

## Introduction

The MAXREFDES1214 is a portable USB charger that uses a lithium-ion (Li+) battery to charge a USB device from a USB Standard-A connector. The battery can be charged through Micro-USB. The MAXREFDES1214 is compliant with USB Battery Charger (BC) revision 1.2 on both USB ports. It has dynamic charger detection to automatically set the maximum charge current allowed to the battery based on the source's capability. It also features a USB adapter emulator that supports Apple® 1A charging in addition to devices that are compliant with USB BC 1.2. For added flexibility, an I<sup>2</sup>C bus provides fault monitoring and shutdown capability for the buck-boost regulator.

Other features include the following:

- Battery Charger Input Current up to 1A
- USB Standard-A Output Current up to 1.5A
- 4400mAh Li+ Battery
- Thermal and Overcurrent Protection on the USB Standard-A Output
- I<sup>2</sup>C Headers for Flexible Logic Levels from 1.8V to 5.0V
- Orange LED to Indicate if the Battery Is Charging
- No External Reverse Blocking Diode Required Between Battery and Charger

## Hardware Specification

The MAXREFDES1214 charges a Li+ battery with the MAX8808X linear Li+ battery charger. A Micro-USB input supplies 5V to the charger, and the charger delivers up to 1A to the battery. The battery charger's output current is determined by USB enumeration using the MAX14636 USB charger detector.

The battery delivers power to a USB Standard-A connector through a synchronous buck-boost converter, the MAX77816C. When a device is connected, the MAX14632 USB charger adapter emulator handles enumeration to ensure that the maximum current is drawn from the source.

The MAX77816C buck-boost converter has an I<sup>2</sup>C bus for fault monitoring and shutdown capabilities. The MAX8891 LDO is used to provide a stable 1.8V rail for the I<sup>2</sup>C bus.

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The MAX14595 is a bidirectional logic-level translator that allows logic voltages from 1.8V to 5.0V to be used with the 1.8V I<sup>2</sup>C bus of the MAX77816C.

Table 1 shows an overview of the design specification.

**Table 1. Design Specification**

PARAMETER	SYMBOL	MIN	MIN	MAX
USB Standard-A Input Voltage	V <sub>IN-USBA</sub>	—	5V	—
Li+ Battery Charger Output Current	I <sub>OUT-CHG</sub>	—	—	1A
I <sup>2</sup> C Logic Voltage	V <sub>L</sub>	1.8V	—	5.0V
LDO Output Voltage	V <sub>OUT-LDO</sub>	—	1.8V	—
Buck-Boost Input Voltage	V <sub>IN-BB</sub>	3V	3.7V	4.2V
Buck-Boost Output Voltage	V <sub>OUT-BB</sub>	—	5V	—
Buck-Boost Output Voltage Ripple	ΔV <sub>OUT-BB</sub>	—	—	<1%
Buck-Boost Output Current	I <sub>OUT-BB</sub>	—	—	1.5A
Buck-Boost Output Power	P <sub>OUT-BB</sub>	—	—	7.5W
Buck-Boost Switching Frequency	f <sub>SW-BB</sub>	2.25MHz	2.50MHz	2.75MHz
Buck-Boost Maximum Efficiency	η <sub>BB</sub>	—	—	96.2%

## Designed—Built—Tested

This document describes the hardware shown in Figure 1 and Figure 2. It provides the design procedure for the MAXREFDES1214, including the USB detection and enumeration circuitry, Li+ battery charger, buck-boost converter, and logic-level translation. The design has been built and tested, details of which follow later in this document.

## MAX14636—USB Charger Detector

The MAXREFDES1214 uses the MAX14636 to determine the charging capabilities of any connected USB host. The MAX14636 can detect an Apple charger, dedicated charging port (DCP), charging downstream port (CDP), and standard downstream port (SDP). These ports are all defined by USB BC 1.2. Read more about USB BC 1.2 in [Application Note 5801](#).

