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Referat 3

CONTRIBUŢII PRIVIND OPTIMIZAREA ŞI IMPLEMENTAREA VLC
(CONTRIBUTIONS CONCERNING THE OPTIMIZATION, AND THE IMPLEMENTATION OF VISIBLE LIGHT COMMUNICATIONS (VLC))

Coordonatori științifici,
Prof. univ. dr. ing. **Valentin POPA**
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Table of Contents

TABLE OF FIGURES:

LIST OF ABBREVIATIONS:

ADC	Analog to Digital Converter
ASCII	American Standard Code for Information Interchange
AGC	Automatic Gain Control
BER	Bit Error Ratio
DSSS	Direct Sequence Spread Spectrum
FOV	Field of View
IEEE	Institute of Electrical and Electronic Engineers
ITS	Intelligent Transportation System
I2V	Infrastructure to Vehicle
LED	Lighting Emitting Diode
LoS	Line of Sight
MIMO	Multi Input Multi Output
OOK	On Off Keying
RSU	Road Side Unit
RF	Radio Frequency
SNR	Signal to Noise Ratio
VANET	Vehicular Ad-hoc Networks
V2V	Vehicle-to-Vehicle
VLC	Visible Light Communications
VPPM	Variable Pulse Position Modulation

1. INTRODUCTION

This research activity report presents the development, optimization and the performance evaluation of a Visible Light Communications (VLC) prototype aimed for vehicle applications. The testing of the system was performed under different situations and environmental conditions. Since the usage in automotive applications implies mobility, within this report a solution that allows the system to work for variable distances is proposed. The results are encouraging, and prove that the VLC technology is a strong candidate for wireless data transfer for traffic safety applications. This report approaches every issue regarding the communication-based safety applications, investigating the appropriateness of the VLC technology for both Infrastructure to Vehicle (I2V) and Vehicle to Vehicle (V2V) communication. Furthermore, the cooperation between the two is investigated and demonstrated for the first time.

Within the previous chapter a theoretical and analytical evaluation of the Manchester and Miller codes was performed. Simulation results showed that the two codes exhibit similar Bit Error Ration (BER) performances and noise sensitivity [1]. Concerning the flickering performances of the Miller code, it has been showed that it does not introduce perceivable flickering. However, in terms of spectral efficiency, the Miller code clearly outperformed the Manchester code [2]. Considering that the Manchester code is the code specified by the IEEE 802.15.7 standard for wireless communication using visible light [3] in the case of outdoor applications, and that the simulation results confirmed its performances, it can be considered that the code is suitable for single channel communication. However, in the case of Multi Input Multi Output (MIMO) applications, the Miller code is better suited. Due to these reasons, this report continues the investigation of the two codes, presenting the experimental performance evaluation.

This work was part of an industrial project called "Co-Drive" [4].

2. THE CO-DRIVE PROJECT

2.1. Description of the Co-Drive project

Co-Drive is a French project intended to increase the safety and efficiency of the transportation system. The project has a duration of 36 months and a 6.8 million euro budged from witch 2.8 million € are from public funding. Coordinated by Valeo, the project brings together several industrial companies (Clemessy, APRR, Mediamobile, Sopemea, Comsis, Vivitec, Tecris, Citilog, Navecom) and research institutions (INRIA, INRETS, INSA Rouen, University of Versailles).

2.2. Main objectives of the Co-Drive project

Co-Drive aims to design and develop a cooperative driving system that will bring together information form vehicles and infrastructure, in order to enhance mobility by offering secure and optimized alternative routes for the user. Fitted on a vehicle, the system provides the user with information regarding the traffic, like speed limits or traffic conditions (weather, accidents, road closures, road-works, etc), guiding the driver, or even takes actions meant to enhance security and improve efficiency.

Inside the project, a reliable user-orientated traffic management service will be developed. This service offers the driver guidance, by listing relevant data coming from neighboring vehicles and/or infrastructure. The traffic management tool enables data collection and dissemination between vehicle and infrastructure. The project has to provide technical specifications to ensure the system's robustness.

At the end of the project it is expected that a demonstration of the system, consisting of intelligent infrastructure and intelligent vehicle, will take place. Least but not the last, the project analyses the impediments and come with solutions associated with user acceptability, legal constraints and application norms. One can say that Co-Drive project aims to provide today, a vision on tomorrow's transportation system.

Since the cooperative driving involves wireless communication technologies, within the Co-Drive project, besides the traditional Radio Frequency communications, VLC is also investigated because it is an emergent technology with huge potential.

3. VLC SYSTEM IMPLEMENTATION AND CHARACTERISTICS

This section presents some of the aspects related with the design and the implementation of an of VLC system, justifying some of the choices made in the different implementation phases. The issues concerning both the transmitter and the receiver modules are approached. As showed in Fig. 3.1, and presented in [5], the system consists of a broadcast station unit represented by a LED-based traffic light and a photo-diode based receiver that is supposed to be embedded on a vehicle. Both emitter and receiver are interfaced with PCs.

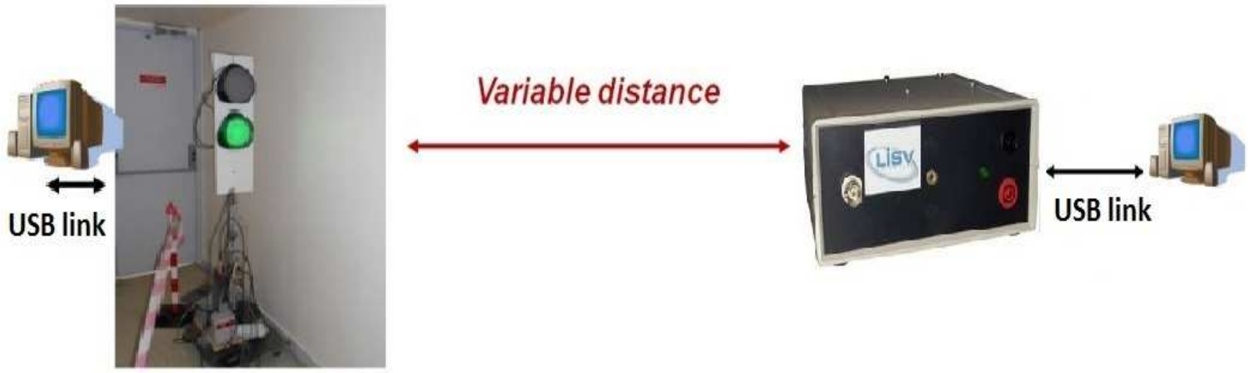

Fig. 3.1: Visible light communication system consisting of a LED traffic light and a vehicle mounted receiver.

3.1 Considerations regarding the data broadcasting module

In order to fit in the traffic regulation standard, the diameter of traffic lights has to be 200mm or 300mm. In the case of the proposed system, the VLC emitter module was developed based on a 200mm commercial LED-based traffic light and not on a custom made traffic light as in other works [6-19]. In the case of the custom-made traffic lights some of the parameters can be enhanced in order to increase the communication's performances. Increasing the transmission power by using a larger number of LEDs or using an optimized irradiation pattern are the main improvements that can increase the communication range, improving this way the system performances. Even though from a VLC point of view a LED traffic light can be enhanced, so that it exhibits improved performances, and still comply with the standards, in this case a commercial traffic light was chosen in order to prove that any traffic light can become a data broadcast unit with little modifications and at an extremely low implementation cost. In the case of VLC, any source of light can become a broadcast station without affecting the original purpose of signaling.

The hearth of the emitter module, responsible for data processing and decisions is represented by a low-cost 8-bit microcontroller, namely Microchip PIC18F2550. It converts the message into a binary array and deals with the data encoding and packaging. After creating the data frames, the microcontroller commands a digital power switch that handles the switching of the LEDs according with the digital data and the modulation frequency. These aspects are schematically illustrated in Fig. 3.2. Due to the limited computation power of the microcontroller, the modulation frequency cannot exceed 40 kHz in this configuration. However, the purpose of the setup is to demonstrate the reliability of the VLC system for outdoor communication. This aspect must not be considered an impediment, since for outdoor VLC the data rates are as low as 11.67 kHz [3]. Also, in vehicle safety application the connectivity is more important that the data rate.

