Modeling and Analysis of Electromagnetic Interference for Broadband Powerline Communication

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Abstract— The power line has been extensively studied as the media for broadband data communication over the band of frequencies up to 30 MHz. This requires mains injected radio frequency levels that are Electromagnetic Compatibility (EMC) critical, with common-mode currents on wires. Power line cables are often unshielded, thus becoming sources and targets of electromagnetic interferences (EMI). Phase 1 of NTIA's study addresses issues deemed most important to formulation of a regulatory framework that would limit the risks of local interference from outdoor elements of power line systems. This paper represents a theoretical model for electromagnetic interference from power lines in the near field. Simulated results using MATLAB can be considered as a good approximation to find out the near-field values and it can be deduced that the deployment of power lines for broadband services will not cause much debated interference problems for the radio receivers placed in the near field.

Index Terms— Broadband over Power lines (BPL), Broadband Fixed Wireless Access (BFWA), Digital Subscriber Line (DSL) Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), Federal Communications Commission (FCC),National Telecommunications and Information Administration (NTIA), Power Line Communication (PLC), Radio Frequency Interference (RFI).

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1 INTRODUCTION

Power line communication is not a new idea, as several power utility companies have used power lines for a couple of decades for narrowband applications such as metering & control. In the past few years however, there has been a renewed interest in the possibility of exploiting power line cables as a broadband communication medium for several important applications like broadband internet access, in-vehicle data communication, indoor wired LAN for residential & business premises.

The basic rationale for such enthusiasm is that the power gird provides an infrastructure that is much more extensive and pervasive than any other wired alternative, and that virtually every line-powered device can become the target of value added services [1] .Therefore, PLCs can be considered as the technological enabler of a plethora of future applications that would probably not be available otherwise. PLC refers to a variety of broadband services provided over the electric power gird .PLC opens up a new communication infrastructure as electricity is more prevalent in homes than telephone lines. Along with telephones (via DSL) and BFWA type of technologies, PLC offers an alternative for the last link for the delivery of broadband services.

The concept of running data over electric wiring is not new. PLC technology has been around since the 1950's power companies have been using PLC to send control messages & had been limited to low data rates for the power company's own internal applications [2]. It was never seriously thought of as a medium for communications due to its low speed, minimal functionality & high deployment cost. The major challenge was trying to use the same wire that carries strong current, to also accommodate data signals .However, new modulation techniques supported by recent technological developments have finally enabled the power line to become a means for high speed for, broadband communications over low & medium voltage lines.

Technologically, BPL works as a means of high speed internet access and BPL has a number appealing features, including transmission speeds that can be higher than cable and DSL. With BPL, both uplink and downlink speeds are equally fast, making it a better option when compared to the slower uplink speeds of cable and DSL. BPL can help utilities with activities such as automated outage detection and restoration confirmation .BPL can be less expensive than satellites. Moreover, the equipment needed to set up PLC in the home is cheaper on average than that of other broadband solutions such as DSL and Cable modem. PLCs outperform its competitors with speeds of up to 14 Mbps [3].

Despite all this recent enthusiasm, there is still some skepticism about the technology and its commercial viability. Among the main technical challenges of PLCs, we have: The power line channels are very harsh and noisy transmission medium that is very difficult to model. The power line channel is frequency selective, time varying and is impaired by colored background noise and impulsive noise. Moreover power line cables are often unshielded, thus becoming both sources and targets of capital EMI, last but not the least; regulations about EMC differ on country by country basis. EMC is a key issue in determining the deployment of BPL. Perhaps the major obstacle to ubiquitous deployment of BPL is high frequency radio frequency interference (RFI). The deployment of BPL can create RFI which is detrimental to users of these high frequencies, which consist of amateur HAM radio operators, emergency and public safety frequency and short wave channel users. RFI is not only a technical challenge but also a great political significance as the licensed HAM radio frequency users are among the most affected and most vocal in their criticism of BPL.

