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

In the Matter of	)	
	)	
CARRIER CURRENT SYSTEMS INCLUDING BROADBAND OVER POWER LINE SYSTEMS	)	**ET Docket No. 03-104**
	)	
AMENDMENT OF PART 15 REGARDING NEW REQUIREMENTS AND MEASUREMENT GUIDELINES FOR ACCESS BROADBAND OVER POWER LINE SYSTEMS	)	**ET Docket No. 04-37**

To: The Commission

RESPONSE OF ARRL, THE NATIONAL ASSOCIATION FOR AMATEUR RADIO TO CURRENT GROUP, LLC WRITTEN *EX PARTE* PRESENTATION

ARRL, the national association for Amateur Radio, formally known as the American Radio Relay League, Incorporated (ARRL), by counsel and pursuant to Section 1.1206(b)(1) of the Commission's rules [47 C.F.R. §1.1206(b)(1)], hereby submits its response to the written *ex parte* submission of Current Group, LLC ("Current") dated August 8, 2012. Therein, Current claims to respond to "new matter" that ARRL allegedly first raised in the *Reply of ARRL, the National Association for Amateur Radio to Oppositions of the Homeplug Power Alliance and Current Group, LLC to Petition for Reconsideration.* ARRL's brief response to Current's *ex parte* filing is as follows:

1. As an initial matter, it is disingenuous for Current to base its argument for its entitlement to submit a post-reply surrebuttal in a proceeding on reconsideration on ARRL's alleged submission of "new matter" in ARRL's Reply pleading. The entire thrust of Current's *Opposition of Current Group LLC to Petition for Reconsideration*, filed July 17, 2012 was that

ARRL had not, in its Petition for Reconsideration in this proceeding filed December 20, 2011, raised any new "discussion or evidence" in this docket proceeding. Current's principal effort in its Opposition pleading and in its August 8, 2012 surrebuttal is to attempt to justify retaining the 40 dB/decade of distance extrapolation factor for assumed signal decay of radiated BPL emissions from power lines. It alleges that ARRL has *only now*, in its reply pleading, alleged that fields decay rapidly only in the *reactive* near field. That, as anyone who has read ARRL's pleadings diligently would know, is *not* a new argument. As shown below and in the attached Exhibit A, ARRL has made this argument consistently.

2. Although the Commission's rules[1] do not permit a surrebuttal to a reply to an opposition to a petition for reconsideration in a docket proceeding (and it is arguable that Current's August 8, 2012 surrebuttal is impermissible as the result), that is not here determinative because Section 1.1206 of the Commission's rules appears to permit *ex parte* submissions in this context, thus allowing Current, by so identifying its surrebuttal, to prolong the pleading cycle in this case indefinitely. However, nothing in Current's August 8, 2012 filing validates the indefensible 40 dB/decade extrapolation factor. It is disingenuous as well for Current to assert that ARRL has presented new material in its reply pleading when Current itself, in its surrebuttal pleading, has introduced a new argument concerning near-field boundaries, and has introduced (but misapplied) a formula not heretofore mentioned in the record, in an effort to establish those boundaries.

3. Current attempts once again to justify the Commission's baseless affirmation of the 40 dB/decade of distance extrapolation factor by claiming (again) that BPL systems are not long radiating elements but in effect point source radiators. Even if they were long radiating

[1] See, 47 C.F.R. § 1.429.

elements, Current asserts that "all practical measurement distances fall within the reactive near field." It bases this assertion on a formula that it claims describes the reactive near field of an electrically larger antenna. On this argument, Current once again claims that the correct extrapolation factor is 40 dB/decade for HF BPL systems.

4. Current is flatly wrong; its argument is wrong; its formula is misapplied; and it either knows all this or should know it. Attached hereto as Exhibit A is an analysis of Current's argument provided by ARRL Laboratory Manager Ed Hare. Attached hereto as Exhibit B is a statement of Dr. Kazimerz "Kai" Siwiak, Ph.D., P.E., which (1) supports Mr. Hare's analysis, and (2) explains in detail that Current has completely misapplied the formula of Constantine Balanis and others in its effort to define the boundary delineating the dominance of near and far regions.

