Generating a negative voltage from a wide input range: how an inverting buck regulator saves space and power

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Designers are periodically faced with the requirement to generate a negative voltage rail in order to provide a bias voltage for applications using sensors which read signals both above and below ground. For many engineers, the first thought will be to use inverting regulated charge pumps: in fact, these are ideal for handheld applications where the output voltage required is less than -5V and the input is typically a lithium-ion battery. In applications that require negative voltages greater than -5V, SEPIC inverters and transformer-based designs can also produce a positive-to-negative voltage conversion, but only at the cost of complexity and a high component count.

Inductor-based switching buck inverters offer the benefits of good efficiency with low component count. Depending on the buck inverter, they can provide high efficiencies over both a wide dynamic load and input range, an area where charge pumps tend to fall down due to their seesaw efficiency curves. The designer must be mindful of the total system power consumption in a scenario in which a -5V rail must be generated from a 12V or 24V system voltage. For instance, a sensor application might require a -5V bias voltage at a 1-200mA load range, operating from a 24V system supply feeding multiple sensors distributed through a building. The designer could connect an inverting charge pump to the 5V output that has been stepped down from the 24V system rail to provide the -5V. The efficiency of such a circuit, however, would be the product of the charge pump's efficiency – typically 70% - and the efficiency of the step-down regulator – typically 90%. This gives an overall system efficiency of 63%. Multiplied across multiple sensors, this loss can add up.

This brings into focus the advantages of implementing an inverting buck regulator circuit, a simple technique that involves exchanging V_{out} with ground on a buck regulator. Not all buck regulators can be used this way, however, since the inversion of V_{out} with ground can introduce a right half plane (RHP) zero in its control-to-output transfer function, opening up the regulator to the risk of instability.

Figure 1 shows a -5V negative buck/boost inverter circuit, using the AS7620 positive buck regulator from austriamicrosystems. This IC is specified for a 3.6V to 32V input voltage range, uses a 1.2V feedback voltage and has an internal 500mA power switch. The switch current is monitored so that the converter always operates in discontinuous current mode (DCM): this means that it is intrinsically stable, and no external compensation circuitry is needed. It also means that it does not have an issue with stability due to the RHP zero, because this only occurs in flyback, boost and Ćuk circuits, and then only in continuous current mode.

