ELEKTROTEHNIŠKI VESTNIK 78(4): 171–176, 2011
ENGLISH EDITION

Simple digital filter implementation of the HV PLC channel model

Asmir Gogić[1,†], Nermin Suljanović[1], Aljo Mujčić[1], Mitja Kolenc[2], Jurij F. Tasič[2] and Matej Zajc[2]

[1]*Faculty of Electrical Engineering, University of Tuzla, Franjevačka 2, 75000 Tuzla, Bosnia and Herzegovina*
[2]*Digital Signal, Image and Video Processing Laboratory, Faculty of Electrical Engineering, University of Ljubljana, Tržaška 25, 1000 Ljubljana, Slovenia*

[†] *E-mail: asmir.gogic@untz.ba*

Abstract. The paper presents a simple implementation model of the high-voltage power line communication (HV PLC) channel using digital filters. The model utilizes three identical finite impulse response (FIR) filters. The amplitude characteristic of the FIR filters matches the HV PLC channel amplitude characteristic for a given coupling, without taking into consideration reflection. The reflection phenomenon occurring at the HV power line terminals is implemented in the model by using a parallel feedback branch and additional filter delay corresponding to the traveling time of the reflected wave. The approach presented in this paper is applied to a 400 kV power line with three phase conductors in horizontal disposition. Results are given for two optimal couplings, middle phase to ground and outer phase to middle phase coupling.

Keywords: Power grid, power-line channel, channel modelling, power-line communications

1 INTRODUCTION

The recent research in the Smart Grid domain has reintroduced the interest for HV PLC [1]. The latest trends in power system operation and control incorporate comprehensive measurements over large geographic areas. This fact increases the amount of data to be transmitted and requires a communication system with an adequate bandwidth and reliability. Even though optical links incorporated in HV power lines will completely fulfill this task, these links are not always available. Utilization of power lines for the communication services is generally motivated by long distances in different countries around the globe where power lines usually present the only infrastructure. Furthermore, a redundant communication path is always required.

Analog PLC (aPLC) systems over HV power lines are usually used in transmission of voice, protection signals and low bit rate data for the power utility purposes. For the current SCADA (Supervisory Control and Data Acquisition) systems and communications with RTUs (Remote Terminal Units), aPLC system presents a satisfactory solution. Also, aPLC is commonly used in protection systems of HV power lines. Compared to the aPLC system, digital HV PLC systems (dPLC) can achieve higher bit rates by utilizing digital communication techniques. Another advantage of dPLC is compatibility with other digital equipment. Nowadays, dPLC covers transmission of voice and data. On the other hand, aPLC is still used for protection due to its reliability, robustness and low costs.

Received August 12, 2011
Accepted October 15, 2011

HV PLC communications utilize the frequency range from 30 to 500 kHz, which is divided into bands [2]. The aPLC channel bandwidth is 4 kHz. On the other hand, the dPLC channel bandwidth should be a multiple of 4kHz bands to be compatible with the analog PLC systems. Frequency planning demands an extra care to avoid interference with other channels and with local radio and navigation stations.

The digital PLC system design is grounded more on the communication characteristics of HV power lines than analog, making new requirements for accurate determination of HV power-line frequency characteristics [3]. Selection of appropriate communication techniques such as modulation, channel coding, and equalization are directly related to these characteristics.

A discrete-frequency communication model of HV power line appropriate for dPLC analysis is available [3], [4]. This paper describes digital filter implementation of the proposed model in the manner to be used in numerical simulations of communication systems. Such model is appropriate for the implementation using FPGA technology. Time and costs required for HV PLC device field testing can be reduced by usage of FPGA based channel model for laboratory tests.

