculations for total field strength. In this case, there is no significant energy found in Hx.

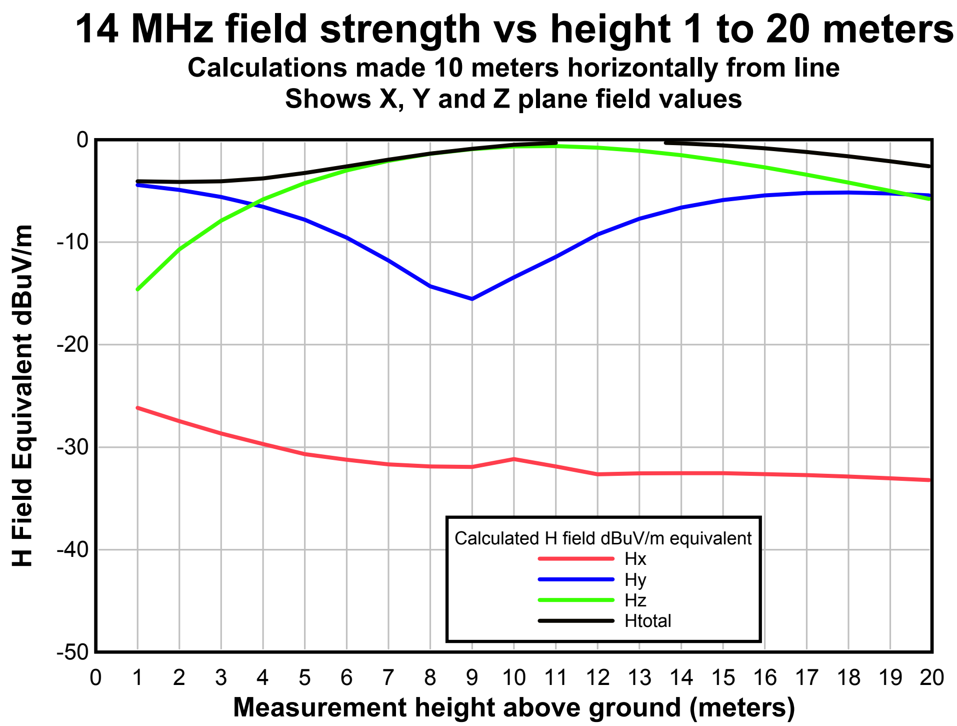

Figure 7. This shows the same calculations done on the same model at 14 MHz. The results are essentially the same, indicating that all three axes should be measured and combined to obtain an accurate reading of the total field.

ARRL recommends that test engineers making measurements of BPL systems be required to make measurements with the loop oriented in all three axes. The three readings should be combined to obtain a reading of the total field present at the measurement point. If the test antenna is located at a convenient 1 meter above ground, this will not pose a major testing burden. As will be shown in a subsequent graph, there is also a strong Hx component radiated from some power-line models at the point where vertical ground wires are present on the utility-pole structure.

As an alternative, if a reading is taken of the maximum value obtained with the loop vertically oriented and that result is combined with a second reading is taken with the plane of the vertically oriented loop rotated 90 degrees, this should be acceptable except in those cases where the measurement point is closer than 30 meters from any vertically polarized wires connected to one of the phases (or closely coupled into them). In those cases, it will be necessary to obtain readings in all three axes to prevent a significant error in the test results.

The following model shows how the Hx-oriented field increases significantly near a vertical ground wire added to the model of the 200-meter power line. The vertical ground has been added at the X = 0 point on the line. In addition to requiring that the magnetic loop antenna be oriented horizontally to pick up the field from this part of the radiator, the recommended test procedures should also require that measurements be made of the two nearest such vertical wires from the connection point being measured. These may be made at a horizontal separation distance of 10 meters and corrected for slant range distance between the test antenna and the vertical radiator.

