Tiny SOT-23 Buck Regulator Accepts Inputs from 3.6V to 25V

by Jeff Witt

The LT1616 is a complete fixed frequency step-down switching regulator in a SOT-23 package. It meets the needs of circuit designers who require a large input voltage range or the smallest solution possible. The LT1616 accepts an input from 3.6V to 25V, produces a low voltage output at 400mA and occupies less than 0.15in^2 of board space. With this wide input range, the LT1616 can regulate a large variety power sources, from 4-cell alkaline batteries to lead-acid automobile batteries, from 5V logic supplies to unregulated AC adapters.

Complete Switcher in SOT-23 Results in Compact Solution

Several features of the LT1616 enable this combination of small size and large voltage range. The high (1.4MHz) switching frequency allows the use of small inductors and capacitors. The current mode control circuit with its internal loop compensation eliminates additional components and handles a wide variety of output capacitors, including ceramic capacitors. The internal NPN power switch drops just 200mV at 300mA. In order to fully saturate this switch, the LT1616 generates its own bias supply above the input voltage using an external diode and capacitor tied to its BOOST pin.

An external resistor divider programs the output voltage to any value above the part's 1.25V reference. The operating current is 2mA. The shutdown mode reduces the supply current to 1µA and disconnects the load from the input supply.

An internal undervoltage lockout (3.4V typical/3.6V max) prevents the LT1616 from switching at low input supply. The LT1616 will also withstand a shorted output. An internal current limit protects the circuit in overload and limits output power; when the output voltage is pulled to ground by a hard short, the LT1616 reduces its operating frequency to limit dissipation and peak switch current.

Applications

The LT1616 Produces 3.3V at 400mA

Figure 1 shows a typical application of the LT1616. This circuit generates 3.3V at 300mA from an input of 4.5V to 25V. From a slightly more restricted input range of 4.7V to 25V, it will supply 400mA to the load. Figure 2 shows the circuit's operating efficiency at several input voltages (it also shows the efficiency for a 5V output). This wide input range makes it possible to generate a local 3.3V logic supply from just about any source available.

Ceramic Capacitors Are Best

The LT1616's ability to work with ceramic capacitors is a significant advantage. Where achieving low output ripple from a switching regulator is concerned, low equivalent series resistance (ESR) is the most important characteristic of a capacitor. For a given package size or capacitance value, a ceramic capacitor will have lower ESR than other bulk, low ESR capacitor types (including tantalum, aluminum and organic electrolytics).

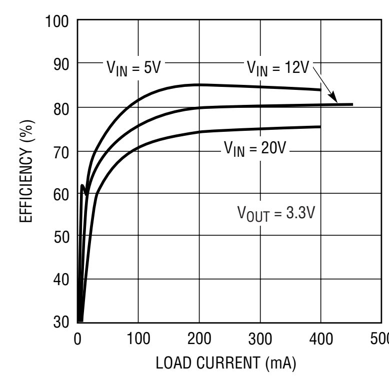

Figure 2a. Efficiency of Figure 1's circuit, output = 3.3V

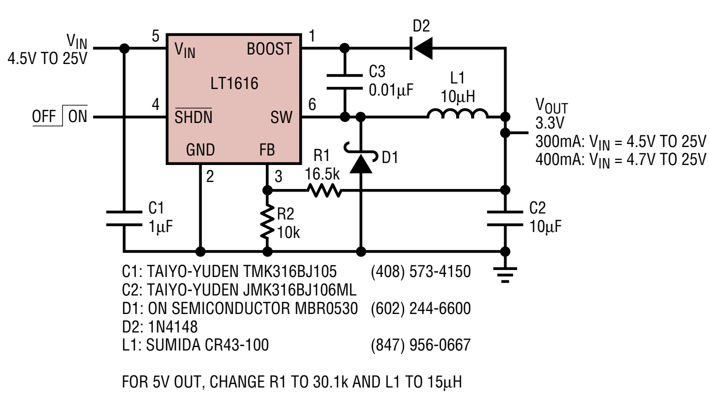

Figure 1. This LT1616 application accepts an input from 4.5V to 25V and produces an output of 3.3V at up to 400mA. The circuit is easily modified for a 5V output.

