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Current Mode Logic based Semiconductor Laser Driver Design for Optical Communication System

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Abstract

In optical communication systems, semiconductor lasers are widely in use as an optical source but the performance of laser are limited due to temperature variation, design incompetency, and power consumption issues. The direct output of semiconductor laser may destroy the additional component attached in the system. In this research, semiconductor laser, driver is implemented by utilizing the current mode logic technique to control the output of semiconductor laser. Current Mode Logic (CML) is one of the compatible technique to work integeratedly with optical components. CML based design of semiconductor laser driver has achieved the current ranges from 5.6 mA to 6.8 mA and efficiently working up to 10 GHz frequency and consume 75% less power than typically available laser drivers. In future, the semiconductor laser may have implemented using System on Chip (SoC) configuration to make the design more energy efficient, in terms of temperature sensitivity and power consumption.

Keywords: Current Mode Logic, Driver Circuits, N-Metal Oxide Semiconductor Transistor, Semiconductor Lasers, Switching Efficiency

1. Introduction

In modern society, the advancement in communication systems has increased the amount of data transported enormously. The analog and digital communication techniques have developed the great expansioncommunication systems. Research is ongoing to resolve the power consumption, commercial costand other issues for communication system[1,2]. Optical fibers provide the high data rates for long haul communication systems[3]. Transmitter, medium and receiver, are three basic components of an optical communication system, similar to traditional electronic communication systems[4,5]. The optical system is distinct from electronics system that optical system uses light as a carrier[6]. In optical transmitter, laser or Light Emitting Diode (LED) are used as optical source along with circuits to maintain the output of both laser and LED, such laser drivers[7]. In high-speed applications semiconductor lasers are presently, the main light output source[8].Laser drivers interface the electronic and optical devices[9–20].

2. Literature Review

In Literature review, brief concepts of semiconductor laser and laser drivers are discussed to clarify the concept, before discussing the problem statement and methodology for its solution. In optical communication systems, the two main sources of optical sources are LED and Laser. Why is the laser preferred over LED?[21]. The reason is that its small size with narrow spectral region with high efficiency[21]. In [22,23], it was discussed to improve the laser parameters such as; onset and offset current, high quantum productivity with high stability. In Figure 1, the P-I curves for semiconductor laser and LED is shown[24,25]. Figure 1 states that below threshold values (edge value i) of current, the laser has minimum power is minor and respond as a Light Emitting Diode (LED)by spontane-

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ous emission. Moreover, above threshold value, the laser responds to stimulated emission and behaves as laser.

2.2 Laser Drivers

Laser driver works as a modification device that respondsover an input signal modulated by the data pulses[26,27]. In Figure 1, the laser characteristics are demonstrated the laser is dependent on voltage instead of current because the small change in independent parameters will change the laser characteristics and that produces the large variation in current at continuousvoltage. To resolve, this issue, the laser drives are used to protect the large current variations[28–41]. The main challenge to design the laser drivers is that 1-10 mA current with fall and rise time with limited bandwidth is causal for high output current. Laser drives is configured in two ways; single ended and open-ended. In single ended, freeloadingelements used such as; inductance and other respondswith the impedance of the laser driver circuit and reduces power supply ripples from the output signal. In open-ended, the laser is connected to the direct path of the circuit and the current is regulated by lasing region of light and power (P-I curve)[42–44].

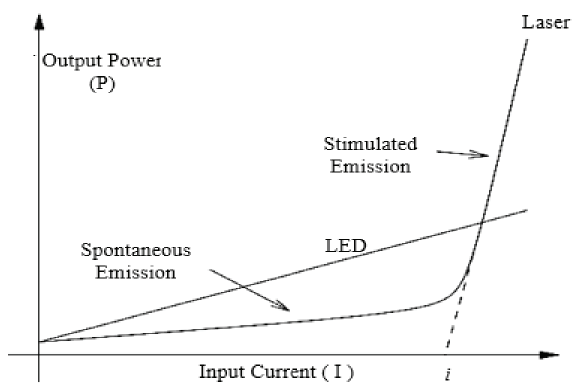

Figure 1. Curve for LED and Laser in terms P-I.

3. Problem Statement

The directed interaction of semiconductor laser diode with system ahead is very risky in terms of operation and current variation rather than voltage, produces large fluctuations in output power due to temperature dependency. The implementation of semiconductor laser driver is quite power consumptive.

