DIGITAL REGULATED PARALLEL POWER AND CURRENT SOURCES FOR LASER DIODES DRIVING

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This paper is about some switching regulator improvement techniques, especially designed for high power laser diode driving. The first one consists in the usage of several power stage capacitors connected in parallel, forming a capacitance sum, witch is determining the output current or power. In this way an easier and more accurate digital control over the output parameters is achieved. Another improvement technique consists in the usage of several power stages, connected in parallel. In this way the output pulsations are much less. A practical solution circuit is designed to illustrate the improvement techniques.

Keywords: Laser diode, driving, power source.

1. INTRODUCTION

This paper is about some switching regulator improvement techniques, especially designed for high power laser diode driving. The first one consists in the usage of several power stage capacitors connected in parallel, forming a capacitance sum, witch is determining the output current or power. In this way an easier and more accurate digital control over the output parameters is achieved. Another improvement technique consists in the usage of several power stages, connected in parallel. In this way the output pulsations are much less. A practical solution circuit is designed to illustrate the improvement techniques.

2. PARALLEL CAPACITORS IMPROVEMENT TECHNIQUE

The output power in the widespread switching regulators [1] can be determined only with duty ratio changes by the control circuit. The present paper describes a method and a practical solution, based on changes in a power stage capacitor value to determine the output current. It can be realized using capacitors with certain weight ratio connected in parallel, where every particular capacitor presence in the capacitance sum is determined by the control circuit. A power stage circuit built on these considerations is shown in fig. 1.

The work principle of this circuit is the same as the widespread switching regulators work principle with the only deference that the output power P_{OUT} and the output current I_{OUT} are limited by the capacitors C_i.

$$(1) \quad P_{OUT} = \frac{2.C.E^2}{T} \cdot \frac{\delta^2}{(1-\delta)^2},$$

where T is the regulation period, C is the capacitance sum, δ is the duty ratio and E is the supplying voltage.

The output voltage U_{OUT} can be considered as a constant, because the output load is a laser diode. Then the output current I_{OUT} can be determined by the next formula:

$$(2) \quad I_{OUT} = \frac{2.C.E^2}{T.U_{OUT}} \cdot \frac{\delta^2}{(1-\delta)^2},$$

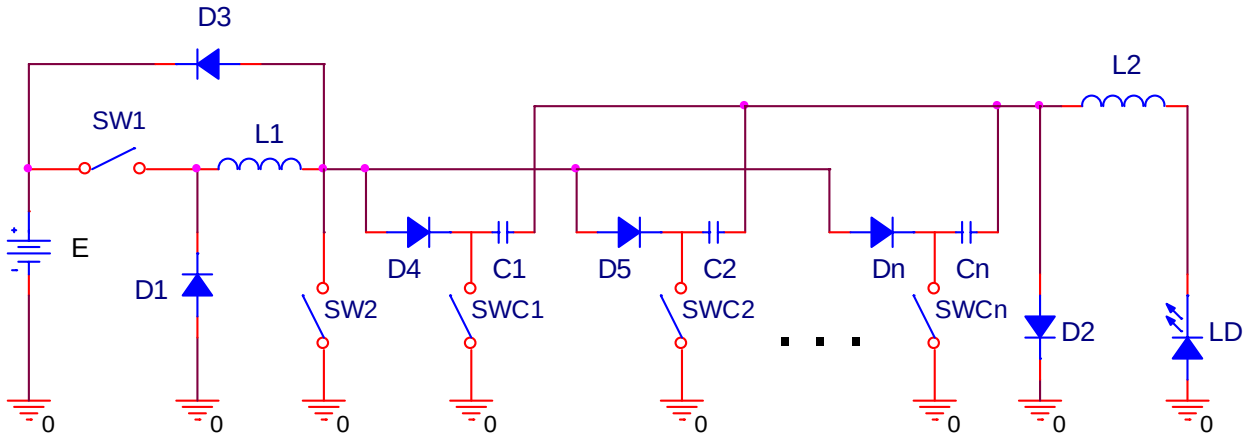

Fig.1 Power and current source circuit

If any of the switches SWC_i, i=1,2,…,n is turned on by the control circuit during the first part of the regulation period, then the capacitor C_i take part in the capacitance sum forming. If any switch SWC_i is turned off by the control circuit during the whole period, then the capacitor C_i is charged a single time to the maximum capacitor voltage U_{CMAX} and doesn't take part in the capacitance sum forming.