The MAX14636 has an open-drain output CHG\_AL\_N, which is low when charging is allowed. This output drives the active-low enable input of the MAX8808X linear Li+ battery charger. When there is no valid VBUS (no USB host is connected), CHG\_AL\_N is high impedance, thus it is pulled high to the battery voltage by an external pullup resistor. There is also a push-pull CHG\_DET output which is high for a DCP, Apple charger, or CDP. It is low for an SDP. This output is used to set the maximum charge current the battery charger can draw. The maximum charge current setting is explained in the MAX8808X section. See [Figure 3](#) for the CHG\_AL\_N and CHG\_DET connections.

## MAX8808X—Linear Li+ Battery Charger

The MAX8808X is a 1A Li+ battery charger that uses constant-current/constant-voltage (CCCV) charging. Its charge current is programmable using a single resistor and

the ISET pin. The charge current is set to either 0.5A or 1A by the MAX14636's CHG\_DET output. The CHG\_DET output drives a logic-level MOSFET to add or remove a parallel resistor at the ISET pin, as shown in [Figure 3](#). When an Apple charger, DCP, or CDP is detected, the charge current is 1A. If an SDP is detected, the charge current is 0.5A.

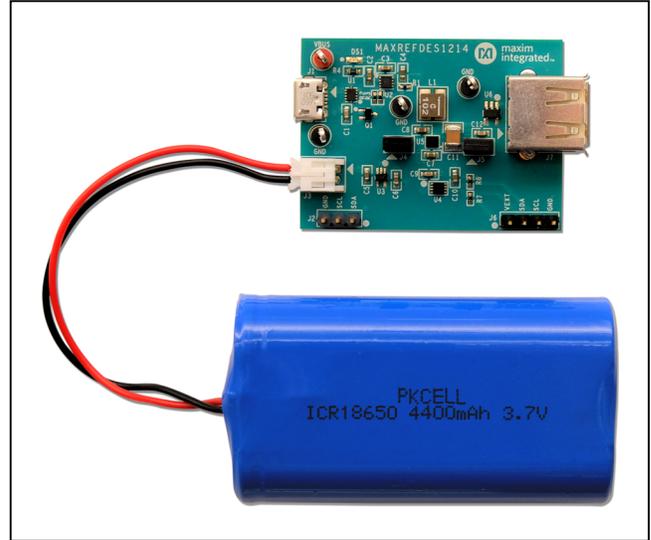


Figure 1. MAXREFDES1214 hardware.

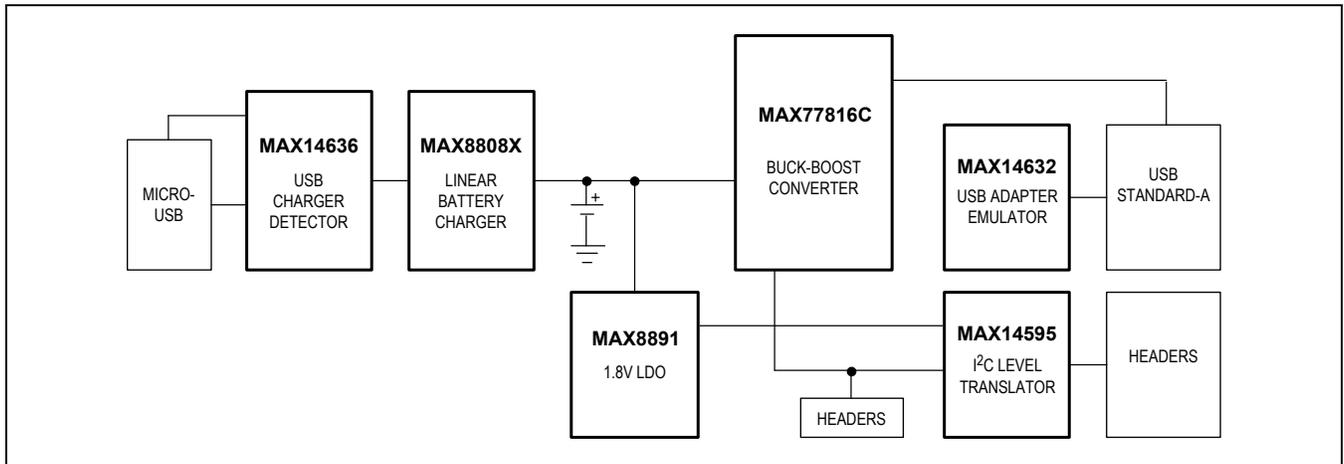


Figure 2. Block diagram of the MAXREFDES1214.

