NATIONAL ENERGY TECHNOLOGY LABORATORY

HV-BPL Phase 2 Field Test Report

DOE/NETL-2009/1388

U.S. DEPARTMENT OF ENERGY

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HV-BPL
Field Test Report

DOE/NETL-2009/1388

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HV-BPL Phase 2 Field Test Report

August 2008 to October 2008

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Overview

Today telecom service providers are phasing out pilot wire services and forcing utilities to explore other methods of achieving the same function. The goal of the High Voltage Broadband over Power Line program (HV-BPL) is to develop a disruptive technology that can not only replace the pilot wire relaying systems currently used to protect some high voltage transmission lines, but also to provide a secured broadband communication path for other services. Applications such as digital protective relaying, SCADA, station video surveillance, synchro-phasor data streaming and voice communications can all utilize this communication path. Given today's security concerns, many utilities prefer internal ownership and management of the communication channels that control their electrical grid. HV-BPL can provide a secure, low-cost alternative to the conventional expensive and time consuming option of deploying optical fiber communications systems along 69 kV and 138 kV transmission lines.

This report addresses two project development phases. Phase 1 covers progress in the initial testing of an OFDM (Orthogonal Frequency Division Multiplexing) based Broadband over Power Line (BPL) system for a 69 kV transmission line and its successful deployment over a 0.77 mile line. Phase 2 covers the continued development and field testing of HV-BPL systems and work performed to extend its operating range.

1. Background

This document provides a record of the collective learning's from a joint AEP/Amperion/ DOE HV-BPL trial. **The HV-BPL demonstration trial was funded in part by AEP and the DOE/NETL under RDS contract number 41817M3748**.

Phase 1

Phase 1 was implemented in April of 2008, and successfully established a high capacity Broadband over Power Line (BPL) connection operating on the in-service, 0.77 mile, 69 kV transmission line between the Heath and Granville substations near Columbus Ohio. Data transfer rates no lower than 1 Mbps, and as high as more than 20 Mbps, have been consistently achieved and FCC compliance has been demonstrated. Differential coupling using standard utility grade lightning arresters, combined with appropriate Amperion ancillary circuits, has produced stable performance and also serves as a mechanism to reduce radiated emissions. The equipment has been operating reliably since the last week of April 2008. Attenuation of the BPL signal on HV lines has been found to be far lower than that experienced on MV distribution lines, making HV-BPL increasingly attractive as a cost-effective communications technology for the transmission grid.

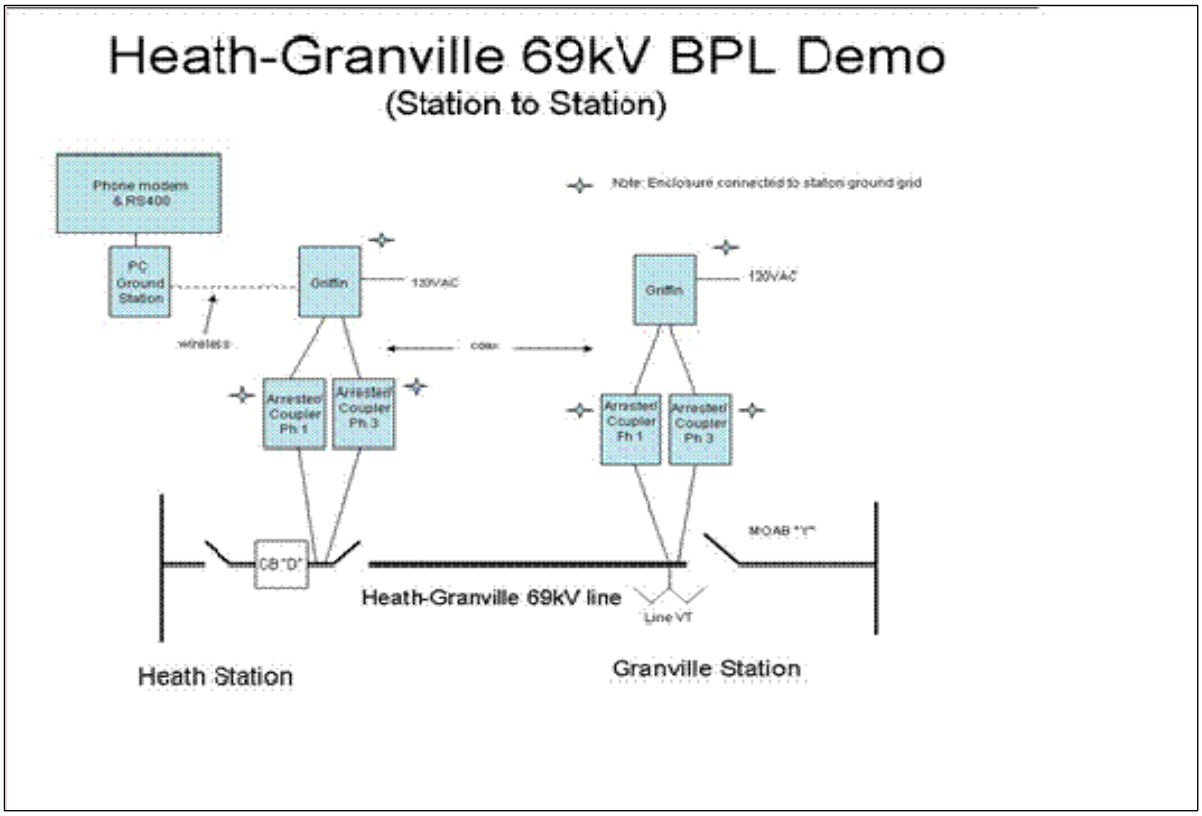

Figure 1: Phase 1 Heath-Granville HV-BPL Demo Configuration

Figure 1, shows the configuration installed during Phase 1 of the trial. The system works by overlaying a high frequency, wideband OFDM signal on the 60Hz transmission power lines between the substations. The Griffin communications node in the Heath station uses its master modem and the Griffin node in the Granville station uses its slave modem for point to point BPL communications. Each HV-BPL coupler uses 69 kV station class utility arresters to couple the RF signal onto the HV transmission line. The arresters are used as a capacitive coupler and not as a lightning protection device. However, the arresters do provide additional lighting protection, a desirable by-product of this coupling method. The coupler's electrical circuit has a secondary mechanism for lightning protection of the Griffin in case the primary arrester is discharged. The coupler uses an impedance matching circuit to optimize the system's impedance with the HV line impedance. The coupler was carefully designed to minimize attenuation and enhance RF signal performance. In order to reduce signal loss through the ground, ferrite beads were added in the ground path. These beads saturate instantly whenever an arrester discharges, hence they do not diminish the ground's primary role. The ferrite beads were tested at AEP for proper saturation performance.

2. Goals for Phase 2

For the second phase of the trial, the performance of the hardware communication platform and the coupling technology was improved. This required designing a new in-line coupler capable of being installed on a wooden transmission line pole structure outside the station. It also involved the development of the Network Management System (NMS) to verify that the BPL connection was available 24/7 with appropriate latency for protective relay operations.

The primary objective of Phase 2 involved creating a HV-BPL communications path between two stations that are 4.4 miles apart. The project was broken into Phases 2A and 2B. Phase 2A in August 2008 measured the transfer function between substations, and Phase 2B in October 2008 involved installing the appropriate configuration to establish a link.
Phase 2 involved the following milestones:

- Measuring the transfer function between Granville and West Granville Stations.
- Converting the transfer function information into a repeating system configuration.
- Developing an in-line repeater solution.
- Developing a powering solution for in-line repeaters
- Developing a network management system (NMS) capable of validating system availability.
- Optimizing system performance for Frequency Division Multiplexing (FDM) repeating architecture.
- Validating Time Division Multiplexing (TDM) repeating architecture.

The team successfully demonstrated that long distances can be traversed using either FDM or TDM repeating methods. This report discusses the findings from Phases 2A & 2B covering the period of three months from August 2008 to October 2008.

3. Phase 2 Configuration

Phase 2 expanded on the success of the prior Phase 1 work. The goal was to demonstrate a cost effective method of connecting two substations at six times the distance spanned during Phase 1. This problem was solved by breaking this phase into a two parts. Phase 2A of the program would gather information about the operating environment and Phase 2B would install an operational system based on the 2A learning's.

Phase 2A was implemented in Aug 10-15, 2008. The task involved the installation by AEP crews of HV-BPL couplers (two per station) at Granville and West Granville substations, measuring the transfer function between the stations, launching test signals between the two locations and tracking down noise sources. Data from Phase 2A testing was applied to developing the tools and skills required to successfully establish a reliable, low-latency, high-capacity, broadband connection over the 4.4 mile distance connecting the 69 kV stations. This included developing a new in-line coupler for injecting / extracting the OFDM signal at an intermediate point along the transmission line. The plan prior to the Phase 2 experiments called for multiple repeating units to be distributed between Granville and West Granville. This requirement was reduced to a single repeater element after completing Phase 2A. **(Today the system is operating over the full 4.4 miles line without a repeater.)**

