W H I T E   P A P E R

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TEXAS INSTRUMENTS

How to design boost, SEPIC and flyback regulators with wide V$_{IN}$ boost power management ICs

Introduction

The demand for boost regulators has increased recently due to emerging applications in automotive, industrial and consumer marketplaces. Examples of new applications include emergency call (eCall) systems, start-stop systems, audio power amplifiers (PAs), smart grid data concentrators, Thunderbolt™ data ports, power bank for mobile devices, tablet docking stations and many more. In these applications, input power usually comes from low voltage batteries, solar panels, or other low voltage rails, while a higher output voltage is desired. Therefore, a boost (step-up) DC/DC regulator is essential.

Boost power management integrated circuits (ICs) can be configured as either a single-end primary inductance converter (SEPIC) to perform both step-down and step-up (buck and boost), or a flyback regulator to achieve galvanic isolation for enhanced safety and improved noise immunity.

This document explains how to implement boost, SEPIC and flyback regulators with boost power management ICs, and how to choose the right solution. Also covered are approaches to achieve higher output power, improve efficiency, extend input-voltage range, and provide short-circuit protection.

Versatile configurations

Wide V$_{IN}$ boost power management ICs can be configured in various DC/DC topologies to meet different system requirements. The following configurations have in common a low-side control switch.

Boost DC/DC regulator

A boost regulator, widely used in low voltage battery-powered systems, provides a higher output voltage than the input. **Figure 1** shows the simplified schematic of a boost regulator with the LM5001, high-voltage switch-mode regulator from Texas Instruments (TI). This regulator features an integrated FET which reduces the total solution size.
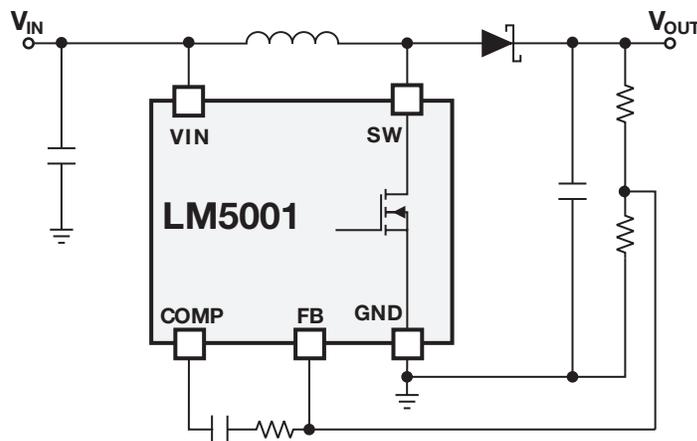

Figure 1. Boost regulator with an integrated FET.

SEPIC DC/DC regulator

In applications where the input voltage may be either higher or lower than the desired output voltage, a regulator capable of performing both step-down and step-up is required. SEPIC is one of the promising candidates due to its minimal number of active devices and clamped switching waveforms which mitigate electromagnetic interference (EMI). SEPIC, having a low-side control switch in common with the boost regulator, usually is implemented with a boost power management IC. **Figure 2** shows a SEPIC regulator using the LM5001, the same IC used in the aforementioned boost regulator example.

This schematic shows two separate inductors, which can be a coupled inductor with two windings wound on a common magnetic core to save circuit area.
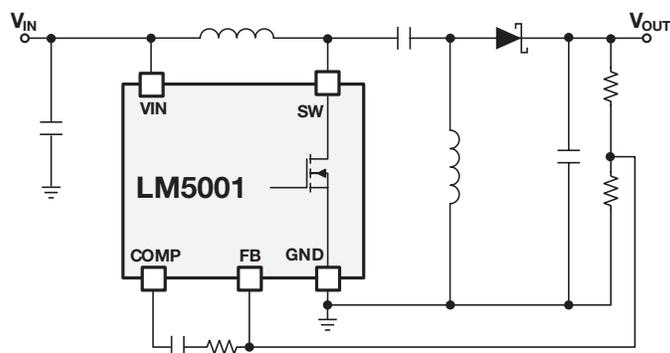
Figure 2. SEPIC regulator with an integrated FET.

