

Techniques For Implementing A Positive And Negative Output Voltage For Industrial And Medical Equipment

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Many analog circuits in industrial and medical applications require both positive and negative supply voltages to operate. If a negative supply voltage is not available on the circuit board, a small and efficient solution takes some power management expertise to develop, especially when the output power is more than a few watts. A discrete switching regulator is often used to derive both a positive and negative output voltage, but implementing an inverting buck-boost topology with a coupled inductor can be burdensome.

However, recent advancements in dc-dc power modules allow straightforward implementation of a split-rail power solution. This article surveys several discrete and module-based negative output and split-rail positive and negative output solutions for powering split-rail amplifiers, analog sensors, data converters, and audio amplifiers. Key factors such as complexity, component count, relative cost, and performance are explored. Tools are also referenced to learn more about implementing the solutions. The power solutions presented here are based on Texas Instruments' power ICs. However, in some cases, similar designs may be implemented using ICs from other vendors.

Generating A Negative Output Voltage

Positive output voltages are very common. Typically, printed circuit boards contain several positive voltages that are derived from an intermediate bus voltage by employing stepdown regulators. When considering the popular split-rail voltage requirements like ± 5 V, ± 12 V, or ± 15 V, the negative voltage becomes the challenge. In many cases, the designer must develop the negative voltage separately. The inverting charge-pump, inverting buck-boost switching converter, and the Fly-buck converter are popular solutions employed to generate a negative output voltage from a positive input voltage.

Inverting Charge Pump

Inductorless switching regulators, or charge pumps, are an attractive alternative to inductor-based positive-to-negative switching regulators. A charge pump can be internally configured to invert the applied input voltage. For example, with the TPS60400 shown in Fig. 1, the internal switches are configured to connect the positive terminal of $C_{(fly)}$ pin to ground and the negative terminal of $C_{(fly)}$ pin to the output. As a result, the output voltage is a negative value of the input voltage. However, the output voltage is unregulated and lower in magnitude than the input voltage due to internal switching losses.

A negative-output-voltage charge pump has advantages over an inductor-based solution, such as lower parts count, lower electromagnetic emissions, smaller total solution size, and lower solution costs primarily due to the absence of an inductor. On the other hand, the output current and voltages are limited with a charge-pump solution.

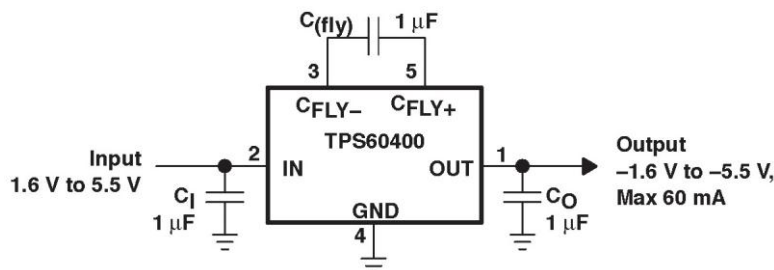


Fig. 1. Negative output voltage charge-pump.

Buck-Boost Voltage Inverter

A stepdown switching regulator can be configured into the inverting buck-boost topology to generate a negative output voltage. When compared to a nonsynchronous buck circuit, the inductor and the catch diode of the inverting buck-boost circuit have switched places, and the output capacitor is reversed in polarity.^[1]

Another way to describe the implementation is that the ground pin of the stepdown converter is connected to -VOUT and the positive lead of the output capacitor is connected to ground. The example in Fig. 2 shows a complete schematic of the inverting buck-boost topology, using the TPS5430, a 36-V input, 3-A stepdown converter. The output voltage (VOUT) is set to -5 V and can be adjusted by selecting the values of the resistor divider R1 and R2.

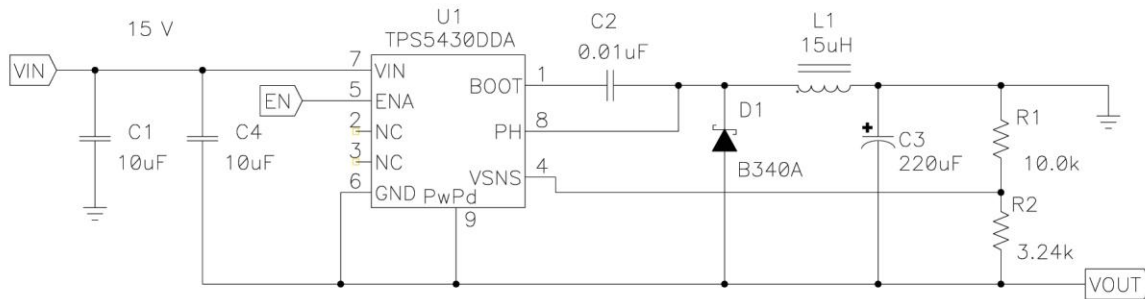


Fig. 2. Inverting buck-boost topology using a stepdown converter.