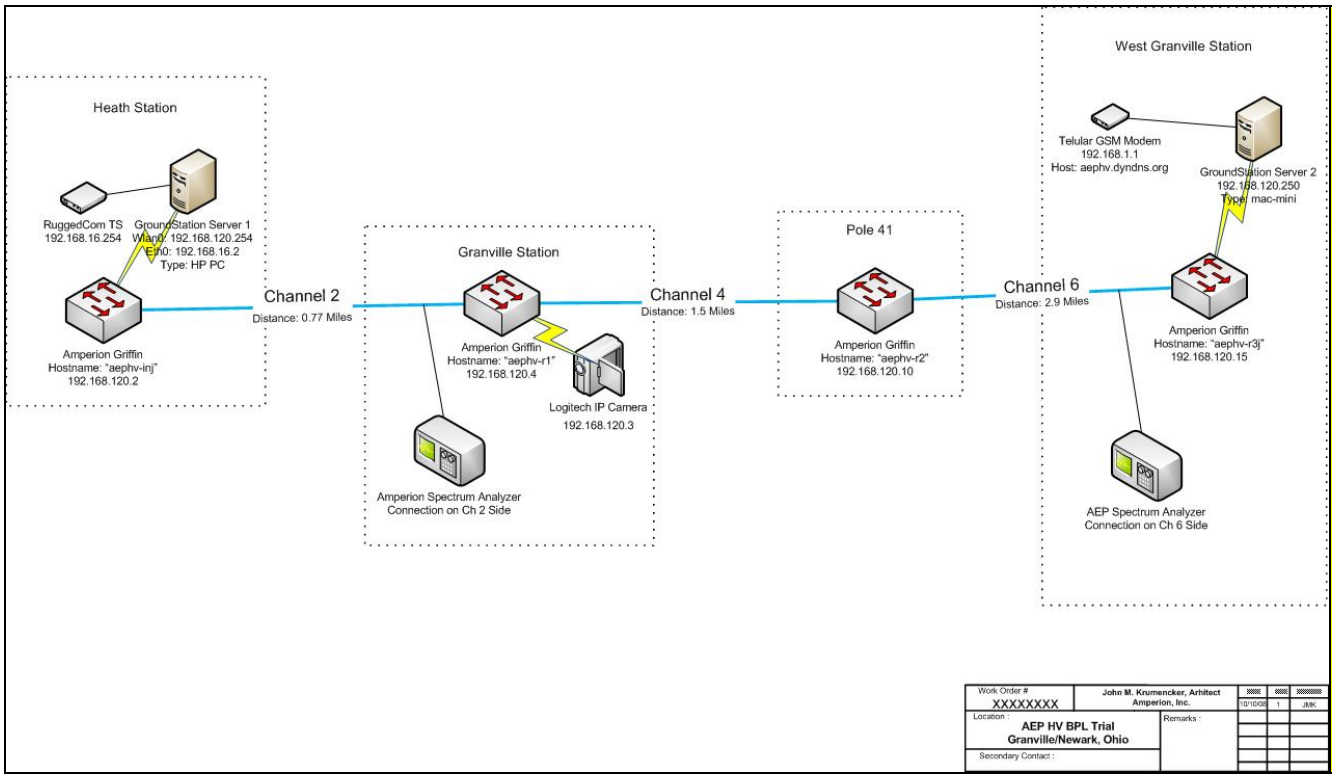

Figure 2: Final Phase 2B Network Configuration

Phase 2B was implemented in Oct 6-10, 2008. The work involved installing four new In-Line HV-BPL couplers and three Amperion Griffin systems. AEP crew installed the four new in-line, couplers at Pole 41, which is located 1.8 miles from Granville station. Amperion crew installed the Griffin units at Granville, Pole 41 and West Granville. The team also upgraded the Amperion NMS systems (one at Heath and one at West Granville Stations) and established remote connectivity from each NMS to Amperion's office in MA. The remote connection to Heath is a less than 56 kbps dial-up connection, while West Granville is operating with a cell-based wireless connection at about 300 kbps. Performance with 6 different operational frequencies was tested and verified. The team spent time searching for noise sources referred to as Electromagnetic Interference or EMI. EMI is defined here as intentional or unintentional noise created by a utility, a customer of the utility or a by third party (e.g. in the form of a radio station), that contributes to diminishing the Signal to Noise ratio (SNR) of the 69 kV transmission line. EMI sources near the Granville station and along the Granville to West Granville transmission line were found and mitigated.

4. HV-BPL Installation History

Phase 1:

The installation of the couplers on the HV transmission structures inside the Heath and Granville stations was professionally conducted by AEP's station crew during the weekend of April 26. The Griffins and the NMS systems were installed during the week of April 28 by Amperion and AEP personnel on site. The figures below are photos from the installations at the two stations.

The NMS is a network management system used for continuous monitoring of the HV-BPL link and the two Griffin devices at each end. An analog phone line was installed at Heath with a dial-up capability for remote monitoring. This enabled 24/7 monitoring and management of the link from the Amperion office in Massachusetts. A process was established for receiving daily reports of BPL performance, line conditions (indicating the presence of EMI) and temperature of the units.

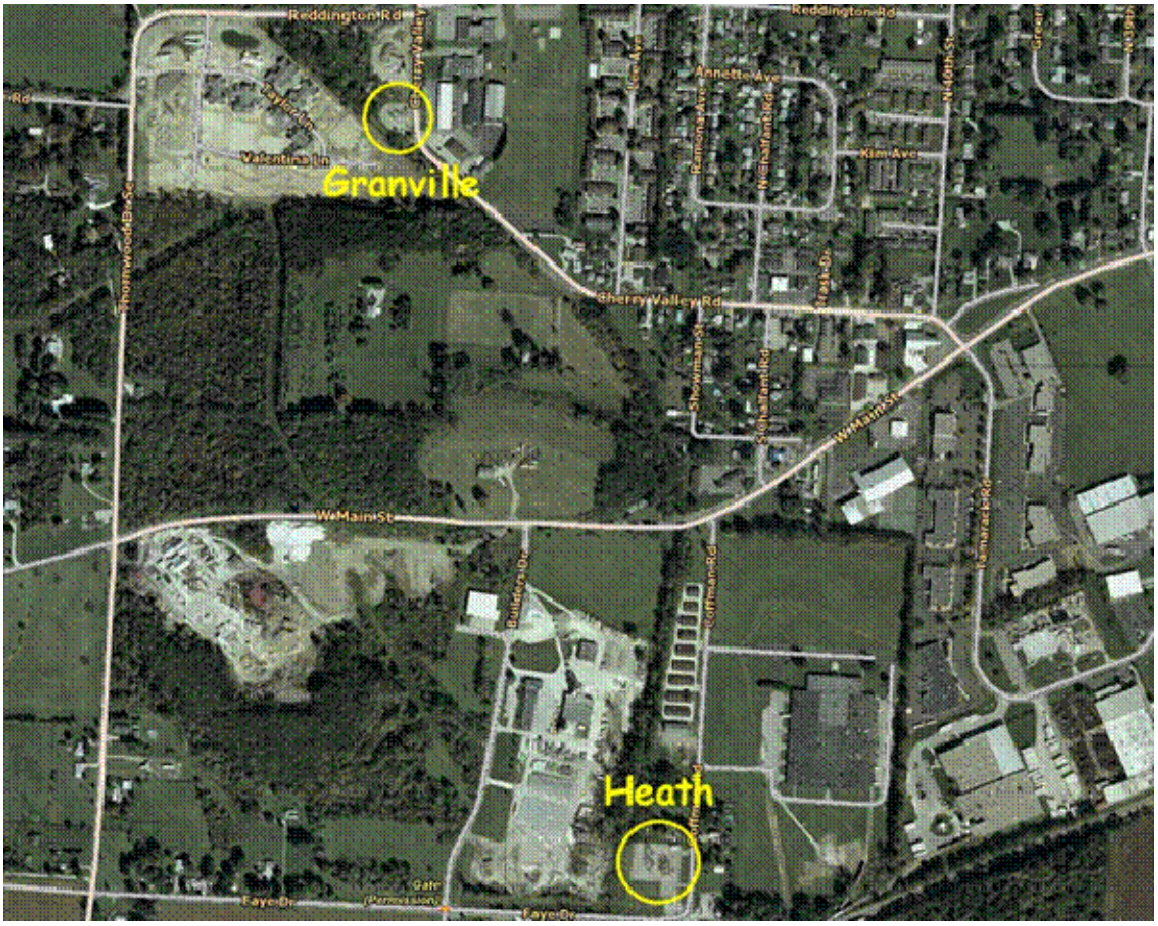

Figure 3: Heath and Granville substations in Newark Ohio

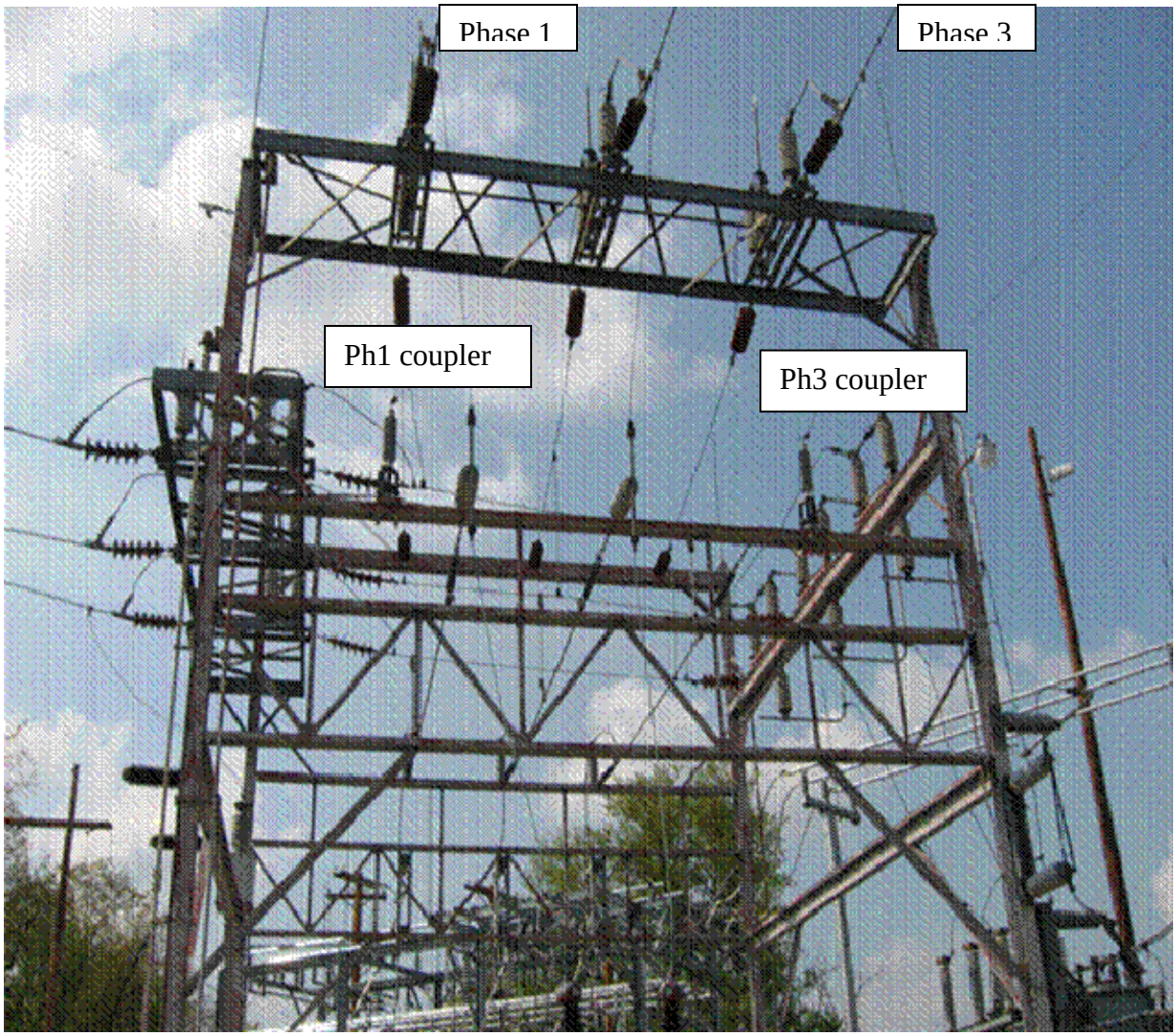

Figure 4: HV couplers installed at Granville on electric phases 1 and 3

Phase 2A:

The installation of the couplers on the HV structures inside Granville and W. Granville stations was professionally done by AEP's station crew during the weekend of Aug 10, 2008. AEP and Amperion personnel installed spectrum analyzer packages at both stations to monitor the 69 kV transmission line for any unusual RF signature. This monitoring program was very important in identifying the source of strong RF interference patterns.