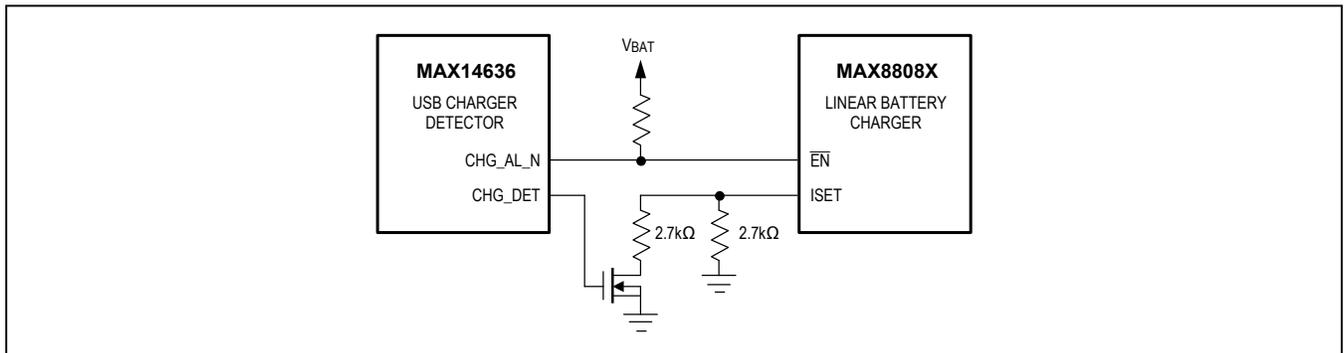


Figure 3. CHG\_AL\_N and CHG\_DET connections from the MAX14636 to the MAX8808X.

## MAX77816C—Synchronous Buck-Boost Converter

The MAX77816 is a highly efficient, synchronous buck-boost converter. The C version of this part has an input pin to select either a 3.3V or 5V output. The input to the MAX77816C is a Li+ battery. The battery voltage is 3.0V to 4.2V, and the output voltage is 5V. The 5V output is connected to  $V_{BUS}$  of the USB Standard-A connector. Under these conditions, the MAX77816C only operates as a boost converter. The MAXREFDES1214 output is capable of sourcing up to 1.5A, but the output current will change based on the attached USB peripheral.

The MAX77816C has an I<sup>2</sup>C bus for fault monitoring and software shutdown. The MAXREFDES1214 will operate without using the I<sup>2</sup>C bus, but is available for evaluation purposes.

## MAX14632—USB Charger Adapter Emulator

When a USB peripheral is connected to a MAXREFDES1214 USB Standard-A connector, the peripheral will enumerate with the host to see how much current the host can safely deliver. The MAX14632 is a USB charger adapter emulator that manages the enumeration. When a peripheral is connected, the MAX14632 will tell the peripheral that the MAXREFDES1214 is an Apple 1A and BC 1.2 compliant charger. It does this by connecting resistors to the USB data lines. These resistors and the enumeration process are described in [Application Note 5801](#).

## MAX8891—1.8V LDO

The MAX8891 is an LDO that uses the battery voltage as an input to create a 1.8V output. This 1.8V rail is used as the logic level for the MAX77816C I<sup>2</sup>C bus.

## MAX14595—Bidirectional Logic-Level Translator

The MAX14595 is a bidirectional logic-level translator. If the I<sup>2</sup>C master operates with a logic voltage higher than 1.8V, the MAX14595 converts the higher logic level to the 1.8V level of the MAX77816C. The MAXREFDES1214 can handle logic voltages from 1.8V to 5.0V.

## Buck-Boost (Boost) Regulator Theory of Operation

The MAX77816C buck-boost regulator utilizes a four-switch, H-bridge configuration to realize buck and boost operating modes. This topology maintains output voltage regulation when the input voltage is greater than, equal to, or less than the output voltage.

