Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Inquiry Regarding Carrier Current	)	ET Docket No. 03-104
Systems, Including Broadband over	)	
Power Line Systems	)	

TO: THE COMMISSION

REPLY COMMENTS OF AMEREN ENERGY COMMUNICATIONS INC.

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SUMMARY

In these Reply Comments, Ameren Energy Communications, Inc. ("AEC") first responds to the two main points that have been raised in this proceeding in opposition to broadband over power line technology ("BPL"). First, AEC refutes the notion that electric power lines, when attached to BPL equipment, will become blocks-long antennas that will cause considerable interference over a large area. As AEC explains in more detail herein, BPL emissions come from only short stretches of the power line adjacent to the BPL device and any BPL emissions quickly diminish.

Second, AEC rebuts the argument that multiple BPL users will result in an aggregation of harmful interference. Rather, BPL systems are built on a network architecture that permits only one BPL device within a cell to transmit at any one time. Although this architecture is unnoticeable to end users, it results in only one modem operating at a time in any given cell, and hence, only a single emissions source.

AEC next replies directly to the National Association for Amateur Radio ("ARRL"), which supported its initial comments with a lengthy report that claimed to show the high interference potential of BPL systems. The ARRL study is atypical of actual BPL deployments, however, as the study is premised upon a single transmission line, which will radiate differently when operating in isolation from the network than if it were embedded in the network. Further, the ARRL study has several flaws that discredit its usefulness in this proceeding.

Finally, AEC attaches, and comments upon, the preliminary data released by the Commission regarding In-House BPL system testing. Although the study is in its infancy, AEC commends the Commission's work to date and offers in this Reply several suggestions and poses several questions for the Commission to consider as it continues its analysis.

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INTRODUCTION

Virtually every party to this proceeding agrees that Broadband over Power Lines ("BPL") is a promising technology that can offer ubiquitous broadband services throughout the nation.[1] The parties only disagree as to the extent to which BPL may pose harmful interference to licensed users of spectrum.

Although interference objections to BPL have been voiced by hundreds of amateur radio operators, as well as a few other classes of licensed spectrum users, the objections have been based primarily upon two fundamental misunderstandings as to the way in which BPL systems function, as well as the underlying BPL technology. First, certain parties believe that the entire electric network, including power lines, will become a giant, blocks-long antenna that will cause interference to every user in its path. Second, they believe that the presence of multiple BPL users will result in an aggregation of ambient noise from the operation of multiple BPL devices. As explained more fully below, neither of these fears is well founded; BPL emissions come only from short stretches of line adjacent to the BPL device, signal strength falls off precipitously, and only one BPL device will transmit at a time in any given cell, thereby eliminating the aggregation concern.

I. Opponents of BPL Misunderstand BPL Technology.

A. The Transmission Line Will Not Act As A Blocks-Long Antenna.

The principal concern of parties voicing opposition to BPL systems is that the power lines, which host BPL signals, will act as efficient antennas and pollute their

[1] Several parties also have taken the opportunity in this proceeding to advance policy arguments that range from the regulatory status of other forms of broadband to pole attachment access issues. The Commission should ignore these comments because policy arguments have no place in this proceeding, which seeks technical guidance as to how best to deploy and regulate BPL.

surroundings with harmful interference.[2] Specifically, and implicit in these comments, is the assumption of superimposed multiple radiation sources, and a power line acting as a continuous radiation source, which thereby convey and radiate signals to distances far from the BPL devices. This notion is not supported by scientific measurements, however, or even rigorous theoretical proofs.[3]

Most of the charges leveled against BPL in this proceeding to date have been unsubstantiated by empirical evidence, or even relevant literature. Therefore, in the interests of further clarification regarding BPL technology, AEC offers additional clarification for the Commission to consider regarding the antenna properties of a typical transmission line and the electromagnetic ("EM") fields around it, which are central to the antenna/power line concerns expressed by various parties in this proceeding.[4]

1. Single Line

To best understand the behavior of a power line, it is perhaps easiest to begin with a single power line that is not connected to the network and that is situated in open space. The minimum number of conductors needed to transmit a differential mode (*e.g.* an aerial mode) over such a line is two. The average distance between line conductors for 12 kV or lower voltage lines is less than 2 m. The wavelength of a wave transmitted on the line around or below 30 MHz is greater than 10 m. Such a line supports mostly transverse

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[2] *See, e.g.,* Comments of the Information Technology Industry Council, ET Doc. No. 03-104 (filed July 7, 2003) ("use of BPL with overhead power lines would create large antennas with potentially significant radiated emissions as the transmission travels down throughout the lines [and] propagate[s] throughout entire neighborhoods causing potential interference to many electronic devices and licensed services throughout that service area").

[3] The National Association for Amateur Radio ("ARRL") presents certain simulated case studies that it argues show that BPL systems will cause harmful interference to licensed users. *See* Comments of ARRL, ET Docket No. 03-104 (filed July 7, 2003). As discussed below in Section II, however, the ARRL tests are wholly unrepresentative of an actual system, and are refuted by the experience of AEC and other companies that have worked with BPL technologies.

electromagnetic ("TEM") modes.[5] When a line carries a TEM wave, it acts as a wave guide. Radiation from such a line does not occur continuously throughout the line length, but occurs at points of discontinuity.[6] The principal mechanism of radiation is the detachment of the EM field lines taking place at the point of discontinuity. For the single power line in consideration, such discontinuity occurs at the line termination. For a power line embedded in an interconnected distribution network, additional points of discontinuity include, but are not limited to: junctions with other lines, sharp line turns, and on-line equipment such as transformers and capacitors.

Conversely, if the line was a continuous radiator, the strength of the transmitted signal will decay dramatically as the signal loses energy throughout the line length. The distance the signal could reach would then be decreased significantly with most of the signal concentrated around its source, which would make the immediate vicinity of the BPL source the principal radiation source and would, therefore, assign near point-radiator properties to the line. Yet, such a result flatly contradicts text book knowledge and practical experience. As such, the hypothesis of a line behaving as a continuous radiation source is not accurate or suitable for power lines carrying TEM waves.

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[4] Because AEC's experimental measurements do not represent a set of data so comprehensive as to quell all concerns regarding the behavior of the power line, AEC also will refer to scientific literature and field experience to demonstrate the anticipated behavior of the line.

