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

NTIA Report 04-413

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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.

[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.

[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.

[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.

[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.

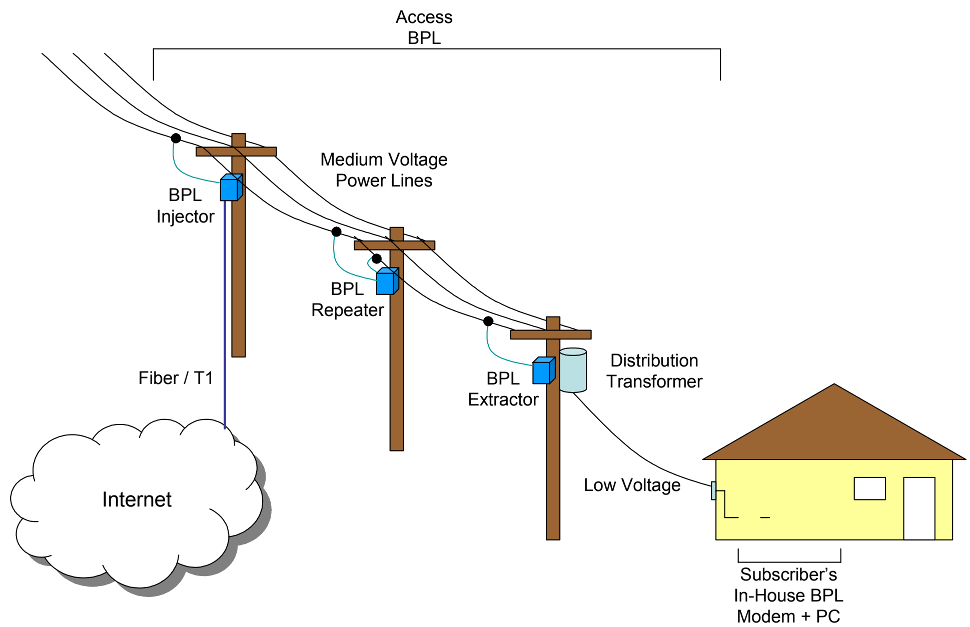

Figure 2-1: Basic BPL System

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.

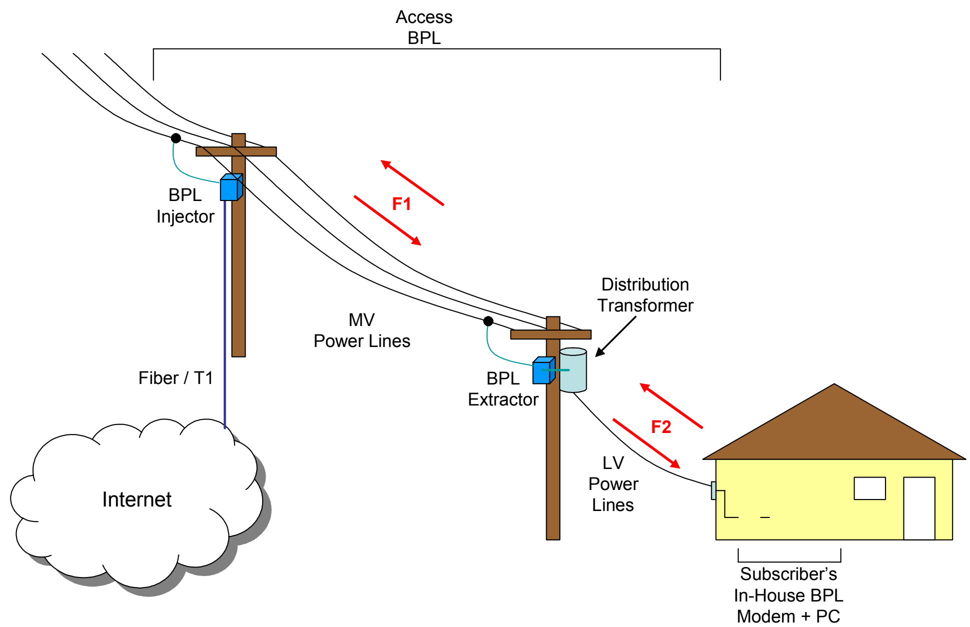

Figure 2-2: BPL System #1

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.

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

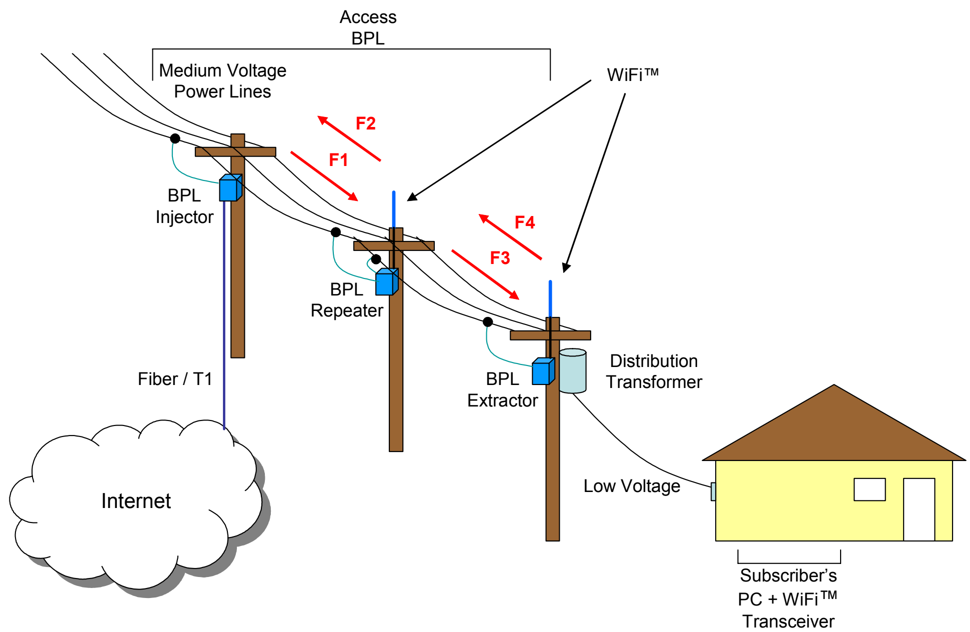

Figure 2-3: BPL System #2

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.

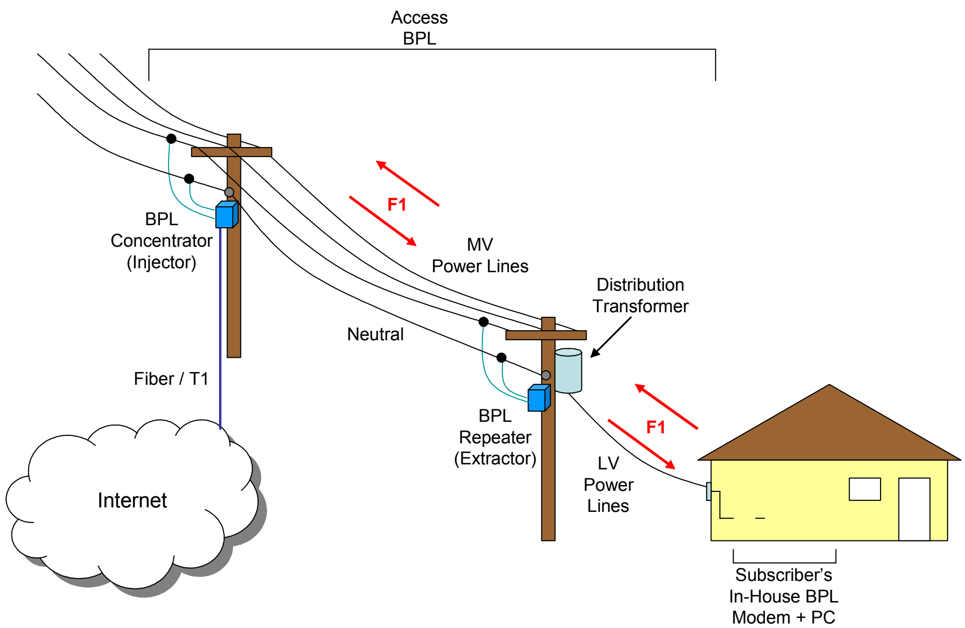

Figure 2-4: BPL System #3

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.

[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	$H_{peak} = -29.7 - 8.15 \, Log_{10}(f_{MHz})$,	9 kHz	peak

[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	$E_{peak} = 21.8 - 8.15 \, Log_{10} (f_{MHz})$, (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.

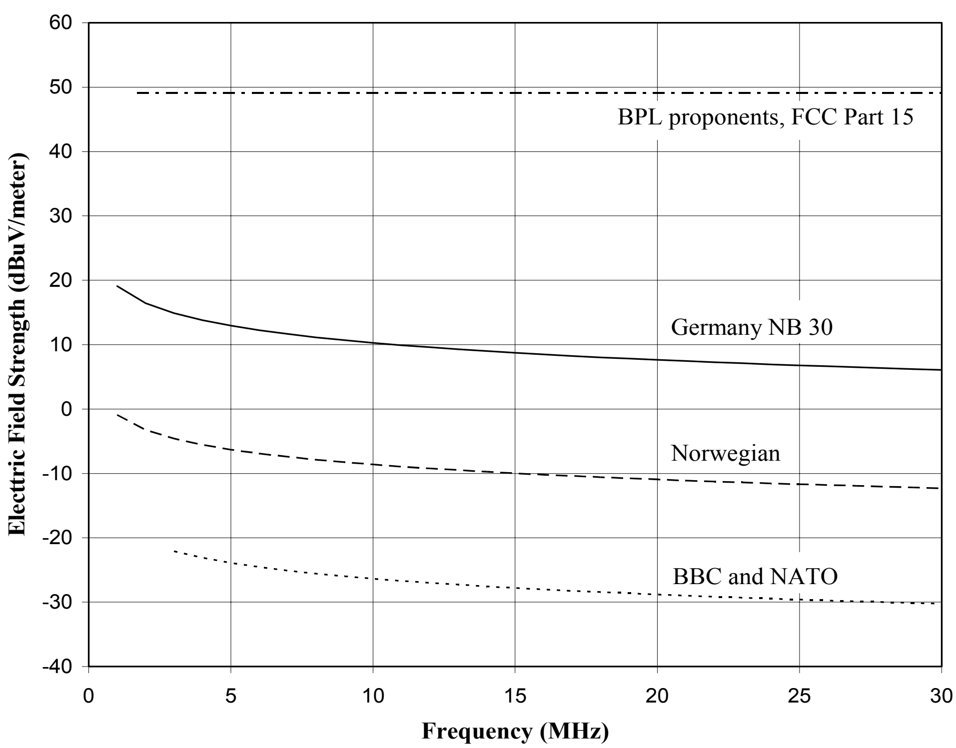

Figure 3-1: Comparison of Proposals for Regulating BPL Emissions

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.

[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

[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).

[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

[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

[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 $0.62 \cdot \sqrt{(D^3/\lambda)} < r < 2 \cdot D^2/\lambda$, 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, ground-wave 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

[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.

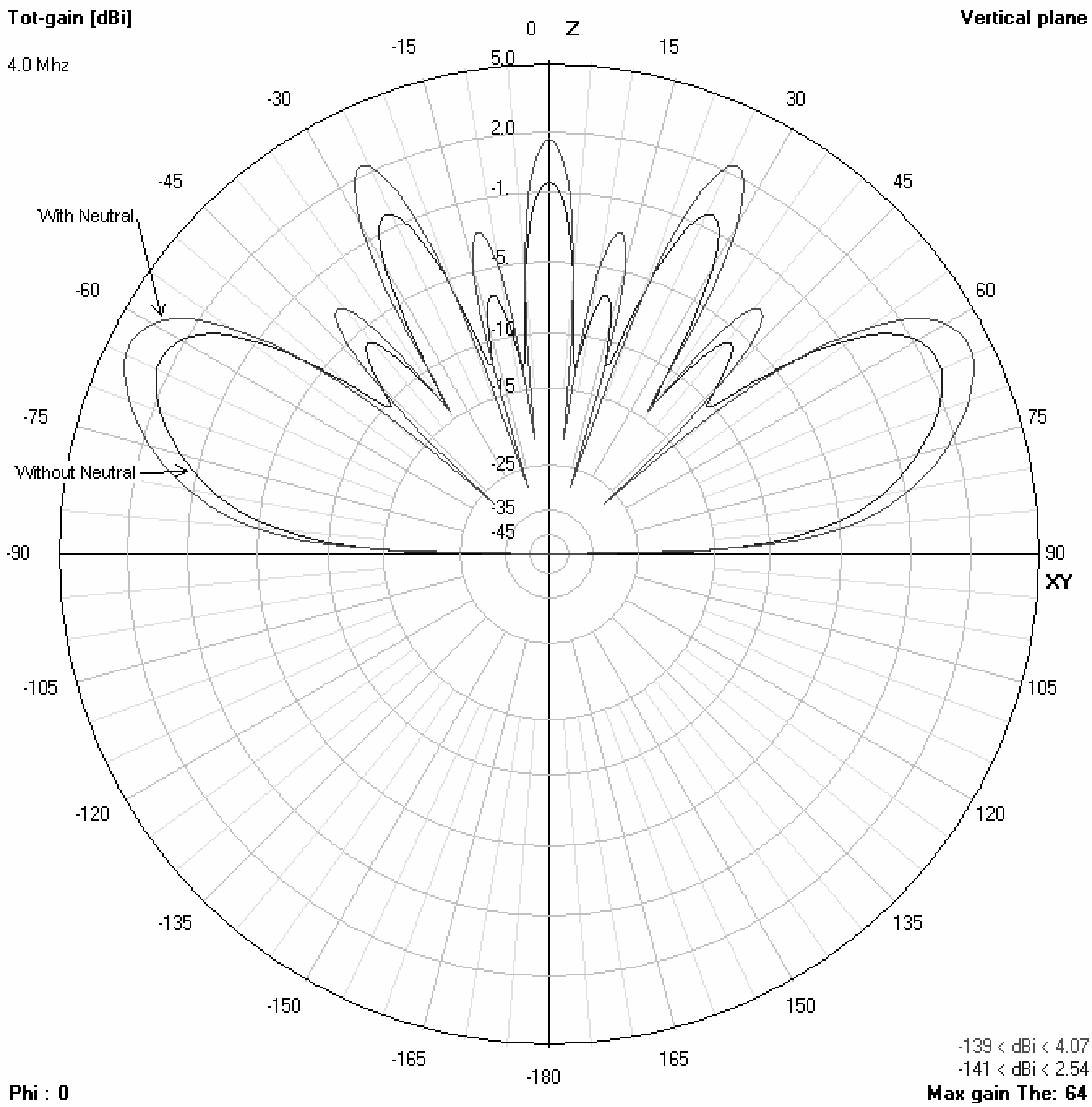

Figure 5-1: Comparison of NEC model with and without a parasitic multi-grounded neutral at 4 MHz.

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).

[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.

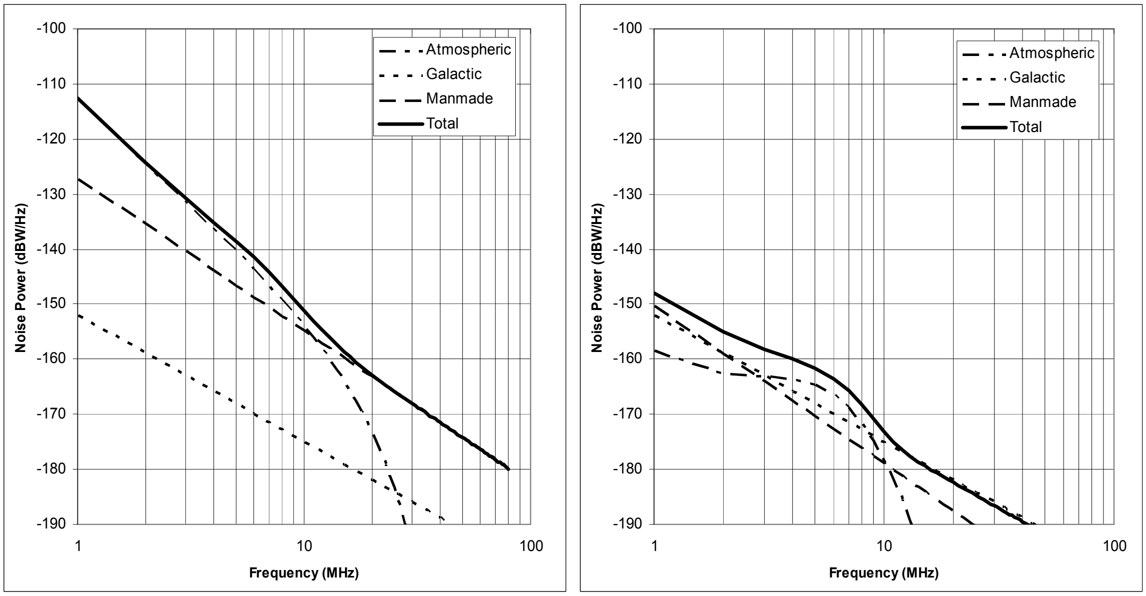

Figure 5-2: Example calculated median background noise levels. Left: industrial environment during the height of thunderstorm season in the Midwest United States. Right: rural Alaskan environment during the winter.

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.

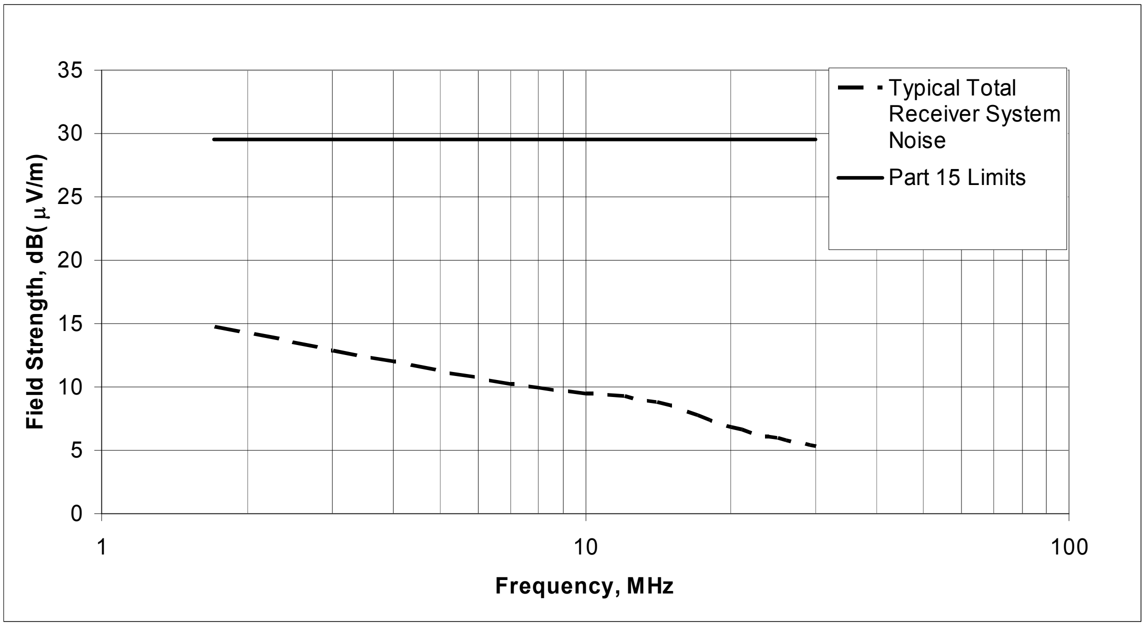

Figure 5-3: Typical median noise field strength and FCC Part 15 limits at 30 meters, 1.705 MHz to 30 MHz, 9 kHz bandwidth.

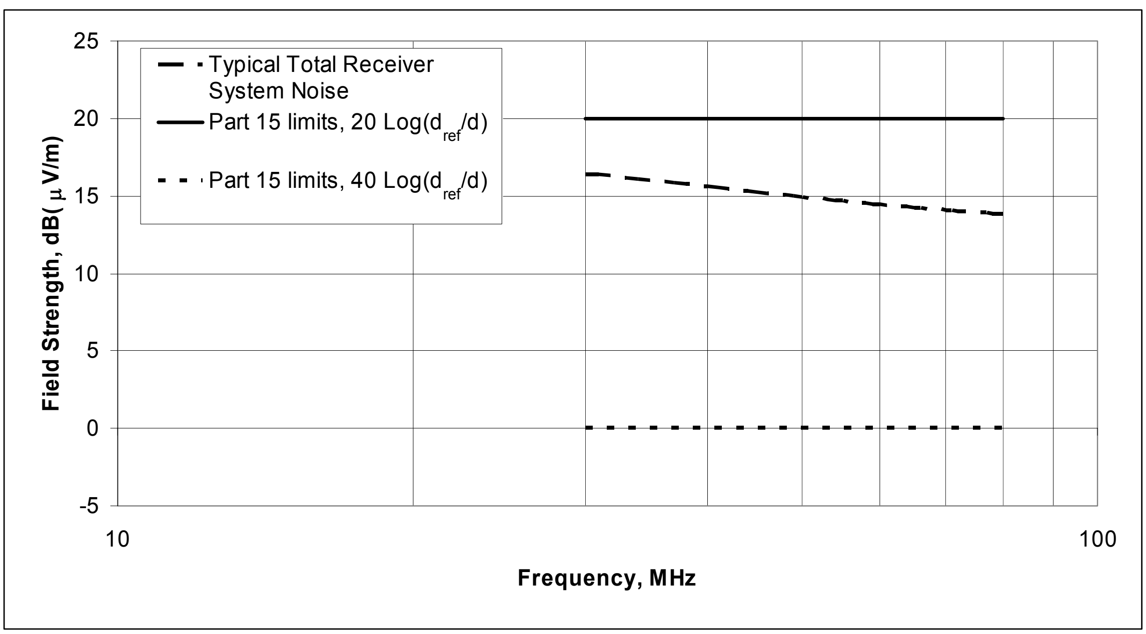

Figure 5-4: Typical median noise field strength and FCC Part 15 limits at 3 meters

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

[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 -ΔS/N).

[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.")

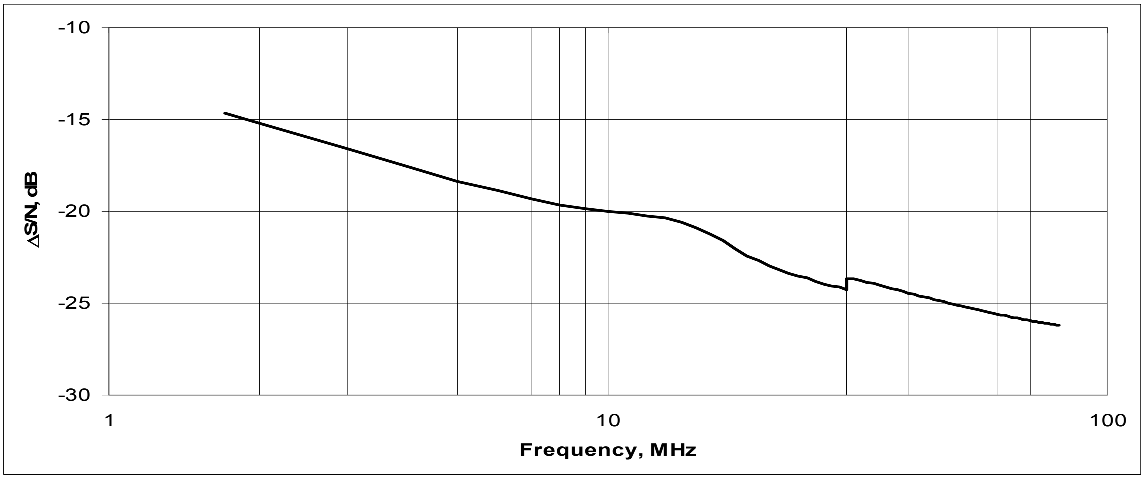


Figure 6-1: Change in Receiver Signal-to-Noise Power Ratio Caused By Unintentional Emissions at the Part 15 Limit[47]

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.

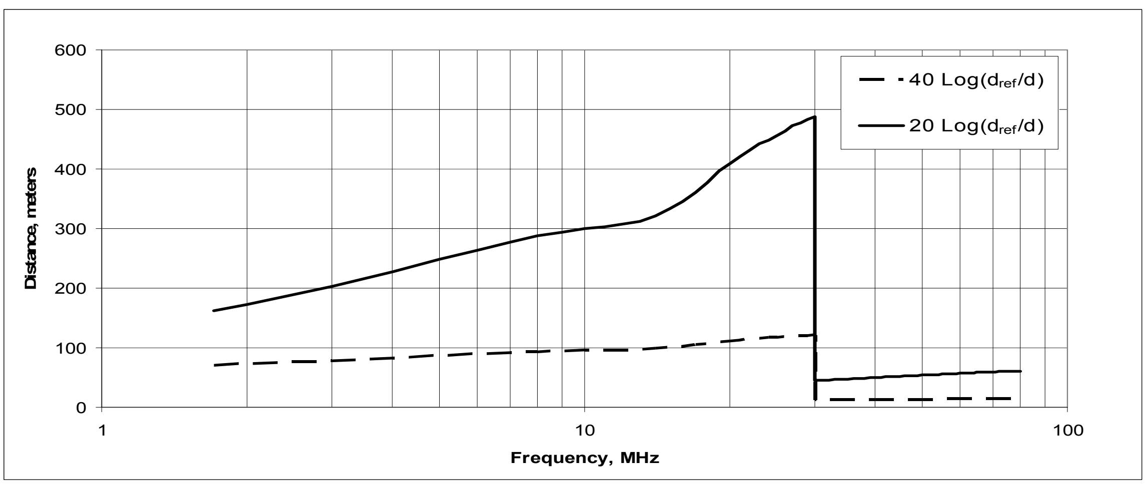


Figure 6-2: Distance at which external noise levels equal FCC Part 15 radiated emission limits (Class B)[48]

[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.

[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:

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

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:

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

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.

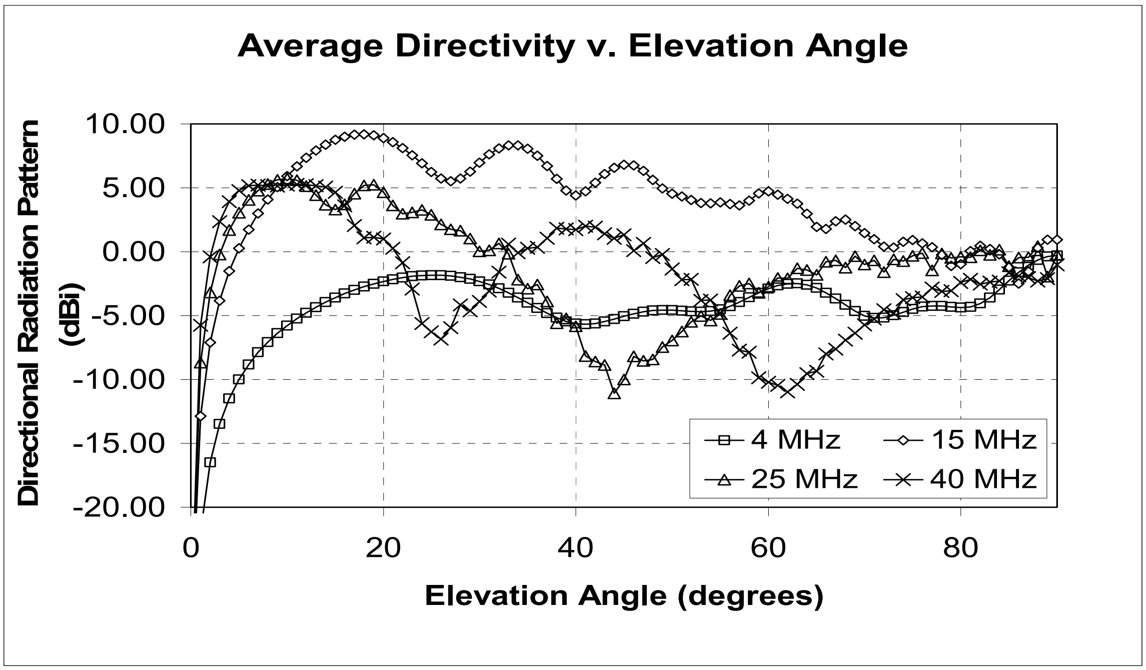


Figure 6-3: Average far field directional gain antenna patterns used for aeronautical interference calculations.

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

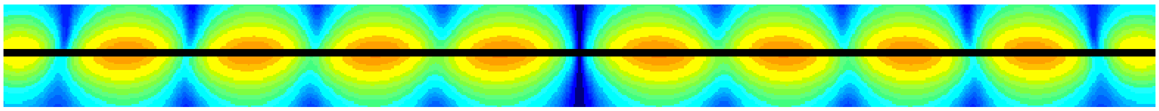
Calculations of close-to-the-line interference potential for vehicular land-mobile receivers due to a BPL transmitter operating at FCC Part 15 limits show that there would be significant increases in the noise floor due to interference. As can be seen in Table 6-3, for frequencies less than 30 MHz, virtually 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.

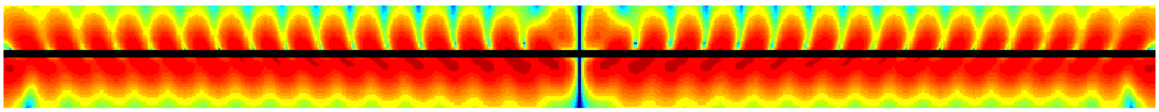
Frequency (MHz)	Radiated Power (dBW)	Noise (dBW)	3 dB (I+N)/N	10 dB (I+N)/N	20 dB (I+N)/N	30 dB (I+N)/N	40 dB (I+N)/N	50 dB (I+N)/N
4	-69.8	-111.3	99.3%	93.2%	54.7%	6.2%	0.0%	0.0%
15	-67.3	-128.8	99.8%	99.7%	95.7%	59.5%	4.3%	0.0%
25	-64.9	-135.6	99.8%	99.0%	92.1%	58.5%	18.5%	0.0%
40	-81.1	-134.3	87.9%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

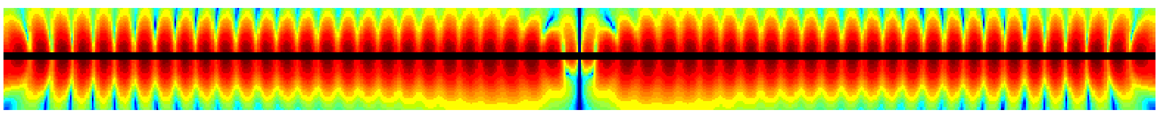
It can be inferred from these calculations that a vehicle-mounted HF receiver operating in a residential environment on a roadway adjacent to a BPL-energized power line may experience harmful interference, depending upon the frequency, the distance along the line away from the BPL transmitter, the BPL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



(a)



(b)



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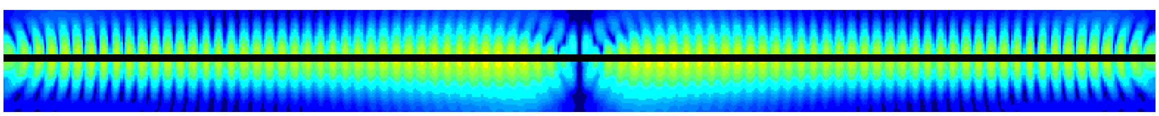
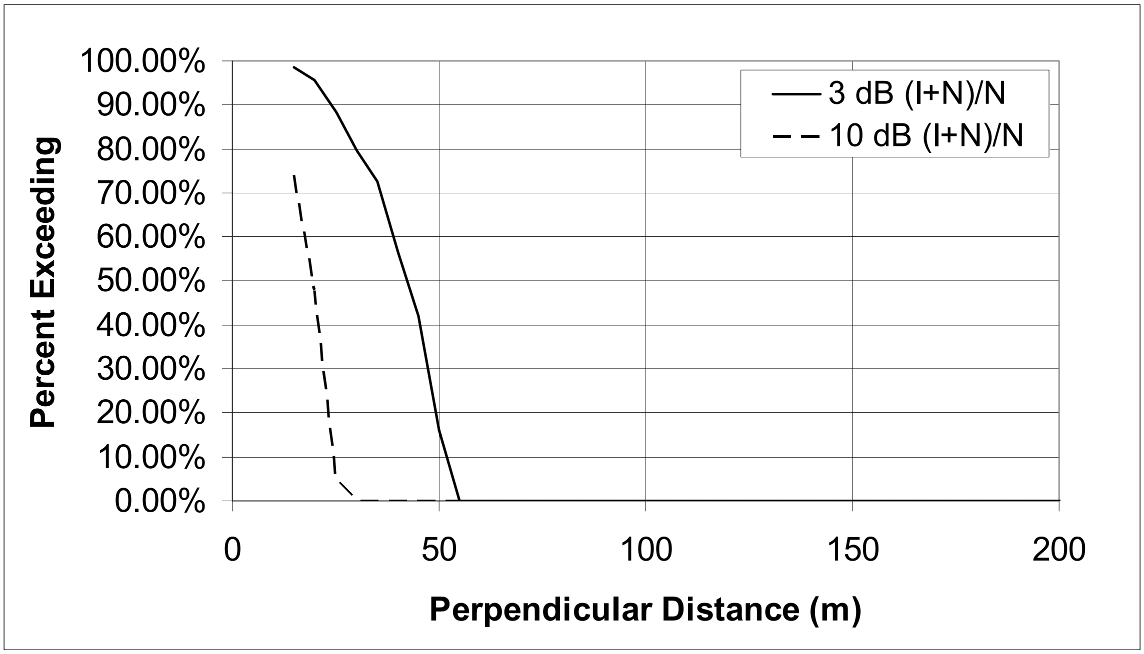


(d)

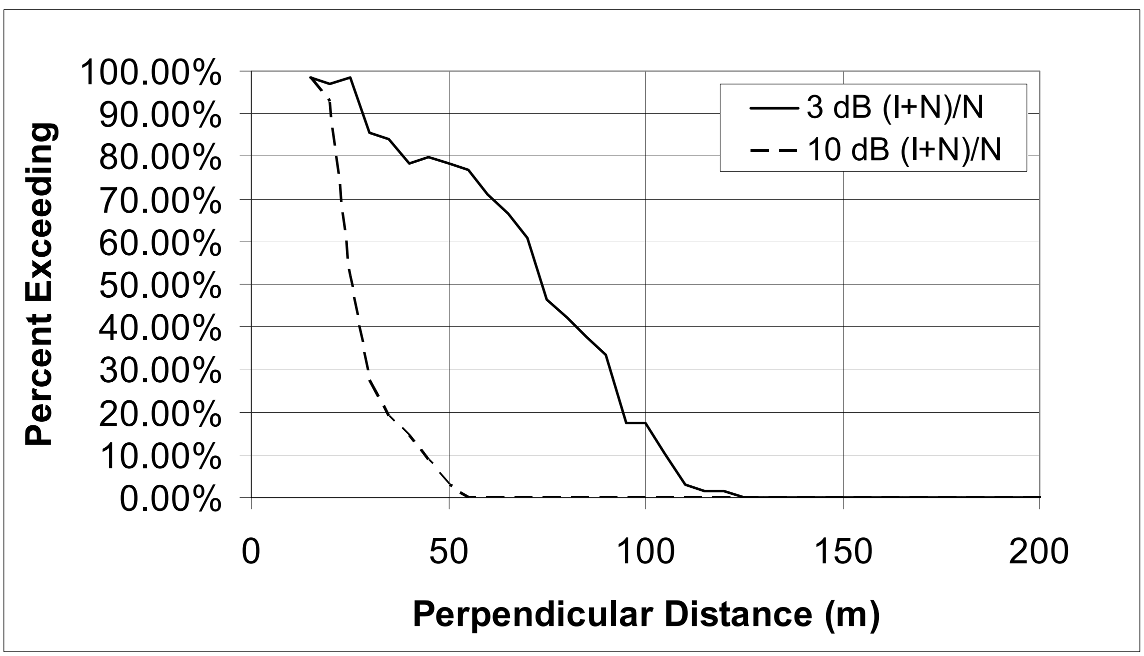
Figure 6-4: (I+N)/N values around the modeled power line, to a distance of 15 meters. Colors represent a range from zero dB (dark blue) to 50 dB (dark red). a) 4 MHz. b) 15 MHz. c) 25 MHz. d) 40 MHz. The BPL structure is denoted with a dark horizontal line in the center of each plot.

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.

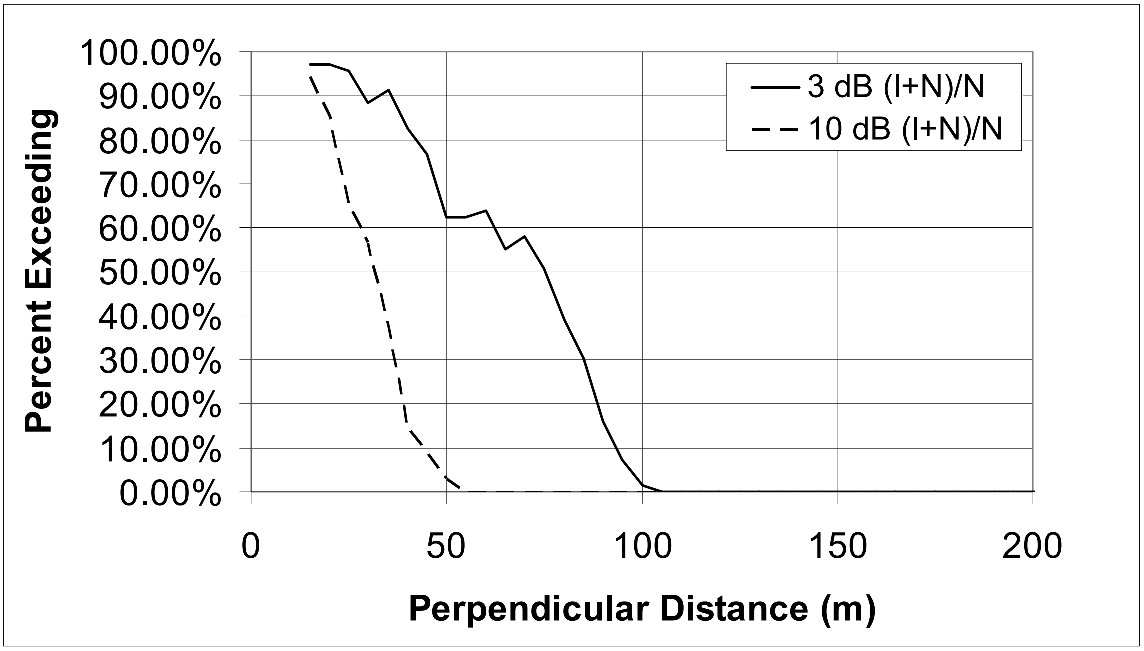


(a)



(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.



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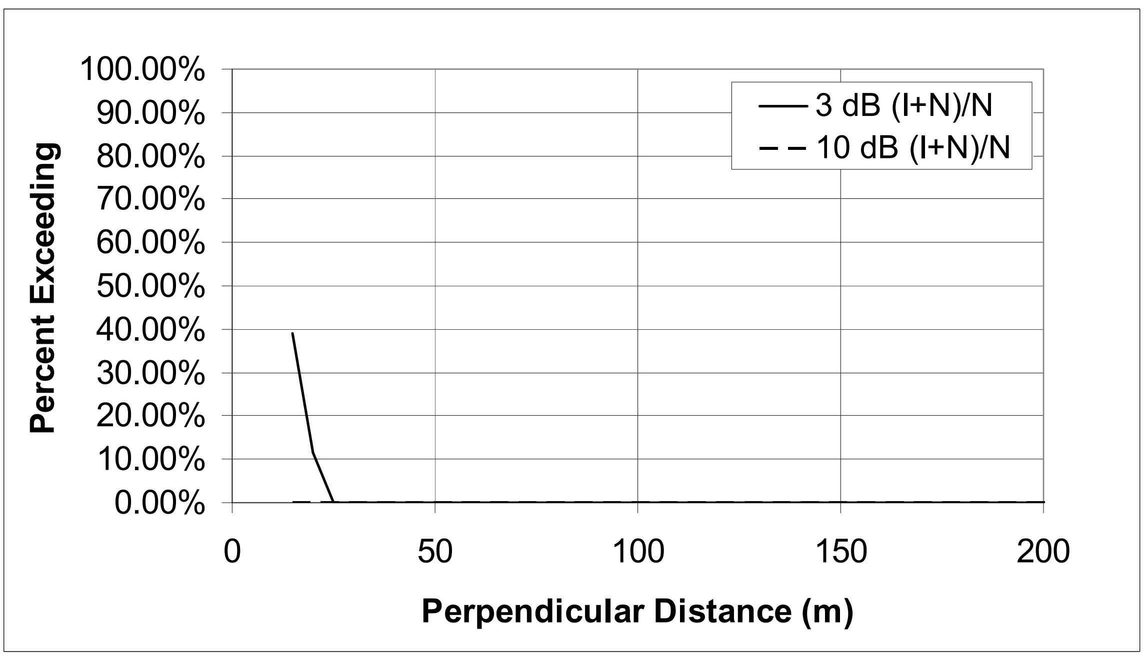


(d)

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.

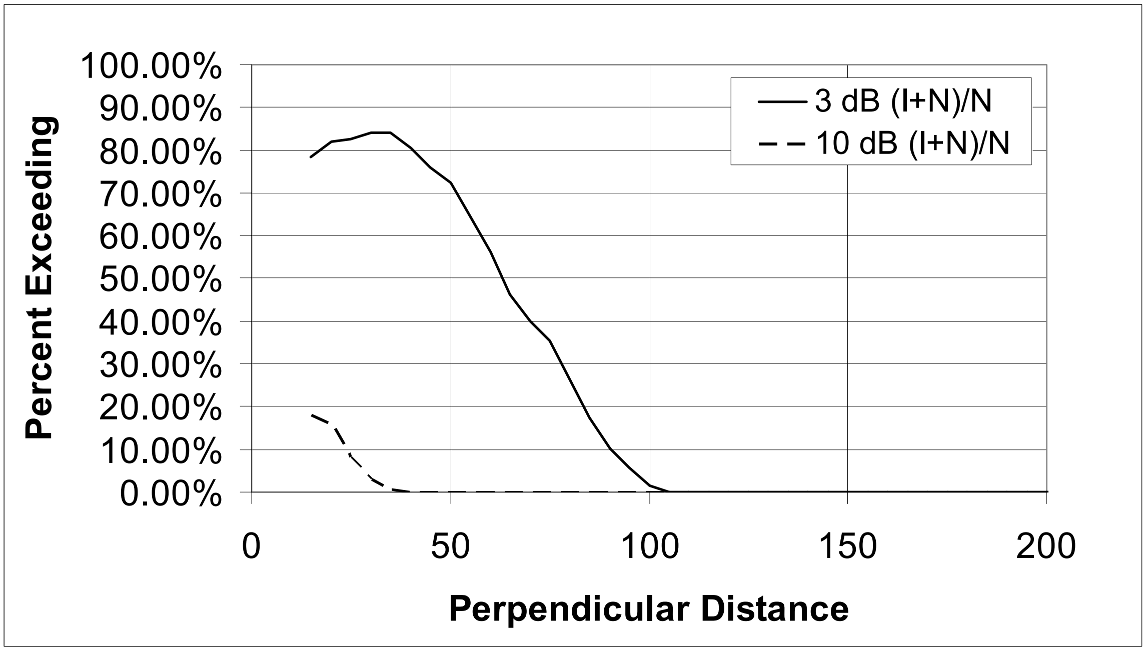
The differences in potential interference found with different frequencies are partly due to the ambient noise floor decreases as the frequency is increased. However, the increased gain of the modeled antenna with frequency also plays a part, which means that higher gain antennas and lower-noise areas 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

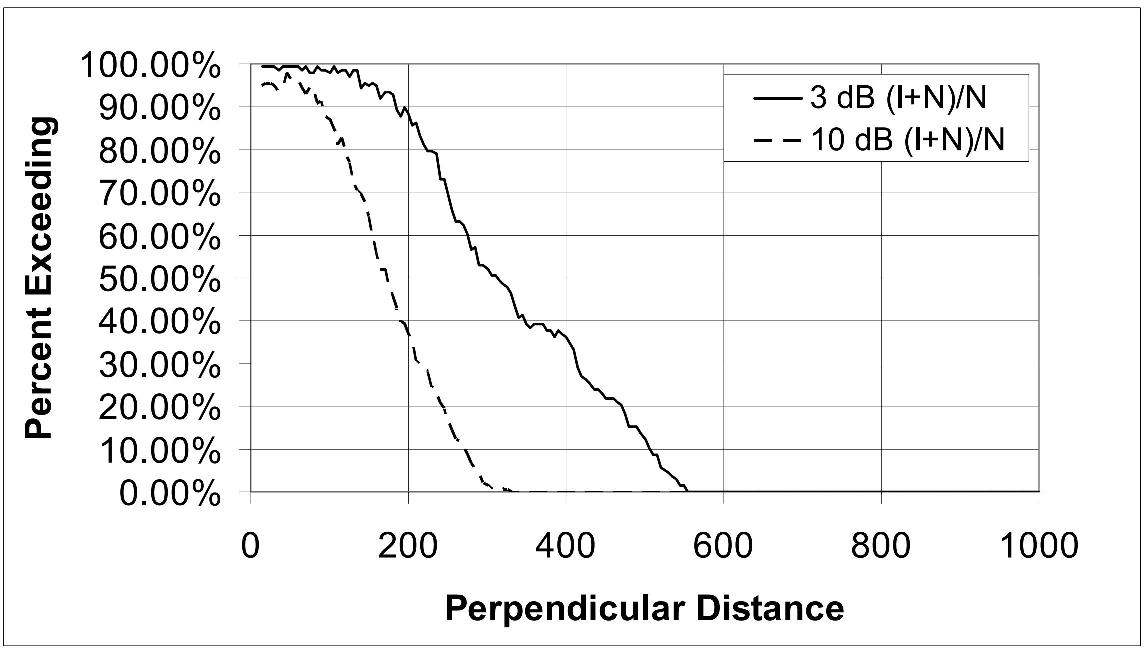
As noted previously, the calculations for a ship receiver differed from the fixed and land-mobile services in two important respects: the use of lower ambient noise levels and the use of salt-water ground characteristics. This model assumed a power line running along the shoreline, and the ship receiver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

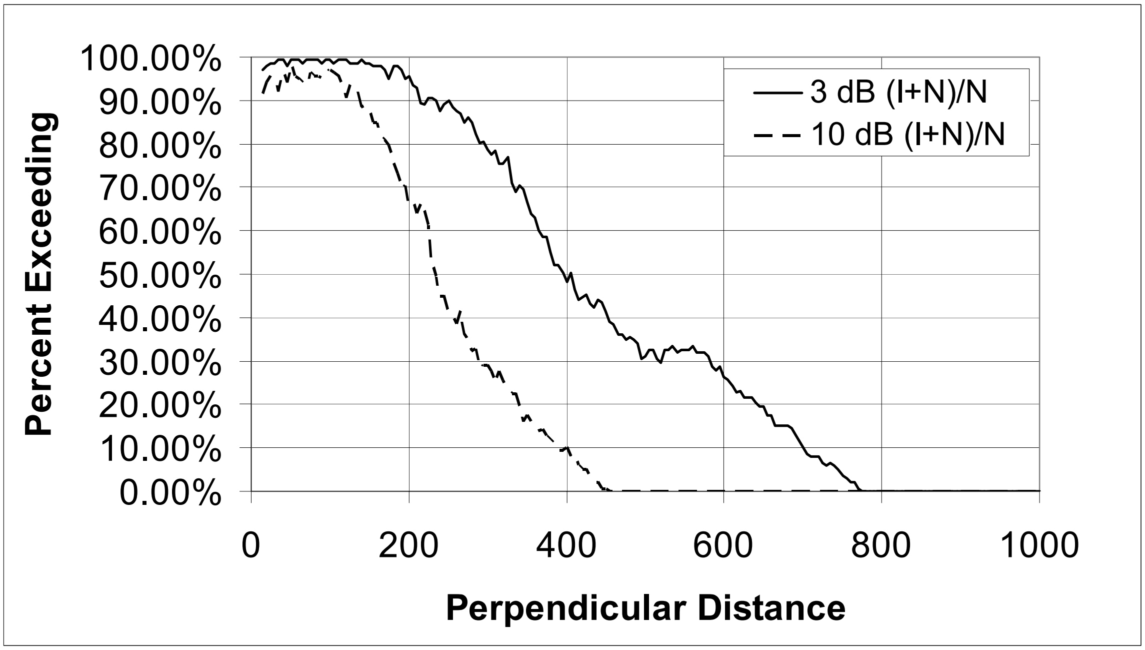


(a)



(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.



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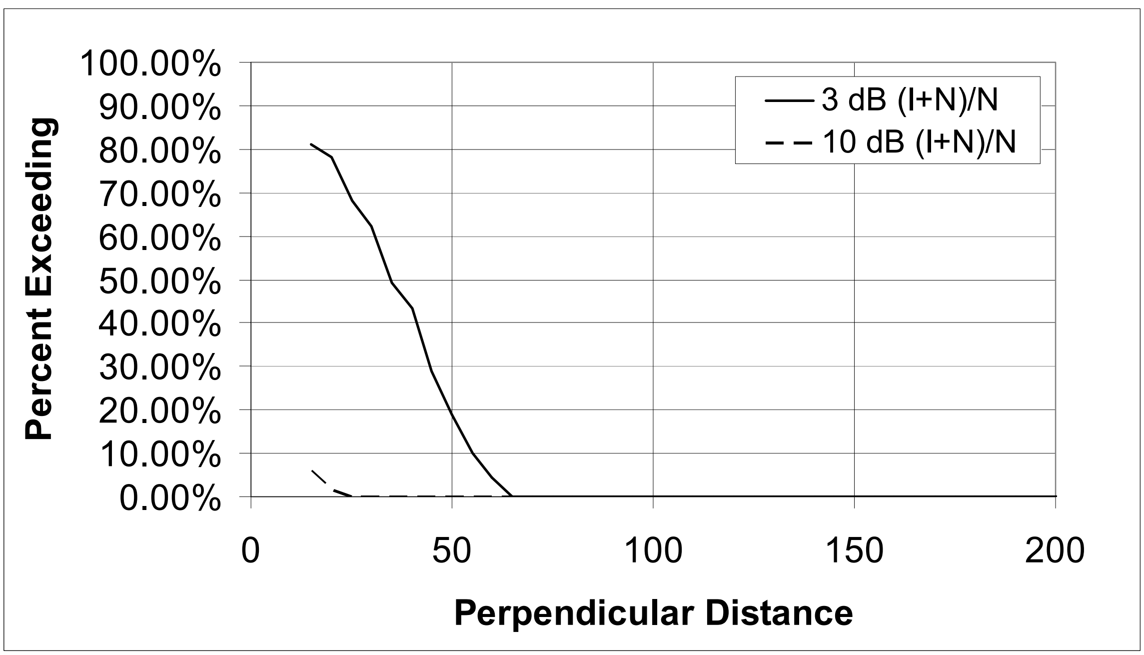
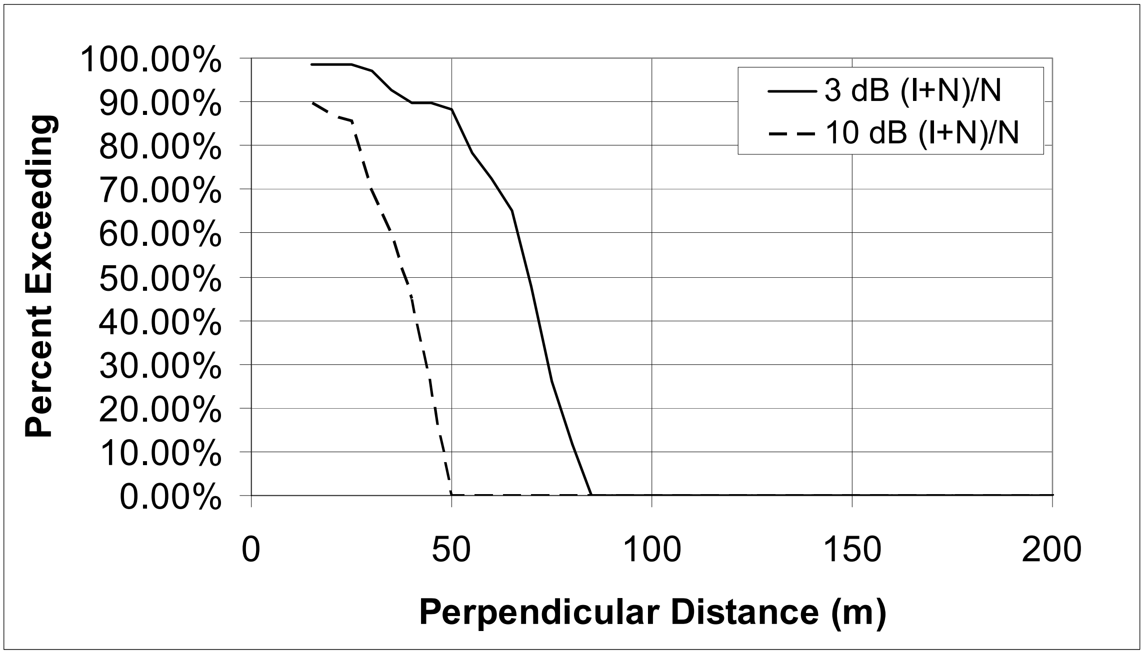
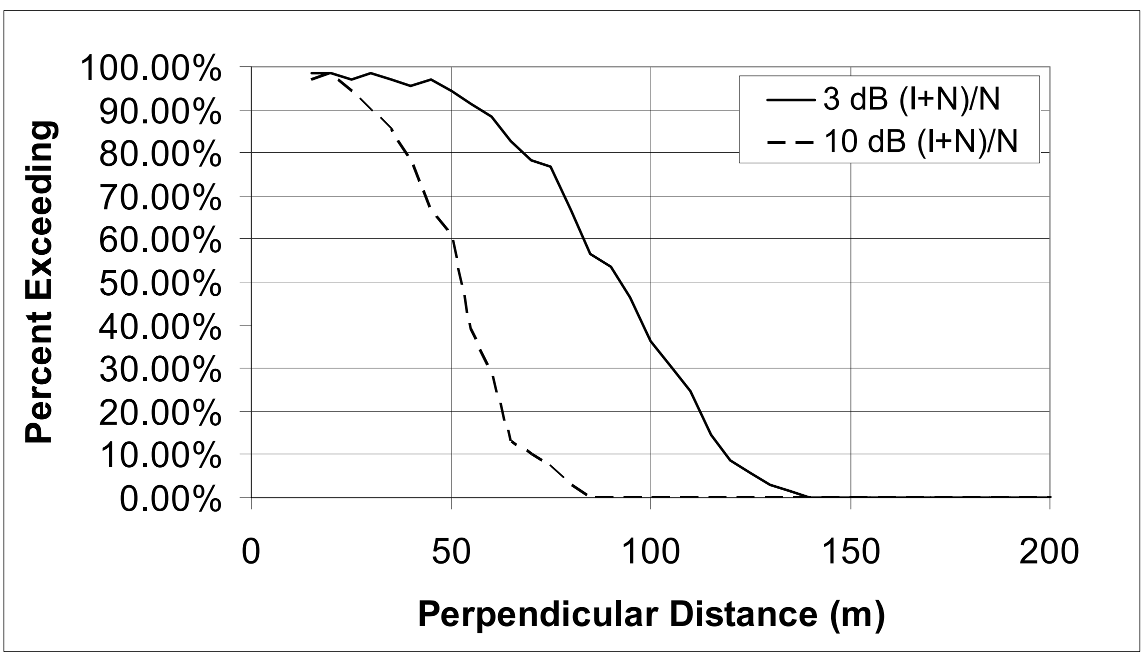


(d)

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

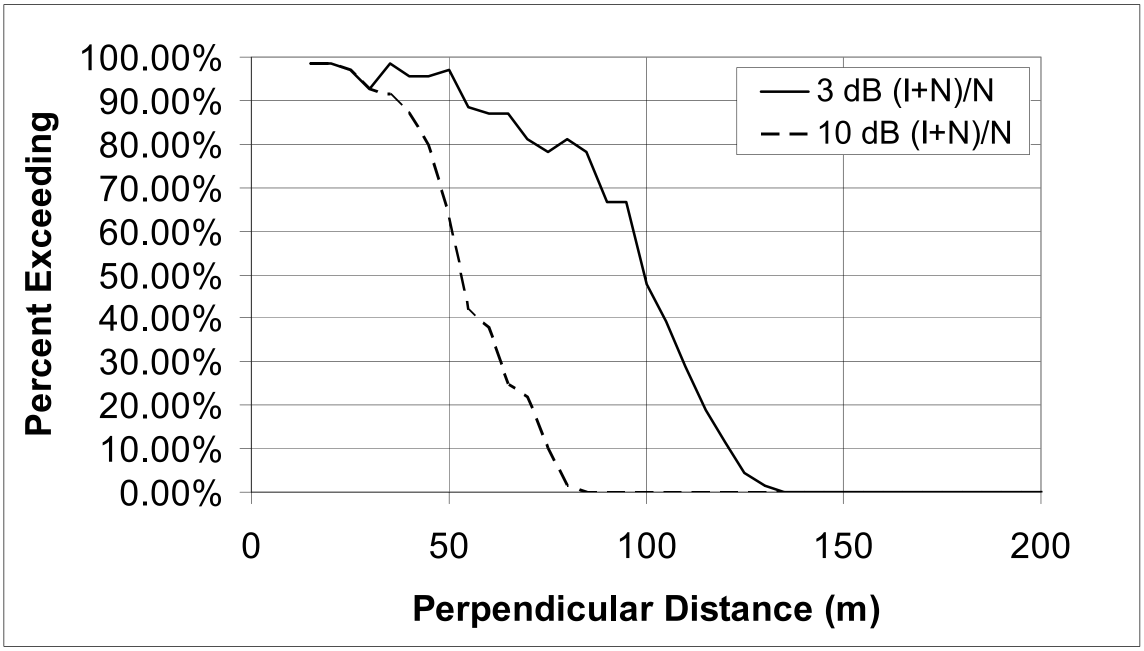


(a)



(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.