Below are photos from the installations at the two stations.

Figure 5: Granville Station, Granville – W.Granville Bus Work

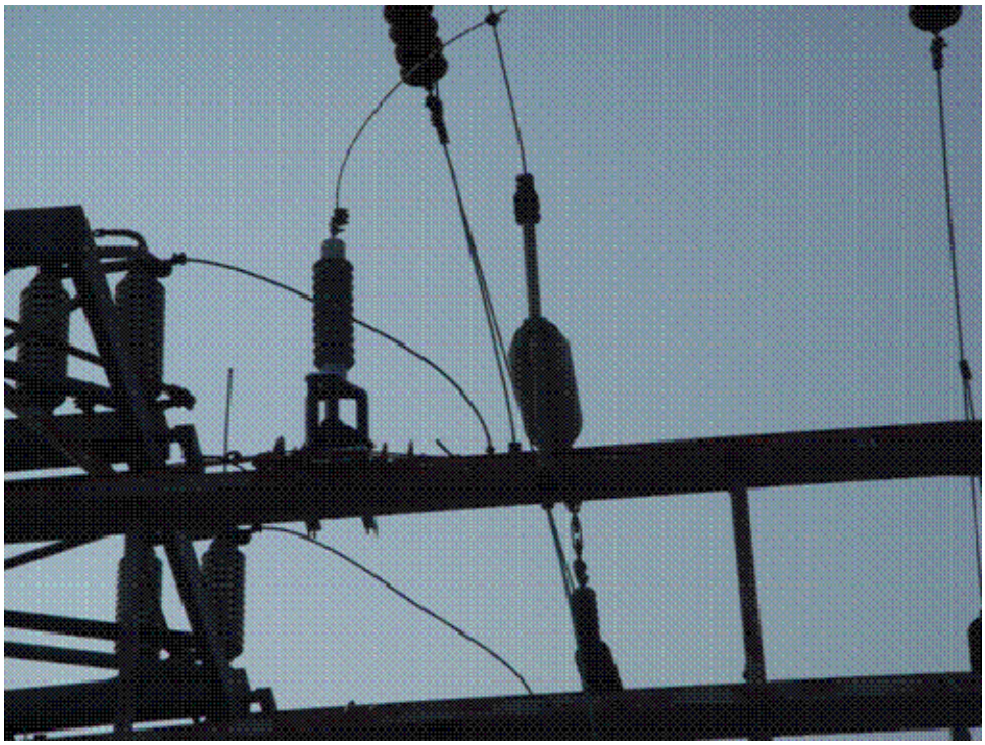

Figure 6: Granville Station, HV-BPL Coupler

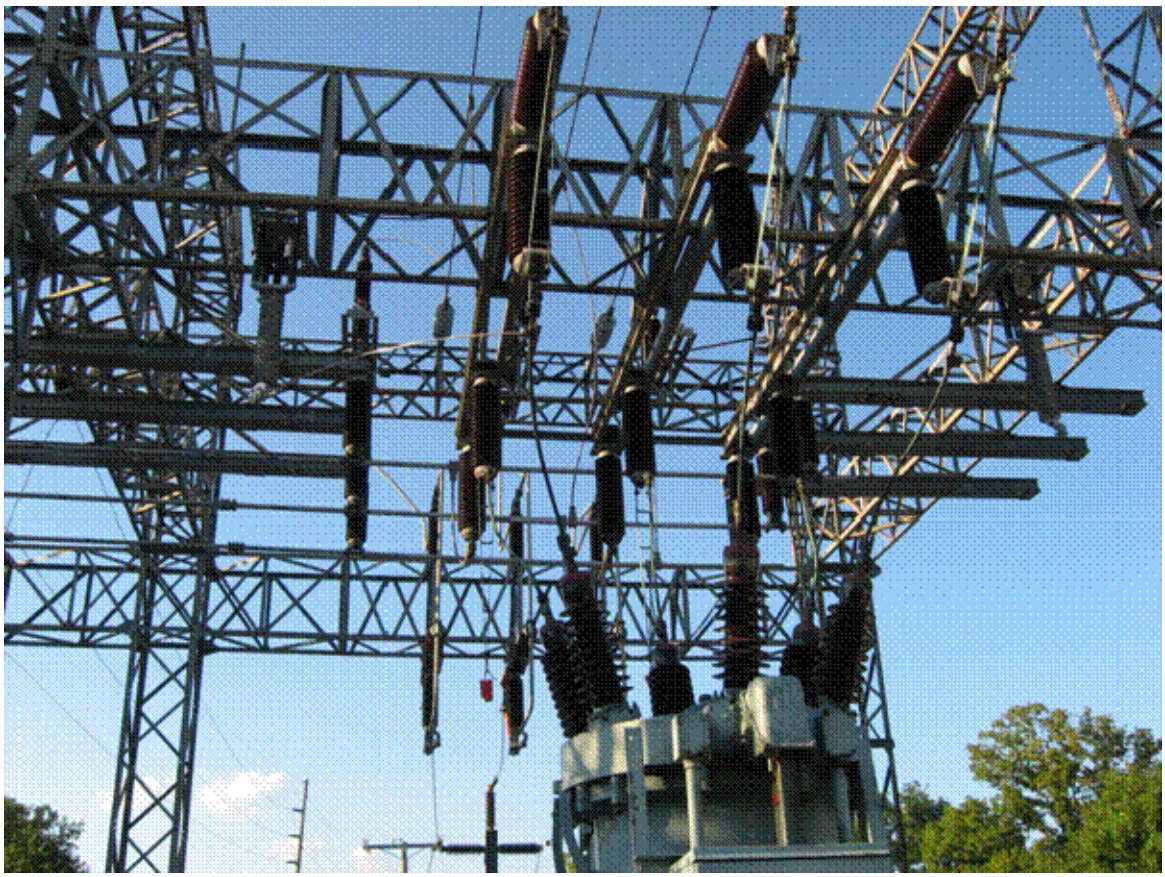

Figure 7: West Granville Station Bus

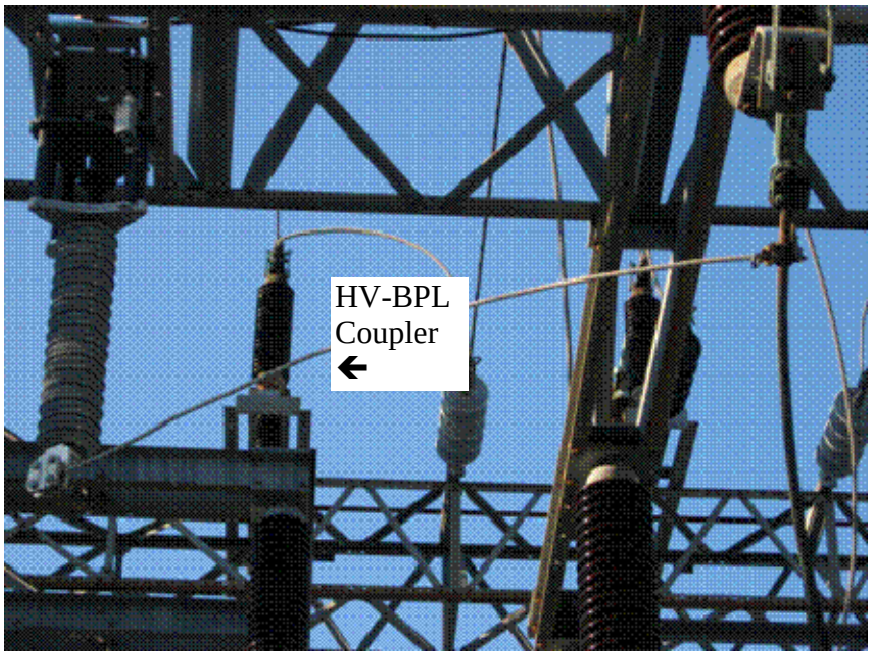

Figure 8: HV-BPL Coupler West Granville Station

Phase 2B:

This phase involved installing three Griffin units and four new T-Line 69 kV couplers. A second Amperion NMS (Network Monitoring Station) was installed at West Granville Station along with a cell-based wireless communication system. The cellular wireless system was added to provide a faster remote access for the 24/7 monitoring and management system. The system allows Amperion to monitor the system from Amperion's office in Massachusetts.

A process was established for receiving daily reports of the BPL performance, line conditions (indicating the presence of EMI) and temperature of the units.

A 69 kV T-Line HV-BPL Coupler was developed for the Granville and West Granville stations. With a line length of 4.4 miles, an in-line BPL repeater was also believed to be required.

The installation of the T-Line couplers on the HV lines at Pole 41 was performed by AEP's transmission line crew during the weekend of Oct 6th, 2008. Below are photos from the installation.

Figure 9: Start of installation at Pole 41.

Figure 10: Installing T-Line RF Coupler at Pole 41

Figure 11: Installing T-Line RF Coupler at Pole 41

Figure 12: (4) T-Line Coupler Installed at Pole 41

Figure 13: BBU Battery Backup System

The 69 kV line was de-energized to perform the coupler installation at pole 41. While the power was out, a test was conducted to determine if the BPL system could operate over the full 4.4 mile distance without a repeater under ideal conditions. The test successfully established a BPL connection between the Griffin systems mounted in Granville and West Granville stations. This test was important because it established that the MAC (Media Access Control layer), PHY (Physical layer) and clock synchronization subsystem of an OFDM-based modem could operate over the 4.4 mile line without a repeater.

