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CARRIER TRANSFORMATION FOR DATA TRAVELLING FROM A WHITE-LIGHT LED TO AN IR RECEIVER MODULE

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Abstract. *To set up an optical link with the features of a white-light LED and an IR receiver module, a scheme for carrier transformation from white light to infrared is proposed here. It costs significantly to develop an optical receiver dedicated to a visible-light data transmitter with satisfied signal-to-noise ratios. However, the pair of a white-light LED for illumination and an IR receiver module for conventional remote control can save much time and expense if the distance of the connection between them can be extended. In this paper, a photodiode responsive to the emission of the white-light LED and an IR LED paired with the IR receiver module are introduced into the connection to implement the transformation of the carrier for the transmitted data. The results show that the data transmitted by the white-light LED are received correctly by the IR receiver module with the carrier transformation proposed here and the distance between them is sufficient to build an optical link for home appliances under a minimum illuminance of 500 lux.*
Keywords: Optical link, Carrier, White-light LED, IR receiver module, Free-space optics (FSO)

1. **Introduction.** No matter in optical fibers or in free space, data bits can be transmitted by use of light-emitting diodes (LEDs) and received by the photodiodes responsive to the lights on the corresponding wavelengths. The modulation characteristics of LEDs and the responsivities of the paired photodiodes contribute to the development of optical communications [1,2]. Nowadays, lighting with white-light LEDs has not only been used for daily illumination but also been studied to transport data wirelessly to the place which is being illuminated [3,4]. To carry out the optical link for data transmission, an optical receiver responding to white light is required. Inside the optical receiver, a p-intrinsic-n (PIN) diode or an avalanche photodiode (APD) is often used as a photodetector to perceive diverse light intensities modulated in high frequencies. Compared to PIN diodes, APDs have superior responsivities because of avalanche multiplication. With rather high internal gains, APDs exhibit more satisfactory signal-to-noise ratios when their performance is compared to the external amplification circuitry needed for PIN diodes [1,2]. However, APDs are very expensive. In other words, the cost will be increased much to equip an optical receiver with an APD. And it will become time-consuming if the optical receiver accompanying with satisfied signal-to-noise ratios turns to be created with a PIN diode responsive to white light.

In [5], an infrared (IR) receiver module was directly used as an optical receiver to recognize the optical data emitted by a white-light AC LED because the module is functional and economic to the reception task. The IR receiver module is often used in consumer electronics for remote control [6]. However, it works only for quite limited reception distances in [5] because the radiant energy around the wavelengths emitted by the white-light

AC LED and perceptible to the IR receiver module is much weak. The limited reception distances are insufficient to support remote control for home appliances. In essence, white light can be detected by some dedicated sensors. The detection can work far away depending on the light intensity remaining on the sensors. The light supposed to be responded by an IR receiver module in the distance is infrared, such as those emitted from IR LEDs. As a result, it could be a useful approach to extend the reception distance in [5] by transferring the data from the white-light carrier generated by the white-light AC LED to an infrared one that is perceptible to the IR receiver module. The energy of white light can be converted into electricity by some optical sensors and IR LEDs need electricity to emit infrared. The white-light sensors can work together with the IR LEDs to carry out the carrier transformation for data reception in the distance.

In this paper, the scheme of the carrier transformation from white light to infrared used to develop an optical link with sufficient reception distances for remote control of home appliances is introduced first. Then the operation of the IR receiver module used here is reviewed briefly before the receiver circuitry is proposed next. According to the performance of the carrier transformation, the efforts and the benefits of this approach are investigated and discussed at last.

