Linear-assisted DC/DC regulator-based current source for LED drivers

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A proposal of current source based on a linear-assisted DC/DC converter is presented, in which a linear voltage regulator assists a switching DC/DC converter in order to obtain a compact circuit with advantages of both alternatives; i.e. high efficiency (similar to the switching converter), and low output ripple and fast reaction to the load changes (similar to the linear regulator). To reduce the power dissipation in the linear regulator, it is considered as an assisted circuit for providing just a little fraction of the load current. Furthermore, this stage provides the required clock signal for the switching counterpart, resulting in reduction of the complexity in the design of the control scheme for the switching converter and a compact topology, especially for on-chip practical implementations, since no output capacitors are required. This last advantage provides the possibility of obtaining good-performance current-source drivers for LED technology in lighting applications. The implementation and results indicate that the proposed linear-assisted DC/DC regulator-based current source can achieve a notably compacting and higher performance, while consuming less power in comparison to linear alternatives.

Introduction: In recent years, the demands for energy-saving, perennial, and low-cost lighting sources have been increased. Nowadays, the paradigm of the aforementioned lighting sources is based on LED technology. In fact, high efficient and reliable LED chips with enhanced packaging have been presented for last year's [1, 2]. However, providing low cost and reliable LED drivers, which play an important role in a high quality LED lighting fixture, is still a challenge.

Nowadays there are two common driver methods for LED light sources: (i) voltage regulatory LED driver circuits and (ii) constant current LED driver circuits. However, the constant current alternative is favourable for obtaining improved performance LED drivers. It has some interesting advantages; e.g. under constant current circuit, the output current remains stable and constant while the output voltage varies with load resistance values. In addition, the constant current LED driver circuit can still work under short-cut circuit circumstance. Thus, for LED lighting applications, constant current circuit is rather plausible although the cost could be undesirable in some implementations. Current sources can be implemented using linear implementations. However, they have poor efficiency as a main disadvantage. The second possibility is to use switching-mode current sources. In this case, although the efficiency that can be achieved is good enough, the design, especially the control block, and their practical implementation is a complicated and difficult task. This Letter presents an alternative of current source based on linear-assisted DC/DC converter, in which a linear block assists a switching DC/DC converter in order to achieve a circuit with advantages of both alternatives.

Concept and description: A linear-assisted DC/DC regulator (Fig. 1*a*) consists of a parallel combination of a linear regulator and a switching DC/DC converter. The control of the second one is carried out by sensing the current flowing through the linear regulator $i_{reg}(t)$ and using a hysteretic control realised by an analogue comparator, through which the switching frequency is fixed [3, 4]. To maintain the efficiency at the same level of a sole buck converter, the linear regulator is considered as an *assisting* circuit for providing just a little fraction of the load current while the excess current is supported by the switching converter. Consequently, the output current can be written as

$$I_{out} = i_{reg}(t) + i_L(t) \tag{1}$$

The boundary current, named *threshold switching current*, I_γ, is determined by the reference voltage V_{ref} and the sensor transresistance R_m, as below:

$$I_\gamma = V_{ref}/R_m \tag{2}$$

When the load current is lower than I_γ, the switching converter will be disabled and, as a consequence, the load current is satisfied by the linear regulator. Nevertheless, for a load current greater than I_γ, the switching converter is enabled through the control signal provided by the analogue comparator, increasing the converter output current linearly, in order to provide the excess load current. In this case, considering that the load current is constant and equal to V_{out}/R_L, the current of linear regulator $i_{reg}(t)$ will tend to decrease in a linear way (Fig. 1*b*), just reaching a value below I_γ. It is noted that, selecting a suitable I_γ (with the objective of not decreasing the efficiency), the circuit has the capability to provide almost all the output current I_{out} thanks to the switching DC/DC converter. In fact, under these conditions, only a few part of the aforementioned output current is provided by the linear regulator, which acts as an 'active output capacitor' in order to remove output voltage ripples.

