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A Signal Amplification-based Transceiver for Visible Light Communication

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ABSTRACT

Visible light communication (VLC) is an upcoming wireless technology for next-generation communication for high-speed data transmission. It has the potential for capacity enhancement due to its characteristic large bandwidth. Concerning signal processing and suitable transceiver design for the VLC application, an amplification-based optical transceiver is proposed in this article. The transmitter consists of a driver and laser diode as the light source, while the receiver contains a photodiode and signal amplifying circuit. The design model is proposed for its simplicity in replacing the trans-impedance and transconductance circuits of the conventional modules by a simple amplification circuit and interface converter. The system was tested at communication distances of 1m and 3.5m using a terminal emulation program for data transfer between two computing devices.

.**Keywords:** Amplifier, Communication, Laser Diode, Photodiode, VLC

جهاز الإرسال والاستقبال لاتصالات الضوء المرئي على أساس تضخيم الإشارة

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الخلاصة

الاتصالات بالضوء المرئي (VLC) هي تقنية لاسلكية قادمة للجيل القادم من الاتصالات لنقل البيانات بسرعة عالية .لديها القدرة على تعزيز السعة بسبب عرض النطاق الترددي المميز المميز لها .فيما يتعلق بمعالجة الإشارات وتصميم جهاز الإرسال والاستقبال المناسب لتطبيق VLC ، تم اقتراح جهاز إرسال / استقبال بصري قائم على التضخيم في هذه المقالة .يتكون المرسل

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من محرك ودايود ليزر كمصدر للضوء ، بينما يحتوي جهاز الاستقبال على صمام ضوئي ودائرة تضخيم الإشارة .يُقترح نموذج التصميم لبساطته في استبدال دارات transimpedance و transconductations للوحدات التقليدية عن طريق دائرة تضخيم بسيطة ومحول واجهة .تم اختبار النظام على مسافات اتصالات من 1 م و 3.5 م باستخدام برنامج مضاهاة طرفية لنقل البيانات بين جهازي كمبيوتر.كلمات البحث VLC :، ليزر ديود ، الضوئي ، مكبر للصوت ، الاتصالات.

1. INTRODUCTION

In recent years, there has been an unmatched request for wireless technologies. Commonly, Radio Frequency (RF)-based wireless technology is utilized for wireless data transmission; a number of limitations of this technology have arisen due to its limited and licensed spectrum. Since data traffic is growing exponentially, Visible Light Communication (VLC) is considered instead as a complementary capacity upgrade in the emerging heterogeneous network. VLC is based on communication in the perceptible part of the electromagnetic (EM) spectrum and has a wavelength that ranges from 380nm to 780nm (**Ibhaze *et al.*, 2020a**) (**Li *et al.*, 2017**). This comprises of a transmitter that conveys information by modifying its light output and a receiver that is adept in interpreting the transmitted information. Optical sources such as light-emitting diodes (LEDs) and laser diodes transmit data in VLC, while photo-detectors are used for signal reception (**Ibhaze *et al.*, 2020b**) (**Rajagopa *et al.*, 2012**) (**Biliwonski, 2015**), (**Shin *et al*., 2011**). Several modulations and signal conditioning techniques exist to boost the system performance in VLC. For VLC, easy and inexpensive intensity modulation and direct detection methods are used to convey data. Pulse modulation schemes like pulse position modulation, pulse width modulation, and on-off keying (OOK) are utilized in some VLC systems (**Wang and Zang, 2017**). Also, several variants of subcarrier modulations (orthogonal frequency division multiplexing (OFDM)) having high spectral efficiency are also being investigated (**Komine and Nakagawa, 2004**). VLC could be applied in the automation of homes, indoor navigation, high-speed data communication, underwater communication networks, intelligent transportation system, health monitoring, location-based services, downhole exploration, communication on fields, and energy proficient illumination (**Saadi and Wuttisittikulkij, 2017**), its design and implementation comes with some challenges relative to the impact of external light sources and line of sight communication which could degrade the eventual system throughput (**Khan *et al.*, 2015**). VLC has been studied by various researchers in academia and industry with conceptualized systems built and implemented. The possibility of deploying white LEDs has been investigated for both illumination and communication at low rates (**Komine and Nakagawa, 2004**).

