

NCS TIB 07-1



NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN 07-1

Broadband over Power Lines

January 2007

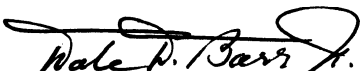
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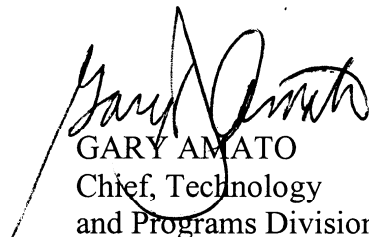
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FOREWORD

Among the responsibilities assigned to the Office of the Manager, National Communications System (NCS) is the management of the Federal Telecommunications Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunications Standards Committee identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunications systems or to the achievement of a compatible and efficient interface between computer and telecommunications systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the International Organization for Standardization, the International Telecommunication Union Telecommunications Standardization Sector, and the American National Standards Institute.

This Technical Information Bulletin presents an overview of the "state of the art" of Broadband over Powerline (BPL) technologies. It has been prepared to inform interested Federal and industry activities. BPL is a proven telecommunications transmission technology that can support – and expedite - emergency NS/EP response. The FCC closely monitors and coordinates BPL applications to avoid any regulatory or technical issues.

Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

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Broadband over Power Lines



**Office of the Manager
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January 2007

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Broadband over Power Lines

Abstract

Over the past few years advances in signal processing technology have enabled the advent of modem chips that are able to overcome the transmission difficulties associated with sending communications signals over electrical power lines. In the United States, this capability has been termed “Broadband over Power Lines” or BPL. There are two predominant types of BPL communications configurations: Access BPL and In-Home BPL. Access BPL is comprised of injectors (used to inject High Frequency (HF) signals onto medium or low voltage power lines), extractors (used to retrieve these signals) and repeaters (used to regenerate signals to prevent attenuation losses). In addition to taking advantage of the power line infrastructure, In-Home BPL modems utilize the existing house wiring to provision a Local Area Network (LAN) that can be used throughout the home. One of the largest commercial markets for BPL is the ability to provide Internet Services by means of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocols, which can support voice, data, and video services. Another significant benefit of BPL is the ability to employ “intelligent” power line networks that make use of Supervisory Control and Data Acquisition (SCADA)¹ devices, dynamic provisioning, and other forms of modernized electrical power networks. A SCADA system can save time and money by reducing the need for service personnel to physically visit each site for inspection, data collection, and routine logging or even to make adjustments. The benefits also include the ability for real-time monitoring, system modifications, troubleshooting, increased equipment life, and automatic report generating.

The Federal Communications Commission (FCC) monitors approximately 59,000 frequencies for military, National Security & Emergency Preparedness (NS/EP), and other purposes. A key concern associated with BPL is that coupling of HF signals onto unshielded wiring, such as that used for outdoor power lines, may generate interference signals that could impact licensed services such as amateur radio, or “hams”. Public safety agencies including fire, police, the Red Cross and other agencies also depend on the use of the special propagation properties found only in the HF radio spectrum. This Technical Information Bulletin (TIB) examines the architecture and considers possible benefits and concerns of BPL technology with respect to the National Communications System (NCS) and the communication requirements for NS/EP.

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1 Introduction

The National Communications System (NCS) was established through a Presidential Memorandum signed by President John Kennedy on August 21, 1963. The memorandum assigned the NCS the responsibility of providing necessary communications for the Federal Government under national emergency conditions by linking together, improving, and expanding the communication capabilities of the various agencies.

In April 1984, President Ronald Reagan signed Executive Order (E.O.) 12472, Assignment of National Security and Emergency Preparedness (NS/EP) Telecommunications Functions,ⁱⁱ which broadened the mission and focus. Since that time, the NCS has been assisting the President and the Executive Office of the President (EOP) in exercising wartime and non-wartime emergency telecommunications and in coordinating the planning for, and provisioning of, NS/EP communications for the Federal Government under all circumstances. In this regard, the Office of the Manager, the NCS (OMNCS) continually seeks to improve the Federal Government's ability to respond to the telecommunications requirements to support national security and emergency situations. Among these responsibilities, the NCS seeks to ensure that a national telecommunications infrastructure is developed that "is capable of satisfying priority telecommunications requirements under all circumstances." The OMNCS is the appropriate body to communicate NS/EP requirements to standards bodies and participate in related standards activities.

As part of this mission, the NCS Technology and Programs Division (N2) identifies new technologies that enhance NS/EP communications capabilities and ensures key NS/EP features, such as priority, interoperability, reliability, emerging standards support, availability, and security. In concert with this approach, the N2 manages the Federal Telecommunications Standards Program (FTSC). Additionally, the N2 division directs efforts in both NS/EP management and applications services.

On March 1, 2003, President George W. Bush transferred the NCS from the Department of Defense (after nearly 40 years of serving as the NCS's Executive Agent) to the Department of Homeland Security (DHS). The NCS was one of 22 Federal agencies transferred to the Department in accordance with Executive Order(E.O.) 13286.ⁱⁱⁱ A revised Executive Order 12472 reflects the changes of E.O. 13286. Today, the NCS is part of the Office of Cyber Security and Communications (CS&C). CS&C is an element of the DHS National Protection and Programs Directorate headed by the Under Secretary who also serves as the National Communications Manager. This Technical Information Bulletin (TIB) examines Broadband over Power Lines (BPL). It incorporates by reference the FCC 04-245 Report and Order of October 14, 2004 titled: "Amendment of Part 15 Regarding New Requirements and Measurement Guidelines For Access Broadband Over Power Line Systems Carrier Current Systems, Including Broadband Over Power Line Systems" and the updated revised FCC Part 15 regulations released on September 19, 2005.

1.1 Goals

The goals of this TIB are to:

- Present a brief introduction to BPL technology
- Identify the potential benefits of BPL for NS/EP applications in support of Critical Infrastructure Protection (CIP) requirements
- Describe technical issues related to BPL for NS/EP
- Identify areas for further development of the technology that would enhance the government's NS/EP mission performance capabilities

This TIB is intended to provide technical, administrative, and other information pertaining to BPL technology for consideration by the agency members of the NCS. BPL technology has a variety of names around the world including: Power Line Telecommunications (PLT), Power Line Communications (PLC) and others. For consistency, even when material from foreign countries is referenced, BPL is applied throughout this TIB.

1.2 Background and Introduction

According to the Institute for Electronic and Electrical Engineers (IEEE)^{iv} and the International Telecommunications Union (ITU) the United States is lagging behind other countries in the deployment of broadband telecommunications networks. In December 2005 the ITU documented (see Figure 1) that among the top 20 worldwide economies, US broadband deployment ranks in the bottom 20%. In the US, broadband services to the home are largely provided by cable modems and digital subscriber loop (DSL) services. These broadband services operate mostly in the range of 1 - 6 megabits per second (Mb/s) downstream to the user, but only 750 kilobits per second (Kb/s) or less upstream. In most of South Korea, residents have access to 50 - 100 Mb/s, which in many cases is symmetrical. South Korea achieved this infrastructure through a government policy supporting deregulation, competition and investment.

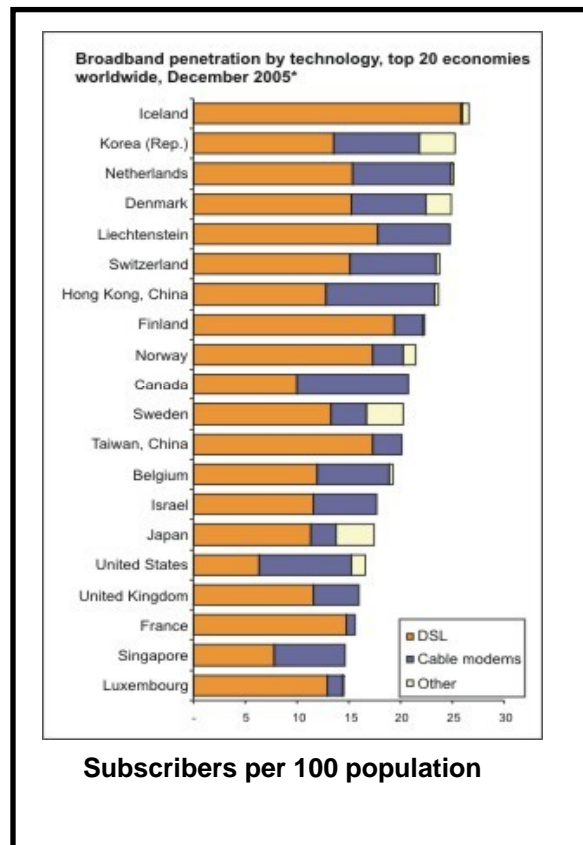


Figure 1: ITU Broadband Adoption.

Japan also adopted competitive policies leading to widespread 50- to 100-Mb/s symmetrical operations with low prices.^v Japan is rapidly deploying symmetric optical fiber networks connected directly to the home. Gigabit per second (Gb/s) availability to Japanese homes began in 2005.

In April of 2003 the FCC issued a Notice of Inquiry (NOI) titled: *“Inquiry Regarding Carrier Current Systems, including Broadband over Power Line Systems.”*^{vi} In the notice the FCC identified BPL as a new type of carrier current system that operates on an unlicensed basis under Part 15 of the FCC’s rules. BPL systems use the existing electrical power lines as a transmission medium to provide high-speed telecommunications capabilities by coupling Radio Frequency (RF) energy onto the power line. In the NOI, the FCC proposed that “because power lines reach virtually every community in the country, BPL could play an important role in providing additional competition in the offering of broadband infrastructure to the American home and consumers.” Additionally, the NOI offered that “BPL could bring internet and high-speed broadband access to rural and underserved areas, which often are difficult to serve due to the high costs associated with upgrading existing infrastructure and interconnecting communication nodes with new technologies.” Thus the FCC has identified that BPL has the potential to become an effective means for “last-mile delivery of broadband services and may offer a competitive alternative to digital subscriber line (DSL), cable modem services, satellite, Wireless Fidelity (WiFi™), fiber optic, and other high speed internet access technologies.” The FCC received approximately 5,000 comments from the NOI and subsequently on October 14, 2004 issued *“Amendment of Part 15 Regarding New Requirements and Measurement Guidelines For Access Broadband Over Power Line Systems Carrier Current Systems, Including Broadband Over Power Line Systems.”*^{vii} This ruling placed the United States under the most liberal BPL regulatory environment found anywhere in order to encourage the rapid deployment of BPL systems.

The capability of using the electrical supply networks for telecommunications has been known since the 1800s. In the US, during the 1920s, AT&T was awarded several patents for these technologies. During the 1930s, ripple carrier signaling (RCS) began to operate on power lines. RCS used the frequency range 125 Hz - 3 KHz with amplitude shift keying (ASK) modulation. RCS provided data rates in the order of a few bits per second but this was sufficient for the load management and automatic reconfiguration of power distribution networks that were the most important tasks performed using RCS. In the 1950s, power utilities were using low frequencies (<1 kHz) to send control messages to equipment on the power grid. By the 1980s, bi-directional communications in the 5 – 500 kHz band were being used. Following these narrowband, low-data-rate BPL applications, broadband BPL started to develop and today commercialized products for LAN applications and Internet access are becoming more widely available.

BPL is an interdisciplinary topic that includes: antennas and propagation, power engineering, electromagnetic compatibility, telecommunications, and others. The FCC categorizes the new low-power unlicensed BPL systems into two general types: (1) Access BPL systems that couple RF energy onto medium and low voltage power lines, and (2) In-home BPL networks, which use electrical outlets available within a building or home to provision a LAN.

2 BPL Overview

In the past few years, the availability of much faster digital signal-processing capabilities and the development of sophisticated modulation, encoding, and error correction schemes have allowed the introduction of new, low-power designs for carrier current devices. These new designs can overcome earlier technical bandwidth limitations caused by the inherent noise and impedance mismatches that are common on commercial power lines. The new designs include the use of spread spectrum or multiple carrier techniques that employ highly adaptive algorithms to effectively counter the noise on the line. They also include the use of “turbo code” (TC) techniques such as concatenated Reed-Solomon Forward Error Correction (FEC) and convolutional coding employing the Viterbi algorithm, which can provide decibel (dB) gains that approach Shannon’s famous channel capacity law¹.

BPL Access and In-home technologies currently suffer from the absence of recognized international and, in most cases, national standards. Consequently, there is relatively little detailed public technical information available on BPL systems, reflecting their proprietary state. BPL manufacturers today maintain a secretive posture with respect to the technical details of their equipment. Although the US does follow the electrical power standards set by the International Electrotechnical Committee (IEC), each power company has wide flexibility in how their own transmission facilities are implemented. Thus it is difficult to render accurate generalizations about even the underlying power structure that facilitates BPL. This will improve over the next few years after a number of current standardization efforts, discussed later, are concluded.

2.1 Power Line Infrastructure

BPL is designed to take advantage of the in-place electrical power grid, which varies among countries around the world. In the United States, the three-phase alternating current (A/C) electrical power grid is a three-tiered hierarchical system that is comprised of: (1) high voltage (HV); (2) medium voltage (MV); and (3) low voltage (LV) transmission lines. HV lines connect electricity generation stations to distribution stations. HV lines carry in the order of hundreds of kilovolts over distances that are tens of kilometers. MV lines connect the distribution stations to pole-mounted transformers. MV lines typically carry in the order of double-digit kilovolts over distances of a few kilometers. LV lines connect pole-mounted transformers to individual businesses and homes. LV lines carry only a few hundred volts over distances of a few hundred meters. In the US, each transformer supports only a few (e.g., 1-8) customers.

For the past 100 years, electric utilities have been using various gauge aluminum-conductors, steel-reinforced cables for electric power distribution (See Table 1 on next page for properties of power line transmission materials). The cables have a core of steel strands surrounded by aluminum, which delivers electricity to consumers.