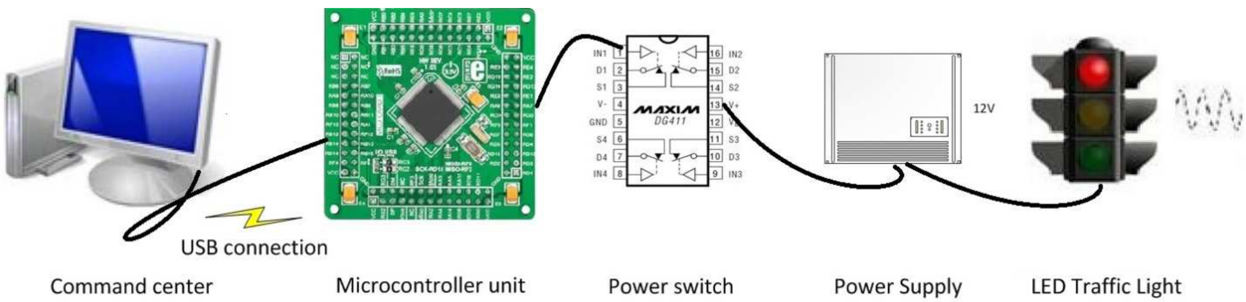

Fig.3.2: Hardware structure of the VLC emitter.

To maintain the complexity level and the implementation cost as low as possible, the system uses asynchronous transmission. A digital frame has been defined as illustrated in Fig. 3.3. It consists of several synchronization bits used to alert the receiver that a message is being sent and to provide information regarding the coding, start and stop bits, an additional flag that notify the data frame length and the data to send.

Fig. 3.3: Structure of the proposed frame.

As a modulation technique, the IEEE 802.15.7 standard [3] specifies for outdoor application the usage of On-Off Keying (OOK) amplitude modulation and also of Variable Pulse Position Modulation (VPPM). Since, the VPPM is intended mostly for applications that require dimming, which is not the case of a traffic light, only the utilization of OOK was considered. As a coding technique, two types of coding were analyzed and implemented: the biphase (Manchester code) and the Miller code. Both the codes are simple OOK based, without having any error detecting or error correcting capabilities. To easily test different configuration without rebooting or uploading the commands, the used coding technique is specified by the frame, so that the receiver can decode messages encoded using both the codes. The reasons for the selection of these two codes were detailed in the previous report.

The designed traffic light has two operating modes. In the first one, it can work independently, broadcasting a predefined message, (e.g. the speed limit or road works in progress). In this operating mode it is able to control the changing of the traffic light and to broadcast data regarding the time before the next color change. In the second operating mode, it can be connected with a PC through an USB link, broadcasting in real time any message coming from a traffic center (e.g. traffic jams, alternative routes, etc).

The developed module can be easily integrated into any LEDs-based traffic light. It was designed with low cost electronics, so that large scale implementation of such a system would have a reasonable cost. Moreover, substantial savings will be made by the usage of LEDs instead of classical lighting sources which will rapidly cover the cost of the device.

3.2. Considerations regarding the data receiving module

The VLC receiver is a crucial component of the VLC system. Its design determines the overall system performances. Concerning the VLC sensors, they use sensing elements which can be either camera systems or photodetectors. The usage of embedded cameras was considered based on the fact that the new generation vehicles are already equipped with cameras used for pedestrians and traffic lane detection. However, the automotive industry considers the usage of low-cost cameras like the ones used in smart phones. The noise performances of such CCD (Charge Coupled Device) cameras are lower than for independent photo-elements. The performances VLC sensors that use such sensing elements are also affected by the camera's limited number of frames per second (fps). Under these conditions, such VLC systems [21], [22] can cover distances of 1-2 m with data rates around 1 kbps, which is insufficient for such applications. Much better performances are achieved when high speed cameras are used. For example, the detection of a led traffic light with embedded high speed camera has been demonstrated in [19]. The traffic light is composed of a led matrix and the perception and the recognition of the form can be subject to complex image processing. BER lower than 10^{-3} has been obtained over tens of meters for low data bit rate. Nevertheless, the camera has to be a high speed camera model which is still too expensive for a broad distribution regarding the automotive industry. On the other hand, photosensing elements like photodetectors are quite efficient regarding noise performances and can be used over long distances. However, long range induces small angles and directional conditions. The photosensing element must be integrated in the vehicle with an optical system in order to focus the light and to increase the signal to noise ratio. Mechanical and optical systems must be precisely adjusted since the solid angles are very small. Active control of the position of the sensing element has been achieved to enhance the BER [20]. For shorter ranges, the solid angle of emission of the light is wide enough for a passive photosensing element to be efficient without active control of the position.

The receiver module is responsible for data recovery from the amplitude modulated light beam. The sketch of the reception module is presented in Fig. 3.4. Despite, the electronic is not embedded, all the components have been chosen for their low cost and their compactness. In the next paragraphs, the VLC receiver implementation process is presented along with some of the encountered challenges.

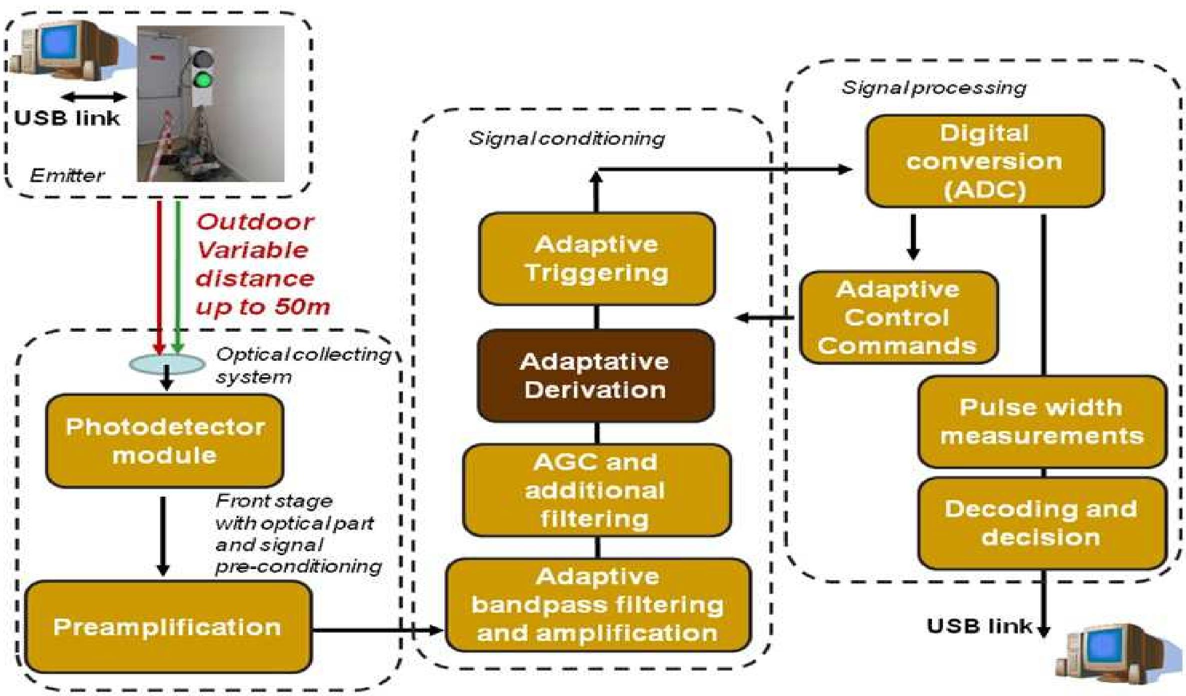

Fig. 3.4: Representation of the visible light receiver.

Considering the upper mentioned aspects, developing a VLC receiver that uses a photodiode as the light sensing element was considered as the most appropriate choice. The photodiode's quick response enables the possibility of high-speed communications. However, the performances of such a system are affected by the unwanted captured light that can lead to low SNR levels. To understate the effect of the background light, the usage of an optical concentrator is an effective solution. The optical concentrator reduces the receiver's Field of View (FOV) and increases the robustness against noise from daylight or from other VLC transmitters [23]. The concentrator gain is given by eq. 1 [24], [25].

$$g(\psi) = \begin{cases} \frac{n^2}{\sin^2 \Psi_c}, & 0 \leq \psi \leq \Psi_c \\ 0, & \Psi > \Psi_c \end{cases} \tag{1}$$

where $g(\psi)$ is the concentrator's gain, n is the refractive index, ψ is useful signal reception angle and Ψ_c is the concentrator's FOV.

Reducing the receiver FOV has the disadvantage of narrowing the service area, which accordingly reduces the mobility. Under these conditions, selecting the optical concentrator represents a trade-off between the gain and FOV. In the case of the implemented system, the optical reception system reduces the reception angle to ±10°. After passing through the optical lens the light is focused on the silicon photodiode. The photodiode generates an electrical current proportional with the incident light.

In the next step, the signal from the light sensitive element is processed through a classical transimpedance circuit for signal pre-conditioning. This circuit limits the bandwidth to 100 kHz according to eq. 2, and prevents the photoelement's saturation in case of direct exposure to high intensity light (e.g. sunlight). As far as 100 kbps, this data rate is sufficient for most of the applications.

$$BW = \sqrt{\frac{GBP}{2\pi(C + C_p)}} \tag{2}$$

where GBP is the gain-bandwidth product of the operational amplifier, R the gain resistance, C_p the capacitive part of the photodetector and C the capacitive part of the amplifier.

