An Enhanced Powerline Channel Noise Model

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Abstract-OFDM has been proved to be a robust technique when it is used in hostile telecommunications media due to its capability to overcome intersymbol interference (ISI). Such a hostile environment is the powerlines when used for communication purposes in the frequency range 1MHz-30MHz. Nevertheless, it is important to understand the noise characteristics in the frequency domain, since OFDM is the parallel transmission of data using orthogonal carriers. In this paper the spectrum is discriminated in narrow bands. In each band the noise characteristics are studied. The non-Gaussian character of the powerline channel noise is proved and new models are constructed after statistical analysis of the noise samples. The noise samples are obtained after a measurements campaign in the laboratory and in apartments.

Key-Words: -Powerline noise, Discrete Multitone Systems, Powerline communications

1 Introduction

Powerlines provide a hostile environment for communication signals. However, as the knowledge of their characteristics increase new methods are invented to counterbalance the problems. After so many years of systematic efforts researchers are convinced that Orthogonal Frequency Division Multiplexing (OFDM) is an appropriate candidate for data transmission over power lines. OFDM is very resilient when a communication link suffers from great delay spread [1]. Delay spread is a major problem over power lines [2].

OFDM is the parallel transmission of data over subchannels separated in the frequency domain. When OFDM is applied it is essential to know the subchannel characteristics at the frequencies of interest. A channel model that describes the subchannels' noise characteristics is of major importance, as based on that the bit load per subcarrier can be calculated and additionally, the probability of error of a multicarrier system can be determined. This noise model is the aim of this study. The models are obtained after statistical processing of the data acquired during a great measurements campaign since [3-4]. The results verify already known characteristics and provide new substantive information on the power line channel. The data are obtained in the frequency domain.

There are several attempts in the past trying to estimate the power line capacity [3], [5]. Those attempts did not approach the problem correctly due to the lack of a complete statistical power line channel model. For instance, the capacity was calculated based on average values of the noise power $E[n^2]$ per frequency. Those values are sufficient when the noise model is gaussian. However, the noise has been proved that is not gaussian [6]. Another approach is to calculate the best or worst noise scenario and calculate extreme levels of capacity [6]. Hence, a communication system that accomplishes to work for the worst noise scenario is ensured that it can work properly under all noise circumstances. However, such an approach should be accompanied with a study concerning the period of time that the channel suffers from the worst scenario. Otherwise, there is a waste of resources because the system does not exploit the current channel's condition, which may be better compared to the worst case.

The power-line channel noise consists of several types of noise due to the different nature of the noise sources. The power line modems have to confront the superposition of all those components that affect the communication signal. There are noise components having a power level that is variant, in terms of seconds, minutes or hours and characterized as colored gaussian background noise. On the other hand there are noise impulses periodic, synchronous or asynchronous to the mains frequency, and non-periodic asynchronous [7]. When impulsive noise hits its magnitude is greater than background noise. Thus, impulsive noise is dominant and causes the greater problem to a communication system. Impulsive noise is parameterized by its amplitude, width and interarrival time. All of them are parameters in the time domain. Nevertheless, when OFDM is applied it would be of great importance if its characteristics are examined in the frequency domain.

In this study we confront the noise as a superposition of its components in the frequency domain. Particularly, we are trying to investigate the specific characteristics that the noise presents in each frequency and create a noise model that is dependent on frequency. Since a general noise model is the target, a great number of samples per frequency are gathered. The noise samples are collected through different hours a day and different days of the years that the measurements campaign lasted. The noise models are extracted and presented for the first time at the best of the authors' knowledge. The paper is organized as follows. In section 2 the noise characteristics are explained. Particularly in section 2.1 the well-known power-line noise components are repeated here for quick reference. Then in section 2.2 the power-line noise sample characteristics are presented in the frequency domain. It is one of the contributions of the paper the indication of the periodicity that the correlation coefficient present between any two distinct in the frequency, noise samples. In section 3 the probability density functions are presented for 241 different frequencies. These parameters are the constituents of the complete noise model of the noise samples in the frequency domain. This is also a novel contribution of the paper. Then in section 4 the validity limits of the models are discussed and the paper concludes in section 5 with some general remarks and proposals for further work.

