SECTION 9
SUMMARY OF RESULTS

9.1 INTRODUCTION

Section 9.2 summarizes the results of NTIA's preliminary investigations (Sections 2 – 5). These investigations helped refine the scope and approach of NTIA's analyses and established certain technical assumptions. Section 9.3 summarizes the results of NTIA's Phase 1 analyses of interference risks (Section 6), measurement procedures (Section 7) and techniques for prevention and mitigation of interference (Section 8). Section 9.4 summarizes matters requiring further study.

9.2 PRELIMINARY INVESTIGATIONS

9.2.1 Descriptions of BPL Systems

NTIA identified three architectures for access BPL networks (Section 2): (1) BPL systems using different frequencies on medium- and low-voltage power lines for networking within a neighborhood and extensions to users' premises, respectively; (2) BPL use of only medium voltage lines for networking within a neighborhood, with other technologies being used for network extensions to users' premises; and (3) BPL use of the same frequencies on medium- and low-voltage power lines for networking in a neighborhood and extensions to users' premises. Responses of BPL manufacturers and operators to the FCC's BPL NOI generally indicate that BPL systems will operate at or near the Part 15 field strength limits in order to achieve maximum throughput and distance separation between BPL devices. NTIA addressed simple BPL deployment models in the Phase 1 interference risk analyses (Section 6). Specifically, a single BPL device and associated power lines were considered for cases of potential interference to ground-based radio receivers and several co-frequency BPL devices were assumed to be deployed throughout the area covered by an aircraft receiver antenna. For future studies, NTIA developed preliminary BPL deployment models addressing three geographic scales (Appendix F): a "neighborhood" deployment model useful for analyses of interference to radio receivers having antennas at heights lower than power lines; an "antenna coverage area" model useful for consideration of radio antennas atop buildings and towers and on aircraft; and a "regional" deployment model for studies of potential interference via ionospheric signal propagation.

9.2.2 Studies and Relevant Regulations

NTIA reviewed studies performed by other parties and applicable FCC and foreign regulations to ensure that NTIA's studies would address important interference mechanisms and factors as well as potential means for effectively accommodating BPL and radio systems (Section 3). NTIA noted that BPL apparently has been implemented with success in some countries, while other countries have postponed implementation of BPL systems until further interference studies are being conducted. Still others have withdrawn their approval for operation of BPL systems after experiencing interference problems. Several emission limits have been adopted or proposed for evaluation on international, national and regional bases. Most studies have sought to determine whether interference will occur at the variously proposed limits.

In contrast, NTIA has oriented its study to appropriately manage the risk of interference to radio systems.

Technical information and analyses submitted in response to the FCC NOI included several relevant observations. BPL signals unintentionally radiate from power lines, although there is substantial disagreement as to the strength of the emissions and their potential for causing interference to licensed radio services. Analyses indicate that the peak field strength due to unintentional BPL radiation occurs above the physical horizon of power lines. Current ad hoc measurement techniques used in Part 15 compliance tests may significantly underestimate the peak field strength generated by BPL systems as a result of using a loop antenna in the near field; performing measurements with an antenna situated near ground level (*e.g.*, 1 meter); and measuring emissions in the vicinity of BPL devices without also considering emissions from the power lines.

9.2.3 Federal Government Radio Systems and Spectrum Usage

Frequencies between 1.7 MHz and 80 MHz are allocated to a total of 13 radio services, with the Federal Government using most of these radio services to satisfy various mandated mission requirements (Section 4). Federal agencies currently have over 59,000 frequency assignments in this frequency range. Allocations for the fixed and mobile services accommodate communications for homeland security, distress and safety, and other critical functions. These communications occupy over one-half of the frequency range and NTIA chose them as the focus of this Phase 1 study. Characteristics of fixed and mobile equipment largely group into uses below 30 MHz and above 30 MHz and the equipment characteristics show considerable consistency within these two categories.

Both NTIA and FCC have long recognized that certain frequencies or bands in the radio spectrum require special protection from interference because of the critical or sensitive functions they support, including distress and safety, radio astronomy, radionavigation, and others. NTIA identified forty-one (41) such frequency bands between 1.7 MHz and 80 MHz, totaling approximately 4.2 MHz (5.4% of the total spectrum under study), that may warrant special protection from interference by licensed and/or unlicensed transmitters. NTIA will further review the appropriateness of applying geographic BPL restrictions or other special BPL provisions to these and other frequencies that warrant special protection in its Phase 2 study.