## H-Bridge Controller

The H-bridge controller operates at a 2.5MHz fixed frequency with a pulse-width modulated (PWM), current-mode control scheme. This topology is a cascade of a boost and buck regulator using a single inductor,

output capacitor, and input capacitor. Buck and boost stages are synchronous for highest efficiency. There are three phases implemented with the H-bridge switch topology, as shown in [Figure 4](#):

- $\Phi 1$  (HS1 = ON, LS2 = ON) – Charges the inductor by ramping up the inductor current at a rate proportional to the input voltage divided by inductance:  $V_{INBB}/L$
- $\Phi 2$  (HS1 = ON, HS2 = ON) – Ramps the inductor current up or down, depending on the differential voltage across the inductor, divided by inductance:  $\pm(V_{INBB} - V_{OUTBB})/L$
- $\Phi 3$  (LS1 = ON, HS2 = ON) – Ramps down the inductor current at a rate proportional to the output voltage divided by inductance:  $-V_{OUTBB}/L$

Two-phase boost topology is utilized when  $V_{INBB} < V_{OUTBB}$ . A switching cycle is completed in one clock period. Switch period  $\Phi 1$  is followed by switch period  $\Phi 2$ , resulting in an inductor current waveform like [Figure 5](#).

## Boost Converter Topology

Because the MAXREFDES1214 uses the MAX77816C with a 5V output and 4.2V maximum input, the MAX77816C only operates as a boost converter. [Figure 6](#) shows the topology of a synchronous boost converter. In a boost

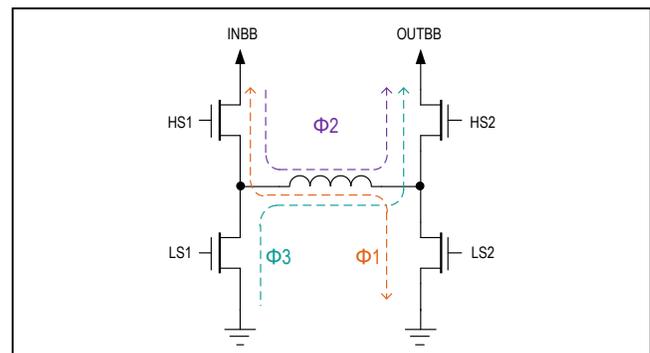


Figure 4. MAX77816C H-bridge architecture.

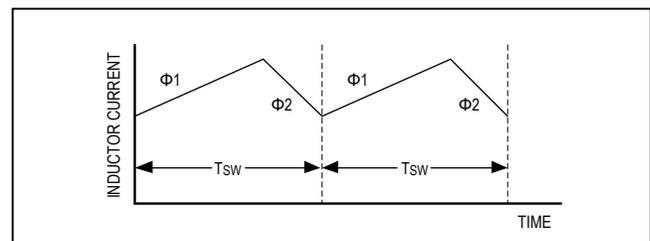


Figure 5. MAX77816C boost phase inductor current waveform.

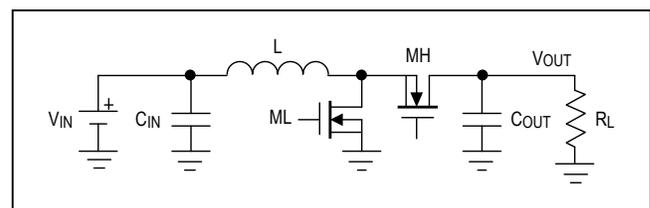


Figure 6. Synchronous boost converter topology.

converter, the output voltage is larger than the input voltage. In other words, the output is “boosted” from the input. In a synchronous boost converter, the MOSFETs ML and MH are always inverses of each other (i.e., when one is on, the other is off). The boost converter has two switching cycles, which are described in the following sections.

### ML = Closed, MH = Open

To begin, assume that all components are ideal. Also, assume that the converter is operating in steady state, meaning that it has already started and is stable. MH is open, and ML is closed (see Figure 7). This pulls one of the inductor terminals to ground and forces the inductor voltage  $V_L$  to be equal to the input voltage  $V_{IN}$ . The output current is supplied by the output capacitor  $C_{OUT}$ . The inductor voltage is then:

$$V_L = V_{IN} = L \frac{di_L}{dt}$$

Solving for the rate of change in inductor current when ML is closed and MH is open:

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_{IN}}{L}$$

where D is the duty cycle for ML closed and MH open, and T is the switching period in seconds. Thus, the change in inductor current for ML closed and MH open is:

$$(\Delta i_L)_{ML-CLOSED} = \frac{V_{IN}DT}{L} = \frac{V_{IN}D}{f_{SW}L}$$

where L is the inductance in H and  $f_{SW}$  is the switching frequency in Hz.