2. **Carrier Transformation.** A 38 KHz IR receiver module is designed to read data bits carried by an infrared signal of 38 KHz. Therefore, the bit streams for it are usually output through an IR LED. However, the bit streams in the study are generated by a white-light LED instead, because the LED is getting popular for our daily illumination. In other words, all data bits are carried by white light. As mentioned above, the IR receiver module can only read them when it is very close to the light source. An approach transforming the optical carrier is proposed here to release the limitation on the reception distance. Transferring data bits from the white-light carrier generated by the white-light LED to an infrared one perceptible to an IR receiver module illustrates the carrier transformation. In Figure 1, the carrier with data bits on it is generated by a white-light LED in the beginning. On the way of light travelling, an optical sensor dedicated to white light receives it in the distance. With the help of the optical sensor, the optical carrier is transformed into an electrical one that determines the infrared emitted by the following IR LED. Ideally, the IR LED will reproduce the carrier signal with infrared. And the carrier transformation is done. In the end of the reception, an IR receiver module returns the data bits from the infrared carrier signal. With the scheme proposed in Figure 1, the advantages of the IR receiver module become available for non-infrared optical communications and facilitate the development of data transmission with white-light LEDs when these LEDs are working for illumination at the same time [4].

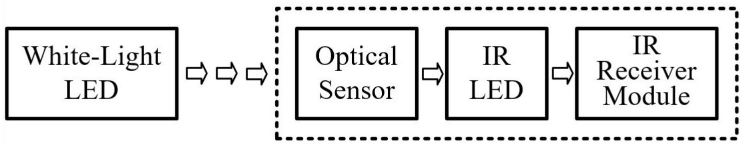

Figure 1. Scheme of the carrier transformation from white light to infrared

3. **Implementation.** According to the specification of the IR receiver module used in the study, data bits for it are required to be carried by a square wave at a frequency of 38 KHz and their pulse widths have to be at least 400 us typically no matter for high-level or low-level data bits. In other words, data bits can only be generated one by one with the throughput no more than 2500 bps. To arrange data bits to meet the requirements of the IR receiver module in advance, a microcontroller is used to prepare the data bits before they are transmitted. With the microcontroller, the bit stream is generated through a

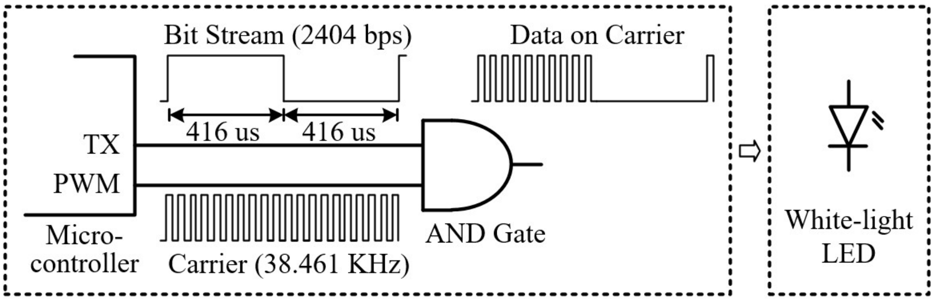

Figure 2. Preparation of data bits for a 38 KHz IR receiver module before they are transmitted with a white-light LED

serial interface operated on the protocol of EIA232 at a baud rate of 2404 bps. At the same time, a square wave repeating in 38.461 KHz is produced with the PWM function of the microcontroller and used as a carrier for data transmission. Then an AND gate is used to combine data bits with the carrier. After that, the carrier with data bits on it is ready to be emitted by a white-light LED, as shown in Figure 2. More information about the circuit of the data transmitter shown in this figure can be found in our previous studies [5,7].

It is well known that the white-light LED used for illumination usually has two peaks at its spectrum. The biggest one appears around the wavelength of the blue light because the white-light LED is conventionally made up of a blue-light LED chip and some yellow phosphor on it [8]. As a result, the modulation on the light emitted from the white-light LED can be recognized by a photodiode used to detect blue light or an optical sensor dedicated to daylight. The photodiode or the optical sensor is able to respond to the modulation of the white light emitted from the LEDs in the distance. Therefore, they can be used at the far reception end of the optical link to convert the presentation of the carrier from white light to electricity. If the electrical counterpart of the white-light carrier can be used to operate an IR LED to reproduce the same carrier with infrared, then the IR receiver module can take over to complete all the other reception tasks as those done in [5].

