Single-Input Dual-Output (SIDO) Linear–Assisted DC/DC Converter

H. Martínez [(1)], J. Silva-Martinez [(2)], A. Conesa [(1)], and A. Poveda [(3)]

[(1)] College of Industrial Engineering of Barcelona (EUETIB)
Department of Electronics Eng.
Technical Univ. of Catalonia (UPC)
C/ Comte d'Urgell, 187.
08036 Barcelona. SPAIN
herminio.martinez@upc.edu

[(2)] Analog and Mixed Signal Center
Electrical and Computer Engineering Department (ECE)
Texas A&M University
College Station, TX, 77843-3128, USA
jsilva@ece.tamu.edu

[(3)] School of Telecommunications Engineering of Barcelona (ETSETB)
Department of Electronics Eng.
Technical Univ. of Catalonia (UPC)
C/ Gran Capitán s/n, Ed. C4,
08034 Barcelona. SPAIN
poveda@eel.upc.edu

***Abstract*— This article describes a single-input dual output (SIDO) linear-assisted DC/DC converter. Linear-assisted DC/DC converters are structures that allow to take advantages of the two classic alternatives in the design of power supply systems: voltage linear regulators and switching DC/DC converters. Thanks to the combination of a switching converter and two voltage linear regulators, the proposed SIDO converter provides two independent outputs with suitable load and line regulations. In the presented topology the SIDO linear-assisted DC/DC converter operates at the boundary of continuous conduction mode (CCM) and discontinuous conduction mode (DCM) with variable switching frequency.**

I. Introduction

Recently, multiple regulated supply voltages are becoming a need in many electronics applications that require different supply voltages for different function modules. Possible applications include mobile phones, microprocessors, wireless transceivers, personal digital assistant (PDAs), etc. [1]. In order to obtain these output voltages, switching converters and voltage linear regulators have become an indispensable part of many power-management systems [2]-[6]. As all designers put effort into size reduction, a converter with different output voltages cannot stay out of that trend, forcing designers to find a method to shrink the size in both on-chip and off-chip implementations [7]. Of all of the approaches, single-inductor single-input multiple-output (SIMO) converters come to prevail.

SIMO converters can support more than one output while requiring only one off-chip inductor, promising many appealing advantages, in particular the reduction of bulky power devices, including inductors, capacitors and control ICs [1], [7]. In this way, the cost of mass production is remarkably reduced. Therefore, SIMO topology shows up as the most suitable and cost-effective solution in the future development of power management systems, attracting many manufacturing companies with different applications in portable devices. However, it is still a big challenge to find the best method for the implementation of this sort of converter.

In order to obtain these SIMO converters, two main alternatives have been historically used: (1) The use of voltage series linear regulators, that have been widely used for decades [8]-[11], and (2) the use of DC/DC switching converters, thanks to which high current power supply systems can be obtained [12]-[14]. However, linear-assisted DC/DC converters (also known as linear-switching hybrid converters) are circuital structures that present an increasing interest to implement power supply systems that require two important design specifications: (1) high slew-rate of the output current and (2) high current consumption by the output load. This is the case of the systems based on modern microprocessors and DSPs, where both requirements converge [15], [16].

Linear-switching hybrid converters are compact structures that preserve the well-known advantages of the two typical alternatives (voltage linear regulators and switching converters) mentioned above for the implementation of DC/DC voltage regulators, diminishing as well their drawbacks.

Linear-assisted DC/DC converters can be implemented on printed circuits using discrete components. Nevertheless, they are also an attractive alternative susceptible to be integrated in on-chip power supply systems as a part of the power management system, especially in SIMO DC/DC converters.

II. Basic Topology of a Linear-Assisted DC/DC Converter

The basic scheme of a single-input single-output (SISO) linear-assisted converter is shown in figure 1.*a* [17], [18]. This structure consists, mainly, of a voltage linear regulator ***in parallel*** with a step-down switching DC/DC converter. In this type of converters, the value of the output voltage, theoretically constant, is fixed with good precision by the voltage linear regulator. The current through the linear regulator is constantly sensed by the current sense element R_m. Based on this value, the controller activates or not the output of comparator CMP_1 which controls the switching element of the DC/DC converter. Notice that the current flowing through the linear regulator constitutes a ***measurement of the error*** of the power supply system.

