SECTION 7
BPL COMPLIANCE MEASUREMENT PROCEDURES

7.1 INTRODUCTION

The BPL Inquiry states that Part 15 of the Commission's rules do not specifically provide measurement procedures that apply to BPL systems and notes that the Commission has "…allowed measurements of radiated emissions at three installations that the operator deems as representative of typical installations."[51] This approach is allowed under Part 15 (§15.31(d)) when it is impractical to perform compliance measurements at Open Air Test Sites (OATS). Compliance measurements must be designed to be practical, but they should also be accurate with any composite measurement error biased toward overestimation of actual field strength.[52]

In Section 5.2, it was noted that peak levels of BPL field strength may arise from standing waves on the power lines that are generated by reflections of signals at impedance discontinuities along the power lines. It is essential that these standing wave conditions be addressed during compliance measurements. These radiation conditions have little to do with the BPL device itself; instead, they result from various features of power lines that cannot be readily emulated in a laboratory or at a conventional OATS.

NTIA has reviewed three proprietary reports of BPL measurements that were performed by contractors hired by BPL proponents to test compliance of trial BPL systems with Part 15 field strength limits. In all cases involving outdoor overhead power lines, measurements were performed using a one-meter high antenna on radials emanating from a power line pole to which a BPL access device was mounted. While consistent with §15.31(f)(5), this ad hoc measurement approach does not demonstrate compliance with the field strength limits because as shown by NTIA's measurements and models, peak field strength levels are not centered at the BPL device and do not occur at a height of one-meter above the ground.[53] Other sources of potential BPL measurement inaccuracies include: the measurement distance and extrapolation factor; frequency-selective radiation effects; estimation of electric fields using a loop antenna; and selection of representative BPL installations for testing. Potential solutions to most of these measurement challenges are at hand within existing Part 15 measurement procedures, as discussed below (also see the listing of applicable Part 15 rules in Appendix A).

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[51] BPL Notice of Inquiry, at ¶2 and 21-23.

[52] *See e.g.*, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*, CISPR 22:2003, ("CISPR 22"), Section 7.1.2. "The significance of the limits for equipment shall be that, on a statistical basis, at least 80% of the mass-produced equipment complies with the limits with at least 80% confidence."

[53] *See Potential Interference from Broadband over Power Line (BPL) Systems to Federal Government Radiocommunications at 1.7 – 80 MHz*, NTIA Report 04-413, ("NTIA BPL Report"),Volume I, Section 5.2.

7.2 MEASUREMENTS MUST ADDRESS RADIATION FROM POWER LINES TO WHICH BPL DEVICES ARE CONNECTED

Part 15 already clearly specifies that compliance measurements must address the device under test (DUT, also referred to as equipment under test or EUT) while it is connected to all cables, wires and companion devices normally used with the DUT.[54] The measurement distances are specified to be relative to an imaginary, ground-based boundary around the DUT and the interconnected cables, wires and companion devices. Nonetheless, because BPL measurement contractors have applied measurement distances with respect to only the BPL DUT, the Commission should consider clarifications to the provisions that apply to BPL systems.

When applying measurement distances relative to the BPL DUT, the peak field strength may be substantially overestimated or underestimated. As shown in NEC models of BPL radiation (see Appendix E), vertical electric field strength varies substantially over small distances along radials from the BPL DUT and, depending on geometric and electrical factors, the measurement location may coincide with a local field strength peak or trough. There is no apparent need to measure local field peaks under power lines because radio receivers operating in the subject frequency range inherently should not be located directly under power lines in order to avoid degradation from ambient local power line noise.

7.3 MEASUREMENTS SHOULD ADDRESS AGGREGATED EMISSIONS FOR THE FULLY DEPLOYED BPL NETWORK

Part 15 specifies that the aggregate emissions from a composite system must satisfy the field strength limits applicable for a single device.[55] As BPL networks are substantially deployed in a community, the aggregated BPL emissions for the overall network are expected to increase above the levels generated by a single BPL device. This aggregation has already been observed by NTIA at one of the trial BPL systems where multiple simultaneous transmissions occur.[56]

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[54] *See* 47 C.F.R. §15.31(g)-(k).

