Electromagnetic Modeling of Powerline Channel using Multiconductor Transmission Line

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Abstract

The paper introduces a novel method for modeling Powerline channels. The methodology is based on the use of three conductor transmission line. The mutual component of the three conductor line is varied to embrace the effects of multipath and impedance mismatches, without having any prior knowledge about them. In this way, the measured frequency response of the channel is finally reached. The method results in a versatile model that can be used for various studies like Electromagnetic Compatibility, Performance analysis and so on. The paper also suggests various ways of improving the precision of the prescribed method.

1. Introduction

The electric power supply system has become one of the important medium for connectivity. It is very much attractive for Internet access and home networking [1, 2]. The major reason behind such an attraction lies in the fact that they are already installed and can be directly deployed for these applications in a cost effective manner.

The systems involved in power line communication encounters hostile channel properties. The multipaths and impedance mismatches are the main reasons behind such channel behavior. Due to the enormous multipaths and impedance mismatches, the task of modeling is plagued and still remains a challenging one. There have been efforts in the past to counteract the challenges. There have been both bottom-up and top-down strategies reported in the past. The bottom-up approaches clings to the bases of defining the network in terms of a large number of distributed components. There have been methods based on scattering matrix [3] and four-pole impedance and admittance values [4-6], derived from the components property. The above models are defined only for frequency ranges below 150 kHz. Hence the analysis of electromagnetic compatibility can't be carried out using such models. On the other hand, a model based on the top-down approach has been reported in [7]. Even though the relevant parameters are not derived from the component properties, it does require an idea about the overall network topology. Moreover the above model is validated only up to a frequency of 20 MHz.

In this paper, a novel method of modeling is proposed. It is based on the top-down approach. It uses the measured frequency response of the channel, along with the length, attenuation constant and characteristic impedance of the main distribution line. It requires no knowledge about neither the network topology nor the multipaths and impedance mismatches involved.

The paper is presented in the following manner. Section II discusses about the Multiconductor transmission line, which forms the basis for the proposed model. While Section III brings forth the proposed method of modeling, Section IV provides a validation of the model by simulation. Section V suggests about the ways of improving the precision of modeling. The paper completes with a conclusion on Section VI.

2. Multiconductor Transmission Line

2.1 Two Conductor Transmission Line

Two conductor transmission lines is one of the basic medium of transmission. They share many of the basic properties with that of Multicondutor counterparts. The two conductor transmission line is modeled using distributed parameters as shown below in Figure 1. One can readily find out these distributed parameters from the characteristic impedance and attenuation constant of the line, using the relationships in [8]. Generally the value of conductance (g) per unit length is assumed to be zero in the frequency of interest.

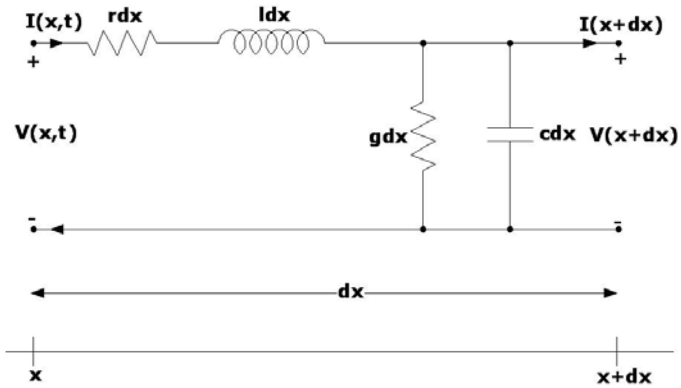

Figure 1. The constants for an incremental length of a typical two conductor transmission line are depicted.

2.2 Three Conductor Transmission line

The basic version of Multiconductor transmission line is a three conductor transmission line. A typical three conductor transmission line modeled using distributed parameters is shown in the Figure 2. The three conductor line is similar to that of a two conductor line except the fact that crosstalk exists in Multiconductor lines. The effect of crosstalk is included by the mutual components (l_m, C_m, g_m). The above model can be readily modified to study the radiated emissions and susceptibility of the line. Computational technique such as Finite Difference in Time Domain can be used effectively to study the noise component induced due to the susceptibility of the line.

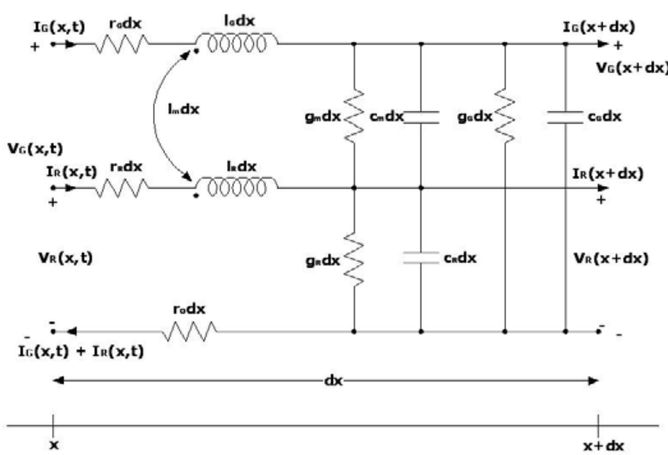

Figure 2. The constants for an incremental length of a typical three conductor of a transmission line are depicted.

