NTIA Report 04-413

POTENTIAL INTERFERENCE FROM BROADBAND OVER POWER LINE (BPL) SYSTEMS TO FEDERAL GOVERNMENT RADIOCOMMUNICATIONS AT 1.7 - 80 MHz

Phase 1 Study

VOLUME I

technical report

U.S. DEPARTMENT OF COMMERCE ● National Telecommunications and Information Administration

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Phase 1 Study

VOLUME I

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PREFACE

This Report contains two Volumes. Volume I presents the main text and Volume II contains appendixes that provide additional detail and backup information that is fully summarized in Volume I.

EXECUTIVE SUMMARY

On April 23, 2003, the Federal Communications Commission (Commission or FCC) adopted a Notice of Inquiry (NOI) seeking information on potential interference from Broadband over Power Line (BPL) systems and associated changes that may be needed to accommodate BPL systems in Part 15 of the Commission's rules.[1] As described in the NOI, "access" BPL systems transmit Internet and other data at radio frequencies over neighborhood power lines and use electrical outlets in BPL users' premises as data ports for computers and other devices. "In-house" BPL systems use indoor wiring for networking within the user's premises.

In its response to the NOI, the National Telecommunications and Information Administration (NTIA) described Federal Government usage of the 1.7-80 MHz frequency range, identified associated interference concerns, and outlined the studies it planned to conduct to address those concerns.[2] NTIA reviewed relevant studies and regulations in order to help refine the scope and priorities for its studies. NTIA parsed its planned studies into two time phases, first addressing technical issues of the most immediate importance. As reported herein, Phase 1 defines interference risks to radio reception in the immediate vicinity of overhead power lines used by "access" BPL systems. It also suggests means for reducing these risks and identifies techniques for mitigating local interference should it occur. Phase 2 of NTIA's studies will evaluate the effectiveness of NTIA's Phase 1 recommendations and address potential interference via ionospheric propagation of BPL emissions from mature large-scale deployments of BPL networks.

NTIA reviewed the comments submitted in response to the NOI in order to characterize existing and potential future BPL systems and deployments. Simple BPL deployment models were addressed in the Phase 1 interference risk analyses. NTIA also developed more sophisticated deployment models for use in future studies.

NTIA summarized technical and operating parameters of over fifty-nine-thousand (59,000) Federal Government frequency assignments in the 1.7-80 MHz frequency range. This information may help operators of BPL systems in development of BPL frequency plans. NTIA then defined representative radio systems for consideration in interference analyses: (1) a land vehicular receiver; (2) a shipborne receiver; (3) a receiver using a rooftop antenna (e.g., a base or fixed-service station); and (4) an aircraft receiver in flight. Federal communications require exceptional protection on frequencies amounting to about 5.4% of the 1.7-80 MHz frequency range. NTIA will address the associated protection requirements in on-going studies.

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[1] *Inquiry Regarding Carrier Current Systems, including Broadband over Power Line Systems*, Notice of Inquiry, ET Docket No. 03-104, April 28, 2003 ("BPL Inquiry").

[2] Comments of the National Telecommunications and Information Administration, BPL Inquiry, August 13, 2003.

NTIA executed three two-week measurement campaigns and used Numerical Electromagnetic Code (NEC) software to characterize BPL signal radiation and propagation. These efforts revealed that BPL systems generate the highest electric field strength near the BPL device for horizontal-parallel polarized signals. However, these systems generate peak vertically-polarized field strength under and adjacent to the power lines and at impedance discontinuities at substantial distances from the BPL device. BPL systems generate peak field strength having horizontal-perpendicular polarization at small distances (e.g., less than 30 meters) from both the BPL device and power lines. Thus, measurements intending to demonstrate compliance with the Part 15 field strength limits should not focus solely on the BPL device.

Using NEC, NTIA evaluated interference risks in terms of the geographic extent of locations where interference may occur to radio reception at four frequencies used by outdoor, overhead BPL systems conforming to existing Part 15 rules. Interference to land vehicle, boat, and fixed stations receiving moderate-to-strong radio signals is likely in areas extending to 30 meters, 55 meters, and 230 meters, respectively, from one BPL device and the power lines to which it is connected. With low-to-moderate desired signal levels, interference is likely at these receivers within areas extending to 75 meters, 100 meters and 460 meters from the power lines. Assuming that co-frequency BPL devices are deployed at a density of one per km^2 within a circular area of 10 km radius, interference to aircraft reception of moderate-to-strong radio signals is likely to occur below 6 km altitude within 12 km of the center of the BPL deployment. Interference likely would occur to aircraft reception of weak-to-moderate radio signals within 40 km of the center of the BPL deployment area. However, at two of the four BPL frequencies considered with the assumed power lines, NTIA predicted smaller areas over which interference is likely.

Critical review of the assumptions underlying these analyses revealed that application of existing Part 15 compliance measurement procedures for BPL systems results in a significant underestimation of peak field strength. Underestimation of the actual peak field strength is the leading contributor to high interference risks. As applied in current practice to BPL systems, Part 15 measurement guidelines do not address unique physical and electromagnetic characteristics of BPL radiated emissions. Refining compliance measurement procedures for BPL systems will not impede implementation of BPL technology because BPL networks reportedly can be successfully implemented under existing field strength limits.[3] Accordingly, NTIA does not recommend that the FCC relax Part 15 field strength limits for BPL systems. Further based on studies to date, NTIA recommends several “access” BPL compliance measurement provisions that derive from existing Part 15 measurement guidelines. Among these are requirements to: use measurement antenna heights near the height of power lines; measure at a uniform distance of ten (10) meters from the BPL device and power lines; and measure using a calibrated rod antenna or a loop antenna in connection with appropriate factors relating magnetic and electric field strength levels at frequencies below 30 MHz.

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[3] Comments of PowerWAN, Inc., BPL Inquiry, July 3, 2003 at 8-9; Comments of Amperion, Inc., BPL Inquiry, July 7, 2003 at ¶4.8; Reply Comments of PowerComm Systems, Inc., BPL Inquiry, August 20, 2003 at ¶40.

NTIA suggested several means by which BPL interference can be prevented or eliminated should it occur. Mandatory registration of certain parameters of planned and deployed BPL systems would enable radio operators to advise BPL operators of anticipated interference problems and suspected actual interference; thus, registration could substantially facilitate prevention and mitigation of interference. BPL devices should be capable of frequency agility (notching and/or retuning) and power reduction for elimination of interference. NTIA further recommends that BPL developers consider several interference prevention and mitigation measures, including: routine use of the minimum output power needed from each BPL device; avoidance of locally used radio frequencies; differential-mode signal injection oriented to minimize radiation; use of filters and terminations to extinguish BPL signals on power lines where they are not needed; and judicious choice of BPL signal frequencies to decrease radiation.

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GLOSSARY

AC	Alternating Current
ACA	Australian Communications Authority
AERO-SAR	Aeronautical Search and Rescue
ALE	Automatic Link Establishment
AM	Amplitude Modulation
ANSI	American National Standards Institute
APD	Amplitude Probability Distribution
ARRL	Amateur Radio Relay League
AWG	American Wire Gauge
BBC	British Broadcasting Corporation
BBG	Broadcasting Board of Governors
BPL	Broadband over Power Line(s)
BW	Bandwidth
CA	Collision Avoidance
CB	Citizens Band
CCS	Carrier Current System
CD	Collision Detection
CEPT	European Conference of Postal and Telecommunications Administrations
CISPR	International Special Committee on Radio Interference
CONUS	Continental United States
COTHEN	Customs Over The Horizon Enforcement Network
CSMA	Carrier Sense Multiple Access
CW	Carrier Wave
dB	Decibel
dBi	Decibel referenced to an isotropic radiator
dBm	Decibel referenced to 1 milliWatt
dBW	Decibels above 1 Watt
DHS	Department of Homeland Security
DOA	Department of Agriculture
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOJ	Department of Justice
DRM	Digital Radio Mondiale
DSC	Digital Selective Calling
DSL	Digital Subscriber Line
DSSS	Direct Sequence Spread Spectrum
DUT	Device Under Test
E	Electric
EBU	European Broadcasting Union
ECC	Electronics Communications Committee
EFIE	Electric Field Integral Equation

EM	Electromagnetic
EMC	Electromagnetic Compatibility
EN	European Norm (Standard)
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FICORA	Finnish Communications Regulatory Authority
FM	Frequency Modulation
FNRCS	FEMA National Radio Communication System
ft	Feet
GHz	Gigahertz
GMDSS	Global Maritime Distress and Safety System
GMF	Government Master File
GPS	Global Positioning System
GRWAVE	Ground Wave Propagation Program
H	Magnetic
HF	High Frequency
HPA	HomePlug Powerline Alliance
Hz	Hertz
I	Interference Power
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
ILS	Instrumentation Landing System
IMO	International Maritime Organization
IRAC	Interdepartment Radio Advisory Committee
ITS	Institute for Telecommunication Sciences
ITU	International Telecommunications Union
ITU-R	International Telecommunication Union Radiocommunication Sector
ITU-T	International Telecommunication Union Telecommunication Standardization Sector
JARL	Japan Amateur Radio League
kHz	Kilohertz
km	Kilometer
LAN	Local Area Network
LF	Low Frequency
LORAN	Long Range Aid to Navigation
LV	Low Voltage
m	Meter
MARS	Military Affiliate Radio System
Mbps	Megabits per second
MF	Medium Frequency
MFIE	Magnetic Field Integral Equation
MHz	Megahertz
MPHPT	Ministry of Public Management Home Affaires, Post and Telecommunications of Japan

MPT	Ministry of Posts and Telecommunications
mS	Siemens/meter
ms	Millisecond
MSI-HF	Marine Safety Information – High Frequency
MV	Medium Voltage
MWARA	Major World Air Route Areas
N	Noise Power
NATO	North Atlantic Treaty Organization
NB30	Usage Provision 30
NBDP-COM	Narrow-Band Direct Printing - Communications
NEC	Numerical Electromagnetics Code
NIST	National Institute of Standards and Technology
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rulemaking
NRCS	National Radio Communication System
NSEP	National Security Emergency Preparedness
NTIA	National Telecommunications and Information Administration
OATS	Open Air Test Site
OFCOM	Swiss Federal Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OR	Off-Route
OTH	Over the Horizon
PLC	Power Line Communications
PLT	Power Line Telecommunications
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
R	Route
RA	Radio Communications Agency of UK
RAM	Random Access Memory
RBW	Resolution Bandwidth
RDARA	Regional and Domestic Air Route Areas
RF	Radio Frequency
rms	Root Mean Square
RR	Radio Regulations
RSGB	Radio Society of Great Britain
RSMS	Radio Spectrum Measurement System
RTP-COM	Radio Telephony - Communications
S/N	Signal-to-Noise Ratio
SF&TS	Standard Frequency and Time Signal
SHARES	Shared Resources network
SINAD	Signal to Interference and Noise Ratio
SINCGARS	Single-Channel Ground and Airborne Radio System
SNR	Signal-to-Noise Ratio
SOLAS	Safety of Life at Sea
SSB	Single Sideband
TEM	Transverse Electromagnetic Mode

TV	Television
TVA	Tennessee Valley Authority
UHF	Ultra High Frequency
UK	United Kingdom
US&P	United States and Possessions
USCG	United States Coast Guard
USGS	United States Geological Survey
UTC	Coordinated Universal Time
VDSL	Very high-speed Digital Subscriber Line
VHF	Very High Frequency
VOA	Voice of America
VOACAP	Voice of America Coverage Analysis Program
VOLMET	Meteorological Information for Aircraft in Flight
WiFi	Wireless Fidelity
xDSL	Various types of Digital Subscriber Lines
μA	Microampere
μV	Microvolt

SECTION 1
INTRODUCTION

1.1 BACKGROUND

On April 23, 2003, the Federal Communications Commission (Commission or FCC) adopted a Notice of Inquiry (NOI) seeking information on several aspects of Broadband over Power Line (BPL) systems as well as associated changes that may be needed to accommodate BPL systems in Part 15 of the Commission's rules.[1] The NOI described "access" BPL systems as a backbone network of devices that use low and medium voltage electrical power lines for transmission of broadband data to, from, and within the geographic area of BPL network users.[2] "In-house" BPL systems were described as using low voltage wiring and electric power outlets for networking within the user's premises, and for connecting end-user devices to the access BPL network. Because BPL systems unintentionally radiate emissions at radio frequencies, the NOI focused several questions on Part 15 provisions that control the risk of interference to radio reception. In its comments to the Commission, the National Telecommunications and Information Administration (NTIA) summarized Federal Government usage of the 1.7-80 MHz frequencies of prime interest to BPL developers, identified associated interference concerns, and outlined the studies it planned to conduct to address those concerns.[3]

Over five-thousand comments and replies were filed with the Commission in response to the NOI. These comments provided substantial technical details of BPL system design and operating features as well as analyses of potential interference and the underlying factors that may cause interference. Working independently of, but in coordination with the Commission's Office of Engineering and Technology (OET), NTIA designed its study approach to add substantially to the information filed in response to the NOI. Considerations and findings of Phase 1 of NTIA's study are reported herein. Phase 2 of NTIA's study will evaluate potential interference from mature deployments of BPL systems via ionosperic signal propagation and further assess risks of local interference under various candidate BPL rules, including rules suggested in NTIA's Phase 1 study.

1.2 OBJECTIVES

The objectives of this technical study are to define interference risks from operation of BPL systems under field strength limits and associated compliance measurement procedures specified in Part 15 of the Commissions rules, identify interference risk mitigation techniques

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[1] *Inquiry Regarding Carrier Current Systems, including Broadband over Power Line Systems*, Notice of Inquiry, ET Docket No. 03-104, April 28, 2003 ("BPL Inquiry").

[2] The Commission further expanded the definition of access BPL to include high voltage electrical power lines carrying greater than 40,000 Volts. *See Amendment of Part 15 regarding new requirements and measurement guidelines for Access Broadband over Power Line Systems,* Notice of Proposed Rule Making, ET Docket No. 04-37, February 23, 2004 ("BPL NPRM"), at ¶32.

[3] Comments of the National Telecommunications and Information Administration, BPL Inquiry, August 13, 2003.

that may be employed by BPL manufacturers and system operators and, if appropriate, recommend modifications to Part 15 provisions that will reduce the interference risks.

1.3 APPROACH

Phase 1 of NTIA's study addresses issues deemed most important to formulation of a regulatory framework that would limit risks of local interference from outdoor elements of BPL systems. NTIA reviewed publications and comments submitted in response to the FCC NOI to characterize existing and potential future BPL systems and deployments (Section 2). NTIA also reviewed relevant domestic and foreign studies and regulations to help refine NTIA's analysis approach and to prevent unneeded redundancy (Section 3). Technical and operating parameters of potentially affected Federal Government radiocommunications systems were compiled and representative systems were identified for consideration in the analyses (Section 4). NTIA analyzed BPL signal radiation and propagation and summarized key findings from NTIA's measurement and computer modeling efforts to date (Section 5). The report discusses environmental Radio Frequency (RF) noise levels insofar as ambient noise is an important factor in the evaluation of interference. Recognizing these considerations and assuming that BPL systems comply with existing Part 15 provisions, NTIA evaluated the risks of interference to representative Federal Government systems (Section 6). NTIA then developed recommendations for clarification and modification of existing Part 15 compliance measurement procedures to reduce the potential for underestimating the peak field strength (Section 7). NTIA identified techniques for preventing and mitigating BPL interference (Section 8). NTIA applied the results of these studies in recommendations regarding the Part 15 field strength limits and compliance measurements relevant to BPL systems, identified areas where further investigation by BPL proponents may lead to means for reducing interference risks and facilitating rapid elimination of interference, and outlined the focal points for NTIA's Phase 2 studies (Section 9).

1.4 SCOPE

This study considers BPL systems utilizing fundamental frequencies in the 1.7 - 80 MHz frequency range.[4] In this Phase 1 study, NTIA defines risks of interference from BPL systems to local radio reception assuming BPL systems comply with existing Part 15 field strength limits and compliance measurement procedures. Issues not addressed in Phase 1 include the following:

- Regulatory framework, including the suitability of Part 15 for accommodation of BPL.
- Aggregation of interfering signals from BPL systems via ionospheric propagation. This is of concern insofar as skyward emissions from hundreds of co-frequency BPL systems deployed over a large area theoretically could produce a significant composite interfering signal level at a very distant receiver. This phenomenon would not be possible until BPL technology is widely deployed.

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[4] The BPL Inquiry identified the 1.7-80 MHz frequency range to be of principal interest for BPL operations. BPL Inquiry at ¶15.

- Potential BPL emissions at frequencies other than the fundamental frequencies employed by the BPL system. In other words, BPL out-of-band emissions and intermodulation products were not a focal point.

- Radio systems typically used by non-federal entities, except to the extent that their technical and operating parameters are similar to those of Federal Government systems.

- BPL transmission over indoor low voltage wiring, noting that this is a focal point of the Commission's studies.[5]

- Potential interference or damage to BPL systems from local radio transmissions.

NTIA's Phase 2 study will assess the interference risks due to aggregation and ionospheric propagation of interfering signals from BPL systems. NTIA has developed BPL deployment models in the Phase 1 study to support the analysis of BPL signal aggregation and propagation (Appendix F); however, these models will be refined and applied in the Phase 2 Study. In its Phase 2 study, NTIA will also evaluate the effectiveness of proposed Part 15 measurement refinements and provide additional clarifications as appropriate.

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[5] Comments of the Office of Engineering and Technology (*Initial results of FCC tests related to in-house Power Line Communications (PLC))*, BPL Inquiry, September 16, 2003.

SECTION 2
TECHNICAL DESCRIPTION OF BPL SYSTEMS

2.1 INTRODUCTION

Access BPL equipment consists of injectors (also known as concentrators), repeaters, and extractors. BPL injectors are tied to the Internet backbone via fiber or T1 lines and interface to the Medium Voltage (MV) power lines feeding the BPL service area.[6] MV power lines may be overhead on utility poles or underground in buried conduit. Overhead wiring is attached to utility poles that are typically 10 meters above the ground. Three phase wiring generally comprises an MV distribution circuit running from a substation, and these wires may be physically oriented on the utility pole in a number of configurations (*e.g.*, horizontal, vertical, or triangular). This physical orientation may change from one pole to the next. One or more phase lines may branch out from the three phase lines to serve a number of customers. A grounded neutral conductor is generally located below the phase conductors and runs between distribution transformers that provide Low Voltage (LV) electric power for customer use. In theory, BPL signals may be injected onto MV power lines between two phase conductors, between a phase conductor and the neutral conductor, or onto a single phase or neutral conductor.

Extractors provide the interface between the MV power lines carrying BPL signals and the households within the service area. BPL extractors are usually located at each LV distribution transformer feeding a group of homes. Some extractors boost BPL signal strength sufficiently to allow transmission through LV transformers and others relay the BPL signal around the transformers via couplers on the proximate MV and LV power lines. Other kinds of extractors interface with non-BPL devices (*e.g.*, WiFi™) that extend the BPL network to the customers' premises.

For long runs of MV power lines, signal attenuation or distortion through the power line may lead BPL service providers to employ repeaters to maintain the required BPL signal strength and fidelity. Figure 2-1 illustrates the basic BPL system, which can be deployed in cell-like fashion over a large area served by existing MV power lines.

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[6] MV lines, typically carrying 1,000 to 40,000 volts, bring power from an electrical substation to a residential neighborhood. Low Voltage distribution transformers step down the line voltage to 220/110 volts for residential use. *See* BPL Inquiry at ¶ 13.

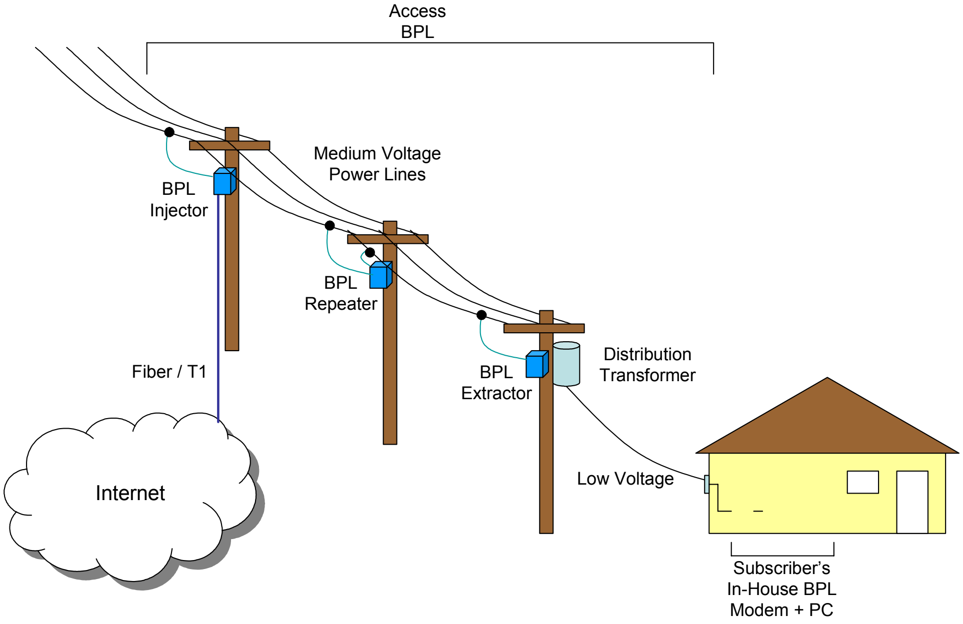

Figure 2-1: Basic BPL System

2.2 BPL System Architectures

NTIA identified three different network architectures used by BPL equipment vendors. These architectures are described below.

2.2.1 System #1

System #1 (see Figure 2-2) employs Orthogonal Frequency Division Multiplexing (OFDM) to distribute the BPL signal over a wide bandwidth using many narrow-band sub-carriers. At the BPL injector, data from the Internet backbone is converted into the OFDM signal format and is then coupled onto one phase of the MV power line. An injector also converts BPL signals on the MV power lines to the format used at the Internet backbone connection. The two-way data are transferred to and from the LV lines, each feeding a cluster of homes, using BPL extractors to bypass the LV distribution transformers. The extractor routes data and converts between access and in-house BPL signal formats. The subscribers access this BPL signal using in-house BPL devices. To span large distances between a BPL injector and the extractors it serves, repeaters may be employed.

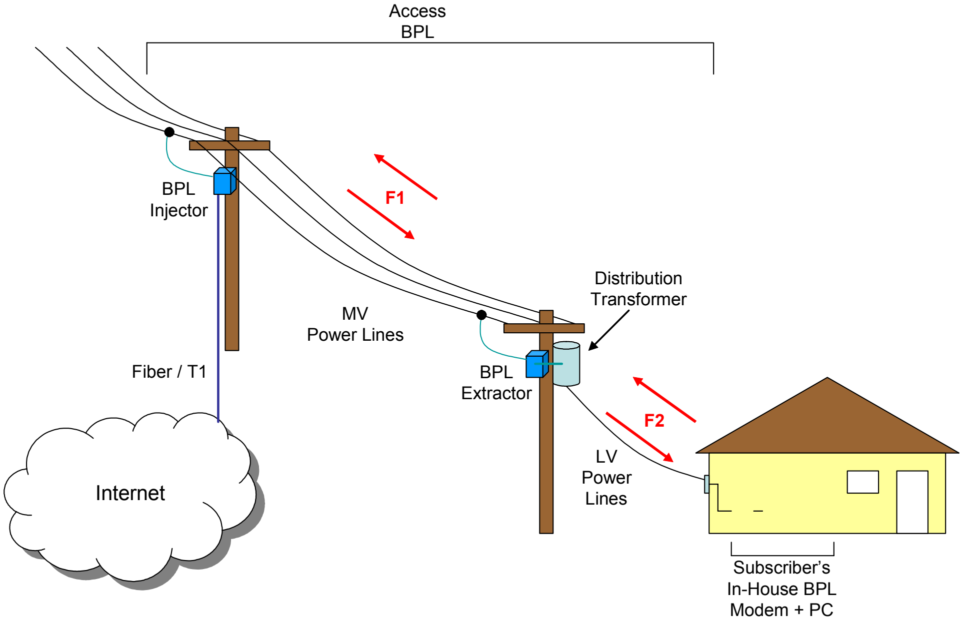

Figure 2-2: BPL System #1

The System #1 injector and extractors share a common frequency band (F1) on the MV power lines, different than the frequency band (F2) used on the LV lines by the subscriber's in-house BPL devices. In order to minimize contention for the channel, Carrier Sense Multiple Access (CSMA) is used with Collision Avoidance (CA) extensions. This type of system is designed to accept some amount of co-channel interference between quasi-independent BPL cells without the use of isolation filters on the power lines, as all devices on the MV lines operate over the same frequency band. The BPL signal may be sufficiently tolerant of co-channel BPL interference to enable implementation of two or three of these systems independently on adjacent MV power lines.[7] System #1 couples BPL signals into one phase line.

2.2.2 System #2

System #2 also uses OFDM as its modulation scheme, but differs from System #1 in the way it delivers the BPL signal to the subscribers' homes. Instead of using a device that uses LV power lines, System #2 extracts the BPL signal from the MV power line and converts it into an IEEE 802.11b WiFi™ signal for a wireless interface to subscribers' home computers as well as local portable computers (see Figure 2-3). Technologies other than WiFi™ might also be used to interface to subscribers' devices with the BPL network, the important point being that BPL is not used on LV power lines in System #2.

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[7] A degree of coupling occurs between BPL signals on adjacent phases.

