Analog Filters Design in VLC Analog Front-End Receiver for Reducing Indoor Ambient Light Noise

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***Abstract*—Visible Light Communication (VLC) technology in indoor implementation is challenged by ambient light and other lighting noise, such as fluorescent lamp and bulb. The ambient light could create a DC offset or signal with specific frequency range. Thus, we propose analog filters design in the VLC Analog Front-End (AFE) receiver that can eliminate the ambient light noise. The proposed design uses DC offset removal, incorporated with automatic and manual adjustment mode. In automatic mode, we design the analog filter using High Pass Filter (HPF) which have f_c = 10Hz; meanwhile, in manual mode we design a reference circuit using potentiometer and differential amplifier for direct current blocking. For reducing signal interference from lamp flickering, the proposed design uses Band Stop Filter (BSF) which has f_c = 100Hz. The experimental results, both simulation and real-time, show that our proposed design can reduce signal interference and ambient light. We also test the design using PWM and BPSK modulation to evaluate Bit Error Rate (BER) performance.**

Keywords—VLC; Analog Filters; Analog Front-End; Ambient Light Noise; Indoor Implementation.

I. Introduction

Visible Light Communication (VLC) technology offers several advantages compared with other communication technologies, such as Radio Frequency (RF) or Infra-Red (IR). Considering the security factor, RF provides connection which could penetrate a physical barrier (e.g. wall). Meanwhile, VLC and IR could not do that. Thus, from that point of view, VLC and IR are arguably more secure than RF. Considering the health risks which could be caused by the technology, IR is dangerous to human skin and eyes, because IR spectrum can be absorbed easily [1]. RF is vulnerable to electromagnetic interference and potentially could cause a cancer if the human are overly exposed by RF microwave signal [2]. Meanwhile, VLC technology is safe for human. Considering those two factors, we can see that VLC provides secured and fast sharing information, safety and robustness againts electromagnetic interferences [3].

From those advantages, we conclude that VLC technology is worth to explore and develop further. But, unfortunately, the main weakness of VLC is the ambient light or interference from other light sources [6]. Lighting noise and ambient light can significantly influence the VLC optical channel and corrupt the transmitted data, either by direct exposure or reflection [7].

Based on field applications, VLC implementation target is divided into two purposes, indoor and outdoor. In this case, we develop VLC system for indoor (e.g. office, home, hospital, convention center, market, etc.). Therefore, the ambient light sources are usually from conventional fluorescent lamp, bulb, LED, or other lighting sources which have flickering effect. According to [4], a bulb is emitting sinusoidal frequency around 100Hz when it is supplied by 220V/50Hz. The harmonic frequency can be measured under 2KHz, but only under 800Hz which carry influential significant energy. The conventional fluorescent lamp also generates distorted sinusoidal signal and its harmonic frequency at 50Hz - 20KHz, while, the fluorescent lamp which uses electronic ballast produces interference frequency between 50Hz - 100Hz or 1MHz. These interferences can be reduced using filters with specific configuration [8] at the receiver of VLC systems. This research target is to design analog filters circuit to reduce signal interference, either from light noise or ambient light. Thus, the received signal in receiver (*Rx*) can be processed correctly.

This paper is divided into five parts. First part discusses about background and research target. Second part discusses about our VLC platform as main reference. It is followed by our proposed analog filters design using commercially available OP-AMP (i.e. LM741). Meanwhile, Fourth part discusses thoroughly about the evaluation results, such as simulations, experimental tests, Bit Error Rate (BER) performance, etc. Last parts are conclusions and references, respectively.

II. VLC Platform

Firstly, we design a VLC system environment, completed with its transmitter (*Tx*) and receiver (*Rx*), as shown in Fig. 1. It is a platform for conducting the research. Initially the data are sent from Computer-A to microcontroller (i.e. STM32). The microcontroller will process and transmit the data with selected modulation scheme, either PWM or BPSK. Next, the data are transmitted by visible light which is emitted by white color LED. Transmitted data will be received by a photodiode. During transmission through free space, data could be faded away or distorted and corrupted by noise or interference.

