The Parallel Universe of Negative-Input Voltages

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Nonisolated positive-input topologies have mirror-image topologies that can be used with a negative-input voltage, but require special attention to controller selection and the implementation of bias power and feedback.

Switching dc-dc power supplies are prolific in today's consumer electronics. Most applications use an input source that provides a positive dc voltage referenced to system ground. These sources often include batteries, wall adapters or regulated ac power supplies. Well-established converter topologies like the buck, boost, inverting buck boost and single-ended primary inductor converter (SEPIC) are typically used to generate regulated voltages from an unregulated dc source. These common topologies convert positive-input voltages into either positive- or negative-output voltages.

Difficulty arises when a negative-input voltage must be used as the input source for a dc-dc converter. A transformer-isolated topology, like the flyback or forward, could be used with a negative-input voltage. However, transformer-isolated topologies tend to be larger than nonisolated topologies. Additionally, the transformers are almost always custom devices that require additional procurement time and higher cost.

Fortunately, all of the common nonisolated positive-input topologies have mirror-image topologies that can be used with a negative-input voltage. Fig. 1 helps to visualize the topology selection. In this figure, output voltage is plotted against input voltage. A dashed diagonal line is drawn, depicting where the input and output voltages are equal. The right half represents the familiar positive-input topologies, while the left half-plane represents the less-common negative-input topologies. Similarities between these converters reveal what may seem like a parallel universe of negative-input voltages.

Buck Topologies

The buck converter is the first switch-mode topology taught in every power electronics course, yet most power designers would hesitate when drawing a negative-input buck. A negative-input buck, just like its positive-input counterpart, has an input that is always larger in magnitude than the output. Simplified schematics for both
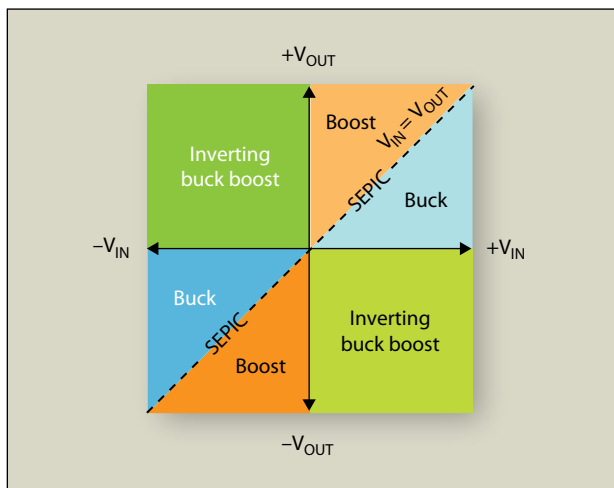
Fig. 1. *All of the common nonisolated, positive-input topologies have mirror-image topologies that can be used with a negative-input voltage.*
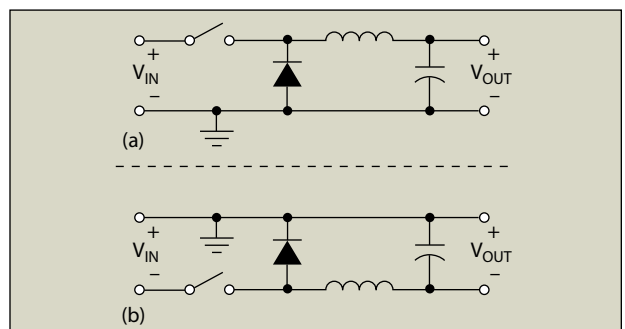
Fig. 2. *When compared with the typical positive-input buck (a), the negative-input buck (b) is a near mirror image of that extremely popular topology.*
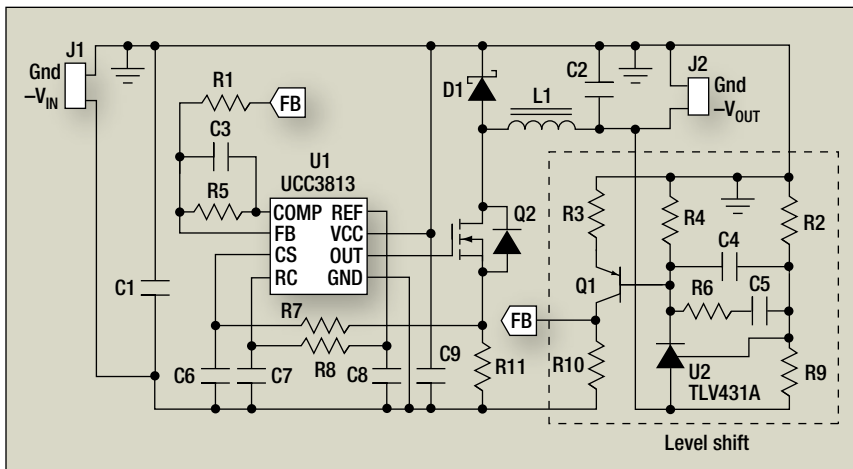
Fig. 3. *The negative-input buck uses an n-channel FET and requires a feedback level-shift circuit.*

