Noise and Bandwidth in Operational Amplifiers for Conventional TIAs used in Visible Light Communication

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Syifaul Fuada(✉), Trio Adiono
Institut Teknologi Bandung, Indonesia
syifaulfuada@pme.itb.ac.id

Abstract—Transimpedance amplifiers play an essential role in the physical layer of visible light communication systems. They are applied in the first stage of a visible light communication receiver. This short paper is a follow-up from a previous study about the bandwidth and noise of Op-Amp based transimpedance amplifier as used in visible light communication systems through two approaches: calculation and simulation. The results of both calculation and simulation are then compared through several scenarios. In this study, the Orozco approach is used as a fundamental reference in calculating the transimpedance amplifier's bandwidth and noise. Whereas for simulation, we used TINATM-SPICE®.

Keywords—Bandwidth, Noise, Op-Amp, Transimpedance amplifier, VLC

1 Introduction

There has been a rapid increase in the number of scientific documents (papers, dissertations, thesis, patents, etc.) of the visible light communication (VLC) topic around the globe. This is mainly because of the growing interest in this research area over the last decade [1]. The VLC research topic itself can be divided into several focuses such as the following points which we conducted at the University Center of Excellence on Microelectronics, Institut Teknologi Bandung, Indonesia.

- Modulation development for VLC system: Using PWM [2-5], PPM [6], BPSK [7-8], QPSK [9], QAM [10], etc.
- Analog signal processing (ASP): Circuit design [11-13], analog filter [14-15], AGC [16-17], LED driver [18-22], high-bandwidth TIA [23], etc.
- Noise investigation in VLC system: Internal noise [24-26] & external noise [27];
- DSP focus: Prototyping of DSP [28], Viterbi encoder [29-30], VLC based SoC [31-33], etc.;
- Modeling and Simulation [34];
- Selecting components methodology for a low cost custom-build VLC system [35-37];
- The applications: Medical concerned [38-39], multimedia transmission [40-43], Li-Fi [44], for education [1], etc.

- Security in VLC [45]; and
- Others [46-50].

When designing a high-speed or low-speed VLC system for many applications employing commercially available electronics components (low-cost custom- built VLC), we must consider several problems. One of them is a noise that comes from the external source (such as background light or an optical interference noise) as well as an internal factor generated by electronic circuits.

In this paper, we will discuss the third topic, VLC noise, specially sourced from an internal factor such as Transimpedance amplifier (TIA) noise. The motivation of this study is to continue our previous work [26] wherein, only a mathematical approach was used for investigating the integrated circuit (IC) with higher and lower amounts of current density (In) and voltage noise density (en) to the various types of TIA's noise. In case [26], we use IC Op-Amp OPA656 and AD8011AN, then we compare the voltage noises (NV), current noises (NC), feedback resistor noises (NRF) and total noises (NTot.) among others.

The result of [26] is ideal with the values of noise densities being within the Op-Amp which highly influence the higher noise levels in the optical wireless communication (OWC) receiver system, especially the VLC. Thus, we were very eager to extend our previous work [26] by utilizing a simulator tool (TINATM-SPICE® software) and compare the results of a simulation-based system to a mathematical calculation-based one for noise analysis purposes. In this extended study, we employed an IC OPA656 as the primary material and OPA620KP to substitute the AD8011AN, due to the TINATM- SPICE®, only to accommodate the Op-Amps model from Texas Instruments.

Different with [26] that analyzed NV, NC, NRF, and NTot to the Gain Bandwidth Product (GBW), this study will investigate the GBW against cut-off frequency (f-3dB) & f-3dB against NTot in the calculation approach only. Then we will compare the GBW to the NTot in calculation and simulation as well.

2 Methodology

2.1 TIA Model

Following the reference of [26], we still use a conventional TIA circuit with photovoltaic configuration which is a zero bias operation [51]. The circuit itself consists of a single Op-Amp, Rf, feedback capacitor (Cf), and single photodiode. To simulate the bandwidth and noise present in the TIA circuit, firstly, the TIA must be modeled as illustrated in Fig. 1. The Op-Amp has an intrinsic capacitance, namely input capacitor (Cin) as commonly mentioned in its datasheet, while the internal capacitance of the photodiode can be called as photodiode's shunt capacitance (Csh), which is also known as a junction capacitor (Cj).

According to an article of [52], the TIA circuit in the OWC receiver has three noises: NV, NC, and NRF , all of them can be combined as NTot by the root-sum- square (RSS) approach.

