Dual Monolithic Ideal Diodes Provide a Single-Chip Power Management Solution

by Andy Bishop

Introduction

The LTC4413 dual monolithic ideal diode helps reduce the size and improve the performance of handheld and battery operated devices. It packs so many features into a tiny package that it is possible to build an entire power management solution in a 3mm × 3mm footprint. Figure 1 shows how simple it is to build a complete battery-wall-adapter PowerPath™ manager.

Despite its compact size, the LTC4413 includes features that are necessary in demanding applications, including thermal management, short circuit protection, and system-level power management and control.

Two isolated p-channel MOSFET transistors serve as low voltage (2.5V to 5.5V) monolithic ideal diodes. Each ideal diode channel provides a low forward voltage drop (typically as low as 40mV when conducting 10mA) and a low $R_{DS(ON)}$ (below 100mΩ)—important in battery-powered applications.

Furthermore, each channel is capable of providing 2.6A of continuous current from a small 10-pin DFN package. If the load attempts to draw more than 2.6A, the internal current limit threshold is reached. At this point the LTC4413 fixes the output current at the over-current maximum. This causes the output voltage to collapse and the power dissipation within the chip to increase. Current limit protects the internal p-channel MOSFET diodes against shorts and overloads. Sustained overloads that result in excessive die heating are mitigated by thermal shutdown.

System-level power management and control are available through a status signal pin to indicate conduction status, and two active-high disable input pins, which independently control the operation of each of the PowerPath ideal diodes.

The low forward voltage drop, low $R_{DS(ON)}$, and low reverse leakage current of the LTC4413 offer several additional benefits. The tiny forward voltage drop directly results in extended battery life. The low $R_{DS(ON)}$ reduces power dissipation, further enhancing battery performance. The very low reverse leakage current, when compared with a Schottky diode, is also beneficial in many applications particularly where leakage current into a battery from a reverse biased Schottky diode could cause damage or failure.

"The LTC4413 packs so many features into a tiny package that it is possible to build an entire power management solution in a 3mm × 3mm footprint."

The LTC4413 can be used as a replacement for two LTC4411 monolithic ideal diodes, or it can be used in applications that may have used one LTC4411 along with a Schottky diode, thereby providing an improvement in terms of space and power consumption.

How it Works

Figure 1 shows an application where the LTC4413 is configured as an automatic power switch between a battery and a wall adapter (or other auxiliary power source) to supply continuous power to the load attached to the output.

The operation of this circuit is shown in Figure 2, where the inputs are ramped slowly to illustrate how the LTC4413 functions.

First the battery input at INA is ramped up from 0V while the auxiliary input at INB is left floating (A0). Once the battery voltage exceeds the under voltage lock-out (UVLO) rising threshold of 2.2V (A1), the LTC4413 begins to conduct in forward regulation mode, pulling the output voltage up to within 20mV of the battery voltage (the voltage drop across the LTC4413 depends on the load current). As the battery voltage continues to increase (time interval A1–A2) up to 3.5V, the output voltage follows the battery voltage minus the small forward voltage drop across the LTC4413. During the forward regulation mode of operation (from time A2 to B0), the STAT pin is an open circuit and the 560kΩ resistor pulls the STAT pin voltage up to V_{CC}, indicating that the load current is supplied by the battery connected to INA. Alternatively, this resistor

