Hardware Design of a Prototyping Platform for Vehicular VLC Using SDR and Exploiting Vehicles CAN Bus

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***Abstract*—Ever-increasing world population in big cities demands intelligent transportation systems (ITS) that are efficient and resilient, which in turn need a practical communication paradigm for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-vehicle (I2V) communication. Visible light communications (VLC) open new alternative technologies that use a license-free spectral band, with several Terahertz of bandwidth. Those technologies will be cost-effective because LED infrastructure is already widely deployed in traffic lights, car lights and signs. To start experimenting with VLC, software defined radios (SDRs) are a versatile platform that, combined with an LED and a Photodetector, can rapidly prototype systems. Data from the vehicle can be gathered by reading its control area network bus (CAN Bus), where all the electronic sensors and actuators are connected. This paper shows the design of a VLC platform based on SDRs, capable of prototyping various communication schemes in outdoor and indoor scenarios. Also, the design of a CAN Bus reading interface is shown. Both systems, the VLC platform and the CAN Bus interface, are combined to make an ITS communication system prototype based on VLC.**

Keywords*—Control Area Network Bus (CAN Bus), Intelligent Transport Systems (ITS), Software Defined Radios (SDRs), Visible Light Communications (VLC).

I. Introduction

In the last years, lots of research has been done on technology developments for the implementation of intelligent transportation systems (ITS). Such developments aim to achieve great improvements on the performance of existing transportation systems, in terms of traffic management, efficient use of transportation infrastructure, reduction of congestion and travel times, and improving road safety. Congestion and accidents are worldwide phenomenons that translate into considerable economic costs [1] and loss of human lives, and which could be greatly reduced through the implementation of ITS. Key services and features of an ITS depend on fast and robust communication involving the whole vehicular network. Visible light communications (VLC) appears to have the required transmission rates to meet these goals [2], and is also a cost-effective alternative [3]. As shown in [4], researchers have reported data rates higher than 10 Gbit/s for short-range VLC, but for a longer than 10 m range, Wu *et al.* [4] reached 34.13 Mbit/s with a bit error ratio (BER) of 10^{-6}. Proposals also involve providing Internet access to the transport network via the infrastructure but in order to do so within a real scenario, higher data rates must be achieved.

Several technologies and techniques for vehicular communication have been investigated and tested, but most efforts focus on dedicated short range communications (DSRC) and standard 802.11p, which establishes the regulations for wireless access in vehicular environments (WAVE)[5]. DSRC comprises 75 MHz of spectrum in the USA and 30 MHz of spectrum in the EU, both in the 5.9 GHz band [6], [7]. It was meant as a global vehicular networks communication standard, but there are many issues with it and it hasn't still been widely deployed. In [5], its vulnerabilities and capabilities are summarized along with those of VLC, and the work concludes by pointing out the strong potential presented by the combination of these technologies, since their unique features make them complementary.

There has been ongoing research about how other complementary technologies can work together to make transport communications more resilient and improve their performance. [8] proposes a set of rules to use 3 technologies (LTE, 802.11p, and DSRC) simultaneously, reducing latency and increasing throughput. As VLC works in a different band of frequencies and is effective under different scenarios, its use together with these technologies is possible and would improve performance even more.

The essential concept of VLC is to transmit information through common visible light sources such as LEDs, thus taking advantage of existing infrastructure. VLC opens new alternative technologies that use a license-free spectral band roughly from 400 - 700 nm, which translates into an available bandwidth of hundreds of THz. A recent survey [9] provides a wide view of VLC research and technology to the date by reviewing literature about: components, physical layer characteristics, multiple access issues, programmable platforms, and indoor and outdoor applications.

As LED infrastructure is already widely deployed and has become the illumination standard due to its high efficiency, including traffic lights and vehicles' headlamps, VLC is considered a cost-effective solution. Also, its implementation in vehicular networks would have a faster market dispersion than its RF counterparts which require additional hardware. Another key aspect of LEDs is that they have a high response speed in light intensity against rapid voltage variations, which presents the potential for effective intensity modulation schemes achieving high data rates [3].