[5] *See* M. D'Amore & M.S. Sarto, "Electromagnetic field radiated from broadband signal transmission on power line carrier channels," *IEEE Transactions on Power Delivery, Vol. 12, No. 2, April 1997, pp. 624-31.* The work presented in D'Amore demonstrates this theoretically for any multi-conductor line. That work shows that the predominant wave is TEM (even for the common modes) and that additional TE propagations may exist, but with considerably lower amplitudes.

[6] *See* Constantine Balanis, *Antenna Theory, Analysis, and Design*, John Wiley and Sons Inc., (2nd ed. New York); R.J. Lytle, D.L. Lager, E.K. Miller, & F.J. Deadrick, "The multiwire beverage antenna-Theory and experiment", *International Symposium on Antennas and Propagation, June 1974, pp. 193-5;* A.G.P Boswell, "Beverage antennas for HF reception", *9th International Conference on Antennas and Propagation, April 1995, ICAP-95, Vol. 1, No. 407, pp. 455-8;* B.R. Rao, "Characteristics of high frequency beverage antenna using a fiber-optic measurement technique," *Antenna and Propagation Society International Symposium, 1991, Digest, 24-28 June, 1991, Vol. 2, pp. 1190-3.*

In rough terms, the fields around a single transmission line are divided into two qualitatively different types: the near fields and the far fields.[7] The near fields are predominately reactive, corresponding to the energy stored near and around the line, and do not correspond to the energy radiated from the line. The far fields, on the other hand, when observed at significant distances from the line, have a spherical distribution and correspond solely to the radiated energy. The pattern of the far fields establishes the antenna properties of the line. Harmful interference, however, is a matter of magnitude; not existence or pattern.

Near field interference may occur by another antenna coupling to BPL signals through the line's reactive fields. Experimental measurements by AEC indicate that near fields caused by BPL are indistinguishable from native noise.[8] Thus, for the levels of output currently utilized by the AEC BPL devices, the degree of potential harm to a third party operating near the power line is unaffected by the BPL signal. It is more likely that the BPL maybe harmed by a third party transmitting high power densities near the line.[9]

The radiation pattern of a single power line is determined by the distribution along the line of the current magnitude and phase associated with the RF signal. Figures 1(a) through 1(d) demonstrate this for a 60 m long four-conductor power line. The line length corresponds to a typical span between two medium voltage ("MV") distribution poles. The line is excited by an aerial mode at 30 MHz.[10]

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[7] *See* Balanis, pp. 32-34.

[8] Unlike narrow band, the spectrum of broadband signals carries considerably less power density.

[9] *See* Weilin Liu, Hans-Peter Widmer, James Aldis, and Thomas Kaltenschnee, "Nature of power line medium and design aspects for broadband PLC systems", *Proceedings of the 2000 International Seminar on Broadband Communication, 15-17 Feb. 2000, pp. 185-9.*

[10] The calculations are based on the theory of linear antennas presented in Shen, pp. 225-50 and in Balanis, pp. 133-60, both providing exact formulae for the calculation of far fields resulting from a known current distribution on the line.

In this example, the ground plane is assumed to be a perfect conductor (resulting in zero additional losses). Figure 1(a) results when the receiving end of the line is matched, corresponding to a reflection coefficient of 0.[11] Radiation, as noted above, occurs at the receiving end of the line as the electric field lines detach. Figures 1(b), (c), and (d) correspond to a 30, 70 and 100% reflection coefficient; the latter value simulating an open-ended line. These figures illustrate that, as the reflection at the receiving end of the line causes two opposite traveling waves, radiation occurs from both ends of the line tending to produce a four-quadrant symmetry (Figure 1(d)).

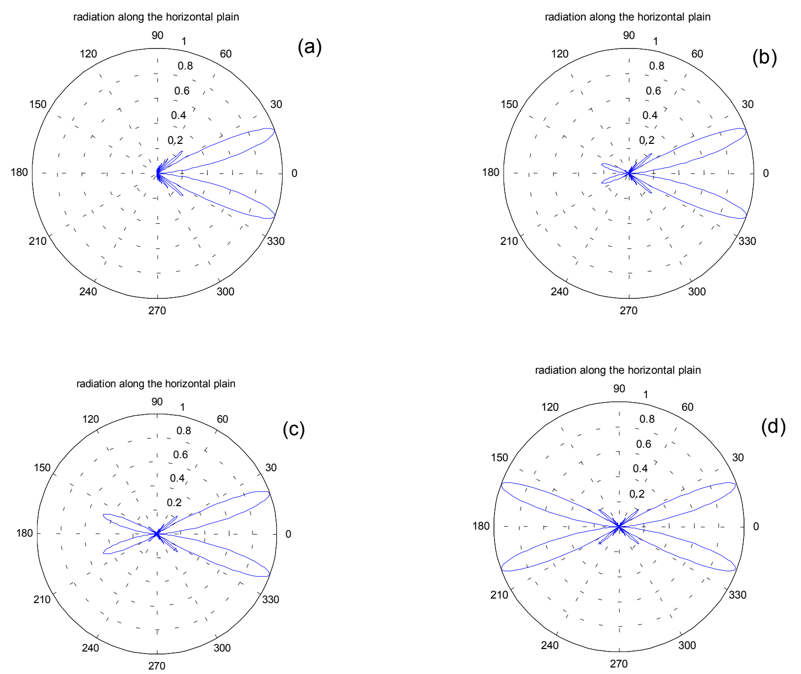

Fig. 1. Radiation pattern from a 60 m-long four-conductor line excited by an aerial mode at 30 MHz. Figures (a) through (d) depict the radiation patterns for reflection coefficients 0, 30, 70 and 100%. The line is directed in the 0 deg. direction.

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[11] The radiation pattern is very directive and can be compared to that of the traveling wave antenna in Rao, supra n. 6.