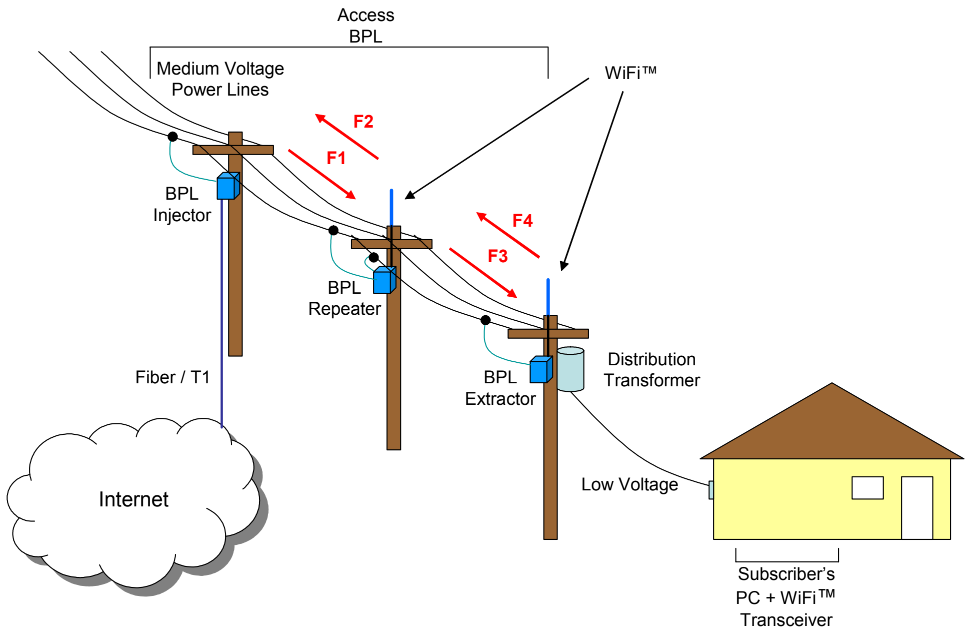

Figure 2-3: BPL System #2

This system uses different radio frequency bands to separate upstream (from the user) and downstream (to the user) BPL signals, and to minimize co-channel interference with other nearby access BPL devices. To span large distances between a BPL injector and the extractors it serves, repeaters may be employed. Like the injectors, BPL repeaters transmit and receive on different frequencies, and they use different frequencies from those used by the injector and other nearby repeaters. System #2 repeaters may also provide the capabilities of an extractor when outfitted with a WiFi™ transceiver. System #2 couples BPL signals onto one phase of the MV power line.

2.2.3 System #3

System #3 uses Direct Sequence Spread Spectrum (DSSS) to transmit the BPL data over the MV power lines. All users within a BPL cell share a common frequency band. In order to minimize contention for the channel, Carrier Sense Multiple Access (CSMA) is used. Like System #1, this type of system is designed to accept some amount of co-channel interference between cells, as all devices operate over the same frequency band. At one trial deployment of the System #3 architecture, the BPL service provider independently implements two phases of the same run of three phase power lines.

Each cell in System #3 (see Figure 2-4) is comprised of a concentrator (injector) that provides an interface to a T1 or fiber link to the Internet backbone, a number of repeaters (extractors) to make up for signal losses in the electric power line and through the distribution transformers feeding clusters of dwellings, and customer premises BPL equipment, used to bridge between the user's computer and the electrical wiring carrying the BPL signal. Adjacent cells typically overlap and the customers' BPL terminals and repeaters are able to communicate with the concentrator that affords the best communication path at any time.

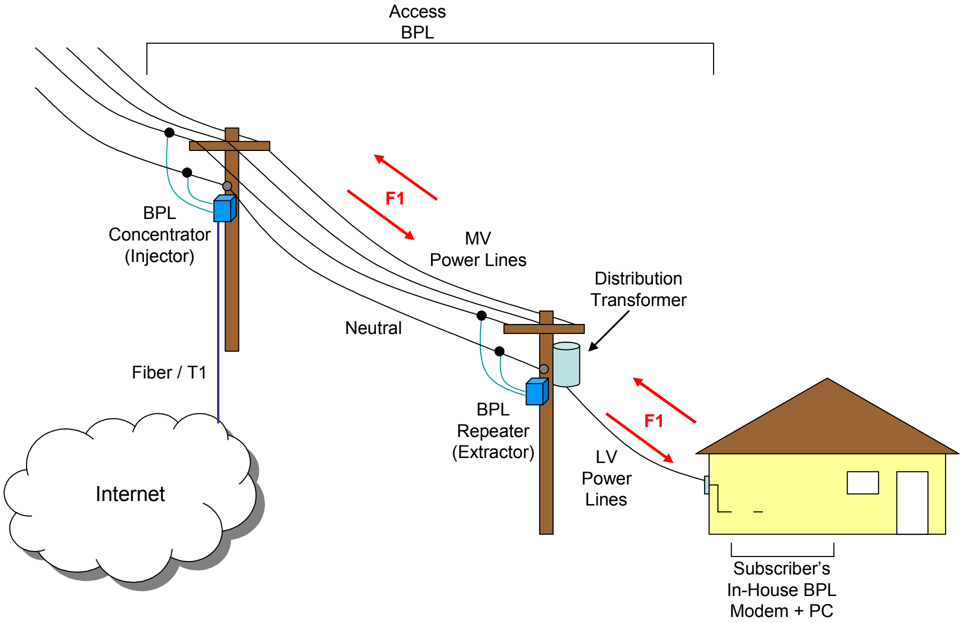

Figure 2-4: BPL System #3

System #3 couples the BPL signal onto the power line using a pair of couplers on a phase and neutral line.

2.3 POTENTIAL FUTURE SYSTEMS

BPL manufacturers and service providers anticipate a wide range of applications that may be offered to their subscribers. High quality, multi-channel video, audio, voice over Internet Protocol (VoIP), and on-line gaming applications are expected to rapidly increase the demand for additional bandwidth.[8] To support the typical subscriber at 1 Mbps, BPL systems are expected to operate at speeds of 100 Mbps or more on the MV power lines in the near future. A number of comments filed in response to the NOI indicate that the BPL industry is already preparing for this growth.[9]

A number of BPL vendors have suggested use of frequencies up to 50 MHz.[10] At least one vendor is considering use of 4 MHz to 130 MHz, while excluding frequencies

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[8] Comments of HomePlug Powerline Alliance, BPL Inquiry, July 7, 2003 ("HPA Comments") at 3-5.

[9] Comments of PowerWAN, Inc., BPL Inquiry, July 3, 2003, ("PowerWAN Comments") at 2; Comments of Main.net Communications, Ltd., BPL Inquiry, July 7, 2003 ("Main.net Comments") at 3.

[10] PowerWAN Comments at 2; Comments of Amperion, Inc., BPL Inquiry, July 7, 2003, ("Amperion Comments") at 4.

that are actively in use by certain licensed services.[11] One solution put forward in an attempt to mitigate interference with licensed services is to attenuate or "notch" BPL signals in frequency bands where licensed services are in nearby use.[12] Future BPL systems may be able to accomplish this automatically without system operator intervention. To implement this solution while simultaneously maximizing the useable bandwidth, BPL systems are expected to use new modulations that can support more sub-carriers that are more finely spaced.[13]

As data rates and bandwidth requirements grow, the BPL systems may require operation at greater transmitted power levels but not necessarily with higher power density than is used today. BPL vendors may employ techniques to dynamically adjust the power level to maintain a minimum signal-to-noise ratio (SNR) over the entire BPL spectrum, while limiting emissions to levels compliant with Part 15. One vendor has proposed such a solution for adjusting transmitted power to maintain a constant SNR across the BPL spectrum, with a hard limit based on Part 15 rules.[14] The challenge will be to develop the control mechanism that can maximize transmitted power while simultaneously limiting the radiated emissions, perhaps in conjunction with frequency agility.

Nortel has developed and patented a filter that blocks BPL signals while concurrently passing medium-voltage AC power. The judicious use of such blocking filters will enable optimal segmentation of BPL networks into cells of various sizes having low conducted co-channel interference from neighboring cells. This will enable a greater level of frequency reuse than what is currently available.[15]

Another BPL technology utilizes the 2.4 GHz and 5.8 GHz unlicensed bands.[16] An implementation using multiple IEEE 802.11b/g WiFi™ chips sets has been used to demonstrate the concept of carrying data over medium-voltage power lines at rates exceeding 200 Mbps. However, no party filed comments contending that this technology and these frequencies should be considered in the BPL proceedings.

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[11] Reply Comments of PowerComm Systems, Inc., BPL Inquiry, August 20, 2003, ("PowerComm Reply Comments") at 14.

[12] Main.Net Comments at 7; Comments of Ambient Corporation, BPL Inquiry, July 7, 2003, ("Ambient Comments") at 8; PowerWAN Comments at 3.

[13] PowerComm Reply Comments at 17.

[14] Ambient Comments at 6-7.

[15] *System, device, and method for isolating signaling environments in a power line communication system*, United States Patent No. 6,590,493, Rasimas, et al., July 8, 2003.

[16] *Corridor Systems Announces Breakthrough Technology For Broadband Over Powerlines (BPL), Demonstrates 216Mbps over PG&E's Medium-Voltage Grid*, Santa Rosa, CA, September 22, 2003 http://www.corridor.biz/0309-corridor-pr.pdf.

2.4 SUMMARY

Three architectures for access BPL networks were identified: (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. BPL systems currently provide data rates ranging from 1 Mbps to 10 Mbps, and operate at frequencies between 2 MHz and 50 MHz. In the future, BPL systems will operate at data rates exceeding 100 Mbps, utilizing greater bandwidth and/or advanced modulation schemes. BPL equipment vendors may employ additional signal processing techniques to optimize performance while simultaneously limiting emissions to Part 15 levels.

SECTION 3
BPL RELATED STUDIES AND REGULATIONS

3.1 INTRODUCTION

This section describes regulations applicable to BPL systems and studies conducted by various parties to investigate the characteristics of BPL emissions. The regulations include both the established and proposed radiation limits applicable to BPL systems.

3.2 REGULATIONS

3.2.1 Part 15 of the Commission's Rules

Appendix A of this report delineates key field strength and compliance measurement provisions of Part 15 applicable to BPL systems. The Part 15 field strength limits are shown in Table 3-1, below. BPL systems fall under the Part 15 definition of carrier current systems.[17] BPL systems are designed to transmit RF energy over the power line wiring by conduction; therefore, these systems are treated as unintentional radiators and the restricted bands of operation defined in 47 C.F.R. §15.205 do not apply.

Although Part 15 emission limits are intended to limit the risk of harmful interference to licensed services, compliance measurement procedures are equally important to the risk of interference because measurement uncertainty may ultimately result in BPL operation at field strength levels that are significantly higher or lower than the limits.

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[17] *See* 47 C.F.R. §15.3(f). Carrier current system. A system, or part of a system, that transmits radio frequency energy by conduction over the electric power lines. A carrier current system can be designed such that the signals are received by conduction directly from connection to the electric power lines (unintentional radiator)…

Table 3-1: FCC Part 15 Radiated Emission Limits Relevant to BPL

Usage	Frequency (MHz)	Field Strength (µV/meter)	Measurement Distance (meters)	Measurement Bandwidth (kHz)	Detector	Source
Carrier Current Systems	1.705-30.0	30	30	9	quasi-peak	15.209
Class A, in commercial, business, and industrial areas	30-88	90	10	120	quasi-peak	15.109
Class B, marketed for use in residential areas	30-88	100	3	120	quasi-peak	15.109

3.2.2 Foreign Regulations

Some administrations have established rules or regulations for BPL implementation or have deferred BPL implementation pending the results of on-going studies. BPL has been successfully implemented in some countries, while other administrations have postponed BPL implementation while further interference studies are being conducted. Still others have implemented BPL, experienced interference problems, and then prohibited BPL operation at least for the time being. Regionally, emission rules have been proposed for evaluation. Some of these are presented here. Note that information collected here is not comprehensive and may not be current in light of the rapid pace of BPL studies and development. In the summaries presented in this section, the acronyms BPL (for Broadband on Power Line), PLC (for Power Line Communications), and PLT (for Power Line Telecommunications or Technologies) will be used in accordance with each original report.

3.2.2.1 Administrative Rulings on BPL

As summarized in Table 3-2, several administrations reportedly have already established rules applicable to BPL implementations.

Table 3-2: Countries and Their Rulings on BPL Implementations

Country	Ruling or Ruling Rationale	Source of Information
Australia	ACA has no mandatory standards for BPL equipment for frequencies above 525 kHz.	http://www.aca.gov.au/consumer_info/fact_sheets/industry_fact_sheets/fsi23.pdf
Austria	The Ministry of Traffic has terminated pilot projects on PLC. It concluded that the interference caused by PLC to communications in the frequency range 2 - 30 MHz could not be reduced to acceptable levels.	http://futurezone.orf.at/futurezone.orf?read=detail&id=205693&tmp=4659
Finland	FICORA Annual Report 2001: From measurement results, it decided that PLC technology can be accommodated only after interference and security problems have been solved and when the technology complies with official requirements. Favors compliance with NB30 until a pan-European norm is specified.	http://www.ficora.fi/2001/VV_vsk2001.pdf
Germany	NB30 (see Table 3-3)	http://www.darc.de/referate/emv/plc/c3.4-rev1-PLC5RPRT.pdf
Japan	The MPHPT of Japan has determined that at this stage, increasing the bandwidth to be used for power line communications would be difficult. Proposed feasibility tests promoting modem research and development.	http://www.soumu.go.jp/joho_tsusin/eng/Releases/Telecommunications/news020809_3.html
U.K.	No official position yet for the range 1.6 MHz to 30 MHz.	http://www.radio.gov.uk/publication/mpt/mpt_pdf/mpt1570.pdf

ACA: Australian Communications Authority
BBC: British Broadcasting Corporation
DARC: Deutscher Amateur-Radio-Club
EN: European Standard NF
FICORA: Finnish Communications Regulatory Authority
IEC: International Electrotechnical Commission
MPHPT: Ministry of Public Management Home Affaires, Post and Telecommunications of Japan
NB30: Usage Provision 30, issued by German RegTP in January 1999. It contains a limiting curve for the radiation of telecommunications services in and alongside of cables (including Cable TV, xDSL, and PLC) for the frequency range from 9 kHz to 3 GHz.
RA: Radiocommunications Agency of U.K.
RegTP: The Regulating Administration for Telecommunications and Posts of Germany

Table 3-3: German NB30 Limits

Frequency Range (MHz)	Limit of Peak Field Strength at 3 meters (dBµV/meter)	Measuring Bandwidth	Detector
>1 to 30	$40 - 8.8 * \log_{10} (f_{MHz})$	9 kHz	peak
>30 to 1000	27 (equivalent to radiated power of 20 dBpW)	not specified	peak

3.2.2.2 Proposed New Regulations

Several proposals have been presented on a regional basis for consideration to regulate emissions from cable and BPL equipment, and the parts of these proposals relevant to BPL systems operating in the frequency band of 1.7 – 80 MHz are listed below.[18] The first proposal, from Germany and taken from NB30, is shown in Table 3-4.

Table 3-4: German Regional Proposal

Frequency Range (MHz)	Limit of Peak Field Strength at 3 meters (dBµV/meter)	Measuring Bandwidth	Detector
>1 to 30	$40 - 8.8 * \log_{10} (f_{MHz})$	9 kHz	peak
The limit is given in terms of the electric field strength. Below 30 MHz the limit applies for the magnetic field strength, assuming an intrinsic impedance of 377 Ω. This proposal is supported by Austria, Finland, France, Germany, Romania and Switzerland.			

A second proposal, from Norway, is shown in Table 3-5.

Table 3-5: Norwegian Proposal

Frequency Range (MHz)	Limit of Peak Field Strength at 3 meters (dBµV/meter)	Measuring Bandwidth	Detector
>1 to 30	$20 - 7.7 * \log_{10} (f_{MHz})$	9 kHz	peak
Magnetic field data, in dBµA/meter, are measured with a loop antenna. The equivalent E-field data are converted from the H-field data by the factor of 51.5 dB which corresponds to the free space impedance of 120π Ω. This proposal is supported by Ireland.			

A third proposal, from BBC of U.K. and NATO, is shown in Table 3-6.

Table 3-6: Proposal from BBC and NATO

Frequency Range (MHz)	Limit of Peak Field Strength at 1 meter	Measuring Bandwidth	Detector
3 – 30	$H_{peak} = - 29.7 - 8.15 \text{ Log}_{10} (f_{MHz})$,	9 kHz	peak

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[18] European Conference of Postal and Telecommunications Administrations (CEPT) Electronic Communications Committee (ECC) Report 24, "PLT, DSL, Cable Communications (Including Cable TV), LANs and Their Effect on Radio Services," Section 7.

	(dBμA/meter, measured)		
3 – 30	$E_{peak} = 21.8 - 8.15 \text{ Log}_{10} (f_{\text{MHz}})$, (dBμV/meter, calculated from H_{peak})	9 kHz	peak
The H-field data are measured with a loop antenna, and the E-field data are converted from the H-field data by the factor of 51.5 dB. This limit is derived with the reference noise level from ITU-R Rec. P 372-7 and the protection distance of 10 meters where the sensitivity of a victim receiver degraded by less than 0.5 dB. It is supported by the radio users (military, broadcasting, civil aviation, amateur, etc.) of the LF, MF and HF bands.			

A fourth proposal, from BPL manufacturers and utility industries and taken from the FCC Part 15 limits, is shown in Table 3-7.

Table 3-7: Proposal by Certain BPL Proponents

Frequency (MHz)	Field Strength at 30 meters (μV/meter)	Measuring Bandwidth	Detector
1.705 - 30.0	30	9 kHz	quasi-peak

A comparison of these four proposals is shown in Figure 3-1. In this figure, the data are scaled to a 10 meter measurement distance according to §15.31 (f)(2) guidelines for measurement distance extrapolation under 30 MHz.

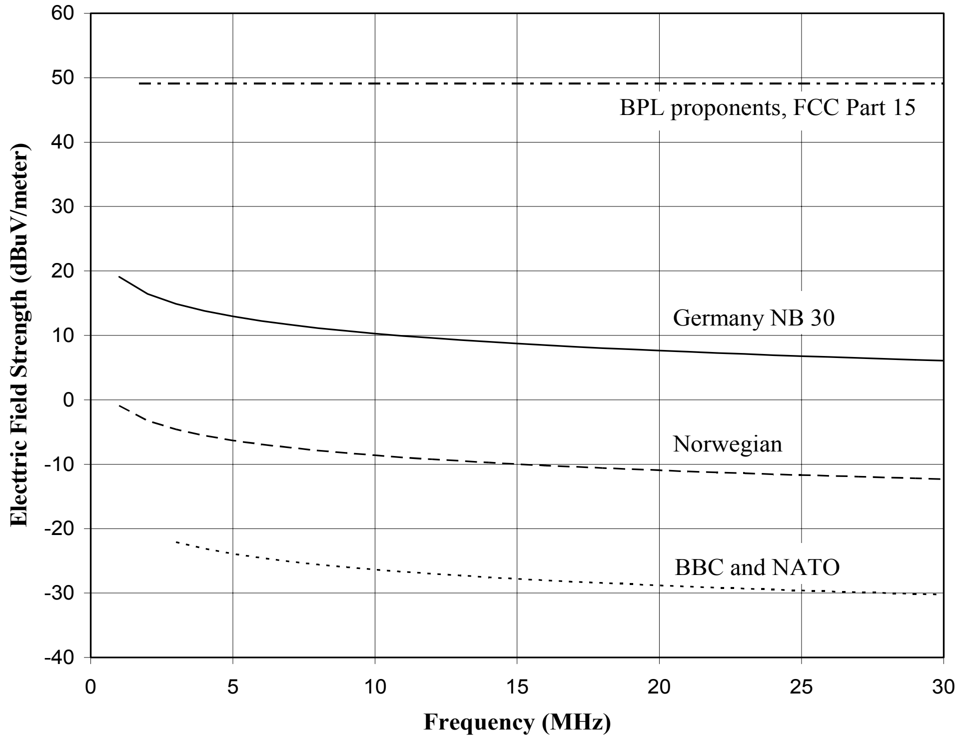

Figure 3-1: Comparison of Proposals for Regulating BPL Emissions

3.3 STUDIES

3.3.1 Analyses of Interference from BPL Filed Under the FCC NOI

Proponents and opponents of the Commission's NOI regarding Broadband over Power Lines submitted relevant technical information and analyses of the implications BPL will have on existing licensed services between 1.7 – 80 MHz. Some of their key points are summarized in the following paragraphs.[19]

3.3.1.1 Power Lines as Unintentional Radiators of BPL Signals

Ameren Energy Communications, Inc. (Ameren) analyzed the Medium Voltage (MV) power line with respect to its ability to act as an unintentional antenna for frequencies below 30 MHz.[20] In their analysis, Ameren stated that a two-conductor power line segment, driven differentially (*e.g.*, an "aerial" mode[21]), supports mostly transverse electromagnetic modes (TEM) of propagation and acts like a wave guide. This line radiates only at points of discontinuity, such as at line terminations, junctions with other lines, sharp line turns, and at power distribution equipment such as transformers and capacitors. They further state that reflections at the receiving end of the power line cause the formation of two opposite traveling waves, with radiation at both ends of the line.

Ameren noted that when calculating the radiation efficiency and gain of the power line, the source impedance at the BPL transmitter should be fixed and the load impedance should be allowed to vary. This contrasts with a line operating as a traveling wave antenna in that load impedance should be matched to the line's characteristic impedance (between 350 to 420 Ω for frequencies between 1 and 30 MHz). Their calculations show that as the line termination varies, not only does the line's radiation efficiency and gain change, the ability of the fixed source to couple power onto the power line decreases with the load mismatch. Ameren indicated that a single line is expected to be an inefficient radiator. Further, Ameren calculated the array factor for two conductors and show a 17% increase in radiation over the single conductor case. Ameren believes that transmission lines carrying TEM waves should not be compared with linear array elements as their radiation mechanisms are different.

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[19] Inclusion or exclusion of any analysis in this section has no significance; NTIA reviewed all filings under the BPL Inquiry.

[20] *See* Reply Comments of Ameren Energy Communications Inc., BPL Inquiry, August 20, 2003, ("Ameren Reply Comments").

[21] As described in Ameren Reply Comments, "aerial modes" direct their peak radiation skyward.

Ameren also discussed the case of interconnected segments of MV power distribution line and pointed out that the radiation pattern is determined by the current distribution in the lines running in different directions, and the radiation is likely to be more isotropic. This, they believe, will result in lower gains and increased attenuation of signals as they divide amongst each interconnected segment and reflects at discontinuities. Ameren concludes that the strongest radiation will be at the source and that is the critical part of the system for determining radiation of BPL signals.

The ARRL submitted a paper presenting calculated antenna gains and patterns as a function of frequency for a simple power line model.[22] Their results indicated that as frequency increases, the power line acts more like an antenna, with a complex and highly directive radiation pattern.

In another paper, ARRL described their model of a MV distribution power line and compared the following three methods of injecting the BPL signal into the model[23]:

- Differential feed between two phases, with the feed at one end of the power line;
- One phase to Earth ground, with the feed in the center of the line;
- Single phase fed differentially; with one conductor grounded to a relatively poor RF ground and the ungrounded phase feed point was offset from center.

Based on their model, ARRL presented results for the antenna gain of the power line, with the single phase – differential feed with one conductor grounded as being the worst case. This case resulted in higher antenna gain for the modeled power line, and greater coupling to the simulated amateur radio antennas included in their model. ARRL noted that the calculated gain for this power line at 14 MHz rivaled many amateur HF antennas. A final observation was made that the radiated emission patterns for this model were very complex and that the peak radiation at 3.5 MHz is skyward.

3.3.1.2 Existing Part 15 Rules Regarding BPL Signals

Ameren questioned the validity of using a loop antenna to measure magnetic field strength.[24] Ameren pointed out that power lines act as “large radiators” and measurements close to power lines (e.g. 30 meters) are in the near field where the value of free space impedance typically used in the far field, 377 Ω (51.42 dB), is no longer valid. They presented graphs of electric (E) and Magnetic (H) fields, and H field + 51.42 dB to make the case that the far field value of free space impedance is incorrect in the near field.

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[22] *See Power Lines as Antenna From 100 kHz to 50 MHz*, Ed Hare, Exhibit A to Comments of ARRL, BPL Inquiry, July 7, 2003, (“ARRL Comments”).

[23] *See Methods of Feeding Overhead Electrical Power-Line Distribution Lines With BPL Signals and the Relationship of These Methods to the Radiated Emissions of the Conductors*, Ed Hare, Exhibit B to ARRL Comments.

[24] *See Use of Loop Antennae near Large Radiators*, Appendix to Ameren Reply Comments.

Ameren stated that the estimation error from the use of a loop antenna could be as high as 10 dBμV/m for measurements made along the power line, and as high as 20 dBμV/m moving away from the power line, even as far out as 700 meters. The model used for this analysis showed that the peak field strength is above the horizon, at an elevation angle of 12°. Ameren concluded that the loop introduces significant measurement errors near power lines and recommended use of a monopole antenna for BPL measurements.

In another paper, ARRL calculated the conducted emissions power levels based on several BPL manufacturers submissions to the Commission in response to the NOI.[25] ARRL stated that their calculations show a resultant level of conducted emissions exceeding 47 C.F.R. §15.107(a). ARRL further stated that, based on its understanding of how BPL couplers function, the typical losses for these couplers would lead to widespread radiated or conducted emissions.

ARRL addressed the possibility that inaccuracies may occur in measured results when following current Part 15 rules.[26] ARRL stated that from their model of power lines, BPL radiation patterns are complex and it would be difficult to predict where to make measurements to obtain the peak value of the electrical field. Another potential source of error may arise in arriving at an extrapolation factor, as they indicated that the HF electric field does not fall off at a 40 dB/decade inside 30 meters. Using the results from their power line model, ARRL noted that the power line field strength is greater above the power lines; therefore, measurements made near ground (1m) will typically underestimate the peak field strength.

To maximize the likelihood that measured results accurately characterize the BPL field strength, ARRL recommended in-situ testing at closely spaced distance intervals above, below, and to the sides of BPL system installations. The practice of using 3 "typical" installations to characterize emissions is considered by ARRL to be unrealistic and will result in measurements unrepresentative of the emissions in a real installation. Finally, ARRL noted that there are definitely standing waves in the simulation results for the power line modeled.

Using their power line model, ARRL calculated the received signal level from BPL emissions in the vicinity of an amateur radio antenna and the expected increase in noise floor. The BPL transmitted power spectral density was estimated and, from this, ARRL calculated that the radiated field strength will exceed Part 15 limits.[27] ARRL assumed ideal (high) coupling between the power line and the amateur radio antenna, and

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[25] *See Broadband Over Power Line Devices and Conducted Emissions*, Ed Hare, Exhibit B to Reply Comments of ARRL, BPL Inquiry, August 20, 2003, ("ARRL Reply Comments").

