Employing LM13700 as AGC for Mobile Visible Light Communication System

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***Abstract*—The optical channel distance greatly influences the optical power received by the photodiode, the farther the distance between the receiver and the transmitter in the VLC system, the lower SNR, and the higher BER. To mitigate the mobility issue on the VLC system, we involve an AGC circuit put on the receiver side. Thus, the received information (signal) can adjust at specifically required voltage even though the distance and angle were changed. In this paper, the AGC circuit employs a single channel LM13700; this is commercially available as well as a low-cost Integrated Circuit (IC). The application method to design a VLC system using LM13700 configured as AGC is presented. Then the AGC performance evaluation by using two different modulations is also conducted. The results show that the weak information (signal) due to changing the optical distance and the receiver angle can be gained to a required voltage level as well. Therefore, the LM13700 can be recommended for the mobility VLC system. Our system focused on low-rate VLC applications due to bandwidth limitations within the used IC. Moreover, our system is aimed at the Line-of-Sight VLC channel.**

***Index Terms*—Automatic Gain Controller, LM13700, LOS, visible light communication**

I. Introduction

Visible Light Communication (VLC) is an optical communication type that employs visible light-medium which is currently considered as a step forward to make the "Green Communication" concept [1]. VLC is also a solution to the problem of prohibiting the Radio Frequencies (RF) used in the free electromagnetic-waves areas, e.g., in mining and oil refineries, hospital, aircraft cabins, military, and other areas [2]. As a communication system, VLC is also vulnerable to optical noise, and it has a range limitation because the nature of light is not uniform. Other light interferences as mentioned before like incandescent, fluorescent, sunlight, flashlight, and so on. Many considerations must be taken to design a robust VLC system against these optical noises. Besides, we must compensate the coverage limitations of the VLC system (e.g., reception angle and the optical distance). We can select a proper link configuration. The most commonly used configurations are directed Line-of-sight (LOS) and Non-line-of-sight (NLOS) [3].

In this case, the LOS link configuration is excellent compared to NLOS because it can offer faster data rates up to hundreds kbps within a coverage range of several meters and even up to kilometers, as conducted by [4]-[6]. Therefore, LOS configuration is very suitable to be applied in an outdoor environment, which requires that the receiver's position must be upright to the transmitter.

Another advantage of the directed LOS link is not susceptible to the distortion comes from multipath signal induction. Even the noise from ambient light also can not affect it when using a photodiode with a narrow field-of-view (FOV) [7], [8]. However, the disadvantages of LOS configuration are as follows: it covers a close area, and if the photodiode is blocked by a solid object (ex. a wall) or by the living things activity (ex. human and pet movement), then the VLC receiver device will not receive any signal at all. Despite the disadvantages as mentioned earlier, the directed LOS configuration can be implemented in specific schemes; this offers secure communication compared to RF communication because VLC coverage is limited to certain sides/areas.

The directed LOS link has another problem; it cannot support mobile users. As a wireless communication system, VLC must offer good mobility access to the users, as similar as possible to RF communication performance. Fig. 1 illustrates an indoor VLC application that uses directed LOS link containing single light-emitting-diode (LED) and mobile user.

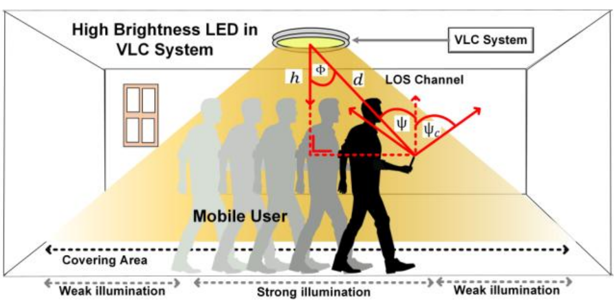

Fig. 1. VLC System containing mobile receiver in an indoor environment.

