Analysis of the Channel Capacity, for different Line Length and Tap Bridges of Indoor Power Line Network for Broadband Communication

[1]K. Mondal, [2]D. Banerjee and [3]P. K. Ray
[1]Department of Electronics and Communication Engineering,Modern Institute of Engineering and Technology,Bandel-712123.
[2]Department of Electronics and Communication Engineering,Modern Institute of Engineering and Technology,Bandel-712123.
[3]Department of Electronics and Communication Engineering, Heritage Institute of Technology, Kolkata-700107
India

ABSTRACT

In this paper, a multi- branch Power Line Communication channel is modeled using ABCD matrix of two port network which leads to the formation of a transfer matrix, the element of which are used to find the transfer function of the multi-branch transmission line network consisting of taps up to ten number. From the calculation of the transfer function we observed the nature of variation of signal attenuation channel capacity for combination of different transmission line parameters such as, source, branch impedance, channel length, number of taps and load impedance respectively. Investigation on simulated result was carried out using MATLAB under different conditions in the frequency bands 1 Hz to 40 MHz typical Broad Band for Power Line Communications.

Keywords

Power Line, Transfer Function, Power Line Communication Network, Channel Capacity.

1. INTRODUCTION

In the last few years, a revival of the interest in residential power line communications (RPLC), i.e., digital communication from the customer's premises to the distribution transformer and back over the 220 V power grids can be noticed. Especially in Europe, with the fall of the telecom monopoly for the national PTT's on January 1, 1998, the question whether or not it is possible to use the residential power circuit (RPC) as the basis of a second fixed-line telephone network gained a lot of attention. However, due to a lack of data on the characteristics of this transmission channel, clear statements could not be made. In a research paper [1], the authors theoretically Transfer function have calculated using ABCD parameters of Two-port networks for actual cables and the results were correlated with the theoretical assumptions underlying power line channels. In [2] the model takes into consideration the type of cable used and the cable mounting method. The LV power network is then regarded as a branch network, which is sub divided into several cascades of smaller networks. The channel transfer function is later determined by combining the scattering matrices of the cascaded sub networks. Both the model parameters and the transfer characteristics have been verified successfully through practical measurements on actual power line. In this paper, a multi-branch power line communication channel is modeled using ABCD matrix of Two-Port network which is then simulated using MATLAB. The effects of multiple loads, multipath, channel capacity and mismatching are also investigated in this work. The channel transfer function is obtained and investigated using a given number of cable lengths, and with known number of bridge taps and given loading conditions.

2. POWERLINE MODEL

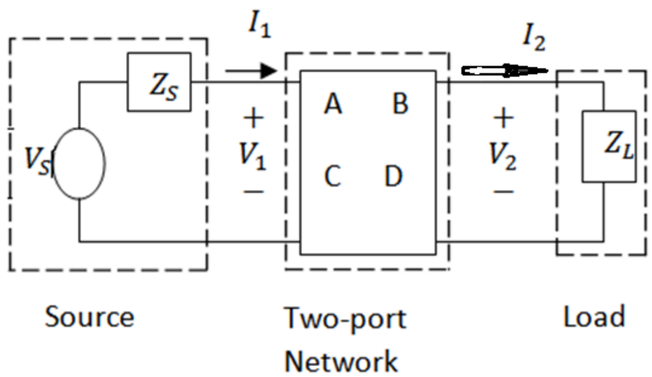

Fig 1: Power line model

The ABCD representation of a two-port circuit is very convenient for the calculation of transmission line transfer function. Transfer Function: The transfer function is the ratio of the output to the input of the channel. The output is the voltage V_L across the load while the input is supply voltage

$$H = \frac{V_L}{V_S} \quad (1)$$

$$H = \frac{Z_L}{AZ_L + B + CZ_LZ_S + DZ_S} \quad (2)$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \quad (3)$$

$$Z_c = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}} \quad (4)$$

where R, L, G and C are resistance, Inductance, Conductance and Capacitance per unit length of transmission line.

3. POWER LINE MODEL WITH BRIDGE TAPS

However, power line communication systems do not usually consist of simply a source, transmission line and a load as depicted in Figure 1. Bridge taps with different cable lengths and cable types usually exist along the transmission line to form a power line network made of sections. The ABCD matrix is determined by utilizing the chain rule which involves multiplying the ABCD matrices for the different sections of the network to produce the overall ABCD matrix. where Z_c, l_{br}, Z_b, , l_1 T_i and γ_{br} are the characteristic impedance, bridge tap length, branch impedance, cable length, segments of transfer function and the propagation constant of the branch circuit respectively. Consider the transmission line with one bridge tap connection and its equivalent circuit as shown in Figure. 2 and Figure.3.

