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The Effect of Spread Spectrum Modulation on Power Line Communications

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Abstract: Interference in Power Line Communication (PLC) is examined in this paper. PLC is a wired communication technology that provides communication and data transmission over the existing electrical network. It uses the electrical wiring in buildings or the electrical grid to transmit data signals between devices, rather than using dedicated communication cables or wireless signals. Many applications employ PLC technologies, which have the benefit of leveraging existing power connections for both power and data transfer, reducing cost and complexity. These interactions may be observed in contemporary smart grids and automobile power networks, where lengthy cables, switching power supplies and communication links all work together but exacerbate Electromagnetic Interference (EMI) problems. This research examines the effects of spread spectrum methods used to reduce EMI from power converters on PLC systems. Spread Spectrum Modulation (SSM) and its three variants, Sine, Random and Sawtooth, are frequently employed to meet the requirements of electromagnetic compatibility, however, there are some repercussions that may be detrimental to the converter or the rest of the electrical network. These outcomes occur for various modulation algorithm settings and at various frequencies. Measurements are made utilising the Frame Error Rate (FER) value provided by the PLC link system to ascertain the interference produced by a Silicon Carbide (SiC)-based DC-DC converter in order to investigate these concerns and standardise an assessment approach. To examine the effect of SSM on reducing EMI in the frequency domain, the peak index of a CISPR-16 EMI receiver is used.

Keywords: power line communication; modulation; spread spectrum; DC-DC converter; EMI mitigation

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1. Introduction

Power Line Communication (PLC) is a widely used communication method. It makes use of the system's existing power connections to enable data transmission capabilities and is one of the most widely utilised methodologies for smart-meter applications in smart-grid and micro-grid environments [1]. PLC technology is defined as the realisation of data communication while executing generation, transmission and distribution operations over the existing electricity network. With the development and gaining importance of high-frequency applications, PLC has started to be used for remote control and network monitoring in electricity generation transmission and distribution processes [2].

PLC has been researched and continues to be researched from different perspectives. The first study on PLC was used to remotely measure the voltage level of the batteries in the telegraph system in England in 1838. At the end of the 1890s and the beginning of the 1900s, the foundations of PLC technologies used today were laid with the patents obtained in England, Germany and America [3,4]. At the beginning of the 2000s, the importance of communication technologies for data exchange increased as a result of the widespread use of the concept of a smart grid throughout the world, and studies on PLC have increased in this direction.

PLC results in lower initial investment and ongoing maintenance costs since it uses existing power connections for data transfer. The narrowband PLC used by smart meters is in accordance with European Norm (EN) 50065, which was created by the European Committee for Electrotechnical Standardization (CENELEC) in 1992 [5]. While the PRIME Alliance has published the industry standard PRIME (Power-line Related Intelligent Metering Evolution), several industries start the development of a PLC solution based on the regulation G3-PLC, which was established by the G3-PLC Alliance [6,7]. However, a variety of issues might affect how well the PLC performs. In fact, the majority of switching-mode power converters use a switching frequency between 9 and 150 kHz in the International Special Committee on Radio Interference (CISPR)'s A band [8]. As a result, the produced Electromagnetic Interference (EMI) is located in the same frequency region of the PLC as that of the CENELEC-defined PLC (between 3 and 150 kHz) [5,9]. There is a parasitic coupling channel between the power circuit and the communication circuit that allows EMI to be coupled from the power circuit (the source of EMI) to the communication circuit (the victim). Data transmission errors and, occasionally, communication failure result from EMI because it lowers the signal-to-noise ratio (SNR) below the level required for noise-free communication [10].

This wired communication link can be a victim of EMI in state-of-the-art grids for common electrical installations, such as DC and AC distribution grids, especially in DC microgrids where the converters generate low- and high-frequency conducted emissions. This may interrupt the data transmission capability of the PLC system, which affects the microgrid control operation [11].

The recent techniques for mitigating EMI originating from a known source, i.e., a power converter, are to apply filtering strategies [12] or modulation techniques for the switching frequency, as presented in [13]. The latter has demonstrated well-known advantages due to the straightforward methods in which additional components or modifications to the original devices are not required. Spread Spectrum has been used widely as a method to control and limit the interference generated by the converter at the exact point of EMI generation, and it can even be used to selectively decrease the interference of a certain harmonic peak [14].

Spread Spectrum Modulation (SSM), with its different variations, Sine, Sawtooth and Random, is used as a valid method for decreasing EMI at the very moment of its generation. This represents an important advantage as it complies with the limits of the current standards of different countries. A signal in the time domain will generate a particular shape in the frequency domain, as demonstrated by Pareschi et al. in [15]. One constant frequency is typically used to operate a DC-DC converter; this practice is known as Deterministic Modulation (DetM). To show the effect of such signals, a simulation in Matlab was developed that considers three signals being modulated with a baseline frequency of 20 kHz. An example of this behaviour for different signals, (a) Deterministic, (b) Sine, (c) Sawtooth and (d) Random, are shown in Figure 1, respectively.

In many studies, SSM methods have been used to eliminate the effect of EMI in PLC communication. In [16], to mitigate the EMI in PLC communication, Random Carrier Frequency Modulation with Fixed Duty cycle (RCFMD) has been used, and the results show that, despite the reduction in spectra amplitude of randomised PWM techniques, they introduce more problems into PLC performance. Additionally, in a similar study [17], the use of RCFMFD showed that the increase in spreading factor decreases the EMI noise in the channel. In another study [18], the performances of DetM and Random modulation used on a converter were compared considering the converter supply voltage in the PLC, and it was concluded that Random modulation generates a greater FER than DetM.

As mentioned earlier, PLC is affected by EMI from power converters operating in close proximity. In this study, different modulation types were tried on converters to mitigate the effects of EMI in PLC and the results were compared. In this study, unlike other studies, the performances of the Sine, Sawtooth and Random modulation types in mitigating EMI were compared by considering parameters such as modulation index, sampling frequency and spreading factor. In addition, another difference between this study and the other studies in the literature is that the peak index was given by a CISPR-16 EMI receiver in order to realise behaviour in the frequency domain for Random modulation with the highest FER value.

