Single Inductor Dual Output DC-DC Converter Design with Exclusive Control

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***Abstract*—This paper proposes a single inductor dual output (SIDO) DC-DC Converter with exclusive control circuit. We propose two kinds of converter: a buck-buck and a boost-boost converter. Multiple voltage outputs are controlled exclusively, using error voltage feedback. This approach requires few additional components (a switch, a diode and a comparator), requires no current sensors and does not depend on the value of output voltage or output current. We describe circuit topologies, operation principles and simulation results.**

I. Introduction

DC-DC converters are indispensable for virtually all electronic devices, from cell phones to large manufacturing machinery. In many applications, multiple output voltages are required. In a conventional system, the DC-DC converter needs a single inductor for each output, hence many inductors are needed in the system as a whole. In order to reduce cost and volume of the system, it is desirable to reduce the number of required inductors.

Single-inductor multi-output (SIMO) converters have been recently reported, especially dual output (SIDO) converters [1], [2].

In this paper we propose a new control method for SIDO converters which requires few additional components (a switch, a diode and a comparator), while not requiring current sensors (of the inductor or the loads). We introduce their operating principles and show simulation results to verify their basic operation and performance.

II. SIDO Converter With Two Buck Converters

A. Proposed Circuit and Operation

The proposed buck-buck SIDO converter is shown in Fig. 1 and Fig. 2, where the red solid line shows the direction of current flow when the inductor is charged, and the blue dashed line shows the current flow when the inductor is discharged. Fig. 1 shows the condition when converter 1 (V_1) is selected to be controlled and Fig. 2 shows when converter 2 (V_2) is controlled.

Consider the situation when the converter 1 is selected and the output voltage V_1 is controlled, as shown in Fig. 1 and Fig. 3a. In this case, switch S_2 is always OFF and switch S_0 is controlled ON/OFF by the PWM1 signal at a frequency

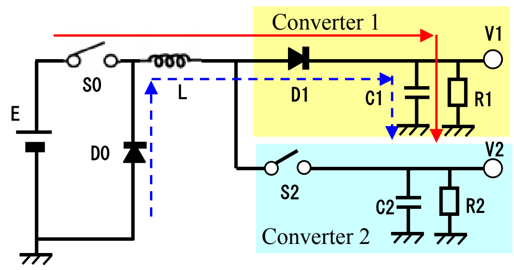


Fig. 1: SIDO converter (when V_1 is controlled).

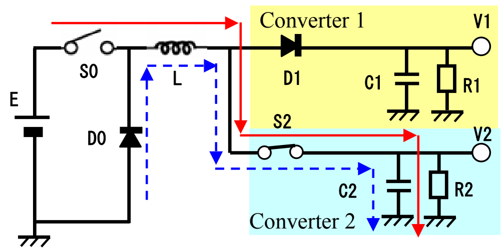
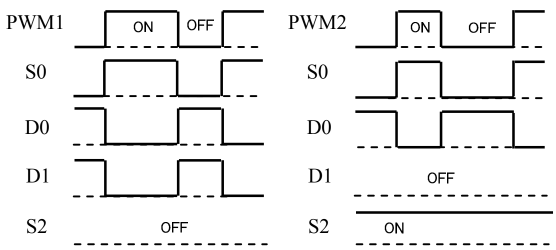


Fig. 2: SIDO converter (when V_2 is controlled).

of 500 kHz. Additionally, switch S_0 is ON (closed) and the inductor is charged when the PWM1 signal is HI. Next, PWM1 goes LO, the switch S_0 turns OFF (open) and the inductor is discharged through diodes D_0 and D_1. In this case, converter 2 is not charged and the load current is supplied from the bulk



(a) Converter 1 control. (b) Converter 2 control.

Fig. 3: Timing chart of switches.