5. Mr. Hare's analysis notes that the description of the near-field boundary asserted by Current invokes a generally accepted, recognized and authoritative reference, but presents it incompletely, out-of-context, and in some respects simply inaccurately. Most of Current's errors are based on mutually-exclusive arguments. It argues on the one hand that power lines are point-source radiators, and on the other that power lines are large sources. Both arguments as made by Current involve fundamental errors in the underlying electromagnetic theory. Mr. Hare's exhibit illustrates that Current has repeatedly and consistently provided graphs of signal decay along power lines that are flawed. In one case, Current's argument that BPL emissions are consistent with a point source emitter is based on a graph that may or may not have been created from data from actual measurements, but in any case is consistent with a system that is operating at around 40 MHz, not below 30 MHz, which is the frequency range at issue in this proceeding. Mr. Hare

also shows that Current has twice asserted in this proceeding that point sources decay at 40 dB/decade in the *far field.*

6. ARRL's numerous submissions in this proceeding have consistently shown that field strength decays "in the reactive near field" at 40 dB /decade. Though ARRL may not have, in each instance, defined that reference as "the region bounded by the wavelength $\lambda/2\pi$", it is clear from the context in every case that ARRL was addressing only the part of the near-field region bounded by $\lambda/2\pi$. By contrast, the formula that Current uses to describe the reactive near-field boundary of a large radiator is used in a misleading way. Current assumes that the rapid decay of field strength with distance that is found in the closer near-field region bounded by $\lambda/2\pi$ is found in the entire reactive region where there are phase differences from far-field conditions. As shown by Mr. Hare in Exhibit A, Constantine Balanis has made clear that Current cannot apply the formula to predict field strength at any distance from a radiating source. Instead, Maxwell's equations are applicable, as ARRL has repeatedly noted. These demonstrate that for very small radiators, field strength with distance may vary at greater than 20 dB/decade, but only in the reactive near-field region bounded by $\lambda/2\pi$. The formulas also show that for larger radiators, the field strength with distance will decay at rates approaching 20 dB/decade, even right up to the radiator. This is described in Exhibit B, attached. As Mr. Hare asserts, it is reasonable to presume that fields decay at 20 dB/decade, and although that is something of a simplification, it is a reasonable one and one that is in fact generous for larger radiators.

7. The record in this proceeding establishes clearly that Current's argument is not supported by accepted electromagnetic field theory, or with antenna models in the record. Nor is it consistent with summaries – also in the record – of testing done by several government entities of deployed BPL systems. Tests in Canada conducted by the Research Centre Canada (CRC) of

17 residences concluded, for example, that the field strength versus distance of BPL radiated emissions decayed at a consistent 20 dB/decade rate.

8. Finally, in its August 8 surrebuttal, Current assumes but does not have any apparent authority for the premise that overhead BPL lines are 28.6 meters in size, thus having a near-field boundary that encompasses both the 10-meter measurement points typically used to make measurements, and the 30-meter distance specified in the Commission's rules. This is at odds with Current's heretofore consistent argument that BPL is a point source radiator. This inconsistency is a matter of necessity for Current, because it must make this presumption in order to attempt to use the formula that it suggests validates the Commission's extrapolation factor. The larger problem, however, is that Current's calculation of the reactive near-field region, which it claims encompasses the 30-meter distance, applies to a frequency of 30 MHz. At 5 MHz, as Mr. Hare shows, the formula offered by Current, as used by Current, would result in a boundary of 12.4 meters, typical of the slant-range distance between typical measurement points and typical overhead wires. Moreover, if the formula is misapplied to a determination of the boundary within which fields decay at 40 dB/decade of distance, as Current would have it, this would yield, as the frequency increases above 30 MHz, results that are inconsistent with the presumption that distance extrapolation above 30 MHz is 20 dB/decade. In other words, Current's argument would extend the 40 dB/decade extrapolation to greater and greater distances as frequency is increased.