The power stage (that is, the switching converter) injects at the output the current required to force to a minimum value the current flowing through the linear regulator. As a consequence, it is obtained, altogether, a power supply system in which the switching frequency comes fixed, among other parameters (such as the possible hysteresis of the analog comparator), by the value of the current flowing through the linear regulator. In the linear-assisted converter shown in figure 1.*b*, a step-down (buck) switching converter [19], [20] is used. On the other hand, the linear regulator consists of a push-pull output stage (transistors Q_{2a} and Q_{2b}). In this strategy, the main objective of the DC/DC switching converter is to provide ***most of*** the load current in steady-state conditions (to obtain a good efficiency of the whole system). Thus, in steady state, the linear regulator provides a small part of the load current, maintaining the output voltage to an acceptable DC value.

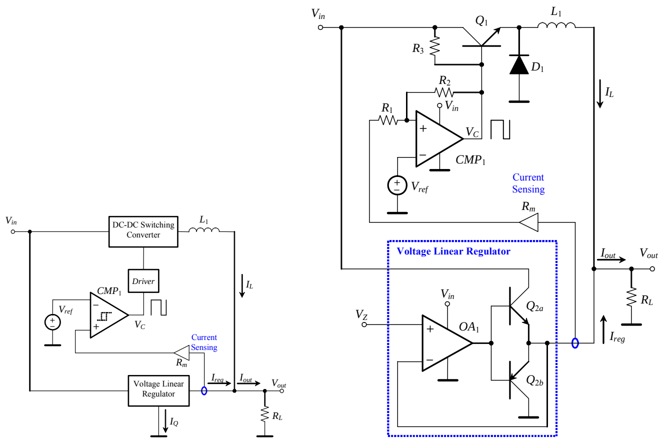

Fig. 1.- (*a*) Block diagram of the proposed linear-assisted converter. **(*b*)** Basic structure of the proposed linear-assisted DC/DC converter.

If the current demanded by the load I_{out} is inferior to a maximum value of current, denominated ***switching threshold current***, $\boldsymbol{I_\gamma}$, the output of comparator CMP_1 will be at low level, disabling the DC/DC switching converter. Thus, the current through inductor L_1 will be zero (figure 2). Therefore, the voltage linear regulator supplies the required output current ($I_{reg}=I_{out}$).

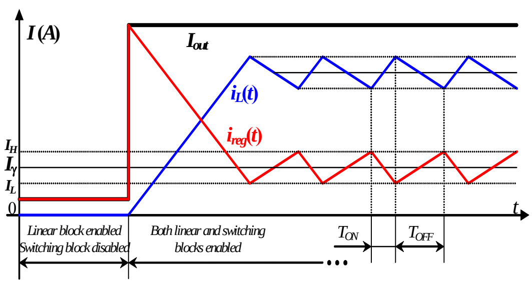

Fig. 2.- Principle of operation of the proposed linear-assisted DC/DC converter.

However, when the current demanded by the load overpasses this current limit I_γ, automatically the output of the comparator will pass to high level. As a consequence, the current flowing through the inductance L_1 will grow linearly according, approximately, to equation (1)

$$i_L(t) = \frac{V_{in} - V_{out}}{L_1} t + I_L(\tau_1) \qquad (1)$$

In this expression, the conduction collector-emitter voltage of transistor Q_1 is ignored. $I_L(\tau_1)$ is the initial value of the inductor current at the time interval T_{ON}. Considering that the output current $I_{out}=I_{reg}+I_L$, and is assumed to be constant (equal to V_{out}/R_L), the linear regulator current I_{reg} will decrease also linearly, until becoming slightly smaller than I_γ. At this moment, the comparator will change its output to low level, cutting the switch transistor Q_1 and causing that the current trough the inductor decreases according to:

$$i_L(t) = -\frac{V_{out}}{L_1} t + I_L(\tau_2) \qquad (2)$$

In this expression, it is considered that the diode D_1 is ideal (with zero direct voltage). $I_L(\tau_2)$ is the peak value of the inductor current (just at the beginning of the interval T_{OFF}). When the inductor current decreases to a value in which $I_{reg}>I_\gamma$, the comparator changes its state to high level, repeating the cycle again.