Based on literature review, several offered solutions are using a focus lens or Fresnel lens [9]. Hence, the inequality of light level (intensity) in a large room can be

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compensated by collecting light from the LED source through the lens used. Even with a small beam, high flux density on the photodetector is still can be achieved. The second solution is to use multiple LEDs arranged in the form of cells. Thus, a VLC system can cover a large enough room. But there are many light sources (i.e., LED) installed as base stations. Moreover, it will cause a roaming problem.

In previous work, we have designed a robust VLC prototype [10]. The VLC receiver device is equipped with automatic gain controller (AGC) circuit which functions to control the voltage gain (A_{VOL}) from the output signal although the input signal varies. If the input signal amplitude is greater than the maximum tolerance of A_{VOL}, then the AGC circuit will reduce A_{VOL} automatically, and vice versa. We used LM13700 configured as AGC as depicted in Fig. 2 whose working principle is the opposite of TIA, where the input is voltage, and the output is current. LM13700 is a current-controlled feedback amplifier, with a differential input and push-pull output. LM13700 detects the peak voltage from the output to adjust A_{VOL} dynamically until an appropriate value is obtained.

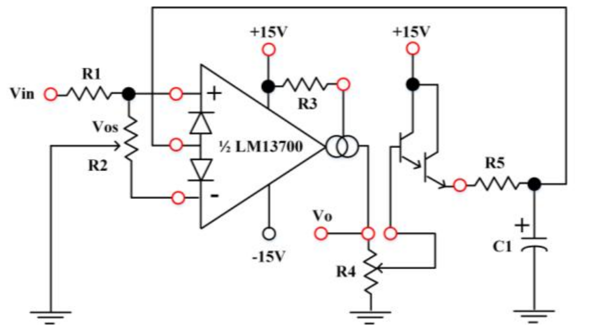

Fig. 2. AGC circuit with LM13700, reproduced from [11]

But in previous work [10], bit-error rate (BER) analysis was not performed. Also, the optical channel distance in the experiment is still limited (a few centimeters). And the AGC module realization in the printed circuit board (PCB) has not been integrated with DSP module, PC, and other analog front-end (AFE) receiver blocks, e.g., trans-impedance amplifier (TIA), pre-amplifier, and analog filter). Therefore, this work is a continuation of [10]. We will observe the AGC performance in the VLC system containing signal analysis, gain voltage analysis, and BER analysis.

In this work, we used the VLC system consists of a digital signal processing (DSP) module that uses an STM32F4 microcontroller and an analog transceiver module. The modulation used in this work for AGC circuit performance is analog and digital.

II. Methods

A. VLC Systems

The AGC circuit resides on the VLC receiver device as pointed out in the red-colored block (Fig. 3). This work correlates with other research related to "hardware" and "software", thus the AGC circuit function cannot be separated from other parts.

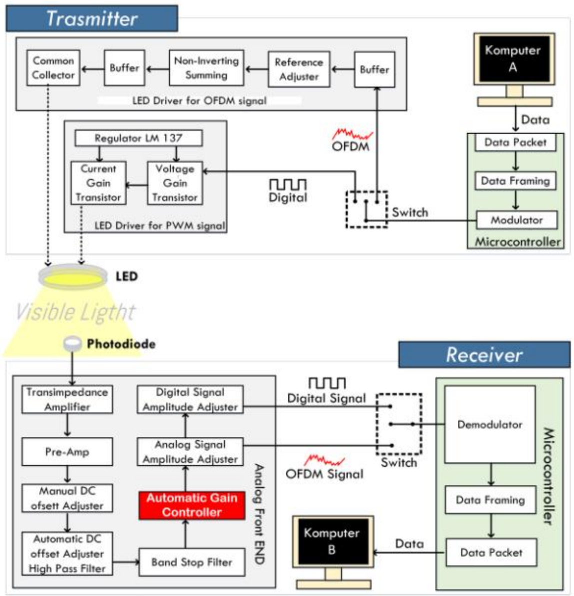

Fig. 3. The whole VLC system

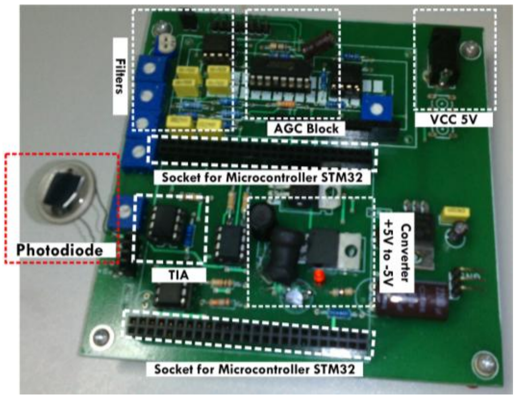

Fig. 4. Hardware of VLC receiver

The VLC hardware includes three main blocks, i.e.