Flyback DC/DC regulator

Another popular topology using wide V$_{IN}$ boost power management ICs is the flyback regulator, which can be either isolated or non-isolated. A non-isolated flyback regulator (**Figure 3**) is an alternative solution to SEPIC to realize both step-up and step-down conversion. An isolated flyback regulator (**Figure 4**) is an attractive solution to provide galvanic isolation, enhanced safety, and improved noise immunity. Besides the simplicity of the flyback regulator, another notable advantage is that no additional magnetic components are required to add multiple outputs.
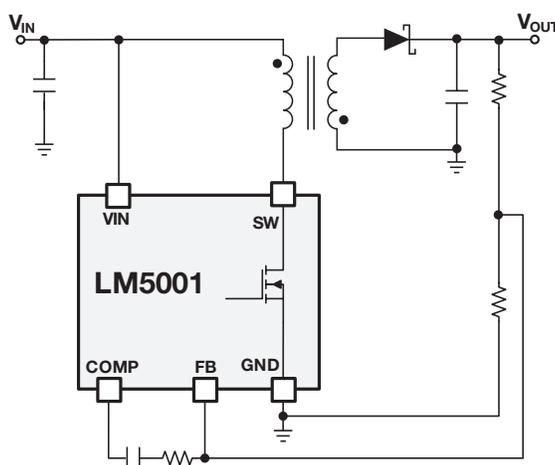
Figure 3. Non-isolated flyback regulator with an integrated FET.

In isolated flyback regulators, either an optocoupler or a tertiary winding is commonly used to implement output voltage feedback. In an isolated flyback with optocoupler, an adjustable shunt regulator such as the LM431, or a standard error amplifier plus a voltage reference, can be employed for feedback from secondary to primary. The design with an optocoupler (**Figure 4a)** provides tight load regulation for V$_{OUT}$ on secondary side, while the design with a tertiary winding (**Figure 4b**) features simplicity without additional optocoupler and error amplifier. The output of the tertiary winding (Vaux) also can serve as the bias supply to the regulator to reduce its internal power loss at high V$_{IN}$.
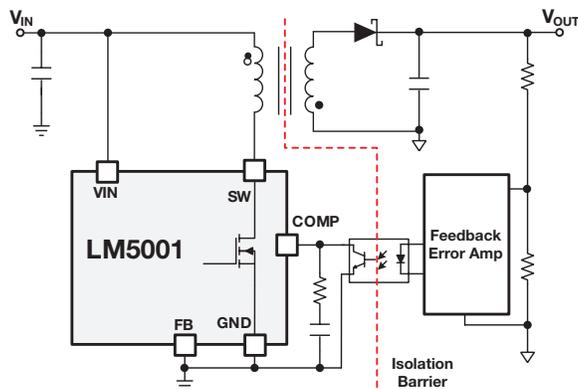
(a)   Isolated flyback regulator with an optocoupler.
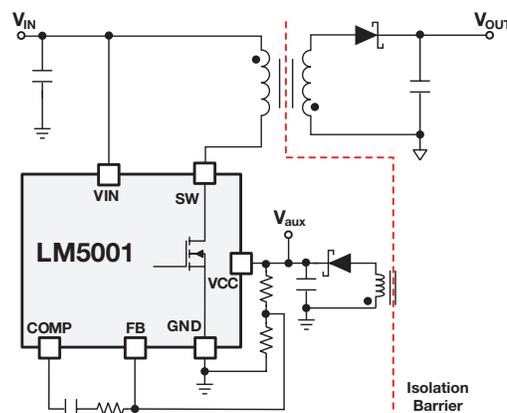
(b)   Isolated flyback with tertiary winding.

Figure 4. Isolated flyback.

Choose the right solution

Since there are a wide variety of boost power management ICs, the first question for power supply designers is how to choose the right IC solution for a specific application.