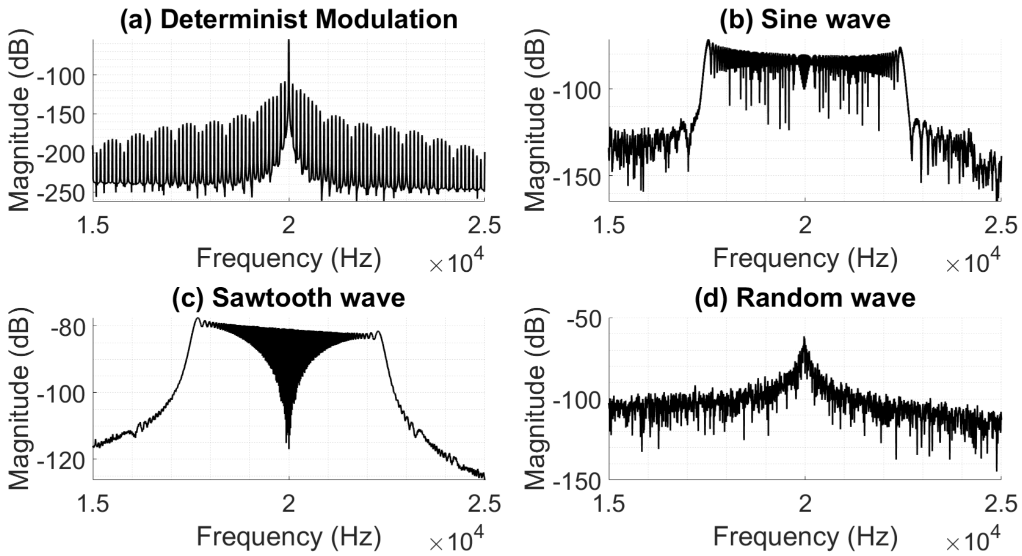

Figure 1. Comparison of different driving signals in time domain and their results if in frequency domain for Deterministic, Sine, Sawtooth and Random.

2. G3-PLC

G3-PLC is designed for use in smart grid applications, and it enables long-distance, extremely dependable, high-speed communication over the current powerline system. The G3-PLC's characteristics and capabilities were created to meet the complex requirements of PLC. Although earlier methods were a good start, they don't fulfil the technical and dependability standards needed in the challenging PLC context [19]. G3-PLC is based on the Orthogonal Frequency Division Multiplexing modulation (OFDM) scheme and operates in the frequency range from 3 kHz to 490 kHz.

Narrow Band (NB)-PLC is known as a PLC type with an intensive processing volume and is used to obtain smart meter data remotely, especially in the electricity network. In this direction, the organisations CENELEC to [20] of European origin, FCC of American origin and ARIB of Japanese origin have determined the frequency bands that will establish their own standards for the NB-PLC level. Table 1 shows these frequency ranges.

Table 1. G3-PLC system parameters.

Parameter	G3-PLC Standart	Frequency
EUROPEAN	CENELEC	3–148.5 kHz
ABD	FEC	10–490 kHz
JAPAN	ARIB	10–450 kHz

CENELEC, which regulates European standards, has divided the 3–148.5 kHz operating frequency range into four sub-frequency bands to ensure efficient and trouble-free operation, taking into account the diversity of operations. CENELEC's frequency bands cover Band A, Band B, Band C and Band D. This can be seen in Table 2.

Table 2. CENELEC frequency bands.

CENELEC Frequency Band	Frequency Range
Band A	9–95 kHz
Band B	95–125 kHz
Band C	125–140 kHz
Band D	140–148.5 kHz

The equipment used for the experimental tests was provided by Microchip Atmel AT360. The main parameters of this communication link are shown in Table 3. More information can be found in the datasheet [21].

Table 3. NB-PLC Frequency Range.

Parameter	G3-PLC
Type of Modulation	OFDM
Sampling Frequency	400 kHz
Number of FFT Points	256
Max. Data Rate	33.4 kbps
First Frequency	35.9 kHz
Last Frequency	90.6 kHz
Number of Cyclic Prefix Samples	30
Sub-Carrier Spacing	1.5625

Data are transferred between a transmitter and receiver points with the PLC method. This is carried out over the traditional electricity grid, but the conventional electrical grid is designed to carry power, not to provide data communication between two points. For this reason, the signal carrying the data must be adapted to the PLC channel where the data are carried. In this direction, the transformation of the characteristics of one of the phase, amplitude or frequency parameters of the data-carrying signal according to the regulating signal is defined as modulation. With the modulation process, the signal carrying the data between two points is made suitable for the PLC channel. With modulation, the use of a single carrier for the signal to be transmitted is known as single-carrier modulation. The cases in which modulation types use more than one carrier for signal transmission are expressed as multi-carrier modulation. The most well-known structure of multi-carrier modulation is the OFDM technique, called orthogonal frequency division multiplexing. In the PLC channel, OFDM is used for multi-carrier modulation.

3. Orthogonal Frequency Division Multiplexing

In the OFDM system, without changing the transmission rate, the high-bit-rate data are divided into several parallel low-bit-rate data. By extending the symbol time, the frequency-selective channel becomes a flat fading channel [22]. By creating more than one carrier within a PLC channel, signal multiplexing methods were developed to protect it from interference and increase its robustness. The method created by dividing the operating frequency range of the PLC channel into sub-frequency ranges for multiple carriers is known as frequency division multiplexing. A high spectral efficiency is achieved in the OFDM system by dividing the frequency band used into perpendicular narrowband sub-channels [23]. Since the bandwidth is partitioned separately for the sub-carriers in the FDM method, different signals can be carried without interacting with each other. However, since the segmented frequency bands are assigned to a single carrier, it prevents the channel from being used efficiently. With OFDM, a spectral efficiency of approximately 50% is achieved by overlapping the sub-channels across the frequency spectrum, unlike the traditional multi-carrier system. The spectral efficiency is increased by choosing one of the subcarriers to be mathematically orthogonal to the other. For lower-speed parallel subcarriers, the distortion in time due to the echo channel increases as the symbol duration increases. As seen in Figures 2 and 3, orthogonality in the time domain means that each subcarrier has an integer number of periods during a symbol; orthogonality in the frequency domain means that each carrier spectrum has zero value at the centre frequency of the other carriers in the system. As a result, although the carriers overlap spectrally, no interference occurs [24].