There are several design considerations involving the inverting buck-boost topology that differ from a standard buck regulator. First, the input voltage is limited, and the voltage across the device's VIN pin to GND pin is now VIN minus (-VOUT) instead of VIN with the buck converter. Second, the available output current is reduced by a factor of (1-D), where D is the duty cycle, since the peak inductor current cannot exceed the device's rated switch current. The duty cycle for an inverting buck-boost topology is shown in Equation 1 and is different from a buck topology duty cycle formula shown in Equation 2.

$$D_{BUCK/BOOST} = -V_{OUT} / (-V_{OUT} - V_{IN}) \quad \text{Equation 1}$$

$$D_{BUCK} = V_{OUT} / V_{IN} \quad \text{Equation 2}$$

Third, the minimum input voltage is limited by the dc-dc converter's undervoltage lockout (UVLO) circuit. The UVLO is relative to the device ground, which is configured as VOUT. When the device starts up, the output voltage is 0 V, and the minimum input voltage to guarantee start-up is the same as the UVLO level. However, because of input undervoltage, the UVLO circuit is not able to shut down the converter after start-up is complete. Finally, there are significant differences between discontinuous conduction mode (DCM) and continuous conduction mode (CCM) operation in the inverting buck-boost topology. A design stable in CCM may be unstable in DCM under changing load conditions.^[2]

A buck converter configured into an inverting buck-boost topology has several advantages such as high efficiency and flexibility with output voltages and currents. When switching regulators with integrated MOSFETs and internal compensation are employed, external parts count is kept low. However, the implementation may be challenging to inexperienced power designers so be sure to seek out resources available from vendors such as datasheets, application notes, evaluation modules, design tools and so on.

Transformer-Coupled Split-Rail Design

Both positive and negative output voltages can be derived by implementing the inverting buck-boost topology with a transformer-coupled split-rail design. First, the negative output voltage is implemented in the same manner as the inverting buck-boost topology shown in Fig. 2. Note that the dc-dc converter also can be configured to regulate the positive voltage and use the secondary winding to regulate the negative output.

When a coupled transformer is used, the transformer's primary-side output voltage is reflected to the secondary-side. The polarity of the primary and secondary windings are opposite to configure a positive secondary-side voltage from a negative primary-side voltage. The circuit in Fig. 3 demonstrates transformer-coupled split-rail operation with dual outputs providing ± 18 V at up to 100 mA. The -18 V is used as the ground reference for the converter in this application.^[3]

Other output voltages are possible by changing the values of the converter's resistor divider. The design example provides up to 100 mA for the positive and negative output voltages.

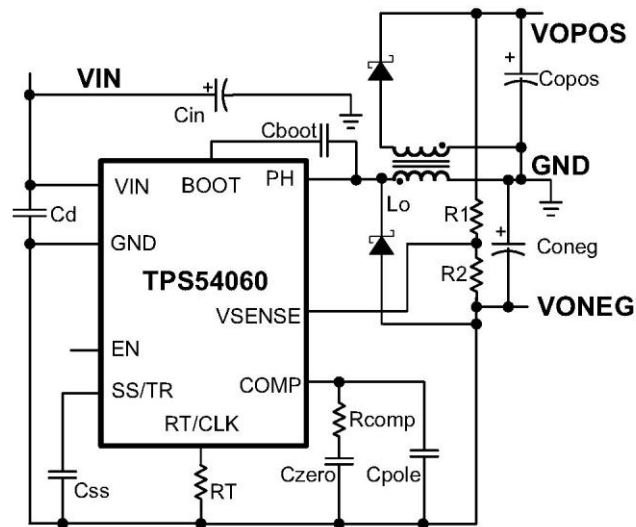


Fig. 3. Transformer-coupled split-rail design with a stepdown converter.

The heart of the design is the coupled inductor (L_o) and a nonsynchronous stepdown converter. There are several manufacturers that offer off-the-shelf coupled inductors in a variety of standard values, saturation currents, and sizes. The converter uses external compensation for stability optimization and an integrated power MOSFET to reduce the total parts count.

Besides the inductor and the dc-dc converter, the other main external components are two power diodes and ceramic input and output capacitors. The remaining components are small resistors and capacitors that configure the dc-dc converter. This solution does not provide isolation between the input and the output.

