Comments on Access BPL NPRM
(By, James K. Boomer, April 30, 2004, Corrected, May 17, 2004, corrections in red)

Purpose

The purpose of this paper is to respond to the FCC Notice of Proposed Rule Making (NPRM) for Access Broad Broadband Over Power Line (BPL)--ref. ET Docket No. 03-104, and ET Docket No. 04-37.

In particular, this paper addresses and quantifies the electromagnetic compatibility (EMC) issues. In addition, recommendations are included in response to the NPRM questions.

Summary

The analysis herein clearly demonstrates the electromagnetic compatibility (EMC) challenge that Access BPL suppliers, users, and radio station licensees face. In fact, a technical solution to the EMC problem may not be possible.

The field strength 30 meters from the Access BPL system, including the transmission media, must be no greater than $3x10^{-4}$ microvolt per meter in a 100 Hz bandwidth, in order that there be EMC with modern licensed radio stations operating in the 1.8- to 30 MHz frequency range.

Access BPL systems must be able to perform satisfactorily in the presence of a received interference power greater than -2 dBW (+28 dBm) from licensed radio stations located 30 meters from the Access BPL transmission line system.

The most important requirement is to reduce BPL emissions to the point where EMC is assured. Accordingly, cable or fiber optic media would provide this assurance. However, these techniques are already in use, as well as wireless systems, the costs of which will continue to decrease. This, then, opens the question regarding the true market for Access BPL—an issue that the business community must address.

Coupling BPL signals to a power distribution system is in itself complex because there is a virtual infinite number of configurations, all of which will radiate energy in a wide variety of levels and spectra. In addition, the susceptibility of BPL systems to radiated energy from licensed stations is another random variable, wherein the BPL system will be called upon to operate in the presence of high levels of interference.

The current excitement over Access BPL communications is understandable. However, the technical, business, and political issues must be understood, quantified, and resolved.

The notion that adaptive techniques can be used to create BPL EMC is questionable because the extremely large number of combinations and permutations of both systems seem to defy such an approach. In addition, the notion that licensed radio stations can orient their

antennas to create electromagnetic compatibility is open to serious question because licensed radio station users orient their antennas for most effective radio communications, not for minimum interference from unlicensed sources—the goal of licensed radio communications is connectivity, not reduction of unwanted radiated interference from power systems, or systems that utilize the power transmission system.

For continuation of the current BPL experiment, Part 15, Section 15.209 emission limits for BPL systems must be revised as follows in order provide reasonable assurance that BPL systems have EMC with licensed radio stations operating in the 1.8- to 30 MHz frequency range:

The Access BPL system maximum radiated field strength shall not exceed $3x10^{-4}$ microvolt per meter in a 100 Hz bandwidth at a 30-meter measurement distance from the power line media.

In reading the analysis presented in this paper, knowledgeable readers will correctly conclude that the Access BPL EMC issue is extremely complex and varied and may not lend itself to a single solution. For example, readers will note that a simple power transmission line some 300 meters long is a very effective antenna, with high directivity gain at many frequencies. In addition, many licensed stations operating in the 1.8- to 30 MHz frequency range have very high directivity gain antenna arrays, modern sensitive receivers, and high transmitted power. This combination creates a substantial EMC issue--the environment for BPL to interfere with licensed station operations, and licensed stations to interfere with BPL—major social and economic issues.

Finally, the proposed "shut down" feature to avoid interference from BPL appears to be impractical. A "real-time" adaptive system would be required for EMC, which appears impossible to implement, both technically and politically.

BPL Signal Sets

The author understands that there is no single standard signal set for BPL, and that efforts are underway to establish standards. Nevertheless, some BPL suppliers (e.g. Homeplug) seem to establish goals for data rates up to 14Mbps. A notional data rate might be the 10Mbps Ethernet signaling rates we enjoy in everyday computer systems.

Modulation seems to include orthogonal frequency division multiplex (OFDM), simple frequency division multiplex (FDM), and multiple phase shift keying (MPSK). Obviously, various error detection and correction systems are in use to assure reliable communications.

FCC Regulations

As proposed in the NPRM, Access BPL is governed by FCC Part 15, Section 15.209, which states that the maximum allowable field strength from carrier current systems, including BPL, shall not exceed 30 microvolts per meter at a distance of 30 meters from the system, in the 1.705- to 30 MHz frequency range. We will evaluate this specification later in our technical analysis.

BPL System Considerations

One might think that “black box” suppliers can simply build equipment that, itself, meets FCC Part 15 regulations, and BPL will be compatible with other carrier current and licensed stations. However, the problem is much more complex than that. Indeed, these black boxes will be coupled to electrical power transmission wire distribution systems. These transmission systems are basically radiating antennas with an almost infinite combination of directivity gains, depending on their length, height above earth, and the surrounding environment that affects directivity gain.

From the above, we see that *every* BPL installation will have to be evaluated as a *system* that takes into account not only the black box characteristics, but also the final black box-“antenna” *total system* characteristics. Importantly, any time new or modified BPL equipment or transmission systems are put in place, the total system will have to be re-certified for electromagnetic compatibility (EMC) with other carrier current systems, and systems licensed for operation in the frequency bands of interest—e.g. 1.705- to 30 MHz.

“In-House BPL” brings the uncertainty of the transmission medium, in that there will be many combinations of house wiring and utility pole hook-ups that become radiating conductors. Here, we are coupling wideband signals to power lines, which will most likely create EMC issues with household communications and electronic equipment. Additionally, In-House BPL systems are vulnerable to interference from broadcasting licensed radio stations, particularly where a licensed station antenna may be only a few feet from the power system being utilized for In-House BPL.

“Access BPL” wherein BPL systems are coupled to high voltage outdoor transmission lines poses a similar challenge. However, the outdoor high voltage transmission lines are much more efficient radiators of BPL signals, and receivers of interference, as well as transmissions from licensed radio stations, particularly in the 1.8- to 28 MHz frequency range. Therefore the remainder of this paper addresses Access BPL.

Technical Analysis

Let us look at a typical receiving system operating in the 1.8- to 30 MHz radio frequency bands.

We will determine the maximum permissible interference from an outside source that allows us to still maintain satisfactory communications, even though some degradation will exist. Then, we will calculate the maximum permissible BPL radiated power and field strength for satisfactory single-sideband suppressed carrier (SSB) voice and binary phase shift keying (BPSK) communications. Finally, we will quantify the interference that BPL systems will encounter from licensed stations operating in the 1.8- to 30 MHz frequency range.

Receiver Considerations

The noise power density output from a receiver with no added input noise is,

$$N_o = KT_o\, F \text{ Watts/Hz} \qquad \text{Equation 1}$$

Where,

N_o=Noise power density in watts per Hertz of bandwidth

T=Temperature in degrees Kelvin (standard temperature, T_o=290 degrees Kelvin)

K= Boltzmann's Constant=1.38×10^{-23} Joule per degree Kelvin

F=Receiver noise factor (power ratio)

Since we are concerned with ratios, we assume the receiver has unity gain. Hence the absence of the receiver gain in Equation 1. We could include receiver gain in our analysis, but the gain term cancels out, and thus need not be carried along on all calculations.