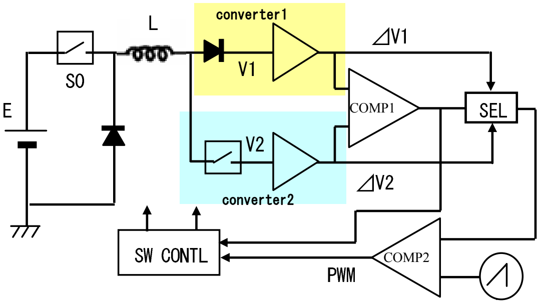


Fig. 4: Simulation circuit.

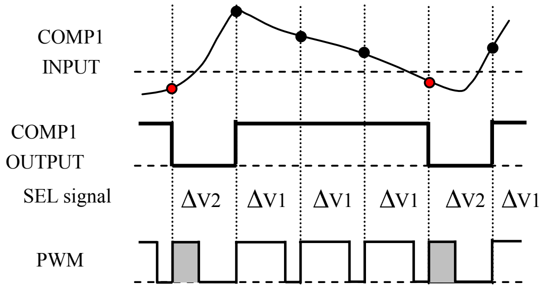


Fig. 5: Timing chart of Fig. 4.

capacitor C_2.

Next, consider the case when converter 2 is selected and the output voltage V_2 is controlled, as shown in Fig. 2 and Fig. 3b. In this case, switch S_2 is always ON and diode D_1 is always OFF, since $V_1 > V_2$. In this system, we set E=9V, V_1=6V and V_2=4V. In this situation, converter 2 is operated just like a usual buck converter. Note that while converter 2 is selected, converter 1 is not charged and the load current is supplied from the bulk capacitor C_1.

B. Simulation Results

The circuit schematic for simulation is shown in Fig. 4. Both outputs of the error amplifiers are compared at comparator1, which determines whether to select ΔV1 or ΔV2. The selected error voltage is compared at comparator2 with a sawtooth wave in order to get a PWM signal. The switch controller operates S_0 with a PWM signal and S_2 with the select signal.

The parameters of the SIDO converter in this simulation are shown in Table I. In this case, the value of the inductance is L=0.5μH, and the circuit operates in discontinuous conduction mode (DCM) as shown in Fig. 6. The peak current at $t = 3.39$ and 4.04ms is a result of the control signal changing from converter 1 to converter 2.

TABLE I: Simulation parameters of Fig 4.

Parameter	Value
E	9.0 V
L	0.5 μH
C	470 μF
V_1	6.0 V
V_2	4.0 V
F_{ck}	500 kHz

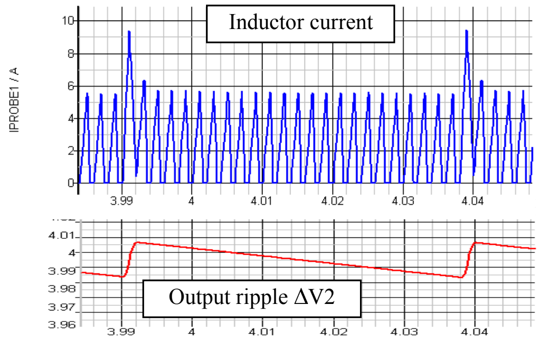


Fig. 6: Waveform of inductor current in DCM.

The waveforms of output voltage V_1, V_2 and output current I_1, I_2 are shown in Fig. 7. Here we simulated the transient responses when the output currents I_1, I_2 are both changed from 1A to 2A and vice versa.

Fig. 8 and Fig. 9 show the output ripple ΔV_1 and ΔV_2 when I_1=2A, I_2=0.2A and I_1=1A, I_2=2A. In Fig. 8, the ratio of output current is 10× ($I_1 = 10I_2$) and the output ripple is ΔV_1=11mVpp and ΔV_2=19mVpp which are less than 0.5% of output voltage. In this case, the control of converter 1 lasts for 46μs (23 clock periods) and the control of the converter 2 lasts for only 2μs (1 clock period). The waveform of the output voltage ripple ΔV_2 has a linear slope because no current is supplied during this period.

In Fig. 9, I_2 is larger than I_1, thus the controller operates V_2 more frequently than V_1. When converter 1 is operated, S_2 is ON just after S_0 is OFF, so there is a small amount of dead-time to ensure that both converters are not ON at the same time.