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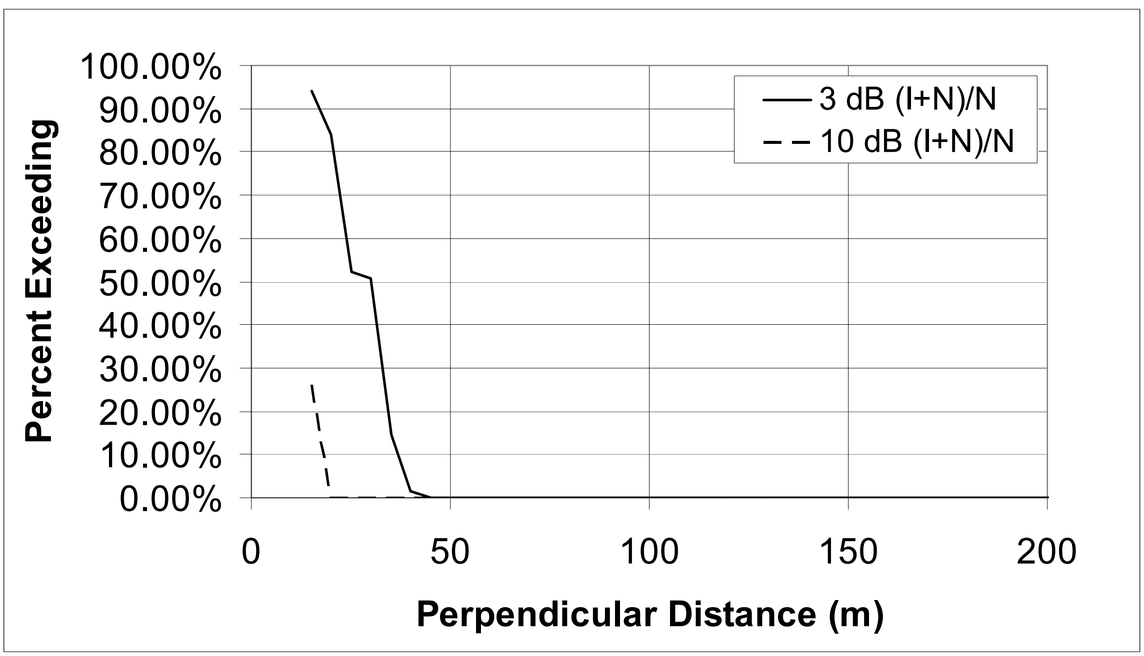


(d)

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

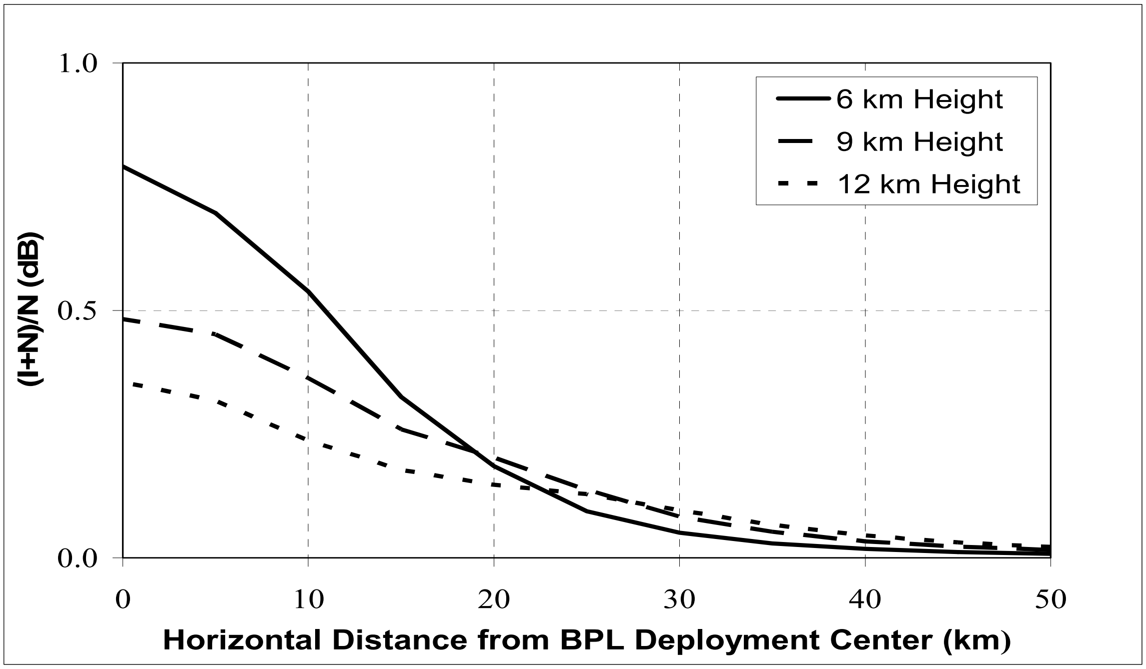
6.6.4 Aeronautical Service

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.

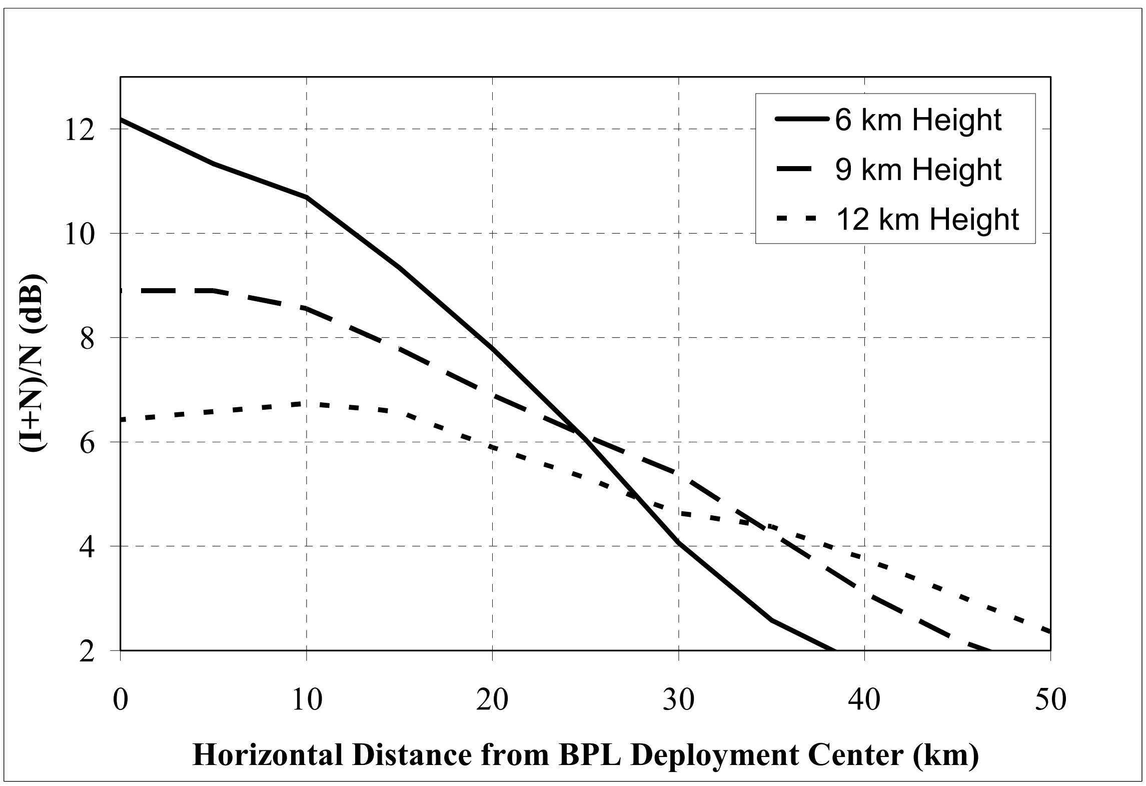
Table 6-4: Calculated (I+N)/N values, in dB, for aircraft receiver at listed distance, frequency and height, with 300 BPL units visible to the receiver in a 314 km^2 area.

	(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.

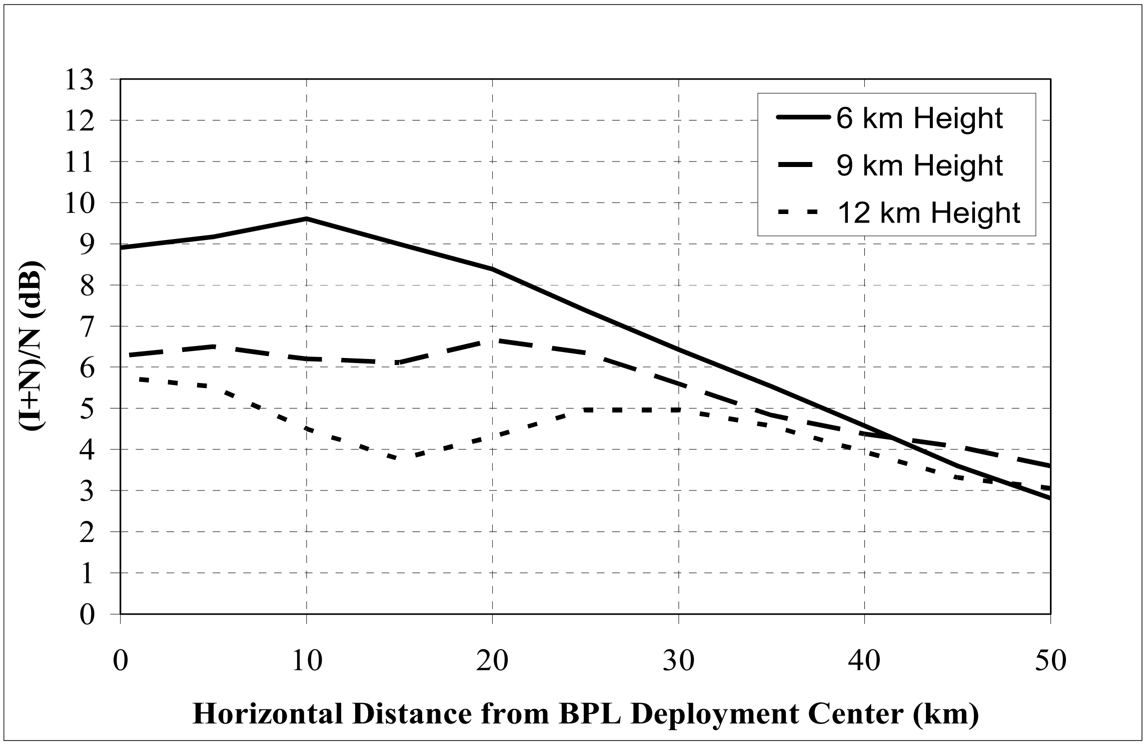


(a)

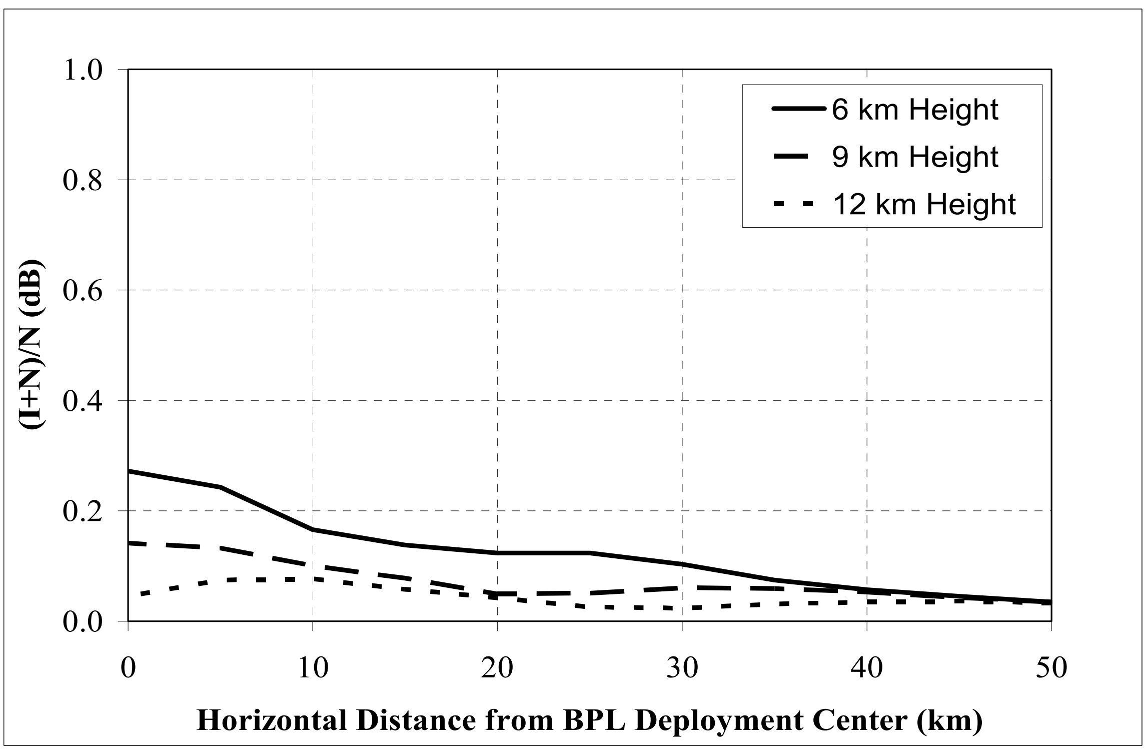


(b)

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]

[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

[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

[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.

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Phase 1 Study

VOLUME II

technical report

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

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Phase 1 Study

VOLUME II

U.S. Department of Commerce
Donald Evans, Secretary

Michael D Gallagher, Acting Assistant Secretary
For Communications and Information

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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

APPENDIX A
RELEVANT PART 15 PROVISIONS

Part 15 provisions regarding field strength limits and compliance measurements are quoted or paraphrased below. Observations relevant to the application of these provisions to BPL systems are presented in footnotes.

A.1 PROVISIONS REGARDING FIELD STRENGTH LIMITS

§15.15(c) "*Parties responsible for equipment compliance should note that the limits specified in this part will not prevent harmful interference under all circumstances.*"

§15.109(a) "*...the field strength of radiated emission from unintentional radiators at a distance of 3 meters shall not exceed the following values...*" [1]

§15.109(e) "*Carrier current systems used as unintentional radiators...shall comply with the radiated emission limits for intentional radiators provided in* §15.209 for the frequency range 9 kHz to 30 MHz."

§15.109(g) "*As an alternative to the radiated emission limits shown in paragraphs (a) and (b) of this section, digital devices may be shown to comply with the standards contained in the Third Edition of International Electrotechnical Commission ("IEC"), International Special Committee on Radio Interference ("CISPR") Pub. 22 (1997)...*"

§15.113(b) "*The operating parameters of a power line carrier system (particularly the frequency) shall be selected to achieve the highest practical degree of compatibility with authorized or licensed users of the radio spectrum*." [2]

§15.113(c) "*Power line carrier system apparatus shall be operated with the minimum power possible to accomplish the desired purpose.*"

§15.205(a) "*...only spurious emissions are permitted in any of the frequency bands listed below:..*" [3]

§15.209(a) *"...emissions...shall not exceed the field strength levels specified in the following table...*" [4]

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[1] NTIA recommends a uniform ten (10) meter measurement distance. *See* Section 7.5.

[2] In Section 7, NTIA has identified potential means for enhancing compatibility of BPL systems with radio systems.

[3] NTIA 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 (*see* RR No. 4.22).

[4] NTIA recommends a uniform ten (10) meter measurement distance. *See* Section 7.5.

A.2 PROVISIONS SPECIFYING COMPLIANCE MEASUREMENTS

§15.31(a) "*The following measurement procedures are used by the Commission to determine compliance with the technical requirements of this part.*"

§15.31(a)(6) Digital devices are to be measured using procedures specified in American National Standards Institute (ANSI) C63.4-1992 to determine compliance with the technical requirements of Part 15.

§15.31(b) "*All parties making compliance measurements on equipment subject to the requirements of this part are urged to use these procedures.*"

§15.31(d) Measurements are to be made at a calibrated test site to the extent possible. CCS are cited as a case where measurements can be made only at an installation site. Measurements "*...shall be performed at a minimum of three installations that can be demonstrated to be representative of typical installation sites.*" [5]

§15.31(f) "*To the extent practical, the device under test shall be measured at the distance specified in the appropriate rule section.*" The measurement distance is applied horizontally with respect to a boundary around the device and any interconnection cables.[6]

§15.31(f)(1) "*At frequencies at or above 30 MHz,...measurements are not made in the near field except where it can be shown that near field measurements are appropriate due to the characteristics of the device; and it can be demonstrated that the signal levels needed to be measured at the distance employed can be detected by the measurement equipment.*"[7] "*When performing measurements at a distance other than that specified, the results shall be extrapolated to the specified distance using an extrapolation factor of ...*" [8]

§15.31(f)(2) "*At frequencies below 30 MHz, measurements may be performed at a distance closer than that specified in the regulations; however, an attempt should be made to avoid making measurements in the near field.*" "*...when performing measurements at a closer distance than specified, the results shall be extrapolated to the specified distance....*"

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[5] *See* Section 7.9.

[6] None of the three proprietary access-BPL measurement reports reviewed by NTIA applied §15.31(f). Instead, these measurements were performed on radials at distances measured from the "telephone" pole on which the BPL device was mounted.

[7] NTIA's Phase 1 Study indicates that BPL emissions must be measured in the near-field because of its large expanse.

[8] NTIA's Phase 1 Study shows that BPL radiation characteristics may not be consistent with the extrapolation factors specified in §15.31(f). Further study is needed.

§15.31(f)(4) "*When measurements of 30 meters or less are specified in the regulations, the Commission will test the equipment at the distance specified unless measurement at that distance results in measurements being performed in the near field*."

§15.31(f)(5) "*The maximum field strength at the frequency being measured shall be reported in an application for certification*." [9]

§15.31(g) "*Equipment under test shall be adjusted, using those controls that are readily accessible to or are intended to be accessible to the consumer, in such a manner as to maximize the level of emissions. For those devices to which wire leads may be attached by the consumer, tests shall be performed with wire leads attached. The wire leads shall be of the length to be used with the equipment if that length is known. Otherwise, wire leads one meter in length shall be attached to the equipment.*" [10]

§15.31(h) "*For a composite system that incorporates devices contained either in a single enclosure or in separate enclosures connected by a wire or cable, testing for compliance with the standards in this part shall be performed with all of the devices in the system functioning.*" [11]

§15.31(i): "*The emission tests shall be performed with the device and accessories configured in a manner that tends to produce maximized emissions within the range of variations that can be expected under normal operating conditions.*"

§15.31(j): "*If the equipment under test consists of a central control unit and external or internal accessory(ies) (peripheral) and the party ...applying for a grant of equipment authorization manufactures or assembles the central control unit and at least one of the accessory devices that can be used with the control unit, testing of the control unit and/or the accessory(ies) must be performed using the devices manufactured or assembled by that party, in addition to any other needed devices which the party does not manufacture or assemble.*"

§15.31(k): "*If the individual devices in a composite system are subject to different technical standards, each such device must comply with its specific standards. In no*

[9] Regardless of whether certification ultimately is required for BPL authorizations, under NTIA's recommended measurement provisions (Section 7) the maximum field strength at a given measurement frequency is determined from measurements made while operating the BPL system at each frequency at which it is capable of operating.

[10] The "consumer" for outdoor BPL devices normally will be the BPL system operator, whereas the consumer for indoor BPL devices normally will be the BPL subscriber. The length of outdoor "wire leads" used with access and in-house BPL devices vary substantially among the potential BPL installation sites and, as recommended by NTIA (Section 7.9), the representative power lines selected for BPL testing should encompass various features that significantly affect peak field strength levels. In no case can a one-meter or other short length of power line be used for BPL compliance measurements because standing waves associated with peak field strength will not be manifest.

[11] NTIA interprets §§15.31(h), (i), (j) and (k) to mean that at any frequency, during measurement and operational use, a network of BPL devices may not generate an aggregate field strength that exceeds the field strength limit for BPL systems. See Section 7.3.

event may the measured emissions of the composite system exceed the highest level permitted for an individual component."

§15.33(b)(1) "...*the spectrum shall be investigated from the lowest radio frequency signal generated or used in the device, without going below the lowest frequency for which a radiated emission limit is specified, up to the frequency shown in the following table*..."

§15.35(a): The limits are based on measurement using a CISPR quasi-peak detector and related bandwidths. [12]

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[12] *See* Publication 16 of the International Special Committee on Radio Interference (CISPR) of the International Electrotechnical Commission. Measurement bandwidths of 9 kHz and 120 kHz are to be used with a quasi-peak detector at frequencies below and above 30 MHz, respectively.

APPENDIX B
SUMMARY OF FOREIGN TECHNICAL REPORTS

B.1 INTRODUCTION

This appendix summarizes foreign technical reports related to BPL implementation. NTIA reviewed these reports in the course of designing and refining its technical approach. Citation and summarization of a report herein does not, in itself, signify NTIA concurrence with any aspect of the report and inclusion or exclusion of a report has no significance. In this appendix, the acronyms BPL (for Broadband on Power Line), PLC (for Power Line Communications), and PLT (for Power Line Telecommunications or Technologies) are synonymous and will be used in accordance with each original report.

B.2 IMPLEMENTATION REPORTS

Several telecom equipment manufacturers have teamed up with utility companies to build BPL systems in order to test the technical and economical feasibility of BPL. Results of some of these implementation efforts are presented in Table B-1.

Table B-1: BPL Implementation Results

Company / Nation	Result	Source of Information
SIEMENS / Germany	SIEMENS decided in March 2001to leave the PLC business. Power companies which were due to use SIEMENS equipments are now supplied by ASCOM.	http://www.darc.de/referate/emv/plc/PLC-in-Germany-3-2001-Press-release.pdf
NUON / Netherlands	NUON stops offering digital services through the power lines in the beginning of July, 2003.	http://www.webwereld.nl/nieuws/14920.phtml (in Dutch)
ASCOM / Switzerland	According to DARC, ASCOM has declared that it was unable to supply all PLC main outlets with sufficient low failure rate because it can not be supported by the NB30 requirement.	http://www.darc.de/referate/emv/plc/c3.4-rev1-PLC5RPRT.pdf
ASCOM: Swiss PLC equipment supplier NUON: Dutch energy company SIEMENS: German PLC equipment supplier		

B.3 MEASUREMENT REPORTS

Many EMC measurements conducted by government agencies and private groups have been reported. Some of these reports are presented in Table B-2.

Table B-2: Measurement Reports

Country or Agency	Report or Result	Source of Information
OVSV / Austria	Video Showing Effect of PLC in Tirol, Austria	http://www.darc.de/referate/emv/plc/plc_video_tirol.rm
OVSV / Austria	Video Showing Effect of PLC in Linz, Austria	http://www.darc.de/referate/emv/plc/plc_video_linz.rm
Austria	During an emergency exercise of the Austrian Red Cross in May 2003, communication was massively disturbed by PLC, with interference levels exceeding the limits by a factor 10,000.	http://futurezone.orf.at/futurezone.orf?read=detail&id=205693&tmp=4659
Finland	In October 2001, FICORA measured disturbance levels in the PLC test network in a residential area. The measurements revealed that data transmission caused a significant rise in disturbance levels inside buildings, and outside near buildings and underground cables. The measured levels were significantly higher than NB30.	http://www.ficora.fi/2001/VV_vsk2001.pdf
Germany	"PLT, DSL, cable communications (including cable TV), LANs and other effect on radio services"	ECC Report 24, Section 8.1.2
Germany	"PLT, DSL, cable communications (including cable TV), LANs and other effect on radio services"	ECC Report 24, Section 8.1.3
Germany	"PLT, DSL, cable communications (including cable TV), LANs and other effect on radio services"	ECC Report 24, Section 8.1.4
JARL / Japan	"On Radio Interference Assessments of Access PLC System"	http://www.qsl.net/jh5esm/PLC/isplc2003/isplc2003a2-3.pdf
JARL / Japan	"On Radio Interference Assessments of Access PLC System – Presentation Material"	http://www.qsl.net/jh5esm/PLC/isplc2003/isplc2003a2-3presentation.pdf

Japan	"Interference measurements in HF and UHF bands caused by extension of power line communication bandwidth for astronomical purpose"	http://www.qsl.net/jh5esm/PLC/isplc2003/isplc2003a7-1.pdf
VERON / Netherlands	"The Radio Amateur and the Effects of the Use of the 230-Volt Power Line for Broadband Data Communications"	http://www.darc.de/referate/emv/plc/VERON_PLC_Report.pdf
VERON / Netherlands	"HF radio reception compatibility test of an in-house PLC system using two brands of modems"	http://www.arrl.org/tis/info/HTML/plc/files/ModemRPRTVeron11-04-03.pdf
Netherlands	"Current Situation on the Field Trials and Other Tests Performed in the Netherlands" (in Dutch)	http://www.agentschap-telecom.nl/informatie/plc/Position_NL_PLC_C..pdf (special access required)
Netherlands	"Information on radiating properties of mains networks" (in Dutch)	http://www.agentschap-telecom.nl/informatie/plc/NL_versie 6_final.pdf (special access required)
Norway	"PLT, DSL, cable communications (including cable TV), LANs and other effect on radio services"	ECC Report 24, Section 8.1.1
Switzerland	"Power Line Communication at Fribourg" (study report in French only)	http://www.bakom.ch/en/funk/elektromagnetisch/plc_freiburg/index.html
BBC/U.K.	In October 2002, the Technical Working Group completed final report on the "Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz", in which Appendix M contains emission limit proposed by BBC.	http://www.radio.gov.uk/topics/interference/documents/dslplt.htm
RA / U.K.	RA Technical Working Group Final Report "Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz" (Sections 7.2 & 7.3, Appendices P, Q)	http://www.radio.gov.uk/topics/interference/documents/dslplt.htm
RSGB / U.K.	"Notes on RSGB Observations of HF Ambient Noise Floor"	http://www.qsl.net/rsgb_emc/RSGBMeasurements_1b.pdf
RSGB / U.K.	"A paper on the difficulty of measuring broadband interference emissions from cables and the problem of assessing the results with respect to interference to radio reception. Tests and experiences from an installed PLT system"	http://www.qsl.net/rsgb_emc/PLTREP.pdf
RSGB / U.K.	"Background noise on HF bands"	http://www.qsl.net/rsgb_emc/emcslides.html

RSGB / U.K.	"Notes on the RSGB investigation of PLT systems in Crieff"	http://www.qsl.net/rsgb_emc/CRIEFF%20Notes%20Version_1.html
White Box Solutions / U.K.	"Some Practical Measurements of Far Field Radiated Emissions from a PLT Cell and an Estimation of the Cumulative Ground-Wave Effects of PLT Deployment on a Sensitive HF Surveillance Site protected by a Non-Deployment Area of Radius 1500m", Appendix X of the RA Technical Working Group Final Report "Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz"	http://www.radio.gov.uk/topics/interference/documents/dslplt.htm
ARRL / U.S.	"Home Phone Networking Alliance Testing"	http://www.arrl.org/tis/info/HTML/plc/files/hpnatests.html
ARRL / U.S.	"HomePlug and ARRL Joint Test Report", January 24, 2001	http://www.arrl.org/tis/info/HTML/plc/files/HomePlug_ARRL_Dec_2000.pdf
ECC: Electronic Communications Committer (within CEPT) JARL: Japan Amateur Radio League, Inc. OVSV: Austrian Amateur Radio Society RSGB: Radio Society of Great Britain VERON: Vereniging voor Experimenteel Radio Onderzoek Nederland		

Abstracts of some of the reports are presented as follows.

"Measurement results from PLT field trials – Germany, System A," ECC Report 24, Section 8.1.2. The section presented the measurement result of the radiated noise level from a PLT system. System A is designed for outdoor and indoor communication in several frequency bands. The outdoor portion begins at a transformer station and ends in the cellar of several houses, mostly in front of the power meter. At the same location the indoor portion begins using another frequency range and ends at the plugs in the rooms. The characteristics of a PLT signal is determined by switching off the PLT system, then comparing the scans made with the system on and off. The measurement results showed that the PLT signal in the field trial exceeded the NB 30 limit with an injected power level of +10 dBm. It was noted that the field trial was based on two examples of cabling and using PLT equipment which is still under development, and it covered only one injection point (outdoor master) and only less than three households, hence the result was not representative.

"Measurement results from PLT field trials – Germany, System B," ECC Report 24, Section 8.1.3. The section presented the measurement result of the radiated noise level from a PLT system. System B is designed for outdoor and indoor communication in the same frequency bands. The outdoor portion begins at a transformer station and ends in the cellar of several houses, mostly in front of the power meter. The indoor portion begins at the same location using the same frequency range and ends at the plugs in the rooms. A filter is inserted between outdoor slave and indoor master devices to suppress influence. The characteristics of a PLT signal were determined by switching off the PLT system, and comparing the scans made with the system on and off. The measurement results showed the PLT signal in the field trial exceeded the NB 30 limit with an injected power level of +17 dBm. It was noted that the trial was based on one example of cabling and using PLT equipment which was still under development, and covered only one injection point and only three households, hence the result was not representative.

"Measurement results from PLT field trials – Germany, System C," ECC Report 24, Section 8.1.4. The section presented the measurement result of the radiated noise level from a PLT system. System C was developed under the assumption that there would be no EMC problems if the system used low enough signal level such that the radiated noise met the threshold values specified in NB 30. The field strengths generated by the PLT signals, both inside and outside of buildings, were measured using the method in Measurement Specification 322MV05. The results showed that the radiated field strength at a distance of 3 meters from the injection point was close to the threshold values in NB 30, while the field strength at the "transformer station" exceeded the threshold.

"On Radio Interference Assessments of Access PLC System," JARL/Japan. Measurements were conducted to evaluate the impact of overhead access PLC to the amateur radio service and broadcasting service. Three cases were examined. First, the S/N of an AM signal and SINAD of a CW carrier were measured, and the results showed unacceptable degradation of HF broadcasting services from PLC interference. Second, observation using a spectrum analyzer showed that the HF broadcasting signal was completely jammed by the BPL modem operation. Third, measurement of the far-field component showed that short wave radio was jammed by the PLC signal at 156 meters away, and the PLC signal became undetectable at a distance of 200 to 400 meters. The experiment concluded that access PLC systems jam HF broadcasting and other radio communication services.

"Interference measurements in HF and UHF bands caused by extension of power line communication bandwidth for astronomical purpose," Japan. Two sets of modems, spread spectrum and OFDM, of the access PLC system were tested for the interference effect to radio astronomical observation. It was found that in the HF band, the PLC noise exceeds the level of the galactic noise by more than 30 dB when the two systems were 180 meters apart. In the UHF band, spurious emission near 327 MHz was observed at a 55 meter distance. In both cases, the interference noise exceeds the limit in ITU-R Rec. RA 769-1 for protection of radio astronomical observation. Safety separations to meet RA 769-1 limit are estimated to be 219 km and 12 km at 9.2 MHz and 327 MHz, respectively. The report concluded that PLC is harmful to radio astronomical observation in both the HF and UHF bands.

“The Radio Amateur and the Effects of the Use of the 230-Volt Power Line for Broadband Data Communications,” VERON/Netherlands. Measurement was conducted to evaluate the risks of interference from PLC to an amateur station. Both in-house and outside field strength measurements were taken and compared with the CEPT proposed radiation limits (NB 30, Norwegian Limit and BBC limit). The coupling between the mains wiring and the antennas of the amateur station was also determined. In the audio test, the level of interference in the HF amateur bands was evaluated using amateur antennas and receiver. The results showed that adequate protection can be provided against mains injected interference signals only in the BBC limit which was the strictest. Additional measurements were performed to find the “normal” interference levels on the mains wiring. The results showed that (1) it was apparent that the present interference levels in a quiet rural area are far below the CISPR 22 limits, and (2) injection of interference signals with a level equal to the CISPR 22 limit level causes harmful interference to the reception of signals in the amateur bands.

“HF radio reception compatibility test of an in-house PLC system using two brands of modems,” VERON/Netherlands. Tests were performed on the emissions of two types of in-house PLC modems developed to the HomePlug® standard. The measurements were done in a laboratory set-up, and in a residential house. The laboratory set-up, with many PCs running, was used to measure the mains disturbance voltage, field strength, and background noise; the residential house was used to measure the interference on an amateur radio receiving antenna, background signals, and noise on mains. The results show that one modem seems just to meet the mains disturbance limit in EN55022 for residential environment, and the other modem shows a level approximately 20 dB higher. Also, the following general observations were made: (1) interference from the modems is probably not a threat to the radio amateur service for a reasonably well constructed outdoor receive antenna, (2) interference may be harmful to the broadcasting services outside the spectrum notches, and (3) the background mains disturbance level is 30 dB or more below the EN55022 B limit in both the laboratory and residential environments.

“Measurement results from PLT field trials – Norway,” ECC Report 24, Section 8.1.1. The Norwegian Post and Telecommunications Authority conducted measurement tests on all experimental PLT systems in Norway in order to obtain information on unwanted radiation to other spectrally collocated radio systems in the HF band. The EMC requirement of PLT equipment for the mains port in wood buildings, a worst-case scenario, is 20 dBμV/m quasi-peak measured at a distance of 3 meters from the cable structure. The measured data are combined with a coupling factor to give the extent of field emission from equipment for the mains port. The measurement results show EM field levels 20–40 dB higher than 20 dBμV/m. This clearly indicates the need for a significant reduction in the spectral power density of the PLT signal to achieve compliance with existing EMC standards. Moreover, the report asserts that the field emission requirements for PLT should be somewhat more restrictive than the 20 dBμV/m limit because the PLT signal might be an ”always on” signal, and the geographical concentration of PLT units within a certain area might be fairly high.

“Power Line Communication at Fribourg,” Switzerland. A PLC network had been installed at the Swiss city of Fribourg. The Swiss Federal Office of Communication (OFCOM) accomplished extensive interference measurements on site with the goal to find out if and to what extent radio services in the short wave range would be disturbed. The already existent man-made noise at urban and rural areas has been analyzed and accounted for as well. The statistical interpretation of measurement data shows that PLC interference below 10 MHz is of little impact at urban areas because of already existent interference from other sources. However, at frequencies above 10MHz, PLC emissions are clearly the predominant cause for interference. Furthermore it has been shown that the limit of the German standard NB30 is exceeded at all frequencies of interest between 2.4 MHz and 25.4 MHz at urban areas. This report is available only in French.

“Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz,” RA Technical Working Group Final Report, RA/U.K., Sections 7.2 & 7.3. Measurements of radiated emission from access and in-house PLC systems were conducted and data were presented. There was no discussion on the interference effect.

“Notes on the RSGB investigation of PLT systems in Crieff”, RSGB/U.K. Two PLT systems, ACOM and MAINNET, were tested. The primary objective was to obtain information on levels of interference noise generated by PLT systems and how this will affect radio amateurs and short wave listeners. Interference noise was observed, but no quantitative data were reported. No analysis or conclusion was presented.

“Some Practical Measurements of Far Field Radiated Emissions from a PLT Cell and an Estimation of the Cumulative Ground-Wave Effects of PLT Deployment on a Sensitive HF Surveillance Site protected by a Non-Deployment Area of Radius 1500m,” White Box Solutions/U.K. Field strength measurements were undertaken in a suburban/rural area. The results of these measurements were applied to the scenario of a sensitive HF radio surveillance site. It was concluded that for a non-deployment zone of radius 1500m, the dominant source of noise remains atmospheric noise (including man-made) and that the cumulative contribution from the surrounding PLT interferers would, in a worst case scenario, have less than 0.1 dB impact on the noise floor.

“HomePlug and ARRL Joint Test Report,” ARRL/U.S. The experiment examined the interference effect from the BPL waveform and power spectral density (PSD) limits proposed by HomePlug to the amateur radio services. Tests showed in general that with moderate separation of the antenna from the structure containing the HomePlug signal that interference was barely perceptible. The cases of objectionable interference were noted for an antenna located close to the power lines, a configuration chosen to mimic the situation in which the HomePlug equipment was in one house and the amateur radio in another.

B.4 MODELING AND ANALYSIS REPORTS

Several studies have developed models to analyze the potential BPL EMC problems. Some of the reports are listed in Table B-3.

Table B-3: Modeling and Analysis Reports

Country or Agency	Report	Source of Information
CEPT	"Determination of limiting values for emissions from PLT to protect DRM"	ECC PT SE35
Japan	"Sharing studies between the radio astronomy telescopes and the power line communication systems in the HF region"	http://www.qsl.net/jh5esm/PLC/isplc2003/isplc2003a7-4.pdf
BBC / U.K.	"Cumulative Effects of Distributed Interferers", Appendix R of the RA Technical Working Group Final Report "Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz"	http://www.radio.gov.uk/topics/interference/documents/dslplt.htm
White Box Solutions / U.K.	"Application of Power Control and Other Correction Factors to PLT Systems and their Subsequent Impact on the Cumulative Effects, via Space Wave Propagation, on Aircraft HF Receivers", Appendix Y of the RA Technical Working Group Final Report "Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz"	http://www.radio.gov.uk/topics/interference/documents/dslplt.htm
ARRL / U.S.	"Calculated Impact of PLC on Stations Operating in the Amateur Radio Service" (p.9-13)	http://www.arrl.org/tis/info/HTML/plc/files/C63NovPLC.pdf

Abstracts of these reports are presented as follows.

"Determination of limiting values for emissions from PLT to protect DRM," CEPT/ECC PT SE35. This report presents measurement result for determining PLT emission limits to protect DRM transmission. The DRM system uses either 9 or 10 kHz channels or multiples thereof, QAM/OFDM modulation with channel coding, time interleaving, and FEC. The PLT system has neither defined bandwidth nor standardized modulation. The measurements were conducted in the HF band. The DRM reference field strength is 40 dBμV/m, which is the minimum sensitivity of an average AM receiver; this level is about 10 to 20 dB above the minimum usable field strength of DRM receivers. The PLT signal was transmitted with a mains power supply cable connecting two PLT modems. It was observed that the PLT signal in file transfer mode affects noticeably the DRM receiver sensitivity threshold by 7 to 15 dB. Moreover, the DRM receiver threshold is affected even when the PLT was switched on but not transferring files. It was also observed that when the PLT signal level reaches the NB30 limit (32 dBμV/m), the DRM receiver sensitivity threshold is 3 dB higher than the protected minimum field strength in mode 1 (43 dBμV/m instead of 40 dBμV/m), and 9 dB higher in mode 2. Therefore, the limiting value for emissions from a radiating PLT source to protect DRM receiver at less than 3-meter distance shall be equal to or less than 16 dBμV/m in the HF band. This value is 16 dB more stringent than the NB30 limit defined at 3-meter distance. The results clearly show that the NB30 limits are not sufficient to protect DRM receivers in presence of a PLT signal.

"Sharing studies between the radio astronomy telescopes and the power line communication systems in the HF region," Japan. The report develops a methodology to calculate the necessary distance between a radio astronomy antenna site and a metropolitan PLC system by using two equations in ITU-R P.525. First, it uses an equation for point-to-area links to calculate the radiation field strength at 30 meters. Then, it uses an equation for point-to-point links to calculate free space loss of the radiated field. Considering that 30-meter distance is likely in the near-field range for a BPL system, and that the BPL emission source may not be a point source, the accuracy of this model may be subject to examination.

"Cumulative Effects of Distributed Interferers," BBC/U.K. This model develops methodologies to estimate the aggregate interference power from a distribution of PLC sources. The receiver can be in either an aircraft or a ground-based system. This is a far-field model, and curvature of the Earth surface is being considered. The analysis indicates that the interference received by an aircraft is nearly independent of aircraft height when the entire visible earth is populated with the PLT systems. Limiting the area of distributed interferers from the visible earth to a smaller area representative of a major conurbation does not decrease the interference very greatly, unless the aircraft is very high. For ground receivers, the analysis indicates that sky-wave interference from widespread PLT systems to ground-based receivers may not always be negligible, even though it is less than that shown to be suffered by aircraft.

"Application of Power Control and Other Correction Factors to PLT Systems and their Subsequent Impact on the Cumulative Effects, via Space Wave Propagation, on Aircraft HF Receivers," White Box Solutions/U.K. This study utilizes the model in the report "Cumulative Effects of Distributed Interferers" to examine the possibility of using power control and other correction factors for the PLT systems to alleviate the impact from the distributed BPL systems to aircraft HF receivers. Its result indicates that practical PLT systems employing power control and power density less than -60dBm/Hz would not appear to raise the HF noise floor at an aircraft at any reasonable operational altitude.

"Calculated Impact of PLC on Stations Operating in the Amateur Radio Service," ARRL/U.S. ARRL uses EZNEC 3.1 with the NEC-4 engine to model a power line of 300 feet as an antenna. Its result shows that the emitted PLC signal at 30-meter distance is 275μV/m/9kHz, which exceeds the FCC limits by about 15 dB. ARRL claims that the data is supported by actual measurements made in Japan. Another message from this paper is that, by using a line source instead of a point source, the signal strength vs. distance relationship should be 20dB/decade instead of 40dB/decade.

APPENDIX C
CHARACTERIZATION OF FEDERAL GOVERNMENT SPECTRUM USAGE AND OPERATIONS, REPRESENTATIVE SYSTEMS AND TYPICAL PARAMETERS

C.1 INTRODUCTION

As summarized in Section 4, the 1.7-80 MHz frequency range hosts a number of radio services and supports well over one-hundred-thousand Federal Government RF systems. Frequencies in this range are intensively used on the bases of time-and geographic-sharing by several radio systems. This appendix provides a more detailed discussion on federal spectrum usage and operations under each radio service. In addition, this appendix provides a general characterization of Federal Government RF systems that includes presentation of representative federal systems and typical system parameters.

The main data sources used in the description of the Federal Government RF systems, spectrum usage and, in some cases, the radio services are the Government Master File (GMF), federal agencies' inputs, and an earlier NTIA study.[1] Section C.2 discusses the nature of relevant radio services and their allocations in the 1.7-80 MHz band. Special systems are described in Section C.3, and special operating considerations are summarized in Section C.4.

C.2 SERVICES AND EXAMPLE SYSTEMS

C.2.1 Fixed Service (1.7-29.7 MHz)

The use of radio frequencies below 30 MHz for domestic fixed service by the Federal Government is delineated in Section 8.2.11 of the NTIA Manual. An excerpt from the NTIA Manual regarding the use of fixed service below 30 MHz by the Federal Government is presented in Section C.4. The frequency bands allocated to the fixed service in the 1.7-30 MHz band are shown in Table C-1.

In general, the Federal Government fixed service applications include voice and data transmissions over intermediate and long-range distances (25 km to over 2,000 km). Many fixed stations are located in the vicinity of power lines which could eventually be used by BPL systems (*e.g.*, *see* Figure C-1). The DOD, for example, uses HF radios on military installations, both for ground and skywave modes of operations, on or near major urban environments. The DOJ and DHS employ fixed systems throughout the United States, including urban and suburban areas, in support of law enforcement activities.

[1] Grant, W.B., et al., *Spectrum Resource Assessment of Government Use of the HF (3-30 MHz) Band*, NTIA Technical Memorandum 89-141, June 1989. Relevant information from this study is included in this Appendix.

Table C-1: Frequency Bands Allocated to the Fixed Service in the 1.7-30 MHz Band

Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)
1705-1800	95	5730-5900	170	13410-13570	160	19029-19680	651
2000-2065	65	5900-5950	50	13570-13600	30	19800-19990	190
2107-2170	63	6765-7000	235	13800-13870	70	20010-21000	990
2194-2495	301	7300-7350	50	13870-14000	130	21850-21924	74
2505-2850	345	7350-8100	750	14350-14990	640	22855-23000	145
3155-3230	75	9040-9500	460	15600-15800	200	23000-23200	200
3230-3400	170	9900-9995	95	15800-16360	560	23350-24890	1540
4438-4650	212	10150-11175	1025	17410-17480	70	25330-25550	220
4750-4850	100	11400-11600	200	17480-17550	70	26480-26950	470
4850-4995	145	11600-11650	50	18030-18068	38	27540-28000	460
5005-5060	55	12050-12100	50	18168-18780	612	---	
5060-5450	390	12100-12230	130	18900-19020	120	---	
Total Bandwidth = 12,030 kHz							

Both the DOJ and DHS HF systems that support law enforcement activities in many cases use encryption in both ground and skywave modes of operations.[2] Some of these systems support crisis response teams, including the Federal Government's SHARES network program that is described below. The vast majority of fixed systems in this portion of the spectrum operate in the simplex mode. Table C-2 shows the representative technical characteristics of fixed systems in the 1.7-30 MHz band.

Many foreign governments operate HF fixed stations at their embassy and mission facilities that typically are located in major cities throughout the United States. While many of these operations may backup or supplement other means of communications, these HF systems become critical sole means of communications in certain times of crises.

SHARES. The mission of the shared resources (SHARES) network is to provide backup or supplemental communications for exchange of critical information among federal entities during certain crisis situations. Normally, frequency assignments that support the SHARES network are nationwide or assigned under the United States and Possessions (US&P) category. The HF portion of the spectrum is most suitable for the operation of the SHARES network because it offers a medium in which a reliable, geographically expansive network can be established, without satellites, using easy to implement equipment operating over a range of frequencies (Federal Government satellite facilities are used for other purposes in certain times of crises). A summary of the emergency use of Federal Government HF frequencies for the SHARES program is provided in Section C.4.2.

[2] Interference to encrypted radio channels can be particularly harmful insofar as considerable time is needed to reestablish communications in an encrypted mode of operation.

Figure C-1: An Example of a Federal Government Radio Antenna near Power Lines.

Table C-2: Typical Technical Characteristics of Fixed Systems (1.7-30 MHz Band)

System	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (ft)	Ant. Type/ Polarization	Modulations
Typical Fx	2.8	0-2	30-140	Dipole/ V& H	Analog, single channel, suppressed carrier, telephony

C.2.2 Fixed Service (29.7-80 MHz)

There are twelve fixed service bands, as shown in Table C-3, allocated to the Federal Government to support federal fixed service requirements in the 29.7-80 MHz band. The fixed systems operated by the federal non-military agencies in this frequency range normally compliment the mobile or land mobile service. They provide relay connectivity (repeater stations) to hand held and vehicular mobile phones used by the federal agencies for: management, protection, and preservation of the natural resources; search and rescue operations; and law enforcement activities. These fixed systems are also used for: exchange of meteorological data; detection of unauthorized vehicular traffic, such as on or near shuttle landing areas; and for fire alarm supervisory systems at various facilities.

Table C-3: Frequency Bands Allocated to the Federal Government for Fixed Service in the 29.7-80 MHz Band

Frequency (MHz)	BW (MHz)	Frequency (MHz)	BW (MHz)	Frequency (MHz)	BW (MHz)	Frequency (MHz)	BW (MHz)
29.89-29.91	0.02	34-35	1.0	38.25-39	0.75	49.6-50	0.4
30-30.56	0.56	36-37	1.0	40-42	2.0	74.6-74.8	0.2
32-33	1.0	38-38.25	0.25	46.6-47	0.4	75.2-75.4	0.2
Total Bandwidth = 7.78 MHz							

The DOD also employs their fixed systems as repeaters for: land and air networks; tactical and training purposes; and support of military bases operations. These include tactical communications exercises for base defense missions; command and control; law enforcement; remote control of multiple cameras on test ranges; airfield lighting; and acoustic range traffic lights. In addition, these fixed systems support research, development, test and evaluation of DOD systems.

Federal Agencies' Repeaters (Relay Stations). The vast majority of fixed systems used by the federal agencies in the 29.7-80 MHz band compliments or provides relay connectivity for land mobile systems. The majority of the federal fixed assignments that support relay operations are under the US&P category. Some of these assignments are required for short term intermittent use at unspecified locations and used for notification of planned regular operations. Typical technical characteristics of these systems are provided in Table C-4.

Table C-4: Typical Technical Characteristics of Fixed System (29.7-80 MHz Band)

Fixed Systems	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
Non-DoD	16	0-3	16-250	Whip, yagi, collinear & dipole/V&H	Analog and digital, frequency modulated, single channel, data and telephony.
DoD	16-40	0-2	10-400	Whip, dipole, collinear, & coaxial/V&H	Analog and digital, frequency modulated, single channel, data and telephony.

C.2.3 Mobile Service

A total of 42 bands are allocated to the Federal Government for mobile service in the 1.7-80 MHz band. Of these, 13 bands provide secondary allocation to the mobile service and 17 bands exclude the use of aeronautical mobile service as indicated in Table C-5. Typical systems parameters are described below.

Table C-5: Frequency Bands Allocated to the Mobile Service in the 1.7-80 MHz Band

Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)
1705-1800	95	5060-5450 *	390 **	14350-14990 *	640 **	34000-35000	1000
2000-2065	65	5730-5900	170 **	18168-18780 *	612	36000-37000	1000
2107-2170	63	5900-5950	50 **	20010-21000 *	990	38000-38250	250
2173.5-2190.5	17	6765-7000 *	235	23000-23200 *	200 **	38250-39000	750
2194-2495	301	7300-7350 *	50	23350-24890	1540 **	40000-42000	2000
2505-2850	345	7350-8100 *	750	25330-25550	220 **	46600-47000	400
3155-3230	75 **	10150-11175 *	1025 **	26480-26950	470 **	49600-50000	400
3230-3400	170 **	13410-13570 *	160 **	27540-28000	460	74600-74800	200
4438-4650	212 **	13570-13600 *	30 **	29890-29910	20	75200-75400	200
4750-4850	100 **	13800-13870 *	70 **	30000-30560	560	—	--
4850-4995	145	13870-14000 *	130 **	32000-33000	1000	---	--

* Mobile service is secondary in this band

** The use of aeronautical mobile is prohibited in this band.

Total Bandwidth = 17,560 kHz

For the most part, federal mobile service requirements in this portion of the spectrum include voice and data, which also encompass intermediate and long-range operations. The military, for example, uses HF mobile radios in ground wave modes (*e.g.*, hundreds of kilometers) and skywave modes (thousands of kilometers) the same way they use the their fixed systems. The vast majority of military mobile radios operations are for tactical training, including tactical communications to ground units, ships and aircraft, base operations, and as back-ups or supplements to satellite communications. Normal training occurs in military bases which may be in the vicinity of power lines. Example systems used by the DOD for training and tactical communications are described below (AN/VRC-100 and SINCGARS).