¹ ($C = W \log_2(1 + S/N)$)

Table 1: Electrical Properties of Power Line Transmission Metals^{viii}

The steel center provides support for the wire as it hangs between two towers and the

| Metal | Relative Conductivity (copper = 100) | Electrical Resistivity at 20°C, $\Omega * m(10^{-8})$ | Temperature Coefficient of Resistance (per °C) |
|-------------------------------|---|---|---|
| Copper (HC, annealed) | 100 | 1.724 | 0.0039 |
| Copper (HC,hard-drawn) | 97 | 1.777 | 0.0039 |
| Aluminum | 61 | 2.826 | 0.0040 |
| Mild Steel | 12 | 13.80 | 0.0045 |
| Lead | 8 | 21.4 | 0.004 |

surrounding aluminum conducts the electricity. The International Electrotechnical Commission (IEC) Technical Committee (TC) 7 was established in October 1919 to prepare recommendations for bare aluminum wires and conductors. Due to their cost advantages over the other metals, aluminum conductors account for the majority of all bare conductors used by the electric power industry worldwide. Increasingly, use is being made of optical fibers (e.g. optical ground wire) and composite center materials such as carbon and glass surrounded by aluminum (See Figure 2)



Photo courtesy of Composite Technology Corporation

Figure 2: Composite Center Aluminum Cable

Electric power line cables have been optimized for an average transmission of power of 50-60 hertz (Hz) and a maximum in the range of 400 Hz. In Figure 3, the 50-60 Hz portion of the electromagnetic spectrum is identified as the frequency range known as “extremely low frequency,” or ELF. Most BPL systems are designed to operate in the frequency spectrum from 1.705 to 30 megahertz (MHz), but occasionally up to 80 MHz, using MV and LV power distribution network lines. The frequency spectrum from 1.705 to 30 MHz constitutes a limited natural resource that includes the High Frequency (HF) band, which is 3-30 MHz. HF has the rare ability to support long distance, point-to-point communications

with no infrastructure (e.g., repeaters) other than the transmission and reception equipment at each end. The propagation medium for HF is the Earth's ionosphere, which reflects signals in this frequency range. Above the HF band, the frequency spectrum from 30 to 54 MHz is reserved for use by public service and business communications. The spectrum from 54 to 80 MHz hosts television channels 2 to 5 with a small segment used for wireless alarms systems such as fire alarms.

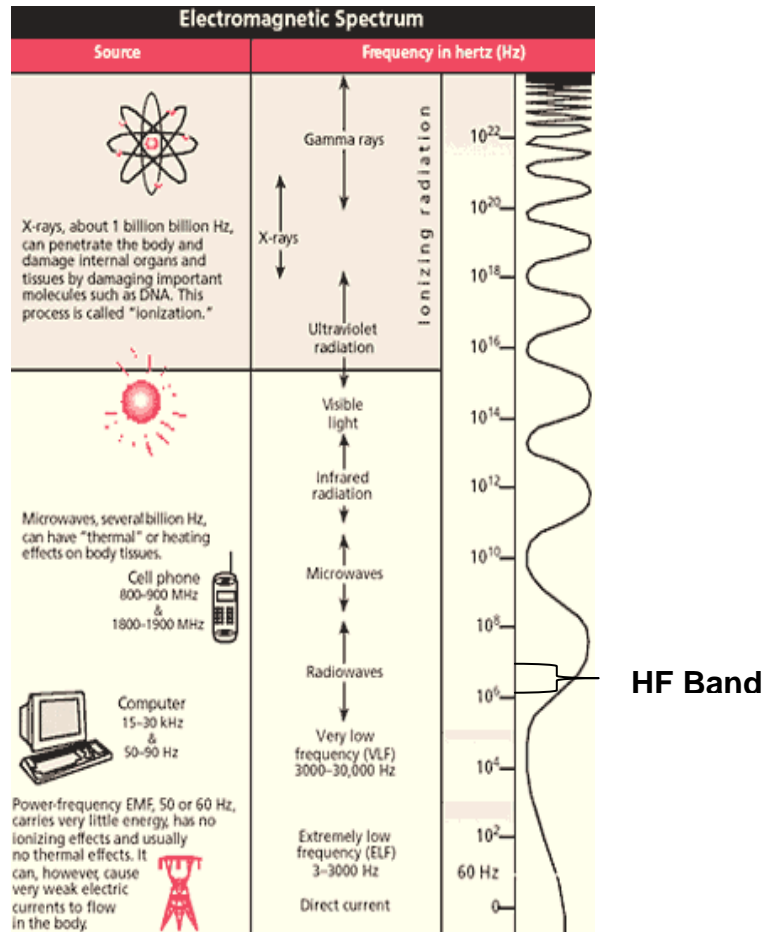


Figure 3: Electromagnetic Spectrum^{ix}

2.2 Power Line Characteristics

The use of power line cables for HF data transmission presents a number of technically difficult challenges. In addition to large attenuation, the power line cable network is one of the most electrically contaminated environments. Power line networks have been assembled with a variety of materials and cross sections are joined almost at random. This means that the inductive reactance along the wire itself will render a wide range of characteristic impedances at different points in the network. Further, the power line network terminal impedance varies both at different communication signal frequencies and with the time of day as the network's electrical load pattern varies. Atmospheric conditions, such as temperature, humidity, barometric pressure, lightning, sunspots, and the distance above ground all have an effect. Power-transmission-line engineering is a highly specialized field.

Despite the aforementioned transmission impediments, MV power lines are excellent carriers of RF energy as they are comprised of open wire equipment. The number of MV line crossovers is much less than is found on LV lines. Thus, a low power transmission of only 10 watts can be sufficient to overcome distances of 500 kilometers or more.

HF signals can be injected onto a power line by using an appropriately designed high pass filter. Received signal power will be maximized when the impedance of the transmitter, power line and the receiver are matched.

2.3 Advantages of BPL

The fact that electrical outlets are universally available throughout the US makes the potential for convenient customer access to broadband communications one of the greatest advantages that BPL has to offer. The investment cost savings that companies are able to realize through use of the already in-place infrastructure means that BPL can also potentially offer a low-cost method for implementing broadband service. The FCC has pointed out that BPL may provide the means to deploy broadband services to rural areas where infrastructure upgrades are the most cost prohibitive. The FCC has sought to encourage the deployment of BPL systems to provide urban consumers with a “3rd wire” that can compete with DSL and cable. Figure 4² depicts areas within the US where the

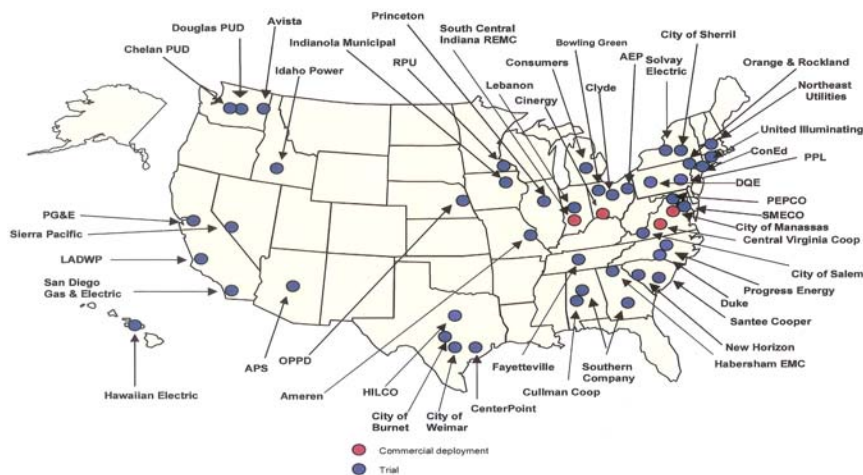


Figure 4: Map of US BPL Activities^x

Source: The United Power Line Council

United Powerline Council has identified BPL activity. However, a review of numerous public information sources regarding the current status (e.g., prototype, operational testing, operation ceased, etc.) of many of these sites is conflicting or changing rapidly. Thus, it is difficult to state with certainty that BPL is a growing industry and, if so, what real growth rate of operationally stable systems is being experienced.

² A survey of BPL activities is maintained online, but not guaranteed accurate, by the ARRL at: <http://plk.arrl.org/~ehare/bpl/ex2.html#Summary>. The FCC relies on the UPLC/UTC BPL Interference Resolution web site at <http://www.bpldatabase.org>. The map was produced in April 2005 and the document has been annotated accordingly. The UPLC does not currently offer a BPL activities map or listing.

Two of the largest publicized BPL deployments to date have involved Current Communications Corporation of Gaithersburg, Maryland, which manufactures BPL equipment and has entered into joint-venture agreements with large utility companies. The largest operational deployment to date began in 2004 as a joint venture between Current Communications and Cinergy Corporation (which provides electricity to the greater Cincinnati, Ohio area) and parts of Northern Kentucky. This project is reportedly on schedule to offer service to 250,000 customers by 2007. In December of 2006, Current Communications announced another large-scale, joint-venture with TXU Corporation of Dallas, Texas to offer BPL service to two million homes and businesses in the Dallas Fort-Worth metroplex area. Solutions from Current Communications are noteworthy for their capability to enhance the control over the electrical power grid by improving the reliability, efficiency, and security capabilities. These enhancements include: (1) automated outage detection and restoration; (2) automated meter reading; (3) electricity load management; (4) software applications and databases that collect and visually display voltage readings at every transformer where BPL equipment has been installed; (5) network planning and asset management; and (6) security camera applications for real-time monitoring of substations and other important assets.

A number of intangible BPL benefits can also be identified including:

- “Self-healing” power network capabilities
- Improved security from physical and cyber threats
- Enabling the use of distributed power generation
- Customer- and utility-timed control of appliances and equipment energy consumption
- Improved load management and electric grid utilization
- User applications, including automated meter reading, extension of SCADA control to the end-user level, outage detection, and equipment performance monitoring

2.4 NS/EP Uses of BPL

Many of the natural and man-made disasters that would require the involvement of the NCS agencies are accompanied with a disruption of the electrical power system upon which BPL operations are dependant. This is a limiting factor, with respect to the ability of BPL to support NS/EP, which is easily overcome through the deployment of a portable power supply along with appropriate BPL equipment. Thus, in disaster emergencies, BPL could provide first responders with an enhanced range of communications applications including Voice over Internet Protocol (VoIP) and high-speed computer applications. During non-emergency conditions, BPL can also provide an enhanced level of Critical Infrastructure Protection (CIP)^{xi} capabilities that can serve to reduce the vulnerability of the US power grid and its associated SCADA devices from acts of terrorism such as cyber attacks. The potential for an increased level of control over the operation of the electric power grid also has potential NS/EP benefits.

In planning for the deployment of BPL, it is important for the NCS to insure that NS/EP requirements are well defined and identified to the standards organizations. Examples may include requirements for support of real-time communications such as VoIP by means of Multiprotocol Label Switching (MPLS)^{xii}. In conjunction with MPLS, the Internet

Engineering Task Force (IETF) is defining the Differentiated Services (DIFFSERV)^{xiii} architecture. The DIFFSERV architecture supports the establishment of priority-based, per-hop forwarding with guaranteed network performance. The ability of BPL to support customer requested Quality of Service (QoS) performance parameters such as throughput, delay, delay variation, and probability of packet loss is critical for the support of NS/EP applications. These requirements need to be reflected in the evolving BPL standards that are today being developed by IEEE, the Internet Engineering Task Force (IETF), and other standards organizations. QoS and DIFFSERV are mandatory requirements for NS/EP.

2.5 Access BPL Building Blocks

Access BPL equipment is comprised of three elements: (1) injectors; (2) repeaters; and (3) extractors (see Figure 5). BPL injectors are connected to the Internet backbone via fiber-optic or digital signaling level 1 (DS1), or faster, phone lines. The injectors interface to the MV power lines feeding the BPL service area. MV power lines may be located overhead on utility poles or underground in buried conduit. Overhead wiring is attached to utility poles that are typically 10 meters above the ground.

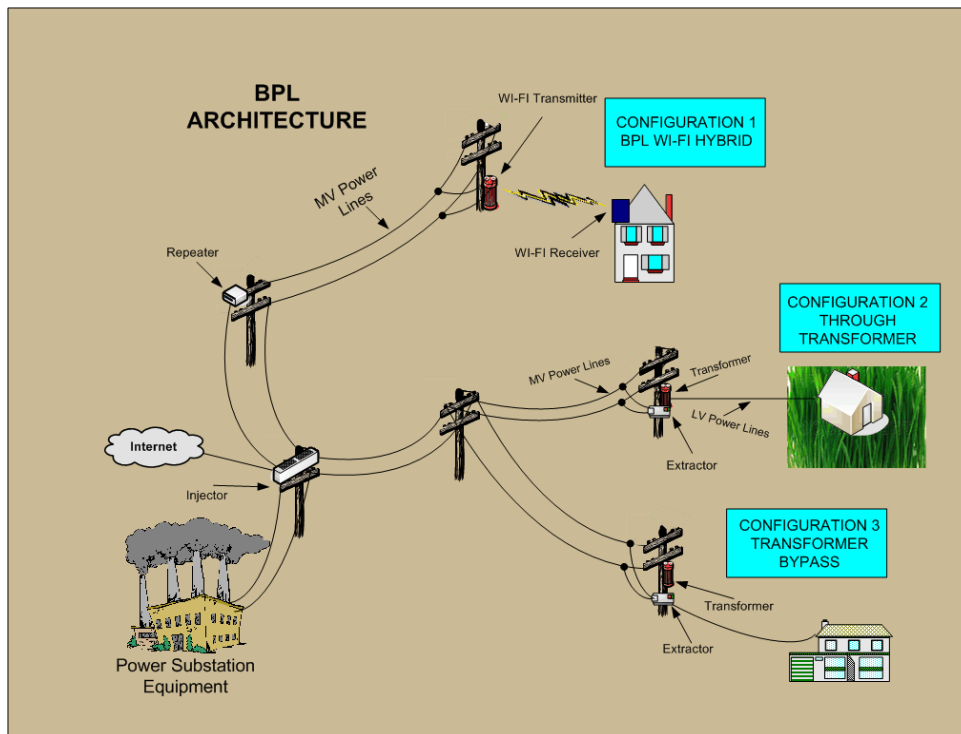


Figure 5: Access BPL System Configurations

Three-phase wiring typically comprises an MV distribution circuit running from a substation. These wires may be physically oriented on the utility pole in triangular, horizontal, or vertical configurations. 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 LV electric power for customer use.

BPL signals may be injected onto MV power lines: (1) between two phase conductors; (2) between a phase conductor and the neutral conductor; or (3) onto a single phase or neutral conductor. Extractors provide the interface between the MV power lines carrying BPL signals and the customers within the service area. BPL extractors (See Figure 6) 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 such as 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 require the BPL service provider to employ repeaters to maintain the required signal strength and



Figure 6: BPL Extractor^{xiv}

fidelity. Figure 7 (shown below) illustrates the basic BPL configuration, which can be deployed in cell-like fashion over a large area served by existing MV power lines.

