

Development of Visible Light Communication System for Automotive Applications Based on Organic Light Emitting Diode Panels

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Abstract— Classical traffic light systems in various forms have served public transport for more than a hundred years now. Their basic principle is to inform drivers of all types of vehicles and also pedestrians of their current active status. The number of cars has increased drastically so that it is very common to get stuck in traffic in rush hours. The road infrastructures in cities use multiple lanes and also traffic lights to direct traffic and to ensure and safety. Today traffic lights can also be used simultaneously to establish communication between vehicles and infrastructure with the help of visible light communication (VLC). This new feature could be key in attempting to diminish road accidents with the use of important information. Real-time analysis of traffic information is required in order to pass relevant information to the driver. This can be gained with an interconnected infrastructure throughout the city. Therefore when a certain level of traffic is reached, redirection of traffic would prevent traffic jams, and also urgent messages like an incoming ambulance/fire truck/police car in the mission would be passed to drivers to allow free passage. In this era of information, informing prevents panic and also the sudden course of action. This paper describes the development of such capable traffic light, based on OLED decorative panels. The obtained traffic light system has been tested indoor for its suitability for vehicular applications.

Keywords— *OLED, VLC, decorative lighting, traffic light, vehicular applications, indoor testing*

I. INTRODUCTION

With the introduction of solid-state lighting [1] as light sources and also of organic optoelectronic devices as a solution for interior lighting, information displays [2], OLED (Organic Light-Emitting Diode) may as well become a solution for visible light communications for vehicle-to-vehicle (V2V), vehicle to infrastructure (V2I), infrastructure-to-vehicle (I2V) and their incorporation into intelligent lighting systems with its many technological advantages [3]. The production costs of OLED devices are lower than those based on LEDs. OLED devices have lower electricity consumption, long service life, fast dynamic response. However, a disadvantage for OLED is that in comparison with LED technology have a smaller

This work was supported by contract no. 18PFE/16.10.2018 funded by Ministry of Research and Innovation within Program 1 - Development of national research and development system, Subprogram 1.2 - Institutional Performance -RDI excellence funding projects.

luminous efficiency, over 50 lm/W for OLED and over 200 lm/W. The OLED technology is continuously developing, so in the near future, we may expect OLED devices and light sources with higher efficiencies commercially available.

VLC technology uses small variations in light intensity to transmit data. The current infrastructure for traffic signaling can be used by adding a driving circuit along with the power supply. The data received through the city road network infrastructure is passed to the driving circuit. The data values will cause the light to fluctuate between two values “on” and “off”. This driving circuit would be able to transmit information regardless of the traffic light color. For intermittent traffic lights, other schemes of transmission should be applied.

VLC has the advantage and potential of being present almost everywhere. This is possible because solid-state light sources are implemented in interior lighting and also in outdoor lighting. Most important outdoor applications consist of street lighting and road signaling. By using the light wave spectrum to our advantage, we can cover the radio wave spectrum and prevent congestion of communication channels in high traffic, traffic jams. This particularity is not only beneficial, but it also raises the ability to prevent road accidents, so their use with radiofrequency channel systems is complementary [4].

The organic light-emitting diodes (OLED) is a more recently solid-state lighting technology than light-emitting diodes (LED). First OLED electroluminescence (EL) research was conducted in 1953 by Bernanose and coworkers [5] by applying alternative current (AC) on derivatives of acridine. Later work on organic anthracene crystals in 1963, Pope and coworkers [6], stimulated EL by applying a direct current (DC). Due to high operating voltage for EL at 400V interest waned. Later efforts of Tang and Van Slyke in 1987 demonstrated EL performance of a green-emitting thin film OLED based on a small organic molecule tris(8-8-hydroxy quinoline) Al (Alq3) with operating voltages under 10 V[7]. Another essential work on OLED EL of Burroughes et al. in 1990 was done on poly(p-phenylene vinylene) PPV [8]. All mentioned works have been critical to later shown interest in industry and research. This impulse led to the development of OLED display technology with the help of vacuum deposition

techniques including thermal vacuum evaporation used to obtain active-matrix full color and passive matrix displays. Among the first commercial displays were Pioneer vehicular stereo OLED display in 1999 and Motorola cell phone OLED display in 2000.

