User Guide for PLC channel generator v.2

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1 Objective

This is a quick guide of the power-line channel generator implemented in the software package *PLC_channel_generator.zip*, which can be downloaded from www.plc.uma.es. It contains a MATLAB© function, *PLC_channel_generator_2.p*, which implements the main processing tasks, and some other auxiliary functions [1]. The fundamentals of this channel generator can be found in the paper:

F.J. Cañete, J.A. Cortés, L. Díez and J.T. Entrambasaguas, "*A Channel Model Proposal for Indoor Power Line Communications*", to appear in *IEEE Communications Magazine.*

Release notes [2]: This is version 2 code. It is essentially the same generator as in version 1, but some minor changes have been performed that preserve or improve, in some cases, the statistical behavior of the generated channels. For such reason, upgrade to version 2 code is recommended. As the generator core is different, users of version 1 code can obtain different channel responses for a given network topology. In particular, in version 1, for channels random generation, the statistical distribution of the cables length is uniform (between 0.5 and 50m); whereas, in version 2, a Gamma distribution has been selected (with "shape parameter" a=1.5 and "scale parameter" b=18). Also, the examples of default channels for manual generation have been changed (see section 3.5).

Default channels: In addition, some examples of generated channel responses are provided in the file *default_channels.mat*. These can be used with any tool based on MATLAB© language like Octave.

[1] The code has been created with MATLAB Version 7.5 (R2007b), it is expected to work fine with later versions but not necessarily with other earlier ones.

[2] ACKNOWLEDGEMENT: The authors would like to thank many users for their comments and especially to Giuseppe Marrocco, from the Telecommunications Research Center Vienna (FTW), who detected a bug in one parameter of the cables.

2 Channel Model

This section provides a brief explanation of the channel model underneath this generator. The model has been designed for broadband indoor power-line channels and it is based on a structural modeling of the power network from which the channel frequency response is synthesized. Both LTI (Linear Time-Invariant) channel and LPTV (Linear Periodically Time-Varying) channel cases are considered.

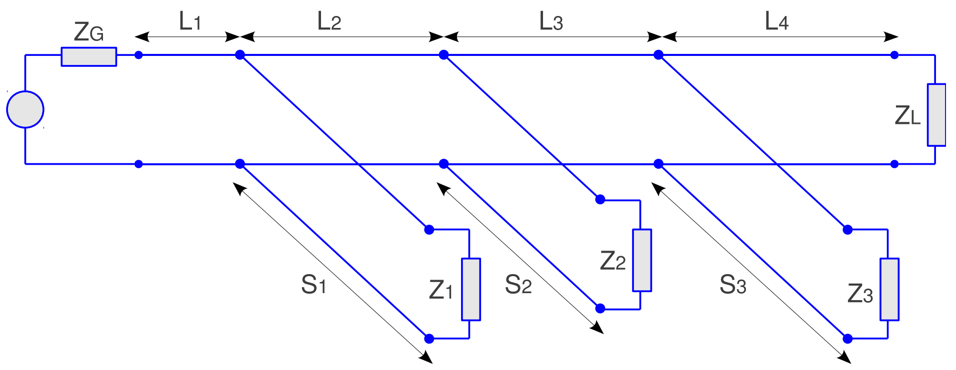


Figure 1: Network topology for the model.

2.1 Network model

The following assumptions apply:

1. The indoor power grid is represented by the interconnection of multiple transmission lines with passive loads as terminations.
2. The transmitter and receiver are connected by using differential transmission mode between two wires, line and neutral.
3. All loads, including transmitter and receiver, are modeled as an impedance.
4. The transmission line model for sections of cable is a two parallel wires structure.

A simplified network topology is used, as shown in Fig.1. It comprises seven line sections, from which three are stubs. The topology parameters are: L_i $(i \in \{1, 2, 3, 4\})$ and S_i $(i \in \{1, 2, 3\})$.

The transmission line parameters R, L, G and C (per unit length) are estimated from electrical cable manufacturers, according to different sections, and are listed in Table 1.