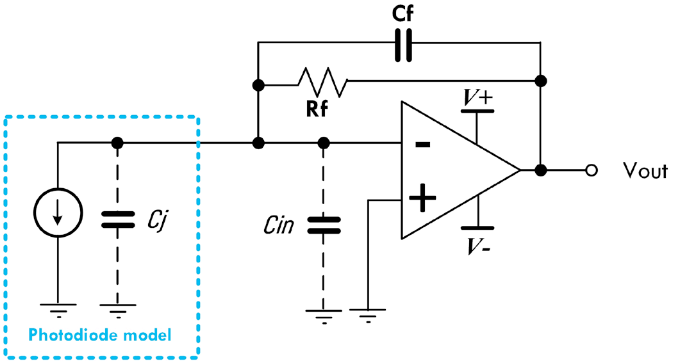


Fig. 1. TIA model, the figure is reproduced version from the original article at [26], [53]

2.2 Mathematical Calculation

The manual calculation must be done before performing a measurement using a simulator. In [54] the formula derivation of the TIA photo receiver model's ability to analyze the internal noises in detail is exemplified. We used the approach from [52] to calculate the value of f-3dB and total noise in order to match our previous work [26]. The total noise can be calculated by 'RSS calculation' of three types of noises as elaborated in Eq. 1, while to obtain TIA's bandwidth can be solved by Eq. 2.

$$N_{Total} = \sqrt{N^2_{Resistor-feedback} + N^2_{current} + N^2_{voltage}} \tag{1}$$

$$f_{-3dB} = \sqrt{\frac{f_{GBP}}{2\pi * R_f * (C_{in} + C_j)}} \tag{2}$$

Where,

$$N_{Resistor\text{-}feedback} = \sqrt{4kT * ENBW * Rf}$$

$$N_{current} = I_n * R_f * \sqrt{ENBW}$$

$$ENBW = f_{-3db} * \frac{\pi}{2}$$

$$N_{Voltage} = e_n\left(\frac{C_{in} + C_j + C_f}{C_f}\right) * \sqrt{\frac{\pi}{2} * \left(\frac{C_f}{C_{in} + C_j + C_f}\right) * f_{GBW}}$$

$$C_f = \sqrt{\frac{C_J + C_{in}}{2\pi * R_f * fGBW}}$$

Note that,

ENBW : Equivalent noise bandwidth [Hz]

f_{GBW} : Frequency of gain bandwidth product [Hz]

T : Temperature [K]

k : Boltzmann's constant = 1.38 × 10−23 [J/K]

2.3 Noise and Bandwidth Simulation

As stated in the introduction, we employed two Op-Amps IC for this study, OPA620KP and OPA656, because each has a significant difference in noise density value as shown in Table 1. Fig. 2 depicts the configuration in a simulator tool where it was used for an overall investigations objective. Similar to [26], we employed a photodiode that has 3.4 pF of Cj and Rf = 8 kΩ.

Table 1. Parameters of the Op-Amp used

Op-Amp	Cj	Cin	Voltage gain (dB)	GBP (MHz)	en (nV/√Hz)	In (fA/√Hz)
OPA656	3.4 pF	3.5 pF	65	230	7	1.3
OPA620KP	3.4 pF	1	60	200	2.3	2300

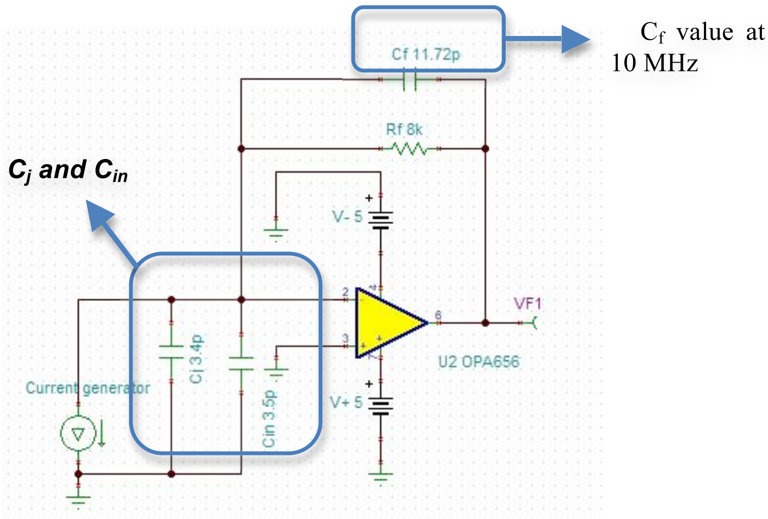
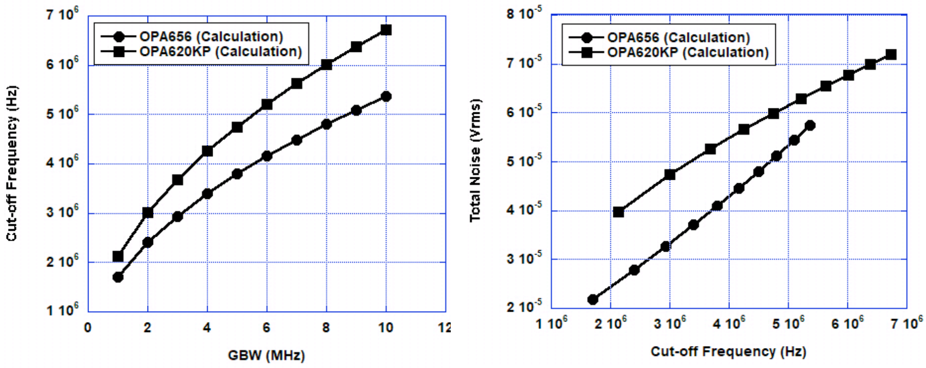