Without hysteresis in the comparator, the switching instant of the DC/DC converter is given by the *switching threshold current*, I_γ, of the linear regulator. This one can be adjusted to a value thanks to the gain of the current sensing element, R_m, and the reference voltage V_{ref}, according to the expression:

$$I_\gamma = \frac{V_{ref}}{R_m} \qquad (3)$$

In case of considering a comparator without hysteresis, intrinsic delays of the electronic circuits determine a small hysteresis that limits the maximum value of the linear-assisted converter switching frequency. However, with the objective of fixing this switching frequency to a practical value in order not to increase significantly losses by the switching process, it is important to add the aforementioned hysteresis to the comparator CMP_1 (figure 1.*b*). Denoting V_H and V_L as the superior and inferior levels switching of this comparator (figure 2), the value of this frequency can be determined as [19], [20]:

$$f = \frac{R_m}{L_1}\frac{V_{out}}{V_H - V_L}\left(1 - \frac{V_{out}}{V_{in}}\right) = \left[\frac{R_m}{L_1\left(V_H - V_L\right)}\left(\frac{V_{out}}{V_{in}}\right)\left(1 - \frac{V_{out}}{V_{in}}\right)\right] V_{in} \qquad (4)$$

The plots in figure 3 show how the switching frequency (normalized to the maximum frequency) varies as a function of the output voltage (normalized to the input voltage, V_{out}/V_{in}) and as a function of the input voltage (normalized to the output voltage, V_{in}/V_{out}). Notice that, on the one hand, fixing the input voltage V_{in}, the maximum switching frequency is given when $V_{out}=V_{in}/2$. On the other hand, it can be shown that for a fix V_{out}/V_{in}, the switching frequency is linearly related with V_{in}.

It is important to emphasize that reducing the value of the power dissipated in the pass transistor of the linear regulator increases the efficiency of the set, even for significant output currents. Therefore, it is important to fix the current limit I_γ to an appropriate value between the minimum necessary to operate the regulator properly but without penalizing its good characteristics of regulation. For commercial voltage linear regulators, this value is around few *mA*. In fact, in figure 4 we can appreciate the output current and the current flowing through the inductor and the linear regulator when the switching threshold current I_γ is adjusted to 50 *mA*. In this simulation the reference voltage V_Z=5 *V*. Transient response of the converter can be observed with V_{in}=10 *V*. It is also shown the circuit response to a step of the converter input voltage from 10 *V* to 13 *V* at *t*=20 µs, as well as the transient from a reduction of the load resistance of the 100%, from 5 Ω to 2.5 Ω at *t*=40 µs. Notice that the regulation of the output voltage is excellent under all operating conditions.

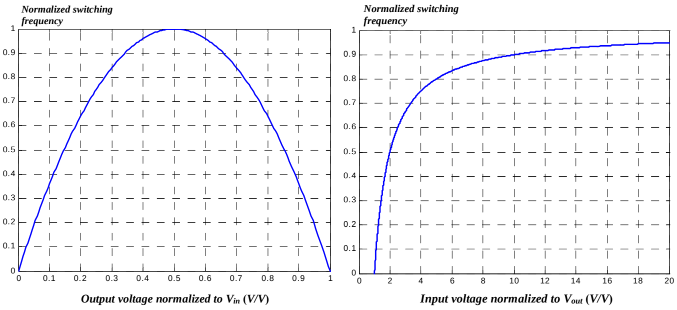

Fig. 3.- Switching frequency normalized to the maximum frequency as a function of the output voltage (normalized to the input voltage, V_{out}/V_{in}) and as a function of the input voltage (normalized to the output voltage, V_{in}/V_{out}).

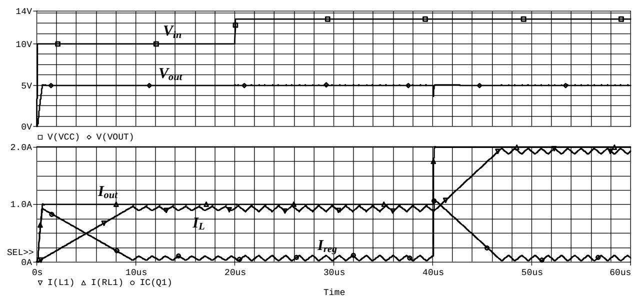

Fig. 4.- Response of the converter shown in figure 1.*b* with V_{in}=10 *V*. In addition, it can be seen the circuit response to a step of the input voltage from 10 *V* to 13 *V* at *t*=20 µs, and a variation in the load resistance from 5 Ω to 2.5 Ω at *t*=40 µs. The switching threshold current I_γ has been fixed to 50 *mA*.

In figure 5 we can appreciate the system behavior when the threshold current I_γ is 10 *mA*. Notice that the regulation of the output voltage degrades significantly when the current I_γ is reduced down to small values. Therefore, the switching current threshold must be set at a value such that:

- It does not significantly increase the power dissipation of the pass transistor in the linear regulator and does not excessively diminish the efficiency of the linear-assisted converter.
- It does not significantly deteriorate the regulation of the output voltage.