Regarding traffic signaling, traffic lights are necessary that they pass the required European standard EN 12368:2015 regarding luminous traffic and pedestrian signaling. According to [9] the axial luminous intensity of traffic signals with 300 mm light aperture: red and green require more than 400 cd, yellow require more than 600 cd – regarding class A 3/1 prEN 12368. For 200 mm light aperture: red and green more 250 cd, yellow more than 400 cd – class A 2/1 prEN 12368.

Communication through visible light with organic optoelectronic devices in applications mentioned above requires a large operating area. This is translated into a slow dynamic response due to the capacitive behavior of OLED panels[10]. This is a problem of OLED devices for VLC applications, and it is essential that we improve their dynamical response.

Light emission takes place at the OLED panel after the recombination of electrons and holes and exits through the transparent anode and its substrate. These phenomena take place initially at the emissive organic interface layer where holes and electrons meet and release energy in the form of light. The operation voltage range for typical OLED is between 2 and 10 V. The color of the light emitted depends on the composition of the organic emissive layer. The more simultaneous emissions take place, the intensity of the light rises.

The dynamical response is tested through the appliance of a variable current through the OLED electrodes, which is translated into a variation in light intensity. The variable current should vary between the optimum operating parameters for illumination and the ‘off’ state of the device without discharging completely the OLED panel. This operation varies differently in relation to time. As the time of appliance shortens, the frequency increases. The ability to push and withdraw electrons from the device is mainly limited by the insulating behavior of organic molecules, thus the device capacitance.

For remote VLC applications, high brightness OLED lighting panels are preferred. But enlarging the area leads to increased capacitance. The equivalent capacitance C is expressed as:

$$C = \epsilon_0 \epsilon_r \frac{S}{L} \quad (1)$$

With ϵ_0 (F/m) and ϵ_r defined as the permittivity of free space and the dielectric constant of an organic molecule, respectively. L (cm) and S (cm^2) indicate the device length (the distance between anode and cathode electrodes) and the surface-emitting area, respectively. As a consequence, is imperative to design a circuit for supplying current for the operation of the OLED device, but also to translate information supplied, input signal, into varying current and light intensity. As a research project, a series of rectangular decorative OLED panels were purchased, studied, and used to obtain a traffic light for VLC.

II. TRAFFIC LIGHT OLED SYSTEM

Typical traffic light systems consist of three circular panels, called signal heads. Their dimensions depend on country traffic regulation: 200 mm (Germany) or 300 mm (the United States and China). The panels are colored red, yellow and green by a few hundred small LEDs. Their scope is to control the traffic and to avoid conflicts between road users using the same space. Other appliances in traffic control are at pedestrian crossings, road construction sites and safeguarding of railway crossings [10].

For our project, we have developed a traffic light with three signal heads. Each head consisting of 4 panels, totaling 12 OLED panels. Each panel was individually tested for its capacitance and its response to current. Current-Voltage characteristics are represented in Fig. 1.

Without knowing further details of the layers structure of an OLED panel, information like exact organic composition and thickness, we were able to determine an approximate thickness of the emitting layer. First, we have measured the equivalent capacity of the device and its active surface. The capacitance of the OLED panels was consistent for all with a value of 2.2 μF . An average value for relative electrical permittivity $\epsilon_r = 3.8$, dimensions of 94 mm x 94 mm as active area emission led us to value of 134 nm by using equation (1). The obtained value is in agreement with the typical value length of the typical 100-200 nm OLED devices.

The first frequency response was conducted by connecting a signal generator to the terminals of an OLED panel and the same terminals to an oscilloscope. A signal with a constant amplitude has been applied and its frequency has been varied from 10 Hz until the amplitude of the signal shown on the oscilloscope halved around the frequency of 300 Hz. As the resulting band is too short, thus insufficient for visible light communication, we have studied the possibility to extend the band by designing of OLED driving circuit capable of performing optimum static light emission and also to be able to transmit information into amplitude variations of light. The value of the exhibited capacitance of the OLED panels led us to design a circuit driver to supply current to the panel for optimal emission and also to facilitate VLC communication