There are two dominant constraints for HV power lines to be used for communication purposes: the corona noise and reflection. The corona on HV power line refers a phenomenon of ionization of air surrounding charged conductor (power-line phase conductor). In general, the HV power line as a communication channel is characterized by a relatively high noise level compared to the other communication media since noise is time-variant and weather dependent. Moreover, a power line itself is a noise source. The noise level caused by the corona strongly varies in the power-frequency period and is dominant during rainy and snowy weather. The second important property of the power-line channel is reflection since the HV power line is not terminated with a characteristic impedance. The presence of reflection introduces echoes in the impulse response and oscillations in the frequency characteristics (amplitude and phase characteristics, group delay, input impedance) of the PLC channel, and consequently introduces a smaller signal-to-noise ratio (SNR) and higher bit error rates (BER) in a digital communication system.

Digital filter implementation of the proposed HV PLC channel model provides a frequency response (amplitude and phase characteristic) that incorporates the reflection phenomenon. Noise generation is not included in this implementation. Noise implementation in the HV PLC channel is described in [5].

2 Discrete frequency model based on reflection coefficients

The wave propagation phenomenon along the power line is described by the telegrapher's equations. Time-harmonic voltage and current propagation on a transmission line is considered and time t is ommited as argument in telegrapher's equations. Since the HV power line is considered as a multiconductor line, voltage $\mathbf{V}$ and current $\mathbf{I}$ at an arbitrary point on the power line are found from the telegrapher's equations in the matrix form:

$$\frac{d^2\mathbf{V}(x)}{dx^2} - \mathbf{ZYV}(x) = -\frac{d\mathbf{E}(x)}{dx} + \mathbf{ZJ}(x) \quad (1)$$

$$\frac{d^2\mathbf{I}(x)}{dx^2} - \mathbf{YZI}(x) = -\frac{d\mathbf{J}(x)}{dx} + \mathbf{YE}(x) \quad (2)$$

Elements of matrices $\mathbf{Z}$ and $\mathbf{Y}$ form a set of primary parameters of the power line parallel to the earth plane. Those parameters are determined by geometrical design of the power line and electrical parameters of the conductors and earth [4]. Influence of the earth with finite conductivity is considered in the manner defined by Carson [6]. In the above equations, vectors $\mathbf{E}(x)$ and $\mathbf{J}(x)$ represent the voltage and current sources distributed along the line. In general, vectors $\mathbf{E}(x)$ and $\mathbf{J}(x)$ model the noise sources on the HV power line. Voltage source $\mathbf{E}(x)$ represents interference with other PLC devices and radio stations. Current sources $\mathbf{J}(x)$ on the HV power line are usually used to represent the noise appearing due to corona [5]. In a passive network, vectors $\mathbf{E}(x)$ and $\mathbf{J}(x)$ are equal zero. Eqs. (1) and (2) are written in the original (phase) coordinates. Therefore, vectors V and I correspond to the phase values in the three phase system. The solution of these equations is found through modal transformation [4], [7]

$$\mathbf{V} = \mathbf{SV_s}, \mathbf{I} = \mathbf{QI_s} \quad (3)$$

which introduces modal coordinates where the voltage and current are described by vectors $\mathbf{V_s}$ and $\mathbf{I_s}$.

Complex matrix $\mathbf{S}$ is chosen to be a matrix of eigenvectors of product $\mathbf{\Gamma}^2 = \mathbf{ZY}$ while matrix $\mathbf{Q}$ equals to $(\mathbf{S}^T)^{-1}$. $\mathbf{\Gamma}$ denotes the propagation function matrix in phase coordinates. Transformation defined by (3) decouples equations (1) and (2) into a set of ordinary non-homogeneous differential equations that can be written in a matrix form

$$\frac{d^2\mathbf{V}_s(x)}{dx^2} = \gamma^2\mathbf{V}_s(x) + \mathbf{Z}_s\mathbf{J}_s(x) - \frac{d\mathbf{E}_s(x)}{dx} \quad (4)$$

$$\frac{d^2\mathbf{I}_s(x)}{dx^2} = \gamma^2\mathbf{I}_s(x) + \mathbf{Y}_s\mathbf{E}_s(x) - \frac{d\mathbf{J}_s(x)}{dx} \quad (5)$$

Solution of the ordinary differential equation set corresponds to the wave (natural) modes that are independent from each other and posses their own propagation functions and characteristic impedances.

