Methods of Feeding Overhead Electrical Power-Line Distribution Lines With BPL Signals and the Relationship of These Methods to the Radiated Emissions of the Conductors

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1. Introduction

1.1 There are differences in the way that medium-voltage (MV)[2] power-distribution lines conduct and radiate signals based on the way that RF power is fed to the lines. ARRL used a well-known antenna-modeling program, EZNEC PRO[3] 3.0 with the NEC-4.1 calculation engine[4] to model a simple MV power line and two nearby amateur antennas, conservatively located 30 meters from the lines. A pictorial diagram of the model is shown in Figure 1.

1.2 Tables 1 and 2 show the results ARRL obtained by modeling three different ways of feeding the antenna:
- Differential feed between two phases, at one end
- One phase to earth ground, in the center
- One phase fed differentially similar to the way a dipole antenna is fed, offset on the ungrounded phase

2. Description of the Model

2.1 The power-line radiator antenna model was configured with two 12.7 mm copper conductors[5], 200 meters in length. They were placed 10 meters above ground. The ground was modeled with average conductivity and dielectric constant. The two conductors were parallel, spaced 1.0 meter. One of the conductors was grounded to simulate typical imbalance in the line. The ground connection consisted of four 10-meter radials, 5 cm above ground. This is a relatively poor RF ground, to simulate the typical poor RF characteristics of power-line grounds. (This also allows those that don't have access to the NEC-4.1 software to duplicate the results using the more available NEC-2 calculation engine, which cannot handle direct ground connections the same way NEC-4.1 does.)

2.2 Differentially connected loads were placed at each end of the transmission line to properly model the signal losses from various loads present on the line (transformers, BPL modems). This power would not be radiated, so must be accounted for in the model. This also allows

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[2] The FCC NOI refers to the power-line distribution lines as "medium-voltage" lines. The power-line industry usually categorizes lines as distribution equal to or less than 13 kV, sub-transmission less than 69 kV and transmission equal to or greater than 69 kV. In this paper, the term medium-voltage refers to lines that are typically 13 kV or less.

[3] EZNEC software is available from Roy Lewellan, P.E., PO Box 6658, Beaverton, OR 97007, Tel: 503-646-2885, Email: w7el@eznec.com, Web: http://www.eznec.com

[4] NEC-4.1 is a licensed software program distributed by the Lawrence Livermore National Laboratories, http://www.llnl.gov/.

[5] EZNEC considers modeled conductor losses when making its calculations.

the software to calculate the relative efficiency of feeding the system at different points by comparing the power fed to the system and the power that reaches the load, simulating a BPL system modem or repeater.   These loads are 50-j0 ohms.

2.3 Two amateur receive antennas are also included in the model. Antenna 1 is a half-wave dipole located 10 meters above ground, at the height of the power line, typical of many amateur tree-mounted antennas. This antenna is 30 meters distant from the line. Antenna 2 is a half-wave dipole located 30 meters above ground, 30 meters diagonally from the line. The height of this antenna is representative of taller amateur tower installations. Each of these antennas has a 50-j0 ohm load in the center and EZNEC is used to calculate the power that reaches each load by radiation.

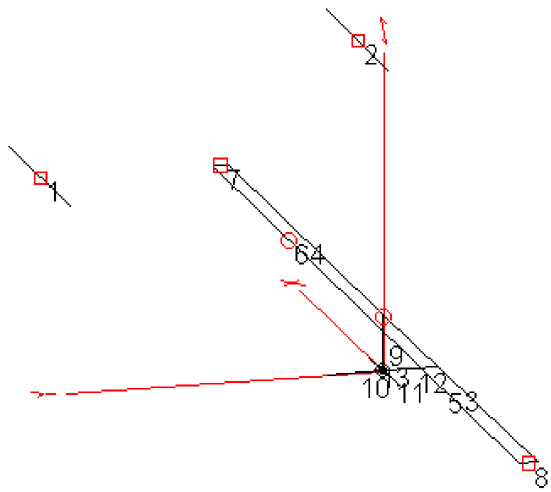

Figure 1: This is a pictorial of the model used by ARRL to calculate differences in the performance of BPL systems fed in different ways.

Point 1 = Amateur half-wave dipole antenna, 10 meters high, 30 meters from line.
Point 2 = Half-wave dipole antenna, 30 meters high, 30 meters diagonally from line.
Point 6 = Single-phase differential “dipole” feed point.
Points 7 and 8 = Two phase differential feed or load, as specified in Tables.
Point 9 = Ground wire, fed where it connects to the phase.
Point 10= Earth ground radials (4).

