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# *Immunité aux interférences des systèmes de communication à lumière visible*

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Les systèmes de communication basées sur la lumière visible recourent au double usage des infrastructures d'éclairage pour transmettre données. Cette technologie est considérée sécurisée, à bon marché et immune aux interférences causées par les fréquences radio. L'interférence optique est l'unique source de perturbation externe normalement considérée dans les modèles de canal. Néanmoins, toutes les interférences sur les composants électroniques, susceptibles d'avoir un impact sur les performances du système, doivent être intégrées dans le modèle de transmission afin d'améliorer les performances du système de communication. Dans ce papier, on analyse l'interférence et l'immunité des systèmes VLC en ce qui concerne les fréquences couvrant tout le spectre jusqu'à 1 GHz. Nous fournissons une évaluation détaillée de l'immunité d'un système VLC réalisé en chambre anéchoïque, en considérant des interférences avec différents niveaux de puissance. Les résultats sont très intéressants. En considérant des valeurs de fréquence spécifiques, le signal transmis par VL est trop perturbé pour être correctement récupéré. Afin d'évaluer l'impact de cette interférence, on a estimé le Bit Error Rate (BER) pour différents indexes de modulation, en considérant une modulation de position d'impulsions (mPPM).

**Mots-clefs :** Visible Light Communication, Electromagnetic Compatibility, Signal Processing

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## 1 Introduction

Visible Light Communication (VLC) employs the dual use of light for illumination and for wireless information. It is recognized as a green communication technology and as a safe technology to human people in comparison of Radio Frequency (RF) based technology, guaranteeing a wider bandwidth, and an inherent security. It is well-known that VLC is vulnerable to the optical interference noise. A previous analysis with characterization and modeling of artificial light interference on optical wireless communication system has been proposed in [1]. In [2] the authors propose a signal processing mitigation approach for "mitigating" the impact of external light sources and improving the performance of the VLC in terms of Bit Error Rate (BER). So far, the main contributions on VLC interference focus on noise and interference deriving from other natural/artificial light sources. A different perspective of interference is introduced in [3], where the authors consider the effect of ripple interference on the receiver filter, proposing a new BER expression to account for this aspect.

In this paper, we focus on the immunity to electromagnetic interference, considering a completely controlled suite of experiments in an anechoic chamber, with and without external interference as an antenna transmitting a signal at different frequencies up to 1 GHz and at different powers. Results are surprising, since at certain frequencies, we detect very high interference. We implemented different m-Pulse Position Modulations (mPPM, with  $m = 2, 4, 8, 16$ ) and we considered different scenarios to identify the specific conditions impacting on the communication system. A detailed discussion of our work is provided in [4], which is, to the best of our knowledge, the first paper focusing on RF electromagnetic immunity of VLC.

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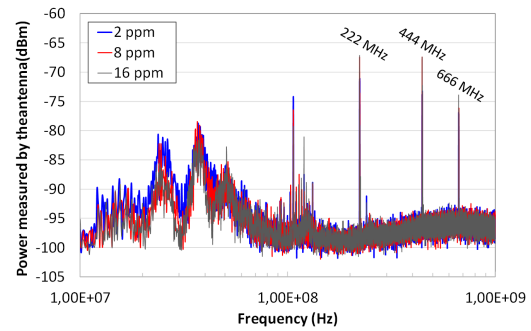
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## 2 System Setup

The VLC system is characterised with a LED as transmitter and a photodiode as receiver. A specific circuit has been designed and implemented to drive the LED lamp in the transmitting stage and another one for conditioning the signal delivered to the photodiode. A Software Defined approach has been used for modulating, demodulating and processing the signal. Two Universal Software Radio Peripheral (USRP 2922), integrated with two low frequency daughterboards (LFTX and LFRX) have been used. All the operations (e.g. modulation, demodulation, filtering) are implemented using the commercial software Labview. In all the experiments, we applied a fixed distance of 1 meter between the transmitter and the receiver. Both USRPs have been kept outside the anechoic chamber and only the communication system was inside the chamber 1. We activated the VLC system and measured the emissions of the system with a wide frequency band antenna and a spectrum analyzer. The measurements are presented in Figure 1 for three different modulations. The most important radiated emissions of the VLC system are at 222, 444 and 666 MHz. These are signals that are produced by the VLC system during its operation and are radiated by the components or printed tracks in which the signals travel. These frequencies can therefore be considered as potential disturbing frequencies for the system.



