A Realization of Stabilizing the Output Light Power from a Laser Diode

A Practical Approach

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Abstract-Semiconductor Laser Diodes (LDs) are known for their sensitivity to variation in ambient temperature. With the rise in case temperature the threshold current of the LD increases, causing the output light power to deteriorate drastically. Therefore, it is necessary to stabilize the temperature of the diode. Various approaches could be adopted in this regard. In this paper, an active cooling approach using the temperature compensation technique has been followed and presented in the form of a full design of the circuit according to the various datasheet parameters of the LD and other components. As a result of temperature stabilization, a significant improvement in the output light power stabilization was observed and the results are presented.

Keywords-electronics; laser power; temperature stability

I. INTRODUCTION

Laser Diodes (LDs) have been known for their sensitivity towards changes in the case temperature due to operation over long durations or to ambient temperature. With the change in temperature, their operating point keeps shifting, i.e. with the increase in the temperature it keeps shifting away from the original operating point which results in reduced levels of optical power output. A proposed remedy to these problems is a temperature compensating bias system, which is capable of keeping track of any changes in the ambient temperature and hence providing a higher safety to the LD. Many approaches have been adopted for keeping the operation of LDs stable to work in continuous wave mode. One traditional method of achieving the objective is attaching a heat sink to the LD.

Authors in [1] designed a stabilized pump laser system to achieve square wave modulation. They managed to attain a spot size radius of 7mm, hence obtaining a uniform laser beam cove. Authors in [2] proposed an optical scanning system wherein they suggested changing the intensity distribution from the center and the edge of the beam using a prism. Authors in [3] used a double Fabry Perot interferometer acoustic sensor to get rid of temperature drifting. Authors in [4] tried a number of alterations using silicone converters which helped increase the top-limit excitation power ranging from 60 to 180Wcm. Authors in [5] developed a heat sink having micro channels, for sinusoidal type channel structures which increased the stability and life time of the LD. Authors in [6] reported a diamagnetic

spring to act as a radiation pressure meter. Authors in [7] developed a model using Pspice simulation software and a comparison between the model and the actual diode was studied. The same problem of temperature dependence and stabilization in case of high power laser was encountered and studied in [8] in the case of high power diode-pumped Tm: YLF. The authors achieved optical-to-optical efficiency of 36.8%. Authors in [9] reported a self-referenced stabilization of a diode laser. However, the work was related to a high power laser of 2.1W. Similarly, authors in [10] reported the stabilization of optical power in high power laser which achieved lateral mode stability. This property has been used in improving the stability of beam quality. Authors in [11] worked towards power stability of a LD output power by controlling low and high frequency noises. However the stability remained short-term. Authors in [12] achieved enhanced stability using double Q switching hence attaining mode locked output. The LD under test had a peak power up to 20W with a good repetition rate. Authors in [13] reported an electronic circuit based upon the principle of feedback. The circuit was implemented using CMOS technology and gave promising results for average output power of hetero-structure laser for stabilized continuous operation.

In order to keep the output optical power constant for a constant level of input current it is necessary that the bias voltage fed to the LD must track any changes in the temperature. Authors in [14] studied the structure of an LD in order to compare the LD and a conventional light emitting diode. Authors in [15] discussed a technique using Labview software to compensate the non-linearity in temperature measurement using traditional sensors. A comparison between various modes of laser operation has also been presented. Authors in [16] presented a review and discussed LD chaos and suggested various methods and their advantages for harnessing and application of chaos in various applications. Changes in the temperature of the LD may cause the operating point voltage of the LD to exceed the typical rating value and may cause permanent damage or may give a lower than desired amplitude of optical power. If the applied voltage exceeds the operating voltage (as a result of a decrease in the temperature), a permanent damage to the LD may occur. Additionally, a rise in temperature will shift the operating point, leading to a drop in

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optical power output. Authors in [17] studied a semiconductor laser using simulations to determine various parameters in relation to laser structure hence observing maintenance of output parameters at certain structural measurements. Authors in [18] discussed a CO_2 stabilized laser in cutting processes and they carried out a discussion validated by the Analysis Of Variance (ANOVA). However, nothing was discussed for the stabilization of power. In previous works the temperature compensation in a range of applications have been presented by using passive [19] as well as active methods which are mostly based upon Peltier coolers [20]. The present work has been carried out by making use of temperature sensor and reference. Therefore, this work is considered as an active method but without the use of a Peltier cooler. The complete design and calculations are presented with the aim that the users would be at ease to carry out calculations on the same pattern. However, the researcher has to use parameters, such as the temperature coefficient, according to the devices which would be chosen for the new system under consideration.