[26] *See Electric and Magnetic Fields Near Physically Large Radiators*, Ed Hare, Exhibit D to ARRL Comments.

[27] *See Calculated Levels from Broadband Over Power Line Systems and their Impact on Amateur Radio Communications Circuits*, Ed Hare, Exhibit C to ARRL Comments.

that the antenna is located in a direction where the BPL signal's radiated emissions are at their peak. In addition, ARRL used the results of their model of the power lines to estimate power line "antenna gain." ARRL further described potential measurement errors that can mistakenly lead BPL vendors to believe that they are meeting Part 15 limits.

In a paper by the BBC, various proposals were considered for limits on emissions that are under review in CEPT SE35 (a European technical committee) and evaluated the amount of protection that these limits would provide to broadcast receivers near cabling carrying xDSL and PLT (BPL) signals.[28] The author concluded that none of the proposed limits adequately protect broadcast reception and that a proposal limiting the increase in noise floor appears to offer the most promise.

3.3.1.3 BPL Impact on Existing Licensed HF Communications Services

The ARRL modeled the reliability of HF communications for various noise floor levels.[29] Their modeling used noise floor levels for a quiet residential environment, the ITU-R Recommendation P.372.8 (2003) for median noise level in a residential environment, the ITR-R Recommendation level +10 dB, and the noise plus BPL signal level calculated by ARRL for a wide-scale BPL deployment where these devices operate at the maximum field strength allowed under Part 15. ARRL modeled these conditions at 5 MHz and 14 MHz using the VOACAP inverse-area coverage program.

A number of plots of HF link availability were provided in this ARRL report. The results indicated that the reliability of HF communications is already degraded when operating a receiver in the presence of the ITU-R median level noise, and if BPL use increased the noise floor by 10 dB, or to the level ARRL says will result from widespread BPL deployment at Part 15 limits, ARRL concludes that worldwide HF communications will be severely degraded.

In another paper, the BBC analyzed the cumulative effects of wide-scale deployment of xDSL and BPL. The BBC considered the skywave propagation effects on aircraft receivers and distant ground-based receivers due.[30] The author concluded from his analysis that the extent of skywave interference to aircraft and ground-based receivers from widespread xDSL/PLT system deployment may not be negligible. The author suggests that the relevant competent authorities should further investigate this interference potential.

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[28] *See AM Broadcasting and Emissions from xDSL/PLT/etc.*, J. H. Stott, BBC R&D White Paper WHP-012, Attachment to Comments of David A. Lewis, BPL Inquiry, June 23, 2003, ("David Lewis Comments").

[29] *See Impact of Man-Made Noise From Broadband Over Power Line Systems Operating at the FCC Part-15 Radiated Emissions Limits on Worldwide HF Communications*, Ed Hare, Exhibit of ARRL, BPL Inquiry, August 20, 2003, ("ARRL Exhibit").

[30] *See Cumulative effects of distributed interferers*, J. H. Stott, BBC R&D White Paper WHP-004, Attachment to David Lewis Comments.

3.3.2 International Telecommunications Union (ITU) Activities

At least two of the three ITU Sectors have addressed BPL: the Telecommunications Standards Sector (ITU-T) and the Radiocommunications Sector (ITU-R). Working documents of the Study Groups in both of these sectors are not freely available to the public, so descriptions of current documentation and activities are presented in this section without comprehensive citations.[31]

3.3.2.1 ITU-T Study Group 5

In mid-2003, ITU-T Study Group 5 approved Recommendation K.60, which addresses "Emission Limits and Test Methods for Telecommunication Networks". Specifically, its intended application is for investigation of complaints of radio interference and its scope includes all telecommunications networks using LV AC electrical power lines and frequencies between 9 kHz and 400 GHz. The recommended "target" field strength limits for the 1.7-80 MHz frequency range are listed in Table 3-8. Associated measurement and administrative procedures are specified in the Recommendation. The procedures feature a number of interference mitigation steps that should be taken by the parties directly involved before consideration is given to filing an interference complaint with government authorities.

Table 3-8: Target Electric Field Strength Limits of ITU-T Rec. K.60

Frequency Range (MHz)	Field Strength (dBμV/m)		Measurement Distance	Measurement Bandwidth
	Peak	Quasi-Peak		
1 to 30	52 - 40 log (f)	40 - 20 log (f)	3 m	9 kHz
30 to 230	52 - 8.8 log (f)	40 - 8.8 log (f)	3 m	120 kHz
NOTES: f = frequency (MHz); below 30 MHz, 377 Ω impedance is assumed in estimating electric field strength from measured magnetic field strength; only the quasi-peak limit applies if background noise is too high for a peak measurement.				

3.3.2.2 ITU-R Study Group 1

Working Parties 1A (Spectrum Engineering) and 1C (Monitoring) met in November 2003 and examined BPL studies in response to Questions 221/1 and 218/1.[32] France presented an extensive, non-conclusory European study of potential interference from BPL and other wire-bound telecommunications systems. The United States (represented by ARRL) presented a paper outlining BPL interference measurement and

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[31] Information on obtaining access to ITU documents, *e.g.*, via corporate membership, is provided at www.itu.int.

[32] The texts of Question 221/1, "Compatibility between radiocommunication systems and high data rate telecommunication systems using electricity power supply or telephone distribution wiring," and Question 218/1, "Techniques for measurement of radiation from high data rate telecommunication systems using electrical power supply or telephone distribution wiring," are freely available at www.itu.int.

analysis considerations consistent with the Commission's open BPL proceeding. Korea presented a paper describing an approach for measuring BPL emissions in a laboratory environment. A Liaison Statement presenting relevant Study Group 6 (broadcasting service) studies was reviewed. Insofar as Working Party 1A is the lead ITU-R group for development of recommendations regarding potential interference from BPL systems, it requested information from all other Working Parties responsible for signal propagation models and analysis and matters affecting specific radio services. Working Parties 1A and 1C both expect to complete their BPL studies in 2005.

3.3.2.3 ITU-R Study Group 3

The November 2003 meetings of Study Group 3, Working Parties 3J, 3K, 3L and 3M, generated extensive discussions on propagation aspects of Power Line Telecommunication (PLT) systems. The Study Group 3 Chairman declared this to be one of the three most important topics for these meetings. Subgroups 3K-1 and 3L-2 spent appreciable time discussing PLT systems and Subgroup 3J-C contributed relevant information regarding environmental noise. Working parties 3J, 3K and 3L jointly drafted a liaison statement to Working Party 1A, identifying concerns and suggesting methods of estimation of PLT signal radiation levels.

The concerns expressed included: the unbalanced nature and diverse characteristics of power lines; the possibility of both point and line sources of radiation; power aggregation of emissions from multiple sources; and the presence of both ground and sky waves. It was noted that in developing criteria for acceptable PLT use of radio frequencies, measurements of both electric and magnetic fields must be considered because of the unknown relationship between these fields in the near-field. It was suggested that: a model such as NEC be used for estimation of radiation; either ITU-R Rec. P. 368 or the software GRWAVE be used for evaluating ground wave propagation of PLT emissions; and ITU-R Rec. P. 533 be used for evaluating PLT propagation via sky wave. It was also suggested that ITU-R Rec. P. 372 be used for estimating levels of noise.

In addition to the Liaison Statement, Working Party 3L drafted a new question and formed a new Correspondence Group to work on the PLT Communications. The draft new question focused on prediction methods and models applicable to PLT systems. Defined studies were also given high priority. The defined studies address radiation mechanisms of PLT systems, modeling techniques, effects of local ground planes and conductors, methods of aggregation, propagation models for calculation of interference and measurement of radiated fields in the near field. The Correspondence Group will exchange ideas and communicate outputs of various studies under progress for review by the international group.

3.3.2.4 ITU-R Study Group 6

In ITU WP 6E, the European Broadcasting Union (EBU) submitted a document recommending revision of PLT field strength limits and measurement distance identified in an earlier study. This contribution suggested three shortcomings in the earlier study. First, digital broadcasting transmission, not Amplitude Modulation transmission, should be used to derive the allowable PLT signal strength. Second, the required signal-to-noise level should not support only a relatively interference-tolerant channel operating in a rugged mode with restricted capacity. Third, the 3-meter measurement distance specified in the NB30 limit (Table 3-3) is unrealistically large for indoor reception. Therefore EBU concluded that the NB30 limits were unacceptably lax by a large margin and proposed that: (1) the maximum allowable PLT interference should be at least 10-20 dB lower; and (2) reception at 1-meter and larger distances from the PLT emission source should be protected.

3.3.3 Other Technical Literature

Appendix B summarizes additional technical literature that was not filed in response to the BPL Inquiry.

3.4 SUMMARY

Studies performed by other parties and applicable FCC and foreign regulations were reviewed 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. NTIA noted that BPL 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 been oriented to determine whether interference will occur at the variously proposed limits. In contrast, NTIA has oriented its study to find a solution that accommodates BPL systems while appropriately managing 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 Part 15 measurement techniques 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.

SECTION 4
CHARACTERIZATION OF FEDERAL GOVERNMENT RADIO SYSTEMS AND SPECTRUM USAGE

4.1 INTRODUCTION

The 1.7-80 MHz frequency range encompasses the high end of the medium frequency band (MF, 1.7-3.0 MHz), the high frequency band (HF, 3-30 MHz), and the low end of the very high frequency band (VHF, 30-80 MHz) portion of the spectrum. At HF frequencies and below, communications can be made possible over a very long distance (*i.e.*, thousands of miles) using skywave, ionospheric propagation. A significant feature of communications using the HF bands is the great variability in radio propagation and ambient radio noise levels. These variations as a function of time of day, season, year, and geographic location have been extensively studied and are well understood. Modern technology, especially automatic link establishment (ALE), has reestablished HF as an important, reliable mode of communications. At VHF frequencies, communications are more local, generally limited to tens of miles.

The 1.7-80 MHz band supports a variety of radio services that are adapted to the propagation characteristics inherent in this range. In all, thirteen radio services are supported in the 1.7-80 MHz band (Table 4-1). Most of these radio services are used by federal agencies and are instrumental to the Federal Government in meeting its various radiocommunications requirements and responsibilities.

Table 4-1: Radio Services in the 1.7-80 MHz Bands

Fixed
Mobile
Land Mobile
Maritime Mobile
Aeronautical Mobile (R)
Aeronautical Mobile (OR)
Radiolocation
Amateur
Amateur-satellite
Radio Astronomy
Broadcasting
Aeronautical Radionavigation
Standard Frequency and Time signal

4.2 ALLOCATIONS OVERVIEW

In the United States, the 1.7-80 MHz range is made up of 157 frequency bands. In accordance with the National Table of Frequency Allocations, each of these bands is designated for either exclusive federal use, exclusive non-federal use, or shared. The spectrum allocations in this band include many cases of band-sharing between the federal and non-federal users, and between different radio services. A total of 110 bands are shared by federal and non-federal users. Only 12 bands are allocated exclusively to the Federal Government for fixed and mobile services (Table 4-2). In comparison, 34 bands are allocated for non-federal use on an exclusive basis for various radio services including: amateur, amateur-satellite, fixed, land mobile, and broadcasting (Table 4-3). Over 50 footnotes to the allocation tables are associated with these bands, providing for additional spectrum sharing or constraints on operations.

Table 4-2: Frequency Bands Allocated Exclusively to the Federal Government

25330-25550 kHz	30-30.56 MHz	38.25-39 MHz
26480-26950 kHz	32-33 MHz	40-42 MHz
27540-28000 kHz	34-35 MHz	46.6-47 MHz
29.89-29.91 MHz	36-37 MHz	49.6-50 MHz

Table 4-3: Frequency Bands Allocated Exclusively to Non-Federal Use[33]

1800-1900 kHz	28–29.89 MHz
3500-4000 kHz	29.91-30 MHz
7000-7300 kHz	30.56-32 MHz
10100-10150 kHz	33-34 MHz
14000-14350 kHz	35-36 MHz
18068-18168 kHz	37-37.5 MHz
21000-21450 kHz	39-40 MHz
24890-24990 kHz	42-46.6 MHz
25005-25010 kHz	47-49.6 MHz
25210-25330 kHz	50-73 MHz
26175-26480 kHz	75.4-88 MHz
26950-27540 kHz	

The allocations to radio services in the 1.7-80 MHz band can be broadly grouped into four overall categories as shown in Table 4-4.

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[33] Some bands are grouped together.

Table 4-4: Frequency Allocations in the 1.7 – 80 MHz Band by Service Category[34]

Service Category	Bandwidth	Percent of Total 1.7 – 80 MHz Band
Fixed & Mobile Communications	40.9 MHz	52%
Broadcasting (including shortwave & TV)	25.7 MHz	33%
Amateur/Amateur-Satellite	10.4 MHz	13%
Other	3.1 MHz	4%

The largest category, fixed and mobile communications, includes a number of specific allocations for various land, air and sea communications services. For purposes of this summary, the "Other" category is comprised of the aeronautical radionavigation, radio astronomy, radiolocation, and standard frequency and time signal. Table 4-5 shows the breakdown of the total number of bands allocated to all the radio services, including their respective total bandwidths. This Phase 1 study focused largely on fixed and mobile communications systems. The NTIA Phase 2 effort will further explore other services.

Further discussion on these radio services and spectrum use are presented in Appendix C.

Table 4-5: Summary of Bands Allocated to the Radio Services (1.7-80 MHz Band)

Radio Service	No. of Bands (Fed. Gov't)	Total Bandwidth (kHz)	No. of Bands (Non-Federal)	Total Bandwidth (kHz)
Aeronautical Mobile (R)	11	1331	11	1331
Aeronautical Mobile (OR)	10	845	10	845
Aeronautical Radionavigation	1	400	1	400
Amateur	--	--	12	7650
Amateur-Satellite	--	--	6	2700
Broadcasting	18	3720	20	25720
Fixed	58	19810	55	18235
Land Mobile	--	--	17	14064
Maritime Mobile	15	4857	15	4857
Mobile	42	17560	19	5531
Radiolocation	3	365	3	365
Radio Astronomy	4	2270	4	2270
Standard Frequency & Time Signal	13	90	13	90

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[34] Note that the combined percentage of spectrum for all the radio services exceeds 100 % of the total spectrum in the band. This is because a band could be allocated to two or more radio services.

4.3 OVERVIEW OF FEDERAL GOVERNMENT SPECTRUM USE

The Federal Government agencies use the 1.7-80 MHz band, specifically the HF band, extensively for emergency services, including communications support for the Department of Defense (DoD); Coast Guard operations for distress, digital selective calling, search and rescue, and other safety of life operations; Department of Interior (DOI) and Department of Agriculture (DOA) for the management, maintenance, and preservation of our natural resources; Department of Justice (DOJ) and Department of Homeland Security (DHS) for law enforcement activities, and backup or emergency uses of the other federal agencies. Backup systems play a crucial role in times of national security emergency preparedness (NSEP) emergencies, when regular communications links are disrupted, inadequate or non-operational. In an emergency situation, the Federal Government has a program for the use of government HF frequencies for the shared resources (SHARES) network. The SHARES network intends to provide backup capability to exchange critical information among federal entities by HF radio in crisis situations.

Federal agencies, especially the DoD and law enforcement community, utilizing this portion of the radio spectrum employ over the horizon and encrypted radios that may utilize ALE which samples channels periodically to determine channel availability. All these systems could be a part of the emergency communications network. As indicated earlier, the 1.7-80 MHz band, for the most part, is shared by the federal and non-federal users and is extensively used by both communities for numerous radio applications.

There are more than 59,000 Federal Government frequency assignments authorized in the 1.7-80 MHz band.[35] Table 4-6 shows the number of frequency assignments by radio service and by entity. These assignments support the numerous federal activities and requirements in the 1.7-80 MHz band (*see* Appendix C).

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[35] Statistics on frequency assignments are current as of October 2003.

Table 4-6: Federal and Non-Federal Frequency Assignments by Radio Service in the 1.7-80 MHz band

Entity	Aero. Mobile	Radio-nav.	BC	Fixed	Land Mobile	Mar. Mobile	Mobile	Radio - location	SF & TS	Others	Total by Entity
A	76		1	753	188		175				1193
AF	2491	18		1112	844	323	217	23		103	5131
AR	192	142	1	5521	2350	433	1844	20		30	10533
BBG			469	146	3						618
C	130			644	625	512	31	1	12	32	1987
CG	888	3		554	9	7034	15				8503
DHS	40			1118	33		72				1263
E	232			252	301	17	86	2		4	894
EPA				90	30	10					130
FAA	293	1564		1506	129		24			1	3517
FCC				459	484						943
HHS				571	32		25				628
I	124		3	317	421	145	330				1340
J	2			1890	295	16	167				2370
N	2433			2950	2525	5346	2663	26		56	15999
NASA	16			72	41	62	26			6	223
NG	399	119		1158	1191	1252	646	144		1135	6044
S				118	3		10				131
SI					1	7	106				114
T	149			56	199	8	708				1120
TRAN				137	9	6	3				155
TVA				22	82	2	144	2			252
VA				107	52						159
Others	5		8	1366	145	106	383			17	2030
Total Assignments											**65,277**

Legend: Aero = Aeronautical, Nav = Navigation, BC = Broadcasting, SF&TS = Standard Frequency and Time Signal, Mar = Maritime, A =Agriculture, AF = Air Force, AR = Army, BBG = Broadcasting Board of Governors, C = Commerce, CG = Coast Guard, DHS = Homeland Security, E = Energy, EPA = Environmental Protection Agency, FAA = Federal Aviation Administration, FCC = Federal Communications Commission, I = Interior, J = Justice, L= Labor, N = Navy, NASA = National Aeronautics and Space Administration, NG = Non-Government, NS = National Security Agency, NSF = National Science Foundation, S = State, SI = Smithsonian Institution, T = Treasury, TRAN = Transportation, TVA = Tennessee Valley Authority, VA = Veterans Administration

4.4 SUMMARY OF REPRESENTATIVE FEDERAL GOVERNMENT SYSTEMS IN THE 1.7-80 MHz BAND

Federal agencies employ a number of radiocommunication systems that have a significant presence in the 1.7 – 80 MHz band. These systems, summarized in Table 4-7, are presented as the representative systems for certain radio services because they are prevalent (*e.g.*, the number of frequency assignments supporting these systems overwhelm the others) and their uses are widespread in the band. The functions and operations of these systems are described in Appendix C, as appropriate.

Table 4-7: Summary of Representative Federal Government Radio Systems in the 1.7-80 MHz Band

Radio Service	Freq. Band (MHz)	Federal Entity	Representative System
Fixed	2-30	Many federal agencies	HF Shared Resources (SHARES)
		DHS/FEMA	FEMA National Radio System (FNRC)
		Army/Corps of Engineers	HF Emergency Operations Net
		FAA	National Radio Communications System (NRCS)
Fixed	30-50	Many federal agencies	Base Stations (Repeaters)
Land Mobile	2-30	DHS/US Customs	Custom's Over the Horizon Enforcement Network (COTHEN)
Land Mobile	30-50	DoD	Single-Channel Ground and Airborne Radio System (SINCGARS)
Maritime Mobile	2-30	DHS/USCG	Global Maritime Distress and Safety System (GMDSS)
Aeronautical Mobile (R)	2-30	FAA	Air Traffic Control (VOLMET)
Aeronautical Mobile (OR)	2-30	DoD	Tactical Radios (AN/ARC Series)
Radionavigation	74.8-75.2	FAA	Marker Beacons
Radiolocation	2-3.4	DoD	Over the Horizon Radars (OTHR)
Broadcasting	2-30	BBG	Voice of America (VOA)
Standard Freq. & Time Signal	2-30	DOC/NIST	WWV & WWVH Stations

4.5 REPRESENTATIVE TECHNICAL CHARACTERISTICS OF FEDERAL EQUIPMENT

The technical characteristics of equipment in the 1.7-80 MHz band can be largely grouped into uses below and above 30 MHz, with considerable consistency within these two frequency bands. Table 4-8 summarizes representative technical characteristics of federal radio equipment in the 1.7-80 MHz band. Appendix C provides a more in-depth presentation of these technical characteristics.

Table 4-8: Representative Technical Characteristics of Receivers in the 1.7-80 MHz Band

Radio Service	Station Type	Freq. Band (MHz)	BW (kHz)	Antenna Gain (dBi)	Antenna Height (ft)	Antenna Type/Pol	Modulation Type
Fixed	Fixed	2-30	2.8	0-2	30-140	Dipole/V&H	J3E, simplex operation
Fixed	Fixed	30-50	16	0-3	10-400	Whip/V	F3E, simplex and half duplex
Land Mobile	Base	2-30	2.8	0	30-100	Whip/V&H	J3E, simplex operation
Land Mobile	Land Mobile	2-30	2.8-3	0-2	6-32	Whip/V&H	J3E, simplex operation
Land Mobile	Base	29.7-50	16	3	30-400	Whip/V	J3E, simplex and half duplex
Land Mobile	Land Mobile	29.7-50	16	0	6-32	Whip/V	J3E, simplex and half duplex
Aeronautical Mobile (AM(R)S)	Aeronautical (Ground)	2-30	2.8	0	unknown	Various/V	J3E, simplex operation
Aeronautical Mobile (AM(R)S)	Aircraft	2-30	2.8	0	18000-40000	Conformal/V	J3E, simplex operation
Aeronautical Fixed (NRCS)	Fixed (Ground)	2-30	6	0	unknown	Whip/V	J3E, simplex operation
Aeronautical Mobile	Aircraft	30-50	16	0	18000-40000	Blade/V	J3E, simplex operation
Maritime Mobile	Ship & Coast	2-30	2.8	0-2	unknown	Whip/V	J3E, simplex operation
Maritime Mobile	Ship & Coast	30-50	16	2	30-100	Whip/V	J3E, simplex operation
Aeronautical Radionavigation Services (ARNS)	Aircraft	74.8-75.2	0.8-6	-2.5 - 2	0-3000	Blade/H	A2A
Standard Freq. & Time Signal	In-home	2-30		0	6-30	Whip/V	A2
Radio Astronomy	Fixed	13.36-13.41 37.5-38, 73-74.6		23	100	Parabolic	Receive Only

Legend: Freq. = Frequency, **Pol.** = Polarization, **V** = Vertical, **H** = Horizontal
J3E = Single sideband with suppressed carrier, using a single channel containing an analog signal for telephony
F3E = Frequency modulated, using a single channel containing an analog signal for telephony
N0N or P0N = No modulating signal and no information transmitted
A2A = Double sideband using a single channel containing a quantized or digital signal with modulating subcarrier

4.6 SENSITIVE OR PROTECTED FREQUENCIES IN THE 1.7-80 MHz BAND

All spectrum regulatory organizations, including the FCC, NTIA, and the ITU, have long recognized that certain frequencies or bands in the radio spectrum, including the 1.7-80 MHz range, require special protection because of the critical or sensitive functions they support. Some of these functions include: distress and safety, standard frequency and time signal, radio astronomy, and radionavigation.

Three parts of the FCC Rules and Regulations, Parts 15, 80 and 87, provide specific lists of protected frequencies in this range. While all three impose limitations on licensed services or unlicensed intentional radiation devices in these bands, the concept may be relevant as well to the unintentional radiation from BPL systems because of the interference risks. The ITU Radio Regulations, Appendices 13 and 15, provide similar lists of protected frequencies. Table 4-9 summarizes and compares these lists of protected frequencies adopted by the FCC and ITU, showing the various functions being protected.

Based on these FCC and ITU sources, NTIA proposes a candidate list of 41 protected frequencies for BPL systems. This candidate list, shown in Table 4-9, comprises a total of less than 6% of the spectrum in the 1.7-30 MHz range and about 5.5% of the spectrum in the 30-80 MHz range. Operations supported by these frequencies are vital to certain federal communications requirements such as safety of life and property, disaster communications, reception of weak galactic signals by the radio astronomy community, and safety of flight. In some cases, these frequencies or frequency bands provide for essential communications incident to or in connection with disasters or other incidents that involve loss of communication facilities normally available or that require the temporary establishment of communication facilities beyond those normally available.

The applicability of these candidate sensitive frequencies or others with respect to BPL systems will be examined further in the NTIA Phase 2 effort.

Table 4-9: Lists of Protected Frequencies Recognized by the FCC and ITU in the 1.7-80 MHz Band

FCC 15.205	FCC 87.149 80.229	ITU-R App15 (GMDSS)[36]	ITU-R App 13 (Non-GMDSS)	ITU-R App 27 AM(R) S	FUNCTION	CANDIDATE LIST OF PROTECTED FREQUENCIES FOR BPL
	2091					
2173.5-2190.5	2174.5, 2182, 2187.5	2174.5 2182 2187.5	2174.5 2182 2187.5		NBDP-COM RTP-COM DSC	2173.5-2190.5
	2500				SF&TS	2495-2505
				2850-3025	ATC	2850-3025
	3023	3023	3023		AERO-SAR	3023-3026
				3400-3500	ATC	3400-3500
	4000					
4125-4128	4125-4128	4125	4125		RTP-COM	4125-4128
4177.25-4177.75	4177.5	4177.5	4177.5		NBDP-COM	4177.25-4177.75
	4188					
4207.25-4207.75	4207.5	4207.5	4207.5		DSC	4207.25-4207.75
				4650-4700	ATC	4650-4700
	5000				SF&TS	4995-5005
	5167.5					
				5450-5480	ATC	5450-5480

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[36] ITU RR AP13-8 "... any emission capable of causing harmful interference to distress, alarm, urgency or safety communications [on these frequencies] is prohibited."