We are interested in how much the receiver noise level is raised by externally induced noise. For every dB increase in receiver output noise level, we have a corresponding dB decrease in carrier-to-noise ratio from a desired signal source.

Let us characterize externally induced noise level as mKT_o.

Then, the receiver output noise power density with this externally induced noise is,

$N_o' = KT_oF + mKT_o = KT_o(F+m)$ Watts/Hz Equation 2

The increase in receiver output noise level from the addition of this externally induced noise is,

$N_o' / N_o = KT_o(F+m) / KT_o F = (F+m)/F = 1 + m/F$ Equation 3

Recall that noise factor is a power ratio, whereas noise figure is just ten times the logarithm of the noise factor.

For example, a typical modern high frequency receiver has a 6 dB noise figure, and thus a noise factor of 4 (actually 6 dB is a power ratio of 3.98≈4).

Reference Data for Radio Engineers, Sixth Edition (1975), Figure 3, on page 29-3, gives us useful data on the radio noise outside the antenna system, relative to KT_o. These data are shown in Table 1 for the 1.8- to 30 MHz frequency bands. The values are taken with a short vertical antenna over perfectly conducting ground. Some antennas tend to reject noise more than others. In addition, the polarization of received noise energy varies. Accordingly, actual values at a particular installation will vary, however the numbers in Table 1 are reasonable assumptions.

Frequency (MHz)	Wavelength (meters)	Noise level, above KT_o
1.8	160	45 dB
3.5	80	40 dB
7	40	30 dB
10	30	25 dB
14/18	20/17	23 dB
21/24	15/12	20 dB
28	10	17 dB

Table 1 – Approximate Radio Noise Level vs. Frequency (Data source: see text)

There will be times when the external noise will be more or less than the levels shown in Table 1.

To illustrate the methodology for arriving at the final objective, namely, specifying the maximum allowable BPL radiated power and field strength, we will use a licensed station operating at 7 MHz. Then, we will show results for the 1.8-28 MHz frequency range to arrive at the maximum allowable BPL radiated power and field strength. Accordingly, consider a 7 MHz radio station, and a receiver noise figure of 6 dB (noise factor of 4). For simplicity, assume the antenna is omni-directional with a directivity gain of 0 dBi (dB with respect to an isotropic radiator). Note that in practice, one might be using a dipole or a very high gain antenna. In this case we can adjust the analysis accordingly.

With no external noise, the receiver output noise is, from Equation 1,

$$N_o=KT_o\,F=4\,KT_o$$

From Table 1, we note that the typical external noise is 30 dB above KT_o.

Then,

$$m\,KT_o=1000\,KT_o$$

That is, 30dB is a power ratio of 1,000, hence the number in the above equation.

From Equation 2, we have,

$N_o' = KT_oF + mKT_o = KT_o(F+m) = KT_o(4+1000) = 1004\ KT_o$

Note that the added noise outside the receiver masks the receiver noise itself. That is N_o', above, is nearly 1000 times the magnitude of N_o.

For analysis purposes, it is convenient to convert some numbers to a decibel base. In particular, we want to end up with levels in terms of decibels with respect to a Watt. Then, we can further convert to more convenient representations, as you will see below.

For Equation 1, we have,

$$N_o = KT_o\ F\ \text{Watts/Hz} = [10\log(1.38\times10^{-23}) + 10\log290 + 10\log F]\ \text{dbW/Hz}$$

$$= [-228.6+24.6+F(\text{dB})]\ \text{dBW/Hz} = [-204+F(\text{dB})]\ \text{dBW/Hz} = [-174+F(\text{dB})]\ \text{dBm/Hz}$$

Using the above relationship, let us examine the 6dB noise figure receiver; substituting in the equation, we have an output noise power density of:

$$N_o = [-204+6]\ \text{dBW/Hz} = -198\ \text{dBW/Hz}$$

We determine the output noise power by taking into account the receiver's bandwidth, as follows:

$$No = [-204+F+10\log B]\ \text{dBW} \qquad \text{Equation 4}$$

Where, B=Bandwidth in Hz

So, for a receiver with a 6dB noise figure, and a bandwidth of 3 kHz, we have:

$$No = [-204+6+10\log 3000] = [-204+6+34.8] = -163.2\ \text{dBW}$$

Now let us calculate the required input signal for a given output carrier-to-noise level:

$$(C/No)_{out}\ (\text{dB}) = Cin\ (\text{dBW}) - No\ (\text{dBW}) \qquad \text{Equation 5}$$

$$Cin\ (\text{dBW}) = (C/No)_{out}\ (\text{dBW}) + No\ (\text{dBW}) \qquad \text{Equation 6}$$

From Equation 6, for us to have an output carrier-to-noise ratio of 10 dB in the receiver with a 3 kHz bandwidth, we need:

Cin (dBW)=[10+(-163.2)] dBW= -153.2 dBW

Now, consider the system with the external noise levels of Table 1.

From the above, with an external noise level 30dB above KT_o, the output noise power density is:

N_o=1004KT_o Watts/Hz=[10log1004+(-204)] dBW/Hz= -174 dBW/Hz

In a 3 kHz bandwidth, the noise power is:

No=-174+10log3000 dBW= -139.2 dBW

For a 10 dB output carrier-to-noise ratio, we need a carrier input level of:

Cin (dBW)=10+(-139.2) dBW= -129.2 dBW (-99.2 dBm)

We can calculate the voltage input to the receiver as follows:

$Ec= (PcR)^{1/2}$

Where,

Ec=Input voltage at the receiver terminals, Volts

Pc=Carrier input power at the receiver antenna terminals, Watts

R=System impedance, Ohms

From the above, we have an input power level of -129.2 dBW.

To convert this to power level:

dBW=10log (Pc/1),

where Pc is in Watts

Then,

$DBW/10=\log (Pc/1)=\log (Pc)$

From which,

$Pc=10^{(dBW/10)}$ Watts

So, we convert -129.2 dBW to power in Watts as follows:

$Pc=10^{(-129.2/10)}= 1.2x10^{-13}$ Watt

Then,

$Ec= (PcR)^{1/2}=(50x1.2x10^{-13})^{1/2}$ Volt=$2.45x10^{-6}$ Volt=2.45 microvolts

Notice that without external noise, the 2.45 microvolt signal would give a 34dB output signal-to-noise ratio, as follows:

Recall the noise output power from the 6 dB noise figure receiver with a 3 kHz bandwidth is –163.2dBW without external noise.

From Equation 5, we have,

$(C/No)_{out}$ (dB)= Cin (dBW) – No (dBW)= -129.2-(-163.2)=34 dB

Propagation and Field Strength Considerations

Now, let us examine field strength considerations and the received power from an Access BPL system as well as the interference from licensed radio services that the BPL system will encounter.