2.6 BPL Issues

The introduction of BPL technologies around the world has not been received with universal, unbridled enthusiasm due largely to interference concerns. The interference characteristics associated with BPL can be divided into two broad categories: (1) conducted and (2) radiated. In the FCC Report & Order 04-245, Access BPL systems are exempted from the conducted emissions limits in FCC Part 15 rules because measuring the conducted emissions presents a safety hazard due to the 1-40 kilovolt energy on the power lines. Instead, the FCC has focused on compliance with established radiated emission requirements.

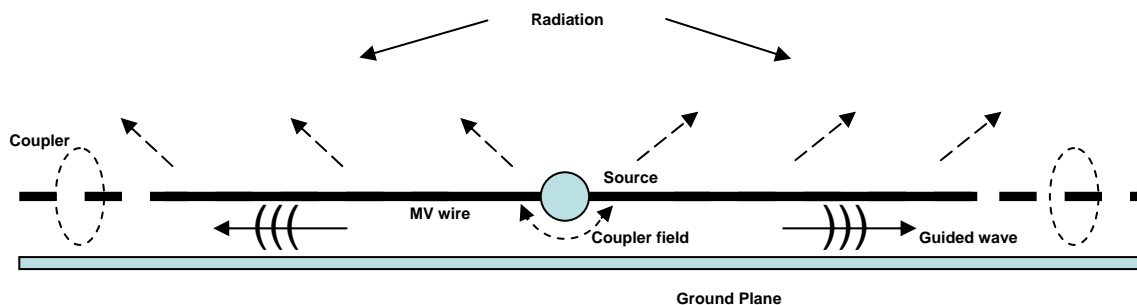


Figure 7: BPL Electromagnetic Model^{xv}

BPL interference can be categorized into two distinct groups: (1) near-field and (2) far-field radiation. Federal Standard (Fed-Std) 1037C, “*Glossary of Telecommunications Terms*,”^{xvi} provides definitions for each. Near-field interference is defined as the “close-in region of an antenna wherein the angular field distribution is dependent upon distance from the antenna.” Far-field interference is defined as the “region commonly taken to exist at distances D greater than $2D^2/\lambda$ from the source, where λ is the wavelength.” (NOTE: You should also mention what linear dimension is used for the antenna when using the formula for Far-field interference. Is it the power line between two fixed nodes?) As presented by Figure 7, the resulting BPL electromagnetic fields can be placed into three categories: (1) Guided mode; (2) Radiation mode; and (3) Coupler fields. The guided mode is responsible for transporting signal energy along the electrical power line. This energy is known to decay rapidly in directions perpendicular to the wire but slowly along its length. The radiation depicted in Figure 7 carries power into space and serves no constructive purpose in a BPL system. This radiation, however, can be the source of long-range interference effects because the fields decay relatively slowly at $\sim 1/\text{distance}$. The coupler fields are associated with the coupler itself rather than the MV line. The near-field effects persist along the entire length of the wire and are not constrained to just the immediate vicinity of the coupler. The far-field effects can be quite troublesome because HF emissions, unlike microwaves, can travel thousands of kilometers via ionospheric bounce. Techniques such as employing a balanced configuration of two MV wires driven differentially and appropriately spaced can be employed in an effort to achieve less radiated energy.

Due to the ionospheric propagation characteristics that allow low-power radios to communicate around the world, the HF (3-30 MHz) and the lower portion of the very high frequency (VHF) (e.g., 30-300 MHz) radio spectrum are limited and valuable natural resources. According to the National Telecommunications and Information Administration (NTIA), there are more than fifty-nine-thousand (59,000) Federal Government frequency assignments in the 1.7-80 MHz frequency range. Thus, the potential impact of any BPL interference could include: the NCS government agencies, the US military, commercial shortwave broadcasts, commercial aviation, maritime communications, and even citizens-band users. Ionospheric propagation of interference from BPL may also have national security, international treaty, and commercial implications. To reduce harmful interference in these frequencies, telephone wires are both twisted and shielded. Cable systems also employ shielded cables for the same reasons. However, electrical power lines are unshielded and as such may be expected to behave like a city-wide (or larger) antenna system that radiates the applied RF energies. These important considerations were open to public discussion during the FCC Notice of Inquiry (NOI) process.

In addition to the BPL base frequency, harmonics is another area where concerns have been raised. The frequency of the BPL sine wave is called the fundamental frequency or the first harmonic. The second harmonic occurs at twice the fundamental frequency, the third harmonic is three times the fundamental frequency, and so forth. A BPL system operating, for example, at 10 MHz as the first harmonic will produce a second harmonic at 20 MHz, a 3rd harmonic at 30 MHz, etc.

In comments to the FCC, the National Academy of Sciences noted those signals studied by Earth-based radio astronomers are extremely weak and vulnerable to interference from systems such as BPL. A typical radio telescope receives less than 1×10^{-12} (one-trillionth) of a watt from the strongest cosmic sources. Thus, radio astronomy receivers are especially vulnerable to interference from in-band emissions, spurious, and out-of-band emissions from licensed and unlicensed users of neighboring bands, and transmissions that produce harmonic emissions that can occur in radio astronomy bands.

Last, but not least, there are numerous open questions regarding the economic viability of BPL as a 3rd wire. DSL, cable, Fiber to the Home, and satellites have larger installed customer bases than BPL. Additionally, WiFi and Worldwide Interoperability for Microwave Access (WiMAX) are generally viewed within the telecommunications industry as more popular candidates for becoming a 3rd wire than BPL. Nevertheless, BPL proponents are actively seeking a share in the lucrative market of Internet Services Provider.

2.6.1 RF Noise Issues

The introduction of BPL raises issues related to the determination of RF noise sources. Since 1951, the International Telecommunications Union-Radiocommunications (ITU-R) sector has periodically published the results of an ongoing study of the sources of RF noise in Recommendation P.372-8 titled: “Radio Noise.” The ITU-R has identified that radio noise external to a radio receiving system can be caused by a variety of different factors including:

- Radiation from lightning discharges (atmospheric noise due to lightning)
- Unintended radiation from electrical machinery, electrical and electronic equipment, power transmission lines, or from internal combustion engine ignition (man-made noise)
- Emissions from atmospheric gases and hydrometeors
- The ground, or other obstructions, within the antenna beam
- Radiation from celestial radio sources such as sunspots

Recommendation P.372-8 documents the ongoing historical evidence that each of these factors has upon communications. Since the study includes unintended radiation from power transmission lines it provides a recorded basis for insuring that BPL does not generate undetected interference. Figure 8 depicts ITU-R recorded median values of man-made noise power for business, residential, rural, and quiet rural environments along with galactic noise. The results are consistent with a linear variation of the median value, F_{am} , with frequency f of the form:

$$F_{am} = c - d \log f$$

With f expressed in MHz, c and d take the values given in Table 2.

Table 2. Values of the constants c and d

| Environmental category | c | d |
|--------------------------|------|------|
| Business (curve A) | 76.8 | 27.7 |
| Residential (curve B) | 72.5 | 27.7 |
| Rural (curve C) | 67.2 | 27.7 |
| Quiet rural (curve D) | 53.6 | 28.6 |
| Galactic noise (curve E) | 52.0 | 23.0 |

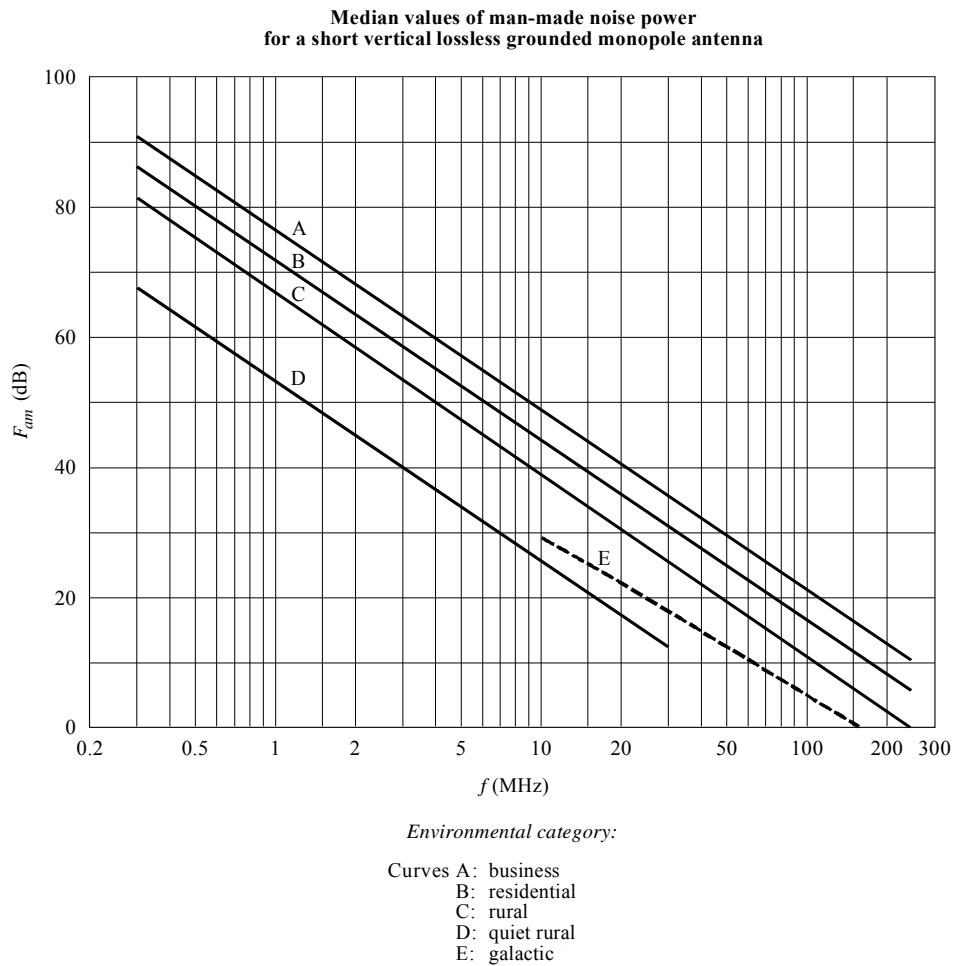
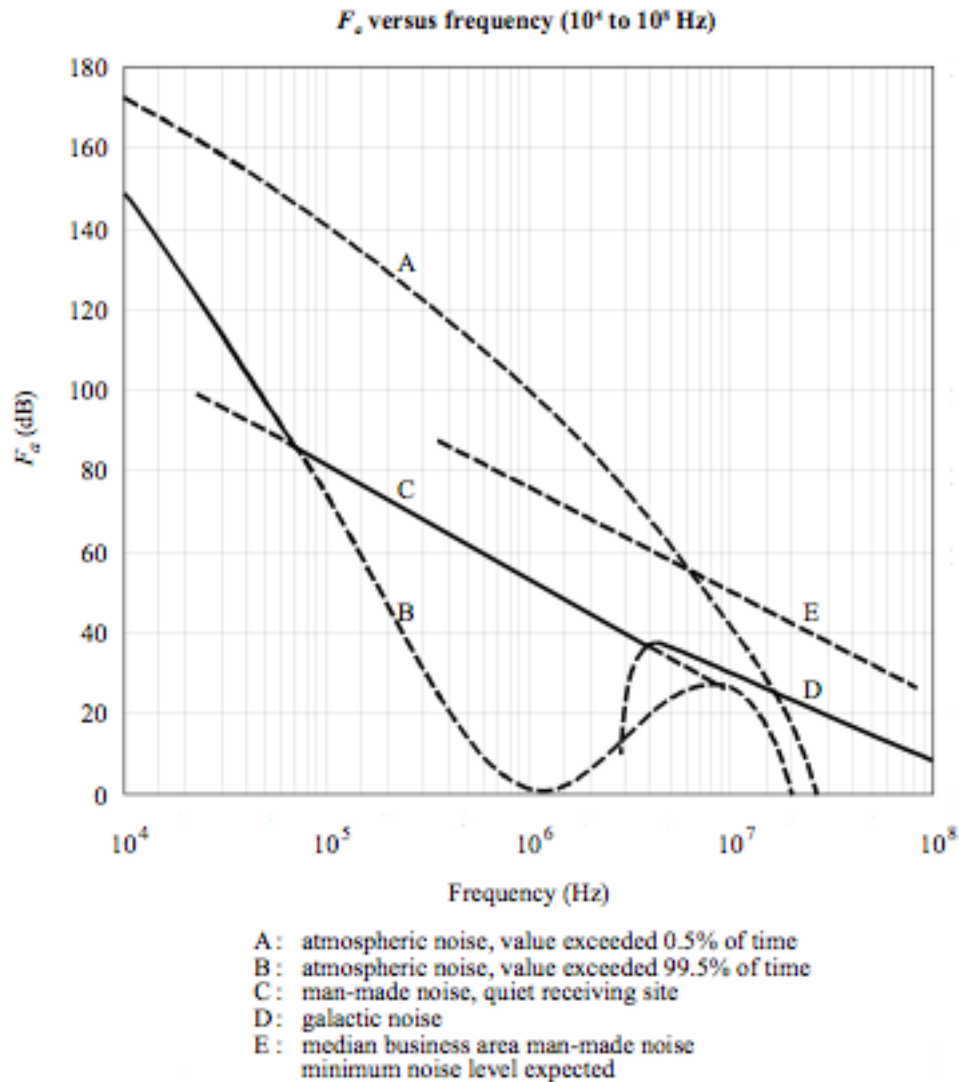


Figure 8: ITU-R Recommendation P.372-8 Median Values of Man-Made Noise

The standard also provides Figure 9 which shows the expected values of noise levels (F_a) as a function of frequency in the range of 10 kHz -100 MHz for various categories of noise. The minimum expected noise is shown by the solid lines. For atmospheric noise, the

minimum values of the hourly medians expected are taken to be those values exceeding 99.5% of the hours and the maximum values are those exceeding 0.5% of the hours. All times of day, seasons, and the entire earth's surface have been taken into account for these atmospheric noise curves.



Frequency (Hz)

Figure 9: ITU-R Recommendation P.372-8 Expected Noise $10^4 - 10^8$ Hz

By international treaty the United States has agreed to use ITU-R P.372-8 in the design and measurement of radio systems. Conformance to this standard by BPL system designers and operators will help insure that the existing radio spectrum is preserved from new or unmanaged sources of interference.

As depicted in Figure 10, sunspots presently are nearing the bottom of the solar cycle. The current sunspot is cycle number is 23. The sun's cycles are at approximately 11-year intervals. This means the effect of solar activity on HF transmissions is nearing a low and will be expected to increase interference during the next cycle.