The notice adopted by the Federal Communications Commission (FCC) [4] proposes that BPL devices use technologies that lessen the possibility of interference. BPL vendors such as Amperion and Current Technologies have begun offering BPL services in limited areas. National Telecommunications and Information Administration (NTIA) phase 1 study [5] found that greatest interference risks stem from compliance measurement provisions. Irregular spatial distribution of field strength greatly complicates compliance measurements.

A practical compliance measurement procedure for Access BPL systems can reliably identify the field strength level that is not exceeded at 80% of possible receiver antenna locations at the specified measurement distance from the radiating structure --- this is the procedure that was specified in the FCC report [4] and order. Practical and technical considerations dictate that BPL compliance measurements can be made in the near field. NTIA's BPL measurements [5] and NEC radiation models both manifest near field behavior at large distance (over 300 mts) in many directions from BPL system. In many cases, the field strength at large distance in the near field is at levels too low for reliable measurement. In this paper we developed a theoretical model of electromagnetic interference from power lines in the near field. In this model, the characteristics impedance and the propagation constant of the power line are derived based on the transmission line theory using the concept of distributed parameters. The currents along the power-line conductors can then be calculated so that the radiated emission can be established using the model. Then the estimated fields were cross-checked from the available data from NTIA's phase1 study [5]. Finally the calculated field values were compared to the extrapolated far field values [6] and from the FCC standard (part 15) [4].

2 CALCULATIONS

The geometrical configuration of power line is shown in Figure 1. The characteristics impedance and the propagation constant of the Power line are derived using the two-wire transmission line theory. For a two-wire transmission line, we have the distributed parameters per unit length at high frequencies as follows [7]:

Resistance $$R(\Omega / m) = \frac{1}{\pi a \delta \sigma_c}$$

Inductance $$L(H / m) = \frac{\mu \cosh^{-1}(d / 2a)}{\pi}$$

Conductance $$G(S / m) = \frac{\pi\sigma}{\cosh^{-1}(d/2a)}$$

Capacitance $$C(F / m) = \frac{\pi\varepsilon}{\cosh^{-1}(d/2a)}$$

The characteristics impedance and propagation constant as follows:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

Where,

δ =skin depth of the conductor = $1/\sqrt{\pi f \mu_c \sigma_c}$
a = radius of the line
d = separation between the wire
$\omega = 2\pi f$, f is frequency of the signal
ε = permittivity of the surrounding media (air)
σ = conductivity of the dielectric filled between the wire (air)
σ_c = conductivity of the copper wire
Zo = characteristics impedance of the wire
γ = propagation constant of the wire

For each line LC=$\mu\varepsilon$ *and G/C=*σ/ε, the conductors are characterized by $\sigma_c, \mu_c, \varepsilon_c = \varepsilon_o$ and the homogenous dielectric separating the conductors is characterized by $\sigma, \mu, \varepsilon.$ [7].

To determine the radiated field we replaced the coupler in series with the center segment of the wire by equivalent source impedance. The current distribution was assumed constant and depends only on the voltage applied and the equivalent input impedance.

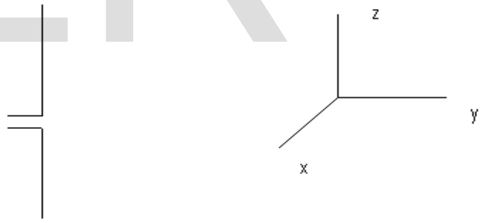

Fig 1. Power line configuration

To derive the fields, the first thing is to specify the current distribution which is of the form:

$$I_e(x', y', z') = I_0; -\ell / 2 \le z \le \ell / 2$$

Then, the vector potential ***A*** is determined using the following formula:

$$A(x, y, z) = \frac{\mu}{4\pi} \int_c \frac{I_e(x', y', z') \exp(-jkr)}{r} dl$$

This gives the value of the vector potential as:

$$A(x, y, z) = \frac{\mu I_0 l \exp(-jkr)}{4\pi r} \hat{z}$$

Then, the magnetic field vector ***H*** is determined using the formula:

$$H = \frac{\nabla \times A}{\mu}$$

This gives the H- field as:

$$H = \frac{jkl \sin\theta \left[1 + 1/jkr\right] \exp(-jkr)}{4\pi r} \hat{\phi}$$