2.2 Loads model

Three models for the loads impedances can be selected: constant, frequency-selective time-invariant, and frequency-selective time-varying functions.

Cable type	1	2	3	4	5
section (mm^2)	1.5	2.5	4	6	10
ε_{eq}	1.45	1.52	1.56	1.73	2
$Z_0(\Omega)$	270	234	209	178	143
C (pF/m)	15	17.5	20	25	33
L (μH/m)	1.08	0.96	0.87	0.78	0.68
R_0	12	9.34	7.55	6.25	4.98
G_0	30.9	34.7	38.4	42.5	49.3

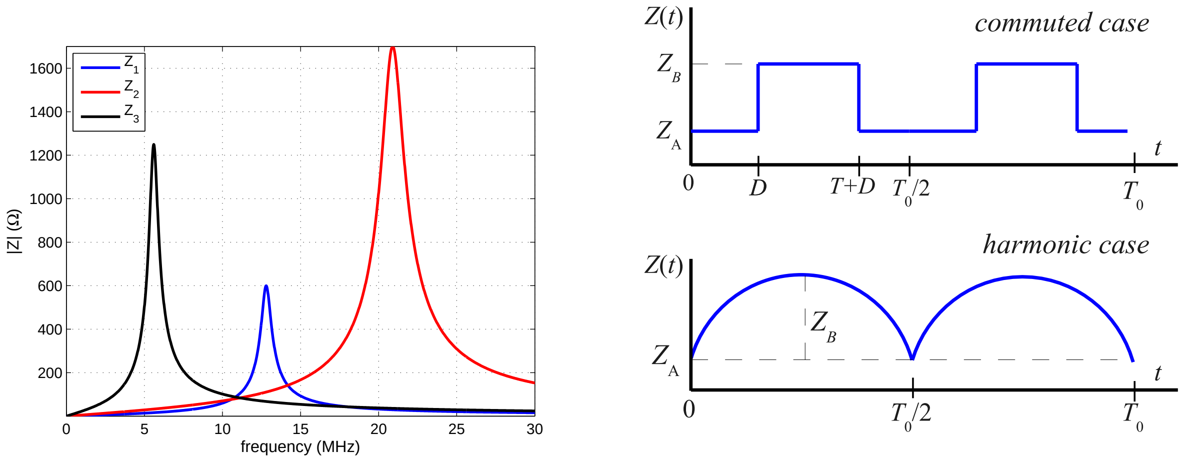
Table 1: Characteristics of actual indoor power network cables. $R = R_0 \cdot 10^{-5}\sqrt{f}$ (Ω/m) and $G = G_0 \cdot 5 \cdot 10^{-14} \cdot 2\pi f$ (S/m).

Possible values for the **constant impedances** are $\{5, 50, 150, 1000, \infty\}\Omega$. They represent, respectively: low, RF standard, similar to transmission line Z_0, high and open-circuit, impedances.

For the **frequency-selective impedances** the model is a parallel RLC resonant circuit,

$$Z(\omega) = \frac{R}{1 + jQ(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega})} \quad (1)$$

The three parameters are: R, resistance at resonance; ω_0, resonance angular frequency; and Q, quality factor (determines selectivity). In Fig.2, some examples can be seen.



(a) (b)

Figure 2: Impedance functions: (a) frequency-selective case; (b) time-varying case.

For the **time-varying impedances** two classes are considered. Impedances with a *commuted behavior*, between two values Z_A and Z_B, synchronous with the mains voltage. These impedance values can be frequency selective. The parameters describing this time variation are: the state duration, T, and the delay respect to the mains voltage zero-crossing, D (see Fig.2).

Let us denote the second class of impedance as, *harmonic behavior*, modeled as,

$$Z(\omega, t) = Z_A(\omega) + Z_B(\omega)|sin(\frac{2\pi}{T_0}t + \phi)|; \quad 0 \leq t \leq T_0 \quad (2)$$

The parameters are: the offset impedance, Z_A, the amplitude of the variation, Z_B, and a phase term ϕ, to relate the variation with the mains voltage zero-crossing (see Fig.2).

