Doing More with Buck Regulator ICs

Switching regulators are widely used and one of the most popular switching regulator topologies is the buck converter (also known as a step-down converter). Manufacturers typically offer buck regulator ICs with built-in controller and integrated FETs. Such buck regulators primarily implement step-down voltage conversion. Nevertheless, they can also be used to create many other designs, such as inverting power supplies, bipolar power supplies, and isolated power supplies with single or multiple isolated voltage rails. This article introduces a variety of designs using buck regulator ICs, explains their operational principles, and discusses the practical considerations to implement these designs. **Sitthipong Angkititrakul, Applications Engineer, Renesas/Intersil Electronics Corporation, USA**

Renesas' ISL8541x family of buck regulator ICs feature integrated high-side and low-side FETs, internal boot diode, and internal compensation, which minimizes the amount of external components and enables very small total solution size. In addition, this family of regulator ICs has a wide input voltage range of 3 V to 40 V to support a multi-cell battery and a variety of regulated voltage rails. In this article, the ISL85410 buck regulator IC is used to illustrate various application designs.

Step-down converter with a buck regulator IC

A step-down converter is required when the desired voltage level is lower than the available voltage source in the system. For example, take a system that has a 12 V battery as input, but lower voltage rails such as 5 V, 3.3V , or 1.2 V are desired to power microcontrollers, I/O's, memory, and FPGAs. By efficiently converting a high voltage to a low voltage, the buck converter extends the system's battery life, reduces heat dissipation, and improves reliability. Figure 1 shows the simplified schematic of a step-down converter using the ISL85410 buck regulator IC.

The output voltage has the same polarity as the input voltage, and the voltage conversion ratio in continuous-conduction-mode (CCM) can be expressed as

$$V_{OUT} \;/\; V_{IN} = D \qquad (1)$$

where D is duty cycle and ranges from 0 to 1, which indicates the output voltage (V_{OUT}) is always less than or equal to the input voltage (V_{IN}).

Inverting power supply with a buck regulator

While positive voltages are commonly used and available in electronic systems, negative voltages are sometimes also required. In such cases, an inverting power supply will be required to generate a negative voltage from a positive input. The inverting buck-boost converter is one of the popular solutions to address these application needs.

Figure 2 compares the power stage of a buck converter with an inverting buck-boost converter, showing that an inverting buck-boost converter can be derived by switching FET Q2 and inductor L1. This