II. SUGGESTED OPTIONS TO MAINTAIN OPTICAL POWER OUTPUT

The three most common solutions to this problem are:

- Constant current operation.
- Maintenance of the temperature of the LD at a constant level.
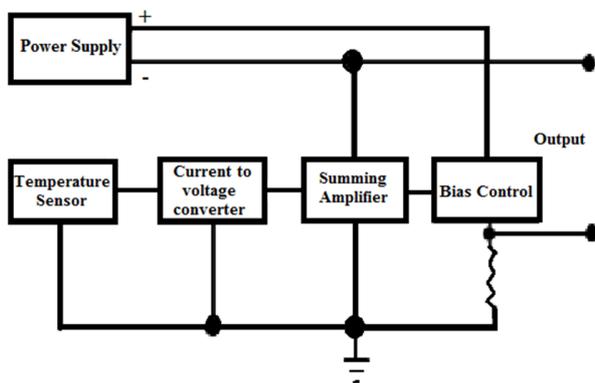- Bias the LD using a temperature compensated power supply.

Fig. 1.   Block scheme for temperature stabilization.

The constant current power supply circuit is the one suggested in [21]. In this circuit a current stabilizer has been used to bias the avalanche photodiode, whereas a capacitor Cs was used in charge banking role. However, the same arrangement may be used for achieving temperature and hence output light power stability. This may require a careful redesign of the circuit according to the specifications of the LD under consideration. Another method of temperature compensation can be achieved by ensuring that the voltage of the LD tracks any temperature change by using another diode to produce a reference voltage signal. The schematic arrangement for such a circuit though for photodiode has been presented in [22]. In this

scheme, a Zener diode was used as a reference diode mounted on the same heat sink. The configuration of a differential amplifier has been used in the circuit for the purpose of bias control. The second method mentioned above, may cause condensation on the LD window and hence a poorer delivery of optical power output and the need to clean the window frequently. The third method to stabilize an LD is to design a circuit using temperature sensing components, as shown in Figure 1. Usually, temperature sensing components produce a current signal which varies with any change in temperature. This output current may be converted to voltage with the use of an operational amplifier, configured as a current to voltage converter. The output of this op-amp can then be fed to a summing amplifier in a non-inverting configuration, thereby summing up the voltage with the negative value from a conventional high voltage power supply and a reference voltage. The resultant output is used to control the base current of the bias control transistor.

III. DESIGN CONSIDERATIONS

A Toshiba LD was used in this study. The temperature coefficient for this particular LD as given by the data sheet is 1×10^{-3}%/°C. In order to convert this temperature coefficient into a voltage variation (Volts/°C), noting that:

$$\beta = \frac{1\times10^{-3}}{100} \quad (1)$$

where β is the temperature coefficient of the LD in volts/°C and VB is the bias voltage of the LD. The value of VB for this case is 3V, so (1) leads to [23]:

$$\beta = \frac{30\mu V}{°C} \quad (2)$$

The practical circuit for a temperature compensated bias supply for an LD is illustrated in Figure 2.
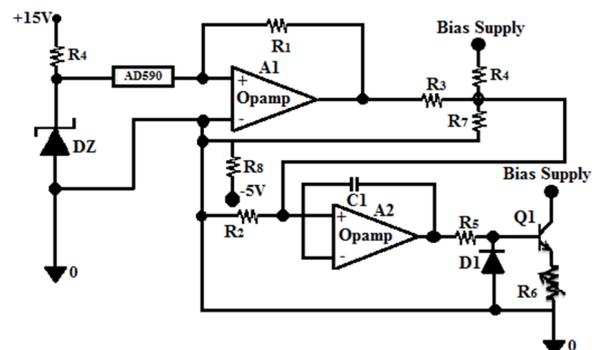

Fig. 2.   Schematic of the temperature compensated bias supply for LD.

In order to understand the functioning of this, a gradual design and analysis of the circuit is presented below.

A. Constant Reference Voltage

A constant voltage reference of −6.8V was obtained using the precision reference diode package LM329. This constant

reference voltage was then supplied to the temperature sensor 1C AD590, which has a temperature coefficient of 1μA/°K.