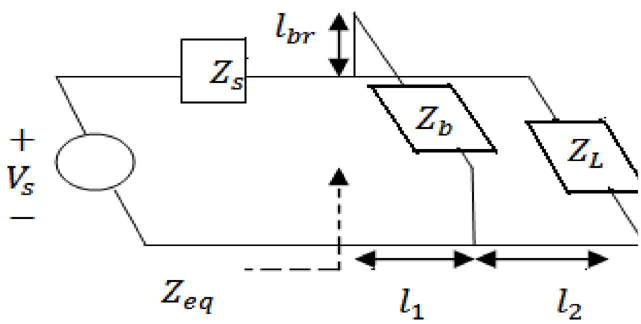

Fig 2: Transmission Line with Bridge Tap Connection.

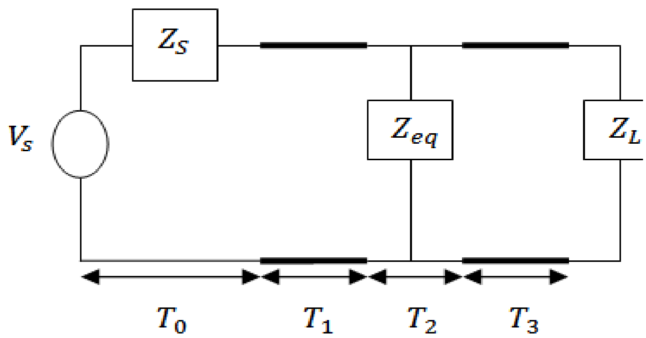

Fig 3: Equivalent Network Circuit for Bridge Tap Connection.

3.1 Overall transfer matrix for one bridge tap

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \prod_{i=0}^{3} T_i = T_0 T_1 T_2 T_3$$

(5)

3.2 Overall transfer matrix for n number taps

$$\begin{bmatrix} \mathrm{A} & \mathrm{B} \\ \mathrm{C} & \mathrm{D} \end{bmatrix} = \prod_{\mathrm{i}=0}^{2\mathrm{n}+1} \mathrm{T_i}$$

(6)

4. ANALYSIS AND RESULTS

Computational results are obtained by modeling power line communication channels using different cable lengths, different number of bridge taps and different loading conditions. All cables used in the model are considered to have R L G C parameters, R = 1.9884 Ω/m,G =0.01686 nS/m, C= 0.13394 nF/m, L = 362.81 nH/m. The channel models are realized by using MATLAB scripts to code the channel parameters and equations. The transfer function plots for the different configurations are shown in the frequency bands between 0 Hz and 35 MHz.

4.1 Power Line Model with Different Branch Impedance at Fixed Cable Length, Load and Source Impedance

From Figure 4, when source impedance and cable length are kept constant at Zs=30 Ω and 40 m respectively and only branch impedance Z_{br} is changed from 10 Ω to 30 Ω the transfer function value gradually increases, coupled with gradual decrease of attenuation.

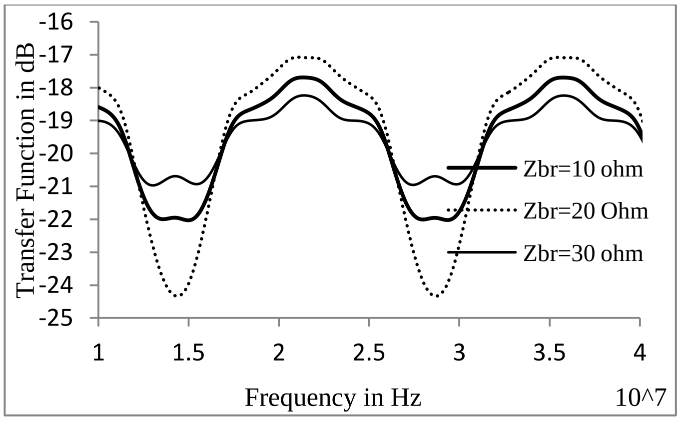

Fig 4: Transfer function plot with frequency at Z_S=30 Ω , Z_L=30 Ω , l_1=20m ; l_2= 20m; and L_{br1}=5m.

4.2 Power Line Model with Different branch Lengths at Fixed Source and Load Impedance

From Figure 5, the change in branch length shows the effect that for increase of branch length from 5m to 30m via 10 m at the fixed value of source impedance Z_s=30 Ω and load impedance Z_L=30 Ω transfer function values decrease as frequency increases, and that attenuation steadily increases.