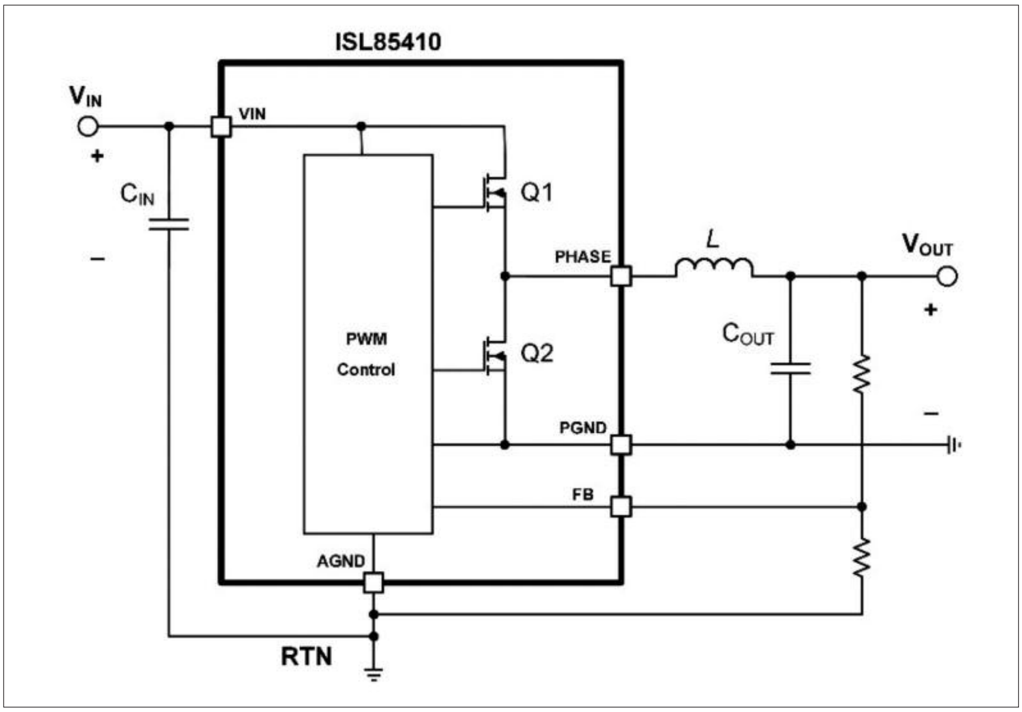

Figure 1: Simplified schematic of a step-down converter

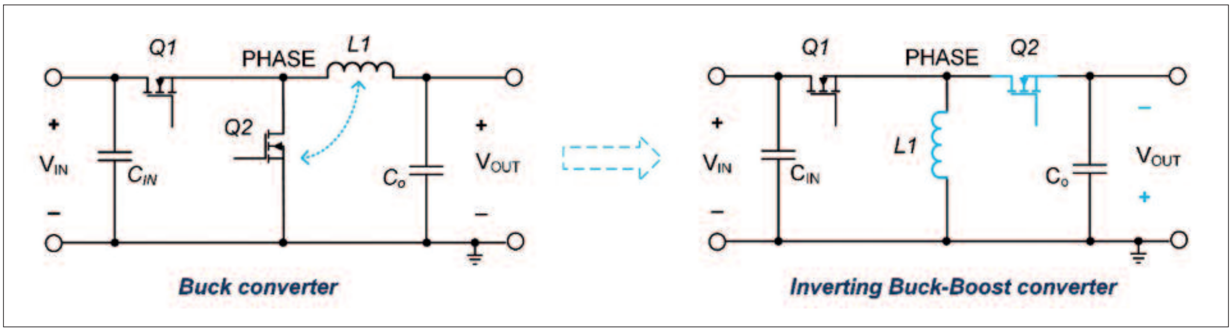

Figure 2: Power stages of buck converter and inverting buck-boost converter

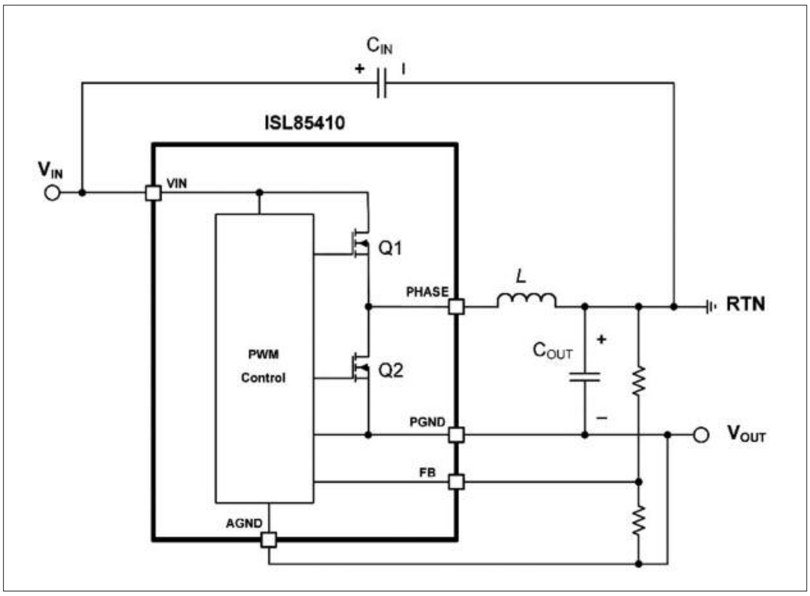

Figure 3: Simplified inverting buck-boost converter implementation

topology change results in different voltage conversion ratio and inverting polarity of the output voltage

$$V_{OUT} / V_{IN} = - D / 1 - D \qquad (2)$$

In an inverting buck-boost converter, the output voltage amplitude can be either higher or lower than the input voltage, and the output voltage is negative with respect to ground of the input voltage source.