9.2.4 Characterization of BPL Emissions

Numerous textbooks explain the electromagnetic theory behind wires serving as transmission lines or antennas. For unshielded wires such as power lines, the magnitude of radiation is largely affected by the degree of balance between radio frequency currents in adjacent wires and the spacing of those wires. Common mode currents (traveling in the same direction) in parallel wires generally produce mode radiation than differential currents (traveling in opposite directions) because for differential currents, the fields generated by each wire tend to cancel if the wires are closely spaced (*e.g.*, twisted pair used for telephone lines). Impedance discontinuities can occur on power lines at transformers, branches and turns, and can produce radiation directly or cause signal reflections in the power lines that produce standing waves and associated radiation along the line. The fields generated by radio frequency currents have different types of spatial distributions in three successively more distant areas around a radiator: the reactive- and radiative-near-field and far-field regions. The distances over which reactive and radiative near-field regions extend increase with the size of the radiator and frequency. In the far field region, which could start several kilometers away from a radiating power line, the radiation patterns are independent of distance and field strength in free space generally decreases in proportion to increasing distance.

The relevant signal propagation modes in the 1.7 – 80 MHz frequency range are ground wave, space wave and sky wave. The ground wave signal can consist of a direct wave, ground reflected wave and/or a surface wave, each of which exhibit a different characteristic relationship between signal loss and distance. The direct wave signal power from a point source (*i.e.*, very small in relation to wavelength) is inversely proportional to the square of the distance and when combined with a strong ground-reflected wave from a radiator several wavelengths above the ground, the composite signal power is inversely proportional to distance to the fourth power. The latter high rate of attenuation does not occur for radiators closer to the ground. A surface wave propagates close to the ground and exhibits substantially higher rates of attenuation than the direct wave. Thus, groundwave propagation is pertinent on BPL signal paths below the power line horizon. Space wave propagation involves only a direct wave and occurs over elevated signal paths, *e.g.*, on signal paths above the power line horizon. Sky wave propagation also occurs above the power line horizon and most consistently at frequencies between 1.7 MHz and 30 MHz. Skywave signal paths are represented as rays that are refracted and reflected by the ionosphere and can extend to distances of thousands of kilometers depending on the signal elevation angle and frequency as well as parameters of the ionosphere that exhibit temporal and spatial variability.

As a part of its study, NTIA modeled an overhead, three-phase Medium Voltage power line using the NEC software program. The far field patterns of the electric field indicate that the number of local peaks in the radiation pattern increase as the ratio of line length to BPL signal wavelength increases. Varying the source and load impedances have a minor effect, although the highest radiation was generally associated with the largest impedance mismatch between source and load. The far field radiation patterns and radiating near-fields at a height of two meters both indicate that BPL signal reflections from impedance discontinuities can generate standing waves that cause radiation from power lines. Along the direction of the power lines, the peak field strength in the far field occurs above the horizontal plane containing the power lines. In the near field, the peak level of the vertical electric field never occurs at the BPL source; instead, multiple local peaks occur near and under the power lines. Similarly, the peak horizontally polarized field in the direction perpendicular to the power lines never occurs at the BPL source; instead, peaks occur at various distances away from the BPL source and power lines. Based on the models considered to date, only in the case of the horizontally polarized electric field in the direction parallel to the power lines does the peak field occur at the BPL device. NTIA's modeling showed that inclusion of a neutral line with three phase medium voltage wiring tended to increase the overall radiation. Thus, models omitting the neutral wire tend to predict lower field strength. These modeling results imply that compliance measurements, taken only around a BPL device and at heights below the power lines, may significantly underestimate the peak electric field.

NTIA performed measurements at three different BPL deployment sites in order to characterize the BPL fundamental emissions. Measurements indicate that the BPL electric field does not generally decay monotonically with distance from the BPL source as the measurement antenna was positioned near to and moving along the length of the power line. As the measurement antenna was moved away from the BPL energized power line, the radiated power decreased with increasing distance, but the decrease was not always monotonic and a number of local peaks were observed at some locations. In some cases, the BPL signal decayed with distance away from the power line at a rate slower than would be predicted by space wave loss from a point source. At one measurement location where a large number of BPL devices were deployed on multiple three-phase and single-phase MV power lines, appreciable BPL signal levels (*i.e.*, at least 5 dB higher than ambient noise) were observed beyond 500 meters from the nearest BPL energized power lines. Finally, NTIA's measurements show that the radiated power from the BPL energized power lines was consistently higher when the measurement antenna was placed at a greater height (*e.g.*, 10 meter vs. 2 meter). These results indicate a need to refine the Part 15 compliance measurement guidelines to ensure that the peak field strength of any unintentional BPL emissions is measured.