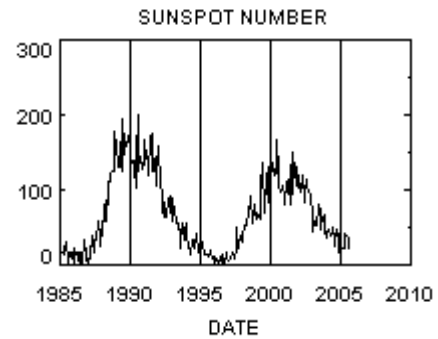


Figure 10: Solar Flare Cycles ^[14]

Source: NASA Marshall Space Flight Center

2.6.2 BPL Testing Issues

Presently, there are no completed technical standards from recognized organizations [e.g., American National Standards Institute (ANSI), ITU] that specifically address BPL technology. Further, there are no standardized methods to test for BPL interference beyond the measurements provided in ITU-R 372-8. Within the United States, the FCC Part 15 rules, which were not originally designed for situations involving an uninterrupted 24 x 7 interference source such as BPL, provide a national starting point for testing guidance.

However, the revised Part 15 rules do provide sufficient details about where BPL field strength measurements are to be made and at what frequencies. The FCC stipulates that measurements should normally be performed at a horizontal separation distance of 30 meters from the overhead line. If necessary, due to ambient emissions, measurements may be performed at a distance of three meters. Distance corrections may be made in accordance with Section 15.31(f) of the Rules. The rules further specify that at distances greater than 30 meters and frequencies at or above 30 MHz, measurements should not be performed unless it can be demonstrated that measurements at a distance of 30 meters or less are impractical. When performing measurements at a distance other than that specified, the results are required to be extrapolated to the specified distance using an extrapolation factor of 20 dB/decade (inverse linear-distance applies for field strength measurements or inverse linear-distance-squared for power density measurements). At frequencies below 30 MHz, measurements may be performed at a distance closer than 30 meters but near field measurements should be avoided. The FCC specified slant range distance measurement using a loop antenna axis both parallel and perpendicular to the power line. The FCC stipulated that until an appropriate procedure for measurements below 30 MHz can be defined, results from measurements taken from a distance closer than specified must be extrapolated to the specified distance. This can be done by either making measurements at a minimum of two distances on at least one radial to determine the proper extrapolation factor, or by using the square of an inverse linear distance extrapolation factor (40 dB/decade).

The FCC requires that BPL Access testing be performed at distances of 0, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 wavelength from the BPL power line injection point. The mid-band frequency determines the wavelength spacing to be used. If, for example, the mid-band frequency exceeds the lowest frequency injected onto the power line by more than a factor of two, testing is required to be extended in increments of $\frac{1}{2}$ wavelength of the mid-band frequency until the

distance equals or exceeds $\frac{1}{2}$ wavelength of the lowest frequency injected. Testing is required to be repeated for each Access BPL component (e.g., injector, extractor, repeater, booster, and concentrator).

The FCC rules further specify that the distance correction for the overhead-line measurements are to be based on the slant range distance, which is the hypotenuse of the triangle represented by line-of-sight distance from the measurement antenna to the overhead line. A measurement taken at a horizontal distance of 10 meters (1 meter antenna height) and a BPL device height of 11 meters results in a slant range distance of approximately 14.1 meters. The measurements are extrapolated to the required 30-meter reference distance by subtracting $40 \log(30/14.1)$, or 13.1 dB from the measured values for measurement of frequencies below 30 MHz. The correction uses a 20-log factor and the reference distance specified in Part 15.109 for measurement of frequencies above 30 MHz.

During the rule-making process the FCC rejected a proposal to require BPL system operators to include a “BPL signature” that would enable receivers to unambiguously identify the source of interference. The NTIA indicated in a letter dated September 24, 2004, that no practical method has been identified for Access BPL systems to transmit an identifying code. Field measurements are required to use calibrated equipment, but this practice is not always common and continues to be a source of testing disagreements. A common complaint from both BPL proponents and opponents alike has been that the testing procedures provided by the FCC are too ambiguous to assist in developing a consensus about whether or not interference is present or even about the source of the interference. It has been pointed out that the 30-meter testing parameter established by the FCC has, in practice, proven to be operationally difficult. Homes and businesses are typically located closer than 30 meters from power lines. Streets are also typically located closer than 30 meters from power lines and so in order to conduct testing as per FCC instructions it commonly requires the placement of test equipment in undeveloped property, which introduces variables such as hills, valleys, and other natural barriers to obtaining precisely the test specified. For now, the FCC has provided ample extrapolation instructions for BPL in the revised Part 15. Additional BPL standards development is currently under way by the IEEE so it appears likely that the FCC revised Part 15 methods will evolve to take advantage of improvements as they become available to assist BPL designers and operators within the US.

2.6.3 Harmonics and Intermodal Interference

Almost all signals contain energy at harmonic frequencies in addition to the energy found at the fundamental frequency. In theory, a signal can have an infinite number of harmonics. A perfect sign wave is formed only if all the energy of a signal is contained at the fundamental frequency. Examples of waveforms that contain large amounts of energy at harmonic frequencies include: square waves, triangle waves, and sawtooth waves such as those depicted by Figure 11.

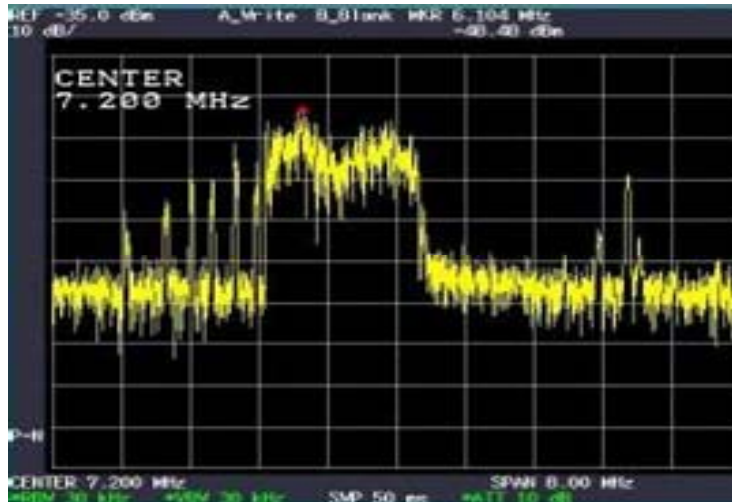


Photo courtesy of George Tarnovsky

Figure 11: BPL on a Spectrum Analyzer

For a signal whose fundamental frequency is f , the second harmonic has a frequency $2f$; the third harmonic has a frequency of $3f$, and so on. Let w represent the wavelength of the signal or wave in a specified medium. The second harmonic has a wavelength of $w/2$, the third harmonic has a wavelength of $w/3$, and so on. Signals occurring at frequencies of $2f$, $4f$, $6f$, etc. are called even harmonics while signals at frequencies of $3f$, $5f$, $7f$, etc. are called odd harmonics. Due to the higher frequencies, BPL harmonics radiate better than the fundamental frequency. The interference caused by BPL harmonics is not reduced even if the fundamental frequency is notched. Weak HF signals, VHF, ultra-high frequency (UHF) and microwave stations are the most vulnerable to BPL harmonic interference.

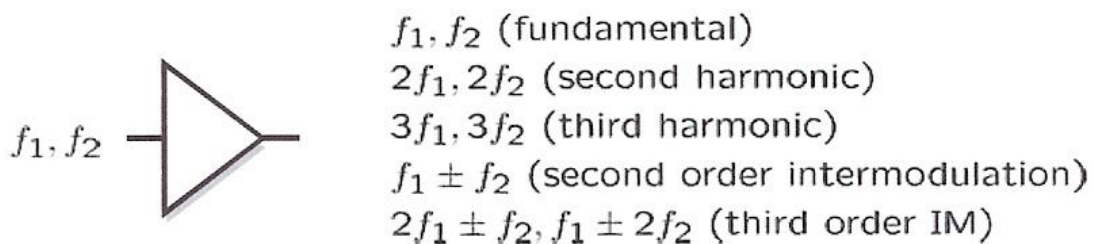


Figure 12: Harmonics and Intermodulation Properties^{xvii}

Figure 12 above illustrates both the multiplier effect of harmonics and the additive or subtractive characteristics of intermodulation. Federal Standard 1037C defines intermodulation as “The production, in a nonlinear element of a system, of frequencies corresponding to the sum and difference frequencies of the fundamentals and harmonics thereof that are transmitted through the element.” Intermodal is commonly referred to as “out of band” interference. Intermodulation products are frequently encountered in power lines at bad joints, which readily produce mixing.

2.6.4 Electromagnetic Interference

The components of BPL interference include: (1) Sky Wave (3-30 MHz); (2) Space Wave (0.1-30 MHz); and (3) Ground Wave (0.1-3MHz). Ground waves and sky waves raise the possibility of interference being caused to radio services at distances of tens or even hundreds of kilometers due to the cumulative effect of a large number of BPL systems. International shortwave broadcasts (e.g., Voice of America, BBC World News) are also threatened by the potential for increase in the noise floor. The ability to achieve satisfactory communications depends on the ratio between the wanted signal and the noise. The noise consists of four components: (1) internally generated receiver noise; (2) atmospheric; (3) man-made; and (4) galactic or cosmic. The usual ITU-R standard for non-safety-of-life radiocommunication data services is an Interference-to-Noise (I/N) ratio of –6 dB, which has the effect of raising the noise level no more than 1 dB.

The creation of electromagnetic interference is an obstacle that BPL needs to overcome in order to flourish as a successful technology. Around the world BPL installations are being tested to verify that their radiation levels do not exceed authorized limits. In the United States, the National Telecommunications and Information Administration (NTIA) has completed, but not released, a study of the cumulative effects of BPL system deployments in major cities around the world on the users of HF spectrum.

2.6.5 Security Issues

Data transmitted over a BPL system needs to be encrypted if interception by other users on the same power network is to be avoided. BPL Access systems use a shared communication medium where multiple (e.g., 5 or more) homes are associated with a single-power transformer. BPL signal propagation operates in a LAN-like manner that makes detection and interception of neighboring transmissions simple. A BPL system can also suffer interruption or degradation of service by the operation of local HF-transmitting stations in a manner that produces results that are similar to a denial of service attack. Security requirements are currently being addressed by standards committees in the IEEE (See Section 4.5) and other standards organizations. Security specifications produced by the HomePlug Powerline Alliance (See Sections 4.2, 4.3) provide for the use of either 56-bit Data Encryption Standard (DES) or 128-bit Advanced Encryption Standard (AES).

2.7 BPL Studies

A number of private corporations, governments, and other organizations have undertaken studies of the effects of BPL technology. This section provides a non-exhaustive overview of several major studies and findings.

2.7.1 NTIA Phase I Study

The NTIA concluded a Phase I study of BPL and completed, but not released, a Phase II study in January 2006. Phase I studied interference risks to radio reception in the immediate vicinity of BPL and made mitigating recommendations to the FCC. The NTIA also summarized technical and operating parameters of Federal Government frequency assignments in the 1.7-80 MHz range in the Phase I report. This information was intended to help operators of BPL systems in the development of BPL frequency plans. The NTIA then defined representative radio systems for consideration in interference analyses: (1) a

land vehicular receiver; (2) a ship borne 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 protection on frequencies amounting to about 5.4% of the 1.7-80 MHz frequency range.

The NTIA performed measurements at three different BPL deployment sites in order to characterize the BPL fundamental emissions. The NTIA measurements indicated 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 field strength decreased with increasing distance, but the decrease was not always monotonic. That is 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. Present 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). Based on the results of these tests, the NTIA recommended that the FCC refine Part 15 compliance measurement guidelines to ensure that the peak field strength of any unintentional BPL emissions is measured.

The 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 to 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. The NTIA also recommended that BPL devices should be capable of frequency agility (notching and/or retuning) and power reduction for elimination of interference. Further, the NTIA recommended that BPL developers consider several interference prevention and mitigation measures, including: (1) routine use of the minimum output power needed from each BPL device; (2) avoidance of locally used radio frequencies; (3) differential-mode signal injection oriented to minimize radiation; (4) use of filters and terminations to extinguish BPL signals on power lines where they are not needed; and (5) judicious choice of BPL signal frequencies to decrease radiation.

2.7.2 BBC Studies

The British Broadcasting Company (BBC) employs a staff of Research & Development engineers, scientists, and mathematicians for the purpose of keeping BBC at the forefront of technology. During the period from 1999 to 2005, the BBC produced a series of White Papers covering various aspects of BPL. The BBC was early to identify BPL as a technology that could support censorship by being employed to keep unwanted foreign shortwave signals from reaching citizens in various parts of the world.

In October 1999, the BBC produced a study titled: "Protection of 'sensitive' receiving sites,^{xviii}" which included aeronautical/marine safety, monitoring, surveillance, and radio astronomy. The study concluded that the size of an "exclusion zone" (e.g., BPL-free area)

must be chosen by the operators of the exclusion zones themselves. It identified that a 50-100 km exclusion zone may be required in some cases. The study concluded that ground wave propagation presents the greatest threat to sensitive receiving sites but this risk could be controlled by choosing a sufficiently large exclusion zone. The study also concluded that the threat of sky-wave interference from wide-spread deployment of BPL systems has no apparent solution.

In July 2000, a BBC study titled “The Threat to New Radio Systems from Distributed Wired-Communication Installations”^{xix} concluded that many radio users stand to suffer serious disruption of their services if BPL communications systems were allowed to be widely deployed. The BBC stated that the problem “has an international dimension” because interference can be caused at very considerable distances from the source and any “local” permission to ‘use’ a part of the HF band for wired systems would deny it to others elsewhere for licensed radio. The BBC also said that BPL will hamper subsequent re-planning of the HF band for radio users and new radio systems.

A BBC research and development study published in June 2005, titled “Co-existence of Power Line Telecommunications and Radio Services – a possibility?”^{xx}, concluded that if HF bands are manually notched that both cost and delay in processing complaints is a concern. However, the BBC postulated that a system employing dynamic notching based on voltages on the power lines during quiet periods could be used to distinguish the parts of the spectrum that should not be used by BPL. Unfortunately, the study concluded that dynamic notches may not be deep enough to satisfy the requirements of amateur radio and that some permanent frequency notches may be needed. BBC recommended that the BPL industry needs to resolve this through voluntary standards before major deployments of the technology occurs. It was noted that the World Radio Conference needs the flexibility to be able to adjust world frequency allocation tables and thus permanent notches might not provide sufficient flexibility for that purpose.

