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# Optical Interference Noise Filtering over Visible Light Communication System utilizing Analog High-Pass Filter Circuit

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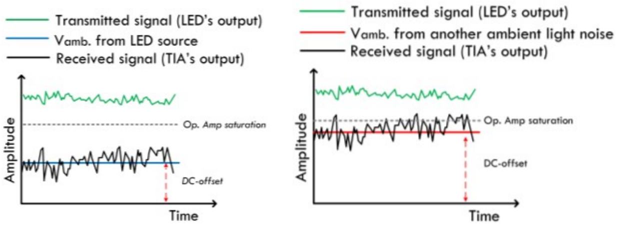
**Abstract–** One of the weaknesses of the Visible Light Communication (VLC) system is its susceptibility towards noise interference which comes from indoor/artificial intelligence lamp such as modern fluorescent and incandescent lamp. Besides that, it is also susceptible to ambient light of sunlight, flashlight, LED lamp, or handphone screen light as DC interferences. In this paper, we use a low-cost analog filter to reduce static interference noise from incandescent and fluorescent light. To reduce ambient light, we use manually configurable analog DC-offset adjuster. According to the experiment result, the design is able to perform well in reducing these noise sources.

**Keywords**: Visible Light Communication; analog filter; ambient light noise; optical interference noise

## 1. Introduction

In Visible Light Communication (VLC) system, photodetector device that is commonly used in the system is photodiode **[1]**, which combined with Op Amp (as a trans-impedance amplifier to convert current to voltage) **[2]**. We have observed in our previous research **[3]** that LED not only transmitting information signal but also carrying DC signal as shown in Fig. 1(a). The photodiode also receiving DC signal which comes from ambient light (environment light). This DC component needs to be eliminated because it can make the information signal clipped (saturation in receiver Op Amp) such as illustrated in Fig. 1(b).

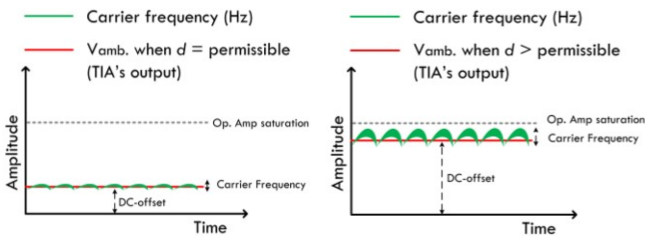



**(a)** **(b)**

Fig 1. (a) TIA output voltage ($V_{TIA}$) vs *ambient light* effect from LED sources; (b) $V_{TIA}$ towards ambient light from other ambient light sources (i.e. flashlight, DC lamp, sunlight or background light)

Interference lamp, such as incandescent and fluorescent lamp, not only carrying DC signal but also carrier signal with a certain frequency such as illustrated in Fig. 2(a). The shorter the distance of photodiode to the interference lamp, the larger the DC component and amplitude of noise.

The signal which carried by the DC lamp and also interference lamp must be eliminated because it can increase bit-error rate (BER) which degrades the VLC system performances.




**(a)** **(b)**

Fig 2. Interference optical noise characteristics which come from fluorescent: (a) $V_{TIA}$ when interference lamp on the permissible of distance; (b) $V_{TIA}$ when the distance of interference lamp to the VLC system is closer

Methods that can be used to reduce both of these noises can be based on analog or digital, such as done by *Y. Zhao, et al.* by using adaptive minimum-voltage detector. Their experiment can eliminate DC component which comes from direct sunlight and based on OOK modulation **[4]**. Later, *K. Sindhubala*, *et al.* uses dual solar cell. The first solar cell is used to receiving the data and the second solar cell is used to receive the DC component which then connected to the differential amplifier so that the resulted output voltage is information signal without DC **[5]**. Using similar method, *M.R. Alam et al.* also using the dual solar panel as receiver and DC component producer from LED and ambient light, where the circuit is connected as a voltage divider and without signal processing (Op. Amp component) **[6]**. The use of solar panel is improper for high-speed application. The three mentioned researches is based on analog circuit, meanwhile *Edirisnghe, et al* uses the same topology with an addition of 'ambient noise cancellation' on DSP **[7]**. Whereas, *S. Verma, et al.* only proposed a model to reduce ambient light source, and doesn't explain the verification of the experiment by simulation or real implementation **[8]**.

