APPENDIX F
NTIA PHASE 2 STUDY BPL DEPLOYMENT MODELS

F.1 INTRODUCTION

The potential interference from mature large-scale deployments of BPL networks due to signal aggregation and propagation will be addressed in NTIA's Phase 2 study. NTIA's BPL deployment models[1] encompass three scenarios where the effects of aggregated BPL emissions are of interest. Differing mainly in geographic size and the potential interference impact to licensed radio service receivers, these three deployment models are:

- the neighborhood deployment model, in which the radio receiver antennas are at heights lower than the power lines (*e.g.*, a land mobile vehicle antenna);
- the antenna coverage area deployment model where radio receiver antennas are located above power lines (*e.g.*, atop buildings and masts and on aircraft) having a view of one or more neighborhoods; and
- the more expansive regional deployment model, from which BPL signals could arrive at a receiver via ionospheric ("skywave") propagation.

The objective for NTIA's family of BPL deployment models is to define potential physical layouts of BPL systems having various architectures that, when coupled with realistic cross-sections of radiation, propagation and signal aggregation, will aid in predicting the total levels of co-frequency BPL signals at various radio receiver antenna locations. Each model is parametric (*i.e.*, several factors will be varied), recognizing that many factors are variables that may greatly influence the predictions. For example, the geographic densities of emitting elements within the successively larger neighborhood, coverage area and regional geographic domains are expected to be highly influential, and the degree of influence will be determined in sensitivity analyses. At one extreme, we have the present limited deployment of experimental systems. Once BPL services are commercially available, there could be a rapid ramp up in deployment densities in all three geographic domains. In the long term, but at different times in the neighborhood, coverage area and regional domains, the deployment densities will converge on maximum levels. The interference risks in each geographic domain will concurrently increase over time. Variants of the BPL deployment parameters will be based on information filed in response to the BPL NOI as well as NTIA's research.

F.2 NEIGHBORHOOD DEPLOYMENT MODEL

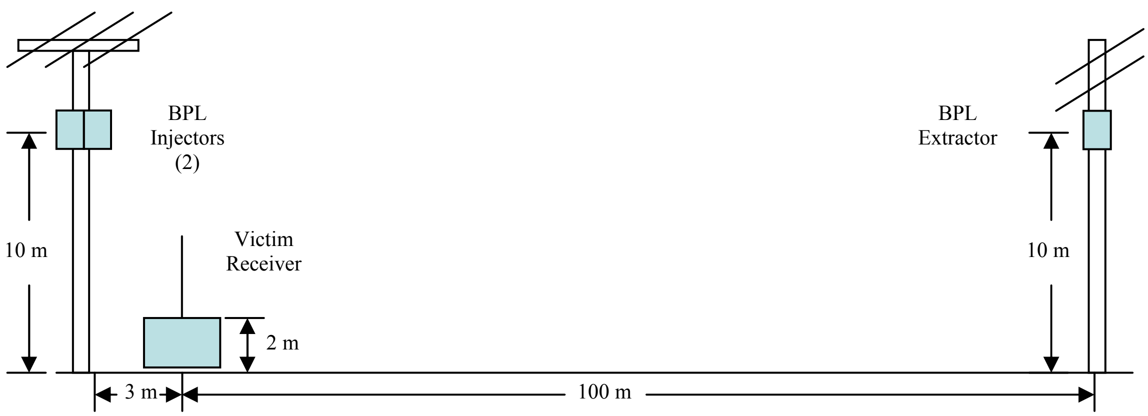
The neighborhood deployment model addresses the case of a land mobile radio operating inside a BPL service area. The land mobile radio may be within 10 meters of the nearest active BPL device and one block away from another simultaneously active,

[1] The deployment models presented herein are preliminary. Comments from BPL proponents and opponents will be considered as the models are finalized and applied in NTIA's Phase 2 study.

co-channel BPL device.[2] An initial analysis is presented in Section 6, assuming the case of a single co-channel BPL device operating under existing Part 15 rules. The worst case which will be considered for the neighborhood deployment model would consist of a land mobile receiver operating in the presence of three co-channel BPL systems, two operating over power lines in close proximity to the receiver and one operating on a power line located one block away from the receiver. Considering the manner in which separate MV power lines are deployed and the coupling between adjacent power lines, it is unlikely that co-channel emissions from more than 3 BPL devices will aggregate significantly at any given land mobile receiver location.