- LED driver circuit with switch topology, we can select this block if the digital modulation types are used. The reader can find out at following references [12], [13],
- Linear LED driver circuit, we can select this block if the OFDM technique is used. The reader can find out at following references [14], [15],
- AFE receiver [16], [17].

Whereas VLC software part is related to the modulation used, i.e., BPSK [18], [19], QPSK, QAM-16, and PWM [20]-[22]. The readers can trace these previous works by finding them in the reference section of this paper [18]-[22].

The AGC block is composed of components referring to the LM13700 datasheet's recommendations as depicted in Fig. 2.

Fig. 4 shows a photograph of VLC receiver hardware. The AGC block is a small part of our VLC system, but it is essential part to maintain the SNR value as high as possible, but the BER value must be as low as possible. Using AGC, we expect that the information signal received by the VLC receiver device is still of high-quality (fewer errors) even though the optical channel (distance and angle) changes.

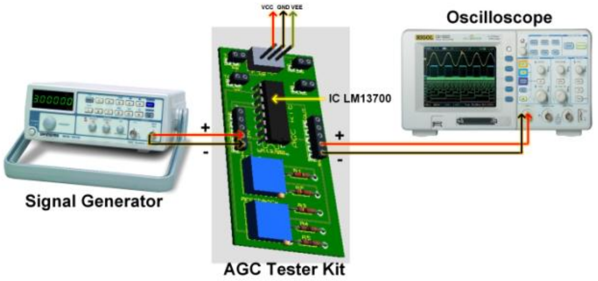

Fig. 5. Test setting in the scenario I

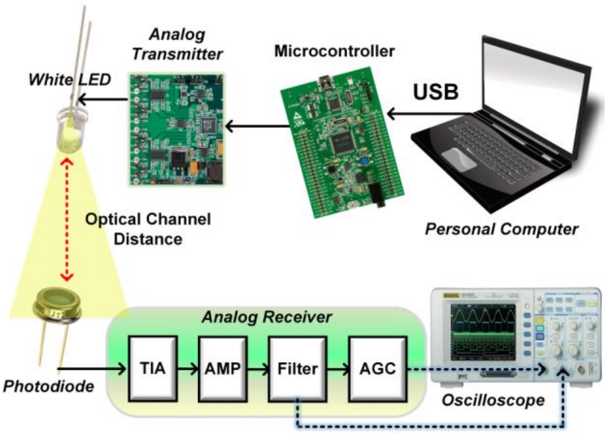

Fig. 6. Test setting in the scenario II

B. Scenario Test

As explained in Section I, the AGC block by utilizing LM13700 is not a stand-alone system but must be integrated with other blocks. Furthermore, to find out the LM13700 functionality required several test scenarios. In this work, there are three scenarios. The first scenario, we measure A_{VOL} using the formula: $20\times\log(V_o/V_{in})$.

The input signal (V_{in}) is a signal that comes from the Signal generator, while the output signal (V_o) is AGC output. The oscilloscope displays V_o and V_{in} signals. The test setup of the scenario I is shown in Fig. 5, which is similar to the test setup in the previous work [10].

After ascertaining that the AGC circuit was successful in maintaining V_{in}, then, the AGC is connected to other blocks as shown in Fig. 6. Other blocks are digital and analog blocks.