A two-way lighting system with LEDs was reported in (**Li *et al.*, 2017**), a system that used double LED devices for a two-way VLC system; i.e., LEDs were used as transmitters and receivers. An on-off keying modulation (OOK) scheme with Manchester coding was the modulation and coding techniques used alongside an exclusive-or decoding scheme for the receiver, and a transmission rate in the order of kbps was achieved. Also, a scheme to compensate for lighting loss as a result of phase correction during synchronization was proposed. In (**Fahs *et al.*, 2016**); a CMOS-Compatible PN Photodiode was used for the receiver and a 650nm IF-E99B red LED source; the authors reported usage of a PN photodiode for VLC indoor applications and used a second-order LCR equalizer to increase the transmitting rate and a bit error rate of $1.3x10^{-6}$ was achieved. The authors in **(Azhar *et al.*, 201)** proposed a system with a 2x1 array of white LEDs that could transmit data to a nine-channel receiver consisting of a 3x3 photo-detector array. In (**Vucic *et al.*, 2010**) and (**Vucic *et al.*, 2011**), VLC links based on discrete multitone (DMT) modulation were described. In (**Vucic *et al.*, 2010**), Quadrature-amplitude modulation (QAM) with bit loading, power stacking, and symmetrical cutting were proposed. The system of (**Vucic *et al.*, 2011**) was centered on DMT modulation with an offline digital signal processor. It used a solo RGB LED (that generates a bright flux of 105 lm with a radiation angle of 120°) for transmission, and a silicon APD (3mm diameter, eighty megahertz bandwidth) joined with a lens for detection. An analog communication using light was demonstrated in (**Riurean *et al.*, 2017**), the transmitter circuit composed of three transistors, some inert components, and a 5mm white

LED. The receiver consisted of a photo-detector, a power amplifier, and a speaker. The prototype was used to transmit an audio file over a distance of about 3 cm. In (**Sindhubala and Vijayalakshmi, 2015**), a cost-effective VLC system was designed. A white LED, and an LM555 timer was utilized in the transmitting package, and a monolithic photodiode, trans-impedance amplifier, and an electrical high pass filter at the receiver. The experimental results showed that the transmission distance achieved was about 0.45m and observed that the output voltage and optical power decreased with respect to an increase in the transmission distance. The VLC system (**Maruf and Othman, 2013**) was used to transmit audio files. At the transmitter, a laptop was used as the data source, an audio jack cable to transfer audio signals, and an amplifier to strengthen the signals relative to the LED. The receiver consisted of a photo-detector and amplifier; the transmission distance was limited to 20cm. The amplifier circuit implemented at the transmitter and receiver helped to improve the signal quality of the audio signals in the VLC system. Through orthogonal frequency division multiplexing (OFDM), a communication distance of 5cm was achieved by (**Tsonev *et al.*, 2014**). The VLC system used only a 50 µm (µLED) gallium nitride LED; pre-, post-equalization methods, and adaptive data stacking were useful in data transmission. According to (**Wu *et al.*, 2012**), a carrier-less amplitude and phase modulation (CAP) was used to achieve the VLC scheme. A white LED-based VLC scheme using CAP was reported for data transmission. A phosphorescent white LED was utilized for transmission. Photosensitive blue filtering and DFE were used for the recovery of the frequency response of the LED device. In (**Wang *et al.*, 2013**), an anachronous two-way VLC process was described for data transmission using a single blue LED for uplink and red and green LED for downlink communication. Pre-equalization and post-equalization were used to compensate for system distortions, which further added to the system complexity. An RGB-type white LED component was used as the transmitter and a silicon PIN photo-detector to sense optical signals. An algorithm named recursive least square (RLS) adaptive equalization, which is commonly used in VLC systems because of its quick convergence, was also employed to improve system performance. It was used for indoor free-space transmission over 1.5 meters. This system used a hybrid post equalizer, which comprises of a linear and non-linear equalizer and a least mean square equalizer with an aim to instantaneously lessen the direct and indirect alterations of the VLC system (**Wang *et al.*, 2015**). In (**Wang *et al.*, 2014**), a method for multiple user access built on multiple band-CAP was proposed. A solo RGB LED was utilized for WDM, and six-level three sub-bands CAP64 was used on every chip for about nine users' access. A commercially available Hamamatsu APD was used at the receiver for direct detection. For transmission, a one-sided pre-equalization technique was used to compensate for the non-linear distortion of the LED, and a post-equalizer centered on the adapted cascaded multi-modulus algorithm (CMMA) was applied at the receiver. In the literature, there is a trade-off between design complexity and performance in the integration of the trans-impedance and transconductance module (**Syifaul Fuada *et al.*, 2016**). This research, therefore, tends towards proposing a design with less complexity by replacing the trans-impedance module used for the conversion of input current to an equivalent output voltage by a simple amplifier that takes the voltage response to the received signal into consideration. Similarly, the transconductance amplifier was not required in the design since the transistor-transistor logic (TTL) levels are already in discrete levels. The remaining part of this article is organized as follows: the next section describes the design technique, after which the model testing and results follow and then the conclusion.