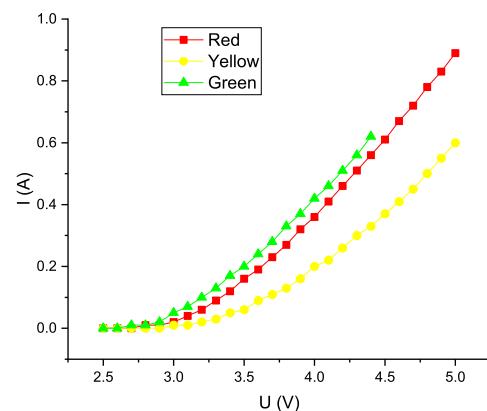


Fig. 1 Current Voltage characteristics

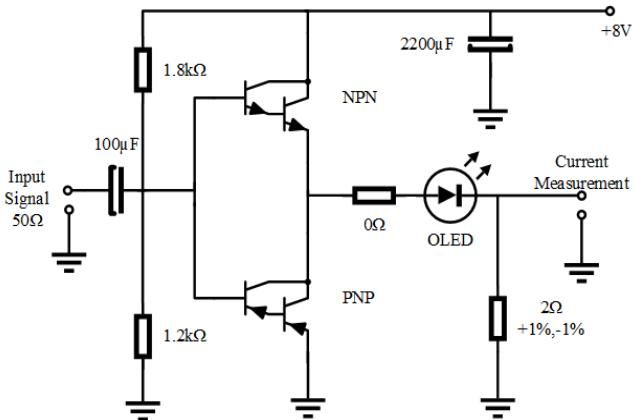


Fig. 2 OLED circuit driver

using a class B amplification circuit represented in figure 2, to raise the operating frequency of the panel. Coupling between the amplifier and panel supplying circuit has been made by an electrolytic capacitor with a higher capacitance than equivalent capacitance of a panel. The developed amplifier circuit consists of push-pull configuration using complementary NPN and PNP transistors with a high amplification factor. The chosen TIP102 and TIP107 transistors were specifically selected for their high output current. After careful assembly, frequency test and optimization of the circuit, following again the previous measurements, using square wave pulse on the generator as an input signal, the signal received onto the oscilloscope halved around the frequency of 50 kHz. Above this value, distortion effects take place on the waveform, but it is still usable up to 100 kHz. The waveform above this frequency of the output signal changes from rectangular to triangular. The above-mentioned circuit has been multiplied for all 12 OLED panels.

After obtaining OLED driving circuits, the development of the traffic light took place. After studying the dimension of the panels, CAD designing has been conducted to obtain a PLA (Polylactic Acid) frame for OLED panels and also for the circuit drivers with the help of 3D printers. Individual 3D printed supports have been made to accommodate each panel, thus four individual supports have been used to form signal heads for each color of the traffic light. Also, a metal frame was constructed to constitute the firm body of the traffic light as shown in figure 3. After the wire soldering, management and validation, the system was prepared for testing.



Fig. 3 OLED based traffic light - on state, front and back

It is worth mentioning that dimensions of individual colors form a rectangular shape with dimensions of 208 x 208 mm, with an active area of 188 x 188 mm. This implies that the developed traffic light falls within the class A 3/1 prEN 12368 for colors red and green with a light aperture of 200 mm where specification sheet of panels exceeds the required 250 cd/m² within tolerance. Both red and green color panels exhibit a brightness of 300±30 cd/m² with the specific chromaticity CIE (0.566, 0.272), CIE (0.242, 0.562) respectively. This implies that the panels used are suitable for pedestrian traffic light use and also for the red and green light for traffic light use. It is also important to say that these OLED panels are developed by the manufacturer for decorative use, so their performance regarding power efficiency is lower than the current state of the art lighting.

Future development of an OLED traffic light VLC ready design, with the use of reported work of [12], [13], luminance levels of 9000 cd/m² for red, 14700 cd/m² for green and 10000 cd/m² for super yellow can be achieved and adapted for ambient conditions like direct sunlight for continuous operation A 3/1 prEN 12368 or A 2/1 prEN 12368. For the first two colors emitters, the authors have tested in display applications, small displays can be driven at frequencies tens of kHz. At higher frequencies, however, the RC time of the device becomes a limiting factor and luminance decreases.