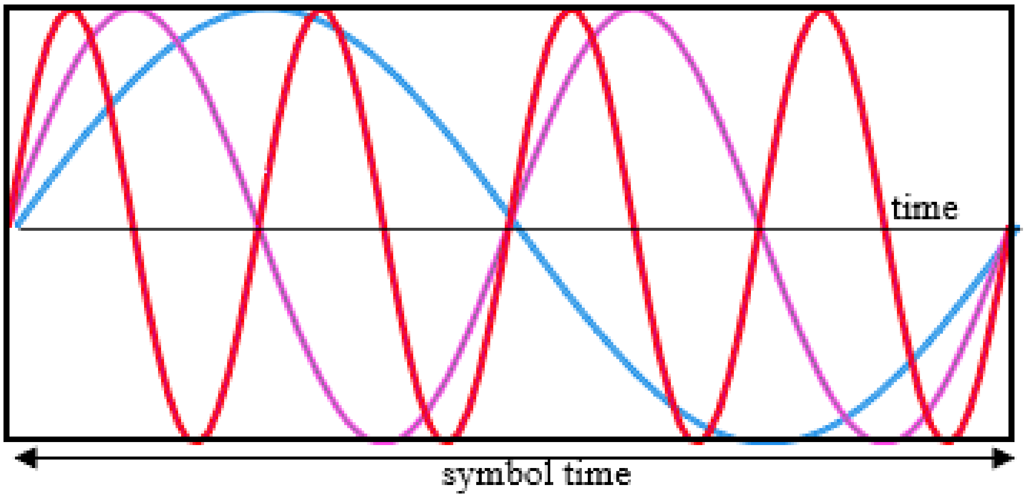

Figure 2. Orthogonality in time domain.

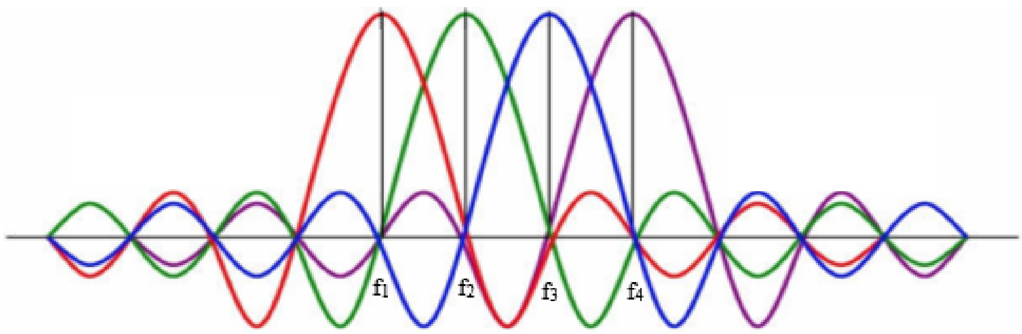

Figure 3. Orthogonality in frequency domain.

In order to eliminate the efficiency problem here, the concept of OFDM has emerged. With this concept, the subcarriers in the channel are converted to orthogonal form, reducing the bandwidth usage while enabling effective utilisation.

4. Spread Spectrum Modulation

Many studies have been conducted on SSM as a method to lower measured EMI from power converters [15,25]. One method for diffusing noise is SSM, which focuses on a certain frequency. This is an effort to re-distribute the EMI's energy of an interfering signal. By dispersing the waveform energy over a larger frequency range, it lowers the peak energy of a narrowband interference signal to a broadband interference signal [26], as can be seen in Figure 4. This can be done with periodical, non-periodical or even hybrid algorithms.

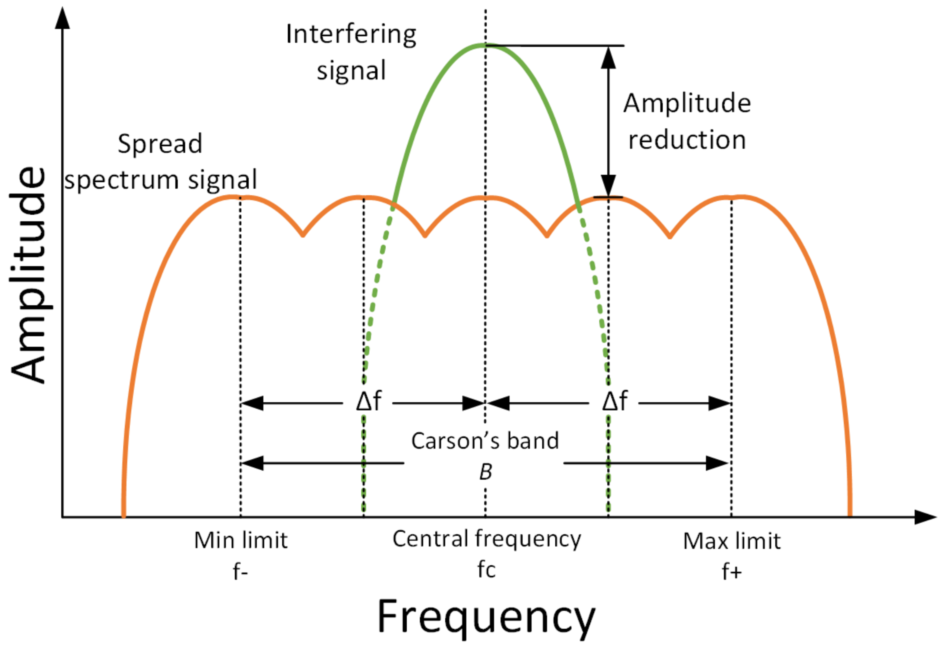

Figure 4. Graphical explanation of Spread Spectrum for noise dispersion.