Thus, we can denominate this type of control as a ***strategy control with nonnull average linear regulator current***. After some simulations it can be concluded that, for load currents below 10 *A*, the suitable value of I_γ that fulfills the two previous conditions is found to be between 10 *mA* and 50 *mA*.

The proposed linear-assisted DC/DC converter is suitable for SIMO linear-assisted DC/DC converters. Next sections are devoted to the extension of a single-output linear-assisted converter to obtain a SIDO converter.

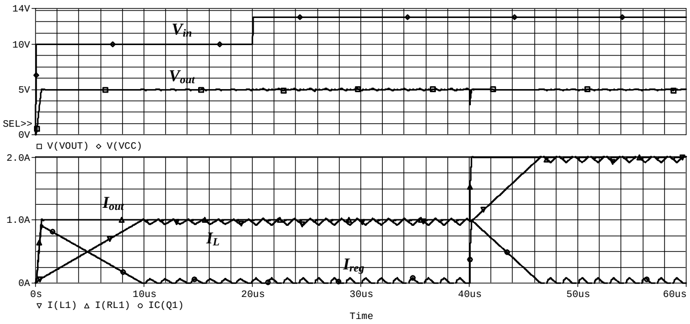

Fig. 5.- Transient response of the converter in figure 1.*b* with V_{in}=10 *V*. It can also be observed the response of the circuit to a input voltage step from 10 *V* to 13 *V* at *t*=20 µs, and a variation in the load resistance from 5 Ω a 2.5 Ω at *t*=40 µs. The switching threshold current I_γ is fit in this case to 10 *mA*.

III. Basic Topology of the SIDO Linear-Assisted DC/DC Converter

From the structure of a single-output linear-assisted DC/DC converter, the extension to a SIDO linear-assisted DC/DC topology is now developed. Based on figure 1.*b*, the structure of the SIDO linear-assisted DC/DC converter is obtained as shown in figure 6. In this topology, two identical voltage linear regulators (*A* and *B*), one for each output, are employed and one buck DC/DC switching converter (without the output capacitor) provides part of the output current for the two outputs. In the presented topology the SIDO linear-assisted DC/DC converter operates at the boundary of continuous conduction mode (CCM) and discontinuous conduction mode (DCM) with variable switching frequency.

On the other hand, four switches, which determine the operation phases of the DC/DC converter, channel the inductor current of the switching converter. In this case, synchronous rectification is a technique in order to replace free-wheeling diodes by transistors with low on-resistance, and emulate the diodes by switching off the transistors when the circuit currents attempt to flow in the reverse direction.

Thanks to the current sensing circuit, the controller generates the control signals for the four switches of the SIDO linear-assisted DC/DC converter. In this particular application, it is necessary to sense the two output currents (sensing signals V_{SO1} and V_{SO2}). On the other hand, the current flowing through the inductor of the switching converter (sensing signal V_{SL1}) has to be sensed too.

The controller block can be constructed in order to implement different control algorithm as shown in the following section.

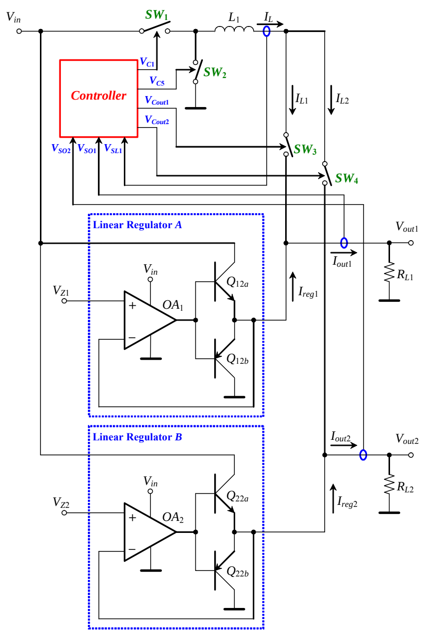

Fig. 6.- Basic structure of a SIDO linear-assisted DC/DC converter.

IV. Control Algorithms of the SIDO Linear-Assisted DC/DC Converter

The idea of SIMO control algorithms has been disclosed in different papers [21]. In classical approaches, the control and timing scheme is a form of ***time division multiplexing***. This time multiplexing can be extended from two outputs (SIDO converter) to N outputs, and each output should occupy a time slot for charging and discharging the inductor, to form a SIMO converter. In all cases, the structure can work with constant or variable switching frequency.