Fig. 4. *The positive-input boost (a) and negative-input boost (b) appear quite similar with both having a dc path between the input and the output.*

of these topologies are shown in Fig. 2. While the same power components are used, only their locations relative to ground are changed. Some of the challenges in implementing a negative-input buck include controller biasing, output feedback and driving the power switch.

Fig. 3 shows a practical implementation of a negative-input buck regulator. In this example, the controller receives power directly from the negative-input rail, and the system ground is powering the controller's V_{CC}. Care should be taken to ensure that the magnitude of the input voltage never exceeds the maximum V_{CC} rating of the controller. The control circuit drives an n-channel MOSFET, since the controller has the same ground reference as the FET source. In addition, the switch current can be sensed in the source lead of the FET for easy implementation of current-mode control.

Unlike a positive-input buck, the output voltage does not share the same ground as the control circuit, so the feedback is somewhat more complicated and requires a level-shift circuit. To keep the output voltage in regulation, the TLV431 sinks current into its cathode, forcing a current to flow in R10. This provides the feedback voltage necessary for output regulation, but shifted to the controller's ground reference.

Boost Topologies

The boost converter can be considered the opposite of the buck converter, increasing rather than decreasing the output voltage with respect to input voltage. The simplified circuits in Fig. 4 show the similarities between the positive-input boost and its negative-input counterpart.

Functionality between the two is complementary, particularly the dc path between the input and the output through the inductor and the diode. The "nonswitched" path from input to output provides a path for current to always flow to the output. As a result, the output voltage remains very close to the input voltage before the converter begins switching. This allows the boost controller to be biased by the output voltage, as shown in Fig. 5.
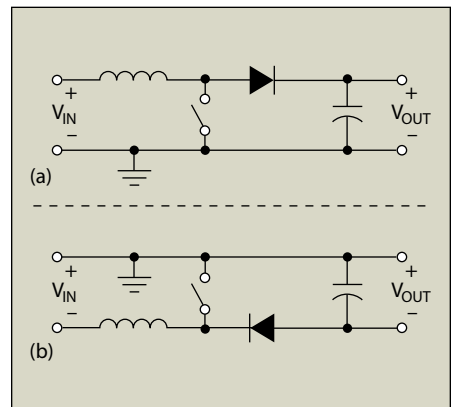
The controller must have a turn-on voltage threshold that is slightly below the minimum input voltage and must also be capable of withstanding the boosted output voltage. The positive-input boost's n-channel power switch changes to a p-channel FET in the negative-input boost. An n-channel FET could be used, but it would require a level-shifting driver such as a gate-drive transformer, which increases cost and complexity.
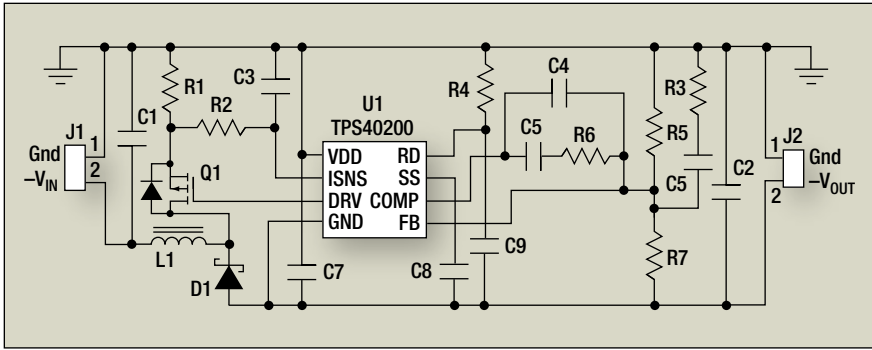
Fig. 5. *The negative-input boost's controller avoids level shifting in the feedback path.*
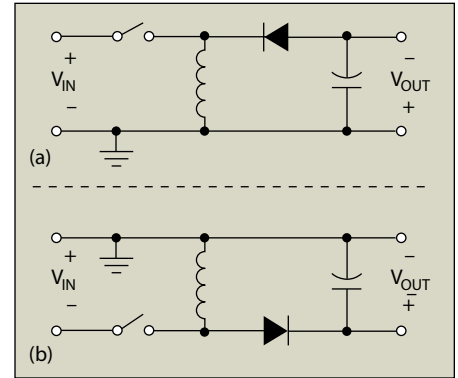