In order to reduce these noise and interference effects, we design design AFE which comprises four blocks, namely transimpedance amplifier, pre-amp, manual and auto DC offset adjuster, Band Stop Filter (BSF), Automatic Gain Controller (AGC), and analog and digital amplitude adjuster. In this paper, focus of the discussions are about manual and auto DC offset adjuster, and BSF. They are indicated as three blue-boxes in AFE section illustrated in Fig. 1. Output data from AFE are translated into ASCII characters by microcontroller and sent to Computer-B. Table I shows the specifications used in the tests.

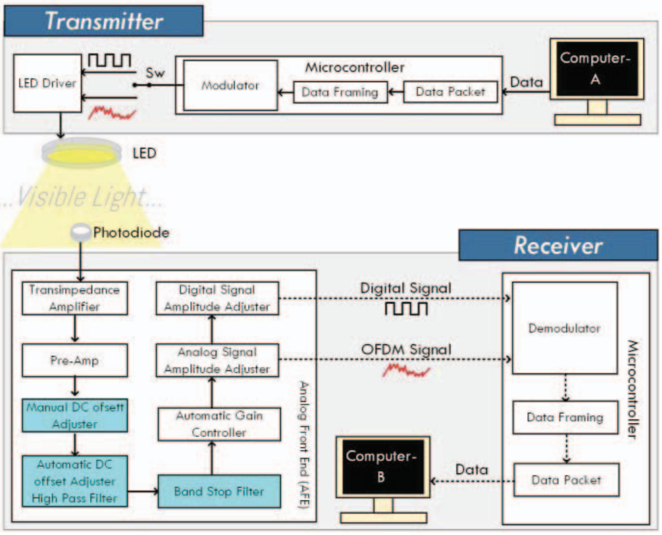


Fig. 1. VLC platform

TABLE I. PARAMETERS IN VLC PLATFORM FOR ANALOG FILTER TEST

Variable	Description
Application / coverage range	Indoor / max. ~1.5 m
Communication models	Point to point
Transmitter	LED specifications: • Voltage rating: 10 - 14 V • Power : 9 W (max) • View angle : 120° • Luminous intensity: 400 - 500 lux • Wavelength : 380 - 760 nm (white)
Receiver	Photodiode specifications: • Spectral response : 400 – 1000 nm • Rise/fall time : 50 µs • Cutoff frequency : 4 MHz • Effective area size : 2 cm^2
OP-AMP	General OP-AMP (LM741) with dual supply ±5V$_{DC}$ and 1 MHz bandwidth
Channel model	Direct LOS link
Microcontroller	STM32
Bitrate max.	100 Kbps
Modulation	PWM, BPSK
Interference lamp addressing	Fluorescent, Bulb

III. ANALOG FILTERS CIRCUIT DESIGN

A. DC Offset Removal with Manual Adjustment

In this block, we remove the DC offset which appears because of the ambient light. Circuit design in this block is shown in Fig. 2. OP-AMP1 with the potensiometer act as manual adjuster and OP-AMP2 as differential ampilifier. Fig. 3 shows the signal removal illustration. Signal v_2 is signal from non-inverting amplifier (pre-amp), v_3 is DC signal reference and v_4 is output of OP-AMP2 and connected to high pass filter (HPF).

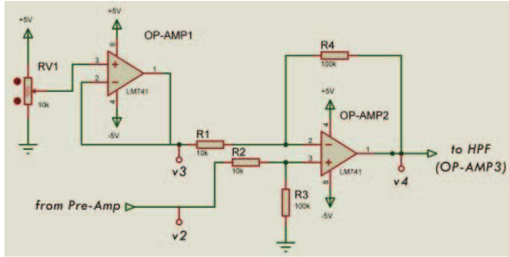


Fig. 2. DC offset removal circuit with manual adjuster

B. DC Offset Removal with Automatic Adjustment

In DC offset removal with automatic adjustment, HPF has a function to eliminate the DC offset from ambient light. It is constructed by OP-AMP3 as shown in Fig. 3. This is a second order butterworth type active filter of Sallen-key topology. This topology was proposed due to high quality factor (Q) value and consist of simple components [5]. The design parameter of HPF is cut-off frequency f_c = 10 Hz. Based on (1), we got $R_5 = R_6 = R$ = 750 kΩ and $C_1 = C_2 = C$ = 22 nF. In order to achieve R = 750 kΩ, we can put R = 1500 kΩ with parallel configuration.