The eigenvalues of matrix $\mathbf{ZY}$ define the square of modal propagation functions γ^2. Propagation function γ is a diagonal matrix $N \times N$ whose elements are modal propagation functions. The power line with three phase conductors in horizontal disposition has three modes as presented in Fig. 1. The highest attenuation characterizes the ground mode where energy propagates through three phase conductors (Fig. 1) and returns via the ground. The ground mode has much higher attenuation than other two modes and ground mode component disappears approximately after $20 \div 30$ km [4]. Modes 1 and 2 have significantly lower attenuation

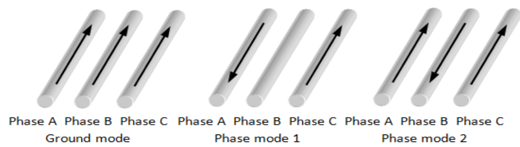

Figure 1. Three modes of the HV power line with three phase conductors in horizontal disposition

since their energy propagates and returns through phase conductors. High-frequency power-line characteristics (amplitude and phase characteristics) can be computed using the method of reflection coefficients in modal coordinates [4]. The method is briefly described in this section, while derivation of the amplitude and phase characteristic expressions for a given coupling is presented in [8] with details. A problem that arises in derivations of such expressions is related to the multi-conductor system, e.g. the voltages at all output ports are related to the all the voltages at all input ports.

Denoting V_1 and I_1 as the voltage and current at the sending terminal, and V_2 and I_2 at the receiving terminal, the amplitude and phase characteristics can be computed from the equations

$$\alpha = 10\log\left|\frac{V_2 I_2}{V_1 I_1}\right| [dB] \tag{6}$$

$$\beta = Im\left\{\ln\frac{V_2 I_2}{V_1 I_1}\right\} \tag{7}$$

For the homogeneous power line, voltages at transmitting $\mathbf{V}_1$ and receiving end $\mathbf{V}_2$ are related with voltage transfer matrix $\mathbf{T}$

$$\mathbf{V}_2 = \mathbf{T}\mathbf{V}_1 \tag{8}$$

and in modal coordinates

$$\mathbf{V}_{2s} = \mathbf{T}_s\mathbf{V}_{1s} \tag{9}$$

Matrix $\mathbf{T}_s$ is the voltage transfer matrix in modal coordinates and is equal to [4]

$$\mathbf{T}_s = (\mathbf{I}+\mathbf{K}_{2s})\, e^{-\gamma l}\, (\mathbf{I}+\mathbf{K}_{1s})^{-1} \tag{10}$$

where $\mathbf{K}_{1s}$ and $\mathbf{K}_{2s}$ represent the modal reflection coefficients at the sending and receiving ends, respectively, while $e^{-\gamma l}$ is a diagonal matrix. In the case of a power line with three conductors, it is a 3x3 matrix

$$e^{-\gamma l} = \begin{pmatrix} e^{-\gamma_0 l} & 0 & 0 \\ 0 & e^{-\gamma_1 l} & 0 \\ 0 & 0 & e^{-\gamma_2 l} \end{pmatrix} \tag{11}$$

The order of matrices $\mathbf{K}_{1s}$ and $\mathbf{K}_{2s}$ is determined by the number of modes, that is the number of conductors. The modal reflection coefficient at the receiving end is found from reflection coefficient $\mathbf{K}_2$ in phase coordinates as

$$\mathbf{K}_{2s} = \lambda^{-1}\mathbf{K}_2\lambda \tag{12}$$

while matrix $\mathbf{K}_2$ is computed via line characteristic impedance $\mathbf{Z}_c$ and load admittance $\mathbf{Y}_L = (\mathbf{Z}_L)^{-1}$.

$$\begin{aligned}\mathbf{K}_2 &= (\mathbf{I}+\mathbf{Y}_L\mathbf{Z}_c)^{-1}(\mathbf{I}+\mathbf{Y}_L\mathbf{Z}_c) \\ &= (\mathbf{Z}_c+\mathbf{Z}_L)^{-1}(\mathbf{Z}_c-\mathbf{Z}_L)\end{aligned} \tag{13}$$