We will first examine near-field field strength and power considerations, where the licensed station antenna is in the near field of the BPL radiating system at some frequencies. Then, we will examine the far-field field strength and power considerations, where the licensed station antenna system is beyond the near field of the BPL radiating system. Finally, we will discuss sky wave propagation considerations.

Near-Field Field Strength and Power

As noted earlier, FCC Part 15.209 requires that the field strength 30 meters from a carrier current system be no more than 30 microvolts per meter.

A distance of 30 meters from an emitting device is in the near field of a licensed radio station operating in, say, the 1.8 MHz frequency band, where the wavelength is 160 meters. In fact, typically a distance of less than five wavelengths is considered to be the near field of a radiating system.

Near-field analysis is rigorous, because of the mutual impedance between the radiators. However, the EZNEC antenna software program can be used to calculate the field strength and power in the near field. Thus, we will use it to analyze the following scenario:

- BPL signals coupled to a 333-meter (0.2 mile) overhead power line.
- Collocated licensed radio station using a half-wave dipole.
- Both the power line run and radio station antenna 50 feet above the ground

To illustrate the methodology, we will assume that the licensed station is operating at 7 MHz. Then, we will develop data for the complete range of the 1.8-30 MHz frequency range, from which we will determine:

- The maximum allowable interference level from a BPL system
- The interference level to the BPL system from a licensed station

For the 7 MHz case noted above, we have the external noise 30 dB above KT_o. Classically, data communications signals such as BPL can be treated as random signals, or basically, noise, because there are multiple signals being switched pseudo-randomly to transmit data. Also, some BPL systems use spread spectrum waveforms, which approximate band-limited white noise.

<u>Single-Sideband Suppressed Carrier (SSB) Voice Communications</u>

For SSB communications, we like a 10 dB output signal-to-noise ratio, but we can live with 6 dB. So we'll assume we can tolerate a 4 dB degradation of performance in the presence of BPL interference. With external noise 30 dB above KT_o as mentioned earlier:

As noted earlier, the system noise level is –139.2 dBW in a 3 kHz bandwidth. In addition we previously calculated that we need a signal input of –129.2 dBW to have a 10 dB output signal-to-noise ratio.

Converting –139.2 dBW to power, we have 1.2×10^{-14} Watt.

For a degradation of 4 dB in output signal-to-noise ratio, we can stand a total system noise power of 3×10^{-14} Watt (-135.2 dBW), which is 4 dB above the -139.2 dBW system noise. Then we can calculate the added input noise required to raise the output noise level 4 dB, from –139.2 dBW to –135.2 dBW.

So, we have,

$$3\times10^{-14}=1.2\times10^{-14}+N_{intf}$$

Where,

N_{intf}=Added interfering noise from BPL

Then,

$N_{intf}=3x10^{-14}-1.2x10^{-14}=1.8x10^{-14}$ Watt= -137.4 dBW (-107.4 dBm)

Data Communications

Let's take a look at a typical simple data communications system. Some popular systems use binary phase shift keying (BPSK), a convolutional code with powerful error detecting and correcting capabilities, and provide about 50 bits per second throughput. Figure 1 shows the bit error performance of a typical system that uses a rate one-half (r=½) convolutional code with a constraint length (C/L) of seven, and an uncoded BPSK system. Typical implementation allowances are included in the figure.

Note from Figure 1 that a 6.5dB carrier-to-noise ratio in the coded system provides a bit error rate (BER) of $1x10^{-5}$. Also, note that a 1.5 dB decrease in carrier-to-noise ratio to 5 dB results in a BER of $1x10^{-3}$, which is generally accepted as the maximum BER for satisfactory data communications. This relatively steep BER curve is typical of systems with powerful error detection and correction codes.

Recall from earlier analysis, above, that our 7 MHz receiving system with a 6 dB noise figure and 30 dB above KT_o external noise has a noise output power density of -174 dBW/Hz.

Then from Equation 4, we have:

No= [-174+10log B] dBW

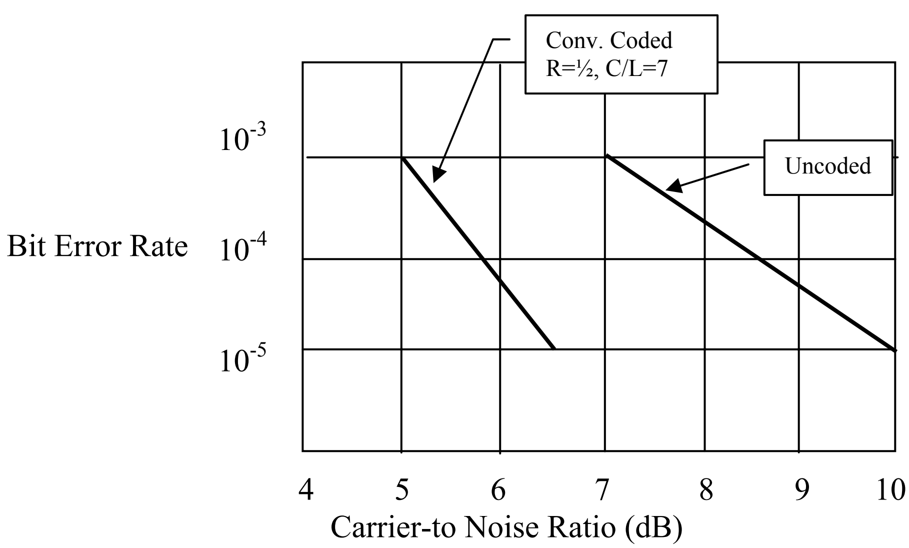

Figure 1-Binary Phase Shift Keying (BPSK) Error Rates

For the above system,

B=100Hz, and F=6 dB

We choose a 100 Hz bandwidth, because the signaling rate is twice the throughput to accommodate the rate one-half code. Some systems use different error detection and correction codes, and require less bandwidth. However, the system we are analyzing is also typical.

Thus, without additional interfering external noise, we have a receiver system output noise level of,

No= [-174+10log100]= -154dBW

Then, for a 6.5 dB output carrier-to-noise ratio, which gives us a BER of 10^{-5}, we need an input signal of (from Equation 6):

Cin (dBW)= $(C/No)_{out}$ (dBW)+No (dBW)=6.5+(-154)= -147.5 dBW (-117.5 dBm)

For a BER of 10^{-3} we can stand the noise level to increase by 1.5 dB, resulting in a $(C/No)_{out}$ of 5 dB.

The system noise without any interfering noise is –154dBW (3.98×10^{-16} Watt) as noted above. A 1.5 dB increase in noise is a power ratio of 1.41, thus, we can stand a total system noise of:

No (total)= $3.98 \times 10^{-16} \times 1.41 = 5.61 \times 10^{-16}$ Watt (-152.5 dBW), from which the maximum allowable additional external noise is:

$N_{intf} = 5.61 \times 10^{-16} - 3.98 \times 10^{-16} = 1.63 \times 10^{-16}$ Watt (-157.9 dBW or –127.9 dBm)

In order to arrive at the BPL radiated field strength limits, it is necessary for us to calculate the maximum allowable BPL radiated interference level that will have electromagnetic compatibility (EMC) with a licensed station receiving system operating in the presence of typical atmospheric noise. Accordingly, Table 2 has been prepared using the above analysis approach, including EZNEC analysis as discussed further below. A half-wave dipole antenna is assumed for the licensed station.