Fig. 2. TIA circuit in TINA™-SPICE® in OPA656 simulation case

3 Results

Fig. 3(a) shows the graph of the GBW (1 – 10 MHz) to the f_{-3dB} in calculation approach, the bandwidth OPA620KP is higher than OPA656 because its C_{in} and e_n are less than OPA620KP. Fig. 3(b) depicts the graph of the f_{-3dB} to the N_{tot} that is also in calculation approach because it is difficult to simulate in TINA™-SPICE®. The OPA656 has lower N_{tot} compared to OPA620KP. Based on the two graphs, it can be assumed early that the higher the GBW, the higher the N_{tot}, or vice versa.

To verify the assumption (hypothesis), we specialize the comparison of GBW against N_{tot}. For this investigation, the simulator tool was included. It can be seen in Fig. 4 that the hypothesis is proven correct. However, the simulation results look lower than calculation both for OPA620KP and OPA656, possibly due to the fact that approach parameters in TINA™-SPICE® are not same as the approach of [54] in which the reference [54] is only for Analog Devices Inc model. For gaining the optimum results of the noise and bandwidth simulation, it is recommended to use software from Analog Devices instead of TINA™-SPICE®.



(a) (b)

Note:
f_{-3dB} is calculated using Eq. 2
N_{tot} is calculated using Eq. 1

Fig. 3. Comparison results of OPA620KP to OPA656 for different parameter: (a) GBW against f-3dB; (b) f-3dB against NTot

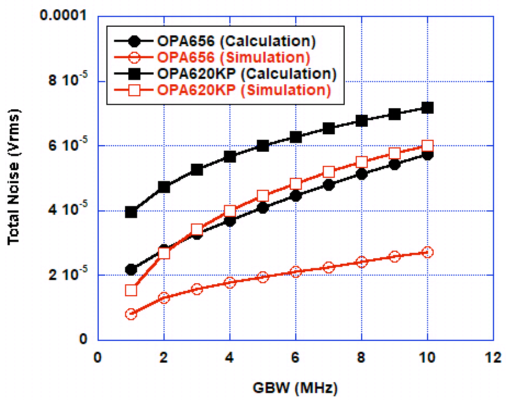


Fig. 4. Comparison results using mathematical calculation and simulation approach to investigate the GBW against NTot of the two Op-Amps

4 Conclusion

The TIA's bandwidth and its noise are investigated in this paper by using the calculation approach from *Orozco's* model [58] and simulator (TINA^{TM}-SPICE® from Texas Instruments). Although there is a difference between the results of simulation and calculation, the range of its variation is not too high because in units of µV (means is still intolerable). The N_{Tot} is lower than OPA656, though the OPA620 has a more significant I_n value than OPA656. In all, it can be concluded that the higher C_{in} and en, the larger is the bandwidth and higher will be the noise.

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7 Authors

Syifaul Fuada is affiliated with the IC Design Laboratory, University Center of Excellence on Microelectronics (syifaulfuada@pme.itb.ac.id). Jln. Tamansari No. 126, Gd. PAU Lt. IV, ITB Campus, Bandung city, 40116, Indonesia.

Trio Adiono is affiliated with the IC Design Laboratory, University Center of Excellence on Microelectronics and School of Electrical Engineering and Informatics, Institut Teknologi Bandung (tadiono@stei.itb.ac.id). Jln. Ganesha No. 10, Bandung city, 40132, Indonesia.

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