Some figures of merit describing the efficacy of the line as an antenna are its radiation efficiency[12] and the radiation gain.[13] The antenna gain is a macroscopic property given by Equation (1) below, where U_{max} is the maximum radiation intensity (in W/stereo-rad), and P_{inp} is the input or coupled power to the antenna (in W). The radiation intensity is another macroscopic property showing the power available in a cone area radiating from the antenna. This number remains constant with respect to the distance from the antenna and it only depends on the direction of observation. Its maximum value is observed at the direction of maximum directivity of the antenna. The maximum radiation density is, in turn, related to the maximum power density W_{max} (in W/m^2) at a distance r (in meters) by Equation (2) below. The power density (also a macroscopic quantity) is the power per sq. meter carried by the wave. Its value decreases with the square of the distance from the antenna. The maximum power density represents the maximum value of the power density observed at a constant distance r from the antenna over all directions. Finally, the maximum power density relates to the maximum rms value of the electric field E_{max} by (3), where η=377 Ω is the free-space wave impedance.

$$G = 4\pi \cdot \frac{U_{\max}}{P_{inp}} \tag{1}$$

$$U_{\max} = r^2 W_{\max} \tag{2}$$

$$W_{\max} = \frac{E_{\max}^2}{\eta} \tag{3}$$

Equations (1) to (3) are valid for any antenna, provided that the observations are done in the far fields. Thus, they cannot be used to predict the near fields. The distance

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[12] The radiation efficiency of a single line can be defined in a similar manner as in an antenna; it is the ratio of the total radiated power to the power coupled to the line (input power).
[13] The radiation gain defined for an antenna is the ratio of the maximum radiation intensity to the coupled power. The gain combines the directivity of the antenna with the antenna efficiency.

of the far field-region boundary from the radiator depends on the size of the radiator and the wavelength radiated. In essence, far fields are reached when the radiated pattern from the antenna becomes independent of the radial distance from the antenna.[14] Accordingly, for electrically large antennas, the far field boundary is at a distance $R=2D^2/\lambda$ from the radiator, where D is the largest dimension of the device and λ the radiated wavelength (it must be that $D>\lambda$). Applying this rule to the 60m-long line at 30 MHz, the far fields begin at 720 m away from the line in any direction.

The Commission must be cautious, however, when calculating the gain for a transmission line by distinguishing what parameters remain constant in the system. For example, when calculating the radiation efficiency and gain of a line intended to operate as a traveling wave antenna (*i.e.* a long-wire or a beverage antenna), the load of the receiving end should match the line characteristic impedance. Similarly, the source at the sending end must be fixed to obtain maximum power transfer onto the line. With these steps taken, the calculation of the properties may ensue.

On the other hand, when attempting to calculate the same properties for an incidental power line antenna, only the source at the sending end should be fixed and the load at the other end should be permitted to vary. This would correspond more realistically to varying terminations of line segments embedded into the network. The result of the latter is that as the line termination varies (resulting in higher mismatch), not only the gain and radiation efficiency of the line change, but the ability of the fixed source to couple power onto the line also decreases consequently with the mismatch.

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[14] Balanis, pp. 32-33, provides some practical formulae for predicting the boundary of the far field region from the antenna dimensions and the wavelength.

In the example line of Figure 1, above, the lowest efficiency and gain are observed for 1(a) when the line is perfectly matched, yielding values of -41 and -5 dB respectively. For this case, the power coupled onto the line from the source is the highest, but only a small fraction of it is converted to radiation, therefore yielding a low gain. As the mismatch at the receiving end increases for cases 1(b) to 1(d) resulting in a higher standing wave along the line, both the radiation efficiency and gain increase reaching a maximum of -25 and 11 dB respectively for case 1(d). Although these dramatic increases could lead to the false conclusion that the line becomes an efficient and effective antenna, it must be recalled that, at the same time, the amount of power coupled from the fixed source to the line decreases equally dramatically from the maximum amount achieved in 1(a). Therefore, in order to obtain a meaningful comparison when a fixed source is used, the radiation efficiency and gain should be computed not based on the coupled power at each case, but on the maximum source capacity (Figure 1(a)). Re-computing the line properties using this approach, both radiation efficiency and gain remain approximately constant, at -40 and -4 dB respectively. These values indicate that the single line is expected to be a rather inefficient radiator.

Equations (1) to (3) may be used to predict the maximum electric field in the far fields at a given distance from the line. Converting (1) to (3) into the dB scale and solving for the maximum peak electric field at a distance r from the line yields Equation (4):

$$E_{\max}[dB\mu V/m] = P_{inp}[dBmW] + G[dB] - 20\cdot\log(r[m]) + 104.7 \tag{4}$$

Equation (4) applies in the far field region only, and may be used to predict the radiation effects from the single 60m-long line at 30 MHz, if it is operated by a single BPL source with a -60 dBmW/Hz spectrum density (used by AEC modems). The source has a total power output capacity within a 9 kHz band of -20.46 dBmW. Assuming a 10 dB loss due to couplers,[15] the total coupled power is -30.46 dBmW. If a gain of -4 dB is assumed for the single line, the maximum field observed at distances greater than 720 m is less than 13.1 dBμV/m.[16]

Another concern made by various commenting parties is the potential amplification of radiation as a result of the power lines acting as array antennas. The premise of this argument is that, because a power line has many conductors, their combined effect will be similar to that of an array antenna. AEC disagrees with this argument, however, and can illustrate that the array effect is small for a differential transmission mode.

Figure 2, below, shows the array factor of a two wire antenna at 30 MHz as a function of the azimuthal position from the line (the line is directed at 0 deg.).[17] The conductor separation is 2 m. This function is computed according to standard formulae for linear arrays.[18] With reference to Figure 2, the maximum value of the array factor is 1.17 occurring at the vertical direction from the line. That is, the maximum effect of the two-conductor array is only 17% higher than that from the single conductor. Because the separation distance between the line conductors is approximately 1/5 of the wavelength at

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[15] *See* Weilin.
[16] Notice that the field will decay at a rate of 20 dBμ per decade.
[17] The array factor is a multiplicative number that multiplies the fields of a single element in an array antenna to obtain the combined field of the array.
[18] *See Applied Electgromagnetism*, 3rd edition, by Liang Chi Shen & Jin Au Kong, PWS Publishing Co., (Boston 1995), p. 234.

30 MHz, the fields emitted from each conductor tend to cancel each other (provided a purely differential mode of propagation exists). A lower array factor results in a shorter conductor separation. Thus, if the two conductors are separated by 1 m, the array factor at 30 MHz is 0.62; the combined effect of the two conductors will be 38% less than that of a single conductor.

