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IN-HOME POWER LINE FREQUENCY DOMAIN NOISE MEASUREMENT AND ANALYSIS FOR BROADBAND COMMUNICATION

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ABSTRACT

In this paper, frequency domain noise measurement and analysis is presented for in-home power line broadband communication. A design measurement system was set up that captured the noise in frequency domain for broadband indoor power line communication. Noise samples were captured with spectrum analyzer in the frequency band from 3 to 30MHz considered to be range of frequencies for in-home power line broadband communications system.The measurement were conducted in residential buildings at Afe Babalola University Nigeria, within months; April, May and early June, 2020. From the measured data, the parameters of the noise measurements in terms of its noise amplitude, noise power level, and power spectral density were examined. Our study confirms and mirror those of the previous findings and contributes additional evidence that suggest considrably that more work will need to be done to mitigate the effects of noise in an indoor PLC environment.

Keywords: background noise, narrowband noise, impulsive noise, frequency domain, powerline network.

1. INTRODUCTION

The power line communication (PLC) is a technology that entails the use of electrical power network transmission for conveyance of data communication. PLC utilizes the already installed power line network to transmit information such as data, video and voice messages. This technology is attractive because it leveraging on an infrastructure that is already in place for electrical power transmission. The electrical power network is an ubiquitous and expansive network all over the world. The development is faster where broadband power line communication lines are available and slower where it is not available. The inhabitants of these unavailable areas feel isolated and lagging behind from the rest of the world. The power line communication significantly influences the economic and the social growth of that region [1]. PLC has numerious advantages among which are avoidance of new installation of cables, since the already installed electrical power can also be utilized for data transmission. It allows access to internet via wall socket at homes and offices. The same socket that power electronics gadget enable us to access the internet from the power line [2]. Similar advantages and diverse applications of PLC are load management and control, remote meter reading, control of street lighting, power home automation and networking, provision of video services,voice data and internet services, among others [3]. Unlike many other technology, PLC is faced with numerous technical challenges as a result of environment in which it operates. The problems and significant challenges associated with PLC channel are mainly due to the fact that the channel characteristics are very dynamic due to many branches of the network, significant difference in topology, the varying cable diameters found in different section of the grid, unknown characteristics of the power cable, and the electrical devices connected to the network [4] [5]. The electrical appliances connected to the powerline network generates noises which are stationary and impulsive in nature. It can also be induced into the network from external sources, transient activities or faults. All these and the power devices are a source of noise in PLC which is a major cause of transmission errors during On/OFF switching. The noise produced by these equipments can wipe out data streams, causing loss of communication. The frequency dependent attenuation, multipath and noise are the major impairment of PLC channels and of all these, noise is the greatest of all [6]. The multipath effects are caused by the reflections of the signal back and forth at different cable joints. The signal reflections at the various cable joints are due to the complex nature of the power network. It is also caused by the impedance mismatches which is mainly dependent of physical topology and characteristics of the of the channel [7]. The quality of the channel are determined by these two factors.The quality is mostly a parameters of the attenuation of the electrical signals at different frequencies and noise level at the receiver end. The higher the noise level, the tougher it is to detect the received signal.When the signals on it way to the receiver gets attenuated, this could make decision harder because the signal gets more hidden by the noise, which is expressed as signal-to-noise-ratio (SNR level of the signal [8]. The signal to noise ratio (SNR) is a measure to enumerate how much a signal has been corrupted by noise [1]. Therefore, if the noise is strong and signal is weak, the SNR will be low and reception will be poor and unreliable. Hence, the higher the SNR, the better is the communication. In power network, SNR can be expressed in voltage or power values but majorly expressed in terms of power rather than voltage.

For voltage in decibels:

$$V_{dB} = 20Log10\frac{P_{Signal}}{P_{Noise}} \quad (1)$$

For power in decibels:

$$\mathrm{P_{dB}} = 10\mathrm{Log}10\frac{\mathrm{P_{Signal}}}{\mathrm{P_{Noise}}} \quad (2)$$

The SNR higher than 0 dB implies higher signal power than the noise. If the signal ratio is less than 1, the decibel value will be negative, which designates stronger noise [1].

However, of all the factors that impede ideal powerline communication network, noise interference is the most critical factor affecting the performance of PLC. The design of high performance PLC required a full understanding of the indoor noise both in time and frequency domain. In contrast, the noise in communication system is said to be Additive White Gaussian (AWGN), while the noise in powerline network differs from Additive White Gaussian noise found in many other communication systems. Non-Gaussian but additive, very complex and unpredictable. Also, noise in PLC systems can also be regarded as white noise only in a broadband range and hence, in narrowband range, the noise is coloured [2]. Acording to International Telecommunication Union (ITU), broadband PLC systems occupies a wide available frequency bands that can be grouped into three categories; broadband PLC technology (1.8 MHz-250 MHz), Narrow - band PLC technology (3 KHz - 250 MHz), and Ultra - narrow band PLC technology (30Hz - 3 KHz) [6], [9].

In this paper, measurement results and analysis of the noise phenomena measured in indoor low voltage distributions residential building, and apartment blocks, with reference to the frequency band suitable for broadband indoor power line communications is presented. The noise samples were measured with spectrum analyser in frequency domain, in the bands from 3-30MHz, which is a range of frequencies for indoor power line communication systems [10]. In that context, line impedance, attenuation and noise effects vary with frequency, time and location. This makes it a serious challenge to measure, characterize and model the broadband indoor powerline communication. Moreover, to analyse and define the nature of power line channel, noise is significant parameter that required measurement and characterization in broadband PLC.