9.3 PHASE 1 ANALYSES

9.3.1 Evaluation of Potential Interference Risks

NTIA evaluated interference risks using NEC models for four representative types of federal radio stations operating in the fixed and mobile services (Section 6): a land vehicular radio; shipborne radio; a fixed or mobile-base station with roof top antenna; and an aircraft radio in flight. These risks were gauged from the size of geographic areas in which BPL emissions would reduce the ratio of desired radio signal power to ambient noise power by amounts associated with moderate and high probabilities of interference (*i.e.*, 3 dB and 10 dB reductions in (S/N), respectively). Predicted nationwide, Springtime, median ambient noise power levels were assumed and analyses were performed for frequencies of 4 MHz, 15 MHz, 25 MHz and 40 MHz. Three-phase power lines were modeled as straight American Wire Gauge (AWG) 4/0 copper wires, 340 meters in length, and horizontally spaced by 60 centimeters. No neutral line was included in the model in order to reduce NEC execution time; this benefit was in trade for underestimation of field strength by a few dB (Section 5.4.3). The three phase lines were assumed to be 8.5 meters above ground having typical electrical characteristics. The BPL device was assumed to present a source impedance of 150 Ω, coupled on an outer power line, halfway between the ends of the lines. The lines were terminated with 50 Ω loads to emulate an impedance discontinuity (*e.g.*, transformer) and on-going power lines with additional loads; however, emissions beyond the ends of the lines were not considered because field strength levels may be non-typical and radio receivers would more typically be located adjacent to power lines. The BPL device output was adjusted to produce emissions at the limits of Part 15 for unintentional radiators (Class B above 30 MHz), as generally determined by compliance measurement practices extant with the exception that measurement distances were applied with respect to the BPL device and power lines rather than only the BPL device. This exception generally results in compliance at BPL output power levels lower than output levels that yield compliance when distances are measured from the BPL device. For all of these analyses, the frequencies at which the lowest and highest reductions in S/N occur may change for different power line configurations.

The results for the vehicular mobile receiver predict that the received BPL signal power near the Earth surface falls off rapidly with distance from the lines. For the two frequencies at which the highest BPL signal power levels were received (15 MHz and 25 MHz), signal power from one co-frequency BPL system (one device) equaled noise power (3 dB reduction in S/N) at 50% of the locations within 70 and 75 meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at 50% of locations within 25 and 30 meters of the power lines. The distances within which these thresholds were exceeded at 50% of locations were modestly smaller at a third frequency (4 MHz) and much smaller at the fourth frequency (40 MHz). In all land vehicular cases considered, reductions in S/N were less than 3 dB and 10 dB beyond 125 meters and 55 meters, respectively.

The results for the fixed service (or mobile base station) receiver predict that the received BPL signal power falls off less rapidly with distance from the power lines than occurred for the land vehicle case. For the two frequencies at which the highest BPL signal power levels were received, signal power from one co-frequency BPL system (one device) equaled noise power (3 dB reduction in S/N) at 50% of the locations within 310 and 400 meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at 50% of locations within 175 and 230 meters of the power lines. In all cases, reductions in S/N were less than 3 dB and 10 dB beyond 770 meters and 450 meters, respectively.

The results for the shipborne receiver predict that the received BPL signal power falls off rapidly with distance from the power lines, but less rapidly than for the land vehicle case. For the two frequencies at which the highest BPL signal power levels were received, signal power from one co-frequency BPL system (one device) equaled noise power (3 dB reduction in S/N) at 50% of the locations within 100 meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at 50% of locations within 55 meters of the power lines. In all cases, reductions in S/N were less than 3 dB and 10 dB beyond 135 meters and 85 meters, respectively.

For the aircraft receiver, aggregate interference effects were considered for simultaneously active, co-frequency BPL systems deployed at a density of one per square kilometer over an area having a 10 kilometers radius. The power lines were assumed to be randomly oriented and an average of the power line far-field gain levels were used in each direction under consideration. Aircraft were assumed to be operating at altitudes of 6 to 12 km at locations ranging from 0 to 50 kilometers from the center of the BPL deployment area. Results showed that aggregate interference levels to the aircraft could exceed average ambient RF noise levels at two frequencies (15 MHz and 25 MHz), at distances ranging from 33 kilometers (6 kilometers altitude) to over 50 kilometers (altitudes between 6 and 12 kilometers). The S/N reduction exceeded 10 dB at only one frequency, at 6 kilometers altitude within 12 kilometers of the center of the BPL deployment area. At the two frequencies where the assumed BPL systems produced the lowest interfering signal power levels (*i.e.*, 4 MHz and 40 MHz), S/N reductions peaked at about 0.8 dB and 0.3 dB directly over the center of the BPL deployment area. Higher or lower densities of active co-frequency BPL units would raise or lower the predicted interference levels in direct proportion to the unit density.