To achieve easier circuit regulation, it's convenient to choose the capacitor values with binary weight ratios: $C_1=C_0.2^0$; $C_2=C_0.2^1$; …$C_n=C_0.2^{n-1}$. If any capacitor C_i, i=1,2,…,n, take part in the capacitance sum forming, then we will consider $k_i=1$ and in the other case $k_i=0$. The output current I_{OUT} can be determined by the next formula:

$$(3) \quad I_{OUT} = \left(\sum k_i.2^{i-1}\right) \frac{2.C_0.E^2.\delta^2}{T.U_{OUT}.(1-\delta)^2}$$

The main advantage of this circuit consists in simplified regulation. Another circuit advantage consists in easier to satisfy requirements to the SWC_i switches, because the current flowing through any switch is only its proportional part of the output current.

3. PARALLEL POWER STAGES IMPROVEMENT TECHNIQUE

Several stages (n in number), with the topology shown in fig.1 [2], connected in parallel can be used to reduce the output pulsations. In this case the switch commutation moments are separated in the time between the stages on a step t_{STEP}, determined by the regulation period T and the number of stages n: $t_{STEP}=T/n$. In this

way a phase difference between the separate output stage currents is achieved and the output pulsations are compensated. Simplified connection in parallel of four stages is shown in fig.2.

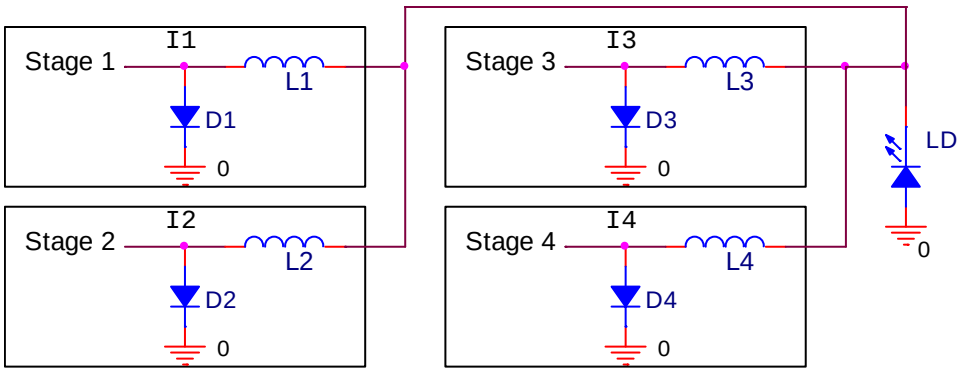

Fig.2 Simplified connection in parallel of four stages

Unwanted interaction between the output stages like flowing one stage output current through another output stage, shunting the laser diode, is impossible. That's impossible because the diodes D_1, D_2, D_3 and D_4, allow only one way current flowing through the laser diode.

If the nth stage output current is I_n, then the output current of the whole device can be calculated as a sum of the stages output currents:

$$(4) \quad I_{OUT} = n.I_n = n.\frac{2.C.E^2}{T.U_{OUT}}.\frac{\delta^2}{(1-\delta)^2}$$

One can see that during a particular stage output current rising, all of the others stage output currents are falling. If Δt is the time period, in witch a particular stage output current is rising, we can consider Δt<T/n. Then during the time interval 0<t<Δt only one particular stage output current is rising and all of the others stage output currents are falling. During this time interval the output current of the whole device i_{OUT} can be determined by the formula:

$$(5) \quad i_{OUT} = \frac{U_{CMAX}}{L_{OUT}}.t - \frac{U_{CMAX}}{2.L_{OUT}.\Delta t}.t^2 + I_{STMIN} + (n-1).I_{STMAX} - \frac{U_{OUT}}{L_{OUT}}\left((n-1).(t-\Delta t) + T.\left(\frac{1}{n}+\frac{2}{n}+\ldots+\frac{n-1}{n}\right)\right),$$

where I_{STMAX} and I_{STMIN} are the maximum and the minimum particular stage output current values and L_{OUT} is the output filter inductor value.