2. METHODOLOGY

The block diagram in **Fig. 1** shows the fundamental blocks of the proposed signal amplification-based transceiver module. The three major parts in this setup are the transmitter, the free space channel, and the receiver. Devices such as laptops are used as the interface for the transmission and reception of information signals. The module was designed to enable serial communication between two laptops. A universal serial bus (USB) to serial converter was connected to the computer system to convert USB signals to the needed serial signals. Then, this weak signal was sent to the amplifier for signal boosting, whose output voltage/current drives the laser diode (LD).

The optical driver has to drive the emitter (LD) with sufficient power for long-distance communication conveyed over the free space channel. The receiver is made up of a photodiode, amplifier, and a serial to USB converter. The photodiode acts as a photo-detector, i.e., it collects the light radiating from the LD and converts it to a weak electrical signal. The signal is boosted to a sufficient signal by the amplifier and is sent to the computer using the serial to USB converter.

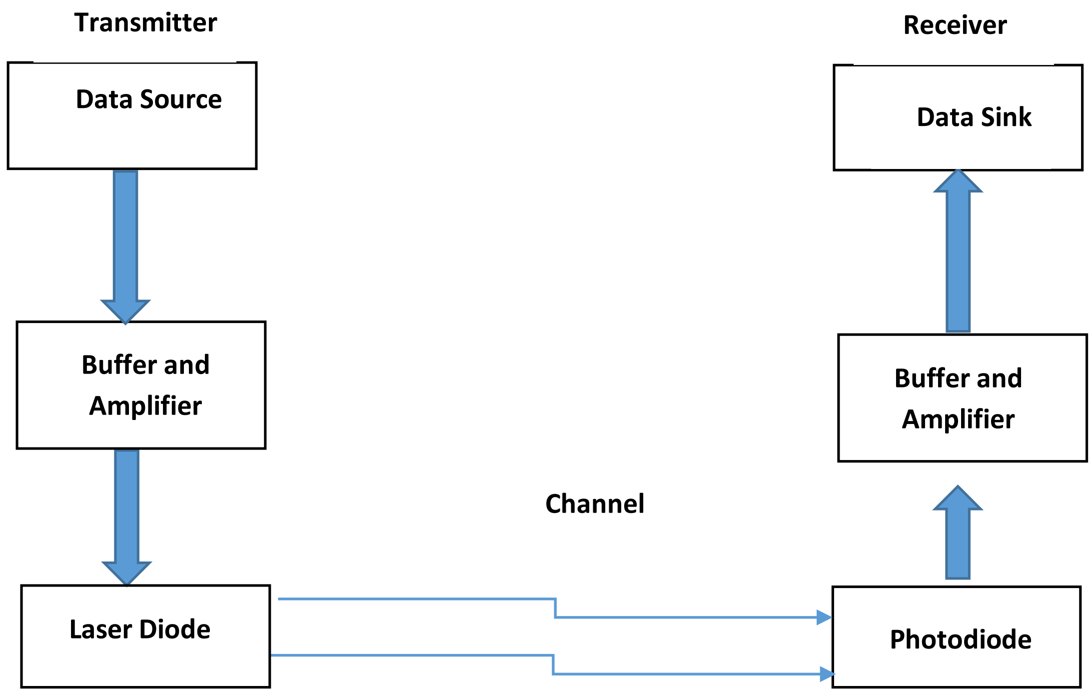


Figure 1. A Signal Amplification-based VLC Transceiver Module.

Generally, when the properties of a high-frequency carrier signal are varied correspondingly to a message signal, the signal has been modulated. Conversely, Signal amplification is achieved by boosting the strength of the signal. Amplifiers produce maximum gain and, at the output, balance the voltage. Amplifiers are required to have low noise properties, large gain, and high bandwidth. A Laser diode (LD) is used as the photosensitive source for this design. Lasers offer stimulated emission and have high electrical to optical conversion efficiency. An LED can also be used, but LDs perform better because of the features of high visual power and light beam convergence (**Zafar *et al.*, 2017**). Laser diodes produce substantial optical power when driven above the threshold current. The transmitter uses an ATmega328 microcontroller on the Arduino board. This board cannot drive the laser diode directly so a current amplifier is used. A push-pull amplifier is used to drive current; it consists of a transistor pair made up of BC547 and BC557 transistors. The BC547 is an n-p-n transistor with a maximum current gain of 800A that pushes the output on the positive half cycle; BC557 is a p-n-p transistor that pulls on the negative half cycle. The transmitter module is shown in **Fig. 2**. For the circuit simulation, a 1 kHz clock voltage source of +5V was used to partly imitate the binary inputs from the computer through the USB.