The Coast Guard uses the HF and MF portions of the spectrum extensively for sea and air operations that include monitoring distress calls, both international and domestic digital selective calling including for distress calls, and search and rescue operations along the coastal areas of the United States. A total of about 160 base stations sites, including command and control sites, in the United States are used for these purposes. In addition, there are approximately 100 HF/MF-equipped buoy tenders and other vessels that operate on inland waters, up rivers and inshore along the coasts. These vessels/boats are frequently near power lines.

The DOJ and the DHS substantially use mobile radios in the HF band. The vast majority of these radios are dedicated for law enforcement or used in support of emergency and crises responses; as such, these systems are authorized to operate anywhere in the United States. Mobile radios employed by both agencies use encryption technology and some use ALE. An example system is the U.S. Customs Over the Horizon Enforcement Network (COTHEN). A brief description of the COTHEN system is presented below.

Single-Channel Ground and Airborne Radio System (SINCGARS). The SINCGARS is a family of VHF-FM combat net radios which provide the primary means of command and control for infantry, armor, and artillery units in the Army. It is capable of short range or long range operation for voice or digital data communications. The system's configurations include man-pack, vehicular, and airborne units. These units can be used for single channel operation or in a jam-resistant, frequency hopping mode which can be changed as needed. When configured for use of low VHF frequencies, the system operates on any of the 2320 channels between 30-88 MHz in 25 kHz increments and is designed to survive a nuclear environment. The SINCGARS Program is continuously evolving to provide the latest in improvements and capabilities to the soldier and to meet the Army's objectives for widespread digitization.

The SINCGARS system, which was once a conventional voice-only radio used for communications up and down the chain of command, has evolved into a software-defined, open architecture system with extensive networking capabilities. It offers clear or secure voice and data communications capabilities that provide situational awareness and transmit command and control information across entire theaters of battle or control.[3] A handheld unit, an airborne unit (AN/ARC-210D), a man-pack (AN/PRC-119F(V)), and various vehicular components (AN/VRC-90F(V), AN/VRC-87F(V), AN/VRC-87F(V), AN/VRC-89F(V), AN/VRC-91F(V) and VRC-92F(V)) are under production.[4] The SINCGARS program office has fielded more than 136,000 radios to training base and Army units worldwide.[5]

COTHEN. This network became widely operational in 1985. Previously, only Custom's marine vessels were equipped with the COTHEN radios; however, because of the success of this initial deployment, the network now provides communications support for more than 235 aircraft, numerous maritime interdiction vessels, several command offices, and numerous allied agencies including the Coast Guard, Drug Enforcement Administration, Border Patrol, Army, Navy, and Joint Interagency Task Forces.

The network integrates radio, computer, and a tactical voice privacy unit in a extremely reliable, state-of-the-art communications network that meets the demanding requirements of Customs' tactical interdiction aircraft and boats in their fight against smuggling activities. High powered fixed station transmitters located across the United States are connected to Customs' air, marine, and Special Agent In Charge (SAIC) locations via dedicated telephone lines. Tactical interdiction platforms equipped with COTHEN radio can place a call to any other platform or

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[3] http:/www.acd.itt.com/sincgars.htm.

[4] *Id.*

[5] http:/www.globalsecurity.org/military/systems/ground/sincgars.htm.

office in the network thousands of miles away typically using an ALE protocol. Units on the COTHEN network use encryption for most of the voice communications. The COTHEN network uses frequencies throughout the HF band in order to obtain both the needed capacity and frequency diversity (*see* Section C.4.1).

AN/VRC-100 (V). The Army's AN/VRC-100 (V) system works in conjunction with the AN/ARC-220 (V) to provide air-to-ground, ground-to-air, ground-to-ground, and air-to-air non-line of sight communications with aircraft at low altitude (30 meters to ground level in the HF band). These radios will support normal voice and encrypted voice communications, as well as message data. The AN/VRC-100 (V) uses multiple modulations and coding techniques and it uses an ALE tone (8-ary frequency shift keying). Table C-6 shows typical technical characteristics of mobile systems.

C.2.4 Land Mobile Service

For so many decades, the federal agencies land mobile requirements have been fulfilled in the mobile bands listed in Table C-5. The vast majority of federal agencies usage of the land mobile service are for: national defense (DOD); law enforcement (*e.g.*, DHS and DOJ); management and preservation of national resources; search and rescue; and emergency and safety communications operations in national seashores, lakes, forests, water resources, and wildlife refuge, including Tribal Lands and reservations (*e.g.*, DOI and DOA). Frequency assignments that support land mobile radios for law enforcement are under the US&P category. The areas of operation for these radios include the urban, suburban, and rural areas, both off-shore and in-land. Operation of these land mobile radios typically occurs near power lines that may be used for BPL systems.

Table C-6: Typical Technical Characteristics of Mobile Service in the 1.7-80 MHz Band

Mobile Systems	Freq. Range (MHz)	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft))	Ant. Type/ Polarization	Modulations
Fx Station	1.7-30	2.8	0	30-100	Whip/V& H	Analog, single channel. Suppressed carrier, telephony
Mobile unit	1.7-30	2.8-3.0	0-2	6-32	Whip/V & H	Analog, single channel. Suppressed carrier, telephony
Fx Station	29.7-80	16	0-3	30-400	Whip, Dipole/V&H	Analog or digital, single channel, Frequency modulated, telephony and data.
Mobile unit	29.7-80	16	0	6-32	Whip/V	Analog or digital, single or multiple channels. Frequency Modulated, telephony and data

In some cases, especially in areas lacking adequate commercial telephone facilities, alternative communications that involve the use of non-government stations (*e.g.*, citizens radio service (CB)) are provided by the federal agencies. Such uses are in accordance with Part 95 of the FCC Rules and Regulations. In a practical sense, these systems typically may not be in areas where power lines are deployed.

The DOE's most prominent use of the HF spectrum is for secure communications. The DOE's HF system provides a nationwide communications capability to facilitate shipments in support of national defense. The system supplements existing physical security measures by providing normal and emergency communications between vehicles and the DOE's operations office control center.[6] The DOE also relies upon HF to provide essential communications during periods of critical emergencies around various DOE facilities throughout the United States. Typical technical characteristics of land mobile systems in the 1.7-80 MHz band are shown in Table C-7.

Table C-7: Typical Technical Characteristics of Land Mobile Services in the 1.7-80 MHz Band

Land Mobile Systems	Freq. Range (MHz)	Bandwidth (kHz)	Antenna Gain (dBi)	Antenna Height (Ft))	Antenna Type/ Polarization	Modulations
Base Station	1.7-30	2.8	0	30-100	Collinear, whip, dipole/V&H	Analog or digital, single channel., suppressed carrier, telephony and telegraphy
Mobile Unit	1.7-30	2.8-3.0	0-2	6-32	Whip/V&H	Analog or digital, single channel, suppressed carrier, telephony and telegraphy
Base Station	29.7-80	16-25	0-3	30-400	Collinear, whip, dipole/V&H	Analog or digital, single channel, suppressed carrier, telephony and telegraphy
Mobile Unit	29.7-80	16-25	0	6-32	Whip/V	Analog or digital, single channel, suppressed carrier, telephony and telegraphy

C.2.5 Maritime Mobile Service[7]

The maritime mobile bands in the 1.7-80 MHz frequency range allocated to the Federal Government are shown in Table C-8. The Federal Government's main users of the maritime mobile bands are the Coast Guard, Navy, DOI, and the Department of Commerce (DOC).

The Coast Guard operates HF systems for communications between shore stations and ships, and from ship-to-ship. These systems support command and control communications with cutters, aircraft, and shore facilities for various purposes including: off shore search and rescue; drug interdiction; enforcement of laws and treaties; and Arctic and Antarctic operations. Because of the Coast Guard's important role in the drug interdiction, a significant increase in the use of HF systems for air/ground and ship-to-shore communications has taken place over the last

[6] *Supra* note 1 at 66.

[7] *Id.* at 69.

few decades. The Coast Guard also relies on the HF band for services such as distress and safety communications, broadcast of maritime safety information, emergency medical assistance communications, broadcast of weather observation reports, and receipt of vessel position reports for safety purposes.

Table C-8: Frequency Bands Allocated to the Federal Government for Maritime Mobile Service in the 1.7-80 MHz Band

Frequency Band (kHz)	BW (kHz)		Frequency Band (kHz)	BW (kHz)		Frequency Band (kHz)	BW (kHz)
2065-2107	42		6200-6525	325		18780-18900	120
2170-2173.5	3.5		8100-8195	95		19680-19800	120
2190.5-2194	3.5		8195-8815	620		22000-22855	855
4000-4063	63		12230-13200	970		25070-25210	140
4063-4438	375		16360-17410	1050		26100-26175	75
Total Bandwidth (BW) = 4,857 kHz							

In addition, the Coast Guard has an HF network that ties its major bases together, including bases in Alaska, throughout CONUS, Hawaii, Puerto Rico, the U.S. Virgin Islands, and the trust territories of the Pacific Ocean. The Coast Guard also has communication networks in the HF band to support the Long Range Aid to Navigation-C (LORAN-C). Although, the LORAN-C was earmarked for replacement by the Global Positioning System (GPS), the existing LORAN-C chains will be maintained and upgraded, at least till the year 2008, in the transition period to satellite-based navigation.[8]

The Coast Guard carefully monitors several protected HF channels 24 hours a day from several locations in the U.S. and its possessions for distress and maritime safety information communications. Some of these frequencies are used by the Global Maritime Distress and Safety System (GMDSS). Table C-9 shows the specific frequencies monitored by the Coast Guard for distress calling. Consistently over the last few decades, the Coast Guard annually responded to about 2000 search and rescue cases from boats and ships in trouble, where alerting is via frequencies listed in Table C-9.

The Navy also has communication systems between shore stations and ships, as well as ship-to-ship in the HF maritime mobile bands. Navy uses include: communications support to hydrographic surveys; tanker operations; weapon system testing; secure voice communications, and the naval telecommunications system that provides command, control, and communications for the Navy and Marine Corps operating forces. For the Navy, the HF band provides major back-up and supplemental capabilities for long distance emergency and war time communications and will continue to be very important asset to the Navy for fleet-wide communication needs.

[8] http://webhome.idirect.com/~jproc/hyperbolic/loran_c_future.html.

Table C-9: Frequencies Monitored by Coast Guard for Distress and Safety Communications in the HF Band[9]

Freq. (kHz)	Usage		Freq. (kHz)	Usage		Freq. (kHz)	Usage
2174.5 *	NBDP-COM		6215 *	RTP-COM		12577 *	DSC
2182 *	RTP-COM		6268 *	NBDP-COM		12579 *	MSI
2187.5 *	DSC		6312 *	DSC		16420 *	RTP-COM
3023	Aero-SAR		6314	MSI		16695 *	NBDP-COM
4125 *	RTP-COM		8291 *	RTP-COM		16804.5 *	DSC
4177.5 *	NBDP-COM		8376.5 *	NBDP-COM		16806.5	MSI
4207.5 *	DSC		8414.5 *	DSC		19680.5	MSI
4209.5	MSI		8416.5	MSI		22376	MSI
4210	MSI		12290 *	RTP-COM		26100.5	MSI
5680	Aero-SAR		12520 *	NBDP-COM		—	--

* Except provided in the ITU Radio Regulations, any emission capable of causing harmful interference to distress, alarm, urgency or safety communications on these frequencies is prohibited.

Legend:
NBDP = Narrow band direct printing
COM = Communication
RTP= Radio Telephony
DSC = Digital Selective Calling
Aero-SAR = Aeronautical Search and Rescue
MSI = Marine Safety Information

The DOI uses the HF maritime mobile bands for its U.S. Geological Survey organization (USGS) in support of marine geology exploration and mapping tasks. The DOI also has systems in the HF maritime mobile bands to support communications for the Pacific trust territories of the United States. This includes communications between the islands and ships, the outer island dispensary communications system in the marshal Islands, between islands in the Marianas group, and between islands in the American-Samoan group.

The DOC uses HF maritime mobile systems to support ships and boats used by the National Marine Fisheries Service and for communication links between major fishery centers and research vessels of the National Oceanic and Atmospheric Administration (NOAA) Corps Fleet. The National Ocean Service has radio communication facilities in the HF band to support ships and mobile field teams engaged in oceanographic and marine, and geodetic survey activities.

[9] *Frequencies for Distress and Safety Communications for the Global Maritime Distress and Safety System*, ITU Radio Regulations, Appendix S15, Geneva 1998.

GMDSS. The GMDSS is a distress alerting and safety communications system that relies on satellite and terrestrial communications links, and has changed international communications networking from being primarily ship-to-ship to ship-to-shore (Rescue Coordination Center). In addition, the system provides for location determination in cases where a radio operator does not have time to send a complete SOS or MAYDAY call. Ships are required to receive broadcast of maritime safety information via the GMDSS. In 1988, the International Maritime Organization (IMO) amended the Safety of Life at Sea (SOLAS) Convention, requiring most ships to be retrofitted with GMDSS equipment. In the absence of interference, the GMDSS is able to reliably perform the following functions: alerting, including position determination of the unit in distress; search and rescue coordination; locating (homing); maritime information broadcasts; general communications; and bridge-to-bridge communications.

Section 5.4 of the NTIA Manual states that, "stations in the maritime and other radio services employing frequencies and techniques used in the GMDSS shall comply with the relevant ITU-R recommendations with respect to the technical characteristics of, among others, digital selective calling (DSC) distress call formats and . . . other broadcasts of maritime safety information using narrow band direct-printing (NBDP) in the bands 4-27.5 MHz." Additionally, such stations when using DSC shall conform to the calling, acknowledgment, and operating procedures for DSC contained in the ITU Radio Regulations (Article 32) and the relevant ITU-R recommendations. Table C-10 provides typical technical characteristics of maritime mobile systems in the HF band.

Table C-10: Typical Technical Characteristics of Maritime Mobile Systems (1.7-30 MHz Band)

System	Freq. Band (MHz)	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
Distress/ SAR *	2-30	2.8	0-2	unknown	Whip, Cone/V	Single sideband-suppressed carrier, single channel, analog, telephony

* SAR = Search and Rescue.

C.2.6 Broadcasting Service

In the Federal Government, HF broadcasting from the U.S. is conducted by the Broadcasting Board of Governors (BBG). The BBG has the mission to promote understanding abroad of the United States, its policies, its people, and its culture. HF radio is a very practical means of communicating directly with the people of other nations because of the extensive availability of inexpensive broadcast receivers. The BBG's global radio network, the Voice of America (VOA), consists primarily of two powerful HF transmitter sites (located in California and Virginia).

The power levels for equipment at VOA installation can be as high as 500 kW. The modulation designator typically is 10K00A3E. This accommodates a 10 kHz bandwidth signal, amplitude modulation, and audio communication. A multi-band, curtain-array antenna is a representative type of antenna for VOA broadcast installation.

While the intended receivers of the VOA's transmissions generally are abroad there are numerous broadcasting receivers owned and operated by foreign citizens and government personnel in the United States that could be susceptible to BPL interference because of proximity to power lines. Protecting other administrations' broadcasting is critical because of reciprocity. The current ITU-R B-03, Seasonal Broadcasting Schedule, shows multiple administrations broadcasting to the United States for every timeframe within a 24- hour period.[10]

The 18 bands allocated to the Federal Government for broadcasting service in the HF portion of the spectrum are listed in Table C-11. Because of frequency reuse capabilities inherent in HF broadcasting, one should expect that broadcast receivers located in the United States are tuned within these bands.

Table C-11: Frequency Bands Allocated to the Federal Government for Broadcasting Service in the 1.7-80 MHz Band

Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)	Frequency (kHz)	BW (kHz)
5900-5950	50	11650-12050	400	15600-15800	200
5950-6200	250	12050-12100	50	17480-17550	70
7300-7350	50	13570-13600	30	17550-17900	350
9400-9500	100	13600-13800	200	18900-19020	120
9500-9900	400	13800-13870	70	21450-21850	400
11600-11650	50	15100-15600	500	25670-26100	430
Total Bandwidth (BW) = 3,720 kHz					

C.2.7 Aeronautical Mobile Service

The aeronautical mobile service is subdivided into two distinct radio services; namely, aeronautical mobile route (R) and aeronautical mobile off-route (OR) services. By definition, the aeronautical mobile (R) service is reserved for communications relating to safety and regularity of flight, primarily along national or international civil air routes; while, the aeronautical mobile (OR) service is intended for other communications, including those relating to flight coordination, primarily outside national or international civil air routes.[11] In the 1.7-80 MHz band, a total of 21 bands are allocated to these services with a total of 2176 kHz of spectrum. Out of the 2176 kHz of spectrum, 1331 kHz is dedicated for the aeronautical mobile (R) service and 845 kHz is assigned to aeronautical mobile (OR) service. In general, the Federal Government frequency assignments in the bands allocated to the aeronautical mobile service in this portion of the spectrum are used for controlling aircraft traffic. Other uses in the United

[10] Broadcasting Board of Governors Response to NTIA Memo, *Questionnaire Regarding Equipment and Operations in the 1.7-80 MHz Frequency Range*, November 7, 2003.

[11] NTIA, *Manual of Regulations and Procedures for Federal Radio Frequency Managers,* U.S. Department of Commerce, National Telecommunications and Information Administration, Washington, D.C., January 2004 Revision.

States may include Airline Operational Control (AOC) communications of foreign air carriers, including for scheduled traffic.

C.2.7.1 Aeronautical Mobile (R) Service

Frequency assignments to stations in the aeronautical mobile (R) service, in the HF band, must be assigned in conformity with the provisions and the allotment plan of Appendix 27 of the ITU Radio Regulation (RR). Such assignments conform to the plan for the allotment of frequencies to: (a) Major World Air Route Areas (MWARAs); (b) Regional and Domestic Air Route Areas (RDARAs); (c) VOLMET Allotment Areas; and (d) Worldwide Allotment Areas contained in Appendix 27 (RR) or, to meet operational requirements not otherwise met by the Allotment Plan, must comply with the provisions of Appendix 27 for the adaptation of allotment procedures. Assignments in support of International Air Routes (MWARA and VOLMET allotments) are also within the purview of applicable International Civil Aviation Organization (ICAO) frequency assignment plans that have been agreed internationally and are recognized in the ITU RR.

As a matter of general policy, HF is not normally used for aeronautical mobile (R) communications in the domestic services within the conterminous United States, the need for such frequencies having been generally eliminated through successful use of the VHF communications.[12] However, Appendix 27 (RR) Part II, Section I, Article 2 provides for the allotment of frequencies to the RDARAs, which include the conterminous United States, and also Alaska, Hawaii, Puerto Rico, and the Virgin Islands. This then enables special aeronautical communication requirements, not conforming fully to the definition of the aeronautical mobile (R) service, to be satisfied by use of frequencies from these allotments within the limitations of the national criteria established jointly with the FCC.[13] Section C.4.4 provides these national criteria.

Certain frequencies in the HF band are available to all government agencies for operational control and safety of civil government aircraft in certain specified areas. These frequencies, as listed in Table C-12, are intended for support of operations not exclusively en route in nature. These frequencies were chosen so as to avoid those channels in which operation might result in harmful interference to aeronautical stations dedicated to the safety and regularity of flight.

[12] *Id.* at 8-13.

[13] *Id.*

Table C-12: Frequencies Designated for Operational Control of Civil Government Aircraft

Assigned Freq. (kHz)	Carrier Freq. (kHz)	Areas of Operation	Assigned Freq. (kHz)	Carrier Freq. (kHz)	Areas of Operation
2897.4	2896	AK, HI, CONUS	10055.4	10054	HI
2948.4	2947	AK, HI, CONUS	11307.4	11306	CONUS
3002.4	3001	AK, HI, CONUS	17950.4	7949	AK, HI, CONUS
6539.4	6538	CONUS	21926.4	21925	AK, HI, CONUS
8886.4	8885	CONUS	21929.4	21928	AK, HI, CONUS
8910.4	8909	AK, HI, CONUS	21935.4	21934	AK, HI, CONUS

The Federal Government aeronautical stations that operate in the aeronautical mobile (R) service within the US&P are normally authorized only for the Federal Aviation Administration (FAA), mainly for its HF system called the National Radio Communications System (NRCS). As such, Federal Government spectrum use of the aeronautical mobile (R) service in the HF band is limited to few federal agencies. For example, the DOI use of the aeronautical mobile (R) service is mainly outside of the contiguous United States. Specifically, their use is mostly in Alaska, Hawaii, and the trust territories of the Mariana and Marshall Islands in the Pacific Ocean. Operations in the trust territories include inter-island communications. In Alaska, Hawaii, and CONUS, the DOI assignments are required for en route communications and flight following of aircraft in support of national resource programs.

Frequency assignments belonging to the Department of Treasury are used for aircraft in support of law enforcement responsibilities. Table C-13 specifies the particular bands used for aeronautical mobile (R) and respective bandwidths.

Table C-13: Frequency Bands Allocated to the Aeronautical Mobile Service (R) (1.7-30 MHz Band)

Frequency (kHz)	Bandwidth (kHz)	Frequency (kHz)/Service	Bandwidth (kHz)
2850-3025	175	10005-10100	95
3400-3500	100	11275-11400	125
4650-4700	50	13260-13360	100
5450-5680	230	17900-17970	70
6525-6685	160	21924-22000	76
8815-8965	150	—	---
Total Bandwidth = 1331 kHz			

Table C-14 shows typical technical characteristics of Federal Government systems in the aeronautical mobile (R) service.

Table C-14: Typical Technical Characteristics of Aeronautical Mobile (R) Systems (1.7-30 MHz Band)

System	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
Airborne	2.8	0	18000-40000	Conformal/V	Analog, single channel, suppressed carrier, telephony.
Ground	2.8	0-3	unknown	Various /V	Analog, single channel, suppressed carrier, telephony.

C.2.7.2 Aeronautical Mobile (OR) Service

Frequencies in bands allocated exclusively to the (OR) service are internationally alloted to countries by Appendix 26 of the ITU RR, which also establishes frequency sharing criteria, protection ratios, and other technical and operational principles. These principles recognize the possible necessity for the adaptation of the allotment plan to meet valid requirements of the various administrations, provided these adaptations do not decrease the protection to frequencies assigned in strict adherence to the plan.[14]

Frequencies in the bands allocated exclusively to the (OR) service are nationally used primarily for the satisfaction of military aeronautical requirements. Assignments of frequencies in these bands are subject to coordination with the Military Departments through the Interdepartment Radio Advisory Committee (IRAC) mechanism.

Nationally, the use of the aeronautical mobile (OR) service bands is mainly for military operations that include controlling traffic routes and special military needs. The Navy and Air Force are the major users of the aeronautical mobile (OR) bands. The vast majority of their assignments are dedicated for air-ground-air communications provided by the AN/ARC family of radios. The AN/ARC-190 is a typical radio used by the Air Force in the HF band and is described below. Other uses of the aeronautical mobile (OR) service bands by the Air force are: global command and control stations required for air and ground communications; flight testing; ground tactical communications; communications for the Strategic Air Command (SAC) forces; data coordination; and de-orbiting satellite recovery operations.

Table C-15 shows the frequency bands allocated to the aeronautical mobile service (OR) in the 1.7-30 MHz band and Table C-16 shows a typical technical characteristics of aeronautical mobile service (OR) system in the HF band.

[14] *Id.* at 8-14.

Table C-15: Frequency Bands Allocated to the Aeronautical Mobile (OR) Service (1.7-30 MHz Band)

Frequency (kHz)	Bandwidth (kHz)	Frequency (kHz)	Bandwidth (kHz)
3025-3155	130	11175-11275	100
4700-4750	50	13200-13260	60
5680-5730	50	15010-15100	90
6685-6765	80	17970-18030	60
8965-9040	75	23200-23350	150
Total Bandwidth = 845 kHz			

AN/ARC-190. The AN/ARC-190 works in conjunction with the AN/TRC-181 to provide short-, medium-, and long-range voice and data communications employing an automatic communications processor for auto link and anti-jam capabilities. These systems employ multiple modulations and coding techniques, including sideband suppressed carrier, single sideband reduced or variable level carrier, continuous wave employing frequency hopping and pseudo random pre-selection technique.

Table C-16: Typical Technical Characteristics of Aeronautical Mobile (OR) Systems (1.7-30 MHz Band)

System	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (ft)	Ant. Type/ Polarization	Modulations
AN/ARC (airborne)	3.5	0.0	30,000	Blade/V	Analog and digital, single channel, reduced or suppressed carrier, telephony and data.
AN/TRC (ground)	3.5	0.0	6-32	Whip/V	Analog and digital, single channel, reduced or suppressed carrier, telephony and data.

C.2.8 Standard Frequency and Time Signal[15]

The Federal Government, via the National Institute of Standards and Technology (NIST), has provided standard time and frequency services since 1923 in the HF band. These services are important to a community of technical users in support of basic activities such as navigation, power generations, and communications. However, many of these HF capabilities are being supplemented by the GPS. The services provided include: time announcements; standard time intervals; standard frequencies; geophysical alerts; marine storm warnings; Omega Navigation System status report; Coordinated Universal Time (UTC) corrections; and digital time code.

NIST provides time and frequency services at 2.5 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz. The services are broadcast from stations WWV, in Fort Collins, CO, and from WWVH, in Kauai, HI. Table C-17 shows the radiated power for the transmissions at each location. The antennas at WWV are omnidirectional, half-wave dipoles. At WWVH, the

[15] *Supra* note 1 at 72.

antennas are phased vertical half-wave dipole arrays with maximum gain in a westerly direction. Double sideband amplitude modulation is employed at both stations. Four modulation levels (25, 50, 75, and 100 percent) are used depending on the particular information transmitted.

Table C-17: Radiated Power for Transmissions at Stations WWV and WWVH

Frequency (MHz) [a]	Radiated Power at WWV (kW)	Radiated Power at WWVH (kW)
2.5	10	10
10	10	10
15	10	10
20	2.5	--

[a] The 25 MHz is currently not in use.

As the GPS and other communications systems become more widely assimilated, HF time broadcasts service may become obsolete. Currently, the main users of the HF standard frequency and time signal services are hobbyists, amateurs, and signal propagation researchers.

In the 1.7- 30 MHz frequency range, 13 bands are allocated to the standard frequency and time signal radio service on a primary basis. Table C-18 shows these bands and their respective bandwidths.

Table C-18: Frequency Bands Allocated to the Standard Frequency and Time Signal Service in the 1.7-30 MHz Band

Frequency (kHz)	Bandwidth (kHz)	Frequency (kHz)	Bandwidth (kHz)
2495-2505	10	14990-15010	20
4995-5005	10	19990-20010	20
9995-10005	10	24990-25010	20
Total Bandwidth = 90 kHz			

C.2.9 Aeronautical Radionavigation

In the 1.7-80 MHz frequency range, the 74.8-75.2 MHz band is allocated to the aeronautical radionavigation service. The federal agencies that operate on this band are the Air Force, Army and the FAA. Basically, use of this band is for marker beacons that provide navigational aids, including the Instrumentation Landing System (ILS). Marker beacons provide the pilot a reliable altitude indicator as it approaches the runway (barometric altimeters are not accurate at low altitudes). Most ILS and localizer landing approaches incorporate at least one marker and as many as three. The first marker (Outer Marker) is anywhere from four to 10 miles from the end of a runway and, normally, supports navigation for the initial approach. The marker beacon transmit in the ground-to-air direction at 75 MHz and is modulated with a 400 Hz intermit tone. The second marker (Middle Marker) is normally used about 3,000 feet off the end of the landing runway. The Middle Marker is normally used about 200 feet above ground level. This marker is transmitted at 75 MHz with a 1,300 Hz tone modulation. The third marker (Inner

Marker) is normally installed around 1,000 feet from the end of the runway. Again, the transmit frequency is 75 MHz but the tone is at 3,000 Hz.[16]

ITU RR No. 5.180 states that,

> "The frequency 75 MHz is assigned to marker beacons. Administrations shall refrain from assigning frequencies close to the limits of the guardband to stations of other services which, because of their power or geographical position, might cause harmful interference or otherwise place a constraint on marker beacons. Every effort should be made to improve further the characteristics of airborne receivers and to limit the power of transmitting stations close to the limits 74.8-75.2 MHz."

About 98 percent of the federal assignments that support marker beacons operation belong to the FAA. Because many major airports are within the vicinity of metropolitan or urban areas, BPL operations generally should not be considered in the 74.8-75.2 MHz band. Typical technical characteristics of aeronautical radionavigation systems operating in the 7.4-75.2 MHz band are shown in Table C-19.

Table C-19: Typical Technical Characteristics of Radionavigation Systems in the 74.8-75.2 MHz Band

System	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
Marker Beacon	0.8-6	-2.5-2.0	0-3000	Blade/H	Amplitude modulation, double sideband, single channel, digital and telegraphy

C.2.10 Radiolocation Service

The radiolocation service is a radiodetermination service used for detection and positional location of distant objects (targets).[17] There are three bands allocated to the radiolocation service in the 1.7-80 MHz range, as shown in Table C-20.

Table C-20: Frequency Bands Allocated to the Radiolocation Service (1.7-80 MHz Band)

Frequency Band (kHz)	Bandwidth (kHz)	Allocation
1705-1800	95	Primary
1900-2000	100	Primary
3230-3400	170	Secondary

In these bands, three federal entities (Navy, Army, and Tennessee Valley Authority (TVA)) are currently employing radiolocation systems. The Navy uses these bands in support of fleet operations and for surveillance. Specifically, the Navy's radiolocation systems provide position fixing in support of mine countermeasure operations and long range surveillance. For

[16] http:/www.avionicswest.com/marker beacon receiver.htm.

[17] *Id.* at 6-11.

surveillance, the Navy employs a long range, re-locatable over the horizon radar system (AN/TPS-71). This system is described further in Section C.4. The Army has multiple radiolocation requirements in these bands, namely, for test range and off-shore operations, including such as; target scoring; hydrographic surveys; and for determining location of missile payloads during recovery operations. The TVA has two radiolocation assignments for establishing boat positions while conducting water quality surveys in the vicinity of thermal-electric generation plants in TVA service areas. Typical technical characteristics of a radiolocation system in the 1.7-80 MHz band are presented in Table C-21.

Table C-21: Representative Technical Characteristics of Radiolocation Systems in the 1.7-80 MHz Band

System Station	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (ft)	Ant. Type/ Polarization	Modulations
Land & Ship	0.001-0.600	0-3	unknown	unknown/V	Amplitude modulation, double sideband, single channel, digital and telegraphy

C.2.11 Amateur and Amateur-Satellite Services

The amateur service is a radiocommunication service for the purpose of self-training, inter-communication and technical investigation that is used by duly authorized persons interested in radio techniques solely with a personal aim and without pecuniary interest.[18] Amateur radio operators' licenses are granted by the FCC and uses must adhere to technical standards as given in the FCC Rules and Regulations, Part 97 — Amateur Radio Service. The Amateur-satellite service is a radiocommunication service using space stations on earth satellites for the same purposes as those of the amateur service.[19]

Amateur radio operators extensively assist the law enforcement community and other public service organizations during all kinds of emergencies including: hurricanes, earthquakes, tornadoes and floods, motorist accidents, fires and chemical spills, and search and rescue operations.[20]

There are 13 bands allocated to the amateur and amateur-satellite services (1.7-80 MHz band). The majority of these bands is in the lower portion of the HF band and is presented in Table C-22.

[18] 47 C.F.R. §2.1(c).

[19] *Id.*

[20] http://www.arrl.org/hamradio.html.

Table C-22: Frequency Bands Allocated to the Amateur and Amateur-Satellite Services in the 1.7-80 MHz Band

Frequency Band (kHz)	Radio Service	Bandwidth (kHz)	Total Bandwidth (kHz)
1800-1900	Amateur	100	Amateur = 7650 Amateur-Satellite = 2700
3500-4000	Amateur	500	
7000-7100	Amateur/Amateur-Satellite	100	
7100-7300	Amateur	200	
10100-10150	Amateur	50	
14000-14250	Amateur/Amateur-Satellite	250	
14250-14350	Amateur	100	
18068-18168	Amateur/Amateur-Satellite	100	
21000-21450	Amateur/Amateur-Satellite	450	
24890-24990	Amateur/Amateur-Satellite	100	
28000-29700	Amateur/Amateur-Satellite	1700	
50000-54000	Amateur	4000	

The DOD administers the Military Affiliate Radio System (MARS). The MARS is managed and operated by the Army, Navy and the Air Force. The MARS program consists of civilian and military licensed amateur radio operators who are interested in supporting military communications. The MARS volunteer force includes more than 5,000 dedicated and skilled amateur radio operators.[21] They contribute to the MARS mission providing auxiliary or emergency communications on a local, national, and international basis as an adjunct to normal communications.[22] The radios used in the MARS program are the same or equivalent systems used by the amateur radio operators.

The MARS system continues to play an important role in the military for: (1) helping to maintain morale through assistance in the maintenance of contacts with spouses or friends even when the distance separation is great, and (2) when needed, it can augment emergency communication services within the military. The morale of servicemen and women is always an important area of concern for military commanders, particularly for personnel stationed in remote areas away from family and friends. Another area of concern for the military is to maintain an independent system that can be used in time of war, emergencies or other national disasters in ready-to-use condition. The MARS HF network is constantly being tested by calls made by the military personnel. Another benefit of this active system is as a training tool for reservists and active duty servicemen on a system they may be called upon to operate in an emergency situation.[23] Typical technical characteristics of a MARS radio are presented in Table C-23. Note, however, that the antennas used vary widely.

[21] http:/www.asc.army.mil/mars/mars/.

[22] http:/www.//afmars.tripod.com/mars1.html.

[23] *Supra* note 1 at 83-84.

Table C-23: Representative Technical Characteristics of MARS System (1.7-30 MHz Band)

System	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
MARS	2.7	0-10	0-80	Dipole, yagi, log periodic/ H & V	Amplitude modulated, Analog and digital, single or multiple channels, suppressed carrier, telephony and telegraphy.

C.3 FEDERAL GOVERNMENT SPECIAL OPERATIONS

C.3.1 Automatic Link Establishment (ALE) Systems

The Federal Government employs ALE subsystems in the medium to high frequency (MF-HF) range of the radio spectrum to eliminate the need for extensive training needed for manual establishment of HF and MF radio channels that use ionospheric (skywave) signal propagation. An ALE system is characterized by periodic polling of several frequencies (typically seven or more) that are assigned to a station to determine if ionospheric circuits are available at these frequencies. An ALE equipped radio automatically selects the best channel for communications by maintaining in real time a data base of link performance (*e.g.*, received signal-to-noise power ratio) versus frequency for each addressee in the users net and using that data to choose frequencies on which to initiate a link. A network of stations is assigned a number of frequencies over which to communicate, and each station is assigned a unique address (*e.g.,* alpha-numeric).

For example, station A, attempting to establish a link with station B will repetitively broadcast the address code for station B over one of the assigned network frequencies. This transmission will last long enough for station B to automatically scan its assigned frequencies. If station B receives and recognized its address code, it stops on that frequency. The equipment at both ends of the link will then automatically handshake and alert the operators that the link has been or can be established, and the desired traffic can be transmitted (*e.g.*, voice, secure voice, and data). If communications fail, the ALE equipment tries another frequency in the preset list until a link is established or the operator is informed of communications failure. Failures will occur, for example, if interference prevents communications on frequency assignments that an ALE system would otherwise determine to be the best available channels, in which the user will not realize that interference is the cause.

C.3.2 Sounders

In general, sounders are used to gain an in-depth real-time knowledge of the ionosphere conditions important to communication applications. In a stable ionospheric condition, sounder data need only to be taken every 15 minutes, and a complete record can be obtained in a fraction of a minute. Sounders data typically are used in support of non-ALE applications.

There are three main types of sounding systems; namely, backscatter, oblique and vertical incidence sounders. Backscatter sounders typically receive weak signals originating from a signal transmitted to the ionosphere, scattered back to the Earth's surface, back to the ionosphere, and scattered back to the original transmitter site and its associated receiver system. This technique is well suited for obtaining the propagation conditions as they relate to range, azimuth bearing, and frequency of operation. Oblique sounding uses an intermittent beacon located at a known distance from the receiver site. Since the range variable is removed, the resulting signal will be due to the ray-path distance associated with the various layers in the ionosphere. With good synchronization between the beacon and the receiver system, detailed information can be readily obtained. With this method, it is possible to determine the ionospheric virtual height. However, for this method to be applicable, the beacon must be placed in the area under the portion of the ionosphere that is of interest. Vertical incidence sounding provide information regarding the portion of the ionosphere that is directly overhead. The advantage of this type of sounding is that the transmitter and the receiver are co-located and this greatly simplifies the synchronization problem between the transmitter and the receiver. Operationally, however, the vertical incidence sounders are the least desirable type of sounder for determining appropriate communication system parameters. Table C-24 provides a summary of the Federal Government agencies sounding systems and relevant technical characteristics.

C.3.3 Over the Horizon (OTH) Radars[24]

Over the horizon radar systems are employed by the DOD. The OTH radars use skywave propagation to detect targets at long ranges from the radar transmitter site. The target return is a result of the backscatter signal traversing the path to the ionosphere and back to the original transmitter site (primary radar) or an alternative site (secondary site). OTH radar systems generally utilize more bandwidth than is typically used for communications. These systems place increased demands on the amount of spectrum used and performance is greatly affected by the characteristics of the ionospheric channel. OTH-HF radars are capable of detecting targets at distances beyond the horizon and therefore, targets located well beyond the range of the conventional microwave radar. This increased range is possible due to the ability of the HF signals to propagate well beyond the line-of-sight either by ground wave diffraction around the curvature of the Earth or by skywave. An example OTH radar system operating in the HF portion of the spectrum is the AN/TPS-71. A brief description of this system is provided below.

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[24] *Supra* note 1 at 74.

Table C-24: Federal Government Sounding Systems and Technical Characteristics

Federal Agency	Receiver Type	No. of Assignments[25]	Operating Frequency (kHz)	Emission Bandwidth	Antenna Type	Gain/ Polarization	Function(s)
AF	DIGISONDE 128	2	415-20012.5	20KM0N	--	15/T	-Provides ionosphere data to AF Global Weather Center
	DPS-4	2	1000-40000	30KV7D	--	10/T	-Ionospheric research. -Propagation research
	DIGITAL IONOSONDE	1	2220.5-2465	60KM1N	---	1	-Regional ionospheric forecast and specification
	AN/FMQ-12	20	1012.5-30000	2H5N0N 75KM0N 75KP0N 600HF9W	Broad-band dipole	0-16/ T/H	-Weather forecasting. -Ionospheric research -Provides ionospheric data to AF Global Weather Center
AR	AN/TRQ-35	2	2000-30000	2H5N0N	Double Delta		-Support Army's fixed communications
N	R-2368/URR AN/TPS-71 AN/ARC-191	15	2000-30000	2H5N0N 100HN0N 600HF1B 4K2F3N 4K2Q1N 100KQ1N 100KF3N	Phased array/ Whip/ Log periodic	0-36/ V&H	-Wide area surveillance. -Detection, location, tracking of aircraft and ships. -Air Defense warning.
C	---	1	1000-20000	40KP0N	--		-Propagation research studies
DOE	STQIONOSONDE	5	2505-14990	100HNON	Inverted-V	2	-Doppler shift measurement to support DOE earthquake monitoring system.

[25] In the Government Master File, an assignment may represent multiple radio equipments.

AN/TPS-71. The Navy's AN/TPS-71 is transportable OTH radar, with an operating frequency range of 5-28 MHz that can provide wide area active surveillance in support of tactical forces. Uses include detection, location, and tracking of aircraft and ship targets at a range of up to 1600 nautical miles in high interest marine areas. Transportable, in this sense, refers to having the capability to redeploy the system to another location over a period of time, as opposed to tactical mobility. This provides the Navy flexibility to be responsive to changing threat patterns and capabilities. This is a frequency agile system. There are a few OTH radar sites in the United States (AK, TX, and, two in VA), and few more overseas. The basic technical characteristics of the AN/TPS-71 receiver are shown in Table C-25.

Table C-25: Technical Characteristics of the AN/TPS-71 System (1.7-30 MHz Band)

System	Bandwidth (kHz)	Ant. Gain (dBi)	Ant. Height (Ft)	Ant. Type/ Polarization	Modulations
AN/TPS-71	4.2-100	9-36 *	Not available	Phased Array/ Vertical	FM/CW or Angle-modulated, single channel, with analog or digital signals.

* The 9 dBi and 36 dBi antenna gains are measured at the 5 MHz to 28 MHz, respectively.

C.4 SPECIAL OPERATIONAL CONSIDERATIONS

C.4.1 Operational Requirements for Access to Several Frequency Assignments within an Allocation

Ionospheric (skywave) signal propagation is frequency selective and frequencies usable for communications between any two points changes over time throughout the day. This is why several different segments of the 1.7-30 MHz frequency range are allocated to each radio service (*i.e.*, so that the service has full-time access to frequencies that are usable throughout the day). This is an important factor in assessing the operational impact of broadband interfering signals that typically overlap an entire HF allocation for one or more services. In the event local harmful interference occurs across an HF allocation, the associated service will not be able to operate in that locale for several hours during the day.

Even if only a portion of a given allocation is subjected to local harmful interference, the local communications reliability is greatly diminished for services that utilize multiple frequency assignments within a band. This is because the choice among multiple assignments allows the local radio operator (or ALE system) to avoid channels that are laden with relatively high local noise power levels or are in use by other radio systems.

C.4.2 Federal Government use of Radio Frequencies Below 30 MHz for Domestic Fixed Service

Section 8.2.11 of the NTIA Manual provides restrictions on fixed service use of frequencies below 30 MHz. To insure that, insofar as practicable, sufficient high frequencies will be available for the operation of radio circuits essential to the national security and defense and to conserve frequencies below 30 MHz for services which cannot operate adequately without them, only in following circumstances shall departments and agencies of the Executive Branch of the Government use frequencies below 30 MHz for domestic fixed service within the conterminous United States:

a) When it is indispensable to do so, and on the condition that the characteristics of the stations continue to conform to those in the GMF, a land station may communicate, on a secondary basis, with fixed stations or other land stations in same category, using its assigned frequencies;

b) Where technical and operational requirements dictate, fixed stations may transmit to other fixed stations for the domestic haul or overseas traffic in transit, or destined for the United Sates. Such domestic radio haul shall be a segment of the overall overseas radio system;

c) When there is a need to provide instantaneous transmission of vital emergency, operational command and alerting traffic of such importance as to affect the immediate survival and defense of the nation;

d) When required for use in an emergency jeopardizing life, public safety, or important property under conditions calling for immediate communication where other means of communication do not exist or are temporarily disrupted or inadequate;

e) When there is a need to provide for a communications system manned by fully qualified operators who are military reservists or affiliates (e.g., MARS). Except in emergencies, frequency assignments in this category shall not be used as a means for passing traffic that in the absence of such assignments would require delivery by other means;

f) When other telecommunication facilities do not exists, are inadequate, or are impracticable of installation, and when the use of frequencies above 30 MHz is not practicable; and

g) In an emergency where it has not been feasible to make prior arrangements for alternate means of communications, it is permissible to operate temporarily on regularly assigned frequencies in a manner other than that specified in the terms of an existing assignment or on other appropriate frequencies under special circumstances such as an emergency must actually exist or imminently threaten emergency operations shall be discontinued as soon as substantially normal communications facilities are restored.

Also, Section 8.2.11 (2) and (3) of the Manual supplements or clarifies the above mentioned restrictions with respect to the requests for the authorization of frequencies below 30 MHz for new systems or in circumstances where congestion in the radio spectrum would be increased materially, and establishing adequate radio backup of wireline facilities in advance for use during an emergency.

C.4.3 Summary of the Emergency use of Federal Government HF Frequencies for the SHARES Program

The National Communications System (NCS) SHARES HF Radio Program is a key element in the national telecommunications infrastructure using presently authorized HF radio networks and cooperating federal agencies. SHARES is a collection of existing federal agency controlled HF stations that will interoperate to exchange national security emergency preparedness (NSEP) traffic for any federal entity during a crisis or emergency. Participating agencies agree to accept SHARES actual or simulated emergency traffic, assuming responsibilities for delivery or relay to the extent it does not interfere with their own agency mission. The SHARES HF Program supports Executive Order 12472, 12656, and NSDD-97.

Agencies providing frequencies for the NCS SHARES program must have a US&P assignment in the GMF. Operations under these assignments are limited to SHARES operation and tests. Participating agencies in the NCS SHARES HF Radio Program are authorized to test the operating system periodically provided the respective agency Frequency Assignment Subcommittee Representatives are notified at least 30 days in advance.

C.4.4 National Criteria Established Jointly by NTIA and FCC on the use of Frequencies from Appendix 27 Allotment Plan

In the HF band, there are special and certain related aeronautical mobile requirements not fully conforming to the definition of the aeronautical mobile (R) service that have to be satisfied by the frequencies from ITU RR Appendix 27 allotment plan. However, the use of these frequencies will abide within the limitations of the following national criteria established jointly by the NTIA and FCC:

1) Communications related to safety and regularity of flight between an aircraft and those aeronautical stations primarily concerned with flight along national or international civil air routes shall have absolute priority over all other uses;

2) Use of (R) band high frequencies shall be limited to single sideband air/ground and incidental air/air communications beyond the range of VHF/UHF facilities;

3) Users shall share frequencies to the maximum extent possible;

4) Requirements shall be handled on a case-by-case basis;

5) A showing must be made that the accommodation of the requirements in the bands other than aeronautical mobile (R), *e.g.*, fixed bands, is not satisfactory for technical, operational, or economic reasons;

6) Only those requirements will be considered where the primary need for communications is for the safety of the aircraft and its passengers or for operational control communications, *i.e.*, “communications required or exercising authority over initiation, continuation, diversion, or termination of a flight in accordance with the provisions of Annex 6" (ICAO);

7) Use of aeronautical mobile (R) high frequencies in accordance with the foregoing normally shall be limited to non-military; and

8) If the aforementioned criteria are met, the stipulation that (R) bands are to be used only for flights along national and international civil air routes need not be met.

APPENDIX D
BROADBAND OVER POWER LINE
EMISSION MEASUREMENTS

D.1 INTRODUCTION

This appendix presents measurements performed by NTIA's Institute for Telecommunications Sciences (ITS) that quantified several aspects of BPL signals. The measurements were conducted in three areas where BPL systems are currently deployed for testing and are serving customers. Access BPL was implemented on MV wires in all three areas and in-house BPL was implemented on LV wires in two areas. Some access BPL was on overhead wires and some is on underground wires, whereas, all of the in-house BPL was above ground except where, in some cases, there were buried LV wires leading up to the houses. The objectives for the measurements were to:

1. Measure the received BPL signal power at points along power lines;
2. Measure the received BPL signal power at various distances from power lines;
3. Measure the received BPL signal peak, average and quasi-peak levels for comparison;
4. Measure the received BPL signal power at different antenna heights; and
5. Measure the amplitude probability distributions (APDs) of the BPL signal.

The measurement system used for this testing is described in Section D.2. Figures and tables of measured data are provided in Section D.3. In section D.4 of this report, background information about APDs is covered, and in Section D.5, gain and noise figure calibration is described.

D.2 THE MEASUREMENT SYSTEM

The measurement system block diagram is shown in Figure D-1. An antenna, positioned 10 meters above the ground atop a telescopic mast on the ITS "RSMS-4" measurement vehicle (Figure D-2) and 2 meters above the ground on a tripod, was used to measure the received power. Four different 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, two shielded loops were used to measure the magnetic fields and for the electric fields, a rod antenna over a small ground plane was used. To measure the received power that is expected to be seen by a typical land mobile radio, a 2.13 meter base-loaded whip antenna was mounted on the roof of a vehicle at an approximate height of 1.5 meters. The whips were narrow-band, so several of them were used to cover the measurement frequencies. The signal from the antenna was split into two measurement systems so that simultaneous measurements could occur and to minimize switching instrument setups. A preselector was used on each system in order to prevent an overload condition from occurring and improve the sensitivity. Computers were used to control the measurement instruments and store the data.

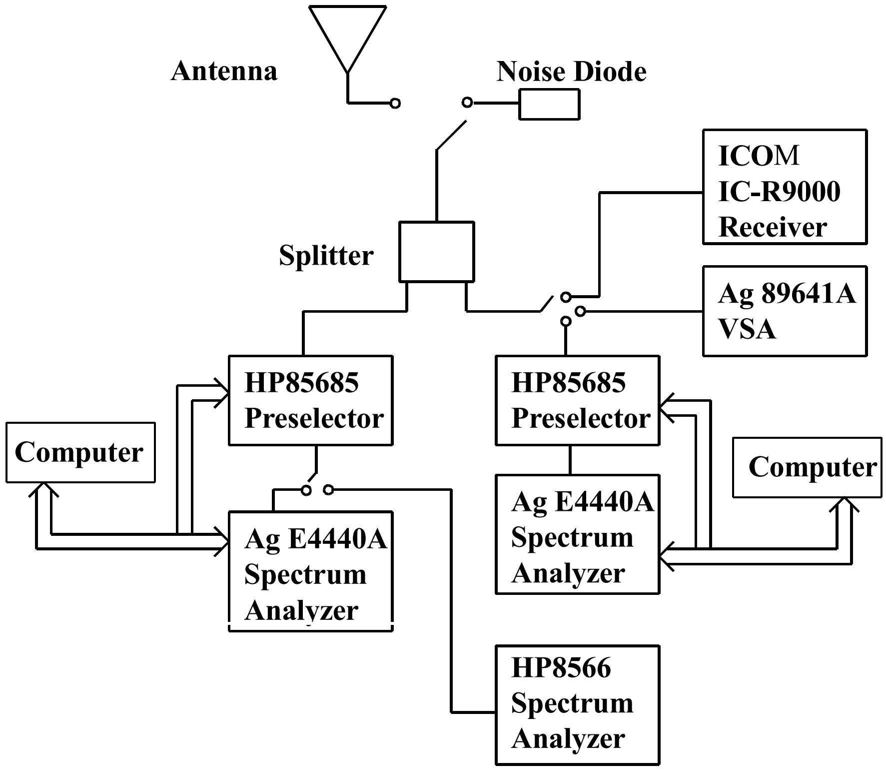

Figure D-1: BPL measurement system block diagram.

Figure D-2: Radio Spectrum Measurement System - 4 (RSMS-4)

The output of one of the preselectors was variously connected to a HP 8566 spectrum analyzer with a quasi-peak detector, a vector signal analyzer or a multi-mode communications receiver. The receiver was used to listen to the BPL signal in several demodulation modes and to assist with distinguishing between BPL and other signals. The vector signal analyzer was used to record the time-waveform for future analysis.

D.3 BPL MEASUREMENTS

D.3.1 Background on BPL Emissions Measurements

This sub-section provides general information on the BPL emissions from the three types of systems under test. These data are provided as an aid to understanding the measurements presented in Sections D.3.2 – D.3.6.

The BPL signal shown in Figure D-3 is representative of the weakest (lowest power density) BPL signals for which data were recorded. That is, nominal interference-to-noise ratio (I/N) levels had to exceed about 5 dB; otherwise no BPL signal level (I) was recorded[1]. Thus, even though much weaker BPL signal levels were measurable when turning the BPL system on and off (i.e., I/N of -6 dB), measurements with I/N ≥ 5 dB ensured that measured signals were unquestionably due to BPL emissions.

System #1

This system used different frequency bands for signals on the MV and LV wiring. Signal strength measurements were performed by acquiring multiple traces from a spectrum analyzer centered on specific frequencies with a zero span and a sampling detection mode. Trace data were downloaded to a computer and later analyzed statistically using Amplitude Probability Distributions (APDs). From these distributions, the temporal statistics of the BPL signal were identified and the power was determined as described in Section D.5. The signal power determined from these distributions is expressed as "100%-duty-cycle" power and represents the maximum power if the packet data were present 100% of the time (i.e. signal pulses occurring back-to-back), as further explained in Section D.4.0.

System #2

The BPL signal used OFDM modulation with a carrier spacing of approximately 1.1 kHz. BPL is transmitted only on the MV lines. The downstream (towards the customer) bandwidth was 3.75 MHz while the upstream (away from the customer) bandwidth was 2.5 MHz. An example portion of the spectrum is show in Figure D-3. The BPL signal displayed a repeating pattern of three carriers, then one carrier missing, and so on. The BPL signal duty cycle was 100% for the downstream signal and between 30% - 100% for the upstream. The envelope of an upstream signal is shown in Figure D-4 and it shows a duty cycle that is in the upper end of the range.

[1] If a measurement is attempted and the BPL signal has an interference to background noise level (I/N) < 5 dB, the results reported in Subsections D.3.2 – D.3.6 will be referred to as "Not measurable." If a particular measurement isn't attempted, it will be reported as "*Not measured*." The 100% duty-cycle power levels presented in this report were analyzed statistically from APD measurements and therefore did not need to satisfy the requirement of I/N ≥ 5 dB.

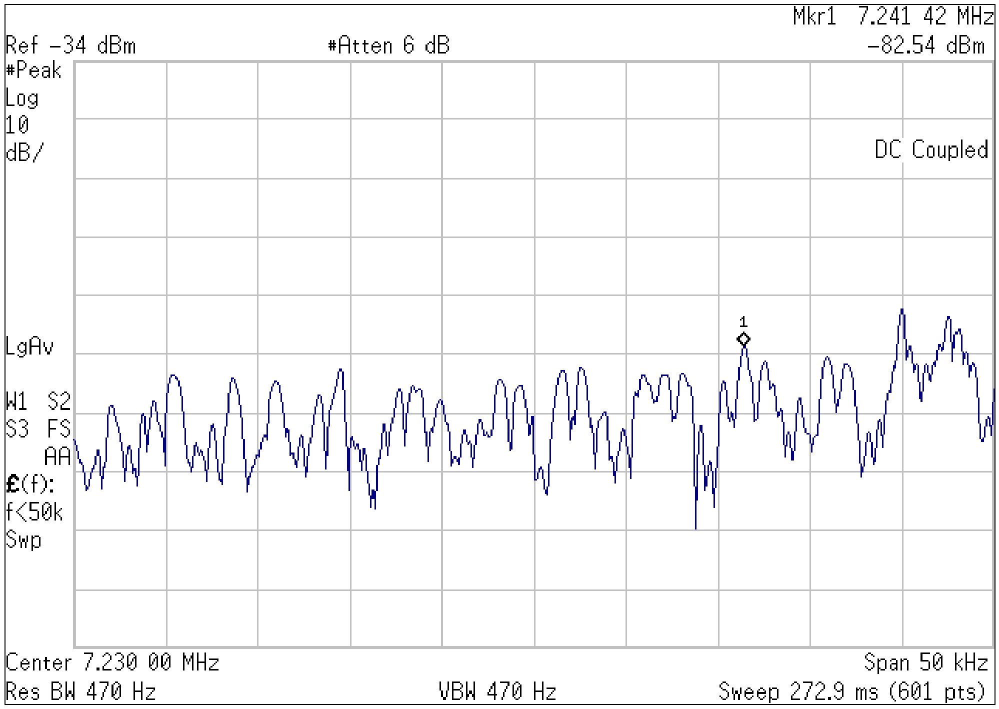

Figure D-3: A portion of the System #2 BPL spectrum.