Finally, from this H-field E-field are calculated as follows:

$$E = \frac{\nabla \times H}{j\omega\varepsilon}$$

That gives the E- field values as:

$$E_r = \frac{\eta I_0 l \cos\theta [1 + 1/jkr] \exp(-jkr)}{2\pi r^2}$$

$$E_\theta = \frac{j\eta k I_0 l \sin\theta [1 + 1/jkr - 1/(kr)^2] \exp(-jkr)}{4\pi r}$$

Breaking the E-field in the Cartesian Co-ordinate, we get the following results:

$$E_x = \frac{\eta I_0 \ell x \cos\theta [3/r^3 + j(3/kr^4 - k/r^2)] \exp(-jkr)}{4\pi}$$

$$E_y = \frac{\eta I_0 \ell y \cos\theta [3/r^3 + j(3/kr^4 - k/r^2)] \exp(-jkr)}{4\pi}$$

$$E_z = \frac{\eta I_0 \ell [(2\cos^2\theta - \sin^2\theta) 1/r^2 - j(2\cos^2\theta - \sin^2\theta)/kr^3 - jk\sin^2\theta/r] \exp(-jkr) 1.316 \times 10^{-14} \left|I_D\right| f^2 \ell s \times \cos\theta}{4\pi}$$

The far-field model can be given as [6]:
For Differential mode excitation-

$$E_x = \frac{1.316 \times 10^{-14} \left|I_D\right| f^2 \ell s \times \sin\theta \cos\varphi}{r}$$

$$E_y = \frac{1.316 \times 10^{-14} \left|I_D\right| f^2 \ell s \times \sin\theta \sin\varphi}{r}$$

$$E_z = \frac{1.316 \times 10^{-14} \left|I_D\right| f^2 \ell s \times \cos\theta}{r}$$

For Common mode excitation-

$$E_x = \frac{1.257 \times 10^{-7} \left|I_c\right| f \ell \sin\theta \cos\phi}{r}$$

$$E_y = \frac{1.257 \times 10^{-7} \left|I_c\right| f \ell \sin\theta \sin\phi}{r}$$

$$E_z = \frac{1.257 \times 10^{-7} \left|I_c\right| f \ell \cos\theta}{r}$$

3 RESULTS

The above derived model is compared with the data given in NTIA's phase I study [5]. To obtain simulation result the used paparameter values are given below :

2a=0.01 m,
Length (l) = 100m, 200m and 340m
f = 2, 10, 40 MHz
Separation between the power lines(s) = 0.6m
Voltage Source = 1V

