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OPTICAL TOMOGARAPHY: TRANSMITTER AND RECEIVER CIRCUIT PREPARATION

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Abstract. This paper focuses on the factors that need to be considered while making the decision for transmitter, receiver and other parts that are needed in the preparation for the optical tomography circuit. The major discussion is on the selection of transmitter and receiver's sensor, operational amplifier, and the arrangement of components in the circuit. This paper provides guidance on how to select the appropriate component and rearrange them to construct a good and functional circuit.

Keywords: Transmitter; receiver; operational amplifier; optical tomography

Abstrak. Kertas kerja ini memfokuskan faktor yang memberi kesan kepada pemilihan penghantar dan penerima dan bahagian-bahagian lain untuk persediaan bagi litar optikal tomografi. Perbincangan major adalah pemilihan sensor penghantar dan penerima, operational amplifier dan penyusunan komponen di dalam litar. Kertas kerja ini menyediakan panduan tentang bagaimana untuk memilih komponen yang sesuai dan menyusunnya untuk membina litar yang baik dan berfungsi.

Kata kunci: Penghantar; penerima; penguat pengoperasian; tomografi optik

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1.0 INTRODUCTION

Sensor plays an important role in the effectiveness of a tomography system. Here the sensor will be applied to an optical tomography system. Optical tomography system is one of the techniques used to visualize what is inside the vessel whereas visualization has become one of the important tools to monitor the state of material inside the enclosed vessel. In addition, this technique allows a crucial measurement which is the mass flow rate monitoring in industrial processes. By having the ability to visualize the enclosed area of the vessel, the troubleshooting process for the system could be easier. The previous researches [1-11] have been successfully developing optical tomography system. The selection of sensor had been done carefully and most of them claimed that the low cost sensor was more acceptable rather than high cost sensor. Some of them also concerned about the angle of half intensity while some focused on wavelength compatibility for transmitter and receiver.

Generally, sensors that are used in optical tomography called the optoelectronic sensor. There are many selections for transmitter and receiver. For transmitter, users can choose LED, infrared or laser source. And for receiver the common selection are photodiode and phototransistor. This paper introduces many types of transmitters and receivers that are used in optical tomography.

2.0 TRANSMITTER

For transmitter, variety of light sources whether visible light or invisible light can be selected according to the designed system requirement. For visible light, the wavelength is the same as the wavelength of a light bulb or any light which is 380-750 nm which this light can be seen by the human eye. The disadvantage of using this light is that the system cannot distinguish between the true light or the ambient visible light which will lower the system's performance, but the advantage is that it is easy to construct the system because we can detect whether the transmitter and emitter is in alignment. Therefore, the probability to make mistake is less than using invisible light.

For invisible light, the wavelength is out of the range of the visible light and this will make the detection of receiver becomes faster and accurate since the visible light would not interrupt the communication process between the emitter and receiver. As the light cannot be seen by human being therefore the handling procedure can be difficult when doing the experiment. Examples of sensors that have invisible light are infrared and laser. The wavelength for infrared is longer than visible light (400-700 nm) but less than terahertz radiation (100 μm – 1 mm) and microwave (~30,000 μm) [12]. This makes infrared sensors widely selected in many research. Table 1 shows the simplicify of the advantages and disadvantages between visible and invisible light.

Table 1 Advantages and disadvantage between visible and invisible light

Type of light source	Advantages	Disadvantages
1. Visible light	The light can be seen by human eyes and easy to construct the experiment.	Cannot distinguish between true and visible light and this will create a noise in the output therefore, lower down the system performance
2. Invisible light	Wavelength is outside of the visible light and this can make the detection of receiver become faster. This will increase the performance	Light cannot be seen and difficult to setup the experiment.

Besides, the types of packaging have always been compared whether to choose between plastic or metal packaging. For plastic packaging it offers advantages in cost, output power, reliability, power dissipation and optical quality [14]. The cost for plastic package is lower because the reduction in labour and material cost. For output power, plastic package have 40% more output power than metal packaging. The reasons are the headers of metal LED allow some of the chip's output power to be radiated into the opaque wall of the package. Much of this radiation is absorbed before it can escape through the lens due to the unperfected of reflectivity at the surface. The second reason is that this type of LED has two surfaces of air and glass and some of the optical radiation which does reach the lens is reflected back into the package and absorbed.