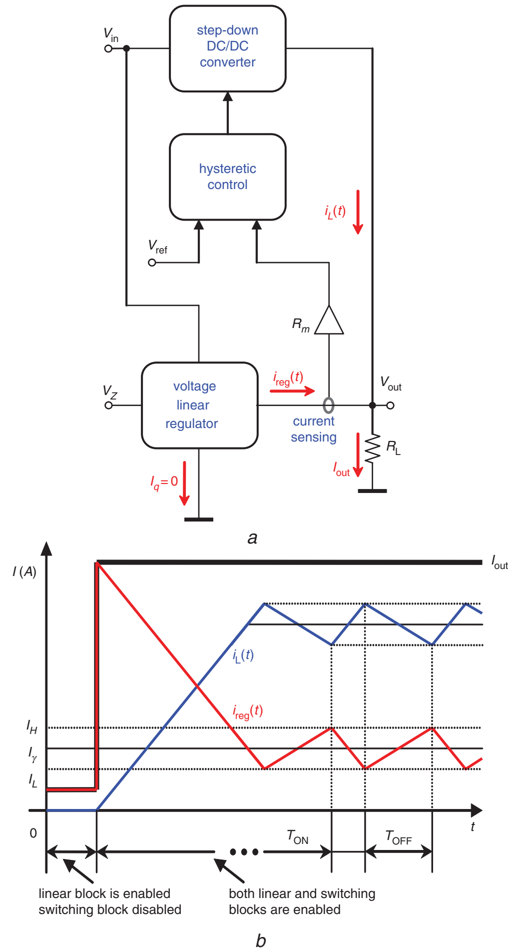

Fig. 1 *Linear-assisted DC/DC hybrid voltage regulator that supplies load R_L*
a Block diagram of basic structure
b Output load current (I_{out}), switching DC/DC converter's output current ($i_L(t)$) and linear voltage regulator' current ($i_{reg}(t)$) in steady state

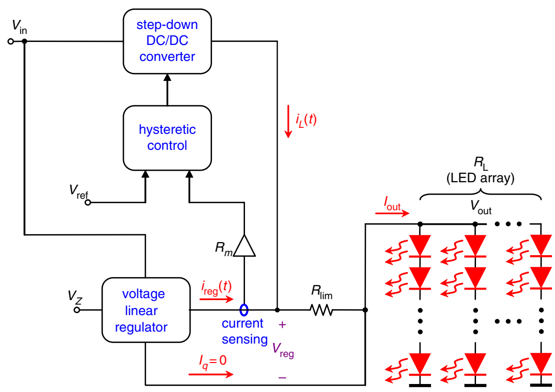

Fig. 2 *Block diagram of proposal of the linear-assisted DC/DC regulator-based current source that supplies LED array*

Proposed circuit: Figs. 2 and 3 show the block diagram and circuit implementation, respectively, of the proposal for the linear-assisted DC/DC regulator-based current source. R_{lim} together with the voltage provided by the linear regulator fixes the load current according to

$$I_{out} = V_{reg}/R_{lim} \tag{3}$$

Therefore, if the output voltage V_{reg} of the linear regulator is constant (thanks to its reference voltage V_Z), the output current provided by the circuit will be also constant, independently of the load. In addition, like the linear-assisted DC/DC voltage regulator (Fig. 1*a*), in the linear-assisted-based current source the output current is given by (1). Again, both reference voltage V_{ref} and sensor transresistance R_m determine the value of the threshold switching current I_γ, according to (2). This is the maximum value of the average current flowing through the linear regulator block, as we can appreciate in Fig. 1*b*. Thus, if the output current overtakes this value, the difference will be provided by the switching converter.