The usage of SSM is mainly based on analogue frequency modulation assumptions. The main idea behind frequency modulation is achieved with two main signals, the carrier and the modulating signals, as given by:

$$f_{out}(t) = \cos(w_c t + \frac{\delta_f}{f_S(t)} \int dt S(t)) \tag{1}$$

where the term w_c is the carrier frequency, δ_f is the frequency deviation, $f_{S(t)}$ is the modulating signal frequency and $S(t)$ is the modulating signal function. This theory can be extended to account for a rule that defines the limits of the frequencies to be modulated. This rule is referred to as Carson's rule, as can be seen in (2).

$$f_{out} = f_c \pm \frac{\Delta f}{2} \cdot \epsilon(t) \tag{2}$$

In this equation, Δf is the frequency deviation (same as δ_f) based on the spreading range defined by the baseline frequency modulation to be mitigated (f_c). The value of $\epsilon(t)$ is the modulating signal and can be periodic (e.g., Sine and Sawtooth) or non-periodic (e.g., Random and Chaotic).

One important aspect of the generation of Spread Spectrum profiles is the sampling time of the main device used to generate the switching frequencies. Utilising a non-fixed frequency clock significantly reduces the EMI's peak energy, which causes the EMI's energy to be dispersed to various frequencies. This can only be formally achieved by randomising the clock of the device, which can be computationally costly; however, many papers focused on Chaotic modulation were analysed to determine the real improvement.

To generate the Spread Spectrum driving patterns, a microcontroller with strong computational capabilities or a Field Programmable Gate Array (FPGA) can be utilised. The sampling ratio of the driving signal and the spreading factor may be adjusted according to particular needs and parameters. In this work, the C2000 microcontroller from Texas Instruments, Dallas, Texas, USA, is used. For CISPR-16 Band A, a Resolution Bandwidth (RBW) of 200 Hz for the measuring apparatus is chosen. A variety of driving signals and sampling ratios have been selected in order to establish the optimal scenario to reduce the influence of the switching frequency for the Device Under Test (DUT).

Common Spread Spectrum techniques applied to power converters for an EMI decrease are being studied due to the growth of smart grids and renewable energy grids. The strategies used are different considering the methods and resources used, which include basic random generators [27]; chaotic generators, such as the ones in [28,29]; and even random generators with controlled repetition rates based on pseudo-random algorithms [30]. In all of these strategies, the peak decrease is considerable and can be between 10–20 dBμV. However, an important feature of the modulating signal is the generation of the clocking of the device used; this is often overseen by the authors applying these modulation techniques.

There are three important parameters in SSM; these are the spreading factor (α), sampling frequency of the signal (f_m) and modulation index (m). The spreading factor is expressed as a percentage in relation to the modulation's intended central frequency (f_c).

$$m = \frac{\Delta_f}{f_m} = \frac{(\alpha \cdot f_c)/2}{f_m} \quad (3)$$

5. Experimental Setup

The experimental setup in this study consists of two parts. The first part is the communication circuit including PLC modems, and the second one is the power circuit including the DC converter. Due to the mutual coupling of the circuit wires, EMI may transfer between these two circuits. Two G3-PLC modems make up the communication circuit, which represents point-to-point communication between a particular transmitter and receiver. As seen in Figure 5, the circuit utilises two Microchip ATPL360 PLC modems, each of which is set up to operate utilising the G3-PLC mode and the CENELEC-A standard frequency range. Two G3-PLC modems are connected by an 18 m long 230 V AC cable to carry the communication signal. In order to isolate outside EMI noise and ensure the durability of the findings, the Line Stabilisation Impedance Network (LISN) and isolation transformer are also connected between the PLC circuit and the grid. The purpose of using the isolation transformer is to separate the AC line and the grid. The communication and power circuits are artificially coupled by means of a low-value capacitor. The equipment used in this experimental setup is briefly described below.

1. **PLC Modems.** Two PL360 modems from Microchip, one of which is the transmitter and one of which is the receiver, in G3 PLC standard were used. They make it possible to assess the effectiveness of point-to-point PLC.
2. **Power Supply.** The power supply provides 60 V with a maximum current of 6 A.
3. **LISN.** The LISN used is the Schwarzbeck NSLK 8127. This LISN is CISPR-16 compliant with a frequency range from 9 kHz to 30 MHz.
4. **Spectrum Analyser.** The configured parameters are given by the RBW of 200 Hz; the frequency bandwidth to be analysed is from 9 kHz to 150 kHz to account for the low-frequency band.
5. **EMI Receiver.** The EMI receiver is the Rohde & Schwarz ESR3 with a frequency range from 9 kHz to 3.6 GHz (CISPR-16 compliant)
6. **Power Converter.** The DC-DC converter is a half-bridge converter with SiC-based Mosfet transistors (manufactured by Wolfspeed). The converter topology is a Synchronous Buck Converter with a base switching frequency of 50 kHz. The converter uses an input capacitor of 5.1 μF, and the output capacitor is 470 μF to decrease the ripple generated and to provide a steady voltage at the output. The switching frequency of the DC converter is set to 63 kHz, which is the intermediate operating frequency of the G3-PLC. The Texas Instruments C2000 board is used to generate the SSM patterns, for all of the cases, a 50% of the duty cycle is used. The output load of the converter is 10 Ω.