The inverting buck-boost converter can be implemented with a highly integrated buck regulator IC. Figure 3 shows a simplified implementation example using the ISL85410 buck regulator. When configuring a buck regulator as an inverting buck-boost converter, power designers must pay attention to two major differences. The first difference is the connection of the return (RTN) of input voltage source (V_{IN}). In the buck converter shown in Figure 1, the RTN of input voltage source is also the device ground (i.e., the AGND/PGND pins of the buck regulator), while the RTN of the input voltage source and the device ground are no longer the same in an inverting buck-boost converter. Hence, the input voltage source must be applied across VIN pin and RTN instead of AGND/PGND pins when implementing an inverting buck-boost converter.

The second difference is the voltage stress on VIN pin with reference to AGND pin. This voltage in a buck converter is always equal to V_{IN} regardless of the output voltage. By contrast, the VIN pin in an inverting buck-boost converter has to tolerate the sum of input voltage and output voltage (V_{IN}+V_{OUT}). For instance, in a design converting 24 V to -5 V, the voltage stress on VIN pin is 29 V rather than 24 V. Keep in mind that the voltage stress on VIN pin should never exceed the absolute maximum voltage rating specified in the IC datasheet.

Bipolar power supply with a buck regulator IC

Many applications, including operational amplifiers and data acquisition systems, need a bipolar ±5 V or ±12 V power supply. One popular method is to use a single switching regulator along with a coupled inductor (also commonly called a transformer) to generate a negative voltage

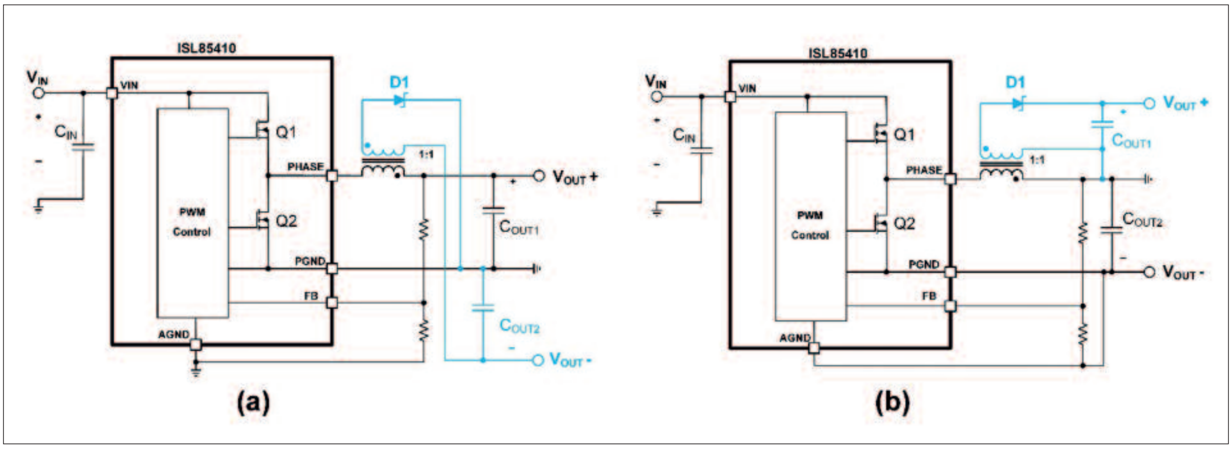

Figure 4: Simplified schematic of bipolar power supply using buck method (a) or inverting buck-boost method (b)