### ML = Open, MH = Closed

In the second half of the switching cycle, ML is open and MH is closed (see Figure 8). The inductor’s energy is now transferred to the output, and the inductor voltage inverts its polarity. Because inductor current cannot change instantaneously, current will continue to flow to the load  $R_L$ , but the current will be decreasing. The inductor’s magnetic field discharges, and the inductor voltage will be negative with respect to the current flow. Calculating the inductor voltage:

$$V_L = V_{IN} - V_{OUT} = L \frac{di_L}{dt}$$

Solving for the rate of change in inductor current when ML = open and MH = closed:

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_{IN} - V_{OUT}}{L}$$

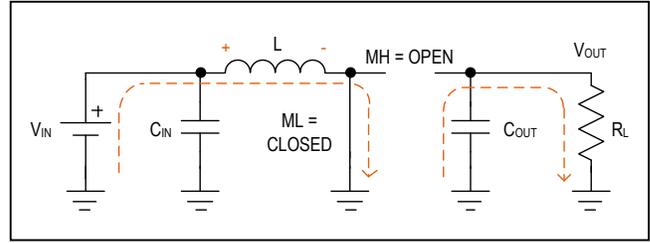


Figure 7. Synchronous boost converter topology.

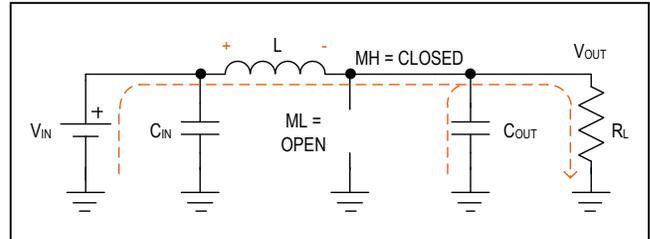


Figure 8. Boost converter equivalent circuit with ML open and MH closed.

Thus, the change in inductor current for ML open and MH closed is:

$$(\Delta i_L)_{ML-OPEN} = \frac{(V_{IN} - V_{OUT})(1-D)T}{L} = \frac{(V_{IN} - V_{OUT})(1-D)}{f_{SW}L}$$

### Useful Calculations

For a visual reference, see the switching waveforms in Figure 9.

Because the boost converter is operating in steady state, the total change in inductor current for one switching cycle must be zero. If we equate the changes in inductor current for each switching cycle, we get the following result:

$$(\Delta i_L)_{ML-OPEN} + (\Delta i_L)_{ML-CLOSED} = 0$$

$$\frac{(V_{IN} - V_{OUT})(1-D)}{f_{SW}L} + \frac{V_{IN}D}{f_{SW}L} = 0$$

Solving for  $V_{OUT}$ :

$$V_{OUT} = \frac{V_{IN}}{1-D}$$

From this result, notice that  $V_{OUT}$  will always be greater than  $V_{IN}$ . Even when  $D = 0$  (ML always open, MH always closed), the output voltage will equal the input voltage, but not go below.