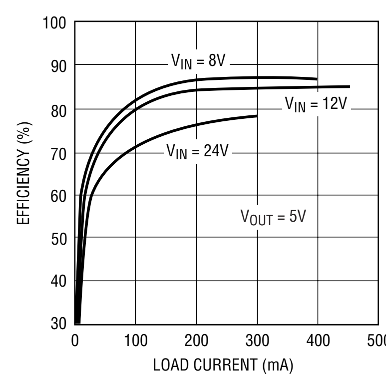

Figure 2b. Efficiency of Figure 1's circuit, output = 5V

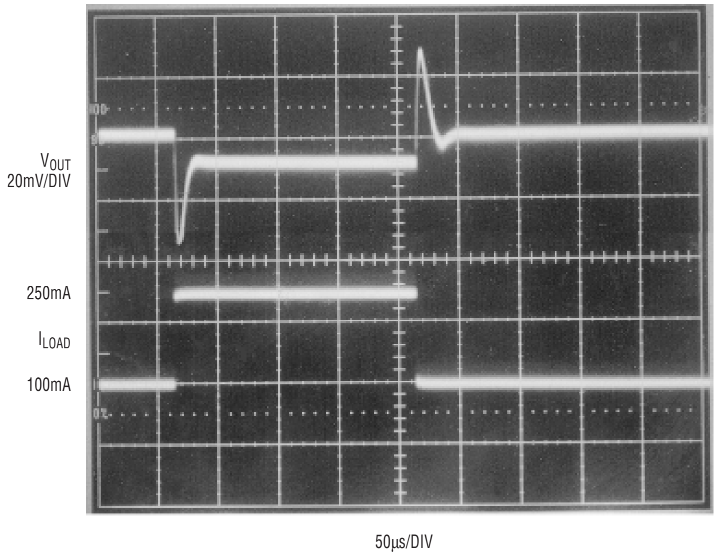

Figure 3. The LT1616 gets along fine with ceramic capacitors, resulting in good transient response and low output ripple (~5mV$_{P-P}$). The upper trace shows output voltage during a stepped load current (circuit of Figure 1 with V_{IN} = 10V).

With its high switching frequency, the LT1616 requires less than 10µF of capacitance at the output. At this value, ceramics are both smaller and lower in cost than the competing low ESR capacitors. (Currently, tantalums may be difficult to obtain.)

To summarize, using ceramics results in low noise outputs and a small circuit size. Figure 3 shows the good transient response of the circuit in Figure 1. The output recovers from a load current step in less than 30µs, without ringing. Because the time scale of 50µs per division is much longer than the LT1616's switching period, the output ripple at the switching frequency is not directly visible. The ripple appears as a broadening of the upper trace and amounts to about 5mV$_{P-P.}$

Smaller than a Linear

The small package size and high operating frequency of the LT1616 result in a very small circuit size. In most applications, the LT1616 circuit will occupy less space than a linear regulator performing the same task and will dissipate much less power. For example, an LT1616 circuit converting 12V to 3.3V at 300mA dissipates only 250mW. A linear regulator will dissipate 2.6W. This requires a TO-220 style package and either moving air or a heat sink to get rid of the heat. Figure 4 compares the size of the LT1616 solution with a TO-220 package. The circuit on the left is designed for a maximum input of 16V and an output of 350mA. The circuit on the right is designed for a maximum input of 25V (requiring a physically larger input capacitor) and uses a larger inductor to keep the efficiency high at its maximum load current of 400mA. Both circuits are low profile, with a maximum height of 2.2mm for the lower cost circuit on the left and 2mm for the circuit on the right.

2.5V Output

Figure 5 shows a 2.5V output circuit using the LT1616. The input range is limited on the low end by LT1616's undervoltage lockout (3.6V max) and on the high end by the voltage rating of the capacitors used and the maximum voltage rating of the LT1616's BOOST pin. The lower output voltage of this application allows the use of a lower inductor value, but also requires the boost voltage to be generated from the input (compare the location of diode D2 to its location in Figure 1).

Bipolar Output Converter

The circuit in Figure 6 generates ±5V from an input above 7.5V. All components are surface mount types. The load current on the positive output should be larger than the load on the negative output. With this restriction satisfied, the magnitude of the negative output will be within 5% of the positive output. For a more complete description of this circuit, see Linear Technology Design Note 100.