2 Characteristics of the Powerline Channel Noise

2.1 Power line noise components

The power line noise components have been determined in several papers [2], [7], [8], [9]. According to the measurement techniques and technical equipment available there were detected three, four or five components in the literature. Nevertheless, all of them deduce that there is a background noise component (such as colored Gaussian and narrowband noise due to radio stations transmitting in frequencies less than 30MHz) and impulsive noise either periodic (synchronous or asynchronous to the mains frequency) or non-periodic asynchronous. From a telecommunications point of view the power line receiver is affected in the time domain from the superposition of all those noise components. When OFDM is applied for data transmission it would be important to know the noise characteristics in the frequency domain, as in fact OFDM is the transmission of data through parallel orthogonal frequencies. Hence, the noise components described in the literature in the time domain should be identified in the spectrum and quantify their effect in every frequency. This is exactly the main target of this paper.

2.2 Power-Line Noise Sample Characteristics

The noise power spectral density is measured using a spectrum analyzer. An automatic measurements set up was used. Special care was taken to equalize "a-posteriori" the attenuation of the noise samples passing through the filter and the isolation transformer before entering the front end of the spectrum analyzer. The frequency range of interest was swept and noise samples were transferred from the spectrum analyzer to a computer's hard disk. The measurements took place in the lab and in an apartment during several different hours per day.

A great number of noise samples were collected. The noise samples from 1.15MHz up to 30MHz are shown in Fig. 1. The noise level has a great deviation. It is strongly dependent on three parameters. The time of the day that the measurements are carried out, the place of the measurements and the frequency. The time of the day has to do with the human activity. The place has to do with the appliances that are connected and in use i.e. in-house, laboratory and industrial area. Finally, when noise is injected to the power lines, it is attenuated with the frequency increase. Moreover, the frequency bands where there are radio stations will present high noise levels.

The best and worst noise scenario is the lower and upper envelope of Fig. 1. Generally, the noise is stronger in the lower part of the frequency band.

Since the noise has a great variance and dependence from time and place the extraction of average values has no practical interest as those values will be dependent on time and place. Hence, statistical noise models are necessary.

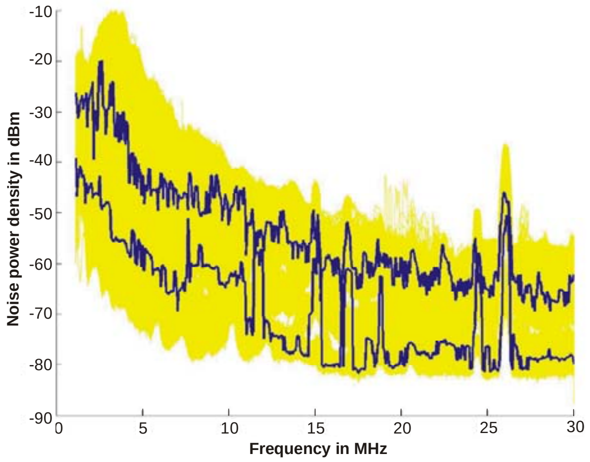


Fig. 1. Noise samples measured in the lab and in-house. The upper and the lower envelope is the worst and the best noise measured scenario. The lower dark line is the average gaussian noise component and the upper dark line is the average impulsive noise component.

It is interesting to find out whether the noise samples that belong to different frequencies, are statistically independent or not. The noise samples at two different frequencies were considered as two variables and the sweeps as observations. The average correlation coefficient for every pair of variables that differ one frequency step (i.e. 120.2KHz for our experiments) has been calculated. The same calculations were made for those variables that differ two steps, three steps and so on. The noise samples at 1.15MHz and 30MHz are distant 240 steps. The results are presented in Fig. 2. The significance of those correlations is shown in Fig. 3. As can be seen the p-values of most of them are below the 0.05 level of significance. That means that noise samples that are distant in the frequency are still correlated. Fig. 2 depicts that the correlation coefficient have a kind of periodicity with period about 50 steps (6.01MHz frequency distance). In every period the correlation increases until it reaches a peak value. Then the correlation decreases with the frequency until the end of the period and then it repeats this behavior. The peaks are observed at 40, 90, 140 and 190 steps. The peak values become smaller with the frequency increase. This is the first time that the periodic behavior of the correlation coefficients of the power line noise samples, in the frequency domain, is revealed. Undoubtedly, the noise samples at different frequencies are correlated and consequently are statistically dependent.