B. *Current to Voltage Converter*

Let us consider the combination of the temperature sensor IC1 and the operational amplifier A1. The total current generated by 1C1 for a rise of T (°K) in the temperature will be $T \times 10^{-6}$A. Hence, the current I supplied by the temperature sensor for a rise of T °K will be:

$$I = T \times 10^{-6} \, \text{A} \Big/ {}_{\circ}\text{K} \quad (3)$$

Therefore, the voltage at the output of the op-amp A1 with feedback resister R_1 can be expressed as:

$$T \times 10^{-6} = V_1 \Big/ R_1$$

Thus, the voltage change V_1, becomes:

$$V_1 = R_1 \times T \times 10^{-6} \, \text{V} \quad (4)$$

C. *The Summing Amplifier*

The operational amplifier A2 was used in a summing amplifier configuration so that it added all three voltages applied at its inputs to produce the output V_o. This output V_o was supplied at the base of an NPN transistor Q1, through a resistor. Transistor Q1 was configured so that the smaller the voltage signal at its base, the lower was the conduction between the collector and the emitter. When conducting, the transistor produced a flow of current between its collector and emitter of Q1. In turn, this caused the +bias voltage point to float, hence, a variation in the -bias voltage point at the output could be observed. Mathematically, this section of the circuitry can be expressed as follows:

Kirchhoff's current law states that, at any point in an electrical circuit, the algebraic sum of the currents meeting at that point is zero (Figure 3). Therefore, the current equation according to Kirchhoff's law at the input of A2 can be written as:

$$\frac{V_{ref}}{R_2} + \frac{V_B}{R_4} + \frac{V_1}{R_3} = 0 \quad (5)$$

However, substituting the value of V, from (4), (5) yields:

$$\frac{V_{ref}}{R_2} + \frac{V_B}{R_4} + \frac{T \times R_1 \times 10^{-6}}{R_3} = 0 \quad (6)$$

Differentiating (6), with respect to T, yields:

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

Putting up $dV_b/dT = \beta$, (7) can then be written as:

$$\beta = -\frac{R_1 \times R_4 \times 10^{-6}}{R_3} \quad (8)$$

This gives the value for the temperature coefficient β of the LD. Substituting this value into (5) gives:

$$V_B = -\frac{V_{ref} \times R_4}{R_2} + T \times \beta \quad (9)$$

Solving (5), (8), and (9) simultaneously, the values for resistors R_2, R_3 and R_4 may be calculated.

IV. PRACTICAL IMPLEMENTATION

From the data provided with the LD, the bias voltage of the particular LD under consideration was found to be 3V and, according to this value, the temperature coefficient as calculated at the beginning was 30μV/°K. In order to calculate the appropriate values of the various resistors to be used in the circuit, this voltage value must be substituted into (2) using R_1=20KΩ. This produces:

$$-30 \times 10^{-6} = \frac{20k \times R_4 \times 10^{-6}}{R_3}$$

Thus:

$$\frac{R_4}{R_3} = \frac{1.5}{1k} = 1.5 \times 10^{-3} \quad (10)$$

Leading to the value $666 \times R_4 = R_3$. Since it was already required that the LD should operate at a temperature of 300°K (i.e. approximating to a normal room temperature, this implied that the following values were already fixed):

$$T = 300°K$$

$$\beta = -300\mu V/°K$$

$$R_1 = 20k\Omega$$

Inserting these values in (9) led to a value for the reversed breakdown voltage:

$$V_B = -V_{ref} \frac{R_4}{R_2} - 0.09$$

Furthermore, it was required to operate the LD at a biasing voltage value V_B = 3 Volts. Therefore:

$$3 + 0.09 = -V_{ref} \frac{R_4}{R_2}$$

but:

$$V_{ref} = 5V$$

$$\frac{R_4}{R_2} = 0.618$$

Assuming that R_2=10kΩ, (10) therefore leads to:

$$R_4 = 10k(0.618) = 6.18k \approx 6k\Omega$$

and:

$$R_2 = \frac{6.18k}{1.5 \times 10^{-3}} = 4.1\text{M}\Omega$$

Inserting these design values for R_1, R_2, R_3, and R_4 into the circuit design, satisfactory performance of the temperature compensated power supply for the LD was obtained. However, in order to set the value of the temperature coefficient precisely, it was decided to insert a variable resistor instead of a fixed value for R_2. This could then be adjusted until the required output value of the bias voltage was obtained. The designed circuit was assembled on a double sided Printed Circuit Board (PCB) and is shown in Figure 3.
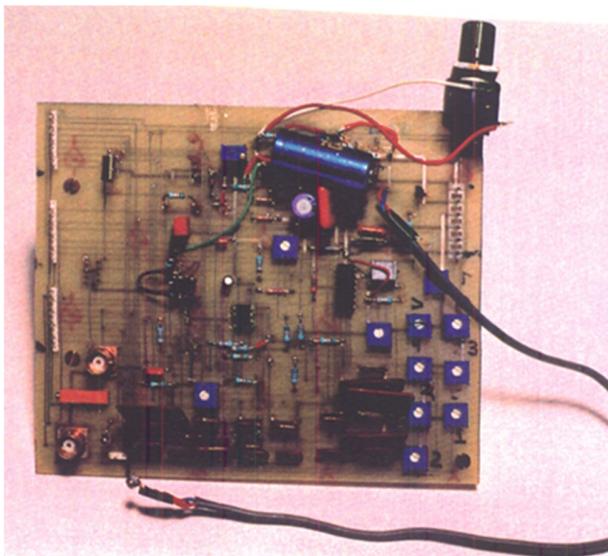