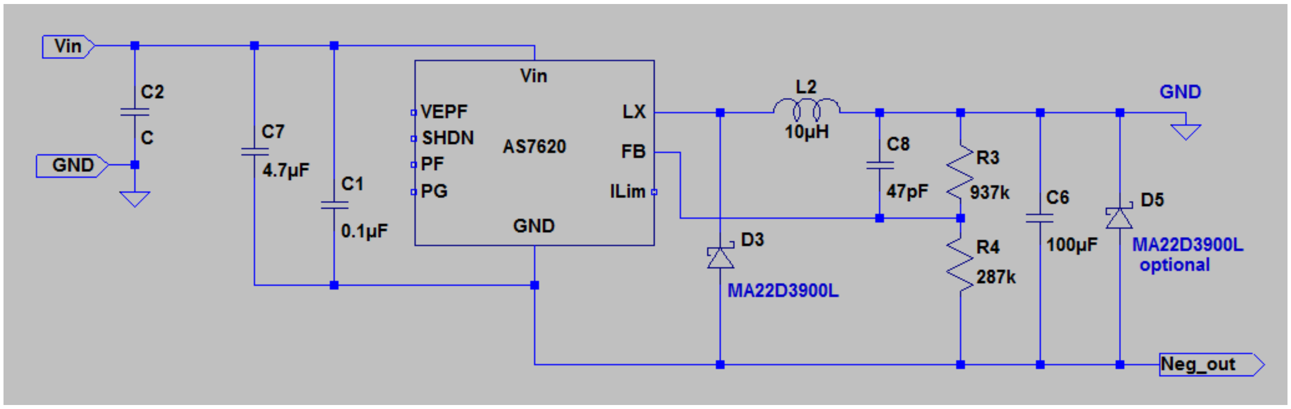


Fig. 1: AS7620 connected as a negative buck/boost regulator

As mentioned earlier, by exchanging V_{out} with ground, it is possible to invert the polarity and produce a negative output voltage. Since the circuit topology is now that of a buck/boost circuit, it might in theory seem attractive to use the part in both boost and buck mode. In practice, however, the efficiency of the buck/boost topology when in boost mode barely exceeds 60%. In buck mode, efficiency is far higher (see Figure 2).

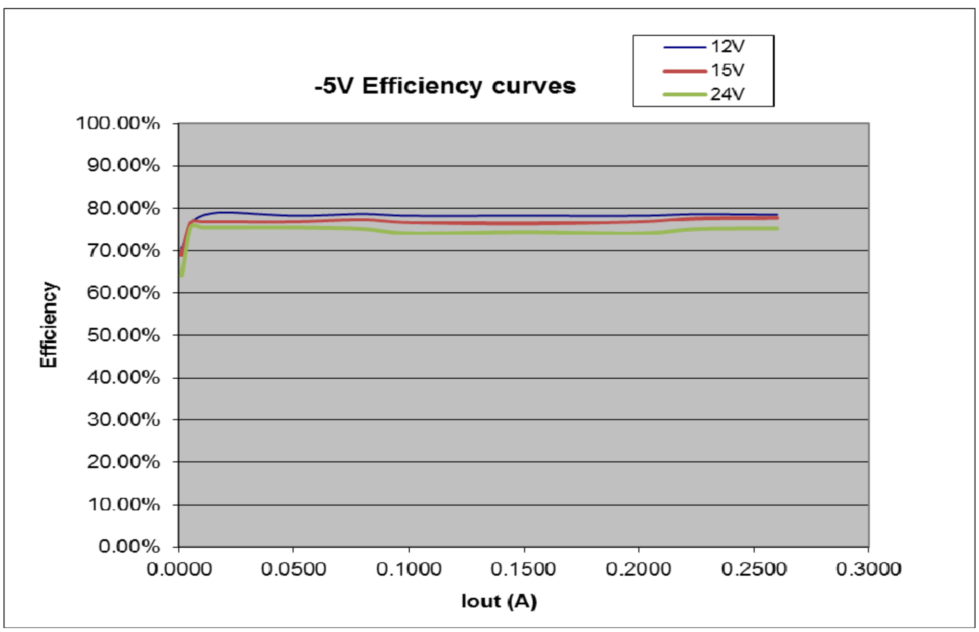


Fig. 2: efficiency curves of AS7620 in buck mode supplying a -5V output

Careful specification of the inverting buck regulator pays dividends in light-load applications in particular. As Figure 2 shows, high efficiency is maintained all the way down to a 1mA load current, and this is a consequence of the AS7620's low internal quiescent current (37µA).

Operation of the inverting buck/boost regulator circuit

During the first stage of the switching period, when the switch is on, the inductor is linearly ramped up to store energy (see Figure 1 again). No current passes to the output. In the second stage, when the internal switch in the IC turns off, the inductor will reverse polarity, inducing the freewheeling diode D3 to forward-bias and transfer energy to the load and the output capacitor C6. The only energy to reach the output via the diode is the energy stored in the inductor - none comes directly from the input DC source. The output voltage is negative because the switch node is negative in reference to ground.

This circuit gives rise to a number of characteristics that are not obvious at first glance, and that must be taken into account if the design is to operate effectively.

1) The voltage across the AS7620 is made up not only of V_{in}, but is equal to the input voltage plus the magnitude of the negative output voltage ($V_{in} + |V_{out}|$). Therefore care should be taken to specify an appropriate voltage rating for the input caps (C7 and C1 in Figure 1). In addition, ($V_{in} + |V_{out}|$) must not exceed the maximum voltage rating of the regulator. The AS7620, for instance, has a maximum voltage rating of 40V. It is feasible to use this part to generate a -12V output from a +12V rail, or a -5V output from a +24 V rail.