The characteristics for this model are depicted in Figure F.1 and are as follows:

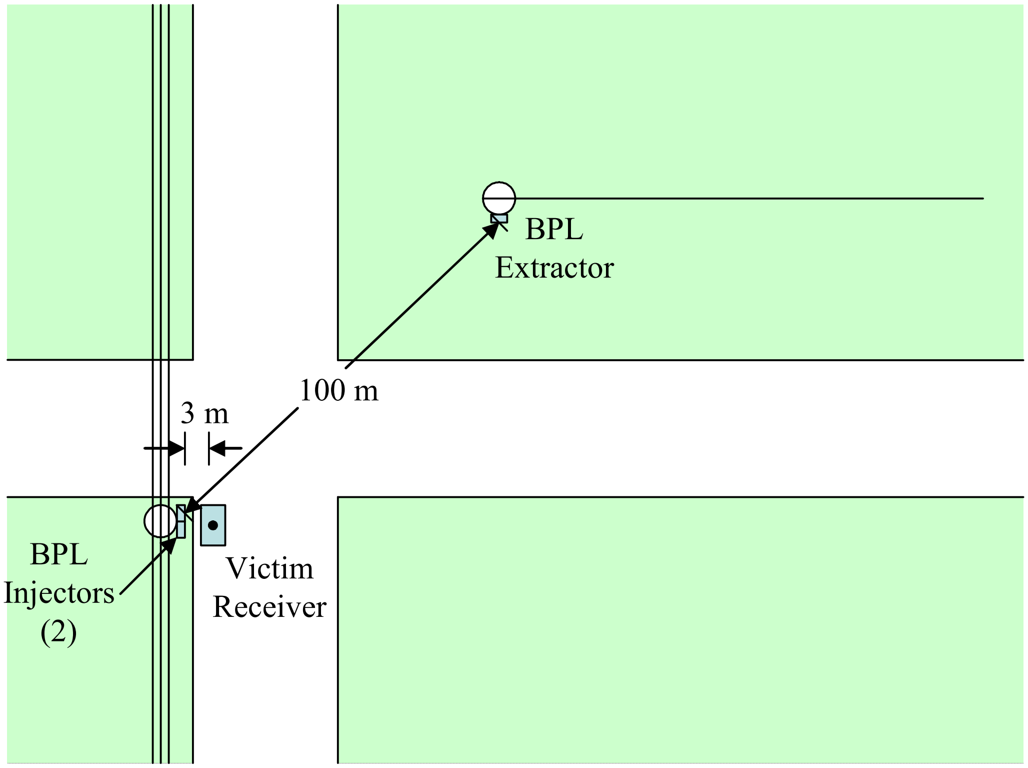
- Victim HF receiver with whip antenna located 2 meters above the ground;
- Two BPL injectors mounted on the same power pole, located no closer than 3 meters lateral to the victim receiver and 10 meters above the ground (location of receiver will be varied);
- A co-channel BPL extractor at 10 meters above the ground, located 100 meters away from the above injectors at a 45° angle. This is consistent with a power line feeding an adjacent street.



(a) Horizontal View

Figure F-1: Assumed Aggregate Neighborhood Deployment Scenario

[2] NTIA personnel have observed and measured signals from two DSSS BPL injectors co-located on a single power pole, isolated by using two different phases of the same run of three phase power lines. Located one block away was a DSSS BPL repeater (extractor) on the third phase line. Even though all three of these devices may be coupled to different, adjacent phase lines of the same MV distribution network serving a community, they would be operating co-channel and may be transmitting at the same time. Later NTIA measured two independent co-channel signals for this case and the composite emission had about twice the power of the individual emissions.



(b) Overhead View

Figure F-1 continued: Assumed Aggregate Neighborhood Deployment Scenario

The transmit duty cycle for the two BPL injectors, T_i, and for the extractor, T_e, are parameters for the model.