Fig. 10 shows the transient responses V_1 and V_2 for the change of load current I_1 and I_2. In this case, the red solid arrow shows self regulation and the blue dashed arrow shows cross regulation. Cross regulation is usually smaller than self regulation occurring at the same time.

III. SIDO Converter With Two Boost Converters

A. Proposed Circuit and Operation

The proposed SIDO converter with two boost converters is shown in Fig. 11 and Fig. 12, where the red solid line shows current flow when the inductor is charged, and the blue dashed line shows the current flow when the inductor is discharged. Fig. 11 shows the condition when converter 1 (V_1) is controlled and Fig. 12 shows when converter 2 (V_2) is controlled.

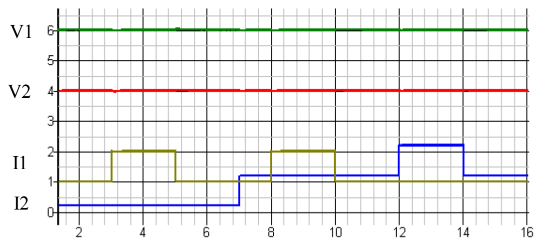


Fig. 7: Waveform of V_1, V_2 and I_1, I_2.

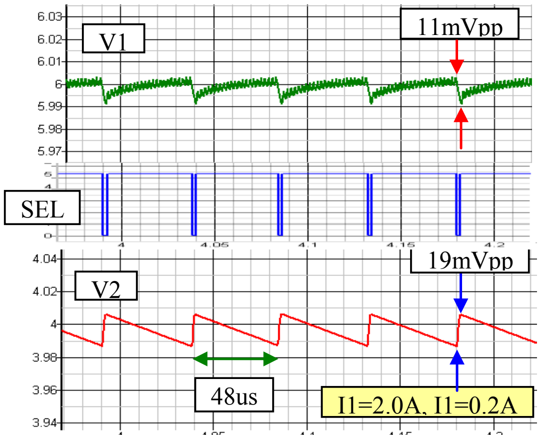


Fig. 8: Output voltage ripple (case 1).

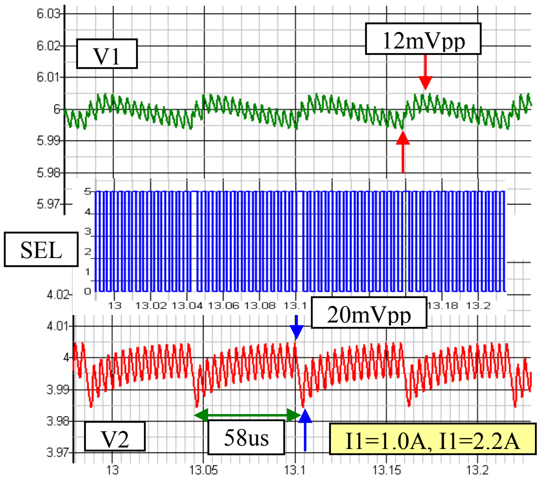


Fig. 9: Output voltage ripple (case 2).

Consider the case when converter 1 is selected and the output voltage V1 is controlled, as shown in Fig. 11 and Fig. 13a. In this case, switch S_2 is always OFF and switch S_0 is controlled ON/OFF by the PWM1 signal at a frequency of 500 kHz. Also, switch S_0 is ON (closed) and the inductor is charged when the PWM1 signal is HI. Next, PWM1 turns LO, the switch S_0 is turns OFF (open) and the inductor is discharged through diode D_1 over the input source E. During this period, converter 2 is not charged and the load current is supplied from the bulk capacitor C_2.

When converter 2 is controlled, the switch S_2 is always ON and the diode D_1 is OFF (because $V_1 > V_2$). The converter is then operated as a usual boost converter as shown in Fig. 12 and Fig. 13b.

The principle of simulation circuit is similar to Fig. 4 except that the topology is now a boost circuit. The simulation parameters of the circuit are shown in Table II.