Mode	Freq (MHz)	Rcvr. N.F. (dB)	Ext. Amb. Noise (dB-kT_o)	Req'd. (C/N)o (dB)	System. Band-Width (Hz)	Rcv. Ant. Gain (dB)	Max. Allow. Intf. (dBW)	Max. Allow. BPL Intf. (µV/mtr.)	C_{in}(dBW)	Max. Allow. BPL Output Power (dBW)[1]	Remarks
SSB Voice	1.8	10	45	6	3000	2.15	-122.4	0.78	-114.2	-108.5	1. See Text
SSB Voice	3.5	6	40	6	3000	2.15	-127.4	0.27	-119.2	-109.4	
SSB Voice	7	6	30	6	3000	2.15	-137.4	0.17	-129.2	-115.1	
SSB Voice	10	6	25	6	3000	2.15	-142.4	0.14	-134.2	-121.1	
SSB Voice	14	6	23	6	3000	2.15	-144.4	0.15	-136.1	-118.6	
SSB Voice	18	6	23	6	3000	2.15	-144.4	0.19	-136.1	-113.6	
SSB Voice	21	6	20	6	3000	2.15	-147.3	0.16	-139.1	-110.9	
SSB Voice	24	6	20	6	3000	2.15	-147.3	0.19	-139.1	-101.0	
SSB Voice	28	6	17	6	3000	2.15	-150.1	0.16	-141.9	-110.5	
BPSK[2]	1.8	10	45	5	100	2.15	-142.8	0.07	-132.5	-128.9	2. r=½ Coded, 50 bps
BPSK	3.5	6	40	5	100	2.15	-147.8	0.03	-137.5	-129.8	
BPSK	7	6	30	5	100	2.15	-157.8	0.02	-147.48	-135.5	
BPSK	10	6	25	5	100	2.15	-162.8	0.01	-152.45	-141.5	
BPSK	14	6	23	5	100	2.15	-164.8	0.01	-154.4	-139.0	
BPSK	18	6	23	5	100	2.15	-164.8	0.02	-154.4	-134.0	
BPSK	21	6	20	5	100	2.15	-167.7	0.02	-157.3	-131.3	
BPSK	24	6	20	5	100	2.15	-167.7	0.02	-157.3	-121.4	
BPSK	28	6	17	5	100	2.15	-170.5	0.02	-160.2	-130.9	

Table 2 – Maximum Allowable BPL Radiated Power for SSB and PSK Electromagnetic Compatibility (EMC)

The Table 2 data were compiled for frequencies of 1.8- to 28 MHz. We used EZNEC to model the scenario with a 333-meter long high line, fifty feet above the ground, carrying BPL signals, and a collocated half-wave receiving antenna, fifty feet above the ground, separated 30 meters from the BPL high line. We adjusted the BPL power output to its 333-meter radiator to the level that induced the maximum allowable interference (see Table 2) power to the collocated half-wave receiving dipole. Figure 2 shows the system geometry. Data were compiled on each frequency with the half-wave antenna located progressively from one end of the BPL radiator to the other on each frequency.

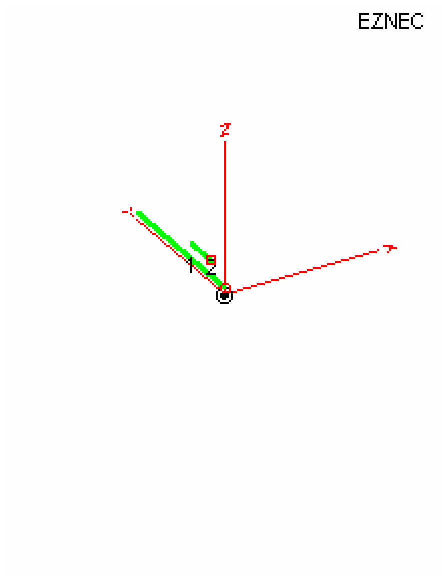

Figure 2- Near-field BPL-Licensed Station Antenna and BPL Radiator Geometry

We calculated the Table 2 maximum allowable field strength corresponding to the received power as follows:

The received power is given as:

$$P_r = E_f^2 G_r \lambda^2 / 480\pi^2 \text{ Watts} \qquad \text{Equation 7}$$

Where,

P_r= Power received by the antenna, Watts

E_f=Field strength, Volts per meter

G_r=Receiver antenna gain with respect to isotropic (power ratio)

λ=Wavelength, meters

Solving Equation 7 for E_f, we have:

E_f=(68.83/ λ)(P_r / G_r) ^{½} Volts per meter Equation 8

Notice that these data are for one specific BPL radiator and licensed station antenna. Clearly, every possible system would have to be specifically evaluated to arrive at the maximum allowable field strength at 30 meters from the BPL radiator. However, as a starting point, we have enough data to make a recommendation for the maximum limits of FCC Part 15, Section 15.209.

For safety, we should assume that a BPL radiator and a licensed station have wire systems and multi-element antenna arrays resulting in at least 15 dB of directivity gain each over a dipole. Thus the maximum allowable field strength should be 30 dB lower than the lowest field strength number in Table 2 (0.01 microvolts per meter), or, approximately $3x10^{-4}$ microvolt per meter in a 100 Hz. bandwidth.

We are also interested in the level of near-field interference a BPL system will receive from a licensed transmitting station. Table 5 shows these data for a transmitted power of 1,500 Watts, with the antenna geometry of Figure 4, for the 1.8- to 30 MHz frequency range. EZNEC can also be used to determine the level of interference when the licensed station uses an antenna with high directivity gain, and any number of assumed BPL and licensed station radiator geometries.

Frequency (MHz)	Lic. Stn. Power (Watts)	Pwr. Induced into BPL High Line (Watts)	Pwr. Induced into BPL High Line (dBW)	Field Strength at BPL High Line (Volts/Meter)	Field Strength at BPL High Line (Microvolts/Meter)
1.8	1500	0.5733	-2.42	0.31	$3.13x10^5$
3.5	1500	0.09993	-10	0.25	$2.54x10^5$
7	1500	0.07881	-11.03	0.45	$4.51x10^5$
10	1500	0.2323	-6.34	1.11	$1.11x10^6$
14	1500	0.3237	-4.90	1.83	$1.83x10^6$
18	1500	0.3405	-4.68	2.41	$2.41x10^6$
21	1500	0.06422	-11.92	1.22	$1.22x10^6$
24	1500	0.004332	-23.63	0.362	$3.62x10^5$
28	1500	0.3495	-14.57	1.20	$1.20x10^6$

Table 5-BPL Received Power From a 1500-Watt Licensed Station with a half-wave dipole Collocated 30 meters from the BPL Radiator

Table 5 presents data for the licensed station half-wave dipole separated 30 meters from the 333-meter high line carrying BPL signals, and located at the point of maximum coupling. Notice that the Table 5 data are with a licensed station using a half-wave dipole 50 feet above the ground. The power levels received by the BPL system will be much higher when licensed stations use high directivity gain multi-element antenna arrays.

