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Temperature Compensated Bias Supply Circuit for Photodiodes

Abstract. *The light detection efficiency of Photon detecting components is very much dependent on the operating temperature. Rise in operating temperature reduces their ability of photon detection and reduced output signal. This effect becomes prominent in the cases where very weak signals are needed to be detected. There are various methods which can be applied to cater for the situation of changing ambient temperature or the temperature of the component itself. This study present a method which tracks the temperature changes as seen by the device and hence adjusts the bias voltage being supplied to it. The bias voltage mainly depends upon the temperature coefficient of the component and hence adjusts itself. Design and testing method of bias power supply are presented along with the graphical presentation of result.*

Streszczenie. *Pomiar światła przy wykorzystaniu fotodiody bardzo zależy od temperatury – szczególnie w przypadku małego sygnału wyjściowego. W zaproponowanym układzie zasilania zmienia się napięcie w zależności od temperaury.* ***Obwód zasilania fotodiody z kompensacją temperatury***

Keywords: Photodiode, Temperature Compensation, DC Bias Supply
Słowa kluczowe: fotodioda, kompensacja temperatury, zasilanie

Introduction

Temperature compensation becomes necessary in situations where the ambient temperatures keep varying or the components itself are prone to temperature changes as their operation goes along[1]. The situation effects the overall operation of electronic circuitry in terms that required output keep changing drastically. In this regard several approaches have been adopted by researchers, these pertain to use of Zener diodes, Peltier elements and N-JFETs [2] as reference for compensation. Nishida etal also presented a temperature compensation model to work with avalanche photodiodes [3], whereas,Webb et al [4] claimed a quantum efficiency of up to 100% after carrying out temperature compensation for an RAPD. Tajammal and Nagi [5] presented a temperature compensation solution for laser diodes.

Suggested Methods for Temperature Compensation

There are a number of techniques which help to compensate temperature variations under various conditions. Three more commonly used techniques are as follows:-

a. Operation under constant current.
b. Operation of desired components at a constant temperature.
c. Biasing of circuitry or components using temperature compensated power supply.

Figure 1 [6] shows a scheme for constant current operation for temperature compensation. In this scheme a current stabilized power supply is connected in series to a photodiode so that the device operates under constant current operation as the changes in temperature causes the reverse current to vary. Another method of temperature compensation is possible in which the bias voltage tracks any changes in the temperature and hence adjusts itself by sensing generated reference voltage.

Figure 2 [7] shows another scheme of temperature compensation by using another alike component to provide reference voltage for the purpose. However, in order to achieve best and efficient results, it is necessary that both the components i.e. original and reference component must be cut out of one epitaxy so that both the diodes have same temperature coefficient.

The method mentioned at number 2 above, is not suitable for situation where light signals are being detected. For example in case of photodiodes, as the temperature maintained constant the risk of vapour condensation on detector window would reduce the efficiency of the detector. The method mentioned at number 3 above will be designed and discussed in this study.

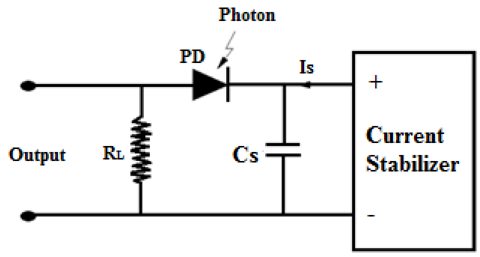

Fig. 1.Constant current temperature compensation.

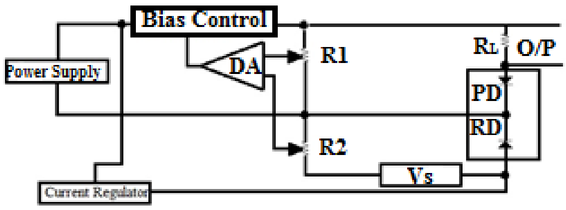

Fig.2.Constant current power supply for Photodiode (PD).

Temperature compensated bias supply for Photo Diodes

The behaviour of a PD depends strongly upon the change in ambient temperature i.e. the input light intensity versus output current level varies with the temperature. To overcome this problem, a temperature compensated power supply has been designed, so that changes in the ambient temperature do not influence the output current from a PD. While designing the component values for such a circuit, it isnecessary to know the temperature coefficient (β) of the PD.Temperature Coefficient is normally obtained from data sheet of respective component. Sometime it is given directly to the form of Volts/oC, whereas in some cases it is mentioned in terms of %/oC (i.e.%β). Before we can start design it is required to transform T.C. from %/oC to volts/oC. This will be more relative to the actual power supply voltage units. Using parametric specifications given in the respective data sheet of a PD, a fully functional circuit has been designed as shown in the following steps.