B. Simulation Results

The waveforms of output voltage V_1, V_2 and output current I_1, I_2 are shown in Fig. 14. Transient simulations were

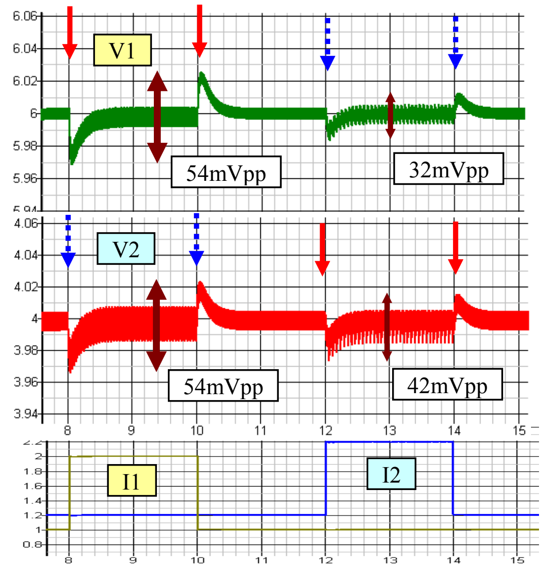


Fig. 10: Transient responses of V_1 and V_2.

performed with the output current I_1, I_2 set to 0.2A, 1.2A and 2.2A.

Fig. 15 and Fig. 17 show the output voltage ripple ΔV_1 and ΔV_2 when I_1=2.2A, I_2=0.2A and I_1=0.2A, I_2=2.2A. The

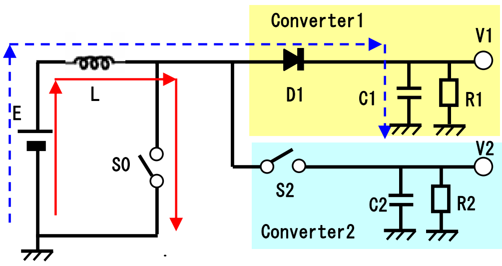


Fig. 11: SIDO converter with V_1 controlled.

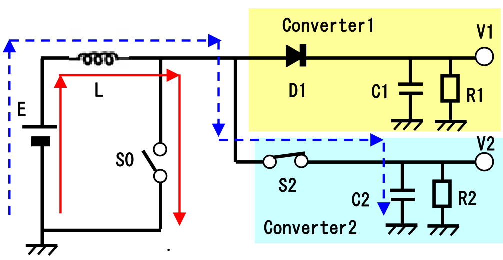
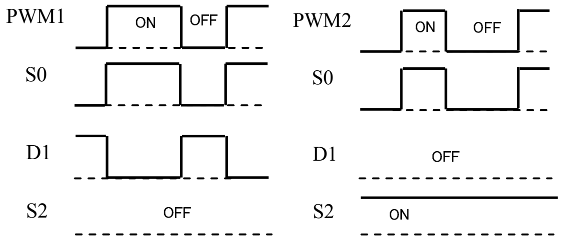


Fig. 12: SIDO converter with V_2 controlled.

TABLE II: Simulation Parameters of boost converter.

Parameter	Value
E	3.0 V
L	0.5 μH
C	470 μF
V_1	6.0 V
V_2	4.0 V
F_{ck}	500 kHz



(a) Converter 1 controlled. (b) Converter 2 controlled.

Fig. 13: Timing chart of switches.

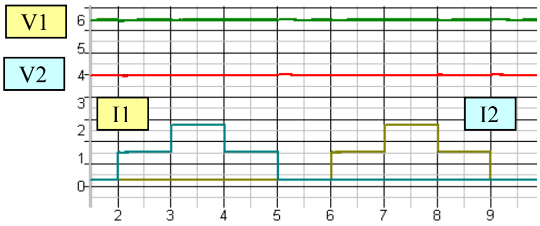


Fig. 14: Waveforms of V_1, V_2 and I_1, I_2.

ratio of output current is 11× and the output voltage ripple values are ΔV_1=22mVpp and ΔV_2=15mVpp which are less than 0.4% of the output voltage.