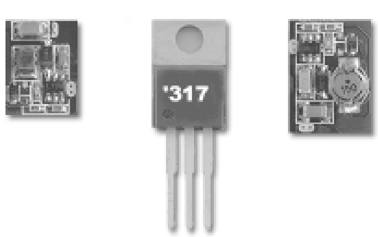

Figure 4. Tired of the heat and bulk of linear regulators? Switch! The entire LT1616 circuit occupies less space than a TO-220.

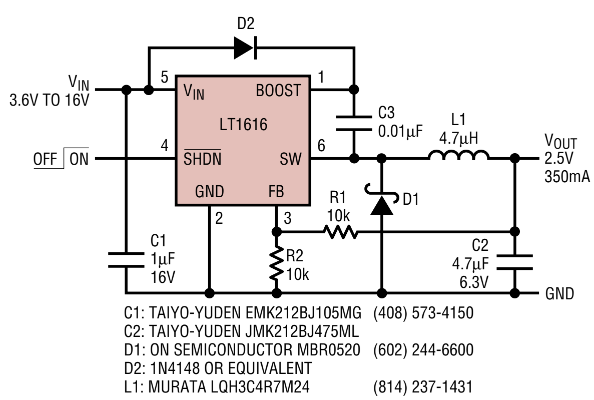

Figure 5. This circuit produces 2.5V at 350mA from an input range of 3.6V to 16V.

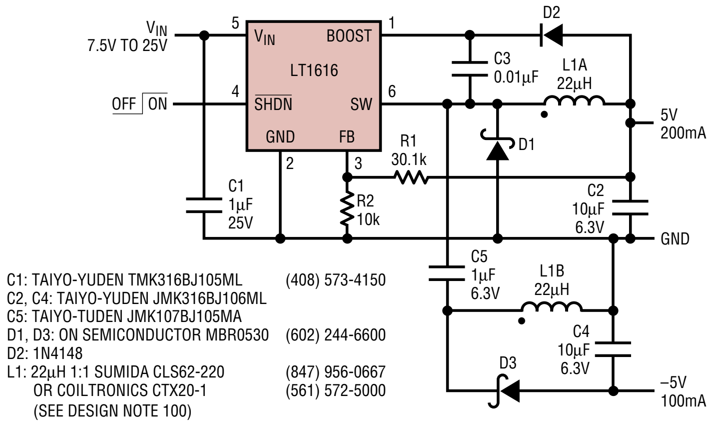

Figure 6. This circuit produces a bipolar output using an inductor with two 1:1 windings.

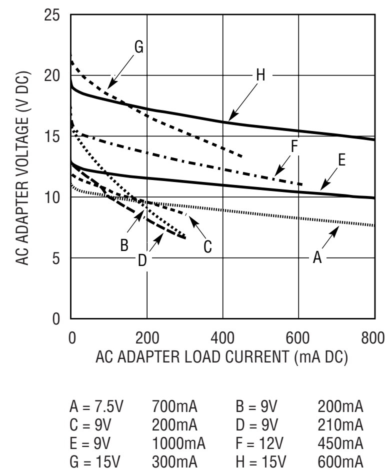

Figure 7. This plot shows the output voltages of several (DC output) AC adapters under load, along with the nominal ratings that appear on their labels. The nearly 2:1 variation of voltage will become even larger with line voltage variations and transients. With its wide input-voltage range, the LT1616 can handle any of these power sources.

Operating from an AC Adapter

A very common power source for small electronic systems is the AC adapter or wall transformer. There are many advantages to powering a product from one of these cubes. They are an inherently safe and inexpensive way to plug into 120V outlets. Using one can avoid bringing high voltage and bulky transformers or complex off-line supplies into an otherwise compact device and safety certification will be easier to obtain. These conveniences come with some disadvantages. AC adapters are relatively large and heavy for the amount of power they deliver. Most adapters (especially low cost examples) have poor output regulation and lots of ripple. The LT1616's wide input operating range and excellent line regulation and transient response will remove these drawbacks.

Figure 7 shows the output voltage and nominal ratings of several AC adapters. The output varies nearly 2:1 with load current, and line voltage changes and line transients result in an even wider range. Note that there is significant variation across AC adapters with the same nominal ratings. With its 25V maximum input, the LT1616 can handle any of these inputs and no problems arise when the customer uses a different AC adapter. A typical AC adapter has more than a volt of line frequency ripple at its rated load; the LT1616 has no trouble rejecting this ripple (Figure 8).