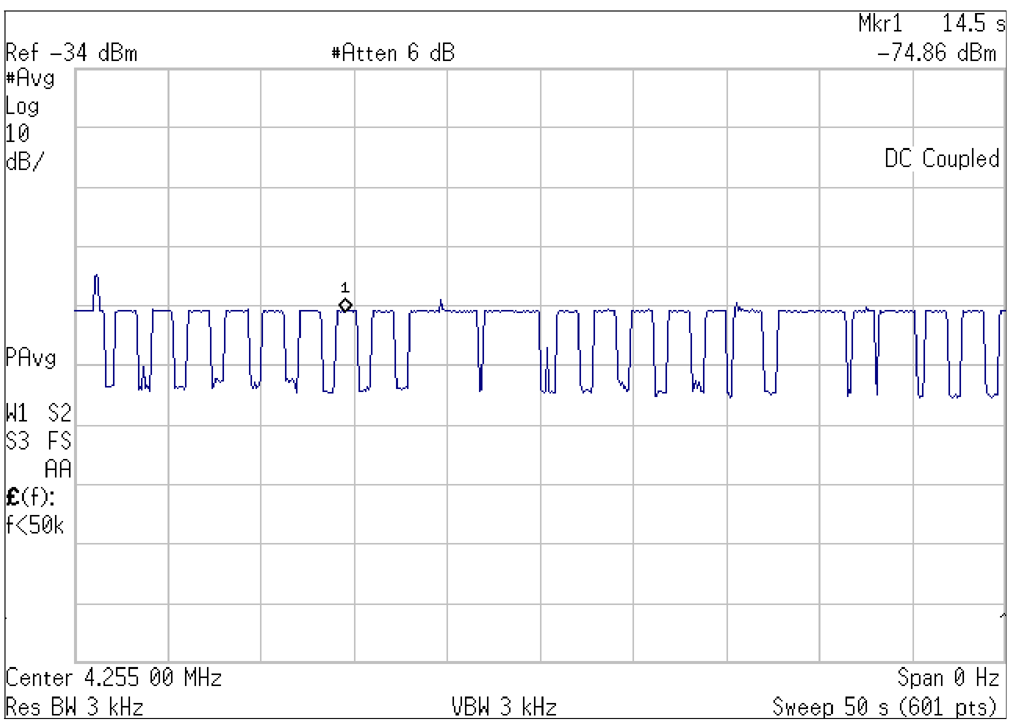

Figure D-4: The envelope of an upstream System #2 signal.

To measure System #2 emissions, the procedure involved examining the spectrum of the BPL transmission (see Figure D-3) and identifying a group of 3 adjacent carriers (since the measurement bandwidth was 3 kHz) that were among the strongest and were clear of background signals. If the signal was too weak (<5 dB above the background noise) to clearly see the spectrum or if background signals contaminated the BPL spectrum at certain frequencies, a measurement was not attempted at those frequencies. The marker in Figure D-3 shows the chosen measurement frequency. The resolution bandwidth was then set to 3 kHz and the marker (see Figure D-5) indicated the measured value using a peak detector. This value was later used to calculate the Received Power at the antenna terminals.

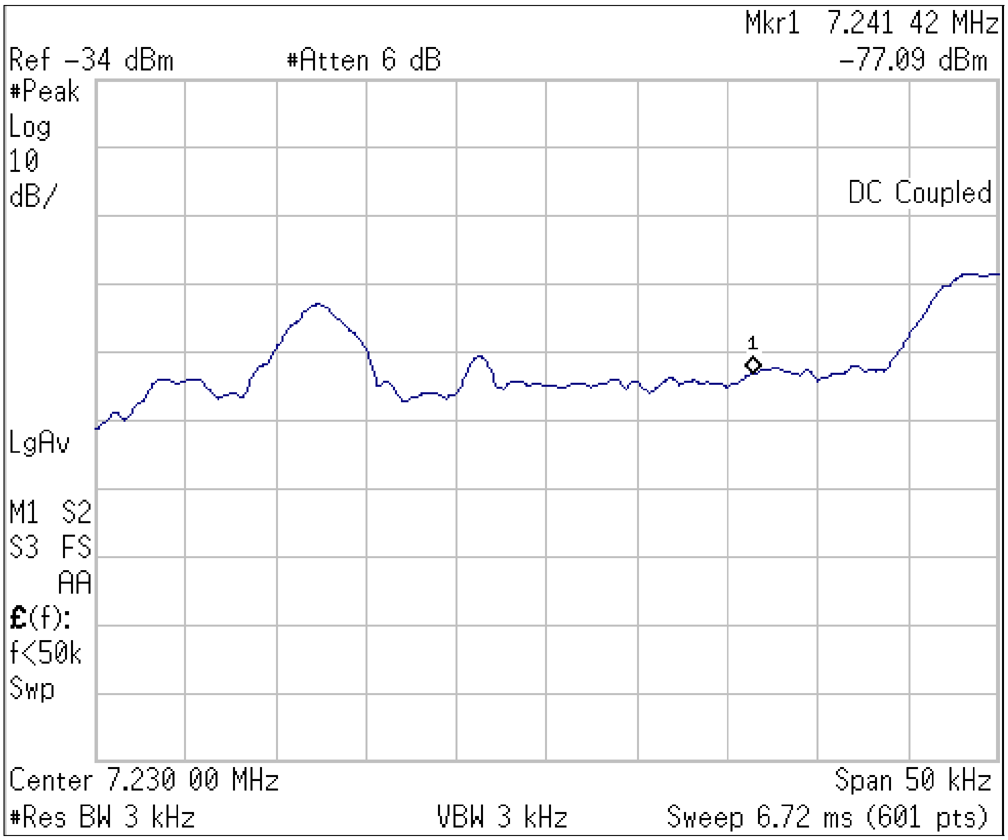

Figure D-5: The System #2 BPL spectrum in a 3 kHz bandwidth.

A measurement was performed to see how the received power varied as the receiver bandwidth was changed. This is shown in Figure D-6 for a frequency of 22.957 MHz. The narrow dips in signal level are due to the signal having a duty cycle of less than 100%. The upward spikes are due to noise sources.

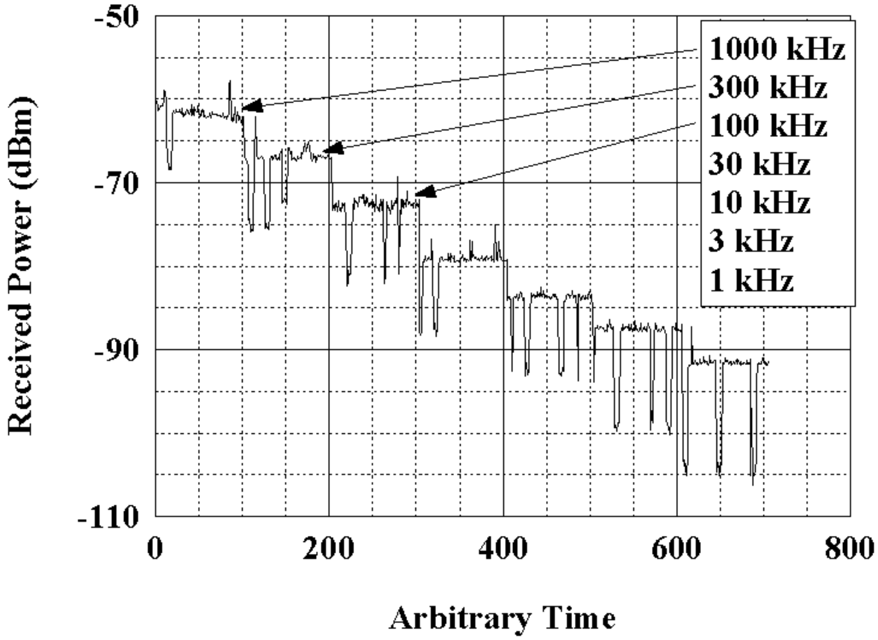

Figure D-6: Bandwidth progression at 22.957 MHz.

System #3

This BPL signal used DSSS modulation over the frequency range of about 1.8 to 21 MHz. BPL signals were transmitted on the MV and LV lines. The BPL signal duty cycle can be up to 90% when transmissions are occurring in both directions and about 87% for one direction. The envelope of the BPL signal is shown in Figure D-7. Four different amplitudes from four different transmitters are being received.

Figure D-7: Four different BPL transmitters.

In System #3, two co-frequency BPL sources were observed transmitting at the same time, as shown in the third graticule in Figure D-8. Noise sources can be present at levels stronger than the BPL signal as shown in the eight and ninth graticules in Figure D-9.

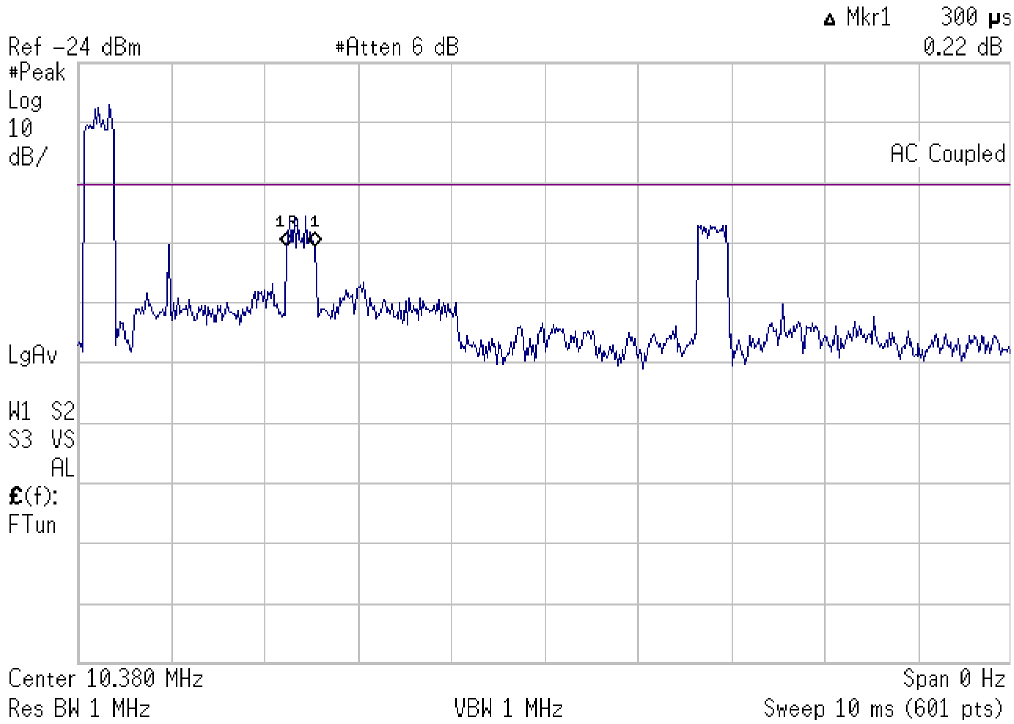

Figure D-8: Two simultaneous BPL transmissions.

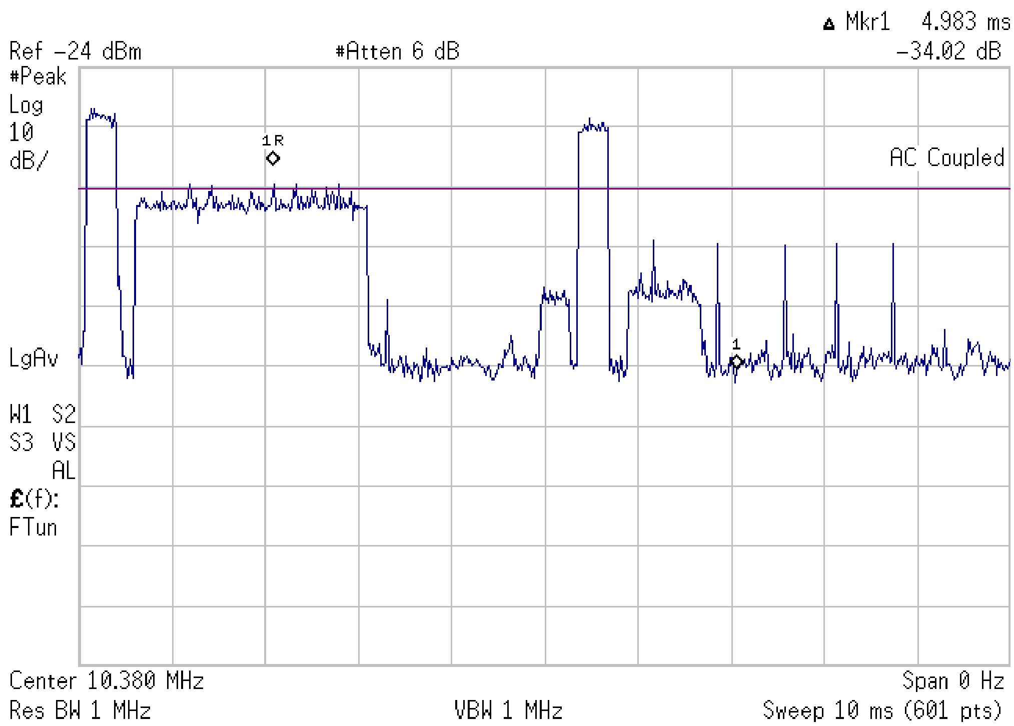

Figure D-9: Three BPL transmitters plus noise.

The measurement procedure for System #3 involved examining the spectrum of a BPL device's transmission and identifying a pair of frequencies that were the strongest and were clear of background signals. For each frequency, the signal envelope was observed for transmission bursts that were of the correct duration and pattern. Initially, the envelope was studied at a location where the BPL signals were received well. The durations of many bursts were measured to determine the typical range. This observation also yielded clearly identifiable transmission patterns that would repeat occasionally. The results of these observations were used to qualify the presence of BPL signals for future measurements. For each measurement location, the strongest BPL transmission was identified and its peak value was measured. The resolution bandwidth was then set to 30 kHz to allow for positive identification since at 3 kHz, the shorter BPL bursts would look like impulsive noise. The measured value was later used to calculate the received power at the antenna terminals.

D.3.2 Measurements of BPL Along the Energized Power Line

Measurements of BPL emissions along the energized power line (Site A, Figure D-10) were made using a variety of antennas. The first measurements were taken along a fairly straight segment of power line having both a repeater and an extractor.

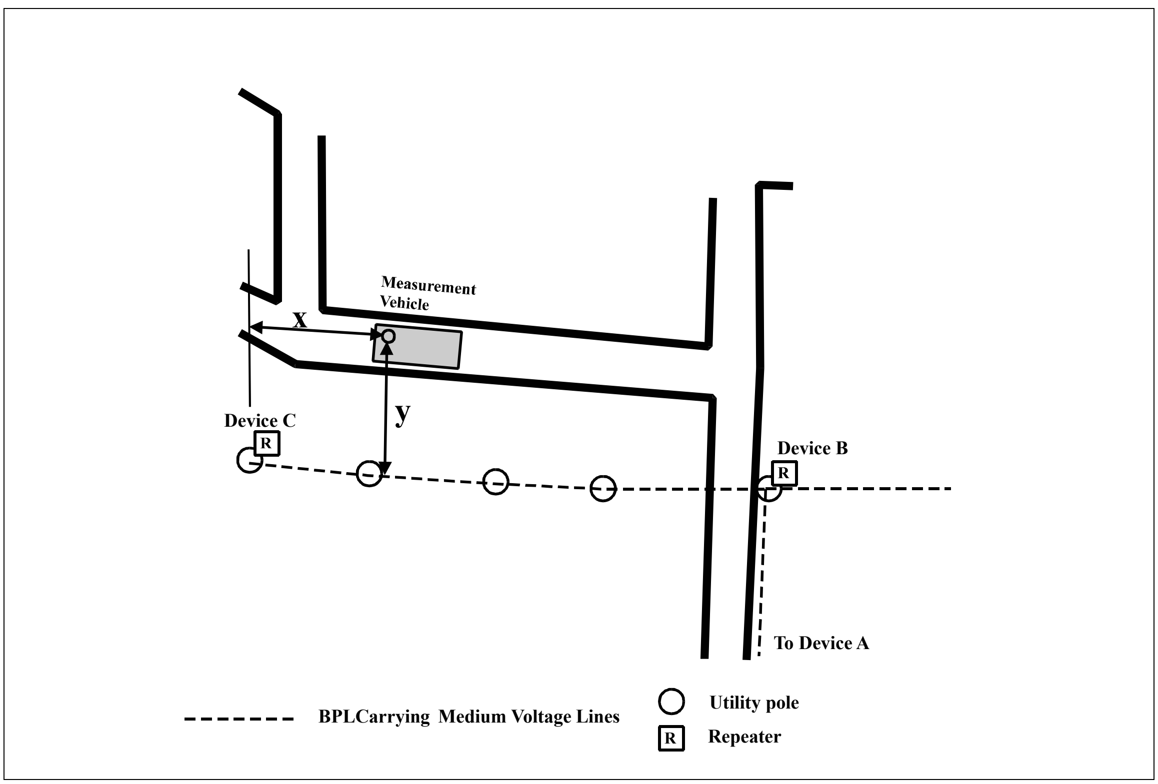

Figure D-10: Measurement Site A for measurements along the BPL energized power line.

Four measurement frequencies were chosen to represent the frequency bands used by this system (downstream injector-to-repeater, upstream repeater-to-injector, downstream repeater-to-extractor, and upstream extractor-to-repeater). Three mutually orthogonal components of the field were measured and plotted as three separate curves per graph for the frequencies 4.303, 8.125, 22.957 and 28.298 MHz, as shown in Figures D-11 through D-14 respectively. The measured peak power levels due to the orthogonal components of the electric field were plotted as a function of x, where x is the distance along the power line from the Device C. Note that in these and all other figures depicting BPL signal power vs. distance, lines connecting data points are connected to show possible trends but should not be interpreted to provide expected, interpolated values.

Measurement Conditions

Measurement Location:	Site A
Antenna Type:	Rod
Antenna Height:	2 meters
Antenna Polarization:	(X) Horizontal Parallel, (Y) Horizontal Perpendicular, and (Z) Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance along power line (x)
Comments:	Measurements were made at 14 positions (x-distances). At some points, the BPL signal was too weak (I/N < 5 dB), hence, some curves have fewer data points.

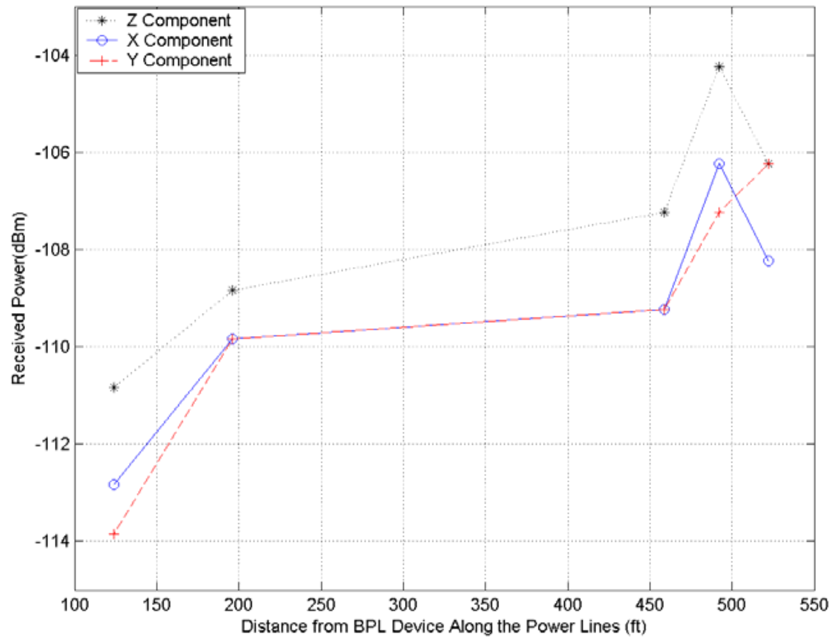

Figure D-11: Measured power levels along the power line – Site A, 4.303 MHz, rod antenna*

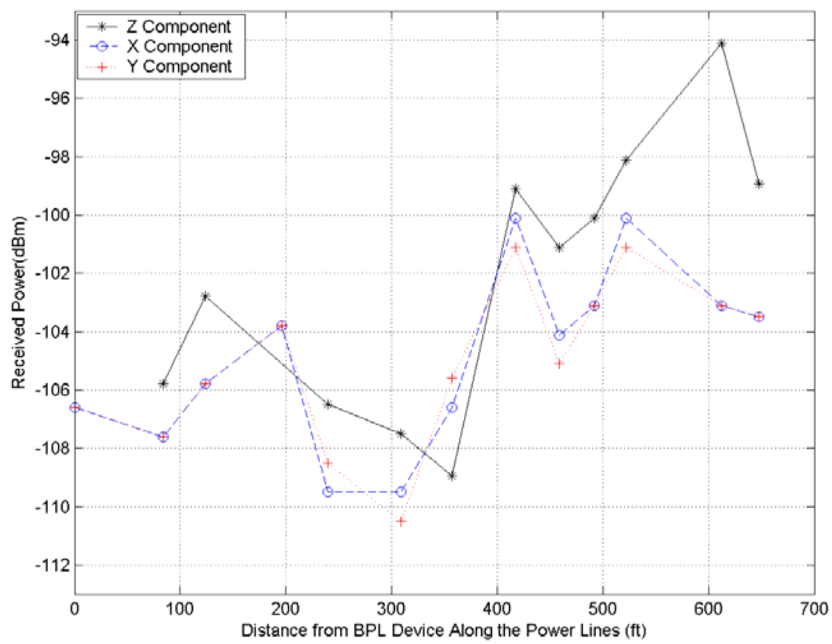

Figure D-12: Measured power levels along the power line – Site A, 8.125 MHz, rod antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

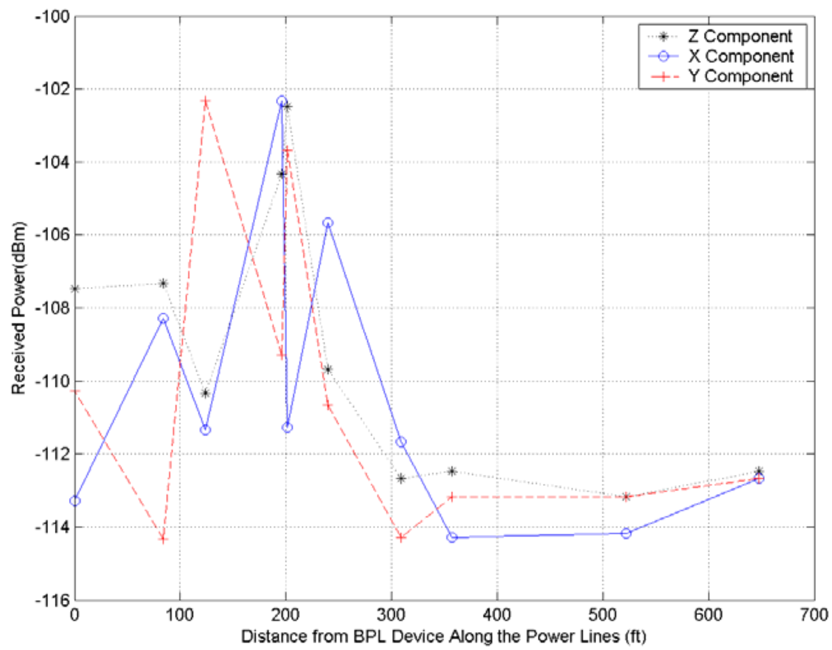

Figure D-13: Measured power levels along the power line – Site A, 22.957 MHz, rod antenna*

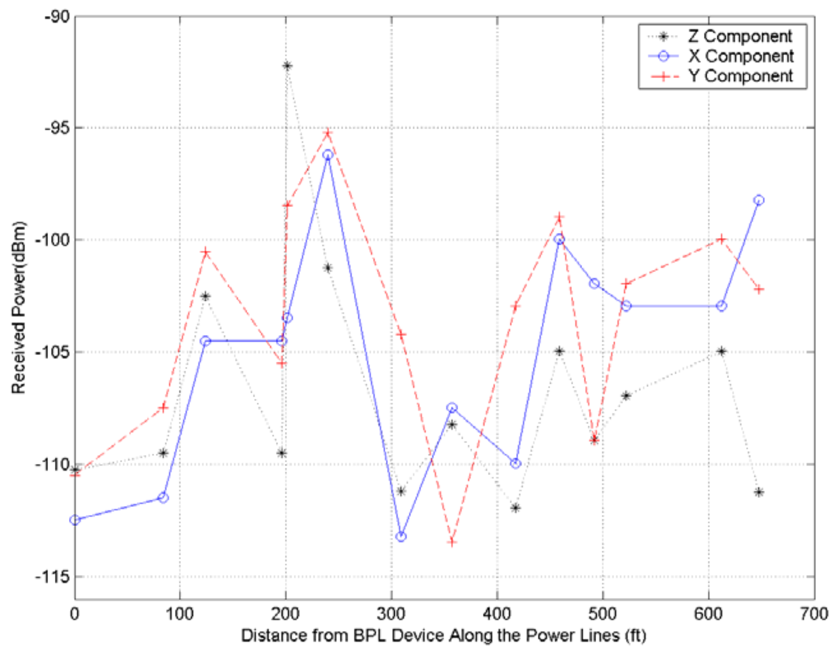

Figure D-14: Measured power levels along the power line – Site A, 28.298 MHz, rod antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

These curves indicate that the BPL electric field (relative to noise) along and near the line does not measurably decay with distance from the device (Device C) and is possibly impacted by the presence of Device B. It is interesting to note that even though the Device C is an injector that transmitted at 8.8 MHz, the electric field actually increased with increasing distance from the device. This is thought to be due to BPL signal reflection by one or more impedance discontinuities (perhaps the coupler of BPL Device B). Device B is a BPL repeater that transmitted at 28.8 MHz and 4.3 MHz. The electric field at 28.298 MHz is high closer to Device B, but is at comparable levels at other distances away from Device B as well.

An attempt was made to characterize the received power from the magnetic field at this same location (Site A, repeated here as Figure D-15). The results are illustrated in Tables D-1 thru D-4. These Tables indicate that the magnetic field using a loop antenna at 2 meters was not measurable along the power line at most locations.

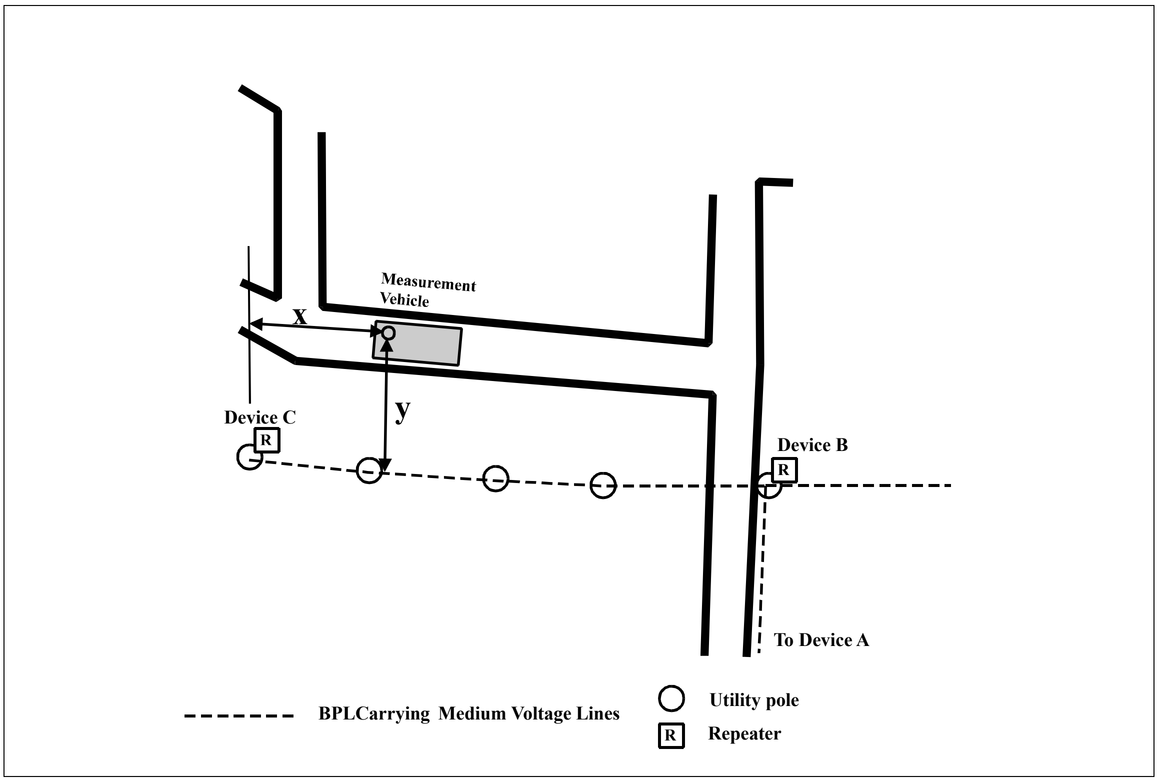

Figure D-15: Measurement Site A for measurements along the BPL energized power line.

<u>Measurement Conditions</u>

Measurement Location:	Site A
Antenna Type:	Shielded Loop
Antenna Height:	2 meters
Antenna Polarization:	(X) Horizontal Parallel, (Y) Horizontal Perpendicular, and (Z) Vertical
Measured Characteristic:	Peak received power due to magnetic field

Measurement Variable: Distance along power line (x)
Comments: This effort was abandoned after no signal was received for many measurements.

Table D-1: Measurements along the power line – Site A, 4.303 MHz, loop antenna

X Distance (feet)	Y Distance (feet)	Received Power Z Component(dBm)	Received Power Y Component(dBm)	Received Power X Component(dBm)
648	107	Not measurable	Not measurable	Not measurable
612	126	*Not measured*	*Not measured*	*Not measured*
522	96	*Not measured*	*Not measured*	*Not measured*
492	93	Not measurable	Not measurable	Not measurable
459	87	*Not measured*	*Not measured*	*Not measured*
417	123	*Not measured*	*Not measured*	*Not measured*
357	120	Not measurable	Not measurable	Not measurable
309	120	*Not measured*	*Not measured*	*Not measured*
240	120	*Not measured*	*Not measured*	*Not measured*
201	120	Not measurable	Not measurable	Not measurable
196	120	Not measurable	Not measurable	Not measurable
124	120	Not measurable	Not measurable	Not measurable
84	135	Not measurable	Not measurable	Not measurable
0	120	Not measurable	Not measurable	Not measurable

Table D-2: Measurements along the power line – Site A, 8.125 MHz, loop antenna

X Distance (feet)	Y Distance (feet)	Received Power Z Component(dBm)	Received Power Y Component(dBm)	Received Power X Component(dBm)
648	107	-114.94	Not measurable	-114.94
612	126	*Not measured*	*Not measured*	*Not measured*
522	96	*Not measured*	*Not measured*	*Not measured*
492	93	Not measurable	Not measurable	Not measurable
459	87	*Not measured*	*Not measured*	*Not measured*
417	123	*Not measured*	*Not measured*	*Not measured*
357	120	Not measurable	Not measurable	Not measurable
309	120	*Not measured*	*Not measured*	*Not measured*
240	120	*Not measured*	*Not measured*	*Not measured*
201	120	Not measurable	Not measurable	Not measurable
196	120	Not measurable	Not measurable	Not measurable
124	120	Not measurable	Not measurable	Not measurable
84	135	Not measurable	Not measurable	Not measurable
0	120	-107.94	Not measurable	Not measurable

Table D-3: Measurements along the power line – Site A, 22.957 MHz, loop antenna

X Distance (feet)	Y Distance (feet)	Received Power Z Component(dBm)	Received Power Y Component(dBm)	Received Power X Component(dBm)
648	107	Not measurable	Not measurable	Not measurable
612	126	*Not measured*	*Not measured*	*Not measured*
522	96	*Not measured*	*Not measured*	*Not measured*
492	93	Not measurable	Not measurable	Not measurable
459	87	*Not measured*	*Not measured*	*Not measured*
417	123	*Not measured*	*Not measured*	*Not measured*
357	120	Not measurable	Not measurable	Not measurable
309	120	*Not measured*	*Not measured*	*Not measured*
240	120	*Not measured*	*Not measured*	*Not measured*
201	120	Not measurable	Not measurable	Not measurable
196	120	Not measurable	Not measurable	-114.33
124	120	Not measurable	Not measurable	Not measurable
84	135	Not measurable	Not measurable	Not measurable
0	120	-112.48	Not measurable	-114.48

Table D-4: Measurements along the power line – Site A, 28.298 MHz, loop antenna

X Distance (feet)	Y Distance (feet)	Received Power Z Component(dBm)	Received Power Y Component(dBm)	Received Power X Component(dBm)
648	107	-107.23	-110.23	-110.23
612	126	*Not measured*	*Not measured*	*Not measured*
522	96	*Not measured*	*Not measured*	*Not measured*
492	93	Not measurable	Not measurable	-112.06
459	87	*Not measured*	*Not measured*	*Not measured*
417	123	*Not measured*	*Not measured*	*Not measured*
357	120	Not measurable	-112.23	Not measurable
309	120	*Not measured*	*Not measured*	*Not measured*
240	120	*Not measured*	*Not measured*	*Not measured*
201	120	-104.23	-105.23	-105.23
196	120	-111.50	Not measurable	-111.50
124	120	Not measurable	-112.50	-113.50
84	135	Not measurable	Not measurable	Not measurable
0	120	Not measurable	Not measurable	Not measurable

The peak received power due to the electric field was measured with the whip antenna along the power line (Site A, repeated here as Figure D-16). The measured received power levels are plotted in Figure D-17 ("x" referenced to Device C) and Figure D-18 ("x" referenced to Device B). The results are similar to those obtained from the electric field measurements previously accomplished using the rod antenna.

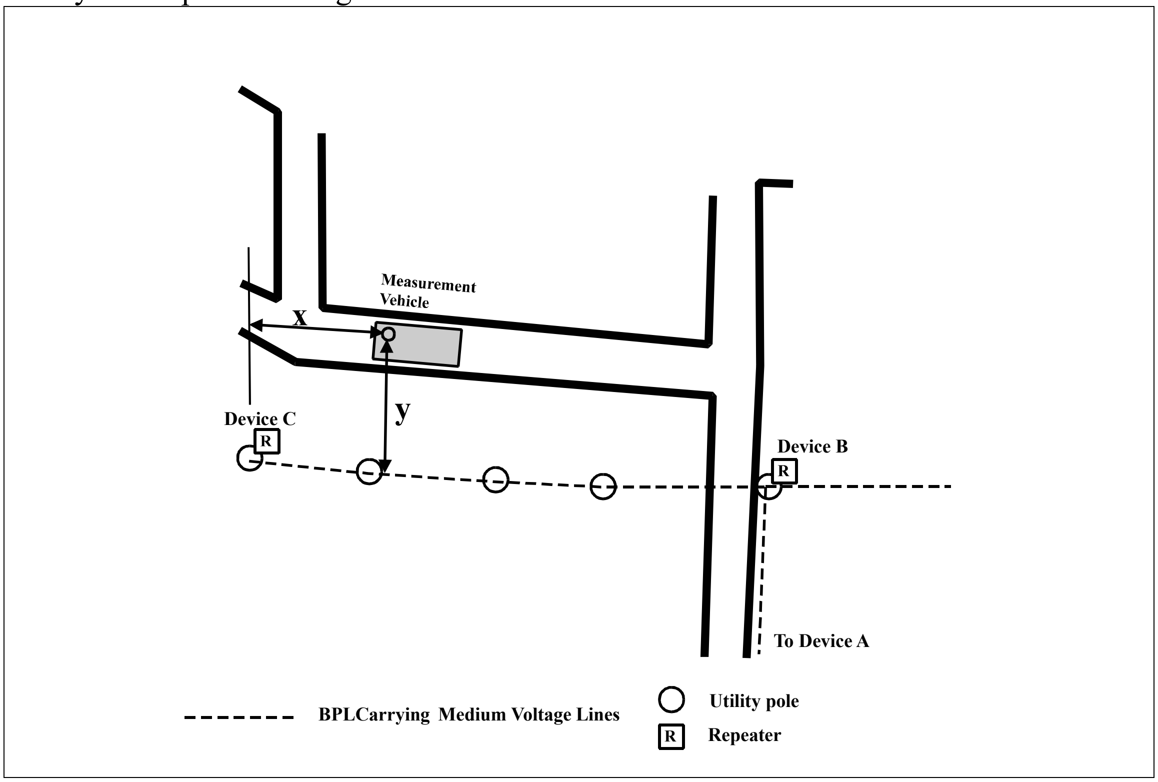

Figure D-16: Measurement Site A for measurements along the BPL energized power line.

<u>Measurement Conditions</u>

Measurement Location:	Site A
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance along power line (x) referenced to (1) Device C, or (2) Device B
Comments:	Note that though the measurements were initially made at a frequency of 7.241 MHz, the frequency was changed to 7.25 MHz due to background signals covering up the BPL signal.

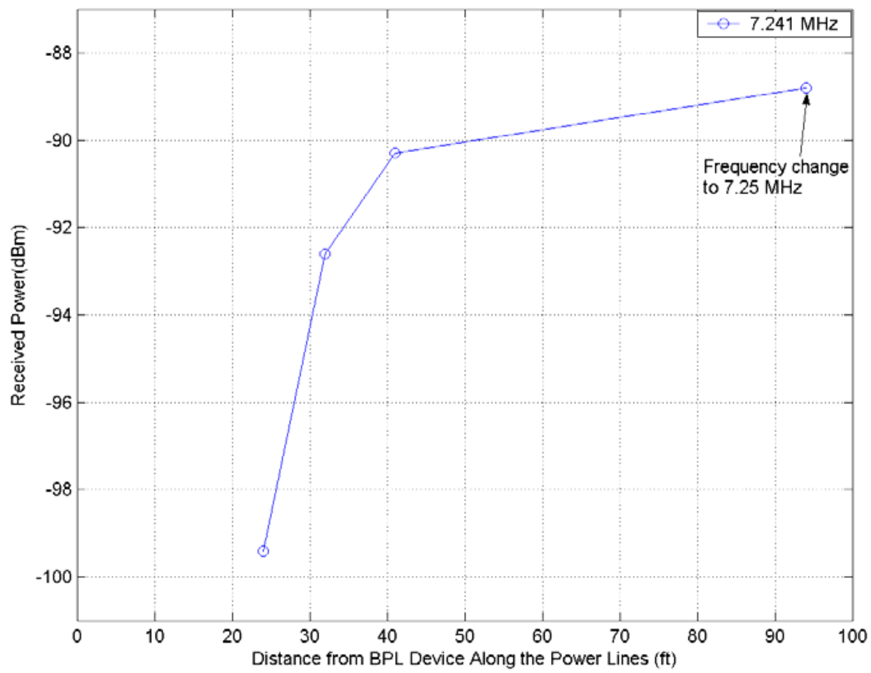

Figure D-17: Measured power levels along power line – Site A, "x" referenced to Device C, whip antenna*

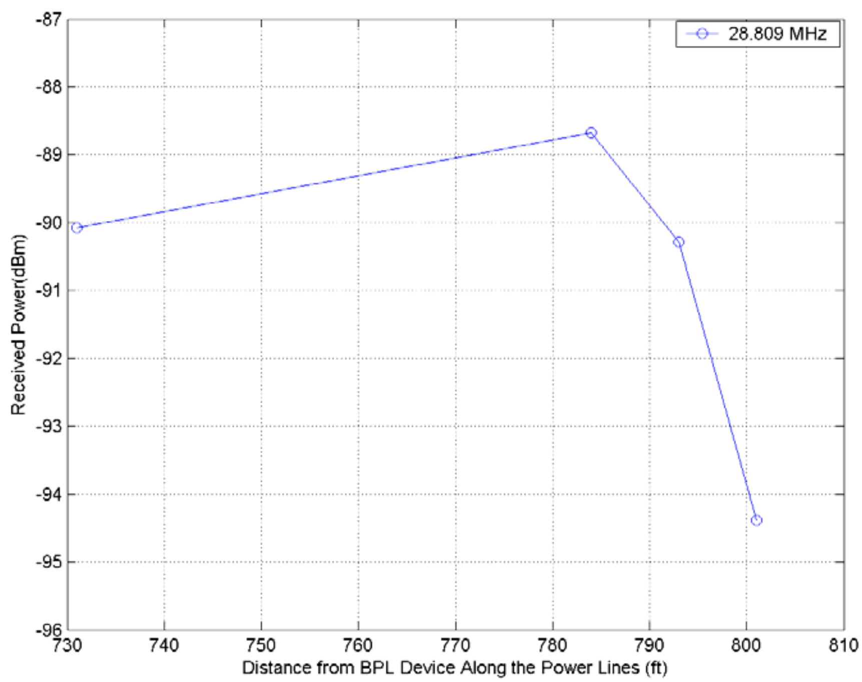

Figure D-18: Measured power levels along power line – Site A, "x" referenced to Device B, whip antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

Measurements were taken along the BPL energized power line (Site B, Figure D-19) using a discone antenna. Figure D-20 shows a picture of the utility lines located at the intersection as viewed from the approximate location of the measurement vehicle at point C. Results are shown in Table D-5 through D-8.

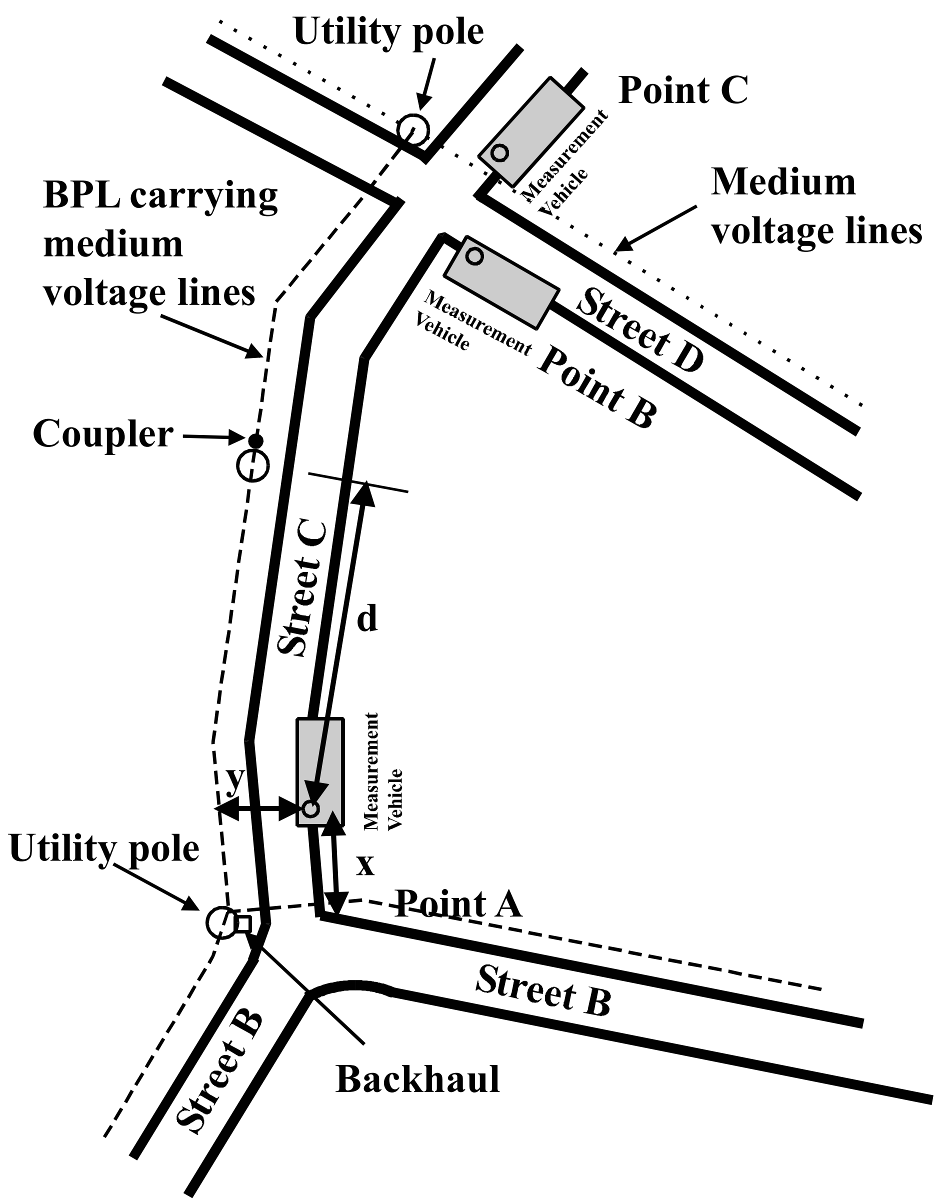

Figure D-19: Measurement Site B for BPL measurements along the power line using the discone antenna.

Figure D-20: Site B power lines as viewed from the measurement vehicle located at Point C

Measurement Conditions

Measurement Location: Site B
Antenna Type: Discone (Model SAS-210/C)
Antenna Height: 2 and 10 meters
Antenna Polarization: Vertical
Measured Characteristic: 100% duty cycle power (from APDs) and pulse power due to electric field
Measurement Variable: Distance along power line (x) referenced to Point A, (y = 7.9 m)
Comments: Measurement frequencies – 32.699 MHz and 42.465 MHz
Resolution bandwidths – 30 kHz and 10 kHz
Pulse power measurements – zero span, peak power detection, 2 ms sweep time (601 pts per sweep)
Power lines approximately 8.5 meters above the ground

Table D-5: Measured 100%-duty-cycle power and pulse power, x = 4.9 meters (16 ft)

	Ant. Ht.	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	10 m	32.699 MHz	30 kHz	-96.3 dBm	-97.6 dBm
Case 2	10 m	42.465 MHz	30 kHz	*Not measured*	-104.4 dBm
Case 3	2 m	32.699 MHz	30 kHz	-101.1 dBm	-111.4 dBm
Case 4	2 m	42.465 MHz	30 kHz	*Not measured*	-116.1 dBm
Case 5	10 m	32.699 MHz	10 kHz	-100.7 dBm	-102.4 dBm
Case 6	10 m	42.465 MHz	10 kHz	*Not measured*	-112.0 dBm
Case 7	2 m	32.699 MHz	10 kHz	-111.4 dBm	-117.5 dBm
Case 8	2 m	42.465 MHz	10 kHz	*Not measured*	-120.2 dBm

Table D-6: Measured 100%-duty-cycle power and pulse power, x = 18.3 meters (60 ft)

	Ant. Ht.	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	10 m	32.699 MHz	30 kHz	*Not measured*	-112.4 dBm
Case 2	10 m	42.465 MHz	30 kHz	*Not measured*	Not measurable
Case 5	10 m	32.699 MHz	10 kHz	-110.1 dBm	-115.2 dBm
Case 6	10 m	42.465 MHz	10 kHz	*Not measured*	Not measurable

Table D-7: Measured 100%-duty-cycle power and pulse power, x = 23.2 meters (76 ft)

	Ant. Ht.	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	10 m	32.699 MHz	30 kHz	-110.5 dBm	-108.6 dBm
Case 2	10 m	42.465 MHz	30 kHz	*Not measured*	-107.7 dBm
Case 3	2 m	32.699 MHz	30 kHz	Not measurable	Not measurable
Case 4	2 m	42.465 MHz	30 kHz	Not measurable	Not measurable
Case 5	10 m	32.699 MHz	10 kHz	-110.5 dBm	-114.9 dBm
Case 6	10 m	42.465 MHz	10 kHz	*Not measured*	-119.3 dBm
Case 7	2 m	32.699 MHz	10 kHz	Not measurable	Not measurable
Case 8	2 m	42.465 MHz	10 kHz	Not measurable	Not measurable

Table D-8: Measured 100%-duty-cycle power and pulse power, x = 103.6 meters (340 ft)

	Ant. Ht.	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	10 m	32.699 MHz	30 kHz	*Not measured*	-110.1 dBm
Case 2	10 m	42.465 MHz	30 kHz	-106.9 dBm	-105.4 dBm
Case 3	2 m	32.699 MHz	30 kHz	Not measurable	Not measurable
Case 4	2 m	42.465 MHz	30 kHz	Not measurable	Not measurable
Case 5	10 m	32.699 MHz	10 kHz	*Not measured*	-114.4 dBm
Case 6	10 m	42.465 MHz	10 kHz	-111.0 dBm	-110.9 dBm
Case 7	2 m	32.699 MHz	10 kHz	Not measurable	Not measurable
Case 8	2 m	42.465 MHz	10 kHz	Not measurable	Not measurable

Figure D-21 summarizes the measured received power along the power lines using data from Table D-5 through Table D-8 for a frequency of 32.699 MHz and for a vertically polarized Discone antenna at a height of 10 meters. This figure indicates that after an initial decrease of received power, the power remains at about the same level along the power line away from a Backhaul point.

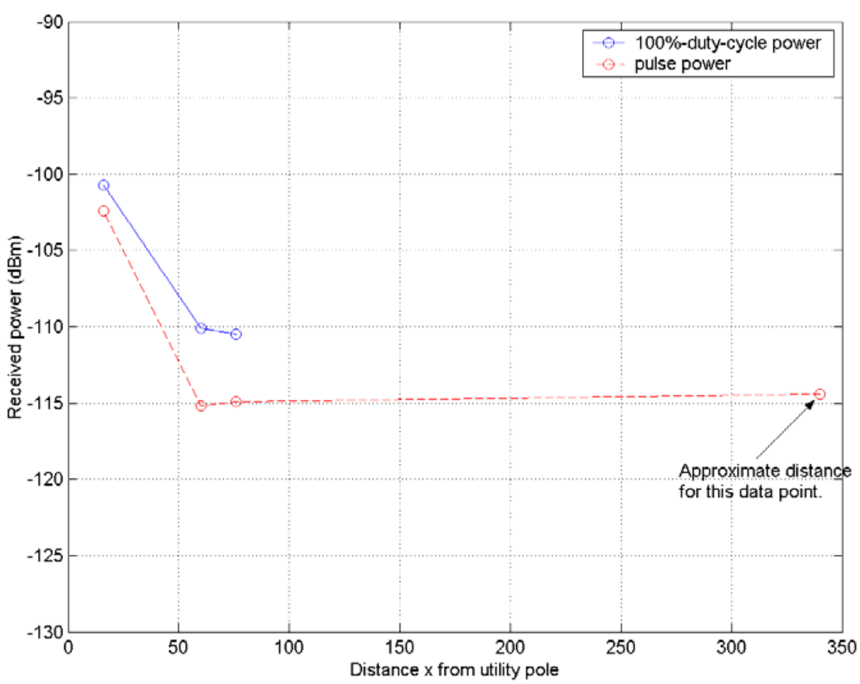

Figure D-21: Measured power levels along power line – Site B, discone antenna, antenna height = 10 m, frequency = 32.699 MHz, data from Table D.3.2-5 through Table D.3.2-8*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

D.3.3 Measurements of BPL Away From the Energized Power Line

A number of measurements of BPL emissions were made with varying distance away from the power line. In general, the measurements started out close to a pole mounted BPL device and moved away until the signal level was too low to make a confident measurement. For the first measurements away from the power line, Site C's physical layout of power lines and BPL devices is illustrated in Figure D-22 and the measured power away from the power lines is plotted in Figure D-23. With a loop antenna directly under the power line at a height of 2 meters, a small signal power was measured on all four frequencies (4.419 MHz, 8.777 MHz, 23.836 MHz and 28.777 MHz). At a distance of 148 feet from the power line, the signal was received only at 28.777 MHz as shown in Figure D-23.

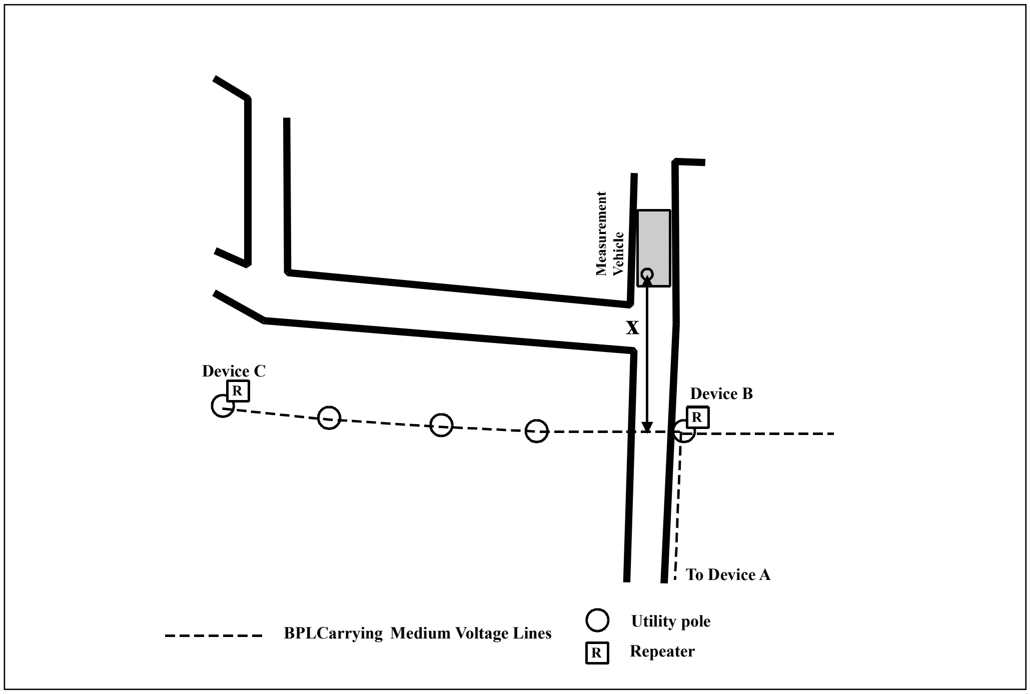

Figure D-22: Measurement Site C for BPL measurements away from the power line at Device B

<u>Measurement Conditions</u>

Measurement Location:	Site C
Antenna Type:	Shielded Loop
Antenna Height:	2 meters
Antenna Polarization:	Horizontal Parallel
Measured Characteristic:	Peak received power due to magnetic field
Measurement Variable:	Distance away from power line (x)
Comments:	Device A is an Extractor transmitting an upstream signal at 23.8 MHz. Device B is a repeater transmitting on 28.8 MHz downstream and 4.4 MHz upstream. Device C is an injector transmitting on 8.8 MHz downstream. When the antenna was moved 45.1 meters (148 ft) away from the power line the signal was not received on 3 of the 4 frequencies.