[55] *See* 47 C.F.R. §15.31(h)-(k)

[56] *See* NTIA BPL Report, Volume II, Appendix D, § D.1

7.4 MEASUREMENT ANTENNA HEIGHTS SHOULD ADDRESS ALL IMPORTANT DIRECTIONS OF BPL SIGNAL RADIATION

Part 15 measurement procedures for testing at OATS require measurement of emissions radiated in all directions and identification of the direction of maximum radiation intensity.[57] This is accomplished using: a turntable on which the DUT and interconnection cables, wires and companion devices are rotated; a reflecting ground plane in conjunction with predetermined normalized site attenuation; and measurement antenna heights varied between 1 meter and 4 meters in order to facilitate determination of the height of maximum radiation. Although these OATS provisions are not practicable when measuring at a BPL installation site, the underlying principles remain critical to measurement accuracy and control of interference risks. Specifically, it is essential that BPL compliance measurements be made in directions where emissions may propagate to radio receivers.

In the case of outdoor BPL systems, radio receivers can be located in any direction around the BPL device and the power lines to which the BPL device is connected. Receiving antennas on masts or buildings near the power lines or on aircraft flying over power lines can be at high elevation angles from the DUT and power lines, whereas land mobile antennas will typically be at low (including negative) elevation angles. The lowest receiver antenna heights typically will be of the order of two (2) meters. Thus, since BPL measurements at an OATS are not practicable (where a one (1) meter antenna height should be considered), there is no need to measure BPL emissions at a height less than two (2) meters. However, to adequately address emissions at high elevation angles, it is necessary to measure BPL emissions at heights comparable to the power line height.

Conceptually, this can be accomplished either through direct measurement at various heights and directions or by application of a standard two-meter or higher measurement antenna height with an adjustment factor that accounts for other heights. The direct measurement approach may require more measurement samples but is favored by NTIA because the logistically simpler adjustment factor approach introduces uncertainty and electric utilities generally have access to bucket-trucks ("cherry pickers") needed to safely perform measurements at and above the heights on MV and LV power lines. In the alternative, NTIA's measurement results to date (see Appendix D, §D.5) indicate that electric field strength generated within tens of feet of the power lines at two (2) meters above ground level generally are 3 dB to 15 dB lower than values generated at a height of ten (10) meters (*i.e.*, typically one (1) meter above the height of power lines). This indicates that at heights above a BPL energized power line, a height adjustment factor would be needed to properly estimate the peak field strength based on measurements made at a two (2) meter height. In light of the large range of potentially

[57] *See e.g.*, 47 C.F.R. §15.31(f)(5) and ANSI C63.4-2001, clause 8.3.1.2. When measurements are made at an installation site, ANSI C63.4-2001, clause 8.3.2 requires identification of the radial of maximum emissions.

required adjustment factors and the need for high certainty of compliance in directions where emissions may propagate to radio receivers, the adjustment factor approach necessarily would have substantial bias toward overestimation of field strength.

To minimize the number of measurement samples associated with direct measurement, it appears feasible to apply only a single, high, standard measurement height, combined with a smaller adjustment factor, unless the measurement height coincides with peak field strength. For example, a 10 meter measurement height may be adequate with a small adjustment factor that accounts for higher field strength levels than could occur above the 10 meter height; however, further study is needed to identify the most practical but accurate approach. Measurement at a lower height may be superfluous since higher peak electric fields appear to consistently occur at heights above the power lines. NTIA plans to further address this potential measurement solution in its Phase 2 studies.

7.5 A SINGLE MEASUREMENT DISTANCE SHOULD BE USED FOR OVERHEAD POWER LINES AND BPL DEVICES

Practical and technical considerations dictate that BPL compliance measurements be made in the near-field. NTIA's BPL measurements and NEC radiation models both manifest near-field behavior at large distances (*e.g.*, over 300 meters) in many directions from BPL systems. In many cases, the field strength at large distances in the near-field is at levels too low for reliable measurement. Thus, avoidance of measurement in the near-field is not practicable and the measurement distance must be based on other factors, such as:

- The possible occurrence of local peak field strength levels at distances beyond the measurement distance, where these local peaks are near or exceed the measured peak level. If this were to occur, the BPL emissions may cause interference over an area much larger than implied by the limits and conventional point-source radiation.

- The desire to not make measurements at multiple measurement distances associated with different frequency ranges. Use of two different measurement distances above and below 30 MHz almost doubles the time needed to conduct the measurements.