(a) System setup



(b) Spectrum of electromagnetic emission generated by the VLC system

FIGURE 1: Tests on the effects of the interference in a VLC system in anechoic chamber

## 3 Interference effects on Bit Error Rate

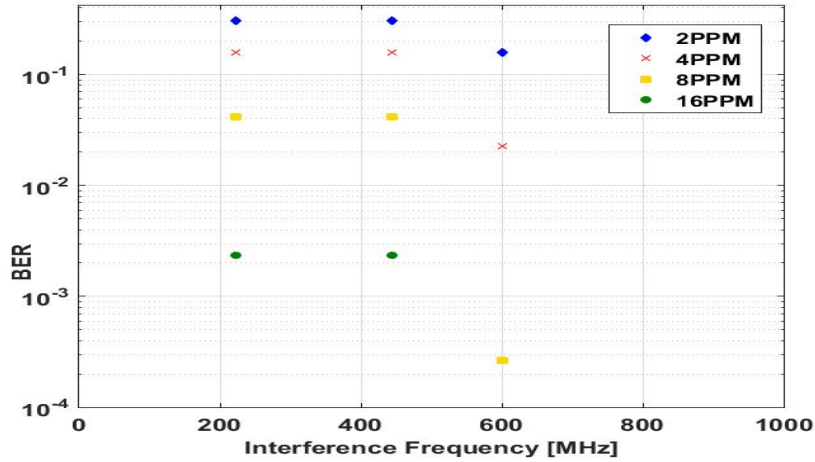
In order to better evaluate the effects of the interfering signal, we have performed a suite of targeted tests in the anechoic chamber, by generating an electrical field equal to  $E_0 = 5V/m$  and varying the frequencies in a wider range. We tested the effects of these radiating interference of the communication performance on 2, 4, 8 and 16 PPM.

We estimate the Bit Error Rate (BER) performed by the communication system on the received data, exploiting measured Signal to Noise ratio and considering a Gaussian distribution of interference effect, according to Central Limit Theorem [4].

In Fig. 2 we show the BER associated to each order of modulation, adding, for each measurement, an interfering signal with a progressive frequency in the range [50 MHz - 1GHz].

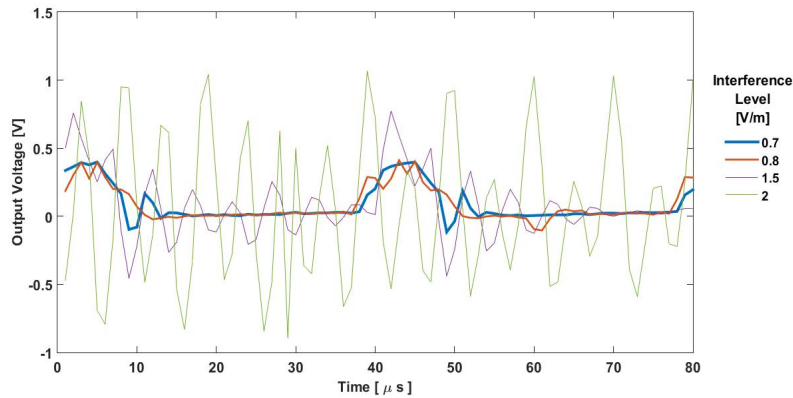
It is evident how interfering signals with different frequencies cause different effects on system performance. Worst performance have been obtained at 222MHz, 444MHz and 666 MHz. Since the two higher frequencies are centered in integer multiple values, into respect to the lowest one, it is reasonable to consider these effects as generated by the same interfering phenomenon, which produces three different harmonics with a significant power level.