Generally, transmission lines carrying TEM waves ought not to be compared with linear array elements, as the radiation mechanisms differ significantly. First, linear arrays are center-fed resonant antennas, in which radiation is caused by the standing wave, and the field detachment involves both ends of the array. Second, lines above ground are more closely comparable to the beverage antenna, in which radiation occurs from a traveling wave reaching the end of the line. Third, field detachment does not occur through out the length of the line, but at the line termination.

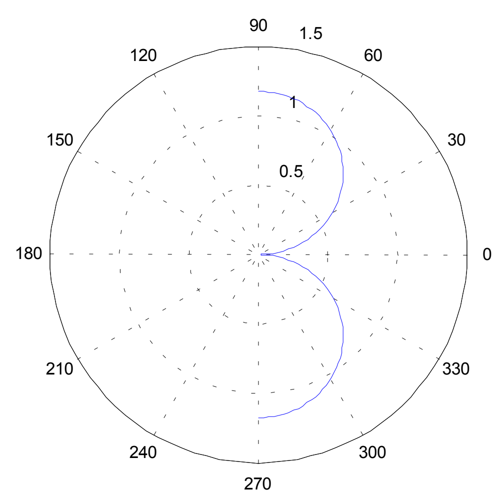

Fig. 2. Array factor at 30 MHz as function of the horizontal position for a two conductor line separated at 2 m. The line is directed at 0 degrees.

2. Interconnected Network

The analysis of a single power line presented above forms a basis to consider the resulting radiation from an interconnected network. To do so, however, the terminating conditions of an embedded line segment must be examined and the current distribution along its length determined.[19]

A typical termination of a MV power distribution line segment is a junction with a lateral line. The node at the junction has four incident lines: the arriving line segment, its continuation segment, and the two departing lateral lines. Assuming that the characteristic impedance does not vary significantly among the four converging segments,[20] the reflection coefficient at the junction point will be approximately 50%. Thus, the current distribution in the line will be between those in Figures 1(b) and 1(c), above.

In AEC's experience, the radiation patterns obtained for the interconnected network powered by a single source tend to be less directive and yield lower gains than those of the single line shown in Figure 1. Specifically, radiation will not occur continuously through the network lines, but at junctions and places where power equipment connects (as it was stated above, these constitute discontinuities). The radiation pattern is now determined not by the current of a single line, but by all the lines in the system running in different directions thereby increasing the isotropicity of the radiation.

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[19] As stated above, the distribution of the current magnitude and phase associated with the RF signal determines the radiation from the line.

[20] The characteristic impedance of a MV distribution line calculated around 30 MHz for TEM modes is between 350 and 420 Ω. This range includes the various conductor configurations (*i.e.* four-conductor vs. three- or two- conductor lines, and vertical vs. horizontal arrangements).

Due to the system variability and complexity, AEC cannot provide the same formulations as in the case of a single line. AEC's field experience and its understanding of the pertinent literature, however, leads it to several hypotheses. First, field detachment, which takes place at a junction, will occur at lower amounts compared to the single line case. This is because the TEM wave can continue to propagate in the subsequent line segments in the junction. The radiated pattern also will be more isotropic than those in Figure 1, resulting in lower gains. Second, when moving away from the BPL source, the signal energy coupled on the line will attenuate as a result of the natural attenuation on the line, as it divides among the several lines in the network, and as it reflects at discontinuities. Third, as a result of the first and second hypotheses, the strongest radiation will be emitted at the location of the source, less radiation will be emitted at the first junction following the source, and progressively less radiation at other junctions thereafter. Therefore, AEC believes that the vicinity of the BPL source is the critical part of the system for determining radiation, see Figure 3, next.[21]

[21] AEC's practical experience does not contradict these hypotheses. Similar conclusions were reached by Current Technologies. *See* Comments of Current Technologies, ET Doc. No. 03-104 (filed July 7, 2003).

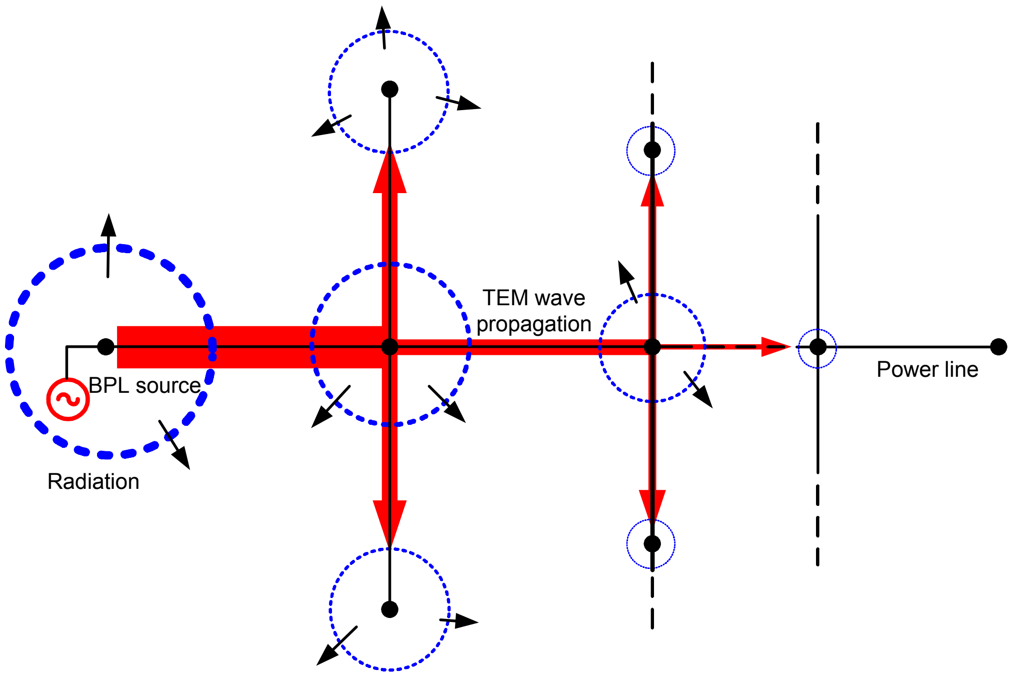

Fig. 3. Conceptual representation of the radiation from a single source BPL. Red line indicates the TEM wave path. Circles indicate the location and strength of radiation points.

B. No Noise Aggregation Within A Cell.

The second major concern raised by opponents of BPL is that noise signals from multiple BPL devices will aggregate to cause harmful interference. That is, however innocuous a single BPL device, an entire neighborhood of BPL devices operating simultaneously will cause the noise floor to rise. Again, this concern is premised upon a fundamental misunderstanding of the way in which a BPL system operates.