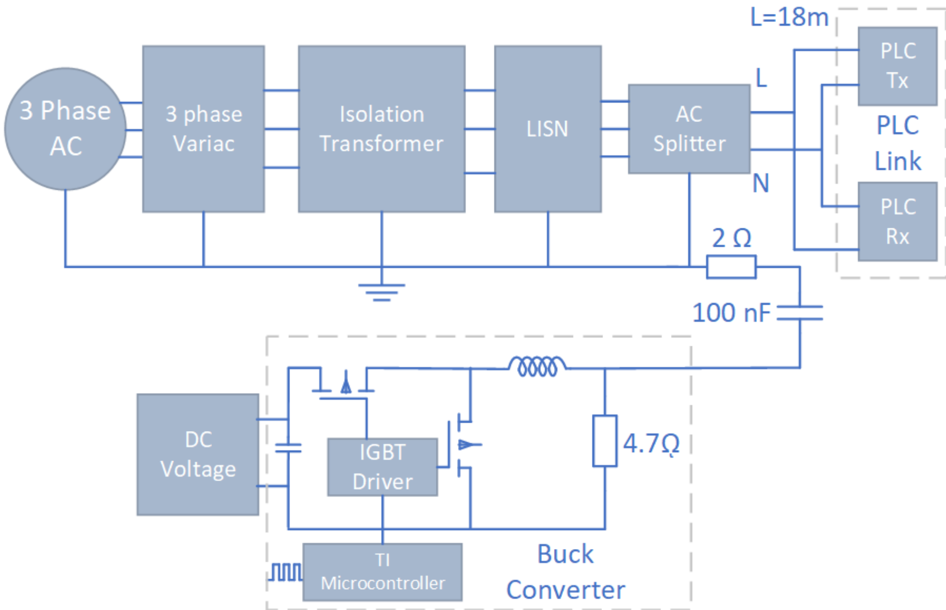

Figure 5. Experimental test setup block diagram.

A complete figure of the setup used for the experimental tests is shown in Figure 6.

The measurement results are based on the Peak index value obtained from the Spectrum Analyser. The parameters of the Spectrum Analyser are shown in Table 4.

The Frame Error Rate (*FER*) is used to evaluate the G3-PLC's performance. The FER may be calculated as given in (4) to show the ratio of successfully received data frames to all data frames transmitted by the communication system:

$$FER(\%) = \frac{Sent\ frames - Received\ frames}{Sent\ Frames} \times 100 \tag{4}$$

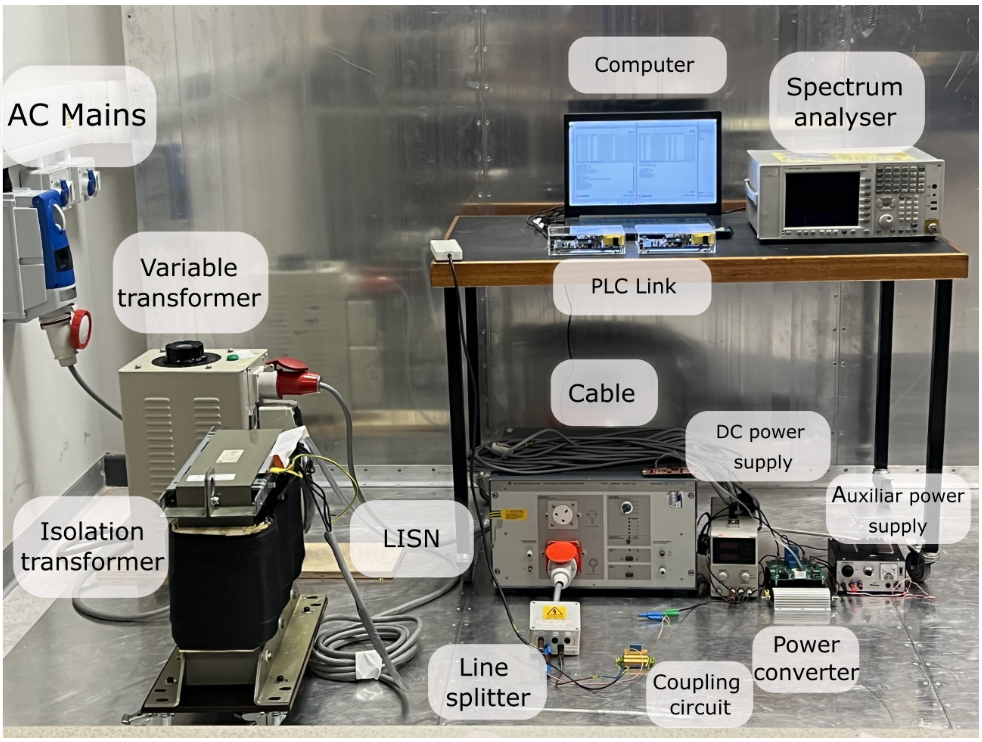

Figure 6. Experimental test setup used for the measurements.

Table 4. Spectrum Analyser Parameters.

Parameter	Value
Frequency Range	9–150 kHz
IF Bandwidth	200 Hz
Dwell Time	100 ms

6. Results

In this section, the results of the experimental tests are discussed. For testing the best value of extreme limits of the spreading, five different α values have been used from 0.1 to 0.5 with a step of 0.1. On the basis of a low-frequency analysis, all measurements were made from 9 to 150 kHz for five samples at the same m value because it covers the Cenelec A band and is in the CRISPR-16 operating frequency.

6.1. Results for α = 0.1

In Figure 7, the results when α = 0.1 can be seen; in this case, the signals perform similarly for the FER measured. It can be difficult to conclude which modulating signal performs better due to the different values measured for different modulation indices. From m = 0 to approximately m = 45, the highest FER measured is for a Random modulating signal but this trend changes at higher values of m, and the Sine modulating signal becomes the highest interfering signal with regard to the FER measured. As for the Sawtooth signal, this shows a decreasing trend from m = 0 to the final modulation index value of 120.

6.2. Results for α = 0.2

For a value of α = 0.2, the measured results are shown in Figure 8. There are interesting values when m is less than 13. For all modulation types, the maximum peaks measured close to 0.1; after this trend, both Sawtooth and Sine modulation signals generated a FER value close to zero. For a Random modulating signal, there is an increasing trend that reaches a maximum point when m = 37. After reaching this point, the trend develops a decrease in the behaviour.