This approach experimentally proved its efficiency, regarding the saturation. However, when the distance is increasing and consequently the SNR decreases, what was actually meant to be a solution for the saturation, became a service area decreasing problem due to insufficient gain. To overcome this new problem, the solution is represented by the usage of an Automatic Gain Control (AGC) mechanism, which will be further described. This way, for this stage, the system is able to work with two amplification values: one for short distance and one for long distance. The two gain values are obtained by setting different values of the gain resistor R, as expressed in eq. 3. C is thus selected so that the BW level is maintained.

$$V_{out} = R \cdot S_{\lambda} \cdot P \tag{3}$$

where V_{out} represents the amplitude of the output signal, S_{λ} the photodiode's spectral sensitivity and P the received optical power.

By using this approach, the pre-amplification ensures minimum magnitude level on the order of tens millivolts whatever the distance (up to 50 m).

The second stage of the sensor is an analog conditioning board. An analog band-pass filter suppresses the offset due to the daylight and filters high frequencies noise. Within the filtering stage, the perturbations from artificial lighting sources, such as neon or incandescent lamps, are also removed. After the filtering process, the signal is amplified until it reaches a value of few volts. For small to medium distances, the current gain is sufficient for proper data recovery, however, when the distance increases, the data recovery process is affected.

In dynamic conditions such as those met in traffic situations, where the vehicles are continuously changing their positions, there are significant variations of the signal's intensity and modifications of the SNR. Experimental tests have been performed and showed that when these conditions are fulfilled, a static value of the amplification is a significant impediment, leading to photodiode saturation or to insufficient signal amplification. Due to these circumstances, the prototype integrates an AGC stage responsible for the system's adaptation to the signal's intensity. After passing through the upper mentioned filtering and amplification stages, the signal is digitalized with the Analog-to-Digital Converter (ADC) included in the microcontroller. Based on the average of the ADC values, the signal level is continuously monitored by the microcontroller. When the signal drops under or raises above the optimum values thresholds, the microcontroller computes a new value for the gain and commands the switches according to the required gain. The AGC block is able to provide a complementary amplification of up to 10 times the previous amplifications blocks, and so, the signal's intensity is maintained while the emitter-receiver distance is changing.

The heart of the sensor is a derivative analog module with slightly adjusted cutoff frequency. The reconstruction process from this stage is mainly based on the width of the pulses rather than on the level. In this stage, the signal passes through a high-pass filter resulting in the derived signal consisting of alternated positive and negative pulses. The positive pulses are the equivalent of the rising edges whereas the negative ones are the equivalent of the falling edges. Based on these pulses, the signal is turned into a digital signal corresponding to light on and light off. The electrical signals illustrating the signal reconstruction process with the derivation are illustrated within Fig. 3.5.

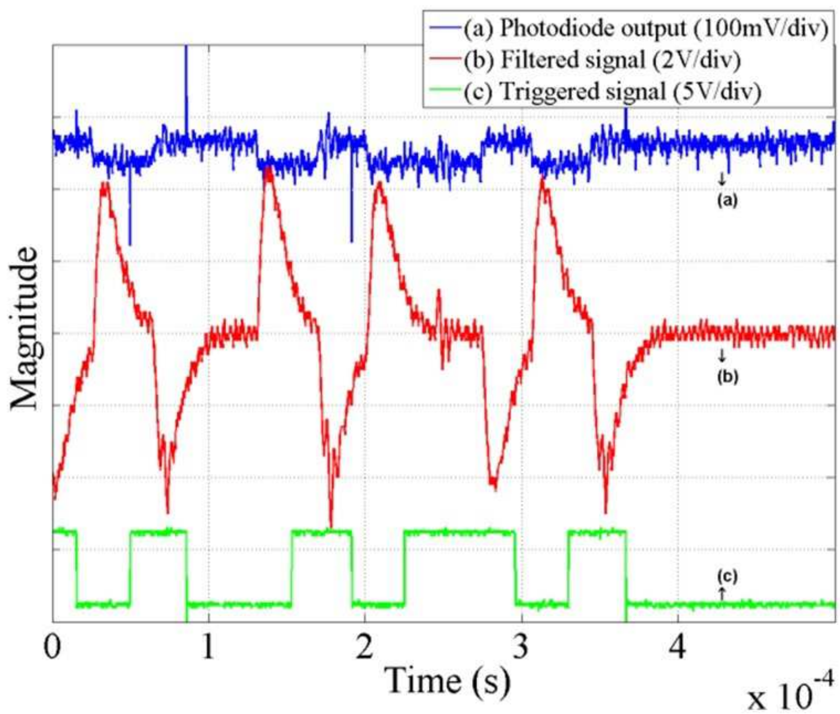

Fig. 3.5: Example of electric signals on the reception board; a) output of the pre-conditioning board; b) output of the conditioning part and c) output of the decoding and decision block. It illustrates that the derivative part emphasizes the front edges.

The third stage of the sensor is responsible for signal processing, information treatment and decision taking and is controlled by a low-cost 8-bit microcontroller Microchip 18F2550. The microcontroller is also responsible for the real time data decoding. Within this stage the signal is digitalized with the ADC included in the microcontroller that is the core element of the signal processing. Depending on the level of the signal, the microcontroller uses a precise algorithm to selects the value of the analog conditioning board. Both the signal monitoring and the settings selection are performed in real time. The message decoding is made based on the detection of the falling and of the rising edge and on pulse width measurement. For the pulse width measurement, the microcontroller uses the precise clock of an external quartz crystal operating at a frequency of 20 MHz. A BER is performed by comparing the original message with the received one. To facilitate the monitoring of the results, the receiver is connected with a PC through USB.

For simplicity and for considerations about the price, the receiver's clock is not synchronized with phase locked-loop. This aspect does not affect the data decoding as long as the frequencies involved do not exceed a few tens of kilohertz.

Variable Gain for robustness

Due to the mobility of the vehicles, in real traffic situations, the distance between emitter and receiver is rapidly changing. What is also changing is the ambient noise. These two factors lead to significant variations of the SNR. In dynamic conditions like those meet on a road, in real traffic, it is strictly imposed that the response of the system to be also a dynamic one. The system must adapt its response to different levels of SNR, corresponding to different distances, different angles and different conditions. Under these circumstances, the performances of a VLC system meant for automotive applications can be substantially improved with the integration of an AGC module which will adjust the gain for different levels of the incoming signal.

For the first version of the AGC stage a simple and effective solution has been implemented. This approach is based on digital switches that connect or disconnect parallel resistors, modifying the value of the equivalent resistor responsible for the gain selection. The first version of the AGC stage uses four digital switches each controlling a resistor. The combination of the 4 switches results in 16 possible gain combinations. Under these conditions, the objective is to control the 4 switches involved in order to adjust the amplification that maintains the signal level at convenient values. In this way the communication is possible at variable distances, from less than 1 meter up to the maximum distance. The digital switches are controlled by the microcontroller (Microchip 18F2550), which responds to the variations of the input signal. In the preconditioning stage the microcontroller is able to select between two available gains, one for short and one for long distance. The two available gains are also helping to prevent the photodiode saturation in sunny conditions. Besides the preconditioning stage, a second stage also offers the possibility for multiple gain settings. The gain of this stage is given by eq. 4.

$$A = \left(1 + \frac{R_{parallel}}{R_1}\right) \tag{4}$$

The schematic of the AGC circuit is illustrated in Fig. 3.6.