Choosing reference voltage

A constant voltage reference of -6.8 volts was chosen to include in the circuit rather than to use another PD or Zener as a reference to main bias supply, in this regard a precision reference diode package LM329 (IC1)has been chosen. This reference voltage is then supplied to a temperature sensor IC which has a temperature coefficient of 1μA/K.

To start with an operational amplifier has been used in non-inverting configuration. Consider the combination of the temperature sensor IC1 and the operational amplifier A1. The total current generated by IC1 for a rise in temperature of T degrees Kelvin will be Tx10-6 A. Hence, the current I supplied by the temperature sensor for a rise of T degrees Kelvin will be

(1) $$I = T \times 10^{-6}\, A/\,^{o}K.$$

Therefore, the voltage at the output of the operational amplifier A1 with feedback resistor (R1) can be expressed as

(2) $$T \times 10^{-6} = \frac{V_1}{R_1}.$$

Thus, the voltage change V1 becomes

(3) $$V_1 = R_1 \times T \times 10^{-6}\, V.$$

The operational amplifier A2 was used in a summing amplifier configuration so that it could add all three voltages which are applied at its inputs to produce the output Vo. This output Vois supplied at the base of an NPN transistor Q1, through a resistor. Transistor Q1 was configured so that the smaller the voltage signals at its baseterminal; the lower was the conduction between its collector and emitter. While conducting, the transistor produced a flow of current between the collector and emitter. In turn, this caused the +VB point to float, hence, a variation in the -VB point at the output could be observed.

Mathematically, this section of the circuitry can be expressed as follows:-

Kirchhoff 's law states that, at any point in an electrical circuit, the algebraic sum of the currents meeting at that point is zero.Therefore, the current equation according to Kirchhoff's law at the input of A2 can be written as

(4) $$\frac{V_{ref}}{R_2} + \frac{V_B}{R_4} + \frac{V_1}{R_3} = 0.$$

However, substituting the value of V1 from equation 3, equation 4 yields

(5) $$\frac{V_{ref}}{R_2} + \frac{V_B}{R_4} + \frac{TR_1 \times 10^{-6}}{R_3} = 0$$

Differentiating equation 5, with respect to T, yields

(6) $$\frac{dV_B}{dT} = -\frac{R_1 \times R_4 \times 10^{-6}}{R_3}.$$

Inserting $\frac{dV_B}{dT} = \beta$, equation 6 can then be written

(7) $$\beta = -\frac{R_1 \times R_4 \times 10^{-6}}{R_3}$$

which gives the value for the temperature coefficient β of the PD. Substituting this value into equation 6 gives

(8) $$V_B = -V_{ref}\frac{R_4}{R_2} + T\beta.$$

Solving equations 4, 7 and 8 simultaneously, values for the resistors R2, R3 and R4 may be calculated as shown in the following section.

Practical implementation

The reverse breakdown voltage provided in a manufacturer’s data sheet was 70 Volts and βwas given as 0.1%/oK. Kiya and Hayashi [8] converted temperature coefficient which was given in terms of %/degree using the relationship to resolve β in terms of volts/oK

(9) $$\frac{\beta}{V_{BR}} = 0.1 \times 100.$$

Therefore, temperature coefficient for 70V reverse breakdown value will be

(10) $$\beta = (0.1 \times 10^{-2}) \times 70 = 70m\, Volts/\,^{o}K.$$

In order to calculate the appropriate values of various resistors to be used in the circuit, this voltage value must be substituted into equation 7 using R1 = 20 k Ω. This yields

(11) $$-70m = \frac{-20k \times R_4 \times 10^{-6}}{R_3}.$$

Thus,

(12) $$\frac{R_4}{R_3} = \frac{70}{20} = 3.5$$

leading to the value R4≅4R3. Since it was already required that the PD should operate at a temperature of 300K (i.e. approximating to a normal room temperature), this implied that the following values were already fixed:-

$$T = 300^{o}K$$

and

(13) $$\beta = -70mV/\,^{o}K\,.$$

From equation 7, we get

(14) $$R_1 = 20 \times 10^{3}\Omega.$$

Inserting these values in equation 8 led to a value for the reversed breakdown voltage

(15) $$V_B = -V_{ref}\frac{R_4}{R_2} - 21\,.$$

Furthermore, it was required to operate the PD at a reverse breakdown voltage value of VB = -70 volts. Therefore,

(16) $$70 + 21 = -V_{ref}\frac{R_4}{R_2}$$

but

(17) $$V_{ref} = 5\, Volts.$$

Therefore,

(18) $$\frac{R_4}{R_2} = 9.8\,.$$

Assuming that R2=100 kΩ, equation 18 therefore yields,

(19) $$R_4 = 100k\,(9.8) = 980k \cong 1M\Omega\,.$$

Similarly, from equation 12,

(20) $$R_3 = \frac{1M}{3.5} \cong 286k\Omega.$$

Inserting these design values for R1, R2, R3 and R4 into the circuit design, figure 3, satisfactory performance of the temperature compensated power supply for the PD was obtained. However, to set the value of the temperature coefficient precisely, it was decided to insert a variable resistor instead of a fixed value for R2. This could then be adjusted until the required output value for bias voltage was obtained. Figure 3 shows detailed schematic of electronic circuit for temperature compensation.

