

Tiny Buck-Boost Converter for Low Current Applications

by Eddy Wells

Introduction

One common challenge for many battery powered portable applications is creating a regulated output voltage above or below the input source. Traditional buck-boost approaches, such as a dual inductor SEPIC converter or cascaded regulators, are unacceptable in most portable devices because of their large solution size and low efficiency. Smaller footprint, integrated charge-pump solutions can switch between buck and boost operation, but charge-pumps achieve good efficiency at only a few operating voltages, while efficiency dips below 50% at others. Another compact and simple approach forgoes a portion of the battery capacity and uses a buck (step-down) only solution, but the advantages are hard to justify when much of the battery capacity is not used, as with certain Li-Ion chemistries and a 3.3V output, or with two alkaline cells and a 3.0V or 2.5V output.

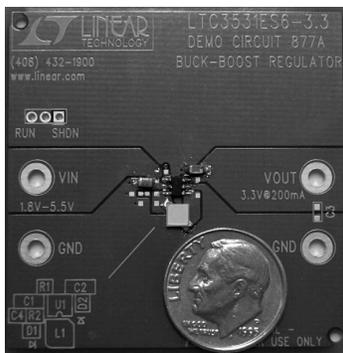


Figure 1. Compact 3.3V buck-boost application

The LTC3531 is a single inductor 200mA buck-boost converter that generates a regulated output voltage from a wide input voltage between 1.8V and 5.5V while maintaining high efficiency. It is an excellent fit for low power applications where a tiny total solution size is required. The LTC3531 is available with fixed outputs [3.0V or 3.3V] or with an adjustable output that can be set between 2.0V and 5.0V. The fixed output versions require only

two small ceramic capacitors, a miniature inductor, and the ThinSOT IC. All versions of the part are available in a thermally enhanced 3mm x 3mm DFN packages. A photo of the LTC3531 demo-board is shown in Figure 1.

Generating a Clean 5V from a Noisy USB Cable

Generating a clean 5V output from a USB cable or wall adapter can be a challenge when the combination of source impedance and load transients cause noise and voltage droops. USB cable voltage can vary between 5.25V and 4.35V, while the maximum allowed decoupling capacitance on the input is 10µF. The trace labeled “V_{IN}” in Figure 2 shows what can occur with a 4.7µF input capacitor and a 100mA load step from a powered device. The LTC3531 produces a clean 5V output (V_{OUT}) with less than 100mV of peak-to-peak ripple using a 22µF V_{OUT} capacitor. V_{IN} and V_{OUT} are DC aligned at 500mV per division in Figure 2, showing significant improvement in noise and voltage droop. Inductor current is also shown with operation in both boost (V_{IN} < V_{OUT}) and buck-boost (V_{IN} ≈ V_{OUT}) modes.

A complete schematic of the USB to 5V application is shown in Figure 3 along with efficiency and power loss curves versus load current. The

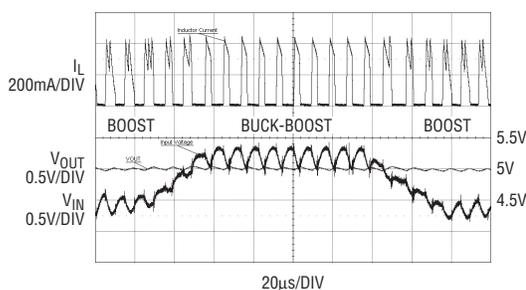


Figure 2. Noisy USB cable input to clean 5V output

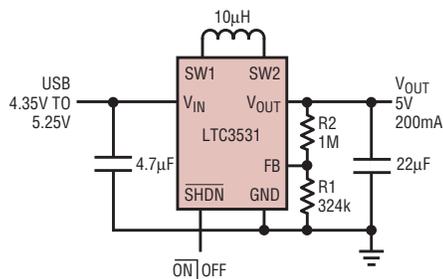


Figure 3. USB to 5V application

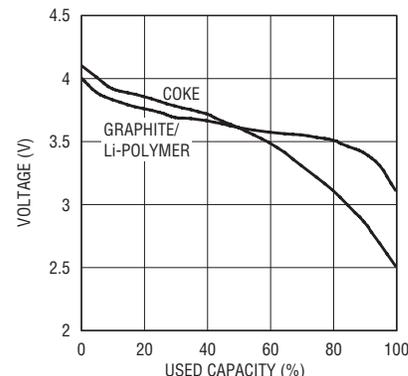
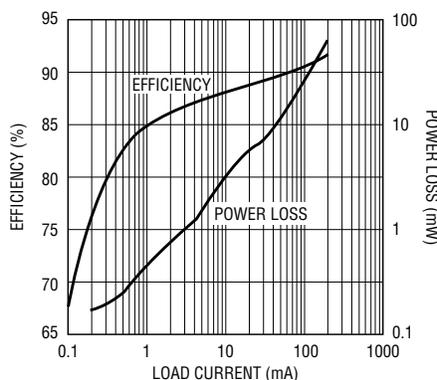


Figure 4. Typical 1C lithium-ion/polymer capacity curves

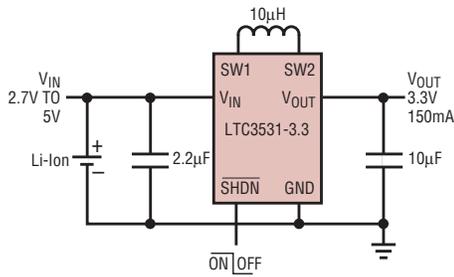


Figure 5. Lithium Ion to 3.3V schematic and 100mA efficiency curve.