FCC 15.205	**FCC 87.149 80.229**	**ITU-R App15 (GMDSS)[36]**	**ITU-R App 13 (Non-GMDSS)**	**ITU-R App 27 AM(R) S**	**FUNCTION**	**CANDIDATE LIST OF PROTECTED FREQUENCIES FOR BPL**
				5480-5680	ATC	5480-5680
	5680	5680	5680		AERO-SAR	5680-5683
6215-6218	6215	6215	6215		RTP-COM	6215-6218
6267.75-6268.25	6268	6268	6268		NBDP-COM	6267.75-6268.25
	6282					
6311.75-6312.25	6312	6312	6312		DSC	6311.75-6312.25
		6314			MSI-HF	
				6525-6685	ATC	6525-6685
	8257					
8291-8294	8291	8291	8291		RTP-COM	8291-8294
	8357.5					
8362-8366	8364		8364		Survival Craft	8361-8367
8376.25-8386.75	8375, 8376.25-8386.75	8376.5	8376.5		NBDP-COM	8376.25-8386.75
8414.25-8414.75	8414	8414.5	8414.5		DSC	8414.25-8414.75
		8416.5			MSI-HF	
				8815-8965	ATC	8815-8965
	10000				SF&TS	9995-10005
				10005-10100	ATC	10005-10100
				11275-11400	ATC	11275-11400

FCC 15.205	FCC 87.149 80.229	ITU-R App15 (GMDSS)[36]	ITU-R App 13 (Non-GMDSS)	ITU-R App 27 AM(R) S	FUNCTION	CANDIDATE LIST OF PROTECTED FREQUENCIES FOR BPL
12290-12293	12290	12290	12290		RTP-COM	12290-12293
	12392					
12519.75-12520.25	12520	12520	12520		NBDP-COM	12519.75-12520.25
	12563					
12576.75-12577.25	12577	12577	12577		DSC	12576.75-12577.25
		12579			MSI-HF	
				13260-13360	ATC	13260-13360
13360-13410	13360-13410				Radio Astronomy	13360-13410
	15000				SF&TS	14990-15010
	16000					
16420-16423	16420	16420	16420		RTP-COM	16420-16423
	16522					
16694.75-16695.25	16695	16695	16695		NBDP-COM	16694.75-16695.25
	16750					
16804.25-16804.75	16804	16804.5	16804.5		DSC	16804.25-16804.75
		16806.5			MSI-HF	
				17900-17970	ATC	17900-17970
		19680.5			MSI-HF	
	20000				SF&TS	19990-20010

FCC 15.205	FCC 87.149 80.229	ITU-R App15 (GMDSS)[36]	ITU-R App 13 (Non-GMDSS)	ITU-R App 27 AM(R) S	FUNCTION	CANDIDATE LIST OF PROTECTED FREQUENCIES FOR BPL
				21924-22000	ATC	21924-22000
		22376			MSI-HF	
	25000				SF&TS (Not Currently Used)	
25500-25670	25500-25670				Radio Astronomy	25500-25670
		26100.5			MSI-HF	
37.5-38.25 MHz					Radio Astronomy	37.5-38.25 MHz
73-74.6 MHz					Radio Astronomy	73.0-74.6 MHz
74.8-75.2 MHz					Aeronautical – Instrument Landing System Marker Beacons	74.8-75.2 MHz

Legend:
AERO-SAR = Aeronautical Search and Rescue
ATC = Air Traffic Control
DSC = Digital Selective Calling
MSI-HF = Marine Safety Information – High Frequency
NBDP-COM = Narrow Band Direct Printing – Communications
RTP-COM = Radio Telephony – Communications
SF&TS = Standard Frequency and Time Signal

4.7 CONCLUSION

Frequencies between 1.7 MHz and 80 MHz are allocated to a total of 13 radio services, with the Federal Government using all but two, in varying degrees, to satisfy various mandated mission requirements. 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 were chosen as the focus of this Phase 1 study. Characteristics of fixed and mobile equipment can largely be grouped 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), and proposes that they receive special protection from interference by licensed and/or unlicensed transmitters.

SECTION 5
CHARACTERIZING BPL EMISSIONS THROUGH COMPUTER MODELING AND MEASUREMENTS

5.1 INTRODUCTION

This section explains theoretical factors in BPL signal radiation and propagation and summarizes key findings from NTIA's measurement and modeling efforts to date (Appendix D and E). Environmental RF noise levels are discussed insofar as ambient noise is an important factor in the evaluation of interference. These considerations are applied in Section 6 in evaluations of risks of interference to representative Federal Government systems.

5.2 THEORY

5.2.1 Relevant Radiation Theory

In the subject range of frequencies, 1.7 – 80 MHz, BPL devices and the power lines that carry BPL signals have the potential to act as unintentional radiators. The amount of radiation depends on the symmetry of the network at radio frequencies. Symmetry is defined in terms of impedance between conductors and ground. If for a two wire line, the impedance between each conductor and ground is equal, the line is symmetrical or balanced. A lack of symmetry leads to an unwanted, common mode signal. Common mode currents flow in parallel in both conductors, while return portions flow through ground. Balanced lines are necessary for differential mode transmission in which currents are equal in magnitude and flow in opposite directions on the signal conductors. The fields radiating from these conductors tend to cancel each other in the far field area. On parallel or nearly parallel, non-concentric conductors, common mode currents at radio frequencies produce more radiation than differential mode currents.[37]

Any impedance discontinuity in a transmission line, which may arise from a BPL coupling device, a transformer, branch or a change in the direction of the line, may produce radiation directly or by reflections of signals forming standing waves that are radiated from the conductors. Even if the RF energy is injected into one of two or more conductors, the remaining wires generally act as parasitic radiators and, therefore, the lines can act as an array of antenna elements at certain frequencies. Radiation may come from one or more point radiators corresponding to the coupling devices as well as one or more power lines. Numerical Electromagnetics Code (NEC), as discussed later in this section, and similar method of moments models, as used with realistic physical arrangements and impedances of the power lines, have been applied to simulate the

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[37] *See e.g.*, *Physical and Regulatory Constraints for Communication over the Power Supply Grid*, M. Gebhardt, F. Weinman and K. Dostert, IEEE Communications Magazine, May 2003, pp. 84-90.

current distribution on the power lines and the radiated fields. Modeling results shown in Appendix E and discussed in this section indicate that, depending on radio antenna polarization, standing waves generated by an impedance discontinuity will produce radiation at numerous points along the power lines.

The space surrounding a radiator can be divided into three regions: the reactive near-field, the radiating near field and the far field. The boundaries of the radiating near field are often given as $0.62 \cdot \sqrt{\left(D^3/\lambda\right)} < r < 2 \cdot D^2/\lambda$, where “D” is the largest linear dimension of the radiator, “r” is the distance from the radiator, λ is the wavelength, and these dimensions and wavelength are expressed in common units (typically meters). In the near-field region, also called Fresnel region, the field pattern is a function of the radial distance. Also, it should be remembered that the criteria for defining these field boundaries are not rigid and the field spatial distributions change very gradually as the boundaries are crossed.[38] Of course, “D” depends on the extent of the line responsible for most of the radiation. For most BPL applications, the victim receivers will be in the radiating near field. However, for interference through sky waves, and at distances seen by aircraft receivers, far fields are important.

5.2.2 Propagation Modes

The dominant, relevant propagation modes in the 1.7 – 80 MHz frequency range are ground wave, space wave and sky wave. The ground wave signal can be a composite of a direct wave, a ground reflected wave and/or a surface wave. For a direct wave from a point source (*i.e.*, infinitesimal D, yield essentially no near field), the received power is inversely proportional to the square of distance (r^2). If the radiator is located several wavelengths above ground, the direct wave and the ground reflected waves are considered as separate rays and the peak combined received power is inversely proportional to r^4. If the radiator is close to ground in terms of wavelength (*e.g.*, BPL below 40 MHz), it is no longer appropriate to consider separate rays. A surface wave propagates close to ground by inducing currents which flow in the ground and support (or potentially interfere with) short range communications. However, horizontally polarized surface waves are heavily attenuated, and, for any polarization, surface wave propagation exhibits substantially higher rates of attenuation with distance than the direct wave, especially at VHF frequencies (*i.e.*, above 30 MHz). In general, sky or ionospheric waves are important up to about 30 MHz, above which propagation is sporadic. Sky wave propagation may be represented by rays which are refracted and reflected from the ionosphere and is responsible for signal transmission to distances ranging from hundreds to thousands of kilometers, depending on elevation angle of the radiated field, frequency and variability of the ionosphere. The ionosphere, which ranges from about 60 to 600 km in height, acts as a low-conductivity dielectric.[39]

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[38] *See e.g.*, Antenna Theory, Analysis and Design, C. A. Balanis, John Wiley, 1982.

[39] *See e.g.*, Propagation of Radiowaves, Edited by M. P.M Hall, L. W. Barclay and M. T. Hewitt , IEE, London, 1996.

Space wave propagation occurs on line-of-sight signal paths above the height of the power lines where surface and reflected waves are received at magnitudes much less than the direct wave magnitude. Friis, or free-space loss typically is assumed for these paths although in most cases, reflected waves (multipath effects) can yield a degree of location variability of the received signal magnitude.

To summarize, propagation mechanisms of concern for BPL emissions toward or below the power line horizon will be by ground waves. For emissions in directions above the power line horizon, the propagation may be either by space and ground waves for shorter distances or by sky waves for larger distances.

Sky waves suffer large losses mainly due to ionospheric absorption and polarization coupling losses. In a dense deployment of BPL systems, there may be aggregation of co-frequency BPL emissions toward the ionosphere. Emissions in directions above the power lines may aggregate via sky wave or via ground wave and space wave, and emissions toward or below the power lines generally may aggregate via ground wave. Preliminary modeling of power lines (Appendix E) suggests that there is relatively strong radiation in directions above the power line horizon (*i.e.*, higher than radiation toward directions below the power lines), and so, aggregation of BPL signals at locations above power lines may be more significant than at lower heights where BPL signal propagation is less efficient.

5.3 BPL MEASUREMENTS

5.3.1 Approach

During the period August to November 2003, NTIA performed measurements with a goal of quantifying key aspects of BPL signals. The measurements were conducted at three sites where BPL systems are currently deployed for testing and are serving customers. All three of the sites had BPL signals on the MV wires and two of the sites also used BPL on the LV wires. The types of measurements of fundamental emission, as detailed in Appendix D, consisted of the following:

1. Identification and characterization of BPL signals.
2. BPL signal power at locations along and near an energized line.
3. BPL signal power at various distances away from an energized line.
4. BPL signal power comparisons using peak, average and quasi-peak detectors.
5. BPL signal power at different receiving antenna heights and polarization orientations.
6. Amplitude probability distributions (APDs) of the BPL signal.

These measurements were made using NTIA's instrumented measurement vehicle and either an antenna positioned 10 meters above the ground on a telescopic mast, or 2 meters above the ground on a wooden tripod. Four types of antennas were used. A small discone antenna over a small ground plane was used to measure the electric fields above 30 MHz. Below 30 MHz, small shielded loops were used to measure the magnetic fields, and a rod antenna over a small ground plane was used for measuring the electric fields. To measure the received power that would be seen by a mobile unit, an off-the-shelf 2.1 meter base-loaded whip antenna was mounted on the roof of a vehicle at an approximate height of 1.5 meters. The whip antennas were narrow-banded so several of them were used to cover the measurement frequencies.

5.3.2 Identification and Characterization of BPL Signals

All measurements were preceded by system calibration as described in Appendix D. At the three BPL deployments, the BPL signals were identified and analyzed by looking at the spectrum and temporal characteristics of the BPL transmission as described in the Section D.3.1.

5.3.3 BPL Signal Power Along an Energized Power Line

The measurement results for BPL signal power along an energized power line are given in Section D.3.2. The peak received power due to the electric field generated by BPL signals was measured with a rod antenna at a height of 2 meters at various points along a power line. Three mutually orthogonal components of the electric field were measured. These measurements indicate that there is a strong BPL electric field (relative to noise) along and near the BPL power line and in general, the field does not measurably decay with distance from the device (along the power lines). In at least one case, the electric field actually increased with increasing distance from the BPL device. This is thought to be due to BPL signal reflection by one or more impedance discontinuities and the generation of standing waves. In general, the location variability in the field is thought to be due to the presence of standing waves in the current distribution along the power line.

The magnetic field using a loop antenna at 2 meters height was not measurable along the power line at most locations as indicated in Section D.3.2.

The peak received power due to the electric field was measured with the whip antenna mounted on the top of a vehicle at various distances along the power lines. The results are similar to those obtained from the electric field measurements using the rod antenna.

The measurements at one site at a frequency of 32.70 MHz and at a height of 10 meters indicate that after an initial decrease of received power with increasing distance from the BPL device along the power line, the power remains at about the same level with increasing distance along the power line.

5.3.4 BPL Signal Power Away from the Energized Power Line

The measurement results for BPL signal power away from an energized power line are given in Section D.3.3. The peak received power due to the magnetic field was measured at one site with a loop antenna directly under the power line at a height of 2 meters and a weak BPL magnetic field was detected on four frequencies (4.4 MHz, 8.8 MHz, 23.8 MHz, and 28.8 MHz). At a distance of approximately 50 meters perpendicular to the power line, BPL signals were received at only 28.8 MHz. The peak received power due to the electric field away from the power line was also measured with the vertically polarized whip antenna at 4.26 MHz, 7.30 MHz and 28.78 MHz. The results indicate that there is a decrease in received power with an increase in distance from the BPL device and power line, but the decrease was not monotonic at 28.78 MHz. The received power and the manner in which it decreased with increasing distance varied substantially at different frequencies.

At the same site, the peak received power due to the vertical electric field was measured with the whip antenna on a different path at various distances from the power line. Even though the received power generally decreases with increasing distance, there are some amplitude oscillations. This non-monotonic behavior is thought to be mainly due to near-field effects and not ground reflections; however, underground power lines that branched from the BPL transmission line were noted to run across the measurement path in the vicinity of a local peak measured signal power level.

The whip antenna was used to measure peak received power due to the vertical electric field at two other sites. At one site, the signal decreased to an immeasurable level within 600 feet. At the second site, comprising a complex arrangement of power lines with many turns and BPL devices, the signal power significantly exceeded the noise power beyond 1,500 feet (approx. 500 m).

Measurements were also conducted using a discone antenna with vertical polarization at a height of 3.4 meters above ground in another power line configuration. Pulse power measurements were made at three different frequencies (35.05 MHz, 39.93 MHz and 45.40 MHz) at various distances from the power line. In this case, the results indicate that the received power decreases as distance from the power line (r) increases at a rate lower than would be predicted by $1/r^2$ (space wave loss).

5.3.5 Measurement of BPL Using Various Detectors

Two sets of measurements were made to compare effects of using three different detectors: peak, average and quasi-peak. The results are provided in Table 5-1.

Table 5-1: Measured peak, average and quasi-peak levels

Frequency	Peak	Average	Quasi-Peak
22.96 MHz	-74 dBm	-81 dBm	-76 dBm
28.30 MHz	-60 dBm	-65 dBm	-65 dBm

5.3.6 Measurement of BPL Using Different Antenna Heights

Measurements of BPL emissions from MV lines were performed using two different antenna heights. The results show that in general, the measured power levels were substantially higher at the greater antenna height. For example, the 100% duty cycle power measured at a frequency of 32.70 MHz and at a 10 meter antenna height was 4.8 to 10.7 dB greater than at 2 meters. The pulse power at a 10 meter antenna height for this same frequency was 8.2 to 15.1 dB higher than at 2 meters.

Measurements were also made of emissions from a LV power line carrying BPL signals from a LV coupler near a pole-mounted transformer to a house (Section D.3.5). The phase lines were twisted about the neutral line. A loop antenna was oriented to maximize the reception of the horizontal magnetic field. The antenna was located at 8.7 meters from the utility pole near the midpoint of the LV line and measurements were made at antenna heights of 2 meters and 10 meters at frequencies of 5 MHz, 6.43 MHz, 10.74 MHz and 18.38 MHz, each with resolution bandwidths of 3 kHz, 10 kHz and 30 kHz. The results indicate that measured power at a 10 meter height is always larger than the power measured at 2 meter height (by 3-9 dBm). Table 5-2 summarizes results from both these measurements for 100% duty cycle power where meaningful comparisons could be made.

Table 5-2: Measured 100% Duty Cycle Power at Two Different Antenna Heights

Frequency	Bandwidth	2 meter height	10 meter height	Difference
6.43 MHz	3 kHz	-113.3 dBm	-108.7 dBm	4.6 dB
6.43 MHz	10 kHz	-109.1 dBm	-106.4 dBm	2.7 dB
18.38 MHz	3 kHz	-115.3 dBm	-106.6 dBm	8.7 dB
32.70 MHz	30 kHz	-101.1 dBm	-96.3 dBm	4.8 dB
32.70 MHz	10 kHz	-111.4 dBm	-100.7 dBm	10.7 dB

5.3.7 Measurements of BPL Amplitude Probability Distributions (APDs)

Several APDs were measured at two of the three BPL deployment sites and the results are given in Section D.3.6. At one site, APD measurements were conducted at two frequencies, 32.70 MHz and 42.47 MHz, at three different resolution bandwidths: 200 kHz, 30 kHz and 10 kHz. A discone antenna with vertical polarization located at 10 meters above the ground and 11.6 meters from the power line was used to measure the APDs and the 100% duty cycle power levels were derived from the APDs. The results show that the 100% duty cycle power is higher for higher resolution bandwidth for the same frequency, and that the power levels are proportional to bandwidth (confirming that 100% equivalent power was accurately estimated from APDs).

With BPL loaded on the power lines, pulse-power measurements and APDs were conducted at 32.70 MHz with two different resolution bandwidths (30 kHz, and 10 kHz) and four different antenna orientations. A discone antenna was located at various direct distances from the power lines and backhaul point (x and y respectively) and set at a vertical height from the ground of 2 meters. The results indicate that the measured power for all four antenna orientations was at similar levels for the same location. A long wire antenna is linearly polarized, but the direction of the linear polarization is not the same in all parts of the pattern.[40] Therefore, in this case, similar power was measured for one set of coordinates, whereas, for another set of coordinates, the measured power for vertical polarization was larger than that for horizontal polarization.

The occasional sampling of environmental noise power levels shown in APDs with the BPL system turned off were lower than the levels predicted by ITU-R Recommendation P.372-8. Thus, the sites for these measurements have relatively low noise power levels and use of the higher noise power levels predicted by ITU-R Recommendation P.372-8 in our analyses may bias results toward underestimation of interference levels.

5.4 ANALYTICAL MODELS OF POWER LINE RADIATION

5.4.1 Numerical Electromagnetics Code (NEC)

NEC is a computer program for analyzing the electromagnetic response of antennas and scatterers.[41] The code is based on the numerical solution of integral equations by the method of moments. An electric field integral equation (EFIE) is used for modeling thin wires and a magnetic field integral equation (MFIE) is used for closed conducting surfaces. This form of simulation breaks the structure of interest down into *moments* or line segments (for solid structures, a wire mesh is used). The current in each segment is calculated and the resulting electromagnetic fields are derived.

NEC 4.1 is the latest version of the NEC, which has been developed and improved over the years at Lawrence Livermore National Laboratory. NEC codes offer features, which include excitation by voltage sources or plane waves, lumped or distributed loading, and networks or transmission lines. The code output includes current distributions, impedances, power input, dissipation, efficiency, radiation patterns, gains and scattering cross section. Among other output, it can be used to produce far-field

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[40] *See e.g.*, Antenna Theory, Analysis and Design, C. A. Balanis, John Wiley, 1982, Chapter 9.

[41] Numerical Electromagnetics Code – NEC-4 Method of Moments, Part I: User's Manual, Part II: NEC Program Description - Theory, Part III: NEC Program description – Code, Gerald J. Burke, January 1992.

(power gain) antenna patterns, near-field electric and magnetic field strength, groundwave field strengths at different distances from an antenna, antenna input impedance and total radiated power. NEC-4.1 can be used to model structures over a ground surface with a wide range of characteristics, insulated wires, impedance and conductivity in loads and wires, and various forms of electromagnetic excitation in a structure, and structures in dielectric media other than air. However, it is important to design and input the physical model correctly, precisely portraying parameters such as segment length, diameter, and wire spacing, insofar as these parameters greatly influence results in many cases. It is important that segment length be small enough that the model is well-behaved (converges) and results change little despite further shortening of the segments.

The most relevant limitation of NEC simulation for the purposes of studying BPL is the computer Random Access Memory (RAM) and computational time necessary to simulate very large structures. Computer memory needed to simulate a structure is directly proportional to the square of the number of line segments used in the structure model, as the calculations are run in a matrix. Because segment length is dictated in part by the frequency of interest, the number of line segments needed to simulate a part of a power grid can be very large. The time required to fill and factor the matrix can also become very large, depending upon the number of segments. Additionally, running a NEC simulation can become prohibitively time-consuming if the size of the matrix becomes so large that the computer's core memory is insufficient, and disk swapping occurs.

5.4.2 Modeling of Power Lines by NEC

Extensive work was done at NTIA's Institute for Telecommunication Sciences (ITS) on a typical arrangement of three phase MV power lines.[42] The modeled power lines consisted of three horizontal parallel copper wires 8.5 meters (27.9 feet) above a ground with average characteristics (conductivity σ = .005 mS, relative permittivity ε_r = 15). Each wire had a diameter of 0.01 meter (approximating AWG gauge 4/0) and the wires were separated in the horizontal plane by 0.60 meter. The feed point was at the center of one of the wires, which ran parallel to the x axis (y = 0). The equivalent of a BPL coupler was placed on the center segment of the wire and was modeled as a voltage source of 1 volt in series with a resistor that represented the source impedance. The other two phase wires ran parallel to the x axis at y = 0.6 and y = 1.2 meters.

All three orthonormal components of electric and magnetic field intensities (E_x, E_y, E_z in dBμV/m, H_x, H_y and H_z in dBμA/m) in the near field were plotted in a plane two meters above the ground at frequencies of 2 MHz, 10 MHz, and 40 MHz. Three different line lengths of 100 m, 200 m and 340 m were used with four different impedance conditions for the source and loads. The impedance conditions were as follows: source impedance of 150 Ω with load impedance of 50 Ω and 575 Ω, and

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[42] *See* The Lineman's and Cableman's Handbook, E. B. Kurtz and T. M. Shoemaker, Fifth Edition, McGraw Hill, 1976.

source impedance of 575 Ω with 50 Ω and 575 Ω load impedances. The field strengths were plotted as contours in 5 dB increments for four different ranges of x and y coordinates, *i.e.*, 0 to 20 m, 0 to 200 m, 0 to 1000 m and 0 to 18000 m. The far field radiation patterns were also plotted at several azimuth angles.

Several representative far field radiation patterns and near field plots for three components of the electric field E_x, E_y and E_z are presented in Appendix E for various combinations of line length, frequency, source impedance and load impedance. The complete results of the above simulation work are available at NTIA.

The far field patterns indicate that there are more lobes in the radiation pattern as the ratio of line length to wavelength (L/λ) increases. Varying source and load impedances have minor effects. The transmission line analyzed here has a characteristic impedance of approximately 575 Ω, therefore, when the load and source impedance are both 575 Ω, the line acts as a traveling wave antenna. The highest radiation was generally associated with the combination of source impedance of 150 Ω and load impedance of 50 Ω which corresponds to the largest mismatch among the cases considered here. In the azimuth angle of 0º, *i.e.*, along the direction of the power lines, the elevation pattern has several lobes and the largest lobe is generally around 30º or lower elevation above the horizontal plane containing the power lines. The larger the L/λ ratio, the lower is this main elevation angle. However, as the azimuth angle increases to 90º, there are fewer lobes and the maximum gain is in or near the vertical direction.

Tables E-1, E-2 and E-3 summarize the results of the near field plots at 2 meters above the ground for three components of the electric field for various combinations of input parameters. Several general trends can be seen from the near field plots at 2 meters from ground near a typical power line configuration. Table E-1 summarizes the characteristics of the vertically polarized electric field, $E_{z.}$ For the vertical electric field E_z, the peak field is never at the BPL source; instead, 2 to 20 local peaks occur near and under the power lines. The first peak occurs at approximately λ/4 down the wire from the device. Several peaks of slightly higher strength occur down the wire at λ/2 intervals. The number of peaks depends on the L/λ ratio. As frequency increases, the peak decreases, but the number of local peaks along the line increases. The peaks gradually diminish down the line because of RF attenuation and radiative losses. As mentioned earlier, varying source and load impedances has only a minor effect on peak field strength (less than 5 dB min-max variation), and peaks generally decrease as the source & load impedances are changed as follows (in decreasing order of peak vertical electric field strength): 150 & 50 Ω, 150 & 575 Ω, 575 & 50 Ω, 575 & 575 Ω.

Tables E-2 and E-3 summarize characteristics of horizontally polarized electric fields E_x and $E_{y.}$ The peak horizontally polarized field is never at the BPL source for the perpendicular case (as was the case for vertical polarization); instead, 2 to 24 local peaks occur at various distances from the BPL source with the first peak occurring at approximately 0.75λ and subsequent peaks occurring at approximately λ/2 intervals occurring at about λ/4 on either side of the wire. In contrast, the peak field is always at the BPL source for the parallel case with additional peaks down the line of equal or lower field strengths.

The far field patterns, the near field surface plots and measurements along power lines indicate that there are standing waves along the power line. Various other representative power line configurations need to be studied with sensitivity analysis with respect to line length, position of the source, position of other conductors in the vicinity, source and load impedances and frequency need to be done. Electric fields at other heights have to be calculated. Limited measurements have indicated that the electric fields at 10 meter high antenna are much higher than that at 2 meter high antenna. To facilitate further investigations, NTIA is developing software for statistical analysis of the spatial distribution of electric field strength.

5.4.3 Effects of a Neutral Line

In the case of power line simulation for a BPL system, the most obvious consideration is the addition of parallel wires, such as a neutral (assuming the three-phase lines are arranged in a "wye" configuration) and telephone and cable wires, which are typically found under the neutral. To determine the effects of a neutral line on the model considered above, sample simulations with and without a neutral wire were run and the resulting outputs compared to one another.

As can be seen in Figure 5-1 for a frequency of 4 MHz, the addition of a grounded neutral line does have an impact on the model output. This impact is dependent upon frequency, and primarily manifests itself in amount of gain found in the main lobes of the far-field radiation pattern. The change in gain is less than 2 dB, and the overall shape of the radiation pattern remains the about the same. The comparisons for frequencies 15 MHz, 25 MHz and 40 MHz are given in Appendix E, showing that the change in gain becomes less at higher frequencies. Equally importantly, at all of the frequencies examined, the addition of a neutral tended to *increase*, not *decrease*, the overall gain of the power line radiation. Additional computations of electric field magnitude also demonstrated an increased electric field around the modeled power line in the presence of a multi-grounded neutral. This would seem to indicate that the omission of a grounded neutral from the NEC power line model would tend to produce a more conservative result, *i.e.*, produce less radiation.