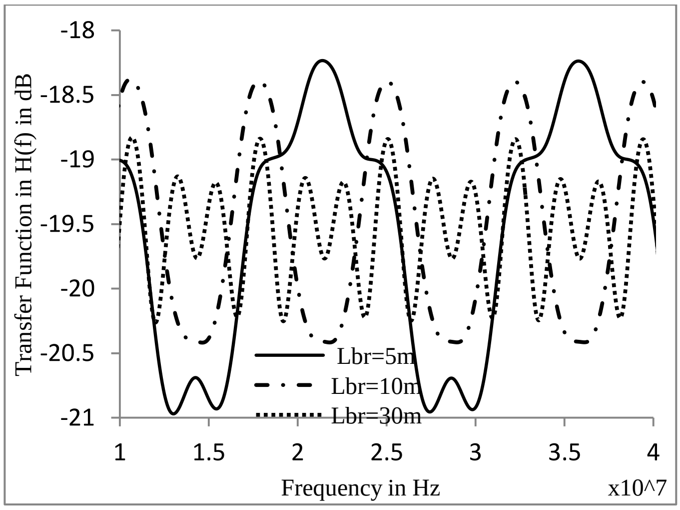

Fig 5: Transfer function plot with frequency at Z_S=30 Ω , Z_L=30Ω, l_1=20m ; and l_2= 20m.

4.3 Power Line Model with Different Bridge Tap Conditions

In Figure 6, one common feature in each case is that transfer function is oscillating in nature which consequently will give rise to the phenomenon of fading. The input and output impedance , bridge tap length and bridge tap load for all models are kept constant at Z_S=50 Ω, Z_L=60 Ω, and l_{br}= 5 m, and Z_b= 500 Ω respectively while the direct cable length and number of bridge taps are varied. The transfer function values decrease gradually with the increase of bridge tap number. It is also true that bridge taps are acting as the source of interference due to reflection and the longer is bridge tap length the stronger will be the effect of the interference. So the longer length and larger number of bridge tap will be prone to signal degradation on the communication line.

4.4 Power Line Model of a Branch Load at Short Circuit, Open Circuit and Match Condition

From Figure 7, the change in branch load from open circuit to matched via short circuit shows the effect that for change of branch impedance from open circuit to short circuit, the transfer function value decrease rapidly as well as the notch position shifted with the increased of frequency in with the same manner and for short circuit the transfer function values are remaining constant with the increase of frequency and that attenuation steadily decrease.

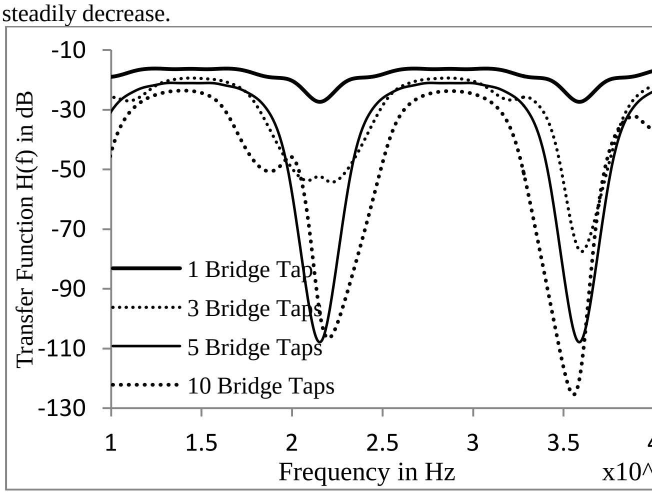

Fig 6: Transfer function plot with frequency at Z_S=50 Ω, Z_L=60 Ω, and l_{br}= 5 m, with Z_b= 500 Ω.

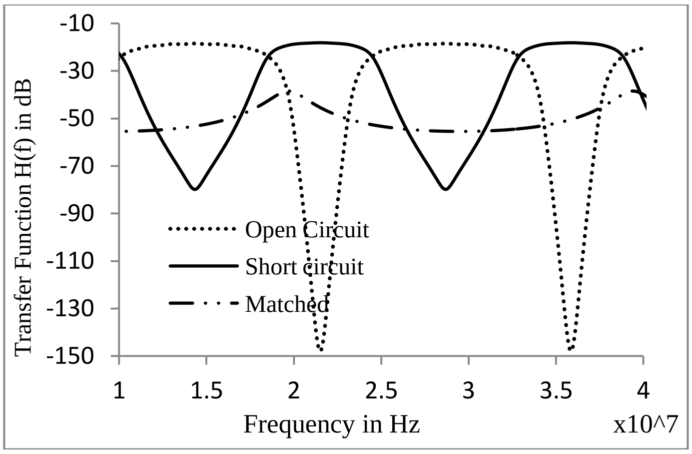

Fig7: Transfer function plot with frequency at Z_S=50 Ω, Z_L=60 Ω, and l_{br}= 5 m, with Z_b= 10^10 Ω, 0 Ω and Z_0 Ω.