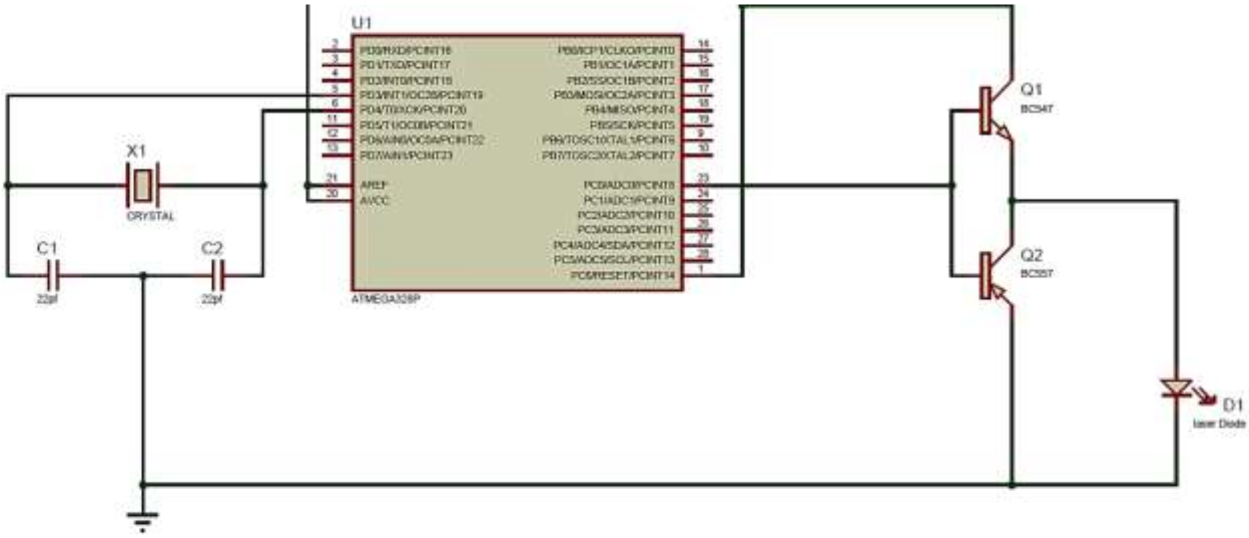
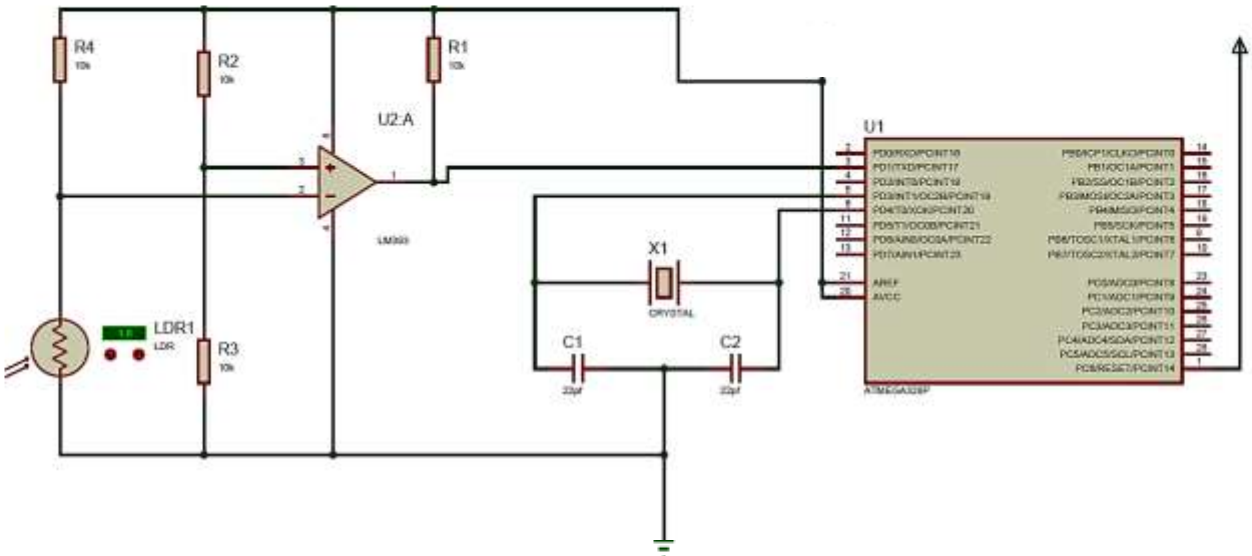


Figure 2. Amplification-based VLC Transmitter Module.

Optical signals are sensed by the receiving system, which is composed of a photodiode, a front end amplifier, and some passive components. The optical signals are captured by a photodiode that produces a weak current with magnitude relative to the intensity of the light detected by the PD. A front end amplifier is used to boost the photodiode currents to a level that a voltage comparator can determine whether a logic ‘1’ or logic ‘0’ was transmitted. In this design, LM393 is used as the differential voltage comparator, and its output is connected to 5 volts, which is supplied from the Computer’s USB port. It produces logic signals that enable data interpretation into digital format. The output of this comparator will read logic ‘0’ if the output voltage of the photodiode is less than that of the reference signal. The photodiode used is the BPW20RF photodiode; the responsiveness of this photodiode on the red region is reasonable, hence the use of a red laser diode in the transmitter. The logic inverter circuit that enables logic inversion is composed of a BC547 n-p-n transistor and two resistors shown in **Fig. 3**.



Fiureg 3. Amplification-based VLC Receiver Module.