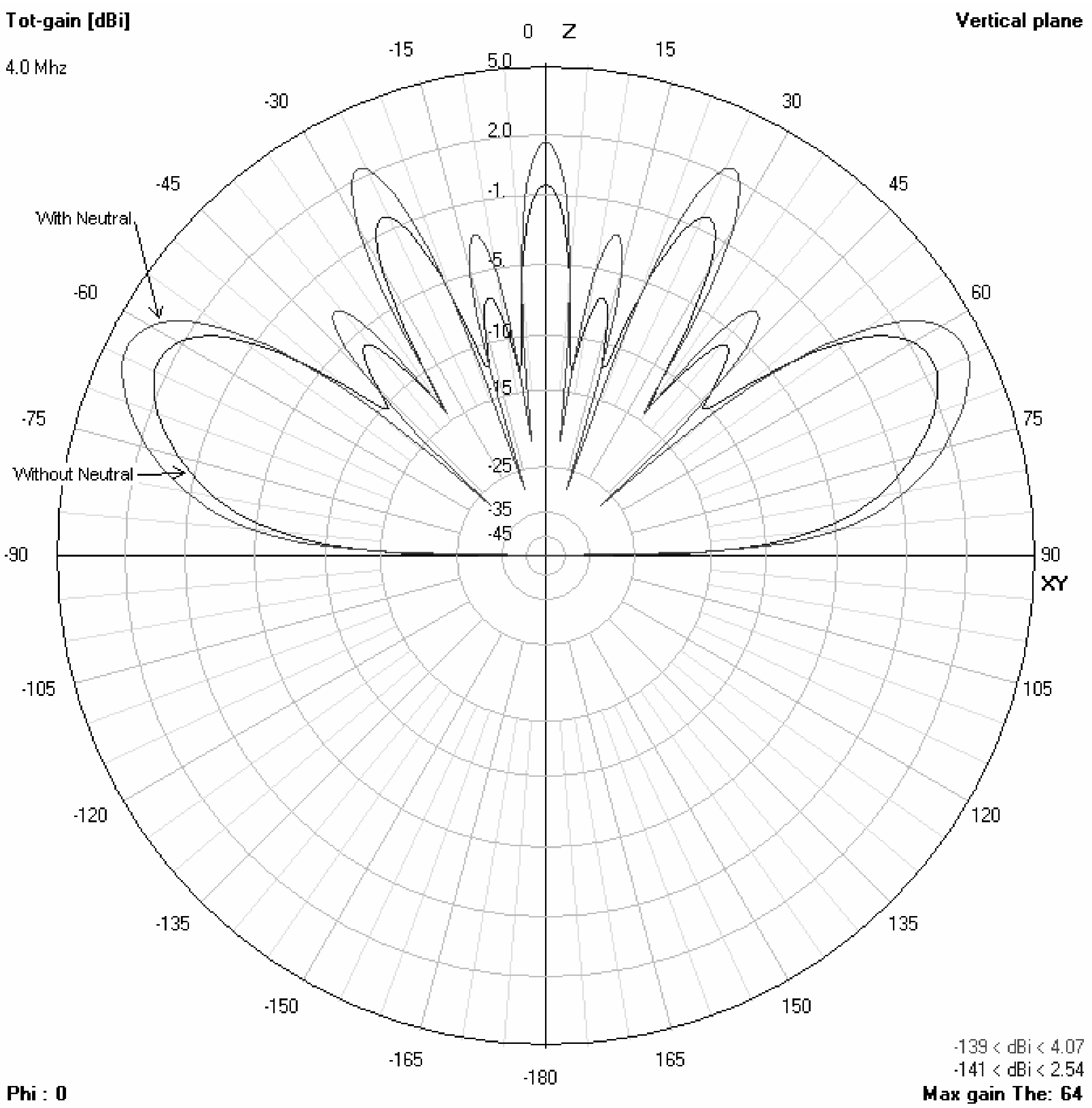

Figure 5-1: Comparison of NEC model with and without a parasitic multi-grounded neutral at 4 MHz.

5.4.4 Environmental Noise

The standard reference for radio-frequency noise is the ITU-R Rec. P.372-8. It includes detailed formulas and charts for predicting median ambient noise at any geographic point due to atmospheric, man-made and galactic noise sources as well as temporal variability. The noise at any given location varies hourly, daily, and seasonally, and predicted levels depend upon frequency, time of day, time of year and the local environment (ranging from industrial to quiet rural conditions).

Noise is especially at issue on lower frequencies in the 1.7 – 80 MHz range, because total ambient noise generally increases as the frequency decreases. In general, the level of ambient noise (the "noise floor") determines the strength of the received signal necessary to carry out communications in the absence of interfering signals. Substantial noise can make HF communications difficult or even impossible, depending upon the strength of the received signal.

The causes of HF radio noise are broadly categorized into man-made, atmospheric, and galactic sources. Each contributes to the overall noise level, and the relative contribution of each source of noise is dependent upon several factors.

Man-made noise is generally produced by electrical devices, ranging from overhead power lines to automobile ignition and household appliances. The level of man-made noise, as statistically characterized, is mainly a function of the area. Industrial areas, for example, tend to have much higher levels of man-made noise than remote rural areas. ITU-R Rec. P.372-8 specifically categorizes areas as business, residential, rural and quiet rural noise environments, in order of decreasing median noise levels. Man-made noise tends to have greater levels at higher frequencies in the 1.7 – 80 MHz range (*e.g.*, typically, above 20 MHz), although this is not always the case for all environments.

Atmospheric noise is primarily produced by lightning. Trends in this form of noise are heavily dependent upon geographic location, time of day and time of year. Areas in the Midwestern United States, for example, tend to see much higher atmospheric noise levels in the afternoon during spring and summer than do other parts of the country. Atmospheric noise tends to account for the bulk of noise at lower HF frequencies.

Galactic noise is radio noise produced by emission from celestial bodies (*e.g.*, stars) in our own galaxy, and tends to become a factor only at higher frequencies and low-noise locales. Galactic noise can serve as an effective "best case" noise level for low-noise conditions, as its level is fairly constant at a given frequency and substantial in relation to relatively low median levels of atmospheric and man-made noise.

The data in ITU-R Rec. P.372-8 is incorporated into software available from the ITU web site; that software was used in this report to obtain ambient background noise values for use in interference analyses.[43]

Noise levels have high location (spatial) variability in addition to temporal variability. For example, a business location in the Midwest United States during a summer afternoon can experience relatively high levels of noise, but a rural locale in Alaska on a winter morning can see low noise levels approaching that of the galactic background noise (Figure 5-2).

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[43] NTIA's *NOISEDAT* program is available from the ITU web site, URL: http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html.

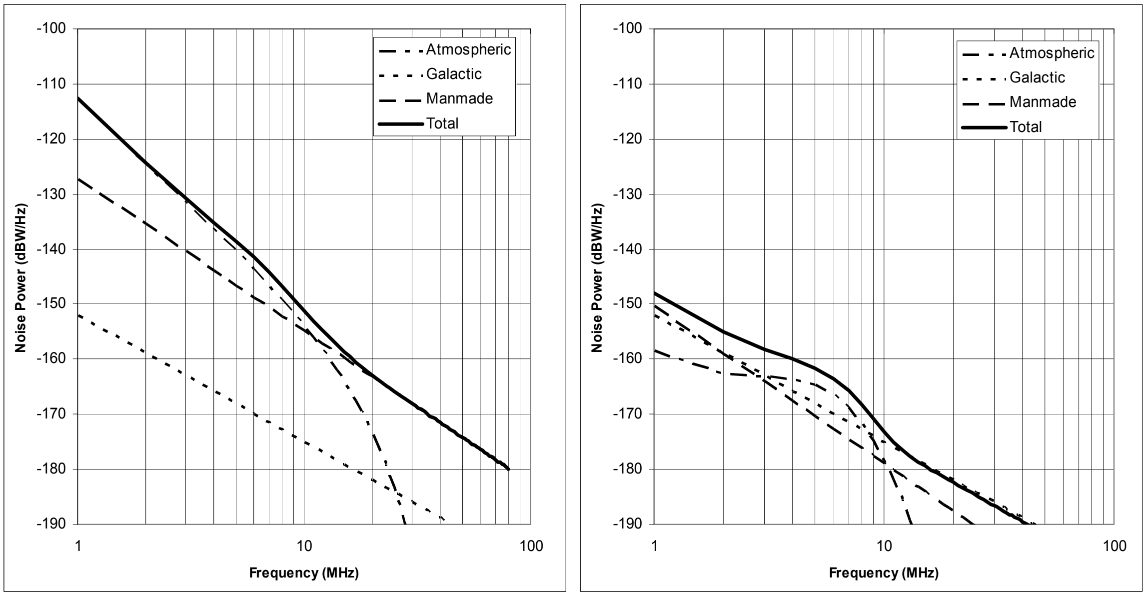

Figure 5-2: Example calculated median background noise levels. Left: industrial environment during the height of thunderstorm season in the Midwest United States. Right: rural Alaskan environment during the winter.

It is instructive to examine typical median noise values in relation to signals meeting FCC Part 15 limits. For the 1.7 - 80 MHz frequency range, Figure 5-3 and Figure 5-4 show typical median levels of receiver system noise power as well as Part 15 field strength limits at the specified measurement distance. For this figure, the noise levels were calculated for 450 locations around the United States assuming a residential environment, and the median of these values for midday in spring were selected. Several geographic points had calculated median noise values that were very close to the overall medians for each frequency; the noise levels for one such point (Kansas City, MO) were used for further calculations in Section 6.

The levels have been translated into electric field strength levels, and both the noise and the Part 15-limit electric field strength levels are presented, assuming they are received by a short vertical monopole antenna. Noise levels shown also include a 12 dB receiver noise factor, referenced to the electric field at the antenna, which (for the most part) is insignificant in relation to the ambient noise levels in question. As can be seen by the figures, signals received at Part 15 limits are 15 dB to 25 dB above the median noise levels.

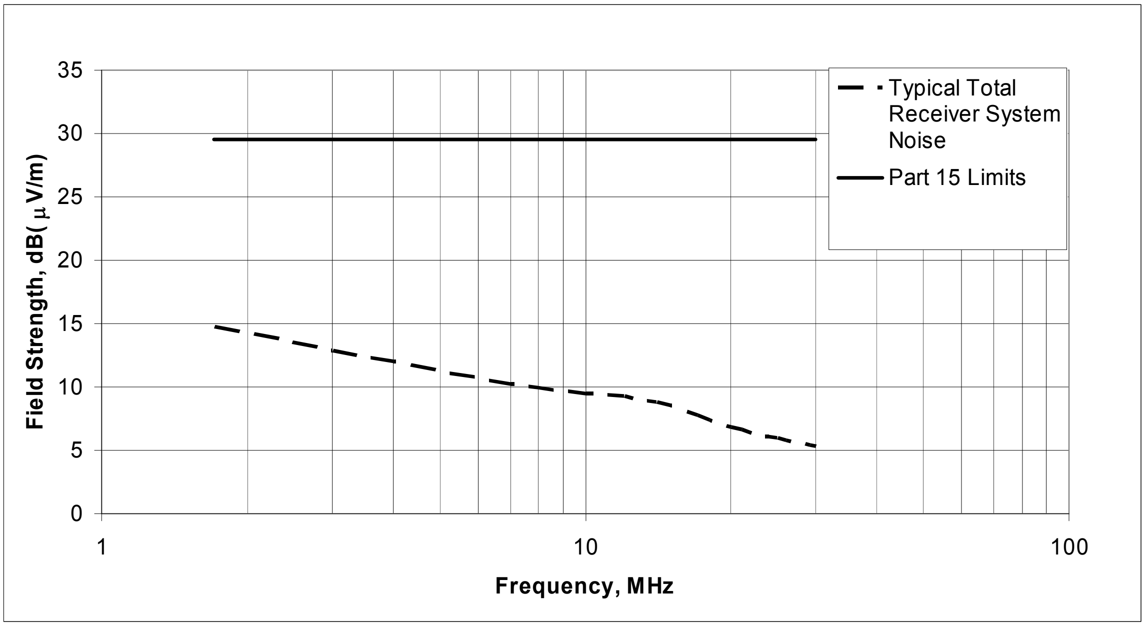

Figure 5-3: Typical median noise field strength and FCC Part 15 limits at 30 meters, 1.705 MHz to 30 MHz, 9 kHz bandwidth.

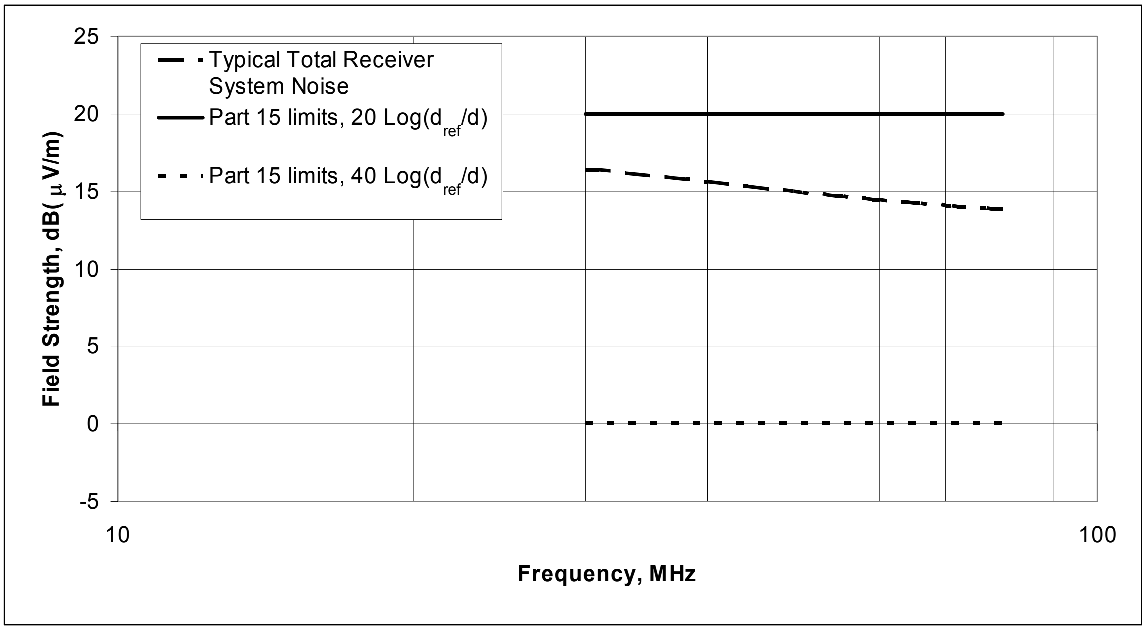

Figure 5-4: Typical median noise field strength and FCC Part 15 limits at 3 meters

5.5 CONCLUSION

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 dominant 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 MV power line using the NEC software program. The far field patterns of the electric field indicate that there are more local peaks in the radiation pattern 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 is never 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 is never 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. The implications of these modeling results are 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 was observed to decay 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.

SECTION 6
ANALYSIS OF INTERFERENCE POTENTIAL TO VARIOUS SERVICES

6.1 INTRODUCTION

The potential impact of a single access BPL device to representative ground-based federal receivers is examined in this section, as is the impact of multiple co-frequency BPL devices on in-flight aeronautical receivers. Because of the wide range of federal systems that are of concern, representative systems in the fixed, land-mobile, maritime and aeronautical services were chosen for analysis.[44] The criteria for evaluating the risk of interference are defined in terms equivalent to moderate and high potential risk levels.

6.2 METHODOLOGY

It was assumed that the BPL systems conform to Part 15 field strength limits using existing BPL compliance measurement practices. Analyses of potential interference to fixed, land-mobile and maritime mobile services used the same methodology. For distances less than one kilometer, a NEC-4.1 model of a three-phase power line driven with a single source was used to estimate electric field strengths, from which received BPL interfering signal power was derived. Analyses of potential interference to aeronautical systems followed a somewhat different approach. An analytical model was developed using a Matlab software shell. In this time simulation, an aircraft operating an aeronautical mobile receiver was flown over and near a BPL deployment area. BPL signal levels were calculated with the aircraft either approaching or directly above the service area.

For all services, the calculated received BPL signal power was used with median background noise values to determine expected (I+N)/N characteristics at the potential radio receiver sites. This parameter was used to illustrate the effective increases in the radio receiver noise power level due to the combination of BPL interfering signals and noise. Calculations were performed at 4 MHz, 15 MHz, 25 MHz and 40 MHz using the same type of BPL system and power line configuration, but in the case of potential interference to aircraft radios, the power lines were randomly oriented.

In these interference calculations, it was recognized that the Part 15 field strength limits are defined in terms of quasi-peak and, as used in interference analyses, the power

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[44] Maritime and aeronautical services also have ground-based receivers. Although not specifically addressed in NTIA's modeling, these stations are expected to be impacted similarly to the fixed service case modeled by NTIA.

levels for noise are root mean square (rms) values. Consequently, to compute a valid ratio of the two, or more specifically the power ratio (interference-plus-noise)-to-noise, (I + N)/N, a quasi-peak-to-rms conversion factor should be applied to the interfering signal power levels so that I and N both are specified as rms values. From a theoretical standpoint, the conversion factor for a pure sinusoidal signal is zero dB, whereas for a non-frequency-agile pulse-like signal having a uniform pulse repetition rate, quasi-peak levels can exceed rms by about 10 dB. BPL signals are expected to fall between these two extremes depending on their duty cycle. Limited measurements documented in Appendix D (See Section D.3.4) for a system employing OFDM modulation, show the conversion factor from quasi-peak to rms to be in the range of 0 to 5 dB. For this preliminary study, quasi-peak values were assumed to exceed rms values by 5 dB. Further study of this factor is needed.

6.3 RISK EVALUATION CRITERIA

6.3.1 Interfering Signal Thresholds

A given level of unwanted (interfering) signal power may cause interference ranging from barely perceptible to harmful levels depending on the magnitude of environmental and equipment noise, the desired signal level, as well as the temporal variability of each of these parameters.[45] Because these and several underlying parameters may vary substantially among locations and over time, the level of interference caused by BPL systems is both temporally and spatially stochastic. Other important considerations are whether the radio system is operating continuously or only occasionally (*e.g.*, as a back-up means of communications) and the speed with which harmful interference can be eliminated should it occur. These considerations relate to risk tolerance.

If the received desired signal is consistently very much more powerful than the noise and unwanted BPL signals, interference will not occur and receiver performance is dictated by the ratio of desired signal to noise power. Likewise, if the received unwanted BPL signal is very weak in relation to environmental noise power, it is unlikely to cause interference and receiver performance is dictated by desired signal and noise power levels. It is instructive to consider both permutations of variables for evaluation of BPL interference risks, namely, the ratio of received BPL signal power to noise power under conditions of strong and weak desired signal levels. As shown in Equations 6-1 through 6-3, below, this interference-to-noise power ratio (I/N) relates directly to an increase in the receiver noise floor or a reduction in the ratio of desired signal-to-total noise (*i.e.*, the ratio (N+I)/N or $-\Delta S/N$).

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[45] "Interference" is defined in 47 C.F.R., §2.1. “Parties responsible for equipment compliance should note that the limits specified in this part will not prevent harmful interference under all circumstances.” 47 C.F.R. §15.15(c).

$$\Delta S/N = -(N+I)/N = -10\log(10^{0.1(I/N)} + 1) \quad (6\text{-}1)$$

$$\Delta S/N \approx -(I/N), \text{ for } I/N > 6 \text{ dB} \quad (6\text{-}2)$$

$$I/N \approx F_u - F_{am},\ F_{am} >> \text{receiver system noise figure} \quad (6\text{-}3)$$

where:

$\Delta S/N$	is the change in signal-to-noise power ratio (dB) caused by the unwanted signal (always a negative number corresponding to a reduction of S/N);
I/N	is the ratio of unwanted signal power to total receiver system noise power (dB), with power levels measured in the same reference bandwidth;
F_u	is the field strength of the BPL signal (dB(μV/m)); and
F_{am}	is the total field strength of all environment radio noise (dB(μV/m)).

In order to minimize potential interference and promote efficient reuse of assigned and adjacent frequencies, by treaty, radio transmission systems should not radiate substantially more power than what is needed to fulfill communications requirements.[46] For most frequency sharing situations, it is well established in international and domestic spectrum management practices to generally limit interfering signal levels in a manner that preserves good control over radio system performance by designers and operators (*e.g.*, (I+N)/N = 0.5 or 1 dB). However, for the interference risk evaluation herein, the focus is on risks under the most typical situations (*i.e.*, the statistical mode of possible scenarios). Less favorable situations are not considered, *e.g.*, where desired signals are near the minimum levels needed to fulfill performance objectives. Thus, in general, it is assumed herein that substantial and perhaps harmful interference will occur in a high percentage of cases if the (I+N)/N ratio exceeds 10 dB (a factor of 10). It is assumed that substantial interference will occur in a smaller but still significant percentage of cases if (I+N)/N is 3 dB (a factor of 2, or a doubling of the "noise floor" of the receiver). There is still a small probability that interference will occur with (I+N)/I of 1 dB or less (I/N of -6 dB or less) and, at the least, unwanted signals at these levels manifest interference during signal fading (*i.e.*, reductions in communications availability). In this phase of study, the extent of geographic areas associated with various levels of (I+N)/N are determined. Levels of (I+N)/N of 3 dB and 10 dB are considered as important interference risk thresholds because these levels relate to moderate and high likelihood of interference, respectively, for unknown levels of desired signal power.

To put the 3 dB and 10 dB (I+N)/N levels (S/N reductions) in perspective, Figure 6-1 illustrates the S/N reduction caused by an unwanted signal at the Part 15 limit level. Figure 6-1 shows that in an environment having the typical median noise power level of a residential environment (Kansas City, MO), field strength at the Part 15 limit would reduce the S/N by over 15 dB.

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[46] *See e.g.*, ITU Radio regulation Nos. 3.3, 4.3, 4.11, and especially 15.2 ("Transmitting stations shall radiate only as much power as is necessary to ensure a satisfactory service.")

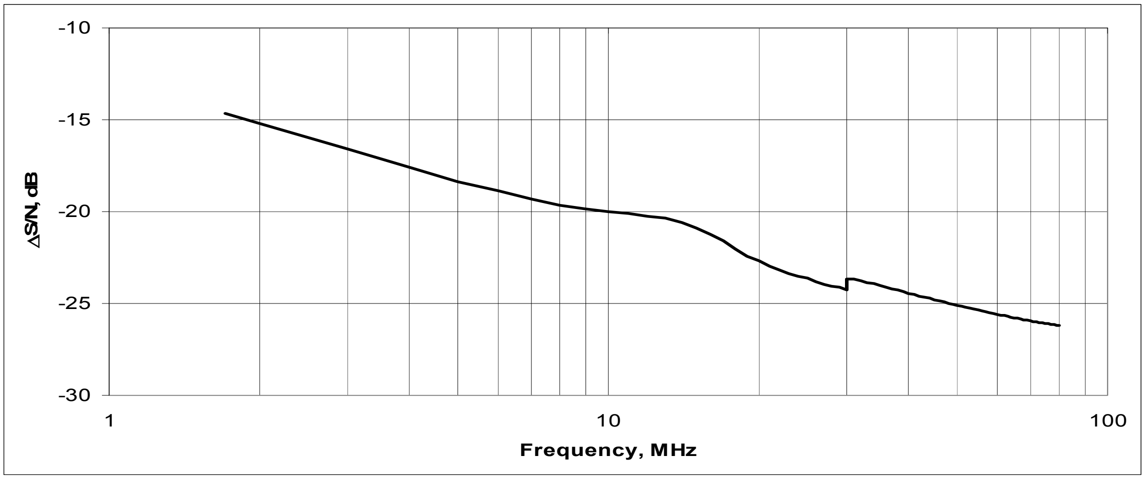

Figure 6-1: Change in Receiver Signal-to-Noise Power Ratio Caused By Unintentional Emissions at the Part 15 Limit[47]

To illustrate the extent of area in which (I+N)/N is greater than or equal to 3 dB, Figure 6-2 depicts the range of separation distances generally needed between a receiving antenna and one Part 15 device acting as a single-point source and radiating power toward the antenna at a level that exactly complies with the Part 15 field strength limit. As noted above, actual BPL system radiating characteristics will be considered in the interference risk analysis, and so, radiation at the level of the present Part 15 limits would occur only in the direction(s) of peak radiation.

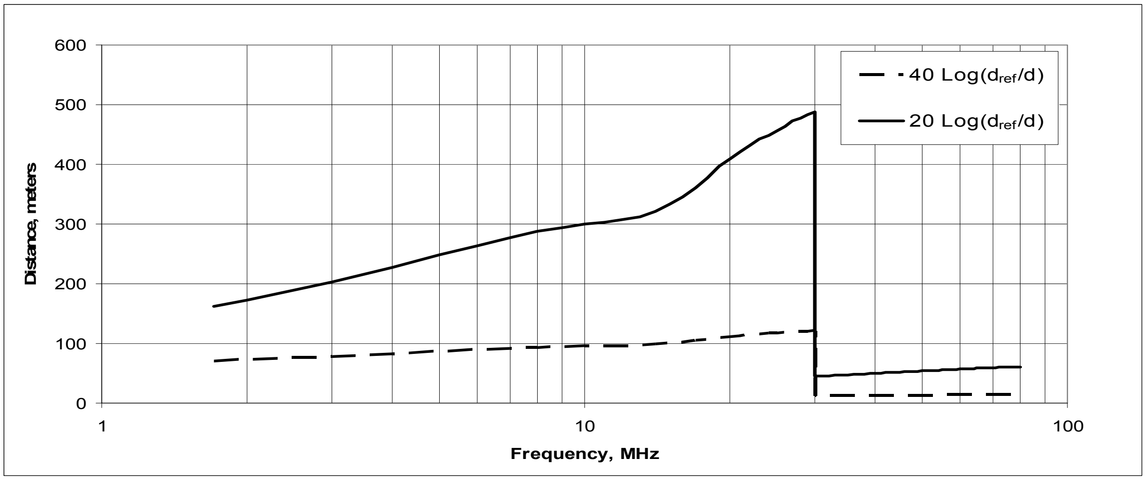

Figure 6-2: Distance at which external noise levels equal FCC Part 15 radiated emission limits (Class B)[48]

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[47] Above 30 MHz, the limit and bandwidth for Class B devices is assumed in Figure 6-1. Noise levels used are median for Kansas City, MO.

