Exclusive Technology Feature

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Simple Stepdown Regulator Generates Multiple Voltage Rails With Good Efficiency and Regulation

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In many applications, multiple voltage rails are required in the system. Common solutions for generating these voltage rails include the use of multiple switching regulators (one for each rail), or LDOs to step down voltage from the nearest available rails. Of these two methods, the use of multiple regulators costs more and requires separate power stage and loop compensation design for each added rail. On the other hand, using LDOs for stepping down voltage is inherently inefficient and dissipative.

Another approach uses coupled inductors with a synchronous buck regulator to generate auxiliary outputs (Figs. 1 and 2). This approach is simple, and can provide both isolated and nonisolated outputs. However, the efficiency degrades at lower values of secondary output voltage (V_{OUT2}) because of diode rectification. In addition, the flyback action of the diode (D1) causes poor regulation at no load. This method, therefore, is suitable only when the secondary output voltage is much higher than the diode drop, and usually requires a ballast resistor to avoid a no-load condition.

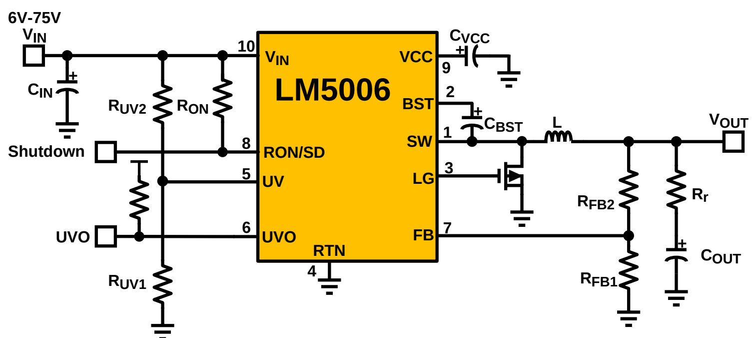

Fig. 1. Application circuit for single-output synchronous buck converter.

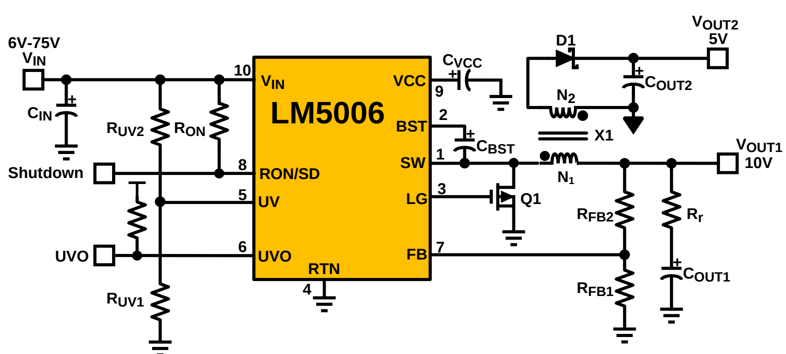

Fig. 2. Application circuit for multiple-output buck: conventional approach using diode rectification on V_{OUT2} (works for isolated and non-isolated application.) $V_{OUT2} = V_{OUT1}\frac{N2}{N1} - V_F$

In this article, a dual-output buck converter employing coupled inductors is presented. This converter is based on the LM5006 constant-on-time (COT) buck regulator with low-side gate drive (Fig. 3). This method uses synchronous rectification for both rails resulting in better efficiency and regulation. Since the COT topology does not require any compensation, significantly less design effort is required to generate multiple output rails that are fairly well regulated. Although the design example described here produces just two output rails, this technique can be extended to generate any number of additional voltage rails. One more FET and one more winding are required for each added rail.

