Tiny SOT-23 Step-Down Regulator Switches at 1MHz for Space-Critical Applications

by Damon Lee

Introduction

As portable devices continue to shrink, the need for progressively smaller components increases. To use smaller capacitors and inductors, switching regulators need to run at ever higher frequencies in ever smaller packages. To help meet this growing demand, Linear Technology introduces the LTC1701 5-lead SOT-23, step-down, current mode, DC/DC converter. Intended for low- to medium-power applications, it operates from a 2.5V to 5.5V input voltage and switches at 1MHz. The high switching frequency allows the use of tiny, low cost capacitors and inductors, which can be 2mm in height or less. Combined with the tiny SOT-23, the area consumed by the complete DC/DC converter can be less than 0.3in^2, as shown in Figure 1.

The output voltage is adjustable from 1.25V to 5V. The LTC1701 can also be used as a zeta converter for battery-powered applications. A built-in 0.28Ω switch allows up to 500mA of output current at high efficiency. OPTI-LOOP compensation allows the transient response to be optimized over a wide range of loads and output capacitors.

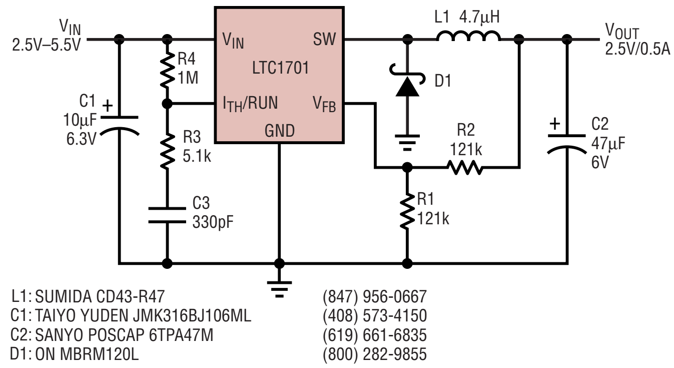

Figure 2. High efficiency 2.5V/500mA step-down regulator

The LTC1701 incorporates a current mode, constant-off-time architecture and includes automatic, power saving Burst Mode operation to reduce gate charge losses at low load currents. With no load, the converter draws only 135µA; in shutdown, it draws less than 1µA, making it ideal for battery-powered applications. In dropout, the internal P-channel MOSFET switch is turned on continuously, maximizing the usable battery life.

High Efficiency 2.5V Step-Down DC/DC Converter

A typical application for the LTC1701 is a 2.5V step-down converter, as shown in Figure 2. This circuit converts a 2.5V to 5.5V input supply to a regulated 2.5V output supply at up to 500mA. The efficiency peaks at 94% with a 3.3V input supply, as shown in Figure 3. The graphs show an improvement in efficiency above 100mA, where Burst Mode operation is disabled. Burst Mode operation provides better efficiency at lower currents by producing a single pulse or a group of pulses that are repeated

