HIGH POWER LASER DIODE DRIVING TECHNIQUES

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The present paper is about driving high power laser diodes. In many areas, such as communication, medicine and military equipments, the high power laser diodes find many applications. In the same time there isn't a lot of literature about their driving. In this paper some driving circuits and algorithms are discussed. The driving circuits are based on the forward d^2 dc/dc converter. They are designed as power sources with current and voltage limitations. The discussed driving algorithms are based on the one-cycle control. Regulation of this type offers high accuracy and high speed reaction.

Keywords: Laser diode, driving, power source.

1. INTRODUCTION - LASER DIODE BASIC REQUIREMENTS

The laser diodes are semiconductor coherent lightening devices [1]. Their work principle is based on the stimulated emission of electrons. The main characteristic of the laser diodes is the dependence between the current floating through the diode I_{LD} and the output light intensity L_{LD} . Typical L/I curve is shown in fig.1.

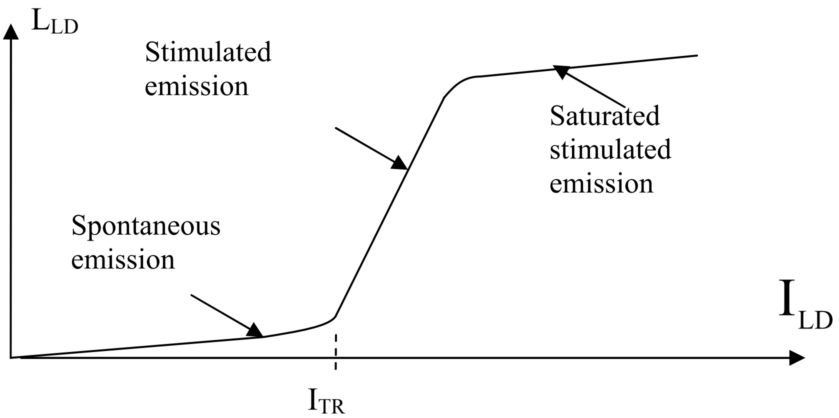


Fig.1 Laser diode L/I curve.

As it can be seen, there are three sections in the L/V curve. In normal working conditions the second section (stimulated emission) is used. It has very good linearity and can satisfy many application requirements.

The laser diodes have very small dynamic resistance (several mΩ). This results in the fact that when there is a small change in the applied voltage, there is much greater change in the floating current. Because of this, the applied electrical power depends mainly on the floating current, as the diode voltage is constant most of the time.

There are two ways to drive such a device. The first way is using current source with output power limitations. In this way although the output power is observed, it is not regulated, but the output current. The second way is using power source with output current and voltage limitations. In this way the output power is regulated, while the output current and voltage are observed.

2. Laser Diode Driving Circuits

Laser diode driving circuits can be built using the standard dc/dc converter topologies. They must be transformed from voltage sources to current or power sources.

In all of the discussed circuits the input voltage E is accepted as constant.

A circuit built on the simplest dc/dc forward bulk converter is shown in fig.2.

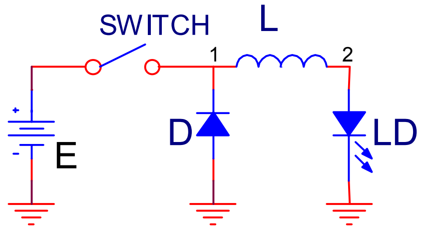


Fig.2 Laser diode driving circuit based on the bulk converter.

It can be derived the regulation characteristic of the circuit:

$$U_{out} = \delta.E \tag{1}$$

where U_{OUT} is the output voltage; E is the input constant voltage; δ is the duty ratio of the circuit, which is set by the controlling circuit.

From (1) it can be seen that the circuit is still voltage source and cannot be used as laser driver.