9.3.2 Risk Reduction Through Compliance Measurement Procedures

The Phase 1 analyses assumed that for outdoor overhead power lines, compliance measurements were performed using a one-meter high measurement antenna (Section 7). 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 1-meter above the ground. Moreover, all of the receiving antennas assumed in the Phase 1 analyses were located at least 2 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 the FCC not relax field strength limits for BPL systems and that measurement procedures be refined and clarified to better ensure compliance. These recommendations should be effected as quickly as possible in order to better protect radio communications. Specifically, NTIA recommends the following BPL compliance measurement provisions.

(a) Consistent with §15.31(f), (h), (j) and (k), BPL measurements should address the BPL devices and power lines to which they are connected. Measurement reports submitted by contractors hired by BPL proponents to test compliance of trial BPL systems with Part 15 field strength limits showed that measurements were performed on radials emanating from a power line pole to which a BPL access device was mounted.

(b) BPL systems should be tested i*n situ* using the maximum potential frequency reuse in accordance with §15.31(h) and (i).

(c) Measurement antenna heights should address all directions of BPL signal radiation toward potential local radio antennas. NTIA's work to date indicates that a measurement antenna height of the order of the power line height may properly protect radio receivers having antennas at rooftop heights. In any case, measurements must identify the peak level of electric field strength consistent with §15.31(f)(5).

(d) A ten (10) meter measurement distance should be used uniformly with respect to the BPL devices and power lines to which they are connected. A uniform measurement distance will greatly simplify compliance measurements.

(e) A modified distance extrapolation factor should be applied for BPL systems that reflect realistic decay in field strength with increasing distance. The extrapolation factors assumed in Part 15 appear to be unrealistic for BPL systems (40 dB/decade and 20 dB/decade below and above 30 MHz, respectively (§§15.31(f)(1) and (2)). Further study is needed to determine the appropriate extrapolation factors.

(f) Radiated emissions must be measured with the BPL devices operating at all frequencies at which they are capable of operating. This will require sequential tuning and measurements in each abutting frequency band within the tuning range of the BPL devices. Measurement with the BPL devices tuned to each possible operating frequency is required for consistency with §15.31(g).

(g) Measurements below 30 MHz should be made with either a calibrated rod antenna (direct measurement of electric field) or a loop antenna in connection with adjustment factors that properly account for the ratio of BPL near-field electric and magnetic field strengths for vertical, horizontal-parallel, and horizontal-perpendicular polarization. NTIA's work to date indicates that in the near-field of BPL emissions, this ratio may differ significantly from the 377 Ω far-field value assumed in Part 15 for other devices.

(h) Consistent with §15.31(d), power lines used for *in situ* testing of BPL devices should be carefully selected to be representative of deployments that produce the highest levels of field strength. Further study is needed of the power line features that should be included.

(i) In the course of measurements, if it is determined that BPL device output power must be reduced in order to obtain compliance with field strength limits, the measurements preceding this discovery should be included in the measurement report and measurements should be repeated with the lower required output power. As required under §15.15(b), the equipment to be marketed should be constructed to prevent operation at field strength levels exceeding the limiting values.

9.3.3 Techniques for Prevention and Mitigation of Interference

NTIA identified a number of currently employed techniques and other potential means to reduce the interference risks or facilitate mitigation of interference problems (Section 8):

Minimize Power Level. The single most effective method for reducing the potential for interference may be to reduce BPL device output power. Consistent with §15.15(c), BPL system operators are encouraged to use the least power needed to carry out power line communications. The use of adaptive transmitter power control could be used to ensure that the furthest subscriber in the line has an adequate but not excessive conducted signal level.