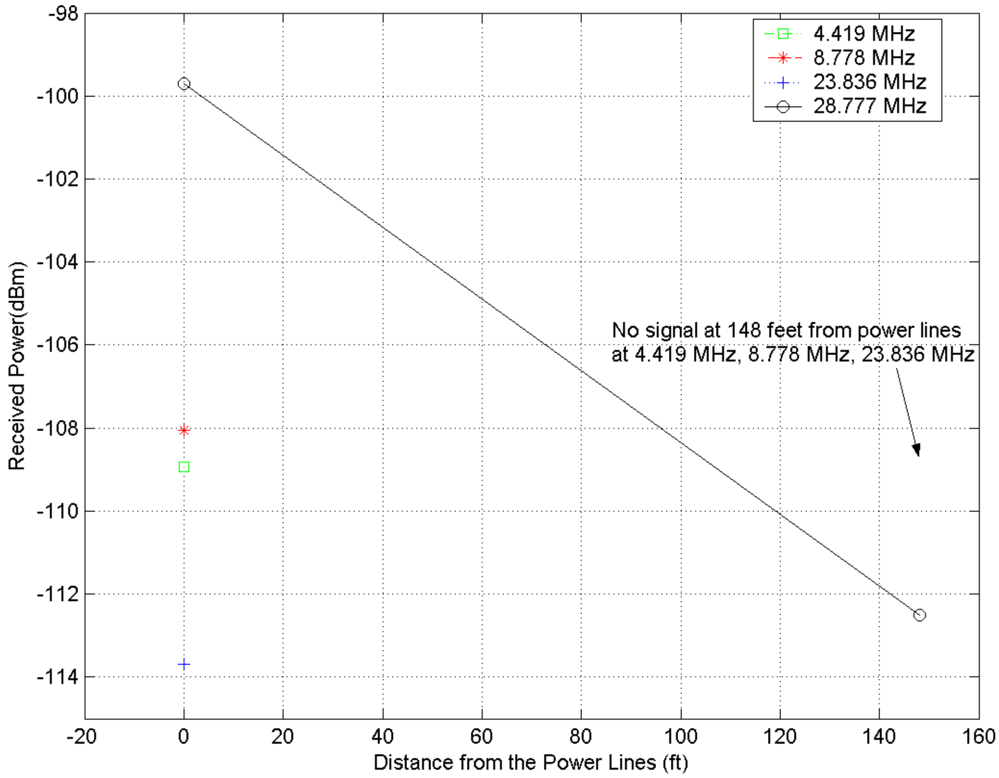

Figure D-23: Measured power levels away from the power line, Site C, loop antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

The peak received power due to the electric field was measured with the whip antenna away from the power line (Site C, repeated here as Figure D-24) at 4.255 MHz, 7.304 MHz and 28.777 MHz with the results shown in Figure D-25. The results indicate that there was a decrease in received power with increase in distance from the BPL device and power line, but the decrease was not monotonic at 28.777 MHz. The received power and the manner in which it decreased with increasing distance varied substantially at different frequencies.

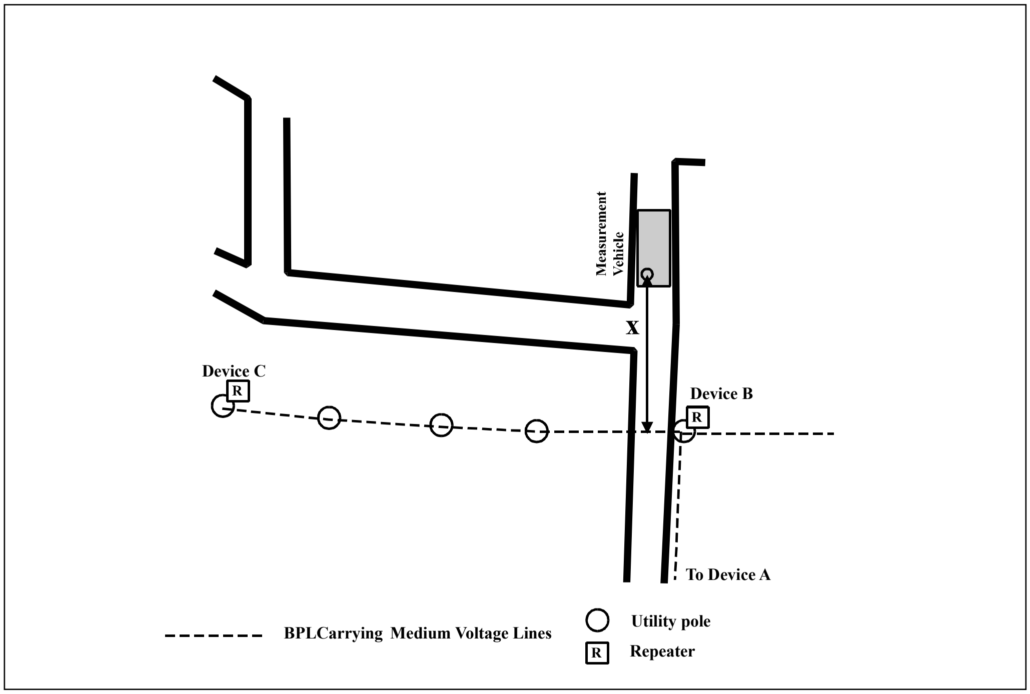

Figure D-24: Measurement Site C for BPL measurements away from the power line at Device B

<u>Measurement Conditions</u>

Measurement Location:	Site C
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance away from power line (x)
Comments:	At 7.304 MHz, the measurement was terminated when background signals appeared and covered up the BPL signal. The frequency change to 4.241 MHz was due to background signals covering up the BPL signal.

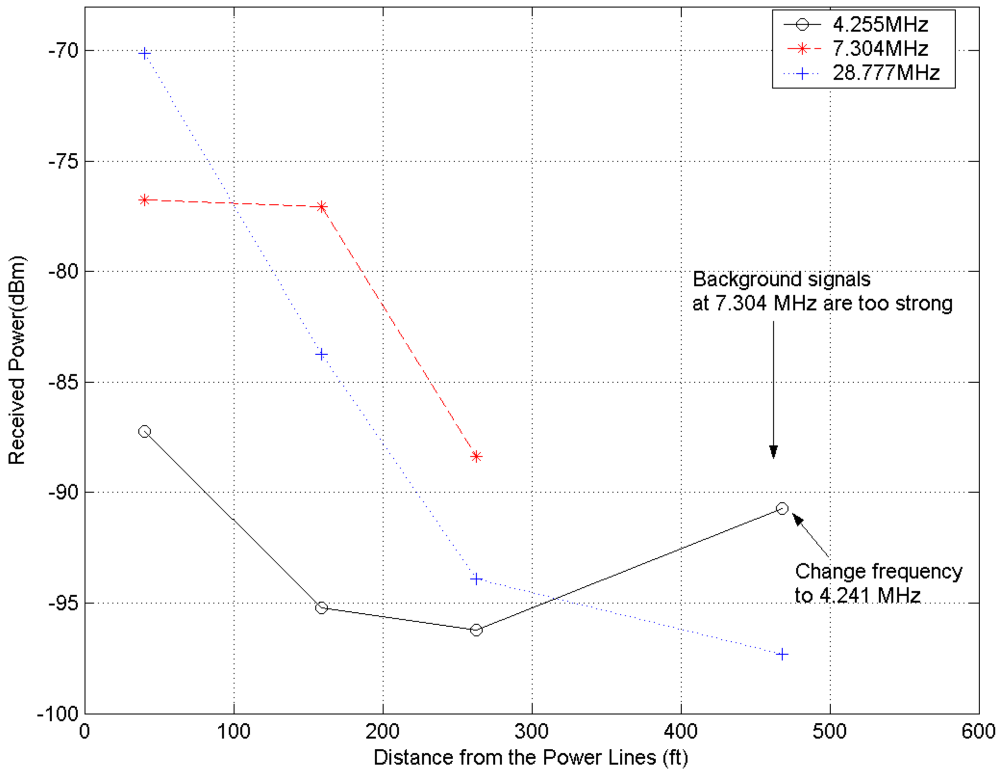

Figure D-25: Measured power levels away from power line at Device B – Site C, whip antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

The peak received power due to the electric field was measured with the whip antenna on a different path (measurement trend line) as a function of distance from the power line as shown in Figure D-26. The results, plotted in Figure D-27, show that even though the received power generally decreased with distance from Device C, the peak power level at 28.809 MHz exhibited significant oscillations as a function of increasing distance.

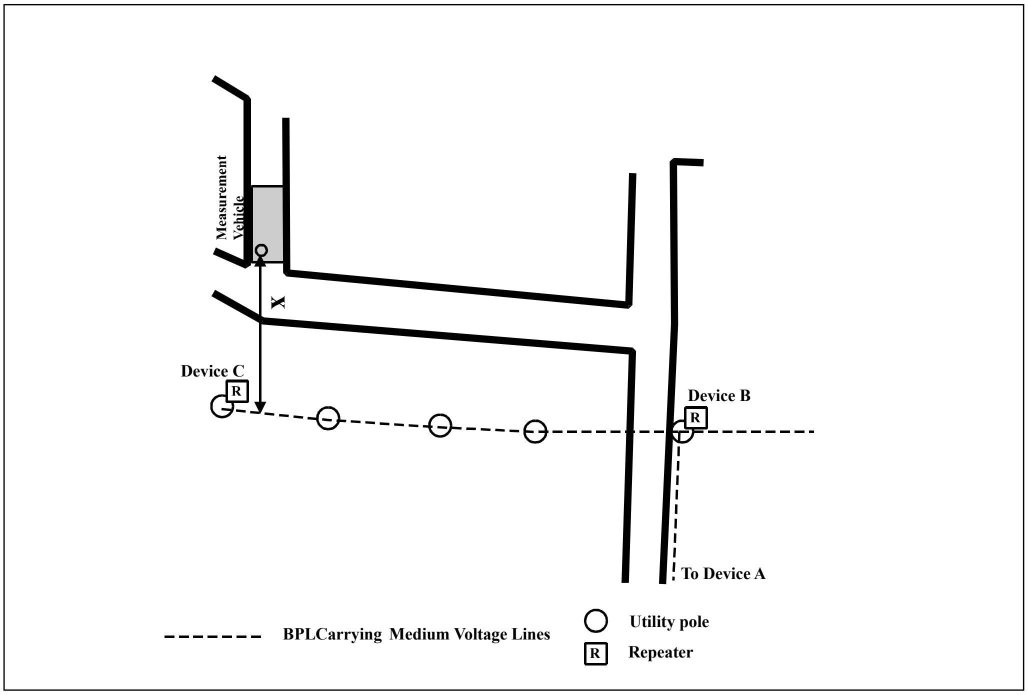

Figure D-26: Measurement Site C for BPL measurements away from the power line at Device C

<u>Measurement Conditions</u>	
Measurement Location:	Site C
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance away from power line (x)
Comments:	At 7.241 MHz, the measurement was terminated when background signals appeared and covered up the BPL signal.

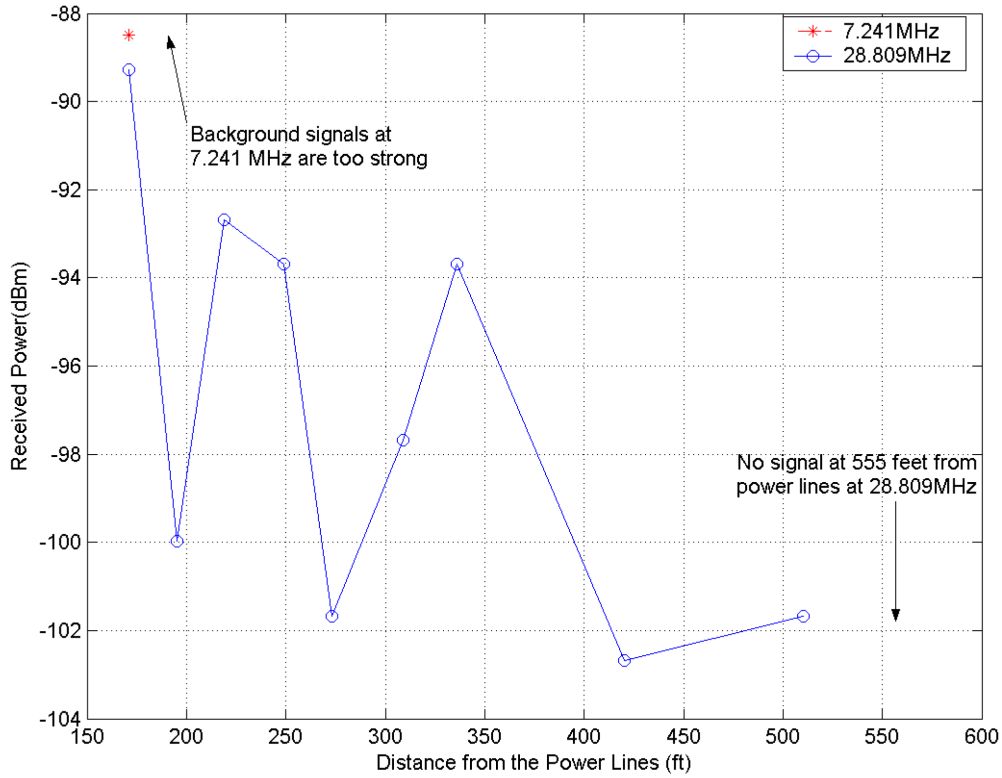

Figure D-27: Measured power levels away from power line at Device B – Site C, whip antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

Another set of measurements were made of the peak received power due to vertical electric field while moving the whip antenna away from the power line as shown in Figure D-28 (Site D). The received power has been plotted versus distance from the power lines in Figure D-29. In Figure D-29, the signal decreases to an immeasurable level within 600 ft.

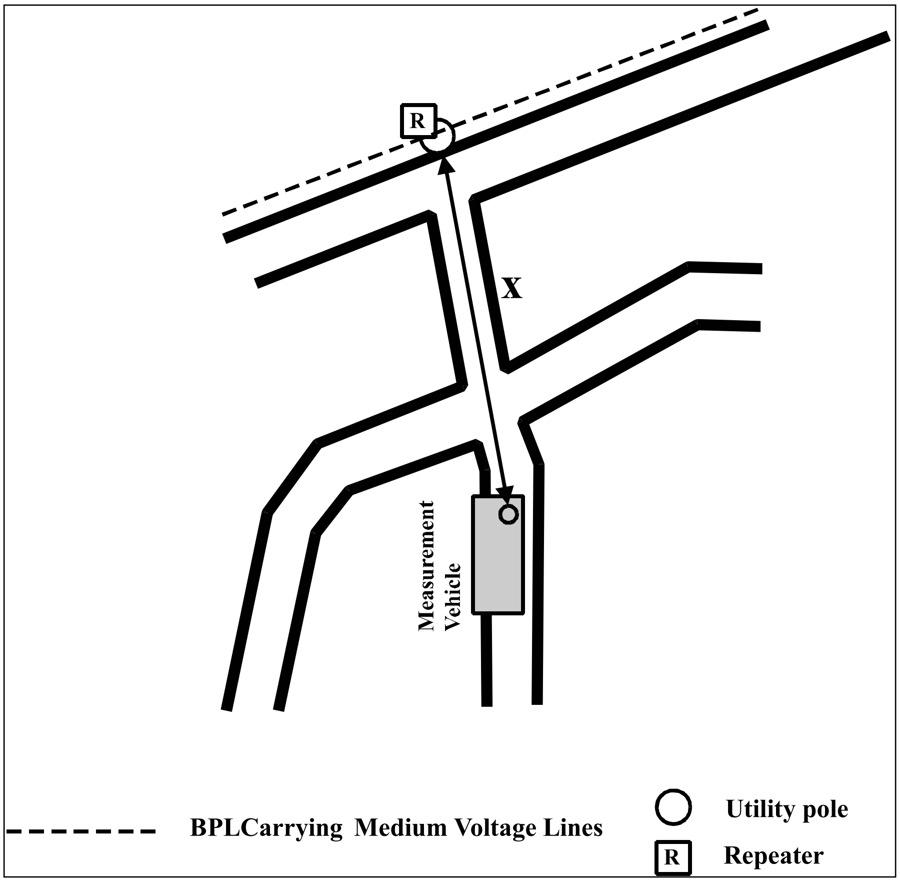

Figure D-28: Measurement Site D for BPL measurements away from power line at a pole mounted repeater

<u>Measurement Conditions</u>

Measurement Location:	Site D
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance away from power line (x)
Comments:	None

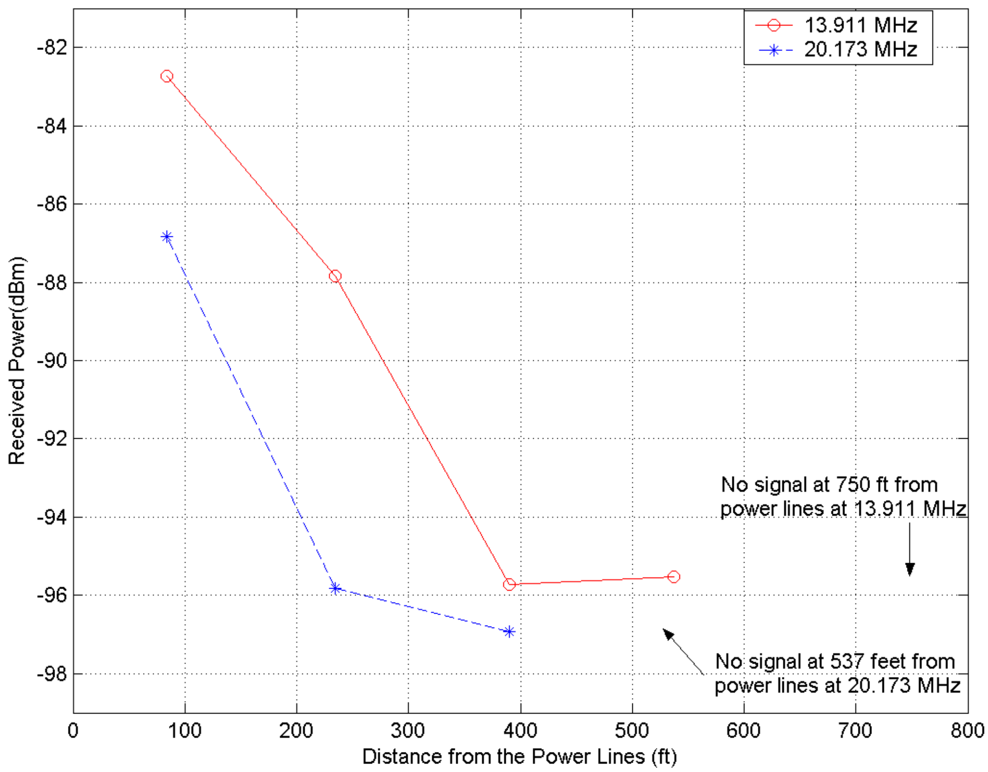

Figure D-29: Measured power levels away from power line – Site D, whip antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

The next measurements were made away from the power lines at Site E. The physical layout (Figure D-30) shows several repeaters and one concentrator (injector) and a network of MV lines all transmitting at various times over the same frequency range. In Figure D-31, the received power at 8.1 MHz and 14.8 MHz are plotted versus distance from the power lines, out to a distance exceeding 1500 ft, where the BPL signal diminished to within 5 dB of the noise floor.

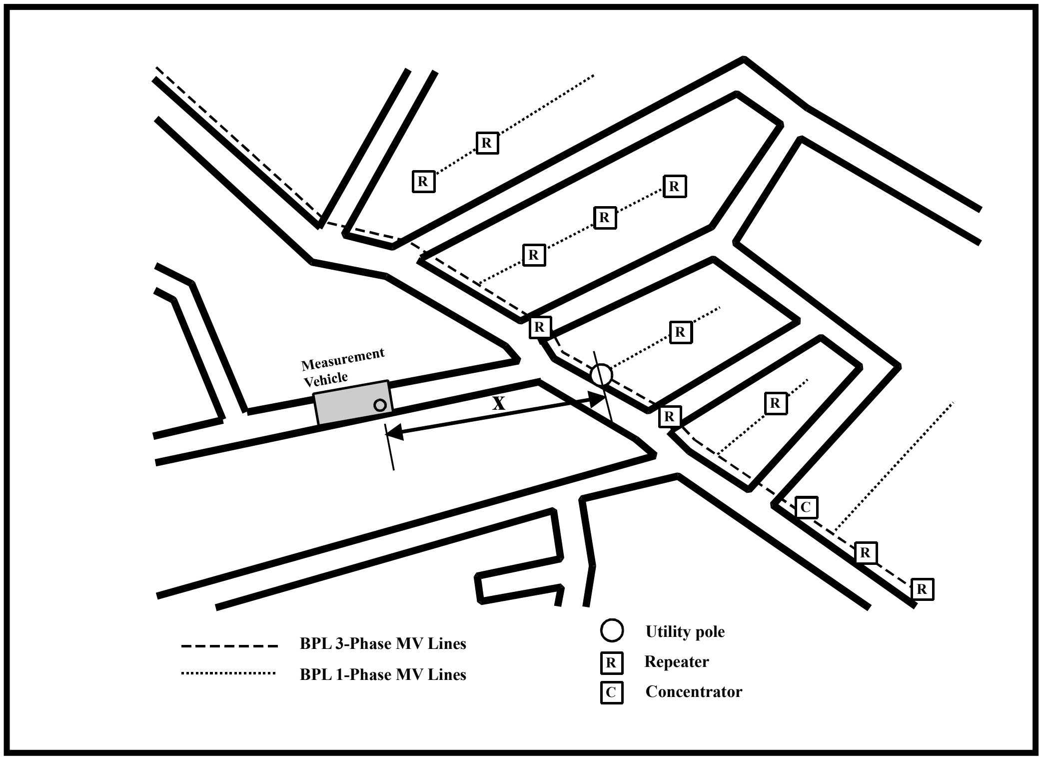

Figure D-30: Measurement Site E for BPL measurements away from power line at a repeater

<u>Measurement Conditions</u>

Measurement Location:	Site E
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance away from power line (x)
Comments:	None

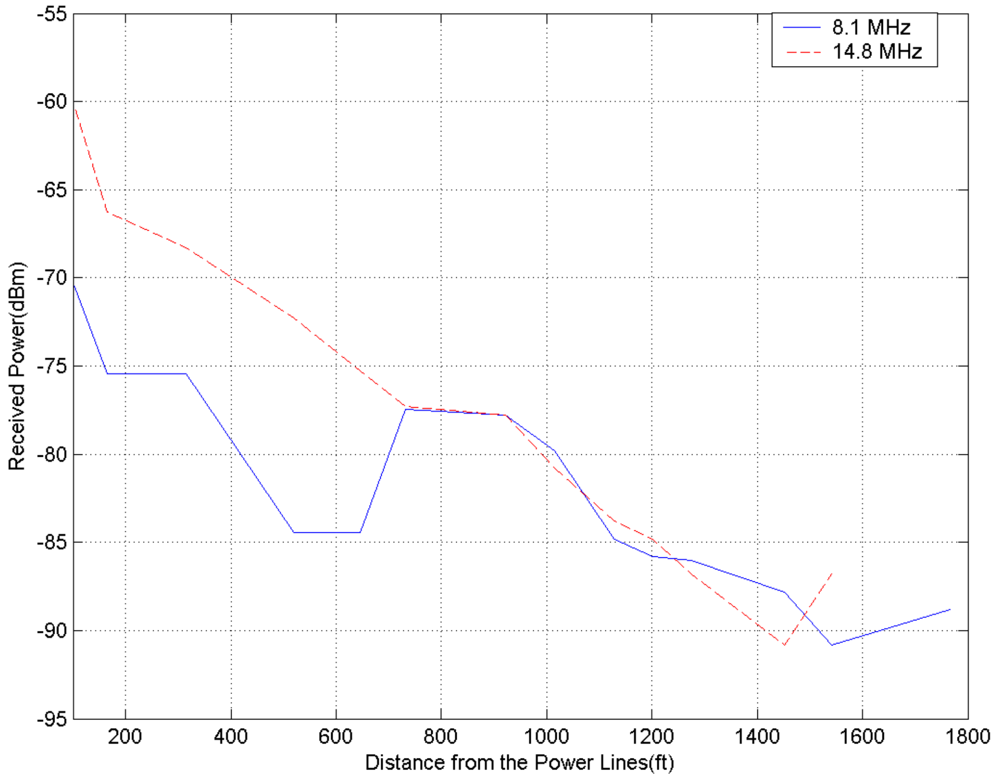

Figure D-31: Measured power levels away from power line – Site E, whip antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

The peak received power was measured using both whip and loop antennas at heights of 1.5 and 2 meters, respectively, near a transformer with underground power lines (Site F) carrying BPL signals. The measurements show that at 6.4 meters (21 ft) from the transformer, the BPL signal power was measurable at one of the three BPL frequencies as shown in Table D-9. At 29.3 meters (96 ft) from the transformer, no signal could be detected.

Measurement Conditions

Measurement Location:	Site F
Antenna Type:	Whip, Shielded Loop
Antenna Height:	1.5 meters (whip) and 2 meters (loop)
Antenna Polarization:	Whip - Vertical, Loop - Vertical Parallel, Vertical Perpendicular and Horizontal
Measured Characteristic:	Peak received power due to electric and magnetic fields
Measurement Variable:	Distance away from power line (x)
Comments:	None

Table D-9: Measure power levels away from power line – Site F, whip & loop antennas

Measurement Distance	Frequency (MHz)	Whip (Vertical)	Loop (Vertical, parallel to the power line)	Loop (Vertical, perpendicular to the power line)	Loop (Horizontal)
6.4 m (21 ft)	3.99	Not measurable	Not measurable	Not measurable	Not measurable
6.4 m (21 ft)	7.502	Not measurable	Not measurable	Not measurable	Not measurable
6.4 m (21 ft)	15.285	-80 dBm	-114 dBm	Not measurable	-114 dBm
29.3 m (96 ft)	3.99	Not measurable	Not measurable	Not measurable	Not measurable
29.3 m (96 ft)	7.502	Not measurable	Not measurable	Not measurable	Not measurable
29.3 m (96 ft)	15.285	Not measurable	Not measurable	Not measurable	Not measurable

Measurements were performed using a discone antenna with the power line configuration as shown in Figure D-32 for Site G. Manual pulse power measurements are plotted for three frequencies, 35.04992 MHz, 39.92954 MHz and 45.40195 MHz, as shown in Figure D-33. Also included are theoretical plots for loss proportional to $1/R$, $1/R^2$, and $1/R^4$, where *"R"* is distance from the power line (*i.e.*, "R" is depicted as the parameter "*x"* in Figure D-32). The results indicate that the received power decreases as distance from the power line increases at a rate lower than would be predicted by $1/R^2$ (space wave loss).

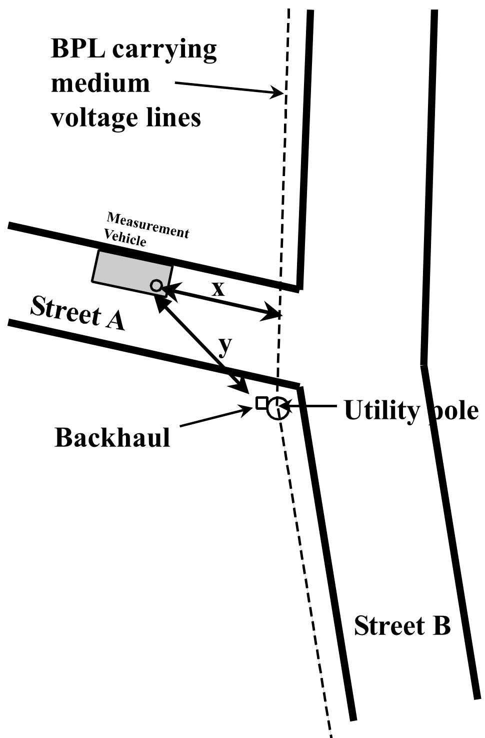

Figure D-32: Measurement Site G for BPL measurements away from power line using the discone antenna

<u>Measurement Conditions</u>

Measurement Location:	Site G
Antenna Type:	Discone (Model SAS-210/C)
Antenna Height:	3.4 meters (11.2 ft)
Antenna Polarization:	Vertical
Measured Characteristic:	Peak received power due to electric field
Measurement Variable:	Distance away from power line (x)
Comments:	Measurement frequencies – 35.04492 MHz, 39.92954 MHz, and 45.40195 MHz Resolution bandwidths – 200 kHz Pulse power measurements – zero span, peak power detection, 2 ms sweep time (601 pts per sweep) Power lines approximately 8.5 meters above the ground

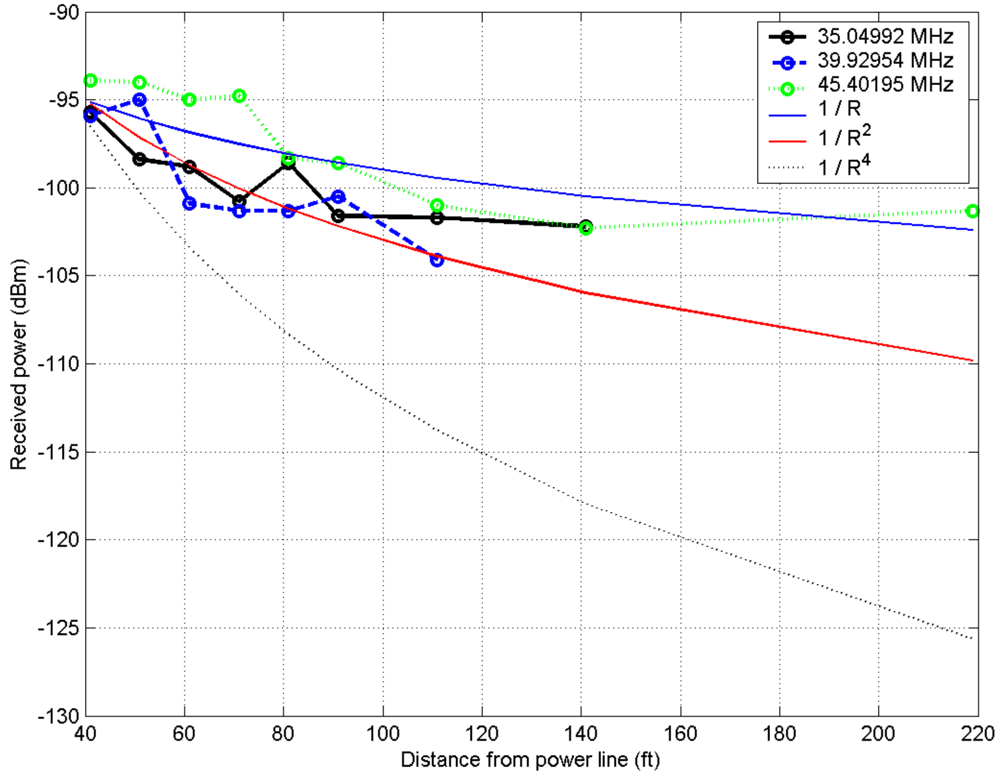

Figure D-33: Received pulse power measured away from power line – Site G, discone antenna*

* Lines connecting data points illustrate potential trends but not expected interpolated values.

Manual pulse power levels were measured at 32.699 MHz and 42.465 MHz with the same discone antenna at points B and C as shown in Figure D-34. Both points B and C are at about the same distance from the power line; however, the measured pulse power at point C is consistently higher than at point B as shown in Tables D-10 and D-11.

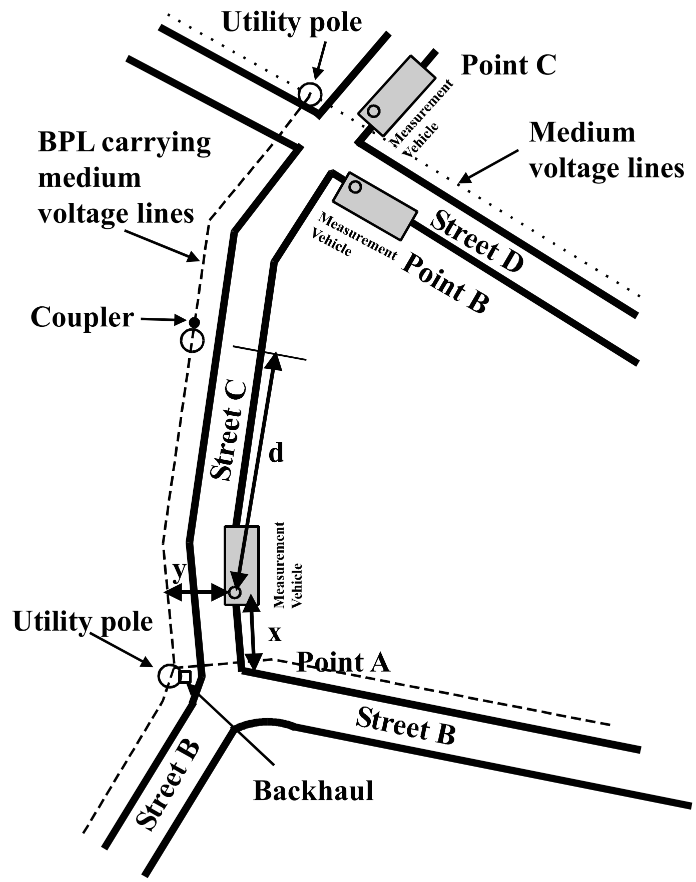

Figure D-34: Measurement Site B for BPL measurements away from power line

Measurement Conditions	
Measurement Location:	Site B
Antenna Type:	Discone (Model SAS-210/C)
Antenna Height:	10 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Pulse power measurements at two different radials; 100% duty cycle power determined from APDs measured at one of the radials
Measurement Variable:	Point B and Point C, radials away from the utility pole at the end of a BPL carrying segment of MV power line.
Comments:	Measurement frequencies – 32.699 MHz and 42.465 MHz Resolution bandwidths – 10 kHz and 30 kHz Pulse power measurements – zero span, peak power detection, 2 ms sweep time (601 pts per sweep)

Table D-10: Measured pulse power – Site B, Point B, discone antenna, radial 20.7 meters from utility pole.

	Frequency	RBW	Pulse Power
Case 1	32.699 MHz	30 kHz	Not measurable
Case 2	42.465 MHz	30 kHz	-112.2 dBm
Case 3	32.699 MHz	10 kHz	Not measurable
Case 4	42.465 MHz	10 kHz	Not measurable

Table D-11: Measured 100%-duty-cycle power and pulse power – Site B, Point C, discone antenna, radial 20.4 meters from utility pole.

	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	32.699 MHz	30 kHz	-104.1 dBm	-106.4 dBm
Case 2	42.465 MHz	30 kHz	*Not measured*	-110.2 dBm
Case 3	32.699 MHz	10 kHz	-109.7 dBm	-109.7 dBm
Case 4	42.465 MHz	10 kHz	*Not measured*	Not measurable

D.3.4 Measurements of BPL Using Various Detectors

Measurements were made using three different spectrum analyzer detectors (peak, average and quasi-peak.) at Site A, as shown in Figure D-35. Table D-12 and D-13 show the detector levels for the two measurement frequencies. The data shown in these tables indicate that the measured quasi-peak power levels for this BPL signal are 0 to 5 dB greater than the average power levels.

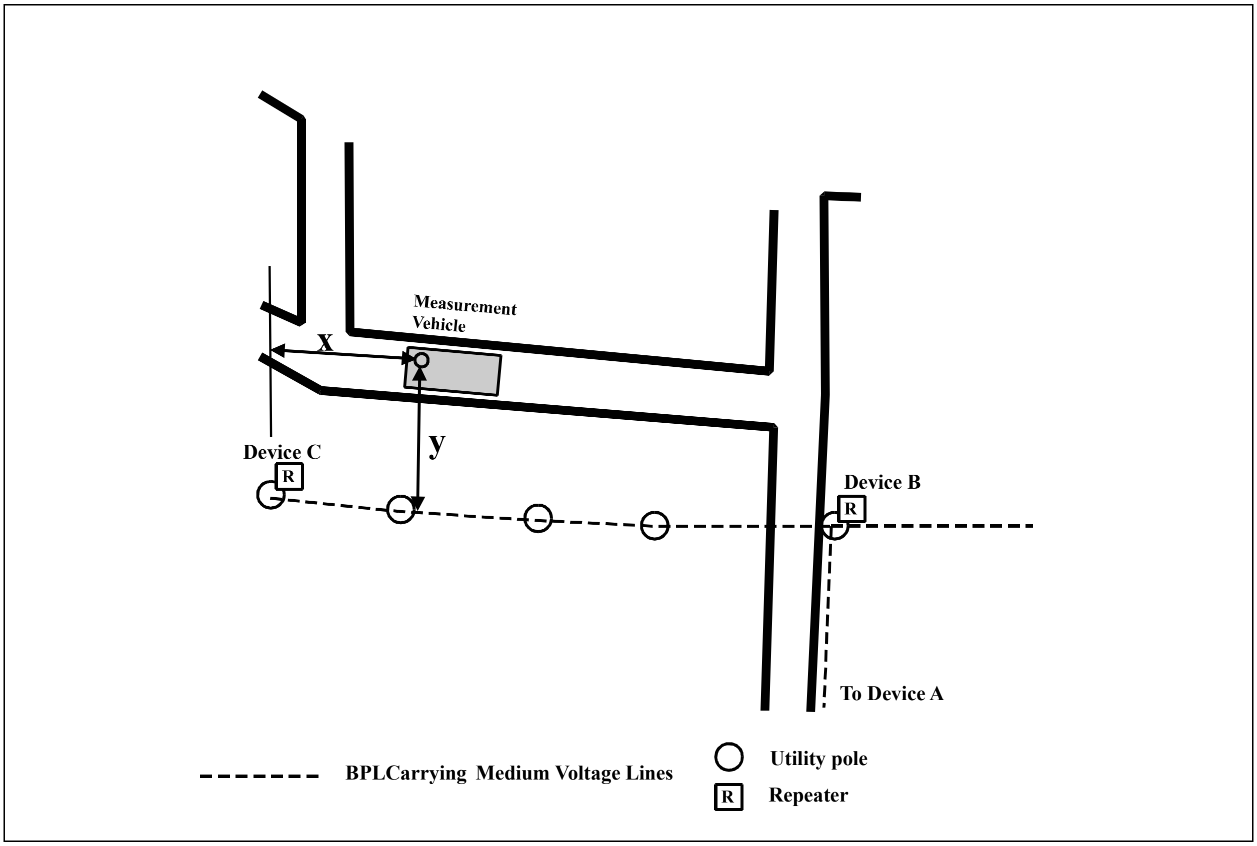

Figure D-35: Measurement Site A for BPL measurements using various detectors

<u>Measurement Conditions</u>

Measurement Location:	Site A
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak, average, and quasi-peak power due to electric field
Measurement Variable:	Distance away from power line (x, y)
Comments:	Resolution bandwidths – 9.1 kHz (peak & average), 9 kHz quasi-peak Signal-to-noise ratio (SNR) at 22.957 MHz was 8 dB SNR at 28.298 MHz was 38 dB.

Table D-12: Measured peak, average and quasi-peak levels, x = 150 m, y = 28.3 m

Detector	Peak	Average	Quasi-Peak
Value at f = 22.957 MHz	-74 dBm	-81 dBm	-76 dBm

Table D-13: Measured peak, average and quasi-peak levels, x = 58.2 m, y = 39.3 m

Detector	Peak	Average	Quasi-Peak
Value at f = 28.298 MHz	-60 dBm	-65 dBm	-65 dBm

The measurements using the various detectors were made in a residential neighborhood environment. There were noise sources present, some of them appear impulsive on a spectrum analyzer and some appear bursty. Figure D-36 shows both kinds of noise sources at levels higher than the BPL signal. While it is possible to read the BPL level in between these noise sources with a peak and average (due to the 100% BPL duty cycle and if the symbol period is short enough) detector, the quasi-peak detector, with its longer time constant, will include the noise power in its measurement. When the BPL signal has a duty cycle less than 100% with a period greater than the period of the noise sources, the average detector will include the noise power in its measurement. An example of this signal is shown in Figure D-37. The period of the noise sources is much shorter than the period of the BPL signal. The off periods are large enough to cause the quasi-peak detector level to decay, Figure D-38, so to obtain a single value the operator chose a value when the BPL signal was on and ignored the noise induced spike near the center of the trace.

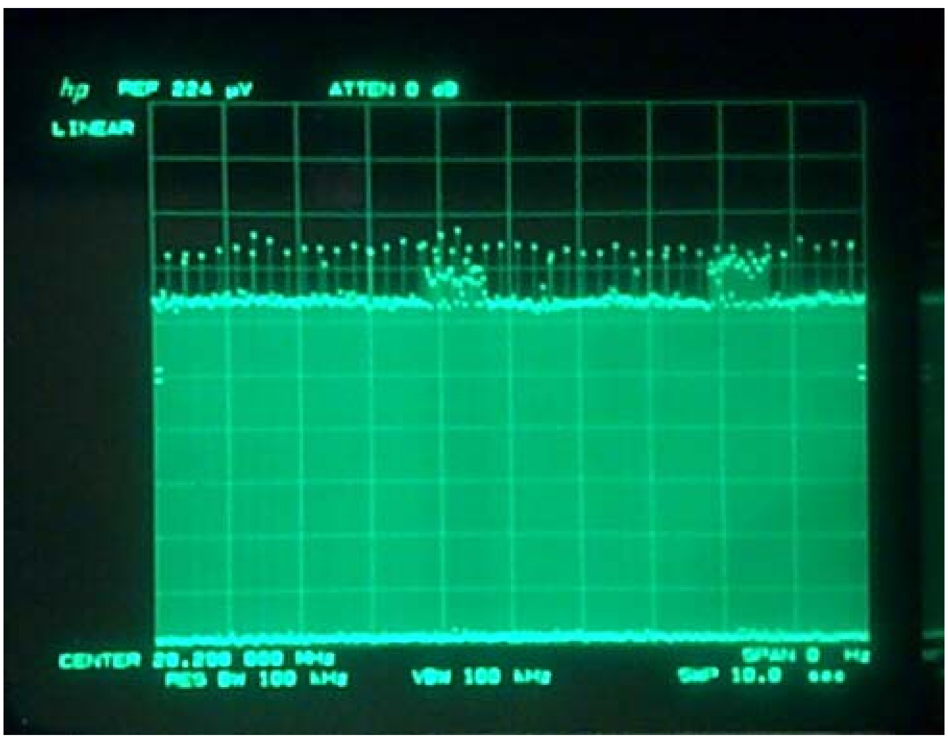

Figure D-36: BPL signal at 28.298 MHz.

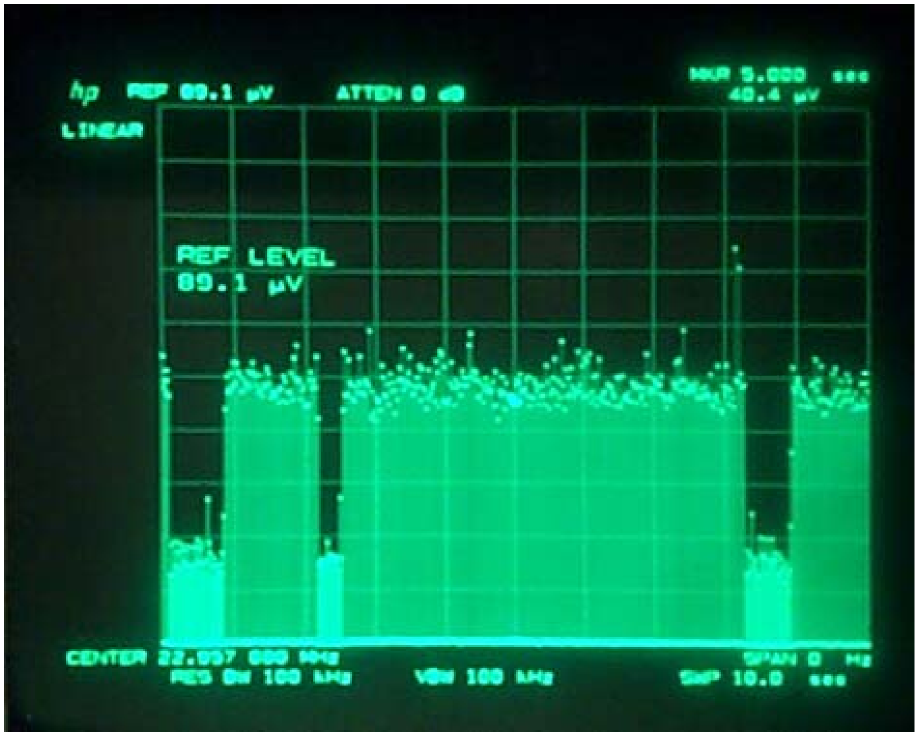

Figure D-37: BPL signal at 22.957 MHz.

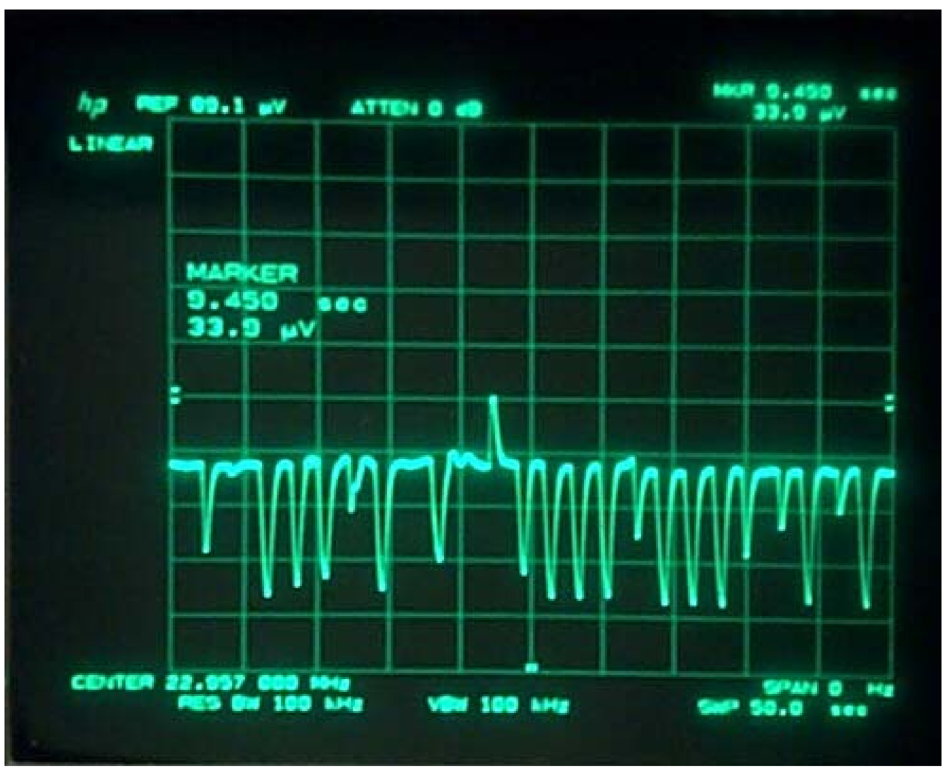

Figure D-38: BPL signal at 22.957 MHz.

Another measurement was made to compare detectors at a different location at Site A and on a different day. The results are in Table D-14.

Measurement Conditions

Measurement Location:	Site A
Antenna Type:	Whip
Antenna Height:	1.5 meters
Antenna Polarization:	Vertical
Measured Characteristic:	Peak, average, and quasi-peak power due to electric field
Measurement Variable:	Distance away from power line (x, y)
Comments:	Resolution bandwidths – 3 kHz , corresponding to a typical land-mobile signal bandwidth in the HF spectrum

Table D-14: Measured detector levels, x – directly in front of Device B, y = 12.2 m

	Frequency		
Detector	4.255 MHz	7.304 MHz	28.777 MHz
Peak	-72 dBm	-60.4 dBm	-54.8 dBm
Average	-74.8 dBm	-63.5 dBm	-56.6 dBm
Quasi-Peak	-71.3 dBm	-59.3 dBm	-55.3 dBm

D.3.5 Measurements of BPL Varying Antenna Height

Measurements were performed using two different antenna heights at Site B, Figure D-39. Results are shown in Table D-15. The results show that in general, the measured power levels were higher at the greater antenna height. For example, the 100% duty cycle power measured at a frequency of 32.699 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.

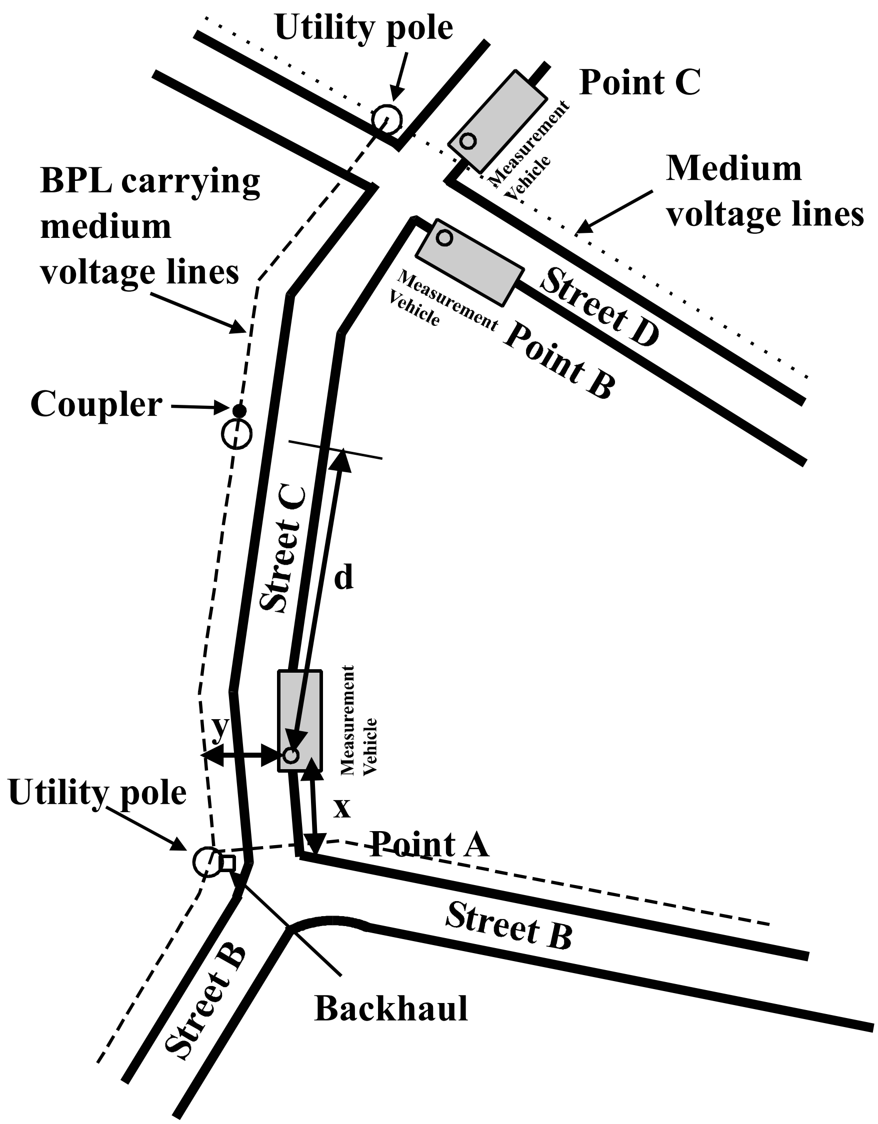

Figure D-39: Measurement Site B for BPL measurements with varying antenna height

<u>Measurement Conditions</u>

Measurement Location:	Site B
Antenna Type:	Discone (Model SAS-210/C)
Antenna Height:	2 and 10 meters
Antenna Polarization:	Vertical
Measured Characteristic:	100% duty cycle power (from APDs) and pulse power due to electric field
Measurement Variable:	Distance along power line (x = 4.9 m) referenced to Point A, (y = 7.9 m)
Comments:	Measurement frequencies – 32.699 MHz and 42.465 MHz

Resolution bandwidths – 30 kHz and 10 kHz
Pulse power measurements – zero span, peak power detection, 2 ms sweep time (601 pts per sweep)
Power lines approximately 8.5 meters above the ground

Table D-15: Measured 100%-duty-cycle power and pulse power – Site B, discone antenna, two antenna heights

	Ant. Ht.	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	10 m	32.699 MHz	30 kHz	-96.3 dBm	-97.6 dBm
Case 2	10 m	42.465 MHz	30 kHz	*Not measured*	-104.4 dBm
Case 3	2 m	32.699 MHz	30 kHz	-101.1 dBm	-111.4 dBm
Case 4	2 m	42.465 MHz	30 kHz	*Not measured*	-116.1 dBm
Case 5	10 m	32.699 MHz	10 kHz	-100.7 dBm	-102.4 dBm
Case 6	10 m	42.465 MHz	10 kHz	*Not measured*	-112.0 dBm
Case 7	2 m	32.699 MHz	10 kHz	-111.4 dBm	-117.5 dBm
Case 8	2 m	42.465 MHz	10 kHz	*Not measured*	-120.2 dBm

Measurements were conducted at Site H as shown in Figure D-40. Figure D-41 shows a picture of the utility lines located immediately in front of the house as viewed from across the street parallel to the approximate location of the measurement vehicle.