Let's consider two consecutively connected circuits like the one shown in fig.2. Then we can suppose that the regulation characteristic would be:

$$U_{out} = \delta.E \tag{2}$$

This characteristic is a little bit easier to regulate than (1). The main advantage of such a consecutive connection is the possibility of fractional energy delivering. The circuit's operation is divided in three steps. In the first step in a regulation period T the switches are on and the energy is delivered from the constant voltage source E to the first stage. In the second step the switches are off and the energy is delivered from the first stage to the second one. In the third step, during the next regulation period, the switches are on and the energy is delivered from the second stage to the laser diode. In this manner the portion delivered energy and respectively the output power are set with the choice of duty ratio by the controlling circuit. Circuit, based on these considerations, which basic idea is shown in [2], is illustrated in fig.3.

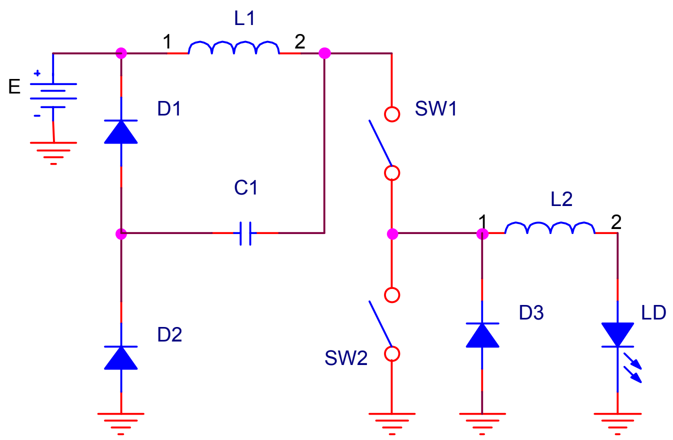


Fig.3 First laser diode driving circuit based on power source.

The following graphs in fig.4 are illustrating the principle of operation of the circuit shown in fig.3.

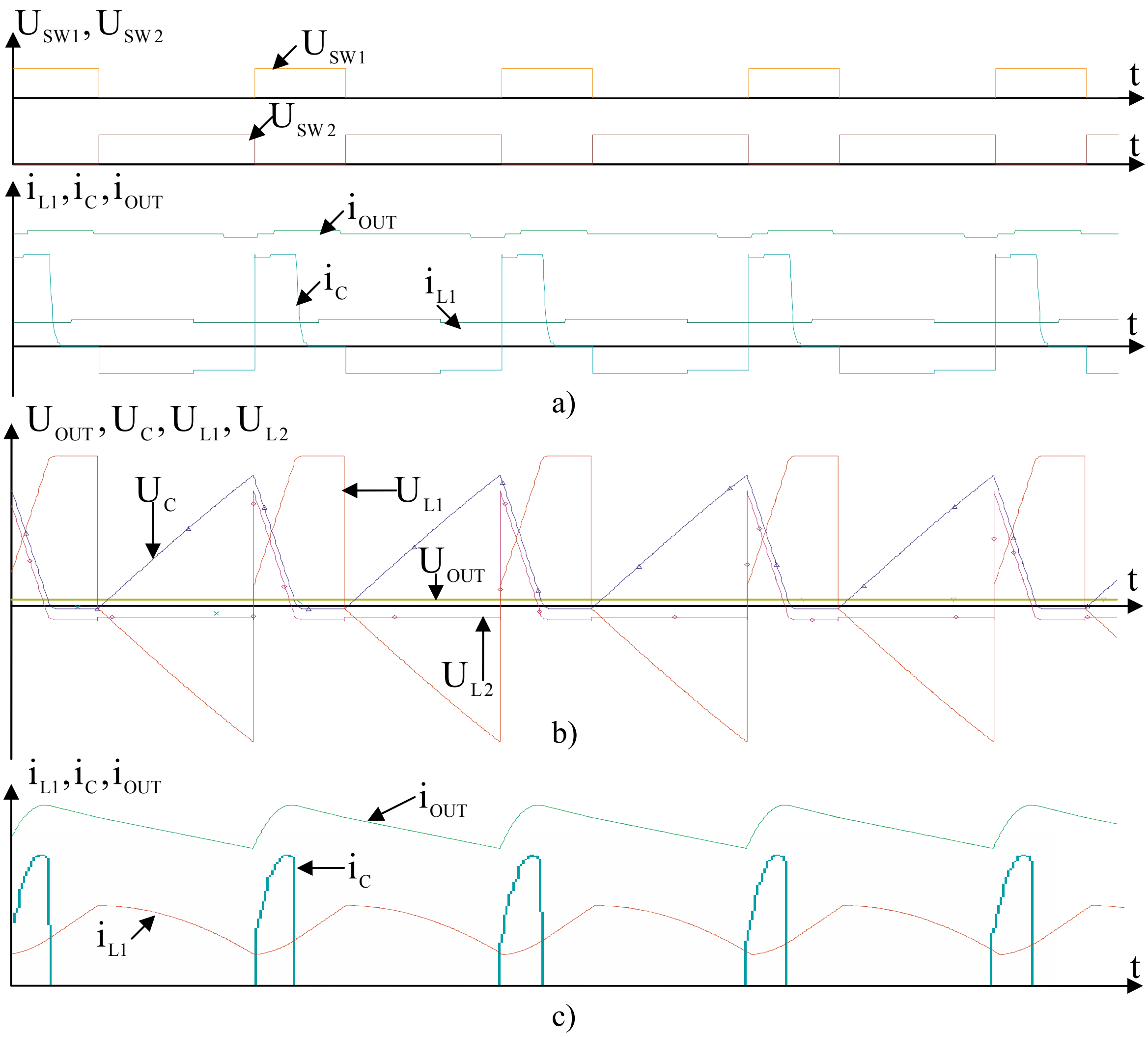
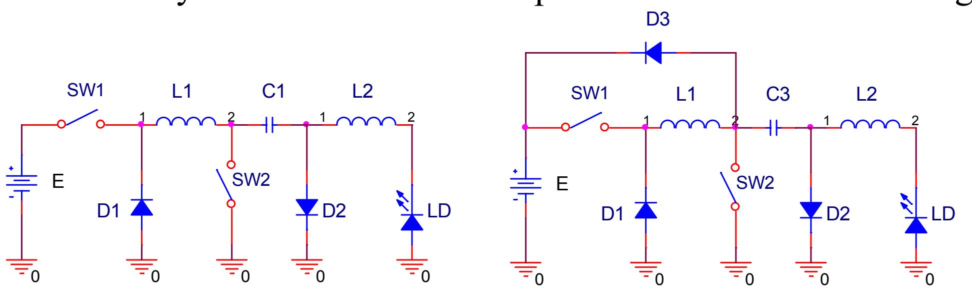