For a multiple-output converter with stable outputs, each output should be independently regulated. If the output voltage of a subconverter is affected by the change of load of another subconverter, ***cross regulation*** occurs. This is an undesired effect that, in the worst case, could make the system unstable [1], [21].

An important component of the proposed SIDO structure shown in figure 6 is the control of the four switches that determine the phases of the operation of the DC/DC converter. As it was mentioned earlier, in this topology the SIDO linear-assisted DC/DC converter operates at the boundary of CCM and DCM with variable switching frequency. In the first control algorithm considered in this work (figure 7), each period is divided into three phases, not necessarily of equal duration. In phase 1, the inductor is charged from 0 A to the bigger of the two output current (I_{out1} in our case). In phase 2, the inductor discharges into the first converter until I_L becomes smaller than the lower output current (I_{out2} in our case). Finally, in phase 3, the inductor drains I_L into the second converter until I_L=0. It should be evident that information from both subconverters is needed to determine which of the two output currents is the biggest, and any change in one phase necessarily affects the other two phases that makes the control of the two output interdependent.

A similar argument can be applied to the second control algorithm (figure 8). In this case, for the control scheme, the SIDO linear-assisted DC/DC converter also operates at the boundary of CCM and DCM with variable switching frequency. In particular, for converter A, the ramp-up time of the inductor is given by $D_{1a}T$ and the ramp-down time is $D_{2a}T$, being D_{1a} the cycle ratio for output 1 and T the switching period of the converter. Similar definitions can be applied to the subconverter B: The ramp-up time of the inductor is given by $D_{1b}T$ and the ramp-down time is $D_{2b}T$, being D_{1b} the duty ratio for the output 2. Note that $D_{1a}T$, $D_{2a}T$, $D_{1b}T$, $D_{2b}T$ (and thus the period T) are subjected to change according to the load currents I_{out1} and I_{out2}. Therefore, the converter works in pulse-frequency modulation (PFM).

Notice that the aforementioned topologies and algorithms can easily be extended to generate multiple output voltages.

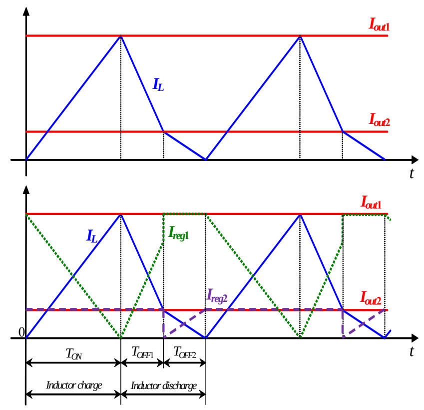

Fig. 7.- Current waveforms of the SIDO linear-assisted DC/DC converter with control strategy A: through the load 1 and load 2 (red color traces), inductance L_1 (blue trace), linear regulator 1 (discontinuous green trace) and linear regulator 2 (discontinuous violet trace).

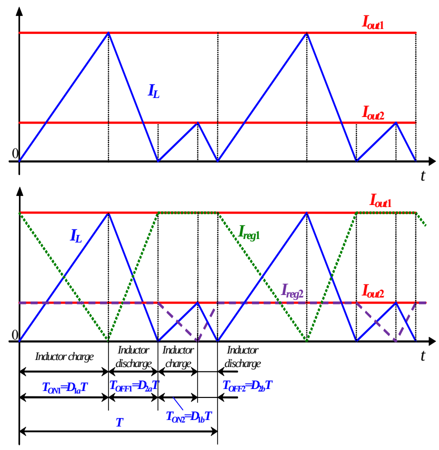

Fig. 8.- Current waveforms of the SIDO linear-assisted DC/DC converter with control strategy B: through the load 1 and load 2 (red color traces), inductance L_1 (blue trace), linear regulator 1 (discontinuous green trace) and linear regulator 2 (discontinuous violet trace).

V. The Controller of the SIDO Linear-Assisted DC/DC Converter

The control algorithm considered in this paper is shown in figure 7. As it was mentioned previously, in order to achieve this control, it is necessary to obtain the signals from the current of interest in the circuit. In particular, it is necessary to sense the two output currents (V_{SO1} and V_{SO2} in figure 6) and the current flowing through the inductor of the switching converter (sensing signal V_{SL1}). As a consequence, four control signals are obtained in order to control the four switches of the SIDO linear-assisted DC/DC converter: Control signal V_{C1} for the switch SW_1, V_{C5} to control SW_2, V_{Cout1} for the switch SW_3 and V_{Cout2} for the switch SW_4.