In the study, the receiver circuitry paired with the transmitter proposed in Figure 2 is illustrated in Figure 3. In this figure, a photodiode (S6428, Hamamatsu) [9] designed for the recognition of blue light is used in the distance to receive the optical carrier with data bits on it emitted by the white-light LED in Figures 1 and 2. The photodiode can perceive the light having the wavelengths from about 400 to 540 nm. Within the range, the photodiode responds with its maximum sensitivity of 0.22 A/W to the light of 460 nm. The photodiode converts the optical signal conveyed by the white light to the electric current at its output. Then the electrical signal obtained is processed to transfer the data correctly to the light emitted from an IR LED. The light intensity emitted by the IR LED peaks at the wavelength of 940 nm that will induce the peak response of the IR receiver module used in the study. As a result, data bits are transferred from the white-light carrier to the infrared one and finally retrieved by the IR receiver module.

4. **Results.** If the carrier transformation proposed here works, the data transmitted through the TX pin of the microcontroller shown in Figure 2 will be returned at the RX pin of the microcontroller shown in Figure 3 after the transformation. The signals appearing at these two pins were recorded with a digital oscilloscope first to investigate if the data received are the same as the data transmitted. The measurement was saved and part of them is shown in Figure 4. After all, the microcontroller on the receiver will verify the data received with its serial I/O module and confirm the correctness. The results obtained from the oscilloscope and the microcontroller on the receiver in Figure 3 all