III. VLC SYSTEM

A. Emitter

VLC emitter represented in figure 4 consists of solid-state light source wired with a circuit driver where besides power supply connectors, the input signal is also supplied. The input signal is provided in by a signal generator and its role is to encode data into the varying intensity of the emitted light. In our case, the solid-state light source is represented by the OLED panels. The input signal selected for indoor testing was square waveform, with a starting frequency of 1 kHz. The frequency was increased during indoor testing up to 100 kHz to see bandwidth coverage at a specific distance.



Fig. 4 VLC emitter – Signal heads testing

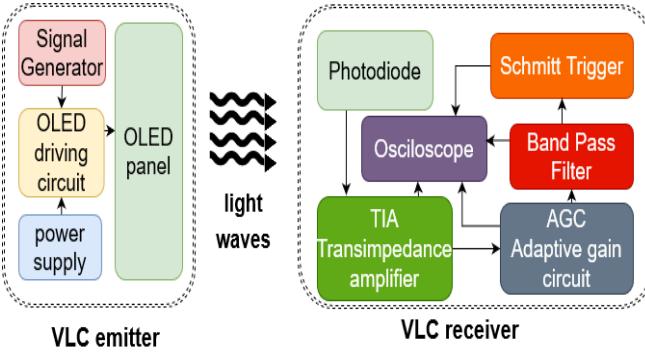


Fig. 5 The block diagram for testing

B. Receiver

The receiver component of a VLC system is comprised of a photodiode, followed by an amplification circuit or by decoding block. Our VLC receiver is comprised of a silicon Thorlabs photodiode with an internal adjustable transimpedance amplifier (TIA). Its output has been passed to an adaptive gain control circuit, followed by a band-pass filter and Schmitt trigger. For indoor testing, we have looked closely at all participating blocks with the help of an oscilloscope Tektronix TBS1104. Thus said, individual measuring channels have been reserved for TIA, AGC (Adaptive Gain Circuit), band-pass filter and also for Schmitt trigger. The receiver part of the system has been operated in order to capture the variable signal upon the direct component of the light emitted by the VLC emitter.

C. VLC system block diagram

The developed VLC system is represented by the block diagram in fig 5. Indoor testing mimics the approaching of a vehicle to a traffic light in lab conditions. This approach is very useful for gaining insight into the capabilities of the system before it is ready for outdoor tests. Weather conditions like heavy rain, wind load, fog, heavy snow, dust are important factors that can damage, interrupt the operation of a traffic light or diminish axial luminous coverage. For these reasons typical traffic lights cases are made of stabilized

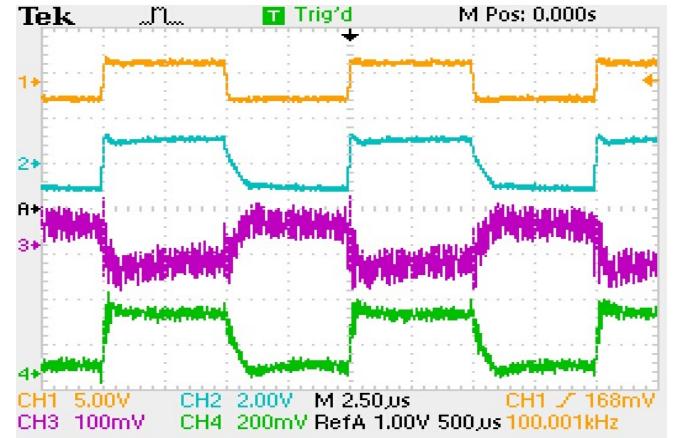


Fig. 7 Measurements at frequency of 100 kHz

polycarbonate and also colorless polycarbonate protective glass is used to cover signal heads. The commercial signals are free of accidental electric failure, highly resistant to mechanical effects, resistant to high humidity, solar radiation, hoar-frost, corrosion-active agents, wind load (up to 150 km/h), have an average service of operation of 10 years, are protected from limited dust ingress and protected from water spray from any direction.

The developed prototype was tested indoor to gain information on the bandwidth coverage and VLC link distance.