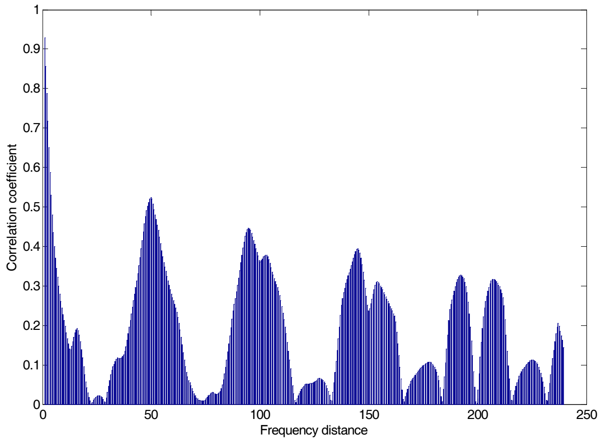


Fig. 2. Average correlation coefficient between noise samples that are 1 step up to 240 steps distant.

The statistical significance of the correlation coefficient of the noise samples measured for different frequencies, even being far away to each other, is attributed to the fact that those noise samples are the frequency components of repeated phenomena in the time domain that have the same general characteristics impressed in the frequency domain. Those are the noise impulses that have certain statistics concerning time duration, amplitude and inter-arrival time. Those characteristics are measured in the time domain. However, the fourier transform could reveal the spectrum characteristics of the noise impulses.

Impulsive noise is more likely to be the reason for the statistically significant correlation among certain frequencies as it is found that is stronger and prevails the background noise. Any relationship that exists among background noise samples in the frequency domain could not be revealed when measurements are not made in the time domain where impulsive noise can be distinguished from background noise.

3 Probability Density Functions of the Amplitude of the Power Line Noise Samples

In the section that follows the probability density functions of the noise density for every frequency where the measurements took place are extracted. The noise samples were processed and the normalized histogram of their amplitudes was extracted for every frequency in the frequency span of measurements.

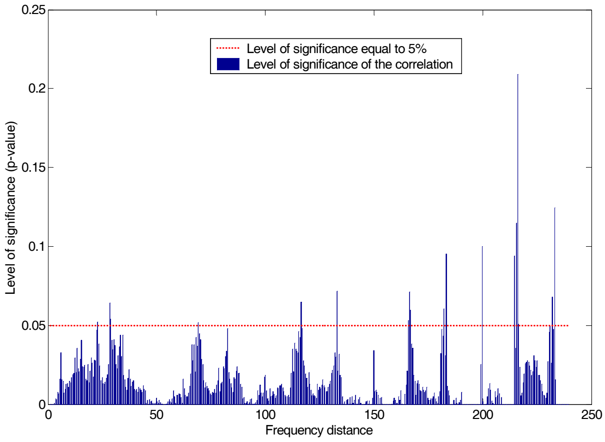


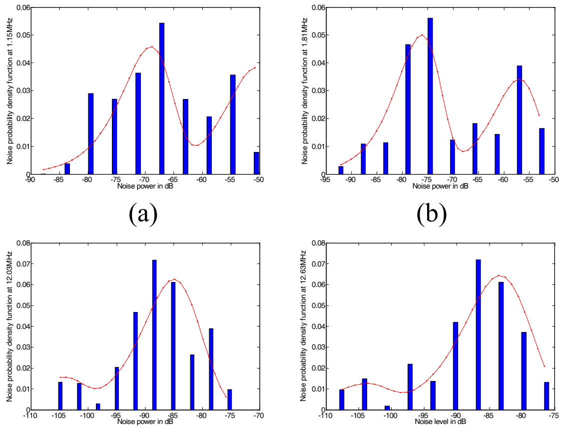
Fig. 3. Average level of significance of the correlation between noise samples that are 1 step up to 240 steps distant.

Using the smoothing splines method [10] the shape of the probability density functions is revealed. For instance, the normalized histograms and the corresponding smoothing spline curves are shown in Fig. 4 for the frequencies 1.15MHz, 1.81MHz, 12.03MHz and 12.63MHz.