2. CLASSIFICATION OF NOISE IN PLC

The transmitted signals designated as, $X_{(t)}$, passes through a PLC channel by its channel transfer function $H_{(f)}$. At the transmitting end, numerous types of noise are added before reaching the receiver side as depicted in Figure-1. The noise is complicated due to different sources of disturbances. The noise measurement at a wall socket can be classified into three categories: coloured background noise, impulsive noise, and narrow-band interference noise [6], [11]. In [12], the noise are grouped into five: coloured background noise, periodic impulsive noise synchronous with the mains frequency, narrowband noise, periodic impulsive noise asynchronous with the mains frequency, and asynchronous noise [2], [13].

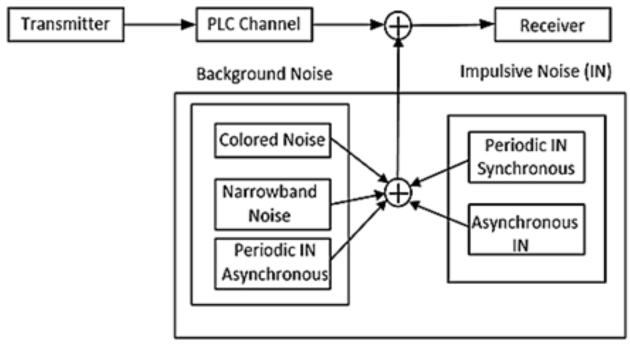

Figure-1. Power line channel Noise [3], [6].

2.1 Background Noise

This is mainly caused by the superimposition of different noise sources from domestic appliances [14]. These appliances can create disturbances in frequency range 0-100 MHz herein considered [13]. The domestic appliances include; desktop, laptop computers, Television sets, light dimmers, microwave oven, cooker, electric iron, electric blender, microwave oven among others. The noise can also be coupled to the powerline network via radiation and conduction from external source which can be assumed to be cyclostationary with level that is absolutely dependent on the type of connected electronics and electrical equipment's to the network[15]. Background noise is the summation of all the numerous sources of white noise with variable amplitudes across the frequency band [6], [11]. It is characterized by a low power spectral density (PSD) and this PSD tend to increases as the frequency decreases. In the frequency band closer to the power mains (50Hz or 60Hz), the PSD attains a significant high value [6], [11]. Therefore the power present in the signal of a background noise is a function of frequency per unit frequency otherwise known as PSD. It actually shows the frequencies at which variation are both strong and weak. It is very low and to large extent increases towards lower range of frequencies. It has average range between -140 and -125dBm/Hz [2]. The colored background noise is given as $[n_{bG}\ (f)]$,

$$[n_{cG}\ (f)] = N_\infty + N_0\, N_{0\,f0}^{\,f} \quad (3)$$

where $[n_{cG}\ (f)]$ is the power spectral density of the background noise and the constant noise density is $N_{\infty,}$ Hence, $f_{0,}$ and $N_{0,}$ are the constraints of the exponential function. The narrow band noise is given as:

$$[n_{nb}\ (f)] = \sum_{i=1}^{N} A_i\ \ (t)\ .Sin(2\pi f_i\ t + \varphi) \quad (4)$$

where,

N indicates the entire number of narrowband interference, and $A_i(t)$, represent amplitude, f_i, frequency level, and φ, the Phase of the conventional narrowband noise. Hence, the power spectral density of a background noise is equal to sum of colored background noise and narrowband noise and this can be expressed from (3) and (4) as:

$$[n_{bG}(f)] = [n_{cG}(f)] + [n_{nb}(f)] \quad (5)$$

where, $[n_{bG}(f)]$, is the power spectral density, $[n_{cG}(f)]$ is the color background noise and $[n_{nb}(f)]$, is the narrowband noise respectively [1]

2.2 Impulsive Noise

The major causes of impulsive noise emanate from switching of rectifier diodes. The impulsive noise includes different components that can be classified as; periodic impulsive noise synchronous with the mains, periodic impulsive noise asynchronous with the mains and asynchronous impulsive noise respectively. The periodic impulsive noise synchronous with the mains is caused by silicon controlled rectifiers in power supplies and it is synchronous with the frequency of 50/100Hz in Europe/Africa/ and 60/120 Hz in United State [13], [16]. Also, periodic impulsive noise asynchronous with the mains is mainly caused by periodic impulses and switching power supplies that are found in various home appliances. It has repetition rates between 50KHz and 200KHz [13]. Both the former and the latter are however, time variant in terms of microseconds and milliseconds. The PSD of the noises are higher during the occurrence of such impulses and this may cause bit or burst errors in data communication [2] [17]. In addition, asynchronous impulsive noise is mainly caused by switching transient in the network. The durations of the impulses are from microseconds up to few milliseconds coupled with random arrival times(s). The PSD values of this noise can be more than 50dB above the background noise [3].