$$f = \frac{1}{2\pi\,(RC)} \qquad (1)$$

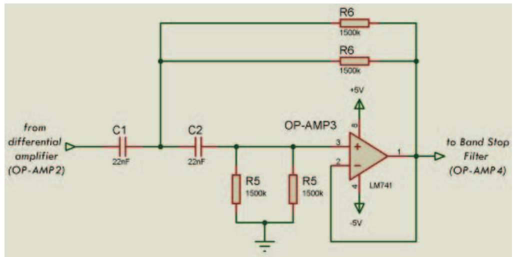


Fig. 3. HPF circuit with Sallen-key topology

C. Band Stop Filter (BSF)

In order to reduce interference from other light sources, such as fluorescent lamp and bulb, we use BSF as illustrated in Fig. 4. Fluorescent lamp usually generates 100Hz interference, therefore we need to eliminate frequency of 100Hz from the signal. Twin-T topology was used due to its simplicity and high Q. From calculation, we got $R_7 = R_8$ = 100kΩ, hence R_9 = 100kΩ/2 = 50kΩ. Since we need to eliminate f = 100Hz, hence f_o = 100Hz, and C becomes $C_3 = C_4$ = 15nF. In order to achieve R = 50kΩ, we can put R = 100kΩ in parallel configuration, while C = 15nF, we can use two C = 30nF in parallel configuration.

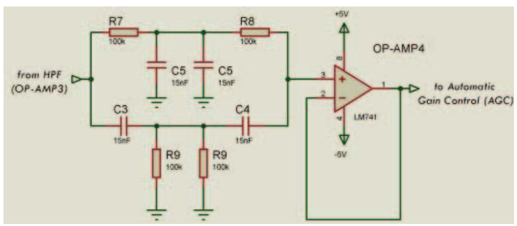


Fig. 4. BSF circuit using Twin-T topology

IV. Results and Analysis

A. Simulation Tests

We use LTSpice® for simulating circuit in Fig. 3 and Fig. 4. Simulation result of HPF with Sallen-key topology is shown in Fig 5. Based on the frequency response graph, we can see that the signal is damped on $f_c \leq 10$Hz. This attenuation is caused by DC-offset removal circuit which eliminate ambient light. The simulations show that the cut-off frequency f_c in -3dB is located at ~15Hz. The 5Hz difference between f_c and light noise frequency is insignificant compared to the bandwith of target coverage. The simulation result of BSF with Twin-T topology is shown in Fig. 6. Based on the frequency response graph, we can see that the signal is damped on f_c = 100 Hz. This attenuation is caused by BSF circuit which eliminate the interference signal from fluorescent lights. In order to improve the quality factor, we need to add additional configuration circuit with higher order. But, it makes the analog circuit in AFE receiver will be more complex. The overall simulation results of all filters are shown in Fig. 7. The analog filters pass the frequencies which are over 10Hz and block the 100Hz frequency. The effective bandwidth is achieved in the range between 500Hz - 50KHz.