2) The switch currents in the buck/boost configuration are necessarily higher than in the buck topology, thus lowering the available output current. The start-up input current of the buck/boost converter is also higher than in the standard buck-mode regulator, and this might overload an input power source that has a current limit set too low. For this reason, the buck/boost circuit employing the AS7620 has an efficiency sweet spot of 1-250mA at input voltages of 12V and higher. At voltages below 12V, the negative output current capability of the part will need to be decreased to 170mA at most.

3) The circuit's Shutdown pin is left floating. The AS7620 provides an internally regulated pull-up circuit, so the device can be shut down if the SHDN pin is pulled to the GND pin (which is the negative output voltage). Since the GND pin of the AS7620 is the negative output voltage in an inverting application, it will be necessary to use a level-shifting circuit, connected to an open drain, to shut the part down. If Shutdown is not used, the pin should be left floating, and no trace should be connected to it in order to minimize noise injection.

4) The current coming from the input capacitor will be choppy because of the switching operation of the internal FET, so care should be taken to provide enough input capacitance; 4.7-10µF is sufficient.

The output current will also be choppy because of the diode current transitions. So for noise-sensitive applications, additional filtering with a negative low drop-out regulator might be necessary.

Example of a working circuit

Figure 3 shows an example of a tested circuit for providing positive and negative 5V output rails from a 12-24V supply. The positive 5V output could generate up to 500mA, while the -5V output could safely provide a 250mA output current while maintaining high efficiency.

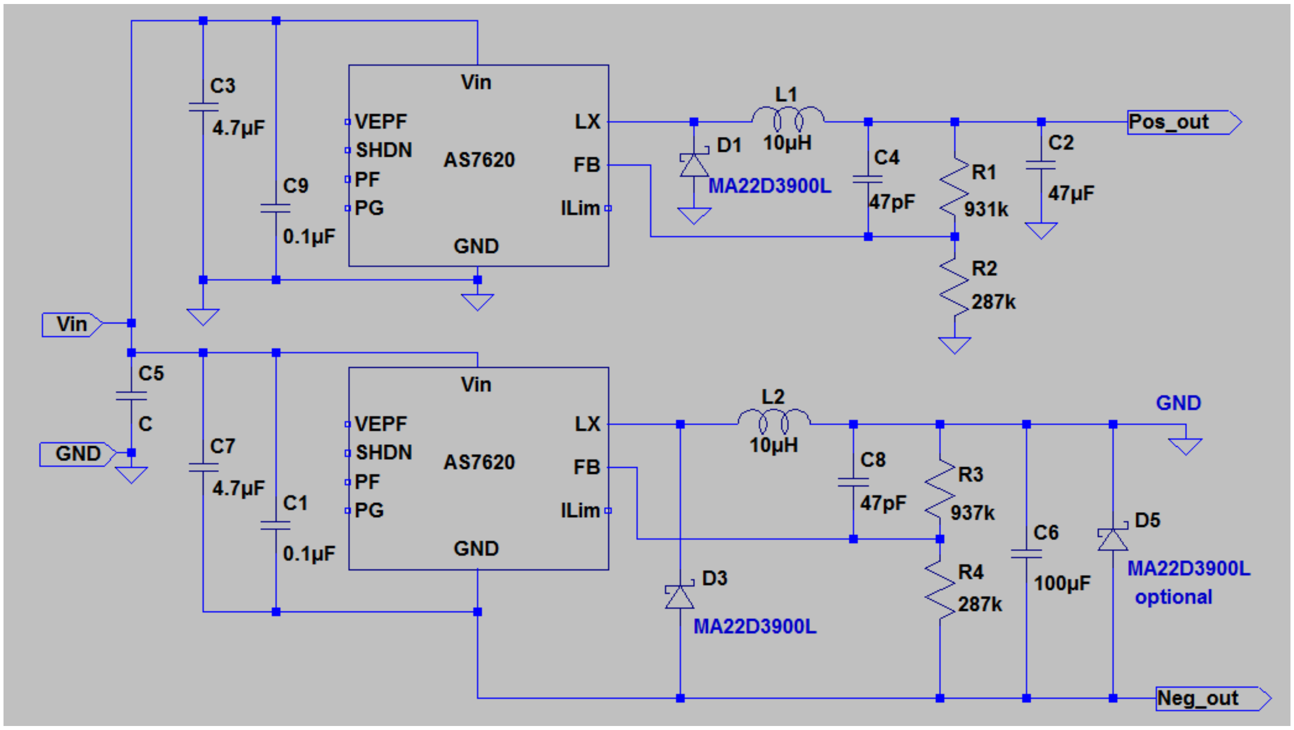
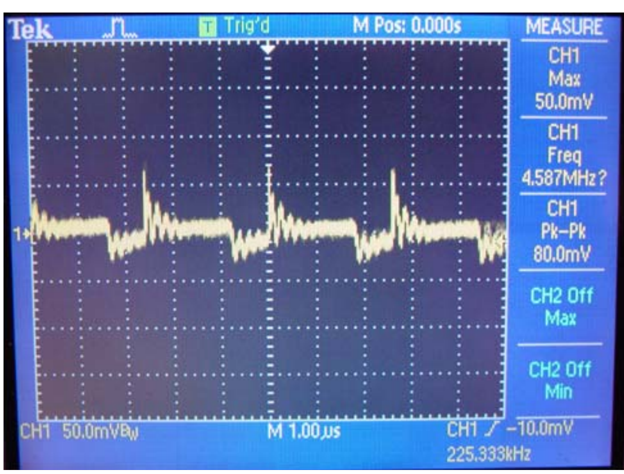