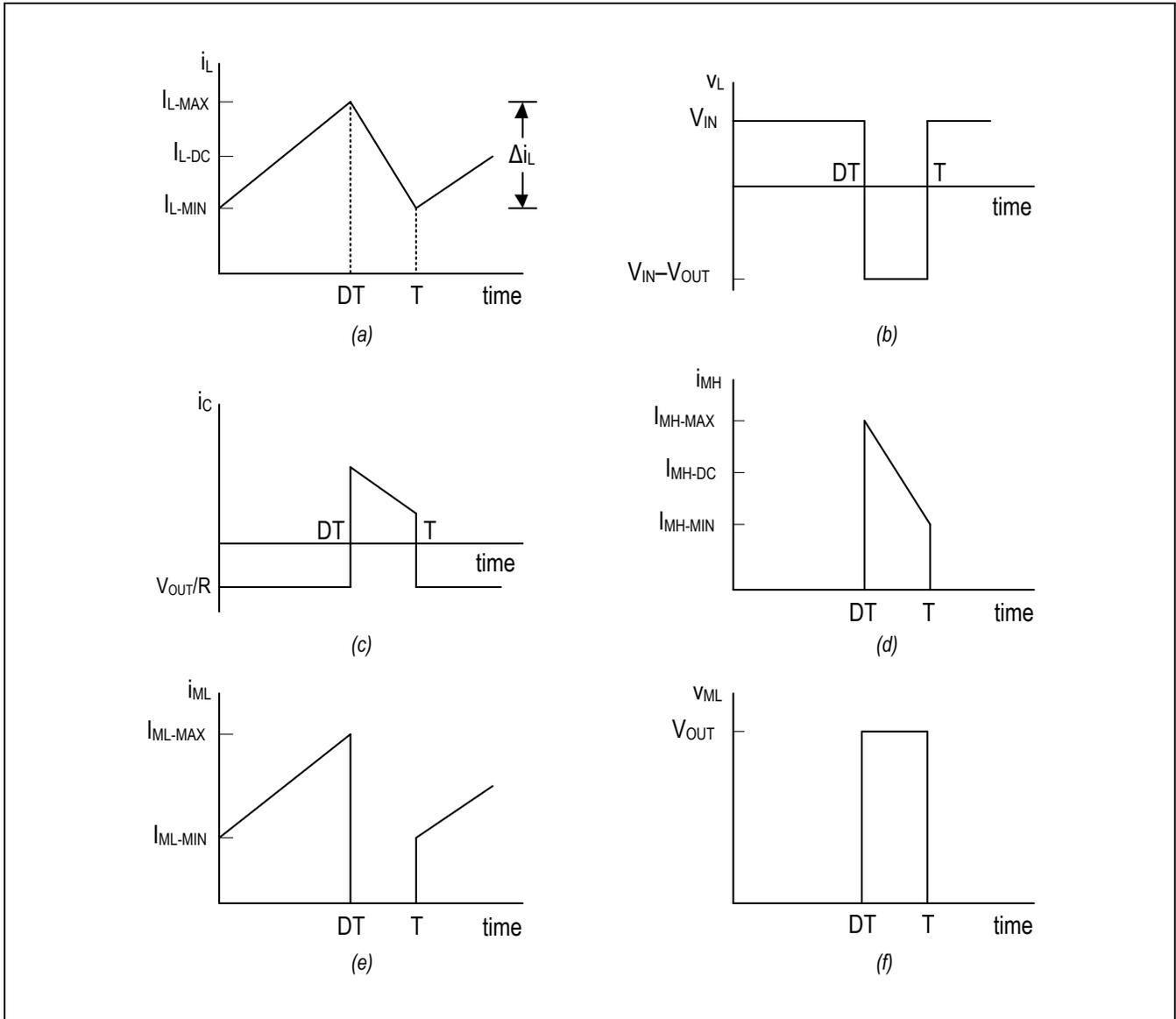


Figure 9. Boost converter waveforms: (a) inductor current vs. time, (b) inductor voltage vs. time, (c) output capacitor current vs. time, (d) current through MH vs. time, (e) current through ML vs. time, (f) voltage across ML vs. time.

We can use the input and output powers to solve for the average inductor current  $I_L$ . From this point, efficiency  $\eta$  will be included in the calculation to estimate the system losses:

$$\begin{aligned} \eta P_{IN} &= P_{OUT} \\ \eta V_{IN} I_{L-DC} &= V_{OUT} I_{OUT} \\ I_{L-DC} &= \frac{V_{OUT} I_{OUT}}{\eta V_{IN}} \end{aligned}$$

From this result, we can add half the total change in inductor current to get the maximum inductor current:

$$\begin{aligned} I_{L-MAX} &= I_{L-DC} + \frac{\Delta i_L}{2} \\ I_{L-MAX} &= \frac{V_{OUT} I_{OUT}}{\eta V_{IN}} + \frac{V_{IN} D}{2 f_{SW} L} \end{aligned}$$

This maximum inductor current is critical when choosing an inductor and low-side MOSFET for an application. Because the output voltage is always larger than the input voltage in a boost converter, the conservation of power

tells us that the input current must be larger than the output current. Thus, the inductor's average current will be higher than the output current.