The determination of the impulsive noise has mainly been in the time domain using digital storage oscilloscope triggered by peak detection output [6]. Impulsive noise is characterized by high amplitudes and short durations ranging from microseconds to milliseconds. The power spectral density of this noise can be up to 50dB above the background noise during occurrence [6]. Hence, the resultant noise is the sum of the two majour noise terms:

$$n(t) = n_b(t) + n_{imp}(t) \quad (6)$$

where, $n_b(t)$, represent the background noise, and $n_{imp}(t)$, is the impulsive noise

3. NOISE MEASUREMENT DESCRIPTIONS

An intensive noise measurement was carried in an indoor staff quarter residential apartment at Afe Babalola University Nigeria. It is on Latitude 7.659470, and Longitude 5.229610. The measurements were carried out in frequency domain using spectrum analyzer GSP-930. This is to obtain the noise frequency response in the frequency band from 3-30MHz [18]. The spectrum analyzer is a 3 GHz designed upon a new generation platform. It has a very low noise floor and provides a high frequency-stability and several tools for setting the sweep range. The continuous range of sweep variables such as power frequency and sweep points time when the analyzer takes measurement is simply refers to as the sweep range. It records and stores the measured data on the external storage in other to obtain the display trace. The trace setting specified the mathematical operations used to obtain traces from the measured data. The stored data was accessed through the analyzer's universal serial bus (USB) connectors, which are used to connect external storage devices for further external processing and analysis [19]. Table-1 shows the parameters of the spectrum analyser.

An AC coupling circuit (Steval-XPLMOICPL) power line communication was used mainly to detach the measuring equipment's from the AC mains. It serves as an interface between the measuring device and the PLC channel. The coupling circuit provides galvanic isolation between mains and measurement equipment and equally facilitates unique reception of the noise signals [2]. It is suitable for laboratory equipment like a spectrum analyzer and to inject a signal from an arbitrary function generator. The coupling circuit is a simple yet very useful tool for power line communication testing on AC power network. It has - two wire connectivity to any PLC receiver or transmitter and a standard connector for an AC power cord.

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Table-1. GSP-930 Spectrum analyzer parameters.

Frequency range	**9KHz - 3GHz**
Resolution and Gain	1 Hz, 18dB
Phase noise	-88dBc/Hz at 1GHz, 10KHz
Noise floor	-142dB
Sweep points	601, span > 0, 6 to 601, span = 0
Sweep mode	Continuous; Single
Resolution	1Hz, 10Hz, 100Hz, 1KHz
Power source	AC 100v to240v, 50/60 Hz
Amplitude range	10MHz to30GHz DANL 30dBm
Connector type	BNC Female
Output impedance	50 ohms
Internal data storage	16MB Nominal
Power Consumption	< 65 W
Warm up time	< 30 minutes
Weight	4.5Kg
Display Average Noise Level [DANL]	10MHz to 3MHz, < -122dB
Various interface	USB Host/drive, RS-232C.
High frequency stability	25ppb (0.025ppm)
Built-in measurement functions	Channel power, N- Db Bandwidth, OCBW, CSO.

The coupling circuit schematic and block diagram are shown in Figures 2 and 3.

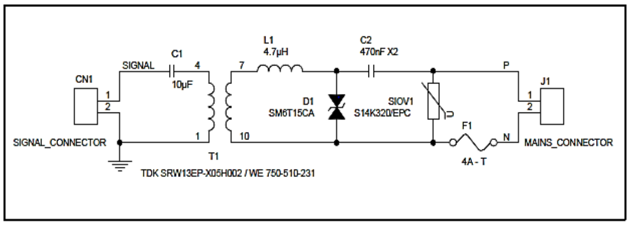

Figure-2. Coupling Circuit [2].

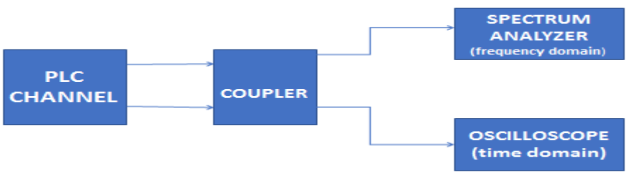

Figure-3. Noise measurement block diagram.

The main components to achieve suitable signal coupling are; PLC 1:1transformer for differential coupling and basic electrical isolation. It has a high voltage AC blocking capacitor with X_2 safety class as well as a varistor for effective protection against voltage spikes large enough to damage the measuring equipments. The turning series is used to adjust the frequency response. However, under normal condition, the frequency response of the coupling circuit is wide enough to fit any narrow-band PLC signals [20]. It can be adjusted easily by changing the turning series inductor L_1 [2]. Algorithm was developed to determine the time frame for the noise measurements. The ultimate goals of the algorithm is to produce a graphical illustration of time, day, and months the measurement was carried out as depicted in Figures 4-7. The noise measurement was carried out within months; April, May and early June 2020 between the hours of 7:00am and 7:00pm, Monday to Saturday. Those times are selectively distributed over the weeks of investigation to capture the actual noise induced at different time of the day into the power line network when the electrical devices are connected to the power network. The proposed algorithm for figure 4-7 is given as;

```
y = [7 8 9 10 11 12; 8 9 10 11 12 13];
bar(y)
set(gca, 'xtick',1:2);
```

Therefore,

```
Set (gca, 'xticklabel',{'April (Week1)','April (Week2)'});
```

where,

y, represent measurement time that varies accordingly.

The dimension of array being concatenated are consistence (Monday to Saturday). The durations varies accordingly and applicable to other figures. The electrical loads connected to the power line network were classified

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into inductive loads, capacitive loads and resistive loads respectively.

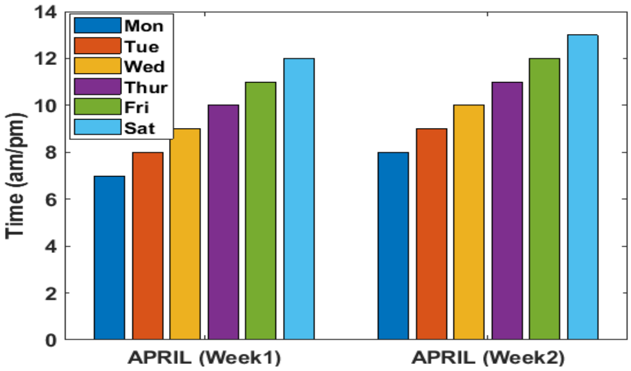

Figure-4. Week 1 and 2 noise measurement duration.