[48] Figure 6 assumes that Fam = Fu (see equation 6-3). The "40 Log…" curve is representative for a point source radiating toward a radio antenna located at most a few meters above the ground. The "20 Log…" curve pertains to a radio antenna located well above ground level (*e.g.*, >10 meters).

6.3.2 Noise Calculations

For the purposes of this study, ambient background noise was calculated using the Institute for Telecommunication Science's NOISEDAT computer program.[49] This program implements the data contained in the ITU-R Rec. P.372-8 discussed in section 5.4.4. Noise was calculated for a centrally-located geographic point (Kansas City, Kansas.) for all times of the day and seasons of the year under residential conditions. From this data, the median noise levels at each frequency of interest were used as background noise for (I+N)/N calculations. The one exception to this regime for the noise power levels used for off-shore ship station calculations, for which noise data at a location off the Atlantic coast near Wallops Flight Facility in Virginia under "quiet rural" conditions was used.

After adjusting for a single-sideband (SSB) receiver noise bandwidth of 2.8 kHz for frequencies less than 30 MHz and a bandwidth of 16 kHz for frequencies greater than 30 MHz, the noise power levels listed in Table 6-1 were used.

Table 6-1: Noise power values for (I+N)/N calculations.

Service	Location and Conditions	Noise Power, dBW (N_{dBW})			
		4 MHz	15 MHz	25 MHz	40 MHz
Land Stations[50]	39.12 N, 94.62 W, Residential	-111.3	-128.8	-135.6	-134.3
Ship Stations	37.69 N, 75.25 W, Quiet Rural	-119.3	-136.9	-150.0	-147.5

6.4 INTERFERENCE MODELS

NEC modeling for this report was used to derive electric field strength and far-field radiation patterns due to a power line energized by a single BPL device. Electric field strength levels generated by the simulated BPL system in areas where the representative ground-based receivers typically operate were evaluated statistically.

6.4.1 Receiving Systems

Representative systems from the land-mobile, fixed, maritime and aeronautical services were chosen, and system characteristics were subsequently used in interference calculations. Various parameters from all the chosen systems are listed in Table 6-2.

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[49] NOISEDAT is available from the ITU Website, URL: http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html.

[50] Land stations include land mobile, fixed, maritime coast and aeronautical stations.

Table 6-2: Receive system characteristics used in interference study.

Receiver Characteristics (2-30 MHz)	**STATION TYPE**			
	Fixed and Land	**Land Mobile**	**Maritime Mobile**	**Aeronautical**
Bandwidth (kHz)	2.8	2.8	2.8	2.8
Modulation	J3E	J3E	J3E	J3E
Antenna Type	Horizontal dipole	Vertical whip	Vertical whip	Vertical whip
Antenna Height (m)	42.7	2	9	6, 9, & 12 km
Antenna Length (m)	24.4	3	4	3
Polarization	Horizontal	Vertical	Vertical	Vertical or horizontal
Noise Environment	Residential	Residential	Quiet Rural	Residential
Antenna Gain (towards horizon) dBi	0	-4.8 @ 4 MHz -0.9 @ 15 MHz 0.3 @ 25 MHz	0	0
Horizontal distance from BPL	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-50 km from center of BPL service area
Interference Criteria (I+N)/N	3 & 10 dB	3 & 10 dB	3 & 10 dB	3 & 10 dB
Receiver Characteristics (30-50 MHz)				
Bandwidth (kHz)	16	16	16	16
Modulation	F3E	J3E	J3E	J3E
Antenna Type	Vertical whip	Vertical whip	Vertical whip	Vertical blade
Antenna Height (m)	42.7	2	9	6, 9, & 12 km
Antenna Length (m)	6	2	2	2
Polarization	Vertical	Vertical	Vertical	Vertical
Noise Environment	Residential	Residential	Quiet Rural	Residential
Antenna Gain (towards horizon) dBi	3	2	2	0
Horizontal distance from BPL	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-4 km from single BPL emitter	0-50 km from center of BPL service area
Interference Criteria (I+N)/N	3 & 10 dB	3 & 10 dB	3 & 10 dB	3 & 10 dB

6.4.2 Power Line Model

The NEC power line model used in these analyses consisted of three parallel straight wires, each 340 meters long, spaced in a horizontally parallel configuration 0.6 meters apart. The three wires were given conductivity characteristics equal to copper wire and AWG 4/0 diameter. They were placed 8.5 meters above a "Sommerfeld" ground with average characteristics (relative permittivity $\varepsilon_r = 15$, conductivity $\sigma = .005$ Siemens/meter) to simulate land-mobile and fixed service conditions, and above a Sommerfeld ground with saltwater characteristics (relative permittivity $\varepsilon_r = 81$, conductivity $\sigma = 5$ Siemens/meter) to simulate power lines along a coast line for maritime conditions. One of the outer power lines was center-fed using a voltage source to simulate the BPL coupler. The source was set to provide 1 volt. The source impedance (modeled by serially loading the segment upon which the source was placed) was given a real impedance of 150 Ω.

The ends of the long wires were connected together at each end by inter-phase loads of 50 Ω each (wires 1 and 2 and wires 2 and 3 were connected in this manner) to simulate a degree of system loading and discontinuity.

The wires used for this model were segmented following recommendations from Lawrence Livermore National Laboratories NEC documentation. Specifically, segment length was set to provide 20 segments per wavelength at the desired frequency, rounded up to an odd number of segments. This resulted in 340-meter-long wires consisting of 91, 341, 567 and 907 segments each for 4 MHz, 15 MHz, 25 MHz and 40 MHz, respectively. Convergence testing (by increasing the number of segments for each frequency) and average gain testing indicated good model stability and behavior.

6.5 INTERFERENCE CALCULATIONS

6.5.1 Scaling Output Power to Meet FCC Part 15 Limits

FCC Part 15 measurement procedures generally follow American National Standards Institute (ANSI) publication C63.4-1992, which specifies measurements with both vertical and horizontal polarization. To ensure the modeled radiation from the wires met FCC Part 15 limits consistent with existing BPL measurement practices, initial NEC runs were executed to find the expected electric field in the x-, y- and z-vector directions at a height of one meter above the ground, 30 meters away from the wire on which the voltage source was placed, for 4 MHz, 15 MHz and 25 MHz, and at a distance of 3 meters away at 40 MHz. The rms values of the NEC-calculated electric field x, y and z-vectors would be found in a straightforward manner, assuming a sinusoidal BPL test signal, as shown in the following equation.

$$E_x = \frac{E_{\circ x}}{\sqrt{2}}, E_y = \frac{E_{\circ y}}{\sqrt{2},} E_z = \frac{E_{\circ z}}{\sqrt{2}} \qquad (6\text{-}4)$$

where

E_{ox}, E_{oy}, E_{oz} are the magnitudes of the NEC-calculated x-, y- and z-vector electric-fields

The calculated electric field values were then divided by the FCC Part 15 limits (30 μV for frequencies less than 30 MHz, 100 μV for frequencies greater than 30 MHz), and the maximum such value found along the line in any vector was used to scale all subsequent electric field calculations. Because measured quasi-peak values of field strength are expected to be near or slightly exceed the above rms values (see Appendix D, Section D.3.4), this scaling process may yield adjusted field strength values slightly in excess of values needed for compliance using a quasi-peak detector. The purpose of this exercise was to ensure the radiated signal complied with FCC Part 15 limits for each frequency.

6.5.2 Analysis Methodology for Land-Mobile, Fixed and Maritime Services

After the initial "scaling" runs, NEC simulations were performed to find the spatial distribution of electric field strength values. The calculations were made for a geographic grid of points with 5 meter spacing along and away from the line to a distance of 1 km, at heights of 2 meters, 42.7 meters and 9 meters to simulate land mobile vehicle, mobile-base/fixed and ship antennas, respectively. This grid included points lateral to the power lines and excluded points off the end of the modeled power line, as it was felt that the arbitrary ending of the power line at both ends of the power line layout would yield unrealistic radiation properties in nearby areas. The NEC simulations indicated substantial radiation off the ends of the line, and real-world power lines do indeed terminate at many points.

Electric field values were calculated using NEC's ground wave capability for distances greater than one kilometer from the line. These values were calculated in cylindrical coordinates, meaning values were found for a given distance and height in a circle around the power line model. Values were calculated in 5-degree increments at distance increments of 100 meters from 1 km to 4 km, at the same antenna heights used for near-field calculations.

In addition to the above NEC runs, a "close-in" simulation was completed to gather fine detail along the line at land-mobile antenna height (two meters). This was done to determine the degree of potential interference expected to be found on streets next to power line runs. This "close-in" run was done using NEC's near-field facility on a grid with 0.5 meter spacing out to a distance of 15 meters from the line.

Once calculated, the electric field values were scaled and the relevant real field value (E_x for the vertical land mobile antenna, E_y and E_z for horizontal fixed and maritime antennas) was translated into received interfering signal power as follows:

$$
\begin{aligned}
P_{(dBW)} &= 20 \cdot Log_{10}\left(E_{V/m}\right) - 20 \cdot Log_{10}\left(F_{MHz}\right) + G_{r(dBi)} \\
&\quad + 10 \cdot Log_{10}\left(BW\right) + 10 \cdot Log_{10}(\phi) + \delta + 12.8
\end{aligned}
\tag{6-5}
$$

where

$E_{V/m}$ is the received signal strength in V/m

F_{MHz} is the measurement frequency in MHz

G is the gain of the receiving antenna

BW is the ratio of receiver to measurement bandwidth

ϕ is the average duty cycle

δ is a quasi-peak to rms measurement factor

For the purposes of this study, the *average duty cycle* (ϕ) was taken to be 55%, which was midway between an always-on (100%) downstream signal and an intermittent (10%) upstream customer-to-internet signal. Additionally, to compensate for differences between ambient noise levels expressed in rms values and BPL signal radiation measured using quasi-peak detection, a *measurement factor* (δ) adjustment of -2 dB was applied to the calculated received BPL signal power.

From the received signal power and the background noise, the (I+N)/N ratio was calculated at each point in the assumed receiver operating areas:

$$
\left(I + N\right)\big/N = 10 \cdot Log_{10}\left[1 + 10^{\left(P_{dBW} - N_{dBW}\right)/10}\right]
\tag{6-6}
$$

Once these calculations were complete, the percentages of locations for each distance value (near field and ground wave calculations) or in areas around the BPL-energized line (for close-in land-mobile situations) exceeding given (I+N)/N values were determined.

6.5.3 Analysis Methodology for Aeronautical Service

In order to calculate interference to an aircraft receiver, several parameters were defined:

- BPL service area: circular area of 10 km radius (6.2 miles)

- Number and density of co-channel BPL transmitters: 1200, 300, and 75 deployed over an area of 314 km^2, with approximately 0.5, 1, and 2 km separation between units, respectively
- BPL unit radiated power:
  - For 4 MHz: -69.8dBW/2.8 kHz
  - For 15 MHz: -67.3dBW/2.8 kHz
  - For 25 MHz: -64.9dBW/2.8 kHz
  - For 40 MHz: -81.1dBW/16.0 kHz

BPL device output power was derived from the NEC scaling runs. NEC-calculated power line input power was scaled by the square of the scaling factor for each frequency, as well as by the ratio between the receiver and measurement bandwidths. Additionally, NEC was used to find the far-field directional gain pattern from the modeled power lines for all frequencies of interest. Simulations were run using the directional gain pattern in azimuthal directions both parallel and perpendicular to the main radiation lobe of the power line. The average directional gain levels for each elevation were found for the two patterns (Figure 6-3) used in the analysis.

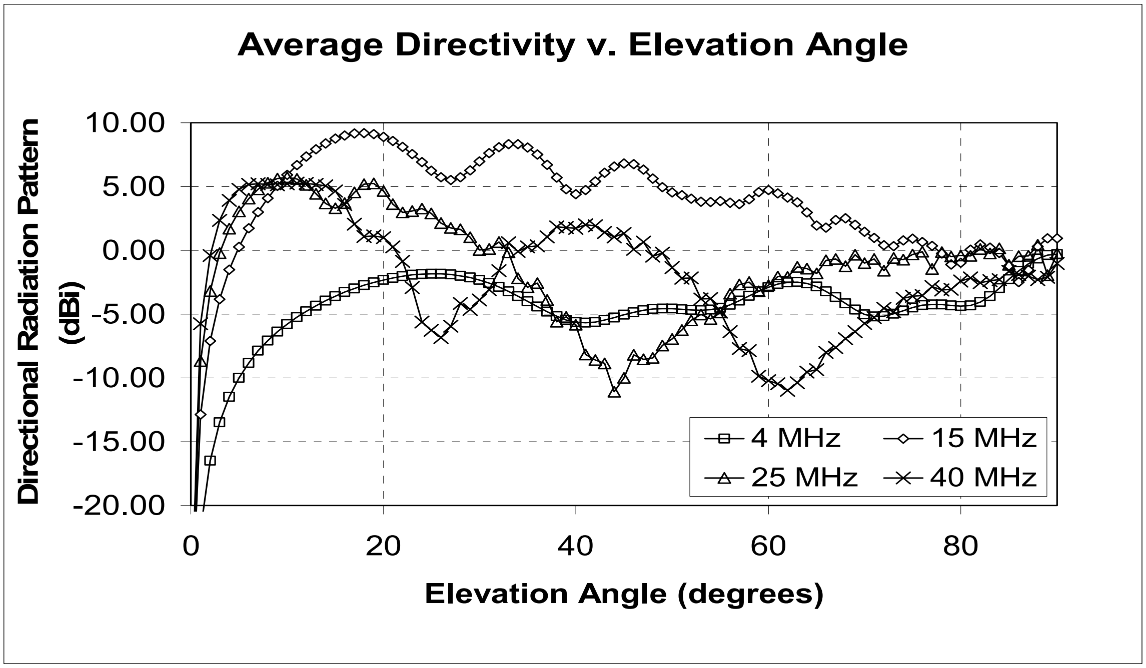


Figure 6-3: Average far field directional gain antenna patterns used for aeronautical interference calculations.

As mentioned previously, a Matlab model was used to simulate an aircraft at various heights and horizontal distances from the centroid of a BPL deployment area. This model simulated the signal effects of multiple BPL devices in different deployment cells at the aircraft location.

As with interference calculations for the other services, several additional factors were taken into account. Two of these, duty cycle (ϕ) and quasi-peak to rms measurement factor (δ) were discussed in subsection 6.5.2, and the same values were used here (55% and -2 dB, respectively). An additional adjustment factor, *polarization mismatch*, was used with aeronautical service calculations. This factor was designed to compensate for the fact that the aeronautical service antenna used in this simulation was vertically polarized, whereas the BPL structure was horizontally polarized. Both structures interacted with radiation of the opposite polarization in NEC simulations. For example, the BPL structure produced significant (or even primary) radiation that was vertically polarized in most azimuthal directions. Further, over a significant number of azimuthal directions, the short aeronautical antenna could be expected to respond well to both horizontally- and vertically-polarized radiation. Nonetheless, for a small number of orientations a cross-polarization effect would likely reduce coupling between the BPL structure and the receiving antenna. In order to account for this effect, an overall decrease of 1 dB in the received BPL signal was assumed.

6.6 RESULTS OF INTERFERENCE CALCULATIONS

6.6.1 Land-Mobile Service

Calculations of close-to-the-line interference potential for vehicular land-mobile receivers due to a BPL transmitter operating at FCC Part 15 limits show that there would be significant increases in the noise floor due to interference. As can be seen in Table 6-3, for frequencies less than 30 MHz, virtually all points close to the line would experience (I+N)/N levels greater than 10 dB. In other words, there would be at least a ten-fold increase in total receiver noise power on the street adjacent to the BPL device and power lines. At 40 MHz, a majority of the areas in a road along the power line would see this level of interference.

Table 6-3: Percent of points exceeding specified interference level, by frequency, for land-mobile receiver system within 15 meters of a BPL-energized power line. Radiated power and noise are into a 2.8 kHz bandwidth for 4 MHz, 15 MHz and 25 MHz, and a 16 kHz bandwidth at 40 MHz.

Frequency (MHz)	Radiated Power (dBW)	Noise (dBW)	3 dB (I+N)/N	10 dB (I+N)/N	20 dB (I+N)/N	30 dB (I+N)/N	40 dB (I+N)/N	50 dB (I+N)/N
4	-69.8	-111.3	99.3%	93.2%	54.7%	6.2%	0.0%	0.0%
15	-67.3	-128.8	99.8%	99.7%	95.7%	59.5%	4.3%	0.0%
25	-64.9	-135.6	99.8%	99.0%	92.1%	58.5%	18.5%	0.0%
40	-81.1	-134.3	87.9%	49.2%	10.0%	0.0%	0.0%	0.0%

The increases in the noise floor a land-mobile system might encounter along a BPL-energized power line are further illustrated in Figure 6-4. In this figure, (I+N)/N values are depicted using colors from red to blue, with dark red representing 50 dB and dark blue representing zero.

It can be inferred from these calculations that a vehicle-mounted HF receiver operating in a residential environment on a roadway adjacent to a BPL-energized power line may experience harmful interference, depending upon the frequency, the distance along the line away from the BPL transmitter, the BPL transmitter duty cycle and the number of BPL devices on the line.

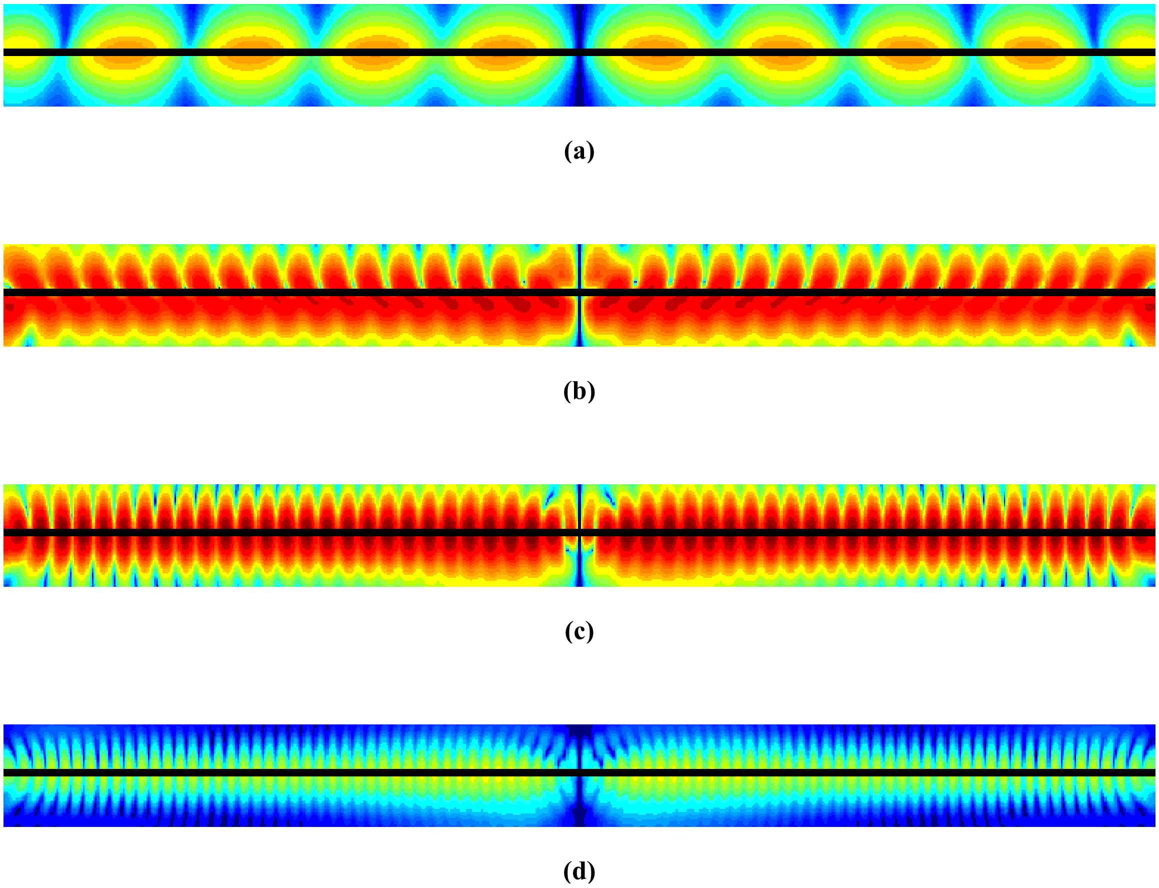
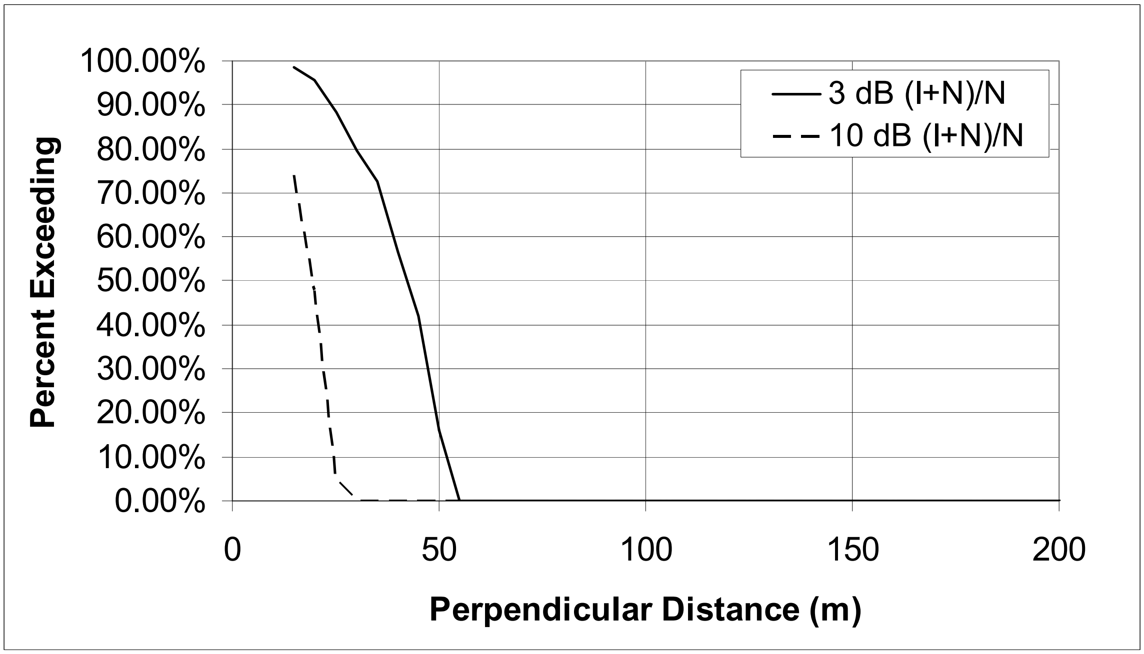


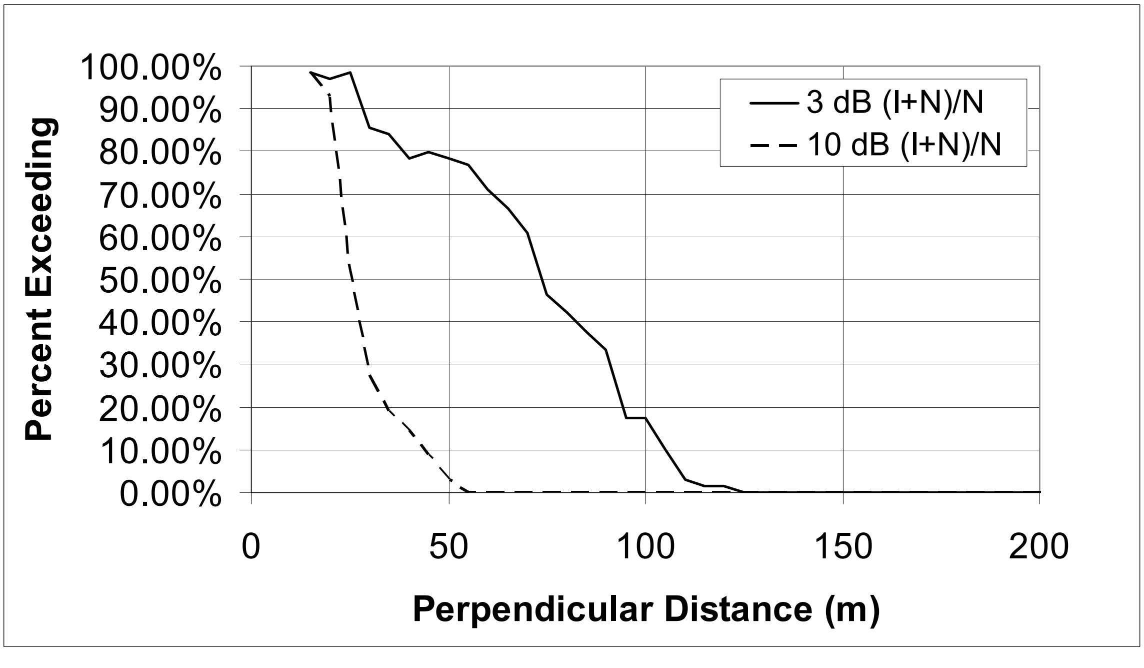
Figure 6-4: (I+N)/N values around the modeled power line, to a distance of 15 meters. Colors represent a range from zero dB (dark blue) to 50 dB (dark red). a) 4 MHz. b) 15 MHz. c) 25 MHz. d) 40 MHz. The BPL structure is denoted with a dark horizontal line in the center of each plot.

