A Universal VLC Modulator for Retrofitting LED Lighting and Signage

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***Abstract*—A universal visible light communication (VLC) modulator design is presented in this paper. The modulator is used to retrofit LED lighting and signage to enable VLC by connecting it between the LED driver output and LED lighting input. The modulator can work with both major types of LED drivers, i.e., constant current type and constant voltage type, and can support a wide input voltage range. Experiments are conducted to verify the modulation function and its impact on the light intensity of the luminaire.**

Keywords—visible light communication, LiFi, VLC modulator, LED lighting, LED signage

I. INTRODUCTION

The use of LED lighting has increased rapidly in recent years due to its higher efficiency and reliability compared to traditional fluorescent and incandescent lighting. In addition to general lighting, LEDs are being extensively used in signage and displays. Owing to its higher modulation bandwidth, LED lighting can also be used for visible light communication (VLC) [1]. With the growing usage of LEDs, the VLC function can provide intelligent ambiance through such lighting and signs and potentially transform ordinary venues into smart venues, e.g., smart homes and smart cities.

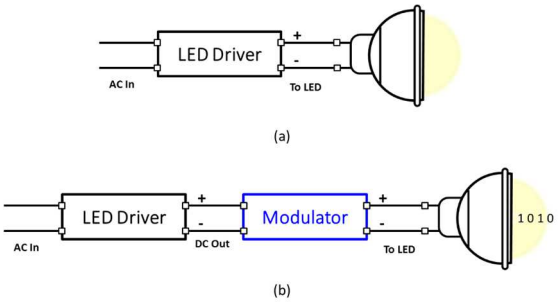

Fig. 1 An LED light driven by an LED Driver: (a) without modulator (b) with modulator

In order to enable high data rate VLC, a large modulation bandwidth is required, which is not achievable in general LED lighting and signage operating at several tens of watts. However, low data rate communication can be enabled in those luminaries to provide indoor positioning [2-3] and other location-aware applications [4]. Therefore, a modulation circuit is proposed in this paper that can enable low data rate VLC functionality in LED lighting and signage.

II. LED DRIVERS FOR LIGHTING AND SIGNAGE

LED drivers are generally divided into two broad categories, namely constant current (CC) drivers, which regulate output current over a specified output voltage range, and constant voltage (CV) drivers, which regulate output voltage for a maximum current or power rating. Since LEDs are inherently constant current devices with their light intensity directly proportional to the amount of current flowing through the LED, most general lighting, which includes light bulbs, tube lights, downlights and spotlights, is driven by CC drivers. However, LED signs, strips and light boxes are driven by CV drivers as they come in various sizes and loads and are often combined to have one driver drive multiple loads by providing a constant voltage regulated supply, while the current regulation is performed inside the sign itself. For these CV drivers, the number of LED loads and the current rating of each do not need to be known in advance, and a driver can operate any number of loads as long as the total required power is within the maximum power rating of the CV LED driver.

In order to modulate the light intensity with information, the current needs to be modulated, which requires the insertion of a modulator circuit between the power supply and the LED, as shown in Fig.1. The modulator circuit modulates the output current of the LED driver according to the modulation and encoding scheme required by the communication system.

III. MODULATOR DESIGN

The block diagram of the modulator circuit is shown in Fig. 2. The modulator comprises of a voltage level converter and a regulator circuit to step down the LED supply voltage and provide a stable low voltage supply for the signal processing and communication circuitry, which mainly features an MCU combined with Bluetooth or WiFi. The modulation and switching circuit is a combination of a driving circuit and a power device to modulate the current flowing through the LED according to the signal pattern produced by the communication block.

A general LDO with a low voltage output of 5-3.3 V usually has a maximum input voltage rating of up to 35 V.

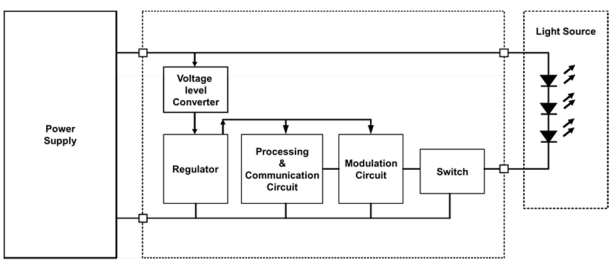

Fig. 2 VLC modulator block diagram

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However, for medium power range general lighting driven by a CC LED driver, the operating voltage can have a very wide operating range that can go as high as 60 V. Therefore, a simple regulator cannot be used and a step down converter must be used before the regulator to produce a stable supply for driving the communication and signal processing block.