The platform hereby presented offers the possibility of prototyping in an easy and effective way a VLC link oriented to V2V communication using the standard vehicle's headlights and a selected photodetector. It incorporates software defined radios (SDRs) for flexible modulation and transmission rates settings, aiming to define the optimal features of a dedicated hardware design under the established conditions. A controller area network bus (CAN Bus) reading system implementation is also included to make the whole system as practical as possible. The key capabilities of the system will be measured and defined step by step.

As a positive impact, full documentation of this work is being developed, so that anyone can reproduce the system and results, and generate derived works and prototypes in the future. This material could be used to design laboratory experiences for experimental courses, both at Universidad de Chile and elsewhere, including tutorials for the setup and configuration of the platform, along with examples of its potential applications.

This platform serves as a testbench for vehicular VLC links that allows for some of the key features to be defined and verify their functionality, before coming up with a fully functional design. This will speed up the process of developing a range of products suitable for the market, thus accelerating the transition to a global deployment.

SDRs are programmable communications hardware based on field programmable gate arrays (FPGAs). They count with voltage controlled oscillators (VCOs), mixers, analog-to-digital and digital-to-analog converters, amplifiers. These components' parameters are configurable by code, allowing rapid prototyping of communication systems of any kind. In particular, a pair of SDRs along with an LED, a Photodetector and off-the-shelf electronic components can implement full VLC systems. This work explores this rather new potential application of SDRs as development tools in the VLC field.

CAN Bus is a bus-architecture network existing inside modern vehicles where all the digital sensors and actuators communicate their values and status. CAN reading allows an ITS system to gather key data from cars, such as instantaneous velocity. This can be used to improve channel modelling (including Doppler Effect for example) and effective modulation adaption, as well as to provide critical traffic services such as emergency braking or synchronized acceleration and deceleration. The presented platform proposes an implementation to directly incorporate CAN Bus information into the system.

Next sections will discuss the design and further development of the platform. In section II, the design and materials that compose the system are described, along with the methods for its development and characterization. Section III proposes an experimental methodology to test the system and achieve practical results, following a logical order in which each experiment sets the conditions for the next one. Finally, the conclusion of this work are stated in section IV.

II. System Design

The platform is both a VLC link and a CAN Bus interface that can be arranged in different configurations. It's formed by three main subsystems: Tx, Rx, and CAN. Both, Tx and Rx subsystems are based on an SDR with an LED and a photodiode respectively, and the CAN subsystem is based on a MCP2515 integrated circuit together with an Arduino microcontroller.

National Instruments (NI) Universal Software Radio Peripheral (USRP) is a family of software defined radios designed to be programmed with NI LabView software. Two USRPs model NI2922 were chosen and were firmware updated to be programmed with GNU-Radio software. The USRPs model NI2922 work within the band from 400 MHz to 4.4 GHz in a pass-band scheme with 20 MHz bandwidth. This hardware is incompatible with the VLC intensity modulation transmission scheme, so a replacement of the original daughterboard is needed. This will be specified in the following subsection. A complete overview of the whole system is included in Fig. 1.

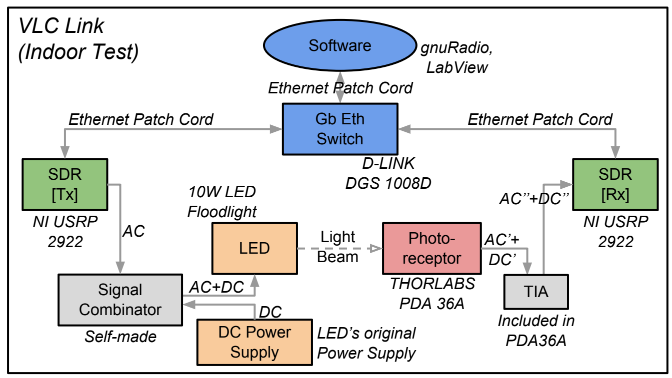

Fig. 1. Block diagram of the VLC system.

The platform is designed to work in an indoor office environment as well as an outdoor vehicular environment. This is intended both for laboratory work and field testing under controlled conditions.