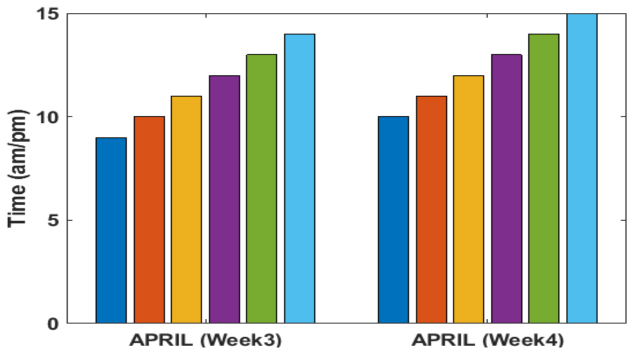

Figure-5. Week 3 and 4 noise measurement duration.

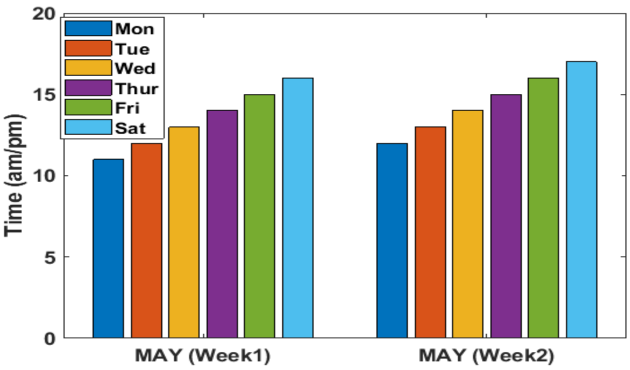

Figure-6. Week 1 and 2 noise measurement duration.

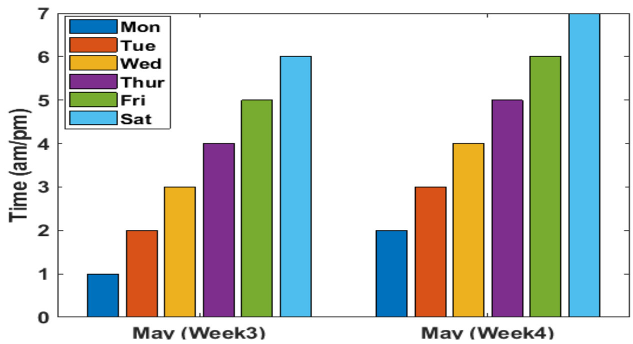

Figure-7. Week 3 and 4 noise measurement duration.

4. POWER SPECTRAL DENSITY ESTIMATION

Power spectral density characterizes the frequency content of signal and also describes how power of a signal is distributed over frequency. It shows at which frequencies variations are strong and weak, and that might be quite useful for further analysis [21]. Periodogram method was used for the noise power spectral density estimation [15]. It is an estimate of the power spectral density of a signal. The method provides a good estimate of noise power spectral at different frequencies. A high resolution spectral analysis of recorded background noise is shown in Figures 17-23. The record has a length of 3ms, and the spectral estimation was performed using periodogram method. It shows signals having different intensity at different frequencies. The units are decibel against frequency. The decibel part indicates that a decibel scale is used, which shows that it is scale relative to a reference value. The periodogram PSD of all the electrical devices connected to the power network increases at lower frequencies and decreases at higher frequencies.The PSD of a continuos function, $x(t)$, is the Fourier traansform of its auto-correlation function [22].

$$F[x(t) * x(-t)] = X(f) \,.\, X^{*}(f) = |X(f)|^{2} \qquad (7)$$

For parameter T with small value, an arbitrarily accurate approximation for $X(f)$ can be observe in the region;

$$-\frac{1}{2T} < f < \frac{1}{2T}$$

of the function:

$$X_{\frac{1}{T}}(f) = \sum_{K=-\infty}^{\infty} X\left(f - \frac{K}{T}\right) \qquad (8)$$

Determined precisely by the samples$x(nT)$, that span the non-zero duration of $x(t)$.

Hence, for a large values of parameter N, $X_{\frac{1}{T}}(f)$, is evaluated through an arbitrarily close frequency by summation of the form

$$X_{\frac{1}{T}}\left(\frac{K}{NT}\right) = \sum_{n=-\infty}^{\infty} T.\, x(nT) \,.\, e^{-i2\pi\frac{Kn}{N}} \qquad (9)$$

Where; $T.x(nT) = x(n)$

and K, is an integer. The periodicity of $e^{-i2\pi\frac{Kn}{N}}$ allows this to be written in discrete Fourier transform.

$$X_{\frac{1}{T}}\left(\frac{K}{NT}\right) = \sum_{n} x_N\,[n] \,.\, e^{-i2\pi\frac{Kn}{N}} \qquad (10)$$

Where the periodic summation is:

$$x_n\,[n] = \sum_{n=-\infty}^{\infty} x[n - mN] \qquad (11)$$

For all integers K, between 0 and N-1, when evaluated the array therefore, is,

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Periodogram:

$$S\left(\frac{K}{NT}\right) = \left|\sum \quad x_N\,[n].\; e^{-i2\pi\frac{Kn}{N}}\right| \;\hat{}\,2 \qquad (12)$$

Therefore, for good estimate of noise power spectral density and signal power at different frequencies, periodogram is a good estimation method.