Matrix λ is normalized matrix $\mathbf{S}$ in respect to the first row. The modal reflection coefficient at the sending line end is computed from

$$\mathbf{K}_{1s} = e^{-\gamma l}\mathbf{K}_{2s}e^{-\gamma l} \tag{14}$$

Vector of the phase currents at the transmitting end is

$$\mathbf{I}_1 = \mathbf{Y}_{in}\mathbf{V}_1 \tag{15}$$

where $\mathbf{Y}_{in}$ is the input admittance matrix

$$\mathbf{Y}_{in} = \mathbf{Y}_c(\mathbf{I}-\mathbf{K}_1)(\mathbf{I}+\mathbf{K}_1)^{-1} \tag{16}$$

Using load admittance matrix $\mathbf{Y}_L$, the current at the receiving terminal is computed as

$$\mathbf{I}_2 = \mathbf{Y}_L\mathbf{V}_2 \tag{17}$$

This concept allows computation of the frequency response of the HV PLC channel for different couplings using equations (6) and (7). Furthermore, the middle phase to ground coupling and the outer phase to middle phase coupling are denoted as optimal couplings for the HV power line with phase conductors in horizontal disposition [4]. The presented method is applied to the 400 kV power line with three phase conductors in horizontal disposition. The computed amplitude characteristic and group delay in the 24 kHz band are given in Figures 2 and 3, respectively. Signal reflection at the HV power line terminals is due to the mismatch between the power-line characteristic impedance and the termination impedance. As a consequence of the reflection phenomenon, oscillations in the amplitude characteristic and the group delay appear. The period between two neighboring maximum and minimum of these oscillations is found as

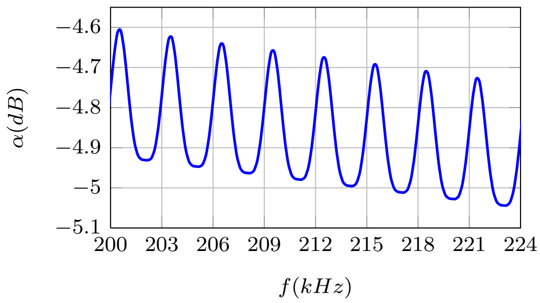

Figure 2. Amplitude charactersitic for the 400 kV power line and middle phase to ground coupling

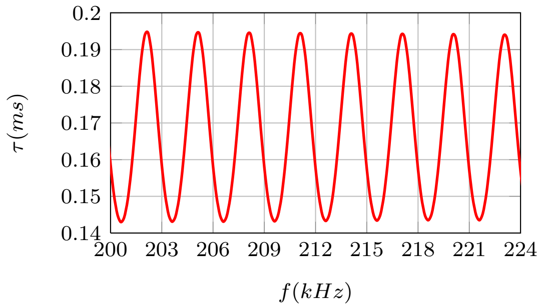

Figure 3. Group delay for the 400 kV power line and middle phase to ground coupling

$$\Delta f_{max-min} = \frac{v}{4l} \tag{18}$$

Since wave velocity v is approximately 300 000 km/s, for a line $l = 50\ km$ long the period of oscillations equals to 1.5 kHz.

The reflected waves on the power line manifest themselves as echoes in the time domain. The echo delay is determined by the line length and velocity of signal propagation. Obviously, the echo delay is correlated with the period of oscillations in the frequency domain. Intensity of echoes is determined by the reflection coefficient and line attenuation, and is proportional to the amplitude of oscillations in the frequency domain.

The second phase mode strongly impacts the reflection intensity since this modal channel is characterized by the lowest attenuation. Additionally, the mismatch between impedances at the line terminals causes energy transfer between different modal channels. The value of the exchanged energy between modes can be seen in the modal reflection coefficient matrix given by (12).