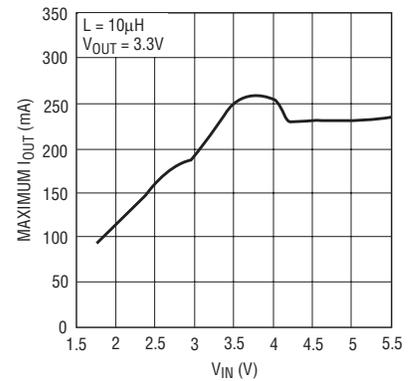
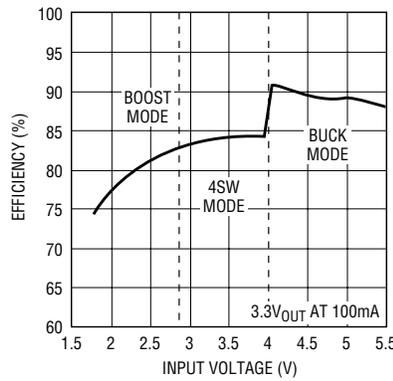


Figure 6. Output current capability vs input voltage ($V_{OUT} = 3.3V$)

LTC3531 operates in Burst Mode operation, with just 20µA of quiescent current, providing high efficiency over several decades of load current. All four switches have an $R_{DS(ON)}$ of about 0.5Ω when operating at 5V, providing >90% efficiency at higher load currents.

Maximizing Li-Ion Capacity for 3.3V

When compared to a straight buck converter, the LTC3531 allows lower input voltage operation when providing a 3.3V output from a Li-Ion input source. Typical capacity curves for

coke and graphite anode Li-Ion batteries are shown in Figure 4. Coke types have a lower cut-off voltage at 2.5V, where graphite types have a flatter discharge curve and a 3.0V cut-off. Solid lithium polymer batteries have discharge curves similar to graphite.

The equivalent series resistance (ESR) of the Li-Ion battery causes additional voltage drops at the terminal at higher load currents. To make matters worse, the battery protector circuit adds additional series resistance and the effects of ESR lower system efficiency as the battery is discharged.

To guarantee a 3.3V output, a buck only design may need to use a cut-off voltage of 3.5V or 3.6V. This translates to a capacity loss of approximately 45% for the coke cell and 20% for the graphite—both significant reductions in run time. Furthermore, while graphite or polymer cells are more popular because of their flat discharge curve, new chemistries with greater capacity per volume are on the horizon with expected discharge curves resembling the coke anode.

The wide input voltage range of the LTC3531 allows a regulated 3.3V to be produced from all Li-Ion chemistries, two or three alkaline cells, or a 5V source such as USB. The LTC3531 automatically transitions between buck, 4-switch (buck-boost), and boost modes based on the voltage difference between V_{IN} and V_{OUT} . Figure 5 shows a 3.3V application circuit, along with efficiency vs input voltage for a 100mA load. Maximum load current capability vs input voltage ($V_{OUT} = 3.3V$) is shown in Figure 6. As expected, efficiency and load current capability are reduced with input voltage.

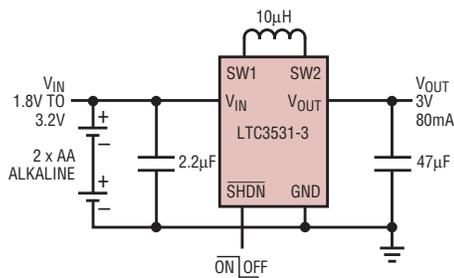


Figure 7. Two AA or two AAA to 3.0V application

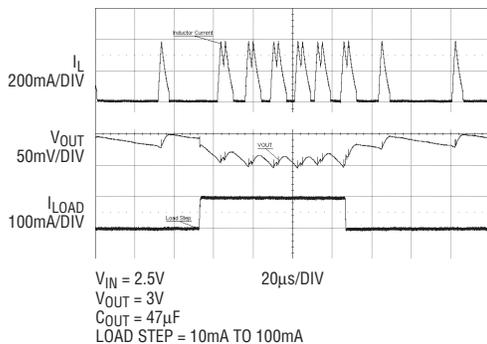
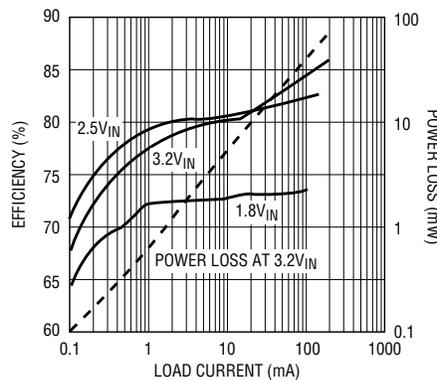