For power dissipation rating, plastic package also gives a better performance compared to metal. Power dissipation is a function of its thermal impedance, which means the ability of the package to get rid of heat generated by the chip. Plastic package are used in a socket or soldered in a PC board and this result in a thermal impedance situated between the maximum values of heat sink and no heat sink. The heat sinks for plastic package are provided by the socket or PC board and leads. The leads have a larger cross sectional area and are made from a more thermally conductive material; the thermal part of the plastic package is normally about 40% better than metal package. Although the metal part has equal infinite heat sink, it is rarely used, therefore the plastic package usually offers better thermal performance. After we discussed the advantages of plastic package compared to metal, we will look at other side of selection.

The parameter that is stated on the datasheet will influence the performance of a transmitter. There are several criteria that need to be looking into, such as:

(i) Forward voltage
(ii) Radiant intensity
(iii) Switching time
(iv) Wavelength Selection

First is the forward voltage which is the voltage that allows current to flow. A lower voltage is better because an LED requires less voltage to allow current to flow. In addition, low and stable forward voltage for example 1.45 V at 100 mA and 2.1 V at 1 A, provides the basis for very uniform operation performance, especially in a series circuit layout [14]. The lower forward voltage is suitable for high pulse current operation [15] therefore, this criteria is suitable for fan beam projection in optical tomography.

The second parameter that is always taken into consideration is radiant intensity. Radiant intensity is a quantitative expression of the brilliance of a source of electromagnetic (EM) energy over the entire electromagnetic spectrum. It is measured in terms of the power emitted per unit solid angle. The standard unit is the watt per steradian (W/sr). An article by Vishay Intertechnology Inc. on 2008, had stated that the company managed to double the radiant intensity in its new IR emitter product, TSAL6100X01 which is 130 mW at 100 mA [15]. Otherwise, this product use GaAIAs on GaAs technology, therefore emitters can produce more than 100% radiant power when compared to standard emitters at same wavelength. Therefore, the higher the radiant intensity is the better the performance as mention from Vishay Intertechnology Inc.

The third important parameter that must be considered is the switching time that determine whether the emitter can operate in high speed or not. The highest value of speed mentioned by Vishay is in nanosecond. For example IR emitter, VSLB3940 that can support data rates up to 30 Mbps for switching times equal to 15 ns [16]. This parameter should be considered if the mode of projection in optical tomography is in fan beam mode every transmitter has to be switched with a fast switching time.

The forth criteria is the angle of half intensity. For tomographic application that needs very accurate and narrow projecting of light, small projection angle optical source is needed. The smallest angle that can be offered by Vishay company is below 5°. As for parallel beam mode projection, small projection angle or narrow angle projection is needed to avoid the signal interfere to the adjacent receiver.

The fifth factor is power dissipation of the transmitter which can be considered as the most critical consideration in emitter selection [17]. The higher power dissipation gives higher luminous output, therefore giving greater heat dissipation and higher cost. We also can get this value by multiplying the maximum forward current rating by the maximum forward voltage rating. In optical tomography, this parameter is important as the solid particles will be dropped continuously; therefore higher power dissipation is needed to monitor the dropped object.

Lastly is the wavelength selection. In order to avoid interference from visible light source to the tomography process, invisible light source is one of the clear options. By choosing the range of wavelength that is out of visible light range for example infrared emitter, noise from visible light source can be eliminated. The work that reported by Goh [18], Pang [19] and Chiam [20] used the wavelength in the invisible light.

3.0 RECEIVER

The selection of receiver is more difficult and limited compared to emitter as the receiver needs to follow all the requirement of the transmitter. There are many factors to be considered especially on the compatibility of the receiver and the selected emitter. The easiest way is to follow the guidelines from the manufacturer for both receiver and emitter. However, sometimes it has other constraints that need to be considered when constructing the circuit. Hence, the selection of the receiver must be done carefully. The wavelength and the peak of wavelength are the main important factors when we perform selection. Both receiver and emitter must be working in the same range. The angle of half intensity also must be the same or greater than the emitter. However, the majority of photodiodes that available in the market have the range of wavelength within the visible light and this has caused limitation in the photodiode selection as the receivers. Due to the limitation of the photodiodes, users prefer to choose phototransmitter over photodiode. Phototransistor offers wider wavelength and the range is above the visible light. But there are a few types of photodiodes which have the wavelength above visible that can be chosen as a receiver.