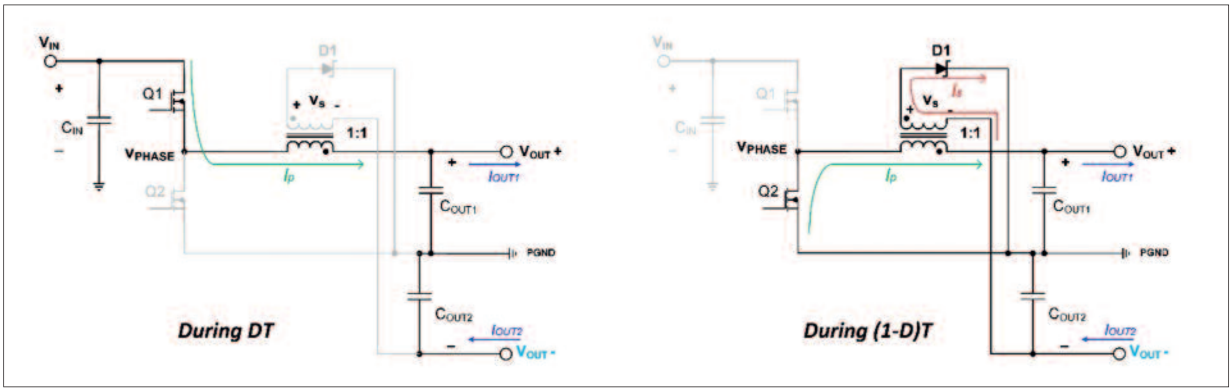

Figure 5: Equivalent circuit of a bipolar power supply using buck method

V_{IN}	V_{OUT+}	V_{OUT-}	I_{OUT1}	I_{OUT2}	f_{SW}
24V	5V	-5V	100mA	100mA	500kHz

Table 1: Key parameters of the bipolar power supply

rail and a positive voltage rail. Figure 4 shows how a buck converter and inverting buck-boost converter can be used to create bipolar power supplies.

As shown in Figure 4(a), the ISL85410 buck regulator is first configured as a buck regulator regulating the positive output V_{OUT+}, and then the negative output V_{OUT-} is generated by adding an additional coupled winding. The positive output V_{OUT+} is regulated as in a buck converter, while the negative output V_{OUT-} reflects V_{OUT+} (for simplicity purpose, forward voltage drop of the rectifier diode D1 is neglected) but with an opposite polarity.

Figure 5 shows the equivalent circuit of a bipolar power supply using the buck method during the time intervals of DT and (1-D)T. During DT, high side FET Q1 is on, which leads to reverse biased rectifier diode D1, and thus no current flows in the secondary winding. During (1-D)T, Q1 is off and the current Ip freewheels through low side FET Q2. The voltage across secondary winding (V_s) reflects V_{OUT+}, and consequently D1 is turned on to charge output capacitor C_{OUT2} and supply power to the load. It is highly recommended to configure the converter in forced CCM to achieve good voltage regulation for the negative output voltage (V_{OUT-}).

A SIMPLIS model of the bipolar power supply, using the ISL85410, was built and simulated to elaborate its operation principle. The key parameters are listed in Table 1.

The simulation waveforms are shown in Figure 6. During (1-D)T when Q2 is on, the reflected current of the secondary winding current (I_s) makes the total primary current (I_p) become negative. Through proper design, this negative current should be kept low enough to avoid triggering the negative current limit of the buck regulator under normal operation conditions.