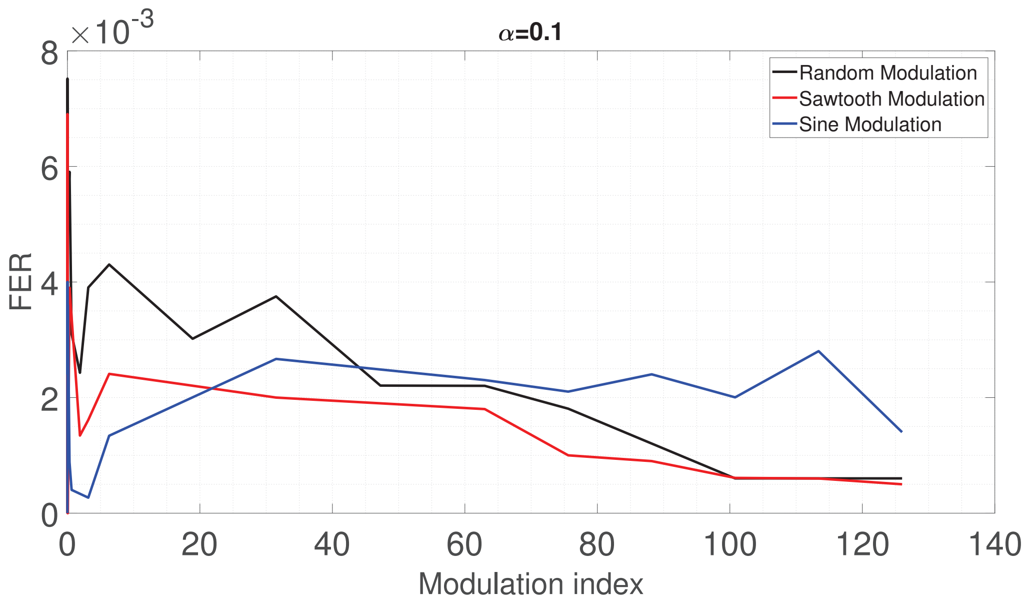

Figure 7. Comparison of Random modulation, Sawtooth modulation and Sine modulation when α = 0.1.

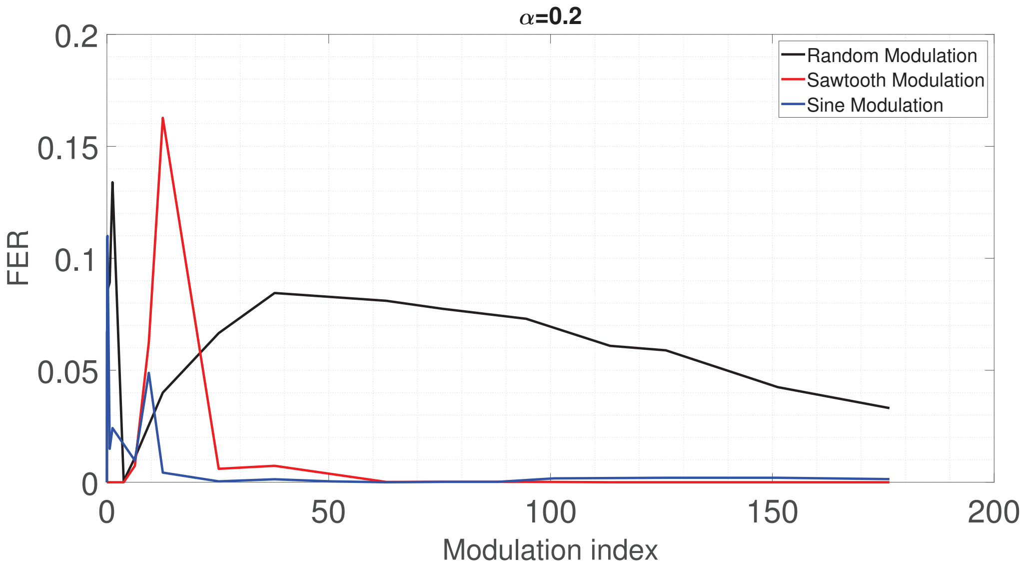

Figure 8. Comparison of Random modulation, Sawtooth modulation and Sine modulation when $\alpha = 0.2$.

6.3. Results for $\alpha = 0.3$

In Figure 9, there is an increasing trend for all modulation types. After reaching the maximum point of the FER, the trend develops a decrease in the behaviour. Sawtooth and Sine have a very similar trend. They have a maximum value of the FER when $m = 14$ and $m = 19$, respectively, which is less than 8%. For the Random modulation, the maximum value of the FER is 34.7%. It is measured when $m = 100$, and then the value of the FER decreases for higher values of m.

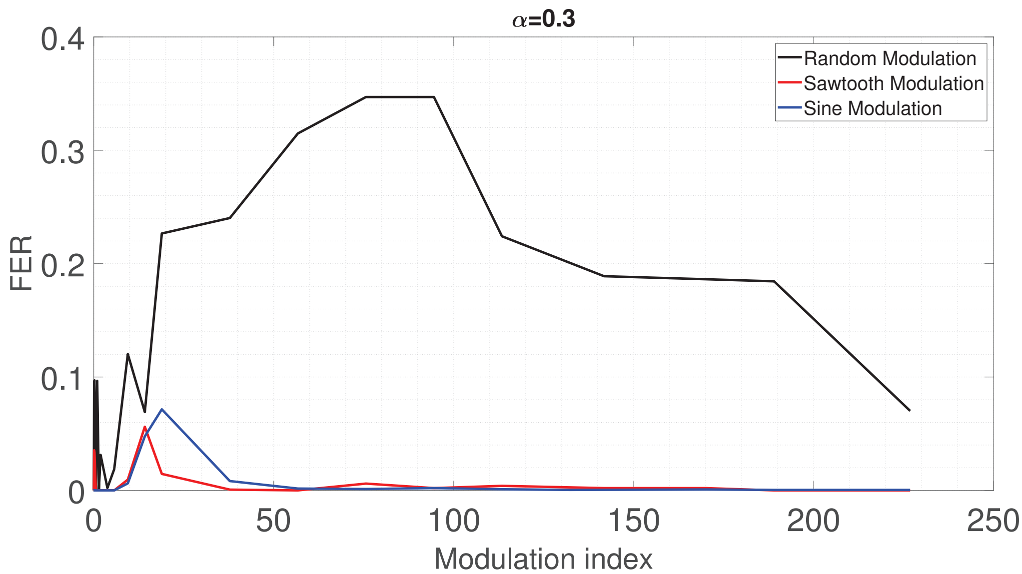

Figure 9. Comparison of Random modulation, Sawtooth modulation and Sine modulation when $\alpha = 0.3$.