Figure 8. Transient response of the circuit in Figure 7

3.0V Flash Memory Application from Two Alkaline Cells

Inexpensive MP3 players and other relatively low capacity, low cost portable devices often replace a hard disk drive (HDD) with flash memory and Li-Ion batteries with disposable alkaline—a good fit for the LTC3531. A complete schematic for a two cell alkaline to 3V flash memory supply is shown in Figure 7. Efficiency is better

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Ideal Diodes Combine Battery Stacks (Minimize Heat and Voltage Loss)

by Mitchell Lee

Introduction

Combining multiple battery stacks to serve a common load is an easy task for a diode. Each stack delivers whatever current it can muster to the load, but back-feeding from a fresh battery to one mostly discharged is precluded by the presence of the blocking diode. If you're concerned with heat dissipation in the diode and voltage drop at end of discharge, diodes may leave you pinning for a better solution.

Active Diode

The circuit in Figure 1 implements an active, ideal diode using a low resistance MOSFET and a micropower op amp. The MOSFET functionally replaces the diode. Placing it in the negative lead of the battery stack permits use of an N-channel device in a simple arrangement, driven on by an op amp if there is a slight forward voltage and off if the voltage reverses.

The forward voltage drop is regulated at 26.4mV, giving freedom from oscillations and preventing reverse current flow. Static current drain for the entire circuit is less than 4μA.

Modifications

Operation over a range of 10V to 36V is practical, and lower voltage operation is feasible by converting to a logic level MOSFET. Because the forward regulation point is a function of the battery voltage, the 10M–10kΩ divider should be adjusted to keep the drop across the 10kΩ resistor in the range of 10mV to 50mV.

In Figure 1 the forward drop exceeds 26.4mV when the product of the load

current and MOSFET $R_{DS(ON)}$ thus dictate. For the 55mΩ IRF540, this point is reached at load currents of 500mA.

Given some finite $R_{DS(ON)}$ there is a practical limit for the load current in any MOSFET, where $R_{DS(ON)} \cdot I_{LOAD}$ ceases to provide any advantage over a diode. In the case of the IRF540 this point arrives in the 5A-to-10A range. For higher current applications, substitute a lower $R_{DS(ON)}$ MOSFET. \square

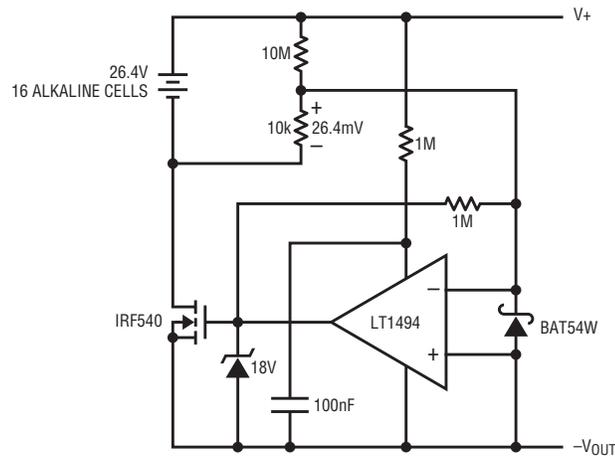


Figure 1. Battery pack ideal diode

LTC3531, continued from page 39

than 80% with fresh alkaline cells and better than 70% with depleted batteries. Note that overall efficiency is lower in this application (relative to the Li-Ion application) because of the lower drive voltage for the switches—switch $R_{DS(ON)}$ increases with decreasing drive voltage. The adjustable version of the part can be used to power lower voltage flash memories (i.e. 2.5V) with similar performance results.

Peak current requirements for flash memory are typically lower than a HDD, since there is no disk spin-up,

but load transients still occur when memory is accessed. The LTC3531's response to a 10mA–100mA load step is shown in Figure 8. Burst Mode[®] operation provides a rapid transient response since there is no compensation loop to slew. Peak-to-peak voltage ripple plus load step is under 50mV with a 47μF output capacitor. The output voltage ripple stays fairly constant over input voltage. Half the output capacitance (22μF) results in approximately twice the load step plus voltage ripple (100mV).

Summary

The LTC3531 provides a simple, compact buck-boost solution for lower current, portable applications. A complete solution, 1mm in height, can fit in a 35mm² footprint. The part maintains high efficiency over a wide range of input voltages and load currents, extending battery run time, while providing the flexibility to address many designs such as 2-cell alkaline, USB, and present day or emerging Li-Ion chemistries. \square

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