Currently, the BBC is developing a BPL modem that makes use of the fact that the short-wave frequencies for broadcast radio change throughout the day as ionospheric conditions dictate. The BBC modem detects which frequency bands are in use at any one time - and filters them out. This technology is not part of any BPL system currently in trial deployment.

2.7.3 Manassas, Virginia Study

In July 2006 an FCC accredited testing laboratory (Product Safety Engineering, Inc.) produced a report on the BPL system deployed by the city of Manassas, Virginia. The testing was conducted in response to a complaint filed with the FCC by several local American Radio Relay League (ARRL) radio operators who asserted that the BPL system is generating unlawful interference. Relevant portions of the ANSI C63.4-2003 “American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz” were employed by the testing laboratory representatives. In addition to the laboratory testing activities, Main.Net (the manufacturer of the Manassas BPL system) set the power level for overhead equipment at 4; the equipment range being 1-7 with 7 being the highest. Additionally, coupling adjustments and other alignments to optimize signal propagation and minimize signal leakage were made by Main.Net. The laboratory testing included

measurements at five overhead and five underground locations, which included both low and medium voltage lines. The test data indicated compliance with FCC Part 15 regulations with frequency notching turned off. With notch filters turned on, the system rendered attenuation of 29.7 dB to 31 dB below FCC Part 15 limits.

Regretfully, ARRL representatives were unavailable to participate with PSE in evaluating the Equipment Under Test (EUT). Subsequently, ARRL operators have voiced criticism regarding the test procedures and results documented by PSE. The ARRL operators have again called upon the FCC to shut down the Manassas BPL system because of interference to amateur radio frequencies. Additionally, ARRL has called upon the FCC to conduct unannounced independent testing of the Manassas BPL system. The resolution of these kinds of BPL testing issues for the early adopters of the technology will benefit all of the parties involved.

2.7.4 ARRL Study

The American Radio Relay League (ARRL) sponsored a study^{xxi}, published by MetaVox Incorporated in March of 2004, of BPL systems located in the vicinities of both Allentown, Pennsylvania and Manassas, Virginia. This was prior to the FCC Report and Order on BPL issued in October 2004.

The FCC testing standards require that frequencies below 30 MHz measurements should not be made in the near field. More specifically, as stated on page 15, measurement results from closer than 30 meters must be extrapolated for compliance with the Part 15 rules.

In comments to the FCC dated July 7, 2003, the ARRL study observed that “Making measurements at distances closer than 30 meters and extrapolating at 40 dB/decade can easily result in an underestimation of the actual maximum field at 30 meters distance, by over 20 dB in some cases.” Furthermore, “the ARRL analysis data for the large radiator systems of overhead power lines resulted in no cases approaching 40 dB per distance decade. The ARRL analysis yields the extrapolation factor of 15 dB per distance decade for the 3 to 30 meter distance ratio for a typical case on 14 MHz with the strongest magnetic field at 3 meters in distance from the radiator system. Another case on 3.5 MHz yielded the factor of 24 dB per distance decade.” Measurements made by MetaVox for the ARRL also suggested that the 40 dB/decade extrapolation factor may not be suitable for use in compliance testing on BPL systems.

The study also documented difficulties that were encountered in making measurements at the FCC specified measurement distance of 10 meters and elaborated that controversies in methods for extrapolation of data for distance between antenna position and conductors of the system make comparison with the FCC limits difficult.

2.7.5 IEEE Report on USA Broadband Networking

In April 2005, the IEEE Committee on Communications and Information Policy (CCIP) published a white paper titled, “*Providing Ubiquitous Gigabit Networks in The United States*,^{xxii}” which advocates that to remain competitive the US needs “gigabit-per-second (Gb/s)” networks instead of “broadband” networks. The IEEE recommended the creation of a new generation of broadband wired and wireless networks as a national priority, to be facilitated by legislative and regulatory action, and achieved through mobilization of

resources by users and incumbent suppliers alike. The CCIP noted that the existing US infrastructure includes broadband upgrades to copper local loops (for example, DSL and T-1s), data modems and cable networks, and fixed and mobile broadband wireless systems. The CCIP also noted that all of the aforementioned facilities are lower in cost, but also lower in capability, than optical fiber. Even considering that rapid technological progress is being made across the board, the fact remains that wire-based alternatives cannot reach the Gb/s speeds future applications will require.

The paper discusses that gigabit networks, in contrast to current broadband networks, provide symmetric data transport capable of gigabit-per-second (Gb/s) speeds and beyond. The IEEE paper noted that the FCC used the terms, "...advanced telecommunications capability and advanced services" to describe broadband services and facilities with an upstream (customer-to-provider) and downstream (provider-to-customer) transmission speed of more than 200 kilobits per second (kbps)." The IEEE asserted that "this definition is clearly inadequate." Further, the IEEE identified that the FCC concludes, "...that advanced telecommunications capability is indeed being deployed on a reasonable and timely basis to all Americans." The IEEE white paper "emphatically" rejected this FCC conclusion. The IEEE paper concluded that "on the contrary, broadband deployment in the United States seriously lags in satisfying the needs of the world's strongest economy."

The IEEE asserts that the US economy is based on knowledge — its creation, dissemination, and application. A knowledge economy uniquely creates new wealth through invention and innovation. Development depends on research that depends on access to the entire body of existing knowledge and the rapid exchange of new knowledge throughout the economy and the society. Modern research typically retrieves, creates and exchanges massive information files at gigabit rates. After the research, many follow-on functions benefit from gigabit networks, including computer-aided design; integration of design, manufacturing, sales, and distribution; and collaboration among all through high quality video conferencing.

Economies of scale occur through fiber, in part because the cost of transporting one more unit of use (that is, its marginal cost) becomes very small by virtue of its huge capacity. For example, future access to a menu of 100 simultaneous video channels at the high definition (HD) digital rate of 20 Mb/s per channel for a diverse audience of end users requires 2 Gb/s capacity. The infrastructure necessary to support facile interaction among the members themselves of such a broad audience demands even greater capacity — a capacity easily available through fiber. Data, music, and voice can be added, once such an infrastructure is deployed because these elements have relatively small bandwidth requirements.

A further example of the future requirements for Gb/s networks can be observed from the research and development efforts underway on Internet2. Internet2 is a US based high-speed network consortium of over 200 university, commercial, and government partners. The main purpose of Internet2 is to develop and deploy advanced network applications and technologies, which facilitate education, research and non-commercial applications, using multicasting, digital libraries, virtual laboratories, etc. All of these applications require high-speed transmission of large amounts of data, highly enhancing collaboration and information-sharing among members. Internet2 was built using fiber-optic transmission technology with speeds typically ranging from 2 Gb/s – 10 Gb/s symmetrical.

Advancements are being made with BPL technologies that are resulting in higher theoretical and practical speed limits being achieved. Reports of futuristic BPL systems supporting speeds of 1 Gb/s have been published. Nevertheless, the IEEE report raises important questions about whether or not a BPL infrastructure could support Internet2 application requirements.

3 BPL Architecture

The International Organization for Standardization (ISO) 7-layer Open Systems Interconnection (OSI) Communications Reference Model is defined in ISO-7498. In this model the first layer is defined to be the Physical (PHY) layer. For BPL, layer 1 is inclusive of all the in-place, power line distribution systems, the electrical power line distribution system, and the in-home electrical wiring down to the wall sockets. In some configurations, however, the power line transformers are bypassed, which excludes them from being part of the communications system architecture.

A BPL Access network is comprised of a base station and a number of users connected via BPL modems. The modems can provide various standardized user interfaces into the BPL network. For example, a BPL modem can provide the user with a standard IEEE 802.3 (Ethernet) interface for connecting a personal computer to the network. The BPL modem connects to the powerline transmission medium by means of a BPL specific (e.g., vendor proprietary) interface. Typically, BPL user interface modems provide the Medium Access Control (MAC) lower sublayer and the Logical Link Control (LLC) upper sublayer functions from Layer 2 of the OSI model in addition to the PHY. The modems also provide the Network Layer functionality of Layer 3 by supporting Internet Protocol (IP) routing. This TIB is focused on the BPL technology standardization efforts that are today largely concentrated at the PHY and MAC layers. The manufacturers of existing BPL systems developed proprietary solutions for the MAC layer that are incompatible. The basic BPL components of injectors, repeaters, and couplers have been implemented in a variety of systems architectures, which feature different modulation techniques and designs at the PHY, MAC, and LLC.

PHY channel impairments in BPL systems include: noise, multipath, strong channel selectivity, and non-linear channel characteristics. To combat these impairments a number of different technologies have been employed that range from spread spectrum to Orthogonal Frequency Division Multiplexing (OFDM). BPL channel impairments reduce the available bandwidth to users, which is especially of concern because BPL access networks operate in a shared transmission medium where subscribers compete to use the same transmission resources. This section identifies a few of the BPL technologies being implemented today.

Table 2 (shown on the next page) illustrates that a variety of chipsets are used to provide solutions for both MV Access BPL and LV In-home solutions over both HF and VHF frequencies. The use of microwave surface wave technology is a special case that does not have the same spectral interference issues as High Frequency/Very High Frequency (HF/VHF) solutions.

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier transmission waveform that was first used on military HF radio links starting in the 1960s. It performs services at the PHY layer of the OSI model. OFDM has been adopted for numerous technologies including: Asymmetric Digital Subscriber Line (ADSL) services, IEEE 802.11a/g, IEEE 802.16a, Digital Audio Broadcast (DAB), Digital Terrestrial Television Broadcast, DVD in Europe, 4G, IEEE 802.11n, IEEE 802.16, and IEEE 802.20. There is no single OFDM standard that has been universally adopted. Instead, there are similar but

different versions of OFDM and several proprietary implementations as various companies attempt to acquire better market penetration through improved efficiency and features.

Table 2: BPL System Architectures

| Chipset | MV Access Signal | LV In-House Signal |
|-------------------------------|--------------------------------|-----------------------------|
| OFDM (orthogonal FDM) | VHF only (30-50MHz) | Home Plug (4-21MHz notched) |
| OFDM (DS2 chipset) | HF/VHF (notched) | HF/VHF (notched) / WiFi |
| DSSS / FHSS (spread spectrum) | HF (notched) | HF (notched) |
| Microwave Surface Wave | 2.4 & 5.8 GHz unlicensed bands | Home Plug / WiFi |

Courtesy of Conformity

OFDM is similar to Frequency Division Multiplexing (FDM) but it achieves greater spectral efficiency by overlapping each sub-channel. To achieve orthogonality, a symbol period equal to the carrier frequency spacing is used. This results in frequencies that are mathematically perpendicular and enables the spectrum of each sub-channel to overlap another without interfering with it. OFDM transmits symbols that employ long-time durations but consume a narrow bandwidth. In OFDM, after the available spectrum is segmented into numerous (e.g., hundreds or even thousands) narrowband sub-channels a data stream is sent by FDM using N carriers with the frequencies f_1, f_2, \dots, f_N transmitted in parallel.

Figure 13 (shown on the next page) depicts five OFDM carriers with overlapping of the sub-carrier spectrum. The orthogonal relationship enables the information transmitted over the sub-carriers to be recovered by the receiver without mutual interference. By employing an Inverse Fast Fourier Transform (IFFT) for modulation, the sub-carrier spacing is chosen such that the received signal is evaluated when all other signals are zero. The receiver uses a Fast Fourier Transform (FFT) to decode the signal. Perfect synchronization between the receiver and transmitter are required to preserve the orthogonality and to guard against any multi-path channel. OFDM is reliant on very high- speed, digital signal processing. There are numerous modulation and access design techniques that can be used in association with OFDM including: Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM), 6 bit 64 constellation QAM, Time Division Multiple Access (TDMA), and Code-Division Multiple Access (CDMA). To illustrate, consider a single OFDM carrier modulated by QPSK with each symbol encoding 2 bits at the rate of 1,000 symbols per second. The spectrum of this signal will have a $\sin(x)/x$ shape with a null at 1,000 Hz.

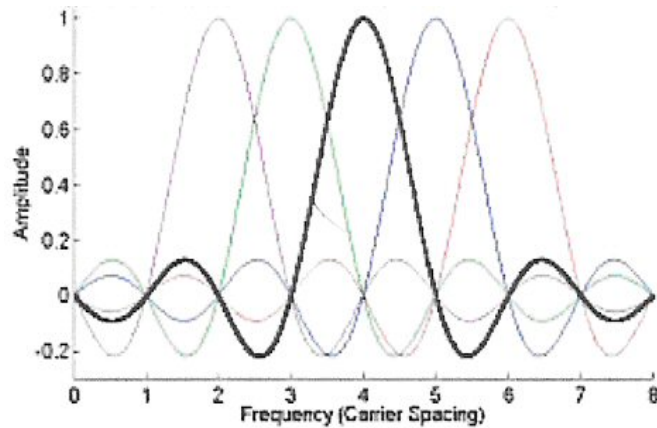
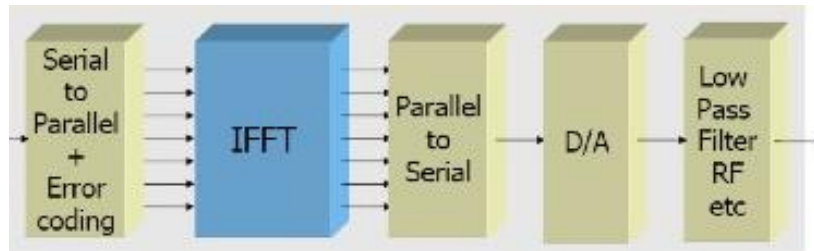


Illustration courtesy of Eric Lawry, James Cook University

Figure 13: OFDM spectrum with 5 carriers

OFDM is very robust against frequency selectivity but any time-varying characteristic of the channel limits system performance. Time variations deteriorate the orthogonality of the sub-carriers resulting in inter-carrier interference (ICI). To eliminate ICI a guard time is inserted with a length longer than the duration of the impulse response of the channel. The insertion of a guard time has a penalty of a loss in the SNR and an increase bandwidth requirement.

Figure 14 depicts an OFDM transmitter that receives serial high-speed data as input. The serial signals are first converted to parallel and error handling code is added. Next, an Inverse Fast Fourier Transformation (IFFT) is performed on the data. In order to prepare the transformed data for RF transmission, a conversion from parallel to serial is first provided. The data are then converted from digital to analog, passed through appropriate (e.g., high-pass, low-pass, band-pass) filters and then finally transmitted via RF energy.