3 FIR FILTER IMPLEMENTATION

This section describes a procedure for a simple FIR filter implementation of the HV PLC channel. The frequency response of the model corresponds to the frequency characteristics of the PLC channel with incorporated reflection. Oscillations in the amplitude characteristic and group delay are present in the proposed model. However, they will deviate from those found in the detailed model. A simple implementation model is given in Figure 4. Three FIR filters are identical and de-

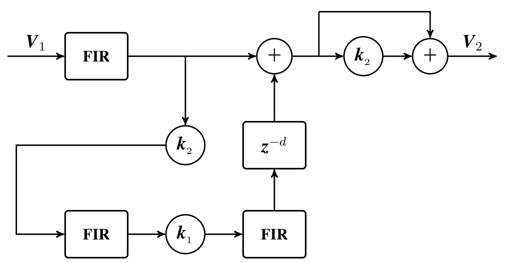

Figure 4. Simple FIR filter implementation model

signed using a simulated discrete frequency response of the HV PLC channel with no reflection. The reflected wave propagation (echo) is inserted through the parallel branch, coefficients k_1 and k_2 and the delay for d samples. Even though these coefficients are introduced into the model as reflection coefficients, their values are determined in the manner that the frequency response of the simple model matches the simulated characteristics as close as possible. As a consequence of such approach, values of k_1 and k_2 are not limited to the range $[-1, 1]$. Therefore, we made a significant simplification by taking scalar constants to act as reflection coefficients instead of the frequency-dependent matrices (explained in Section 2). The number of samples d is computed from the sampling frequency and the signal propagation delay.

The simulated discrete frequency response of the HV PLC channel using the method of reflection coefficients is the input data for the implementation based on FIR filters. Alternatively, parameters of the simple FIR model can be determined using the measured HV PLC channel characteristics [9]. The amplitude characteristic of the FIR filter corresponds to the HV PLC channel characteristic without incorporated reflection. Since the FIR filter is characterized by a linear phase, it doesn't describe the PLC channel phase. This is the first assumption that introduces deviation of the implemented model from the detailed model computed in accordance with the methodology given in Section 2.

The frequency response of the system given in Figure 4 is

$$H(j\omega) = (1 + k_2)F(j\omega) + k_1 k_2 (1 + k_2) F^3(j\omega) e^{j\omega d} \quad (19)$$

where $F(j\omega)$ is the frequency response of the three identical FIR filters. The amplitude characteristic in dB can be computed using the previous equation as

$$\begin{aligned} \alpha_{dB}(j\omega) &= 20\log|(1 + k_2)F(j\omega) + \\ &\quad + k_1 k_2 (1 + k_2) F^3(j\omega) e^{j\omega d}| \\ &= 20\log|F(j\omega)| + 20\log|1 + k_2| + \\ &\quad 20\log\left|1 + k_1 k_2 F^2(j\omega) e^{j\omega d}\right| \end{aligned} \quad (20)$$

In order to discuss the meaning of the three terms in the above expression, we will consider the simulated amplitude characteristic given in Figure 5. This characteristic corresponds to 400 kV power line, 50 km long, and the middle phase to ground coupling. The red dashed line in Figure 5 represents the PLC channel amplitude characteristic without reflection. The first term in (20) determines this characteristic. The FIR filter in the implementation model (Figure 4) is designed to match this amplitude characteristic. Since the frequency range utilized for the HV PLC communications is 500 kHz, the sampling frequency of the designed FIR filter is chosen to be 1 MHz. The observed shift in Figure 5