A. VLC System

The general VLC link design is shown in Fig. 2. It's composed of two subsystems, one for transmission and one for reception.

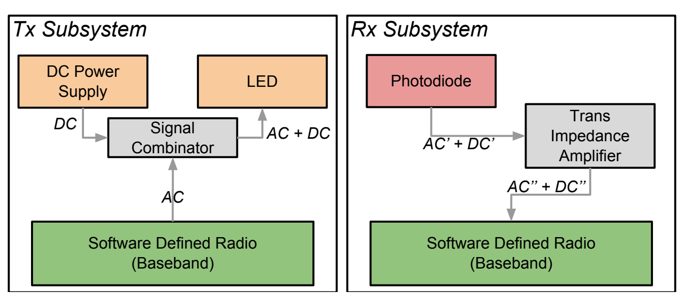

Fig. 2. Tx and Rx Subsystems of the Platform. Tx modulates the intensity of the LED and Rx detects intensity variations from the received light, converting light to electric signals. The modulation and demodulation processes are done with the SDRs.

The platform's VLC link consists of a transmitter, connecting a USRP NI2922 with a LED lamp through a bias-tee, and a receiver, using a USRP NI2922 connected to a

PD36A photodetector. The VLC Tx and Rx subsystems are designed to work in base-band, as opposed to the default USRP scheme which is a pass-band scheme. Because of high integration within the USRPs, it's not possible to access the base-band signal before it's mixed with the local oscillator's signal. Therefore, an internal hardware modification of the NI2922 was performed. Both radios' default pass-band daughterboards were replaced with two low frequency (base band) daughterboards that act as receiver and transmitter, namely Ettus Research LFTX/LFRX 0-30 MHz daughterboards. Such replacement was made in order to improve the transmission rates and to make the system compatible with visible light spectrum transmission. This modification can be appreciated in Fig. 3.

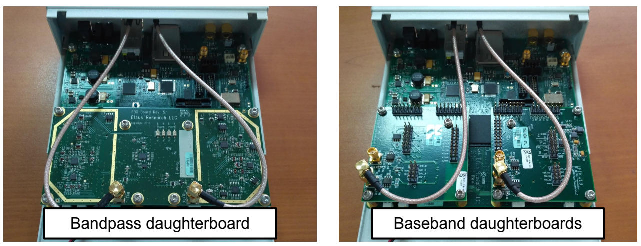

Fig. 3. Modification of the NI USRP 2922 original daughterboard (which works in bandpass) [left side] to baseband daughterboards [right side]

As seen in Fig. 1, the connection between the PDA36A photodetector and the USRP in the receiver side is direct, since the Trans-Impedance Amplifier (TIA) is integrated within the PDA36A. In the transmitter side, however, an AC+DC signal combinator is needed in order for the LED to transmit an intensity-modulated signal. This signal combinator circuit receives the LED's DC power supply and the USRP's AC signal as inputs. There are RLC based signal combinators known as "Bias Tees" [10] that are low cost solutions but they can be easily contaminated with noise because they couple with electromagnetic fields. A better design (in terms of noise) of a signal combinator is proposed by [11]. Its electric design can be seen in Fig. 4, where V_{in} is the USRP's AC signal and V_{bias} is the LED's DC power supply.

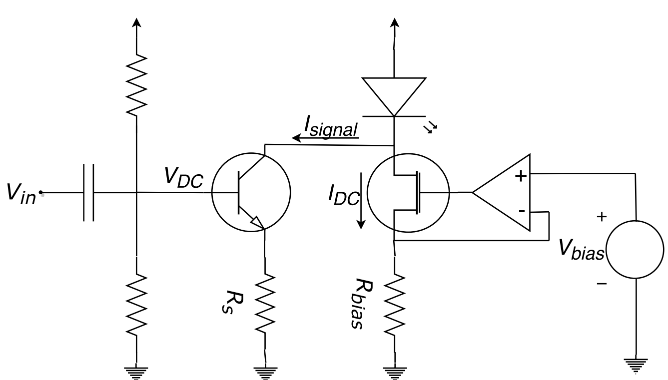

Fig. 4. Signal Combinator. It receives the DC and AC signals coming from the LED's DC power supply and the SDR output, respectively, and sends the sum of both signals to the LED. Source: [11]

