Exhibit B: Broadband Over Power Line Devices and Conducted Emissions

Author: Ed Hare, ARRL Laboratory Manager
Date: August 10, 2003

1. Most of the information and discussion about Broadband Over Power Line (BPL) devices has centered on their radiated emissions. However, BPL devices function by conducting their signals intentionally over building and overhead power lines. The EMC environment in which all electronic devices function includes both radiated and conducted factors and FCC and other regulations appropriately regulate both types of emissions.

2. The Present Conducted-Emissions Environment

2.1 In the US, conducted emissions are limited to the levels in §15.107:

> *§ 15.107 Conducted limits.*
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> *(a) Except for Class A digital devices, for equipment that is designed to be connected to the public utility (AC) power line, the radio frequency voltage that is conducted back onto the AC power line on any frequency or frequencies within the band 450 kHz to 30 MHz shall not exceed 250 microvolts. Compliance with this provision shall be based on the measurement of the radio frequency voltage between each power line and ground at the power terminals.*

2.2 Residential environments and devices are appropriately treated more stringently than industrial areas and equipment (Class A digital devices). Industrial areas are usually distant from residential areas and their RF environment is usually closely controlled by the involved industrial entities. Industrial equipment is often more costly than consumer-grade equipment and thus often has more robust filtering to allow it to function properly in a more-noisy EMC environment. Consumer equipment is designed to be mass produced and sold in a marketplace that is very competitive, so it generally uses only the minimum amount of filtering necessary to allow it to function in the non-industrial EMC environment defined in the rules.

2.3 On HF, the limits for the conducted emissions for devices intended to be used in residential environments is appropriately low: 250 uV between either conductor on an electrical circuit and ground, measured in a 9 kHz bandwidth. The impedance of the power lines is often unknown, but for the sake of this paper comparing Part-15 conducted emissions limits with the conducted signals of BPL devices, this impedance will be normalized to 50 ohms – j0 for both types of systems. Across a 50-ohm load, a 250-microvolt signal produces a level of – 89.0 dBW (-59.0 dBm) peak power in a 9 kHz bandwidth.

2.4 In their comments filed in this proceeding, several BPL manufacturers indicated that their equipment uses a power level of -80 dBW/Hz (-50 dBm/Hz)[1]. Some have indicated that they wish to use a power level of -70 dBW/Hz or more[2]. These power levels will result in conducted signals that are many tens of dB higher than what is currently permitted by §15.107(a) for conducted emissions from non-industrial devices.

2.5 To compare the levels involved, the conducted emissions or signals need to be normalized to 9 kHz, the measurement bandwidth used on HF. To be truly accurate, the actual peak signal would have to be measured in a 9 kHz bandwidth, because the level of peak signal vs bandwidth of a particular signal is a function of the specific nature of that signal. Measurements made of an uncorrelated noise-like signal will vary with approximately a $10\log_{10}$(bandwidth ratio) function, while signals whose modulation components are well correlated[3] can vary as $20\log_{10}$(bandwidth ratio) or more. To be reasonably conservative, this paper presumes that the signal varies with a $10\log_{10}$(bandwidth ratio) function.

2.6 For HF conducted emissions, for noiselike signals that are uniform in power distribution across 9 kHz, the relationship between dBW/Hz and the power that is in the stipulated 9-kHz measurement bandwidth can be calculated with the formula:

Power (dBW / 9 kHz) = dBW / Hz + $10\log_{10}(9000)$

2.7 The relationship between the present Part-15 conducted emissions levels and BPL conducted signal levels can be compared in this table:

Level or standard	Power in dBW/9 kHz	Power relative to 15.107(a) (250 uV)	Power ratio relative to §15.107(a)
§15.107(a)	-89.0 dBW / 9 kHz	0 dB	1 : 1
-80 dBW / Hz	-40.5 dBW / 9 kHz	48.5 dB	70,800 : 1
-70 dBW / Hz	-30.5 dBW / 9 kHz	58.5 dB	708,000 : 1

2.8 The power levels being used and proposed by access and in-building BPL devices are changing the EMC environment by a factor of more than 70,000 compared to the conducted emissions permitted to most other devices. Most BPL manufacturers have told the Commission that they want to increase this by a factor of ten. This is a major change from the present conducted emissions environment and no one can reasonably predict the consequences.

3. Increased Coupling Onto the Distribution Lines

3.1 Some access BPL technology starts the BPL RF signals on the 120- or 240- volt low-voltage (LV) wiring, but then uses a coupling device to conduct that signal from the LV

[1] See the comment of the Ambient Corporation.
[2] See the comment of Satius, Inc.
[3] Examples are pulse signals or signals with multiple carriers, such as OFDM.

wiring onto the electrical-distribution wiring for "last-mile" transmission to an Internet access point located elsewhere in the system. These couplers function as high-pass filters, allowing RF signals to pass around the step-down transformers.

3.2 In the present EMC environment, the conducted emissions from equipment in buildings can and do get onto the low-voltage electrical wiring feeding that building. The transformers that are used to convert the distribution voltage to 240-volts (or other voltages as appropriate) to supply low-voltage power to the building, however, generally offer significant attenuation to the RF conducted emissions on the LV side, preventing them from being coupled onto the distribution wiring. The LV wiring can range from being a poor to a fair antenna, but EZNEC modeling of overhead distribution lines calculates that the MV line can be a good antenna, so conducted emissions or signals that are coupled onto the MV lines will be radiated much more efficiently than the expected radiation from most building electrical wiring. This will add to the effect of the increase in conducted signals discussed above.