The noise samples' magnitude before processing was transformed in dB. The shape of the curves looks like the probability density distribution of Middleton's canonical class A noise as depicted in [11]. The model is described with equation (1).

$$f_I(I)=\sum_{m=0}^{\infty}\frac{A^m}{m!}e^{-A}\cdot 1/(\sigma_g^2+m\frac{\sigma_I^2}{A})\cdot e^{-(\sigma_g^2+m\frac{\sigma_I^2}{A})^{-1}I} \tag{1}$$

Power line noise indeed can be described adequately by that curve. The left part of the probability density function (see Fig. 4) is in fact the noise component when m=0 (no noise impulses occurred) and as claimed in [11-12] it corresponds to the gaussian component of the noise. The right part of the probability density function stands for the impulsive component of the noise. The model for the Middleton's class A noise when the random variable is expressed in dB has some special properties that are quite helpful when a researcher tries to extract the noise probability density function using data obtained by measurements. The model involves three parameters that are adequate to express the p.d.f. Those are the σ_g^2, which is the mean power of the gaussian noise, the σ_I^2 which is the mean power of the impulsive noise and A that expresses the impulsive noise traffic. σ_g^2 and σ_I^2 are connected through equation 2.



(a) (b)

(c) (d)

Fig. 4. Indicative normalized histograms of the noise power density at 4 different frequencies. The splines curve approximation is plotted to show the approximating p.d.f.'s shape.

$$\Gamma_A=\frac{\sigma_g^2}{\sigma_I^2} \tag{2}$$

Those three parameters necessary for equation 1 can be easily determined by a normalized histogram of the measured data. The mean power of the gaussian noise σ_g^2 is the point on x-axis that the left part of the p.d.f. has the peak. The height *h* of the left peak is connected with A with equation 3.

$$A=\ln(0.0847/h) \tag{3}$$

Finally, the distance on x-axis between the left peak and the right peak is connected with Γ_A with equation 4.

$$\Gamma_A=[A(10^{(X_{RightPeak}-X_{LeftPeak})/10}-1)]^{-1} \tag{4}$$

The proofs of equations (3) and (4) are included in [11].

The location on x-axis of the two peaks and the height of the left peak are prominent even when data measurements are rough. Therefore, the determination of the actual parameters of equation 1 is quite accurate. This is the main advantage of the described statistical extraction of the p.d.f.'s. In Table 1 the σ_g^2, Γ_A and A are presented for each measured frequency. Please note that in Table 1 the σ_g^2 has been transformed in dBm.

Table 1. PDF Parameters for 241 frequencies between 1.15MHz and 30 MHz.