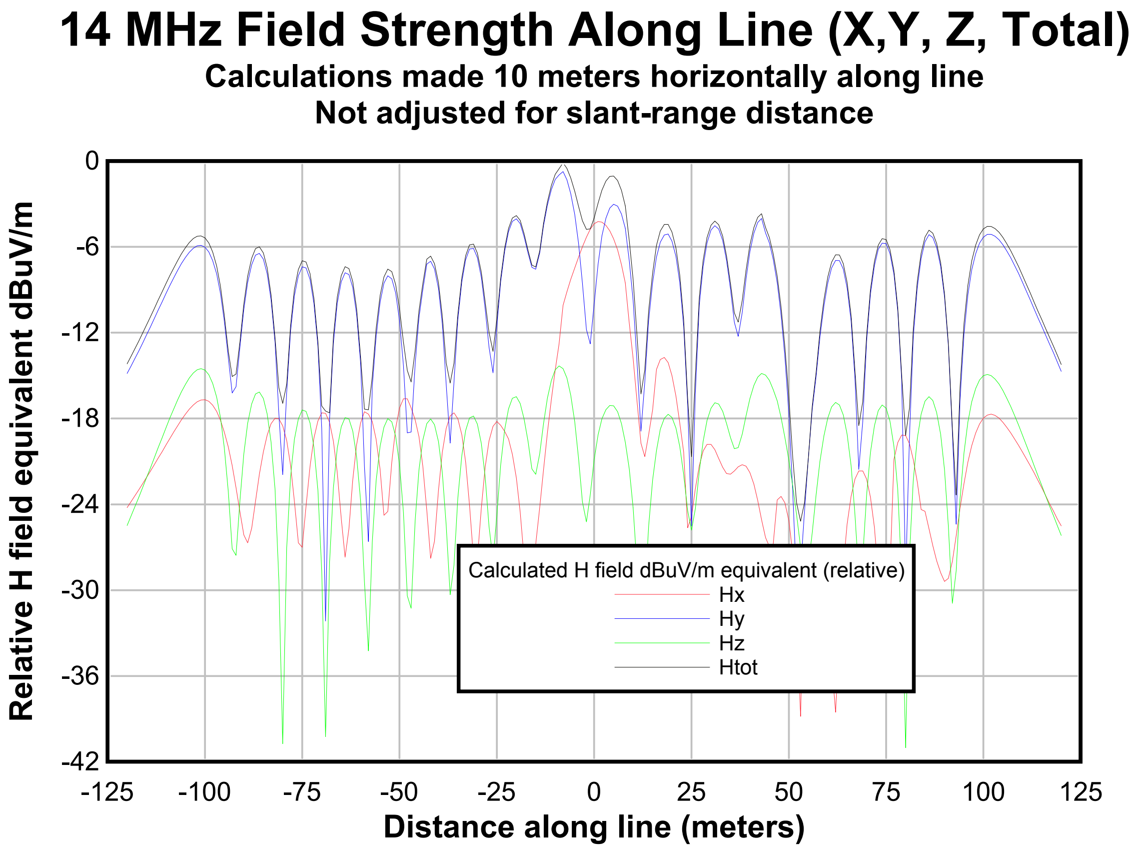

Figure 8: This shows how the Hx component (red line) of the magnetic field can increase significantly near a vertical wire commonly used to ground utility pole structures. A ground connection has been added at X=0 to the 200-meter long model used for previous graphs.

5. Frequency Steps

ARRL asks that the measurement procedures clarify that measurements must be made at multiple frequencies. It proposes a reasonable number of frequency-measurement intervals that should adequately characterize the power-line emissions vs frequency.

The recommended test procedures should specify that testing at more than the center frequency of the emission is required. The efficiency of a power line phase as a radiating element varies considerably with frequency. ARRL recommends that measurements be made between the lowest frequency and the highest frequency for which BPL system emissions are generated. Within this frequency range, the five highest amplitudes should be measured and logged. As BPL signals are broadband, it would be a reasonable practice to vary the frequency slightly from these points to avoid strong ambient signals present on the band.

6. Frequency and Distance along the Line

ARRL supports the FCC proposed requirement to make measurements at distance intervals along the line. ARRL seeks to ensure that the points being measured profile the emission maxima along the power line.

7. Testing at Three Typical Installations

The FCC rules and measurement guidelines require measurements be made at three typical installations which must include both overhead and under ground portions of the system where used. In reality, there is no such thing as "typical" overhead electrical wiring. Any visual inspection of the varying spacing, imbalance, junctions and all sorts of other EMC-related factors shows that the EMC potential of those systems varies considerably. Sections with a high potential to have maximum radiated emissions must be selected for testing. This generally would include sections where the spacing of the conductors carrying BPL signals are 1 meter or greater; section with poorly balanced lines in which one conductor on the line is grounded and measurements made near vertical radiating structures, such as utility ground wires running down a utility pole at one or more measurement points.

8. Conclusion

ARRL agrees with the following points in the FCC test plan. namely: Testing should be done at the maximum power settings and data rates. Measurements should be made where the ambient signals are at least 6 dB below the applicable limit.[12] The quasi-peak and peak requirements with respect to burst rate proposed in the NPRM are reasonable. Electric-field measurements should be made above 30 MHz, at heights from 1 to 4 meters. The six highest emission readings should be reported on each frequency measured[13]. The requirement to test each component is reasonable. A standard measurement distance of 10 meters should be used.[14, 15] The measurement procedures in areas with underground wiring are reasonable. The test methods proposed for in-house BPL and carrier-current devices are also reasonable.