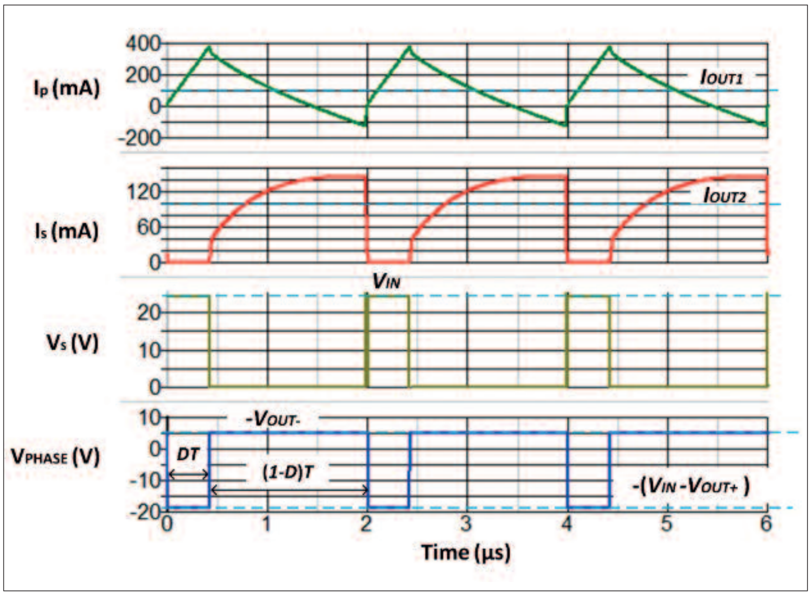

Figure 6: Simulation waveforms of a bipolar power supply using buck method

Figure 4 (b) shows another approach, which uses the inverting buck-boost method to generate a bipolar power supply. In contrast with the approach using buck method, the inverting buck-boost method configures the buck regulator IC in an inverting buck-boost to create a negative voltage rail, while a positive voltage rail is generated using a coupled winding. Unlike the bipolar power supply using buck method, the inverting buck-boost method can regulate the output from an input voltage lower than the output (step-up conversion). However, the voltage stress seen by FETs in the inverting buck-boost method is higher than the buck method. Table 2 summarizes the comparison between these two methods, provides the design guidelines for choosing the best solution for a specific application.

Isolated power supply with a buck regulator IC

Isolated voltage rails often are required to provide galvanic isolation, enhance safety, and enhance noise immunity. Common applications examples include programmable logic controllers (PLCs), smart power metering, and IGBT driver power supplies. Flyback and push-pull converters are two of the popular and cost effective solutions. However, the flyback converter usually requires an optocoupler or an auxiliary winding to regulate output voltage. In addition, the switch in flyback suffers high voltage spikes and thus an RCD snubber is commonly required. The push-pull DC transformer operating with a fixed 50 % duty cycle either suffers bad output voltage regulation or needs an additional LDO for accurate output regulation.

Bipolar Power Supply	Pros	Cons
Buck Method	Lower max voltage seen by VIN pin	Output cannot be higher than input
	Lower voltage stress on FETs	Higher duty cycle is required with same input
	Lower primary inductor current	
Inverting Buck-Boost Method	Output can be either higher or lower than input	Higher max voltage seen by VIN pin
	Lower duty cycle with same input	Higher voltage stress on FETs
		Higher primary inductor current

Table 2: Comparison of bipolar power supply using buck method versus inverting buck-boost method

In the aforementioned bipolar power supply (Figure 4), the additional output voltage rail is achieved by adding a magnetically coupled winding to the inductor in a buck or inverting buck-boost converter. By simply isolating the returns of these two outputs, an isolated voltage rail is achieved (see Figure 7). This approach has recently become very popular.

The two approaches for generating an isolated voltage rail using a buck regulator are shown in Figure 7. These configurations are similar to the bipolar power supply descried in Figure 4 except the returns (references) of the two outputs are separated. Unlike a bipolar power supply where the transformer turns ratio is 1:1, the turns ratio of an isolated power supply can be optimized to set the desired output voltage on the secondary side. Moreover, it can be adjusted to make the controller operate with an optimal duty cycle.

The isolated power supply with a buck regulator offers several advantages. The buck method shown in Figure 7(a) is widely adopted and will be used as an example to explain its benefits. First, it eliminates the optocoupler or tertiary winding required in a flyback converter. Secondly, the buck configuration on the primary side provides low voltage stress on the primary side FETs versus the flyback converter. Lower voltage FETs means lower on-resistance and higher efficiency. Thirdly, the primary side output (V_{OUT1}) is well regulated and the isolated output (V_{OUT2}) reflects V_{OUT1}, which gives good output voltage regulation on the secondary side over a wide input voltage range. Better voltage regulation can be achieved than a push-pull DC transformer without extra LDOs. Highly integrated buck regulator ICs such as the ISL85410 with internal compensation makes these approaches easy to use and attractive for power supply design.