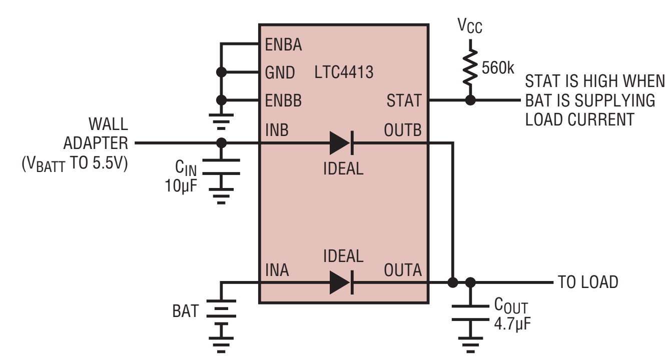

Figure 1. Automatic power switch between a battery and a wall adapter

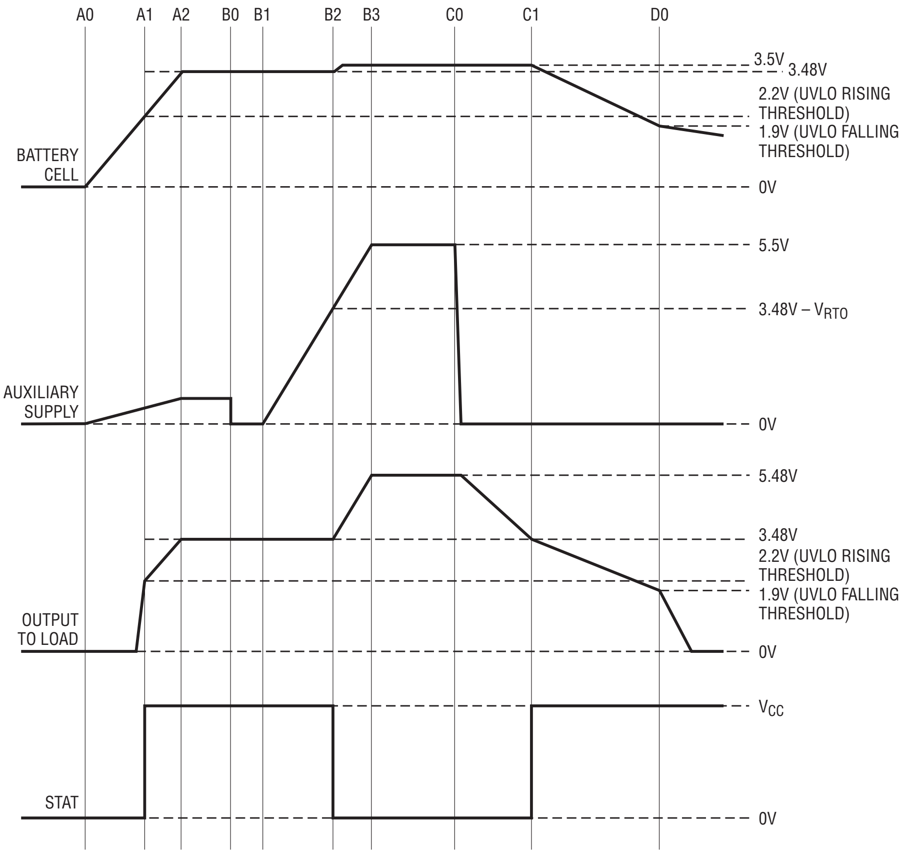

Figure 2. Operation waveforms of the LTC4413.

may be tied to the output as shown in Figures 6, 7 and 8.

Consider next a wall adapter, or other auxiliary supply voltage, applied to pin INB (at time B0). The voltage at INB is then ramped upwards from 0V (starting at time B1). The LTC4413 automatically senses when the voltage at INB is greater than the voltage at the output (at time B2) and reverts to supplying load current from the input applied at pin INB; disconnecting the battery from the load as the voltage at the output rises above the battery voltage at INA. At this point, the STAT pin begins to sink 9µA causing the STAT pin voltage to fall, indicating that the wall adapter at INB is now supplying load current. As the auxiliary voltage continues to rise to 5.5V (B3) the output voltage follows the auxiliary voltage.

When the wall adapter, or auxiliary voltage, is removed (at time C0) and the voltage at INB drops to zero, the output voltage begins to ramp down as C_{OUT} discharges; at a rate depending on the load current. Once the output voltage drops below the battery voltage (C1) the LTC4413 reverts to supplying load current from the battery. At this time the STAT pin becomes an open circuit, and the 560k resistor pulls the STAT pin voltage to V_{CC} to indicate that the battery is now supplying load current.

As the battery voltage continues to discharge below the under voltage lock-out threshold of 1.9V (at time D0), the LTC4413 turns itself off, and the battery is disconnected from the load. The output voltage then collapses as the load discharges capacitor C_{OUT}.