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[12] Most "ambient" signals are actually from licensed users. In most cases, it should be possible to find a 9-kHz measurement channel in the frequency band of interest that contains no strong licensed signals. HF propagation varies with time of day, so it may also be possible to select a time of day for testing in which licensed signals are at their minimum levels. In most cases, the BPL signal being tested will be much stronger than the ambient signal levels, so this requirement should be easy to meet.

[13] If this information were made part of the publicly accessible database proposed in the rules, it could aid in interference identification.

[14] The proposed procedure allows the distance to be reduced to 3 meters to accommodate strong ambient signal levels. This is appropriate for measurements made for pad-mounted transformers or in-house BPL, if an appropriate distance-extrapolation factor is applied. However, for overhead power lines, if the overhead lines are 11 meters in height and measurements are being made at a distance of 1 meter in height, going from 10 meters horizontal separation to 2 meters separation will increase the signal being measured by only 2.6 dB (a slant-range change from 14.14 meters to 10.44 meters). This may not offer much help with ambient signal levels.

[15] ARRL has also filed a separate paper describing why the present 40 dB/decade extrapolation factor should be changed to 20 dB/decade.

EXHIBIT E

Exhibit E

Amateur Service Protection Requirements

ARRL Staff

1. Introduction

The Executive Summary of the NTIA BPL report[16] states, on page vi:

> "… Interference to land vehicle, boat, and fixed stations receiving moderate-to-strong radio signals is likely in areas extending to 30 meters, 55 meters, and 230 meters, respectively, from one BPL device and the power lines to which it is connected. With low-to-moderate desired signal levels, interference is likely at these receivers within areas extending to 75 meters, 100 meters and 460 meters from the power lines. …"

As amateur radio desired signal levels are accurately classed as "low-to-moderate," it is clear that there is a high potential for interference to amateur mobile stations and amateur fixed stations. Amateur mobile stations operating in a BPL area would have likely distances to the power lines between 10 and 20 meters, depending on whether the power line and the amateur mobile station are on the same side of the street or opposite. Amateur fixed stations in residential areas served by BPL are likely at 10 meters and well within 460 meters of a power line carrying BPL.

The objective of this paper is to determine BPL emission levels that would provide adequate protection to amateur mobile and amateur fixed stations. This paper concludes:

- Part 15 levels will cause interference to radio receivers approximately 25 – 35 dB above ambient levels.
- An acceptable level for amateur mobile stations is 0 dBμV/m at the antenna measured at 10 meters away from the power line.

[16] NTIA Report 04-413, "Potential Interference from Broadband over Power Line (BPL) Systems to Federal Government Radiocommunications at 1.7 – 80 MHz," April 2004.

2. Residential Noise Levels

Many amateur stations operate in suburban residential areas. BPL service operates in those same neighborhoods.

While noise levels of residential areas vary by location, seasonally, diurnally and dynamically, Recommendation ITU-R P.372-8 is used for baseline data, specifically:

- Atmospheric noise: Value exceeded 99.5 of time (curve B of P.372-8 Figure 2) Curve B is chosen to indicate that amateur stations take advantage of favorable atmospheric noise, when available.
- Man-made noise: Residential environmental category (curve B of P.372-8 Figure 10 taking into account Table 2).

