

Integrated Single-Inductor Buck-Boost or Boost-Boost DC-DC Converter with Power-Distributive Control

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Abstract—This paper presents a fully integrated single-inductor dual-output (SIDO) buck-boost or boost-boost DC-DC converter with power-distributive control. This converter works under voltage mode control to have better noise immunity, uses fewer power switches/external compensation components to reduce cost, and is thus suitable for system on chip (SoC) applications. The proposed SIDO converter was fabricated in TSMC 0.35 μm 2P4M CMOS technology with input supply voltage 2.7-3.3 V. The first output V_{O1} can operate either at buck mode or boost mode (output voltage in between 2.5V to 5V), while the second output V_{O2} can only operate at boost mode (output voltage 3.6V).

Keywords—component; buck/boost-boost converter; single inductor; power distributive control

I. INTRODUCTION

Today's modern battery-operated portable products demands for advanced power management integration in SoC chips [1]. To minimize power consumption, multiple supply voltages and dynamic voltage scaling schemes are widely adopted [2]. Recently, several single-inductor multiple-output (SIMO) DC-DC converters [3-10] have been proposed as the most promising solution to minimize component (inductor and power switch) counts/footprints and production cost. However, there exists many design challenges for the SIMO converters, such as cross-regulation, efficiency, system stability, and flexibility, for achieving better step-down and step-up conversion.

The operational principles of SIMO DC-DC converters are based on time-multiplexing approaches [11], which deliver energy stored in the inductor to each output in every switching cycle by means of different feedback control mechanisms. They can be classified as voltage control [3-5], peak current control [6-7] [10], and charge control [8-9]. In terms of inductor current waves, converters are divided into discontinuous conduction mode (DCM) [3] [7], pseudo-continuous conduction mode (PCCM) [4] [8-9], continuous conduction mode (CCM) [5], and DCM/CCM [6]. They also can be sorted into boost/boost converters [3-4] [6-7], buck/buck converters [5], and hybrid buck/boost converters [8-10] by using output voltage types. For the embedded SIMO

DC-DC converter in SoC application, although voltage control is slower than current mode control, it has no external current sensors and good noise immunity. Hence, voltage control is more suitable than current control in embedded SoC environments. Converters operated in DCM or PCCM of the conventional time-multiplexing approaches [3-4] will avoid cross-regulation, but DCM suffers large current ripples and has current driving problems. Although PCCM overcomes limitations of DCM, it dissipates unnecessary power due to non-zero current in resistance of inductor and the freewheel-switch. Converters operating in CCM suffer serious cross-regulation problems and are difficult to consider stability analysis [4]. In general, SIMO converters have to combine several compensators which have the same number of output voltage. Recently, there is a reference [6] proposes ordered power-distributive control (OPDC), which can operate in DCM/CCM, and using only one compensator. Besides, compared with familiar SIMO converters [3-4], this time-multiplexing power-distributive approach of [5-9] has less switching number in one cycle, therefore it increase efficiency.

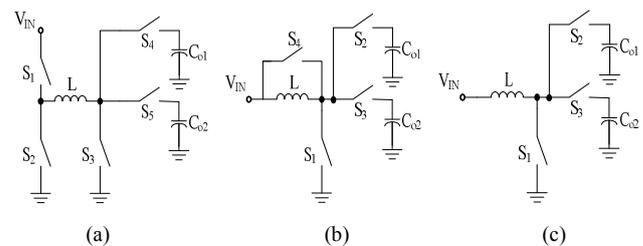


Fig. 1. Architecture of the buck-boost dc-dc converter.

In many applications, there are need for a single-inductor dual-output DC-DC converter with one output voltage set to be lower (buck) and another higher (boost) than the supply voltage. In traditional SIDO buck/boost converters shown in Fig.1 (a), there are five power switches [10]. Fig.1 (b) is another implementation of four power switches [8-9]. This paper adopts the Fig.1 (c) (reduce freewheel-switch S_4 of Fig.1 (b)) topology which has three power switches, and it uses power-distributive control from [6] and applies them to voltage control. Thus, there needs only one output compensation loop, which reduce the amount of external

compensated components used, such as [6]. Moreover, this paper also extends the availability of Fig.1(c) topology to implement Buck-Boost or Boost-Boost converter according to different demands.

In this paper, operation and control of the proposed SIDO converter and the effect of cross regulation are discussed in Section II. Section III presents circuit design and implementation issues. Post-layout simulation and results are shown in Section IV. The conclusions are given in Section IV.