In order to implement the control algorithm presented in figure 7 it is necessary to obtain which of the two output currents is the biggest. In addition, it is necessary to compare the inductor current with these two output current, generating internal control signals. The scheme presented in figure 9.*a* shows the circuit that implements this part, obtaining three internal threshold levels: V_{T1}, V_{T2} and V_{T3}. Notice that the output of the comparator CMP_1 provides the intermediate control signal V_S that indicates which output current (I_{out1} or I_{out2}) is the biggest one.

These three levels (V_{T1}, V_{T2} and V_{T3}) are the intermediate or internal signals that control a state machine, consisting of three R-S bistables (figure 9.*b*). The state machine generates the control signals V_{C1}, V_{C5}, V_{Cout1} and V_{Cout2} for the switches SW_1, SW_2, SW_3 and SW_4, respectively.

Finally, in figure 9.*c*, it is shown the block that, in the inductor discharge interval, decides which output (switch SW_3 or SW_4) is selected first. Note that this decision depends on the signal V_S provided by comparator CMP_1 (figure 9.*a*). Thus, the biggest of the two current is selected in the subinterval T_{OFF1} and the lower in the interval T_{OFF2}. As a consequence, the sequence achieved thank to the controller is given in figure 10.

VI. Simulation Results of the SIDO Linear-Assisted DC/DC Converter

In order to validate the presented structure of the SIDO linear-assisted DC-DC converter depicted in figure 6 and its controller shown in figure 9 and the control algorithm presented in figure 10, simulation results have been obtained from a system that provides 5.0 *V* at V_{out1} and 2.0 *V* at the output V_{out2}, being V_{in}=9 *V*. Figure 11 shows the circuit waveforms when the SIDO linear-assisted converter provides 1.67 *A* at the output 1 and 0.67 *A* at the output 2.

In order to validate the controller's operation when the maximum of the two output current changes, figure 12 shows the current waveforms of the structure of the SIDO linear-assisted DC/DC converter when the output current I_{reg1} changes from the largest value to another one lower than I_{reg2}: From 1.67 *A* to 0.83 *A* at *t*=250 µs and vice versa at *t*=500 µs, being I_{reg2}=1.33 *A*.

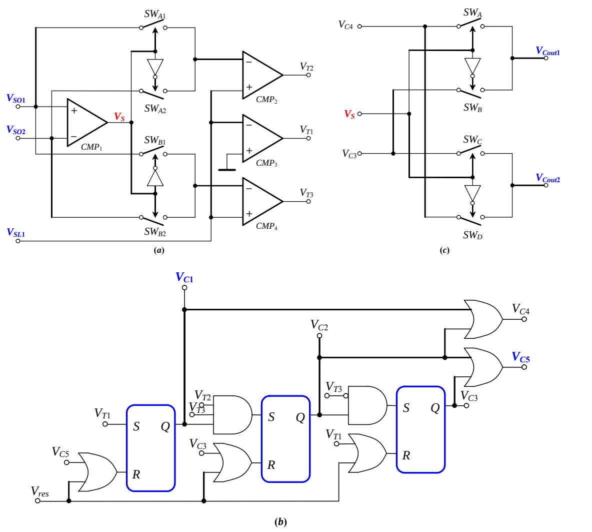

Fig. 9.- Structure of the controller block for the SIDO linear-assisted DC/DC converter: ***(a)*** Generator of the internal threshold levels for the state machine. ***(b)*** State machine that generates the control signals V_{C1}, V_{C5}, V_{Cout1} and V_{Cout2} for the switches SW_1, SW_2, SW_3 and SW_4, respectively. ***(c)*** Block that, in the inductor discharge interval, decides which output (switch SW_3 or SW_4) is selected first.

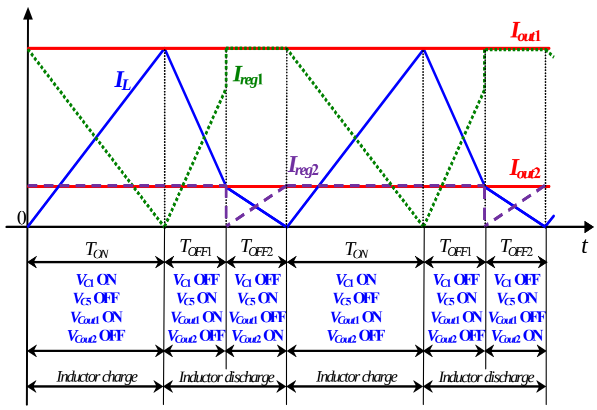

Fig. 10.- Sequence of the generated control signals from the state machine and current waveforms of the SIDO linear-assisted DC/DC converter with control strategy *A*: through the load 1 and load 2 (red color traces), inductance L_1 (blue trace), linear regulator 1 (discontinuous green trace) and linear regulator 2 (discontinuous violet trace).