4. Methodology

In this paper, the construction of laser driver is achieved using CML technique, which is for designing the optical components and provides the one-on-one termination for link. The CML techniques provides, the regulated current with elimination of unwanted common mode noisy signals in comparison with other techniques. Another reason for using the CML is that during operation of the symmetrical nature of the signal can avoid cross talk and these signal increases the wide band transmission. The laser driver moderates, the laser signal's serial data and

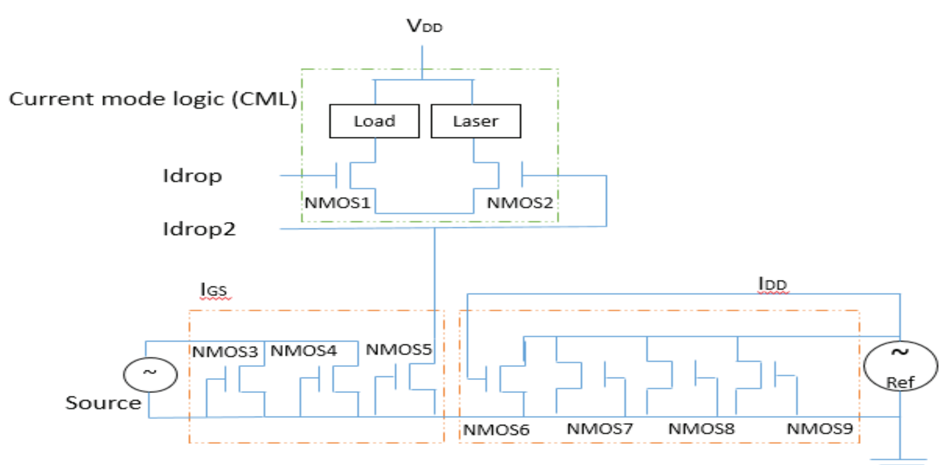

Figure 2. Semiconductor laser driver model.

delivers the DC bias current. The designed laser driver model is demonstrated in Figure 2.

The laser driver model is designed using CML technique that utilizes the N-channel MOSFET transistor in parallel configuration. The CML based laser driver behaves as current switch. The laser driver is placed between the laser and optical fiber or optical system connected to ahead. The laser driver designed using CML is developed using two parallel configured transistors network. The one network is operated using NMOS1 and other network is operated using NMOS2. The current variation is balanced by limiting the current from either NMOS due to change in internal capacitance of NMOS. The selection of NMOS mostly effects the switching speed of semiconductor laser. The laser driver is tested by giving the logic inputs. When logic high or binary 1 is given as an input the NMOS1 is turn-off and this turn-on the NMOS2and the laser currentstart flow in the I*drop* loop. When logic low or binary zero is given as input, NMOS1 is turn-on and turning off the NMOS2. This configuration produces the combined effect of current regulation due to source and reference voltage. The CML based of laser driver has two outputs; one is connected to laser and other is connected to load. The minimum value of input common-mode level i.e. *Isource,CM*, is reached, and at this stage the currentfalls in saturation region.The CML level grasps its maximum valuei.e.*Isource,CMax* is reached and NMOS1 and NMOS2 are in cutoff region, the numerical equation can be calculatedfor this as in[45]:

$$I_{GS} + (I_{GS} + I_{TH}) \leq I_{Source,CM} \leq \min[I_{DD} - Load\frac{I_{SS}}{2} + I_{TH}, I_{DD}] \tag{1}$$

where,*IGS*is overdrive current for common mode oftwo parallel-configured transistors NMOS1 and NMOS2. The over drive current in saturation region is generated with contribution of NMOS3, NMOS4 and NMOS5and in the cut-off region this overdrive current is zero. Another current type *IDD* is contributed due to parallel configuration of NMOS5, NMOS7, NMOS6 and NMOS8. The *IG s*aturation yields the*IDD*zero in cut-off. The *IGS* in cut-off region produces the *IDD*maximum current. Thedereference between both *IGS and IDD*can be calculated using (2) [45]:

$$\Delta I_D = I_{GS-}I_{DD} = \frac{1}{2}\mu_n \Delta I_{SOURCE}\sqrt{\frac{4I_{SOURCE}}{\mu_n}} - \sqrt{\Delta I_{SOURCE}{}^2} \tag{2}$$