II. OPERATION OF SIDO BUCK-BOOST CONVERTER

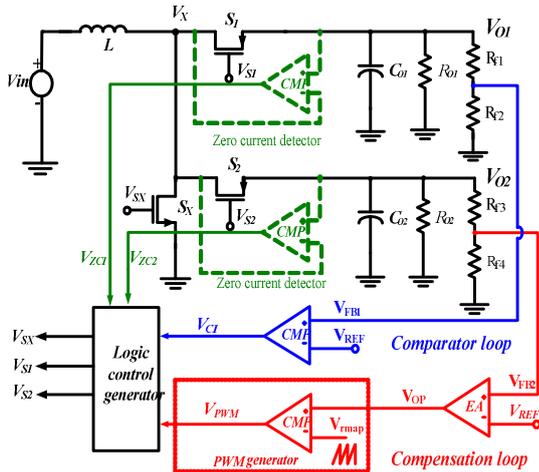


Fig. 2. Architecture of the proposed buck-boost or boost-boost dc-dc converter.

A. Architecture and Control Strategy

The architecture of the SIDO buck-boost or boost-boost DC-DC converter in power-distributive control with one compensator is shown Fig. 2. The output V_{O1} is controlled by the comparator loop, which determines the switching from V_{O1} to V_{O2} . The output V_{O2} is controlled by compensation loop that is responsible for compensating the total control loop. The logic control generator is used to control the timing of the converter. The zero current detectors prevent the reversed inductor current.

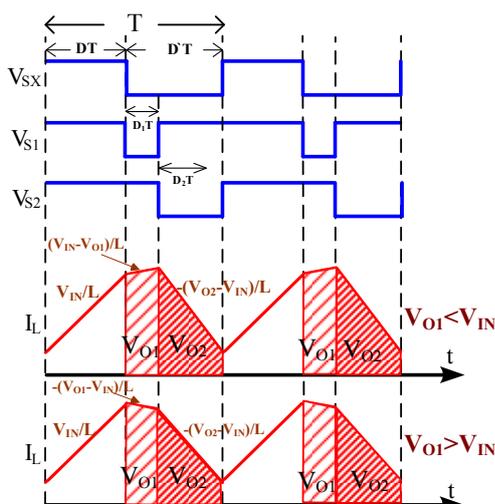


Fig. 3. Timing diagram of buck-boost or boost-boost dc-dc converter.

The operational principle is explained in the timing diagram shown in Fig. 3. The duty-cycle D is determined by PWM generator. During the DT period, the S_x is turned ON, and all other switches are turned OFF. The inductor current ramps up with the slope of V_{in}/L until the output of the error amplifier V_{OP} is equal to the ramp signal. S_x is then turned OFF, and the inductor is connected to V_{O1} by turning ON S_1 . During the D_1T , as soon as the comparator detects V_{O1} is larger than its target voltage, S_1 is turned OFF and the inductor is switched to V_{O2} . If V_{O1} is lower than V_{in} , the inductor current ramps up with the slope of $(V_{in}-V_{O1})/L$, otherwise ramps down with the slope of V_{O1}/L . That is to say V_{O1} can be buck or boost output. During the D_2T , the inductor current ramps down with the slope of $(V_{O2}-V_{in})/L$ until the next DT starts.

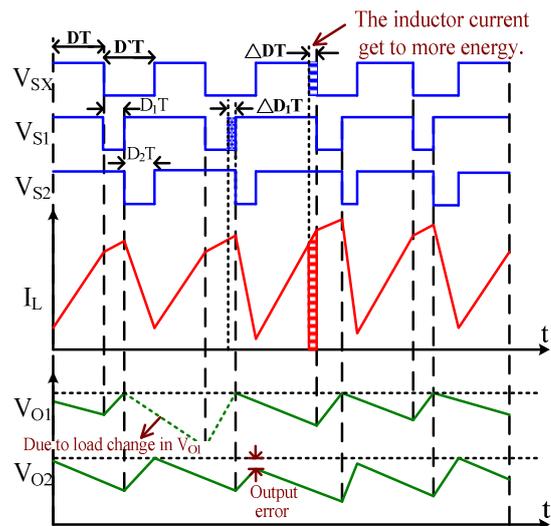


Fig. 4. Timing diagram of the proposed converter encounter cross regulation due to load change in V_{O1} .

B. Cross Regulation

The outputs of the SIMO DC-DC converter control by time-multiplexing power-distributive approaches will cross regulate among themselves, no matter in DCM or in CCM, because they are coupled together and influenced the duty cycles mutually. Our proposed converter can maintain desirable low cross-regulation which is explained in Fig. 4. Suppose that the load current suddenly increases in V_{O1} , which makes V_{O1} drop below the predetermined voltage. While detecting that, the comparator loop increases the duration, ΔD_1T , to deliver more energy of inductor current to V_{O1} until V_{O1} is larger than its required voltage. Then, due to increasing external energy abruptly in V_{O1} , remainder energy of inductor current delivered to V_{O2} is decreased so that V_{O2} drops. In other words, the output error of the comparator-controlled V_{O1} is transferred and accumulated to V_{O2} . Receiving the voltage error of V_{O2} , PWM generator of the compensation loop extends the duty DT to get more energy from the inductor. At the same time, D_1T is reduced by the comparator to maintain V_{O1} . Finally, V_{O1} and V_{O2} return their required voltages levels, and the proposed converter achieved low cross-regulation by

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