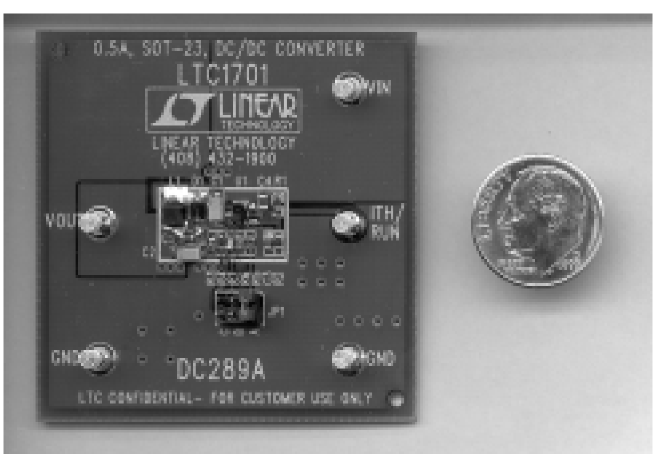

Figure 1. LTC1701 evaluation circuit

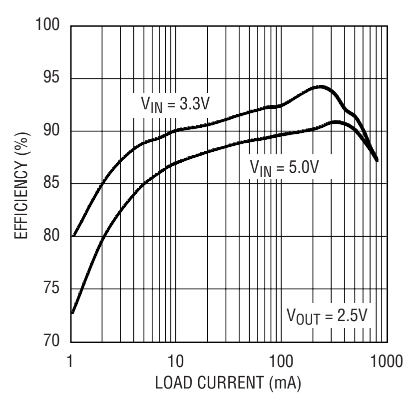

Figure 3. Efficiency of Figure 2's circuit

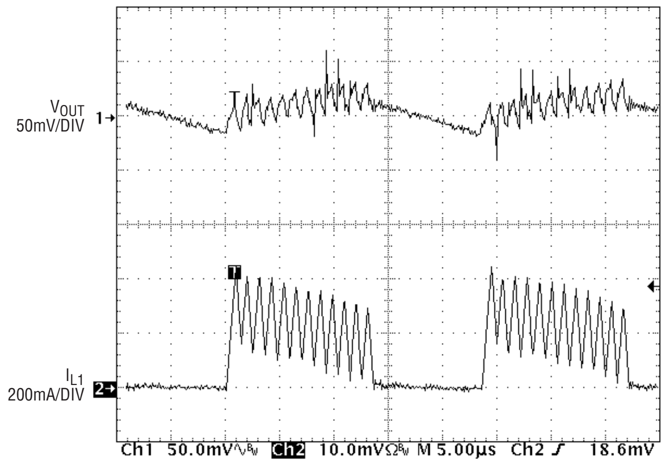

Figure 4. Example of Burst Mode operation

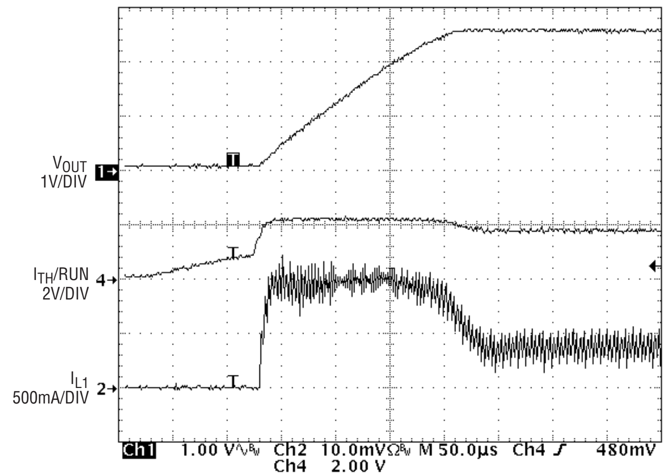

Figure 5. Start-up with 3.3V input into a 6Ω load

periodically, as shown in Figure 4. By switching intermittently, the switching losses, which are dominated by the gate-charge losses of the power MOSFET, are minimized.

Start-up waveforms from a 3.3V input into a 6Ω load are pictured in Figure 5. The converter reaches regulation in approximately 200µs, depending on the load. Soft-start can be implemented by ramping the voltage on the I_{TH}/RUN pin, which requires only an RC delay with a small Schottky diode, as shown in Figure 6.

Single-Cell Li-Ion to 3.3V Zeta Converter

Some designs need the ability to maintain a regulated output voltage while the input voltage may be either above or below the desired output. When the input is above the output, the circuit must behave like a buck regulator; when the input is below the output, it must behave like a boost regulator. The circuit configuration known as a zeta converter is a very simple design that can meet this requirement.

A single lithium-ion battery is a popular choice for many portable applications due to its light weight and high energy density, but it has a cell voltage that ranges from 4.2V to 2.5V. Thus, a simple buck or boost topology cannot be used to provide a 3.3V output voltage.

In Figure 7, the LTC1701 is used in a zeta configuration to supply a constant 3.3V with over 200mA of load current. The circuit uses a single, dual-winding inductor (a 1:1 transformer) for better performance, although two separate inductors can also be used with somewhat lower efficiency. The components shown in the schematic result in a 3mm high converter, suitable for portable applications.