Converter (integrated switch) versus controller (external switch)

TI's power management IC portfolio includes integrated switch boost solutions called converters, as well as devices requiring external switches called controllers. Converters usually offer higher integration and smaller total solution size. However, converters lack flexibility due to the current and voltage restraints imposed by the integrated switches. For instance, the maximum voltage and peak current of the LM5001's integrated MOSFET (metal oxide semiconductor field effect transistor) is 75V and 1A, respectively. Converters are often the preferred choice when an available power management IC supports the voltage and current ratings for the specific application.

In cases where the required maximum current and/or voltage exceed the capability of boost converters, a boost controller and appropriate MOSFET should be used. Similar to boost converters, boost controllers can be configured as either a boost, SEPIC, non-isolated flyback, or an isolated flyback regulator. **Figure 5** and **Figure 6** show examples of boost and non-isolated flyback regulators, respectively, designed with the LM5022 controller. Different from converters, controllers give designers freedom to choose appropriate external switches based on their specific needs. The disadvantages are a relatively larger total solution size and a more complicated design.
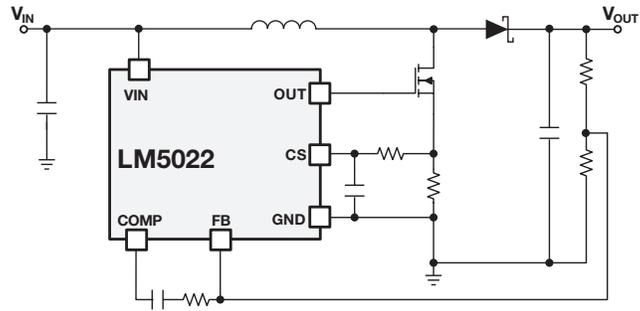
Figure 5. Boost regulator with an external FET.
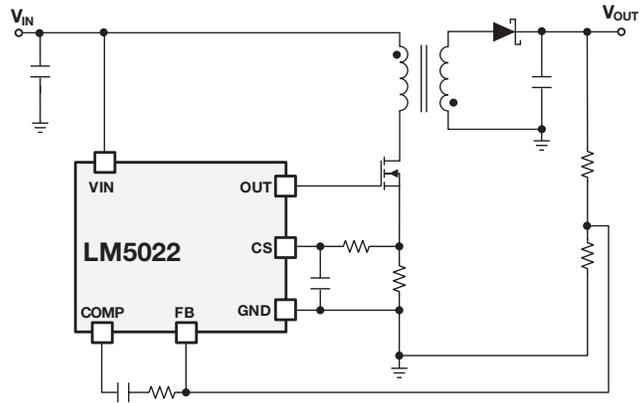
Figure 6. Non-isolated flyback with an external FET.