Automatic Dual Battery Load Sharing

A dual battery load sharing circuit is shown in Figure 3. In this schematic an LTC4413 is used to isolate two batteries, perhaps a main and a backup battery, from the load. This circuit takes advantage of the fact that it is more efficient to discharge the batteries in parallel than it is to discharge them sequentially.

Whichever battery has the higher voltage provides the load current until it has discharged to the voltage of the other battery. The load is then shared between the two batteries according to the capacity of each battery. The higher capacity battery provides proportionally higher current to the load.

As the LTC4413 only allows current to flow in one direction, each battery is isolated from the other so that no reverse current can flow from one battery into the other. This eliminates the possibility of a potentially hazardous situation where one battery may uncontrollably discharge curent into the other. The STAT pin may be used to indicate whether the backup battery attached to INA is conducting, thus providing an automatic monitor to indicate when the backup battery is supplying all of the load current.

Multiple Battery Charging

Figure 4 illustrates an application of multiple battery charging using the LTC4413. In this example, one or both of the batteries can be charged from a single battery charger (not shown), regardless of the state of charge of the other battery. This circuit takes advantage of the fact that charging batteries in parallel is more efficient than charging them sequentially.

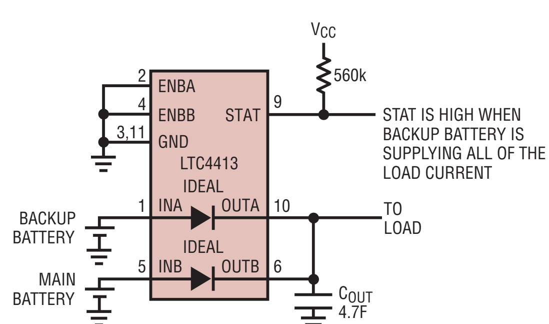

Figure 3. Automatic dual battery load sharing with secondary battery monitor

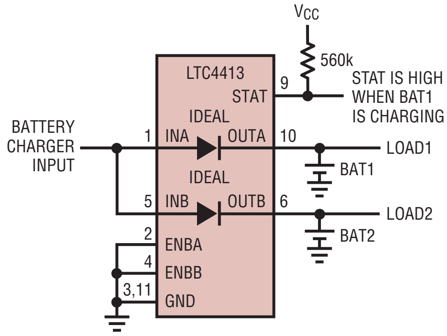

Figure 4. Multiple battery charging

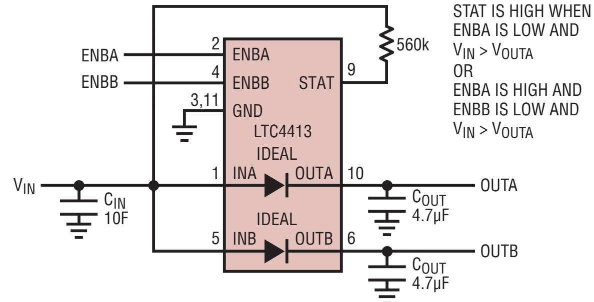

Figure 5. Dual high side power switch

Whichever battery has the lowest voltage receives the full charging current until both battery voltages are the same. Then both batteries are charged simultaneously. One advantage charging multiple batteries in parallel—rather than sequentially—with the LTC4413 is that both batteries are always charged up to the same relative percentage of the cell capacity. So, if the battery charger is suddenly removed in the middle of charging, both batteries are partially charged to the same percentage charge. The enable pins and STAT pin can be used to independently control which of the batteries is charged and monitor if the enabled battery is charging.

Dual High Side Power Switch

Figure 5 illustrates the LTC4413 in use as a dual high side power switch.

When the ENBA pin is a logical low, the LTC4413 turns on ideal diode A, supplying current from INA to the load attached to OUTA. When the ENBB pin is a logical low, the LTC4413 turns on ideal diode B, supplying current from INB to the load attached to OUTB.