IV. RESULTS AND DISCUSSIONS

Before indoor testing of the VLC traffic light, preliminary tests were conducted regarding bandwidth with the frequency of the input signal. Fig. 6 and 7 show the measurements performed on the circuit board following the signal of the generator, OLED panel terminals signal, signal through the decoupling capacitor and current through the OLED panel.

As it can be seen between the measurements shown in figure 6 and 7, the frequency advancement of the input signal has an observable effect on the shape of the emission signal at the panel level. On the increasing portion of the signal, we can observe an increase of 5 μ s and the falling edge of about 20 μ s. Further measurements, where the frequency exceeds 100 kHz,

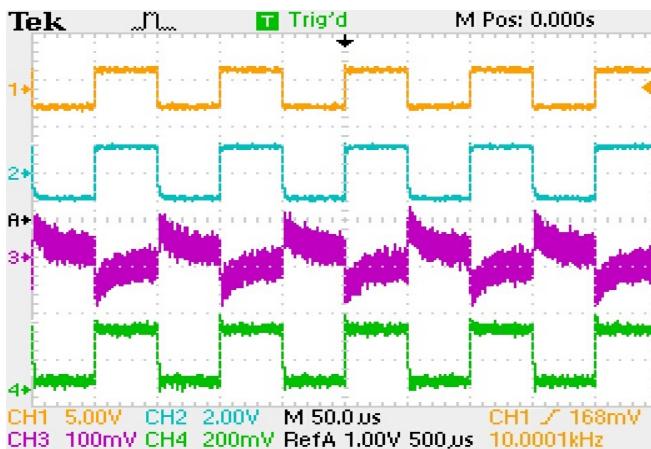


Fig. 6 Measurements at frequency of 10 kHz

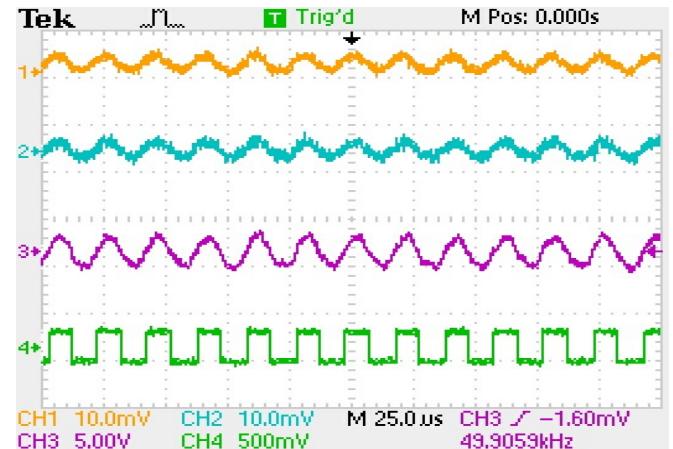


Fig. 8 – VLC link 20 meters at 50 kHz

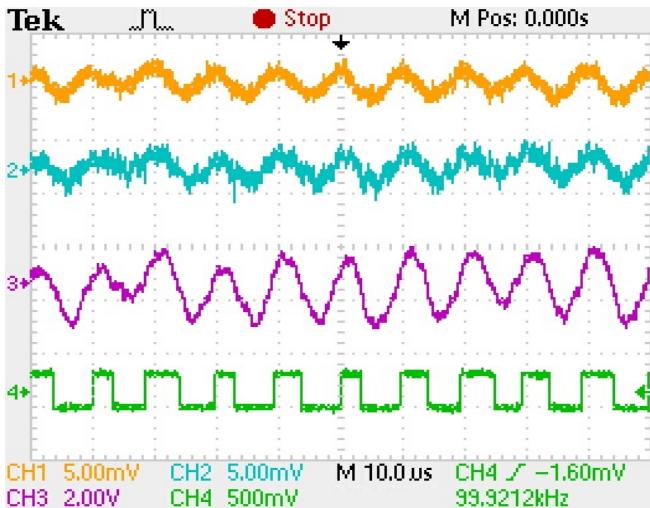


Fig. 9 – VLC link 20 meters at 100 kHz

shape of the output signal changes to triangular. These preliminary results lead us to indoor testing of the OLED traffic panel.

Indoor testing has been conducted in line with the OLED traffic light. The VLC receiver has been moved up to 20 meters to capture the active signal carrying the useful information. The first test was taken at about 20 meters at two different frequencies 50 kHz and 100 kHz.