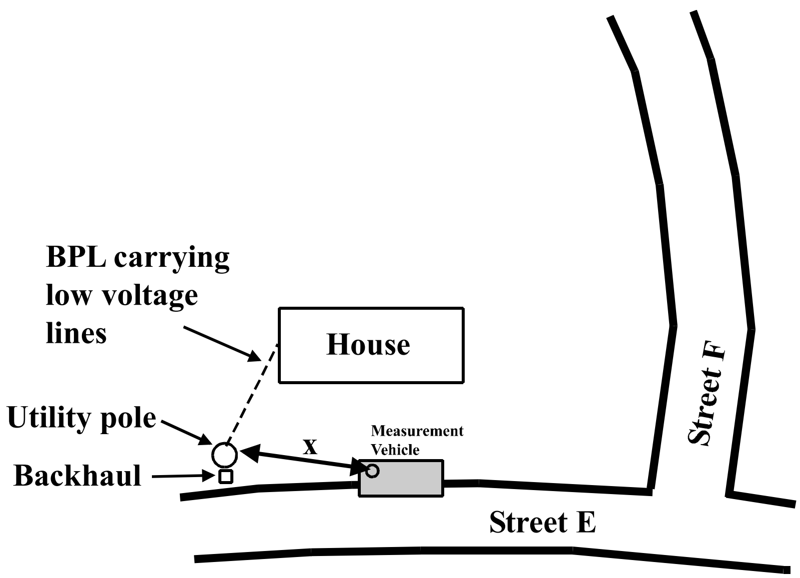

Figure D-40: Measurement Site H for BPL measurements with varying antenna height

Measurement Conditions

Measurement Location:	Site H
Antenna Type:	Shielded Loop
Antenna Height:	2 meters and 10 meters
Antenna Polarization:	Vertical, plane of antenna perpendicular to power line
Measured Characteristic:	Pulse power measurements and 100% duty cycle power (from APDs) of the magnetic field
Measurement Variable:	Distance away from low voltage power line (x = 8.7 meters)
Comments:	Measurement frequencies – 5.00 MHz, 6.43 MHz, 10.74 MHz and 18.38 MHz Resolution bandwidths – 3 kHz and 10 kHz Pulse power measurements – zero span, peak power detection, 5 ms sweep time (601 pts per sweep) Power line height ranging approximately 3 – 4.3 meters

The pulse-power and the 100%-duty-cycle power (both referenced to the antenna output) are shown for each case in Table D-16. The results shown indicate that measured power at a 10 meter height was always larger than the power measured at 2 meter height (by 3-10 dBm).

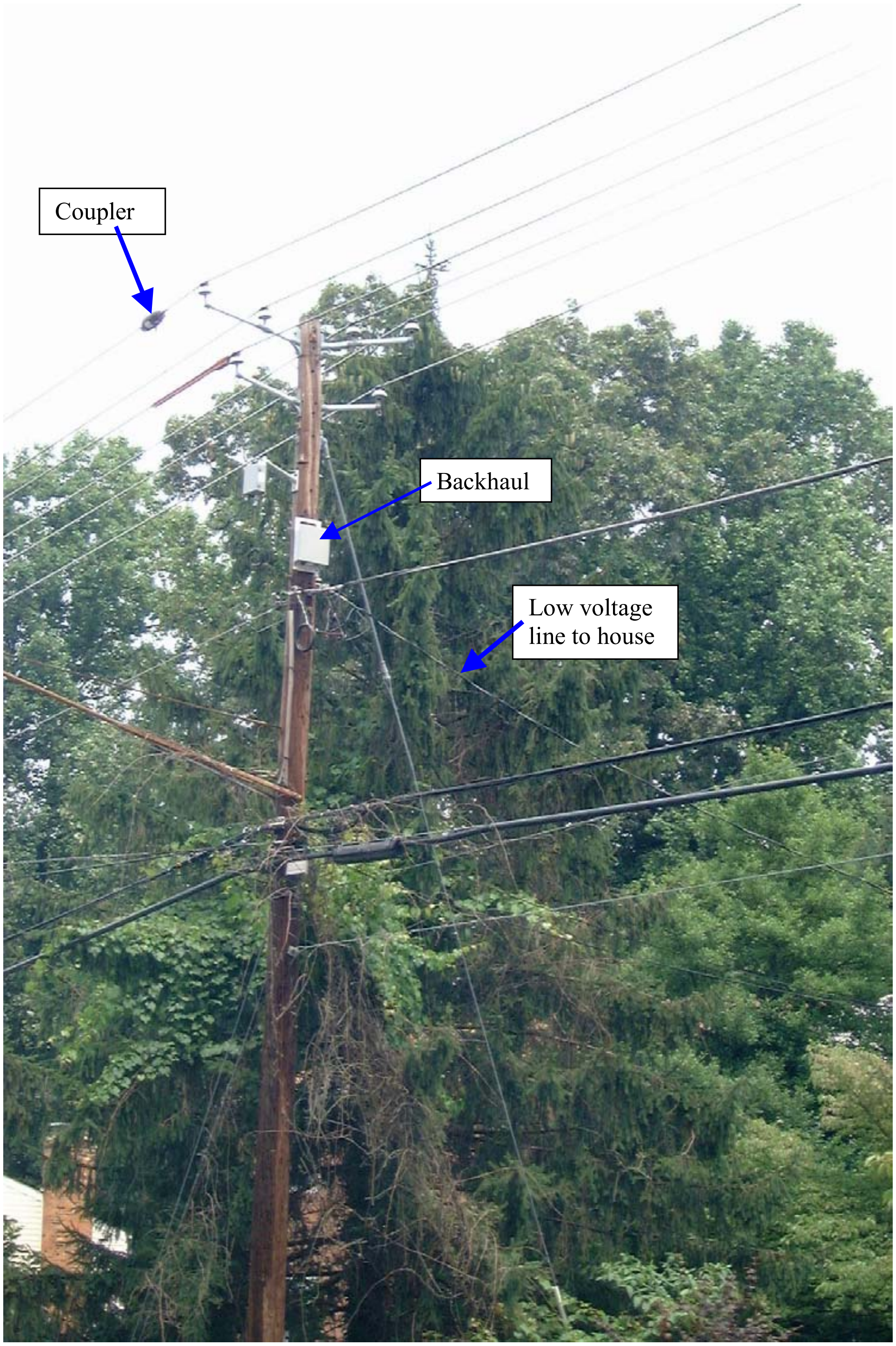

Figure D-41: Measurement Site H utility lines located immediately in front of house as viewed from across the street parallel to the approximate location of the measurement vehicle.

Table D-16: Measured 100%-duty-cycle power and pulse power – Site H, loop antenna, two antenna heights

	Ant. Ht.	Frequency	RBW	100%-duty-cycle Power	Pulse Power
Case 1	10 m	5.00 MHz	10 kHz	Not measurable	Not measurable
Case 2	10 m	5.00 MHz	3 kHz	Not measurable	Not measurable
Case 3	10 m	6.43 MHz	10 kHz	-106.4 dBm	-112.3 dBm
Case 4	10 m	6.43 MHz	3 kHz	-108.7 dBm	-114.0 dBm
Case 5	10 m	10.74 MHz	10 kHz	*Not measured*	-110.3 dBm
Case 6	10 m	10.74 MHz	3 kHz	-114.8 dBm	Not measurable
Case 7	10 m	18.38 MHz	10 kHz	*Not measured*	-101.4 dBm
Case 8	10 m	18.38 MHz	3 kHz	-106.6 dBm	-110.8 dBm
Case 9	2 m	5.00 MHz	10 kHz	Not measurable	Not measurable
Case 10	2 m	5.00 MHz	3 kHz	Not measurable	Not measurable
Case 11	2 m	6.43 MHz	10 kHz	-109.1 dBm	Not measurable
Case 12	2 m	6.43 MHz	3 kHz	-113.3 dBm	-112.6 dBm
Case 13	2 m	10.74 MHz	10 kHz	Not measurable	Not measurable
Case 14	2 m	10.74 MHz	3 kHz	Not measurable	Not measurable
Case 15	2 m	18.38 MHz	10 kHz	-111.2 dBm	-113.3 dBm
Case 16	2 m	18.38 MHz	3 kHz	-115.3 dBm	-117.3 dBm

D.3.6 Measurements of BPL APDs

APD measurements of the BPL signal were taken at Site I, as shown in Figure D-42. Results of these measurements, shown as 100% duty cycle power and / or pulse power levels are shown in Table D-17. This table shows that 100% duty cycle power is higher for higher resolution bandwidth at a given frequency and the power levels are proportional to bandwidth (confirming that 100% equivalent power was accurately estimated from APDs).

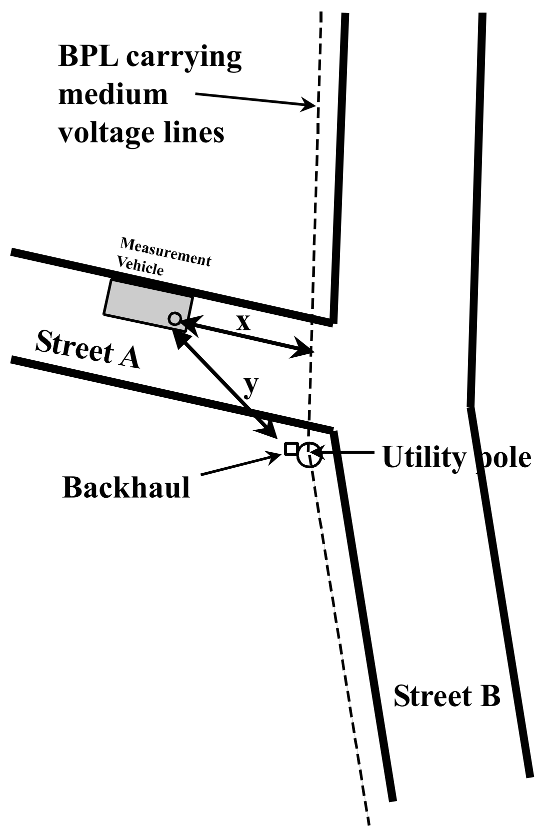

Figure D-42: Measurement Site I for BPL APD measurements

<u>Measurement Conditions</u>

Measurement Location:	Site I
Antenna Type:	Discone (Model SAS-210/C)
Antenna Height:	10 meters
Antenna Polarization:	Vertical
Measured Characteristic:	100% duty cycle power (from APDs) of the electric field
Measurement Variable:	Distance away from low voltage power line (x = 11.6 meters)
Comments:	Measurement frequencies – 32.699 MHz and 42.465 MHz Resolution bandwidths – 10 kHz, 30 kHz and 200 kHz

Table D-17: Measured 100%-duty-cycle power from APDs – Site I, discone antenna, x = 11.6 meters.

	Frequency	RBW	100%-duty-cycle Power
Case 1	32.699 MHz	200 kHz	-93.6 dBm
Case 2	32.699 MHz	30 kHz	-98.9 dBm
Case 3	32.699 MHz	10 kHz	-103.5 dBm
Case 4	42.465 MHz	200 kHz	-95.3 dBm
Case 5	42.465 MHz	30 kHz	-101.8 dBm
Case 6	42.465 MHz	10 kHz	-107.4 dBm

Another set of pulse-power measurements and APDs were performed at Site I at 32.699 MHz with two different resolution bandwidths (30 kHz, and 10 kHz) and three different antenna orientations. These results are shown in Table D-18. Figure D-43 shows APD plots for cases 7, 8, and 9 as described in the Table D-18. Both Table D-18 and Figure D-43 indicate that the measured power for all four cases is at similar levels for the same location.

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Measurement Conditions

Measurement Location:	Site I
Antenna Type:	Discone (Model SAS-210/C)
Antenna Height:	2 meters
Antenna Polarization:	Varies, see Table D.3.6-2
Measured Characteristic:	Pulse power measurements and 100% duty cycle power (from APDs) of the electric field
Measurement Variable:	Distance away from low voltage power line (x) and backhaul pt (y)
Comments:	Measurement frequency – 32.699 MHz Resolution bandwidths – 10 kHz and 30 kHz Pulse power measurements – zero span, peak power detection, 2 ms sweep time (601 pts per sweep)

Table D-18: Measured 100%-duty-cycle power from APDs and Pulse Power – Site I, discone antenna, various x-y distances

	Direct Distances	Antenna orientation	RBW	100%-duty-cycle Power	Pulse power
Case 1	x = 11.7 m y = 15.2 m	Vert. Polarization	30 kHz	-107.5 dBm	-114.6 dBm
			10 kHz	-112.6 dBm	-115.6 dBm
Case 2	x = 17.1 m y = 19.5 m	Vert. Polarization	30 kHz	-107.4 dBm	-112.3 dBm
			10 kHz	-112.2 dBm	-117.2 dBm
Case 3	x = 23.0 m y = 25.0 m	Vert. Polarization	30 kHz	Not measurable	Not measurable
			10 kHz	Not measurable	Not measurable
Case 4	x = 23.0 m y = 25.0 m	Horz. Polarization parallel to lines	30 kHz	Not measurable	Not measurable
			10 kHz	Not measurable	Not measurable
Case 5	x = 17.1 m y = 19.5 m	Horz. Polarization parallel to lines	30 kHz	Not measurable	Not measurable
			10 kHz	Not measurable	Not measurable
Case 6	x = 17.1 m	Horz. Polarization	30 kHz	Not measurable	Not measurable

	y = 19.5 m	perpendicular to lines	10 kHz	Not measurable	Not measurable
Case 7	x = 11.7 m y = 15.2 m	Horz. Polarization perpendicular to lines	30 kHz	-107.9 dBm	-110.1 dBm
			10 kHz	-113.1 dBm	-115.8 dBm
Case 8	x = 11.7 m y = 15.2 m	Horz. Polarization parallel to lines	30 kHz	-106.2 dBm	-110.3 dBm
			10 kHz	-113.3 dBm	-118.1 dBm
Case 9	x = 11.7 m y = 15.2 m	Horz. Polarization pointed to pole	30 kHz	-107.8 dBm	-111.1 dBm
			10 kHz	-109.0 dBm	-116.8 dBm

The 100% duty-cycle power and manual pulse power levels were observed to be nearly the same for measurements performed at the same location with the antenna pointed in different directions (Case 7 – Case 9).

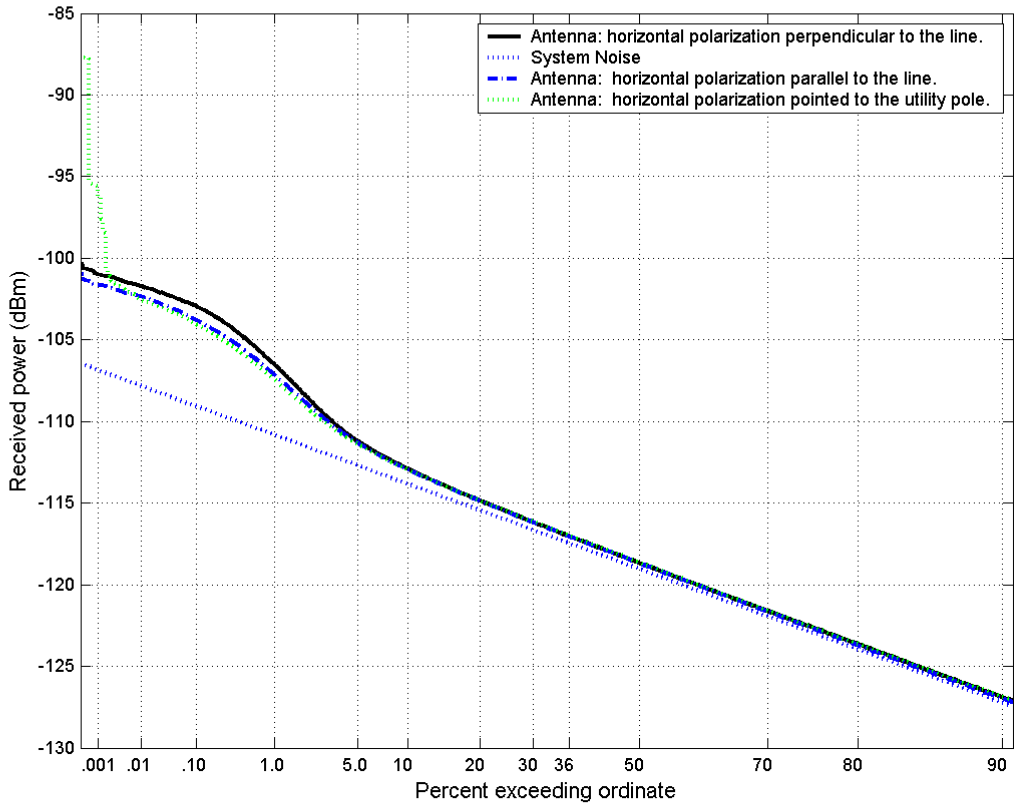

Figure D-43: APD measurements in a 30 kHz RBW for three different antenna orientations – Site I, located with a 11.7 m direct distance from power lines

D.4 BACKGROUND ON AMPLITUDE PROBABILITY DISTRIBUTIONS

Because of the random nature of the system noise, background noise, and the BPL signal itself, signal power data were, at times, collected and analyzed statistically using amplitude probability distributions (APDs).[2]

The reason for using APDs was to differentiate the BPL signal from the background (and system) noise and to extract mean power. While the APD can be used to characterize the background noise, doing so requires a sufficiently large ensemble and adequate sensitivity. It was not the original intention to use these measurements for the purpose of characterizing the background noise; therefore, the extent of sampling and the system configuration limit the use of these APDs for that purpose.

Data for these measurements were acquired by repeatedly collecting power traces from a spectrum analyzer and placing the power values in corresponding 0.1-dB bins of a histogram (later to be used for creating APDs). The spectrum analyzer was set in sample detection mode with a zero span and centered on specified frequencies of interest. So as to assure uncorrelated sampling, the trace sweep-time was set so that adjacent data points were no closer in time than 2/RBW, where RBW is the resolution bandwidth. To provide sufficient probability resolution, a minimum of 500,000 samples were collected for each APD - enough to give a probability of a single occurrence equal to 0.0002% .

By repeatedly collecting power data when the transmission lines are loaded with BPL and when the BPL is turned off, it is possible to identify the power contribution by BPL, assuming that the background noise does not change significantly. For example, Figure D-44 shows the APDs for the two scenarios - BPL on and BPL off. The “system noise” plot is emulated by calculating the curve from the system noise figure. Though the data from the two scenarios were not collected simultaneously, the characteristics of the noise environment, in this case, were changed only by inclusion or exclusion of the BPL signal. The features noted between points B and D are due predominantly to the BPL signal, whereas the features between points A and B for the “BPL-loaded” case and points A and C for the “BPL-off” case are due predominantly to extraneous environmental impulsive noise. The linear regions of the curves are due to system noise.

By taking multiple APDs of these two scenarios, it is possible to identify APD features that are characteristic of the BPL signal. For instance, after examining multiple APDs, it was possible to conclude that, for this example data, the BPL signal is present approximately 10% of the time when loaded. Figure D-45 shows data collected in a slightly different location within the site. However, in this example, changes in the noise environment between “loaded” and “off” cases are due not only to the BPL being turned off, but also due to some additional impulsive noise as noted in the region between points B and D of the “BPL-off” plot. Despite

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[2] “Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems,” J.R. Hoffman, M.G. Cotton, R.J. Achatz, R.N. Statz, and R.A. Dalke, NTIA Report 01-384, Feb. 2001.

this added complexity, it is still possible to identify the power contribution by BPL because the region between points C and E on the "BPL-loaded" plot has the characteristic feature of 10% presence, and this feature of the curve is absent for the "BPL-off" case.

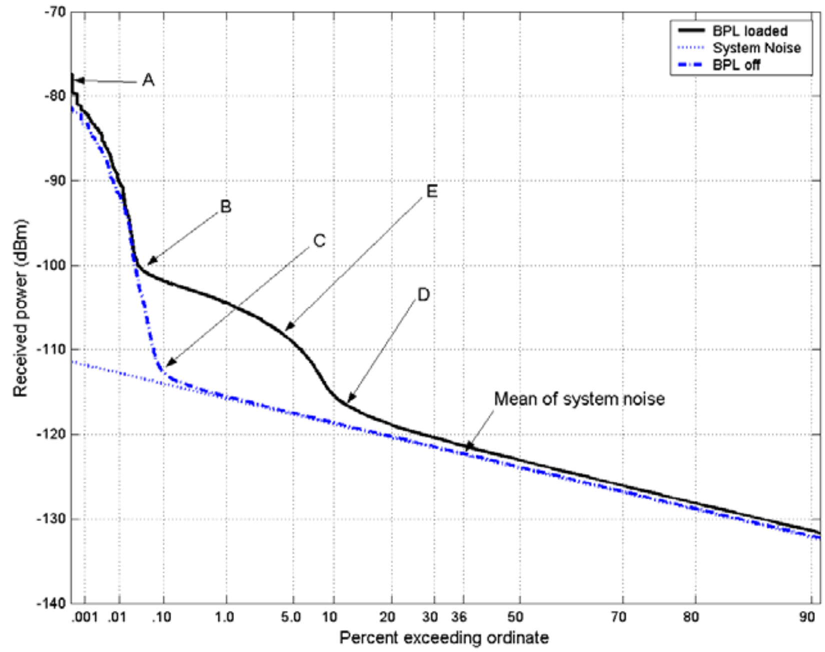


Figure D-44: Example APD plots for two different measurement scenarios - BPL loaded and BPL off.

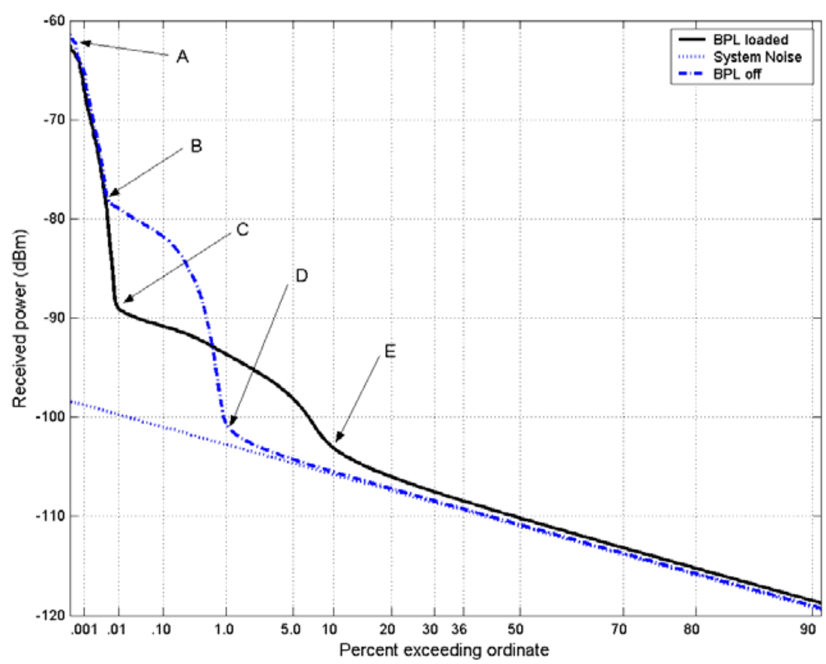


Figure D-45: Example APD plots for two different measurement scenarios - BPL loaded and BPL off.

For each of the APD plots, the powers on the ordinate are referenced to the output of the antenna terminals. Mean powers are calculated from the associated histograms by:

$$\sum_i x_i \frac{n_i}{N} ,$$

where x_i is power in the i^{th} bin, n_i is the number of samples in the i^{th} bin, and N is the total number of samples. In cases where the system noise or environmental noise may contribute significantly to the overall signal power, the mean signal power of the BPL is determined by subtracting the mean system noise power and/or environmental noise from the overall mean signal power. In some cases, the background noise is low enough in power or infrequent enough (for impulsive noise) that their contribution to the overall power can be disregarded.

For data shown in Figure D.46, the BPL signal is pulse-like in nature, and between the pulses, the signal power is dominated by the system (and environmental) noise. The calculated mean 100%-duty-cycle power (*i.e.*, the power when the pulses are present 100% of the time) is determined from the measured percentage of time the BPL pulses are present using the following equation:

$$M_p = M_s - 10 \log_{10} \frac{P}{100} ,$$

where M_p is the mean 100%-duty-cycle power in decibels, M_s is the mean measured signal power in decibels, and P is the percentage of time the measured BPL pulses are present. M_s is determined by subtracting mean power of the system noise from the mean power for the BPL-on data. Though there appears to be some impulsive environmental noise (far left side of the plot) contributing to the mean power of the BPL-on case, the probability (in combination with the magnitude) of this impulsive environmental noise is low enough that it contributes little to the overall mean power. To estimate P, it is assumed that the point at which the curve deviates from the system noise curve by 1.8 dB represents the point at which BPL pulses are starting to significantly contribute additional power above that of the system noise, and therefore, this represents the percent of the time for which the BPL pulses are present.3 For Figure D-46, this point occurs at 11%, and therefore, because the mean signal power is calculated to be -111.7 dBm, the mean pulse power is -103.3 dBm. It should be emphasized, however, that P and M_s are estimates and dependent upon an understanding of the background noise. Because the system noise power is Rayleigh distributed, the mean power occurs at the 37th percentile (true for any Rayleigh distributed power that is predominantly system noise); therefore for Figure D-46, the BPL pulse power is 18 dB above the mean system noise.

[3] 1.8 dB was felt to be the first consistently perceptible deviation from the system noise curve.

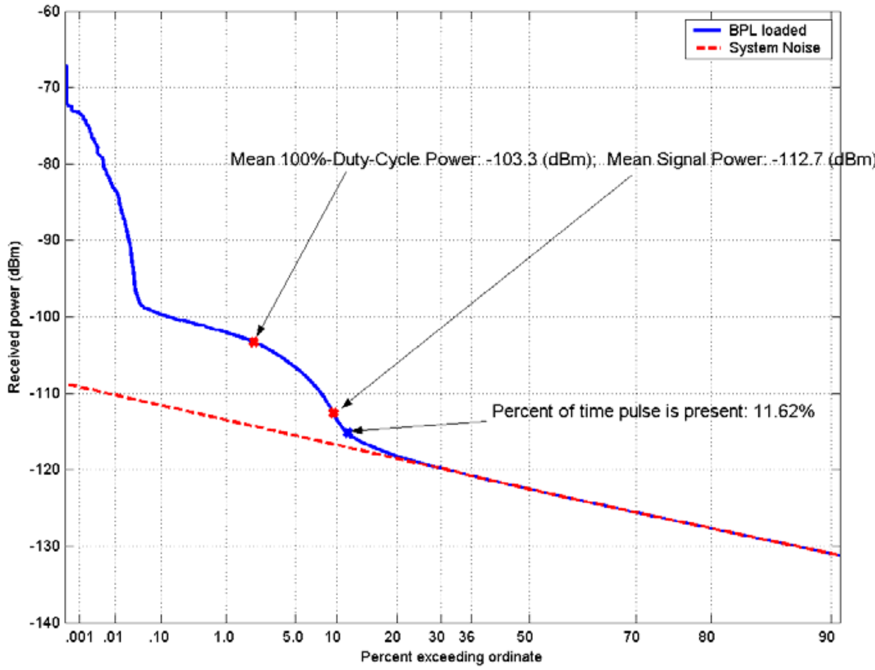


Figure D-46: Mean power for pulse-like BPL signal, dominated by system noise between pulses.

This measurement technique was verified by simulating a pulsed signal of known power and performing the same measurement and processing procedure. The simulated signal was centered at 30 MHz with a 10% duty cycle. Figures D-47 and D-48 shows the signal as measured on a spectrum analyzer with a span of zero. Figure D-47 shows the signal with a peak pulse power well above the system noise. Figure D-48 shows the signal with a peak pulse power approximately 6 dB above the system noise (–105 dBm at the input to the preselector). Because the peak pulse power could not be readily measured for the case where the power is less than 10 dB above the system noise, the peak pulse power was measured when it was well above the system noise and then attenuated prior to the preselector. APDs were performed for two different peak pulse power at the input to the preselector: -83 dBm and –105 dBm. The data were acquired and processed for mean signal power, mean 100%-duty-cycle power, and the measured duty cycle. Results are shown in Figures D-49 and D-50. In both cases, the mean 100%-duty-cycle power coincides well with the actual measured peak pulse power.

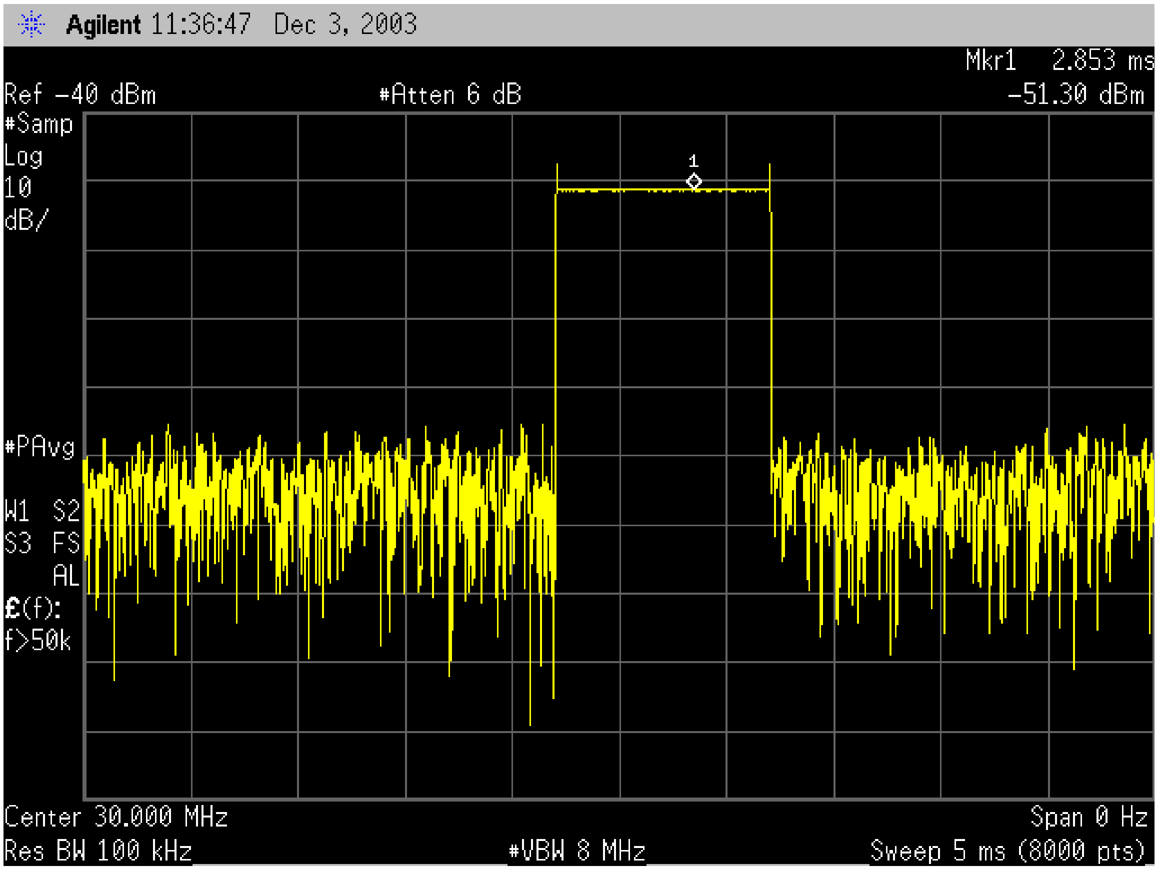


Figure D-47: Simulated signal with a peak pulse power well above the system noise.

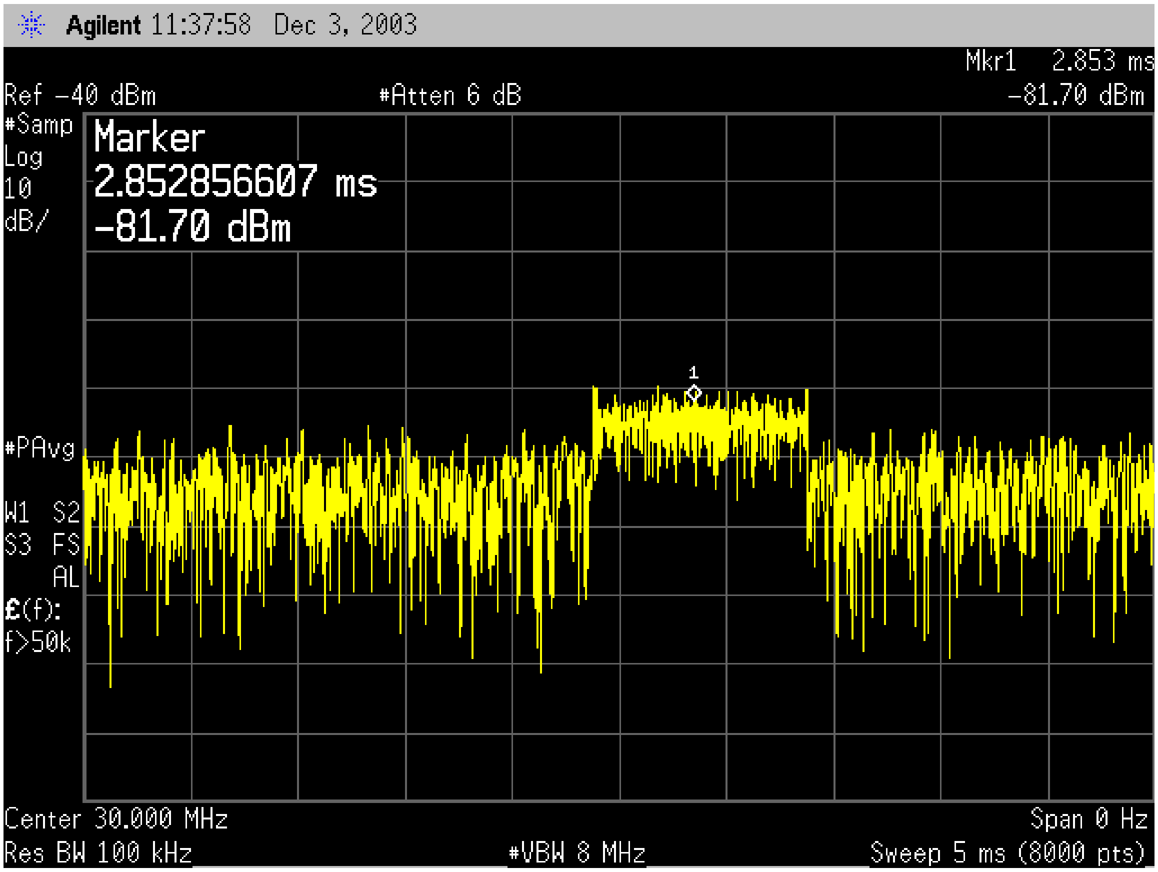


Figure D-48: Simulated signal with a peak pulse power 6 dB above the system noise.

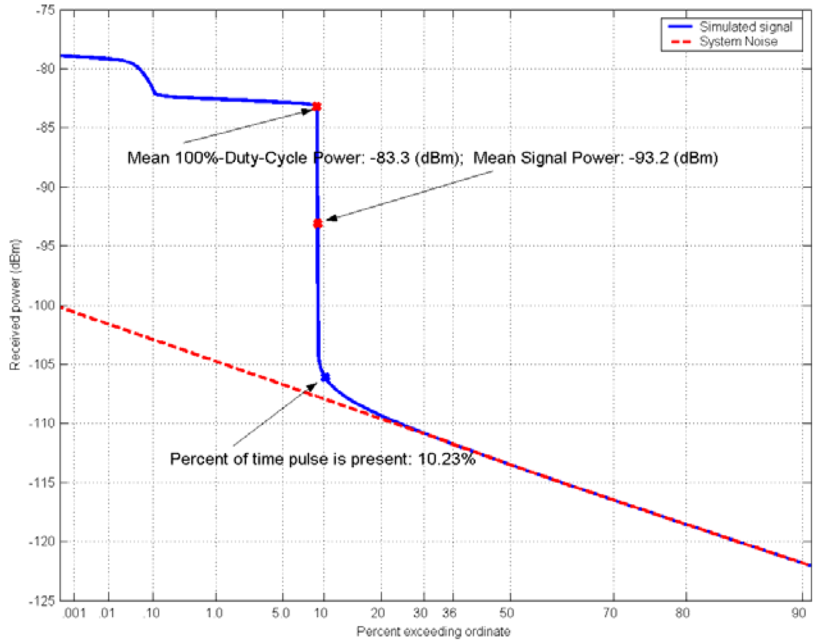


Figure D-49: APD of simulated signal with a peak pulse power of -83 dBm at the input to the preselector.

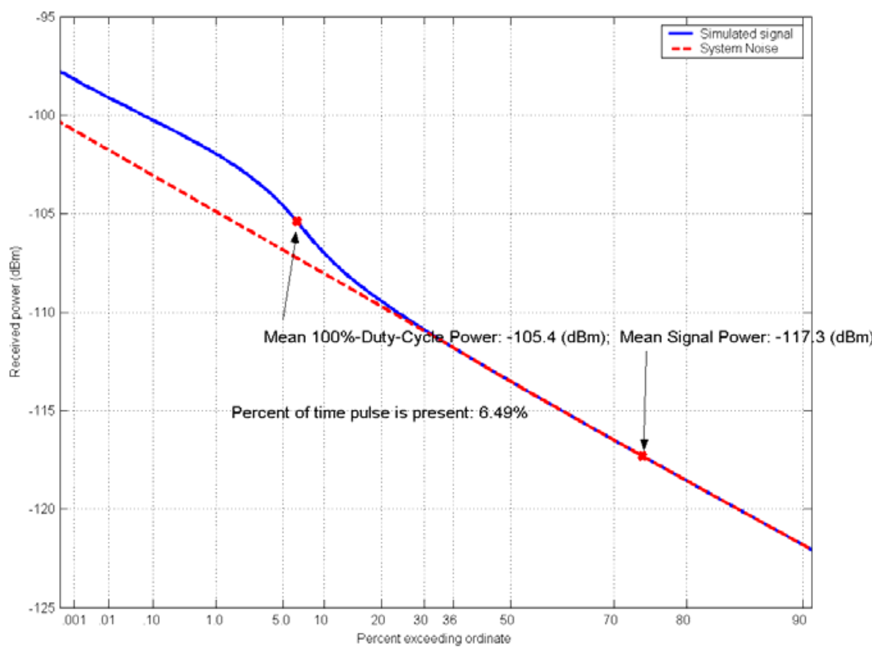


Figure D-50: APD of simulated signal with a peak pulse power of -105 dBm at the input to the preselector.

Figure D-51 shows APDs for data acquired for two conditions: when the BPL was loaded and when the BPL was turned off. In this case, there appears to be some impulsive noise that is present during both acquisitions. And though the contribution to the mean power by this impulsive noise is probably insignificant, it is possible to remove the effects of both environmental impulsive noise and the system noise by finding the difference in mean powers between the two data sets. Therefore, the mean measured signal power (M_s), in this case, is determined by subtracting the mean power for the BPL-off case from the mean power for the BPL-on case. The 100%-duty-cycle power is determined as described in the preceding paragraph.

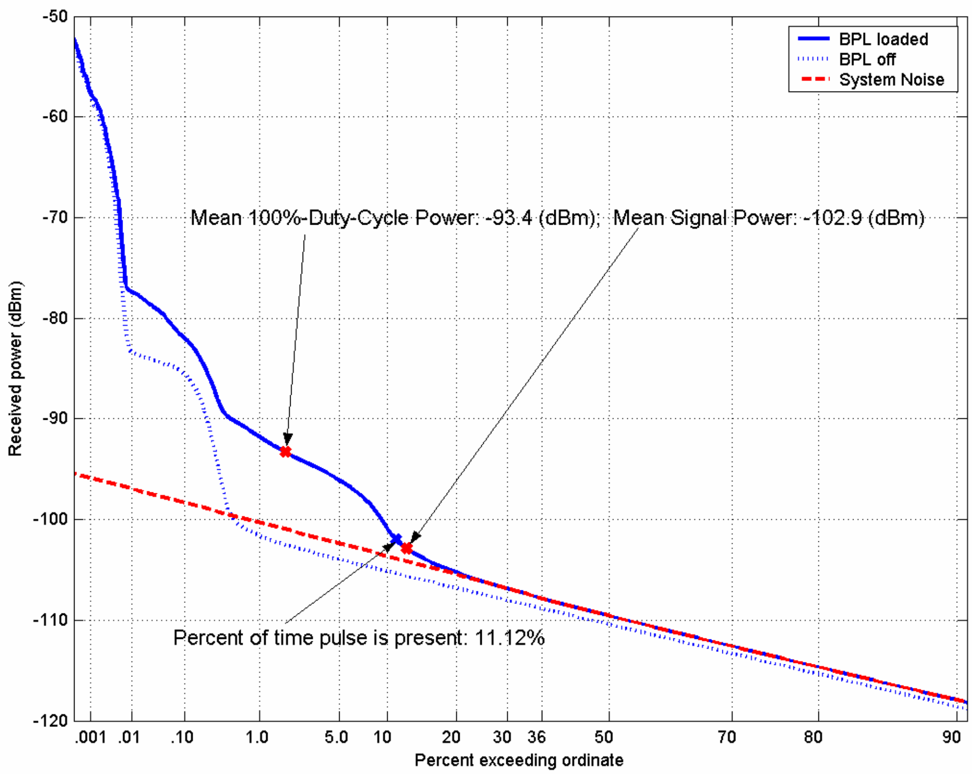


Figure D-51: Mean power for pulse-like BPL signal, dominated by system noise and impulsive noise between pulses.

Figure D-52 shows a BPL signal that (the mean power being less than 5 dB above mean system noise power) appears Gaussian noise-like and is present at least 90% of the time. Since the system noise may contribute significantly to the measured power, the mean measured signal power (M_s) is determined by subtracting the mean system noise power from the mean power for the BPL-on data.

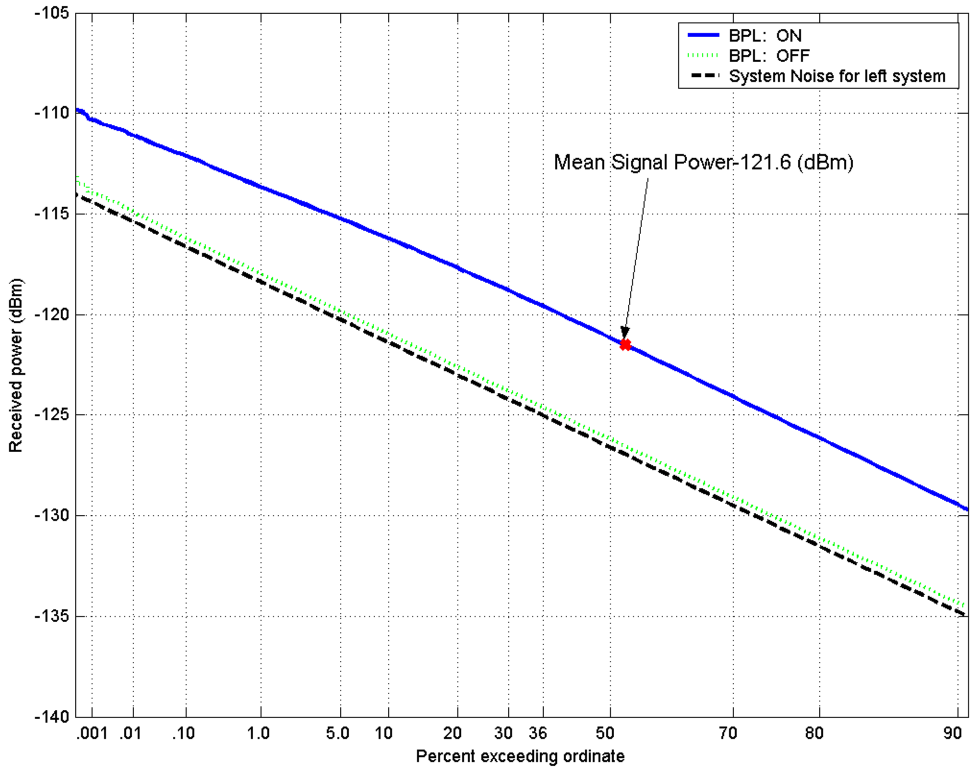


Figure D-52: Gaussian noise-like BPL signal data, the mean of which is less than 5 dB above the mean system noise.

Figure D-53 shows a BPL signal where the power appears randomly distributed with a variance less than system noise. Because the mean power of the signal is greater than 10 db above the mean system noise power, the system noise contributes little to the measured power, and therefore, the mean measured signal power (M_s) is determined only from the measured powers of the BPL-on case.

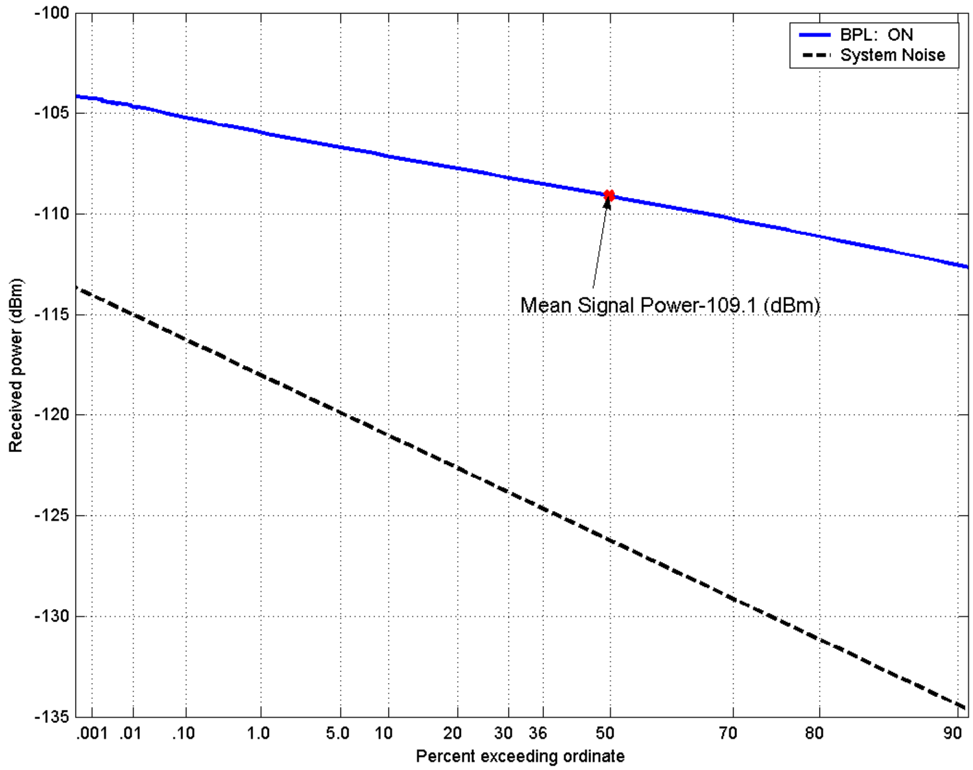


Figure D-53: Randomly distributed BPL signal power, the mean of which is greater than 10 dB above the mean system noise.

D.5 GAIN AND NOISE FIGURE CALIBRATION USING A NOISE DIODE

The RF paths to the E4440 Spectrum analyzers (see Figure D-1) were calibrated by injecting noise with a known excess noise ratio at the antenna input, collecting power data across the frequency range of interest, then terminating the input with a 50Ω terminator, and collecting the power data once again across the same frequency range. Power data were collected by putting the spectrum analyzer in zero span with average power detection and a sweep time long enough to produce a flat trace. Using an automated stepped frequency measurement routine, power levels were measured at approximately 200 kHz intervals across the band of interest. Using the Y-Factor method of calculation (as described below), both the gain through the system and noise figure at the input were determined. All power levels were referenced back to the antenna input by subtracting the gain.

Measurement system calibration should be performed prior to acquisitions where absolute values are required. As measurements are performed, gain corrections may be added automatically to every data point. For measurement system noise figures of 20 dB or less, noise diode Y-factor calibration may be used. The theory and procedure for such calibration are described herein.

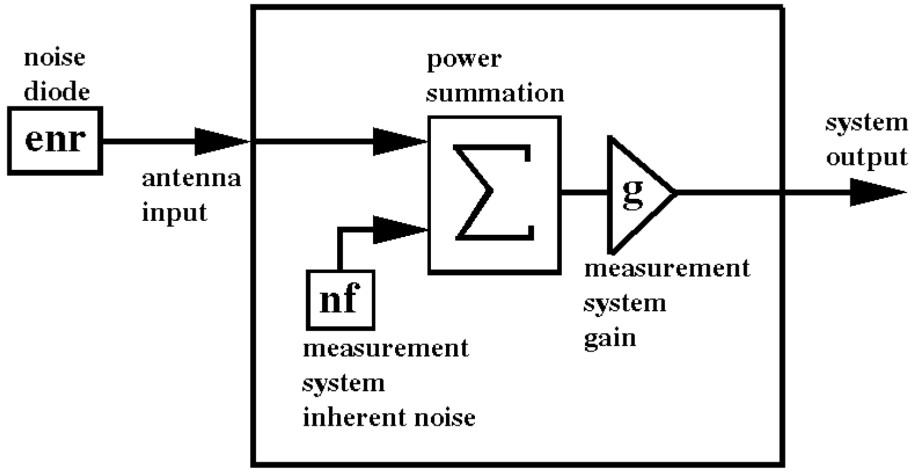


Figure D-54: Lumped component diagram of noise diode calibration

The noise diode calibration of a receiver tuned to a particular frequency may be represented in lumped-component terms as shown in Figure D-54. In this diagram, the symbol "Σ" represents a power-summing function that linearly adds any power at the measurement system input to the inherent noise power of the system. The symbol "g" represents the total gain of the measurement system. The measurement system noise factor is denoted by "nf," and the noise diode has an excess noise ratio denoted as "enr." (All algebraic quantities denoted by lower-case letters, such as "g," represent linear units. All algebraic quantities denoted by upper case letters, such as "G," represent decibel units).

Noise factor is the ratio of noise power from a device, n_{device}(W), and thermal noise,

$$\frac{n_{device}}{kTB}$$

where k is Boltzmann's constant ($1.38 \cdot 10^{-23}$J/K), T is system temperature in Kelvin, and B is bandwidth in hertz. The excess noise ratio is equal to the noise factor minus one, making it the fraction of power in excess of kTB. The noise figure of a system is defined as 10 log (noise factor). As many noise sources are specified in terms of excess noise ratio, that quantity may be used.

In noise diode calibration, the primary concern is the difference in output signal when the noise diode is switched on and off. For the noise diode = on condition, the power, P_{on}(W), is given by:

$$p_{on} = (nf_s + enr_d) \times gkTB$$

where nf_s is system noise factor and enr_d is the noise diode enr.

When the noise diode is off, the power, P_{off}(W), is given by:

$$p_{off} = (nf_s) \times gkTB$$

The ratio between P_{on} and P_{off} is the Y factor:

$$y = \left(\frac{p_{on}}{p_{off}}\right) = \frac{(nf_s + enr_d)}{nf_s}$$

$$Y = 10\log(y) = 10\log\left(\frac{p_{on}}{p_{off}}\right) = P_{on} - P_{off}$$

Hence the measurement system noise factor can be solved as:

$$nf_s = \frac{enr_d}{y-1}$$

The measurement system noise figure is:

$$NF_s = 10\log\left(\frac{enr_d}{y-1}\right) = ENR_d - 10\log(y-1) = ENR_d - 10\log\left(10^{Y/10} - 1\right)$$

Hence:

$$g = \frac{p_{on} - p_{off}}{enr_d \times kTB}$$

$$G = 10\log(p_{on} - p_{off}) - 10\log(enr_d \times kTB)$$

or

$$G = 10\log\left(10^{P_{on}/10} - 10^{P_{off}/10}\right) - ENR_d - 10\log(kTB)$$

In noise diode calibrations, the preceding equation is used to calculate measurement system gain from measured noise diode values.

Although the equation for NF_s may be used to calculate the measurement system noise figure, software may implement an equivalent equation:

$$nf_s = \frac{p_{off}}{gkTB}$$

$$NF_s = 10\log(p_{off}) - 10\log(gkTB) = P_{off} - G - 10\log(kTB)$$

Substituting the expression for gain into the preceding equation yields:

$$NF_s = P_{off} + ENR_d - 10\log\left(10^{P_{on}/10} - 10^{P_{off}/10}\right)$$

The gain and noise figure values determined with these equations may be stored in look-up tables. The gain values are used to correct the measured data points on a frequency-by-frequency basis.

Excluding the receive antenna, the entire signal path is calibrated with a noise diode source prior to a BPL measurement. A noise diode is connected to the input of the first RF line in place of the receiving antenna. The connection may be accomplished manually or via an automated relay, depending upon the measurement scenario. The noise level in the system is measured at a series of points across the frequency range of the system with the noise diode turned on. The noise diode is then turned off and the system noise is measured as before, at the same frequencies. The measurement system computer thus collects a set of P_{on} and P_{off} values at a series of frequencies across the band to be measured. The values of P_{on} and P_{off} are used to solve for the gain and noise figure of the measurement system in the equations above.

APPENDIX E
BPL MODELING OUTPUT

E.1 INTRODUCTION

Extensive work was done at NTIA's Institute for Telecommunication Sciences (ITS) on a typical arrangement of medium voltage power lines. The modeled power lines consist of three horizontal parallel copper wires 8.5 meters (27.9 feet) above average ground. Each wire has a diameter of 0.01 meter and the wires are separated in the horizontal plane by 0.60 meter. The feed is at the center of one of the wires which runs along the x axis (y = 0). The equivalent of a coupler in series with the center segment of the wire is used with a voltage source of 1 volt. The other two wires run parallel to the x axis at y = 0.6 and y = 1.2 meters.

All three components of electric and magnetic fields E_x, E_y, E_z, H_x, H_y and H_z in dBμV/m were plotted in a plane 2 meters above the ground at frequencies 2, 5, 10, 20 and 40 MHz. Three different line lengths of 100m, 200m and 340m were used with four different impedance conditions for the source and loads. The near field data have been plotted for four different scales of x and y coordinates *i.e.*, 0 to 20 m (65.6 ft), 200 m (656 ft), 1,000 m (3,280 ft) and 1,800 m (59,040 ft). The far field radiation patterns were also plotted at several azimuth angles. The complete dataset of the radiation patterns and near-field plots are available at NTIA. A few representative radiation patterns and near field plots are given in this Appendix.