5. RESULT AND DISCUSSIONS

The result of the frequency domain noise were presented and obtained a geographical representation of the noise in the frequencies range from 3-30MHz and the power spectral density of the background noise for both the best case and worst case scenario. We used a simple three-parameter model commonly accepted in literature [13], [6], where the noise is considered to be Gaussian with the power spectral density (PSD) given as [23];

$$\mathrm{PSD}\ (\mathrm{f}) = \mathrm{a} + \mathrm{b}\ |\mathrm{f}|^{\mathrm{c}} \quad [\mathrm{dBm/Hz}] \qquad (13)$$

Where, a, b, and c are measurement parameters and f is the frequency range from 3-30MHz. we obtained a best case scenario by setting the parameters (a, b, c) = [-140, 38.75, -0.72] and obtained the worst case scenario with the parameters (a, b, c) = [-145, 53.23, -0.337]. The results of the power spectral density are depicted in Figures 8 and 9.

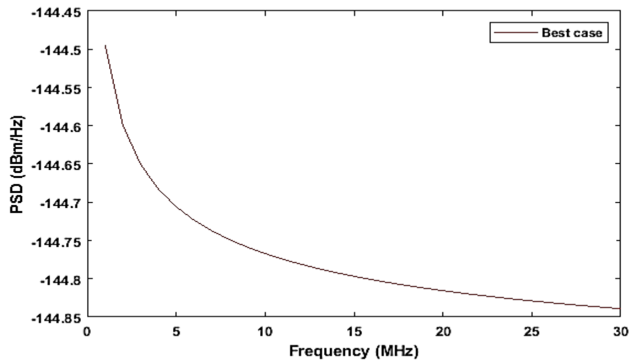

Figure-8. Good background noise PSD.

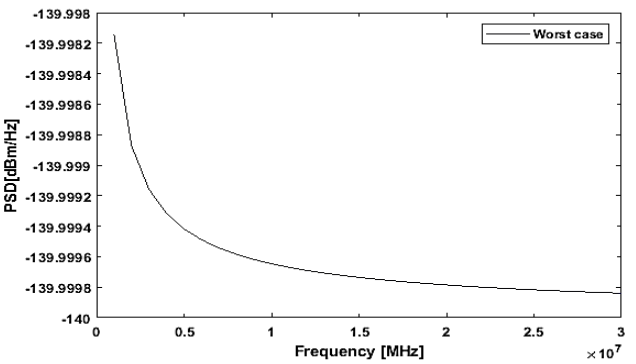

Figure-9. Bad background noise PSD.

The result obtained shows that the background noise has variability in frequency and hence, with parameter c, obviously less than zero, the background noise is much present in lower frequencies than in higher frequencies. The result observed in this study mirror those of the previous studies that have considered both best case and worst case scenario. Therefore, our results are compared to that of literature elsewhere as shown in Table-2.

Table-2. Background noise parameters.

Parameters		Background noise		
		A	**B**	**C**
Best case	Our measurement	-144	28.21	-0.710
	Esmillian et al. [24]	-140	38.75	-0.720
	Modisa et al. [6]	-135	30.71	-0.721
Worst case	Our measurement	-139	26.20	-0.390
	Esmillian et al. [24]	-145	53.23	-0.337
	Modisa et al. [6]	-140	45.26	-0.341

As Table-2 shows, our findings show a significant difference in best case and worst case scenario. This may be attributed to frequencies under consideration and different environment under study. Regardless of the different environments, noise could be defined with reference to power signal specification which differs from country to countries. For instance, Nigeria and South Africa power grids use 220V [50Hz] while United State uses 110V [60Hz]. This indicates that cabling method is different and therefore, the network topology and loading system are the main contributing factors.

By considering Figures 8 and 9, the background noise has reasonably low power spectral densities, which are mainly caused by residential electrical appliances like computer sets, television sets, and electric cockers among others. It shows that the PSD of the background noise increases as the frequencies decreases. It attains high values in the lower frequency range.

In addition, we obtained the noise amplitude level and noise power level through measurements and calculations. In our measurement, noise amplitudes were obtained from spectrum analyzer with span intervals 3 and 4 up to 30MHz lasting about 3 seconds using max-hold function of the measuring instrument. The spectrum analyzer resolution bandwidth was 1 KHz and in all our figures, the noise amplitude levels used is decibels as recorded by the instrument with that resolution. The reference amplitude at each frequency varies accordingly. The indoor electrical devices connected to the wall socket are; Television sets, laptop and desktop computer, Blender, cell phone, electric cocker, electric kettle, standing fan, and microwave oven among others. The noise power levels at a frequency band from 3-30MHz are calculated in equation (14). Due to space constraint, few of the results are shown in table 3 to 6. Hence,

$$\mathrm{P}_{(\mathrm{mW})} = 1(\mathrm{mW}) \times 10^{\mathrm{P}(\mathrm{dBm})/10} \qquad (14)$$

Where $P_{(mW)}$ is Noise power.

Table-3. Electric blender frequency domain noise amplitude and power.

Freq [MHz]	Span [MHz]	Ref. Ampl. [dBm]	Noise Ampl [dBm]	Noise Power [mW]
3.0	3.0	-40.0	-43.02	0.00004988
6.0	3.0	-30.0	-30.73	0.00084527
9.0	3.0	-20.0	-28.54	0.00139958
12.0	3.0	-30.0	-32.51	0.00056104
15.0	3.0	-30.0	-37.05	0.00019724
18.0	3.0	-30.0	-39.54	0.00010864
21.0	3.0	-30.0	-33.37	0.00046025
24.0	3.0	-10.0	-16.20	0.02398832
27.0	3.0	-10.0	-16.28	0.02355049
30.0	3.0	-10.0	-20.27	0.00939723

Table-4. Microwave oven frequency domain noise amplitude and power.