2.3 Proposed Modeling Method

In the proposed method, the powerline channel is finally modeled as a three conductor transmission line using the measured frequency response. The procedure begins with identifying the main distribution line of the network. Then using the characteristic impedance and attenuation factor of the main line, corresponding distributed parameters are calculated at some frequency higher than that of our interest. These values are then substituted for the line parameters of the three conductor transmission line model. Here it is assumed that the model is immersed in a homogenous medium and the parameters of the medium are fixed to particular predefined values. The three conductor transmission line model is assumed to be of same length as that of the main distribution line of the network. This fact helps in the analysis of electromagnetic compatibility problems with ease. The main fact that attributes to the hostility of the powerline channel is the numerous impedance mismatches and multipaths that exist in the network topology. The proposed method includes the effects of such factors in the values of the mutual components, keeping other parameters as constant. Now using any one dimensional search algorithm, the value of the mutual inductance is varied until the frequency response of the model matches with that of the measured one. The variation in the mutual inductance automatically leads to the variation in the other mutual component values through the basic relation between them [9]. The important feature of the proposed method lies in the fact that the channel is modeled by using *very few parameters and by varying just only one of them*. Hence a simple one dimensional search algorithm can be used for the purpose.

3. Verification through Simulations

For verification of the method through simulations, frequency response of the channel from [7] is used. The aforementioned frequency response is claimed to be valid from 500 KHz up to 20 MHz. The main distribution line in that topology is identified as type NAYY 150 cable with characteristic impedance (Z) of 45 Ω with a length of 200m. Using the above values along with its attenuation profile ($\alpha = 7.8 \times 10^{-10} \times f$) and a zero conductance per unit length, as given in [7], inductance (L) per unit length is calculated using the relation shown below as in [8], at a frequency (f) of 35 MHz.

$$L = Z / V \tag{1}$$

$$C = L / Z^2 \tag{2}$$

$$r = \{((2\alpha^2 + \omega^2 LC)^2 - \omega^4 L^2 C^2) \;/\; \omega^2 C^2\}^{1/2} \tag{3}$$

In the above relations, V is the phase velocity, C is the capacitance per unit length, r is the resistance per unit length and ω is the angular frequency. The same values of per unit length parameters are used for each of the corresponding elements in the lines of the model, as in (4) and (5). These values are tabulated in Table 1.

$$r_0 = r_g = r_r = r \tag{4}$$

$$L_g = L_r = L \tag{5}$$

Table 1
Parameters for the Proposed Model

Parameters (Ref Fig. 2.)	Value
Conductivity of the medium	1×10^{-6} Siemens
relative permeability	1
relative permittivity	1
Lg	0.150 micro Henries
Lr	0.150 micro Henries
r_g	1.3491×10^{-20} ohms
r_r	1.3491×10^{-20} ohms
r_0	1.3491×10^{-20} ohms

The three conductor line model is also assumed to be of 200m in length. The basic one dimensional linear search was used and the final frequency response obtained is as shown in Figure 3. The model closely follows the frequency response from a frequency of 5.537 MHz up to the higher limit of 20 MHz. The mutual inductance per unit length for the proposed model was found to be 1.3604 micro Henries.

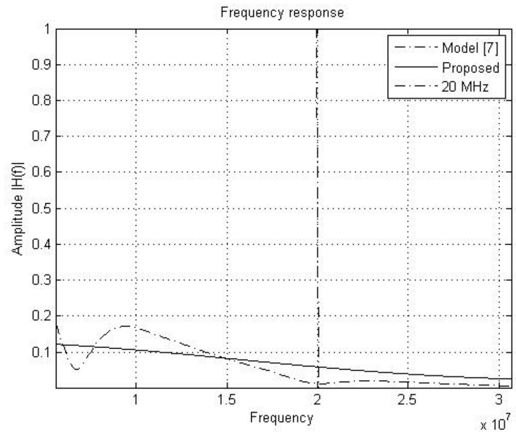

Figure 3. Comparison of the frequency responses of the proposed model from 5.537 MHz. with that of in [7].

4. Precision Enhancement

There exist a lot of variables that can be used for optimizing the model and leading to a better precision. These parameters are the values of distributed elements and medium properties of the model. One can use advanced multidimensional search algorithms [10], with the initially obtained values from the main distribution line as a starting point, to achieve a more precise model. One can even extend this idea of three conductor line model to four or more conductor line model for a higher precision.

5. Conclusion

In this paper, a novel method of modeling powerline channel was proposed. The development of the model requires only the measured frequency response of the channel along with some details about the main distribution line of the network. The versatility of the model lies in the fact that it can be readily deployed for electromagnetic compatibility as well as performance analysis. The paper also pointed out further ways of improving the precision of the model using multidimensional search algorithms.

6. References

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