From the above discussion, and illustrations, we can form the following conclusions:

1. BPL and licensed radio station electromagnetic compatibility (EMC) is a complex subject, since every situation will be different. Indeed, there will be a wide variety of BPL modulations, power levels, and radiators, and the wide variety of licensed station receiving and transmitting equipment, modulations, and antenna array configurations.
2. The degree of EMC depends on BPL and licensed station power levels, receiving system noise, noise figure, radiators (antennas), and system susceptibilities.
3. The degree of EMC depends on the specific BPL and licensed station radiator geometries and proximity.
4. The maximum allowable field strength 30 meters from an Access BPL power transmission system must not exceed $1x10^{-5}$ microvolts per meter in a 100 Hz bandwidth.
5. With the radiator geometry of Figure 4 (i.e. 30 meter spacing between radiators), and a licensed station delivering 1500 Watts to a half-wave dipole, the power induced in the BPL radiator will be as high as -2.42 dBW in the 1.8- to 30 MHz frequency range.

Far Field Radiation Considerations

Figures 3 through 11 are far-field radiation patterns at 1.8 through 28 MHz, at the angle of radiation shown in each figure, for the above end-fed 333 meter BPL wire conductor 50 feet above the ground.

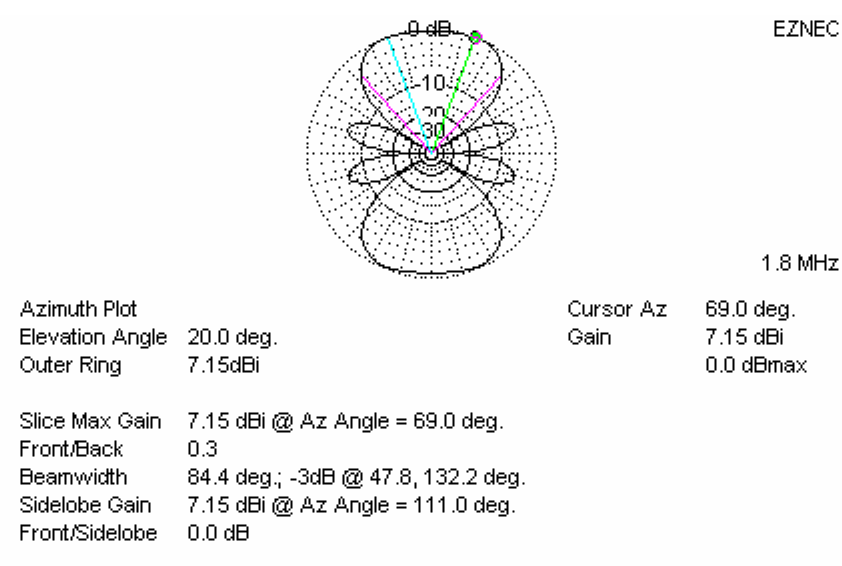

Figure 3- Far Field 1.8 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

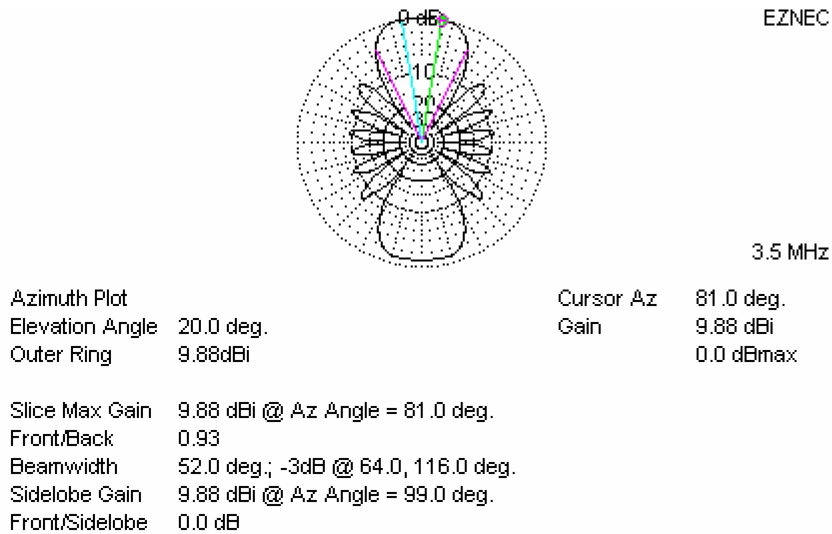

Figure 4- Far Field 3.5 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

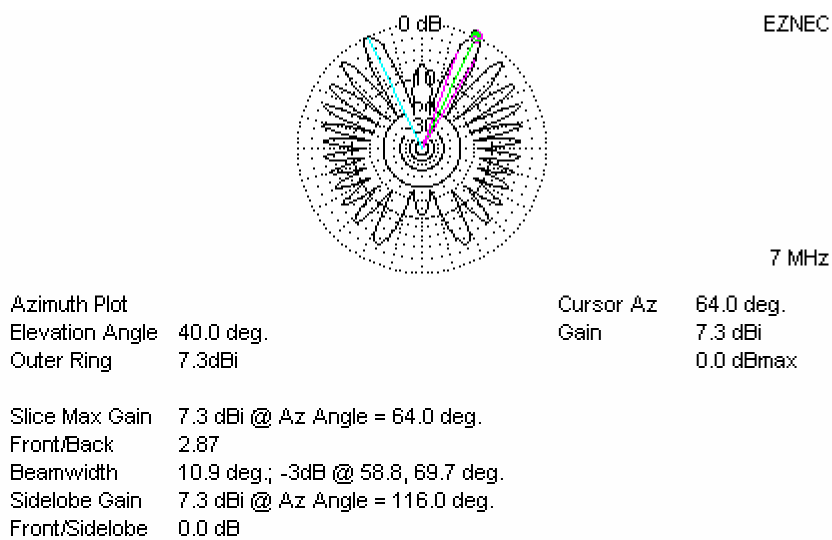

Figure 5- Far Field 7 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