The other factor that needs to be taken into consideration while selecting the receiver is the switching time. In this case, the selection of receiver is between a photodiode and a phototransistor. A photodiode offers better switching time compared to a phototransistor [21]. It refers to the transient time (rise and fall time). The reason for fast switching time in photodiode is because of its device fabrication. The photodiode has two junctions and the capacitance effect is low compared to phototransistor which has three junctions. Based on the need of a fast response, the photodiode is selected as a receiver. However, the phototransistor has an advantage that it does not require additional amplification because of its characteristics.

Lastly, in terms of cost, the photodiode is cost effective compared to phototransistor. This is another reason for the selection of photodiode as a receiver. Table 2 shows the advantages and disadvantages between photodiode and phototransistor.

Table 2 Advantages and disadvantages of selected receiver

Types of receiver	Advantages	Disadvantages
1. Photodiode	A photodiode has a better switching time compared to a phototransistor Photodiode is cost effective compared to phototransistor.	Majority of photodiodes in the market have a wavelength in the range of visible light
2. Phototransistor	Phototransistor have wider wavelength and the range is above visible light Phototransistors do not require additional amplification because of its characteristics.	Low speed because bigger switching time

4.0 OPERATIONAL AMPLIFIER AND RECEIVER CIRCUIT

Operational Amplifier or Op Amp is a one of the important components in the receiver circuit to amplify the measurement signals. The parameter that is always considered when choosing an Op Amp is the slew rate. Slew rate is the maximum speed of the Op Amp. For example the Op Amp has 0.5 V/µs in slew rate, therefore to swing to 5 V, it will require 10 µs. Due to the feedback and input capacitance, and the rate would be slower which is around 15µs. If photodiode was used, Op Amp is needed because photodiode does not contain of any 'built in' circuit that can amplify it signals compared to phototransistor. There are two types of circuit when it is related to Op Amp namely, photovoltaic and photoconductive mode. To choose it, we must know the reason of our application. For the light measurement purposes and want to know how much flux is falling on the photo detector [22], it is better to choose photovoltaic mode. In photovoltaic mode, the photodiode is in zero bias mode. It means that the anode of the photodiode is grounded. The advantage in this mode is it does not have dark current that can increase linearly with the increasing of temperature. Other than that, the op amp is manage to work in linear mode. Most photodiodes work effectively with zero bias, even though originally designed for reverse-based operation [23]. Figure 1 shows the construction of photovoltaic mode.

C1

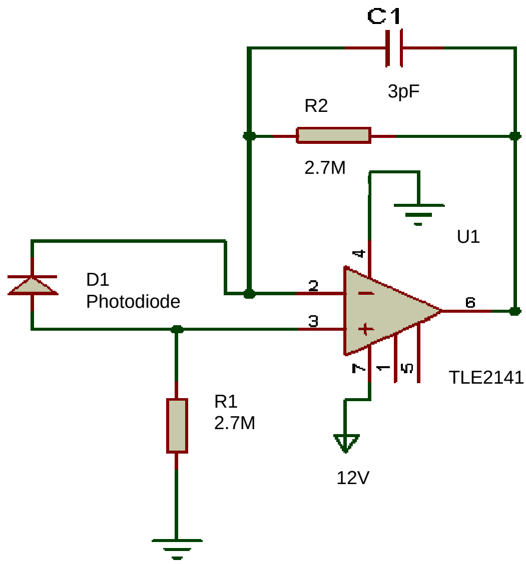

Figure 1 Photovoltaic mode

From Figure 1 there are reviews and suggested improvements that can be done to enhance this basic circuit for photovoltaic mode. This circuit has no room to move where the circuit's input operating range is not as wide as possible for a fixed power supply since it using a not rail to rail op amp [24]. Its output can get close to zero volts but only gets to about 0.1 v. It is also not a CMOS or a JFET input part. It has a high input bias current of 2 uA. Multiply that by the feedback resistance of 2.7 MΩ and it will get an output of 5.4 v, just from the bias. For rail to rail Op Amp, it provides such wide dynamic range. It also gives a freedom to operate near the DC supply rails. A CMOS device will also eliminate input bias concerns. To bias the non-inverting input to the ground it is not a good idea for a single supply. The photodiode is also locked in zero bias mode which can slow down the speed.