Multiple isolated voltage rails can be realized by adding more coupled windings – two examples are shown in Figure 8. The operation principle is similar to the single isolated voltage rail.

Conclusion

Buck regulator ICs make it easy to implement buck converters for realizing step-down power conversion. We have shown how they can be employed to generate inverting power supplies, bipolar power supplies and isolated power supplies with single or multiple isolated voltage rails. The highly integrated ISL8541x family of buck regulator ICs features wide input voltage range, integrated boot diode, and internal compensation. The inverting, bipolar, and isolated power supply solutions implemented with these ICs offer several important benefits, including low external components count, small total solution size, and ease of use.

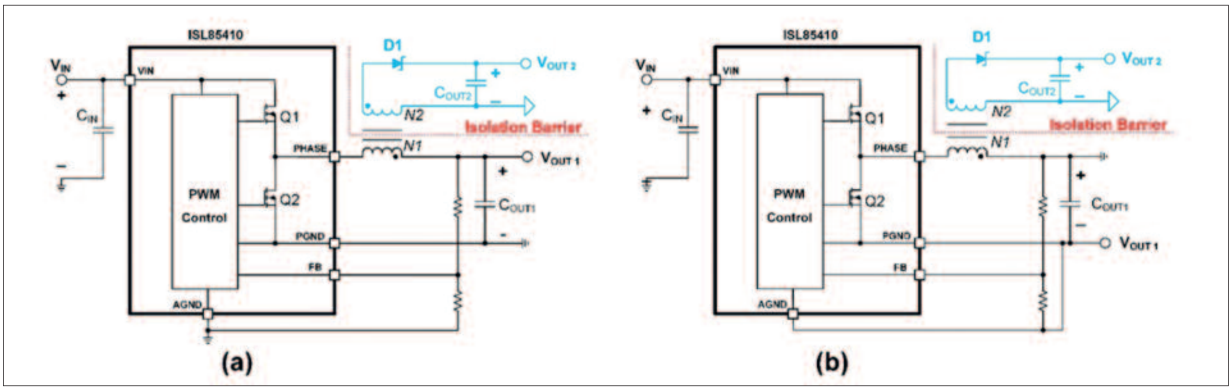

Figure 7: Simplified single isolated voltage rail using buck method (a) or inverting buck-boost method (b)

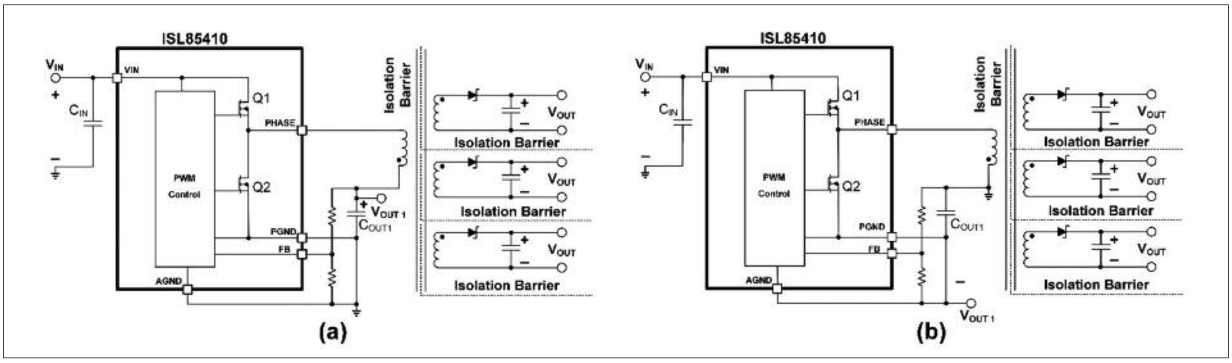

Figure 8: Multiple isolated voltage rails using buck method (a) or inverting buck-boost method (b)