A transmission line crew from AEP installed four couplers at pole 41. After the coupler installation was completed, the HV-BPL repeating node was installed at Pole 41 and the BPL system was fired-up on the de-energized line. The FDM repeating approach operated the BPL system between Granville and Pole 41 on one 5 MHz frequency band and between Pole 41 to West Granville on another 5 MHz frequency band. Testing was conducted with three operating modes (frequency combinations) with the 69 kV line de energized and a safety ground in place. When the testing was completed, the 69 kV line was brought back into service. The BPL system went online between Granville and West Granville; as expected the data rate was lower than in the less noisy de-energized state.

5. Link Performance

Electrical utility systems are designed to efficiently and reliably transmit and deliver 60 hertz power to customers. Inherent with these systems is the creation of electromagnetic interference and electrical discharges. The types and strength of such signals in close proximity to the power grid varies greatly in time due to factors such as distance, weather, elevation, age of the equipment, voltage levels, etc. Although power transmission, distribution, and end use equipment is designed to address these undesired phenomena, the power grid environment can still be an electrically noisy environment, with contributions from both electric utility and customer equipment. Coupled with the fact that the FCC limits BPL signal strength to very low power levels, it is a challenge to maintain adequate Signal to Noise ratios for reliable BPL systems.

Therefore, a practical in-band communication system for the power grid needs to be tolerant of changing noise conditions to ensure reliable communications for a variety of power grid applications. During this investigation, the team has observed that 95% of the time the noise along the power transmission grid is low. The other 5% of the time the noise condition can be very harsh. The OFDM-based communication hardware was designed as a high capacity data transport system for use over variable quality media. OFDM systems can operate in high EMI conditions because the system uses 1024 carriers and the MAC and PHY can dynamically adjust for changing EMI conditions. The data-carrying capacity of each carrier is adjusted independently based on the SNR available for that carrier over time. The BPL modems are specifically designed to maximize the carrying capacity at every moment. During high EMI conditions the BPL modem downshifts to a slower, more robust operating mode. The latest modem designs are aware of the 60 hertz power cycle (to which some forms of noise are synchronized) and can adjust the carrying capacity accordingly, which helps with robustness to noise conditions. The objective of a BPL modem operating in harsh conditions is to maintain acceptable latency at the cost of carrying capacity. The BPL modem measures the PHY and BPC values, and the NMS system reports them to the user.

In Phase 1, the Heath to Granville BPL link operated successfully in the presence of background noise conditions near the Granville station. Strong EMI lowered the capacity of the link but did not disrupt the communication path.

5.1 Analysis of Granville – W. Granville Spectrum Analyzer Data

5.1.1 Overview

During the week of Oct 6-10, 2008 equipment was installed to provide a communication link between Granville and West Granville. The work consisted of installing couplers at Pole 41 and Griffin units at Granville, Pole 41 and West Granville. The solution consists of an FDM repeater configuration with 5 MHz channels. The team identified and eliminated two noise sources near Granville station.

Two spectrum analyzers, one from Amperion and one from AEP have been monitoring the Granville and West Granville links. A laptop PC connected to each spectrum analyzer was used to capture data on line conditions twice per hour. The next section of this report highlights noteworthy events recorded from Oct 10 to 13, 2008.

5.1.2 Granville Station

Figure 14 is a picture of a low frequency EMI source observed on August 18 from Granville station.

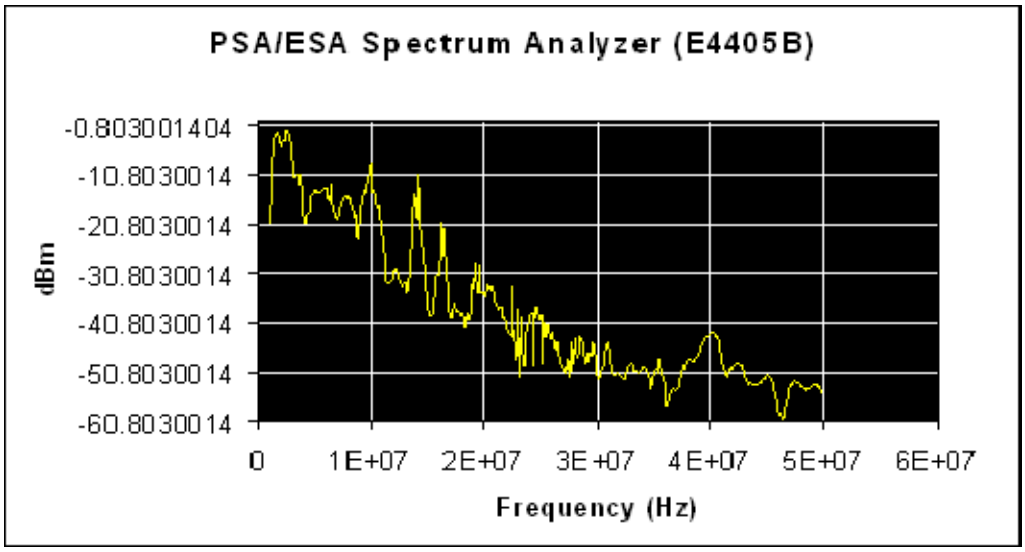

Figure 14: Granville Station Aug 18, 2008 15:36:10

Figure 15 shows the noise source observed in the morning of Oct 10th 2008. At 2 MHz the noise floor is 30-35 dB lower then it was on Aug 18th 2008.

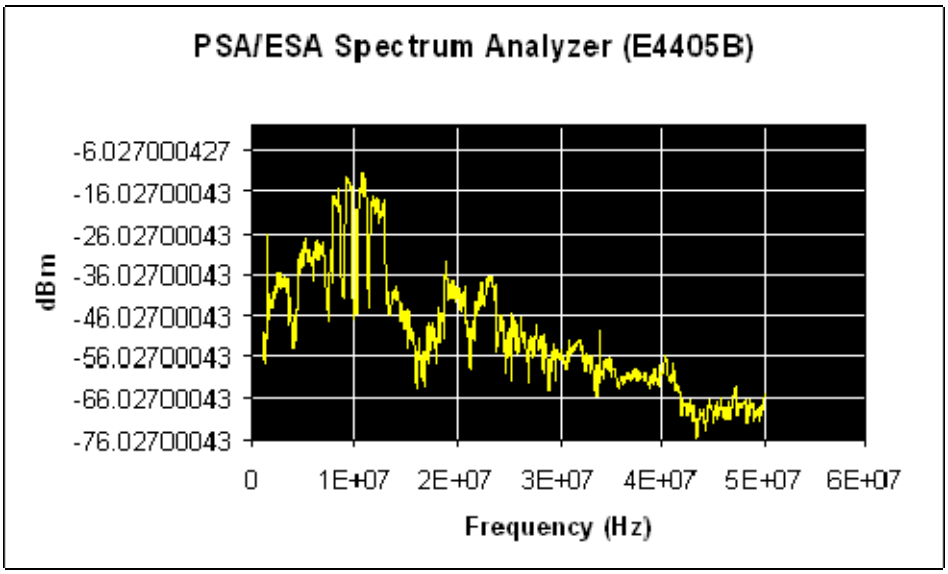

Figure 15: Sample from Oct 10, 2008 9:29AM

Figure 16 shows the noise floor seen at Granville Station after finding and removing the EMI source along the Granville to West Granville line. Figure 16 below is typical of the samples since noon on Oct 10, 2008. Notice that the noise floor at 2MHz has since dropped by 70dB when compared with figure 14. (The BPL signal can be clearly seen in Figures 15-16 in the region of 10 MHz)

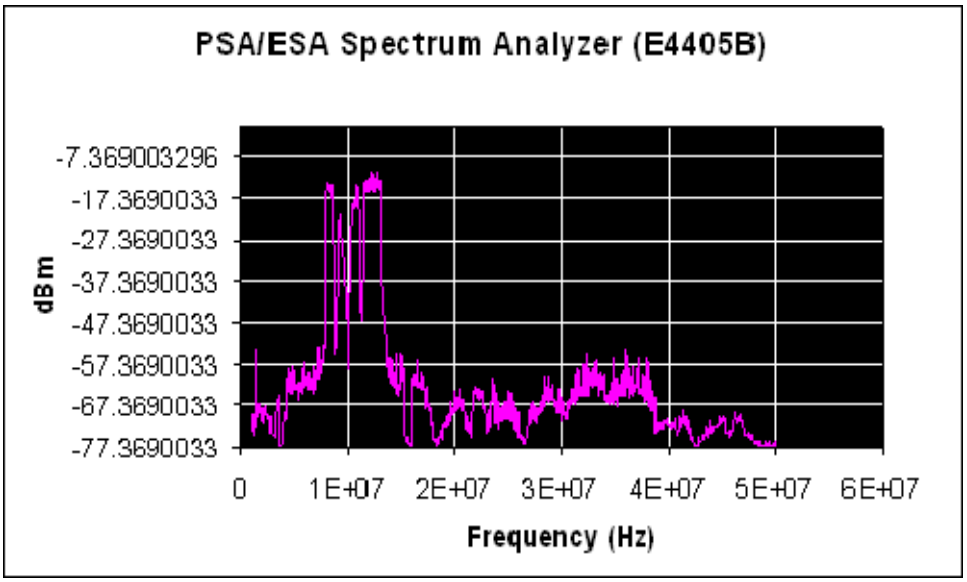

Figure 16: Sample from Oct 10, 2008 16:41 PM

5.1.3 West Granville Station

The two snapshots below compare noise floor signatures at West Granville station, with (on Oct. 10) and without (on Oct. 11) a noise source present. Notice a 30 db shift in the noise floor at the West Granville station when the EMI event was active. The spectrum analyzer at Granville station (Figure 17) does not show the same activity, indicating that this noise source was located near West Granville.

