Characterization of transimpedance amplifier as optical to electrical converter on designing optical instrumentation

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Abstract. Optical to electrical converter is the main components for designing of the optical instrumentations. In addition, this component is also used as signal conditioning. This component usually consists of a photo detector and amplifier. In this paper, characteristics of commercial amplifiers from Thorlabs PDA50B-EC has been observed. The experiment was conducted by diode laser with power of -5 dBm and wavelength 1310 nm; the optical attenuator to vary optical power from 0 to 60 dB, optical to electrical converter from Thorlabs Amplifier PDA50B-EC; multimode optical fiber to guide the laser; and digital voltmeter to measure the output of converter. The results of the characterization indicate that each channel amplification has a non-linear correlation between optical and electrical parameter; optical conversion measurement range of 20-23 dB to full scale; and different measurement coverage area. If this converter will be used as a part component of optical instrumentation so it should be adjusted suitably with the optical power source. Then, because of the correlation equation is not linear so calculation to determine the interpretation also should be considered in addition to the transfer function of the optical sensor.

1. Introduction

Recently, developments in Optoelectronics have been growing very rapidly. At the end of this decade, Optoelectronics was not only dominated by optical fiber for telecommunications, but it was also found in other fields such as health equipment[1–3], material processing[4], and measurement instrumentation. As mentioned at the last, i.e. measurement instrumentations field was found by using optical fiber as sensors for weight of vehicles [5–8], structural health monitoring[9], [10], geotechnical monitoring [11], [12], oil and gas monitoring[13], and other strategic necessity. The use of optical fiber as sensors has several advantages such as resistance to electromagnetic interferences, small size and light weight, small power, high sensitivity, wide bandwidth transmission as well as more resistant to the dangerous area. Besides optical fiber as a well-known chosen sensors in instrumentation-based on optoelectronics, one of the important component in these fields is an optical-electrical converters. These converters can use various kinds that have developed in the marketplace or
research. One kind which is well-known in optoelectronics is transimpedance amplifier[14], usually also called a high-impedance amplifier.

This type of converter is quite good in optical instrumentation, especially in terms of sensor readings that is based on the amplitude because it has a small noise and has been proportionally changing [15].

In this paper, measurements using amplifier from PDA50B-EC Amplifier from Thorlabs has been conducted in the laboratory. This amplifier is a commercial amplifier that is available in the marketplace. The purpose of this paper is to determine for characteristics of the amplifier in order to this amplifier that will be used for electrical optic converters in the design of optical instrumentation. On the other hand, these characteristics also can be used for the development of further amplifiers in order to have better characteristics because of rapid development and complex requirement in the field of optoelectronics.

2. Experiment
The main important component of the optical to electrical converter is a photodiode. The photodiode is a semiconductor element that is sensitive to light energy so as to change it in the form of an electric current. When the energy of the light is greater than the energy band gap in the photodiode (ie., hν > = Eg), it excites the electrons at the valence band to the conduction band. This vacancy of electron creates hole resulting in flow of electricity that is called the photocurrent. The magnitude of the photocurrent can be expressed by the following equation:

\[ I_p = \frac{P_{in} (1-R)e}{h\nu} \left[ 1 - \exp(-\alpha d) \right] \] (1)

Where is the photocurrent produced by photodiode, \( P_{in} \) = total optical power entering photodiode, \( R \) = fresnell reflection coefficient at the air-semiconductor, \( e \) is electron charge, \( h \) = Plank’s constant, \( \nu \) = frequency of the incoming light, \( \alpha \) = absorption coefficient of the semiconductor at the incident wavelength, and \( d \) is the width of the absorption region[16].

A photodiode can be operated in one of two modes: photovoltaic (zero-bias) or photoconductive (reverse bias). The photovoltaic method can be seen at Figure 1. The characteristic of a current source is that its voltage must be determined by other elements in the circuit. Thus, as shown in Figure 1, if the photodiode is connected to a load resistance of RL, the output voltage of the circuit is given by:

\[ V = P \rho R_L \] (2)

Where \( V \) is the output voltage, \( \rho \) is responsivity of photodiode in the selected wavelength of optical source, and RL is resistance of load in this circuit. This equation is valid as long as \( V < V_S \). Figure 1 shows the simplest way to bias a PIN diode to convert the optical signal into a voltage signal.

![Figure 1. Photovoltaic mode of optical to electrical converter[17]](image)
The other one is photoconductive mode using operational amplifier for the optical to electrical converting like the Figure 2. The measured output current is linearly proportional to the input optical power. The photodiode is reversed biased, thus improving the bandwidth while lowering the junction capacitance. The gain of the detector is dependent on the feedback element (RD)[17][18].