Then, researchers to reduce interference lamp is done by *V.G. Ya´nez, et al.* that proposed adaptive filtering techniques **[9]** and *S. Yin, et al.* also proposed adaptive cancellation algorithm **[10]**. Both of those methods are refined by *C.W. Chow, et. al.* who use Manchester coding in LED sources, this technique is without adaptive monitoring, feedback, or optical filtering **[11]**. *Y.F. Liu, et al.* proposed Non-return-to-zero inverted (NRZI) coding and able to effectively reduce the optical interference in a low-frequency band from DC to over 200 kHz **[12]**. This four experiment is done by using the digital domain, whereas by using an analog domain, we proposed high pass filter circuit with the cut-off frequency of 10 Hz to reduce DC ambient light and band stop filter with 100 Hz cut-off frequency to reduce static fluorescent interference. The result of this experiment shows that the filter circuit can reduce BER, verified by using various modulation (BPSK, QPSK, PWM1, and PWM2). But, this experiment is limited by only using interferences of LED and fluorescent lamp **[13]**. In the next research, we also propose analog high pass filter with $f_c$= 1 kHz to reduce all of the optical interference (including incandescent) and has been verified through simulation **[14]**. But the lack of this system is the attenuated frequency is too wide (until 1 kHz) which also eliminated bandwidth that is used for communication

The color filter can also be used to reduces the noise of lamp interferences, such as done by *C-C. Chang, et al.* **[15]** and *S.-H. Yang, et al.* **[16]**. But, *J-Y. Sung, et al.* **[17]** recommended the color filter (especially blue filter) to not be used in VLC system which uses multilevel modulation, such as OFDM and DMT because it can reduce the SNR of the information signal. This statement is also proven by the experiment which is done in **[18]** and **[19]**.

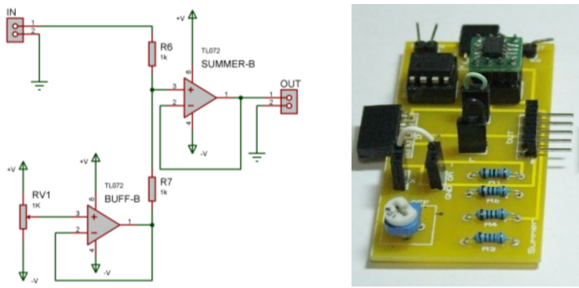
In this paper, we use analog domain approach in designing a high-pass filter to reduce the signal interferences from incandescent and fluorescent which is set to be static at a certain distance. This paper is divided into five parts, first is the introduction. Second is filtering circuit design which consists of DC offset remover and analog high-pass filter circuit. The third is testing and analysis and fourth is the conclusion.

## 2. Filtering Circuit Design

### 2.1. DC offset Remover

For this case, there is three option: **First** is by using a blocking capacitor ($C_b$) which is placed between pre-amp input and TIA output. This option is ineffective because it delays the information signal (caused by an effect of capacitor filling of the DC signal) and unstable (caused by draining the capacitor). the **second** is by using a differential amplifier to reduce the DC using voltage at V+. The **third** is by using summing amplifier to increase the DC with V- so that the output voltage will be 0 Volt. In this research, we use the third option because by placing inverted photodiode (reverse bias), DC remover module can be implemented by adding V+. So the polarity of the photodiode is not affecting the VLC system performances.

DC-offset adjuster circuit that can be tuned manually, consisted of buffer Op. Amp and summing amplifier as shown in Fig. 3(a) which is supplied by negative voltage. Then implementation into PCB packaging is shown in Fig. 3(b) based double layer printing. The testing experiment of the DC-offset remover will be discussed in section III, where the circuit has been connected with the filter.