Isolated Fly-buck Converter For Split-Rail Voltages

The Fly-buck converter is a variation of a flyback converter and consists of a power stage with high- and low-side power MOSFETs, transformer, primary-side capacitor, diode and output capacitor.^[4] The voltage on the primary-side capacitor is regulated by the controller and this voltage is reflected to the output through the transformer. The Fly-buck is a play on words between “flyback” and “buck,” since the transformer is connected as a flyback converter and the input-to-output voltage relationship is similar to a buck-derived converter. The output voltage of the Fly-buck is determined by the turns-ratio of the transformer and the voltage divider resistor values on the VSENSE pin, which provides many options for selecting the output voltage.

Positive and negative outputs can be implemented with a multiple-winding transformer. The design example shown in Fig. 4 features the TPS55010 and a 2- μ H transformer with a 1:8:8 turns-ratio to provide both ± 15 -V outputs at 40 mA, each from a 5-V source. The regulation accuracy of both outputs is mainly dependent on the transformer, low-side MOSFET, and the diode losses. Therefore, the output voltage-drop increases as the output current increases, which tends to limit the maximum output power for a given output voltage.

An advantage of the Fly-buck converter is that the input and output are isolated through the transformer’s magnetic coupling. Additionally, substantial cost is saved due to the absence of an optocoupler, since primary-side feedback is used.

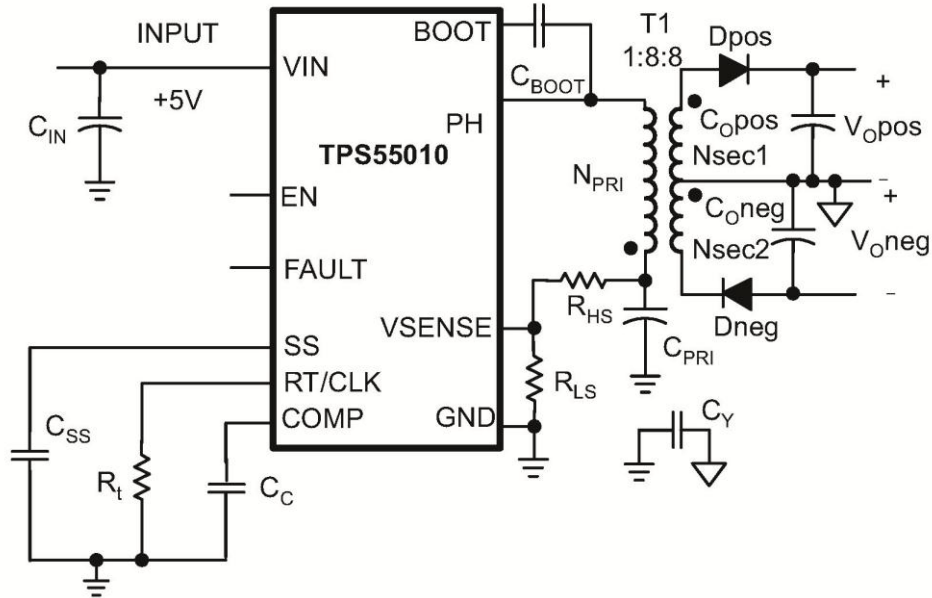


Fig. 4. Split-rail isolated Fly-buck converter.

High-Current \pm Voltages With Power Module

Small, negative-output-voltage power modules are now readily available due to recent advancements in semiconductor, packaging and magnetics technologies. Power modules that integrate the inductor and other passive components are optimized to simplify the layout, reduce external components, and save board space. In Fig. 5, the TPS84259 is a negative-output-voltage power module configured into the inverting buck-boost topology, and the method of operation is very similar to the buck-boost voltage inverter.

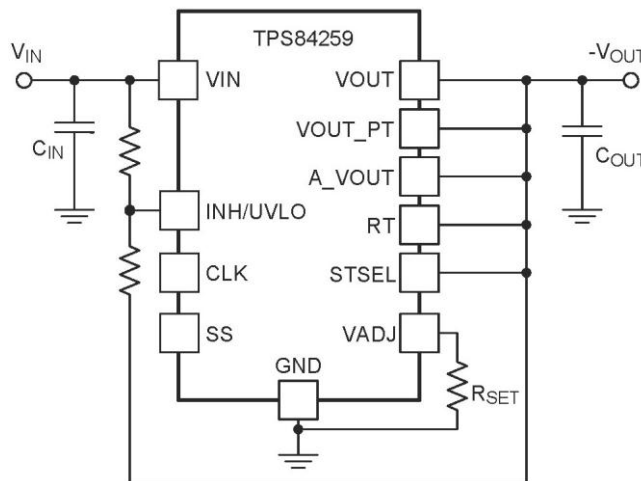


Fig. 5. Negative-output-voltage power module.