3 Channel Generator

This section describes a channel generator implementation based on the previous channel model. It is programmed in the function *PLC_channel_generator_2.p*.

To configure the model parameters the user should edit the routine *config.m* (included in PLC_channel_gener

3.1 Program header

`function [H,f,net,dist]=PLC_channel_generator_2(tipo)`

`inputs`:

tipo : control flag, indicates {0,1,2} = {invariant,harmonic,commuted} channel

`outputs`:

H : complex frequency response, (Nx1) for LTI channels, (NxM) for LPTV channels

f : frequency points, real vector (Nx1)

net : data structure (cell-array, 7x4) that contains the network topology

dist : link distance between transmitter node and receiver node

A **net** structure is a cell-array (a matrix of non-homogeneous elements) with a row for each section of line. The first column indicates the kind of line (longitudinal or stub), the second column is the line length, the third column is the cable type and the fourth columns is the impedance value.

3.2 General parameters

The following list shows general parameters that can be modified in *config.m*, independently of the desired channel time variation.

modo : $\{0, 1\}$, for each of the two **operation modes**, manual or random. The generator can work in *manual mode*, in which the user should define all the parameters to create a certain topology; or in *random mode*, in which the program generates most parameters from random distributions to create a random power network. Default values to work in *manual mode* are given in section 3.5.

f_{min} : beginning of frequency band (in Hz).

f_{max} : end of frequency band (in Hz).

N : Number of discrete frequency points (in the positive axis), length of vector f.

Z_G : Transmitter impedance (in Ω).

Z_L : Receiver impedance (in Ω).

3.3 Parameters for LTI channels random generation

When the input argument **tipo** is set to zero, the following parameters apply:

t : vector of seven elements $\in \{1, 5\}$, cable types chosen at random, with uniform distribution, among the ones in table 1.

l : vector of seven elements with line sections lengths (in m), for L_i and S_i, chosen at random, with Gamma distribution (with $a = 1.5$ and $b = 18$).

Z_1, Z_2, Z_3 : frequency selective function impedances for the loads, chosen at random with the following parameters,

Resistance, $R \in \{200, 1800\}\Omega$ with a uniform distribution.

Resonance frequency, $\omega_0/2\pi \in \{2, 28\}$MHz with a uniform distribution.

Q factor, $Q \in \{5, 25\}$ with a uniform distribution.

3.4 Parameters for LPTV channels random generation

When the input argument **tipo** is set to one, the following parameters apply (i.e. according to a *harmonic variation*):

t : same as above.

l : same as above.

M : Discrete-time resolution, number of invariance intervals in a mains cycle.

Z_1, Z_2, Z_3 : two of them with frequency selective functions (chosen at random, as described above) plus one time-varying impedance with commuted behavior and the following parameters,

Z_B : also a frequency selective function.

Z_A : $Z_A = 50\Omega$.

ϕ : with a uniform distribution between 0 and π rad.

When the input argument **tipo** is set to two, the following parameters apply (i.e. according to a *commuted variation*):

t : same as above.

l : same as above.

M : Discrete-time resolution, number of invariance intervals in a mains cycle.

Z_1, Z_2, Z_3 : two of them with frequency selective functions (chosen at random, as described above) plus one time-varying impedance with commuted behavior and the following parameters,

Z_B : also a frequency selective function.

Z_A : $Z_A = Z_B \cdot 0.5]$.

T : in discrete-time, with a uniform distribution between 1 and $M/4$.

D : in discrete-time, with a uniform distribution between 0 and $M/2 - T$.

[For this purpose the function *impedance2_t*(M,Z_A,Z_B,D,T) is called.]