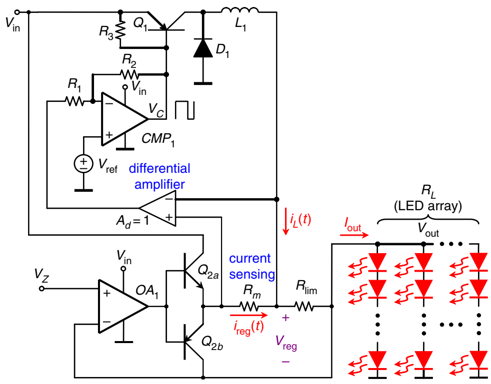

Fig. 3 *Circuit implementation of linear-assisted DC/DC regulator-based current source*

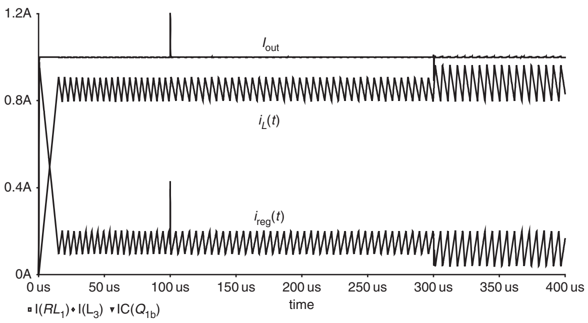

Fig. 4 *Output current and currents flowing through buck converter's inductance L_1, and linear regulator in steady state*

Results and comparison: The discussed linear-assisted DC/DC regulator-based current source is designed and simulated using a discrete implementation in order to explore and characterise the validity of the proposals. Fig. 4 shows the transient response from a system that provides 1.0 A at the output load (adjusting $R_{lim} = 0.5\ \Omega$ and $V_Z = 0.5$ V). The value of the inductor is $L = 100\ \mu$H and $I_\gamma = 200$ mA (adjusting $R_m = 1\ \Omega$ and $V_{ref} = 0.2$ V). At $t = 100\ \mu$s the load changes from 3 to 2 Ω (a decrease of 50%), and the input voltage increases from 10 to 15 V (a variation of 50%) at $t = 300\ \mu$s. Notice the required independence of the output current from input voltage variations and output load variations. Finally, in order to corroborate the efficiency of the proposed current source, Fig. 5 shows the efficiency of the circuit compared to the single switching and linear blocks. Notice that the efficiencies for the linear-assisted current source and switching DC/DC converter are very similar, especially in full-load conditions. In particular the maximum efficiency for the whole regulator-based current source is 89% when the maximum efficiency for the switching converter is slightly higher (around 90%).

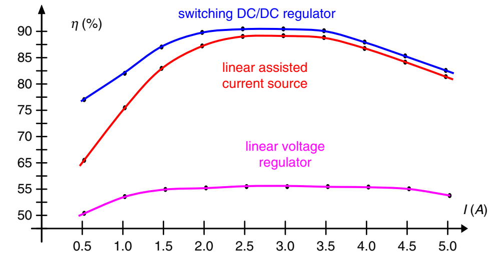

Fig. 5 *Comparison of efficiencies of switching DC/DC regulator (blue line), linear-assisted current source (red line) and linear-voltage regulator (pink line) with respect to variation in output current*

Conclusion: In this Letter, a proposal of current source based on a linear-assisted DC/DC converter is presented, in which a linear voltage regulator assists a switching DC/DC converter in order to obtain a compact circuit with advantages of both alternatives. The power dissipation of the linear regulator is considered low as it provides just a little fraction of the load current. Furthermore, this stage provides the required clock signal for the switching counterpart, resulting in reduction of the complexity of the control circuit required for the switching converter. Thus, the linear regulator is considered as an *assisting* circuit for providing just a little fraction of the load current while the excess current is supported by the switching converter. In addition, an on-chip compact implementation can be achieved due to eliminating the output capacitors, providing the possibility of obtaining good-performance current-source drivers for LED technology in lighting application. The implementation and results indicate that the proposed linear-assisted DC/DC regulator-based current source can achieve a notably compacting and higher performance, while consuming less power, in comparison to linear alternatives.

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