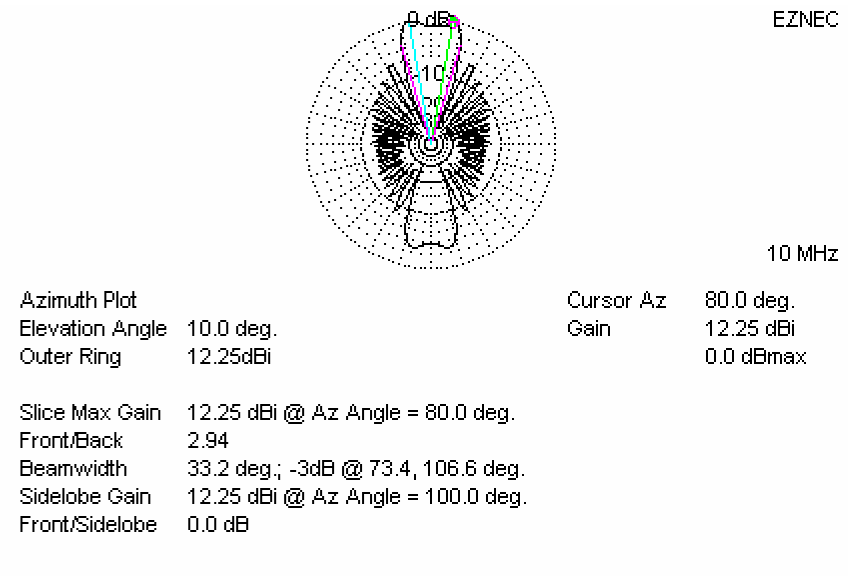

Figure 6- Far Field 10 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

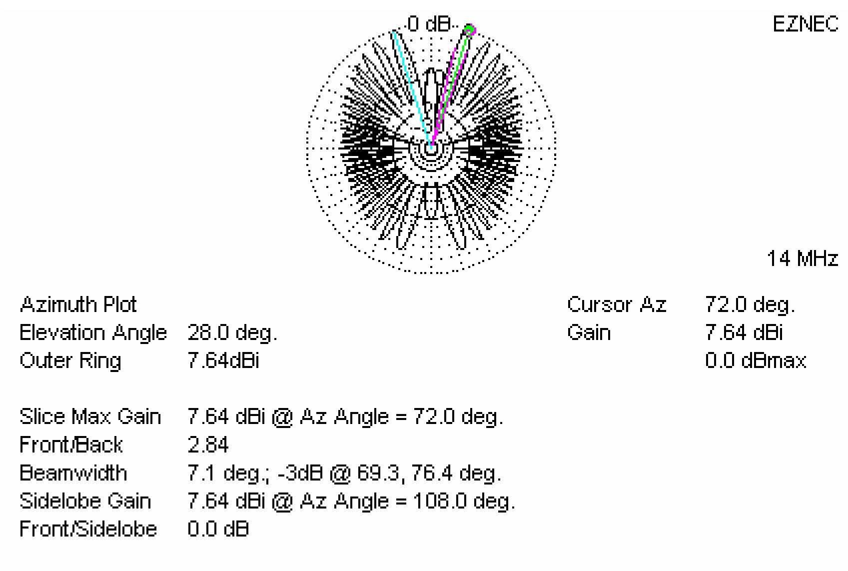

Figure 7- Far Field 14 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

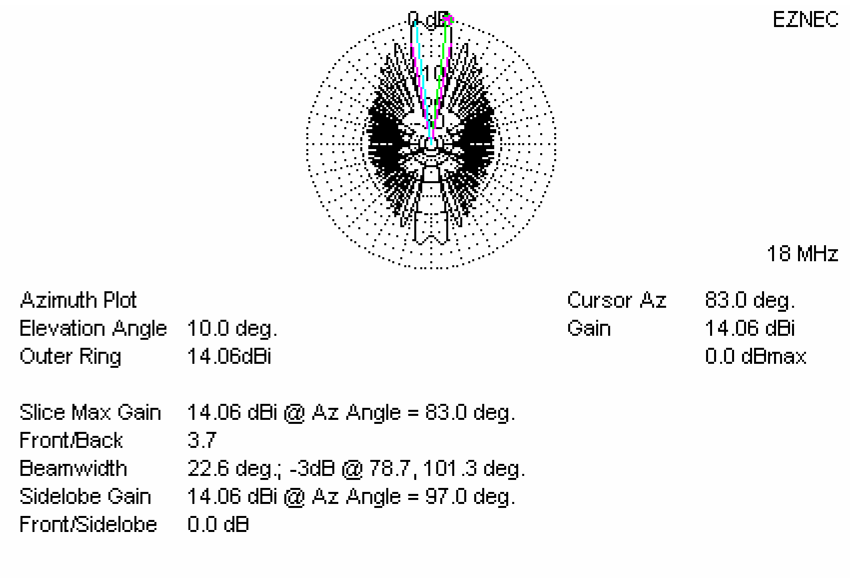

Figure 8- Far Field 18 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

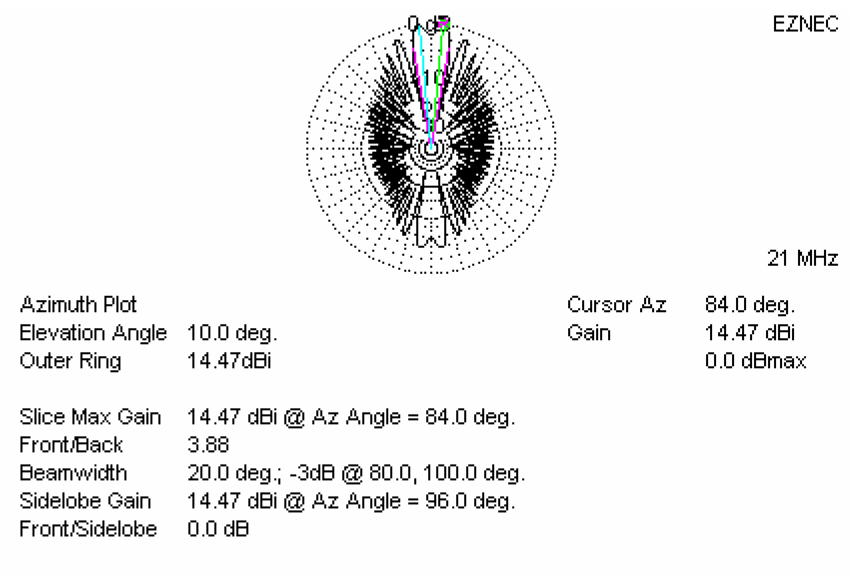

Figure 9- Far Field 21 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

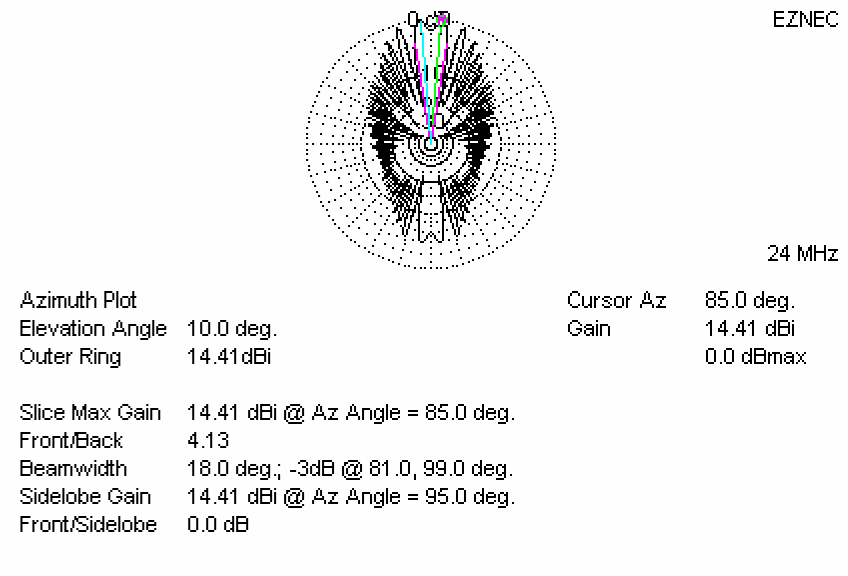

Figure 10- Far Field 21 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

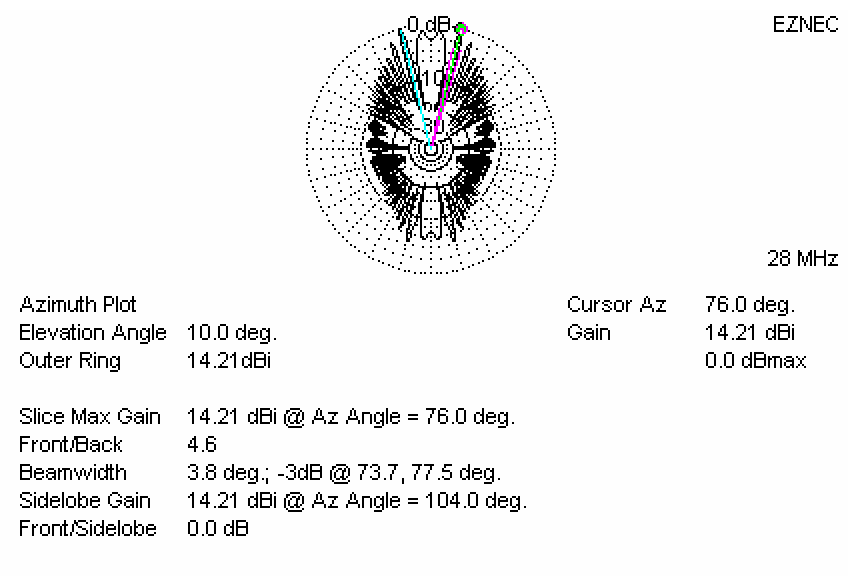

Figure 11- Far Field 28 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

Notice from the above far-field azimuth radiation patterns that the BPL long wire has substantial directivity gain at many frequencies, especially at low radiation angles. This is not surprising, since it is well known that a single long conductor makes a very effective radiating antenna. This will cause the BPL system to not only increase its interference with licensed radio systems, but also be more susceptible to radiated power from these licensed stations.

For near-field EMC, we showed that the field strength 30 meters from the BPL system must not exceed $3x10^{-4}$ microvolts per meter in a 100 Hz bandwidth. This number was arrived at by adding a 30 dB margin, 15 dB of which was allocated to the BPL system, the maximum BPL power output of –141.5 dBW listed in Table 2. This results in a maximum-allowable BPL system power output of –156.5 dBW ($2.24x10^{-16}$ Watt) into a 333.3 meter long high line. Even with a directivity gain of 14 dB, the maximum effective radiated power is only –142.5 dBW. Thus, far field interference from this BPL power level and particular scenario is insignificant.