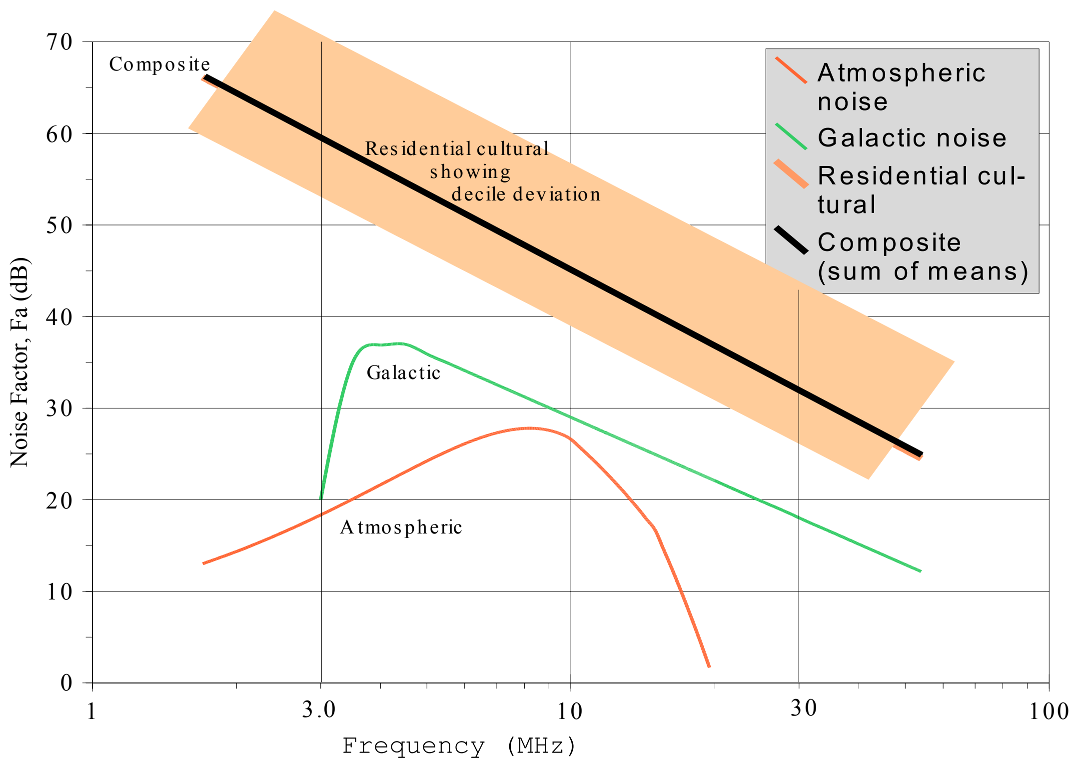

Figure 1 – Noise factors external to an HF receiver.
Ref: Rec. ITU-R P.372-8, Figures 2 and 10.

The composite of the means of the several sources considered in this Figure 1 is used to estimate the field-strength that an amateur would experience in radio operations in such an external environment. The estimate was based on consideration that the amateur station would use a short vertical whip antenna (monopole) with an antenna gain of approximately -3.5 dBd (relative to a half-wave dipole antenna).

While the noise curves in Recommendation ITU-R P.372-8 are widely recognized, the FCC Technological Advisory Council and others have noted the need for more accurate and current data. Amateur operators take advantage of times and locations where atmospheric and manmade noise are quieter than shown in the above Figure.

3. Part 15 Levels

§15.209 sets the radiated emission limit between 1.705 and 30 MHz at 30 microvolts per meter at a measurement distance of 30 meters. In addition, those measurements are to be made using a CISPR quasi-peak detector.

Above 30 MHz, §15.209 sets the radiated emission limit between 30 and 88 MHz at 100 microvolts per meter at a measurement distance of 3 meters. In Figure 2, that limit is shown extrapolated to the 3 distances using the 20-dB/decade factor.

On continuous-wave sine wave signals, the CISPR reading should correspond with the average reading. For signals with a higher peak-to-average ratio, the CISPR reading approaches the peak value rather than following the RMS value. The BPL signals observed at several trial sites generally exhibit a higher peak-to-average ratio than Gaussian noise, thus we can expect a higher level reading on a CISPR detector than on an average detector. The CISPR standard is designed to reflect the subjective annoyance of interference to listeners of amplitude-modulated radio broadcasts. It also does well at relating the impact of interference on J3E communications.

As the distance to the radiating BPL power line decreases, the extrapolation of the signal strength is a matter of discussion as detailed in Exhibit C. For this Exhibit, an extrapolation rate of 20 dB/decade (1/r) is assumed. Figure 2 presents the Part 15 level at 30 meters as a baseline and then extrapolate that level to 20 and 10 meters to represent the maximum BPL interference levels expected at distances more representative of those an amateur station would be constrained to on a residential lot or on a roadway alongside overhead power lines.

The German NB30 standard is specified at 3 meters. That standard extrapolated at 20 dB/decade to 10 meters is also presented on Figure 2 for comparison with a European standard.

4. Protection Criteria

The ITU typically uses an I/N of –6 dB in sharing studies to determine protection required for non-safety-of-life services. Any interference higher than –6 dB relative to the noise level would degrade the performance of a radio receiving system.

In § 6.3.1 (Interfering Signal Thresholds) of the NTIA Report, there is a useful discussion of noise levels in terms of I/N and (N+I/N). The considerations shown therein apply to federal systems, which typically have desired signal levels higher than those used in the amateur service. Although the NTIA Report does not state required signal-to-noise ratios, experience shows that federal systems have S/(N+I) requirements on the order of 12-15 dB for J3E emission and may include a fade margin of about 8 dB for 90% reliability. By contrast, amateur stations successfully operate with J3E signals of approximately 6 dB S/(N+I) with no allowance for fading except that two-way communication affords an opportunity to request repeats of missed transmissions or parts thereof.