As noted above, BPL systems are broken into several cells. Within a single BPL cell, modems cannot transmit signals simultaneously. Rather, the network architecture of a BPL system is such that only one modem transmits at any given time, albeit unnoticeable to the end user. Therefore, only a single RF source will exist at all times within the cell. Consequently, no combined radiated emissions from multiple sources will occur, and no aggregation of noise will result.

C. Large-scale Deployment Will Not Worsen Interference.

With the discussion of the two basic aspects of the BPL system, the transmission line and the cell, better understood, AEC now turns to the potential for interference from a largely deployed (*i.e.*, a multi-cell network covering a significant contiguous geographical location) BPL network, where cells operate independently and simultaneous emissions are to be expected. AEC's analysis is guided by Hanspeter Widmer's, "On the global EMC aspects of broadband power line communications using the 'HF' frequency band," *Proceedings of the 2000 International Zurich Seminar on Broadband Communications, 15-17 Feb. 2000*, pp. 179-84, which considers a largely deployed BPL network and investigates, using theoretical analysis and practical data, its potential interference with radio users as well as the potential increase of ionospheric noise from BPL signals in the frequency range from 1 to 30 MHz.

This investigation yields several useful conclusions stressing that near fields decrease rapidly with the distance from the power lines to insignificant values, and that far field effects are less severe in general. The main conclusion of the study, however, is that "…the present natural noise levels in electromagnetic quiet areas will not change significantly with a possible future large deployment of local access telecommunication systems using the low voltage electricity distribution networks if the maximum transmitted power spectrum density per PLC cell […] is below -40 $dBmHz^{-1}$." The power output ability of the BPL modems employed by AEC is well within this limit.

II. Comments on the ARRL simulated case studies.

In it its initial comments in this proceeding, ARRL submitted a report of findings from a simulation it embarked upon regarding BPL technology.[22] AEC has reproduced the line model using the EZNEC 3.0 software.

ARRL's study is of little value, however, as the model used was atypical to a power system. As explained above, a single transmission line will radiate differently when it is operating isolated from the network than when it is embedded. Therefore, the simulation study offered by ARRL, which is based upon a single line and without any experimental data, is inadequate to provide support to ARRL's assertions regarding BPL system interference.

AEC notes additional flaws in the ARRL study. First, the ARRL report uses a 50 Ω resistance to represent the system load and the modems. Arguably, at the power system frequency of 60 Hz, a 50 Ω resistor can adequately represent the aggregate system load seen at the end of a feeder segment. At higher frequencies, however, this representation is inadequate. Load aggregation at higher frequencies is a much more complex process involving the impedance of equipment between the line and the load (transformers, lateral feeders, and drop cables).

Second, representing the modem and coupler system with a 50 Ω resistor is a poor choice of a model. A combined modem and coupler impedance of 50 Ω would result in a poor impedance matching between the line and the modem. The line characteristic

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[22] The ARRL study consisted of simulating a single 200 meter line consisting of two conductors. ARRL used the EZNEC and NEC software for that study. In addition, in the study report, ARRL provided a website where the model data could be downloaded. *See* ARRL Comments at Exhibit D, n. 45 ("The EZNEC and NEC models used for the calculations in this paper are available for download at http://www.arrl.org/~ehare/rfi/bpl/antenna_models.zip."). AEC repeatedly tried to obtain the model data

impedance from 1 to 30 MHz lies between 350 to 420 Ω. In the best case, the 50 Ω modem impedance at one end of the line and the 50 Ω load at the other end would result in a reflection coefficient of -87.7% at each end. This value corresponds to a near short circuit at each end. The simulated line will operate with a large standing wave, which is unrealistic for a typical BPL operation. In addition, each coupler will incur an additional 6.5 dB loss as a result of the large mismatch. The direct consequence of this in the ARRL calculations is a reduction in the antenna gain by an equal amount.

Third, the numerical example presented in part 6.4, Exhibit C appears to have an error, perhaps typographical; substituting the numbers the author provides into equation 1, the resulting field at 30 m is only 9 dBμV/m and not 29.5 as stated in the report. Alternatively, following the same calculations, the line should have a gain of 20 dBi in order to yield a field strength of 29.5 dBμV/m at 30 m, not -26.7 as reported, which is far greater than the calculated gains for the line listed in table 5 in the same section. Notwithstanding this error, the application of Equation 1 in ARRL's report is improper. Equation 1 is equivalent to Equation (4), above, and should be likewise applied for far field calculations only. For the 200 m-long line simulated in that study, and at 14 MHz, the far fields should occur at distances far greater than 30 m from the line. The Balanis formula cited above predicts that the boundary of the far-field region is at 3800 m from the line when the source frequency is 14 MHz, and 8000 m when it is 30 MHz. These distances are verified by the EZNEC program and demonstrated by Figures 4 and 5 below.

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from the ARRL website, but that site was not available. Subsequently, AEC reconstructed the line model from the description in the ARRL report.

Figures 4 and 5 also show that the far field prediction is a very poor approximation of the fields near the line (compare the calculated fields given by the blue curve to the far field approximation given by the red line in these figures.) Yet, even applying ARRL's Equation (1) for a conservative 500 m distance from the line, which would be well into the radiating near fields region, an EIRP of -32.2 dBW is required to achieve the 29.5 dBμV/m of field. This would imply an antenna gain of 17.7 dBi; again, far greater than those reported in table 5.

