Characterization of Broadband Power Line Channel

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***Abstract*—Recent advances in power line communication technology has created a large demand for access to network services inside premises. Power line communication has emerged as a strong candidate under such circumstances. Quality of service in power line communication relies heavily on characterization of the medium. This paper analyzes the channel characteristics of power line. A transmission line model for high-frequency Power line channel is used to study the transfer characteristics of multi-branch power line.**

***Keywords*– Channel characteristics, Power line channel, Transmission line model**

I. Introduction

Since 1980s, the communication over power lines is being investigated. Since then the Power line communication (PLC) has been used for low data rate up to few kilobits per second. PLC is cost effective due to the existence of infrastructure [11]. There is no need of installing a communication channel. So the efforts are being put to establish a communication system over power lines.

The channel conditions for PLC are adverse so transforming it to a high data rate medium is a challenge. Time and frequency dependent attenuation, coloured background noise, periodic and aperiodic impulsive noise and high signal reflection due to the branching severely hamper the use of power lines for high data rates. However, recent developments in PLC enable broadband transmission over power lines [5].

To analyze PLC, two types of models can be used. First model is based on ABCD parameters of the transmission line. It considers source and load impedance along with characteristic impedance of the line. Second model is based on physical and electrical properties of transmission line such as length of cable, type of cable and channel topology. This model is more suited for testing the effects of physical parameters on Power line channel [6-7]. Multipath effects of signal are considered in this type of channel modeling.

In this paper, a PLC model based on physical and topological channel properties is used. A single tap topology is considered in the initial sections of this paper. Topologies with multiple branches/taps are then analyzed based on the results obtained. The simulations are carried out in MATLAB environment.

The paper is organized as follows. In Section II, a PLC channel model is discussed. Multipath signal propagation is described for a single tap topology. In section III, effects of physical topology on Power line channels are investigated. In section IV, a PLC channel topology with multiple branches is analyzed. Section V outlines the conclusions.

II. Multipath Effects in PLC channels

A. PLC Channel Transfer Function

While modelling a PLC channel, two parameters are primarily considered namely attenuation of signal during the propagation and the delay that signal undergoes. A weighing factor which considers transmission and reflection effects of transmission line is also taken into account in PLC channel transfer function H (f) [1-2]. Equation (1) represents a channel model for power line.

$$H(f) = \sum_{i=1}^{N} g_i.e^{-(\alpha_0+\alpha_1 f^k).d_i}.e^{-j2\pi f.(d_i/v_p)} \tag{1}$$

Where

g_i is weighing factor

$e^{-(\alpha_0+\alpha_1 f^k).d_i}$ accounts for attenuation

$e^{-j2\pi f.(d_i/v_p)}$ accounts for delay

N is number of dominant paths and α_0, α_1, k are cable parameters. These parameters mainly depend upon the type of material used in cable and it's geometry [8].

B. PLC Channel Topology

In order to understand the multipath propagation in PLC, a T network is considered [3]. In Fig. 1, A is transmitter and D is receiver. The channel has a branch at point B. The tap/branch terminates at point C. l_1, l_2, l_3 are cable lengths and Z_1, Z_2, Z_3 are characteristic impedance of the line. γ_{BA}, γ_{BC}, γ_{CB} are reflection coefficients and T_{AB}, T_{CB} are transmission coefficients.

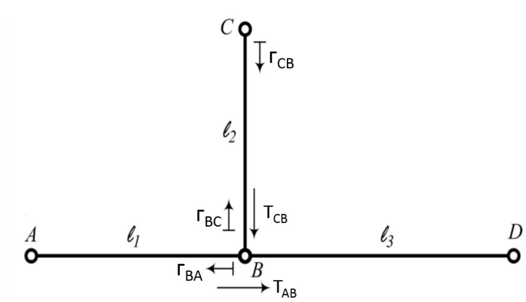


Fig. 1. Single tap PLC Topology

C. Multipath Signal Propagation

In PLC described in section (II.A), the signal propagates from A to D in two different ways. One is a direct path from A over B to D. Another path is A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D. Here the signal reflects at point C. All further waves travel from A to B and undergo multiple reflections at C before reaching D [9]. So practically there are infinite different paths from transmitter to receiver. Each path has weighing factor g_i which is a product of reflection and transmission coefficients along that path. Higher the reflections and transmissions, smaller will be the factor g_i [4],[10].

$$|g_i| \leq 1 \tag{2}$$

Also each path experiences different delay τ_i defined as:

$$\tau_i = \frac{d_i}{v_p} \tag{3}$$

where d_i is the length of the path, v_p is the phase velocity of electromagnetic wave. For analyzing the PLC channel, we consider only 'N' dominant paths.