It is informative to look at the effect of licensed stations in the far field on an Access BPL system connected to a 333 meter high line.

Recall that a ground wave consists of a direct wave and a reflected wave (reflected by the earth).

The Bell Laboratories produced a report for the National Defense Committee, Division 15, in October 1944. These data have proved to be very reliable under actual conditions.

Figure 12 is a set of curves prepared from the data in the above report, and will be the basis of this analysis.

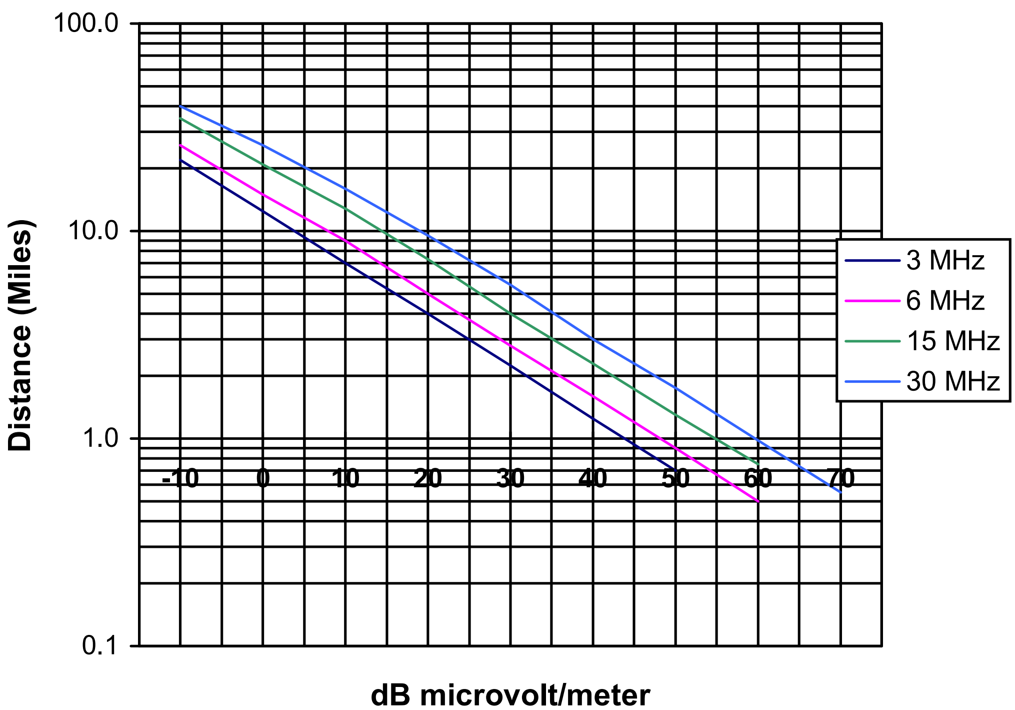

Figure 12- Field Strength vs. Distance 1 KW radiated, Horizontal Polarization, Dipole Antenna, 10 Ft. above Ground Level (Data from Bell Laboratories)

Note: In the original document, the Distance axis numbers were to zero decimal places, thus, the edited “0.1” was “0.”

The Figure 12 data are based on the following:

- Transmitter power: 1,000 Watts
- Transmitter antenna: Dipole
- Transmitting and receiving antenna height above ground: 10 ft.
- Antenna polarization: Horizontal
- Soil Condition: Good
- Terrain: Smooth

Note that Figure 12 includes data for 3-, 6-, 15-, and 30 MHz.

We can use the Figure 12 data to determine the field strength at a given distance from the transmitting antenna for different antenna types, heights, and transmitter powers by applying appropriate correction factors.

For our analysis, we will assume that the radiators are 50 feet above the ground. Accordingly, the height gain correction factors, taken from the Bell Laboratories data, for the above frequencies, are shown in Table 6.