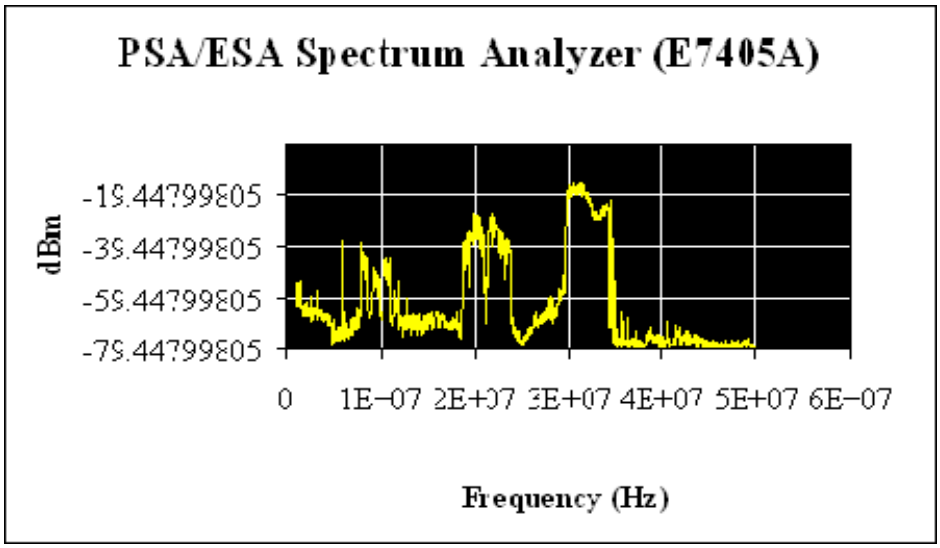

Figure 17: Normal signal and noise levels at W. Granville Oct 11, 2008 0:41:41

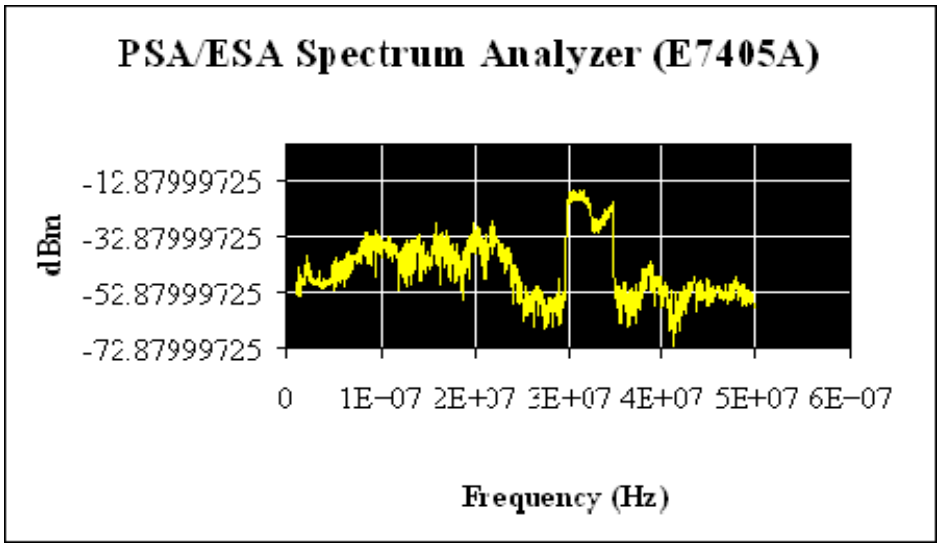

Figure 18: Higher noise floor W. Granville Station Oct 10, 2008 18:31:41

5.1.4 Conclusions:

This data indicates that these EMI events occurred more frequently before eliminating the EMI sources along the Granville – West Granville line. This analysis considers the noise event as either present or not. The graph below shows the distribution of wideband noise events detected over an 80+ hour sample period. At Granville, the noise source was active in the first six samples or 3.7% of the time.

The spectrum analyzer was set to sample (50 seconds sweep) twice per hour. During this testing period 161 samples were collected. Since noon on Oct 10, 2008 an elevated EMI level at Granville station has not been seen.

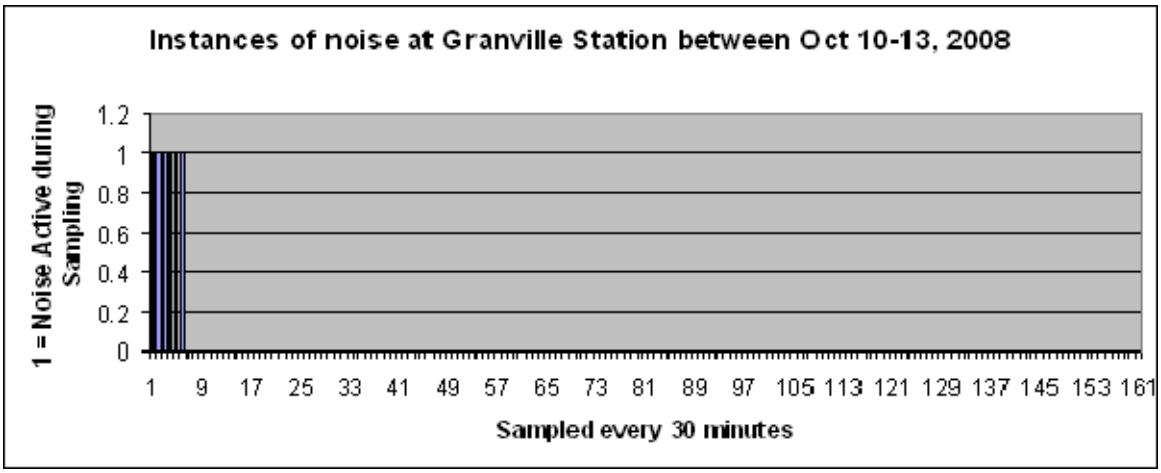

Figure 19: Detection of elevated low frequency EMI events over time

Spectrum analyzer data from the West Granville location still shows a significant number of samples with an elevated noise floor. The noise events occurred in four clusters with duration lasting for 1 to 6 1/2 hours. The noise event was present in 30 of 160 samples or about 19% of the time. Twenty two of the events recorded occurred after mitigating EMI sources along the Granville – West Granville link.

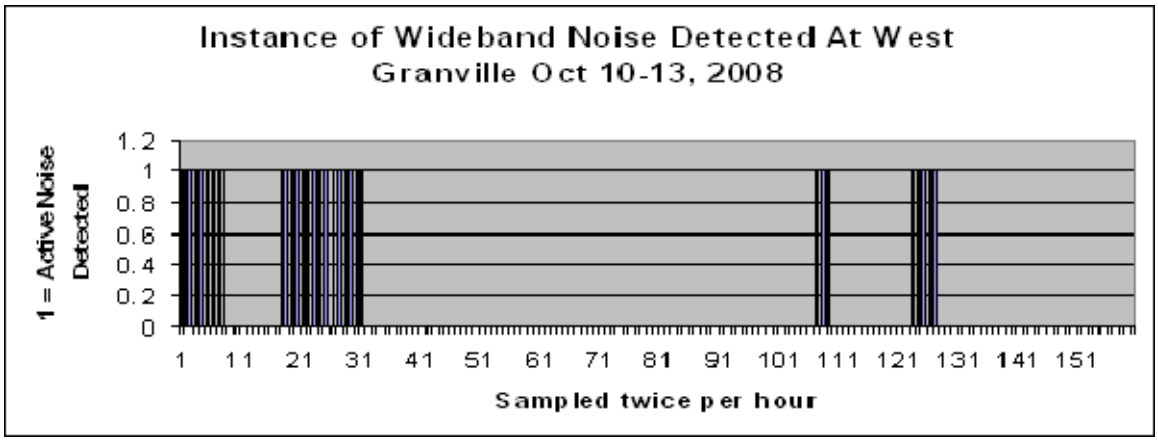

Figure 20: Detection of elevated low frequency EMI events over time

Noise event occurred at the following times:

Start Time: Oct 10, 2008, 9h: 47m: 30s
Ending Time: Oct 10, 2008, 13h: 23m: 20s

Start Time: Oct 10, 2008, 16h: 28m: 20s

Ending Time: Oct 11, 2008, 0h: 10m: 51s

Start Time: Oct 12, 2008, 13h: 41m: 24s
Ending Time: Oct 12, 2008, 14h: 43m: 24s

Start Time: Oct 12, 2008, 21h: 55m: 7s
Ending Time: Oct 12, 2008 23h: 58m: 27s

At least one noise source still exist near the West Granville station.

Given the results from the two graphs above, one would expect the MRTG (BPL performance) graphs to show a significant uptime from Heath to West Granville.

Removing two noise sources near Granville station had a significant impact on the noise floor observed in Figures 14-16. The BPL connection is also influenced by changes in the noise floor. A higher noise floor reduced the carrying capacity of data on the BPL link. The Heath to Granville link was operating for months in the presence of this strong EMI source before it was located. Going forward it should be possible to use internal metrics from the BPL chipset (e.g. the PHY and BPC rate) to identify the number, duration, intensity and directionality of local noise events.

5.2 Heath – Granville Network Performance During May 2008

Amperion has been monitoring the communication link remotely since May 2nd, 2008.

At times the data rate has fallen for multiple hours due to very strong external EMI events. **Yet the HV-BPL link has always remained operational at 100% availability with data rates of at least single Mbps**. **The reboot counters on the BPL system indicate that it has remained operational since installation**. The performance graph below gives an indication of the effect this noise has on the BPL system. The data was recorded for the PHY and BPC value which are internal metrics. The BPC is the "bit per carrier" which represents the capacity of the operational carriers. The PHY rate is the raw capacity of the link before the transport overhead. The blue line indicates BPC and PHY data coming into the station (RX) and the green area indicates data going out (TX) from the station. A higher line has a higher BPC level or Mbps reading and therefore is an indication of a stronger BPL signal. A lower reading indicates that the noise floor is high and is affecting the BPL signal. Figures 21-25 show performance of the Heath to Granville link over the month of May, 2008. Figure 21 shows the BPC graph for May 1- May 7, 2008. Figures 22-25 show the PHY rate from May 8, 2008 thru May 28 2008.