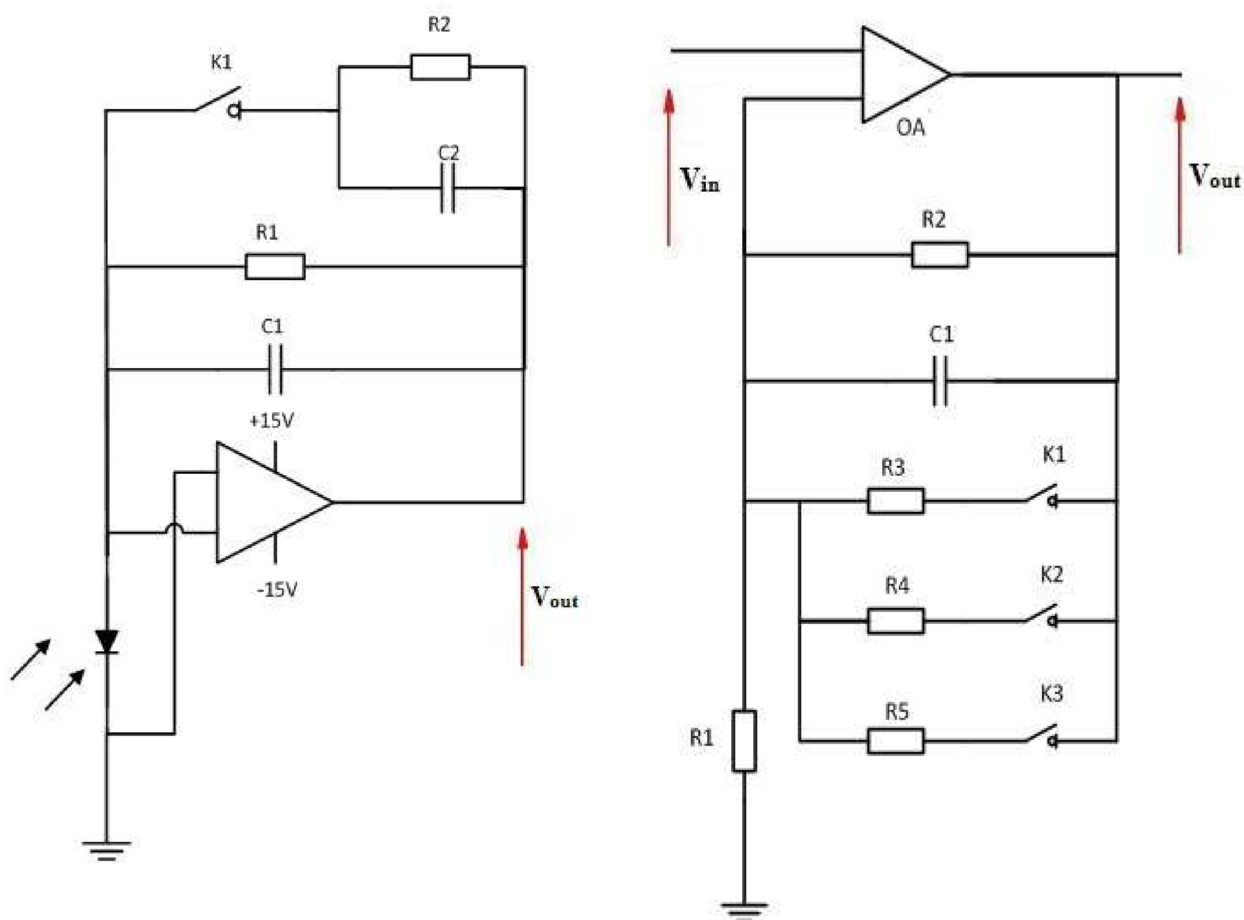

Fig. 3.6: Schematic of the Automatic Gain Control circuit with the two sections; the AGC is able to control the gain for the preconditioning stage and also for the additional gain stage.

Besides the hardware implementation of the AGC circuit, the software control of the architecture is also required. The microcontroller must be always able to select the optimum gain value for the board. A problem encountered during the first tests came at particular levels of the input signal. The problem was that the signal level was little under the low level threshold with current amplification and little above the high level threshold when increasing the amplification to the next available value. These particular cases were resulting in a continuous increase and decrease of the gain, resulting in to errors in message decoding. The solution for these problems was solved by developing an efficient switching control algorithm witch first computes the value of the signal, and calculates the required level of amplification. The switching control algorithm is described in the flowchart from Fig. 3.7.

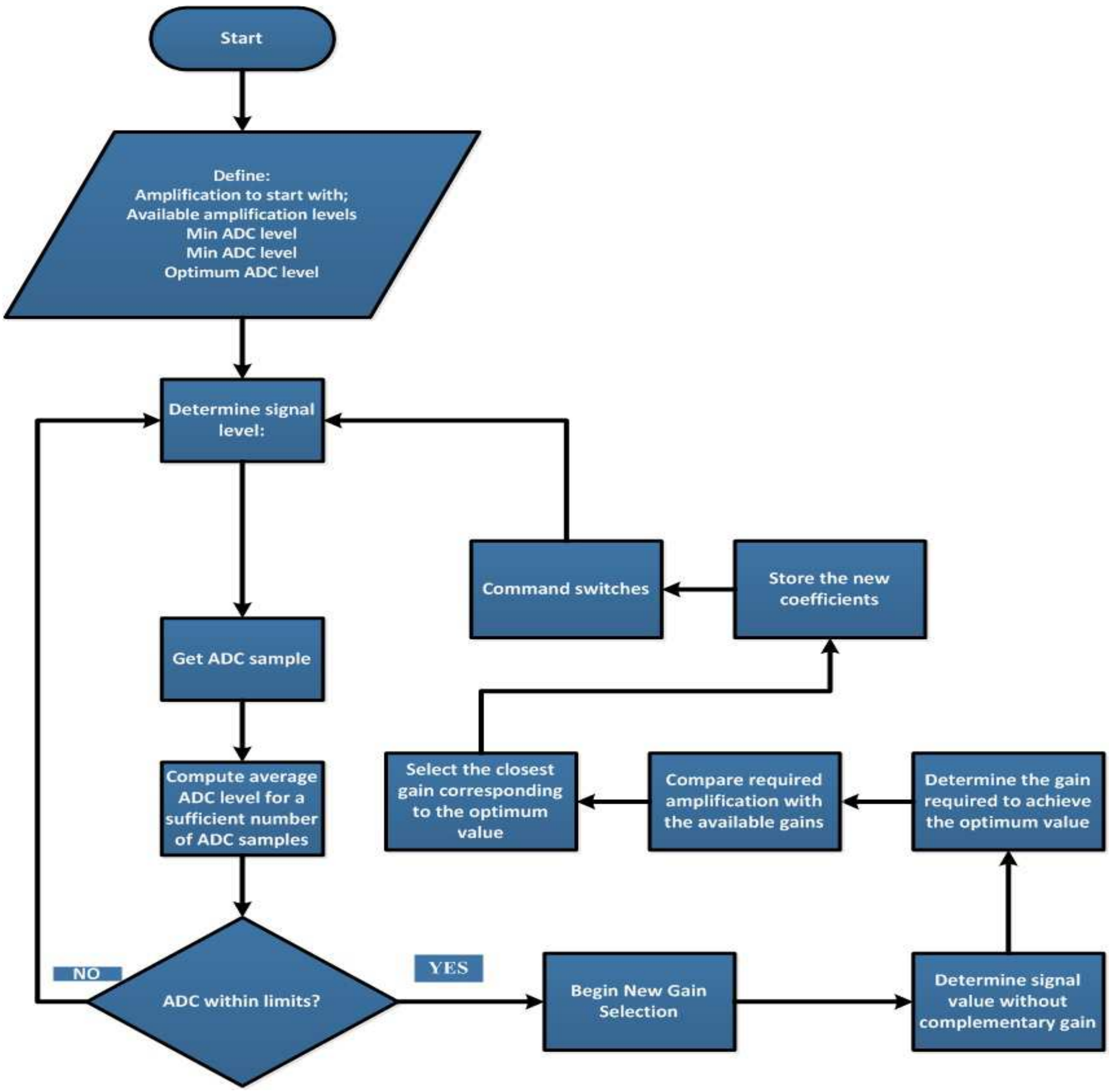

Fig. 3.7: The flowchart of the AGC gain selection algorithm.

4. VLC SYSTEM PERFORMANCE EVALUATION

Majority of the existing studies approaching the issues related to VLC systems for automotive applications design, are focused on a theoretical and conceptual approach [26], [27], without a step towards the implementation of the concept. Experimental verification of a system can point out some of the week points, highlight its advantages and validate the theoretical model. Another significant part of the existing work is conducted concerning VLC systems for in indoor environment [28], where the required communication range is of 1- 3 m (celling to workspace distance). However, the problematic of outdoor VLC is more complex due to the multiple noise sources, their high levels of power and because signal degradation along with the distance. In the light of the upper mentioned, it can be considered that there is a gap concerning the hardware development of VLC systems intended for outdoor long range applications.

Within this chapter, the experimental verification of the proposed VLC system presented in the previous sections is provided. The systems were tested based on the requirements of the ITS, in order to cover the V2V and the I2V communication. The cooperation of the two is also evaluated considering several scenarios that are meant to be similar with the ones encountered in real situations.

4.1. V2V setup and experimental results

In the context in which V2V communication represent one of the most important aspects related with the communication-based vehicle safety applications, the developed VLC system was tested for the mentioned configuration. For the VLC emitter a vehicle red back light had been used, replacing the traffic light from the configuration described in section 3.1. The testing scenario and the components of the tested architecture are illustrated in Fig. 4.1 and in [29].

Since the power of the back light is relatively low compared with the power of a traffic light the purpose of this configuration is to ensure a highly robust data transmission for short or medium distances, up to 15 meters. This VLC system is able to facilitate the transmission of data between vehicles, which is crucial to communicate information concerning the state of the vehicle (brake, speed, acceleration, engine failure, etc).