- The measurements should be made at distances no closer than the minimum typical separation between power lines and radio receiver antennas. Otherwise, measurement uncertainties associated with any extrapolation are unnecessarily incurred.

NTIA's measurements and radiation models, deployment of Federal Government radio receivers, and safety considerations indicate that a measurement distance of

10 meters from any BPL device and its connected power lines satisfies the above conditions. Thus, NTIA recommends that a standard measurement distance of 10 meters be used for BPL compliance measurements.

7.6 A MODIFIED DISTANCE EXTRAPOLATION FACTOR IS NEEDED FOR BPL

NTIA's measurements and radiation models indicate that at distances within several tens of meters of the power lines, BPL field strength does not decrease with increasing distance consistent with the existing Part 15 distance extrapolation factors of 20 dB and 40 dB per decade above and below 30 MHz, respectively. In several cases not deemed to be anomalous, field strength diminishes at a lower rate and NTIA plans in its Phase 2 studies to further investigate this extrapolation factor for outdoor BPL systems.

7.7 BPL FREQUENCY AGILITY AND POWER LINE FREQUENCY SELECTIVE EFFECTS MUST BE ADDRESSED IN THE MEASUREMENT PROCEDURES

Many BPL devices feature frequency agility**,** where the band of frequencies used by each device can be remotely adjusted via network control software.[58] Because the standing waves generated in any given power line depend on the BPL device frequency, it is necessary to perform compliance measurements with the BPL device sequentially tuned across the entire frequency range that it is capable of using. For example, a BPL device that occupies a 3 MHz bandwidth located anywhere in the 4 MHz to 22 MHz frequency range would have to be tuned to five (5) different center frequencies during successive measurements (*e.g.*, 5.5 MHz, 8.5 MHz). The uncertainty in estimating the peak field strength stemming from measurement with the BPL device operating at only one of many possibly frequency settings could exceed tens of decibels.

7.8 NEAR FIELD MEASUREMENT ERRORS MUST BE MITIGATED

At frequencies below 30 MHz, Part 15 measurement procedures dictate the use of loop antennas to estimate electric field strength.[59] Loop antennas inherently respond to magnetic fields and are relatively insensitive to electric fields; yet Part 15 applies to limits on electric field strength. Hence, as noted in several comments in response to the BPL Inquiry, the magnetic field strength measured with a loop antenna must be converted to an estimated electric field strength assuming a certain ratio of electric-to-magnetic field strength. This ratio, which is related to wave impedance, is assumed to be 377Ω.

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[58] Reply Comments of UPLC, BPL Inquiry, August 20, 2003, ("UPLC Reply Comments"), at 7; Ambient Comments at 8; Ameren Comments at 9-10.

[59] *See* 47 C.F.R. §15.31(a)(6) and ANSI C63.4-2001, clauses 4.1.5.1 and 4.1.5.2.

This is a reasonable assumption if not exact in the far field of the radiating structure. However, as noted above, BPL compliance measurements must be made in the near field where the impedance is highly variable and will be substantially higher than 377Ω in many locations.

Loop antennas are used below 30 MHz at OATS in order to avoid effects of reflections that are more vagarious for electric than magnetic fields. In other words, loop antennas yield better repeatability of measurements, but such a goal is readily achievable only in a laboratory or at an OATS (rather than at a BPL installation site). Rather than derive impedance values for various BPL measurement heights, NTIA recommends consideration of BPL compliance testing below 30 MHz using a calibrated rod antenna.

7.9 APPROPRIATE CHOICE OF POWER LINES USED FOR BPL MEASUREMENTS WILL REDUCE STATISTICAL SAMPLING UNCERTAINTIES

One reason Part 15 requires measurement at three or more representative installation sites in cases where OATS are impractical is that there is a significant chance that one such installation site will not manifest the highest field strength levels that will occur in practice. This possibility exists even with three or more measurement sites unless the sites are selected (or established) to yield the highest field strength levels. Measurement venue notwithstanding, CISPR 22 requires use of an adjustment factor accounting for statistical sampling uncertainty.[60] Rather than deal with these adjustment factors, which may lead to significant overestimation of BPL field strength, NTIA recommends that BPL installations be selected (or established) in a manner ensuring that the highest possible levels of BPL field strength will be generated.

