Single-Inductor, Positive-Output Buck/Boost Converter Uses No RSENSE Controller

by Christopher B. Umminger

The LTC1625 No RSENSE™ controller can be used in a power-converter topology that is capable of both up and down conversion and requires only a single inductor. An example of such a circuit, shown in Figure 1, provides a 12V output with inputs that can range from 18V down to 6V. All of the circuitry to the left of the inductor is identical to that of a typical buck converter implemented with the LTC1625. However, the output (right) side of the inductor is also switched, using an additional pair of MOSFETs (M3 and M4). During the first phase of each cycle, switches M1 and M3 are on while M2 and M4 are off. The input voltage is applied across the inductor and its current increases. In the second phase, M1 and M3 are turned off while M2 and M4 are turned on. Current is then delivered to the output with VOUT applied across the inductor.

This type of converter has several significant differences compared to the buck topology that is usually used with the LTC1625. First, the duty cycle relationship is now equal to VOUT/(VIN + VOUT). When VIN is equal to VOUT, a fifty percent duty cycle is required to balance the volt-seconds across the inductor. Second, both the input and output capacitors must filter a square pulse current. This increases the required power handling capability of the output capacitors. Finally, the average value of the inductor current is equal to the sum of the input and output currents. Thus, the inductor is larger than that required by a pure buck or boost converter. This last point also has a bearing on the current-limit behavior.

Figure 1. Single-inductor, positive-output buck-boost converter

Figure 2. Efficiency vs load current for Figure 1’s circuit

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This is given by:

\[
\text{GAIN} = \left[ 1 + \left( \frac{49.4k\Omega}{R_G} \right) \right] \times \left( \frac{R_3}{R_2} \right)
\]

A gain-of-100 composite configuration is realized with \( R_G = 1.5k \). Other gain settings can be realized with various values of \( R_G \), as illustrated in Table 1.

Even though the inputs to the circuit are not required to operate at the positive rail or at ground, wide input common mode operation is always beneficial. In this configuration, the LT1167 input stage can accept signals up to 3.7V (common mode plus differential mode) with no loss of precision. In fact, at low circuit gains, the circuit’s common mode input voltage span is 2.25V to 3.45V. This wide input common mode range allows for this circuit’s common mode input voltage to be injected into the circuit via the differential input terminals still behaving, and is attributable to the LT1167’s input stage. Its 10MHz gain-bandwidth product and 6V/\mu s slew rate ensure that the small-signal performance of the circuit is dominated by the LT1167. Capacitor C1 is recommended for low frequency applications (signal bandwidths <20Hz) to eliminate or significantly reduce noise pickup. Noise can also be injected into the circuit via the input terminals of the LT1167, especially if the sensor is located remotely from the signal conditioning circuitry. This type of noise can cause a shift in the input offset voltage of the LT1167, thereby producing an error. This effect is commonly known as RFI rectification. A differential filter can be easily added to the LT1167’s input terminals to reduce the effects of RFI rectification. Please consult the LT1167 data sheet for additional information on this topic.

### Conclusion

As this design idea illustrates, the precision DC performance of a dual-supply instrumentation amplifier can be successfully applied to single-supply, bridge-type sensor applications using a precision rail-to-rail dual operational amplifier. The combination of the LT1167, the LT1498 and the LT1634 yields a cost-effective solution for 14-bit signal conditioning applications.

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The LTC1625 uses MOSFET \( V_{DS} \) sensing to control the inductor current peaks. Thus, the controller limits the average value of the inductor current rather than the output current in this topology. Because the input current varies as \( V_{IN} \) is changed, the limit on output current depends upon the input voltage. With \( V_{IN} = 12V \), the maximum output current is about 3.3A. Efficiency of the circuit is shown in Figure 2.

Nonoverlapping control signals for the switches M2 and M4 are generated from the LTC1625 and buffered by an LTC1693-2 dual MOSFET driver. Note that the control signal for the PFET M4 must be able to swing between ground and \( V_{OUT} \). Thus, the inverting half of the LTC1693-2 is powered from a diode-OR between \( INTV_{CC} \) (for start-up) and \( V_{OUT} \).

Several simplifications are possible for this circuit. The switch node can be connected directly to M3’s gate, provided that \( V_{IN} \) remains below the maximum rated gate voltage. This eliminates R1, C1, Z1, D2 and the buffer portion of U2. The second stage could also be made nonsynchronous by replacing D2 with a larger diode, such as an MBRD835L, and eliminating M4, D4, D5, C2 and the inverting portion of U2. Nonsynchronous operation reduces the peak efficiency by two to three percent.

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### Table 1. Performance summary of 5V single-supply instrumentation amplifier with rail-to-rail outputs

<table>
<thead>
<tr>
<th>Circuit Gain</th>
<th>( R_G ) (( \Omega ))</th>
<th>( V_{OS} ), RTI* (( \mu V ))</th>
<th>( TCV_{OS} ), RTI* (( \mu V/\mu C ))</th>
<th>Nonlinearity</th>
<th>Bandwidth (kHz) w/o C1</th>
<th>0.1Hz to 10Hz Noise, RTI* (( \mu V_{P-P} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20.5k</td>
<td>1300</td>
<td>6.5</td>
<td>&lt; 0.006%</td>
<td>900</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>5.36k</td>
<td>450</td>
<td>2.3</td>
<td>&lt; 0.006%</td>
<td>850</td>
<td>0.7</td>
</tr>
<tr>
<td>100</td>
<td>1.5k</td>
<td>160</td>
<td>0.8</td>
<td>&lt; 0.006%</td>
<td>500</td>
<td>0.4</td>
</tr>
<tr>
<td>300</td>
<td>487</td>
<td>100</td>
<td>0.5</td>
<td>&lt; 0.006%</td>
<td>160</td>
<td>0.3</td>
</tr>
<tr>
<td>1000</td>
<td>147</td>
<td>90</td>
<td>0.4</td>
<td>&lt; 0.006%</td>
<td>40</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*RTI is an acronym for error “referred to input.”