Freq.	**Correction Factor**
3 MHz	11 dB
6 MHz	13 dB
15 MHz	14 dB
30 MHz	14 dB

Table 6- Antenna Height Correction Factors For Figure 12

Assume the following scenario:

- BPL system that provides EMC in accordance with the above near-field analysis
- Licensed station with a 6-dB noise figure receiver, and a transmitter delivering 1 KW into a 7dBd (7 dB gain over a dipole) antenna.
- 30 MHz licensed station operating frequency.

The BPL antenna system azimuth plot is as shown in Figure 13. Notice that the BPL 333-meter long conductor has a directivity gain of 6.46 dBi (dB with respect to an isotropic radiator), at the 83-degree point (nearly at right angles with the wire) and elevation angle of 1-degree. We choose 1-degree which virtually represents the BPL radiator gain "looking right at" the licensed station antenna, which is also 50 feet above the ground.

Scenario:—BPL receiving, licensed station transmitting.

The correction factors are as follows:

BPL receive:

Item	Correction (dB)
Antenna Height	+14
Antenna Gain	+6.46
Total (dB)	+20.46

Table 7- Correction Factor for BPL Receive for Figure 12 (Data from Bell Laboratories graphs)

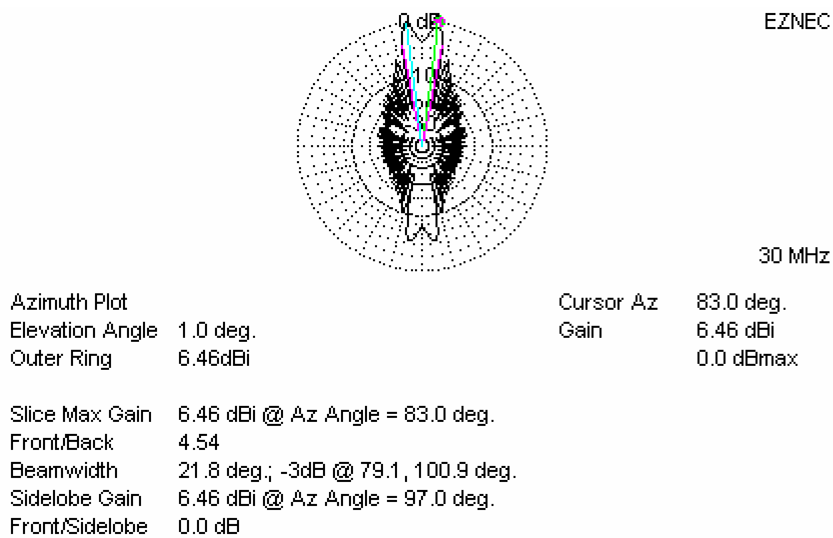

Figure 13- Far Field 30 MHz Azimuth Radiation Pattern, 333 mtr. Wire at 50 Ft.

From Figure 12, at a distance of 5 miles, we have a field strength of 32 dB-microvolts per meter. Applying the transmit and receive correction factors From Tables 7-, and 8,we have:

Corrected field strength at BPL conductor=32+21=53 dB-microvolts/meter.

Then, the field strength in microvolts per meter is:

$E_f=10^{(dB\text{-}\mu V/20)}$=446.7 microvolts/meter=$4.467\times10^{-4}$ Volt/meter

For licensed station transmit:

Item	Correction (dB)
Antenna Height	+14
Antenna Gain	+7
Power	0
Total (dB)	+21 dB

Table 8- Correction Factor for Licensed Station Transmit for Figure 12

From Equation 7, the received power is given as:

$P_r = E_f^2 G_r \lambda^2 / 480\pi^2$ Watts

Where,

P_r= Power received by the antenna, Watts

E_f=Field strength, Volts per meter

G_r=Receiver antenna gain with respect to isotropic (power ratio)

λ=Wavelength, meters

From Table 7, the receive antenna correction factor is 20.46 dB (111.17 power ratio)

Thus,

$P_r = [4.467\text{x}10^{-4})^2 \text{x} 111.17\text{x}10^2] / 480\pi^2 = 4.68\text{x}10^{-7}$ Watt (-63.3 dBW, or –33.3 dBm)

This means that a BPL system connected to a 333-meter high line, fifty feet above the ground, will receive an interfering signal of –63.3 dBW (or –33.3 dBm) from a 1000 watt licensed station with a 7 dBd gain array fifty feet above the ground, and five miles away. Thus, the Access BPL system must be designed to operate in this EMC environment.

Skywave Propagation

In the above analysis, we have not discussed skywave considerations. If the Access BPL system field strength at 30 meters is $1\text{x}10^{-5}$ microvolts per meter or less in a 100 Hz bandwidth, BPL skywave propagation is most likely not an issue. However, Access BPL systems will receive skywave signals from licensed transmitting systems. Indeed, BPL can easily receive –97 dBW (-67 dBm) and higher level skywave signals.

Measurement Recommendations

Regarding the NPRM questions on Appendix C measurements:

1. It is recommended field strength measurements be conducted using classic methods, such as those fostered by the Institute of Electrical and Electionics Engineers (IEEE). In addition, measuring field strength, say, ten meters from a high voltage transmission line appears impractical. From a practical standpoint, field strength measurements can probably be made no closer than 30 meters (98 feet) from the power transmission system associated with Access BPL systems.
2. Measurements should be made at practical distances from the overhead power lines along with appropriate correction factors.
3. It is recommended that IEEE guidelines for measurements and correction factors be used. In addition, classic military standards MIL-STD-461, -462, and –463 should be good references.
4. Measurements should be made, moving the measurement equipment along the total length of a power line run to determine the maximum field strength point. The FCC proposed measurements of 0, ¼, ½, ¾, and 1 wavelength down the line from the BPL injection point appear to be an inadequate sample of the actual radiated field strength.

Summary

From the above analysis, we can form the following sound conclusions:

Access BPL

The analysis herein clearly demonstrates the electromagnetic compatibility (EMC) challenge that Access BPL suppliers face. In fact, there are clear reasons to believe that a technical solution to the EMC problem may not be possible.

The field strength 30 meters from the Access BPL system, including the transmission media, must be no greater than $1x10^{-5}$ microvolts per meter in a 100 Hz bandwidth in order that there be EMC with modern licensed radio stations operating in the 1.8- to 30 MHz frequency range.

Access BPL systems must be able to perform satisfactorily in the presence of a received interference power of at least –2.42 dBW from licensed radio stations located 30 meters from the Access BPL transmission line system.

Recommendation

It is recommended that the FCC issue a warning to potential Access BPL suppliers that severe EMC problems exist, and that these suppliers should make sure they understand the nature of the challenge before proposing to deliver equipment.

James K. Boomer Credentials

- Electronics Engineer, BSEE, 1954 from the University of Nebraska
- Radio and Communication Systems Design Engineer, Staff Engineer and Project Engineer, Collins Radio Company, Cedar Rapids, Iowa, 1954 to 1964
- Communication Systems Project Engineer and Design Engineer for National Cash Register Company, Dayton, Ohio, 1964 to 1966
- Communication Systems Staff Engineer, Design Engineer, Project Engineer, and Engineering Section Manager at Magnavox Company (now Raytheon), 1966-2000