Fig. 6. *Positive-input (a) and negative-input (b) inverting buck-boost power stages. When implementing the latter topology, the control circuit's grounding and FET drive configuration are not always obvious.*

Fig. 5 uses the TPS40200 controller, which directly drives a p-channel FET. Feedback is quite simple, with the output voltage directly sensed by the controller. Since the controller is referenced to the output ground, no ground level-shift circuitry is necessary. Another possible approach for connecting the controller is to bias it from the input voltage rather than across the output. This requires a level-shifting feedback similar to that used in the buck converter.

Buck-Boost Topologies

An inverting buck-boost circuit provides an output voltage that is opposite in polarity from the input voltage. Most inverting buck-boost conversions result in a negative-output voltage from a positive input. Fig. 6 shows how a positive output can be obtained from a negative input. As with most of these negative-input topologies, the control circuit's grounding and FET drive configuration are not always obvious.

Fig. 7 shows a possible practical implementation. This controller arrangement is similar to that of the negative-input buck converter. The level-shift circuit in Fig. 7 must be capable of shifting the feedback over a larger potential, compared to that of the buck. Q1 must have a collector-emitter voltage rating that is nearly equal to the input voltage plus the output voltage. This circuit can be useful in applications such as negative-input telecom that require additional positive voltages.

SEPIC and Other Topologies

The SEPIC converter provides a regulated output voltage for an input that is either greater or less than the output. It combines the functionality of the buck and the boost. The SEPIC also happens to be one of the least understood topologies, due to an additional capacitor and inductor as well as a more complex control characteristic.

Fig. 8 shows the simplified schematics for both the conventional SEPIC and the negative-input SEPIC. During the portion of the switching cycle when the power switch is enabled, current ramps up in the input inductor. The ac coupling capacitor between the two inductors maintains a voltage equal to the input voltage (V_{IN}) at all times.

With the FET switched on, the capacitor's polarity reverse biases the output diode, blocking any energy transfer to the output. Also during this time, current circulates between the ac coupling capacitor and the output inductor. With the diode reverse biased, current supplied to the load is handled by the output capacitor alone. During the portion of the switching cycle when the power switch turns off, the input inductor's polarity reverses, forcing current through the ac coupling capacitor and the diode into the output capacitor and load.