Typically in sharing studies, a victim service is required to determine the amount of time that interference can exceed a given threshold without serious degradation. That consideration is appropriate when the potential interference has a low duty cycle. While BPL data transfers have been sparse in test areas, the activity factor is expected to increase dramatically as subscribers are added to operational BPL systems. (BPL signals are continuous, but their interference profile can vary considerably.) This continuous nature distinguishes BPL from many other forms of interference, thus it is difficult to establish a percentage of time when the interference criteria could be exceeded. Thus, a percentage of time that the interference threshold could be exceeded does not appear to apply to BPL.

5. Amateur Fixed Stations

As stated earlier, amateur fixed stations in areas served by BPL could be typically 10 meters to a power line carrying BPL. Furthermore, BPL energy is conducted in house wiring, which in some situations make the separation distance less than 10 meters. The NTIA Report has stated that interference is likely to occur to fixed stations within 460 meters. In the presence of BPL the amateur can consider relocation of antennas but the possibilities are very limited in typical residential properties. The amateur can also explore directional antennas but testing at trial BPL sites indicates that the interference is not highly sensitive to direction of arrival as demonstrated in Appendix 2 to Exhibit A. In general, amateur station antennas in typical suburban areas are omni-directional below 14 MHz and sometimes directive at 14 MHz and above. Specific directivity is often required to achieve the required gain in a desired direction.

6. Amateur Mobile Stations

Unlike the stations at fixed locations, it is impractical to apply the FCC-proposed mitigation procedures to the mobile situation. The only practical way to solve the mobile interference is to keep the BPL signal low.

In order to find a BPL interference level that amateur mobile stations can accept, two approaches were chosen. The first approach used Recommendation ITU-R P.372-8 as a baseline and determined the tolerable interference level. The second used a field test as detailed in the Appendix to this Exhibit.

Using these two separate methods, it becomes obvious that the Part 15 level is too high to protect amateur mobile stations and that a level of approximately 0 dBμV/m should not be exceeded at the amateur mobile station antenna, i.e., 10 meters from the power line. The measurements in the Appendix were made using a communications receiver calibrated against a CISPR quasi-peak detector/receiver including the bandwidth correction. Based on the noise data of Figure 1, the Part 15 limit should start at +6 dBμV/m at 1.8 MHz and slant down to 0 dBμV/m at 30 MHz at 10 meters from the power line. At this level of noise the average residential amateur station should not see harmful interference above those levels experienced today.