Freq [MHz	Span [MHz]	Ref. Ampl. [dBm]	Noise Ampl [dBm]	Noise Power [mW]
3.0	3.00	-40.00	-55.51	2.81×10^{-6}
6.0	3.00	-20.00	-22.95	5.07×10^{-3}
9.0	3.00	-20.00	-26.19	2.40×10^{-3}
12.0	3.00	-20.00	-27.85	1.64×10^{-3}
15.0	3.00	-30.00	-35.35	2.91×10^{-4}
18.0	3.00	-30.00	-22.94	5.08×10^{-3}
21.0	3.00	-30.00	-33.08	4.92×10^{-4}
24.0	3.00	-10.00	-25.52	2.81×10^{-3}
27.0	3.00	-10.00	-24.32	3.70×10^{-3}
30.0	3.00	-20.00	-24.47	3.57×10^{-3}

Table-5. Television set frequency domain noise amplitude and power.

Freq [MHz]	Span [MHz]	Ref. Ampl. [dBm]	Noise Ampl [dBm]	Noise Power [mW]
8.00	4.00	-30.00	-31.560	0.000698
12.00	4.00	-40.00	-44.390	0.000035
16.00	4.00	-30.00	-29.160	0.001213
20.00	4.00	-30.00	-35.260	0.000297
24.00	4.00	-20.00	-27.750	0.001678
28.00	4.00	-20.00	-25.430	0.002864
30.00	4.00	-10.00	-25.030	0.003140

Table-6. Laptop computer frequency domain noise amplitude and power.

Freq. [MHz]	Span [MHz]	Ref.Amp [dBm]	Noise Ampl [dBm]	Noise Power [mW]
8.00	4.000	-30.00	-52.350	0.0000058
12.00	4.000	-30.00	-37.670	0.0001710
16.00	4.000	-30.00	-38.590	0.0001380
20.00	4.000	-40.00	-40.050	0.0000988
24.00	4.000	-10.00	-28.940	0.0012800
28.00	4.000	-10.00	-25.810	0.0026240
30.00	4.000	-10.00	-25.460	0.0028440

Figures 10-16 illustrate waveforms observed in the frequency band 3-30MHz and their respective amplitudes. As shown in Figure-10, the results reveal that, at frequencies below 3MHz the noise induced by the electric blender into the power line network is very low. Likewise, at frequencies band 12MHz to 21MHz, noise level is low. While, at other frequencies band more pollution were observed coming from the device.

Figure-11 exhibits low noise level behavior at frequencies band below 3MHz. At higher frequencies, the microwave oven induced higher noise into the power line network. Similar behaviours are observed in Figures 13-16, where at low frequencies the noise decreases and increases at higher frequencies which indicate that more pollution were observed coming from these various electrical devices connected to the power line network. It was found that cell phone, electrical Iron, standing fan, and, electric cooker are sources of intensive noise. For example, cell phones were producing significant noise disturbances in 6MHz to 30MHz frequency band which is a majour cause of transmission error.

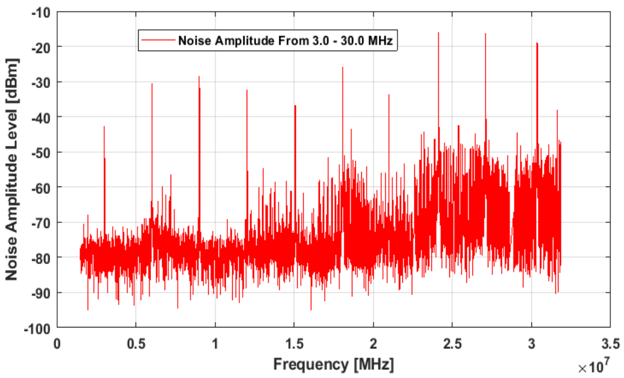

Figure-10. Blender machine observed noise phenomena from 3-30MHz frequency band.

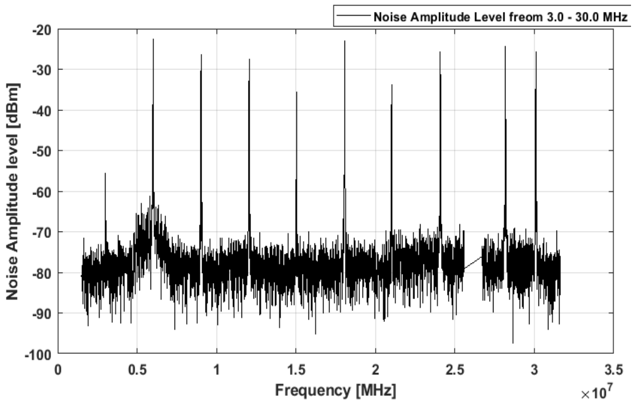

Figure-11. Microwave oven observed noise phenomena from 3-30MHz frequency band.