Fig. 3: two AS7620 buck regulators configured as a positive 5V/500mA regulator and a -5 V/250mA regulator

When voltage is first applied to this circuit, the negative V_{out} rail will momentarily start to rise by a few hundred mV in the first 10µs or so, due to the action of the input capacitor. The magnitude of the positive rise on the negative rail will be a function of the size of the input capacitor; an optional Schottky diode across the output (D5 in Figure 3) can be added to clamp this voltage to below 300mV.

The output of this circuit is shown in Figures 4 and 5.



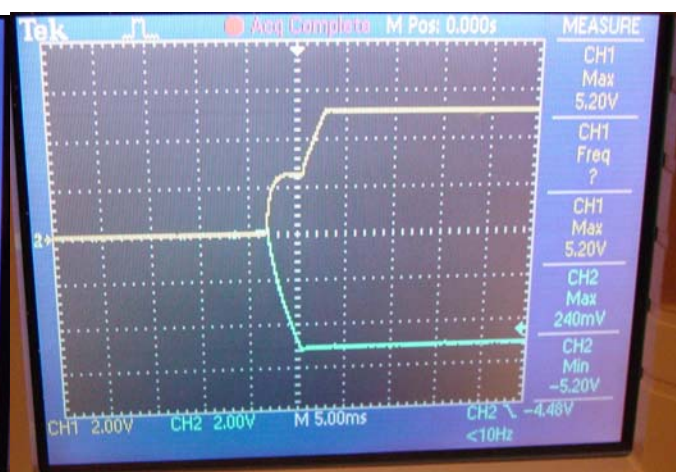


Fig. 4: steady state output voltage with 80mVpp ripple

Fig. 5: start-up waveform for the +5V and -5V rails

Design resources for implementing an inverting buck regulator circuit using the AS7620, including a datasheet with guidance on best layout practice, and information about a useful evaluation board, can be found at www.austriamicrosystems.com.