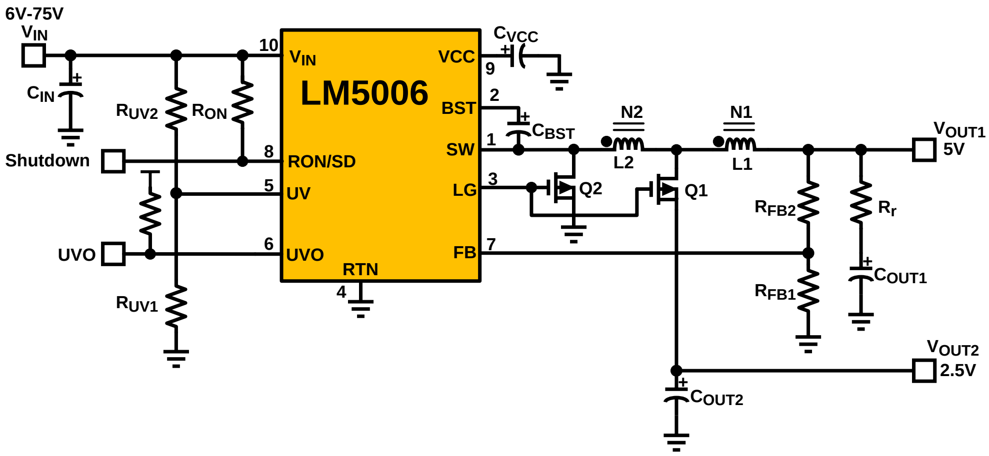

Fig. 3. Application circuit for multi-output buck: proposed method using synchronous rectification on both output rails. $V_{OUT2} = V_{OUT1} \frac{N2}{N1 + N2}$

Multi-Output Buck Operation

Fig. 4 shows the power stage of the dual-output stepdown regulator depicted in Fig. 3. SW1 is the junction of L1, L2, and Q1. SW2 is pin 1 of LM5006. The idealized waveforms for voltages V_{OUT1}, V_{OUT2}, SW1, SW2 and currents I_{L1}, I_{L2}, $I_{L1}+I_{L2}$ are shown in Fig. 5.

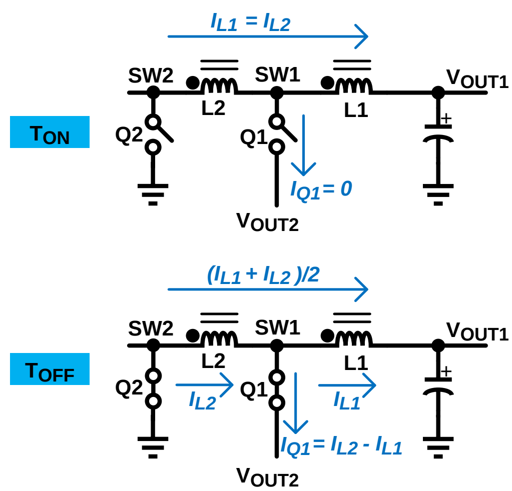

Fig. 4. Power stage components for dual-output buck converter showing the current distribution in windings (L1 = L2).

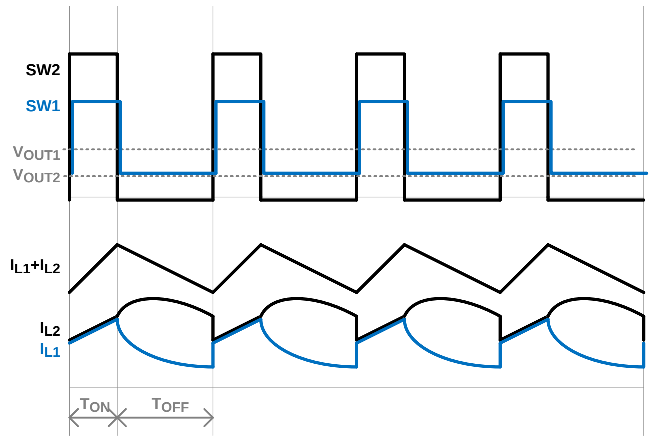

Fig. 5. Operating waveforms for dual-output buck.