3. Results

3.1 The results of the modeling are shown in Tables 1 and 2.

Table 1: 14 MHz

Method of feeding the model	Calculated gain of power-line as antenna, including losses	Calculated free-space path loss to 30 meters distance	Modeled loss to antenna 1	Modeled loss to antenna 2	Loss to simulated modem at end of line	EZNEC file[6]
Differential across two phases	+3.7 dBi	24.9 dB	42.8 dB	36.9 dB	8.0 dB	DIFF14.EZ
One phase to earth ground	+3.3 dBi	24.9 dB	38.7 dB	39.4 dB	10.0 dB	GND14.EZ
One phase differential feed[7]	+7.7 dBi	24.9 dB	37.1 dB	40.1 dB	8.6 dB	DIP14.EZ

Table 2: 3.5 MHz

Method of feeding the model	Calculated gain of power-line as antenna, including losses	Calculated free-space path loss to 30 meters distance	Modeled loss to antenna 1	Modeled loss to antenna 2	Loss to simulated modem at end of line	EZNEC file
Differential across two phases	-1.3 dBi	12.9 dB	26.0 dB	20.8 dB	5.8 dB	DIFF3R5.EZ
One phase to earth ground	-2.2 dBi	12.9 dB	24.4 dB	23.2 dB	7.6 dB	GND3R5.EZ
One phase differential Feed	+1.6 dBi	12.9 dB	17.8 dB	16.0 dB	10.8 dB	DIP3R5.EZ

3.2 It is possible to draw several conclusions from these data. Feeding two phases differentially or from one phase to ground results in less energy being radiated than feeding a single phase differentially. From an EMC point of view, feeding a single phase differentially as a dipole is the worst choice, resulting in a higher power-line antenna gain and generally more coupling to the two simulated amateur antennas. On 14 MHz, the gain of the power-line fed this way is high enough that the power line has more gain than many antennas intentionally used by amateurs on that band.

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[6] The EZNEC and NEC models used for the calculations in this paper are available for download at http://www.arrl.org/~ehare/rfi/bpl/antenna_models.zip

[7] The FCC NOI describes this feed method as feeding a single phase similar to the way a dipole antenna is fed. In this model, the single phase is fed in this fashion 25% from one end.

3.3 The radiation pattern from this model is quite complex, with many lobes and much energy sent skyward. Antennas 1 and 2 are located near a point with significant coupling between the modeled power line and the modeled amateur antennas, but no effort was made to find the absolute worst case for this model. For example, the modeled antenna radiation pattern shown in Figure 2 demonstrates that maximum-coupling point on 3.5 MHz would be straight up from the power line.

3.4 These antennas are also located in the radiating near field region of the large power-line radiator. The near-field effects and the fact that the simulated amateur antennas are not located in the maximum field above the line results in less energy present at the modeled point than the path-loss calculation shown in the table. Of note, however, on 3.5 MHz, the received signal level in the model is within 3 dB of the path-loss calculation.

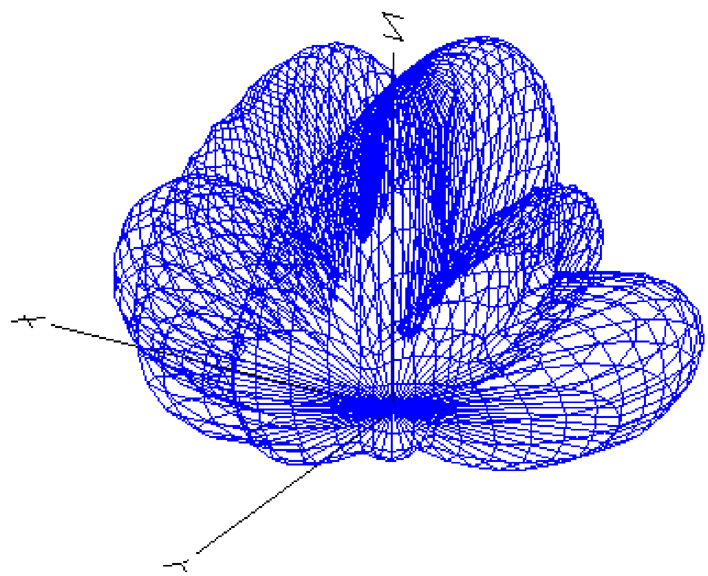

Figure 2: This is the pattern of the 3.5 MHz radiated signal from the power-line model used by ARRL for these calculations. (file: DIP3R5.EZ)