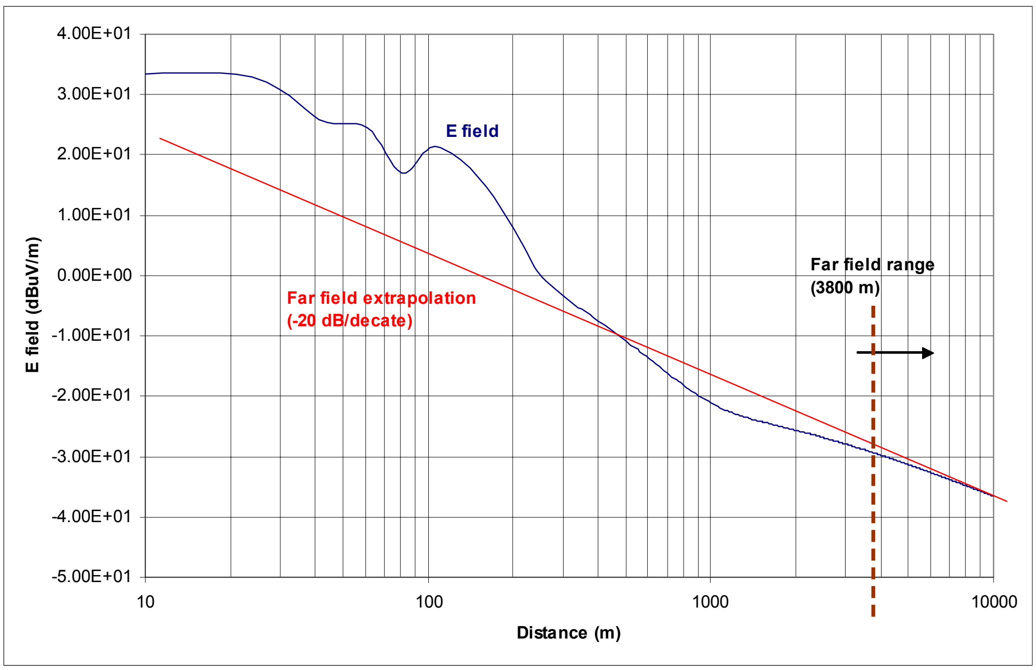

Fig 4. Electric field profile for the 200 m-long line at 14 MHz. The field is calculated along the radial distance from the line in the direction of maximum radiation. In the far field region, the field decays at a rate of 20dB/decade, which is shown by the slope of the red line in the figure. Notice that the computed field approaches closely that decay rate at the distance predicted using the Balanis formula.

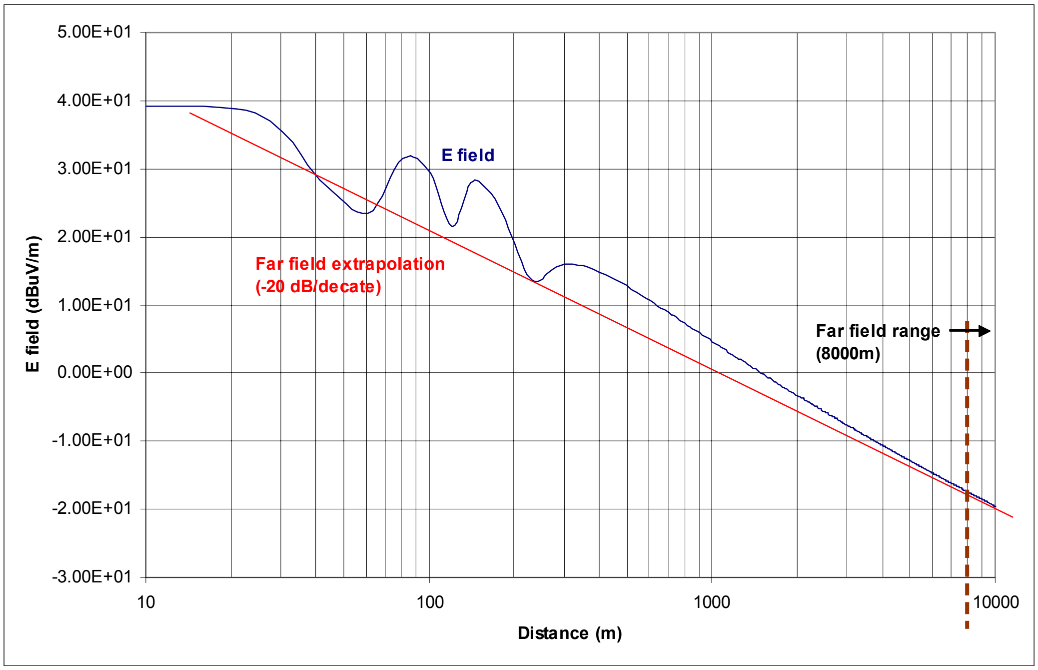

Fig. 5. Electric field profile for the 200 m-long line at 30 MHz. The field is calculated along the radial distance from the line in the direction of maximum radiation. As in figure 4 above, the prediction of the far fields using the Balanis formula is in agreement with the simulation.

Fourth, in part 6.5 of Exhibit C, ARRL asserts that the antenna gain for a large radiator (*e.g.* the 200 m line in the study) is determined by the geometry of the device, and that loading conditions or losses are not a major determining factor in the antenna gain. Part 6.5 also uses the 200m line to show that the antenna gain at 14 MHz varies only by ±1 dB as the line load varies from 10 to 1000 Ω. AEC strongly disagrees with these statements. As mentioned above, radiation from any device is determined by the current distribution along the device, not just the geometry. This is particularly true for a long power line; its loading conditions may vary producing various current distributions. In order to demonstrate this point, AEC calculated the current distribution and the antenna gain for the 200 m-long line at 14 MHz using EZNEC, and for varying loading.

Figure 6 shows the current distribution along the line when the line terminates at a 50 Ω load. Notice the strong standing wave on the line as a result of the large mismatch at the load end of the line. The standing wave ratio ("SWR") is 9.2. The antenna gain computed by the program is -4.28 dBi. Subsequently, AEC loaded the line with a 350 Ω load, which is within the range of the line characteristic impedance. Figure 7 shows the results. Notice that the standing wave is reduced significantly to an SWR of 1.95.[23] The antenna gain is -8.59. Finally, AEC calculated the antenna gain at 14 MHz for the same line when the load end was open. The current distribution in the open-ended line is similar to that of Figure 6 with a high SWR value. The antenna gain in that case was 0.76 dBi (the largest value obtained at 14 MHz). These values demonstrate that the antenna gain can change by as much as 8 dB as a result of the line loading and not by only 2 dB as claimed by ARRL. The reason for this variation is that termination mismatch produces standing waves, and standing waves tend to produce stronger radiation due to the co-phasial (same phase) current distributions within large line segments.

[23] Significant reflections are still present at the source site because it has a 50 Ω impedance.