Table 1. Design specification for parameters of laser driver

Design parameters	Value of the parameters
laser frequency	20 GHz
laser wavelength	1550.1 nm
Laser drive voltage	15.3 V
Laser drive current	16 mA
Laser beam width	270 nm
Laser bandwidth	50 GHz

In (2) ΔI_D is termed as laser driver current. This laser drive current regulated the current for laser to improve the performance by regulating the current during lasing operation. The developed design of laser driver offers the secure interface between laser and other optical system attached to it. The designed laser driver has the certain limit of regulated current that is 5.6 to 6.8 mA rating and another thing, the heat sink is not provided when temperature is increased. Table 1shows, the specification used for designing the semiconductor laser divers that uses different parameters.

Additional to these parameters the room temperature of the laser driver is also important, if the temperature is increased from junction temperature, the device will produce the uncertain output.

5. Result and Discussion

The semiconductor laser output is controlled using the designed driver. The CML techniques optimized the laser driver output than traditional counterpart. The CML is specially used to design the optical communication systems' components. The CML specification, such as fast switching capabilities, high frequency operation, high bandwidth and low power consumption makes the CML optimum choice to be used for designing the laser drivers. One important characteristics of CML is that, it provides the temperature stability to electronic circuits. Semiconductor laser are very sensitive to temperature change, the small change in temperature can produce large drift current in laser drivers. Figure 3 shows, semiconductor based laser driver response using ideal and CML technique. Figure 3, the ideal efficiency for semiconductor laser driver should be 100 %, but using CML technique, 75% efficiency is achieved.

Various other laser drivers also produce the efficiency up to 80%, but their switching and temperature

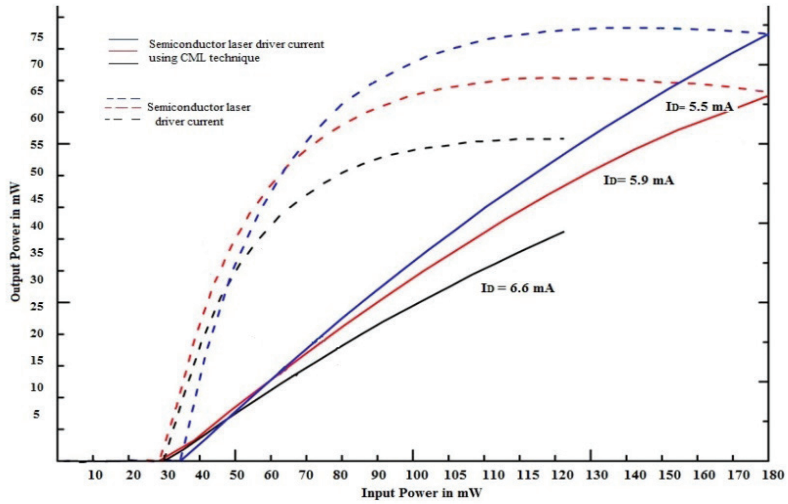

Figure 3. Semiconductor Laser driver current curves with and without CML technique.

dependency; make them less feasible to be used. With our designed CML based semiconductor laser driver, the switching is improved up to 89%, then pervious laser drivers available. This CML laser driver can also produce same efficiency even when the devices are producing 6.6 mA, which is maximum current at room temperature of 24-29 °C. Even though, if the room temperatures are increased up to the 40°C, the device is still sustainable for 5.5 mA to 6.3 mA output ratings. However, in other laser driver cases, when driver produces 6.6 mA the temperature rushes up to 100°C. With this designed we have reduced the temperature sensitivity of the laser driver up to 42%, which is quite appreciable, when operating at high current ratings.

6. Conclusion

It is concluded that deigned CML based laser driver is controlling the output of semiconductor laser ranges from 5.5 mA to 6.6 mA at the frequency of 10 GHz. The additional feature of the design is that the temperature sensitivity is reduced up to 42%, which is significant reduction than available laser drivers. Furthermore, the switching speed is also enhanced up to 89% than previously available semiconductor laser drivers. This designed can fully protect the devices interfaced with the laser driver ahead. In future, it is still need to enhance the design for more range of current for laser driver, so that drivers can produce fast output than their traditional counterparts. Moreover, our upcoming efforts are to demonstrate the designed semiconductor laser driver using SoC. This configuration will not save hardware need but also make the device more energy efficient to make optical communication system green. This type of design increases the accuracy to produce required output without damaging any device.

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