Freq In MHz	A	$[\sigma_g^2]^{-1}$ in dBm	Γ_A	Freq In MHz	A	$[\sigma_g^2]^{-1}$ in dBm	Γ_A	Freq In MHz	A	$[\sigma_g^2]^{-1}$ in dBm	Γ_A	Freq In MHz	A	$[\sigma_g^2]^{-1}$ in dBm	Γ_A
1.1509	0.6473	39.177	0.0516	8.3632	0.7341	56.588	0.2592	15.5755	1.4584	80.227	0.0126	22.7877	1.4778	75.879	0.0425
1.2711	1.1791	43.145	0.0657	8.4834	0.8053	60.754	0.0831	15.6957	1.4207	80.243	0.0069	22.9079	1.5096	76.095	0.0462
1.3914	1.1683	40.745	0.0527	8.6036	0.7816	60.456	0.0950	15.8159	1.6037	80.259	0.0064	23.0281	1.4007	76.143	0.0593
1.5116	1.2860	43.092	0.0233	8.7238	0.7997	60.143	0.0365	15.9361	1.3302	80.275	0.0080	23.1483	1.4507	76.745	0.1143
1.6318	1.0503	43.406	0.0265	8.8440	0.7837	60.215	0.0404	16.0563	1.2536	79.992	0.0178	23.2686	1.5829	79.183	0.0269
1.7520	0.8003	44.030	0.0168	8.9642	0.8077	60.899	0.0151	16.1765	1.3030	79.961	0.0082	23.3888	1.5861	78.599	0.0488
1.8722	0.5559	45.953	0.0192	9.0844	0.8371	60.971	0.0388	16.2967	1.3036	79.929	0.0075	23.5090	1.5114	76.168	0.0864
1.9924	0.7466	44.698	0.0143	9.2046	0.7878	60.786	0.0424	16.4169	1.3744	80.525	0.0128	23.6292	1.3661	76.384	0.1045
2.1126	0.8947	47.183	0.0050	9.3248	0.8039	60.529	0.0162	16.5371	0.0797	65.686	1.8575	23.7494	1.4662	76.553	0.0510
2.2328	1.0238	46.480	0.0224	9.4450	0.8225	64.086	0.0180	16.6573	1.3475	80.478	0.0116	23.8696	1.4388	76.409	0.0485
2.3530	1.0736	46.379	0.0562	9.5653	0.7019	64.187	0.0218	16.7775	0.4281	61.426	0.2962	23.9898	1.7077	80.886	0.0260
2.4732	1.1645	46.630	0.0052	9.6855	0.6088	64.275	0.0287	16.8977	0.4477	61.056	0.1215	24.1100	1.8151	80.541	0.0225
2.5934	1.0678	48.663	0.0040	9.8057	0.6145	64.890	0.0141	17.0179	0.2827	61.426	0.2033	24.2302	2.3668	73.348	0.0195
2.7136	1.0305	48.688	0.0106	9.9259	0.4381	63.811	0.0271	17.1381	0.1740	62.110	0.7616	24.3504	0.3921	61.178	1.0847
2.8338	0.8528	48.475	0.0132	10.0461	0.4083	62.518	0.0834	17.2583	1.3948	81.059	0.0100	24.4706	0.7493	63.804	0.2599
2.9540	0.7928	48.061	0.0138	10.1663	0.4394	61.865	0.0489	17.3785	1.3420	80.808	0.0121	24.5908	0.5216	65.686	0.3403
3.0742	0.7882	48.387	0.0128	10.2865	0.5268	62.066	0.0442	17.4987	1.5211	81.718	0.0202	24.7110	1.9598	81.090	0.0310
3.1944	0.9366	54.931	0.0025	10.4067	0.4649	61.419	0.0299	17.6189	1.4320	81.153	0.0123	24.8312	1.8386	81.404	0.0182
3.3146	0.9044	55.559	0.0008	10.5269	0.5045	62.474	0.0500	17.7392	1.6014	80.855	0.0167	24.9514	1.5973	76.676	0.0686
3.4348	0.7988	54.690	0.0103	10.6471	0.5387	63.085	0.0181	17.8594	2.0584	81.169	0.0045	25.0716	1.5243	76.507	0.0762
3.5550	0.7964	55.245	0.0030	10.7673	0.4816	59.883	0.0429	17.9796	1.6786	74.772	0.0257	25.1918	1.6781	81.404	0.0199
3.6752	0.7783	55.872	0.0103	10.8875	0.6362	63.456	0.0141	18.0998	1.5177	74.844	0.0294	25.3120	1.7590	81.090	0.0345
3.7954	0.7552	55.487	0.0103	11.0077	1.7610	74.063	0.0262	18.2200	1.4590	75.086	0.0296	25.4322	1.6803	80.808	0.0121
3.9156	0.7860	55.318	0.0031	11.1279	1.6517	70.989	0.0125	18.3402	1.4940	77.896	0.0299	25.5524	1.7474	81.090	0.0144
4.0358	0.8079	56.161	0.0110	11.2481	1.5940	70.891	0.0143	18.4604	1.4701	80.525	0.0120	25.6726	1.7255	80.463	0.0087
4.1561	0.8333	57.972	0.0031	11.3683	1.6182	74.239	0.0032	18.5806	1.4708	79.600	0.0063	25.7928	2.2627	72.808	0.0091
4.2763	0.9184	58.815	0.0335	11.4885	0.1751	54.186	1.7358	18.7008	1.3310	75.882	0.0303	25.9131	0.8363	54.549	0.1451
4.3965	0.9584	53.533	0.0309	11.6087	0.3574	57.903	0.3790	18.8210	0.4194	62.690	0.4433	26.0333	0.6343	53.608	0.2089
4.5167	0.9705	54.273	0.1037	11.7289	0.3781	58.032	0.3505	18.9412	1.3066	76.773	0.0201	26.1535	0.2695	51.073	0.4706
4.6369	1.0346	59.901	0.0095	11.8491	0.3187	57.348	0.3979	19.0614	1.3162	79.584	0.0137	26.2737	0.5325	59.255	0.1759
4.7571	0.9704	55.189	0.0330	11.9693	0.2808	57.517	0.5159	19.1816	1.3875	77.363	0.0137	26.3939	1.8422	80.431	0.0100
4.8773	0.8876	56.331	0.0376	12.0895	1.9957	71.986	0.0183	19.3018	1.3858	80.400	0.0093	26.5141	1.6762	73.937	0.0735
4.9975	0.9164	56.407	0.0419	12.2097	1.8833	71.221	0.0114	19.4220	1.3598	80.369	0.0087	26.6343	1.2903	76.409	0.0540
5.1177	0.8453	61.466	0.0493	12.3300	1.8677	72.030	0.0102	19.5422	1.3296	80.729	0.0222	26.7545	1.2770	79.013	0.0214
5.2379	0.7167	58.063	0.0582	12.4502	1.9834	75.506	0.0045	19.6624	1.3992	80.290	0.0070	26.8747	1.3042	80.933	0.0331
5.3581	0.7098	58.051	0.0212	12.5704	2.0405	74.188	0.0068	19.7826	1.3192	80.212	0.0133	26.9949	1.4595	81.075	0.0428
5.4783	0.7089	59.004	0.0588	12.6906	2.0379	74.502	0.0068	19.9028	1.3674	80.055	0.0184	27.1151	1.2915	80.792	0.0511
5.5985	0.7734	62.383	0.0199	12.8108	2.0204	74.276	0.0074	20.0230	1.3737	77.677	0.0139	27.2353	1.1786	80.871	0.0225
5.7187	0.6680	61.078	0.0285	12.9310	1.9232	74.859	0.0075	20.1432	1.3782	79.929	0.0317	27.3555	1.2460	81.122	0.0201
5.8389	0.7244	61.247	0.0250	13.0512	2.0001	74.276	0.0075	20.2634	1.4266	76.698	0.0202	27.4757	1.1212	78.562	0.0364
5.9591	0.8240	61.222	0.0244	13.1714	1.9396	77.294	0.0017	20.3836	1.3112	76.152	0.0297	27.5959	1.1397	78.875	0.0962
6.0793	0.9394	64.579	0.0057	13.2916	1.8793	77.294	0.0036	20.5039	1.0554	75.700	0.0423	27.7161	1.0863	79.007	0.1101
6.1995	0.9013	60.346	0.0502	13.4118	1.8679	77.576	0.0069	20.6241	1.1605	75.707	0.0152	27.8363	1.0501	79.007	0.0619
6.3197	0.8907	61.275	0.0188	13.5320	1.9409	77.843	0.0059	20.7443	1.1608	76.108	0.0164	27.9565	1.0379	78.964	0.0187
6.4399	0.9094	65.639	0.0199	13.6522	1.7157	77.545	0.0069	20.8645	1.2252	77.451	0.0168	28.0767	1.1016	78.875	0.0291
6.5601	0.8965	65.809	0.0068	13.7724	1.8117	77.561	0.0068	20.9847	1.3130	77.583	0.0340	28.1969	1.0993	78.336	0.0572
6.6803	0.9241	65.398	0.0073	13.8926	1.9316	77.278	0.0069	21.1049	1.4544	78.166	0.0445	28.3171	1.1614	78.699	0.0842
6.8005	1.0060	65.614	0.0200	14.0128	2.0784	74.458	0.0284	21.2251	1.4562	77.721	0.0268	28.4373	1.1157	78.518	0.0508
6.9208	1.0575	61.627	0.0241	14.1330	1.9594	77.357	0.0083	21.3453	1.4386	77.407	0.0271	28.5575	1.2202	77.000	0.0893