As can be seen in Figure 8, the overall efficiency does not vary much with supply voltage variations, except at high currents (over 100mA). This

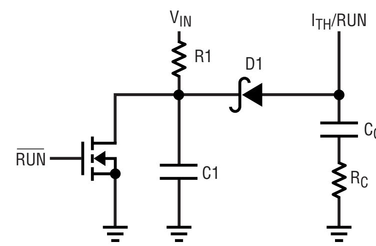

Figure 6. Soft-start hookup

can be attributed to the dominance of switching losses across most of the current range. Since Li-Ion batteries spend most of their lives with a cell voltage in the 3.6V–4.0V range, the typical efficiency is about 81%.

2mm High, 1.5V Converter

In many applications, the height constraint can be more of a concern than the area constraint. Small, low profile inductors and capacitors can be used with the LTC1701, due to the high switching frequency of 1MHz. In Figure 9, a circuit is shown that uses low profile components to produce a 2mm

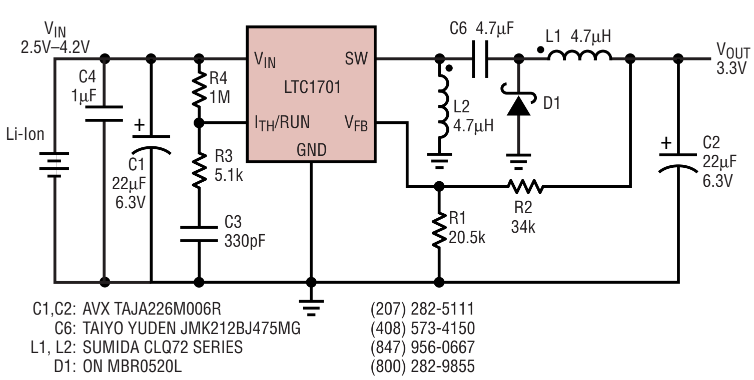

Figure 7. Single-cell Li-Ion to 3.3V zeta converter

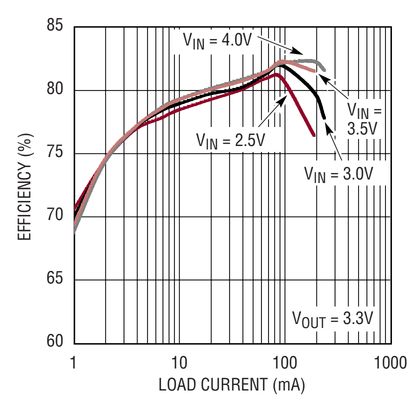

Figure 8. Efficiency of Figure 7's circuit

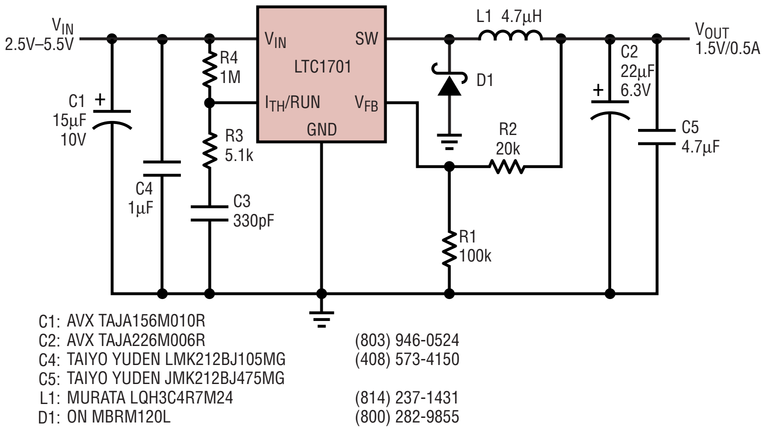

Figure 9. 2mm high 1.5V converter

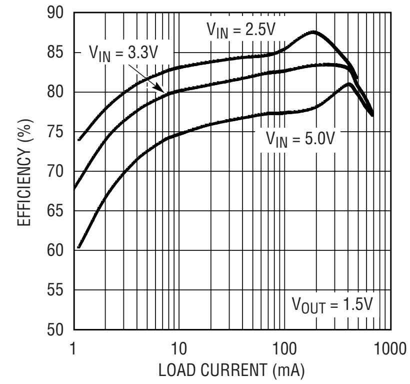

Figure 10. Efficiency of Figure 9's circuit

high (nominal), 1.5V step-down converter that occupies less than 0.3in^2. The photograph in Figure 1 shows an example of a layout with these components. The efficiency, shown in Figure 10, peaks at 88%. As can be seen, the overall efficiency tends to degrade with a larger V_{IN}-to-V_{OUT} ratio, which is typical for step-down regulators.

2.5V Converter with All Ceramic Capacitors