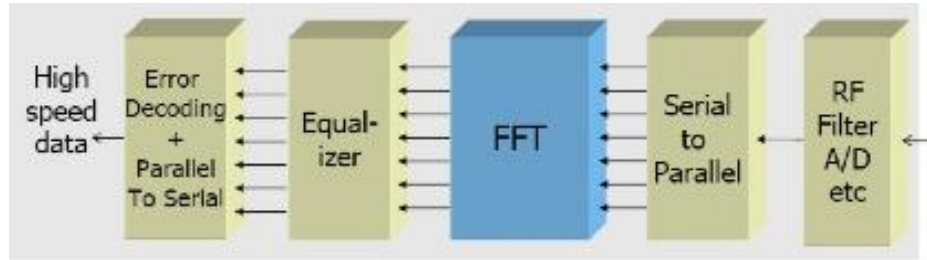


Courtesy of Jean Armstrong, Dept. of Electrical & Computer Systems Engineering, Monash University

Figure 14: OFDM Transmitter Block Diagram

Figure 15 (on the next page) depicts an OFDM receiver side, which receives the RF energy as input. The data are converted from serial to parallel after being passed through the appropriate RF filters. The receiver performs a Fast Fourier Transformation (FFT) on the data and then feeds the result to the OFDM equalizer, which compensates for linear distortion (e.g., multipath effects). Error detection is performed, and a parallel to serial conversion is performed to render the original data stream. In real-world systems, it is possible to arrange and control the order of signal processing modules via software.

Examples of BPL suppliers that employ OFDM technology include: Mitsubishi Electric, EBA Powerline Communications (PLC), and Ambient Corporation.



Courtesy of Jean Armstrong, Dept. of Electrical & Computer Systems Engineering, Monash University

Figure 15: OFDM Receiver Block Diagram

3.1 Hybrid BPL Systems

Hybrid BPL system designs combine the cost savings advantages inherent from using the existing power distribution infrastructure with neighborhood level wireless broadband, and try to isolate potential BPL interference signals further away from residential premises.

3.1.1 WiFi™

Figure 5 (on page 9) depicts the configuration of a hybrid BPL Access system with Wi-Fi™ used to provide the final delivery of broadband to a customer. In this configuration, BPL essentially becomes a means for providing neighborhood internet “hot spots.” The BPL RF signals are not applied to the LV lines that typically run through neighborhoods. BPL Wi-Fi™ can also be used to bridge between above ground and underground power line distribution systems.

Originally, Wi-Fi™ referred only to products conforming to the IEEE 802.11b standard, the standard for wireless LANs operating in the 2.4 GHz (microwave) spectrum with a bandwidth of 11 Mbps. Today, Wi-Fi™ can apply to products that use any IEEE 802.11 standard including: IEEE 802.11 (1-2 Mb/s), IEEE 802.11a (54 Mb/s), IEEE 802.11b (11 Mb/s), IEEE 802.11g (54 Mb/s), and IEEE 802.11n (500 Mb/s). IEEE 802.11b uses either Frequency Hopping Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum. IEEE 802.11a is based on OFDM and it has been widely deployed in many businesses, government agencies, schools, and homes as a convenient alternative to a wired LAN. Today, airports, hotels, and even fast-food facilities offer public access to Wi-Fi™ networks. The 802.11 standards were designed to serve indoor wireless networks. However, vendors built proprietary MAC and PHY systems that extended these capabilities to enable outdoor networks. An example of a supplier configuration that employs OFDM in conjunction with Wi-Fi™ is Amperion, Inc.

3.1.2 WiMAX

In addition to the IEEE 802.11 Wi-Fi™ series of standards, the IEEE 802.16 Working Group is also being considered as a future means to deliver BPL. WiMAX is an improved microwave, wireless protocol. It was intentionally designed to provide mesh and backhaul capabilities, and it overcomes many of the problems associated with 802.11 "hot spot" implementations. It can be used for high-speed, wireless networking at distances up to a few miles. The term WiMAX comes from 'Wireless (Wi) Microwave Access (MA).' WiMAX and WiFi are both constructed using an OFDM waveform.

There are presently two versions of WiMAX: IEEE 802.16-2004 and IEEE 802.16e. They address the demands for different types of access: fixed, nomadic, portable, and mobile applications.

3.1.3 WiMAX Architecture

WiMAX is being developed as a point-to-multipoint (PMP) broadband wireless access standard that covers both the PHY and MAC layers. Development of this standard took into account a number of PHY considerations. For example, at higher frequencies, Line of Sight (LOS) is a requirement. The requirement eases the effect of multipath, allowing for channels that are typically greater than 10 MHz in bandwidth. This enables IEEE 802.16 to provide very high capacity links on both the uplink and the downlink. Non-Line-Of-Sight (NLOS) capability is a requirement at speeds less than 11 GHz. The IEEE 802.16 MAC was enhanced to accommodate different PHY's and services, which address the needs of different environments. The standard is designed to accommodate either Time Division Duplex (TDD) or Frequency Division Duplex (FDD) deployments, allowing for both full and half-duplex terminals in the FDD case.

The MAC was designed specifically for the point to multi-point wireless access environment. It supports higher layer protocols such as Asynchronous Transmission Mode (ATM), Ethernet or IP, and is designed to easily accommodate future protocols that have not yet been developed. The MAC is designed to support bit rates up to 268 Mb/s each way while delivering ATM compatible QoS and four uplink scheduling mechanisms. The frame structure allows dynamically assigned uplink and downlink burst profiles according to the link conditions.

The 802.16 MAC uses a variable length Protocol Data Unit (PDU) along with a number of other techniques that increase efficiency. Multiple MAC PDUs may be concatenated into a single burst to save PHY overhead. Additionally, multiple service data units (SDU) for the same service may be concatenated into a single MAC PDU, saving on MAC header overhead. Fragmentation allows very large SDUs to be sent across frame boundaries to guarantee the QoS of competing services. Payload header suppression can be used to reduce the overhead caused by redundant portions of SDU headers.

The MAC uses a self-correcting, bandwidth request/grant scheme that significantly improves the overhead and reduces the delay associated with acknowledgements, while simultaneously allowing better QoS handling than traditional acknowledge schemes. End systems have a variety of options available to them for requesting bandwidth, depending upon the QoS and traffic parameters of their services. End systems can be polled individually or in groups; steal bandwidth already allocated to make requests for more; signal the need to be polled; and piggyback requests for bandwidth.

3.1.3.1 IEEE 802.16-2004 WiMAX

The "802.16-2004 IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems" is based on a combination of the IEEE subcommittee work and the European Telecommunications Standards Institute (ETSI) HiperMAN specification. It uses OFDM and supports fixed and nomadic access in LOS and non-LOS environments. Vendors are developing indoor and outdoor Customer Premises Equipment (CPE) and laptop PCMCIA cards. The initial WiMAX Forum

profiles are for the 3.5 GHz and 5.8 GHz frequency bands. The theoretical bandwidth is 70 Mb/s but in practice 500 Kb/s – 2 Mb/s per site is more common.

3.1.3.2 IEEE 802.16e WiMAX

On December 7, 2005 the IEEE announced the approval of IEEE 802.16E-2005 “IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands.” IEEE 802.16e WiMAX has been optimized for dynamic mobile radio channels. The 802.16e amendment provides support for handoffs and roaming. It uses Scalable Orthogonal Frequency Division Multiplexing Access (SOFDMA) and a multi-carrier modulation technique that uses sub-channelization. Service providers that deploy 802.16e can also use the network to provide fixed service. The frequency bands for the 802.16e certification profiles range from 2.3-2.4 GHz with 8.75 MHz of channel width to 3.4-3.8 GHz with a 10 MHz channel width.

3.1.4 Interference-Free BPL

At least two BPL system manufacturers appear to have directly addressed HF interference concerns during the design phase of their architectures. This section provides a brief introduction to these systems.

3.1.4.1 Motorola Powerline LV

Motorola has designed a hybrid BPL delivery system that combines a wireless network infrastructure with customer delivery over LV power lines. The basic design is founded on the use of wireless access point clusters, which use unlicensed National Information Infrastructure (NII) frequencies. A point-to-point backhaul unit connects the wireless network infrastructure to the Internet over a range of up to 20 miles. The system only requires a 3.6 Mb/s Internet feed to support up to six access point systems, which means that the bandwidth is divided among up to 1,200 subscribers. A bridge is used to transfer the internet connection from the wireless distribution system onto LV power lines for delivery to customer homes, which use the existing in-home electrical wiring as a LAN. The Motorola system reduces HF band interference by restricting the application of RF to LV power lines only. No MV lines are used. The system also makes use of notches.

3.1.4.2 Corridor Systems Motorola Powerline LV

Corridor Systems has designed a BPL system that operates entirely above the HF radio spectrum and is offered as an “interference free” BPL system. Corridor Systems BPL equipment operates in the range from 800 MHz – 10 GHz.

The system utilizes off-the-shelf commodity RF chipsets to provide a low-cost solution with high-performance delivery of information across MV power lines. Corridor’s system uses a transmission technique that transmits energy over a single conductor of an existing MV power line at frequencies above the HF band, thus avoiding it interference issues. Information carrying energy is coupled on and off the conductor by identical launch devices (see Figure 16 below) on each end of the conductor. The energy, which may extend from VHF through the microwave portions of the spectrum, is launched as a traveling wave

mode around the conductor. This mode exhibits the three characteristics: (1) very low-loss over distance; (2) propagation speeds near the speed of light; and (3) low radiation.



Photo courtesy of Corridor Systems

Figure 16: BPL in 800 MHz - 10 GHz range

3.2 Spread Spectrum Modulation

BPL systems can be realized through the use of spread-spectrum modulation techniques such as the Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) technologies, which have been widely adopted in wireless systems.

Federal Standard 1037C defines direct-sequence spread spectrum (DSSS) as a “system for generating spread-spectrum transmissions by phase-modulating a sine wave pseudo-randomly with a continuous string of pseudo-noise code symbols, each of duration much smaller than a bit.” In this technique, a pseudo-random number (PRN) is applied directly to data entering the carrier modulator. The modulator therefore sees a much larger bit rate, which corresponds to the chip rate of the PRN sequence. The result of modulating an RF carrier with such a code sequence is to produce a DSSS with $((\sin x)/x)^2$ frequency spectrum, centered at the carrier frequency.

DSSS is a packet radio technique in which the signal is spread across a wider carrier frequency in a redundant manner. Multiple transmissions can share the same bandwidth with the transmission separated from each other through the use of a unique code sequence pre-pended to each data packet. Multiple systems may be installed on adjacent lines in a two-phase or three-phase MV distribution line. The ratio, in dB, between the spread baseband and the original signal is called processing gain. Typical DSSS processing gains range from 10dB - 60dB.

An example use of a DSSS implementation can be found in the IEEE 802.11 series of standards where both the initial base standard and the subsequent IEEE 802.11b utilized DSSS. In the 802.11 world DSSS uses the radio frequencies ranging from 2.4 to 2.4835 MHz (83.5MHz bandwidth). It also uses a Differential Binary Phase Shift Keying (DBPSK) and Differential Quadruple Phase Shift Keying (DQPSK) modulation and divides the total bandwidth into thirteen (13) channels [eleven (11) channels in the USA]. When configured, the radio stays on the selected channel. The term "spread spectrum" is used because the radio uses several frequencies at once.

In an IEEE 802.11 implementation it is typical to have 30 MHz between the center frequencies of the deployed access points to avoid interference. This provides enough bandwidth for three (3) access points in an area. The selection of channels varies between

the "US Mode" and the "World Mode." The 30 MHz spacing between center frequencies avoids interference with the other access points.

An example of a supplier that deployed DSSS technology is Main.Net for its first generation BPL systems. However, Main.Net is converting its second generation BPL systems to OFDM.

While DSSS is extremely resistant to narrowband interference it is not very resistant to the effects of being swamped by a nearby transmitter on the same band as itself (using the whole bandwidth). A signal from a far-away transmitter can be blanketed out by a nearby transmitter if the difference in signal strength at the receiver is only about 20 dB.

4 Standards

Open systems standards for Access and In-home BPL systems are at an early stage of evolution but are expected to develop rapidly due to fast-track efforts. Open systems BPL standardization issues are currently being addressed by the International Telecommunications Union – Radiocommunication (ITU-R) Sector, ITU – Telecommunication Standardization Sector (ITU-T), ANSI, and the IEEE. Additionally, the HomePlug Power Alliance has produced the first BPL technology standard that enjoys widespread industry implementation. This section examines evolving BPL standards.

4.1 ANSI C63.4

During World War II the US military needed instruments and methods to measure radio-noise. The result became an Army-Navy specification that was later adopted by the ANSI as C63-1-1946 titled: “American War Standard-Method of Measuring Radio Interference of Electrical Components and Completed Assemblies of Electrical Equipment for the Armed Forces from 150 kHz to 20 MHz.” A number of subsequent revisions were made to enhance the standard, including revisions in 1963, 1988, 1991, 2001, and the latest revision in 2003 was titled: “American National Standards Institute (ANSI) C63.4-2003: American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.”

The 2005 revised FCC Part 15.31 section on Measurements incorporates the use of ANSI C63-4-2003 by reference, except for measurements below 30 MHz. The standard contains an informative Annex G titled: “Step-By-Step Guidance For Testing Unintentional Radiators Other Than ITE” for radiated emission measurements setup and radiated emission measurements.

ANSI C63-4, section 8.2.3, electric field radiated emissions (30 MHz to 1 GHz) recommends that “The measurement antenna shall be varied in height above the reference ground plane to obtain the maximum signal strength.” It further stipulates “At any measurement distance, the antenna height shall be varied from 1m to 4m.” In its Phase I study, the NTIA stated “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. The FCC ruled “In deference to NTIA’s extensive work culminating in the NTIA recommendations in this proceeding, we will adopt NTIA’s recommendations for antenna height and correction factor as an alternative method within the measurement guidelines of Appendix C. We note, however, that the methods are mutually exclusive, i.e., the BPL tester must choose either the NTIA alternative method or the FCC method, and cannot mix and match the two.”

4.2 HomePlug In-Home BPL Specification 1.0

The HomePlug Powerline Alliance was founded in March of 2000 by 13 corporate members whose mission is to promote rapid availability, adoption, and implementation of

interoperable home powerline networks and products. Among the participating members of this Alliance are: Intel, Motorola, Linksys, and Sony. The HomePlug Alliance thus far has produced two major specifications: (1) HomePlug 1.0 and (2) HomePlug AV. These specifications are not available in the public domain but are restricted to members of the Alliance although some high-level, technical overviews have been released. However, in September 2002 the International Journal of Communications Systems published a paper titled: “HomePlug 1.0 Powerline Communication LANs – Protocol Description and Performance Results version 5.4.”^{xxiii} The paper furnished a level of protocol detail that is sufficient to enable consideration for NS/EP purposes and, therefore, provides the basis for a limited description.