Near-field calculations of interference levels stemming from a single BPL device, out to a distance of one kilometer from the power line, indicated a sharp falloff in the level of interference with distance. As shown in Figure 6-5, out to distances on the order of 120 meters from the power line, a land-mobile receiver operating in the modeled noise environment could experience interference.

Ground wave calculations of interference levels at a distance from one to four kilometers were in good agreement with those for the near field. Results at a nominal one kilometer near-field/ground-wave juncture were well-matched. In no areas adjacent to, and more than 120 meters from the power lines would the modeled land-mobile system be likely to experience significant interference from a single BPL transmitter operating at FCC Part 15 limits.

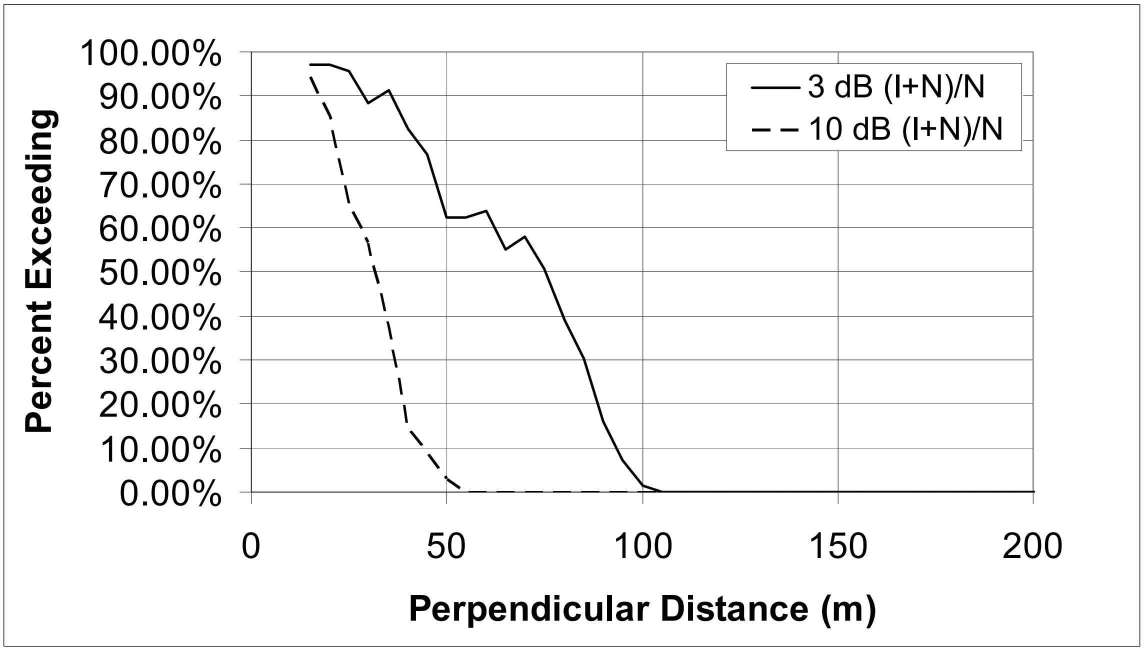


(a)

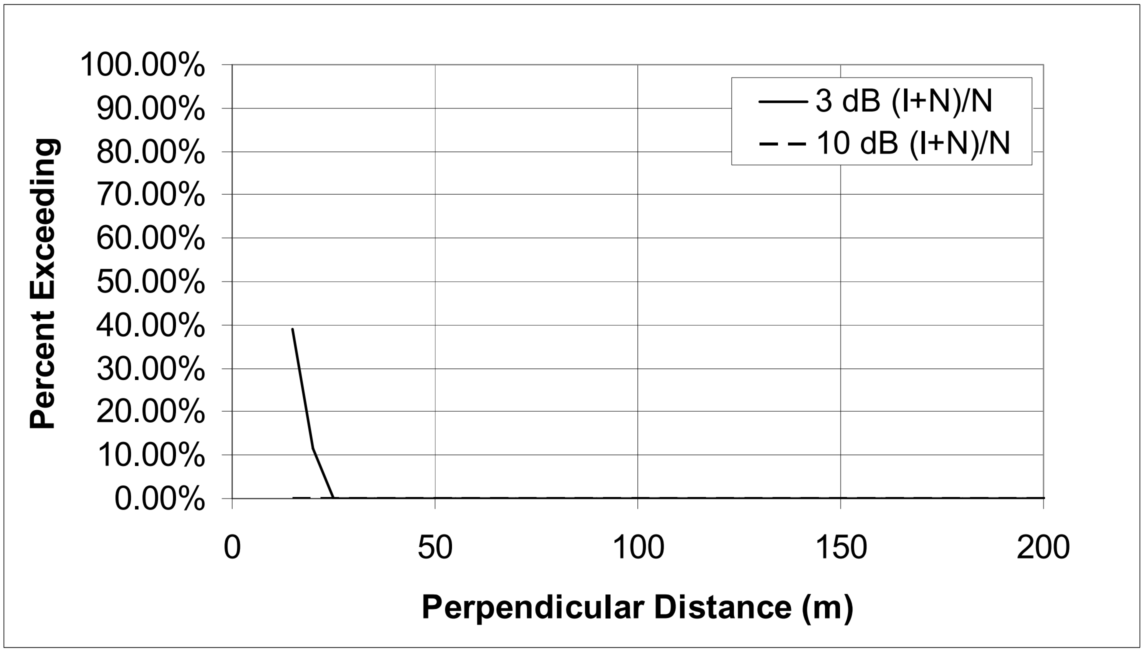


(b)

Figure 6-5: Percent of near-field points, by distance, where a land-mobile receiver would see the specified (I+N)/N levels due to a BPL transmitter operating at Part 15 limits. a) 4 MHz. b) 15 MHz.



(c)



(d)

Figure 6-5 continued: c) 25 MHz. d) 40 MHz.

6.6.2 Fixed Service

NEC interference calculations for an assumed fixed service or mobile base station receiving antenna found substantial (I+N)/N values at greater distances from the line than those found for land mobile receivers. This was especially true at 15 and 25 MHz.

The near field results are depicted in Figure 6.6. As can be seen, at 15 MHz the potential for a 3dB (I+N)/N level exists beyond 500 meters away, and at 25 MHz some locations more than 700 meters away could see this level of interference. Additionally, locations past 300 and 400 meters from the BPL-energized line on 15 MHz and 25 MHz, respectively, could experience (I+N)/N levels in excess of 10 dB.

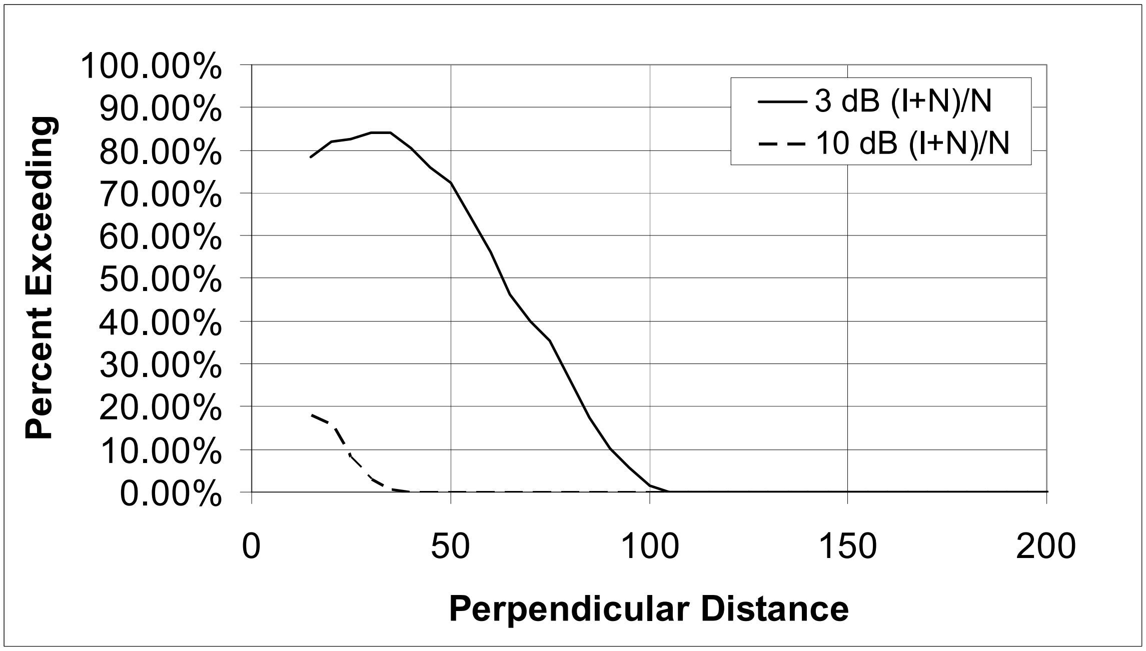
The differences in potential interference found with different frequencies are partly due to the ambient noise floor decreases as the frequency is increased. However, the increased gain of the modeled antenna with frequency also plays a part, which means that higher gain antennas and lower-noise areas could face greater risks of interference at lower frequencies. Likewise, receivers with lower-gain antennas and high-noise environments would likely experience less degradation in the noise floor, but would likely also see a reduced S/N. This is true for all of the services modeled.

6.6.3 Maritime Service

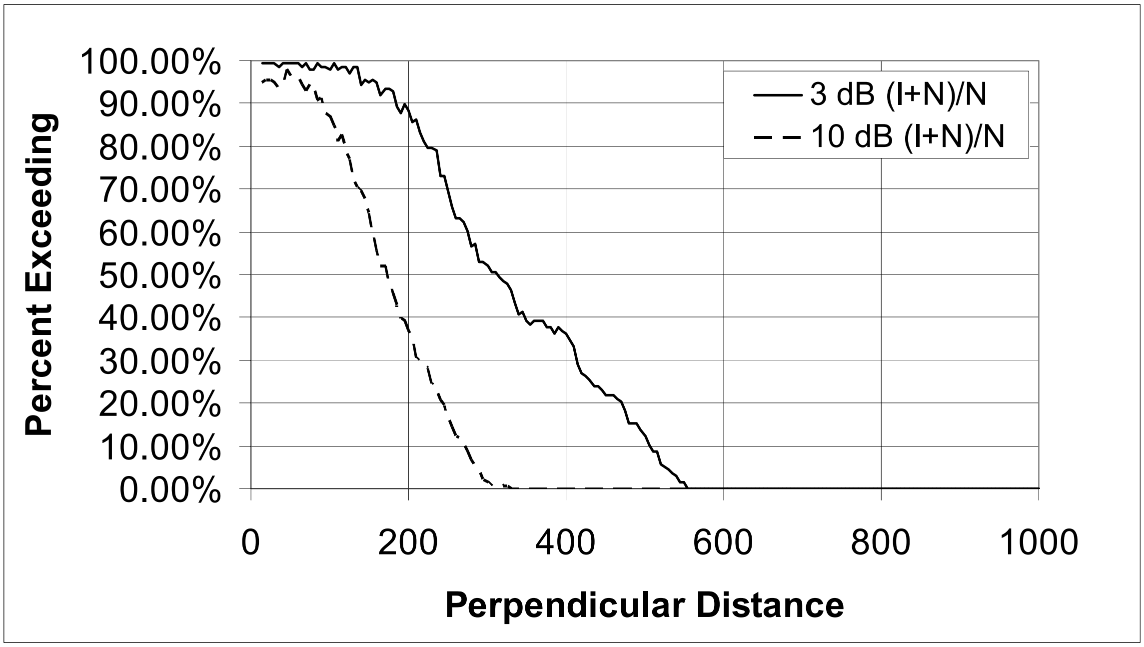
As noted previously, the calculations for a ship receiver differed from the fixed and land-mobile services in two important respects: the use of lower ambient noise levels and the use of salt-water ground characteristics. This model assumed a power line running along the shoreline, and the ship receiver possibly in a bay or harbor.

Results for the simulated maritime receiver were similar to those for the fixed service receiver. Substantial areas near the shore (near field) would likely see greater than 3 dB increases in the noise floor. As with the other services, this effect would be most pronounced at 25 MHz with the assumed power lines. According to the calculations, a single BPL device could S/N at 25 MHz by 3 dB for more than 50% of points within 100 meters of the shore (Figure 6-7).

Despite the lower noise levels seen by the simulated system at distances greater than one kilometer from shore, calculations indicated that at no point would the simulated system experience (I+N)/N levels greater than 3 dB.

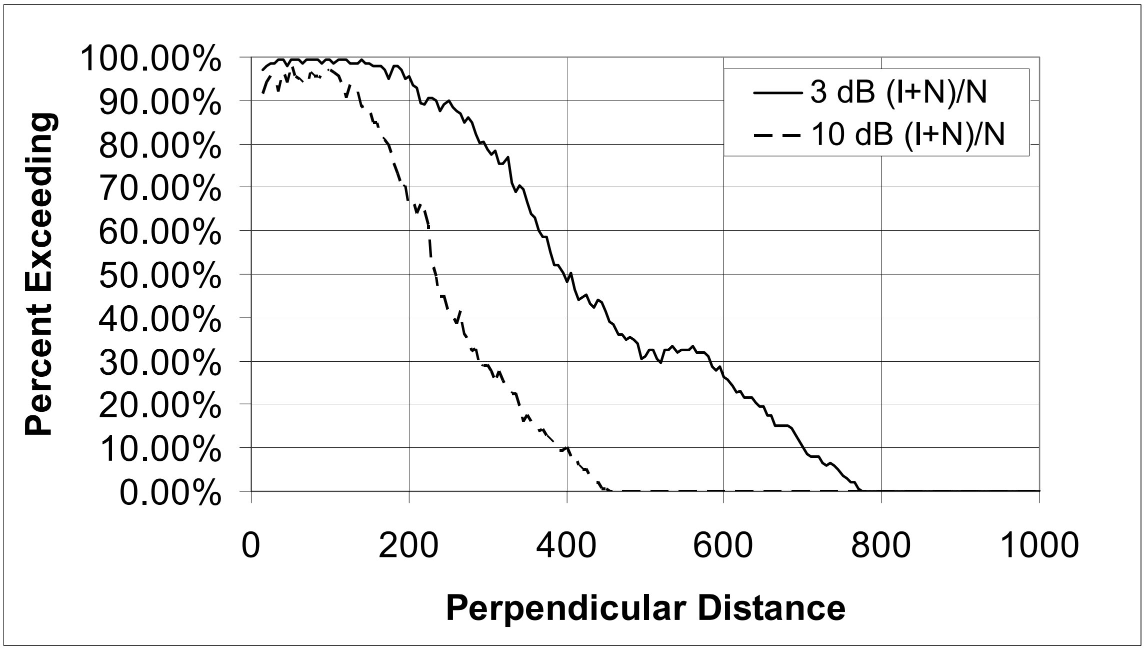


(a)

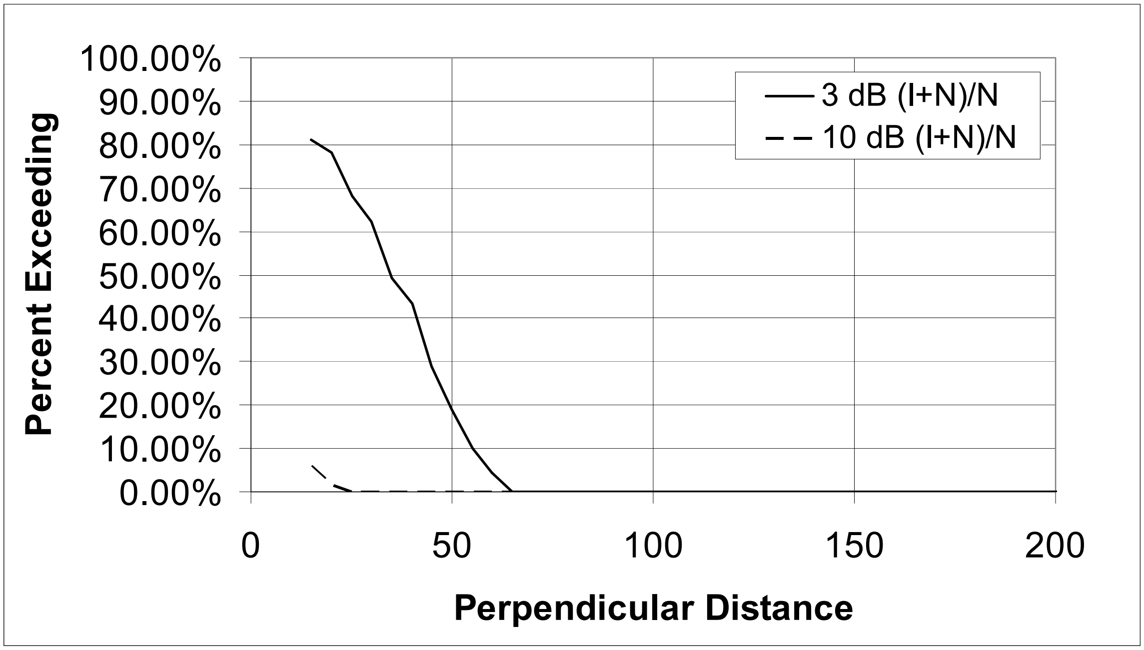


(b)

Figure 6-6: Percent of near-field points, by distance, where a fixed receiver would see the specified (I+N)/N levels due to a BPL transmitter operating at FCC Part 15 limits. a) 4 MHz. b) 15 MHz.

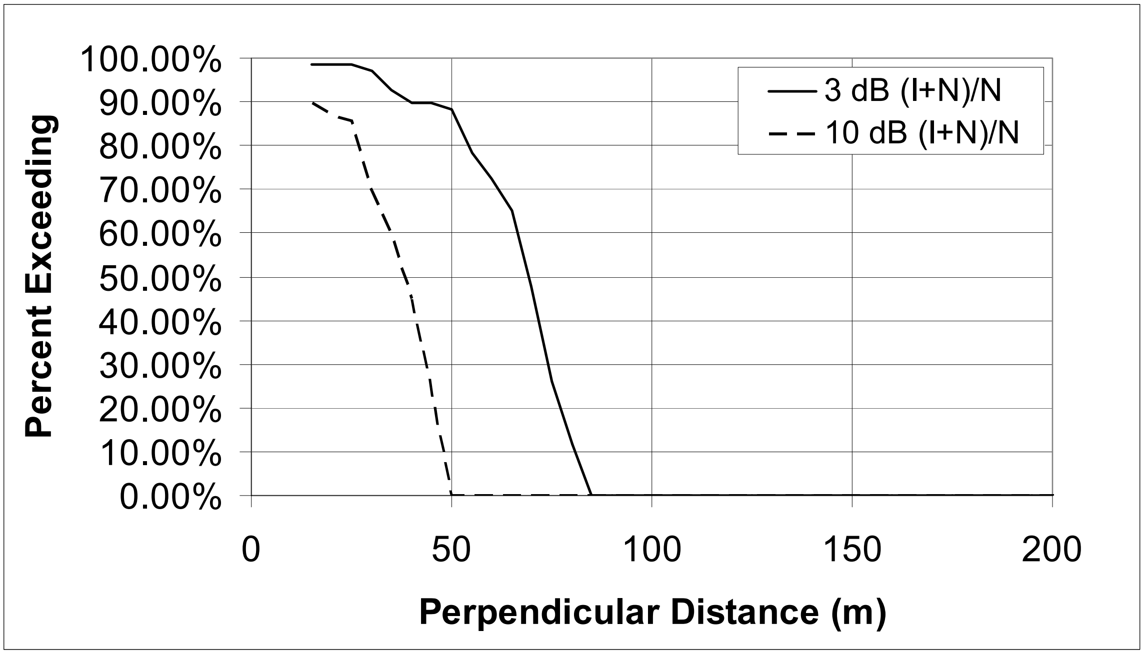


(c)

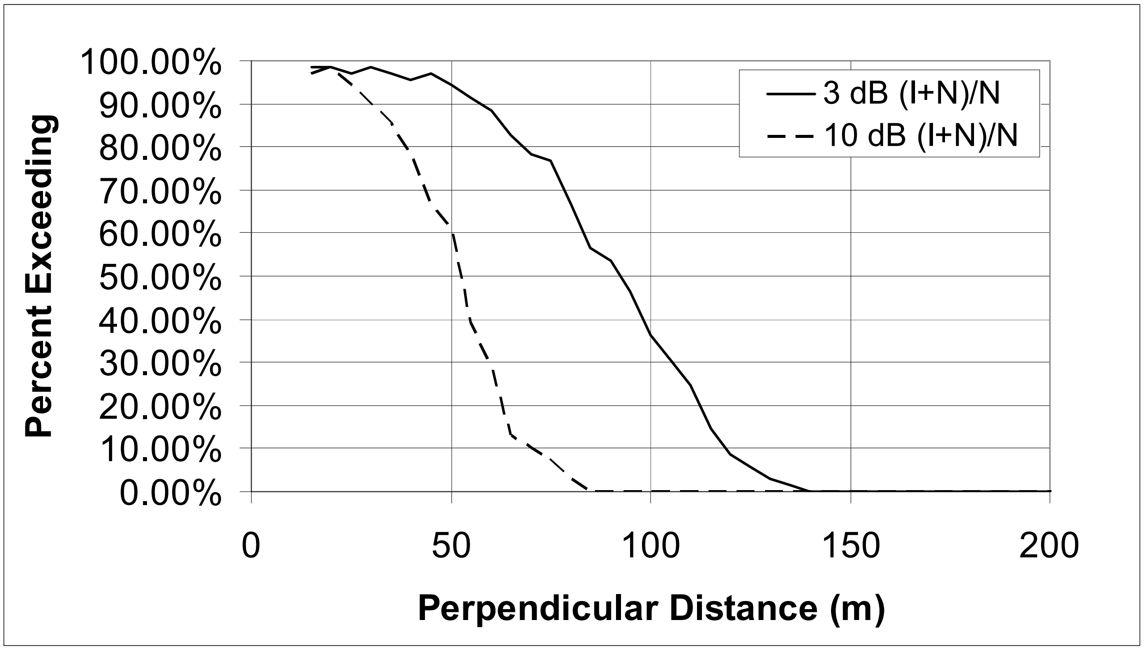


(d)

Figure 6.6 continued: c) 25 MHz. d) 40 MHz.

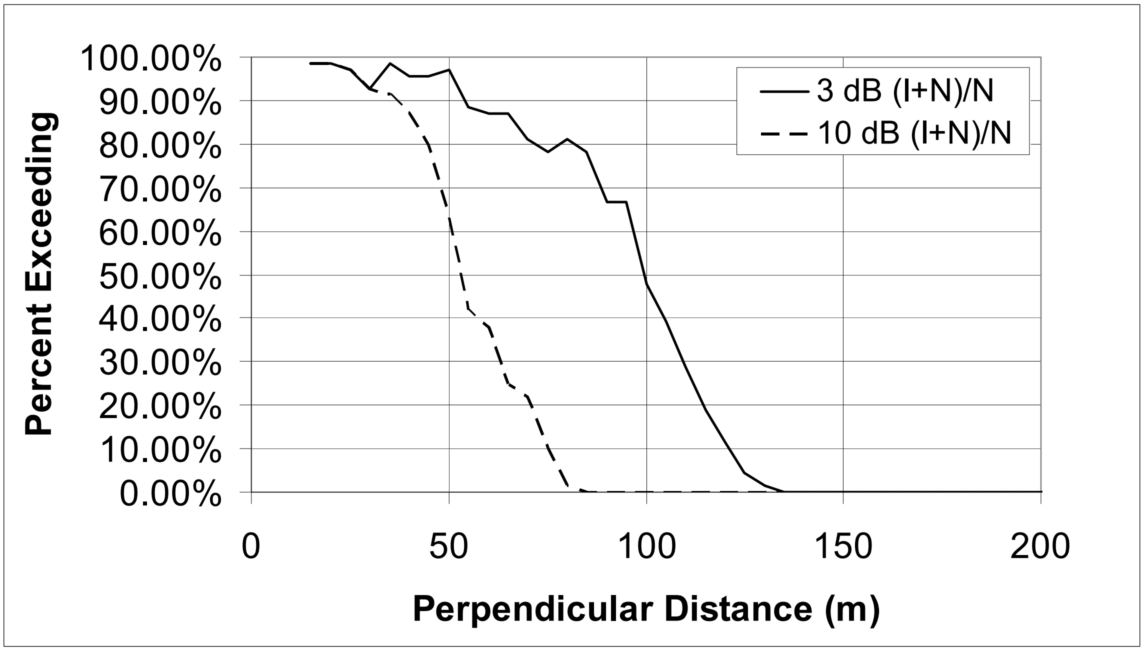


(a)

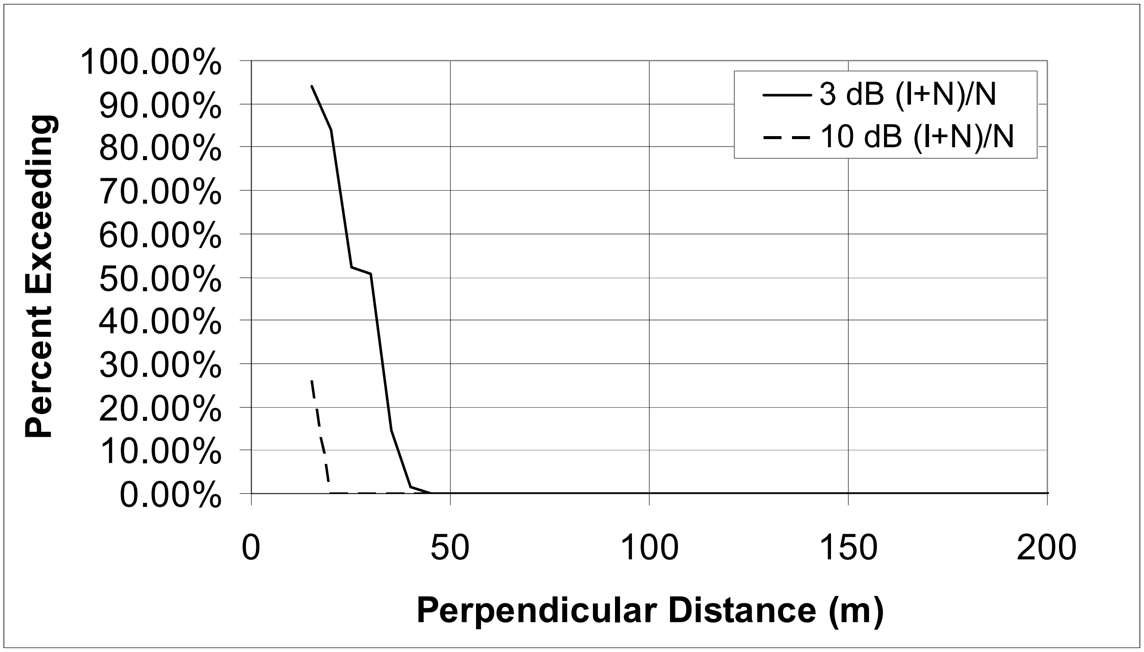


(b)

Figure 6-7: Percent of near-field points, by distance, where a maritime receiver would see the specified (I+N)/N levels due to a BPL transmitter operating at FCC Part 15 limits. a) 4 MHz. b) 15 MHz.