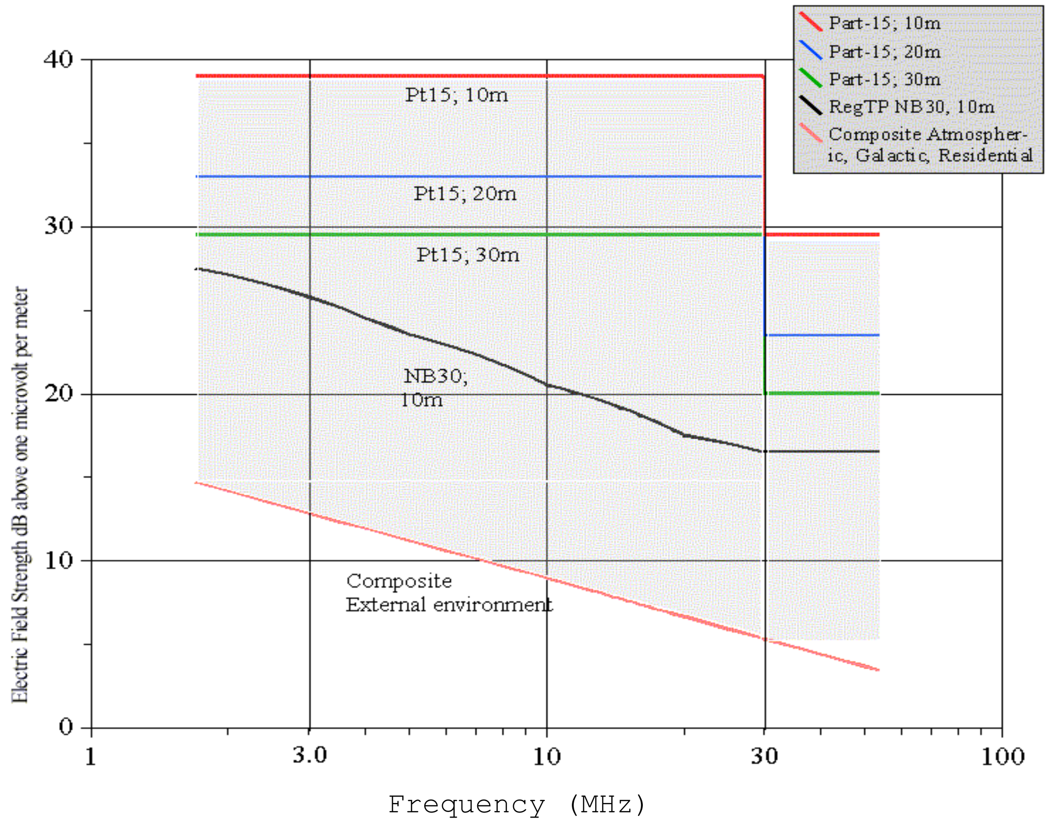

Figure 2 – External noise environment showing the potentially 20-25 dB increase in noise level to amateur mobile stations in a BPL service area.

The decile deviation of noise for the residential environment portrayed in Figure 1 would also apply to the composite here – amounting approximately to 10.5 dB in upper variation of the composite field-strength for the external environment, and approximately 5.5 dB in lower variation.

## 7.	Conclusions

Part 15 level will cause interference to radio receivers approximately 25 – 35 dB above ambient levels. An acceptable level for amateur mobile stations is 0 dBμV/m at the antenna measured at 10 meters away from the power line.

Appendix to Exhibit E
Noise Levels Present at the Antenna of a 28.5 MHz

Amateur Mobile Station

Ed Hare, ARRL Laboratory Manager

1. Overview and Purpose

This document describes the test methods used to determine the typical noise levels at 28.5 MHz encountered in a mobile environment in residential neighborhoods. A 1989 Subaru station wagon was used for these tests.[17, 18] The vehicle was driven to various locations with overhead electrical-distribution wiring[19] in Newington, CT and measurements of the ambient noise levels at these locations were made and recorded. Areas that are representative of the quiet noise levels found in most mobile environments were intentionally identified and used for these tests. Most HF amateur mobile stations are operated from unspecified locations along a route. These tests were performed with the vehicle parked at the side of the road with the motor turned off.

Areas with excessive noise were not selected for testing. In rare instances, an isolated identifiable "birdie" signal could be heard on or near the operating frequency, possibly an unintentional emission from a nearby computer system. These were generally low in amplitude, not heard over a wide geographical area and most frequencies in the amateur band being studied did not include such unintentional signals. To represent the way that amateur operators would use the spectrum in a mobile environment, these emissions were not included in this testing.

[17] An older vehicle was intentionally chosen for these tests because the noise generated by newer vehicles is generally higher due to the increased amount of on-board vehicle electronics. In many cases, newer vehicles can generate noise and microprocessor spurious signals even when the vehicle is turned off.
[18] Additional suppression and shielding was done on the vehicle ignition system, even though the vehicle was parked on the side of the road and turned off for most of the testing described in this report.
[19] Areas of underground utilities would generally have lower noise than those with overhead wiring. Although the Part-15 carrier-current emissions limits would apply equally to areas with underground utilities, underground-wiring locations were not included in the results shown in Table 1.

2. Test Equipment Used

Manufacturer	Model	Description	Calibration date
Rohde and Schwarz	ESH-2	EMC Receiver	5 Feb 2004
ICOM	PCR-1000	Computer-controlled receiver	1 Apr 2004[20]
AH Systems	SAS-563B	Active magnetic loop antenna	11 Mar 2004
Generic	N/A	¼-wave 28.5 MHz mobile whip antenna	1 Apr 2004[21]
Marconi	2041	Signal generator	17 Dec 2003
HP	HP-339A	Audio test set	16 Dec 2003
Compaq	Armada 1700	Laptop computer	N/A
Custom	N/A	Custom applications software	N/A