D. Transmission over Power Line Channels

The signal, while traveling from A to D, undergoes multiple reflections. The reflection and transmission coefficients can be calculated using following formulae [7].

$$\gamma_{BA} = \frac{Z_{B23} - Z_1}{Z_{B23} \times Z_1} \tag{4}$$

$$\gamma_{BC} = \frac{Z_{B13} - Z_2}{Z_{B13} \times Z_2} \tag{5}$$

$$\gamma_{CB} = \frac{Z_C - Z_2}{Z_C \times Z_2} \tag{6}$$

$$T_{CB} = \frac{2Z_{B13}}{Z_{B13} + Z_2} \tag{7}$$

$$T_{AB} = \frac{2Z_{B23}}{Z_{B23} + Z_2} \tag{8}$$

Where

$$Z_{B13} = \frac{Z_1 Z_3}{Z_1 + Z_3} \tag{9}$$

$$Z_{B23} = \frac{Z_2 Z_3}{Z_2 + Z_3} \tag{10}$$

Following table describes possible paths and their corresponding reflection coefficient and length of propagation.

	Signal Propagating Nodes	Reflection Factor	Length of Propagation
1	A – B – D	T_{AB}	$l_1 + l_3$
2	A – B – C – B – D	$T_{AB}\ r_{CB}\ T_{CB}$	$l_1 + 2l_2 + l_3$
3	A – (B – C –)^2 B – D	$T_{AB}\ r^2_{CB}\ r_{BC}\ T_{CB}$	$l_1 + 4l_2 + l_3$
.	.	.	.
.	.	.	.
.	.	.	.
4	A – (B – C –)^N B – D	$T_{AB}\ r^{N-1}_{CB}\ r^{N-2}_{BC}\ T_{CB}$	$l_1 + 2(N-1)l_2 + l_3$

MATLAB simulation was carried out to plot the transfer function of PLC channel. Following parameters were considered for the simulation: Lengths are l_1=15m; l_2=10m; l_3=15m; Characteristics Impedance are Z_1=Z_2=Z_3=100Ω; Terminal C is left open. Then considering 4 dominant paths, we calculated following coefficients:

Path	Reflection Coefficient	Length of Propagation
1	0.6666	30
2	0.4444	50
3	-0.148	70
4	0.0494	90

Simulation Results obtained yield amplitude and phase plots for 4 and 10 dominant paths (N=4 and N=10).

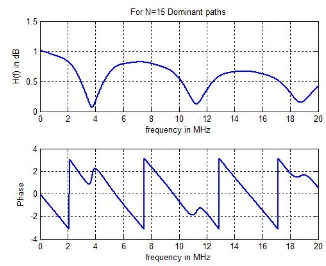


Fig. 2. For N=4

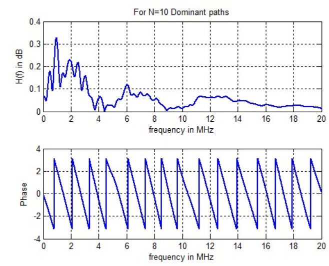


Fig. 3. For N=10

III. Effect of Physical Topology on PLC Channels

A. Length Between Transmitter and Receiver

In order to understand the effect of cable length between transmitter (A) and receiver (D), the PLC topology depicted in Fig. 1 is analyzed. In this case, the distance between transmitter and receiver is varied keeping all other parameters constant. Length between A and D is varied from 30m to 200m while l_2=10m is kept constant. Under all circumstances, branching point B is connected at the midpoint. Characteristics impedance are Z_1=Z_2=Z_3=100Ω. Terminal C is kept open.

4 cases are observed: $l_{(AtoD)}$ = 30m, 50m, 100m and 200m.

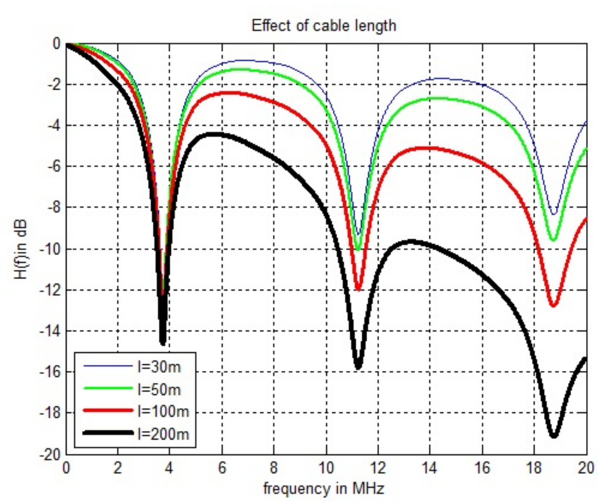


Fig. 4. Effect of cable length between Transmitter and Receiver

From Fig. 4, we can observe that as the length between A (Transmitter) and D (Receiver) increases, the attenuation gradually increases i.e. gain of transfer function H(f) reduces. With longer cable lengths, the signal is exposed to more interference and so its strength decreases over the distance. Hence the drop in transfer function gain was observed.