The change in the output current of the whole device ΔI in the time interval 0<t<Δt can be determined by the formula:

$$(6) \quad \Delta I = \frac{U_{CMAX}}{2.L_{OUT}}.\Delta t - \frac{U_{OUT}}{L_{OUT}}.(n-1).\Delta t$$

During the time interval $\Delta t<t<T/n$ all of the stage output currents are falling. In this interval the output current of the whole device can be determined by the formula:

$$(7) \quad i_{OUT} = n.I_{3BMAX} - \frac{U_{OUT}}{L_{OUT}}\left(n.(t-\Delta t)+T.\left(\frac{1}{n}+\frac{2}{n}+...+\frac{n-1}{n}\right)\right)$$

The change in the output current of the whole device ΔI in the time interval $\Delta t<t<T/n$ can be determined by the formula:

$$(8) \quad \Delta I = \frac{U_{OUT}}{L_{OUT}}.(T-n.\Delta t)$$

In normal steady work mode the output current pulsations ΔI can be determined by the formula:

$$(9) \quad \Delta I = \frac{U_{OUT}}{L_{OUT}}.T.\left(1-n.\frac{U_{OUT}}{E}.\frac{1-\delta}{\delta}\right)$$

The relative output current pulsations value can be determined by the formula:

$$(10) \quad \frac{\Delta I}{I_{OUT}} = \frac{T^2}{2.n.C.L_{OUT}}.\frac{U_{OUT}^2}{E^2}.\left(1-n.\frac{U_{OUT}}{E}.\frac{(1-\delta)}{\delta}\right).\frac{(1-\delta)^2}{\delta^2}$$

One can see, that as greater is the number of the stages, the output pulsations are less.

In practical circuit designing with determined output current of the whole device, the next formula can be used:

$$(11) \quad \frac{\Delta I}{I_{OUT}} = \frac{U_{OUT}.T}{I_{OUT}.L_{OUT}}.\left(1-n.\frac{U_{OUT}}{E}.\frac{1-\delta}{\delta}\right)$$

A typical dependence between the output current of the whole device and the duty ratio with several values for n, is shown in fig.3.

The chosen circuit parameters are as follows: E=48V; I_{OUT}=30A; U_{OUT}=1.9V; L_{OUT}=15μH; T=5μs.

As one can see in fig.3, with increasing the number of the stages n, the duty ratio can be chosen in wider range and the output pulsations are decreasing.

Increasing the number of the stages n meets two circuit limitations. The first one ensues from inadmissible circuit complicating and dimensions increasing. The second one ensues from the maximum possible control circuit speed, witch has limits. The control circuit must be able to separate the regulation period into n equal parts and to determine the time interval $0<t<\Delta t$ with sufficient accuracy.

In practical solutions the switching elements are realized by MOSFET transistors. An appropriate MOSFET driver must be chosen. The MOSFET transistors are driven by the gate to source voltage. Therefore the control signal should be applied to the transistor gates with consideration of the source potential. The switch elements

SW_2,SWC_1,…,SW_{Cn} in the circuit shown in fig.1, are connected to the ground. This means that the corresponding transistor sources are connected to ground and allows the control signal to be directly applied to the transistor gates. The switch SW_1 corresponding source is not connected to the ground and therefore there must be galvanic separation to drive the transistor. A practical solution circuit, based on these considerations is shown in fig.4.