7.0410	1.1428	69.463	0.0096	14.2532	1.8488	78.000	0.0092	21.4655	1.3724	78.210	0.0636	28.6778	1.0509	79.051	0.0641
7.1612	0.9522	65.586	0.0136	14.3734	1.6443	78.361	0.0059	21.5857	1.3676	78.160	0.0473	28.7980	0.9528	78.556	0.0785
7.2814	0.9058	65.005	0.0169	14.4936	1.3975	78.078	0.0148	21.7059	1.3875	78.562	0.0231	28.9182	0.9172	78.556	0.0815
7.4016	1.0350	65.200	0.0122	14.6138	1.4484	78.376	0.0137	21.8261	1.4926	77.633	0.0494	29.0384	0.9318	78.825	0.0775
7.5218	1.2456	62.756	0.0234	14.7340	1.8749	70.035	0.0404	21.9463	1.4616	78.072	0.0187	29.1586	0.9469	79.365	0.0398
7.6420	0.9352	51.182	0.6682	14.8542	1.9446	69.244	0.0134	22.0665	1.5001	75.446	0.0341	29.2788	0.8845	78.781	0.0444
7.7622	1.2224	63.735	0.0072	14.9744	1.3320	61.921	0.2098	22.1867	1.4802	75.832	0.0680	29.3990	0.8786	79.095	0.0447
7.8824	0.9848	60.610	0.0600	15.0947	1.3147	62.235	0.2126	22.3069	1.4108	75.663	0.0218	29.5192	0.8541	78.825	0.0478
8.0026	0.8836	60.554	0.0697	15.2149	0.3586	59.873	0.3170	22.4271	1.4565	75.663	0.0116	29.6394	0.8495	78.556	0.0501
8.1228	0.8527	60.183	0.0284	15.3351	0.0572	59.456	6.3227	22.5473	1.4429	75.180	0.0231	29.7596	0.8251	78.380	0.0247
8.2430	0.8950	60.369	0.0702	15.4553	1.4223	80.243	0.0134	22.6675	1.5413	76.024	0.0244	29.8798	0.5271	78.204	0.0321
30	1.0051	79.914	0.0168												