Fig.4 Time-diagrams of: a) Switch controlling voltages U_{CW1}, U_{SW2}; output current i_{OUT}; currents i_C, i_{L1} trough the capacitor C_1 and inductance L_1; b) output voltage U_{OUT}; voltages U_{C1}, U_{L1},U_{L2} over the capacitor C_1 and inductances L_1 and L_2; c) Output current i_{OUT} and the currents i_{L1}, i_C in much larger scale.

For the output power P_{OUT} is derived the equation:

(3) $$P_{out} = I_{out}.U_{out} = \frac{2.C_1.E^2.\delta^2}{T.(1-\delta)^2}$$

The improvement of the circuit goes through avoiding switch SW_1 failure, because it would destroy the laser diode. An improved circuit is shown in fig.5a).



a) b)

Fig.5 a) Second laser diode driving circuit based on power source. b) Third laser diode driving circuit based on power source

The next improvement in the circuit is to limit the maximum voltage across the capacitor, which can rise to high values with control circuit failure. An improved circuit is shown in fig.5b).

The next improvement in the circuit is to separate the currents through the two inductance, which now are floating through switch SW_2. That would make current measurement and observation much easier. An improved circuit is shown in fig.6.

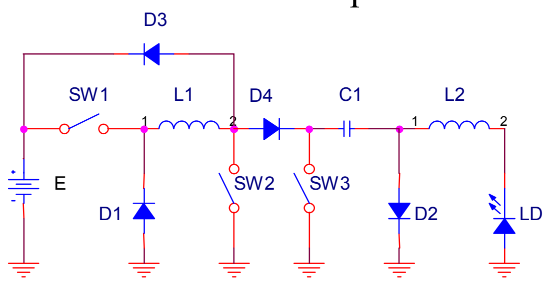


Fig.6 Fourth laser diode driving circuit based on power source.