HomePlug 1.0 offers the ability to create an in-home LAN using the power line infrastructure with data rates up to 14 Mb/s. The specification addresses the physical (PHY) and Media Access Control (MAC) layers but complete architectural independence is not maintained because both layers need packet length information and the MAC also needs information about the priority of the packet and about contention control. Thus, the OSI architecture is compromised slightly in favor of increased efficiency.

HomePlug 1.0 uses OFDM that is specially tailored for powerline environments. It uses 84 equally spaced subcarriers in the frequency band between 4.49 MHz and 20.7 MHz. This is achieved by dividing the band between 0 and 25 MHz into 128 equivalently spaced subcarriers, with 84 allocated between 23-106 MHz inclusively. The HomePlug 1.0 specification requires that 8 subcarriers be permanently masked in order to avoid the 40, 30, 20, and 17 meter HF amateur radio frequencies. The remaining 76 subcarriers are available for data transmission. Cyclic Prefix (CP) and variants of Phase Shift Keying (PSK) modulation techniques such as Binary PSK (BPSK), DBPSK, and DQPSK are used to eliminate the need for equalization. FEC with data interleaving are used to reduce the effects of impulsive noise events. The payload uses a concatenation of Viterbi algorithm and Reed-Solomon FEC. Turbo Codes (TC) are also employed.

HomePlug 1.0 technology uses a combination of adaptive techniques on each link to optimize data throughput. For example, a different amplitude and phase response between any two links can be used. Channel adaptation is achieved by tone allocation, modulation, and the FEC rate chosen. The tone allocations are used to turn off heavily impaired carriers and thereby reduce the bit error rates (BER). The remaining adaptive techniques target the modulation and FEC rate selection to the remaining higher quality channels. HomePlug allows for the selection of various modulation techniques including the following variants of Phase Shift Keying (PSK) modulation: (1) Coherent Binary PSK (CBPSK), (2) DBPSK $\frac{1}{2}$, and (3) DQPSK $\frac{3}{4}$ on all the subcarriers. These adaptation techniques enable the achievement of optimized throughput on all links. A specialized modulation technique called ROBO [Robust Orthogonal Frequency Division Multiplexing (OFDM)] is used for broadcast packets. ROBO modulation uses DBPSK and FEC with bit repetition in time and frequency. In ROBO mode, all carriers are always used, and a different RS code is employed. ROBO frames are indicated by the presence of 0b000000 in the tone map index field, which tells the receiver which map to use to demodulate and decode the frame. A powerline device switches itself into ROBO mode under one of the following conditions:

- There is so much noise on the power line that it is not possible to obtain a connection with other devices using OFDM;

- There are more than 16 devices that need to communicate with the particular device. More than 16 devices will not fit into the device tables, so it becomes necessary to switch to ROBO mode. In ROBO mode, the highest possible speed is 0.9 Mbps.

4.3 HomePlug AV Specification

The HomePlug AV (HPAV) specification is the basis for the second generation of technology from the HomePlug Powerline Alliance. The purpose is to provide high-quality, multi-stream, entertainment-oriented networking over existing A/C wiring within the home. HPAV maintains backward compatibility and interoperability with HomePlug 1.0 devices. HPAV employs PHY and MAC techniques that support up to a 200 M/bps power line network for video, voice, and data. The PHY layer uses the 200 M/bps channel rate to provide a 150 M/bps information rate with robust, near-capacity communications over noisy power line channels. The MAC was designed to support both TDMA and Carrier Sense Multiple Access (CSMA) based access with A/C line cycle synchronization. The TDMA access provides QoS guarantees including guaranteed bandwidth reservation, high reliability and tight control of latency and jitter. The CSMA access provides four priority levels. A/C line cycle synchronization provides channel adaptation in the face of common-line, cycle-synchronized noise. A central coordinator controls the activities of the network, allocating time for CSMA and scheduling TDMA use. HomePlug AV also provides advanced management capabilities as part of the new networking standards. Advanced Network Management functions and facilities are capable of supporting user plug-and-play configurations as well as service provider set-up and configuration. HPAV offers security based on the 128-bit Advanced Encryption Standard (AES) standard and supports dynamic encryption key changes. The design allows a station to participate in multiple AV networks. For backward compatibility with HomePlug 1.0 devices, HPAV offers several mandatory and optional co-existence modes enabling multi-network operation, hidden node service and BPL co-existence.

4.4 IEEE P1675® Standard for BPL Hardware

IEEE P1675 has been proposed as a comprehensive standard that addresses: (1) component standards; (2) capacitive couplers; (3) inductive couplers; (4) cabinets and enclosures; and (5) grounding and bonding. The proposed standard will address the hardware associated with the distribution lines for BPL signal injection. It is expected that the hardware portions of the standard will not be based on any specific manufacturer or technology and will not mandate a specific type of coupler, node, or other device. Instead, the intent of the standard is that if a manufacturer chooses to use a capacitive coupler it must be of a type that meets the specifications of the standard. An inductive coupler will be required to have a specified numeric basic insulation level that provides a particular surge protection capability and environmental expectations, like resistance to weather, ultra-violet rays, vibration, and so forth. These will be specified in the standard. The standard will define the tests that must be conducted to insure that standard specifications are met for the operating voltage and other technical parameters.

It is further expected that the standard will also address equipment installation practices for the purpose of insuring safety, considering that a very common distribution voltage is 12,500 volts. The installation portion of the standard is expected to supplement the hardware portion by giving the directions necessary for properly installation. For example,

on an overhead line, the standard will identify methods for grounding and bonding. In underground situations, the location for installing equipment may be easier to reach. However, the 12,500 volt environment is much closer to the public. Therefore, the standard will provide instructions for reducing this risk. The primary source of information for equipment standards will be the reference material contained in the IEEE National Electric Safety Code (NESC).

4.5 IEEE P1901 Standards for BPL MAC and PHY Specification

The goal of this IEEE project is to develop a standard for 100 M/bps or greater BPL PHY layer speeds. The standard is intended to use transmission frequencies below 100 MHz. It is widely expected that HomePlug specifications will become the basis for IEEE P1901. The standard is intended to be usable by all classes of BPL devices including BPL devices used for the first/last 1500 meters to the premise, for LANs and for use in buildings. This standard will focus on the balanced and efficient use of the power line communications channel by all classes of BPL devices, defining detailed mechanisms for coexistence and interoperability between different BPL devices, and ensuring that desired bandwidth and QoS are supported. The standard will address the privacy of communications between users and allow the use of BPL for security sensitive services. IEEE 1901 is expected to be limited to the PHY and MAC layers and will provide a minimum implementation subset, which allows for coexistence of BPL devices. The full implementation will provide the interoperability among the BPL devices, as well as interoperability with other networking protocols, such as bridging for seamless interconnection via 802.1. This project is still in the review process with an approval no sooner than late spring 2008.

4.6 ITU-T Recommendation K.60 “Emission Limits and Test Methods for Telecommunication Networks”

ITU-T Recommendation K.60 was approved by ITU-T Study Group 5 on July 29, 2003. The Recommendation covers the frequency range 9 kHz to 400 GHz. It specifies the requirements for radiated disturbance emissions in the frequency range 9 kHz to 3 GHz and specifies target limits for electromagnetic disturbances radiated from fixed telecommunication networks (see Table 3.)

Table 3: ITU-T K.60 Limits For Unwanted Disturbance Emissions From Telecommunication Networks Measured In *si tu*

| Frequency range (MHz) | Field strength limit [dB μ V/m] | | Standard measurement distance | Measurement bandwidth |
|-----------------------|-------------------------------------|----------------------|-------------------------------|-----------------------|
| | PEAK | QUASI-PEAK | | |
| 0.009 to 0.15 | 52 – 20*log(f[MHz]) | 40 – 20*log(f[MHz]) | 3 m | 200 Hz |
| 0.15 to 1 | 52 – 20*log(f[MHz]) | 40 – 20*log(f[MHz]) | 3 m | 9 kHz |
| 1 to 30 | 52 – 8.8*log(f[MHz]) | 40 – 8.8*log(f[MHz]) | 3 m | 9 kHz |
| 30 to 230 | 40 (Note 3) | 40 | 3 m | 120 kHz |
| 230-1000 | 47 (Note 3) | 47 | 3 m | 120 kHz |
| 1000 to 3000 | 74 | n.a. | 3 m | 1 MHz |

ITU-T K.60 recommends that in the frequency range 9 kHz to 30 MHz, the magnetic component of the radiated disturbance emission has to be measured and assessed. It also recommends the use of a system calibrated in accordance with the International Special Committee on Radio Interference (CISPR) 16-1, consisting of a radio disturbance measuring receiver or spectrum analyzer, in conjunction with an associated loop antenna for the measurement of magnetic field components, and a tripod. Other specialized equipment such as resonant loop antennas can also be used.

To speed up the measurement process a peak detector is initially used. If the background noise makes this simple measurement unusable, a quasi-peak detector can be used and the quasi-peak limit applied. The standard recommends that both the measuring receiver and the loop antenna have an independent power source with no ground connection (e.g., battery power), especially in the case of indoor measurements.

A loop antenna will be placed with the lower edge of the loop mounted on a tripod at a height of 1 meter and located at the measurement location identified as having the maximum disturbance field strength. The measuring receiver should be set to the frequency carrying the disturbance and should use the required detector. The loop antenna should be positioned so that the maximum reading is obtained. The measurement of magnetic fields radiated from telecommunication networks in the frequency range up to 30 MHz can become complicated due to the presence of a variety of high-level, wanted RF emissions from radio services. Thus, it may be necessary to identify frequencies that are close to the frequency of the radio service being affected, that have low field strengths such that the background noise and ambient signals are below the specified limits. To the extent feasible, the margin should be greater than 6 dB.

5 Conclusions

With the FCC regulatory position of BPL clarified by the revision of Part 15, the technology is poised for expansion in both access and in-home configurations over the next decade. BPL has been considered as a potential 3rd wire that can compete with cable and DSL Internet services. Ultimately, many factors will influence the degree of market penetration that BPL achieves, including cost, standards progress, competition, regulations, and technical acceptance. Electrical power lines offer a clear benefit with regard to the large coverage area from which broadband service could be obtained, but it is important to remember that BPL provisioning does not come without the additional infrastructure costs for injectors, repeaters, extractors, management systems, and operations and maintenance. For initial BPL deployments, lower customer costs appear to be the dominant customer consideration since Access BPL speeds are not competitive with cable Internet. Second generation BPL may offer better performance with speeds of up to 200 Mb/s but to leverage this as a competitive advantage beyond a 3rd wire status, BPL will need to deliver the higher speeds sooner than cable or DSL. The PowerCorridortm product literature from Corridor Systems already promises to deliver BPL performance speeds that exceed 1 Gb/s. At speeds above 1 Gb/s, BPL could serve a role in bridging the transition from Internet to Internet2.

Around the globe, various BPL studies, prototypes, and deployments have been conducted with mixed results. In a noteworthy number of locations, including the United States, BPL prototypes have been terminated in association with interference complaints. However, the FCC accurately recognized BPL as an infancy-stage technology and appropriately assigned it to a regulatory climate that is intended to foster innovation. It is clear that ongoing studies such as that documented in ITU-R P.372-8 Radio Noise provide an excellent baseline to insure that manmade factors contributing to interference are managed appropriately. The FCC support for BPL is already resulting in the emergence of designs that significantly reduce interference concerns, and this trend is expected to continue. US power companies, to date, have not demonstrated a firm stand with respect to BPL investment and deployment in favor of insuring stability for their electrical-power- business customer base. However, as BPL technology advances, this business climate is also subject to change. Initially, power companies' interest in BPL has been focused on its ability to improve control over elements of the electrical power grid.

Altering the mix of communications assets deployed to support NS/EP is presently an expensive proposition that requires long project schedules. Consequently, it is not currently possible to adjust the NCS infrastructure to compensate for rapid technology or regulatory changes. Regulatory agencies such as the FCC need to partner with both industry and the NCS community members to insure that the interests of the private sector and national security are properly balanced. However, these interests are not mutually exclusive, and the NCS can ultimately benefit from technologies like BPL, which offer new means for asset diversification.

The BPL studies that have been conducted by the BBC and others around the world have raised serious concerns about detrimental interference effects on HF radio spectrum. These concerns are resulting in further BPL scientific studies and in additional work within standards bodies around the world. HF radio spectrum is a highly valued natural resource that should be allocated in a manner that serves the greatest good. As required, further

technical refinements will be made to BPL technologies to enable them to reduce harmful emissions.

6 Recommendations

From the creation of the NCS in the 1960s, the HF radio spectrum has been counted on to play a key role in supporting NS/EP operations, especially in areas where electrical power has been disrupted. However, good NS/EP planning has always been based on employing the widest diversification of communications assets feasible. BPL technology potentially offers the NCS an entirely new transmission system infrastructure and thus could add diversification and redundancy to existing NS/EP assets.

The NCS should consider that over time, manmade or natural events will occur, which cause the HF radio spectrum to operate in a degraded mode (e.g., solar flares) and that over time, human progress has tended to increase the overall noise floor within the HF spectrum. These conditions may limit the BPL bandwidth that is available to support NS/EP operations. However, it is recommended that the NCS include BPL planning as part of its overall operational alternatives.

It is recommended that the NCS actively participate in the BPL standardization efforts of the IEEE, the ITU-T, ITU-R, ANSI, and others. Over the next few years, important BPL standards will be developed, which will determine important aspects including: QoS, security, operating practices, interference, grounding and bonding, and others. It is further recommended that the NCS insure that NS/EP systems such as SHared RESources (SHARES) are exercised on an appropriate schedule and geographic locations to coincide with the deployment of BPL systems to insure that the highest quality operational standards are maintained.