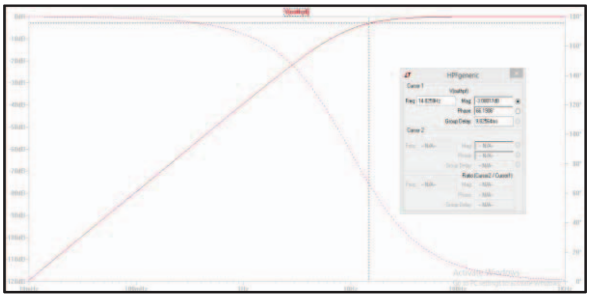


Fig. 5. Simulation of HPF using LTSpice IV®

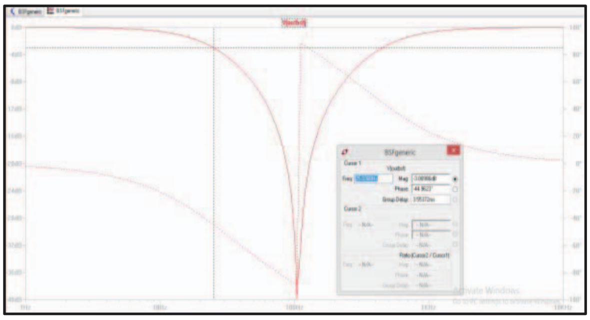


Fig. 6. Simulation of BSF using LTSpice IV®

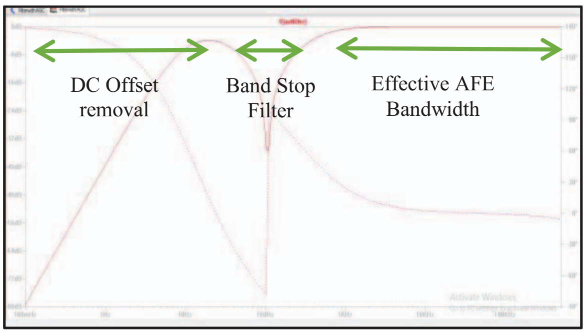


Fig. 7. Simulation of all filters using LTSpice IV®

B. Hardware Implementation

The hardware module of our proposed VLC is shown in Fig. 8. It mainly consists of photodiode, analog receiver circuit, and a microcontroller socket. After the VLC circuit is fabricated in a single layer of Printed Circuit Board (PCB), the next step is performed in real-time experiments.

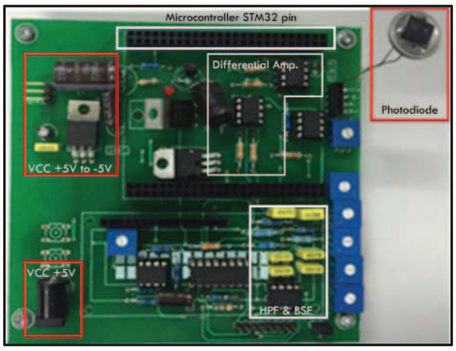
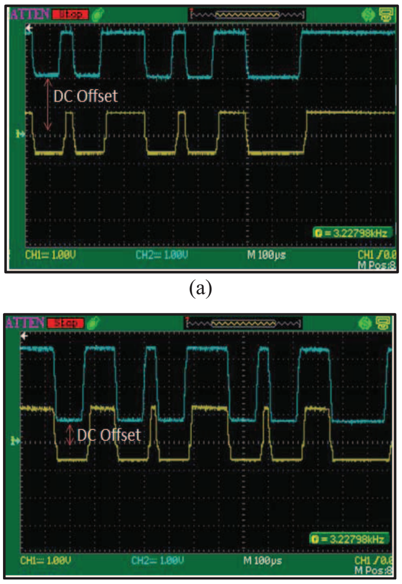


Fig. 8. Analog Front-End receiver hardware implementation

C. DC Offset Removal Test

In this test, we incorporate ambient light noise to know the AFE circuit robustness. We use 2W LED flashlight as DC ambient light source and it is placed around to the photodiode. In this scenario, we send data from Computer-A as transmitter (PC-*Tx*) to Computer B as receiver (PC-*Rx*). During data transfer process, light interference is given to the photodiode in specific distance. We can see the effect of ambient light from DC offset in Fig. 9. It shows that DC offset removal can reduce the effect of the offset and DC offset voltage will be higher if the LED flashlight is placed near to the photodiode.