VII. Conclusions

In the presented paper, the design and simulation of a SIDO linear-assisted DC/DC converter has been carried out. The article has shown that linear-assisted DC/DC converters are structures that allow to take advantages of the two classic alternatives in the design of power supply systems (voltage linear regulators and switching DC/DC converters). In addition, starting from this linear-assisted topology, and thanks to the controller altogether with a switching converter and two voltage linear regulators, the paper has shown the design and simulation results of the proposed SIDO linear-assisted DC/DC converter. This structure can provide two independent outputs with suitable load and line regulations. Finally, note that different control algorithms can be implemented in the proposed SIDO structure in order to obtain the appropriate and accurate load and line regulations.

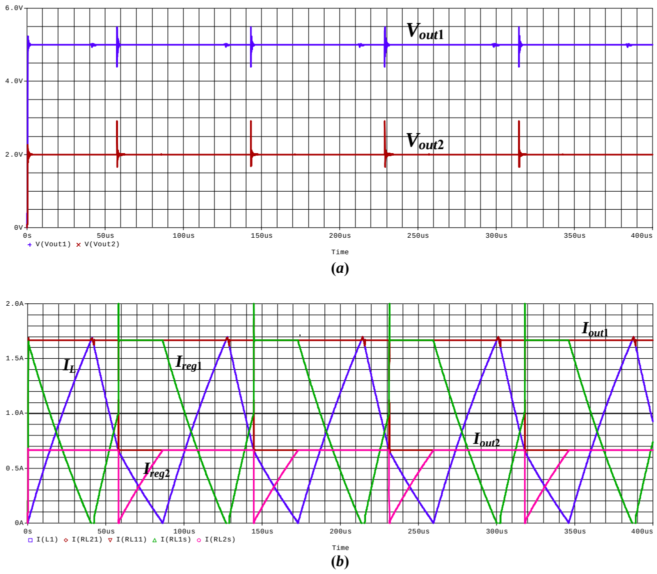

Fig. 11.- Current waveforms of the structure of the SIDO linear-assisted DC/DC converter: ***(a)*** Output voltages V_{out1} and V_{out2}. ***(b)*** Currents of interest in the circuit: I_L, I_{reg1}, I_{reg2}, I_{out1} and I_{out2}.

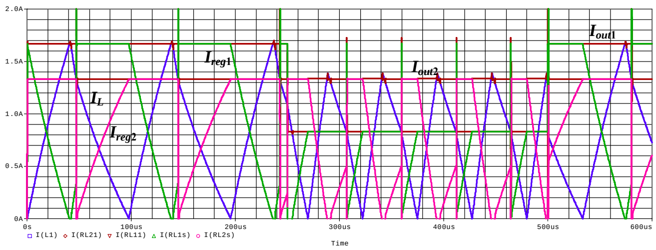

Fig. 12.- Current waveforms of the structure of the SIDO linear-assisted DC/DC converter when the output current I_{reg1} changes from 1.67 *A* to 0.83 *A* at *t*=250 µs and vice versa at *t*=500 µs: Currents of interest in the circuit: I_L, I_{reg1}, I_{reg2}, I_{out1} and I_{out2}.

Acknowledgment

This work has been partially funded by project TEC2007–67988–C02–01/MIC from the Spanish MCYT and EU FEDER funds.

References

[1] D. Ma, W-H. Ki, C-Y. Tsui. “A Pseudo-CCM/DCM SIMO Switching Converter with Freewheel Switching”. *IEEE Journal of Solid-State Circuits*, vol. 38 (nº 6): pp. 1007-1014, June 2003.

[2] K. O’Malley. “Linear Regulator Output Structures”. SR004AN/D, Rev. 1, *ON Semiconductor*, pp. 1-8, April 2001 (http://www.onsemi.com/PowerSolutions/supportDoc.do?type=appNotes&category=366).