Fig. 3.   Assembled circuit as used for testing and confirmation.

V.   RESULTS AND DISCUSSION

The performance of the LD was recorded with and without applying the temperature compensated bias circuit. Figure 4 shows the trend of the LD output power.
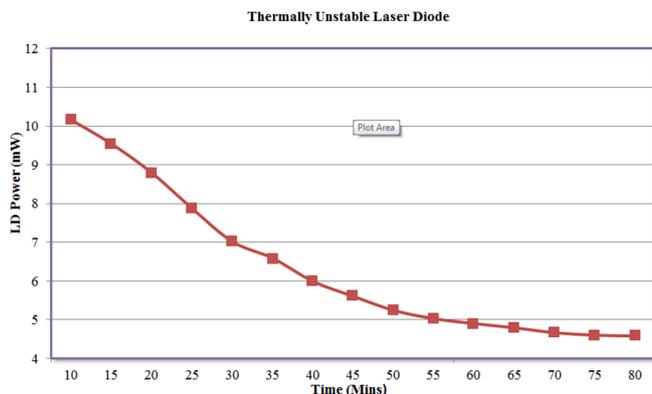

Fig. 4.   LD output power without temperature stabilization.

The graph shows a drastic reduction in output optical power during the first 50 minutes of switching on. After 50 minutes of

biasing up the LD lost more than 50% of its rated value before the output optical power settled down but the level of output power was at such a low level, which is not good enough for the purposed application. Figure 5 shows a power drop of over 1mW before it settles down around 10mW of optical power, which was a sufficient and constant supply of optical power for the system under consideration. The circuit for temperature compensation of the LD was implemented and assembled on a double sided PCB, according to the design values of the components calculated in the previous section. In order to measure the variation in the optical power output, the observations were recorded for power output against time, as shown in Figure 6. These were then plotted in the form of a graph for comparison purposes. The output power level was also recorded without temperature compensation, so that an easy comparison of both the situations could be made. It can be observed that the output optical power is well stabilized after attaching the LD to temperature compensation arrangement.
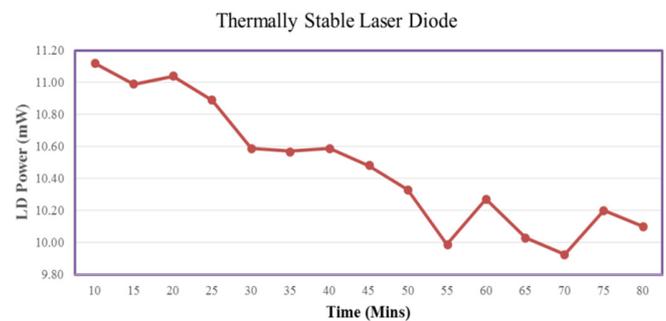

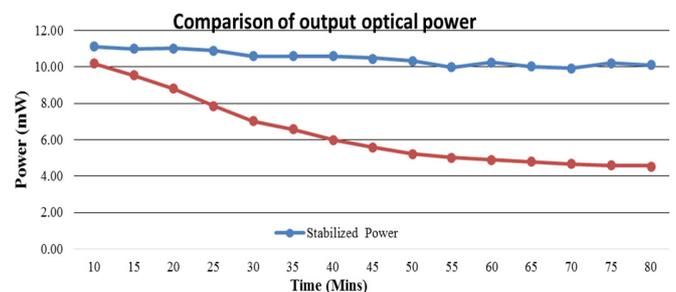Fig. 5.   Stabilized output optical power after applying modified bias circuit.

Fig. 6.   Comparative graph of stabilized and un-stabilized output optical power.

VI.   CONCLUSIONS

Reliable and reproducible results have been achieved using the designed parameters. The circuit was first tested as a prototype and then assembled on a double sided PCB. A complete set of design calculations along with the choice of components and any assumptions made has been presented. The utilization of the designed circuit may be extended to other temperature sensitive applications.

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