Also in all four cases, notches can be observed at frequencies namely 3.75MHZ, 11.26MHz and 18.8 MHz. The position of notches depends on the delays of multipath components which in turn depends on the length of branch BC and not on the cable length between transmitter and receiver. So in every case, notches appear at same frequencies.

B. Length of Branch

The second parameter is the length of branch BC. In this case, the length of branch is varied keeping all other parameters constant. Here l_1=l_3=15m are kept constant. Length of branch l_2 is varied from 5m to 20m. Characteristics Impedance are Z_1=Z_2=Z_3=100Ω. Terminal C is kept open.

4 cases are observed: l_2= 5m, 10m, 15m and 20m.

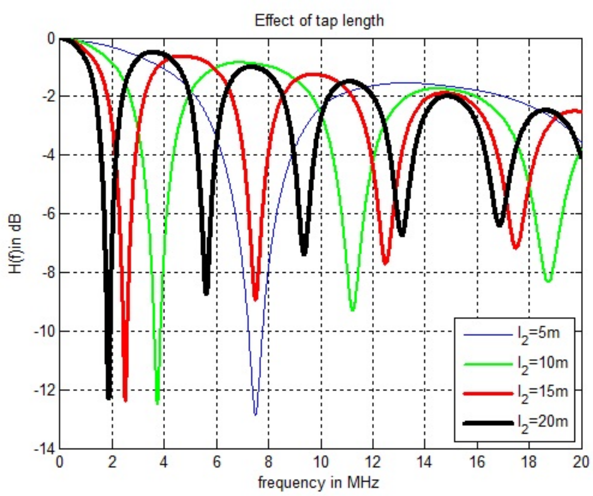


Fig. 5. Effect of branch length BC

From Fig. 5, we observed that number of notches changes with the length of branch. For l_2 = 5m, we observed only one notch while 5 notches were observed for l_2 = 20m. The delay for first received component is constant as first path is a direct path from A to D. Every other path will have to traverse branch length BC and will ultimately suffer multiple reflections at point C.

As the length of branch increases, delay and attenuation values for each received multipath component except the first path increases. Any change in delay causes change in position of notches detected in transfer function H(f). So more number of notches are observed with increasing branch length.

C. Branch Impedance

The transfer function of PLC channel also depends upon the impedance with which the branch is terminated. So branch impedance is varied and other parameters are kept constant. Let Z_0 be characteristic impedance and Z_b be the terminating impedance of the branch.

There are three possible cases:

1) Z_b is less than Z_0
2) Z_b is greater than Z_0
3) Z_b = Z_0, perfectly matched condition

In all three cases, we considered Z_0 = 100Ω. Lengths of cable l_1=l_3=15m are kept constant. Length of tap l_2=10m is also kept constant. Terminal C is terminated by Z_b.

Case (1) : Z_b is less than Z_0

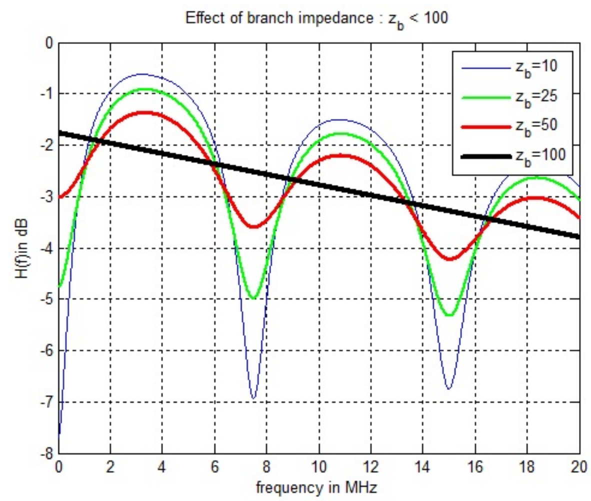


Fig. 6. Effect of Branch Impedance when Z_b is less than 100Ω

From Fig. 6, we observed that depth of notches is changing. Since reflection coefficient γ_{CB} decreases as the branch impedance increases towards Z_0, reflected multipath components attenuate more. Thus, weak multipath components will be received. This leads to a decrement in the depth of the notches in transfer functions.