3.5 Manual channel generation - default values

The following are the default set of parameters in the routine *config.m* for operation in the manual mode:
modo=0; manual mode
f_max=30e6;
f_min=0.1e6;
N=2048; frequency resolution is 14kHz
M=50; time resolution is 400μs
Zg=50;
Zl=50; receiver impedance
l=[0.8,32,13.8,37.6,46.8,50.1,37.2]; vector of line sections length (in meters)
t=[5,5,2,2,5,2,4]; vector of cable types
Z_1=impedance_f(f,863,6,2.7e6); RLC resonator
Z_2=impedance_f(f,394,34,10.7e6); RLC resonator
Z_3=impedance_f(f,1312,9,10.07e6); RLC resonator

By running the channel generator with the default values, a **default LTI channel** (tipo=0) is obtained, whose frequency response is plotted in Fig.3. This can be considered a medium-case channel, which has an average attenuation of 33.6dB, effective impulse response length (the shortest window containing 90% of the energy) of 0.9μs, and coherence bandwidth of 219kHz.

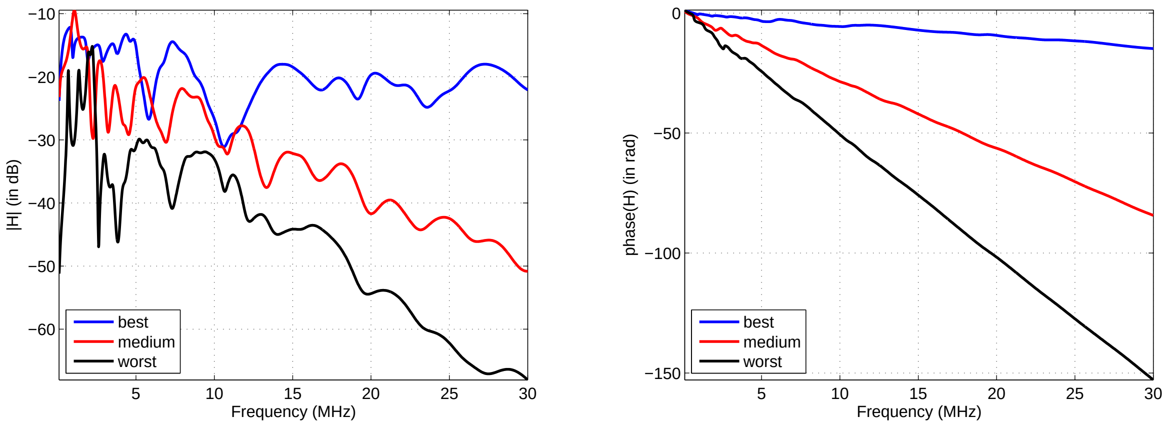
In addition, two other alternative channels are proposed: a best case channel, with lower attenuation and delay spread, and a worst case channel, with higher attenuation and delay spread. This can be accomplished by modifying the network structure parameters as described below.

Parameters value to obtain a best-case channel (average attenuation of 20dB, effective length of 0.3μs and coherence bandwidth of 628kHz.):
l=[4.2,129.4,8.3,10.3,0.3,20.9,4.8];
t=[4,1,3,4,5,2,4];
Z_1=impedance_f(f,1293,40,4.98e6);
Z_2=impedance_f(f,978,42,20.51e6);
Z_3=impedance_f(f,1752,38,23.68e6);

Parameters value to obtain a worst-case channel (average attenuation of 46dB, effective length of 1.6μs and coherence bandwidth of 102kHz.):
l=[14.9,29.1,11.9,9.8,138.8,2.2,8.5];
t=[3,4,5,1,5,1,1];
Z_1=impedance_f(f,552,46,11e6);
Z_2=impedance_f(f,1705.3,19,7.7e6);
Z_3=impedance_f(f,674,39,2.1e6);

All these frequency responses are depicted in Fig.3 and they are provided in the file *default_channels.mat*. These default channel responses have been selected from a random ensemble of generated channels. The worst, medium and best case have been taken among the channels under 10%, around 50% and over 90% percentile of goodness (related to approximated capacity).

ADVICE: It is recommended a realistic pass-band filtering, of the synthesized channel response, to reduce the distortion in the impulse response due to an ideal rectangular filter.



(a) (b)

Figure 3: The three default LTI channels frequency responses: (a) amplitude response; (b) phase response.