The exact weightiness of the σ_g^2 and σ_I^2 parameters is shown in fig. 1 where both of them are plotted simultaneously with all of the noise measurements. The lower dark line is σ_g^2 and the upper dark line is σ_I^2. Neither the one nor the other can be considered as average values of the noise power for every frequency. σ_I^2 does not fluctuate as much as σ_g^2 does. The explanation is simple. The frequencies where σ_g^2 exhibit notches are probably frequencies of radio stations (i.e. narrowband noise). As radio stations have almost constant transmission power their power is added to the background noise level of the power lines because the model cannot distinguish it from the underlying background noise as the latter varies by time in terms of hours just like the power originating from the radio stations. This fact has as consequence the model to be slightly misled and the impulsive noise level to be stronger than it is actually at the frequencies where radio stations transmit. From Fig. 1 it is evident that at the frequencies where σ_g^2 has great notches, the impulsive noise σ_I^2 also seems to be reinforced. The reader can easily see from equation (2) that for certain Γ_A when σ_g^2 is increased, σ_I^2 is also increased.

Finally, the greater the A parameter the more frequent the impulsive noise is. Hence, from Table 1 we can distinguish the frequencies that impulsive noise prefers and hits more frequently. Frequencies greater than 11MHz suffers from greater impulsive noise traffic.

4 Validity Limits of the Power Line Channel Noise Models

In this section some comments are made about the validity limits of the power line channel models. It was observed that the strong and almost constant radio station's emission affects negatively the operation of the models. As already mentioned in section 3 regarding these strong power emissions as constituents of the gaussian component of the power line noise, the impulsive noise power is depicted stronger than it is actually. This was observed when we plotted together the histogram of the noise samples (actual p.d.f.) with the p.d.f. originated from Middleton's formula. Although, the left part of the p.d.f. matched well, the right part could not fit perfectly, even when 100 members of the summation of equation 1 was used. Those frequencies present greater R.M.S.E. (root mean square error) between the smoothing splines curve approximating the actual p.d.f. and the curve from equation 1, compared to the R.M.S.E. in frequencies where there were no radio stations transmissions.

On the other hand, due to the significant correlation that the noise samples have, we can extract noise models for frequencies that are not included in Table 1 by means of interpolation. Obviously, the more narrow the frequency step of the noise measurements is, the more accurate interpolation can be.

The Middleton's canonical formula for class A noise was constructed to describe noise phenomena in the time domain in the first place. In this paper it was used in the frequency domain as it was found, after statistical analysis of the data measured in the frequency domain, that equation 1 can describe sufficiently the p.d.f. of the noise spectral density for every measured frequency. The p.d.f.'s parameters extraction is the major contribution of this study.

5 Conclusions and Further Research

In this paper a power-line channel noise model is proposed. It is based entirely on measurements in the frequency domain since OFDM, is a prominent candidate for power line communications. The model is in fact a family of parallel models in the frequencies of interest. The frequency distance between two models is 120.2KHz. We used thousands of spectrum analyzer sweeps in the frequency range of interest. The family of the noise models must be enhanced with new members. This can be achieved shortening the frequency distance and perform a new campaign of measurements. The narrower the frequency distance is, the more accurate the power line model can be. The enhanced p.d.f.'s family will be attained shortly. Additionally, the dependency of the A, s_g, s_i, from the frequency is a next step in our research.

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