3. Test Fixture

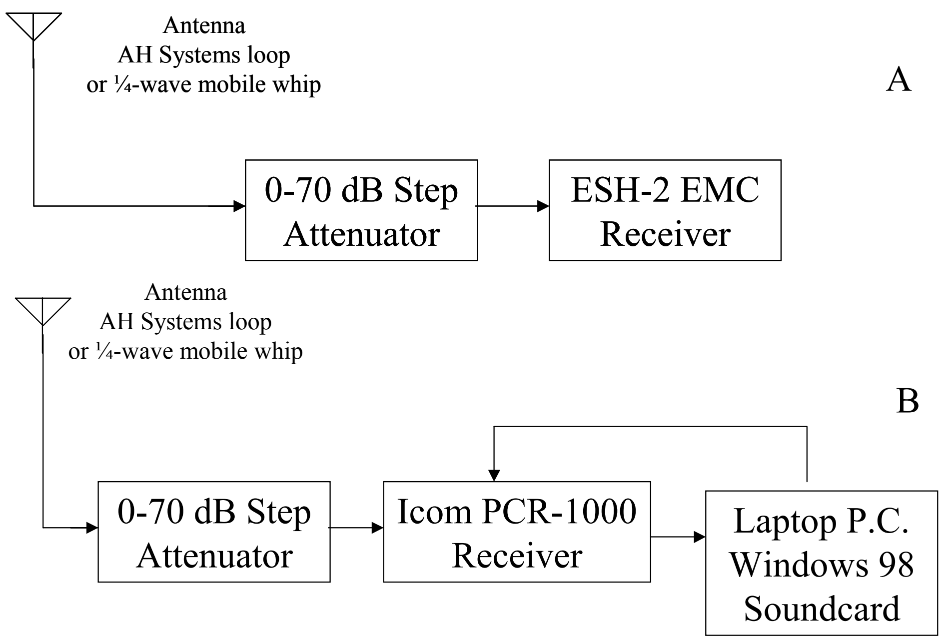

Figure 1:
(A) The ESH-2 receiver was used to verify the accuracy of the measurements made using the PCR-1000 receiver and P.C. sound card.
(B) On 28.5 MHz, the PCR-1000, attenuator and sound card were used to make field strength

[20] Calibrated by ARRL Laboratory staff using the Marconi 2041 signal generator and HP-339 audio-measurement set using the test procedures described in the "ARRL Test Procedure Manual", http://www.arrl.org/~ehare/testproc/testproc.pdf.
[21] Calibrated at –3 dBi gain using NEC-4 based EZNEC software and a wire model simulating an automobile over ground with typical conductivity and dielectric constant. The antenna has an antenna factor of 2.306 dB in situ.

measurements at various locations.

4. Test Method

The primary test method used to measure field strength used the ICOM PCR-1000 receiver[22] and a computer with sound card to measure received signal levels from an antenna with known gain. A step attenuator was used to keep the measured noise signal within the linear range of the receiver, at a level lower than would engage the receiver's automatic gain control circuitry. A ¼-wave whip antenna was used on 28.5 MHz for these tests. The antenna was mounted vertically near the center of the roof of the vehicle. A NEC-4 model of this antenna installed on an automobile over ground with 5 mS/m conductivity and a dielectric constant of 13 calculated the antenna gain of -3 dBi. On 28.5 MHz, the antenna has an antenna factor of 2.306 dB calculated from -3 dBi.

The test software makes an RMS measurement of the receiver output voltage when terminated in a 50-ohm non-radiating load. The receiver is then connected to an antenna. If necessary, the step attenuator can be adjusted to keep the input signal level within the linear range of the receiver. The software then compares the second RMS reading to the reading made with no input signal. If the noise floor is known, the second reading allows a calculation of the received signal level being measured by comparing the two voltage levels[23]. The software also measures the peak-to-RMS ratio of the receiver output voltage. These levels are then used to make received-signal level calculations based on the externally measured receiver noise floor. The results were then adjusted for bandwidth to obtain an estimate of the quasi-peak level in a 9 kHz bandwidth. Several comparative measurements between this test fixture and the use of the ESH-2 EMC receiver and AH Systems calibrated loop showed correlation of 2 to 4 dB for various noise signals.

The test system was installed on a 1989 Subaru station wagon. The use of an older vehicle resulted in less vehicle-generated noise than would be expected from a newer vehicle. Additional suppression and shielding was installed on the vehicle ignition system. On 28.5 MHz, the vehicle noise, primarily from ignition noise, is approximately 5 dBμV/m at the test antenna. For measurements made below this level, the vehicle was parked on the side of the road with the motor turned off.

The mobile test vehicle was driven through several different residential neighborhoods in Newington, CT. One area was found in a light industrial area along Mountain Rd, where the noise level was approximately 30 dBμV/m. This unusually high noise level was excluded from the data in Table 1. In other areas, what appeared to be sparking-type electrical noise was observed at levels of around 10 dBμV/m. Although most locations did not exhibit this high noise level, the results are included in Table 1. Some areas were

[22] The use of conventional receiving equipment to make measurements allows measurements to be made at a lower level than can typically be made with commercial test equipment. This is an appropriate choice of equipment to test the receive system capabilities of mobile amateur stations.
[23] It is necessary to subtract the noise floor power from the measured signal+noise-floor measurement to get the actual signal level. The test software makes this correction.

much quieter, with levels as low as approximately –10 dBµV/m observed at several locations. Most areas had measured noise of around –5 dBµV/m to +5 dBµV/m.