9. In conclusion, Current has in its August 8, 2012 surrebuttal filing introduced a new formula and a new argument attempting to justify the 40 dB/decade extrapolation factor below 30 MHz and to establish the boundaries within which BPL radiated emissions decay at this rate. The argument is flawed in its premises, and the formula cited by Current is misapplied. The full

text of the reference cited by Current belies Current's conclusion. Neither is Current's argument consistent with other authoritative texts describing the way in which field strength decays with distance from large radiators; with the results of electromagnetic modeling of antennas used by the Commission in this proceeding; or with authoritative measurements of deployed BPL systems. In short, Current has failed to demonstrate that retention of the 40 dB/decade extrapolation factor is justified scientifically. Presently accepted science shows, by contrast, that field strength from large emitters decays at a lower rate than does field strength from small emitters.

Therefore, for all of the above reasons and the attached technical showings, ARRL, the national association for Amateur Radio, again respectfully requests that the Commission reconsider and modify the rules governing Access Broadband over Power Line systems in accordance with ARRL's Petition for Reconsideration, and to finally adopt a scientifically justifiable distance extrapolation factor for Access BPL systems.

Respectfully submitted,

ARRL, THE NATIONAL ASSOCIATION FOR AMATEUR RADIO

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By: *Christopher D. Imlay*
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September 24, 2012

CERTIFICATE OF SERVICE

I, Christopher D. Imlay, do hereby certify that I caused to be served, via electronic mail a copy of the foregoing **RESPONSE OF ARRL, THE NATIONAL ASSOCIATION FOR AMATEUR RADIO,TO CURRENT GROUP, LLC WRITTEN *EX PARTE* PRESENTATION** to the following, this 24th day of September, 2012:

Mitchell Lazarus, Esq.
Fletcher, Heald & Hildreth, P.L.C.
1300 North 17th Street, 11th Floor
Arlington, VA 22209
Counsel for Current Group, LLC

Christopher D. Imlay

Christopher D. Imlay

Exhibit A

Analysis of Current Group, LLC Ex Parte filing of August 8, 2012 in ET Docket 04-37

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Current ex parte filing

On August 8, 2012, CURRENT Group, LLC provided to the Commission[1] a written *ex parte* filing, in response to a discussion concerning distance extrapolation contained in ARRL's *Reply to Oppositions* filed in the record in this proceeding July 27. 2012. In its *ex parte* filing, CURRENT attempts to justify its surrebuttal pleading by claiming that ARRL presented new information in its July 27, 2012 Reply pleading, to which Current was responding. CURRENT, however has now introduced a new construct; a new formula; and a new position about near-field boundaries that has not heretofore appeared in the record in this proceeding in *any* form.

What CURRENT has provided is little more than technical obfuscation, taking a description of the near-field boundary from a generally recognized authoritative reference and presenting the same in an entirely different context than what is described in the cited reference.

To explain this, it is necessary to review the record, which pattern of representations made by CURRENT that are presented out of context; are incomplete; or in some cases are made in technical error.

Point Source Emitters

Throughout this proceeding, CURRENT has consistently argued that overhead power lines with connected BPL injectors will radiate as point sources. ARRL and others have shown that these overhead wires are not -- and cannot be -- point source radiators. This fundamental error of fact has been the basis for most of CURRENT's ensuing technical position about distance extrapolation. Of note, even after the Commission conceded that power lines carrying BPL noise are *not* point source emitters, CURRENT has maintained the opposite.

Measurements of the Decay of Field Strength versus Distance

Earlier in this proceeding, in support of its position that emissions from overhead wires and premise wiring decay at 40 dB/decade within 30 meters of the source below 30 MHz,

[1] See *Ex Parte Filing*, CURRENT Group, filed August 8, 2012.

CURRENT provided the Commission with undocumented measurements that it stated supported the retention of a 40 dB/decade extrapolation factor. A figure from CURRENT's Comments in response to the Notice of Proposed Rulemaking in this proceeding is shown below, as Figure 1:

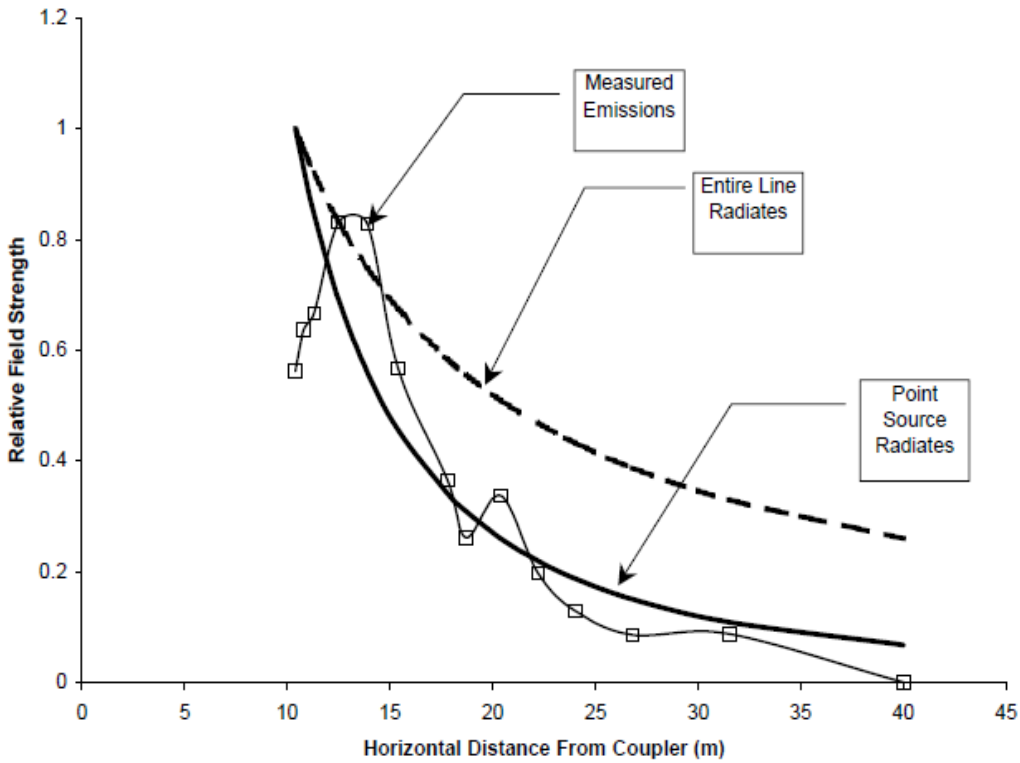

Figure 1 -- BPL Emissions Consistent with Point Source

In Reply Comments and in a series of ensuing *ex parte* submissions, ARRL explained that there were numerous inconsistencies in this CURRENT graph. Among them is the fact that if reasonable assumptions are made about the height of the radiating overhead wire, the "point source radiates" line on CURRENT's graph is not consistent with a 40 dB/decade line corrected for the horizontal distance shown in the graph. Again, making some assumptions about the slant-range involved and the pattern of peaks seen on CURRENT's graph, the measurement was indeed made of a system operating somewhere near 40 MHz.[2] The 40 MHz assumption is consistent with the operating range of the overhead BPL system that CURRENT had manufactured at the time of its filing. This is the most glaring flaw in this graph, as it is unsupportable that measurements made above 30 MHz where the extrapolation is presumed to be 20 dB/decade could be used to justify the retention of a 40 dB/decade extrapolation factor below 30 MHz.

[2] This presumes that the graph represents an actual measurement. CURRENT did not provide information about the measurement frequency, much less any of the other descriptions that would normally be provided in a competently prepared test report.

40 dB/decade in the Far Field

This pattern of presenting inaccurate information (and that is presented out of context) is found in CURRENT's other filings. In two separate submissions, CURRENT has erroneously stated that point sources decay at 40 dB/decade *in the far field.* This is wrong. Such a fundamental error presented twice by CURRENT compromises its credibility on the subject of distance extrapolation.

Wavelength divided by 2π versus other near-field formulas

In its August 8 *ex parte*, CURRENT has misstated ARRL's consistent position throughout this proceeding. All of ARRL's submissions have consistently stated the presumption that field strength decays "in the reactive near field" at 40 dB per decade. Though ARRL did not clarify each and every time that reference was made that ARRL was discussing the region bounded by the wavelength (λ) divided by 2π, it is clear from the context of ARRL's filings that ARRL was addressing *only* the part of the near-field region bounded by λ/2π.

ARRL could not have anticipated that any of the participants in this proceeding would take a formula that applies in an entirely different context; misapply that formula to the issue of distance extrapolation; and falsely state that ARRL claimed that this formula also applies to the near-field region bounded by that formula.