5. CHANNEL CAPACITY

The noise in PLC systems can be classified into three types, namely i). Colored background noise, ii). narrowband noise, and iii). impulse noise. Colored noise is the sum total of various noises from sources with low power. Narrowband noise has amplitude modulated signals caused by induction from radio station signals in medium and shortwave bands. The power spectral density (PSD) for background noise is usually around -145 dBm/Hz and this is about 30 dB above the thermal noise floor [8]. The impulsive noise has maximum amplitude of 40 dBm/Hz higher than background and/or narrowband noise. A typical background noise frequency response in the power line network can be represented as shown in Fig. 8. Next, let us use the channel models and noise in the power line to determine the channel capacities in different power-line channels for various cases of branched and terminal load conditions.

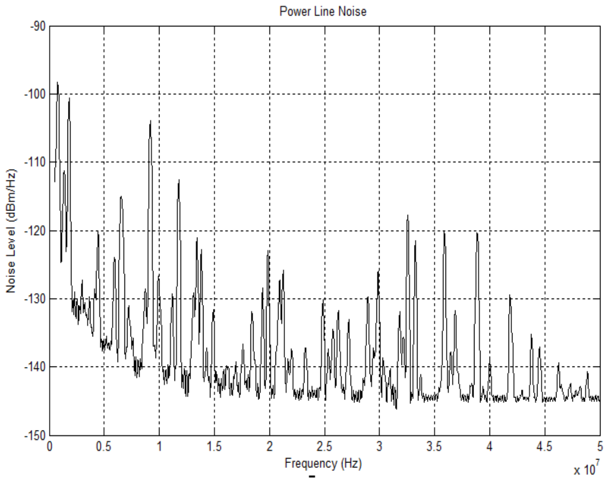

Fig 8: Noise in the power line network.

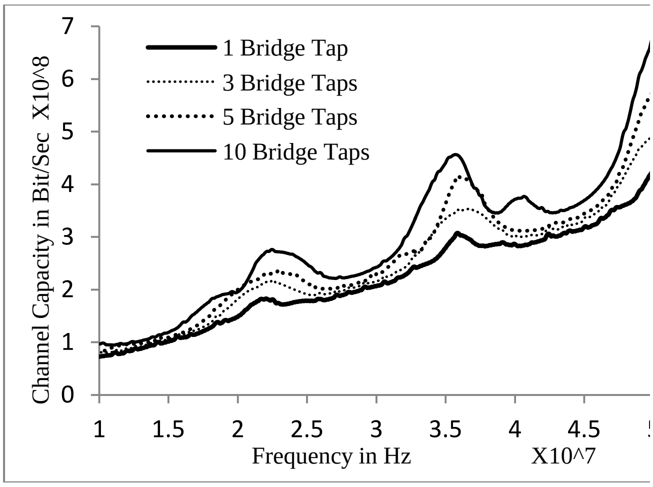

Fig.9: Channel capacity for different number of branches at fixed directs length, load impedance, source impedance and branch load respectively.

The channel capacity was determined using (7), with a frequency variation between 1–50 MHz. S(f) is the received signal power and N(f) is the noise power, which is dependent on the transmitted signal power and channel transfer function as given in (8). The noise power level N(f) for different frequencies is considered based on Fig. 8. Due to the limitations on the transmitted power, the field strength is limited to 30 dB µV/m. Thus, the allowed PSD can be estimated according to (9) and is found to be between -72 dBm/Hz and -52 dBm/Hz [8], corresponding to a coupling factor in the range of -65 dB and -45 dB for a distance of about 30 m, [8]. For this study, we chose the range of PSD to be between -90 dBm/Hz to -30 dBm/Hz

$$C = \int_{f_1}^{f_2} \log_2 [1 + \frac{S(f)}{N(f)}] df \quad (7)$$

$$S(f) = PSD|H(f)|^2 \quad (8)$$

$$PSD = (-CF - 117)(dBm/Hz) \quad (9)$$

Fig.9 shows the variation of channel capacity in megabits per second against PSD in dBm/Hz for various branch numbers and different load terminations. It is seen that channel capacity increase with the frequency in same manner with the increase of number of branched but more oscillating in nature between the sending and receiving ends.

6. CONCLUSION

In this paper modeling of indoor power line network incorporating multiple bridge taps along the length of transmission line was accomplished using the ABCD matrix approach of two port networks. It is further observed that the attenuation of the power line increases as the bridge tap length and the number of taps increase. As the branched line length increases, the number of notches increases. The signal distortions also increase. As the number of distributed branches in the link between the sending and receiving ends increase, the attenuations tends to increase in such a manner that there could be a reduction in the available bandwidth. The reason could be due to the successive reflection from the distributed branches. The channel capacity is more oscillating in nature with the increase in number of branch taps while keeping other different line parameters constant. On basis of results obtained through investigation of multi branch power line broadband power line communication channel can be designed optimally.

7. REFERENCES

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