In this latter set of measurements we evaluate the effect of the power variation of the interference on the communication system, by considering the same setup as in Fig. 1. We consider a case when interference considerably affects the performance of the system (222MHz). The power of electric field has been tuned, for each experiment, in the range [0-10 V/m], considering a step of 0.1 V/m in the range 0-1 V/m and a



**FIGURE 2:** Effects on BER produced by 5V/m interference signal on the proposed VLC system, considering 2,4,8 and 16 PPM modulation : zoom on most critical frequencies

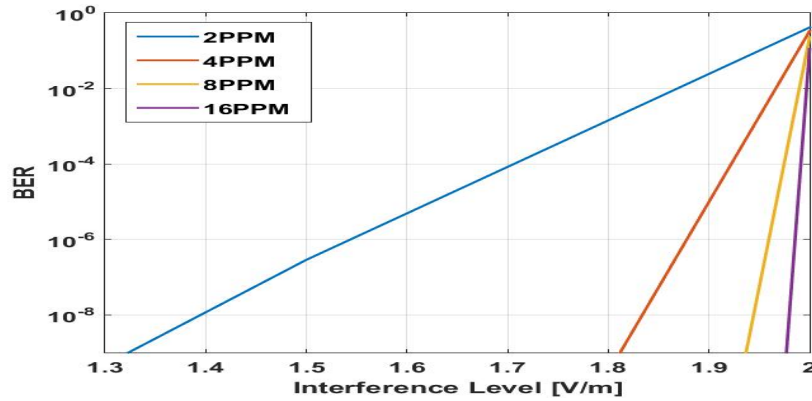
step of 1 V/m in the range 1-10V/m. Results in time domain are shown, respectively, in Fig. 3. For a clear representation of the time evolution of the pulses, signal received using a 8PPM modulation have been considered.



**FIGURE 3:** Effects on pulse shape produced by 222MHz interference signal on the proposed VLC system, considering 8PPM modulation

A devastating effect on received signal is already obtained for low values of emissions. When the external electrical field reaches a level of 2V/m, received signal is completely flooded by interference. For this motivation, we stopped the analysis, in this case, to the above mentioned level of interfering field intensity. In this latter case, Bit Error Rate measurements have been repeated, considering horizontal and vertical polarization of interfering signals, and increasing each observation time from 0.1s to 1s. Results have been shown for each value of field amplitude, considering 2, 4, 8 and 16 PPM.

We observe a significant effect on system performance, which is directly related to the amplitude of interfering field, with a complete lost of information in the worst cases since the BER is too high to correctly decode the received data. External radiated emission, indeed, seriously impact the signal travelling in optical VLC front-end, perturbing components and printed tracks. Based on these results, we argue as the integration of this type of effects in the channel model is of paramount importance in order to experience undesired degradation in the VLC system. A deeper series of measurements, showing also the analytical



**FIGURE 4:** Effects on BER produced by 222MHz interference signal on the proposed VLC system, considering 2,4,8 and 16 PPM modulation

technique for evaluating BER starting from experimental tests in time domain, can be found in [4].

## 4 Conclusions

In this paper we have implemented a VLC prototype with a Software Defined approach in order to evaluate the interference immunity of the communication system. In particular, we have implemented different index of PPM technique and tested the system in an anechoic chamber by spanning on different frequency values and different power levels. Results obtained are surprising, since the VLC system seems very sensible to specific frequencies. In order to evaluate the impact of the interference, we have evaluated the Bit Error Rate (BER) and we have shown that for certain "critical" frequencies, the BER is too high to be able to correctly recover the transmitted data. These results are important in order to include this type of interference in the channel model and improve link performance through new signal process approaches. Indeed, as future works, we plan to better characterise this type of interference with more extensive measurements with higher power levels. Moreover, we will design some ad hoc signal processing technique in order to mitigate the effect of this type of interference.

## Acknowledgment

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