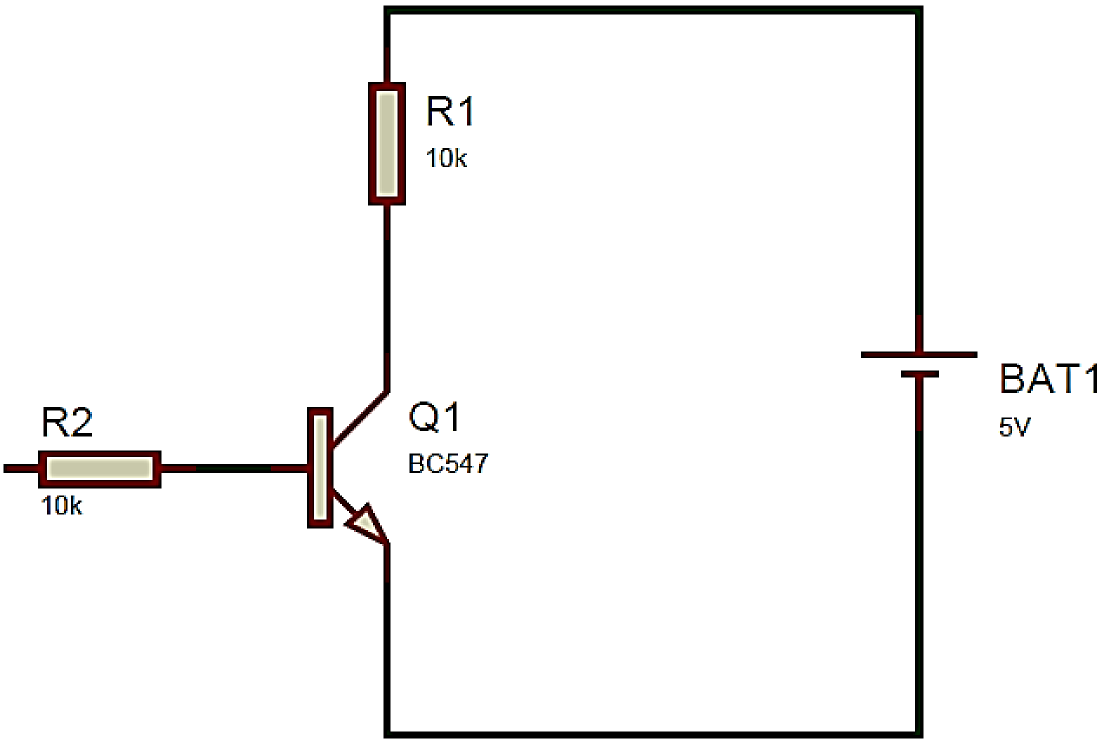


Figure 4. The Logic Inverter circuit.

The logic inverter circuit shown in **Fig. 4** was used to achieve logic inversion. It produces an output whose voltage represents the opposite logic level to its input. i.e., if the input is a logic '1', the output would be a logic '0' and the other way around. The major purpose of this circuit is to invert the signal at the receiver. The encoding method employed in the design is the On-Off Keying (OOK) encoding. This method is used in the transmitter circuit. The presence of the digital data is denoted as binary one (1) and the absence of the digital data is characterized as binary zero (0). This means reading 1s and 0s and converting the signal to the required format.

3. RESULTS AND DISCUSSION

A system that interprets the signal is essential, hence the software system; the hardware circuits drivers were also installed to guarantee communication between the software and the hardware part. These drivers encode and decode the signals and also synchronize the transmitter and receiver. Communication and terminal emulation program called Terminal v1.93b was used as a Graphical User Interface (GUI) for communication between the computers shown in **Fig. 5,** and **Fig. 6**.