The trends observed from the near field plots of the three components of the electric fields are summarized in Tables E-1, E-2 and E-3 for E_z, E_x and E_y respectively.

E.2 TABLES AND NEC PLOTS

Table E-1 summarizes the characteristics of the vertical electric field E_z at various ranges of x and y and at z = 2m as deduced from the near field plots. Similarly Table E-2 and E-3 summarize the characteristics of the horizontal electric field parallel to the wire E_x and horizontal electric field perpendicular to the wire E_y respectively.

Figures E-1 thru E-12 show elevation power patterns for azimuth (Φ) = 0º and 90º for source impedance of 150 Ω, load impedance of 575 Ω and several combinations of line lengths 100m, 200m and 340 m and frequencies 2 MHz, 5 MHz, 10 MHz, 20 MHz and 40 MHz. Figures E-13 thru E-30 show near field plots for E_x, E_y and E_z for a line length of 200 m, source impedance of 150 Ω, load impedance of 575 Ω, frequencies 40 MHz, 10 MHz and 2 MHz, z = 2 m for two different scales of x and y, 0 to 20 m (65.6 ft) and 200 m (656 ft). Figures E-31 thru E-34 illustrate the effect a neutral wire has on the radiation pattern.

Table E-1: Summary of Electric Fields Seen by an Antenna Having Vertical Polarization

Source & Load	BPL Frequency	Length of Line	Peak Field	Number of Peaks[1]	Minimum Distance Between Peak Field and BPL Device
Impedance (Ω)	(MHz)	(m)	(dBμV/m)		(feet)
150 & 575	2	100	83-85	2	59-85
575 & 50	2	100	83-85	2	90
150 & 50	2	100	86	2	58-120
575 & 575	2	100	81	2	100
150 & 575	10	100	75-79	4	33
575 & 50	10	100	74-77	4	38
150 & 50	10	100	74-79	3	33
575 & 575	10	100	71-75	3	36
150 & 50	40	100	69-76	8	7
575 & 50	40	100	69-73	8	7
575 & 575	40	100	70-75	7	6
150 & 575	40	100	72-77	6	7
150 & 50	2	200	84-86	2	58-120
575 & 50	2	200	82-85	2	95
575 & 575	2	200	79-81	2	100
150 & 575	2	200	85	1	58-100
150 & 50	10	200	75-80	4	33
575 & 50	10	200	75-78	4	32
150 & 575	10	200	74-79	4	32
575 & 575	10	200	71-75	4	35
150 & 50	40	200	71-74	8	7
575 & 575	40	200	68-74	7	6
575 & 50	40	200	72-74	6	6
150 & 575	40	200	71-76	5	7
150 & 50	2	340	80-83	3	80
575 & 575	2	340	76-79	3	95
150 & 575	2	340	82	3	85
575 & 50	2	340	81	3	70
575 & 575	10	340	68-74	8	21
575 & 50	10	340	73-77	7	20
150 & 50	10	340	76-79	6	50
150 & 575	10	340	72-78	2	21
150 & 575	40	340	71-77	10	13
575 & 575	40	340	67-73	10	16
575 & 50	40	340	70-76	9	15
150 & 50	40	340	73	2	53

[1] All peak levels of vertically polarized electric field strength occurred near and under the power lines, and all local peaks had approximately the same level. The statistics are presented for one-half the overall length of the power line, which is center fed. Thus, the numbers of peaks for the entire power line are twice the values shown in the table.

Table E-2: Summary of Electric Fields Seen by an Antenna Having Horizontal-Parallel Polarization

Source & Load Impedance (Ω)	BPL Frequency (MHz)	Length of Line (m)	Field at Source[2] (dBμV/m)	Number of Secondary Peaks[3]
150 & 50	2	100	68	2
150 & 575	2	100	67	2
575 & 50	2	100	67	2
575 & 575	2	100	63	2
150 & 50	2	200	68	2
150 & 575	2	200	67	2
575 & 50	2	200	67	2
575 & 575	2	200	63	2
150 & 50	2	340	69	3
150 & 575	2	340	68	3
575 & 50	2	340	67	3
575 & 575	2	340	65	3
150 & 50	10	100	76	5
150 & 575	10	100	75	3
575 & 50	10	100	74	3
575 & 575	10	100	72	0
150 & 50	10	200	77	5
150 & 575	10	200	76	3
575 & 50	10	200	75	3
575 & 575	10	200	72	3
150 & 50	10	340	75	5
150 & 575	10	340	74	5
575 & 50	10	340	74	5
575 & 575	10	340	70	5
150 & 50	40	100	82	1
150 & 575	40	100	81	1
575 & 50	40	100	79	0
575 & 575	40	100	78	0
150 & 50	40	200	82	1
150 & 575	40	200	81	1
575 & 50	40	200	78	0
575 & 575	40	200	78	1
150 & 50	40	340	76	1
150 & 575	40	340	81	1
575 & 50	40	340	80	1
575 & 575	40	340	76	0

[2] Peak horizontal-parallel electric field strength always occurred near the BPL device.

[3] Secondary peaks levels were recorded if they were within 5 dB of the overall peak level near the BPL device. The statistics are presented for one-half the overall length of the power line, which is center fed. Thus, the numbers of peaks for the entire power line are twice the values shown in the table.

Table E-3: Summary of Electric Fields Seen by an Antenna Having Horizontal-Perpendicular Polarization

Source & Load Impedance (Ω)	BPL Frequency (MHz)	Length of Line (m)	Peak Field (dBµV/m)	Distance of Peak from the Line (ft)	Number of Peaks[4]	Minimum Distance From BPL Device (feet)
150 & 50	2	100	70	+/-10-20	1	60-100
150 & 575	2	100	64-69	+/-15-21	2	60-90
575 & 50	2	100	69	+/-10-20	1	65-100
575 & 575	2	100	58-65	+/-13-25	2	90
150 & 50	2	200	70	10-20	1	58-110
150 & 575	2	200	64-69	+/-15-25	2	90
575 & 50	2	200	69	+/-17	2	65-120
575 & 575	2	200	58-65	+/-15-25	2	95
150 & 50	2	340	60-67	0	4	50
150 & 575	2	340	61-66	+/-10-22	3	42-80
575 & 50	2	340	60-65	+/-10-22	2	90
575 & 575	2	340	57-63	+/-15-20	3	85
150 & 50	10	100	60-67	+/-10-25	2	32
150 & 575	10	100	63-67	+/-18	2	32
575 & 50	10	100	58-65	+/-12-23	2	32
575 & 575	10	100	57-63	+/-13-23	3	50
150 & 50	10	200	62-67	+/-10-25	3	32
150 & 575	10	200	61-67	+/-17-21	3	31
575 & 50	10	200	60-65	+/-10-25	3	17
575 & 575	10	200	57-63	+/-15-26	3	31
150 & 50	10	340	62-65	+/-10-25	12	50
150 & 575	10	340	60-65	16-21	2	21
575 & 50	10	340	60-63	+/-10-22	6	21
575 & 575	10	340	52-61	+/-12-23	7	22
150 & 50	40	100	71-73	+/-10-25	4	20
150 & 575	40	100	65-73	+/-15-38	4	32
575 & 50	40	100	69-71	+/-18-30	5	20
575 & 575	40	100	63-69	+/-15-35	6	19
150 & 50	40	200	68-73	+/-10-33	5	18
150 & 575	40	200	66-73	+/-10-30	5	33
575 & 50	40	200	62-72	+/-12-34	5	20
575 & 575	40	200	69	+/-18-30	5	19
150 & 50	40	340	64	+/-10-30	4	23
150 & 575	40	340	69-72	+/-18-23	6	10
575 & 50	40	340	64-70	+/-10-30	6	10
575 & 575	40	340	64-66	+/-17-23	5	10

[4] The statistics are presented for one-half the overall length of the power line, which is center fed. Thus, the numbers of peaks for the entire power line are twice the values shown in the table.

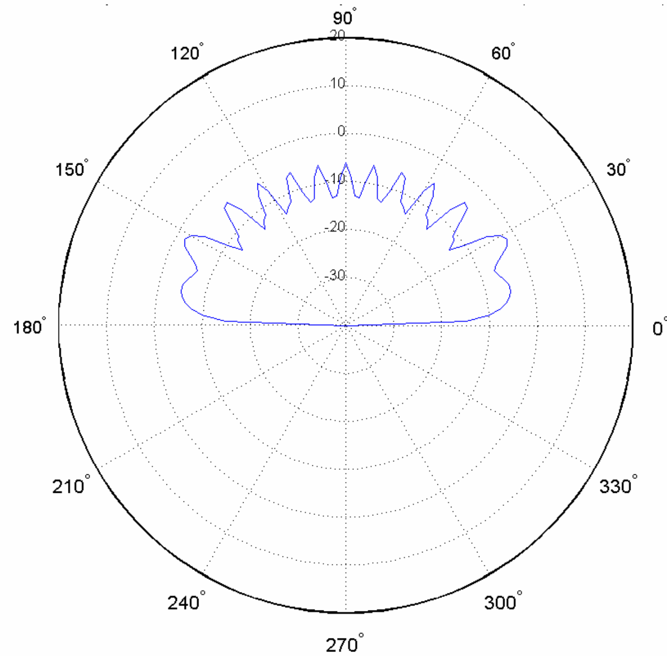


Figure E-1: Elevation pattern at azimuth (phi) = 0, line length = 340 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flc0.png]

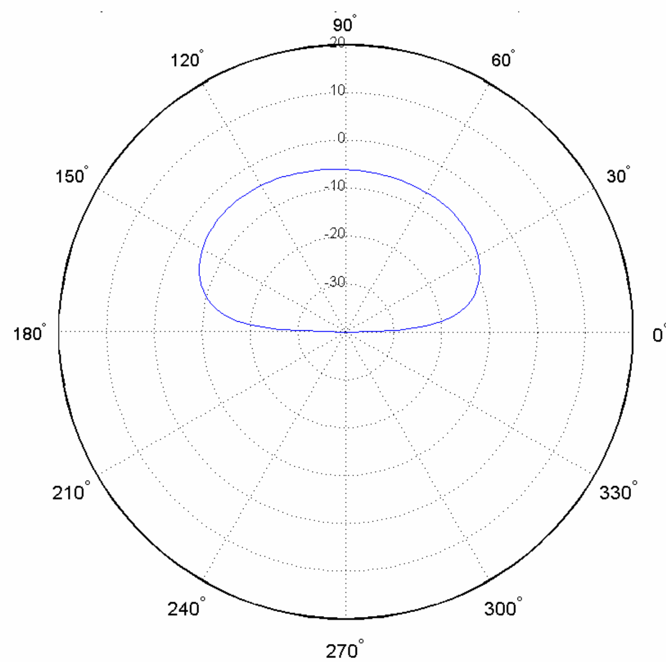


Figure E-2: Elevation pattern at azimuth (phi) = 90, line length = 340 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flc90.png]

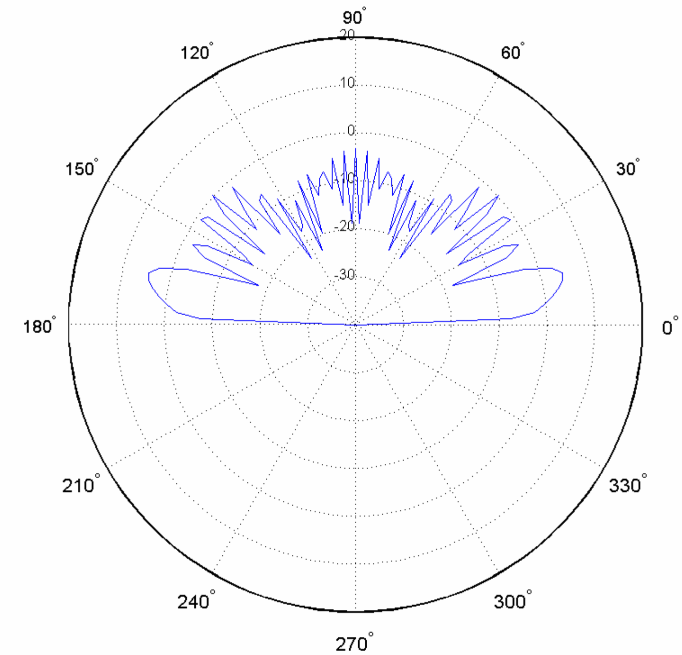


Figure E-3: Elevation pattern at azimuth (phi) = 0, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flf0.png]

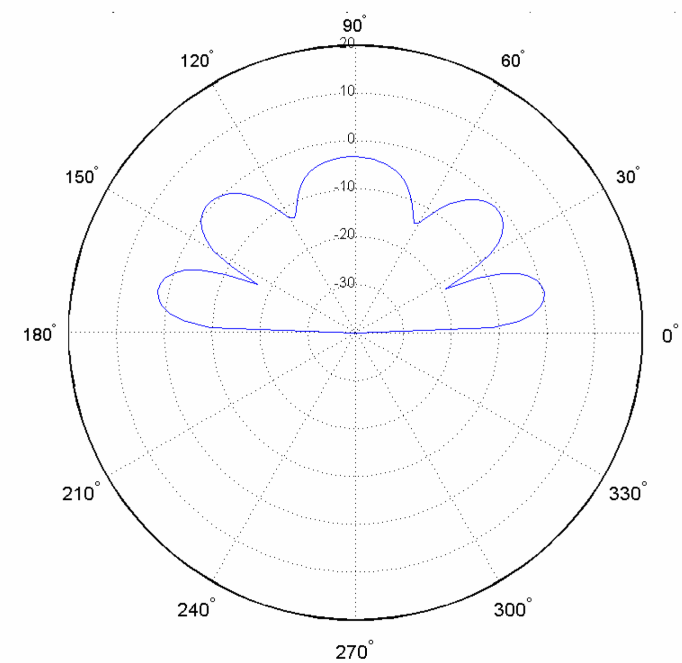


Figure E-4: Elevation pattern at azimuth (phi) =90, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flf90.png]

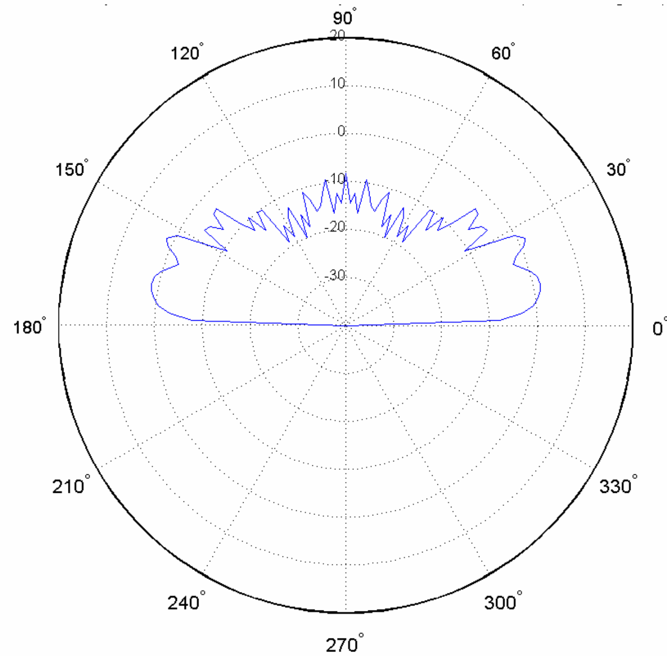


Figure E-5: Elevation pattern at azimuth (phi) = 0, line length = 200 m, frequency = 20 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flg0.png]

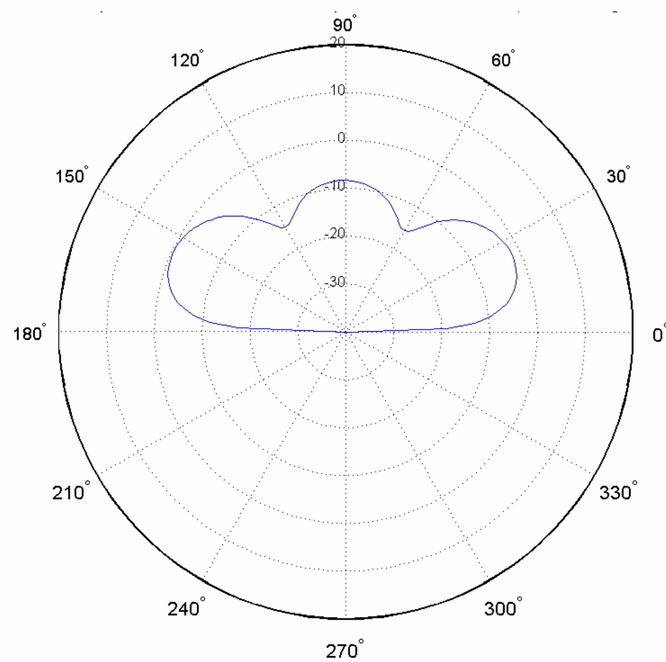


Figure E-6: Elevation pattern at azimuth (phi) = 90, line length = 200 m, frequency = 20 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flg90.png]

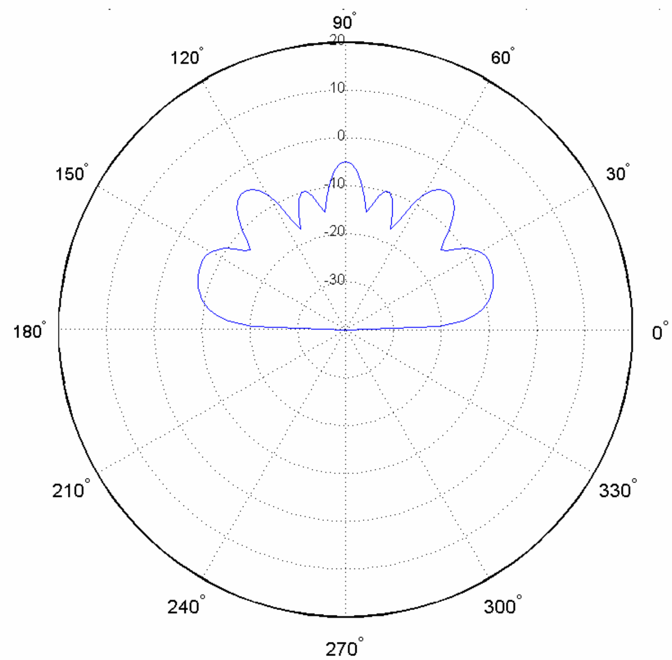


Figure E-7: Elevation pattern at azimuth (phi) = 0, line length = 200 m, frequency = 5 MHz, source impedance = 150 Ω, load impedance = 575 Ω [fli0.png]

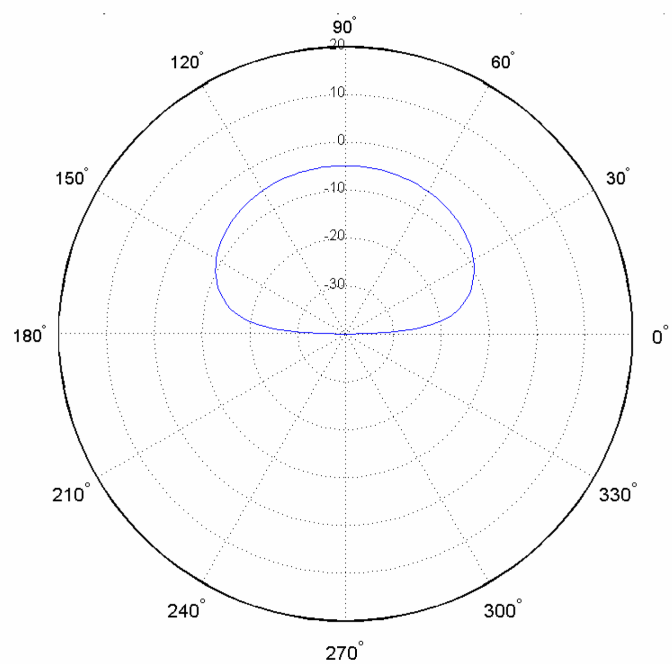


Figure E-8: Elevation pattern at azimuth (phi) =90, line length = 200 m, frequency = 5 MHz, source impedance = 150 Ω, load impedance = 575 Ω [fli90.png]

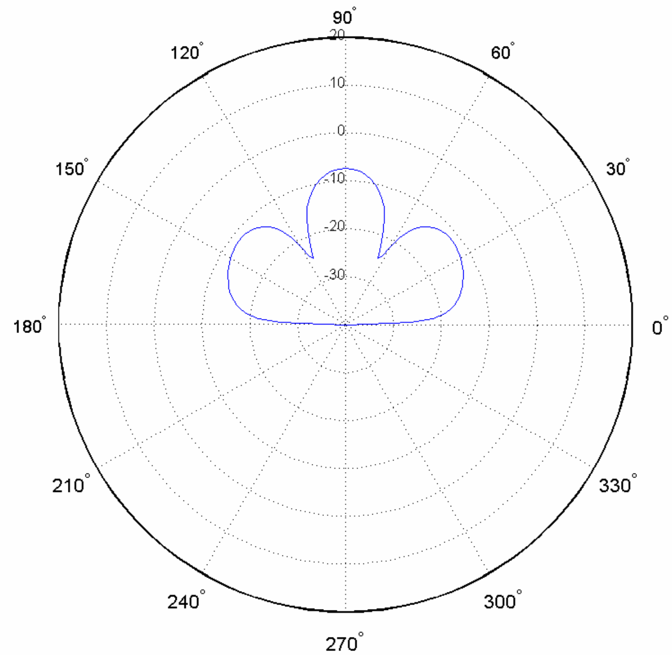


Figure E-9: Elevation pattern at azimuth (phi) = 0, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flj0.png]

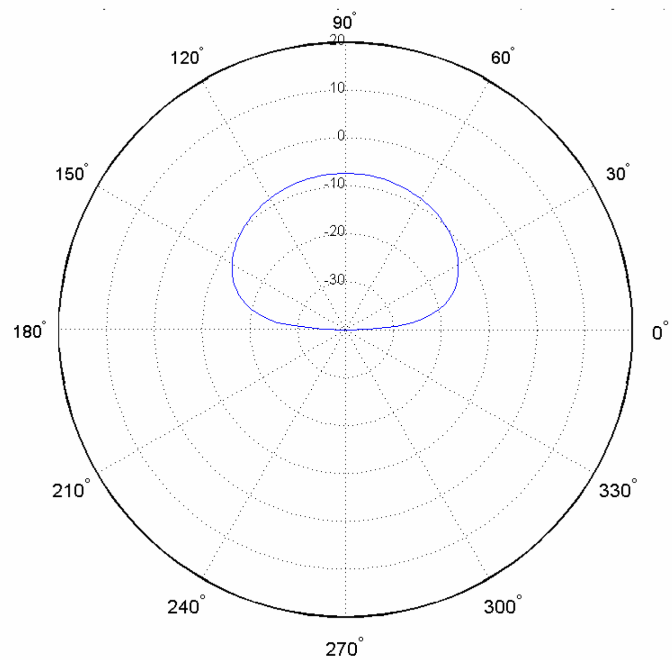


Figure E-10: Elevation pattern at azimuth (phi) = 90, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flj90.png]

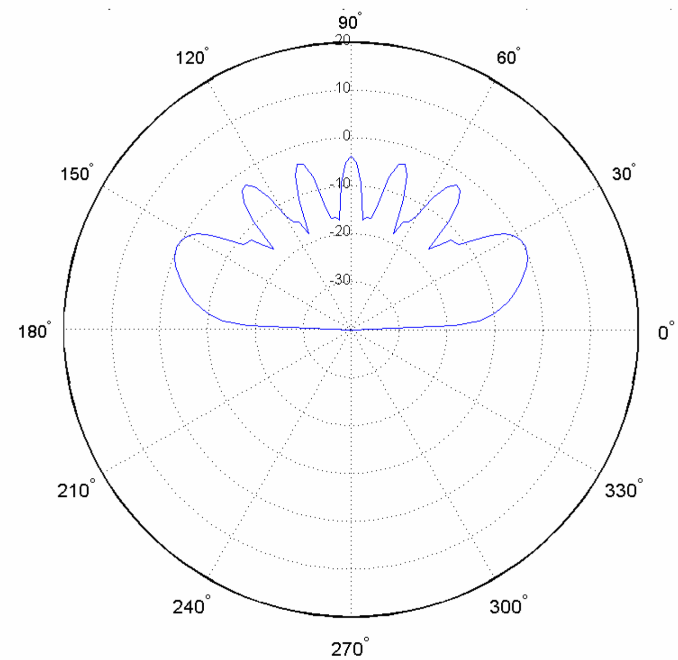


Figure E-11: Elevation pattern at azimuth (phi) = 0, line length = 100 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flm0.png]

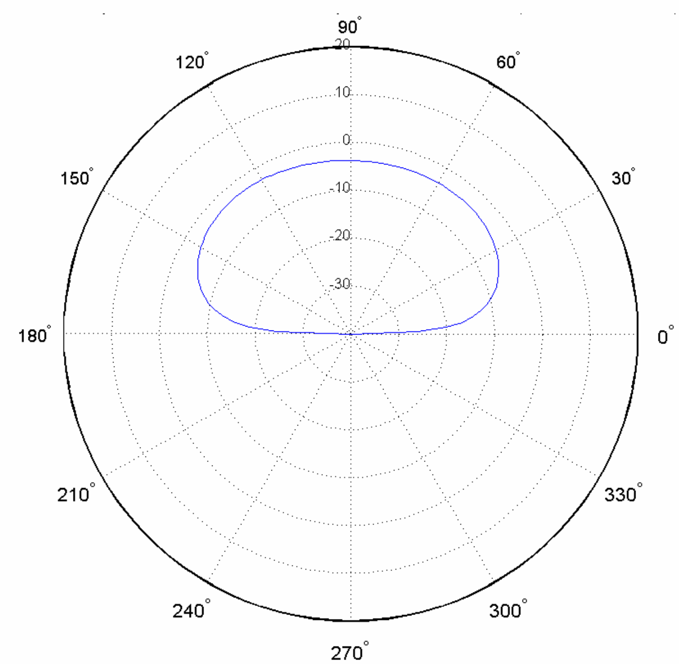


Figure E-12: Elevation pattern at azimuth (phi) =90, line length = 100 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [flm90.png]

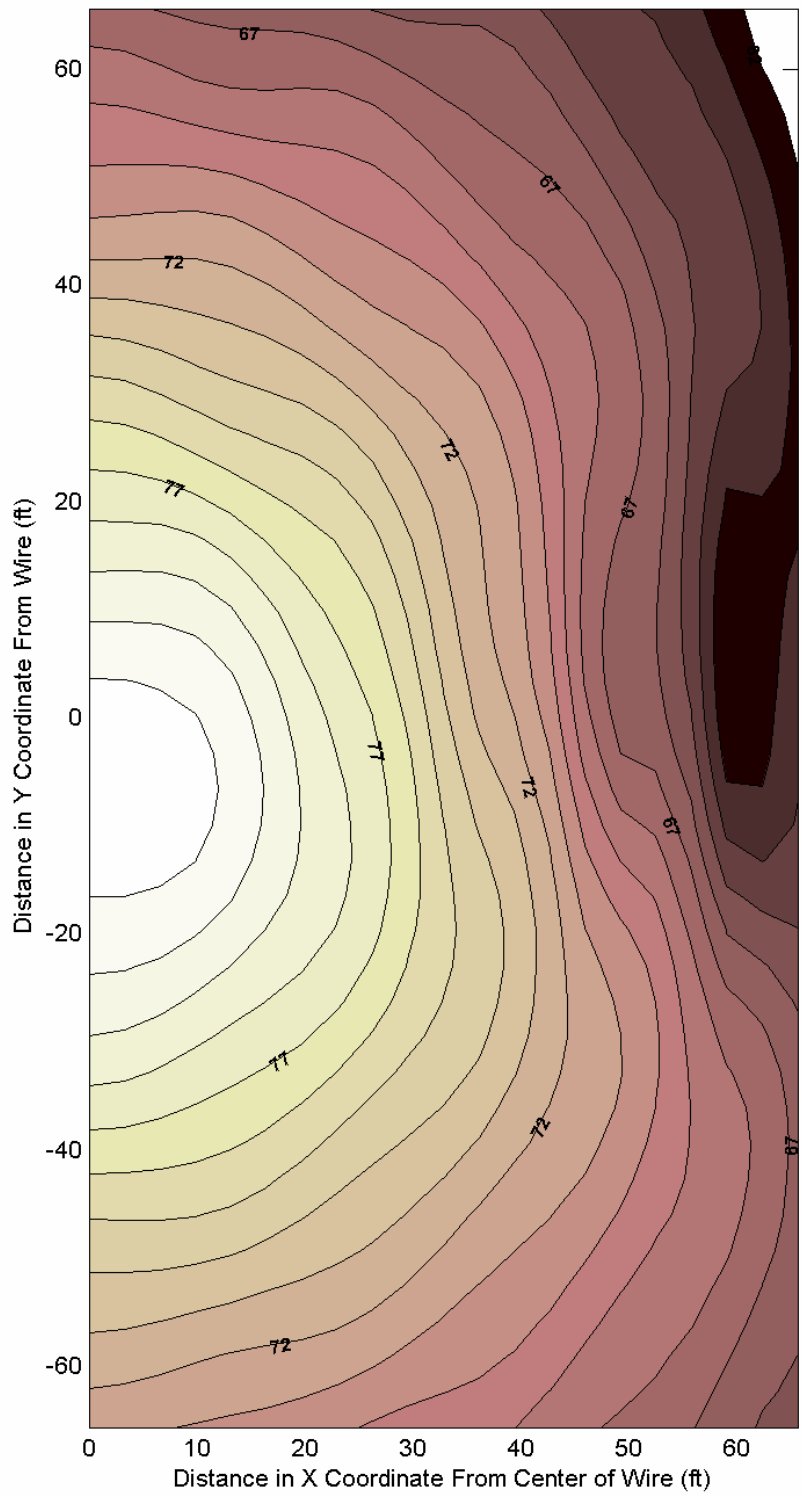


Figure E-13: Electric field strength (E_x) in dBµV/m from 0 to 65.6 feet, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlfex1.png]

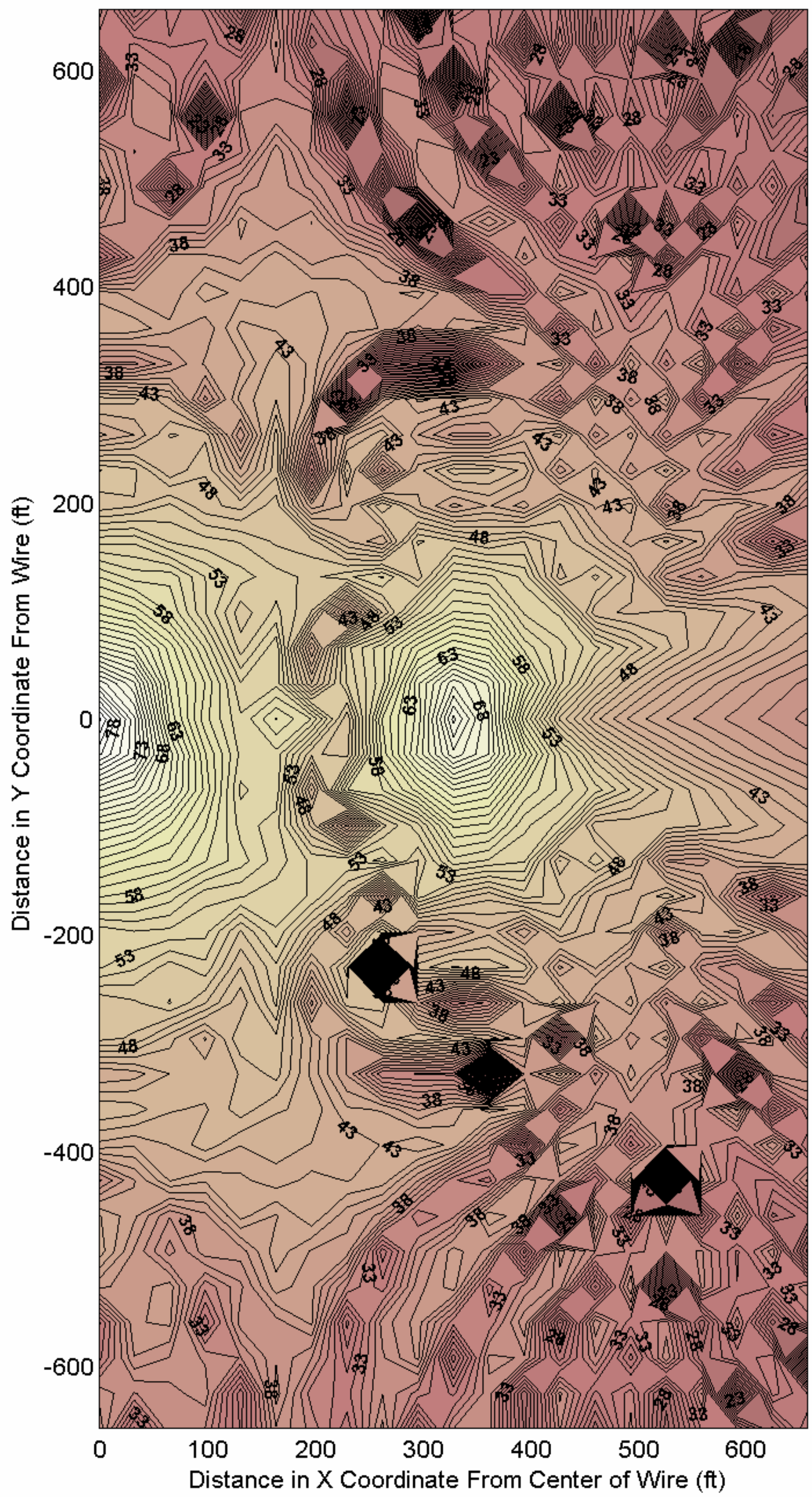


Figure E-14: Electric field strength (E_x) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlfex2.png]

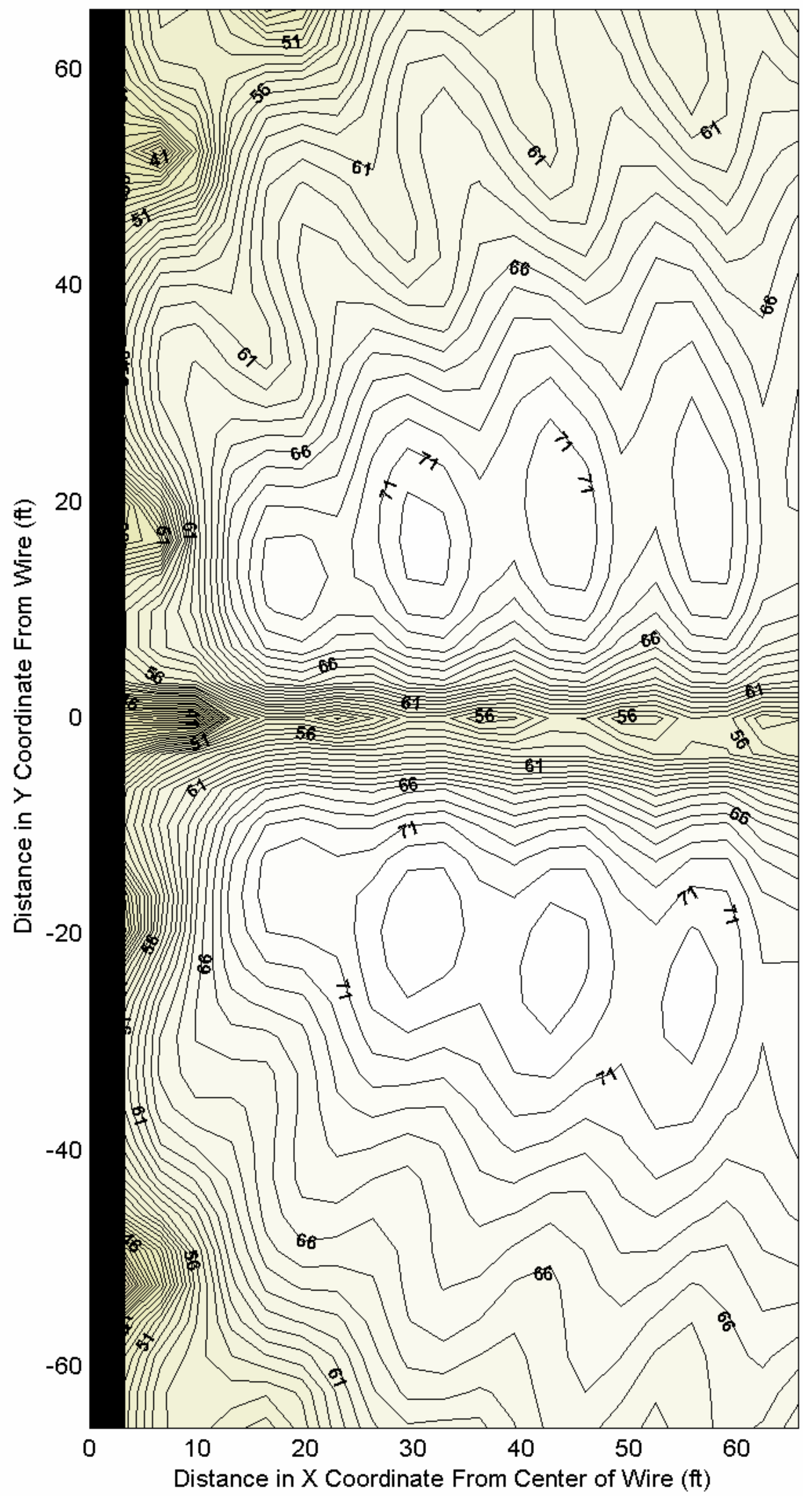


Figure E-15: Electric field strength (E_y) in dBμV/m from 0 to 65.6 feet, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlfey1.png]

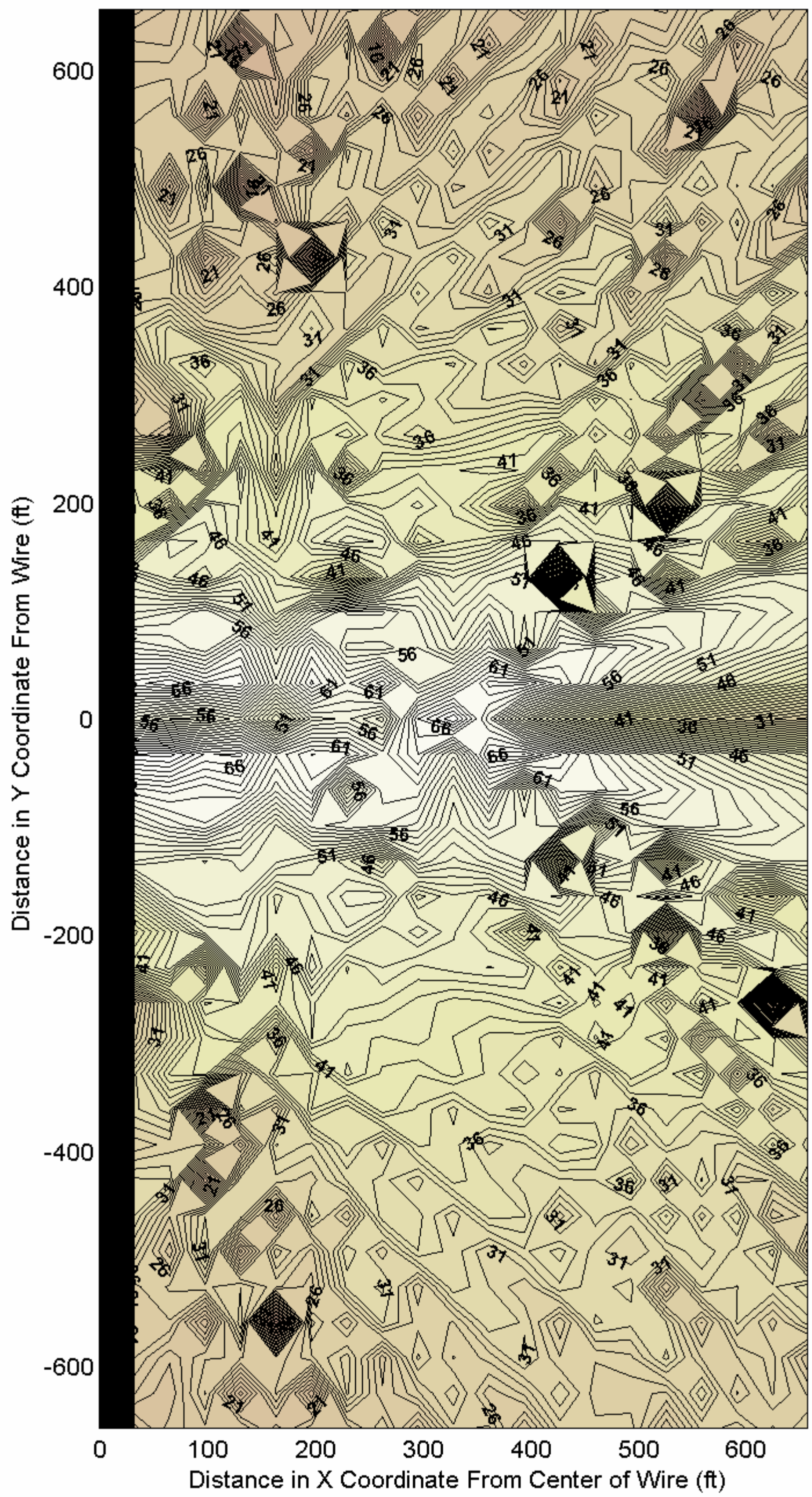


Figure E-16: Electric field strength (E_y) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlfey2.png]

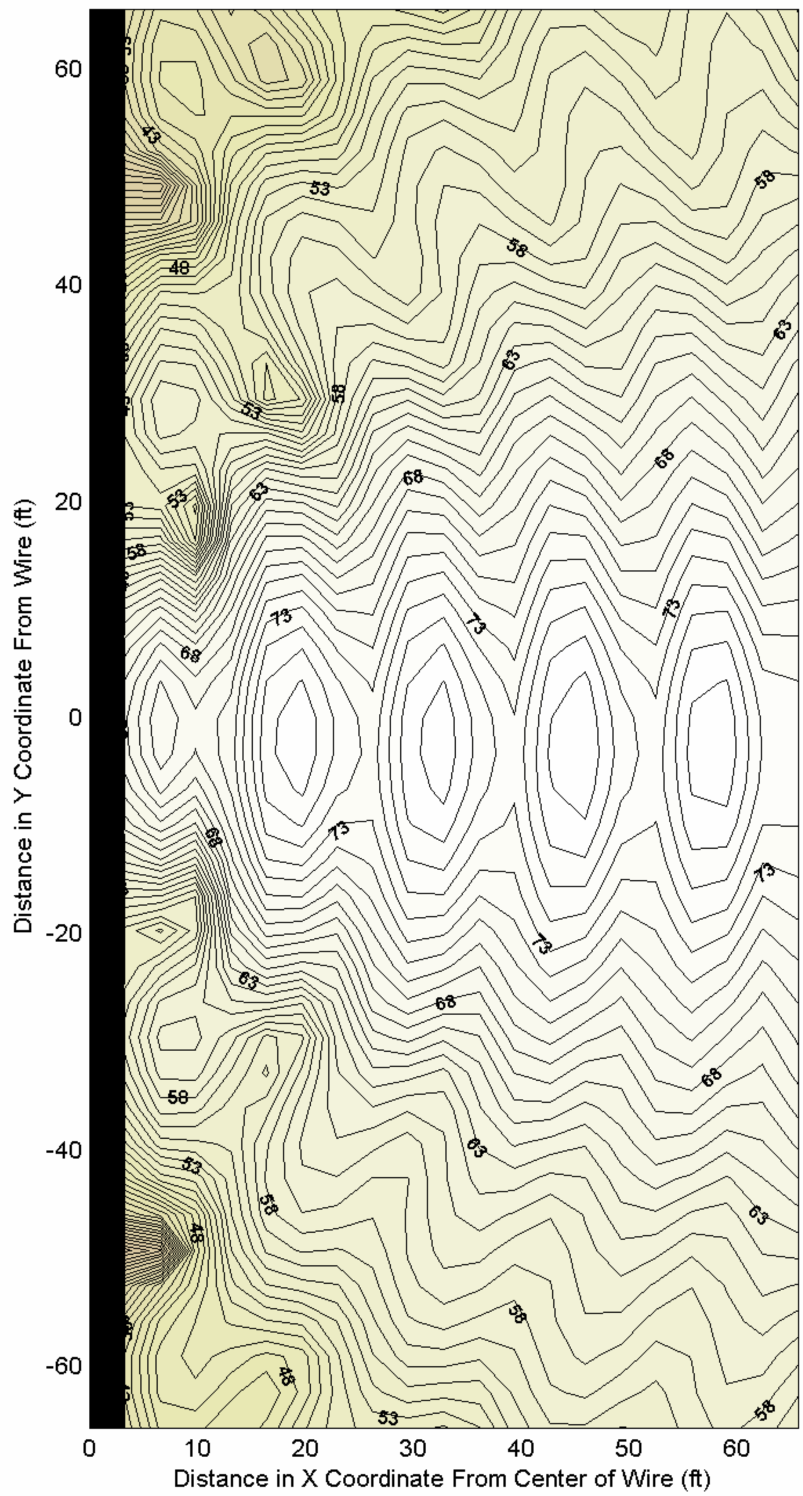


Figure E-17: Electric field strength (E_z) in dBµV/m from 0 to 65.6 feet, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlfez1.png]

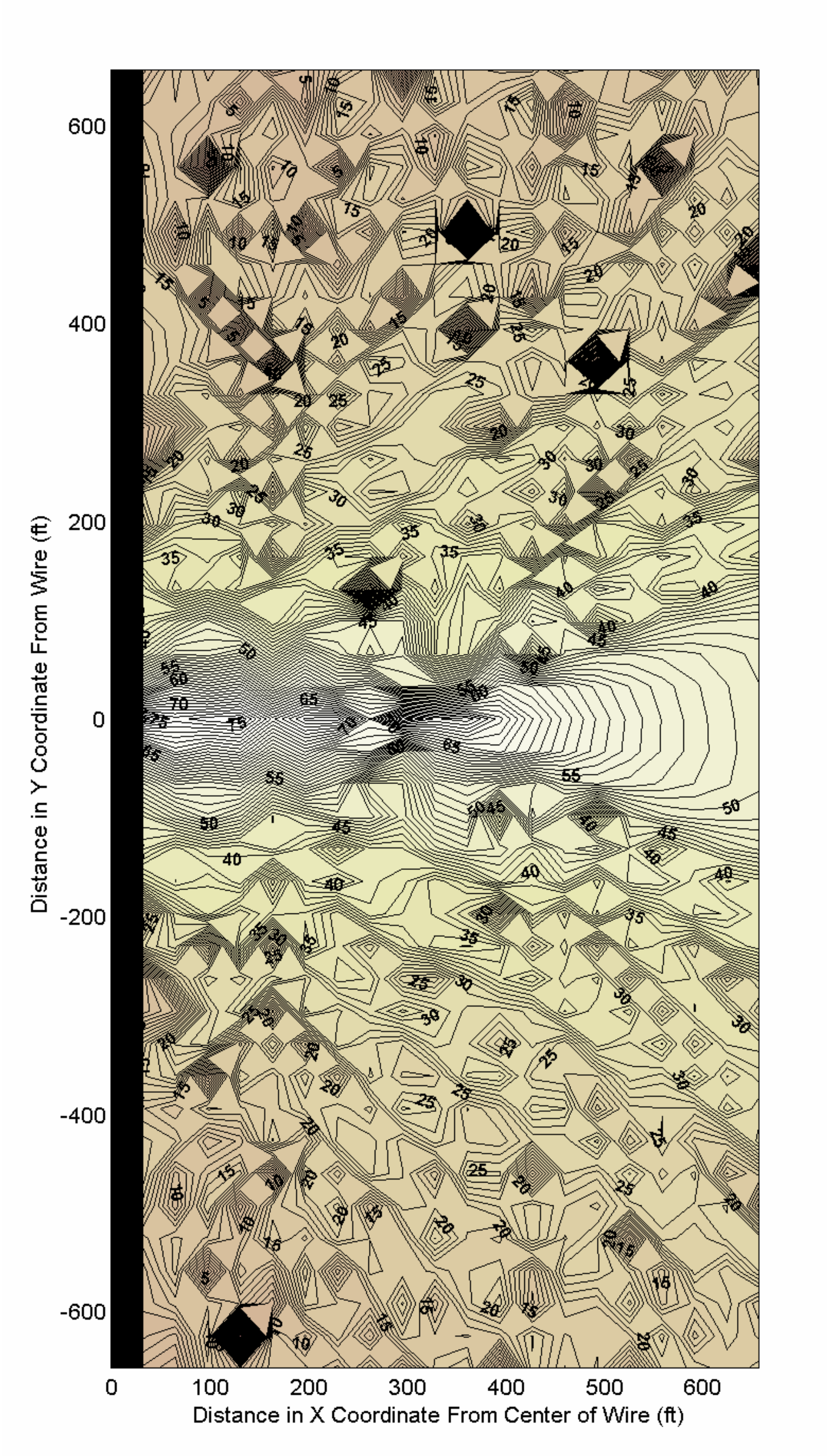


Figure E-18: Electric field strength (E_z) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 40 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlfez2.png]

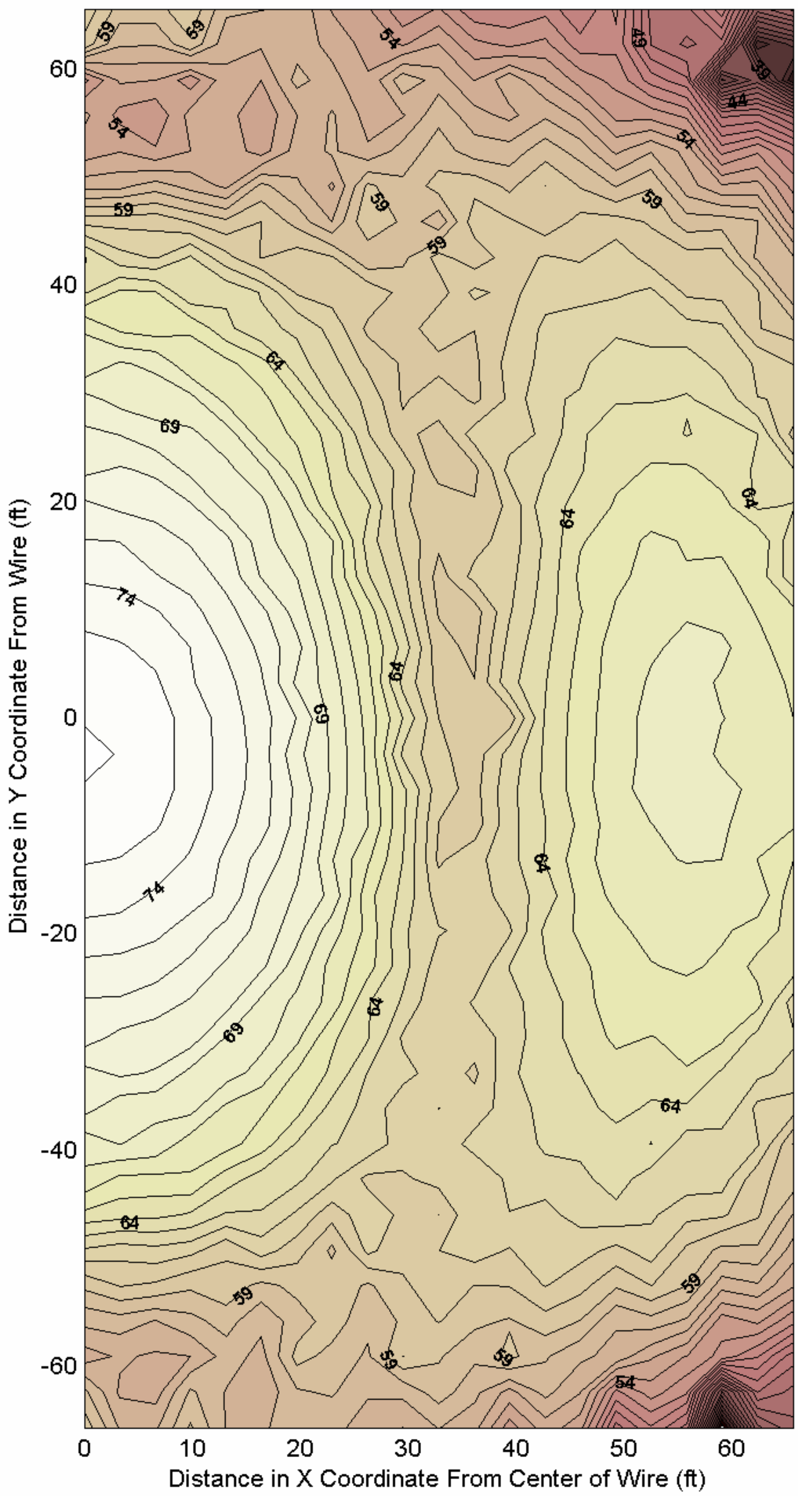


Figure E-19: Electric field strength (E_x) in dBµV/m from 0 to 65.6 feet, line length = 200 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlhex1.png]