The output of the neighborhood deployment model is a probability that three co-channel BPL devices, having the assumed physical orientation relative to the victim receiver as noted above, will be transmitting simultaneously. Using this result along with an emissions model for BPL devices attached to power lines, an analysis will be performed to estimate the percentage of local land mobile vehicle locations where harmful, co-channel interference may occur.

F.3 ANTENNA COVERAGE AREA DEPLOYMENT MODEL

Another case of interest is the mobile-service, aircraft or fixed-service base station receiver operating in close proximity to a fully deployed BPL service area. Receiving antennas for these stations typically can have unobstructed or lightly obstructed views of many more co-channel BPL devices that might affect a land mobile receiver in the neighborhood environment. HF base stations are frequently located in rural areas where the level of man-made noise is expected to be low; however, power lines are present in this environment. Over the years, a number of these remote locations have seen residential areas develop nearby, potentially resulting in an increase in the noise floor seen by the receiver. In some cases, HF stations are located in or near residential communities.[3] Aircraft and fixed stations generally are variously located anywhere.

The coverage area deployment model assumes that the radio station is located within or adjacent to a BPL service area and that the radio antenna has variously obstructed and unobstructed views of the BPL service area. The characteristics of the BPL deployment are described in the following section on the regional deployment model, the main difference being the size of the BPL deployment area being considered. A single county with a predominately suburban population density will be used to arrive at the density of BPL devices in the coverage area deployment model. In addition, the coverage area model assumes that the entire county is covered by the BPL service. This is a reasonable assumption since the housing density will be sufficiently high to provide good incentive for the electrical utility to make this service widely available to all its electricity customers.

The output of the coverage area deployment model will be a density of BPL devices and their locations relative to the radio station. As will be further described in the regional deployment model, the BPL service area will be composed of cells operating on the same or different frequency bands with variable frequency reuse patterns. This will be used to develop a model of aggregated emissions from the BPL service area as seen by the radio receiver.

F.4 REGIONAL DEPLOYMENT MODEL

In order to assess the aggregated electrical field strength arising from future, wide-scale deployments of BPL systems, a regional deployment model for BPL networks is proposed herein. The model characterizes the number and distribution of active BPL devices across the entire United States. Among other things, the results of this model will be used to characterize the effect BPL systems have on distant federal communication systems due to any increase in background noise level as a result of ionospheric propagation of unintentional BPL radiated emissions. This will also help address concerns that other countries may have with deployment of BPL systems in the United States.

The approach taken in developing the regional BPL deployment model is to:

- characterize the number and distribution of households served by the nation's electrical power distribution network based on U.S. Census Bureau data;
- estimate the number of BPL devices based on the density of households and the BPL device capacities and range, as provided by the BPL proponents in their NOI comments and reply comments;
- factor in the characteristics of the various BPL signals such as frequency ranges used, bandwidths, network access mechanisms, and frequency reuse; and

[3] Comments of the Federal Emergency Management Agency on Broadband Over Power Line Implementation, BPL Inquiry, December 4, 2003 at ¶10.

- estimate the percentage of these households that will end up being served by BPL service providers (i.e., market penetration), based on subscriber growth rates of competing technologies, such as cable and DSL.

F.4.1 Regional Deployment Model Description

As of 2000, there were 105.5 million occupied households in the United States,[4] and over the past 10 years, the number of households has been growing at an annual rate of approximately 1.4%.[5] The U.S. Census data provides the number of households (H_{cty}) and the area (A_{cty}) for each of the 3,142 counties and independent cities in the United States, with a breakdown by urban and rural classifications. The housing density within individual counties may vary widely, with a mix of urban, suburban, and rural areas. An individual county may also have large, unpopulated areas where no MV lines are present.

In Phase 1 of the NTIA study, development of the regional deployment model focuses initially on urban area deployment of BPL. Here, the housing densities are sufficient to support a large number of MV power lines in a given area, and access to the Internet backbone is widely available. Closely spaced BPL network cells, and cells sharing the same geographic location but separated by power line phase, will be considered in estimating the extent of frequency reuse in urban areas. The regional deployment model will be expanded in NTIA's Phase 2 studies to include the rural BPL environment, where the wide variability of rural housing density, MV power line density, and the availability of access to the Internet backbone will be considered.