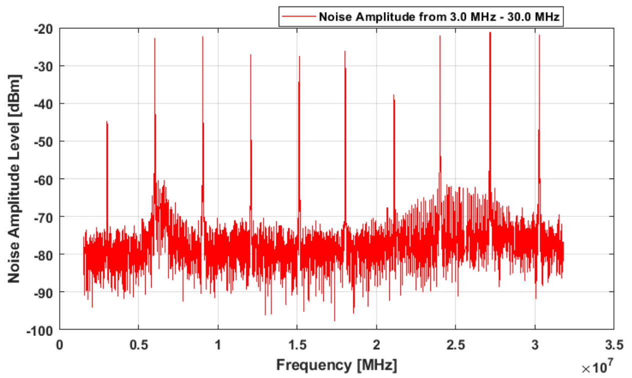

Figure-12. Cell phone observed noise phenomena from 3-30MHz frequency band.

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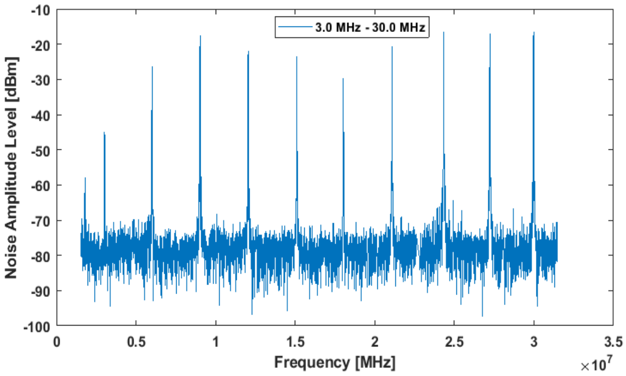

Figure-13. Electric iron observed noise phenomena from 3-30MHz frequency band.

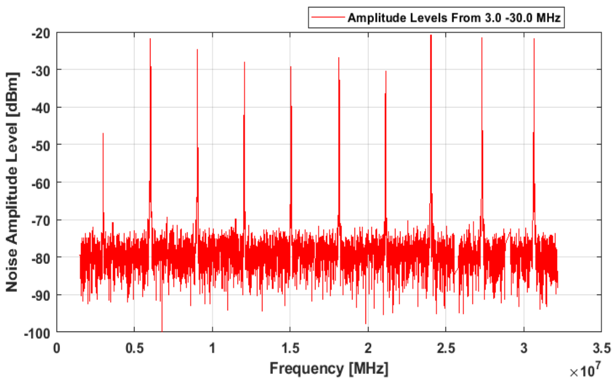

Figure-14. Standing fan observed noise phenomena from 3-30MHz frequency band.

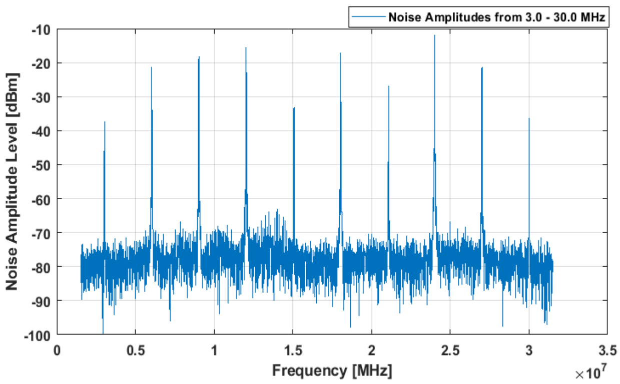

Figure-15. Electric Kettle observed noise phenomena from 3-30MHz frequency band.

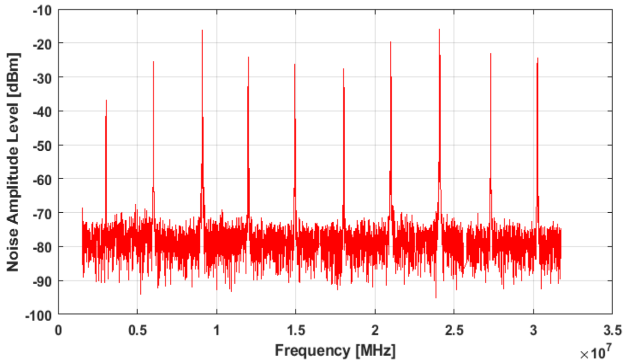

Figure-16. Electric cooker observed noise phenomena from 3-30MHz frequency band.

The PSD estimations are presented in Figures 17-23 which described how signal power is distributed over frequency and, at which frequencies variations are weak and strong. In [2], [25] broadband noise is generally characterized by a reasonably low power spectral density and this PSD tends to decrease as the frequency increases. Our findings justified this. The PSD of all the electrical devices connected to the power line network increases at lower frequencies and decreases at higher frequencies.

Based on our findings, our measurements can therefore be used to model the in-home broadband PLC to determine the likelihood probability distribution functions that in-home broadband PLC will follow. Several theoretic probability distribution functions; exponential cumulative distribution, Rayleigh distributions, Gaussian distributions among others can be tried to fit the data. The outcomes will determine the type of MODEM to be deployed for the in-home broadband PLC.

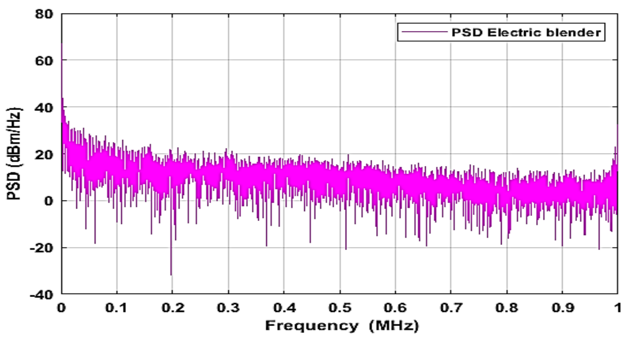

Figure-17. Periodogram power spectral densities for blender.