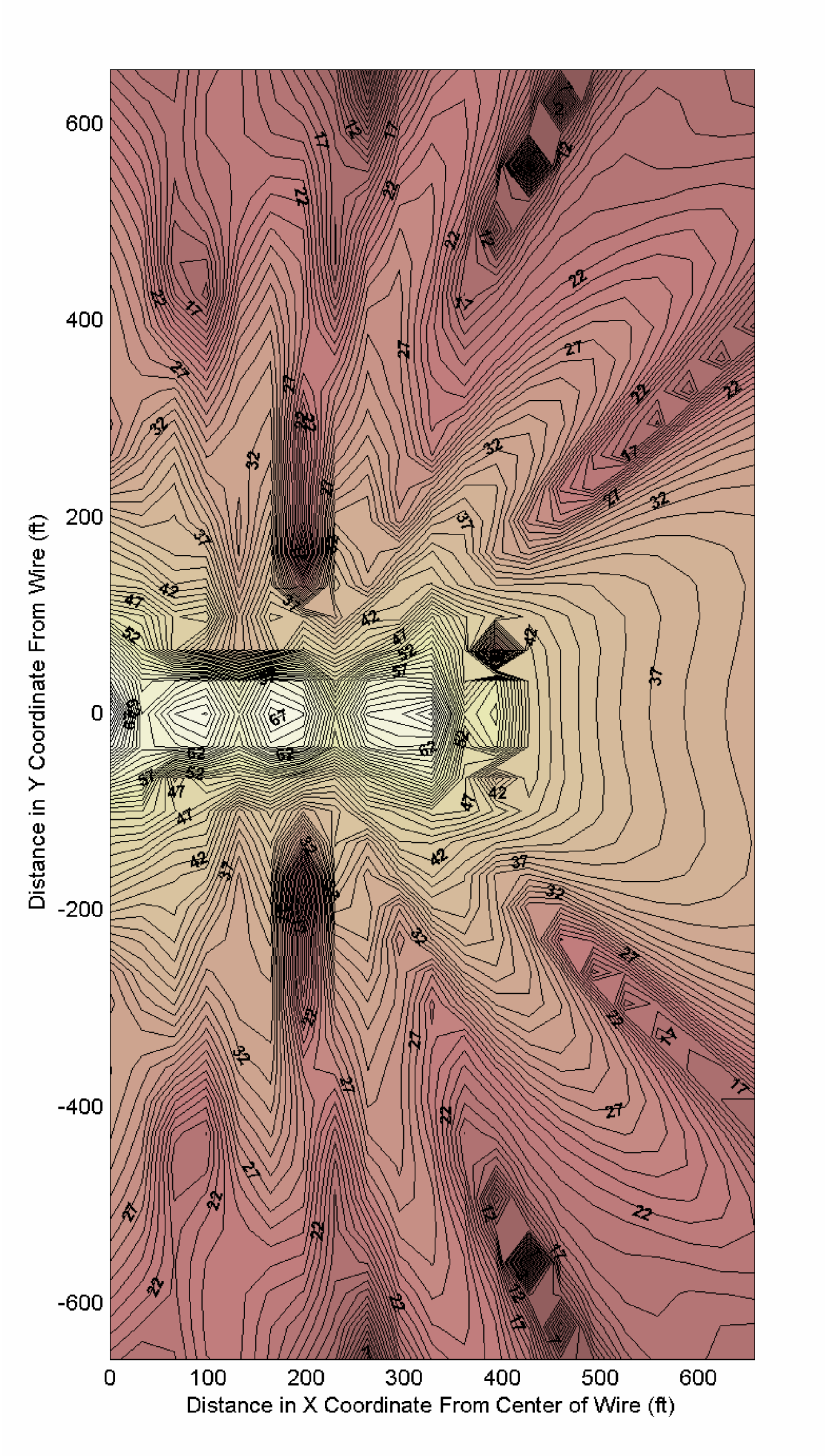


Figure E-20: Electric field strength (E_x) in dBµV/m from 65.6 to 656 feet, line length = 200 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlhex2.png]

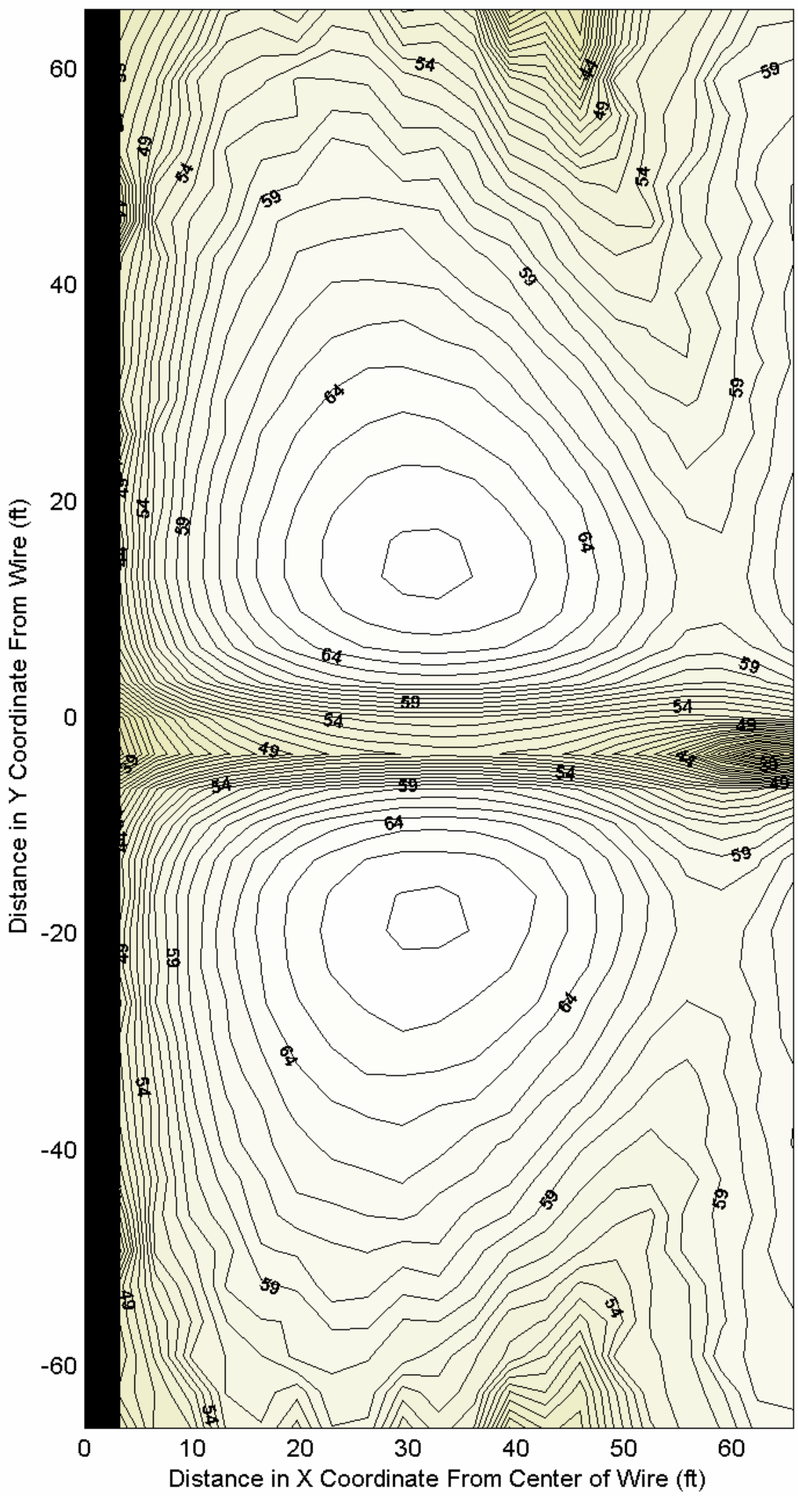


Figure E-21: Electric field strength (E_y) in dBµV/m from 0 to 65.6 feet, line length = 200 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlhey1.png]

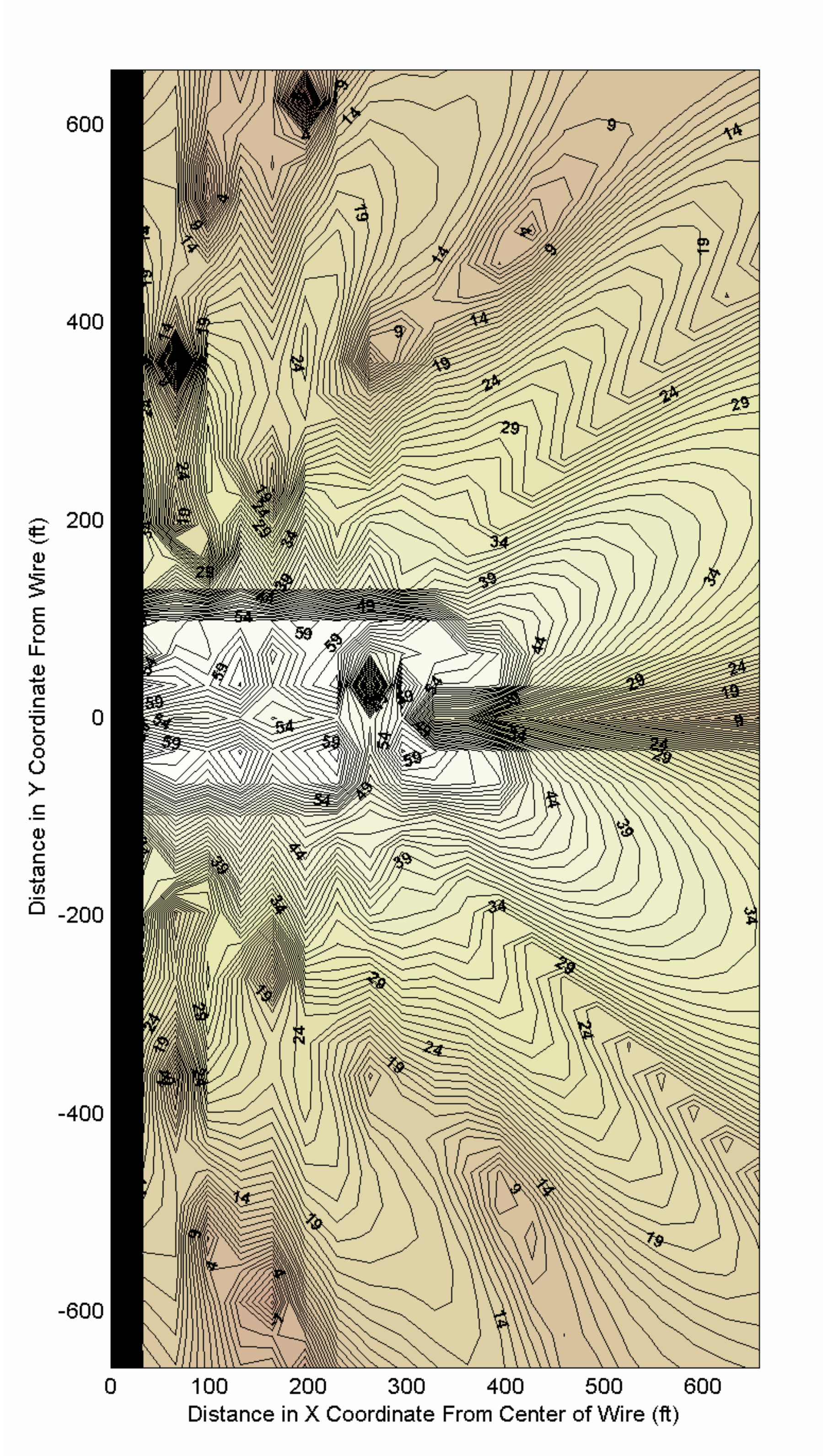


Figure E-22: Electric field strength (E_y) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlhey2.png]

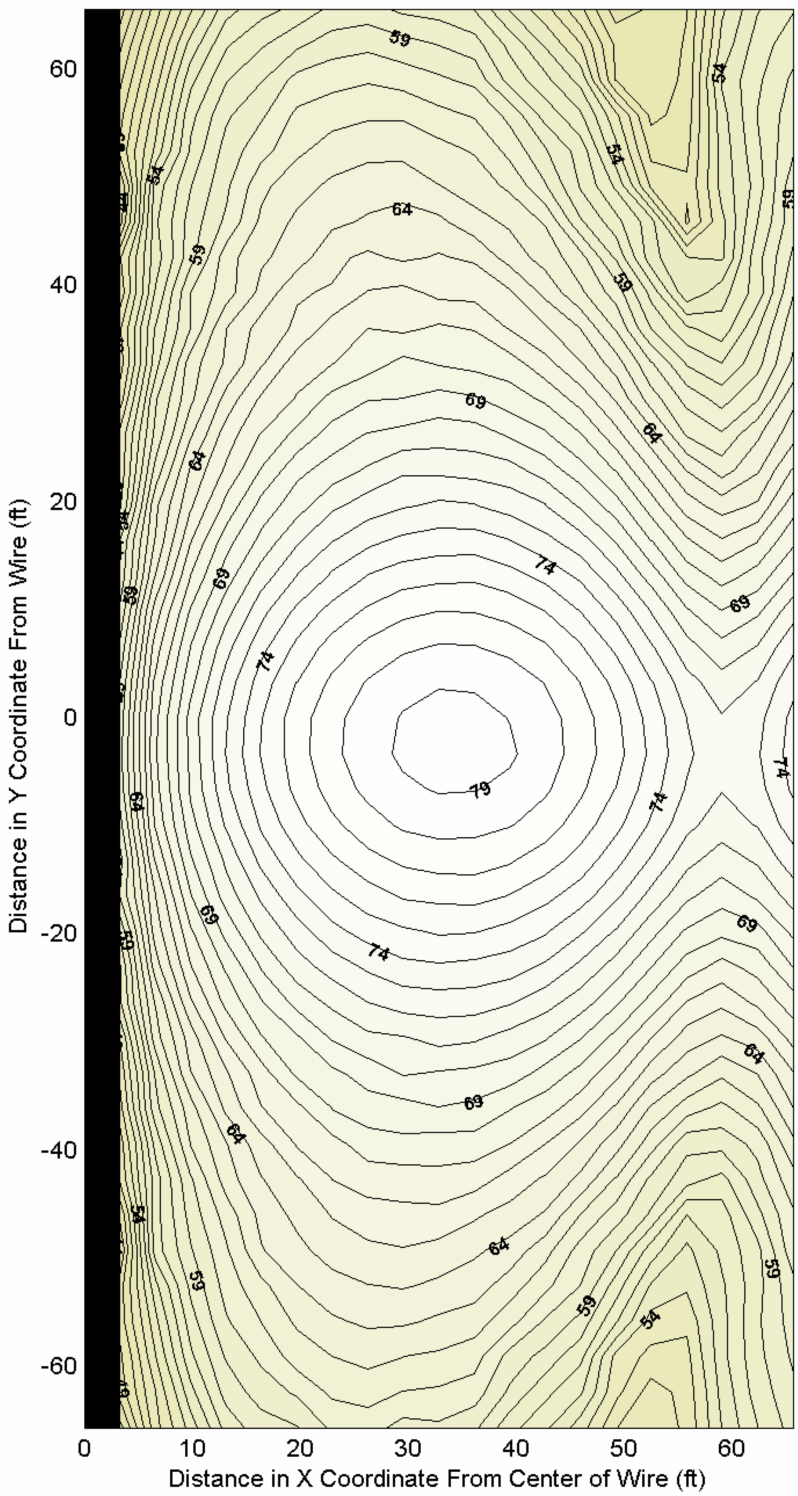


Figure E-23: Electric field strength (E_z) in dBµV/m from 0 to 65.6 feet, line length = 200 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlhez1.png]

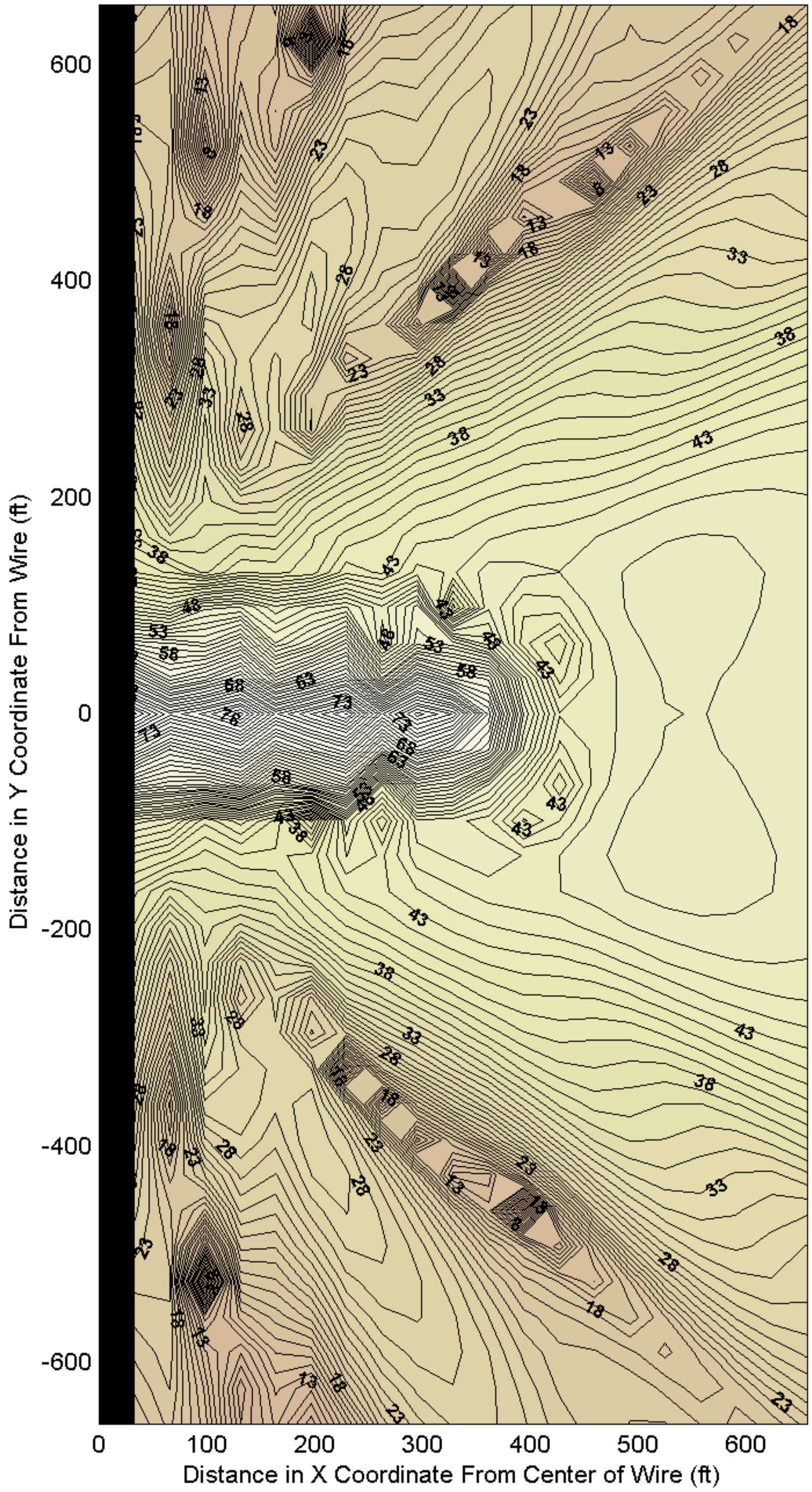


Figure E-24: Electric field strength (E_z) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 10 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nlhez2.png]

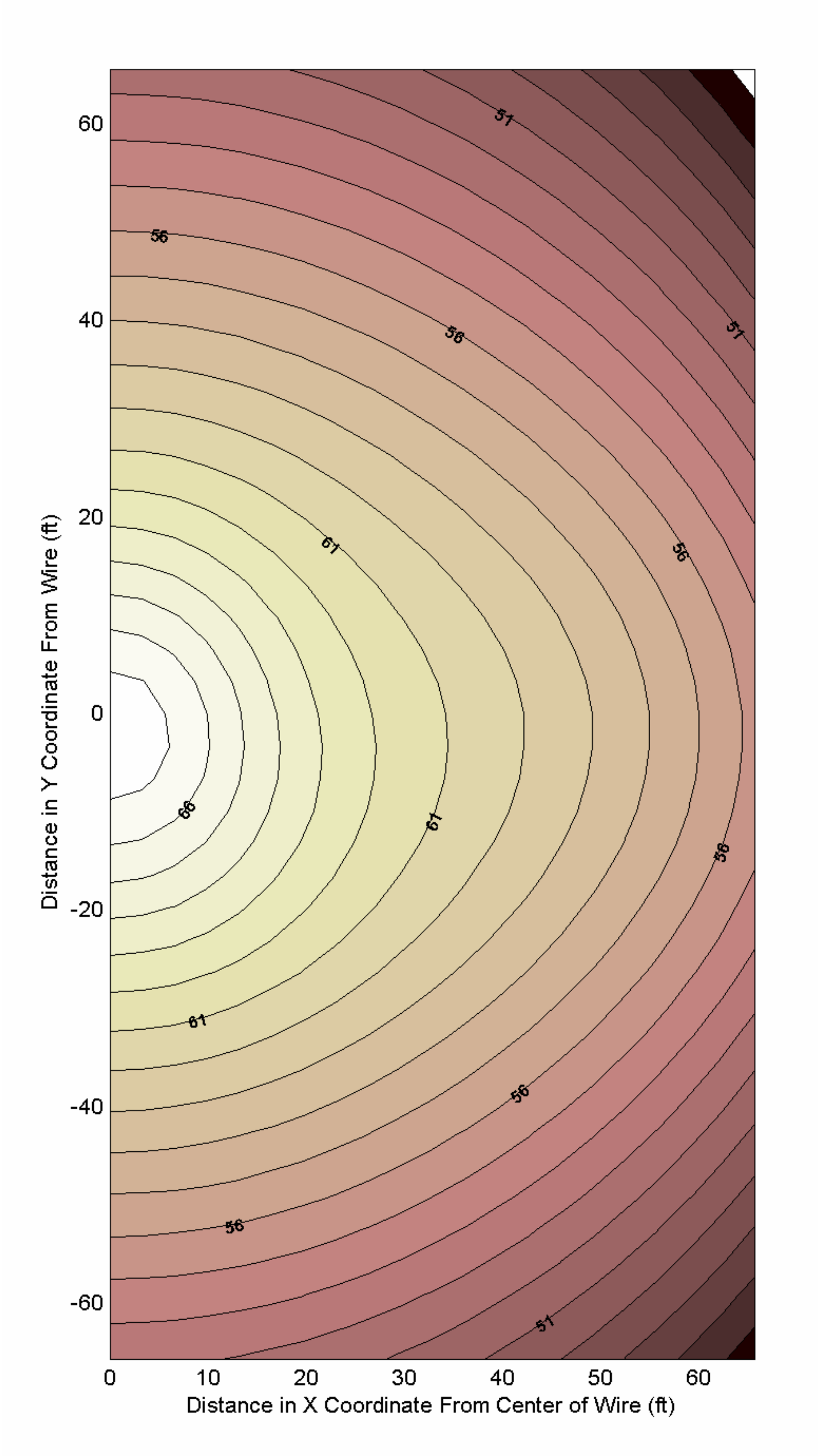


Figure E-25: Electric field strength (E_x) in dBμV/m from 0 to 65.6 feet, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nljex1.png]

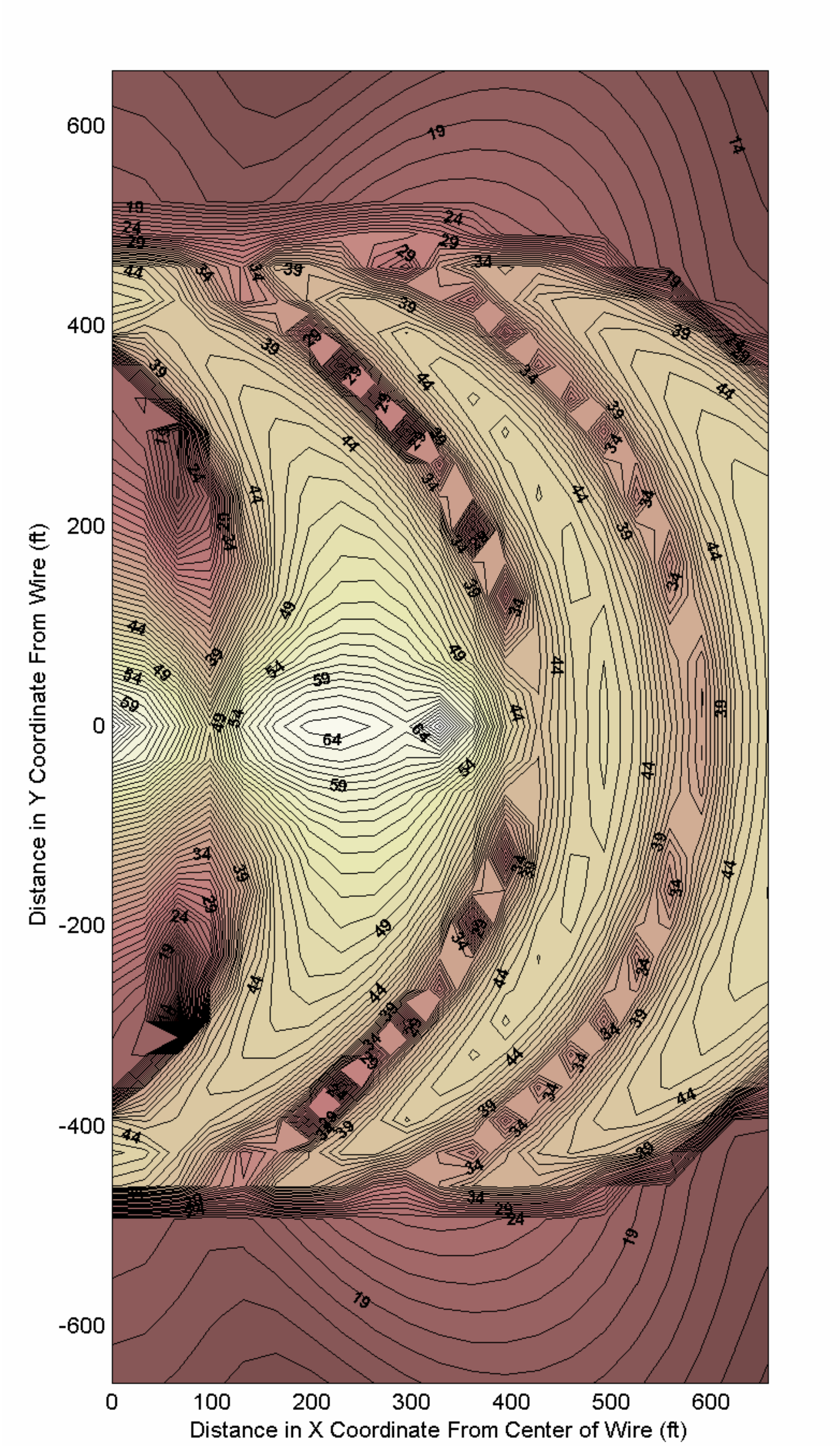


Figure E-26: Electric field strength (E_x) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nljex2.png]

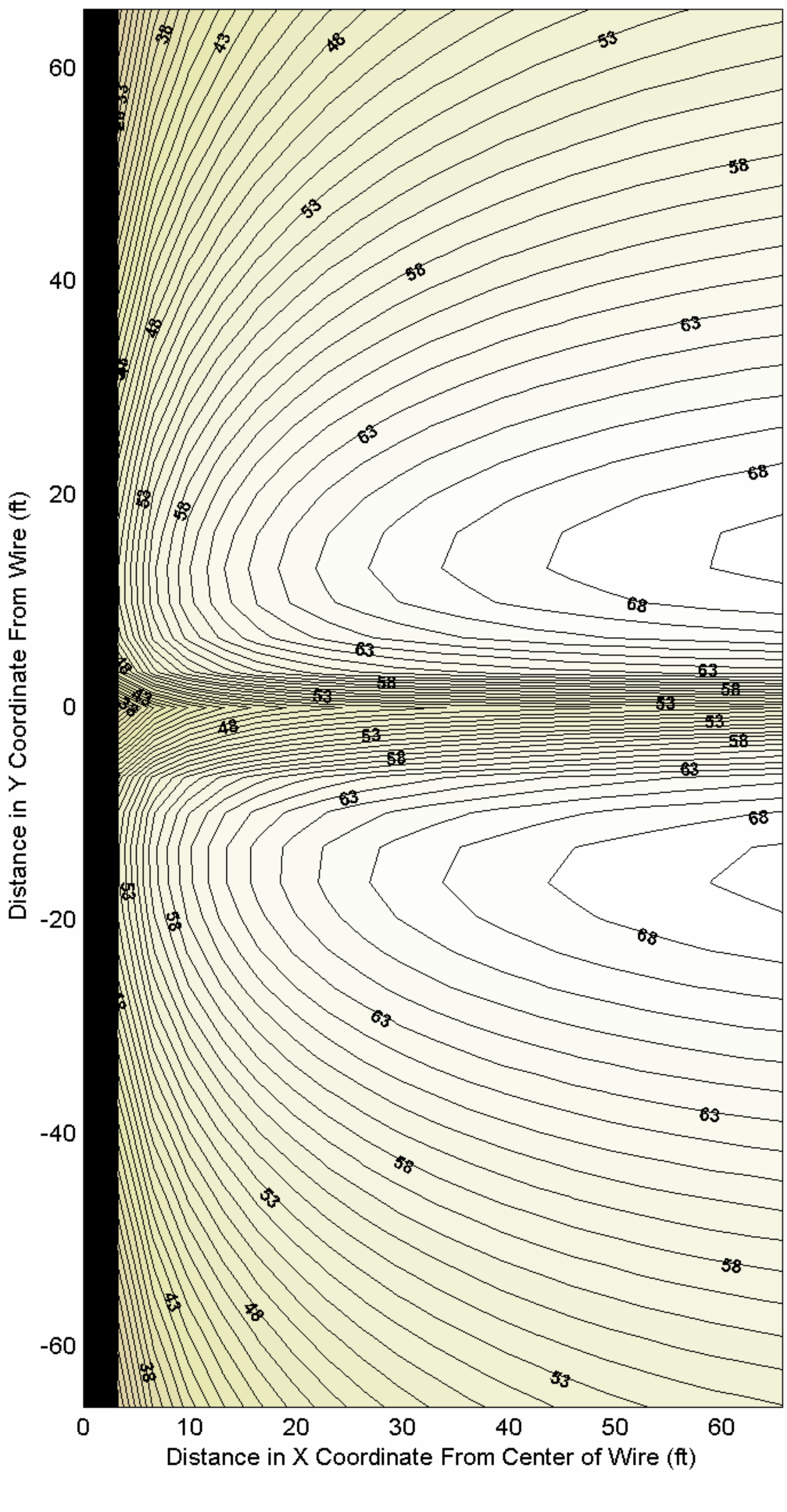


Figure E-27: Electric field strength (E_y) in dBμV/m from 0 to 65.6 feet, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nljey1.png]

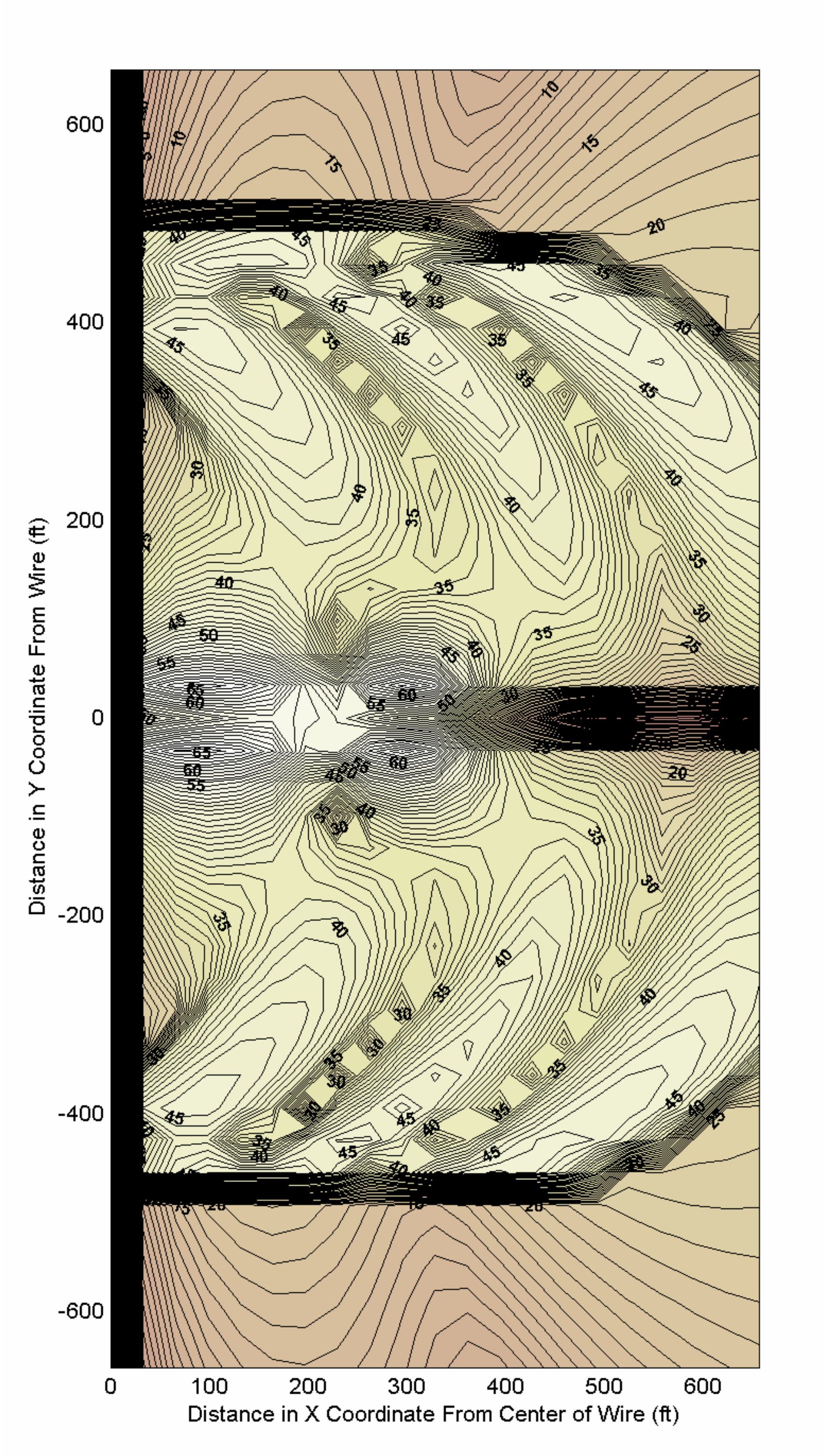


Figure E-28: Electric field strength (E_y) in dBµV/m from 65.6 to 656 feet, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nljey2.png]

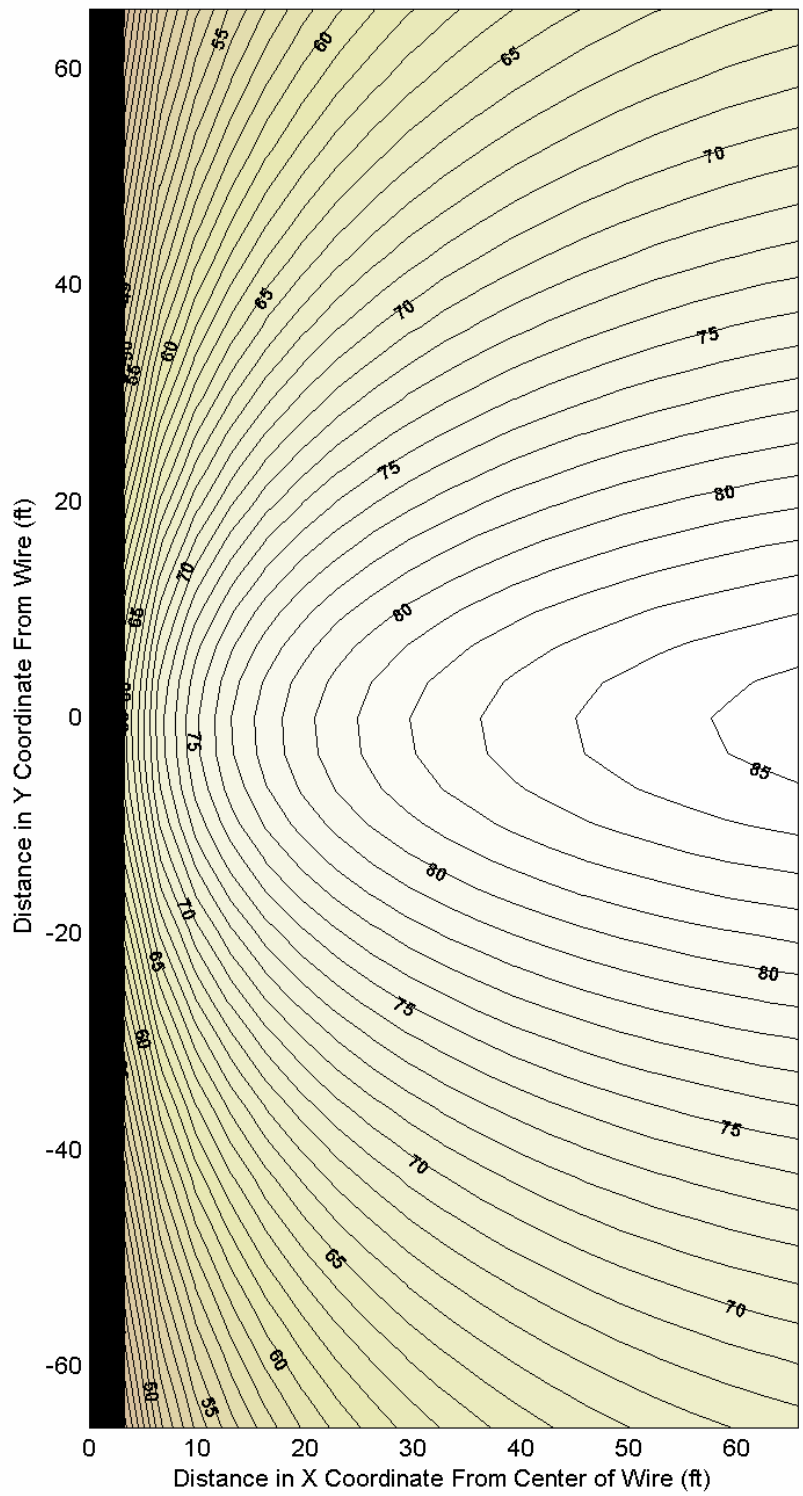


Figure E-29: Electric field strength (E_z) in dBμV/m from 0 to 65.6 feet, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nljez1.png]

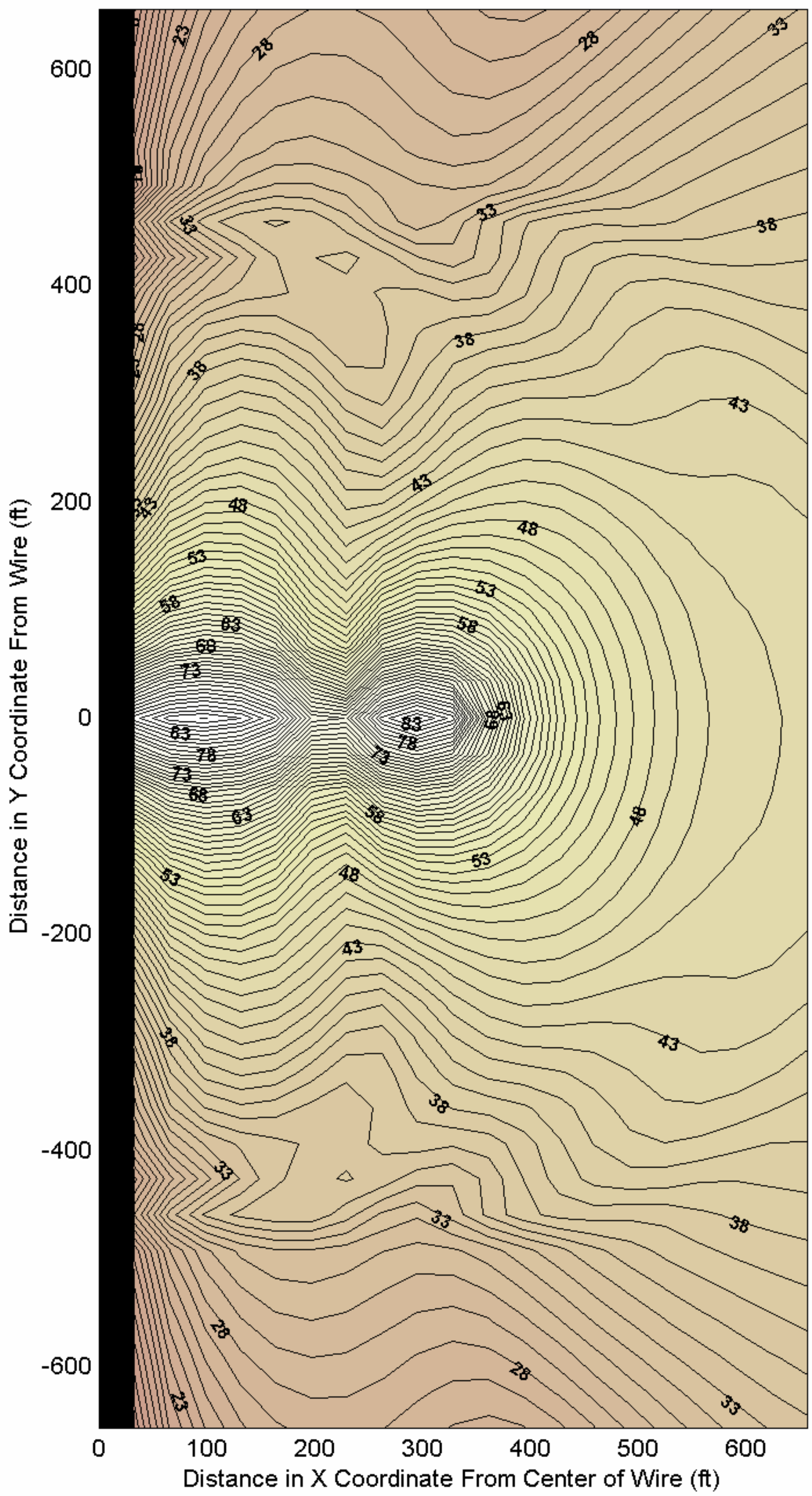


Figure E-30: Electric field strength (E_z) in dBμV/m from 65.6 to 656 feet, line length = 200 m, frequency = 2 MHz, source impedance = 150 Ω, load impedance = 575 Ω [nljez2.png]

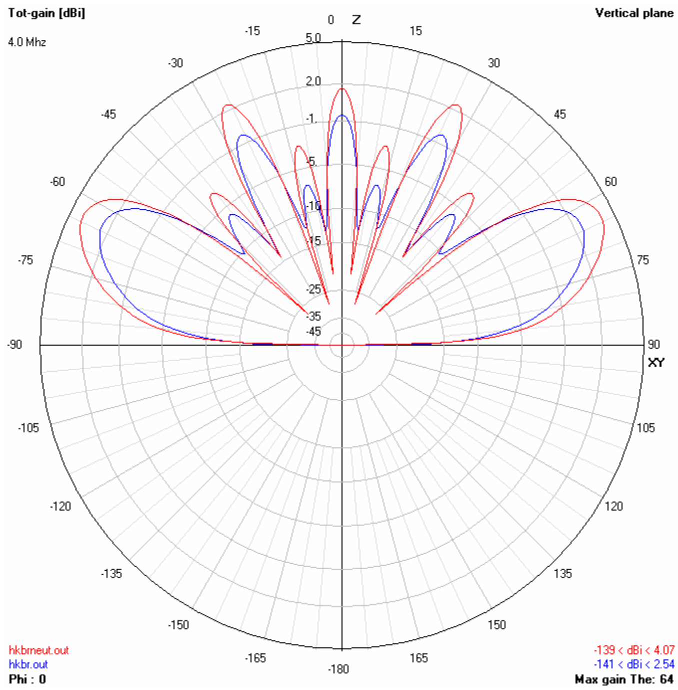


Figure E-31: Comparison of NEC model with and without a parasitic multi-grounded neutral. Red curve is with neutral, blue curve is without a neutral (4 MHz).

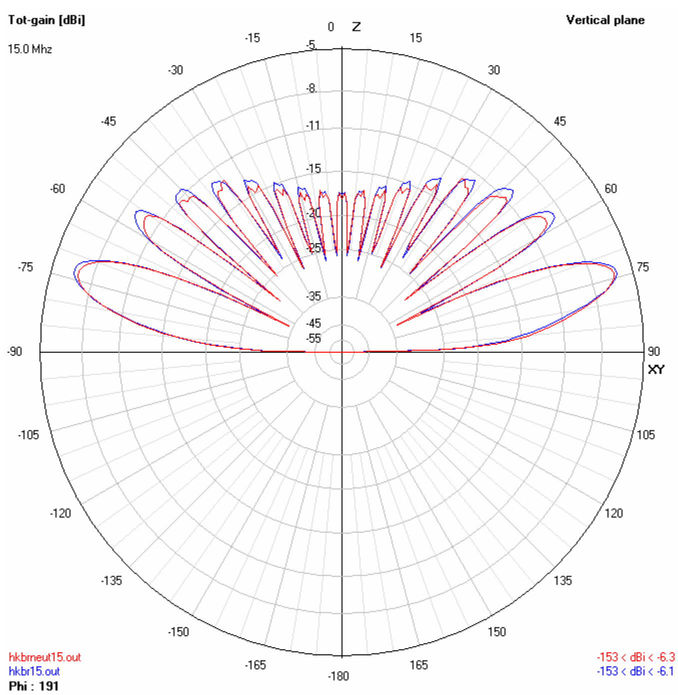


Figure E-32: Comparison of NEC model with and without a parasitic multi-grounded neutral. Red curve is with neutral, blue curve is without a neutral (15 MHz).

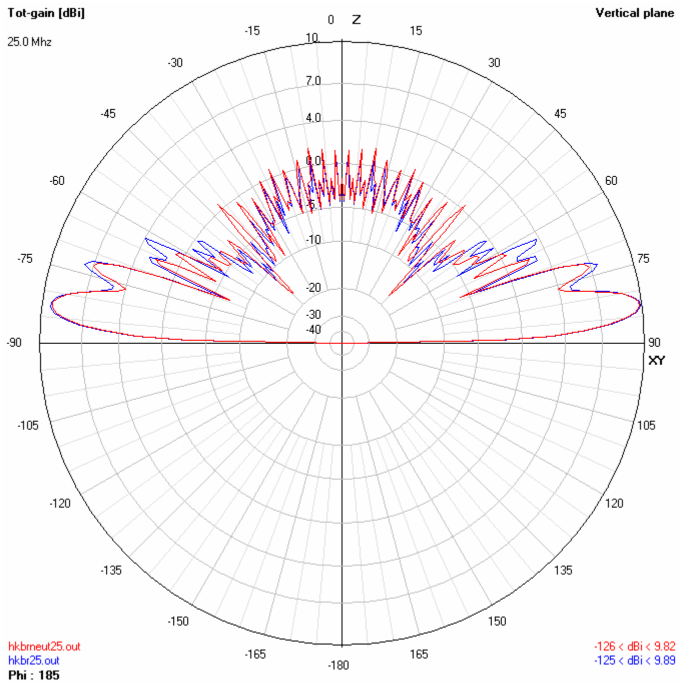


Figure E-33: Comparison of NEC model with and without a parasitic multi-grounded neutral. Red curve is with neutral, blue curve is without a neutral (25 MHz).

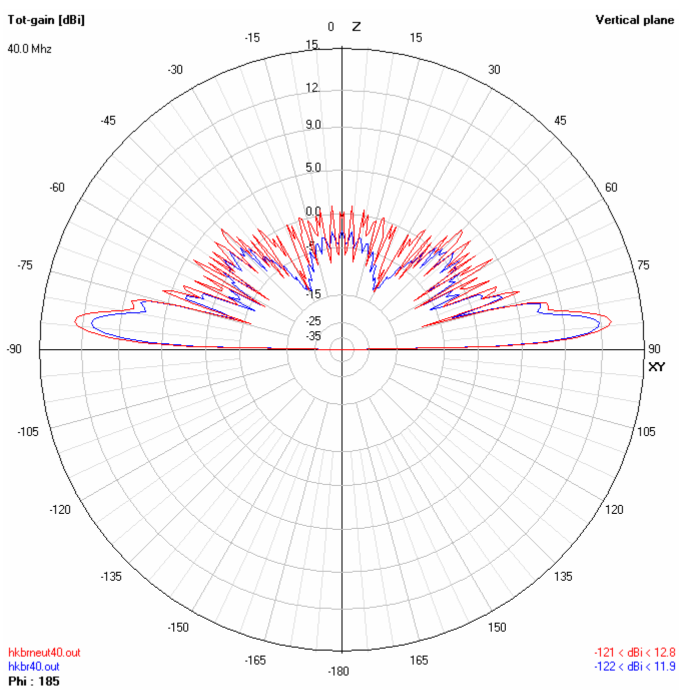


Figure E-34: Comparison of NEC model with and without a parasitic multi-grounded neutral. Red curve is with neutral, blue curve is without a neutral (40 MHz).

APPENDIX F
NTIA PHASE 2 STUDY BPL DEPLOYMENT MODELS

F.1 INTRODUCTION

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

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

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

F.2 NEIGHBORHOOD DEPLOYMENT MODEL

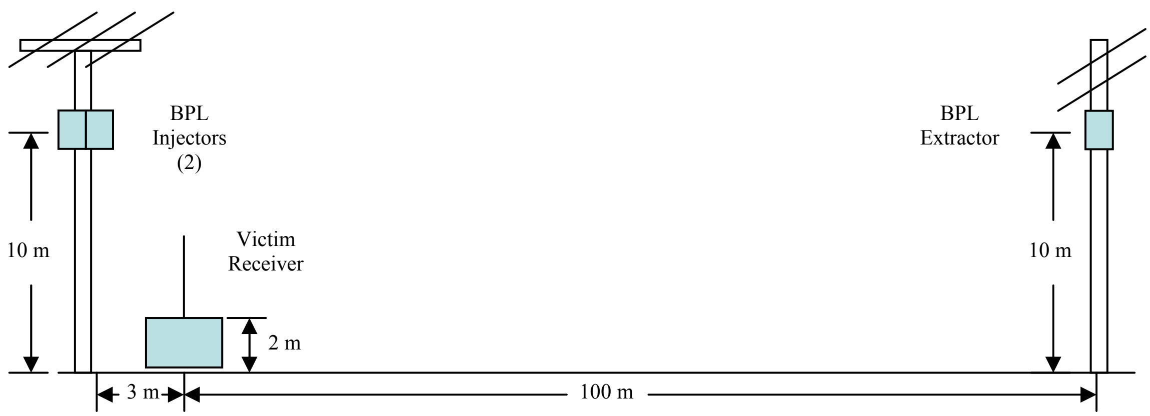
The neighborhood deployment model addresses the case of a land mobile radio operating inside a BPL service area. The land mobile radio may be within 10 meters of the nearest active BPL device and one block away from another simultaneously active,

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

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

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

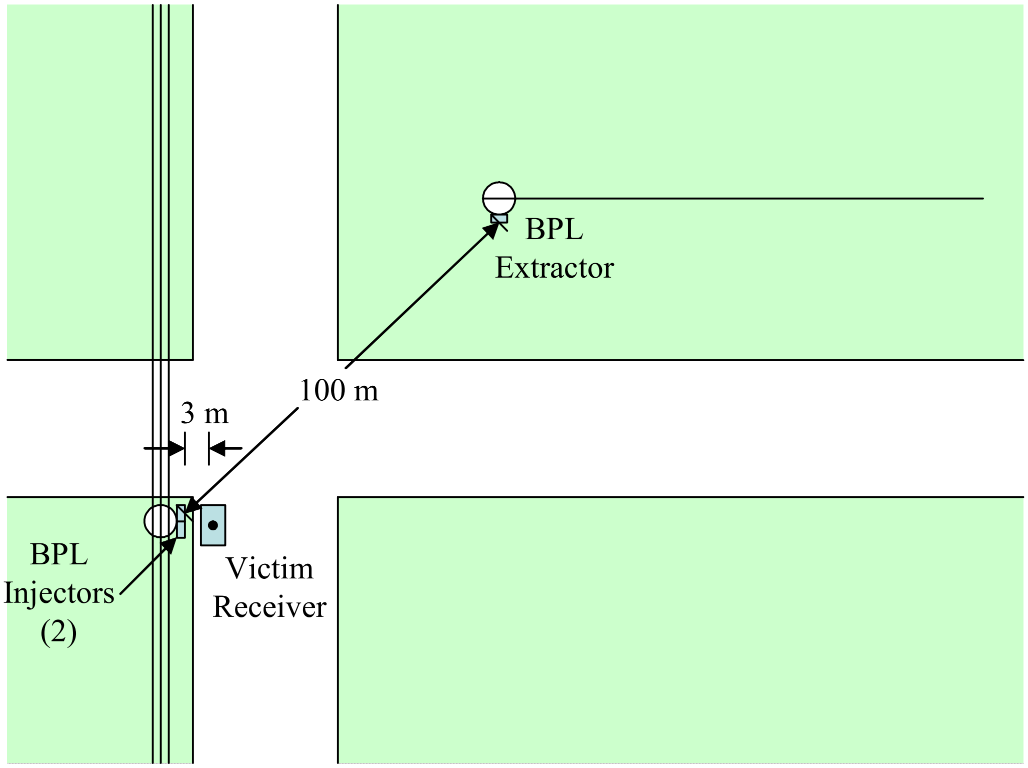
- Victim HF receiver with whip antenna located 2 meters above the ground;
- Two BPL injectors mounted on the same power pole, located no closer than 3 meters lateral to the victim receiver and 10 meters above the ground (location of receiver will be varied);
- A co-channel BPL extractor at 10 meters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



(a) Horizontal View

Figure F-1: Assumed Aggregate Neighborhood Deployment Scenario

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



(b) Overhead View

Figure F-1 continued: Assumed Aggregate Neighborhood Deployment Scenario

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

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

F.3 ANTENNA COVERAGE AREA DEPLOYMENT MODEL

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

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

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

F.4 REGIONAL DEPLOYMENT MODEL

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

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

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

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

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

F.4.1 Regional Deployment Model Description

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

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

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

F.4.2 Density and Distribution of Households

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

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

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

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

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

F.4.3 Density and Distribution of BPL Devices

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

F.4.3.1 Injectors

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

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

F.4.3.2 Repeaters

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

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

F.4.3.3 Extractors

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

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

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

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

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

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

F.4.4 Other Factors

F.4.4.1 Frequency Range

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

F.4.4.2 Frequency Reuse

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

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

Table F-1: BPL Frequency Bands per Cell

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

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

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

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

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

F.4.4.3 Media Access

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

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

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

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

F.4.4.4 BPL Market Penetration

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

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

F.4.5 Regional Model Output

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

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