## Design Procedure for MAXREFDES1214

### Step 1: USB Standard-A Output Current and Adapter Emulator Selection

USB charging is always tricky. When charging a device through USB, the priority is usually charging speed. For a device to charge quickly, the fast-charge current must be high. USB BC 1.2 defines CDPs and DCPs for high-current charging up to 1.5A. However, some manufacturers have chosen to implement their own proprietary USB ports. When a device from one of these manufacturers is plugged into a BC 1.2 compliant port, it may not draw the maximum current for which the port is specified. For example, if an Apple iPhone® (the load) is plugged into a DCP (the source), it will draw 500mA instead of the 1.5A that a DCP is supposed to allow. This is to prevent possible fire if a device is plugged into a poorly designed charger. For this reason, it is difficult to be compatible with all devices.

The MAX14632 is a USB adapter emulator which helps to alleviate this problem by providing support for Apple 1A and BC 1.2 compliant devices. This ensures that up to 1.5A can be drawn from the USB port by these types of devices to minimize charging time.

### Step 2: Inductor Selection

The MAX77816C data sheet recommends a low-ESR 1μH inductor. The Coilcraft® XAL4020-102MEB was chosen, as it is the inductor used on the MAX77816C evaluation kit. Because compensation is internal, it is safe to choose the data sheet's recommended inductor value, as this value was determined to be the best for use with the MAX77816C.

To verify that the 1μH inductor will work with the design, use the following worst-case parameters and equation to calculate the inductor current ratio (LIR):

- Input voltage:  $V_{IN} = 3V$
- Output voltage:  $V_{OUT} = 5V$
- Output current:  $I_{OUT} = 1.5A$
- Efficiency:  $\eta = 0.85$
- Duty cycle:  $D = 0.4$
- Switching frequency:  $f_{SW} = 2.5MHz$
- Inductance:  $L = 1\mu H$

$$LIR = \frac{I_{L-MAX} - I_{L-MIN}}{I_{L-DC}}$$

*Coilcraft is a registered trademark of Coilcraft, Inc.  
iPhone is a registered trademark of Apple Inc.*

First, calculate the DC inductor current:

$$I_{L-DC} = \frac{V_{OUT} I_{OUT}}{\eta V_{IN}}$$

$$I_{L-DC} = \frac{5.0V \times 1.5A}{0.85 \times 3V} = 2.94A$$

Next, calculate the maximum and minimum inductor currents:

$$I_{L-MIN} = I_{L-DC} - \frac{V_{IN} D}{2f_{SW} L}$$

$$I_{L-MIN} = 2.94A - \frac{3.0V \times 0.4}{2 \times 2.5MHz \times 1\mu H} = 2.7A$$

$$I_{L-MAX} = I_{L-DC} + \frac{V_{IN} D}{2f_{SW} L}$$

$$I_{L-MAX} = 2.94A + \frac{3.0V \times 0.4}{2 \times 2.5MHz \times 1\mu H} = 3.18A$$

Finally, calculate the inductor current ratio:

$$LIR = \frac{3.18A - 2.7A}{2.94A} = 0.163$$

Because LIR should typically be in the range of 0.1 to 0.3 to balance efficiency and size of the inductor, 0.163 is an acceptable LIR.

The Coilcraft inductor chosen has a saturation current of 8.7A, which is well above the maximum requirement.

### Step 3: Boost Converter Selection

Select a boost converter with internal synchronous switches to reduce footprint size and maximize efficiency. The input voltage, which ranges from 3V to 4.2V, will come from a single Li+ battery pack. The low-side switch will have a higher RMS current than the high-side switch. The input current will be greatest with a 1.5A USB output and the battery's minimum input voltage of 3V.

The low-side MOSFET's peak current is the same as the inductor's peak current, which was calculated in step 2 to be 3.18A. The MOSFET must be able to handle 3.18A of peak current under worst-case conditions. The MAX77816C buck-boost converter was chosen for this design. Its internal switches can handle up to 5A of current and 4A under worst-case conditions, which provides ample headroom for the design.