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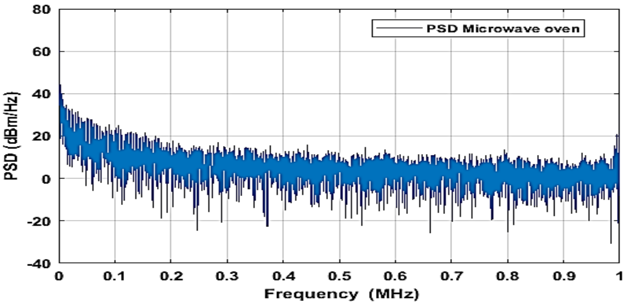

Figure-18. Periodogram power spectral densities for Microwave oven.

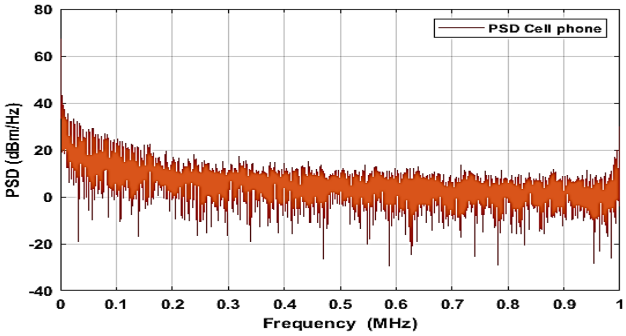

Figure-19. Periodogram power spectral densities for Phone.

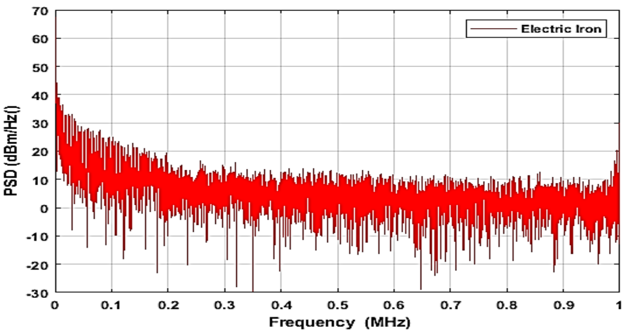

Figure-20. Periodogram power spectral densities for Electric iron.

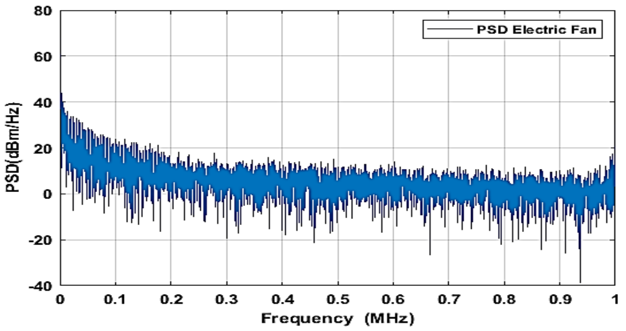

Figure-21. Periodogram power spectral densities for standing fan.

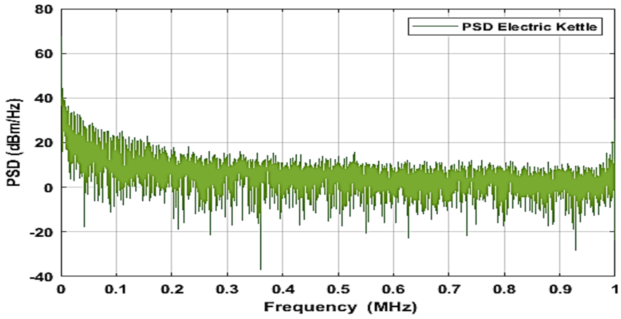

Figure-22. Periodogram power spectral densities for electric kettle.

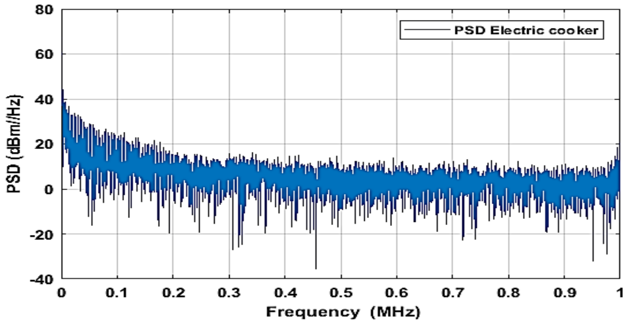

Figure-23. Periodogram power spectral densities for Cooker.

6. CONCLUSIONS

Regarding the hypothesis posed at the beginning of this study, we have been able to set up a measurement system and presented some of the results of our investigation of the noise scenario present in an indoor electrical distribution network, in the frequency band 3-30Hz for broadband indoor PLC. Vis-à-vis measurement and analysis, we established quite low noise level at lower frequencies than higher frequencies which emanated from the electrical devices connected to the power line socket at home. This can affect the reliability and quality of digital communication link. Therefore, this paper provides a more detailed investigation and has gone some ways towards enhancing our understanding regarding the effects of noise phenomena in an in-home broadband PLC. The uniqueness of these findings exists in the fact that in-home noise has been measured, analyzed and findings will help to determine the distributions the in-home broadband PLC will follow. Our study confirms and mirrors those of the previous findings and contributes additional evidence that suggest considerably that more work will need to be done to mitigate the effects of noise in an indoor PLC. In order to overcome these obstacles, a robust and reliable channel noise modeling and coding techniques must be considered.

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