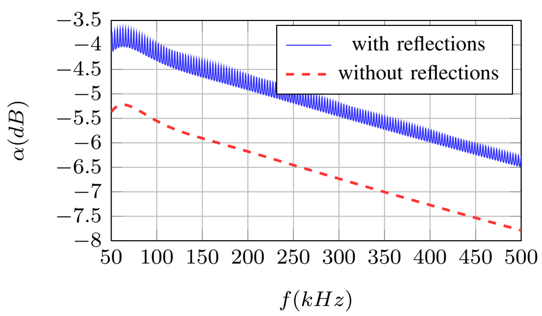

Figure 5. Simulated HV PLC channel amplitude characteristic for the middle phase to ground coupling

between the characteristics with and without reflection corresponds to the second term in (20). Coefficient k_2 is computed to align these two characteristics

$$20\log|1 + k_2| = 1.5 \Rightarrow k_2 = 10^{1.5/20} - 1 = 0.1885 \quad (21)$$

The last term in (20), that contains coefficients k_1 and k_2, represents oscillations in the amplitude characteristic due to reflection. Coefficient k_1 is calculated so that oscillations in the phase characteristic are adequate. The phase of the model given in Figure 4 is

$$\arg\{H(j\omega)\} = \theta(\omega) + \\ + \arctan\left(\frac{k_1k_2|F(j\omega)|^2\sin(\theta(\omega)+\omega d)}{1+k_1k_2|F(j\omega)|^2\cos(\theta(\omega)+\omega d)}\right) \quad (22)$$

where $\theta(\omega) = \arg\{F(j\omega)\}$. To simplify determination of coefficient k_2, $a = k_1k_2|F(j\omega)|^2$ and $x = \theta(\omega) + \omega d$ in the previous expression will be substituted:

$$\arg\{H(j\omega)\} = \theta(\omega) + \arctan\left(\frac{a\sin(x)}{1+a\cos(x)}\right) = \\ = \theta(\omega) + \Delta\theta(\omega) \quad (23)$$

Term $\Delta\theta(\omega)$ is periodic function of ω. Since intensity of oscillations in the simulated phase characteristic is known, we can determine the value of parameter a that corresponds to the amplitude of these oscillations (Figure 6).

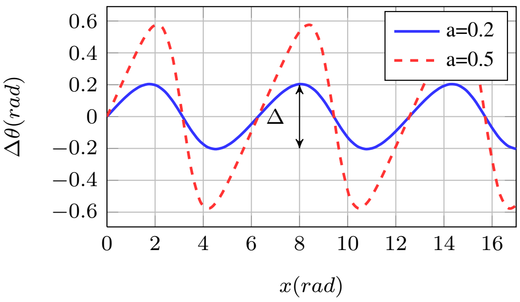

Figure 6. Oscillations $\Delta\theta(\omega)$

The amplitude of oscillations $\Delta = \max\{\Delta\theta(\omega)\} - \min\{\Delta\theta(\omega)\}$ varies with parameter a. The relation between Δ and a, according to (23), is provided in Table I for some characteristic values of a.

Table 1. Correlation between parameter a and the oscillation amplitude in the phase characteristic

a	0.1	0.2	0.3	0.4	0.5	0.6
Δ	0.200	0.403	0.609	0.823	1.047	1.287

The amplitude oscillation in the phase characteristic that corresponds to the amplitude characteristic given in Figure 5 approximately equals 0.2 rad. According to Table I, we choose $a = 0.1$. Since coefficients k_1 and k_2 are constants in order to keep the model simple and $|F(j\omega)|$ changes in the 1.5 dB range (Figure 5), we choose $|F(j\omega)| = 5dB$, that is $|F(j\omega)|^2 = (0.5623)^2 = 0.3162$. Therefore, coefficient k_1 can be calculated as

$$k_1k_2|F(j\omega)|^2 = 0.1 \;\Rightarrow\; k_1k_2 = 0.3162 \;\Rightarrow\; k_1 = 1.81 \quad (24)$$

The amplitude characteristic of the simple system for computed coefficients k_1 and k_2 and the FIR filter with amplitude characteristic given by the red line in Figure 5 is presented in Figure 7. Since oscillations are more emphasized in the group delay than in the phase characteristic, the group delay of this system is given in Figure 8. Comparing the amplitude characteristics presented in Figures 5 and 7, we observe very intensive oscillations in the amplitude characteristic of the simple model. This is due to that coefficients k_1 and k_2 are computed to match the amplitude of oscillations in the simulated phase characteristic. Determination of the coefficients in the manner to achieve oscillations in the simulated amplitude characteristic would lead to a much lower oscillation amplitude in the phase characteristic of the simple model.