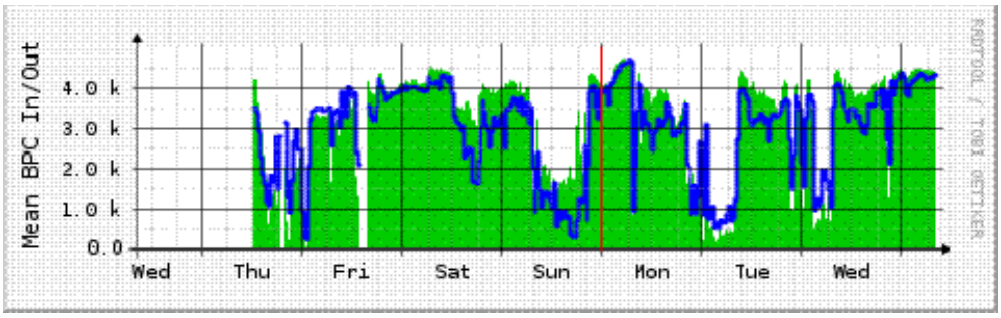

Figure 21: May 1 – May 7 MRTG graph

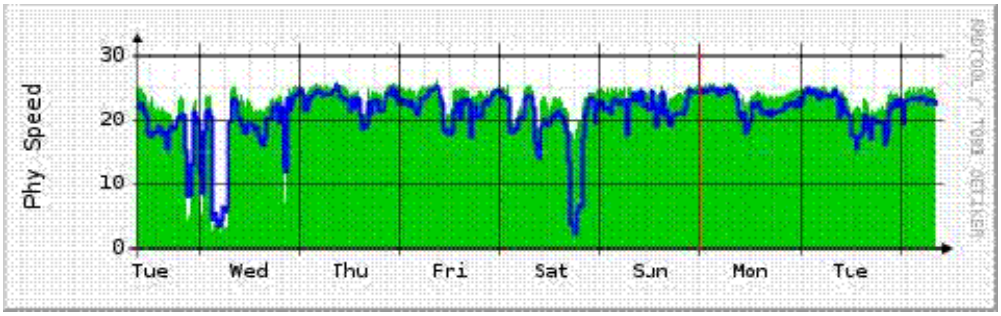

Figure 22: May 6 – May 13 MRTG graph

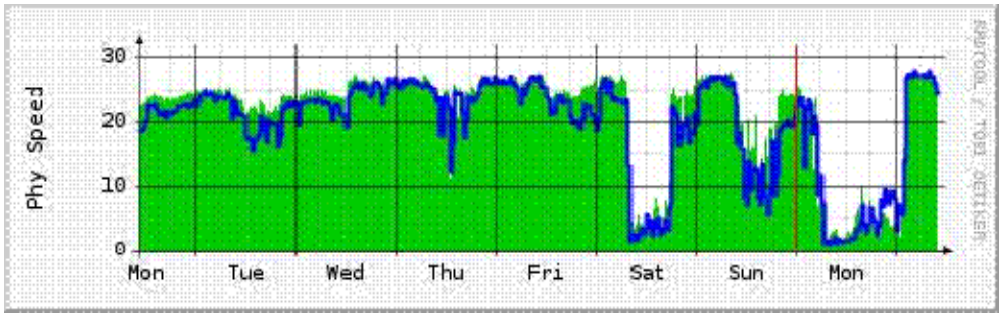

Figure 23: May 12 – May 19 MRTG graph

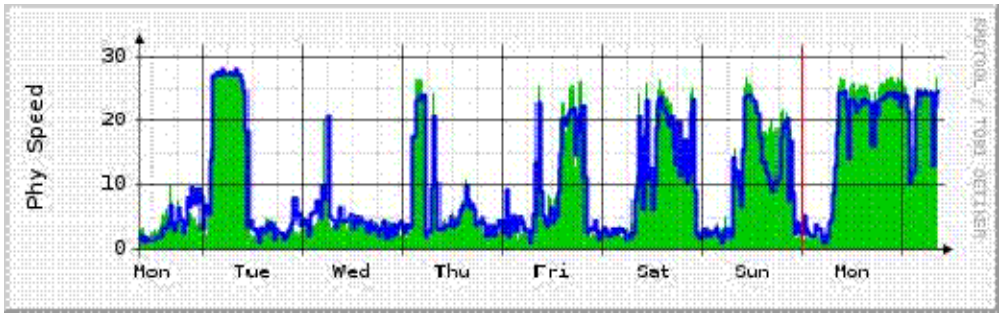

Figure 24: May 19-May 26 MRTG graph

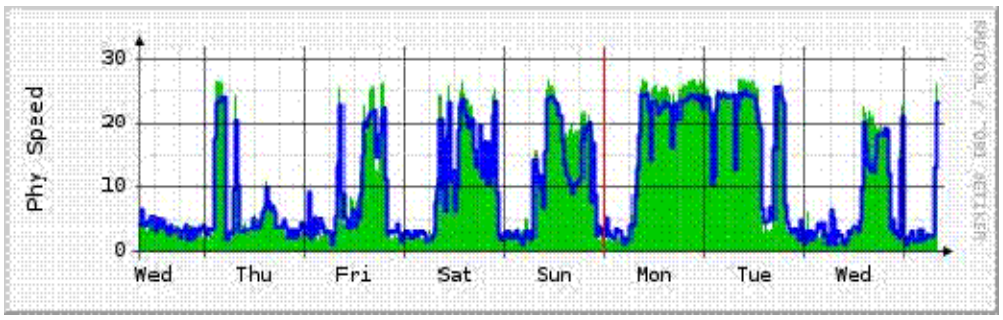

Figure 25: May 21- May 28 MRTG graph

A spectrum analyzer connected to an antenna was used to capture the local EMI conditions. Figures 26 and 27 show the ambient EMI condition recorded from the Heath station. The BPL signal can be seen in the region of 20 to 25 MHz in figures 26 and 27. Figure 27 was captured while a noise source was active.

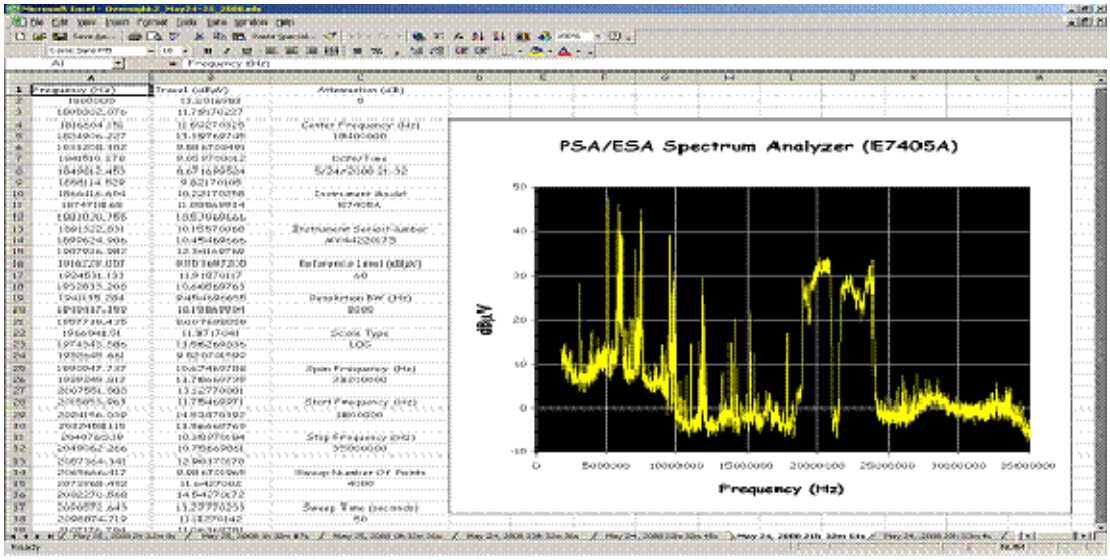

Figure 26: BPL Operating in Normal SNR Conditions

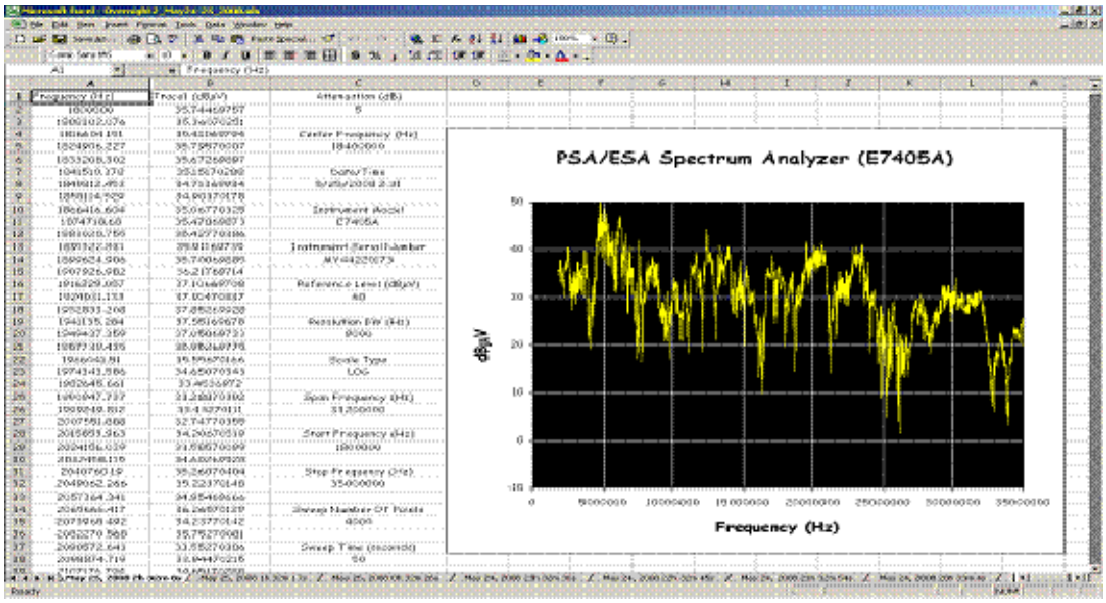

Figure 27: BPL Operating in presence of a 30-40dB Noise Source

The Heath to Granville link remained in service in the presence of this intermittent noise source shown figure 28. The noise source spawned the creation of an automated system with onsite test equipment to understand the EMI patterns and locate its source.

5.3 BPL Performance Oct 2008 - Jan 2009

This section of the report compares the performance of the three BPL links making up a 5.13 mile link between Heath and West Granville station. The data below was extracted from the West Granville NMS system. The missing data in the monthly and yearly graphs, figures 30, 33, 34, 38 and 39 are caused mainly by a failure of the wireless connection between NMS and Griffin at West Granville station.

5.3.1 Traffic Analysis for Heath to Granville

Heath to Granville was the first link installed, spanning a distance of 0.77 miles. The line went into service in early 2008.