![Figure 2. Photoconductive mode of optical to electrical converter][18]

Experiment have been conducted using a laser diode, optical attenuator from Attenuator HP 8156A, Thorlabs Amplifier PDA50B-EC [19], and digital multimeter. Some modules are arranged as shown in Figure 3. The diode laser used to have a wavelength of 1310 nm and an optical power of -5 dBm. The beam of the laser was connected to the multimode optical fiber cable. The variation of the optical power was obtain by pressing to attenuation button from 0 to 60 that has been provided by the this attenuator. Then, the output from attenuator was connected with Thorlabs Amplifier at the photodiode with optical fiber cable too. Measurement results in electrical voltage were measured through a digital multimeter.

![Figure 3. Set up experiment](image)

Thorlabs Amplifer used in this experiment has eight kinds of gain or amplification as shown at the Table 1. These experiments also have used 12 V from DC power supply. Experiments on each gain channel from Amplifier have been done by providing optical power.

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[18]: http://example.com/figure2.png

[19]: http://example.com/figure3.png
attenuation from 0 to 60 dB. The results of the measurement show in the graph to know characterization of Thorlabs amplifier.

Table 1. Addressing of gain channel for Thorlabs Amplifier PDA50B-EC

| Channel | Gain/Amplification (dB) |
|---------|-------------------------|
| 1       | 0                       |
| 2       | 10                      |
| 3       | 20                      |
| 4       | 30                      |
| 5       | 40                      |
| 6       | 50                      |
| 7       | 60                      |
| 8       | 70                      |

3. Discussion

The experimental results are shown in Figure 4. According to this figure, there are some performance indications of each channel gain/amplification. Generally, all of the correlation between optical and electrical showed non-linearly and approached exponentially. Regarding to Equation 1, relation between optical power and current also produced exponentially. On the other hand, the voltage have linear correlation with photocurrent on the transimpedance amplifier circuit. Thus, it should be a non-linear relationship between optical power and voltage like the Figure 4.

![Figure 4. Result of Thorlabs Amplifier PDA50B-EC characterization](image)

Channels 5 to 8 have saturation area, that is closer to the power supply voltage. Consequently, this area causes no conversion from optical power into electrical because of no output changing. At channel 5, saturation occurs when the optical power was attenuated less than 9 dB. Because of the experiments using the diode laser of -5 dBm so it’s saturation was obtained around -14 dBm. In addition, when the optical power is greater than -14 dBm, saturation will occur for this channel. In the same way, it will be determined for other channel.
For instance, channel 6 reached out saturation when optical power is higher than -17 dB; channel 7 when reached out higher than -21 dB, and then channel 8 is higher than -27 dB.

Whereas, output of amplifier has reached out around 0 at any conditions. This conditions also cannot be used in the optical instrumentation because it also causes no conversion from optical into electrical parameter. Each channel from Thorlabs Amplifier PDA50B-EC has this area as shown the Table 2.

| Channel | Optical power made too low output (dBm) |
|---------|----------------------------------------|
| 1       | < -13                                  |
| 2       | < -18                                  |
| 3       | < -23                                  |
| 4       | < -27                                  |
| 5       | < -33                                  |
| 6       | < -37                                  |
| 7       | < -43                                  |
| 8       | < -50                                  |

For optical instrumentation purposes, characteristics of amplifier are very important to be selected. It caused disadvantages including a short-range, sensitivity is too small, and even too big sensitivity if the characteristic is obeyed. In terms of sensitivity and dynamic range, the amplifier has been chosen in area neither saturation nor close to zero output. Thus, if Thorlabs Amplifier PDA50B-EC is used, areas should be noticed as shown as Table 3. In addition, the values shown in the Table 3 are also coverage of readout that can be converted properly. Generally, each channel has a dynamic range of 20 to 23 dB. The channels 1-3 are less than 20 dB because of the limitations of the optical power used in the experiment. Basically, if it is considered 20 dB dynamic range so channel 1 can be used up to 7 dBm, channel 2 up to 2 dBm, and channel 3 can be used up to -2 dBm.

| Channel | Optical power (dBm) | Dynamic range (dB) |
|---------|---------------------|--------------------|
| 1       | -13 to -5           | 8                  |
| 2       | -18 to -5           | 13                 |
| 3       | -23 to -5           | 18                 |
| 4       | -27 to -5           | 22                 |
| 5       | -33 to -12          | 21                 |
| 6       | -37 to -17          | 20                 |
| 7       | -43 to -21          | 22                 |
| 8       | -50 to -27          | 23                 |

4. Conclusion
In optical instrumentation, characteristic of the amplifier is needed to be used for appropriate purposes. The range output from the optical-based sensors must be adapted to the characteristics of the amplifier as described above. The right choice of amplifier characteristics and output sensor can contribute to the measurement accuracy, especially in the field of optics so it should be adjusted suitably with the optical power source. Then, because the correlation equation is not linear so calculation to determine the interpretation also should be noticed beside of the transfer function of the optical sensor.
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