Table 1: Electric field (E_y) in the plane y=6.5

Impedance (Source & load)	Freq	Length	Dist (z)	Field (Calculated)	DM field (Extrapolated)	CM field	NTIA data
150 575	2	100	25.50	73.77	32.25	70.26	83-85
575 50	2	100	27.00	67.47	26.62	64.63	83-85
150 50	2	100	36.00	61.22	23.45	61.46	86
575 575	2	100	30.00	65.21	25.56	63.58	81
150 575	10	100	9.90	92.91	74.08	98.12	75-79
575 50	10	100	11.40	86.54	67.83	91.87	74-77
150 50	10	100	9.90	90.14	71.32	95.35	74-79
575 575	10	100	10.80	87.74	68.98	93.02	71-75
150 50	40	100	2.10	101.86	105.72	117.72	69-76
575 50	40	100	2.10	99.94	103.80	115.80	69-73
575 575	40	100	1.80	98.85	103.93	115.92	70-75
150 575	40	100	2.10	103.86	107.72	119.72	72-77
150 50	2	200	36.00	67.41	29.63	67.65	84-86
575 50	2	200	28.50	72.09	31.86	69.88	82-85
575 575	2	200	30.00	71.24	31.58	69.60	79-81
150 575	2	200	30.00	75.25	35.60	73.61	85
150 50	10	200	9.90	95.35	76.53	100.57	75-80
575 50	10	200	9.60	94.20	75.35	99.39	75-78
150 575	10	200	9.60	99.32	80.47	104.51	74-79
575 575	10	200	10.50	94.14	75.36	99.40	71-75
150 50	40	200	2.10	104.57	108.43	120.42	71-74
575 575	40	200	1.80	104.87	109.95	121.95	68-74
575 50	40	200	1.80	102.29	107.36	119.36	72-74
150 575	40	200	2.10	109.88	113.74	125.74	71-76
150 50	2	340	24.00	71.35	29.09	67.11	80-83
575 575	2	340	28.50	77.27	37.04	75.06	76-79
150 575	2	340	25.50	84.41	42.88	80.90	82
575 50	2	340	21.00	74.52	30.61	68.62	81
575 575	10	340	6.30	104.26	85.36	109.40	68-74
575 50	10	340	6.00	104.57	85.71	109.75	73-77
150 50	10	340	15.00	95.43	76.95	100.99	76-79
150 575	10	340	6.30	108.28	89.38	113.41	72-78
150 575	40	340	3.90	117.07	116.54	128.53	71-77
575 575	40	340	4.80	113.16	111.42	123.41	67-73
575 50	40	340	4.50	114.66	113.27	125.27	70-76
150 50	40	340	15.90	107.89	102.53	114.53	73

Table 3: Electric field values (E_x) in the plane y=6.5 m

Impedance (Source & load)	Freq	Length	Dist (x)	Dist (z)	Field-value (Calculated)	DM-field (Extrapolated)	CM value	NTIA data
150 575	2	100	6.30	27.00	70.92	30.60	68.62	64-69
575 50	2	100	6.00	30.00	63.13	23.86	61.87	69
150 50	2	100	6.00	30.00	64.74	25.47	63.49	70
575 575	2	100	7.50	27.00	68.03	27.93	65.95	58-65
150 575	2	200	7.50	27.00	78.07	37.97	75.99	64-69
575 50	2	200	5.10	36.00	63.29	25.69	63.71	69
150 50	2	200	6.00	33.00	68.45	30.12	68.14	70
575 575	2	200	7.50	28.50	72.68	33.12	71.14	58-65
150 575	2	340	6.60	24.00	84.91	43.41	81.43	61-66
575 50	2	340	6.60	27.00	66.47	26.20	64.22	60-65
150 50	2	340	0.00	15.00	-Inf	-287.89	-249.87	60-67
575 575	2	340	6.00	25.50	78.71	37.73	75.75	57-63
150 575	10	100	5.40	9.60	88.68	71.13	95.17	63-67
575 50	10	100	6.90	9.60	84.74	67.87	91.91	58-65
150 50	10	100	7.50	9.60	86.47	69.89	93.93	60-67
575 575	10	100	6.90	15.00	81.13	63.56	87.60	57-63
150 575	10	200	6.30	9.30	95.32	78.24	102.27	61-67
575 50	10	200	7.50	5.10	91.15	77.26	101.30	60-65
150 50	10	200	7.50	9.60	91.69	75.10	99.14	62-67
575 575	10	200	7.80	9.30	91.39	75.05	99.09	57-63
150 575	10	340	6.30	6.30	101.56	85.67	109.71	60-65
575 50	10	340	6.60	6.30	97.41	81.74	105.78	60-63
150 50	10	340	7.50	15.00	93.96	76.53	100.57	62-65
575 575	10	340	6.90	6.60	97.29	81.65	105.69	52-61
150 575	40	100	11.40	9.60	99.00	97.53	109.53	65-73
575 50	40	100	9.00	6.00	95.60	95.96	107.96	69-71
150 50	40	100	7.50	6.00	98.16	97.77	109.76	71-73
575 575	40	100	10.50	5.70	94.43	95.91	107.90	63-69
150 575	40	200	9.00	9.90	105.57	103.05	115.05	66-73
575 50	40	200	10.20	6.00	98.25	99.22	111.22	62-72
150 50	40	200	9.90	5.40	99.32	100.88	112.88	68-73
575 575	40	200	9.00	5.70	101.37	102.08	114.08	69
150 575	40	340	6.90	3.00	108.10	112.34	124.34	69-72
575 50	40	340	9.00	3.00	104.03	109.59	121.59	64-70
150 50	40	340	9.00	6.90	110.63	110.10	122.10	64
575 575	40	340	6.90	3.00	104.09	108.33	120.33	64-66