3. Laser Diode Driving Algorithms

Two basic regulation methods can be used to drive the above circuits.

The first regulation method is based on the classic PWM regulation. A feedback signal, which is proportional to the output power is compared to a periodic signal, which waveform depends on the circuit equations. In linear applications the periodic signal is a ramp. Using this method the regulated circuit parameters first change and after several regulation periods they achieve the desired values.

The second regulation method can be called one-cycle method [3]. A selected circuit signal is observed, until it reaches a specific value. When it happens, the switches commutate. Using this method the circuit parameters are being regulated while they are changing in one period (one-cycle). This significantly decreases the needed regulation time.

An important choice of controlled circuit parameter should be made. If it is the output current, respectively the output power, there are some limitations. The one-cycle control cannot be used, because the output current reaches its specific value – its peak value, during the on-time and before the commutation. As it can be seen from (1-3), the circuit equations are quadratic and the PWM control is very complicated.

As controlled circuit parameters can be used the maximum capacitor voltage U_{CMAX} and the inductor L_1 current i_{L1}. The advantages of inductor current control consist in a step in advance regulation compared to capacitor voltage control. In this way the delivered energy is directly controlled and the protective module has more time to react, if it's necessary.

It can be derived a direct equation between the output power, the circuit elements and the average current I_{L1AV} through the inductor L_1. Therefore the output power can be regulated directly by regulation of the average current I_{L1AV}.

A possible driving algorithm is to compare the moment current i_{L1} trough the conductor L_1 with a constant maximum value I_{L1MAX}. When they become equal, the switches commutate. This method is not accurate, because with constant maximum value and different duty ratios the average current I_{AV} changes. It's shown in fir.7a).

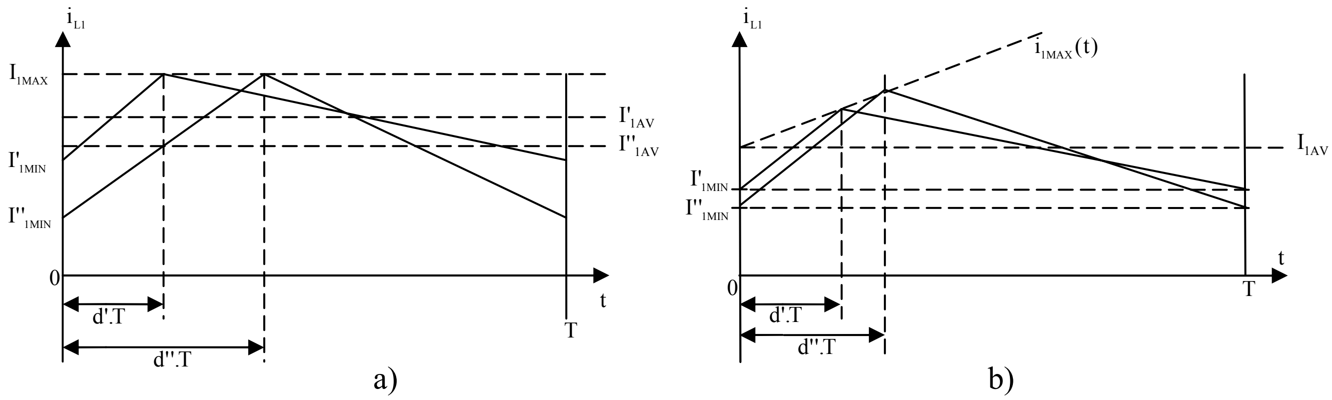


Fig.7 Time-diagrams of: a) Two cases of driving algorithm with comparing to a constant maximum current value I_{1MAX}. Duty ratios (d' and d''), minimal values I'_{1MIN} and I''_{1MIN} and period are shown. b) Two cases of driving algorithm with comparing to a ramp maximum current value $i_{1MAX}(t)$.

Using similar algorithm to maintain constant average value of the current I_{L1AV}, the maximum value must increase linearly with the time. It can be derived that the maximum value must increase twice slower than the moment one.