The regional deployment model makes some simplifying assumptions to reduce data base and computational complexities and a number of the model's characteristics have been parameterized to enable sensitivity analysis of those characteristics.

F.4.2 Density and Distribution of Households

The average housing density (ρH) for each county is then given by

$$\rho H_{cty,u} = H_{cty,u} / A_{cty,u} \qquad \text{urban households / sq. km.} \qquad \text{(F.1)}$$

To account for the growth in the number of households over "y" years, the urban housing densities will be scaled by a factor of $(1+ \text{rate})^y$.

[4] County and City Data Book: 2000, U.S. Census Bureau, Table B-3.

[5] Meyers Group Report on Household Growth, by Bryan Glasshagel, http://www.meyersgroup.com/analysisobjects/householdgrowth.asp?ProductCategory=NHMR.

F.4.3 Density and Distribution of BPL Devices

The regional deployment model estimates the number of BPL devices for the urban areas of each county.

F.4.3.1 Injectors

Within urban areas, where there are a substantial number of power line branches and distribution transformers, the range of BPL injectors without requiring repeaters, "r_u", is expected to be up to ½ to 1 kilometer (¼ to ½ mi).[6] Thus, the number of injectors is given by

$$I_{cty,u} = A_{cty,u} / r_u^2 \qquad \text{urban injectors} \qquad (F.2)$$

F.4.3.2 Repeaters

The transmission ranges of BPL repeaters are expected to be the same as those for injectors. Like injectors in adjacent BPL cells, repeaters are generally expected to transmit using different frequencies to minimize the levels of co-channel interference. In addition, repeaters have two BPL transmitters, whereas injectors have only one BPL transmitter. BPL service providers may vary the size of each cell to account for the availability of fiber or T1 access to the Internet backbone.

From the standpoint of maximizing the utilization of the available bandwidth, it is more advantageous for BPL service providers to deploy injectors instead of repeaters wherever possible. In urban areas where there is ready access to the Internet backbone, the number of repeaters in a given area is assumed to be negligible as compared to the injector quantity for the area under consideration.

F.4.3.3 Extractors

BPL extractors (also referred to as repeaters in System #3) are typically located at each LV transformer. The parameter "x" defines the number of households per distribution transformer and ranges from 3 – 8 households per LV distribution transformer.[7] The resulting quantity of extractors is

$$EX_{cty,u} = H_{cty,u} / x \qquad \text{urban extractors} \qquad (F.3)$$

For System #2, a WiFi™ (or other non-BPL) interface to the subscribers' homes is used instead of the wired BPL interface implemented in the other system architectures.

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[6] Reply Comments of PowerComm Systems, Inc., BPL Inquiry, August 20, 2003, ("PowerComm Reply Comments") at 16; Comments of Ambient Corporation, BPL Inquiry, July 7, 2003 at 5.

[7] Comments of Current Technologies, LLC, BPL Inquiry, July 7, 2003, ("Current Technologies Comments") at 4, 6.

Therefore, the extractors for System #2 have only one BPL transmitter associated with them.

F.4.4 Other Factors

F.4.4.1 Frequency Range

In comments responding to the NOI, the BPL vendors and service providers stated widely varied frequency ranges that they propose using for BPL service.[8] The frequency range assumed for the regional deployment model is 1.7 – 80 MHz, although BPL devices will not be uniformly distributed in frequency (another variable in the models).

F.4.4.2 Frequency Reuse

In order to minimize signal degradation associated with co-channel interference, System #2 uses different frequency bands for upstream and downstream communications, and for adjacent BPL devices. Communication with the subscribers' homes is not accomplished using BPL. System #1 uses one frequency band for all access BPL devices and in-house BPL devices use another band. System #3 uses the same frequency band for all devices. Assuming that an injector serves one BPL cell, the number of frequency bands used in a cell is shown in Table F.1.