Figures 8 and 9 show the measurements regarding the input signal at different channels: TIA, AGC, band-pass filter and Schmitt trigger. The green signal representing the Schmitt trigger is using a threshold value to obtain an output signal comparable to the input signal at VLC emitter. This is very useful to check the correctness of the received information. In figure 9 it can also be seen that a higher frequency for the input signal results in a lower input signal at the photodiode. A higher amplification for the TIA circuit is required to maintain a signal amplitude sufficient to engage Schmitt triggering, thus receiving transmitted information through visible light. The measurements above show the availability of a reliable VLC link at a distance of 20 meters.

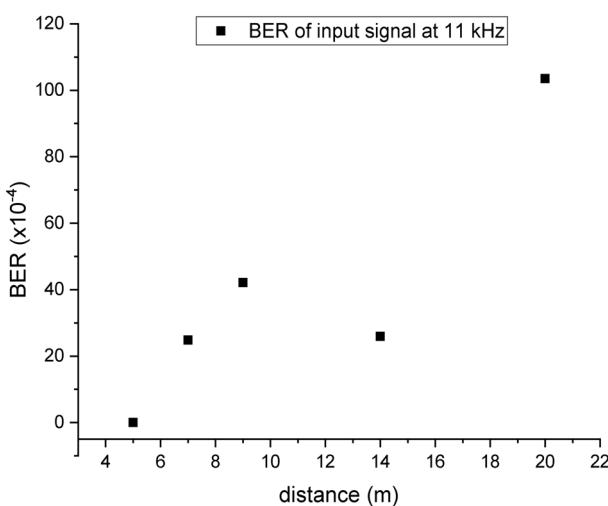


Fig. 2 – Bit Error Ratio (BER) for the input signal at 11 kHz modulation frequency

Our investigation has shown that the operating bandwidth of the VLC emitter is highly influenced by the parasitic capacitance of the OLED cell, which above the frequency 100 kHz introduces distortion to the input signal. Smaller OLED panels in size should be used in order to achieve higher operating bandwidth.

Regarding the robustness of the received signal, several measurements were conducted for BER (Bit Error Ratio) at a fixed frequency of the active signal transmission at 11 kHz. The amplitude of the signal and the parameters for operating OLED panels were kept at a nominal level. The measurement was accomplished through simultaneously sampling the original electrical signal at the generator and the processed signal collected after Schmitt trigger by comparing signal levels. BER has been computed by a microcontroller Cortex-M4F after a sequence of one million of edge events. An algorithm counts the errors in transmission in comparison with the original signal. Error in transmission may appear due to small fluctuations of the amplified signal on the photodiode through AGC. The distance between the VLC receiver and the VLC emitter was varied up to 20 meters. The obtained results in Figure 10 show that the system is able to transmit data over a short distance with levels of BER of 10^{-6} . As the distance increases BER values vary from 10^{-6} from 5 meters to 10^{-2} at 20 meters. This denotes the fact that the obtained VLC traffic light system offers high reliability of the information at a reduced distance.

V. CONCLUSIONS AND FURTHER DEVELOPMENT

As the automotive industry continuously evolves and builds intelligent vehicles, developing intelligent transportation systems like VLC ready traffic light systems will contribute to the safety of transportation users and also the safety of pedestrians. Traffic analysis in real-time can lead to the decisional appliance of scenarios, for example to disperse traffic and ensuring fluency, and also passing relevant information for participants. This is achievable with the informed participation of all vehicles and pedestrians. All participants to traffic could be informed through VLC links between infrastructures, traffic light systems, and VLC receivers. Authors of the paper have conducted design, development, and study of an OLED traffic light capable of visible light communication. The VLC parts, VLC emitter and VLC receiver have used a high amplification circuit in order to raise the operation frequency of the input signal and to reconstruct the input signal through the use of a Schmitt trigger. With the obtained prototype, indoor lab testing has shown a reliable VLC link for up to 20 meters. Further development of this research project will involve extending the VLC link for longer distances, designing OLED drivers with superior performance for passing Miller and Manchester signals and also consider more efficient OLED panels.

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