(c)



(d)

Figure 6-7 continued: c) 25 MHz. d) 40 MHz.

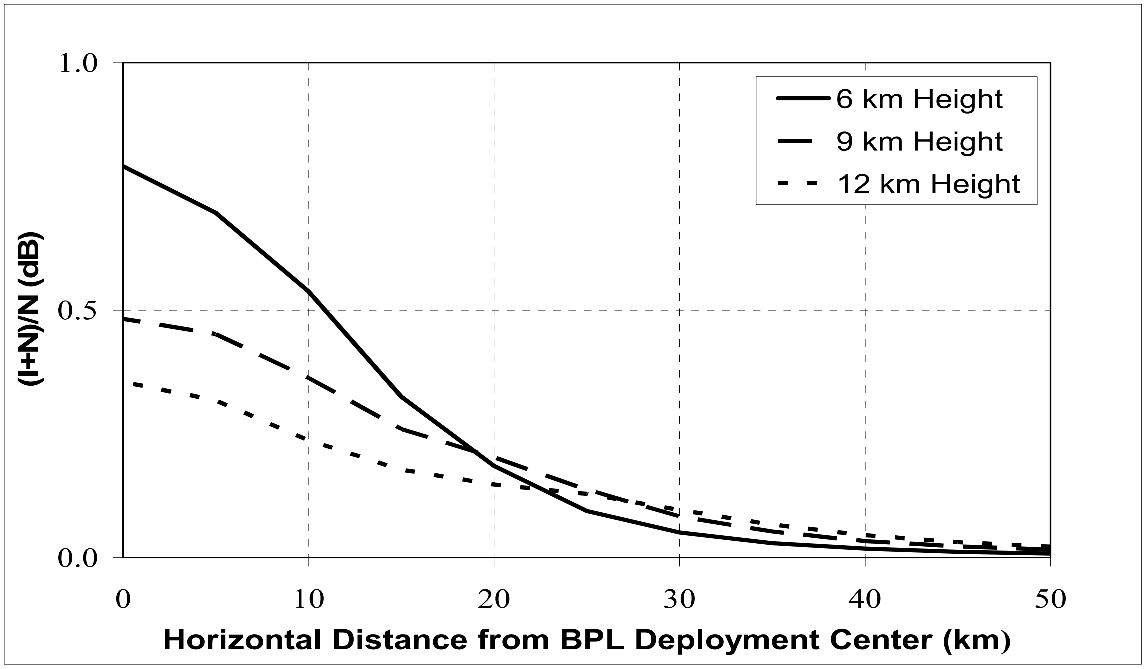
6.6.4 Aeronautical Service

The analysis of potential interference to aeronautical transceivers covered modeled deployments of 1200, 300, and 75 co-frequency BPL devices in an area of 10 km radius. Results indicated that multiplying the number of BPL devices by a factor of four produced a straightforward 6 dB increase in aggregate interfering BPL signal power; therefore only the analysis with 300 units is presented. The calculated data is listed in Table 6-4 and shown graphically in Figure 6-8.

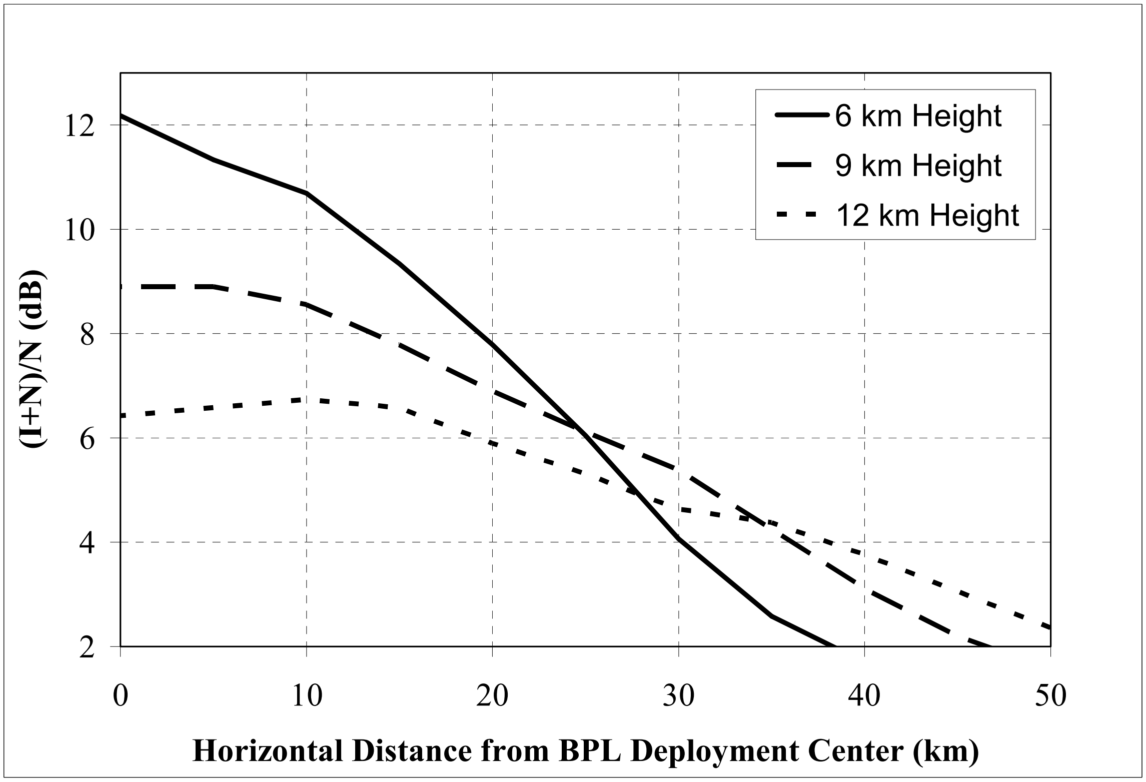
Table 6-4: Calculated (I+N)/N values, in dB, for aircraft receiver at listed distance, frequency and height, with 300 BPL units visible to the receiver in a 314 km^2 area.

	(I+N)/N (dB) 4 MHz			(I+N)/N (dB) 15 MHz			(I+N)/N (dB) 25 MHz			(I+N)/N (dB) 40 MHz		
Height Distance	6 km	9 km	12 km	6 km	9 km	12 km	6 km	9 km	12 km	6 km	9 km	12 km
0 km	0.8	0.5	0.4	12.2	8.9	6.4	8.9	6.3	5.7	0.3	0.1	0.0
5 km	0.7	0.5	0.3	11.3	8.9	6.6	9.2	6.5	5.5	0.2	0.1	0.1
10 km	0.5	0.4	0.2	10.7	8.6	6.7	9.6	6.2	4.5	0.2	0.1	0.1
15 km	0.3	0.3	0.2	9.3	7.8	6.6	9.0	6.1	3.8	0.1	0.1	0.1
20 km	0.2	0.2	0.1	7.8	6.9	5.9	8.4	6.7	4.3	0.1	0.0	0.0
25 km	0.1	0.1	0.1	6.0	6.1	5.3	7.4	6.3	5.0	0.1	0.1	0.0
30 km	0.1	0.1	0.1	4.1	5.4	4.6	6.4	5.6	5.0	0.1	0.1	0.0
35 km	0.0	0.1	0.1	2.6	4.3	4.4	5.5	4.8	4.6	0.1	0.1	0.0
40 km	0.0	0.0	0.0	1.7	3.1	3.8	4.6	4.4	3.9	0.1	0.1	0.0
45 km	0.0	0.0	0.0	1.1	2.2	3.1	3.6	4.1	3.3	0.0	0.0	0.0
50 km	0.0	0.0	0.0	0.7	1.6	2.4	2.8	3.6	3.1	0.0	0.0	0.0

As the figures indicate, an aircraft traveling above or near the modeled BPL deployment area could see substantial S/N degradation. These calculations include parts of the far-field radiation pattern (off the ends of the power lines, or on-axis) that exhibited potentially elevated power gain levels. Further study is needed of representative power line gain levels in skyward directions.

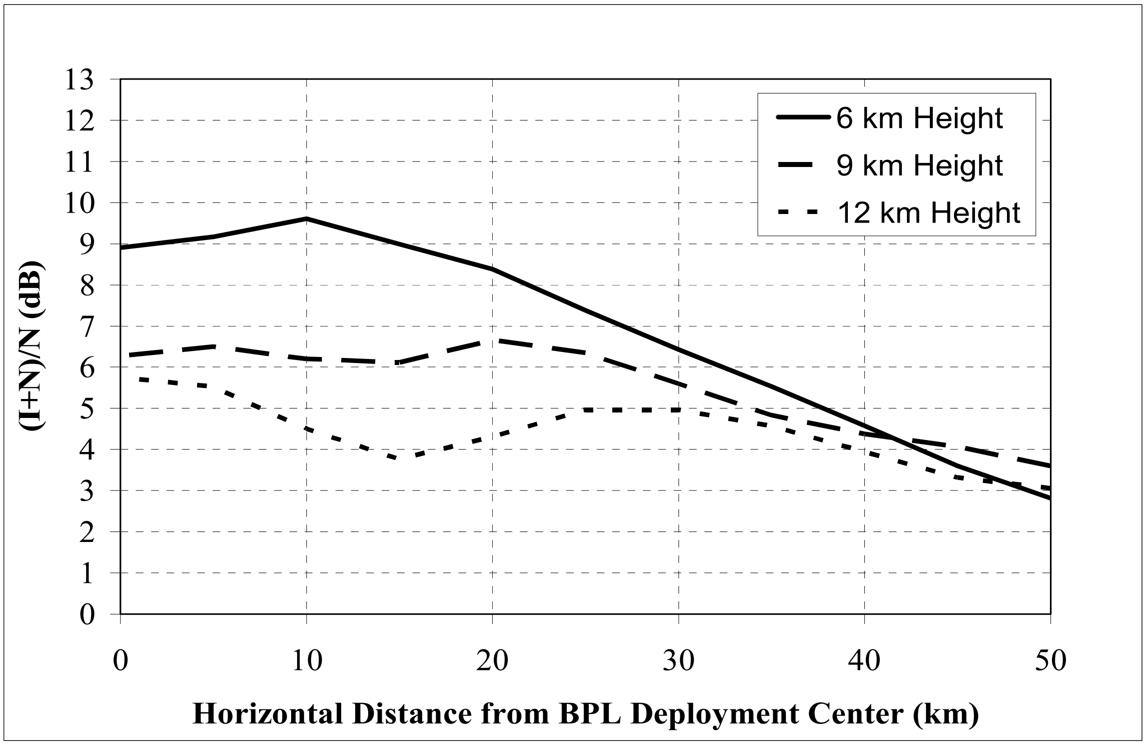


(a)

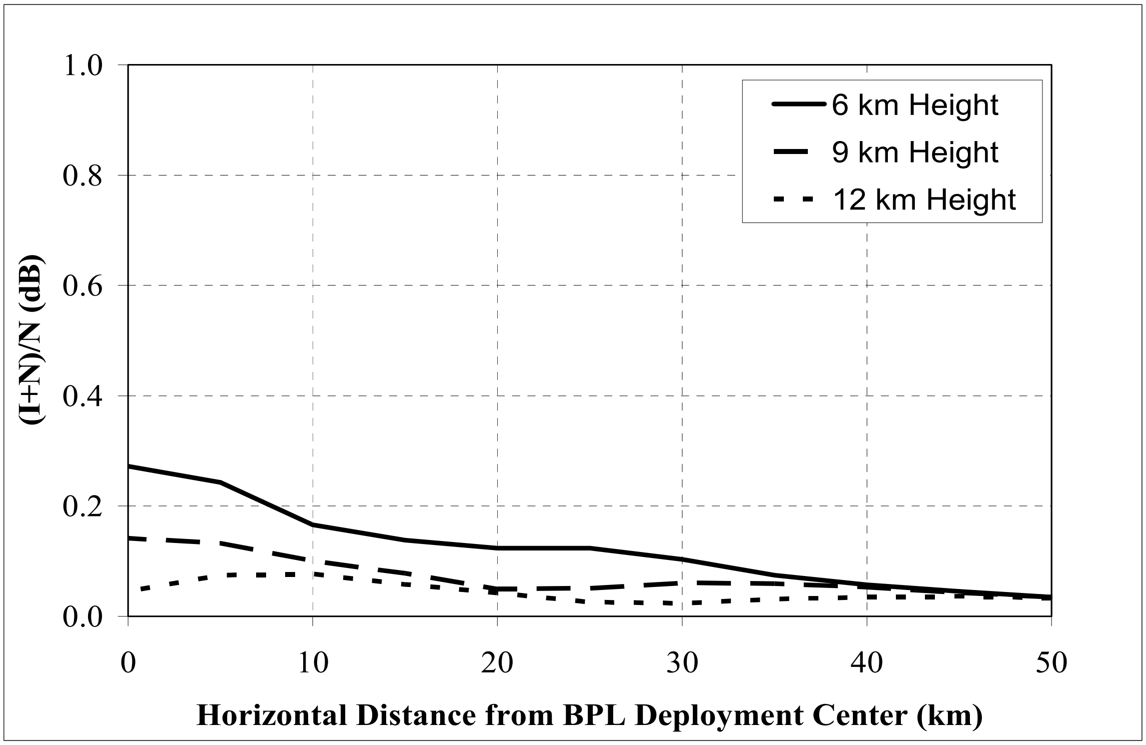


(b)

Figure 6-8: Calculated (I+N)/N level for an aeronautical receiver at the specified distance and height from a BPL deployment, with 300 BPL devices visible to the receiver. (a) 4 MHz. (b) 15 MHz.



(c)



(d)

Figure 6-8 continued: c) 25 MHz d) 40 MHz

6.7 CONCLUSION

Interference risks were estimated using NEC models for four representative types of federal radio stations operating in the fixed and mobile services: 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 extent 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). Along with the four representative radio stations, a three-phase power line structure was modeled using NEC. Predicted nationwide, Springtime, median ambient noise power levels were assumed and analyses were performed at four frequencies between 1.7 – 80 MHz. 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 fifty percent of the locations within seventy and seventy five meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at fifty percent of locations within twenty-five and thirty meters of the power lines. The distances within which these thresholds were exceeded at fifty percent 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 one-hundred-and-twenty-five meters and fifty-five 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 fifty percent of the locations within three-hundred-and-ten and four-hundred meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at fifty percent of locations within one-hundred-and-seventy-five and two-hundred-and-thirty meters of the power lines. In all cases, reductions in S/N were less than 3 dB and 10 dB beyond seven-hundred-and-seventy meters and four-hundred-and-fifty 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 fifty percent of the locations within one-hundred meters of the power lines. At these same frequencies, BPL signals reduced S/N by 10 dB at fifty percent of locations within fifty-five meters of the power lines. In all cases, reductions in S/N were less than 3 dB and 10 dB beyond one-hundred-and-thirty-five meters and eighty-five 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 ten (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 zero to fifty (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 thirty-three kilometers (six kilometers altitude) to over fifty kilometers (altitudes between six and twelve kilometers). The S/N reduction exceeded 10 dB at only one frequency, at six kilometers altitude within twelve 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.

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

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[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

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[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.

SECTION 8
INTERFERENCE PREVENTION AND MITIGATION TECHNIQUES

8.1 INTRODUCTION

The risk of harmful interference from any kind of radiator can usually be reduced through the use of various interference prevention measures, and the risk of sustained interference generally can be eliminated through various interference mitigation techniques. A number of possible means for the prevention and reduction of BPL interference to other services have been proposed and are presented and supplemented herein. Further study is needed of the potential effectiveness of these techniques.

8.2 POWER LEVEL

The single most effective method for reducing the potential for harmful interference from a BPL device may be to reduce the RF power it generates. As the FCC notes in §15.15 (c), "*…the limits specified in this part will not prevent harmful interference under all circumstances. Since the operators of part 15 devices are required to cease operation should harmful interference occur to authorized users of the radio frequency spectrum, the parties responsible for equipment compliance are encouraged to employ the minimum field strength necessary for communications…*" The minimum signal power necessary for BPL communications will obviously depend upon the system configuration used and the specific characteristics of the power line network. In some cases, reduction of BPL device output power may reduce data throughput. Throughput could be restored to the previous levels in existing BPL deployments by the addition of repeaters or in planned new deployments by reducing separation distances between devices. Consistent with §15.15(c), BPL systems should use the least power needed to carry out power line communications.

8.3 AVOIDANCE OF LOCALLY USED FREQUENCIES

Several access BPL systems make use of technology that can enable the avoidance of certain frequencies and frequency bands through capabilities for shifting BPL signal frequencies or notching or filtering out of BPL signals on those frequencies. Various FCC filings have indicated that this type of mitigation technique would not only be possible, but in fact has already been implemented to reduce BPL interference issues.[61]

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[61] PowerComm Reply Comments at 3; Comments of the IEEE Power System Relaying Committee, BPL Inquiry, July 1, 2003 at 1; Comments of Ameren Energy Communications Inc., BPL Inquiry, July 7, 2003, ("Ameren Comments"), at 9-10.

Another, more advanced method of frequency avoidance would be *agile* or *adaptive filtering*. Unlike fixed frequency notching, systems with agile frequency avoidance would monitor frequency bands and dynamically change their frequency usage to avoid radio channels on which strong signals were detected. This is a solution that might enable increased, interference-free use of the RF spectrum by BPL systems.[62] However, there is significant concern that such a system, even if it were to work instantaneously, would not reduce the interference potential to systems operating in duplex mode or local weak-signal reception.[63] Interference to these operations may be discovered at the same time effective radio communications are needed most. Rather, this technique would protect only those radiocommunications using simplex mode and originating from a local radio transmitter.

A more basic form of adaptive filtering should be considered as a requirement. Again, it must be recognized that BPL systems may be susceptible to disabling if subjected to signals from a powerful, nearby transmitter. To the extent that this vulnerability exists, which is a vulnerability commonly found in all kinds of electronic systems, BPL systems must inherently avoid operating at frequencies used by powerful, local radio transmitters.

8.4 DIFFERENTIAL-MODE SIGNAL INJECTION

The use of unshielded, twin-lead lines for achieving non-radiating signal transmission depends upon *differential* or *balanced* line driving (as well as fundamental balance in the lines themselves). In this conceptual mode of signal injection, a signal of equal magnitude and opposite phase is placed simultaneously on both wires, resulting in cancellation of radiation in the far-field. While balanced transmission lines are usually constructed with very small wire spacing relative to the wavelength of the signal, preliminary NTIA NEC modeling of long wires using power-line dimensions, typical loads to neutral lines, and various grounding configurations has shown a decrease of several decibels in RF radiation for balanced differential BPL signal injection as opposed to non-differential injection. At least one BPL manufacturer, in its comments to the FCC, indicated that differential-mode driving should reduce signal radiation as well.[64]

It should be noted, however, that inherently unbalanced systems such as power lines (due to multiple grounds and transformer taps) will not act as true balanced transmission

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[62] Some BPL proponents have indicated that during routine installation of BPL devices, existing noise sources on power lines will be repaired. *See e.g.*, Ambient Comments at 9; Reply Comments of Southern Linc, Southern Telecom, Inc., and Southern Company Services, Inc., BPL Inquiry, August 20, 2003 at 15. Thus, it should not be necessary for BPL operators to select frequencies that also avoid relatively high noise power that is generated by the power lines themselves.

[63] Reply Comments of Current Technologies, LLC, BPL Inquiry, August 20, 2003, at 15, note 33.

[64] PowerComm Reply Comments at 4.

lines regardless of the method of signal injection. Thus, this method of interference mitigation is limited in impact by the power line configuration.

Further reductions in radiated emissions may be possible using unbalanced driving of the unbalanced power and neutral lines, and there may exist ways to couple to all power lines in a manner that yields lower radiated emissions while achieving relatively high BPL signal currents and throughput. NTIA encourages further investigation of these possible solutions by BPL developers as appropriate.

8.5 FILTERS AND SIGNAL TERMINATIONS

Typical BPL signals will travel for at least several hundred meters along power lines before losses attenuate them to below useable levels. In many cases, conduction of BPL signals over these distances is unnecessary, as it means signals may continue far past the couplers, repeaters and customers for whom they are intended. Additionally, frequency re-use for BPL systems may be an issue for closely-spaced cells that renders conduction of BPL signals over extended distances undesirable.

One way to prevent unnecessary signal conduction is to make use of terminations or blocking filters on the transmission line. Since BPL signals are much higher in frequency than the 60 Hz power carrier, such terminations might range from the very simple (a large ferrite bead placed around the power line) to complex (for example, a system that inductively retransmits the signal out-of-phase with the original in a manner that does not disrupt BPL signal reception). Ideally, such a filter would absorb, rather than reflect, the incoming signal.

Additionally, the installation of filters on low-voltage distribution wiring before it enters a premises could help to prevent in-house interference to radio reception from BPL signal leakage. At least one relevant patent on such a filter was recently issued.[65]

Although NTIA's studies were focused on outdoor wiring and Federal Goverment radio systems, it should be recognized that in many cases filtering techniques may reduce interference to other radio receivers that may be vulnerable to interference from signals radiated by indoor LV wiring.

8.6 IMPLEMENTATION OF A "ONE ACTIVE DEVICE PER AREA" RULE

Several manufacturers have noted that BPL devices in a given area tend to transmit one at a time, and their signals therefore do not aggregate.[66] Making such a

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[65] *System, device, and method for isolating signaling environments in a power line communication system*, United States Patent No. 6,590,493, Rasimas, et al., July 8, 2003.

[66] *See*, for example, Ameren Reply Comments at 13.

configuration standard practice (*i.e.*, only using one power line phase in a given area and only one signal injection point per wire) would help to ensure such were the case, at least for a local receiver.

8.7 JUDICIOUS SIGNAL CARRIER CHOICE

Due to the specific physical and electrical characteristics of a given section of power line, it is conceptually possible to find one or more frequency bands at which BPL signal radiation is relatively low. Specifically, on a case-by-case basis during installation or operation, it is theoretically possible to consistently preclude worst-case radiation conditions through avoidance of combinations of certain frequencies and coupler placement geometry (relative to power line impedance discontinuities) that yield worst-case radiation. NTIA's studies have only partially addressed frequency selective characteristics of BPL radiation, but work to date indicates that less than 50% of possible operating frequencies will exhibit this low-radiation characteristic.

To implement this concept, detailed measurements may be needed at every installation site to reliably identify frequency and coupler placement combinations that should be avoided. It likely would be found that use of a substantial amount of bandwidth would be precluded at each segment of a BPL network. NTIA welcomes further investigation of this concept by BPL proponents because if practicable, BPL devices could operate at higher signal power levels while still complying with field strength limits.

8.8 MAINTENANCE OF A SINGLE POINT OF CONTROL

In order to improve the resolution of actual cases of harmful interference, it would be prudent to have one entity in a service area controlling all the devices in that area, as well as one contact point for that entity. This contact point should be capable of addressing cases of suspected interference and resolving actual harmful interference through any and all means available to the BPL provider, without government intervention.

8.9 WEB-BASED ACCESS TO RADIO LICENSE INFORMATION

Knowing what radio operations are located in their immediate environment should facilitate BPL operators in selecting frequencies, power and other technical parameters that minimize interference. The FCC and NTIA both maintain databases of licensed/authorized radio systems across the radio spectrum, including the 1.7-80 MHz frequency range. The possibility of making parts of the NTIA database available to appropriate persons via a web-based mechanism will be further investigated by NTIA. However, it should be recognized at the outset that such an approach could, at most, be only a partial solution due to the nature of such data bases. For example, many frequency assignments are registered for nationwide use rather than use at a specific location. Also numerous uses are not publicly releasable.

8.10 INSTALLATION AND EQUIPMENT REGISTRATION

By centrally 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. Such a registry could assist local radio users in diagnosing suspected interference, which in turn may preclude unfounded complaints of BPL interference. Furthermore, in the event of actual interference that is believed to originate from a BPL system, the radio user could consult the registry to determine the cognizant point of contact with the organization of the BPL operator. By keeping potential requirements for filing of an interference complaint with the FCC to a minimum, the registry would expedite elimination of actual interference should it occur and avoid the buildup of an unfavorable track record at the Commission. Unfavorable track records could precipitate further Inquiry and Rulemaking actions that, in actual fact, may be unnecessary. NTIA will further study and recommend the BPL deployment parameters that should be included in the registrations.

8.11 CONCLUSION

NTIA suggested several means by which BPL interference can be eliminated; some of these and others may be used to reduce the risk of interference. Mandatory registration of certain parameters of planned and deployed BPL systems would enable radio operators to advise BPL operators of anticipated interference problems and suspected actual interference; thus, registration could substantially facilitate prevention and mitigation of interference. Consideration should be given to BPL frequency agility (notching and/or retuning) and power reduction for elimination of interference. NTIA further recommends consideration of the following interference prevention and mitigation measures:

- Routine use of the minimum output power needed from each BPL device;
- Avoidance of locally used radio frequencies;
- Differential-mode signal injection oriented to minimize radiation;
- Use of filters and terminations to extinguish BPL signals on power lines where they are not needed;
- Use of one active device per frequency and area;
- Judicious choice of BPL signal frequencies to avoid efficient radiation;
- Maintenance of single points of contact and BPL network control;
- Use of web-based access to radio license information to avoid locally used radio frequencies.

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.