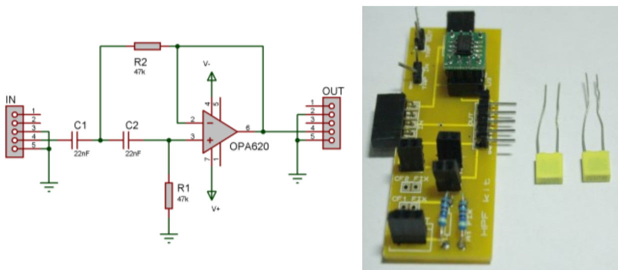

**(a)** **(b)**

Fig 3. DC offset remover circuit: (a) Circuit schematic; (b) PCB implementation (33.32 mm x 62.56 mm)

### 2.1. Sallen Key High-Pass Filter Circuit

As has been explained in the introduction, that ambient light of the interference lamp caused the TIA circuit to generated the DC output voltage with a certain level, that can be eliminated by using summing amplifier circuit by adding the minus voltage (-). But without a filter, the output voltage still contains noise. From the previous experiment, can be known that color filter is ineffective to be used because only reducing the noise. Thus, we implement the analog filter circuit at AFE receiver.

We use high-pass filter Butterworth type with Sallen-key configuration to attenuates the frequency below 150 Hz. This topology is chosen because it provides high Q value even with simple components design. Design parameter of this high pass filter is frequency *cut-off* ($f_c$) = 150 Hz. High-pass filter Sallen-key circuit is shown in Fig. 4(a) and implementation in PCB is shown in Fig. 4(b).




**(a)** **(b)**

Fig 4. The Sallen-key high pass filter: (a) Circuit schematic; (b) PCB implementation (26.75mm x 62.65mm)

To simplify the design, we set the value of R3 = R4 = R and C1 = C2 = C = 22 nF, so the value of R can be calculated using equation (1) then we obtain the value of R = 47 KΩ.

$$f_c = \frac{1}{2\pi RC};\; R = \frac{1}{2\pi\, f_c\, C}; \qquad (1)$$

### 3. Results and Analysis

The measurement of the frequency response is by giving the input signal with varying amplitude (0.5 $V_{pp}$, 1 $V_{pp}$, 1.5 $V_{pp}$ and 2 $V_{pp}$) and frequency from 50 Hz to 525 Hz. Results are shown in Fig. 5 shows that frequency below 150 Hz can be attenuated, which proves the designed analog filter by the simulation and real implementation is able to works as designed.

Next, we do the functional testing of a proposed circuit where the output of TIA circuit is connected into summing amplifier circuit and analog filter. Then on the three output, the signal characteristic is compared.

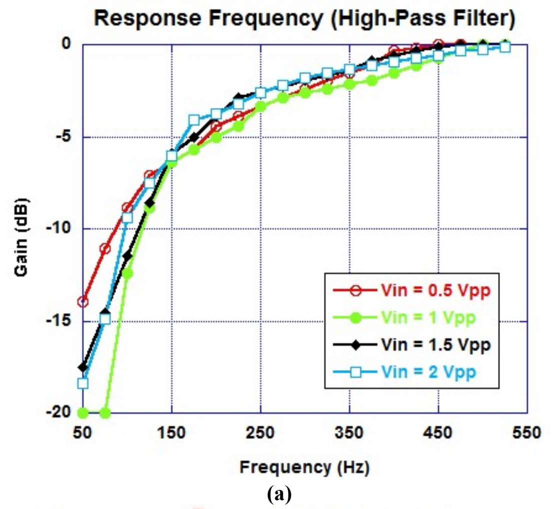



Fig 5. Frequency response of the *Sallen-key high pass filter* module: (a) real implementation; (b) simulation

Fig. 6(a) shows the interference signal from the incandescent lamp (yellow) at distance of 50 cm and the output signal at summing amplifier (blue). Then, on Fig. 6(b) is the output signal of the pre-amp (yellow) with a high-pass filter (blue) on the oscilloscope. Whereas Fig. 6(c) shows the signal characteristics which is shown by frequency analyzer (R&S FSQ ROHDE & SCHWARZ®) at the output of summing amplifier and high-pass filter shown in Fig. 6(d).