B. CAN Bus Reading

All modern vehicles count with a CAN (Control Area Network) Bus that is accessible by an On Board Device Port (OBD Port), usually located inside the cabin. The bus consists of two nodes called "CAN High" and "CAN Low" where all the control units connected, such as sensors and actuators, transmit and receive data by packets, identifying themselves. In a recent work from 2016, a VLC system exploiting CAN Bus data was successfully built [12].

A well-known integrated circuit to read and write CAN Bus data is the MCP2515, that works as a modem of the CAN Bus physical layer protocol. Sparkfun CAN Bus Shield is a MCP2515 based CAN Bus interface. It also counts with a microSD interface, GPS port and other non-considered features. A serial interface is needed to communicate both with the MCP2515 and with the computer controlling the SDR. An Arduino UNO was selected for this task.

The chain of blocks needed to implement the CAN Subsystem of the Platform is shown in Fig. 5. Note that the MCP2515 interface will gather all the data flux of the CAN Bus, therefore, filtering software is needed to isolate relevant sensors, such as the ones measuring velocity, accelerator pedal position, and brake pedal position.

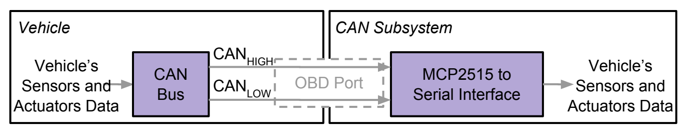

Fig. 5. CAN platform subsystem capable of reading the data of the CAN Bus.

C. ITS Communication

With all the subsystems presented, it's now possible to design an ITS communication configuration of the platform. A vehicle to infrastructure (V2I) was chosen because of the need of just one vehicle. Note that an infrastructure to vehicle (I2V) configuration is analogous. As shown in Fig. 6, a computer controls the CAN interface and the VLC Tx subsystem inside the vehicle. This computer will filter the data stream coming from the CAN interface and will communicate to the Rx subsystem through visible light.

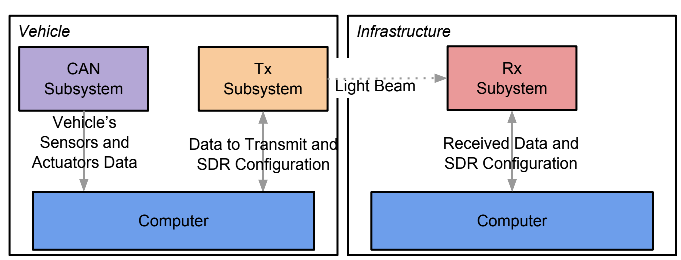

Fig. 6. V2I platform configuration.

III. Experimental Methodology

The hardware designed for the Rx system has been already validated, the CAN subsystem and the Signal Combinator have to be implemented and tested. Other basic hardware to firmly and safely join the elements together has yet to be designed and implemented to operate the whole system.

The configuration shown in Fig. 6 of the V2I communication setup will be used. Random information will be generated at the computer inside the vehicle and will be saved before the transmission starts. The VLC link will be used taking CAN Bus data to include Doppler effect. The computer working as receiver (Infrastructure of the V2I communication) will demodulate and save the data to compare with the original data saved. Then, the performance of the platform will be measured by means of Bit Error Rate (BER) varying the bit energy (E_b) over noise's spectral density (N_0) and varying distance and angle between Tx and Rx (d, θ). This will give (BER vs $\frac{E_b}{N_0}$) curves and (BER vs d, θ) curves (for fixed SNR). First, several SNR-d, θ settings will be tested as to establish reasonable ranges of distance and angle for successful communication under known BER conditions. Thus, a practical BER will be selected, and the maximum distance for a BER not less than the selected one will be determined. The BER must in any case be higher than 1E-6 in order to consider a successful communication. With this defined setup for SNR, Line of Sight (LoS) distance and maximum BER, the maximum misalignment angle θ that preserves secure communication will be measured and determined. This last curve will characterize the constraints for V2V and V2I communication in a realistic scenario. Message latency measurements will also be carried out as to characterize the VLC link's performance under different conditions for specific applications, which will be selected from the ones identified as critical safety applications in [2].