Non-synchronous versus synchronous rectification

The DC/DC switching regulators shown in the previous examples are all non-synchronous in which a rectifier diode is used. In a synchronous regulator, a MOSFET is used instead. Accordingly, an additional gate driver is required for the synchronous MOSFET. The difference can be better understood by comparing the synchronous boost regulator in **Figure 7** with the non-synchronous boost regulator in **Figure 5**. The LM5022 non-synchronous boost controller only has one low-side gate driver, whereas the LM5122 synchronous boost controller has an additional high-side gate driver for the synchronous MOSFET. The LM5122 also can be configured as a non-isolated synchronous flyback regulator (**Figure 8**).
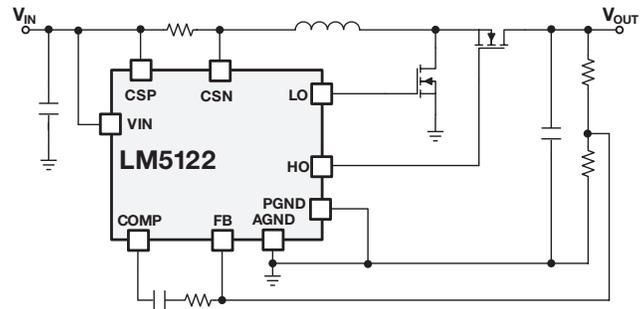
Figure 7. Synchronous boost regulator.
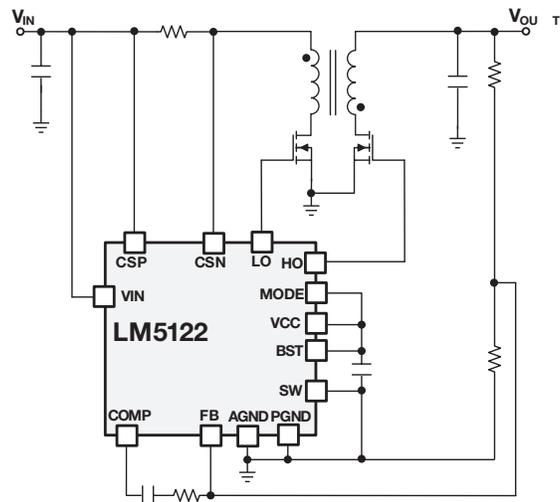
Figure 8. Non-isolated synchronous flyback regulator.

A synchronous recitifier MOSFET usually has lower forward voltage drop than a Schottky diode, which leads to lower conduction loss. Hence, synchronous regulators can obtain higher efficiency, especially in low-voltage and high-current applications. A MOSFET has a positive temperature coefficient of on-resistance, which means the forward voltage drop increases as the temperature goes up. This characteristic causes current to flow equally through multiple devices when they are connected in parallel. As such, a MOSFET is more suitable for parallel operation in high-current applications than Schottky diodes which have a negative temperature coefficient.

Furthermore, paralleling of MOSFETs is much more effective than paralleling of Schottky diodes when it comes to conduction loss reduction. **Figure 9** compares parallel operation characteristics between a MOSFET and Schottky diode. Reducing the MOSFET current to half its original value also reduces the MOSFET conduction loss to half its original value due to linear I-V characteristic. In contrast, reducing the Schottky diode current to half its original value also reduces the Schottky loss. However, the new Schottky loss is higher than half its original value because of exponential I-V characteristic.
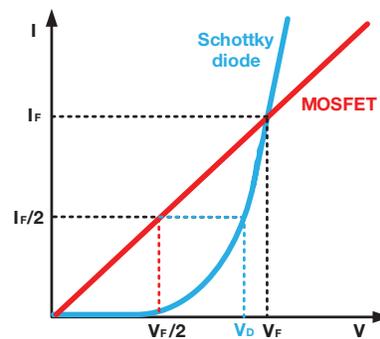
Figure 9. Characteristic comparison between MOSFET and Schottky diode.

The main drawback of a synchronous switching regulator is that it requires an additional driver for synchronous MOSFET, which increases the circuit complexity and driving loss. **Table 1** is a comparison between synchronous MOSFET and schottky diodes. Designers should chose the solution based on their specific design priorities.

	MOSFET (synchronous)	Schottky Diode (non-synchronous)
Pros	Lower conduction loss	Simple implementation
	Good for parallel operation	—
Cons	Complicated implementation	Higher conduction loss
	—	Not suitable for parallel operation

Table 1. MOSFET (synchronous) vs. Schottky diode (non-synchronous).