On the other hand, for CV LED drivers, the voltage is either a standard 12 V or 24 V. Therefore, a simpler circuit can be realized by only using a regulator to directly produce a regulated low voltage supply for the signal processing and modulator circuit.

IV. The Effect of Modulation on Light Intensity

One of the key considerations for VLC modulation is its impact on the light intensity of the LED luminaire as illumination is the primary function of the lighting. From the concept of PWM dimming control, intuitively, the LEDs brightness drops when it is modulated with a VLC signal. However, when the output of the CC LED driver is modulated, the peak current of the LED driver is increased such that the average current going through the LED is kept close to the rated current of the LED driver, i.e., the driver can compensate for the current modulation by increasing the peak current, as shown in Fig. 3. This is due to the fact that the current sense circuitry in the feedback control of the LED driver has a much lower response bandwidth than the modulation frequency of the LED, which ranges from tens of kHz to several MHz.

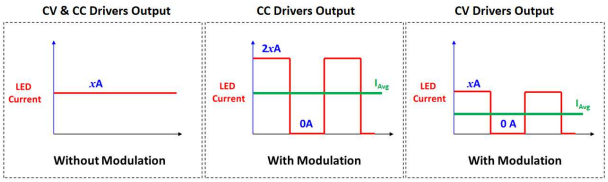

Fig. 3 Effect of modulation on average output current of CC and CV LED drivers

In comparison to CC drivers, CV drivers do not compensate for the current modulation as the current regulation is generally done on the LED light sign itself using current control resistors. Therefore, when the output current of the CV LED driver is modulated, it reduces the amount of average current according to the duty cycle of the VLC signal and hence results in the reduction of light intensity, as shown in Fig. 3.

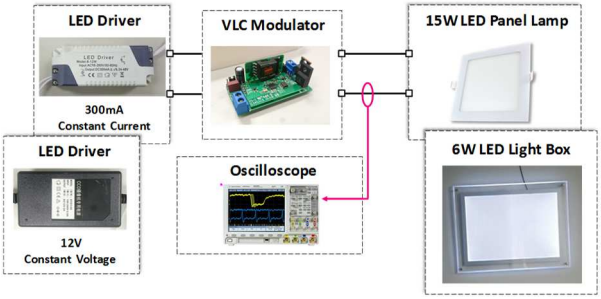

Fig. 4 Measurement setup

V. Measurement Results

The measurement setup, in Fig. 4, shows a VLC modulator connected between the output of the LED driver and the input of the luminaire, while an oscilloscope is used to measure the current flowing through the LED, for both CC and CV types of lightings.

The measured current waveform of the CC LED panel is shown in Fig. 5. It can be seen that the unmodulated current

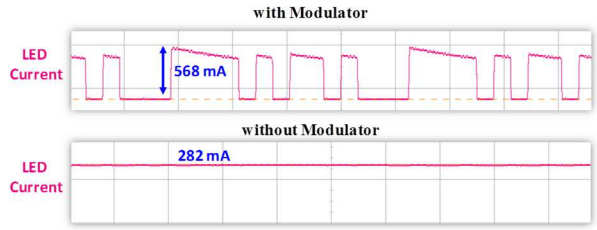

Fig. 5 Measured current waveform of a CC modulated LED light

of 282 mA is almost doubled to a peak modulated current of 568 mA to compensate for the average current drop due to the modulation. The peak current of the CV driven LED light box remains the same, i.e., 500 mA leading to an average current of 250 mA due to the 50% duty cycle VLC signal.

Fig. 6 Measured current waveform of a CV modulated LED sign

VI. Conclusion

A universal modulator design is presented, which can retrofit both CC and CV LED drivers to enable VLC. The measurement results show that CC LED luminaires can be modulated without any drop in the light intensity of luminaire. However, the output current of the CV LED driver drops after modulation leading to a drop in brightness of the LED sign.

Acknowledgement

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