Table 2: E_z values in the plane y=6.5 along and near the power line

Impedance (Source & load)	Freq	Length	Field-value (Calculated)	NTIA data
150 575	2	100	110.82	67
575 50	2	100	106.13	67
150 50	2	100	107.75	68
575 575	2	100	106.81	63
150 575	2	200	116.85	67
575 50	2	200	112.27	67
150 50	2	200	113.93	68
575 575	2	200	112.84	63
150 575	2	340	121.46	68
575 50	2	340	106.06	67
150 50	2	340	106.68	69
575 575	2	340	117.45	65
150 575	10	100	101.28	75
575 50	10	100	96.81	74
150 50	10	100	98.51	76
575 575	10	100	97.26	72
150 575	10	200	107.29	76
575 50	10	200	102.18	75
150 50	10	200	103.72	77
575 575	10	200	103.28	72
150 575	10	340	111.90	74
575 50	10	340	107.84	74
150 50	10	340	109.75	75
575 575	10	340	107.89	70
150 575	40	100	114.41	81
575 50	40	100	110.49	79
150 50	40	100	112.41	82
575 575	40	100	110.40	78
150 575	40	200	120.43	81
575 50	40	200	113.83	78
150 50	40	200	115.12	82
575 575	40	200	116.42	78
150 575	40	340	125.04	81
575 50	40	340	122.50	80
150 50	40	340	125.24	76
575 575	40	340	121.03	76

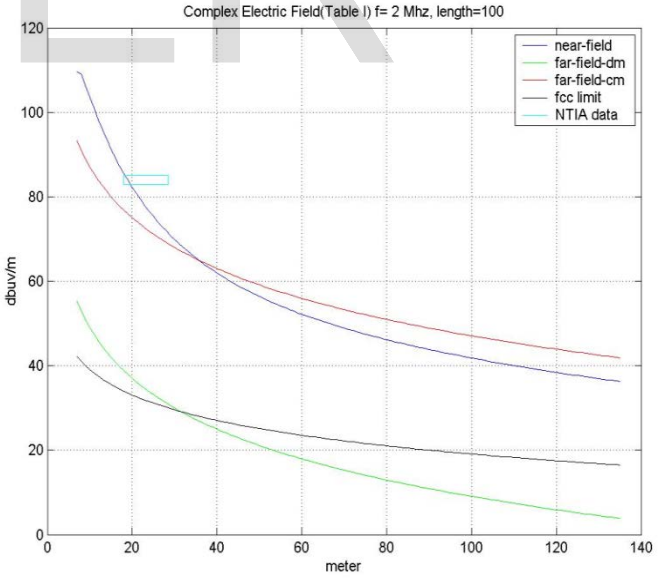

Fig 2. Different field patterns for Z_S=150 ohm & Z_l=575 ohm

4. CONCLUSION

From the simulation results shown in Fig. 2 we can say that the model is very accurate in predicting the near field values. Hence the model can be considered as a good approximation to find out the near field values. Henceforth , we have seen how BPL has become the latest incarnation of attempts to utilize power transmission and distribution infrastructure for electronic communications .Taking all the above factors it can be deduced that most of the power is radiated in the far-field and hence radio receivers placed in the near- field will not be affected much.

Since, along the power line electric field is maximum, where no receiver will be placed so no need to consider that field (Table 2).

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