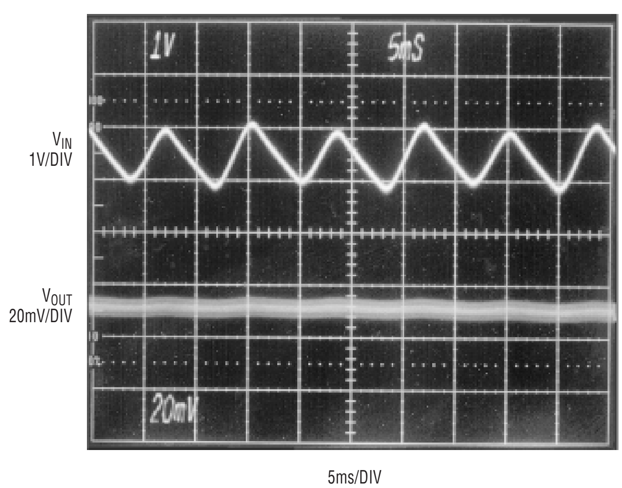

Figure 8. The upper trace shows the line frequency ripple of a 9V AC wall adapter. The LT1616 circuit of Figure 1 regulates this to 3.3V (lower trace) at 300mA, rejecting the 120Hz ripple.

The wide voltage range of the LT1616 makes it possible to choose an adapter with a higher output voltage, which will be physically smaller than a low voltage adapter of the same power.[1] In comparing a linear regulator plus wall adapter with the LT1616 solution, keep in mind that a higher current adapter will be needed and that the adapter will have to be fairly well matched to the final output voltage in order to minimize the power dissipated in the linear regulator. Using a linear regulator will result in both a larger wall adapter and a larger system due to the additional power dissipation (see Figure 4).

In AC adapter applications, it is a good idea to provide reverse voltage protection. Figure 9 shows a circuit to do this. There is another situation to consider in systems where the output will be held high when the input to the LT1616 is absent. This may occur in battery charging applications or in battery backup systems where a battery or some other supply is diode ORed with the LT1616's output. In this case, the LT1616 can pull its operating current through the SW pin. In addition, there is a parasitic diode between the SW pin and the V_{IN} pin. If the input is shorted, a large current can flow through the switch

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pin to the shorted input. The circuit in Figure 9 addresses both problems. The diode at the input prevents a short from drawing large currents, and the part automatically shuts down when the input supply is absent so that no current will flow through the SW pin.

Conclusion

The LT1616's high switching frequency and tiny SOT-23 package result in a very small step-down switching regulator. With its current mode architecture and internal loop compensation, it provides the benefits of an all-ceramic design: low noise, small size and no concerns with tantalum reliability and availability. The 3.6V to 25V input handles power sources ranging from 5V logic supplies to unruly wall transformers and automobile cigarette lighters. The LT1616 is an ideal replacement for bulky (and potentially hot) TO-220 linear regulators.

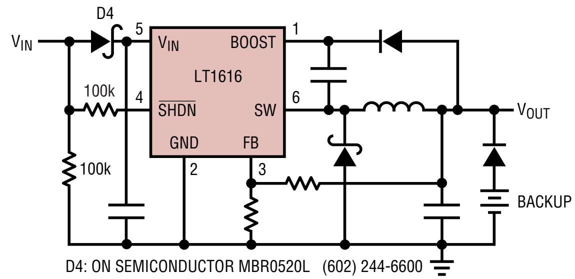

Figure 9. This application circuit protects the LT1616 and its load from reversed input voltage. The LT1616 will enter shutdown mode when the input supply is disconnected.

[1] Among the evils of oversized wall transformers: (a) the polarized blades and the arrangement of your outlet inevitably conspire such that plugging in the transformer covers the second outlet, locally reducing the utility of your AC power system by 50%; and (b) they fall out of the outlet under the force of gravity. I keep my Kitchen-Aid mixer pushed up against an AC adapter to hold it (the adapter) in place. I don't know whether to blame the designer of a radio that needs such a large wall wart or the contractor who installed the outlet a quarter inch too deep in the wall. Kitchen-Aid makes a fine product: with its heavy-duty construction, high torque motor and no-slip rubber feet, the model K5SS mixer can hold even the heaviest wall transformer in place.

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