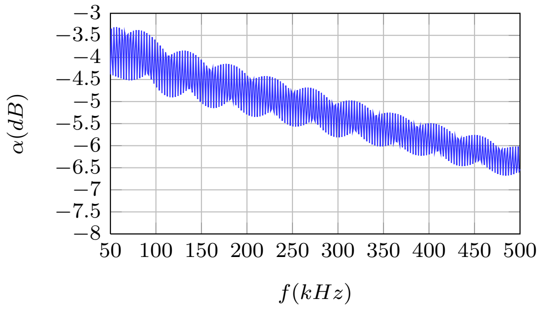

Figure 7. Amplitude characteristic of the implemented model for the middle phase to ground coupling

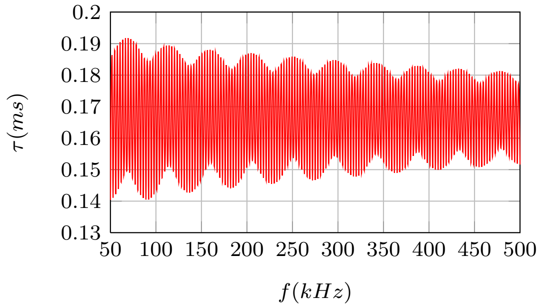

Figure 8. Group delay of the implemented model for the middle phase to ground coupling

The approach presented in the paper led to an implementation model whose characteristics don't significantly deviate from the computed model based on the reflection coefficients. On the other hand, such simple model ensures adequate phase nonlinearities with more intensive nonlinearities in the amplitude characteristic. This is acceptable when the model is used for the HV PLC modem testing. The presented methodology is also applied to the outer phase to middle phase coupling and 400 kV power line.

The simulated amplitude characteristic is given in Figure 9. Figures 10 and 11 show the amplitude characteristic and group delay of the model. The advantage of the proposed model is simplicity and straight forward implementation with the FPGA technology. The frequency characteristics of the simple model differ from the simulated characteristics in the more emphasized oscillations in the amplitude characteristics. However, the simple model incorporates the reflection phenomena on the HV power lines which is a crucial factor, together with the corona noise, for the HV PLC modem performance.

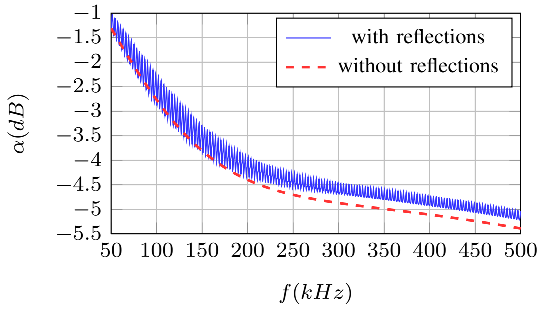

Figure 9. Simulated HV PLC channel characteristic for the outer phase to middle phase coupling

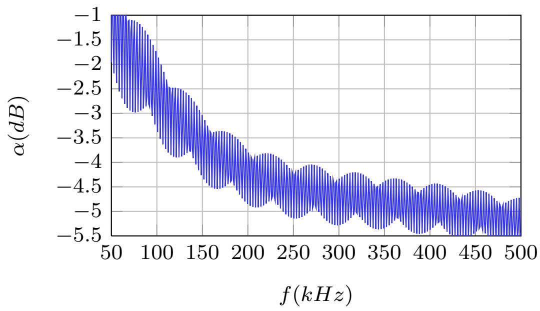

Figure 10. Amplitude characteristic of the implemented model for the outer phase to middle phase coupling

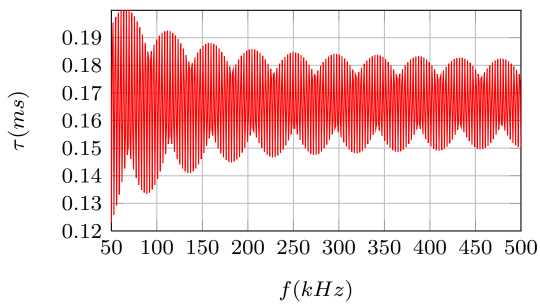

Figure 11. Group delay of the implemented model for the outer phase to middle phase coupling