5. Results and Conclusions

Based on these data, a level of 0 dBµV/m at the antenna represents a reasonable and conservative expectation for the typical low noise level that will be experienced by HF amateur mobile stations. At this level, typical HF communications capability would be degraded by 3 dB and more quiet locations, common in mobile environments, would be degraded even farther.

For this level to be present at the station receiver, the field strength at 30 meters would have to be corrected for the ratio between the actual distances typically found between the mobile antenna and power line and 30 meters. Overhead power lines are typically located at approximately 11 meters in height. They are typically located 2 meters horizontally from a vehicle parked safely on the side of the road. The vehicle test antenna was located with its center approximately 2.8 meters in height. This results in a diagonal slant range distance between the antenna center and the overhead power lines of 8.4 meters.

For a 20 dB/decade extrapolation, the emissions level at 30 meters that is needed to protect amateur mobile operation is:

$$\text{Maximum tolerable field (dB}\mu\text{V/m)} = 0 - 20 \log_{10} (30 / 8.4) = -11.0$$

By comparison if a correction factor of 40 dB/decade were applied, the necessary emission limit at 30 meters could be calculated as follows:

$$\text{Maximum tolerable field (dB}\mu\text{V/m)} = 0 - 40 \log_{10} (30 / 8.4) = -22.1$$

A ¼-wavelength vertical whip antenna will respond to both the electric and magnetic fields of a radiated electro-magnetic wave. Near a long horizontal radiator like a power line, there are both horizontally and vertically polarized components. Studies have shown that most man-made noise is vertically polarized, so it is likely that the test method has measured the strongest polarization component. The test methods used to measure BPL emissions should include measurements in multiple axes, however. In all cases ARRL has modeled using NEC-4, there is significant radiated energy in one or two axes. If the FCC chooses to require that measurements be made in 3 orthogonal axes and the results combined to obtain a total field, the protection levels described above can increased by 3 dB to adjust for measurements that will include equal levels in 2 polarization axes.

When choices had to be made in the assumptions for the calculations in these papers, ARRL has chosen conservatively in all cases, thus asking for the minimum necessary level of protection. Many locations were lower than 0 dBµV/m and additional leeway is given to account for multiple-axis measurement that will not apply in all cases.

Table 1: Testing of noise levels on 28.5 MHz, April 8, 2004 1830-2200 Z, Newington, CT

Location	Description	Measurements	Average[24]
Ellsworth St Location #1	On road, across from overhead power line, residential area	-2.1, -5.1, -1.1, -3.5, -3.7, -2.5, 0.4	-2.4
Ellsworth St Location #2	At end of dead end road, across from overhead power line, residential area	-12.2, -11.6, -11.3, -10.7, -11.6, -9.4, -10.4	-11.0
Ellsworth St Location #3	On road, same side as overhead power lines, residential area, noisy location,	11.1, 11,7, 10.5, 12.1, 12.3, 11.6	11.6
Marris St	On road, across from power lines, residential area, noisy location	17.5, 18.6, 16.1, 18.4, 18.5	17.9
Brentwood Rd	On road, same side as overhead power lines, residential area, moderate noise	9.0, 9.3, 7.0, 10.4, 8.0, 9.0, 10.3	9.1
Mountain Rd	On road, no overhead lines, houses immediately to opposite side of road, approximately 75 feet from vehicles	-11.3, -11.4, -11.5, -9.9, -11.1, -11.2, -10.9	-11.0
Mountain Rd Augusta Dr (Corner)	On road, overhead power lines crossing road directly 10 meters in front of vehicle, residential area	-11.2, -10.2, -8.0, -10.1, -9.9, -6.4, -11.9	-9.5
Augusta Dr Location #1	On road, same side as overhead power lines, residential area	-7., -4.6, -7.11, -4.2, -5.7, -6.6, -6.3, -4.9, -7.8, -6.4	-6.0
Augusta Dr Location #2	On road, same side as overhead power lines, residential area	1.5, 2.1, 2.3, 2.8, 1.9	2.1
Augusta Dr Location #3	On road, same side as overhead power lines, residential area	2.3, 3.6, 3.8, 3.0, 5.2	3.6
Connecticut Ave	On road, same side as overhead power lines, residential area	0.7, 0.4, 1.2, 0.9, 1.4, 2.1	1.1

[24] The average is the square of the sum of the squares of the measured electric fields, converted back to dBμV/m.