For the following discussion it is assumed that L1 = L2. During T_{ON}, the buck switch in the LM5006 is on and the current (I_{L1} = I_{L2}) flows through the series inductor configuration of L1 and L2. The ripple during T_{ON} is given by

$$\Delta I_{L1} = \Delta I_{L2} = \frac{V_{IN} - V_{OUT1}}{4L1}$$

where we have assumed that the coupling k = 1 and L1 = L2. During the off time, T_{OFF}, the buck switch in the LM5006 is off and switches Q1 and Q2 are on.

Since C_{OUT2} is now connected to the mid-point of the coupled inductor, it is charged to a voltage:

$$V_{OUT2} = V_{OUT1} \frac{N2}{N1 + N2} = \frac{V_{OUT1}}{2}$$

since L1 = L2.

If there is a load present on output 2, C_{OUT2} discharges to a level below $V_{OUT1}/2$ during T_{ON}. Therefore, equal and opposite currents build up in L1 and L2, adding up at SW1, and flowing through Q1 to charge C_{OUT2}. These currents do not contribute to the magnetization of the core, which is determined by the voltage '-V_{OUT1}' applied to the combination of L1 and L2. During T_{OFF}, I_{L1} and I_{L2} flow through the leakage inductances in L1 and L2, respectively. This leakage causes spikes at node SW1 at the end of T_{OFF} period when the currents in L1 and L2 are suddenly interrupted and brought back to the same level. Therefore, an effort should be made to minimize the leakage inductances in series with L1 and L2.

Limitation On V_{OUT2} Range

As shown in Fig. 3, the source of Q2 is connected to V_{OUT2}. This limits the maximum V_{OUT2} to

$$V_{OUT2} \le V_{CC} - V_{TH}$$

where V_{TH} is the gate threshold voltage of Q2, and V_{CC} is the voltage at the V_{CC} pin of the LM5006. When regulated by the internal startup regulator, this V_{CC} voltage is typically 7.5 V. With a Q2 FET of $V_{TH(max)}$ = 4 V, for example, the theoretically maximum achievable $V_{OUT2(max)}$ = 7.5 V – 4 V = 3.5 V. The designer should take this into account when designing the converter. If a higher V_{OUT2} is needed, the Q2 should be selected to have a lower $V_{TH(max)}$.

Replacing Q2 With A Diode

To reduce the cost of solution, to reduce the gate driver load, and to simplify the circuit, FET Q2 can be replaced by a schottky diode. When a diode is used, the input-to-output relationship is modified to

$$V_{OUT2} = -V_F + (V_{OUT1} - V_F)\frac{N2}{N1 + N2}$$

where V_F is the forward voltage drop of the diode.

Application Circuit And Performance Characteristics

Fig. 6 shows the complete schematic of a dual-output stepdown converter utilizing the LM5006 regulator. Figs. 7 through 11 show the regulation and efficiency plots for the circuit in Fig. 6.