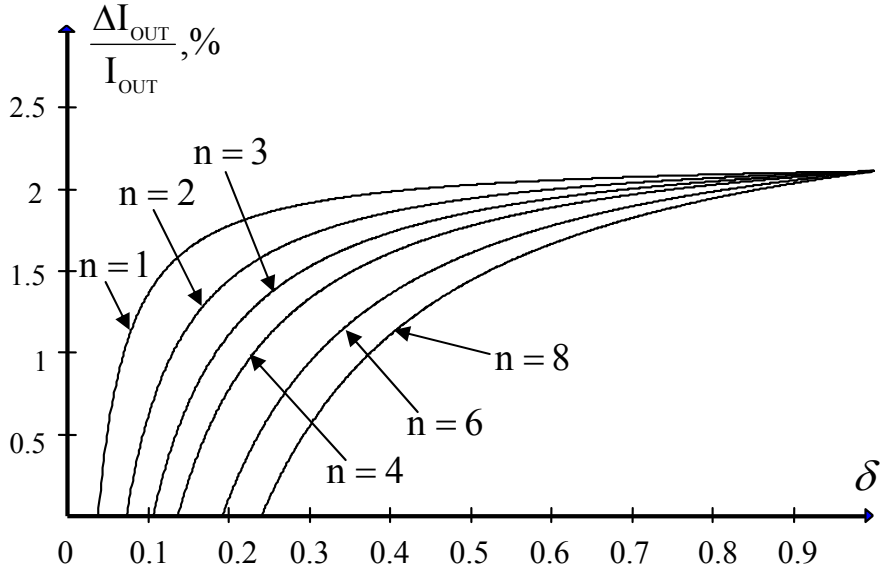

Fig.3 A typical dependence between the output current of the whole device and the duty ratio with several values for n.

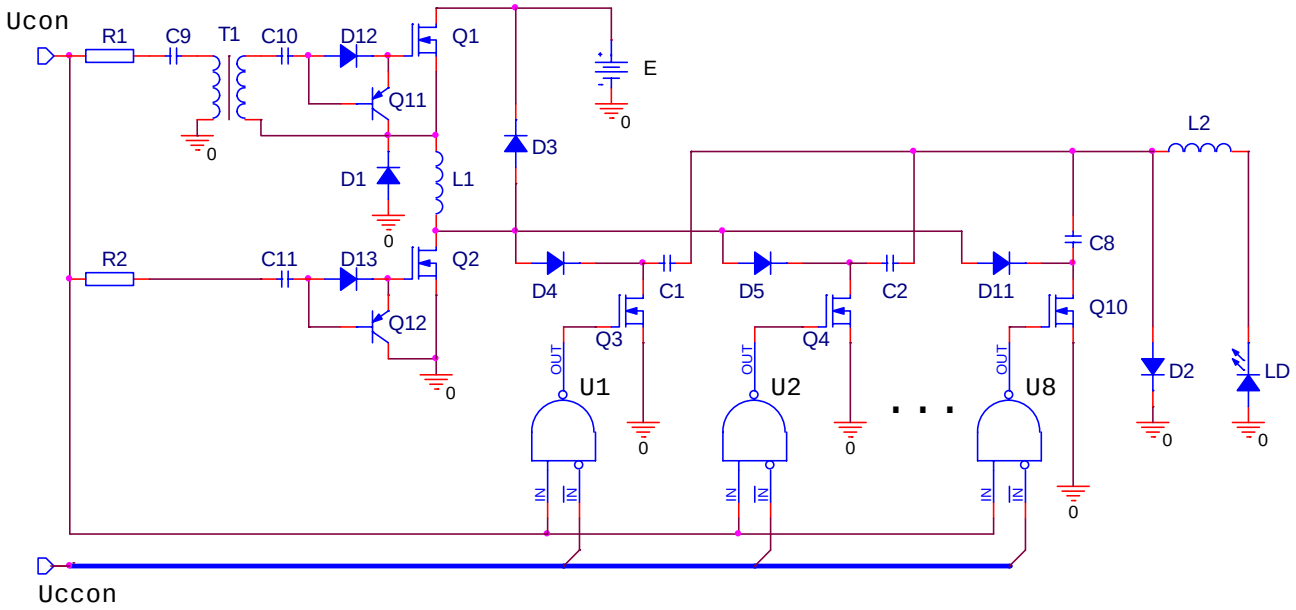

Fig.4 A practical solution circuit

As one can see from fig.4, the switch SWC_1, SWC_2,…, SWC_n driving is realized by logical multiplication of two control signals: U_{CON} and U_{CCON}. The logical

multiplication can be realized by specialized two gate integral circuits, specially designed to drive power MOSFET switches. Decreasing in the switch SW_1 and SW_2 transient period is achieved by using the capacitors C_{10} and C_{11}, the diodes D_{12} and D_{13}, the bipolar transistors Q_{11} and Q_{12}.

4. CONCLUSION

1. An advantage of the described circuit is its easy logical control.
2. There isn't any interaction between the separate stages like flowing one stage output current through another stage.
3. With increasing the number of the stages n, the duty ratio can be chosen in wider range and the output pulsations are decreasing.
4. Increasing the number of the stages n is limited by the maximum control circuit speed. It must be able to separate the regulation period into n equal parts and to determine the time interval $0<t<\Delta t$ with sufficient accuracy

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.