(a)

(b)

Fig. 9. DC offset removal test:
(a) without DC offset removal; (b) using DC offset removal

D. BER Analysis on DC Offset Removal Test

From the experiments, we get that BER will be higher if the distance between LED flashlight with photodiode is closer. It is because the ambient light from flashlight which is received by photodiode, will be brighter. Thus, the information signal are easily disturbed and distorted by interference light. From Fig. 10, we can see that the use of DC offset removal circuit can decrease BER.

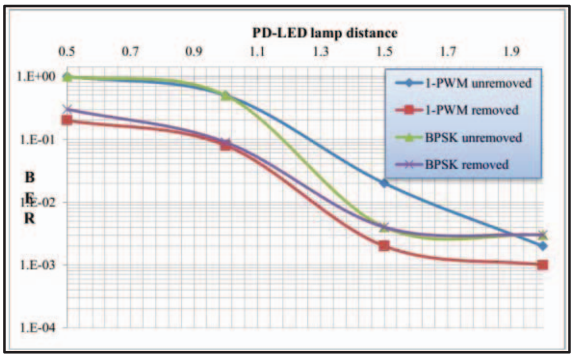
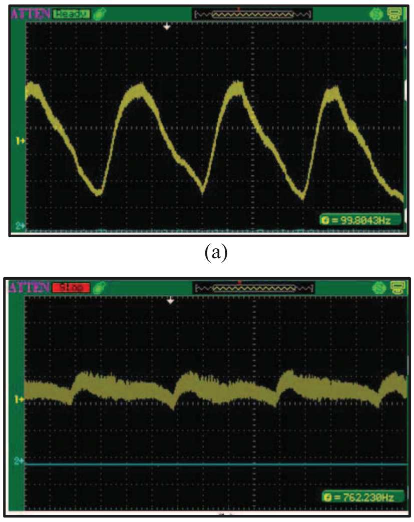


Fig. 10. BER measurement for DC offset removal performance

E. Band Stop Filter (BSF) Test

This test has a function to evaluate the effectiveness of proposed BSF design to eliminate frequency ~100Hz. In this experiment we directly received the light from fluorescence lamp at distance of 80cm using 15W power. The received signal is around 100-150Hz as shown in Fig. 11a. After applying the BSF, the signal changed as shown in Fig. 11b. These results show that the designated filter can effectively reduce the interference signal from fluorescence lamp.



(a)

(b)

Fig. 11. BSF effect test:
(a) without BSF; (b) using BSF

F. BER Analysis at Band Stop Filter (BSF)

In Fig. 12, horizontal axis is distance between photodiode with fluorescent lamp. The graph shows that BER will be higher if the distance between fluorescent lamp with photodiode is closer. It is because the ambient light from light source will be brighter and able to disturb the information signal. But, by using the BSF circuit, BER value can be decreased.

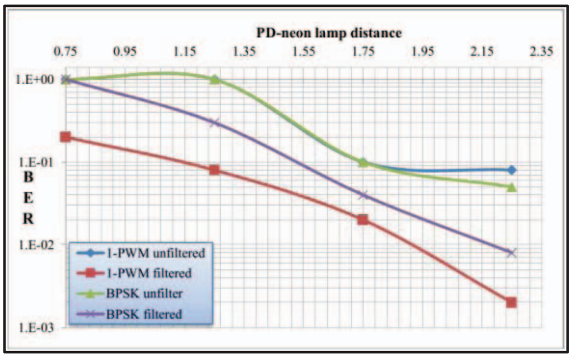


Fig. 12. BER measurement for BSF performance

V. Conclusions and Future Works

In this research, we propose solutions for reducing ambient light noise in indoor environment which cause DC offset and unwanted frequencies. We design DC offset removal and BSF modules for overcoming these problems. DC offset removal is designed for automatic and manual adjustments. HPF reduces ambient light automatically with f_c = 10Hz, while manual adjustment use differential amplifier. BSF reduces interference signal from fluorescent lamp (i.e. unwanted frequency) with f_c = 100Hz. The results show that the proposed design can reduce noise signals in VLC system. Moreover, it is scalable for future developments, such as faster performance, wider bandwidth or better accuracy.

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