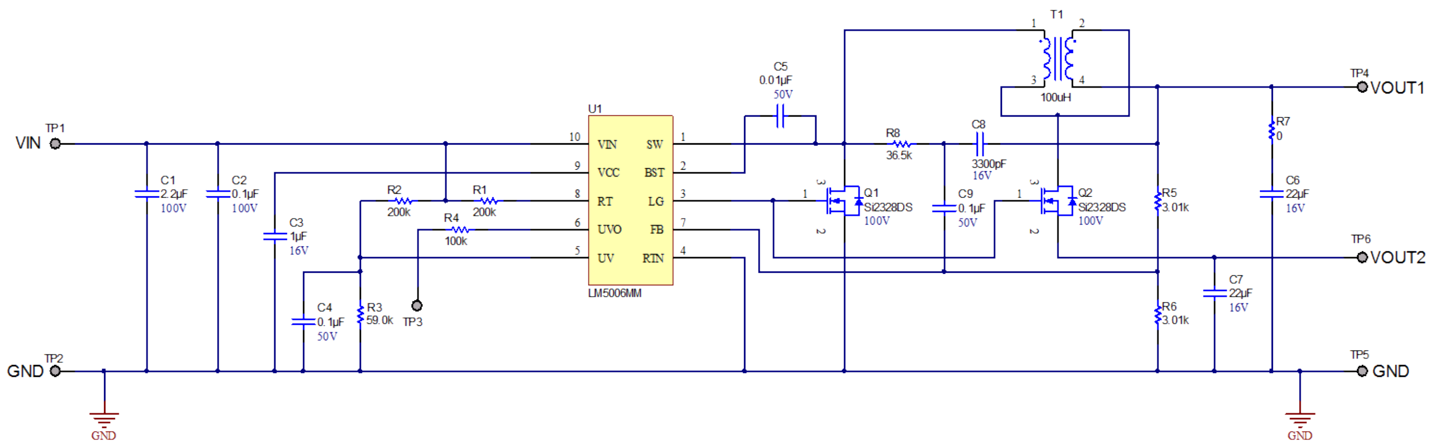

Fig.6. Application circuit for dual-output buck.

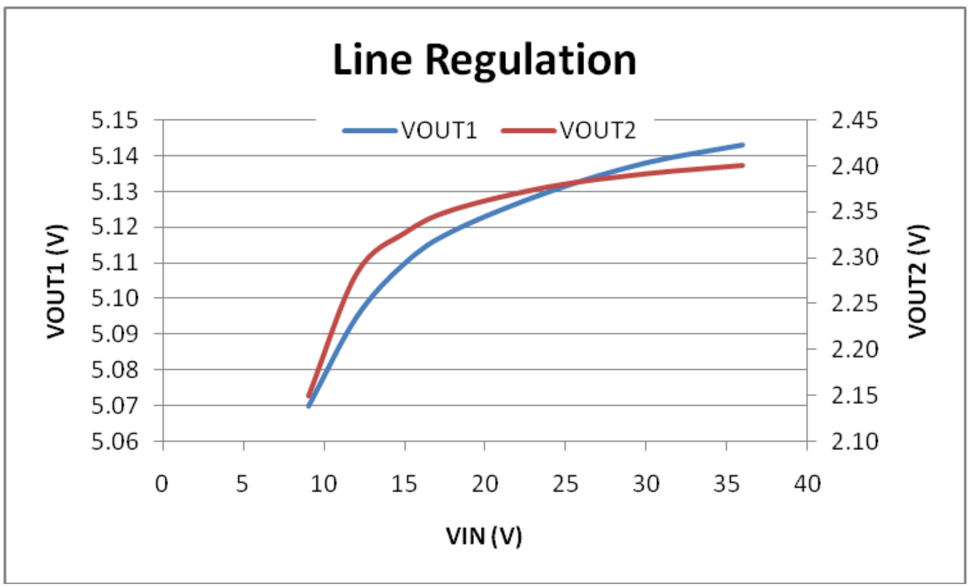

Fig. 7. Regulation at V_{OUT1}, V_{OUT2}, V_{IN} = 9 V to 36 V, I_{OUT1} = I_{OUT2} = 200 mA.