The STM32F4 microcontroller was used as a digital block. Whereas analog blocks, we have designed several circuits, such as TIA circuit as a light to voltage converter [22], amplifier, and analog filter [23], [24], in which these blocks are connected before the AGC circuit. The second test scenario is an extensive VLC system, which involves an LED as an antenna and an SP-8ML photodiode as a light sensor. The closer the distance or, the smaller the photodiode's angle reception to the LED, the higher the power received, as proven in previous studies [25].

In the second scenario, we used analog modulation that is BPSK, as in [18], [19]. The purpose of this test is to determine the effect of changing optical channel distance to A_{VOL}. In this test, we set the sinusoid signal generated by the signal generator as an input. Later, we set the input frequency of 25 kHz as a fixed variable. The optical channel distance is set varied from 30 cm to 190 cm (control variable). Then we probe two pins output to observe the performance comparison. We measure the signal input of AGC circuit compared to the AGC output. As a note that the AGC circuit input comes from the pre-amplifier circuit output.

The last scenario aims to determine the effect of changing the distance to BER result, which has not done in previous work [10]. The test setup is depicted in Fig. 7. We compare the AGC circuit performance against the amplifier circuit-based Op-Amp with a fixed gain. To find out BER accurately, we send text data from the PC transmitter to the PC receiver through visible light. Unlike the second scenario, in the third scenario, two microcontrollers are used as a digital modulator and a digital demodulator. The distance varies from 30 cm to 150 cm. The modulation type used in this test is 1-PWM as in [20], [21], while the method used to measure BER also refers to previous work [20], [21].

The performance test results in the first, second, and third scenarios are described in Section III B, III C, and III D, respectively. In this work, changing the reception angle of the VLC receiver is not carried out which is a research limitation.

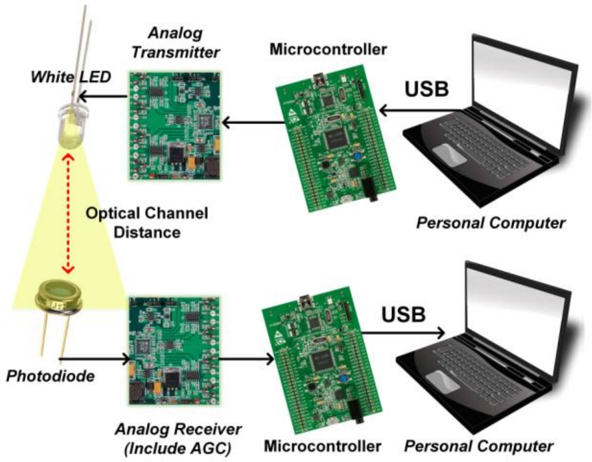

Fig. 7. Test setting in the scenario III

III. METHODS

A. Characteristics of AGC Using LM13700

The test result of the scenario I is shown in Table I. We set the sinusoidal input signals from 100 mV to 2 V. The results show that the LM13700 output ranges from 2.2 V to the IC saturation limit, which is 4.5 V. The AGC circuit can maintain the output signal even though the input signals are varied.

TABLE I. TEST RESULT OF AGC CIRCUIT EMPLOYING LM13700

V_{in} (mV)	V_o (V)	A_{VOL}
100	2.2	22
200	3.4	17
300	3.8	12.6
400	4.0	10
500	4.2	8.4
1000	4.2	4.2
2000	4.5	2.25

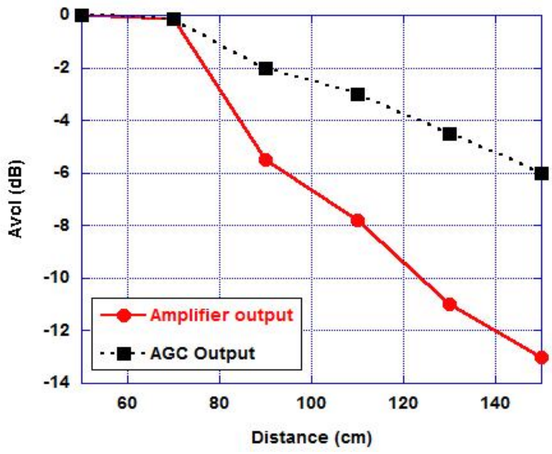

Fig. 8. Graph of the gain voltage against the optical distance

B. A_{VOL} Analysis

Fig. 8 is the A_{VOL} measurements result. In this test, we used a fixed frequency as explained in Section II B, which is 25 kHz. From the graph, it can be observed that the input signal from the AGC circuit is highly dependent on the optical channel distance variable.