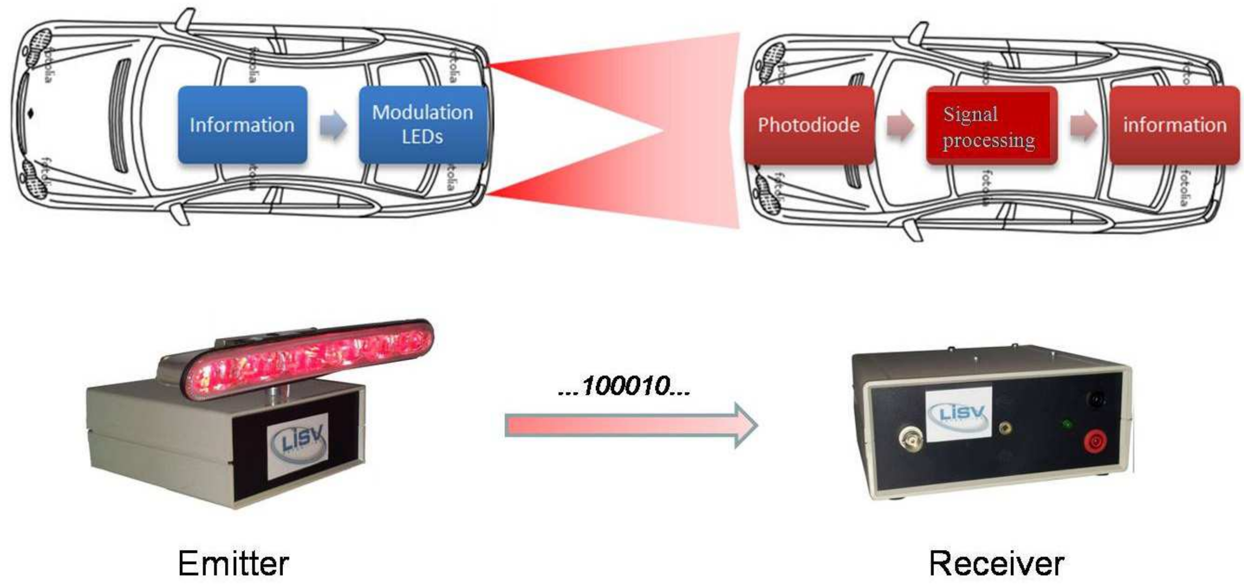

Figure 4.1: V2V prototype for data transmission using VLC.

This section presents the experimental results obtained for a V2V communication setup. The main objective is to demonstrate that the setup is suitable to transmit data using the visible light technology. As previously mentioned, the emitter and the receiver are controlled by microcontrollers, more precisely two Microchip PIC18F2550, as they are low cost and widely used. In order to facilitate the communication with the emitter and receiver modules, the two are interfaced with a PC through USB.

Basically, the message transmitted during the experiment is sent to the emitter and the frame indicates if Miller or Manchester code is selected. The message is therefore converted into a binary array. The red backlight is then set-up to blink periodically according to these values. Then, the receiver decodes the data in real-time and an algorithm counts the wrong bits compared to the original message stored in memory.

The experimental results for this setup are presented in Figure 4.2. As it can be observed, the BER is lower than $3{\cdot}10^{-5}$ over a distance of few meters. However, it quickly increases when the distance is higher than 10 m. Both curves have been made at 10 kHz modulation frequency, a 12 synchronization bits configuration and a data length of 4 ASCII characters (4*8 useful bits). Sets of data are about 3 millions of bits for both configurations.

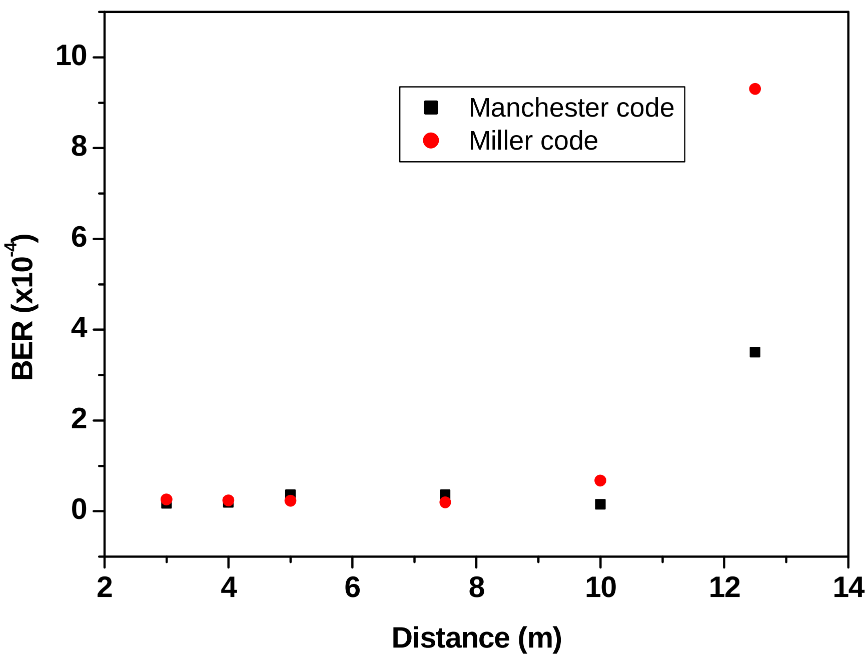

Figure 4.2: Bit Error Ratio (BER) for Miller and Manchester codes at 10 kHz modulation frequencies.

These results demonstrate that the prototype is well suited to transmit data over a short distance. However, it is a limitation as far as communication between vehicles (e.g. on a motorway) is concerned. One of the main reasons is due to the fact that the gain was intentionally limited. For these tests the AGC was disabled which lead to a BER degradation over the distance. As the purpose of this system is to be used for any weather conditions, special attention was paid to select the gain so that the system is not saturated because of sunlight. Consequently, the signal to noise ratio decreases as the distance increases. The second main reason is that the clock of the receiver is not synchronized with the transmitted frame. The analog electronics has been aimed to be very simple and no phase locked-loop is included. Nevertheless some analog filters are included that can modify the bit length, or rising and falling edges. The decoder includes an algorithm based on edges detection with tolerances on the values. To reduce the distortion the electronic part has to be improved or the decoding tolerances have to be adapted as presented in the fallowing section.

4.2. I2V setup and experimental results

Concerning the work regarding the VLC between infrastructures and vehicles, this was mainly focused on the communication between traffic light and vehicles, mainly because the high power of traffic light, which allows for long distance transmissions.

In order to test the visible light I2V communication, a general test bench of LED traffic light communications has been arranged, as presented in Fig. 4.3 and detailed in [30]. The emitter consists of the commercial traffic light – red or green can be switched – put on a mobile platform that allows varying the distance and the positioning.

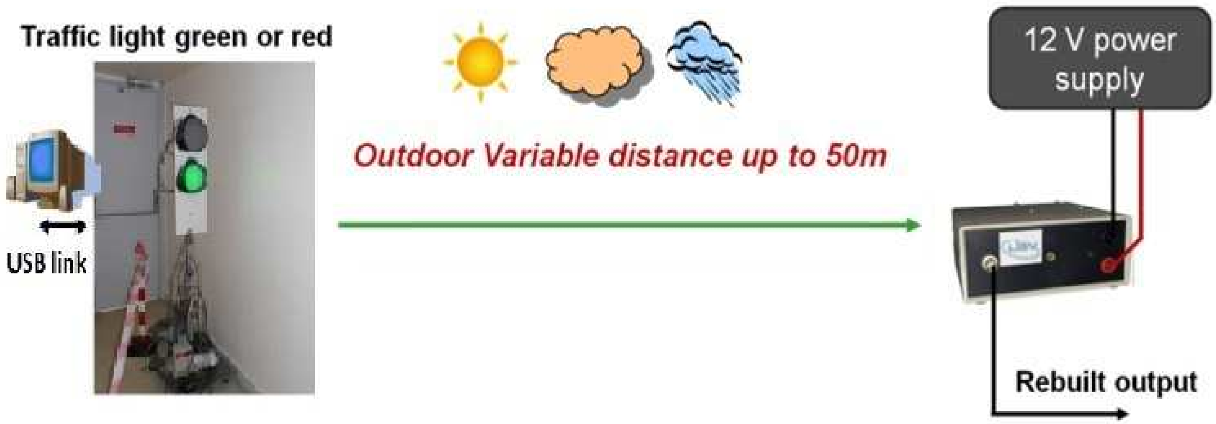

Fig. 4.3: Sketch of the test experiment with the receiver prototype, only supplied by a 12 V battery to be easily embedded. The sent data can be Manchester or Miller coded and composed of a traditional frame with synchronization bits, stat bits, data bytes and stop bits.