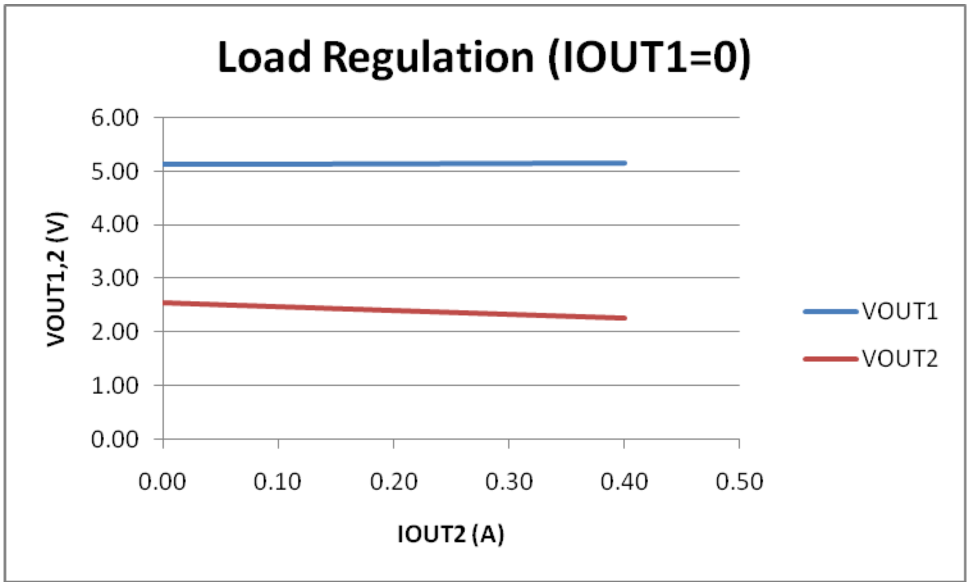

Fig. 8. Regulation at V_{OUT1} and V_{OUT2}, I_{OUT1} = 0 mA, I_{OUT2} = 0 to 400 mA.

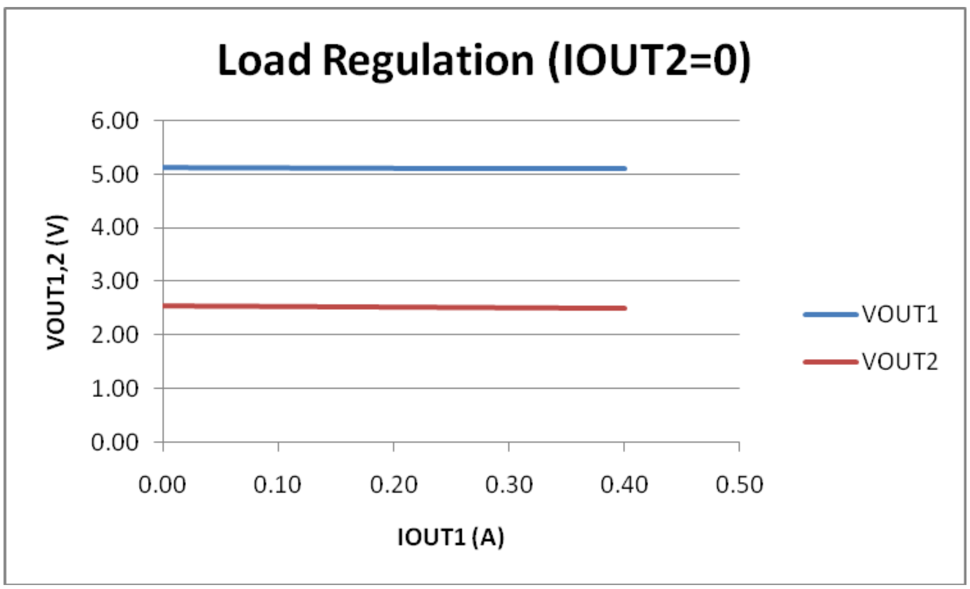

Fig. 9. Regulation at V_{OUT1} and V_{OUT2}, I_{OUT2} = 0 mA, I_{OUT1} = 0 to 400 mA.