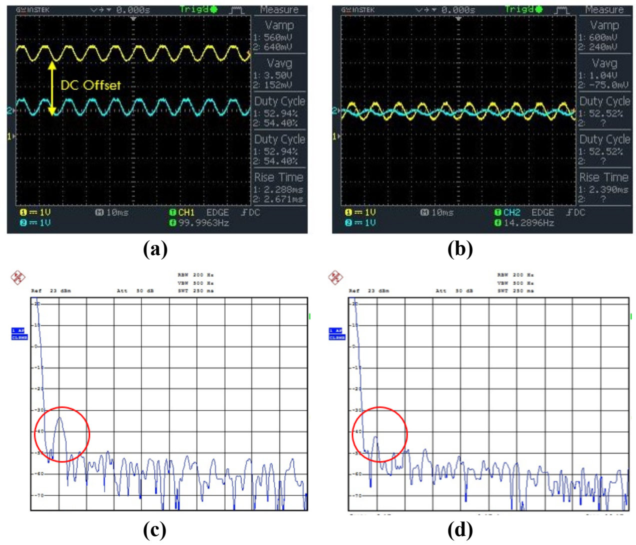



Fig 6. Captured signal from oscilloscope and spectrum analyzer of the output of the AFE receiver circuit with incandescent lamp at the distance of 35 cm: (a) TIA vs *Summing amplifier*; (b) *Pre-Amp* vs *high-pass filter*; (c) *summing amplifier* output signal spectrum; (d) *high pass filter* output signal spectrum

Fig. 7(a) shows the interference signal from the fluorescent lamp (yellow) at the distance of 35 cm and the output signal of the summing amplifier (blue). Then Fig. 7(b), shows the output of the TIA (yellow) with a high-pass filter (blue) on the oscilloscope. Whereas Fig. 7(c) shows the characteristics of the signal as shown by the frequency analyzer at the output of the summing amplifier and high-pass filter is shown in Fig. 7(d).

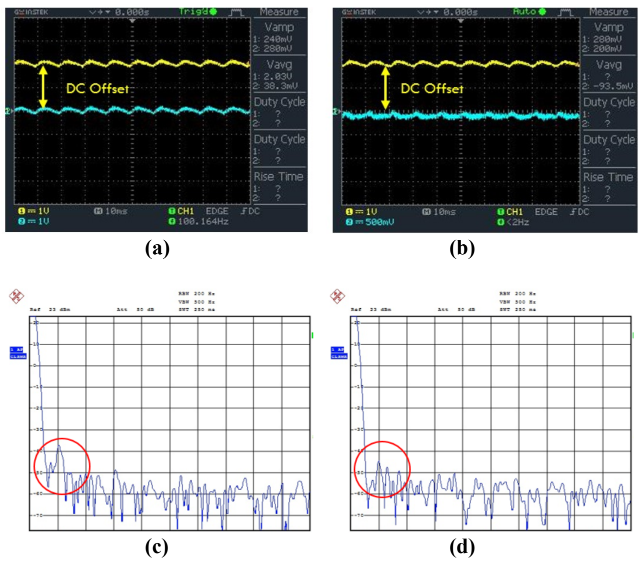



Fig 7. Captured signal from oscilloscope and spectrum analyzer at the output of the AFE receiver circuit with fluorescent lamp at the distance of 20cm: (a) TIA vs *Summing amplifier*; (b) *Pre-Amp* vs *high-pass filter*; *summing amplifier* output signal spectrum; (d) *high pass filter* output signal spectrum

## 4. Conclusion

Based on observation, we can conclude that the analog filter can work properly as expected, by attenuating the frequency below 150 Hz which is carrier frequency of the incandescent and fluorescent lamp. Then, DC-offset remover which uses the summing amplifier configuration is able to eliminate the DC signal from the ambient light. The color filter is slightly able in reducing the signal-to-noise ratio (SNR) of the interference lamp.

In the next research, we will use digital system to analyze the analog filter performance against BER using OFDM modulated signal: (1) interference lamp (fluorescent and incandescent) distance vs BER; (2) analog front-end receiver characteristics with and without analog filter against BER at certain distances; (3) ambient light sources (DC lamp) distance vs BER; and (4) analog front-end receiver characteristics with and without DC offset adjuster against BER at certain distances.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