IV. Conclusion

VLC is an attractive technology for ITS systems that can take advantage of the existing already deployed LED infrastructure. Hardware for an ITS-oriented VLC platform based on SDRs was designed and shown in this paper. The platform consists of a VLC link formed by an LED and a photodetector, both controlled by SDRs and a vehicle's CAN Bus interface was designed to communicate vehicle's sensor data to the transmitting system in a V2I platform configuration.

Upcoming work to start operating the platform considers implementing the designed hardware blocks, software design, and implementation of of the following subsystems: CAN relevant data filtering, Tx and Rx digital signal processing, and simulation routines to experimentally test the platform's performance in terms of BER. The BER will be calculated by varying the bit energy, as well as physical parameters such as distance and angle between Tx and Rx. Further work will be focused in designing the location of the transmitter and receiver, and an optical interface for the photo-detector in the Rx system that ensures continuous communication in a field of vision relative to a V2V scenario. A a multiple-input and multiple-output (MIMO) design for the system that fits the chosen SDR's capabilities will be evaluated.

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References

[1] G. Cookson and B. Pishue, "Inrix global traffic scorecard," INRIX Research, Tech. Rep., 2017.

[2] C. B. Liu, B. Sadeghi, and E. W. Knightly, "Enabling vehicular visible light communication (V2LC) networks," in *Proceedings of the Eighth ACM International Workshop on Vehicular Inter-networking*, ser. VANET '11. New York, NY, USA: ACM, 2011, pp. 41–50.

[3] Z. Ghassemlooy, *Optical wireless communications : system and channel modelling with MATLAB*. CRC Press, 2013.

[4] Z.-Y. Wu, C. You, C. Yang, L. Liu, K. Xuan, and J. Wang, "Research on long-range real-time visible light communications over phosphorescent LEDs," in *2017 29th Chinese Control And Decision Conference (CCDC)*. IEEE, may 2017.

[5] A.-M. Cailean, B. Cagneau, L. Chassagne, V. Popa, and M. i Dimian, "A survey on the usage of DSRC and VLC in communication-based vehicle safety applications," in *2014 IEEE 21st Symposium on Communications and Vehicular Technology in the Benelux (SCVT)*. IEEE, nov 2014.

[6] Federal Communications Commission, "In the Matter of Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5.925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services," *Federal Communications Commision Official Release*, no. 99-305, 1999.

[7] European Commission, "Commission Decision of 5 August 2008 on the harmonised use of radio spectrum in the 5 875-5 905 MHz frequency band for safety-related applications of Intelligent Transport Systems (ITS)," *Official Journal of the European Union*, no. L220, pp. 24–26, 2008.

[8] F. Valle and S. Céspedes, "Enhancing vehicular applications by exploiting network diversity," *Proc. Spring School of Networks*, 2016.

[9] P. H. Pathak, X. Feng, P. Hu, and P. Mohapatra, "Visible light communication, networking, and sensing: A survey, potential and challenges," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2047–2077, 2015.

[10] T. Stratil, P. Koudelka, J. Jankovych, V. Vasinek, R. Martinek, and T. Pavelek, "Broadband over visible light: High power wideband bias-t solution," in *2016 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP)*. IEEE, jul 2016.

[11] Z. Ghassemlooy, L. N. Alves, S. Zvanovec, and M.-A. Khalighi, *Visible Light Communications: Theory and Applications*. CRC Press, 2017.

[12] J.-H. Yoo, J.-S. Jang, J. K. Kwon, H.-C. Kim, D.-W. Song, and S.-Y. Jung, "Demonstration of vehicular visible light communication based on led headlamp," *International Journal of Automotive Technology*, vol. 17, no. 2, pp. 347–352, Apr 2016.