When the ENBA and/or ENBB pins are at a logical high, the LTC4413 turns off the corresponding diode and removes power to that load. If the load at OUTA is powered from another (higher voltage) source, the supply connected to INA remains disconnected from that load; the load connected to OUTB may remain connected to INB independent of the voltage at OUTA and vice versa.

The STAT pin can be used to indicate the conduction STATUS of diode A (if either ENBA is low, or both enable pins are low). Alternatively, the STAT pin can be used to indicate if diode B is conducting (if ENBA is at logic HIGH and ENBB is at logic LOW). If both ENBA and ENBB are logic HIGH, the STAT pin is logic LOW.

Automatic Switchover from a 4.2V Li-Ion Battery to a Wall Adapter and a Battery Charger

Figure 6 illustrates an application where the LTC4413 performs the function of automatically switching a load over from a battery to a wall adapter, while controlling a LTC4059 battery charger.

When no wall adapter is present, the LTC4413 powers the load from the Li-Ion battery at INA, and the STAT voltage is high, thereby disabling the battery charger.

If a wall adapter voltage higher than the battery voltage is connected to INB, the LTC4413 automatically powers the load from the wall adapter. When this occurs, the STAT voltage falls, turning on the LTC4059 battery charger and beginning a charge cycle.

If the wall adapter is removed, the voltage at INB collapses until it is below the battery voltage. When this occurs, the LTC4413 automatically re-connects the battery to the load and the STAT voltage rises, disabling the LTC4059 battery charger.

Dual Battery Load Share with Automatic Switchover to a Wall Adapter

Figure 7 illustrates how to use the LTC4413 to implement a circuit that automatically switches over from a dual battery load share to a wall adapter. As described earlier, with Figure 3, the LTC4413 performs a load sharing function for BAT_A and BAT_B,

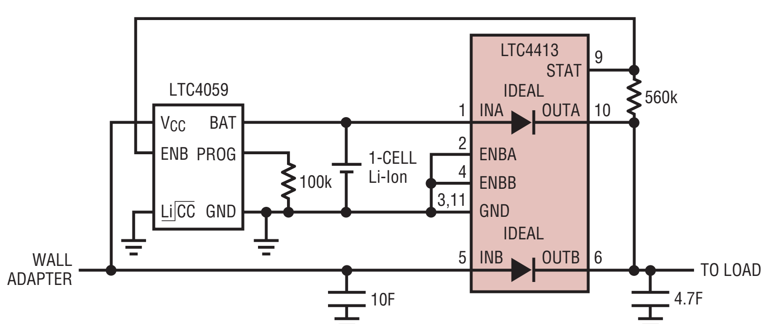

Figure 6. Automatic switchover from a 4.2V Li-Ion battery to a wall adapter and battery charger

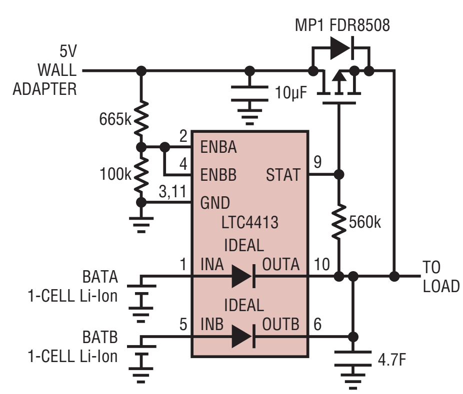

Figure 7. Dual battery load share with automatic switchover to a wall adapter

with the addition of an automatic switchover whenever a wall adapter is applied.

When the wall adapter is connected, both ENBA and ENBB voltages are pulled higher than the turn-off thresholds of 550mV through a user programmable resistive divider. When this occurs, the STAT voltage falls, turning on MP1 so that the wall adapter can provide load current. If the wall adapter is disconnected, the output voltage droops until the ENBA and ENBB voltages fall through their turn-on threshold of 450mV; enabling both ideal diodes. The LTC4413 then connects the higher of BATA or BATB to the load. If the voltage at BATA is highest, the STAT voltage rises, otherwise the STAT voltage remains low.