CURRENT has introduced a formula that describes the reactive near-field boundary of a large radiator. It cites work by Constantine Balanis in support of its position that this formula defines "the reactive near field boundary" of a large radiator. CURRENT does not, however, describe *all* of what Balanis states about the use of this formula. At the top of page 117, Balanis notes that the formula cited by Current can be used to determine the boundary at which the phase error of the electric and magnetic fields are no more than π/8 radians (22.5^{o}) from the condition that would exist if those fields were in the far field. At this distance, the radiating electromagnetic field is sufficiently formed that it is reasonable to make a field-strength measurement that is based on far-field assumptions. These differences in phase are the essence of what makes the reactive near-field region reactive, storing power that is then returned to the antenna.

This definition of the distance beyond which fields measurements may resemble far field measurements is the *only* significance of Equation 2 from Current's filing. Current *seriously* misapplies this formula by presuming that the rapid decay of field strength with distance that is found in the closer near-field region bounded by λ/2π is seen in the entire reactive region where there are phase differences from far-field conditions. The equation provides no additional information about other components and characteristics of the fields, such as information about how they vary with distance. The *only* accurate formulas to use to predict field strength at any distance from a radiating source are Maxwell's equations.

Maxwell's equations demonstrate that for *very small radiators*, field strength with distance may vary at greater than 20 dB/decade. The formulas also show that for larger radiators, the field strength with distance will decay at rates approaching 20 dB/decade, even right up to the radiator. This is described in greater detail in Exhibit B to this filing, which contains additional analysis. The premise that ARRL has consistently proffered-- that it is reasonable to presume that fields decay at 20 dB/decade -- is a reasonable simplification, but one that is actually generous for larger radiators.

CURRENT's Position is Not Supported by the Record in This Proceeding

The claims that CURRENT is making in its August 8 filing are not supported by good electromagnetic-field science or consistent with the overall record in this proceeding. Its claims are not even supported by the very reference it provides in support of its position. **Balanis is clear that this formula applies only to the amount of deviation of phase difference at any point in space from the conditions that can reasonably be assumed to be close enough to far-field conditions to be treated as such.**

CURRENT's position is not supported by authoritative references related to antenna and electromagnetic field theory. In an exhibit[3] filed by ARRL on May 3, 2004, ARRL showed the graph below, showing how field strength varies with distance from small line and planar emitters.

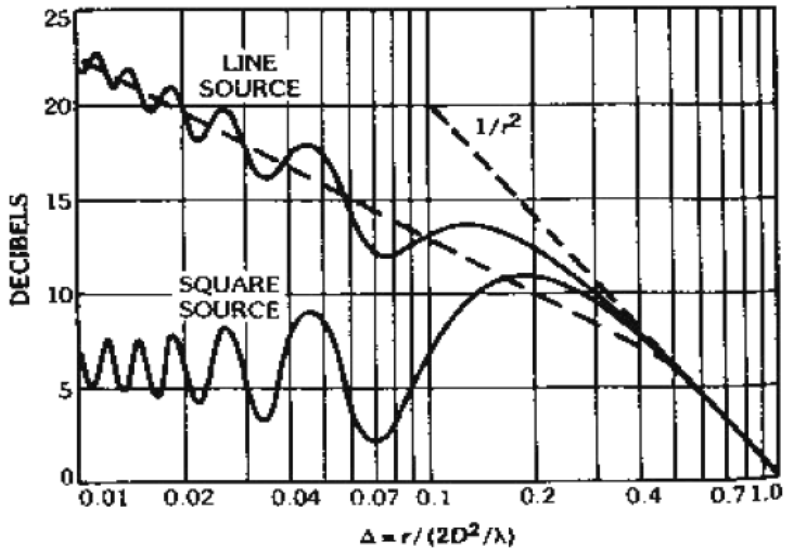

Figure 3 – On-axis power density.

[3] See ARRL Comments on the Notice of Proposed Rulemaking, at Exhibit B, *Proposed Radiation Emission Limits and Extrapolation,* Rinaldo et al., dated May 3, 2004. This figure was identified as "figure 3" as originally filed.