To improve the circuit some steps should be done. Firstly is to change the op amp to rail-to-rail types. Secondly the non-inverting side need to be biased to something off ground therefore 1.0 V should be fine. The anode of the photodiode should remain to be connected to ground while the cathode to the inverting input. This will reverse bias the part with 1.0 V. The output will start at 1.0 V and swing more positive with the light signal. The leakage current of the photodiode will add some DC to the output. The leakage current will increase with temperature of the photodiode. We will never be able to compensate for leakage current. But, it can be ignored by zeroing in on the AC component of the light signal.

In the purpose of getting faster signal, it is better to choose photoconductive mode. For photoconductive mode, the photodiode is in reverse bias mode. But the disadvantage is that it will produce dark or leakage current that increases in the increasing of temperature. To remove the noise from the leakage current we can pull down the photodiode with a negative voltage. Figure 2 shows the photoconductive mode for front end circuit.

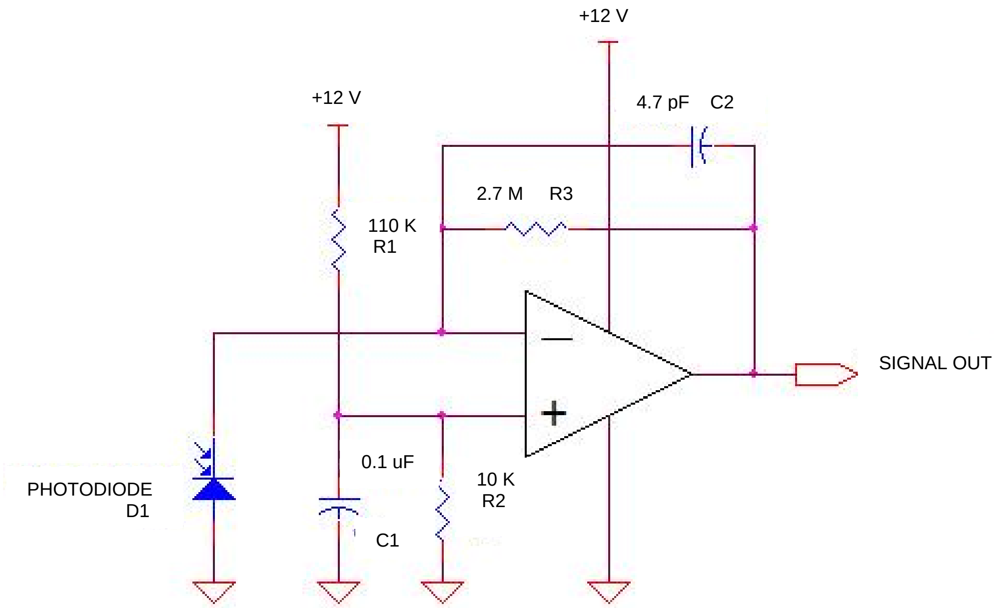

Figure 2 Photoconductive mode

From Figure 2, 1 V is applied to its non inverting input and by using the formula as stated in Equation 1, we can get 1 V as mentioned.

$$V_{bias} = \frac{R2}{R1 + R2}.V_s \qquad \text{(Equation 1)}$$

Therefore when we calculate we get,

4.7pF C2

$$V_{bias} = \frac{4.7k}{4.7k + 470k}12 = 1V$$

There will always be a delay between the input light signal and the op amp response means that there will always be a delay between the actual light pulse and the receiver's response. The best is the time delay should consistent with the speed of the op amp.

5.0 CONCLUSION

There are many factors that can influence the performance of tomographic circuit that depends on the purpose of the application. The selection of transmitter and receiver must match each other to avoid noise. Photodiode and rail to rail op amp are suitable for high speed application.

REFERENCES

[1] R. Abdul Rahim, L.C. Leong, K. S. Chan, M. H. Rahiman and J. F. Pang. 2008. Real Time Mass Flow Rate Measurement using Multiple Fan Beam Optical Tomography. *ISA Transactions*. 47(1): 3-14.

[2] R. Abdul Rahim, J. F. Pang, K. S. Chan, L. C. Leong, S. Sulaiman, and M. S. Abdul Manaf. 2007. Infrared Tomography: Data Distribution System and Software Development for Real-time Velocity Measurement. *ISA Transactions*. 46(2).

[3] S. Ibrahim, and R. G. Green. 2002. Optical Fibre Sensors for Imaging Concentration Profile. In, *Proceedings. ICSE 2002. IEEE International Conference on Semiconductor Electronic*s. 2002.