Automatic Switchover from a Battery to an Auxiliary Supply or to a Wall Adapter

Figure 8 shows automatic switchover from a battery to either an auxiliary supply or to a wall adapter using the LTC4413. This simple circuit handles all combinations of applied power automatically.

Consider two scenarios. In the first, the auxiliary supply is not present and the battery provides load current when the wall adapter is attached. In the second, the auxiliary is present when the wall adapter is attached.

In the first case (aux supply absent), when the wall adapter is applied, the diode in the external PFET (MP1) forward biases pulling the output voltage above the BAT voltage and turning off the ideal diode connected between BAT and the output. This causes the STAT voltage to fall, turning on MP1 and connecting the wall adapter to the load. The load current is then provided by the wall adapter and the battery is disconnected from the load.

When the wall adapter is removed, the output voltage falls until the BAT voltage exceeds the output voltage. When this event occurs the STAT voltage rises, turning off the external PFET, and the ideal diode between BAT and the output automatically turns on to provide power to the load.

In the second case (aux supply present), the voltage divider (R5 and R4) pull ENBA higher than its turn-off threshold, disconnecting the battery from the load, and the auxiliary supply provides the load current.

When the wall adapter is applied, the LTC4413 senses the presence of the wall adapter as the ENBB pin voltage is pulled higher than its turn-off threshold; through resistive divider (R2 and R3). When this occurs, the auxiliary is disconnected from the load and the STAT voltage falls, turning on MP1 so that the wall adapter can provide the load current. When the wall adapter is removed, ENBB falls until the auxiliary is enabled and reverts to providing power to the load.

If the auxiliary is removed while the wall adapter is providing load current, the ENBA voltage falls, enabling the ideal diode between BAT and the output. However, if the wall adapter voltage is higher than the BAT voltage, the ideal diode between BAT and the output is reverse biased and no current flows into the battery from the wall adapter (through the LTC4413). When the wall adapter is removed, the output voltage falls until the BAT voltage exceeds the the output voltage. At this point, the ideal diode between BAT and the output turns-on and the STAT voltage rises, disabling MP1.

When the wall adapter is disconnected while the auxiliary supply is present, the load voltage droops to just below the auxiliary voltage at which point the auxiliary supply begins to source the load current. At this point the STAT voltage rises; disabling MP1. This causes the capacitor C1 to discharge until the ENBA turn-on threshold is reached; this allows the battery to source load current if the output voltage drops below the battery voltage.

If the wall adapter is disconnected when the auxiliary supply is not present, the load voltage drops until the voltage at the ENBA pin (formed by resistive divider R2 and R3) falls below the turn-on threshold of 450mV. When this occurs, the battery is connected to the load and the STAT voltage is pulled high, disabling MP1.

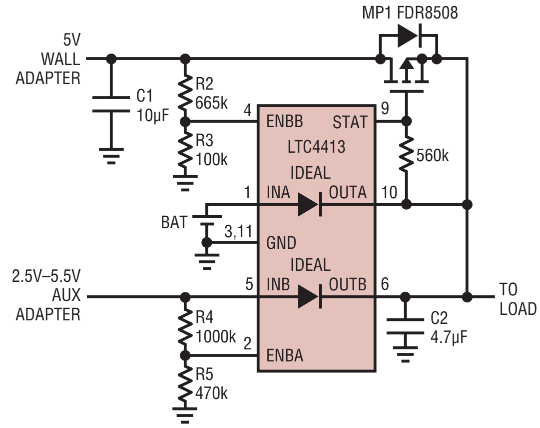

Figure 8. Automatic switchover from a battery to an auxiliary supply or a wall adapter

Conclusion

The LTC4413 dual monolithic ideal diode provides a simple and efficient single-IC solution for low-loss PowerPath management. This device is ideal for battery-powered portable devices. It extends battery life, significantly reduce self-heating, and reduces form-factor with its 10-lead 3mm × 3mm footprint and minimal external parts count.

For more information on parts featured in this issue, see
http://www.linear.com/designtools