The further the distance between the photodiode to the LED, the A_{VOL} is getting lower. But the output signal from AGC is not affected by the optical channel distance (between 70 cm and 130 cm). According to Fig. 8, we can conclude that the AGC circuit using LM13700 can effectively maintain A_{VOL} within a range of 70 cm to 130 cm; it means that the use of LM13700 can contribute to providing the VLC system mobility.

C. Signal Analysis

Fig. 9 visualizes the output signal of the VLC receiver device. The VLC transmitter device emits the modulated data (using BPSK modulation) and then received by the VLC receiver device at an optical channel distance of 10 cm and an elevation angle of 0^o. The purpose of this test is to observe the received signal to different ranges, i.e., 150 cm, 90 cm, 80 cm, 60 cm, 40 cm, and 30 cm. As explained in Section I, the light intensity emitted by the LEDs in a room is scattered. Hence, the output signal from the VLC receiver device also varies; it can be strong or weak as illustrated in Fig. 1. If the received signal is not a strong enough (weak signal), possibility, the SNR will be low and BER value will be high, which causes clipped signal due to Op-amp's saturation on the receiver side.

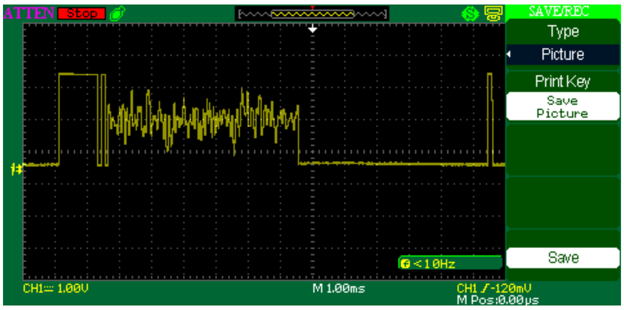

Fig. 9. One symbol of OFDM signal received by the VLC receiver device at the optical channel distance of 10 cm and zero degrees reception angle