Case (2) : Z_b is greater than Z_0

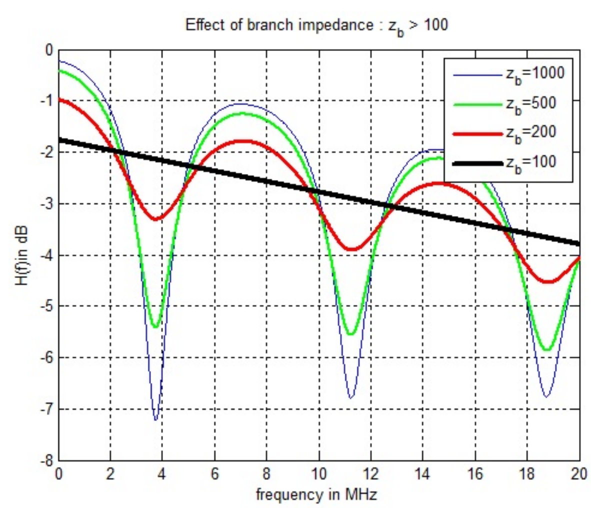
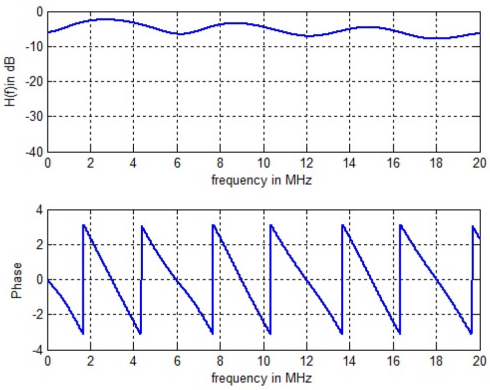
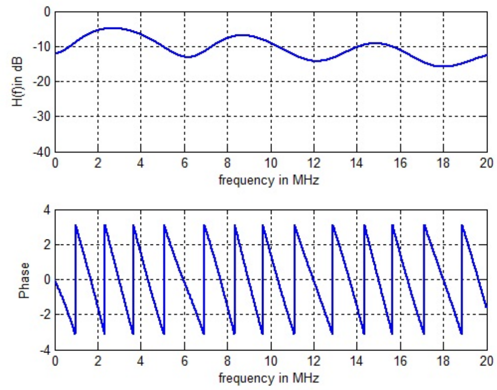


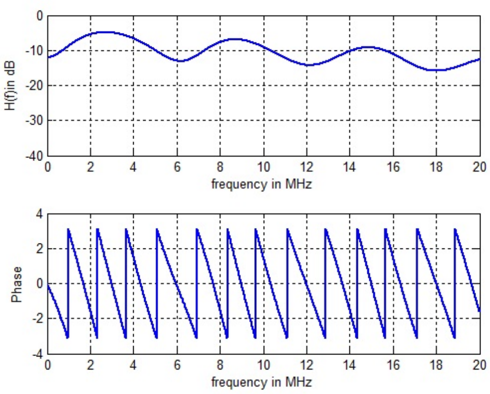
Fig. 7. Effect of Branch Impedance when Z_b is greater than 100Ω



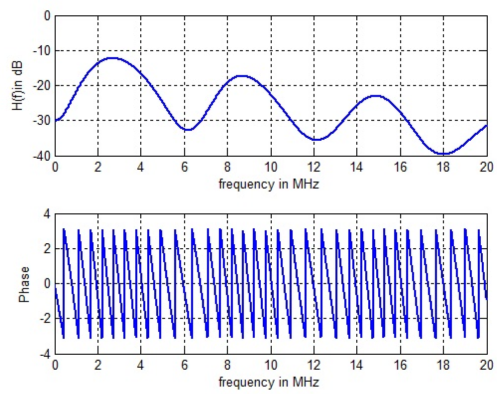
(a) 2 Branches



(b) 4 Branches



(c) 6 Branches



(d) 10 Branches

Fig. 8. PLC Mutli-Branch Transfer function

Form Fig. 7, we can observe change in depth of notches. Since reflection coefficient γ_{CB} increases as the branch impedance tends to be greater values than Z_0, reflected multipath components attenuate less. Thus, stronger multipath components are received. This leads to an increment in the depth of the notches in transfer functions.