Fig. 17 shows the load transient responses of V_1 and V_2 for the change of load current I_1 and I_2. Note that the red solid arrow shows self regulation ripple and the blue dashed arrow shows cross regulation. Self regulation is ΔV_1=75mVpp and ΔV_2=40mVpp. Additionally, cross regulation is ΔV_1=25mVpp and ΔV_2=75mVpp. In this simulation, the output voltage ripple for the change of I_1 is too high—future work will focus on reducing this ripple by modifying circuit parameters.

IV. Conclusion

In this paper, we have described two types of single inductor dual output (SIDO) converter. We have investigated and proposed a new control method for SIDO converters which is independent of output voltage and current. We explained their principles of operation and verified their basic operation by simulations. Simulation results show that the static output voltage ripple is less than 20mVpp and the transient voltage ripple is less than 60mVpp (ΔI =1A) for the buck-buck type SIDO converter. For the boost-boost type SIDO converter, the static ripple is less than 30mVpp and he transient ripple is less than 80mVpp (ΔI =1A).

References

[1] K. Takahashi, H. Yokoo, S. Miwa, K. Tsushida, H. Iwase, K. Murakami, *et al*, "Single inductor dc-dc converter with bipolar outputs using charge pump," in *Circuits and Systems (APCCAS), 2010 IEEE Asia Pacific Conference on*, dec. 2010, pp. 460 –463.

[2] H. Iwase, T. Okada, T. Nagashima, T. Sakai, S. Takagi, Y. Kobori, *et al*, "Realization of Low-Power Control Method for SIDO DC-DC Converter" in *IEEJ Technical Meeting of Electronic Circuits, Yokosuka, Japan*, mar. 2011, ECT–12–037.

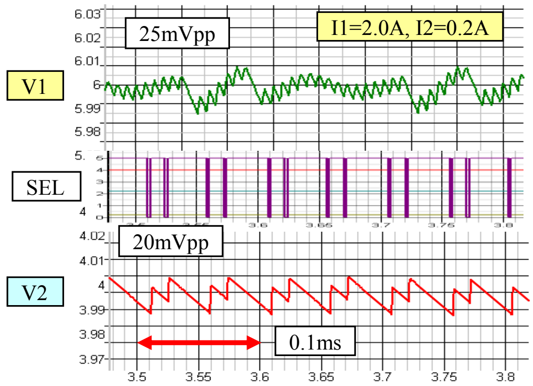


Fig. 15: Output voltage ripple (case 1).

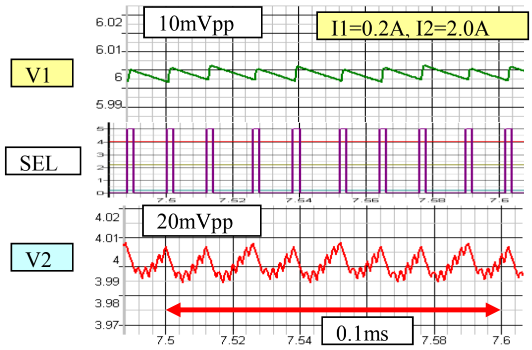


Fig. 16: Output voltage ripple (case 2).

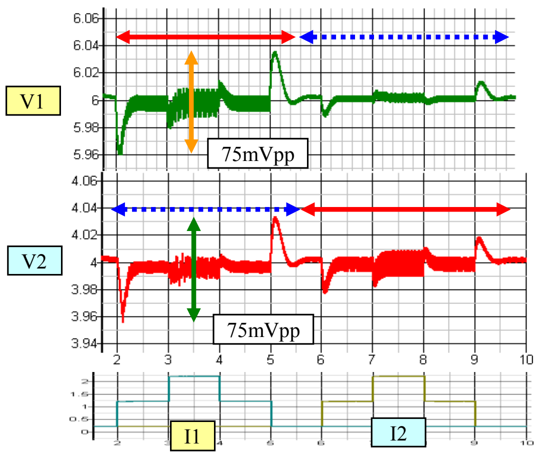


Fig. 17: Transient responses of V_1 and V_2.