Interleaved multiphase topology for high output power

There are a number of ways to handle higher power requirements, of which the interleaved multiphase topology has several advantages. By controlling the phase-shift between the parallel regulators, reduced current ripple, improved efficiency, smaller passive component size, and enhanced thermal performance can be achieved. An interleaved dual-phase synchronous boost regulator with two controllers is outlined in **Figure 10**. The slave at the bottom is synchronized to a clock generated by the built-in oscillator circuit of the master such that the two phases are 180 degree out-of-phase. The current-sharing between two phases is achieved by current-mode control with a single error amp from the master driving the power stage of both controllers.
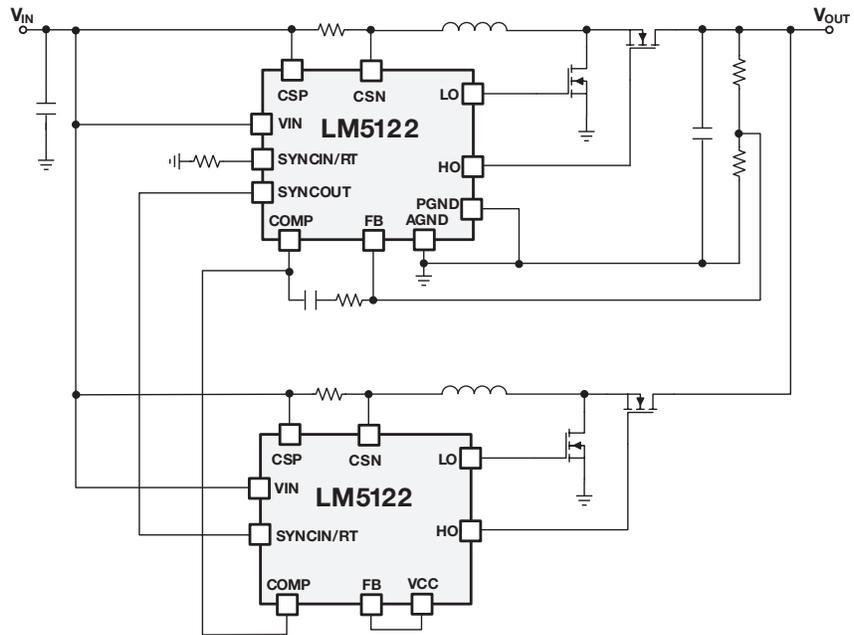
Figure 10. Interleaved dual-phase synchronous boost regulator.

DCR sensing for efficiency improvement

The synchronous boost regulator in **Figure 7** has an additional current-sense resistor between the input and the inductor in the power path. This current sense resistor generates additional power loss which might be significant in high-current applications.

The boost inductor can be represented as a series combination of an ideal inductor and a lumped direct-current resistance (DCR) (**Figure 11**). The inherent DCR of the inductor can be used to measure the inductor current which eliminates the discrete current sense resistor and the corresponding power loss. The voltage across the DCR is extracted using a series R-C network in parallel with the inductor. By matching R-C time constant of this network with L/DCR time constant of the inductor, the voltage across the capacitor of R-C network then equals the voltage across the inductor DCR.
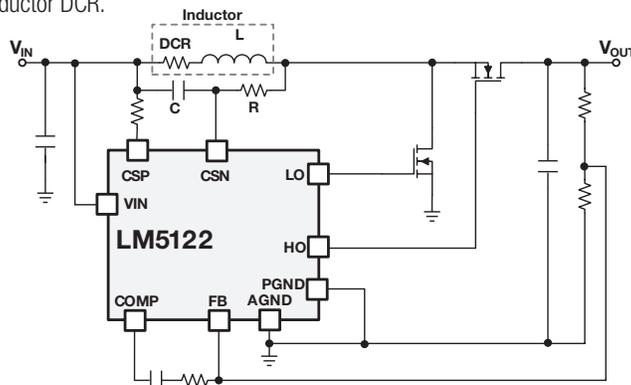
Figure 11. Synchronous boost regulator with DCR sensing.

Split-rail configuration to extend input-voltage range

A split-bias-rail configuration, wherein the power stage input and boost IC bias supply are separated from each other, is an effective way to extend the boost regulator input voltage range. For example, the LM5122 requires 3V of minimum voltage at CSP pin (power stage current sense input) and 4.5V minimum voltage at V_{IN} pin (IC bias supply). If these two pins are connected as shown in **Figure 7,** the shared single input (V_{IN}) must be equal to or above 4.5V to ensure proper operation.