4 Conclusion

The paper proposes a simple implementation model of the HV PLC channel based on FIR filters. Parameters of the proposed model are determined using the simulated discrete frequency characteristics of the HV PLC channel. These parameters can also be computed using the measured frequency characteristics. The simple model incorporates reflection for being, the crucial factor for the HV PLC modem performance. Corona noise generation is not treated in the paper.

An advantage of the given model is simplicity and straight forward implementation using the FPGA technology. Relative drawbacks are more emphasized oscillations in the amplitude characteristic of the simple model than in the simulated amplitude characteristic.

5 Acknowledgement

The work is supported by the Ministry of Higher Education, Science and Technology, Slovenia, under the Scientific Program P2-0246.

References

[1] S. Galli, A. Scaglione and Z. Wang, "For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid",Proceedings of the IEEE, Vol. 99, No. 6, pp. 998-1027, June 2011.
[2] International Electrotechnical Commision, IEC report 663, Planning of (single-sideband) power line carrier, Geneve, 1980.
[3] N. Suljanovic, A. Mujcic, M. Zajc, J.F. Tasic, "High-frequency characteristics of high-voltage power line", Proceedings of EUROCON 2003, The IEEE Region 8, Vol. 2, pp. 310-314, 2003.
[4] G.V. Mikutski, V.S. Skitalcev, "High-frequency links over power lines", Energoatomizdat, Moscow, 1987. (in Russian)
[5] A. Mujcic, N. Suljanovic, M. Zajc, J.F. Tasic, "Corona noise on a 400 kV overhead power line", Electrical Engineering Journal, Springer- Verlag, vol. 86 (2), pp. 61-67, Jan. 2004.
[6] J.R. Carson, "Wave propagation in overhead wires with ground return", Bell Syst. Techn. J., Vol. 5, pp. 539-554, 1926.
[7] L.M. Wedepohl,"Application of matrix methods to the solution of traveling-wave phenomena in polyphase systems" Proc. IEE, Vol.110, No.12, pp.2200-2212, Dec. 1963.
[8] N. Suljanovic, A. Mujcic, Z. Sehic, M. Zajc, J. Tasic, "Computation of transfer function for multiconductor power lines", Proceedings of the Fifteenth International Electrotechnical and Computer Science Conference ERK 2006, Portoroz, Slovenija, Vol. A, p.p. 211-214, 2006.
[9] M. Zajc, N. Suljanovic, A. Mujcic, J. Tasic, "Frequency Characteristics Measurement of Overhead High-Voltage Power-Line in Low Radio-Frequency Range", IEEE Transactions on Power Delivery, Volume:22, Issue:4, pp.2142 - 2149, 2007.

Asmir Gogić is a Teaching Assistant with the University of Tuzla, Bosnia and Herzegovina. His research interests are in modeling and simulation of communication networks, channels and protocols.

Nermin Suljanović is an Associate Professor with the University of Tuzla, Bosnia and Herzegovina. His research interest is the digital communications, communication channel modeling and computer networks.

Aljo Mujčić is an Associate Professor with the University of Tuzla, Bosnia and Herzegovina. His research interests are in the areas of power-line communications, optical communications, information theory and coding techniques.

Mitja Kolenc is a Researcher at the Faculty of Electrical Engineering, University of Ljubljana. His research fields are RT digital signal processing and intelligent power networks.

Jurij F. Tasič is a Full Professor at the Faculty of Electrical Engineering, University of Ljubljana, and head of the Laboratory for digital signal, image and video processing. His research fields are in domains of digital signal processing and adaptive systems.

Matej Zajc is an Assistant Professor at the Faculty of Electrical Engineering, University of Ljubljana. He is active in the domain of digital communication systems and digital signal processing.