Test 1 – preconditioning stage sensitivity

The purpose of the first test related with the I2V configuration was to show the sensitivity of the pre-conditioning stage of the VLC receiver. The tests were performed in the absence of any incoming signal to point out the receiver's noise performances. To point out the signal to noise ratio, the receiver was also tested with an incoming data signal. The results are presented in Fig. 4.4. Two spectrums are plotted: the noise in dark condition, when the photodetector is hidden, and an example of spectrum in Miller case. The experiment has been realized at a short distance (8 m) of the emitter in the laboratory. One can see that the signal to noise ratio is quite good, and that the sensitivity is around – 80 dBm for frequencies above 3 kHz.

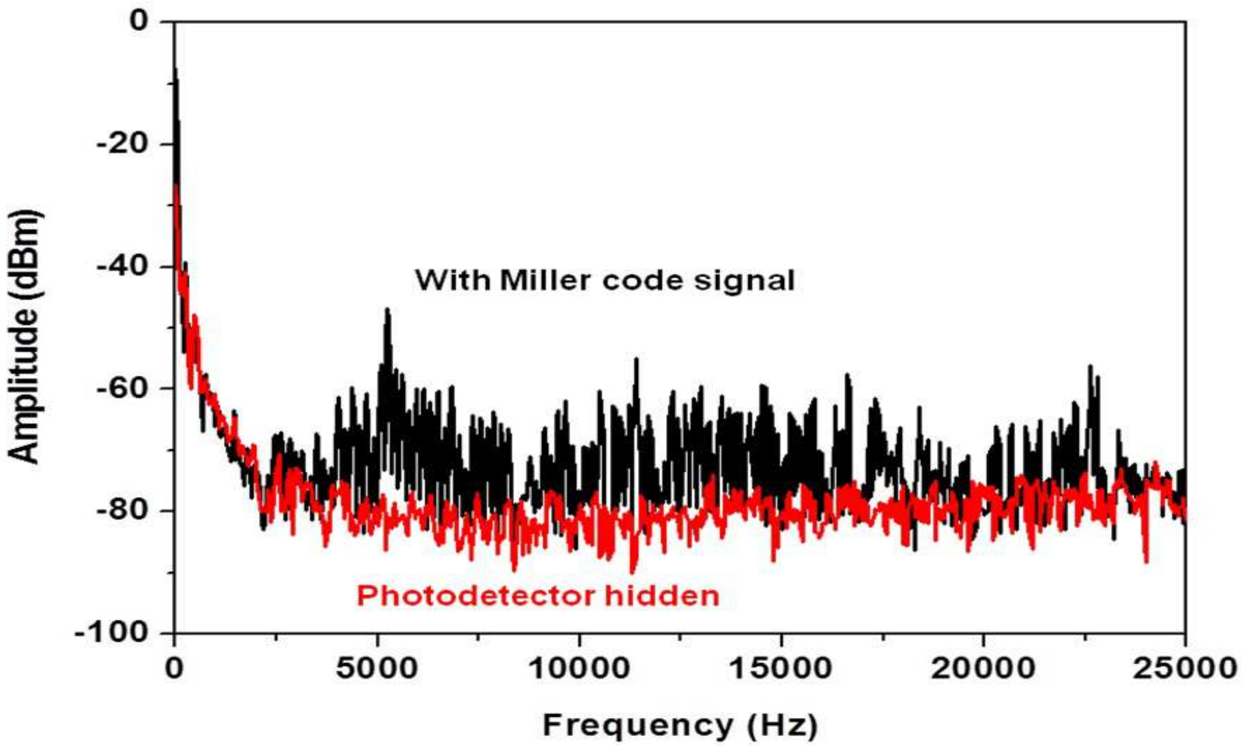

Fig. 4.4: Experiment showing the sensitivity of the front stage of the sensor and example of a spectrum in the case of Miller code; one can see that the signal to noise ratio allows potential detection with low error level.

Test 2 – Automatic Gain Control Unit

The aim of the second experiment is to test the functionality of the AGC stage. The importance of this stage was highlighted in the previous chapter, section 3.2. For these tests the distance between the emitting traffic light and receiver was altered and the response of the receiver was monitored. While modifying the emitter - receiver distance, the microcontroller computes the gain value in real time and adapts the switches on the board. The results illustrating how this value is affected are presented in Table I for some distances.

Table I: Gain value with respect to the distance when AGC is performed.

Distance (m)	**1**	**4**	**5**	**6.5**	**8**	**11**	**12-15**	**16-20**
Gain value (AU)	1	1.3	2.5	3	4	6	8	10

One can see how the gain of this stage is amplified with a factor 10 between the shortest and the longest distance (10 discrete values are possible for the gain). When AGC is performed, the system responds in real time to the variations of the intensity of the incoming signal. This enables the system to maintain a decent BER for the entire length of the service area (SA). The experimental results showed that when the AGC stage is disabled the communication range is reduced when an insufficient gain is preselected. Otherwise, when a high gain is preselected the system becomes unsuitable at short distances, as in the case when the car is too close to the traffic light, which leads to the saturation of the receiving module.

Test 3 – System calibration by pulse width measurement

As previously mentioned, the microcontroller performs the message decoding based on edge detection and by using tolerances for the pulse width measurements. Manchester code leads statistically to a message composed of two main pulse widths separated by front edges. In this case, the elementary modulation width is around 400 clock ticks of the microcontroller. The accuracy and the stability of the clock of the microcontroller are good enough and there is no requirement to synchronize the emitter and reception modules.

The distribution width measurements are illustrated in Figure 4.5 for approximately 5000 bits. Manchester case is reported in case 4.5a. One can see two groups of peaks: one around 400 ticks and the second one around 800 ticks (twice the first width). The two groups are divided into two subgroups because of low-level and high-level values. This phenomenon is due to the triggering electronics part. The threshold to trigger the signal is asymmetrical to separate low-level and the high-level values. The amplitudes of the peaks are lower for the second group because the message sent is not random. One can see also that the four distributions are clearly separated. The most important thing is that the two groups are fully kept away from each other which is the equivalent of no decoding errors. The microcontroller is then counting the width of the pulses with high frequency clocks and determines the digital information easily.

The Figure 4.5b illustrates the same distribution measurements for Miller configuration. Three groups of peaks are visible (elementary width of 800 ticks, one and a half and twice this value) with also subgroups for low and high levels values. In the same manner, the amplitude is only significant of the specific sent message which is not purely random.

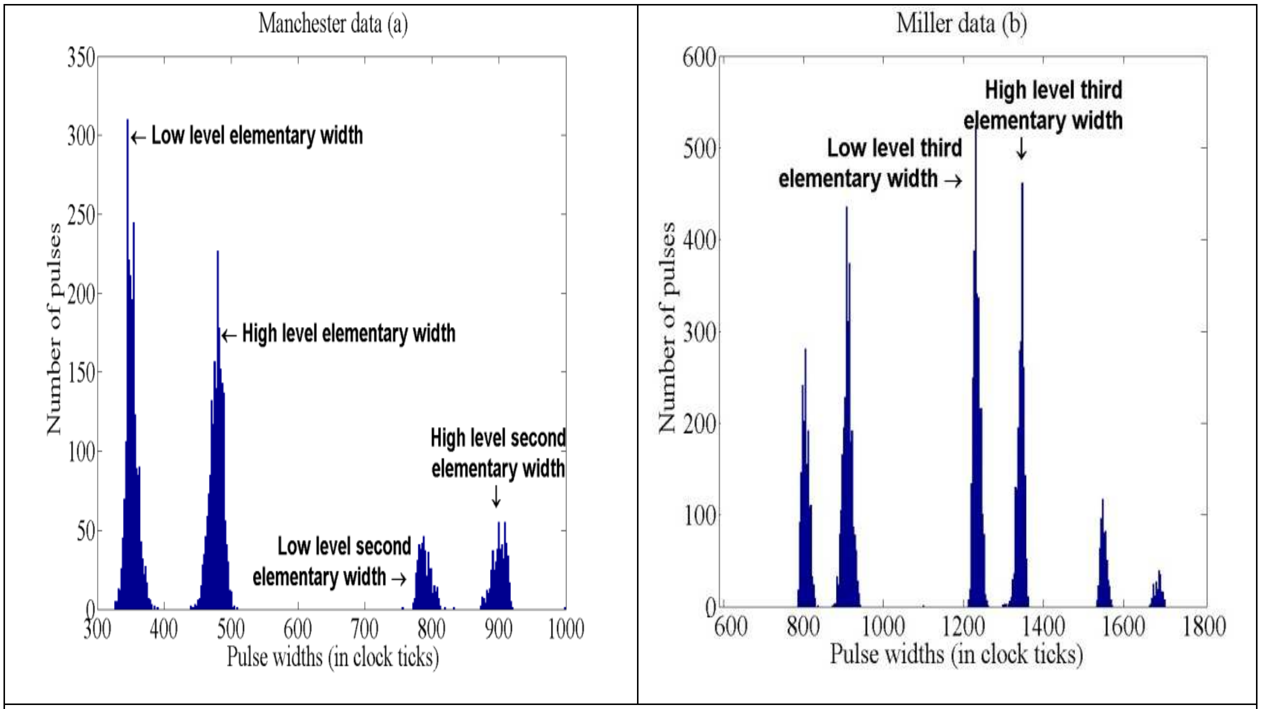

Figure 4.5: Histograms of received pulse widths for both Manchester and Miller configurations; a) Manchester case b) Miller case.