6.4. Results for $\alpha = 0.4$

As seen in Figure 10, there are similar trends in all three graphs for all modulation types. For the Sine modulation, the maximum value of the FER is 5.6% when $m = 25$; for the Sawtooth modulation, the maximum value of the FER is 13% when $m = 30$. When the Random modulation is examined, it is seen that the FER value is very high compared to the others. When $m = 100$, the maximum value of the FER is 42.8%.

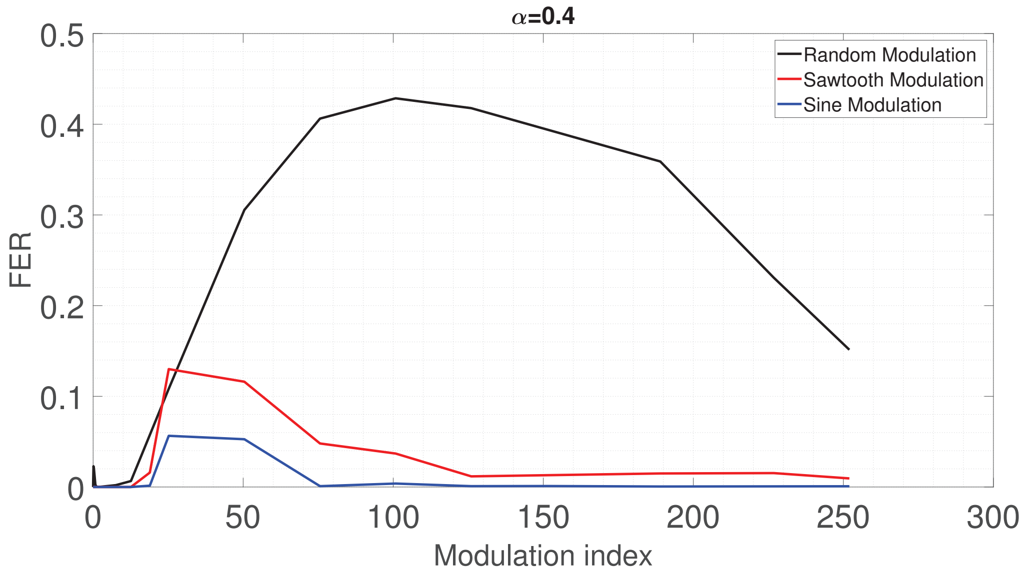

Figure 10. Comparison of Random modulation, Sawtooth modulation and Sine modulation when $\alpha = 0.4$.

6.5. Results for $\alpha = 0.5$

In Figure 11, it can be seen that the graphs of all (Sine and Sawtooth) modulation types have the same trend. While the FER takes values close to zero at low modulation index values, the FER value grows and reaches its maximum value at increasing modulation index values. For the Sine, Sawtooth and Random modulation, the maximum FER values, respectively, are 18% while $m = 63$, 33.1% while $m = 47$ and 55% while $m = 157$. After the maximum FER value, the FER value decreases to zero at $m = 94$ for the Sine and Sawtooth modulations. However, even at $m = 300$ in the Random modulation, it still has a very high FER value, even if it decreases slightly.

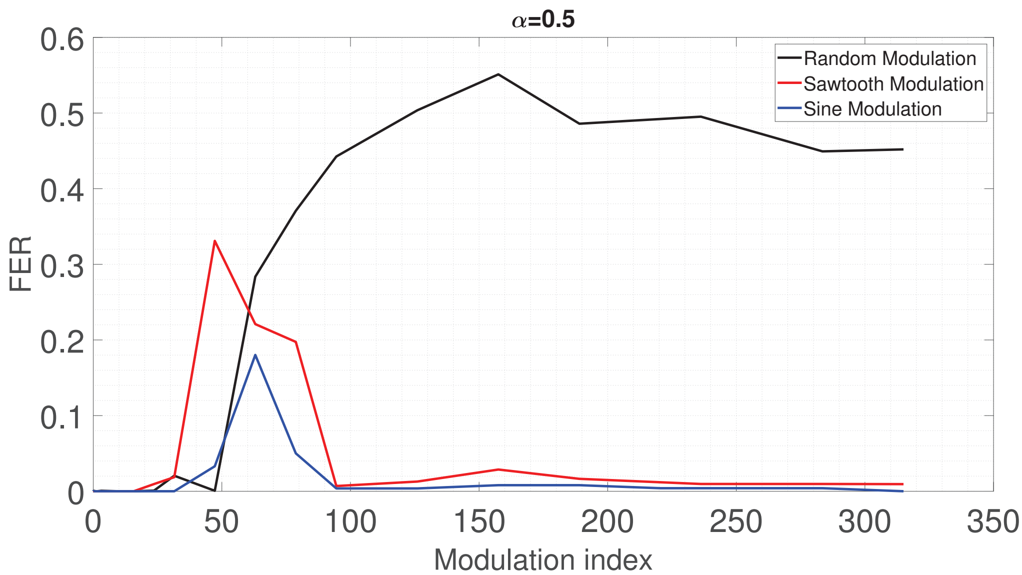

Figure 11. Comparison of Random modulation, Sawtooth modulation and Sine modulation when $\alpha = 0.5$.