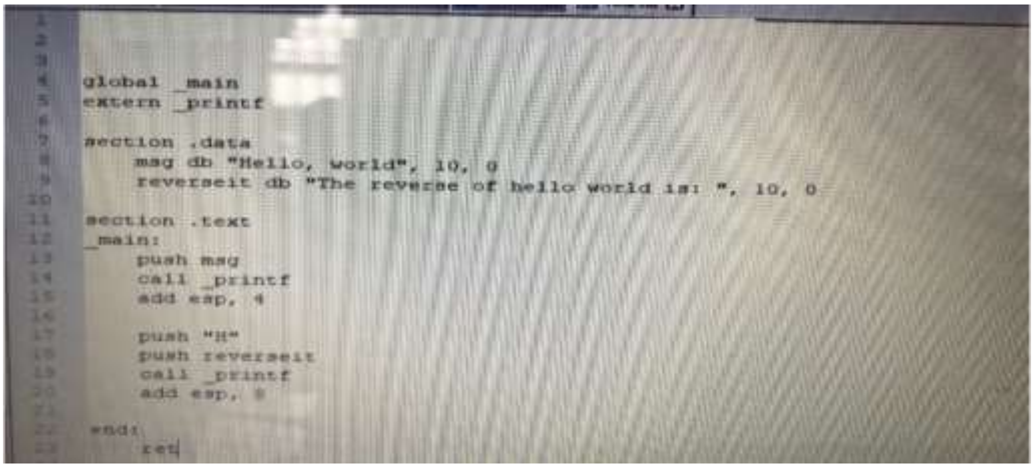


Figure 5. User Interface at the Transmitting end.

Figure 6. User Interface at the Receiving end.

The experimentation was performed in an outdoor environment to ascertain the impact of the external ambient light source on the system performance. Relatively, the setup could be deployed in any indoor environment. The test was performed at 1m and 3.5 m to ascertain the communication distance of the communication module. **Fig. 5** and **Fig. 6** show the user interface on both Laptops, indicating the transmitted and received text files, while **Fig. 7** depicts the implementation of the internal circuitry of the transceiver module.

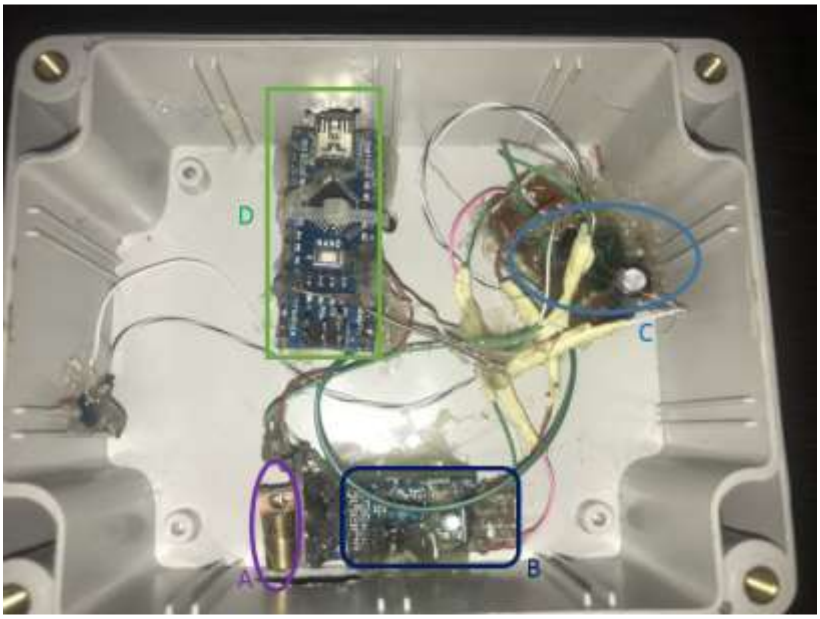


Figure 7. The Internal Circuitry of the Transceiver Module.

Fig. 7 shows the prototype of the signal amplification-based VLC transceiver, where “A” is the transmitter module, “B” is the Receiver module, “C” is the logic inverter circuit, and “D” is the microcontroller to be connected to a PC (Laptop). The communication between two different nodes of the transceiver module was tested at distances of 1m and 3.5m, respectively, at data rates supported by the USB interface, and the transmitted data was received instantaneously without errors. In order to improve on the achievable data rate, sufficient hardware support will be required to cope with the transmission process by redesigning the interfaces for VLC support.

4. CONCLUSIONS

This work has shown a simple demonstration of VLC using off-the-shelf electronic devices suitable for device-to-device communication. The design complexity was surmounted by replacing the trans-impedance and transconductance modules of the conventional design by amplifier and USB to the TTL converter, respectively. The module was able to achieve instantaneously error-free- transmission at 1m and 3.5m communication distances suitable for both indoor and outdoor communication. The data rate support was limited by the achievable rates of the interfaces, which could be redesigned depending on the data rate expectations in future work.

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