[3] B.S. Lee. “Technical Review of Low Dropout Voltage Regulator Operation and Performance. Application Report”. SLVA072, *Texas Instruments*, pp. 1-26, August 1999 (http://focus.ti.com/lit/an/slva072/slva072.pdf).

[4] C. Basso, C. Fourtet, P. Kadanka. “Get the best from your low-dropout regulator”. *EDN*, pp. 115-126, 18th February 1999.

[5] J. Patoux. “Ask The Applications Engineer—37. Low-Dropout Regulators”. *Analog Dialogue 41-05*, Analog Devices, pp. 1-3, May 2007 (www.analog.com/library/analogDialogue/archives/41-05/ldo.pdf).

[6] C. Simpson. “Linear and Switching Voltage Regulator Fundamentals”. *National Semiconductor*: pp. 1-29 (http://www.national.com/appinfo/power/files/f4.pdf).

[7] H-P. Le, C-S. Chae, K-C. Lee, S-W. Wang, G-H. Cho, G-H Cho. “A Single-Inductor Switching DC-DC Converter with Five Outputs and Ordered Power-Distributive Control”. *IEEE Journal of Solid-State Circuits*, vol. 42 (nº 12): pp. 2706-2714, December 2007.

[8] C. K. Chava, J. Silva-Martínez. “A Frequency Compensation Scheme for LDO Voltage Regulators”. *IEEE Transactions on Circuits and Systems–I: Regular Papers*, vol. 51 (nº 6): pp. 1041-1050, June 2004.

[9] R. J. Milliken, J. Silva-Martínez, E. Sánchez-Sinencio. “Full On-Chip CMOS Low-Dropout Voltage Regulator”. *IEEE Transactions on Circuits and Systems–I: Regular Papers*, vol. 54 (nº 9): pp. 1879-1890, September 2007.

[10] R. K. Dokania, G. A. Rincón–Mora. “Cancellation of Load Regulation in Low Drop–Out Regulators”. *Electronic Letters*, vol. 38 (nº 22): pp. 1300–1302, 24th October 2002.

[11] V. Grupta, G. A. Rincón–Mora, P. Raha. “Analysis and Design of Monolithic, High PSR, Linear Regulator for SoC Applications”. *Proceedings of the IEEE International SoC Conference*: pp. 311–315, 2004.

[12] R. W. Erickson, D. Maksimovic. “*Fundamentals of Power Electronics*”. 2nd edition, Ed. Kluwer Academic Publishers, 2001.

[13] J. G. Kassakian, M. F. Schlecht, G. C. Verghese. “*Principles of Power Electronics*”. Ed. Addison–Wesley, 1991.

[14] N. Mohan, T. M. Underland, W. P. Robbins. “*Power Electronics: Converters, Applications and Design*”. Ed. John Wiley & Sons, 1989.

[15] X. Zhou, P. L. Wong, P. Xu, F. C. Lee, A. Q. Huang. “Investigation of Candidate VRM Topologies for Future Microprocessors”. *IEEE Transactions on Power Electronics*, vol. 15 (nº 6): pp. 1172–1182, November 2000.

[16] B. Arbetter, D. Maksimovic. “DC–DC Converter with Fast Transient Response and High Efficiency for Low–Voltage Microprocessor Loads”. *IEEE Applied Power Electronics Conference*, pp. 156-162. 1998.

[17] P. Midya, F. H. Schlereth. ‘Dual Switched Mode Power Converter’. *IECON’89. Industrial Electronics Society*: pp. 155–158, 1989.

[18] F. H. Schlereth, P. Midya. ‘Modified Switched Power Convertor with Zero Ripple’. *Proceedings of the 32nd IEEE Midwest Symposium on Circuits and Systems* (*MWSCAS’90*): pp. 517–520, 1990.

[19] H. Martínez, A. Conesa,. “Modeling of Linear-Assisted DC–DC Converters”. *European Conference on Circuit Theory and Design 2007* (*ECCTD 2007*), 26th-30th August 2007.

[20] A. Conesa, H. Martínez, J. M. Huerta. “Modeling of Linear & Switching Hybrid DC–DC Converters”. *12th European Conference on Power Electronics and Applications* (*EPE 2007*), September 2007.

[21] D. Ma, W-H. Ki, C-Y. Tsui, P. K. T. Mok. “Single-Inductor Multiple-Output Switching Converters with Time-Multiplexing Control in Discontinuous Conduction Mode”. *IEEE Journal of Solid-State Circuits*, vol. 38 (nº 1): pp. 89-100, January 2003.