The statistics were last updated **Sunday, 04 January, 2009 18:50:02 EST**

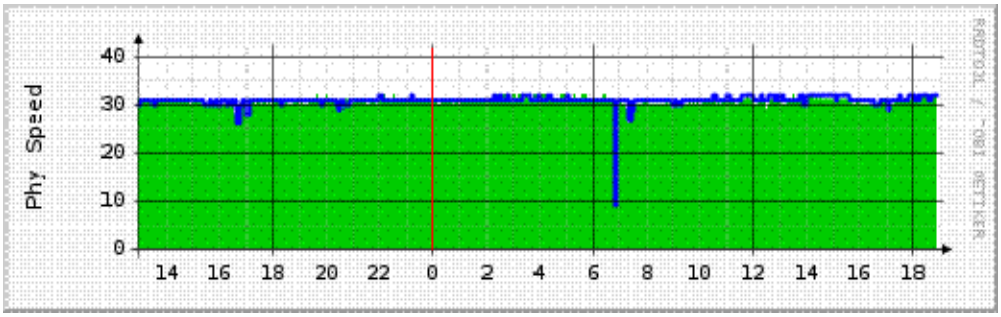

Figure 28: Heath to Granville: `Daily' Graph (5 Minute Average)

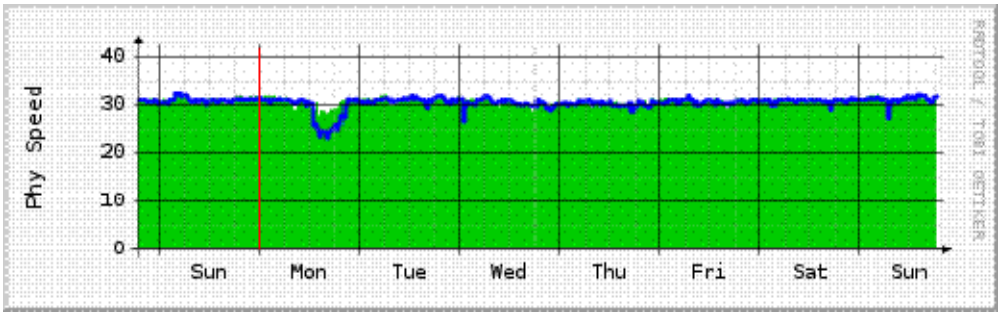

Figure 29: Heath to Granville: `Weekly' Graph (30 Minute Average)

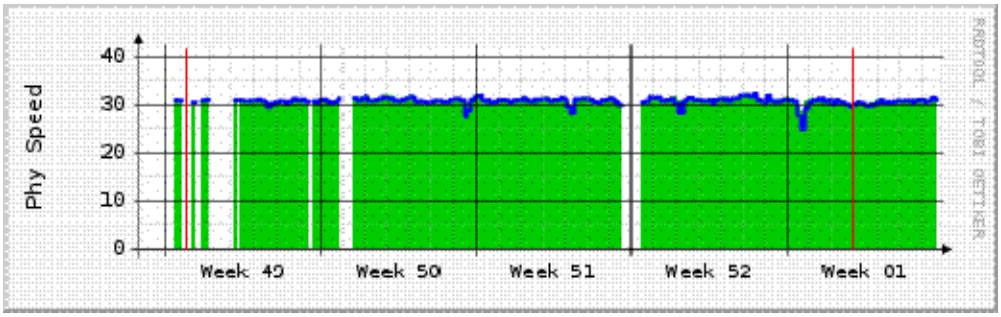

Figure 30: Heath to Granville: `Monthly' Graph (2 Hour Average)

Since eliminating two noise sources near Granville station in Oct 2008, the Heath – Granville link has been very reliable. Figures 28-30 show the performance of the Heath to Granville link after the removal of the two noise sources. This data can be directly compared to Figures 21-25 captured during in May 2008 that show system performance in the presence of the EMI sources.

5.3.2 Traffic Analysis for Granville to Pole 41

The unit installed at Pole 41 is a frequency division multiplexing (FDM) repeater. The repeater is connected to Granville station (1.8 miles) over a 5 MHz wide BPL connection. A second BPL modem at Pole 41 is connected to West Granville station 2.6 miles away using another 5 MHz frequency band. The HV-BPL Phase 2 expansion was successfully put into service on October 10, 2008.

The statistics were last updated **Sunday, 04 January, 2009 19:40:05 EST**

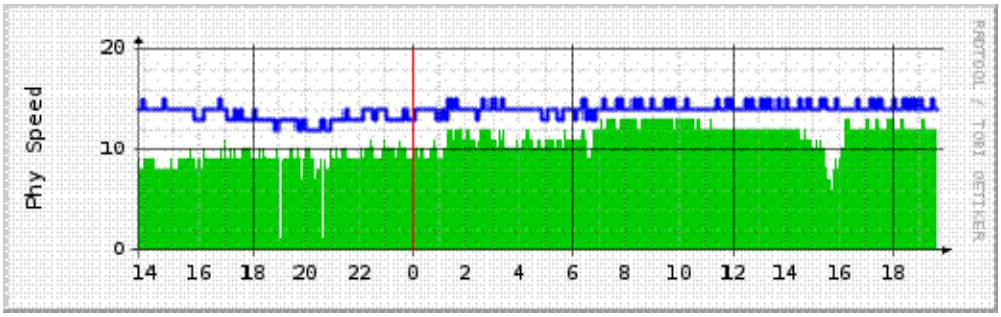

Figure 31: Granville – Pole 41: `Daily' Graph (5 Minute Average)

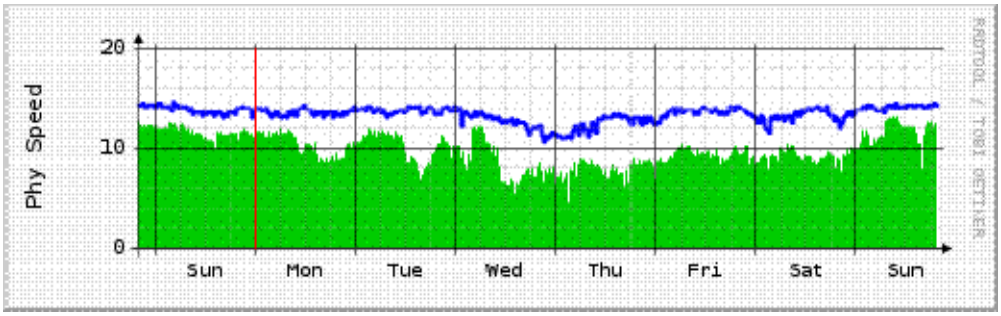

Figure 32: Granville – Pole 41: `Weekly' Graph (30 Minute Average)

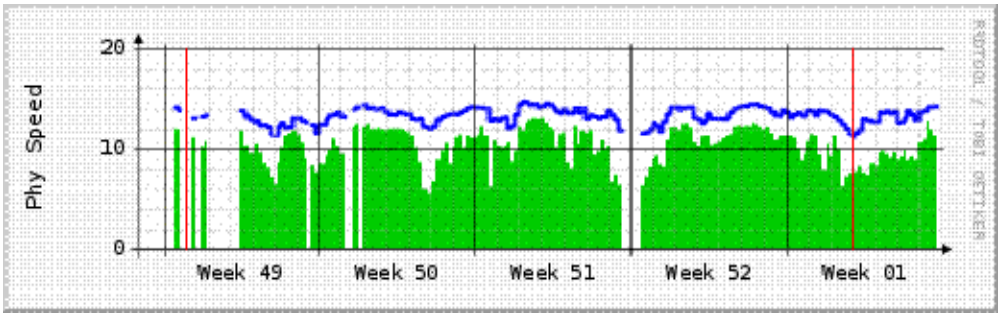

Figure 33: Granville – Pole 41: `Monthly' Graph (2 Hour Average)

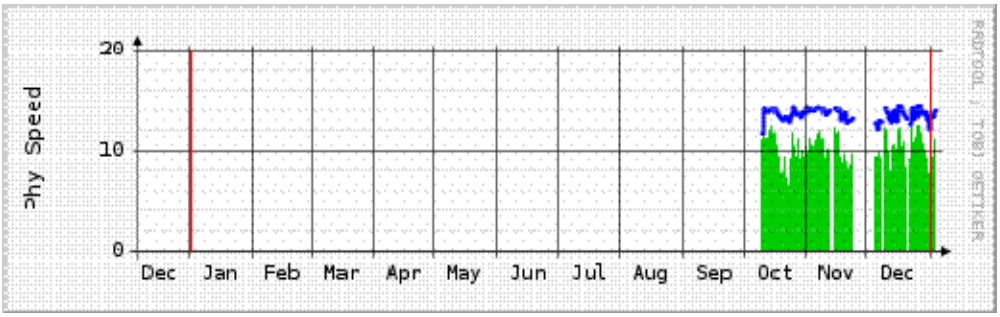

Figure 34: Granville – Pole 41: `Yearly' Graph (1 Day Average)

The Granville to Pole 41 link, a 1.8 mile segment, has been very reliable since going on line on Oct 10, 2008. All graphs in section 5.3.x show stripping caused by a dropout of the wireless backhaul between the NMS and Griffin at West Granville station. The stripping

seen in figures 33 and 34 is a result of viewing the data collected by the West Granville NMS. With the wireless failure mentioned previously, the NMS was unable to collect data from all three links. The BPL connection for the Heath to Granville and Granville – Pole 41 link was in fact up.