Figure 2 - This figure shows how power density (and field strength) varies with distance from different sources.

CURRENT's Position Not Supported by Antenna Modeling

CURRENT's position is not supported by any of the antenna models in the record in this proceeding, some of which the Commission stated that it used in reaching its conclusions. Two examples, previously provided[4] by ARRL, are Figure 3 (identified as "Figure 4" in the document in which it originally appeared) below.

Figure 4 – Magnetic Field Strength Close to a Long Dipole

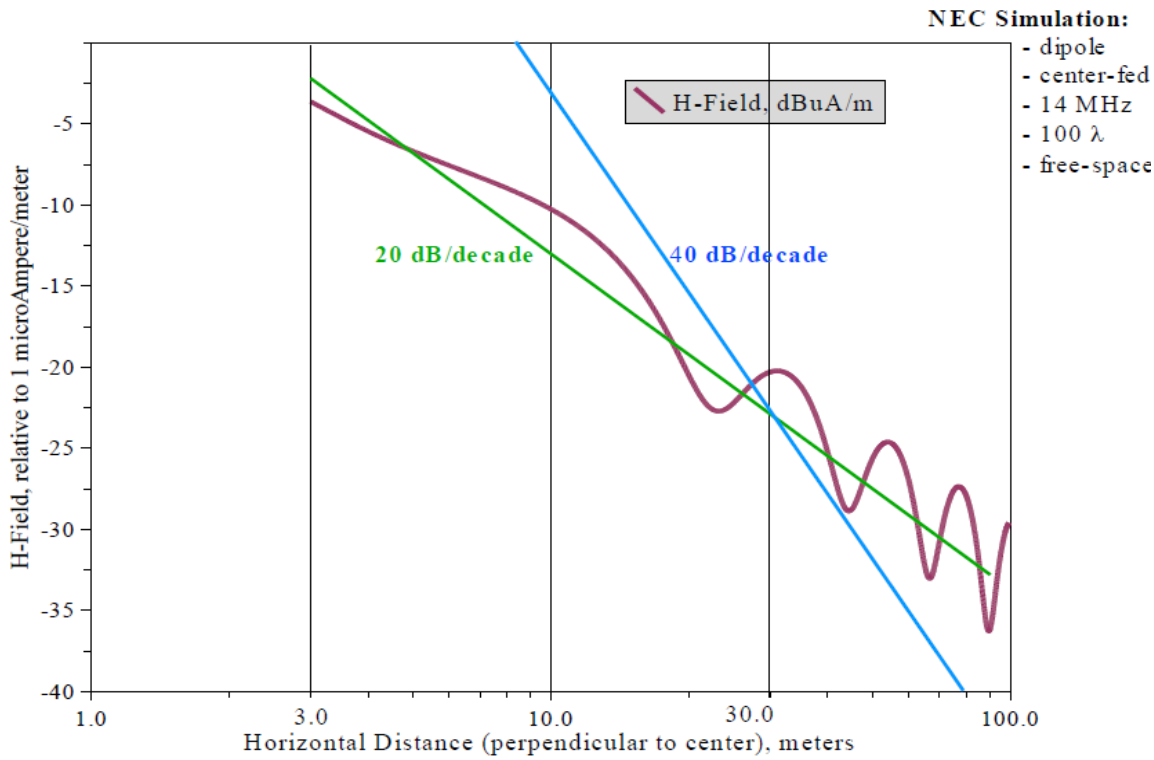

Figure 3 -- This graph, contained in the record in this proceeding, shows that the magnetic field strength from a center-fed long antenna does not decay at a rate greater than 20 dB/decade, even within the reactive or radiating near-field regions.

[4] Id.

CURRENT's Position is Not Supported by Authoritative Testing of Deployed BPL Systems

ARRL has also placed in the record[5] summaries of testing done by several government entities of deployed BPL systems. Perhaps the most significant of this is the Canadian Research Centre Canada (CRC) testing of BPL modems deployed in 17 residences in Canada. The position taken by CURRENT in its August 8, 2012 *ex parte* filing is not supported by this testing, either. The Canadian testing clearly showed that the field strength (versus distance) was decaying at a remarkably consistent 20 dB/decade rate. The wiring in premises has a combination of horizontal and vertical configurations that do provide a reasonable indication of what to expect from the emissions from overhead horizontal wires and the vertical ground wires found on nearly every pole where overhead BPL modems are employed.