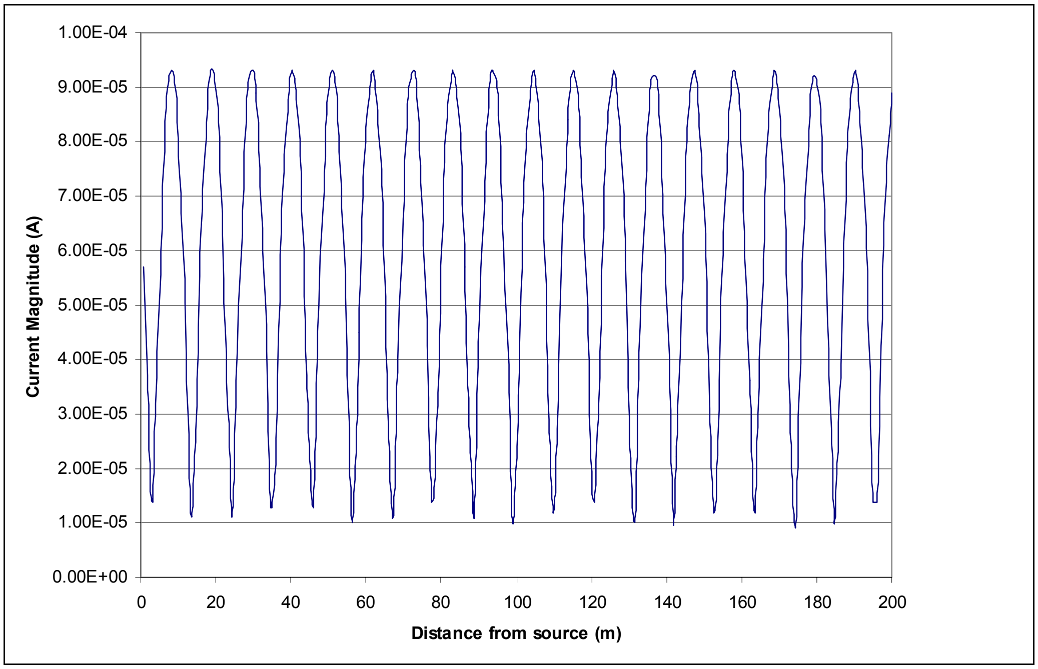

Fig 6. Current distribution along the 200 m-long line at 14 MHz and 50 ohm load. SWR is 9.2. Antenna gain is -4.28 dBi.

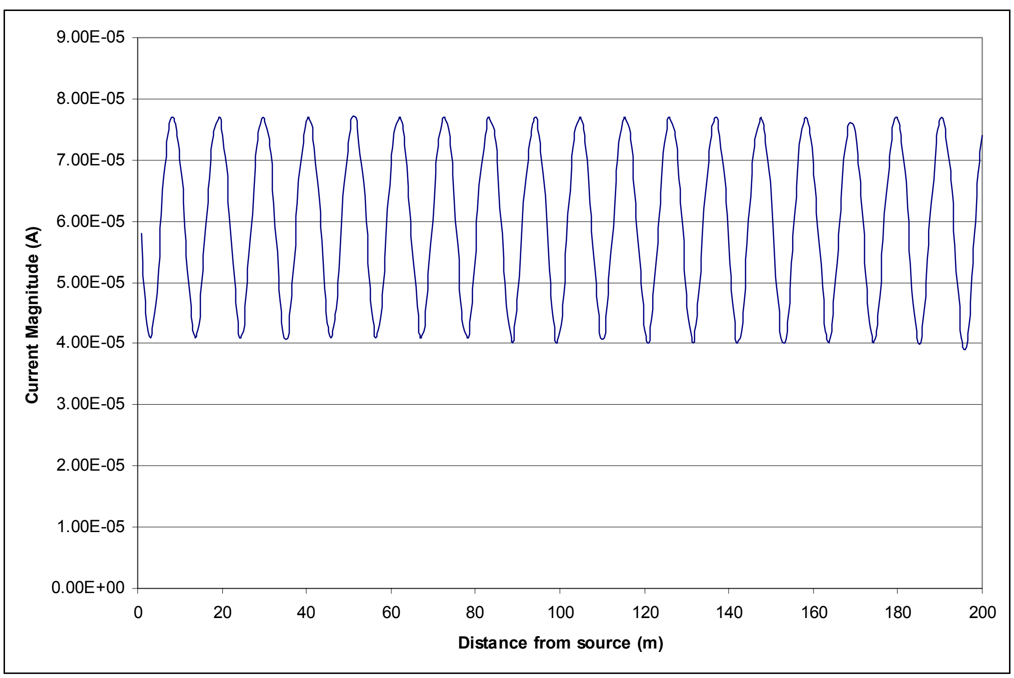

Fig. 7. Current distribution along the 200 m-long line at 14 MHz and 350 ohm load. SWR is 1.95. Antenna gain is -8.59 dBi.

Finally, AEC could not verify the gain values in table 5 of Exhibit C in the ARRL report. This table provides the antenna gains for the 200 m-long line at various frequencies. Using the line model provided in the report and the same EZNEC software, AEC was unable to obtain the same gains. For example, at 14 MHz the largest gain was 0.76 dBi versus the 7.7 dBi in ARRL's table 5. Also at 24.9 MHz, table 5 reports a 10.6 dBi (the highest gain in the table). AEC, using the same model and program, found 6.24 dBi obtained when a 10 Ω resistor is loaded on the line.[24]

III. Comments on the Commission's Preliminary In-house BPL Study Results

Finally, AEC offers its comments on the preliminary tests performed by the Commission's Laboratory Test Program, which are attached to this filing as Appendix A. AEC welcomes the initial report, as it provides much needed information regarding the deployment of In-house BPL.

The Commission's tests described in the report seek to derive a transfer function from the applied In-house BPL signals to conducted and radiated emissions. Even though the test results are still preliminary (as the report points out, only one house is tested), they represent a positive step for developing standards and guidelines for the deployment of In-house BPL. AEC is also planning tests in the same framework for Access BPL, which seek to obtain the transfer function from the applied BPL signal onto an overhead line to conducted and radiated emissions around the line. Accordingly, as the Commission seeks to develop reliable and repeatable tests, AEC offers the following comments.