Appendix A: Acronyms

| | |
|---------|---|
| A/C | Alternating Current |
| ACK | Acknowledgement |
| ADSL | Asymmetric Digital Subscriber Loop |
| AES | Advanced Encryption Standard |
| ANSI | American National Standards Institute |
| ARQ | Automatic Repeat Request |
| ARRL | American Radio Relay League |
| ASK | Amplitude Shift Keying |
| ASN.1 | Abstract Syntax Notation One |
| AT&T | American Telephone & Telegraph |
| ATM | Asynchronous Transmission Mode |
| ATS | Arrival Time Stamp |
| AVLN | AV Logical Network |
| | |
| BBC | British Broadcasting System |
| BC | Backoff Counter |
| BER | Bit Error Rate |
| BP | Beacon Period |
| BPC | Backoff Procedure |
| BPL | Broadband over Power Lines |
| BPSK | Binary Phase Shift Keying |
| | |
| CA | Collision Avoidance |
| CAP | Channel Access Priority |
| CBC | Cipher Block Chaining |
| CBPSK | Coherent Binary Phase Shift Keying |
| CCIP | Communications and Information Policy |
| CDMA | Code Division Multiple Access |
| CFA | Contention-Free Access |
| CIFS | Contention Inter-Frame Space |
| CIP | Critical Infrastructure Protection |
| CL | Convergence Layer |
| CP | Cyclic Prefix |
| CPE | Customer Premises Equipment |
| CRC | Cyclic Redundancy Check |
| CSMA | Carrier Sense Multiple Access |
| CSMA/CA | Carrier Sense Multiple Access/Collision Avoidance |
| CSMA/CD | Carrier Sense Multiple Access/Collision Detection |
| CSPEC | Connection Specification |
| CW | Contention Window |
| | |
| DA | Destination Address |

| | |
|-----------|---|
| DAB | Digital Audio Broadcast |
| DAK | Device Access Key |
| dB | Decibel |
| DBPSK | Differential Binary Phase Shift Keying |
| DC | Deferral Counter |
| DES | Data Encryption Standard |
| DHS | Department of Homeland Security |
| Diff-Serv | Differentiated Services |
| DS1 | Digital Signaling Level 1 |
| DSL | Digital Subscriber Loop |
| DSSS | Direct Sequence Spread Spectrum |
| DQPSK | Differential Quadruple Phase Shift Keying |
| | |
| E-PAD | Encryption Packet Assembler Disassembler |
| EFG | End of Frame Gap |
| EIFS | Extended Inter Frame Space |
| EKS | Encryption Key Select |
| ELF | Extremely Low Frequency |
| E.O. | Executive Order |
| EOF | End of Frame |
| E.O.P | Executive Office of the President |
| EP | Emergency Preparedness |
| ETSI | European Telecommunications Standards Institute |
| | |
| <i>f</i> | Frequency |
| FAIL | Failure |
| FC | Frame Control |
| FCC | Federal Communications Commission |
| FCS | Frame Check Sequence |
| FDD | Frequency Division Duplex |
| FDM | Frequency Division Multiplexing |
| FEC | Forward Error Correction |
| Fed-Std | Federal Standard |
| FEMA | Federal Emergency Management Agency |
| FFT | Fast Fourier Transform |
| FH | Frame Header |
| FHSS | Frequency Hopping Spread Spectrum |
| FTSC | Federal Telecommunications Standards Committee |
| FTTH | Fiber To The Home |
| | |
| Gb/s | Giga-bits per second |
| GHz | Gigahertz |
| | |
| HC | Hybrid Coordination |
| HD | High Definition |
| HF | High Frequency |

| | |
|--------|---|
| HF/VHF | High Frequency/Very High Frequency |
| HLE | Higher Layer Entity |
| HPAV | HomePlug AV |
| HV | High Voltage |
| Hz | Hertz |
| IAIP | Information Analysis and Infrastructure Protection |
| IEC | International Electrotechnical Committee |
| IEEE | Institute of Electrical and Electronic Engineers |
| IETF | Internet Engineering Task Force |
| IFFT | Inverse Fast Fourier Transform |
| I/N | Interference to Noise |
| IP | Internet Protocol |
| ISO | International Organization for Standardization |
| ISP | Internet Service Provider |
| ITU | International Telecommunications Union |
| ITU-R | International Telecommunications Union – Radiocommunications Sector |
| ITU-T | International Telecommunications Union – Telecommunications Sector |
| K/bps | Kilo bits per second |
| LAN | Local Area Network |
| LF | Long Frame |
| LLC | Logical Link Control |
| LN | Logical Network |
| LOS | Line Of Sight |
| LSB | Least Significant Bit |
| LSF | Last Segment Flag |
| LV | Low Voltage |
| MAC | Medium Access Control |
| Mb/s | Mega-bits per second |
| MA | Microwave Access |
| MCF | Multicast Flag |
| MD | Message Digest |
| MHz | Megahertz |
| MLPP | Multi Level Precedence and Preemption |
| MPDU | MAC Protocol Data Unit |
| MPLS | Multi Protocol Label Switching |
| MS | Milliseconds |
| MSDU | MAC Service Data Unit |
| MV | Medium Voltage |
| N2 | Technology and Programs Division |
| N6 | Technology and Standards Division |
| NCS | National Communications System |

| | |
|--------|---|
| NEK | Network Encryption Key |
| NESC | National Electric Safety Code |
| NII | National Information Infrastructure |
| NMK | Network Membership Key |
| NOI | Notice of Inquiry |
| NS/EP | National Security/Emergency Preparedness |
| NTIA | National Telecommunications and Information Agency |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OMNCS | Office of the Manager National Communications System |
| OSI | Open Systems Interconnection |
| PA | Preamble |
| PB | PHY Block |
| PBKDF | Password Based Key Derivation Function |
| PCMCIA | Personal Computer Memory Card International Association |
| PCF | Persistent Contention Free |
| PCS | Physical Carrier Sense |
| PDU | Protocol Data Unit |
| PKCS | Public Key Crypto System |
| PMP | Point-to-MultiPoint |
| PHY | Physical Layer |
| PLC | Power Line Communications |
| PLT | Power Line Telecommunications |
| PPDU | PHY Protocol Data Unit |
| PRN | Pseudo Random Number |
| PRP | Priority Resolution Period |
| PRS | Priority Resolution Signal |
| PSK | Phase Shift Keying |
| QAM | Quadrature Amplitude Modulation |
| QoS | Quality of Service |
| QPSK | Quadrature Phase Shift Keying |
| RCS | Ripple Carrier Signaling |
| RIFS | Response Inter-Frame Space |
| RFC | Request For Comments |
| RFCS | Response Frame Check Sequence |
| RF | Radio Frequency |
| ROBO | Robust Orthogonal Frequency Division Multiplexing |
| RSVP | Resource Reservation Protocol |
| SA | Source Address |
| SACK | Selective Acknowledgement |
| SBM | Subnetwork Bandwidth Manager |

| | |
|--------|--|
| SC | Segment Control |
| SCADA | Supervisory Control and Data Acquisition |
| SDU | Service Data Unit |
| SHARES | SHARed RESources |
| SF | Short Frame |
| SFD | Start Frame Delimiter |
| SL | Segment Length |
| SOF | Start of Frame |
| SOFDMA | Scalable Orthogonal Frequency Division Multiplexing Access |
| SN | Sequence Number |
| | |
| TIB | Technical Information Bulletin |
| TC | Turbo Code |
| TCC | Turbo Convolutional Code |
| TCP | Transmission Control Protocol |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| TDD | Time Division Duplex |
| TDM | Time Division Multiplexing |
| TDMA | Time Division Multiple Access |
| TM | Tone Map |
| TMI | Tone Map Index |
| TXOP | Transmit Opportunities |
| | |
| UHF | Ultra High Frequency |
| | |
| VCS | Virtual Carrier Sense |
| VHF | Very High Frequency |
| VLAN | Virtual LAN |
| VLF | Very Low Frequency |
| VoIP | Voice over Internet Protocol |
| | |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |

Appendix B: Radio Frequency Use

Data courtesy of Tampa Bay Interactive, Inc.

| FREQUENCY RANGE | | TYPICAL SERVICES |
|------------------|-----|---|
| 10 - 510 | KHz | Radio navigation, maritime communication |
| 535-1605 | KHz | Broadcasting (AM) |
| 1.65-3.5 | MHz | Amateur, radio navigation, maritime and aeronautical communication, radio astronomy |
| 3.5-4.0 | MHz | Amateur |
| 4.0-7.0 | MHz | International broadcasting, domestic broadcasting |
| 7.0-7.3 | MHz | Amateur |
| 7.3-9.5 | MHz | International broadcasting, maritime, military |
| 9.5-9.775 | MHz | International broadcasting |
| 10-10.15 | MHz | Amateur, standard time |
| 11.7-11.975 | MHz | International broadcasting |
| 11.975-14 | MHz | Business, government, space, and military |
| 14-14.35 | MHz | Amateur |
| 14.35-15.1 | MHz | Business, government, military |
| 15.1-15.45 | MHz | International broadcasting |
| 15.45-21 | MHz | Business, maritime communication, military, international broadcasting |
| 21-21.450 | MHz | Amateur |
| 21.450-21.75 | MHz | International broadcasting |
| 21.89-21.99 | MHz | Amateur |
| 25.6-26 | MHz | International broadcasting |
| 26-28 | MHz | Radio and television remote broadcasting, business, government, space, and military |
| 28-29.7 | MHz | Amateur |
| 29.7-50 | MHz | Paging stations, television audio (some countries) |
| 50-54 | MHz | Amateur |
| 54-88 | MHz | Television (channels 2-6) |
| 88-108 | MHz | Radio broadcasting (FM) |
| 108-144 | MHz | Aeronautical navigation and communication, space |
| 144-148 | MHz | Amateur |
| 148-174 | MHz | Government, maritime and land communication |
| 174-216 | MHz | Television (channels 7-13) |
| 216-220 | MHz | Government |
| 220-225 | MHz | Amateur |
| 225-420 | MHz | Government |
| 420-450 | MHz | Amateur |
| 450-800 | MHz | Ultra-high frequency (UHF) TV, local government, public services, forestry |
| 800-881 | MHz | Cellular telephone |
| 881-901.05 | MHz | Domestic public land mobile communication |
| 901.05-901.10 | MHz | Narrowband PCS |
| 901.25-901.3 | MHz | Narrowband PCS |
| 901.3-901.35 | MHz | Narrowband PCS |
| 901.8125-901.825 | M | Narrowband PCS |
| 901.825-901.8375 | M | Narrowband PCS |
| 902-928 | MHz | Amateur |
| 930.65-930.70 | MHz | Narrowband PCS |
| 930.70-930.75 | MHz | Narrowband PCS |
| 930.65-930.7 | MHz | Narrowband PCS |

| | | |
|--------------|-----|--|
| 930.7-930.75 | MHz | Narrowband PCS |
| 940.3-940.35 | MHz | Narrowband PCS |
| 940.35-952 | MHz | International public broadcasting |
| 952-960 | MHz | Maritime communication |
| 960-1240 | MHz | Public safety |
| 1.24-1.30 | GHz | Amateur |
| 1.850-1.890 | GHz | PCS (lower band) |
| 1.890-1.930 | GHz | Unlicensed PCS |
| 1.930-1.970 | GHz | PCS (lower band) |
| 2.130-2.150 | GHz | PCS (upper band) |
| 2.180-2.2 | GHz | PCS (upper band) |
| 2.39-2.40 | GHz | Unlicensed PCS |
| 2.402-2.417 | GHz | Unlicensed PCS |
| 4.0-6.0 | GHz | Satellite - C Band - Downlink = 4 GHz Uplink = 6 GHz |
| 9.013-9.0135 | GHz | Narrowband PCS services |
| 9.403-9.4035 | GHz | Narrowband PCS services |
| 12-14 | GHz | Satellite - Ku Band - Downlink = 12 GHz Uplink = 14 GHz |
| 17 | GHz | Satellite - K Band Downlink = 12 GHz Uplink = 17 GHz |

Other Frequencies and Waveforms

| Frequency Range | Description |
|-------------------------------|-------------------------------|
| 3x10E11 (300 GHz) - 4.3x10E14 | Infrared Light |
| 4.3x10E14 - 1x10E15 | Visible Light (Red to Violet) |
| 1x10E15 - 6x10E16 | Ultraviolet Light |
| 6x10E16 - 3x10E19 | X-Rays |
| 3x10E19 - 5x10E20 | Gamma Rays |
| 5x10E20 - 8x10E21 | Cosmic Rays |

TV Broadcast Frequencies (US)

| Channel Number | Frequency Range-MHz | Channel Number | Frequency Range-MHz |
|----------------|---------------------|----------------|---------------------|
| 2 | 54-60 | 3 | 60-66 |
| 4 | 66-72 | 5 | 76-82 |
| 6 | 82-88 | 7 | 174-180 |
| 8 | 180-186 | 9 | 186-192 |
| 10 | 192-198 | 11 | 198-204 |
| 12 | 204-210 | 13 | 210-216 |
| 14 | 470-476 | 15 | 476-482 |
| 16 | 482-488 | 17 | 488-494 |
| 18 | 494-500 | 19 | 500-506 |
| 20 | 506-512 | 21 | 512-518 |
| 22 | 518-524 | 23 | 524-530 |
| 24 | 530-536 | 25 | 536-542 |
| 26 | 542-548 | 27 | 548-554 |
| 28 | 554-560 | 29 | 560-566 |
| 30 | 566-572 | 31 | 572-578 |
| 32 | 578-584 | 33 | 584-590 |
| 34 | 590-596 | 35 | 596-602 |
| 36 | 602-608 | 37 | 608-614 |
| 38 | 614-620 | 39 | 620-626 |

| | | | | |
|------|---------|--|------|---------|
| 40 | 626-632 | | 41 | 632-638 |
| 42 | 638-644 | | 43 | 644-650 |
| 44 | 650-656 | | 45 | 656-662 |
| 46 | 662-668 | | 47 | 668-674 |
| 48 | 674-680 | | 49 | 680-686 |
| 50 | 686-692 | | 51 | 692-698 |
| 52 | 698-704 | | 53 | 704-710 |
| 54 | 710-716 | | 55 | 716-722 |
| 56 | 722-728 | | 57 | 728-734 |
| 58 | 734-740 | | 59 | 740-746 |
| 60 | 746-752 | | 61 | 752-758 |
| 62 | 758-764 | | 63 | 764-770 |
| 64 | 770-776 | | 65 | 776-782 |
| 66 | 782-788 | | 67 | 788-794 |
| 68 | 794-800 | | 69 | 800-806 |
| 70 * | 806-812 | | 71 * | 812-818 |
| 72 * | 818-824 | | 73 * | 824-830 |
| 74 * | 830-836 | | 75 * | 836-842 |
| 76 * | 842-848 | | 77 * | 848-854 |
| 78 * | 854-860 | | 79 * | 860-866 |
| 80 * | 866-872 | | 81 * | 872-878 |
| 82 * | 878-884 | | 83 * | 884-890 |

* = Original TV broadcast band, now allocated to land mobile and 2-way radio systems. Many Cellular services operate within this range.

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