These distributions are useful to adjust the tolerance parameters on the detection threshold for the embedded microcontroller software. In the case of this experiment, the purpose was to determine the characteristics of the pulses, and to experimentally determine the decoding parameters in real working conditions. Using this approach, the performances of the system could be significantly improved.

Test 4 – Bit Error Ratio for Manchester and Miller coding

The fourth experiment for the I2V configuration has been realized to test the BER. A sequence of frames starts and the received bits are compared to the ones of the sent message. The system performs a loop which is stopped when pre-determined quantity of bits is reached. Tests are done either with red light or green light alternatively. Sets of data of 10 million bits have been sent. It can be considered that for most of road applications, a BER lower than 10^{-7} is good enough. Furthermore, the BER has been computed without error detecting codes, correlation techniques, or redundancy coding frames or protocols. This means that only the hardware aspects affecting the receiver's performances were evaluated.

Tests have been realized either for outdoor conditions or inside a building in a corridor with artificial lights (neon lights that provide a strong parasitic 100 Hz signal added on the useful signal). Table II summarizes the main results of the sets of data.

Table II: Bit Error Ratio (BER) for Miller and Manchester codes at 15 kHz modulation frequencies; green and red light have been tested in different conditions.

Code	BER	Conditions
Manchester	$< 10^{-7}$	50 m outdoor, daylight. Red light
Miller	$< 10^{-7}$	50 m outdoor, daylight. Red light
Manchester	$< 10^{-7}$	36 m outdoor, daylight. Green light
Miller	$< 10^{-7}$	36 m outdoor, daylight. Green light
Manchester	$< 10^{-7}$	20 m inside a building with neon light on Red light
Miller	$< 10^{-7}$	20 m inside a building with neon light on Green light

These results demonstrate that the prototype is well adapted for data transmission over short or medium distances up to 50 m. Results show 0 errors for 10^7 bits sent for both Manchester and Miller codes, confirming the simulation that were indicating that the two codes have similar BER performances.

The indoor tests have been made in a corridor, limited to 20 m range because of the limited length of the building. To test the immunity to parasitic signals, tests were performed inside a corridor with artificial lights on. The neon lights provide a strong 100 Hz parasitic signal which is successfully eliminated by the filters without having any influence on the 10^{-7} BER. Some errors can appear when the light is switch on or switch off because of transient pulses that can affect the frames but it is minor drawback. Both red and green lights have same performances.

The outdoor tests have been made in different sun expositions, for distances of up to 50 m distance. The sensor shows lower performances for the green light and the associated maximum distance is around 36 m. This is mainly due to three factors. Firstly, the sensitivity of the photodetector is lower for the wavelength corresponding to the green light than for the red one. Secondly, the sun spectrum is more disturbing in green range than in red one. And thirdly, the used lens is slightly chromatically treated and the transmission coefficient is better for red light. The performances of the receiver for the wavelength corresponding to the green color can be enhanced by using higher gain or plastic color filtering to reduce the influence of the sun light and to improve the signal to noise ratio. The influence of the first two factors is represented in Fig. 4.6.

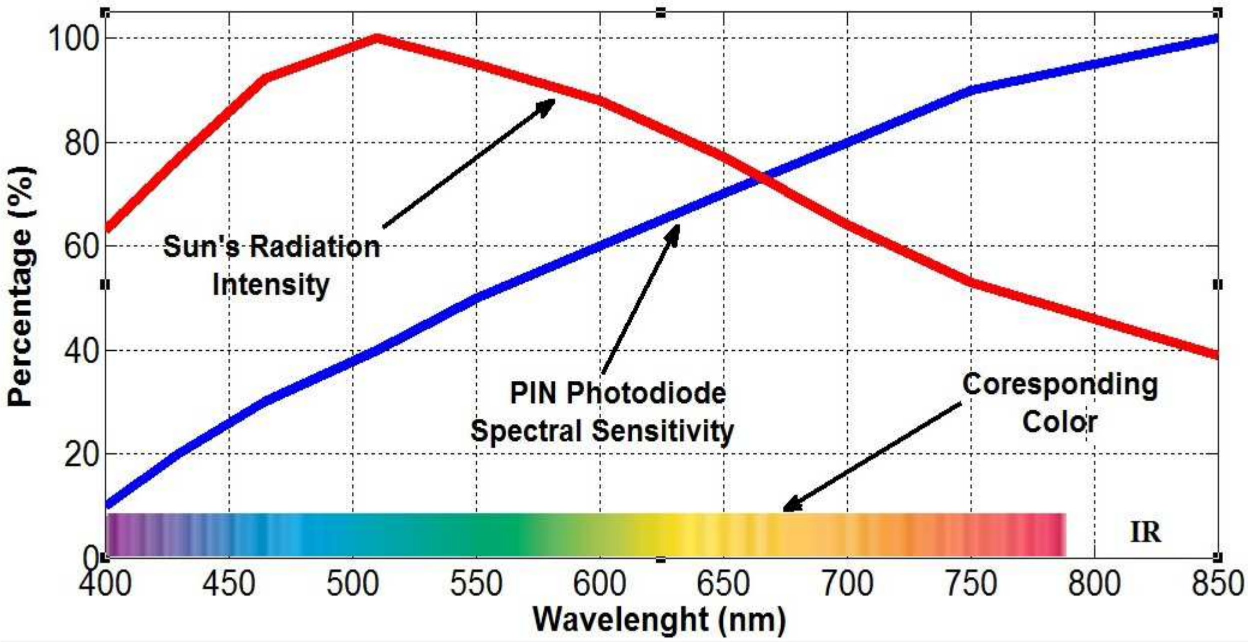

Fig. 4.6: Illustration of the factors that affect the sensor's performances in the case of green light; sun's radiation intensity is higher whereas PIN silicon photodiode's spectral sensitivity is lower in the case of green light.

4.3. VLC COOPERATIVE ARCHITECTURE SETUP AND EXPERIMENTAL RESULTS

The Intelligent Transportation System (ITS) integrates state-of-the-art cooperative technologies to increase the safety and efficiency of the transportation system and also to reduce the CO_2 emissions. By enabling wireless communications among vehicles and between vehicles and infrastructure the safety and the efficiency of road traffic can be substantially improved. Besides these communication technologies, ITS integrates a Cooperative Traffic Control and

Management Center that gathers the data from the traffic, analyses it, takes the required corrective measures and redistributes the information. In this Vehicle Ad-hoc Network (VANET) [31], the vehicles represent the mobile nodes whereas the RSU, as part of the traffic infrastructure, represent the fixed gateways. In order the system to be able to work at maximum potential it needs a high degree of market penetration and a large geographical distribution.

ITS involves cooperative driving technologies, based on wireless communication that allow vehicles and/or road infrastructure to exchange a large amount of dynamic which will generate a large data flow. A serious problem is represented by the fact that the wireless communication technologies on which the cooperative driving relies on, are known to be subject for different type of interferences. This problem is even more acute in the case of VANETs, where different nodes will cause mutual interferences. Under these circumstances, the Line-of-Sight (LoS) condition which is a major disadvantage of Visible Light Communication (VLC), limiting the communication range, may act here as an advantage, preventing interferences or the phenomena called “broadcasting storm” [31]. In these conditions, the major challenge for the ITS, is to be reliable and ubiquitous but at the same time to keep the implementation cost as low as possible.

Considering the upper mentioned, the aim of the fallowing work is to perform one of the firsts experimental demonstration of the cooperation between two major components of the ITS: I2V and V2V communications. For the purpose of this experiment, the two prototypes of led-light communications that have been presented in the previous sections were tested together as part of a complex system, as described in [33]. The aim was to enable the cooperation between the two communication systems. The first one is an example of I2V communication, between a commercial LED traffic light as a RSU emitter and a transceiver. The second one is an example of V2V communication and uses a vehicle’s rear-light emitter, to transmit the original message received from the traffic light to the fallowing vehicles. Of course, additional information, like a time stamp or vehicles coordinates and can be added. Both the prototypes transmit the digital information by using power modulation, which is the most appropriate for wireless optical links.