4. Multiple Buildings

4.1 In the US, a relatively small number of buildings or living units are connected to the secondary windings of a single utility step-down transformer. Most transformers supply power to about 3 to 6 units. Because the transformers act to some degree as RF attenuators, the conducted emissions from one building have the potential to affect only a limited number of other buildings. This serves to control the EMC environment, limiting the scope of potential interference.

4.2 When access BPL using high-pass couplers is installed, however, this changes in very significant ways. Instead of being significantly attenuated by the step-down transformers, the conducted emissions from all the unlicensed emitters on that circuit will be coupled with low loss[4] onto the distribution wiring where they will be radiated or conducted to the rest of the system. Instead of affecting and being affected by the conducted emissions from a limited number of buildings, each building or living unit will be subject to the conducted emissions from all other buildings in the vicinity that are also coupled onto the distribution lines through the high-pass couplers. This will also add to the degradation of the EMC environment near some in-building or access BPL systems.

5. Increased Coupling of Signals Induced Onto the Distribution Lines

5.1 In a document previously provided to the Commission, ARRL showed that overhead electrical distribution lines can exhibit considerable antenna gain on HF[5]. To be conservative, ARRL will use an electrical-wiring antenna gain of 0 dBi for the following calculations.

[4] Ambient Corporation's comments state that their couplers have 10 dB of loss, well below that typical of step-down transformers at RF.
[5] "Power Lines as Antennas From 100 kHz to 50 MHz," Ed Hare, W1RFI, ARRL Laboratory Manager, included as an appendix to ARRL's filing in this proceeding.

5.2 Stations in the Amateur Radio Service are permitted a maximum transmitter power of 1500 watts on most HF amateur bands. There are no limits on the gain of the antenna amateurs are permitted to use. Amateur antennas are located relatively near overhead distribution lines and signals transmitted by amateurs will be coupled onto the lines.

5.3 A good estimate of this coupling from a 1500-watt amateur station can be obtained by using the free-space path-loss formula and the gain of the transmit antenna.

Coupled power = 31.8 dBW – path loss + transmit antenna gain + receive antenna gain

Path loss = -27.55 + $20\log_{10}$(FMHz) + $20\log_{10}$(distance meters)

5.4 The induced power will increase as the frequency decreases, but 14 MHz provides a good example that is in the frequency range being used in the BPL trial areas right now. The following calculation conservatively assumes that the amateur antenna is located 30 meters from the distribution lines.[6]

Path loss = -27.55 +$20\log_{10}$(14 MHz) +$20\log_{10}$(30) = 24.9 dB

5.5 If we presume that an amateur station is using a 3-element Yagi antenna with a gain of 7.5 dBi:

Coupled power = 31.8 dBW – 24.9 dB + 7.5 dBi + 0 dBi = 14.4 dBW = 27.5 W

5.6 Signals from nearby transmitters couple onto building wiring, too, but building wiring is generally not as effective a receive antenna as are overhead distribution lines. The electrical wiring in a building is generally uses a combination of star and daisy-chain techniques, with numerous electrical loads that absorb RF power. In general, the amount of power coupled into each of those loads is considerably less than the 27.5 W from ARRL's calculation of the amount of power that will be coupled into overhead wiring. Nonetheless, RF coupled onto electrical wiring has been implemented in numerous cases of fundamental-overload interference involving amateur equipment. Adding differential-mode and/or common-mode filtering to the AC power connection of consumer equipment is a routine part of troubleshooting and EMI resolution.[7] To date, this has been a troublesome, but manageable, problem for the Amateur Radio Service. It is manageable because generally the scope of the problem is limited to nearby homes.

5.7 Nearby transmitted RF, from amateur, CB, broadcast radio and numerous other sources occurs with or without the presence of BPL equipment on the lines. However, the step-down transformers used to provide low-voltage power to customers offers

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[6] The path loss formula reasonably assumes that the field strength from the radiator will vary at as a function of a $20\log_{10}$(distance decade). If the $40\log_{10}$(ratio) is presumed, as it is for HF measurements made of emission from unlicensed devices, the coupling from antennas located closer than 30 meters from the distribution lines will be higher than the estimate in this paper. ARRL is not using a $40\log_{10}$(distance decade) ratio because the antenna modeling it has done on distribution lines demonstrates that the $40\log_{10}$ function does not apply well to radiators that are not very small in terms of wavelength.
[7] *ARRL RFI Book*

significant attenuation of these induced signals. The presence of BPL couplers changes that by tens of dB. A much greater percentage of all of the signals conducted or induced into the overhead distribution lines will be coupled directly into buildings and living units connected to that line, sometimes from transmitters far away from potentially affected equipment.

6. Effects are Unknown

6.1 Based on the power levels that much of the BPL industry has told the Commission that their systems use, BPL systems will change the EMC environment from the present level of +48 dBuV peak in a 9 kHz bandwidth to a level of +96.5 dBuV, an increase of 48.5 dB. Taken together, the power levels used or proposed by BPL manufacturers and coupling around transformers can easily result in a change in the EMC environment of over 60 dB. The level of conducted noise power possibly affecting all types of equipment connected to the lines could increase by more than a million times. This certainly must have an effect on the present EMC environment that has developed after years of fine tuning regulations, industry standards and equipment. Affected equipment can range from the consumer equipment present in all homes to sensitive medical equipment used in homes and doctor's offices, also connected to the power lines. What will the effect of a 60 dB change in EMC environment to all this equipment be?

6.2 Until scientific studies are done, no one knows the effect of this much change to the EMC environment. Generalized statements that there is no interference potential because no reports have been received from their trial areas are not a substitute for scientific testing by all manufacturers whose products may be affected by such a large change. The trial areas are small and the untrained people using the systems cannot be expected to provide data that is a substitute for rigorous testing.