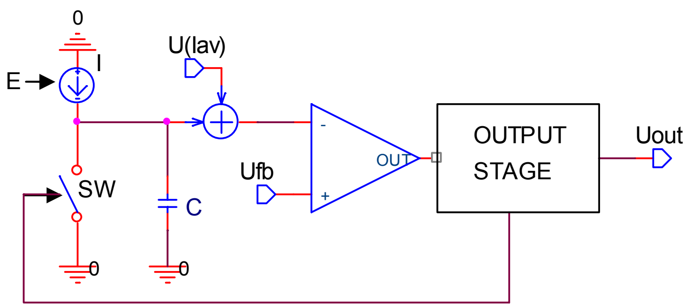
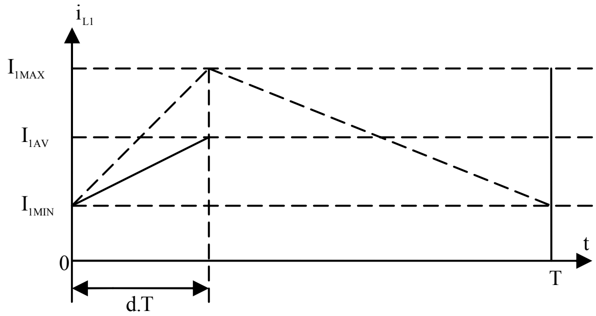


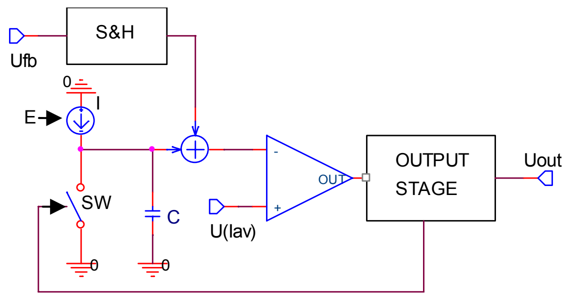
Fig.8 Control circuit, using regulation algorithm, with ramp maximum current value $i_{L1MAX}(t)$.

In fig.8 is shown a control circuit for the described regulation algorithm. The feedback signal U_{FB} is applied to one of comparator inputs. The ramp voltage is applied to its other input. It is a sum of a constant signal $U_{(Iav)}$, proportional to the desired current value, and a ramp signal, formed by a current source (I), capacitor C and switch (SW), controlled by the output stage. For the purpose of elimination the influence of the input voltage fluctuations, the current source (I) is dependent by the input voltage value (E).

Disadvantage of the described method is the absence of noise protection of the feedback signal. Noise protection can be done by taking quickly the feedback signal once a period and saving the received value, until the next period. The most suitable moment to take the feedback signal is the start of the period. The real i_{L1} current slope can be prognosticated, because it depends on the input voltage E and the inductance L_1. Therefore in the control circuit a ramp voltage with twice slower increasing speed can be used. When it reaches the desired average value, the switches commutate. The basic principle of the regulation algorithm is shown in fig.9a).



a)



b)

Fig.9 a) Time-diagram of driving algorithm with prognosticated current slope. A ramp voltage with increasing speed twice slower than the current slope is compared to the desired average current value I_{1AV}. b) Control circuit for the method.

In fig.9b) is shown a control circuit for the described regulation algorithm. A constant signal $U_{(Iav)}$, proportional to the desired average current value is applied to one of comparator inputs. A sum of two signals is applied to the other input. The first one is the feedback, received from the sample and hold circuit (S/H). The second one is a ramp signal, formed by a current source (I), capacitor C and switch (SW), controlled by the output stage.

4. Conclusion

High power laser diode driving circuits based on the δ^2 dc/dc converter, and driving algorithms, based on the one cycle control, were discussed. They give good accuracy, stability and high speed regulation.

5. References

[1] Chang, W. S. C., "Principles of lasers and optics", Cambridge University Press, 2005, pp. 212-245.

[2] http://teslaco.com/circuits.htm

[3] Smedly, K. M., "Control art of switching converters", California Institute of Technology, Pasadena, California, 1991.