An easy-to-use high-output-current split-rail design is possible by employing two power modules with the same input voltage. We used the TPS84259 to provide the negative rail, and the TPS84250, a stepdown power module, to provide the positive output voltage.

We choose these modules because both are available in small 9-mm by 11-mm by 2.8-mm packaging, which occupy only 200 mm² of board space, not counting the input and output capacitance. An example is shown in Fig. 6 that uses optional low-noise regulators to provide low ripple and high power supply ripple rejection (PSRR). The output current is limited by the power modules' output capability, low dropout regulators, and

circuit board thermal constraints. In this example, the low dropout regulators are limited to 1-A output current. The power module implementation is simple with few external components and high-current capability. Note that both power module output voltages are independently regulated. The stability of the power module is not affected by the linear regulator when the linear regulator is placed outside of the power module's feedback loop.

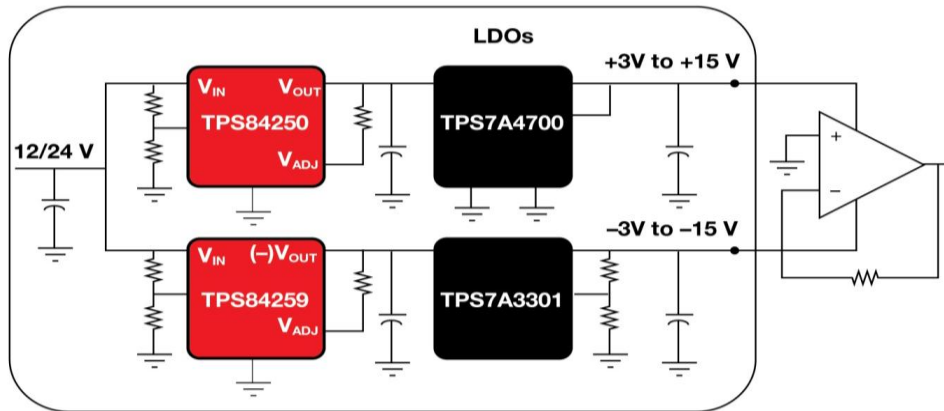


Fig. 6. Split-rail solution with power modules.

Summary

In many cases, a suitable positive voltage already exists in the application, and only a negative output voltage is needed. Three different examples were shown for generating a negative output voltage. A charge-pump voltage inverter is a very small, easy, and low-cost solution with very few external components, but the output current is limited to around 50 to 100 mA. If a higher current is needed, a stepdown dc-dc converter can be configured into the inverting buck-boost topology. However, the design and layout are more complex with higher external component count.

A converter with integrated MOSFETs was also illustrated, but a dc-dc controller with external MOSFETs achieves higher output current and requires more design expertise. A power module provides a simple negative output voltage solution that delivers moderate output power with few external components in a space-optimized package. But, there is a slight price premium for the component integration and board space savings. When both positive and negative output voltages are needed, designers can consider a discrete transformer-coupled dc-dc converter, the Fly-buck converter, or a split-rail power module solution. The table below compares the characteristics of the three split-rail options.

Table 1: Split-rail voltage solution comparison.

	Transformer-coupled converter	Fly-buck converter	Split-rail power modules
Complexity	Similar to Fly-buck converter	Similar to transformer-coupled converter	Easiest
Voltage regulation	Negative rail is regulated	Primary-side feedback only. VOUT depends on diode losses	Both rails are regulated
Component count	Similar to Fly-buck converter	Similar to transformer-coupled converter	Fewest external components
Output power	Highest—can use external MOSFETs	<5 W	Depends on power module rating
Isolation	No	Yes	No
Cost	Similar to Fly-buck converter	Similar to transformer-coupled converter	Need two modules, but no transformer

References

1. "[Using a buck converter in an inverting buck/boost topology](#)," by John Tucker, Analog Applications Journal, Texas Instruments, 4Q2007.
2. "[The Right-Half-Plane-Zero, A Simplified Explanation](#)," by Lloyd Dixon, SLUP084, Seminar Topic 500 DRA, Texas Instruments, 2001.
3. "[TPS54060EVM-590 100 mA, Split Rail SWIFT Regulator Evaluation Module](#)," SLVU374, Texas Instruments, May 2010.
4. "[2.95V To 6V Input, 2W, Isolated DC/DC Converter with Integrated FETS](#)," SLVSAV0A, Texas Instruments, June 2011.
5. For more information, download these datasheets: [TPS5430](#), [TPS54060](#), [TPS60400](#), and [TPS55010](#).

About The Author



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For further reading on dc-dc converters, see the [How2Power Design Guide](#), select the Advanced Search option, go to Search by Design Guide Category, and select "DC-DC converters" in the Power Supply Function category.

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