Variations in the output voltage were observed with respect to temperature changes. The output of power supply was attached to a voltage divider unit which helped to reduce the voltage to an appropriate level. Thus it enabled us to supply it to an analogue to digital converter card which was fitted inside a PC.

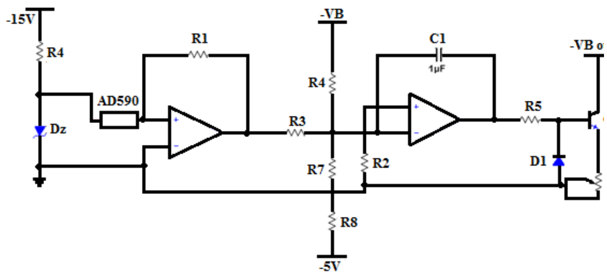

Fig.3. Circuit schematic for temperature compensation.

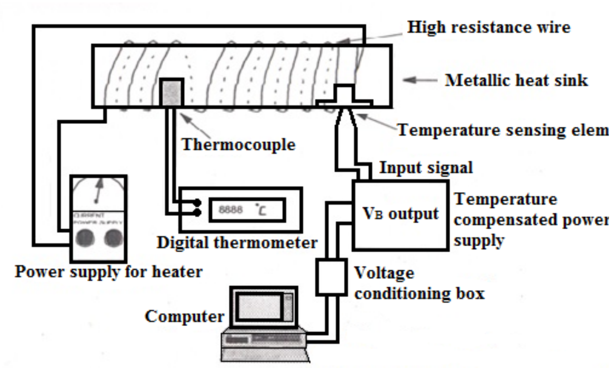

Fig. 4.Performance test arrangement.

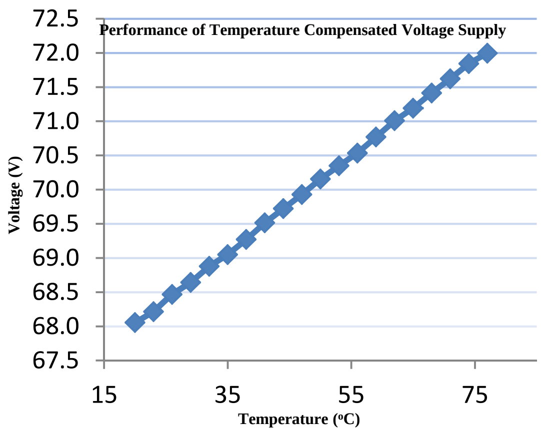

Fig. 5.Performance profile of developed circuit.

A number of observations were taken for a range of heat sink temperatures with data being collected in the temperature range 20-77oC. The results are shown in figure 5, these confirm the follow up of bias voltage with temperature variations and have shown a reasonable linear behaviour as it was expected. The nonlinear part of contour may have existed due to nonlinear characteristics of components used in the circuit.

Results and discussions

Temperature compensated power supply circuit for a PD was implemented and tested against a temperature change. This was achieved by using component values which were calculated in previous section. In order to measure the changes in performance of the circuit with respect to the changes in ambient temperature, a sensing temperature element and a thermocouple were both mounted on the same heat sink. Thermocouple was used to monitor temperature variations directly. For this setup arrangement as shown in figure 4 was used for the purpose of performance test.

Author

Dr. M T Chughtai earned his PhD and MSc degrees in 1988 and 1995 respectively, from the University of Manchester, Manchester, England. He also holds MSc in Physics from University of the Punjab, Lahore, Pakistan.He served the same university twice as Research Associate and Project Officer. Apart from this he also served at a range of universities internationally in countries of Malaysia and Pakistan. He was promoted to Professor of electrical engineering in 2004. At present he is serving at University of Hail, Hail, SaudiArabia.E mail: mt.chughtai@uoh.edu.sa and chughta@yahoo.com. He possesses a wide range of teaching and research experience in the fields such as electronics, laser, fibre optics, technical textiles and instrumentation. He has servedas Assistant Dean, Head of Department responsibilities to procurement, faculty hiring, refereeing papers, quality assurance (ABET) etc. He is a full member of IET (London), IEEE and life time member of Pakistan Engineering Council.

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