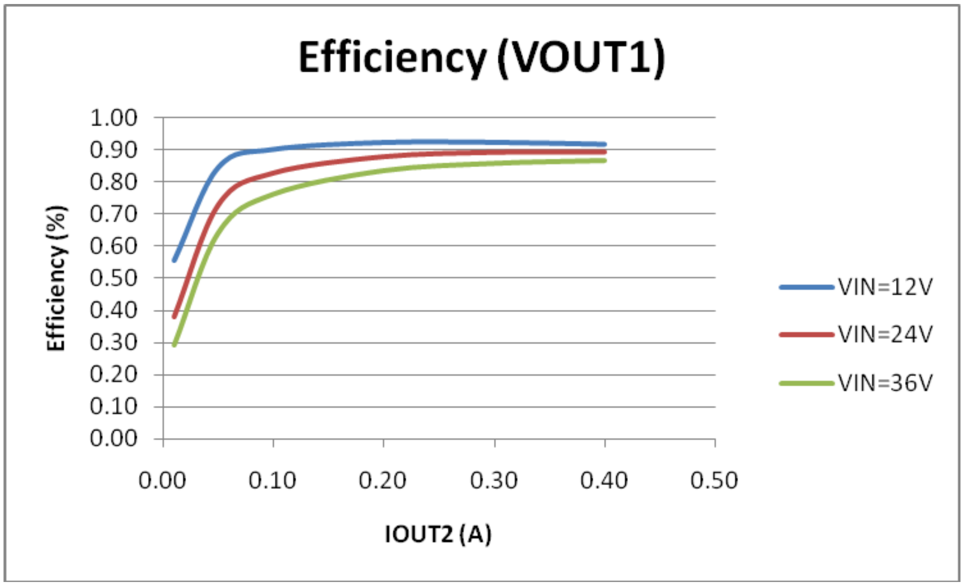

Figure 10. Efficiency V_{IN} to V_{OUT1}, no load at V_{OUT2}.

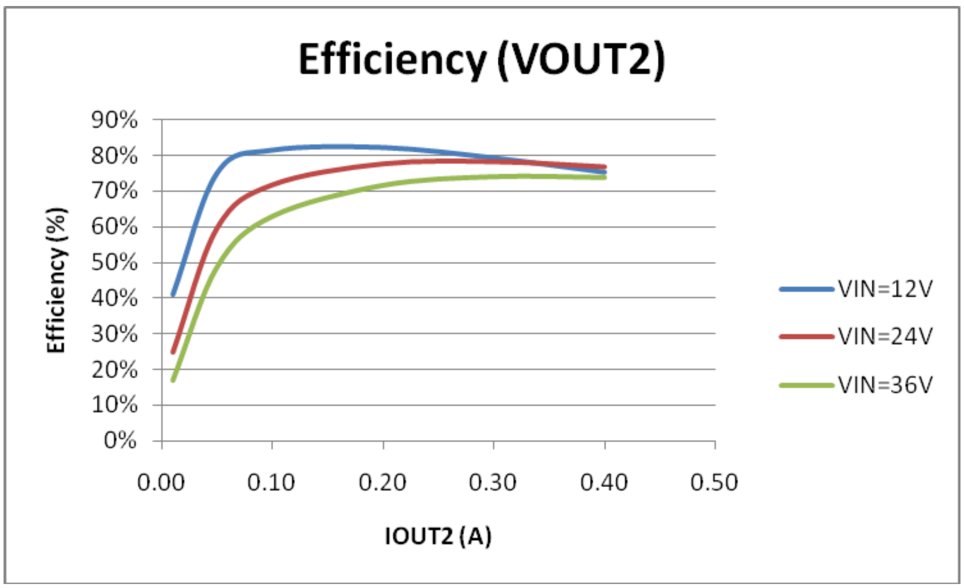

Fig. 11. Efficiency V_{IN} to V_{OUT2}, no load at V_{OUT1}.

Conclusion

A dual-output buck converter implementation using a single LM5006 buck regulator IC is presented. It uses coupled inductors to generate an additional output. The theory of operation, working waveforms, and the performance characteristics curves for the prototype converter are also presented. The idea can be extended to more than two outputs, and provides a cost-effective, compact solution for applications requiring multiple voltage rails.

Reference:

LM5006 Datasheet.

About The Author

Vijay Choudhary is an applications engineer at National Semiconductor's Phoenix Design Center. At National Semiconductor, Vijay has worked on wireless charging and power management ICs for mobile devices. He currently works on isolated and nonisolated switching converters for industrial applications. Vijay has a Bachelor of Technology from Indian Institute of Technology, Kharagpur, and a Master of Science and PhD from Arizona State University. Vijay has written several papers, application notes, and articles in the field of power management.

For more on stepdown converters, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category, and select "Buck Converters" in the Popular Topics category.