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[8] Comments of Ameren Energy Communications, Inc., BPL Inquiry, July 7, 2003 at 12; Comments of Amperion, Inc., BPL Inquiry, July 7, 2003 at 4; Current Technologies Comments at 17; Comments of Electric Broadband, BPL Inquiry, July 7, 2003 at 4; Comments of Main.net Communications, Ltd., BPL Inquiry, July 7, 2003 at 4; PowerComm Reply Comments at 4; Comments of PowerWAN, Inc., BPL Inquiry, July 3, 2003 at 1; Comments of Progress Energy, Inc., BPL Inquiry, July 7, 2003 at 2.

Table F-1: BPL Frequency Bands per Cell

Architecture	Number of Bands
System #1	2 (1 Access + 1 In-House)
System #2	2 (Access)
System #3	1 (Access & In-House)

In the regional deployment model, System #1 is assumed to reuse the same two frequency bands for each injector and its associated extractors. The model will scale the number of simultaneously active System #1 BPL devices in an area by a factor of ½.

In an urban environment, System #2 is expected to utilize separate frequencies for the injectors in adjacent cells. A minimum of 3 cells is required to implement frequency reuse in a cellular transmission architecture.[9] Assuming that the frequency range used for BPL services is 1.7 – 80 MHz, an urban deployment of System #2 devices (2 simultaneous Access transmissions per cell) would result in a maximum duplex bandwidth of approximately 26 MHz per cell (i.e., 78 MHz ÷ 3 cells). The regional deployment model will scale the number of simultaneously active System #2 BPL devices by a factor of 1/(2*3) = 1/6.

System #3 is assumed to reuse the same frequency band for every cell; therefore, the regional deployment model will assume simultaneously active System #3 BPL devices with no scaling.

A final point about frequency reuse is that with 3-phase MV power lines, three co-channel cells could share the same geographic location, assuming they can tolerate any coupling that occurs between the conductors of each phase.

F.4.4.3 Media Access

Based on BPL vendor comments, the media access protocols for their systems permit transmission by only one device at a time per cell in a given frequency band.[10] For System #1, one access BPL device and one in-house BPL device are active at a time. For System #2, one BPL injector and one BPL extractor may be transmitting at a time within a cell, with each transmission using separate frequency bands. For System #3, one BPL device (injector or extractor) will normally be transmitting at a time; however, it

[9] Mobile Cellular Communication Systems, William C. Y. Lee, McGraw-Hill Book Company, 1989 at 52 – 53.

[10] Reply Comments of Ameren Energy Communications Inc., BPL Inquiry, Aug 20, 2003 at 13; Current Technologies Comments at 15; Reply Comments of Current Technologies, LLC, BPL Inquiry, Aug 20, 2003 at 12; Reply Comments of Main.net Communications LTD., BPL Inquiry, August 20, 2003 at 3.

appears that the media access mechanism is CSMA-CD and there is potential for multiple simultaneous co-channel transmissions in the same cell, especially during peak use periods.

F.4.4.4 BPL Market Penetration

There are currently almost 20 million households in the United States with a broadband connection to the Internet. Of these, approximately 6.5 million are xDSL customers and 12 million are cable customers. The growth rate for these services this past year is approximately 2.5 million customers per year for xDSL and 4 million customers per year for cable.[11]

The regional deployment model assumes an insignificant number of BPL customers in 2003, and an initially linear growth rate parameter that has a range of 2 to 4 million households per year. In addition to the growth of the overall BPL market, the model assumes an equal market share for each of the three types of BPL systems described above. The percentage of market share for each type of BPL system will be used to scale the number of BPL devices (injectors, repeaters, extractors) simultaneously using individual frequency bands throughout the United States.

F.4.5 Regional Model Output

The output of the regional deployment model is the expected number and distribution of BPL transmission sources, and the number of simultaneous frequencies in use, based on the expected overall BPL market share over a specified number of years. In NTIA's Phase 2 studies, these results will be used in conjunction with a HF skywave propagation model to determine the increase in noise floor resulting from wide-scale deployment of BPL systems.

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[11] FCC News, *Federal Communications Commission Releases Data On High-Speed Services For Internet Access*, June 10, 2003, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-235274A1.doc.