[4] E. J. Mohamad, R. Abdul Rahim, S. Ibrahim, S. Sulaiman, and M. S. Manaf. 2006. Flame Imaging using Laser-Based Transmission Tomography. *Sensors and Actuators A: Physical*. 127(2): 332-339

[5] R. G. Green, N. M. H., R. Abdul Rahim, F. .J Dickins, B. D. Naylor and T. P. Pridmore. 1995. Optical Fibre Sensors for Process Tomography. *Measurement. Science. Technology*.

[6] R. Abdul Rahim. 1996. *A Tomography Imaging System for Pneumatic Conveyors using Optical Fibres*. Phd diss. Sheffield Hallam University.

[7] R. Abdul Rahim, K. S. Chan, J. F. Pang, and L. C. Leong. 2005. A Hardware Development for Optical Tomography System using Switch Mode Fan Beam Projection. *Sensors and Actuators A: Physical*. 120(1): 277-290.

[8] R. Abdul Rahim, K. T. Chiam, J. Pusppanathan and Y. Shaan-Li Susiapan. 2009. Embedded System Based Optical Tomography: The Concentration Profile. *Sensor Review*. 29(1): 54-62.

[9] Yingna Zheng, Q. L., Yang Li , Nabil Gindy. 2006. Investigation on Concentration Distribution and Mass Flow Rate Measurement for Gravity Chute Conveyor by Optical Tomography System. *Measurement*.

[10] C. Yan, J. Zhong, Y. Liao, S. Lai, M. Zhang, and D. Gao. 2005. Design of an Applied Optical Fiber Process Tomography System. *Sensors and Actuators B: Chemical*. 104(2): 324-331.

[11] Chunsheng Yan, Y. L., Shurong Lai and Zhixing Yang. 2003. Design of a Novel Optical Tomography Sensor Array. *Measurement Science and Technology*. 14(2).

[12] Wikipedia. *Infrared*. 2009 [cited 2009 7 May 2009]; Available from: http://en.wikipedia.org/wiki/Infrared.

[13] M. McCrorey. 1985. A Comparison of Plastic versus Metal Packaging for Infrared Sensors and Emitters, in *Application Buletin*.

[14] Inc., V.I. *IR Emitter Offers 'lowest' forward voltage*. 2008. [cited 2009 28 April 2009]; Available from: http://www.eetindia.co.in/ART_8800553821_1800010_NP_eb6b4 93d.HTM.

[15] Roos, G. *IR emitter doubles radiant intensity*. 2005 [cited 2009 8 May 2009]; Available from: http://www.eetindia.co.in/ART_8800560370_1800010_NP_e8db0eea.HTM.

[16] Inc, V.I. *IR Emitter Offers High Radiant Intensity*. 2009. [cited; Available from: http://www.eetindia.co.in/ART_8800560370_1800010_NP_e8db0 eea.HTM.

[17] Design, L.A. *LED*. 2008. [cited 2009 8 May 2009]; Available from: http://www.lunaraccents.com/design-light-emittingdiodes. html.

[18] C.L Goh. 2005. Real-Time Solids Mass Flow Rate Measurement Via Ethernet Based Optical Tomography System. *Master Thesis*. Faculty of Electrical Engineering, Universiti Teknologi Malaysia: Skudai.

[19] J. F. Pang. 2004. Real-Time Velocity And Mass Flow Rate Measurement Using Optical Tomography. *Master Thesis*. Universiti Teknologi Malaysia: Skudai.

[20] T. K. Chiam, 2006. Embedded System Based Solid-Gas Mass Flow Rate Meter Using Optical Tomography, Master Thesis. Faculty of Electrical Engineering. Universiti Teknologi Malaysia: Skudai.

[21] Leong Lai Chen. 2005. Implementation of Multiple Fan Beam Projection Technique in Optical Fibre Process Tomography. Universiti Teknologi Malaysia.

[22] Paul Rako. 2010. Photodiode Amplifiers: Turning Light into Electricity. National Semiconductor's Online Seminar. [cited 6 July 2010]; Available from http://www.national.com/onlineseminar/2004/photodiode/photodiode_transcript.pdf.

[23] Burr-Brown. 2010. [cited 30 July 2010]; Available from http://www.focus.ti.com.cn/cn/lit/an/sboa061/sboa061.pdf.

[24] David Johnson. 2010. [cited 25 July 2010]; Available from www.discovercircuits.com.