Conceptually, testing should be conducted using various lengths of power lines that include substantial impedance discontinuities at various distances from the BPL device that may result in the generation of standing waves that are associated with the highest possible levels of field strength. This is because the distance between the BPL device and the impedance discontinuity affects the distribution of standing waves (and spatial distribution of field strength) at a given frequency. Based on NTIA's measurements and modeling to date, and noting that further study is needed of the effects of power line branches and turns, the following types of test site selection criteria (or standard test facility design factors) are suggested for further consideration and refinement for the case of outdoor, overhead power lines:

- The BPL device should be located near the center of a straight section of power lines at least 600 meters in length that is devoid of significant impedance discontinuities. This ensures that at the lower frequencies (longer wavelengths), at least four standing wave crests can be generated in the straight section of power lines in order to establish a minimally sufficient

[60] *See* CISPR 22, Section 7.2.2. Here, the error from statistical sampling uncertainties is biased in a manner "…which assures with 80% confidence that 80% of the [equipment] type is below the limit."

number of radiating power line sections. Because BPL devices themselves may establish impedance discontinuities, the other BPL devices operating with the BPL DUT should be located beyond the nearest impedance discontinuity.

- If a standard test facility is established and the power lines used for testing are not a segment of operational power lines that extend well beyond the test facility, the lines should be terminated in the characteristic impedance of the power lines as tested. This avoids inadvertent, unrealistic radiation caused by non-typical termination of the power lines.

- A variety of representative MV power line configurations should be present in the test site (or standard BPL test facility). For example, the site should include single and three-phase power line segments, sharp turns in the power line, and risers that connect overhead lines to underground lines.

7.10 BPL DEVICE OUTPUT POWER SHOULD BE REDUCED AS NEEDED FOR COMPLIANCE WITH RADIATED EMISSION LIMITS

The measurements should be initially conducted while the BPL device is operating with maximum power output as required by §15.31(g). This may yield field strength values that exceed the limits, in which case the BPL device output power should be reduced to the extent necessary to obtain compliance with the limits. Because different limits are applied above and below 30 MHz, and because all possible power line configurations are not being measured, at most two different BPL output power levels may be determined for compliance with the limits (*i.e.*, one above and one below 30 MHz).

In the event that an output power reduction is needed to achieve compliance, all measurements must be made at the reduced output level including any measurements preceding discovery of field strength in excess of the limiting value.

7.11 THE RESULTS OF RADIATED EMISSION MEASUREMENTS SHOULD BE PROPERLY RECORDED IN MEASUREMENT REPORTS AND APPLIED IN BPL OPERATIONS

The measurement report should record all measurements including those preceding any BPL output power reductions needed for compliance with the field strength limits. If a power reduction is needed for compliance, the amount of necessary reduction and the means by which it was achieved during testing should be recorded in the measurement report. As a condition for authorization, where BPL output power can be adjusted, the BPL power control software, firmware and hardware should be modified to prevent operation at output power levels higher than those yielding compliance with the field strength limits. In other cases where BPL device output power is not adjustable, inclusion of a fixed attenuator or suitably lower-power output stage should be mandated in the authorization. In no case should BPL operators be equipped to exceed output power levels at which compliance is obtained.

7.12 CONCLUSION

The Phase 1 analyses assumed that for outdoor overhead power lines, compliance measurements were performed using a one-meter high measurement antenna. This ad hoc measurement approach does not demonstrate compliance with the field strength limits because, as shown by NTIA's measurements and models (Section 5), peak field strength levels are not necessarily centered at the BPL device and do not occur at a height of one-meter above the ground. Moreover, all of the receiving antennas assumed in the Phase 1 analyses were located at least two meters above the ground. Other potential sources of measurement underestimation of BPL field strength include: the measurement distance and extrapolation factor; frequency-selective radiation effects; estimation of electric fields using a loop antenna; and selection of representative BPL installations for testing. Solutions to most of these measurement challenges are at hand within existing Part 15 measurement guidelines.

In light of the above considerations and the high perceived interference risks, NTIA recommends that field strength limits for BPL systems not be relaxed and that measurement procedures be refined and clarified as described in this section to better ensure compliance. These risk reductions should be effected as quickly as possible in order to better protect radio communications.