Fig. 9 shows a practical implementation of a negative-input SEPIC. As with the boost circuit, this circuit typically employs a p-channel FET, so a controller like the TPS40200 with a
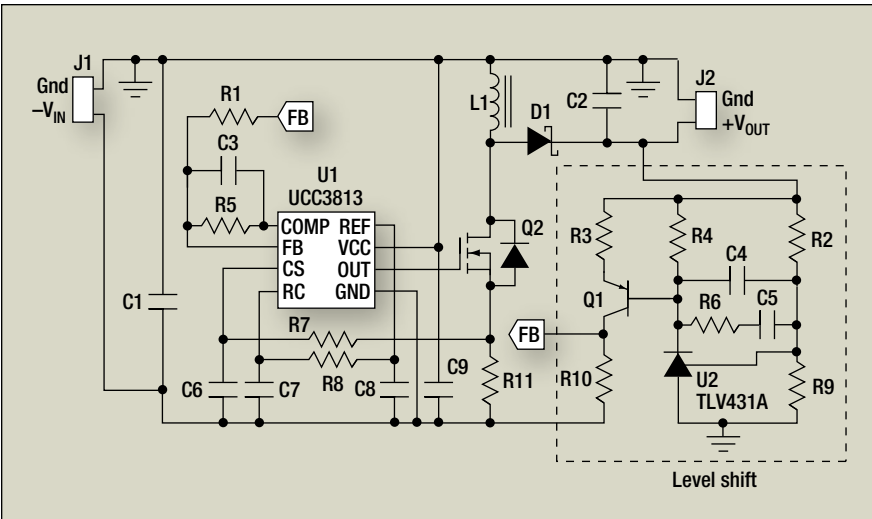

Fig. 7. *A practical implementation of an inverting buck-boost converter uses a controller arrangement similar to that of the negative-input buck converter, but with a level-shift circuit capable of shifting the feedback over a larger potential.*
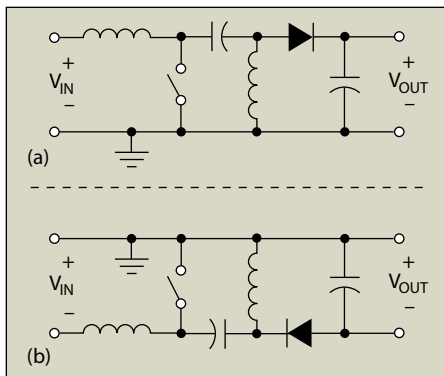
Fig. 8. *The positive-input SEPIC (a) is mirrored by the negative-input SEPIC (b). Each provides a regulated output voltage for an input that is either greater or less than the output.*
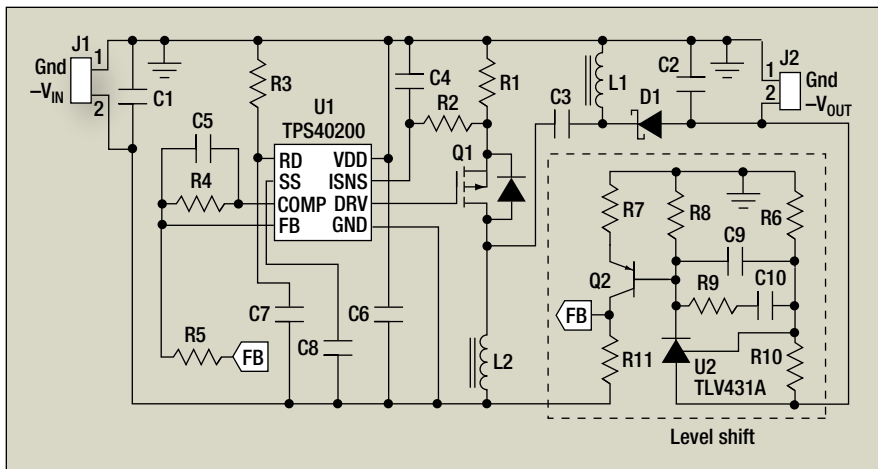

Fig. 9. *A practical implementation of a negative-input SEPIC employs a p-channel FET, which requires a controller with a p-channel driver.*

p-channel driver is a good choice. The feedback requires a level shift, which can be accomplished by the same circuit that was used in the negative-input buck converter. P-channel controllers are typically voltage-mode control, which slightly complicates the control loop.

These techniques for reflecting topologies into the realm of negative-input voltages can be applied to any topology. Two other topologies are the Cuk and ZETA converters. The ZETA converter performs the same function as the SEPIC, and the Cuk could be used in place of the invert-ing buck boost. With a negative input, the ZETA would use an n-channel FET with current-mode control, which may be a better choice than the negative-input SEPIC. The Cuk, however, has many more components and would be larger and more expensive than the inverting buck boost. **PETech**