6.6. EMI for Random Modulation

In Figure 12, the peak index is given by a CISPR-16 EMI receiver in order to understand behaviour in the frequency domain. According to this, when $\alpha = 0.1$, for all of the modulation's index values, modulating the signal exceeds the DetM mitigation limit. Since no mitigation is accomplished, these modulating frequencies must be avoided. The greatest mitigation of EMI is obtained when α = 0.5 and m = 0.315. Afterwards, considerable mitigation is obtained when α = 0.4 and m = 1. As the modulation index grows, the modulation signals for all α values are located above DetM. This means no mitigation is achieved.

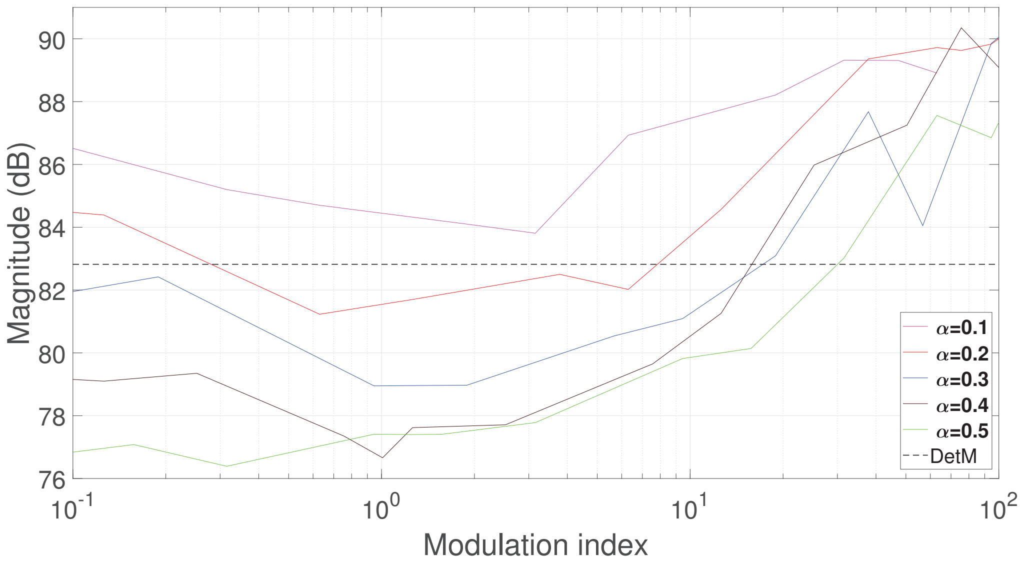

Figure 12. Random modulation results for all α values with different modulation indices.

7. Discussion

Having shown the figures in the last section, it is clear that the selection of a particular signal will generate different FERs. The minimum and maximum FER values according to all α values are given in the Table 5 in order to better understand and examine the graphs. The following can be discussed:

- The usage of a Random modulating signal starts to generate a considerable degradation of the quality of the PLC communication with a spreading factor bigger than or equal to 30%.
- The minimum value of the FER is zero at all α values except α = 0.1.
- Very low values of the FER are measured when the modulation index exceeds a value of 50 for α values of 0.3, 0.4 and 0.5.
- The maximum FER values obtained for increasing α values are examined. It is clearly seen that the FER values increase for all three modulation methods.
- The Random modulation gives the largest FER value.
- In this study, unlike in other studies, three different modulation types used for switching DC-DC converters are emphasised. Again, the effects of the modulation index, spreading factor and sampling frequency of the signal parameters, which were not considered in other studies, on the communication system were examined.
- Thus, depending on how much the EMI decreases in the time domain for each modulation type due to the changing α values, the modulation index and, accordingly, the α coefficient must be decided, taking into account the residual in the FER.

Table 5. Measured values of FER.

α	Sine min FER	Sine max FER	Sawtooth min FER	Sawtooth max FER	Random min FER	Random max FER
0.1	0.0026%	0.28%	0.05%	0.2%	0.06%	0.43%
0.2	0%	11%	0%	16.2%	0%	8.4%
0.3	0%	7.1%	0%	5.6%	0%	34.7%
0.4	0%	5.6%	0%	13%	0%	42.8%
0.5	0%	18%	0%	33.1%	0%	55.1%

Having considered the previous points, it is clear that the application of a certain signal is a process that must be considered according to particular needs since this can have a considerable impact on the quality of the communication link.

8. Conclusions

This study has demonstrated the impact of EMI on the G3-PLC communication channel performance caused by a Spread Spectrum modulated SiC-based buck converter. The modulation index m is an important variable when considering the FER measured. This is due to the close nature of the modulating signal's sampling frequency and the spreading factor α. In fact, for lower values, such as 0.1 and 0.2, the three signals perform similarly considering only the maximum points of the FER value. However, considering higher values of α (0.3 to 0.5), it seems that the Random modulation generates a greater FER when compared to the other signals for higher values of m. For $\alpha > 0.1$, there is a degradation in the communication performance even though the emissions are below the defined limits. The key finding of this study is that using Spread Spectrum to reduce the EMI produced in the frequency domain by the power converter (as its source) results in significant degradation of the communication link quality. The selection of a modulation profile to decrease the EMI generated by a switching converter in close interaction with a communication link, such as the one presented here, must be analysed for a particular problem. It is worth mentioning that for every modulation there will be important trade-offs that must be considered, as demonstrated in this paper.

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Abbreviations

The following abbreviations are used in this manuscript:

CENELEC	The European Committee for Electrotechnical Standardization
CISPR	International Special Committee on Radio Interference
DUT	Device Under Test
DetM	Deterministic Modulation
EMI	Electromagnetic Interference
EN	European Norm
FDM	Frequency Division Multiplexing
FER	Frame Error Rate
FPGA	Field Programmable Gate Array
LSIN	Line Stabilisation Impedance Network
NB	Narrow Band
OFDM	Orthogonal Frequency Division Multiplexing
PLC	Power Line Communication
PRIME	Power-line Related Intelligent Metering Evolution
RanM	Random Modulation
RCFMD	Random Carrier Frequency Modulation with Fixed Duty cycle
RBW	Resolution Bandwidth

SiC	Silicon Carbide
SNR	Signal-to-Noise Ratio
SSM	Spread Spectrum Modulation

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