Avoidance of Locally Used Frequencies. Shifting or notching BPL signal frequencies to avoid interference to local radio receivers may be an effective interference prevention or mitigation technique. More advanced methods would include agile or adaptive filtering in real time, which may be very effective in reducing interference to simplex-mode communications originating in the local environment. These adaptive techniques are not expected to be effective in reducing interference to duplex-mode communications or simplex communications originating outside the local area, where the associated radio transmitter may be tens, hundreds, or even thousands of miles away. NTIA further recommends consideration of excluding BPL use of certain narrow frequency bands, but further study is needed to determine whether these exclusions can be specified on a geographical basis. Generally, BPL systems should not operate in certain frequency bands in order to protect distress, alarm, urgency or safety communications in accordance with ITU Radio Regulations (RR No. 4.22).

Differential-mode Signal Injection. Use of differential-mode injection of the RF signal onto two parallel power lines could potentially reduce radiated BPL emissions in a manner similar to unshielded twin-lead transmission lines used in communications systems. The generally-unbalanced nature of power line pairs will limit the effectiveness of this technique.

Filters and Signal Terminations. The use of filters on the power lines that would absorb, rather than reflect, RF signals at impedance discontinuities or termination points beyond the last subscriber on the line could reduce unnecessary RF emissions from BPL energized power lines. Further, the use of absorbing filters on LV lines to prevent RF signals from entering the premises of non-subscribers may mitigate certain interference problems.

Implementation of a "One Active Device per Frequency and Area" Rule. Several implementations of BPL systems use a technique whereby only one device in a local "cell" is active on the same frequency at any one time. Such techniques would reduce or eliminate the chance of any potential local, ground level aggregate BPL interference effects. However, in order to increase BPL network capacity or decrease network latency in a given area, it may be desirable to operate independent, co-frequency BPL devices on two or three phases of the same run of three-phase power lines. In any case, compliance measurements are to address radiated field strength due to all BPL devices operating co-frequency within the BPL network in accordance with §15.31(k).

Judicious Signal Carrier Choice. Due to the frequency selectivity potentially established by various physical and electrical characteristics of a given section of power line, it is conceptually possible to identify frequency segments within the range 1.7-80 MHz that would allow higher levels of injected signal yet at the same time exhibiting lower radiation levels.

Maintenance of a Single Point of Control. To facilitate rapid resolution of actual cases of interference without third-party intervention, a single point of control should be employed for each BPL service area and a BPL point of contact should be designated to address cases of suspected interference and resolving actual interference.

Web-based Access to Radio License Information. Knowledge of what licensed radio systems may be located in the local environment of a BPL system could assist BPL operators in selecting frequency, power levels, and other technical parameters that minimize interference. NTIA will further investigate which elements, if any, of the federal frequency assignment data base might be made available via a web-based mechanism. The FCC assignment data base already is publicly available.

BPL Installation and Equipment Registration. By registering their current and planned BPL deployment details in a central, publicly accessible data base, BPL operators will have equipped local radio users with information they need to alert the BPL operator of potential interference problems. The database also could assist radio operators in diagnosing cases of suspected interference. NTIA will further study and recommend the BPL deployment parameters that should be included in the registration database.

9.4 TOPICS FOR FURTHER STUDY

(a) The appropriate measurement antenna height and need for a height-adjustment factor should be determined with a goal of identifying the minimum set of measurements that will ensure identification of peak BPL emissions in important directions of radiation.

(b) Measurement distance extrapolation factors reflecting the realistic decay of BPL field strength with increasing distance should be determined.

(c) To enable suitable estimation of electric field strength using a loop antenna below 30 MHz, the appropriate ratio of electric to magnetic field strength should be determined for the recommended ten (10) meter measurement distance and measurement antenna heights.

(d) Quasi-peak to rms conversion factors should be further investigated for BPL systems. This will ensure that the levels due to a radiated BPL signal and noise can be specified in consistent terms for analysis purposes.

(e) Aggregation of emissions from BPL systems via ionospheric propagation and the associated BPL deployment models require further study. This is of concern in the long-term insofar as skyward emissions from many hundreds of BPL systems deployed over a large region might produce significant composite interfering signal levels at a very distant receiver.

(f) The local interference risk reductions obtained from the proposed compliance measurement guidelines (Section 9.3.2 and item (a), above) should be determined to ensure that BPL systems will neither be unnecessarily constrained or pose unacceptably high interference risks.

(g) Possibilities for issuing specific guidance on local Federal Government and other frequency usage should be explored in order to enable interference to be prevented. For example, special current versions of NTIA and FCC frequency assignment databases might be made available via a web site.

(h) Potential new requirements should be identified for more frequent testing of Federal Government radio systems used for backup or emergency purposes in the vicinity of BPL systems.