Figure 12 and **Figure 13** present two split-rail configurations. The design in **Figure 12** requires a V_{IN} input voltage of 4.5V or more for start-up. After start-up, V_{OUT} is fed back to V_{IN} as the bias supply via a diode and the regulator maintains normal operation until V_{IN} drops below 3V. The alternative split-rail approach in **Figure 13** uses a charge pump (TPS60150) to produce the V_{IN} bias which, extends the start-up and operating input voltage down to 3V. This is a notable improvement from the 4.5V required by the single-rail configuration (**Figure 7**).
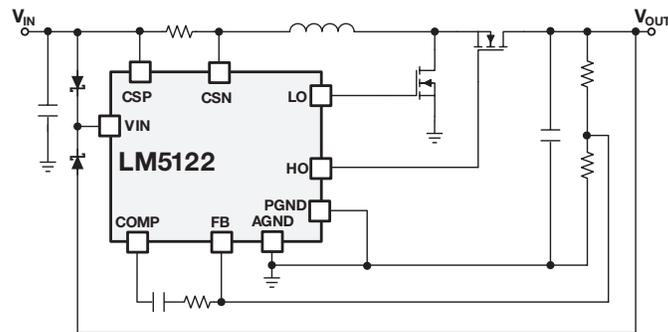
Figure 12. Split-rail approach extending input-voltage range after start-up.
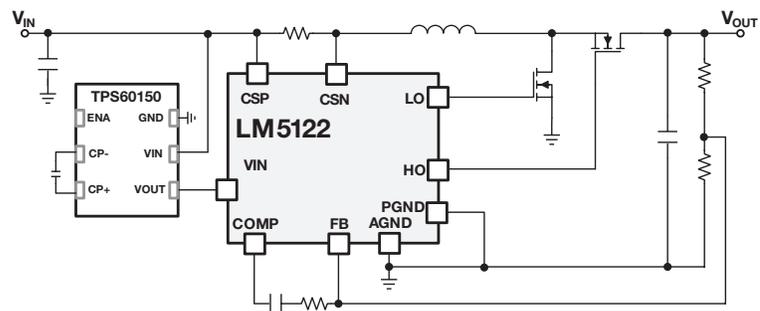
Figure 13. Split-rail approach extending start-up input-voltage range.

Load disconnect switch control for short-circuit protection

A basic boost regulator provides no short-circuit protection because the output is connected to the input through the rectifier and inductor when the output is pulled low. Hence, a load disconnect switch is often incorporated to prevent damage from a short circuit. The LM5121 boost design (**Figure 14**) provides built-in control of the load disconnect switch to provide true short-circuit protection. The additional input MOSFET and gate driver disconnects the output when overload is detected and controls input in-rush current during start-up.
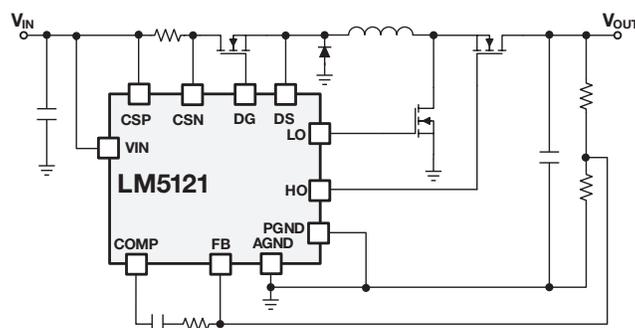
Figure 14. Boost regulator with true short-circuit protection.

Conclusion

Wide V$_{IN}$ boost power management ICs can be configured as either a boost, SEPIC, or a flyback regulator to satisfy various application needs. A converter with an integrated switch provides high integration and small total solution size, whereas a controller and external MOSFET offers more flexibility. Non-synchronous solutions feature simple implementation, while synchronous solutions have lower conduction loss and higher efficiency, especially in high-current low-voltage applications. Interleaving, DCR sensing, split-rail, load disconnect switch control provides additional benefits to the boost regulator design. The right solution should be selected based on the specific design requirements and priorities.

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