The low cost and low ESR of ceramic capacitors make them a very attractive choice for use in switching regulators. Unfortunately, the ESR is so low that loop stability problems may result. Solid tantalum capacitor ESR generates a loop "zero" at 5kHz to 50kHz that is instrumental in providing acceptable loop phase margin. Ceramic capacitors remain capacitive to beyond 300kHz and usually resonate with their ESL before ESR damping becomes effective. Also, ceramic caps are prone to temperature effects, which require the designer to check loop stability over the full operating temperature range.

For these reasons, great care must be taken when using only ceramic input and output capacitors. The OPTI-LOOP compensation components can be adjusted when ceramic capacitors are used. For a detailed explanation of optimizing the compensation components, refer to LTC Application Note 76. Figure 11 shows one example of an all-ceramic-capacitor circuit; its efficiency graph is shown in Figure 12. The efficiency in this case has a very flat peak at 93% due to the relatively low output capacitance and the low ESR of the ceramic capacitors.

Conclusion

The LTC1701 is a small, monolithic, step-down regulator that switches at high frequencies, allowing the use of tiny, low cost capacitors and inductors for a cost- and space-saving DC/DC converter. Although the LTC1701 was designed for basic buck applications, the architecture is versatile enough to produce an effective zeta converter, due in part to its power saving Burst Mode operation and its optimized OPTI-LOOP compensation.

By combining a high switching frequency and an onboard P-channel MOSFET in a tiny SOT-23 package, the LTC1701 is ideal for space-critical portable applications.

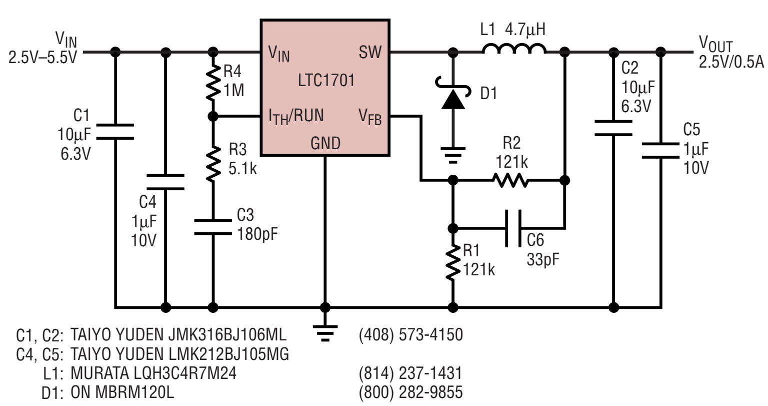

Figure 11. All-ceramic-capacitor converter delivers 2.5V at 500mA.

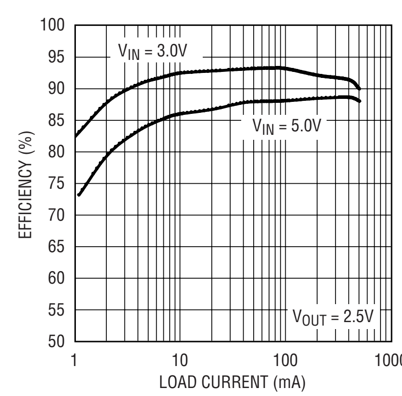

Figure 12. Efficiency of Figure 11's circuit