The proposed cooperative system has several advantages. First, it enables short to medium communication between road infrastructure and also among vehicles without causing mutual interferences. The message is forwarded from node to node, so it can reach to network nodes (vehicles) that are outside the communication area. So, by using multi-hop networking both LoS problem and limited communication range are solved. This scenario is presented in Fig. 4.7, where the first vehicle, which is in the Service Area (SA) of the traffic light, retransmits the received message to the fallowing vehicle, which is outside the traffic light's SA.

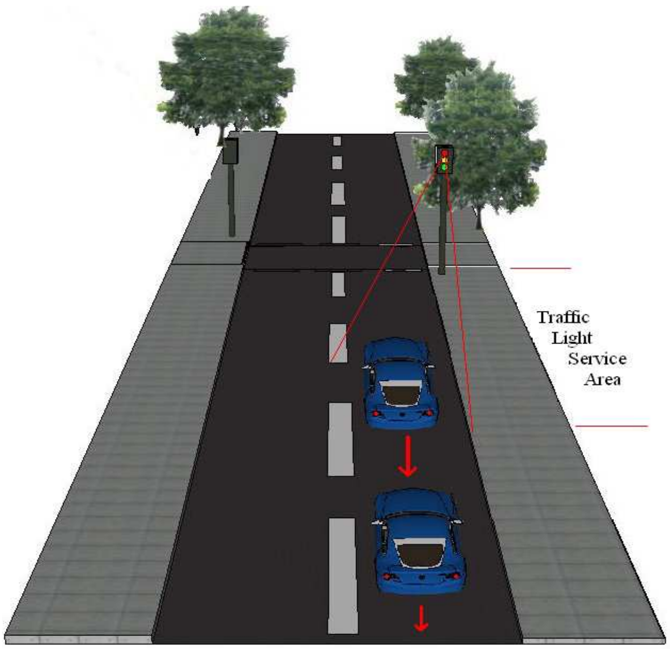

Figure 4.7: Illustration of the proposed cooperative scenario: the traffic light sends a message that is received by the first car and retransmitted to the car behind.

The experiments were conducted in laboratory conditions. The traffic light transmits data sets of 10 million bits. The message transmitted contains 7 ASCII characters of 8 bits, however longer messages can be send. The frame of the message indicates to the receivers if Miller or Manchester code is used. The transceiver receives the data and decodes it in real-time. The transceiver also resends the message for the second receiver by using the tail lights. An algorithm allows post-processing or calculation of errors to determine the BER. The BER is determined by comparing the received bits with the emitted ones. For these experiments a predefined message is sent continuously at a 15 kHz modulation frequency. The experimental setup for these experiments is presented in Fig. 4.8.

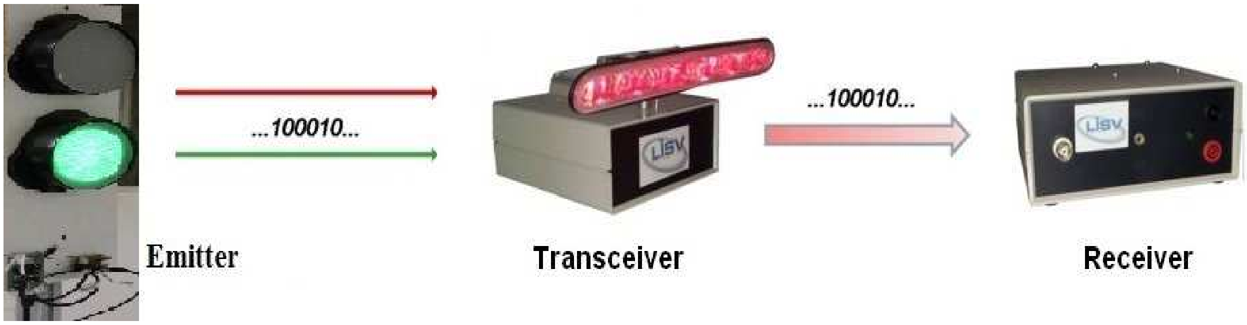

Fig. 4.8: Experimental setup for the VLC cooperative architecture; the LED traffic light broadcasts traffic safety messages; the transceiver receives the message and resends it for the second receiver.

Two scenarios were tested. In the first scenario, the transceiver is situated in the traffic light's SA whereas the second receiver is situated outside the traffic light's SA. The experiments began by setting the transceiver 20 meters away from the traffic light and the receiver 1 meter behind it, with no LoS with the traffic light. Afterwards, the distance between the transceiver and receiver was gradually increased and the BER was measured. Due to space limitation imposed by the building, the distances involved were limited, but the purpose of the experiment was to demonstrate that VLC communication can reach to a vehicle outside the service area. The results obtained for this scenario are presented in Table III.

Table III: Bit Error Ratio (BER) for Miller and Manchester codes at 15 kHz for the cooperative system - Scenario 1

<table>
<tr><th>Communication</th><th>Distance [m]</th><th>BER for Manchester</th><th>BER for Miller</th></tr>
<tr><td>I2V</td><td>20</td><td rowspan="7">$<10^{-7}$</td><td rowspan="7">$<10^{-7}$</td></tr>
<tr><td rowspan="3">V2V</td><td>1</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td rowspan="3">I2V2V</td><td>21</td></tr>
<tr><td>22</td></tr>
<tr><td>23</td></tr>
</table>

In the second scenario, both the transceiver and the receiver are situated in the traffic light's SA, but there is no LoS between the traffic light and the receiver. The transceiver was set 1 meter away from the traffic light and the receiver 1 meter behind it. In the next steps, the distance between transceiver and receiver was increased and also the distance between the traffic light and transceiver was varied. The BER was processed both for the I2V and for V2V communication and the results are presented in Table IV.

Table IV: Bit Error Ratio (BER) for Miller and Manchester codes at 15 kHz modulation frequencies for I2V, V2V, and I2V2V

Distance I2V [m]	Distance V2V [m]	Distance I2V2V (I2V+V2V) [m]	BER for Manchester	BER for Miller
1	1	2	$<10^{-7}$	$<10^{-7}$
	2	3		
	3	4		
5	1	5		
	2	7		
	3	8		
10	1	11		
	2	12		
	3	13		
15	1	16		
	2	17		
	3	18		

The experimental results show a BER of 10^{-7} for both I2V and V2V communication for variable distances. These communication distances can be increased especially in the case of the I2V where the power emitted by the traffic light is high enough to allow longer distances. For such a communication the BER of 10^{-7} can be maintained for distances of up to 50 meters whereas, for V2V the communication the range can be increased in this configuration up to 10 meters, as presented in the previous sections. Even so, it is difficult to achieve communication ranges comparable with those of radio communication.

The results demonstrate that the prototypes are well adapted for data transmission over short or medium distances, for I2V and for V2V, using both Manchester and Miller codes. But, the main objective of the experiment was to test and demonstrate the cooperation between an I2V communication system and a V2V communication system which will be the case for the real traffic scenario.

This experiment demonstrated that the limitation represented by the LoS condition and the limited communication range of VLC, can be overcome by using multi-hop networking. It was showed that the communication between a RSU and a vehicle that is outside the SA of the RSU is possible with the help of a second vehicle that is found inside the SA and that forwards the message. The same working principle could be applied in the case of radio communication. This will allow the emitters to reduce the emission power, just to allow communication with the closest neighbor, without causing interferences to the other vehicles. Of course, in the real traffic case, more complex routing protocols will be required.

5. Conclusions and Contributions

This research activity report presents some of the aspects related with the implementation, optimization and the experimental verification of a VLC system for automotive applications. The experimental results, confirm that the proposed VLC architecture is suitable for the intended applications.

The VLC system was tested in various conditions in order to verify its reliability in the presence of natural and artificial light. Mainly focusing on the hardware part, the system was able to achieve BER results lower than 10^{-7} for distances of up to 50 m. These results are very promising knowing that no error-correcting codes have been used. The calculated BER of 10^{-7} could also be highly improved considering that it was obtained focusing only on hardware techniques. Errors detecting codes, correlation techniques, or redundancy coding frames or protocols are some possible solutions to achieve this.

The proposed system was tested in V2V and I2V configuration. Also, a cooperative VLC architecture was demonstrated for the first time. This way, it was showed that the communication range of VLC systems can be increased by using multi-hop communications and that the emitter - receiver LoS conditions can be overcame with the help of retransmissions.

Within this report, the importance of an AGC stage has been pointed out. With the help of the AGC stage, the VLC system can maintain a decent BER for a longer distance.

The next step of this research project involves implementing the embedded systems in real road configurations. The optical part is made in cooperation with Valeo industry and is also dedicated to be multi-functions. It is also developed to be a vehicle inter-distance sensor.

Considering the coding techniques, within this chapter had further investigated the performances of the Manchester and the Miller code. The experimental results confirmed the simulations that were indicating that the two codes have similar performances in terms of BER. It can be considered that in the two research reports, a significant number of arguments were broth in the favor of the Miller code usage in future MIMO outdoor applications.

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