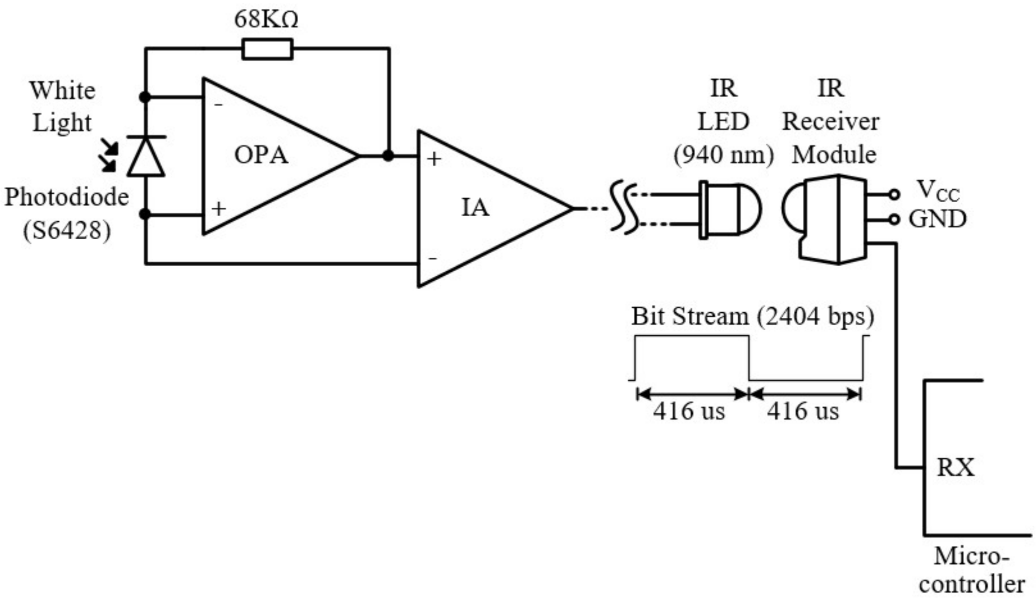

FIGURE 3. Optical receiver paired with the transmitter shown in Figure 2

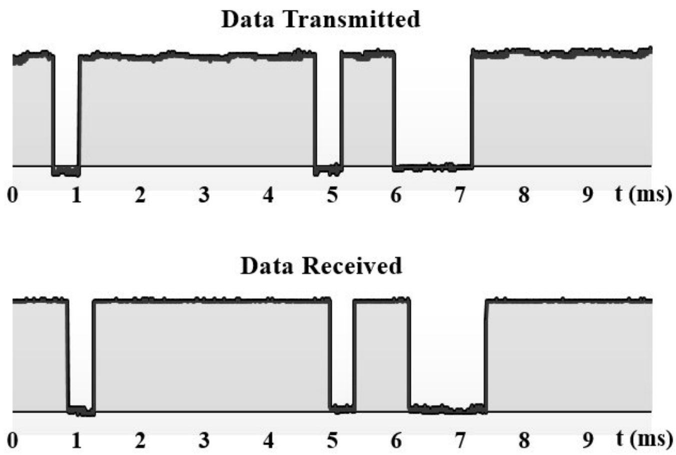

FIGURE 4. Data recorded at the TX pin of the microcontroller on the transmitter (Figure 2) and the RX pin of the microcontroller on the receiver (Figure 3) at the same period

prove that the data transmitted with the white-light carrier in the distance are returned correctly at the RX pin. In other words, the scheme of the carrier transformation shown in Figure 1 and the approaches used to implement it, as those shown in Figure 2 for data transmission and Figure 3 for data reception are successful and feasible.

5. **Discussions.** Instead of voltage levels, the binary states of data bits are represented with the presence of the carrier or not as the bit stream is transmitted with a specific high-frequency carrier signal. The presence of the carrier means a periodical signal oscillating in a preset frequency is found, no matter how much the amplitude is. When a photodiode perceives an optical signal, a corresponding electrical signal is produced. The electrical counterpart marks the binary states of the bit stream with the presence of the carrier or not as well. To process the electrical signal in order to raise the signal-to-noise ratio, the electrical output of the photodiode was simply amplified until saturated in the study. As a result, the electrical carrier at the output was enlarged to oscillate between the maximum and the minimum output levels of the processing circuit in the same central frequency,

and the part without the carrier or the noise with spectra out of 38 KHz was reduced after filtering with a bandpass filter inside the IR receiver module and finally ignored. The mentioned above concludes that the signal processing for the output of the photodiode becomes simple with the help of the carrier and the IR receiver module.

The recommended light level or illuminance for reading or study is 500 lm/m^2 [10,11]. The equivalent luminous flux on the active area (2.4×2.8 mm^2) of the photodiode (S6428) is 3.36×10^{-3} lm. Assume the quantity of the luminous flux (lm) is equal to the amount of the radiant power (W) incident to the photodiode, there will be an electric current of 0.74 mA produced at the output of the photodiode with its photosensitivity of 0.22 A/W. Then a significant voltage signal can be generated as the output current flow through a selected resistor. As shown in Figure 3, a 68 KΩ resistor on the feedback loop of an operational amplifier (OPA) is used for the less incident light intensity emitted by a white-light LED to convert the current generated by the photodiode to the voltage that is forwarded to the inputs of an instrumentation amplifier (IA). According to experimental results partially shown in Figure 4 and the estimation above, the performance of the approaches proposed here is satisfied.

6. **Conclusion.** Under the illuminance of 500 lm/m^2 supplied by an indoor LED lamp, the photodiode with its performance of 0.22 A/W can convert the optical carrier with data bits on it into an electrical one with sufficient signal-to-noise ratios. Consequently, the optical link can be set up from the lamp to the other place inside the room illuminated by the lamp. Hence, the limitation on the reception distance in [5] can be improved. Although, the IR receiver module is a mature device for data reception, it works with infrared, other light sources in the distance will not cause it to respond well. Fortunately, the carrier transformation proposed here makes it possible to work for the data bits carried by a non-infrared carrier, and thus the optical link can be built in less time with the help of the IR receiver module. Besides, the circuit used for the carrier transformation is very simple and cheap. Therefore, the optical link set up with white-light LEDs and an IR receiver module will consume only a little more time and expense to have enough reception distances with the addition of the carrier transformation when compared to [5].

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