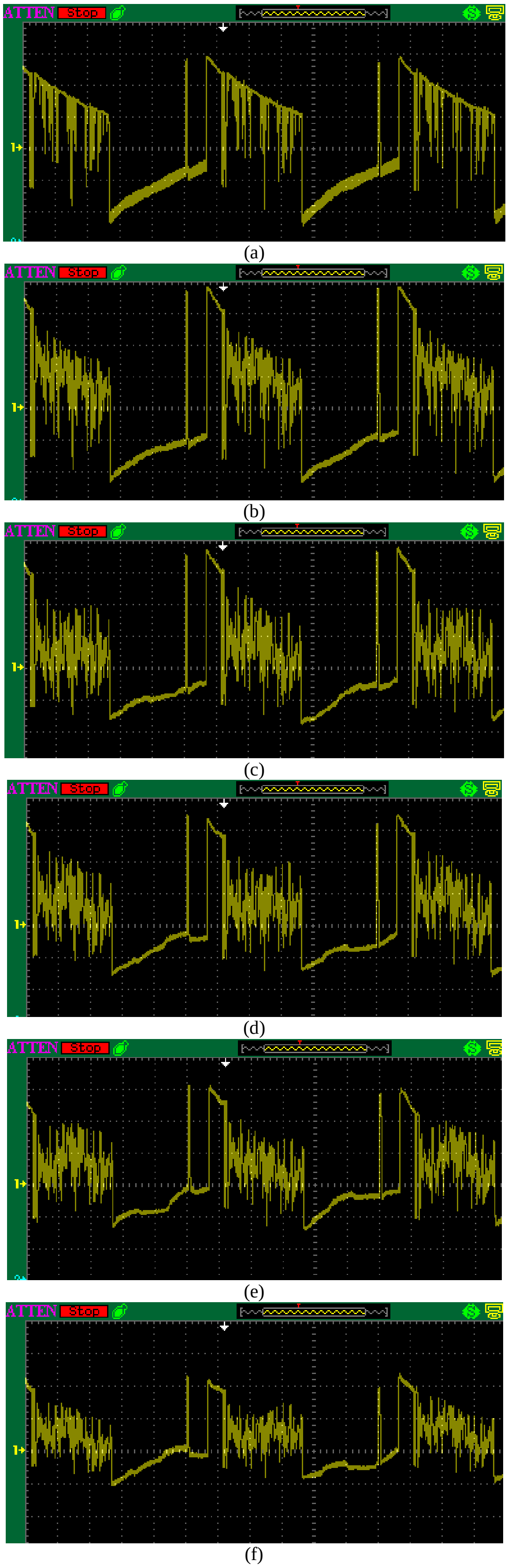

Fig. 10. One symbol of OFDM signal received by the VLC receiver device at the zero degrees reception angle and optical channel distance of: (a) 30 cm, (b) 40 cm, (c) 60 cm, (d) 80 cm, (e) 90 cm, (f) 150 cm

Using the AGC, the receiver's output signal can adjust within a specific voltage range. The results are shown in Fig 10 (a) to Fig. 10 (f). It can be seen, the input signal amplitude decreases, the AGC gain will automatically increase and if the signal amplitude increases, the gain will decrease.

D. BER Analysis

The test result in scenario III is shown in Fig. 11. We can see that the AGC circuits can improve the VLC systems performance for a wider optical channel range.

The optimum distance between the VLC transmitter device and the VLC receiver device using analog circuits with a fixed gain is 70 cm to 90 cm. By using AGC, the optimum range is around 50 cm to 110 cm. The LM13700 configured as AGC enable to extend the distance range of the optical channel. Thus, we expect that the LM13700 can support the mobility of VLC device users.

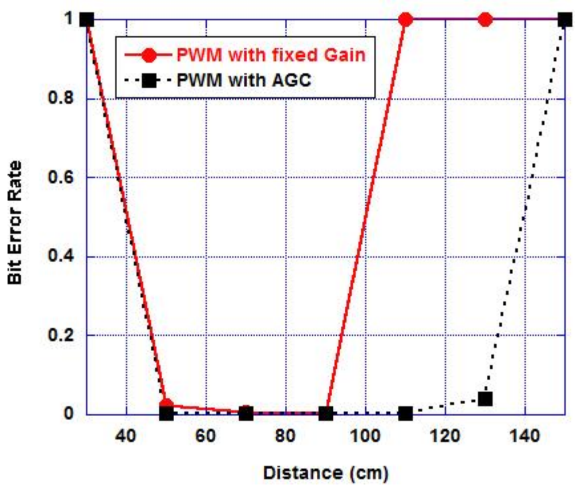

Fig. 11. A graph of BER against optical distance

IV. CONCLUSION

To expand the VLC system coverage, AGC circuit is needed; it can be involved at the VLC receiver device. In this paper, the low-cost integrated circuit, LM13700, is employed as AGC to support mobile VLC system. The results show that the VLC receiver device using LM13700 can amplify the received signals. We prove it by using two types of modulation, i.e., digital and analog, as employed in previous research: BPSK and 1-PWM. In summary, mobile VLC systems in indoor environments can be appropriately realized.

CONFLICT OF INTEREST

The authors declare no conflict of interest

AUTHOR CONTRIBUTIONS

Syifaul Fuada, Trio Adiono, and Angga Pradana proposed the concept; Angga Pradana developed and mounted the printed circuit board (PCB); Syifaul Fuada prepared all of electronic components; Angga Pradana designed the experiment. Syifaul Fuada and Angga Pradana carried out the experimental data; Syifaul Fuada and Angga Pradana analyzed the data; Syifaul Fuada contributed to the writing of the manuscript and designed all of illustrations; Trio Adiono supervised and funded the research.

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