CURRENT's Position Is Not Internally Consistent

In its August 8, 2012 *ex parte*, CURRENT offers no citation of authority for its premise that overhead BPL lines can be presumed to be 28.6 meters in size, thus having a "reactive near-field boundary" that encompasses both the 10-meter measurement points typically used to make measurements and the 30-meter distance specified in the regulations. This is completely at odds with CURRENT's argument that BPL is really a point-source emitter. Its (inconsistent) presumption of a 28.6-meter large emitter is necessitated by the fact that CURRENT has introduced a formula that it believes justifies present measurement practice if 28.6 meters is presumed to be the size of the radiator.

That notwithstanding, its calculation of the reactive near-field region encompassing 30 meters suffers from two rather glaring flaws. The first is that the calculation it used applies to a frequency of 30 MHz. At 5 MHz, the formula gives a "reactive near-field" boundary of 12.4 meters, typical of the slant-range distance between typical measurement points and typical overhead wires[6].

More important, because it is *not* moot, is the fact that if this formula is misapplied to a determination of the boundary within which fields are presumed to decay at 40 dB/decade, then as the frequency is extended beyond 30 MHz, this boundary becomes larger and larger. If this formula were applied above 30 MHz and it is presumed that field strength decays with distance at 40 dB/decade within the boundaries defined by the formula, then the result would be completely at odds with the premise that distance extrapolation above 30 MHz should be presumed to be 20 dB/decade.[7]

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[5] See *Measurements of EM Radiation from In-House Power Line Telecommunication (PLT) Devices operating in a Residential Environment*, Canadian Research Centre Canada, March 24, 2009. This report was filed by ARRL on January, 11, 2010.

[6] *This is, of course, moot because the formula shows only the phase-error boundary that defines the reactive near-field region. It does not define any boundary within which fields decay rapidly.*

[7] *Of course, it is not likely that Current would want to see the presumptions above 30 MHz changed because most measurements are made at a slant-range distance greater than the 10 meters specified as the limit distance in the rules, so a 20 dB/decade extrapolation above 30 MHz is actually more liberal than a 40 dB/decade extrapolation..*

Conclusion

In its August 8 *ex parte* filing, CURRENT has introduced a formula into the record that is new to this proceeding, which CURRENT has misapplied so as to create a presumption that field strength will decay at 40 dB/decade within the boundaries defined by the formula. This premise is not consistent with the *full* text of the reference cited by CURRENT. The premise that CURRENT puts forward is not consistent with other authoritative texts describing the way in which field strength decays with distance from large radiators. The effect that CURRENT claims to exist in this large area is not seen in the results of EM modeling of antenna models that the Commission used to reach its determinations in this proceeding. The decay of field strength with distance that CURRENT claims is not demonstrated in the authoritative measurements made of deployed BPL systems. Nor is CURRENT's position consistent with the premises that CURRENT has urged earlier in this proceeding. CURRENT is presenting a paradigm that would extend the 40 dB/decade extrapolation to greater and greater distances as frequency is increased.

Despite its claims and changed allegations regarding point sources, large emitters and decay of field strength with distance, CURRENT has *not* demonstrated in this proceeding that the retention of 40 dB/decade is justified. If the Commission is to have a reasonable, scientifically based approximation of distance extrapolation, it must rely on known science. If examined, it will become clear that field strength from large emitters decays at a lower rate than does field strength from small emitters.

Exhibit B

∂/∂t TimeDerivative

TimeDerivative, Inc.
10988 NW 14th Street
Coral Springs, FL 33071

September 19, 2012

Mr. Ed Hare
ARRL
225 Main Street
Newington, CT 06111

Re: ET Docket No. 03-104
ET Docket No. 04-37
Broadband over Power Line Systems
Ex Parte Communication

Dear Ed:

I am writing in regard to the CURRENT Group LLC *ex parte* communication to the FCC dated August 8, 2012.