5.3.3 Traffic Analysis for Pole 41 to West Granville

The statistics were last updated **Sunday, 04 January, 2009 19:50:06 EST**

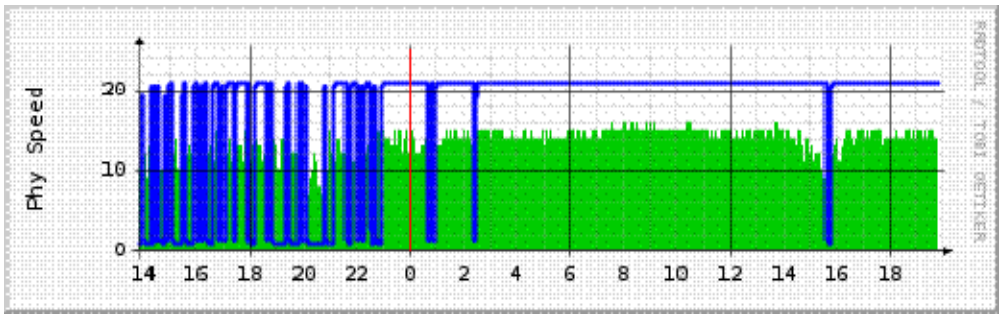

Figure 35: Pole 41 – West Granville: `Daily' Graph (5 Minute Average)

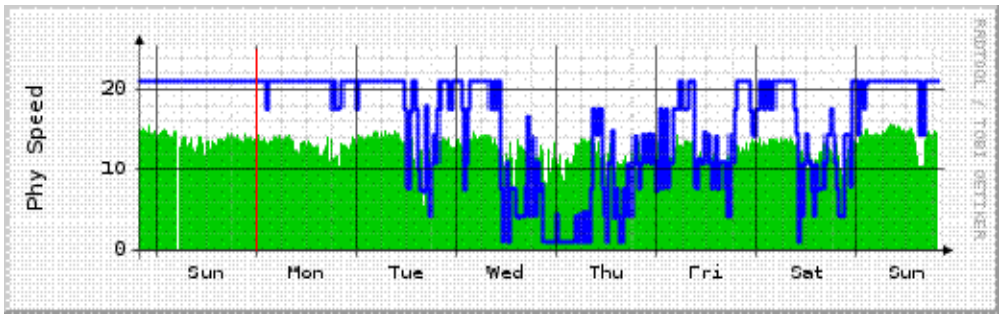

Figure 36: Pole 41 – West Granville: `Weekly' Graph (30 Minute Average)

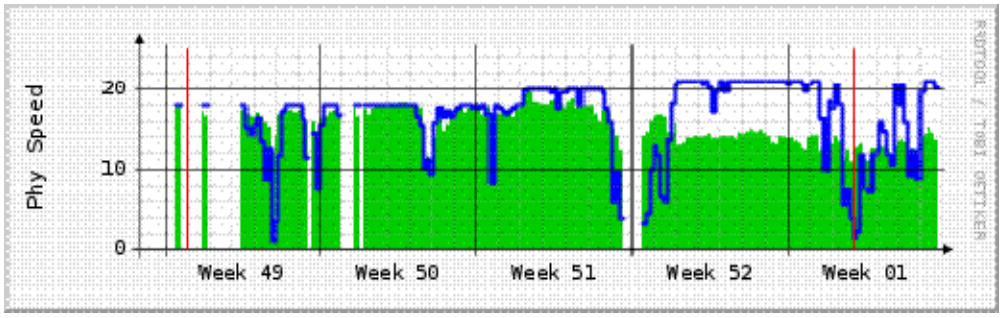

Figure 37: Granville – Pole 41: `Monthly' Graph (2 Hour Average)

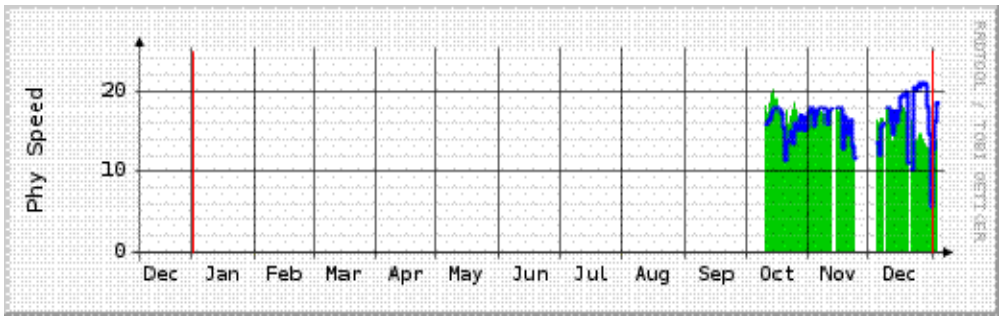

Figure 38: Pole 41 – West Granville: `Yearly' Graph (1 Day Average)

Data collection on the Pole 41 to West Granville link has been impacted by three events.

- The wireless connection was intermittent between the Griffin located in the yard and the NMS located in the building.
- The power supply feeding the NMS was disrupted.
- The BPL signal strength over 2.6 mile path was accompanied by an intermittent noise source.

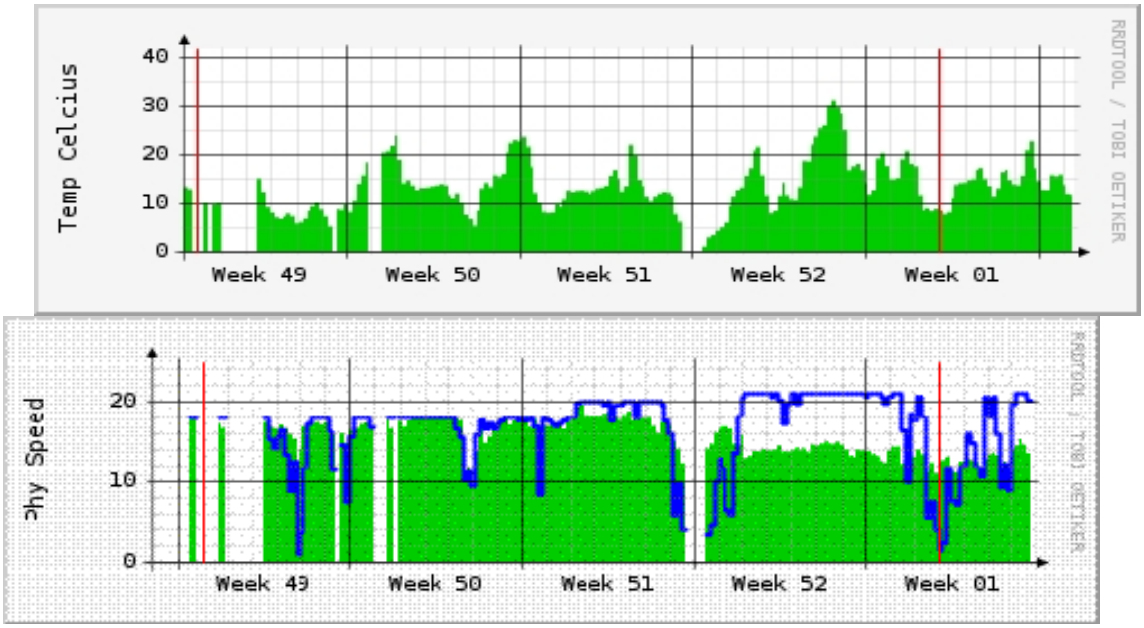

Figure 39 & 40: WG Griffin Temperature vs Uptime on BPL PHY Transport Layer

An analysis of West Granville Network Management System data shows conclusively that down time was due mainly to a failure of the wireless system between the NMS and first Griffin. Temperature graphs from the West Granville Griffin show the same stripping pattern indicating a loss of communication over the wireless connection between the NMS and the first Griffin. Local temperature readings do not traverse the BPL path.

Figures 39 and 40 have been aligned in time to show a correlation in the up time recorded by the NMS. The temperature graph (on top) line up in time with most of the outage events. This strongly suggests that the wireless connection was responsible for most of the down time in figure 41. We believe the BPL connection was up during these wireless outages.

As a corrective action an uninterruptable power supply was installed for the NMS. The wireless connection was replaced by a wired Ethernet connection between the NMS and the Griffin unit. Since Jan 2009 these problems have been resolved and the entire 4.4 mile span is operating reliably without a repeater.

6. Conclusions

Many things have been learned throughout the duration of this project: Not all the items listed below are discussed above, but they are included in this summary for completeness.

- 69 kV HV transmission lines have enough SNR margin to support BPL communications
- Amperion's system can operate on channels 1 through 6 (5 MHZ channels spread across a 2-34 MHZ band)
- FCC compliance can be achieved on channels 1 through 5
- System can be configured for FDM or TDM modes
- Differential path delay balancing was fast and effective
- Differential signal launch works better then single-ended.
- Differential EMI scans show lower noise floor than single ended
- Propagation distance is better than 290ft /dB for the Heath Granville line
- Propagation distance varies with frequency.
- Propagation distance varies with the number of conductors (circuits) on the pole
- Further optimization of the HV-BPL coupling system is possible.
- Exacter system was helpful in spotting noise sources.
- The NMS system can be used to notify the utility when service is required
- The NMS system can be used to notify the utility of unusual EMI events.
- The cellular wireless device has enough bandwidth to support the NMS system
- Isolation between the HV and MV circuits is very good.
- MV noise sources do not significantly impact the HV signal quality.
- A sonic noise detector picks up corona events that have little impact on BPL performance.
- The wireless connection between the Griffin and the NMS system was causing stripping in the MRTG performance graphs.
- A latency measurement tool is needed in the NMS. (This was added in 2009.)
- Noise sources can and do lower the operational performance of the BPL system
- The HV-BPL system is capable of operation in all weather conditions
- The system survived an outage that took down the Heath and Granville stations
- The cellular backhaul service was very effective for remotely monitoring the NMS systems.

- NMS can be expanded to measure real time latency.
- Further enhancements in the modem firmware are expected to help with immunity to EMI sources.
- Additional work is needed to characterize impulse (arcing) events on 69 kV transmission lines
- Methods of simulating noise conditions seen on the transmission line are needed for the lab. The simulation will be used to harden the OFDM systems immunity to power line noise events
- The system has survived multiple lightning storms
- Inline 69 kV power solution is cost effective
- Inline 69 kV coupler works effectively in repeater applications.
- Measured 10 ms latency between stations.

7. Epilog

The goal of the HV-BPL program is to provide a robust secure broadband transport layer for applications such as digital protective relaying, SCADA, station surveillance, and voice communications.

In Phase 2 (2008) the team successfully demonstrated that Broadband over Powerline (BPL) communications technology can be used to interconnect utility substations over high voltage transmission lines. Field tests conducted during August 2008 and October 2008 resulted in the team successfully extending the operational distance to 4.4 miles using a Frequency Division Multiplexing (FDM) repeating architecture.

The program continued in 2009 with work done to extend the range, increase robustness, reduce latency, and to advance to a commercial product stage. These refinements resulted in the elimination of the repeater requirement, allowing station-station, mbps communications over the 4.4 mile line without the addition of any communications devices on the actual 69 KV line outside of its stations. Significant effort was applied to studying field noise conditions and learning how to reproduce them in the lab. That knowledge is now being applied to further hardening the system.

Other advancements include, successfully testing Link Aggregation over the 4.4 mile span, a feasibility study for 138 kV applications, testing of triple DES encryption over BPL and improvement in latency monitoring software on the NMS. Link Aggregation (LACP) provides redundancy at the physical transport layer. The LACP protocol seamlessly switches traffic in the event that one of two active BPL connections, operating in parallel on different transmission line electrical wires (phases), should fail.

The HV-BPL team believes they have met the goals set for the HV-BPL program and expect to deploy the first commercial grade systems in 2010.