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[24] One justification for this troubling disparity may be a difference in the model ARRL used versus the model AEC used for the same line. Regardless, and given that the line simulated has a simple description consisting of only a few parameters, the Commission should be wary of the reliability of simulation

First, the differential and common mode voltages and currents at the coupling point between the house wires and the injection equipment obey (1) below, where Z_{dd} and Z_{cc} are respectively the differential and common mode impedances seen at the injection point, and Z_{cd}=Z_{dc} are the cross-impedances between the two modes at the same point. Equation (1) suggests that, if the two modal voltages and the two modal currents at a given frequency are known, the common and differential mode impedances cannot be found by taking the ratio of the homologue voltage and current parts; the cross coupling term must also be considered:

$Z_{cc} \neq \frac{V_{cmmn}}{I_{cmmn}}$, and $Z_{dd} \neq \frac{V_{diff}}{I_{diff}}$.

$$\begin{bmatrix} V_{cmmn} \\ V_{diff} \end{bmatrix} = \begin{bmatrix} Z_{cc} & Z_{cd} \\ Z_{dc} & Z_{dd} \end{bmatrix} \cdot \begin{bmatrix} I_{cmmn} \\ I_{diff} \end{bmatrix}, \text{where: } Z_{cd} = Z_{dc} \qquad (1)$$

Keeping the above in mind, Figure A-8 in Appendix A plots versus the frequency the differential and common mode impedances calculated from Figures A-6 and A-7, which depict the measured modal voltage and current for a differential and a common mode injection pattern respectively. These figures also indicate that, at certain frequencies, the cross-coupling between the two modes is rather strong. Consequently, AEC asks whether the results in Figure 8 include the effects of the cross-coupling impedance, and whether it has been determined that the magnitude of the cross-coupling impedance is negligible for the tested system.

Second, Figure A-10 shows the radiation field resulting from signal injection into the house lines. This data was collected using a loop antenna. A loop antenna in free

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predictions due to the sensitivity to model parameter variation. This further leads to the need for bench space can provide the intensity of the magnetic field.[25] The intensity of the electric field reported in this figure is found by converting the measured magnetic field intensity through the free space impedance. The relation between the electric and magnetic fields, however, is valid only for a propagating wave. Thus, it should be applied only in the region of the far fields of a radiator. Given that the wiring of a house behaves as a large radiator and that the wavelength below 30 MHz is greater than 10 m, AEC asks whether a distance of 10 m around the house exterior walls is satisfactory to assure that the measurement was taken in the far fields for all frequencies in the range (essentially, to guarantee that the conversion from the magnetic to the electric field quantity is correct).[26]

Third, AEC has conducted tests that show a strong correlation between ambient emissions and noise on the wires of a building. AEC has found that signals emitted by radio stations and other RF devices in the range from 2 to 30 MHz can enter the wires of a house with significant amplitude. Presumably, most of the coupled energy enters through the external power utility wires. The tests in the report were conducted with the house power wires isolated from the utility, but the report is unclear as to how this isolation was achieved (*e.g.* opening the master breaker). Similarly unclear is how it was determined that a sufficient isolation was achieved from the power utility, considering that high frequency signals can "jump" between the conducts of an open switch. Specifically, AEC questions whether the native signal on house wires was measured before and after isolating the house. The report indicates that certain attenuators were

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mark models sanctioned by appropriate technical committees and verified by field tests.

[25] AEC has serious concerns, however, regarding the use of a loop antenna, which may introduce significant measurement error. AEC's concerns regarding the use of a loop antenna are attached to these comments as Appendix B.

[26] AEC notes also that, if the reported values of the electric field are incorrect due to incorrect conversions, the subsequent results in Figures 11 through 14 will be similarly off. AEC wonders, therefore, whether the

used to dampen the levels of these unwanted signals, but does not explain what was the effect of these attenuators on the tested signals.

Fourth, the common mode inductance of 0.38 μH between the baluns and the break-out box appears to have a noticeable effect on the measurements. As a result, AEC questions how reliably the relations/transfer functions in Figures A-8, -9, -11, -12, and -13 can be used to predict the effects of conducted emissions for a given in-house modem and what was the correction factor used to compensate for that inductance, if any. AEC also would be interested to learn whether a sensitivity analysis has been conducted to determine the effect of this and other stray elements on the reported test results. Lastly, and in view of the potentially highly sensitive magnitude of the various transfer functions characterizing the in-house environment with respect to stray elements in the measuring arrangement, AEC asks whether future measurements also should include equipment such as power cords, which exist between a modem and the power outlet, as part of the test network.

Fifth, the transfer functions from the signal applied onto the house wires to the field observed around the house are very useful. As the report explains, they can potentially be used to determine the safe levels of conducted emissions from an in-house device. Anticipating that such transfer functions are going to provide the upper limits for conducted emissions, AEC believes that the investigation of the ability of the in-house system to properly operate at reduced signal injection levels would be useful. Specifically, measurements of the channel transfer function, *i.e.* between the signals at an injection point and a reception point within the same house, as between two different

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use of a monopole antenna would be a better alternative to a loop antenna for measurements done close to the radiator because the monopole antenna measures the electric field directly.

outlets, would be useful. That transfer function can be used in conjunction with the former (from the conducted signal to the ambient fields) in order to determine whether a decrease in the conducted emissions for obtaining a maximum ambient field would impair the ability of the in-house channel to convey signals above the noise floor for proper communication.

CONCLUSION

AEC does not argue that EM pollution from BPL is unrealistic or that it could never be a potential problem. Rather, AEC believes that pollution from BPL signals is far less prolific than is alleged by opponents of the technology in this proceeding. The operational experience of the AEC system on one hand, and of other systems in United States and Europe (as reported in the above-cited literature) on the other, indicates that the BPL system is controllable. Potential problems can be avoided and corrected by proper apparatus design and system deployment. Any standards necessary to guide the technical development of the system should be based on factual knowledge of the system combined with the appropriate science.

The fears regarding BPL expressed by various parties to this proceeding are the result of a lack of understanding of BPL systems and technology and are not grounded in appropriate science. As set forth in these reply comments, power lines will not become blocks-long antennas when they are part of a BPL system, and multiple BPL users will not aggregate interference in a given BPL environment. The only substantive comments in this proceeding that challenge BPL systems, offered by the ARRL, are of limited value as they are premised upon a study of an atypical electric system that bears little, if any, resemblance to actual BPL systems currently in successful operation. Accordingly, the Commission should stay the course as it seeks ways to help proliferate the promising new technology that is broadband over power lines.

Respectfully submitted,

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