Only when we encounter *electrically small antennas*, antennas much smaller than a wavelength (which have a high Q, or a high reactive to radiated power ratio in the immediate vicinity of the antenna), do we see fields that may have $1/R^2$ and $1/R^3$ reactive components in addition to the $1/R$ radiating component which survives to the far field. In that case, the boundary delineating the dominance of near or far regions[1] is correctly given by ARRL as:

$$R = \frac{\lambda}{2\pi} \qquad (1)$$

CURRENT claims that "the reactive near field for an electrically large antenna" is bounded by:

$$R = 0.62\sqrt{\frac{D^3}{\lambda}} \qquad (2)$$

where D is the maximum dimension of the antenna." CURRENT attempts to justify this equation by citing Balanis[2] and others. In fact, the word "bounded" is *very loosely applied* in this case. Balanis actually writes that Equation (2) defines the boundary of the region "when the first three terms of [a bionomial expansion series] for R are significant,

[1] K. SIWIAK and Y. BAHREINI, RADIOWAVE PROPAGATION AND ANTENNAS FOR PERSONAL COMMUNICASTIONS, THIRD EDITION, p. 14 (ARTECH HOUSE 2007).
[2] CONSTANTINE A. BALANIS, ANTENNA THEORY: ANALYSIS AND DESIGN 116-117 (John Wiley & Sons 1982).

and the omission of the fourth term introduces a maximum phase error of less than π/8 radians." Balanis further defines the *full region* as:

$$2D^2/\lambda > R \geq 0.62\sqrt{\frac{D^3}{\lambda}} \qquad (3)$$

"This region is designated as the radiating near-field because the radiating power density is greater than the reactive power density and the field pattern (its shape) is a function of the radial distance *R*." Thus $R = 2D^2/\lambda$ bounds the region where the reactive fields exceed the radiated components. The separation of CURRENT's Equation (2) from the Balanis' full bound in Equation (3) is therefore incorrect, since from Balanis' Equation (3) above, we can see that (2) is a needlessly loose "super-bound" on the near field. Per Balanis, the near field dominates for $R < 2D^2/\lambda$. However, this boundary delineates the region where the far field pattern is fully formed, *not* where the near fields exhibit some inverse power law different from 1/*R*. Like Industry Canada and ARRL, Balanis delineates the intermediate field region[3] where fields include terms with at least $1/R^2$ as $kR>1$, resulting in the boundary at $R = 1/k = \lambda/2\pi$. Thus physics, Balanis, and Industry Canada are in full agreement.

A straightforward application of Maxwell's Equation (Ampere's Law) gives the magnetic fields *H* of a long wire carrying a current *I* as:

$$H = \frac{I}{2\pi R} \qquad (4)$$

Equation (4) is valid from the wire surface to infinity, and there are no other *H* field components. Balanis[4] shows a practical large antenna example of this field behavior in Equation (7.15) for the complete magnetic field of a dipole antenna:

$$H_\phi = -\frac{I_0 L}{4\pi j R}\left[e^{-jkR_1} + e^{-jkR_2} - 2\cos\left(\frac{kL}{2}\right)e^{-jkr}\right] \qquad (5)$$

where *R* is the radial distance away from the wire dipole, and *L* is the dipole length. Equation (5) is exact and valid from the dipole wire surface to infinity. There are no other *H* field components for the dipole. Clearly, *H* varies as 1/*R* everywhere.

We conclude that the total and complete expression for the magnetic field of a long current carrying wire has *only* a 1/*R* dependency for all values of *R* from *the wire surface to infinity*. We further see that if the radiator is small enough to have fields components that vary with $1/R^2$ and/or $1/R^3$, those fields dominate inside the boundary given by

[3] CONSTANTINE A. BALANIS, ANTENNA THEORY: ANALYSIS AND DESIGN, p. 106-107 (John Wiley & Sons 1982).
[4] CONSTANTINE A. BALANIS, ANTENNA THEORY: ANALYSIS AND DESIGN, p. 289 (John Wiley & Sons 1982).

Equation (1). A radiator that is "(s)mall enough to have fields components that vary with $1/R^2$ and/or $1/R^3$" gives rise to a very high Q for the small antenna and consequently an extremely low usable bandwidth, unlike the very long wire case.

With very best regards,

Kazimierz "Kai" Siwiak, Ph.D., P.E.