Case (3) : Z_b is equal to Z_0

In both cases (1) and (2), we observed that at $Z_b = Z_0 = 100\Omega$, we get $\gamma_{CB} = 0$. So it is a perfectly matched condition and no reflection will occur at branch impedance. Also the number of notches remains unchanged in all the cases since it depends on branch length BC.

IV. PLC Topology with multiple branches

A. PLC topology with Equidistant Branches

The discussion so far was only meant for a PLC topology with single branch. Based on this discussion, a PLC channel transfer function can be obtained for topologies with multiple branches [7].

We considered a topology with two branches as shown in Fig. 9. Here Characteristic impedance of cable Z_0 = 100Ω. Length of cable $l_1 = l_2$ = 15m. Length of each branch/tap l_3 = 10m. Branch load impedance Z_b = 50Ω.

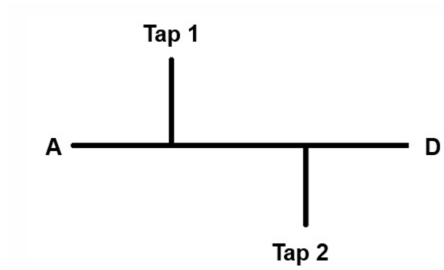


Fig. 9. A PLC topology with two branches

Here we assume that all the taps are equidistant and they are terminated by same impedance value. The same logic can be extended for number of branches more than 2.

Fig. 8 shows the simulation results for number of branches n = 2, 4, 6 and 10. From Fig. 8, it can be concluded that as number of branches increase, the signal undergoes more reflection and thus the weighing factor g_i reduces. Hence the gain of transfer function reduces.

We can observe that in all 4 cases, number of notches remains constant. It is because in all cases, length of branch is constant. Only the depth of notches varies.

B. PLC topology with Non-Equidistant Branches

In section (IV.A), the PLC topologies with multiple branches are analyzed with the primary assumption that all the taps are equidistant and they are terminated by same impedance value. But this may not be the case in practice. So we considered following topology in which taps are not equidistant.

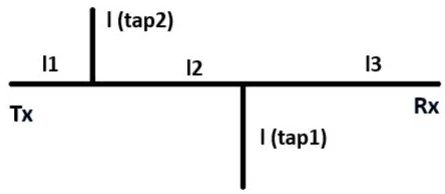


Fig. 10. A PLC topology with Non-Equidistant Branches

In the topology shown in Fig. 10:

1) Lengths of cable are l_1 = 10m, l_2 = 15m, l_3 = 20m, l_{tap1} = 10m, l_{tap2} = 15m.
2) Characteristic impedance are $Z_1 = Z_2 = Z_3 = 100\Omega$, $Z_{tap1} = Z_{tap2} = 50\Omega$.
3) Taps are terminated by $Z_b1 = Z_b2 = 30\Omega$.

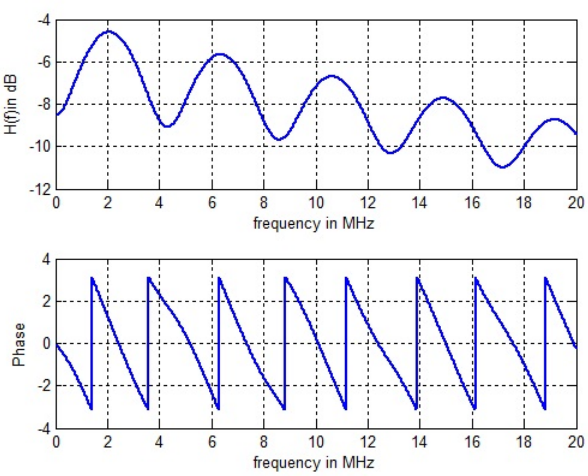


Fig. 11. A PLC Transfer Function with Non-Equidistant Branches

In this case, the branch lengths and the characteristic impedance of the branch are different. Both the branches are terminated by impedance less than characteristic impedance. We can observe from Fig. 11 that the transfer function exhibits more notches than the previous case.

V. CONCLUSION

In this paper, we have modeled a PLC and analyzed the channel under various topological conditions. We observed the transfer function of PLC channel in a simulation environment. Many observations were noted regarding attenuation profile, position and depth of notches. Based on these inferences, it can be concluded that the transfer function of PLC shows more attenuation when length between transmitter and receiver is increased. It shows change in number of notches with change in length of tap. While change in depth of notches can also be observed when the impedance terminating the tap/branch changes. These effects are observed in PLC topology with multiple branches. These results provide basis of channel modeling for broadband PLC.

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