### Step 4: Output Capacitor Selection

The output capacitor is required to keep the output voltage ripple small and to ensure regulation loop stability. The MAX77816C data sheet recommends ceramic capacitors with an X5R or X7R dielectric for small size, low ESR, and small temperature coefficients. The data sheet indicates that a minimum of 16μF of effective capacitance should be used for stable operation.

A 6.3V, 47µF capacitor from Murata was chosen. The part number is GRM32ER70J476ME20. At the DC bias point of 5V, this capacitor exhibits 27.9µF of capacitance, which exceeds the 16µF requirement. It has 6mΩ of ESR at the switching frequency of 2.5MHz.

Using this capacitor, the output voltage ripple under worst-case conditions can be calculated as:

$$V_{\text{OUT-RIP}} = \frac{I_{\text{OUTD}}}{C_{\text{OUT}}f_{\text{SW}}} + I_{\text{L-MAX}}\text{ESR}$$

$$V_{\text{OUT-RIP}} = \frac{1.5\text{A} \times 0.4}{27.9\mu\text{F} \times 2.5\text{MHz}} + 3.18\text{A} \times 6\text{m}\Omega = 28\text{mV}$$

The resulting 28mV is less than 1% of the output voltage, which is good ripple performance even under worst-case conditions.

The output capacitor should also have low impedance at the switching frequency. At a switching frequency of 2.5MHz, the output capacitor has an impedance of 10mΩ, which is acceptable for this design.

### Step 5: Input Capacitor Selection

The input capacitor reduces the current peaks drawn from the battery and reduces the switching noise caused by the MAX77816C. The MAX77816C data sheet recommends a 10µF input capacitor with an X5R or X7R dielectric and low impedance at the 2.5MHz switching frequency.

A 16V, 10µF capacitor from Murata was chosen. The part number is GRM188R61C106M. This capacitor maintains a minimum capacitance of 4.4µF across the input voltage range, which is acceptable for this design.

### Step 6: Battery Selection

Choose a Li+ battery with a nominal cell voltage of 3.7V. Parallel cells can be used to increase battery capacity. Ensure that the battery can be charged with greater than 1A to provide a quick charge time. It must also be able to discharge at 3.18A or greater, which is the maximum input current to the boost converter. Additionally, the battery should have built-in thermal and undervoltage protection.

A cylindrical Li+ battery pack from Adafruit® was chosen for the MAXREFDES1214. The battery is 4400mAh and meets the required battery specifications. The pack contains two 18650 cells in a 1s2p configuration. It also has a JST connector for easy connectivity to the MAXREFDES1214.

### Step 7: Battery Charger Selection

Select a single-cell Li+ battery charger that can deliver up to 1A of fast-charge current to the battery. The MAX8808X linear battery charger was chosen for this design. This part can safely deliver up to 1A of fast-charge current to the battery. In addition, the fast-charge current can be programmed with a single resistor connected from the

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ISET pin to ground. This enables the charge current to be changed on the fly based on the connected USB host. The MAX8808X also has an open-drain  $\overline{\text{CHG}}$  output that indicates when the device is actively charging. On the MAXREFDES1214, this pin is connected to an LED indicator.

### Step 8: LED Charge Indicator Selection

The MAX8808X data sheet lists 5mA as the testing condition for the  $\overline{\text{CHG}}$  pin, which is what should be the target LED current. Choose an orange LED to indicate to the user that the battery is charging. The LED and its series resistor are pulled up to the 5V USB input voltage (see Figure 10). To calculate the required series resistor, use Kirchhoff's Voltage Law:

$$V_{\overline{\text{CHG}}} + I_{\text{LED}} R_{\text{LED}} + V_{\text{LED}} = 5\text{V}$$

$V_{\overline{\text{CHG}}}$  is the maximum turn-on voltage across the internal FET connected to the  $\overline{\text{CHG}}$  pin,  $I_{\text{LED}}$  is the current through the LED,  $R_{\text{LED}}$  is the series resistor, and  $V_{\text{LED}}$  is the forward voltage drop across the LED. The LED part number is LTST-C191KFKT. This is an orange LED with a forward voltage of 1.8V at the specified LED current of 5mA.  $V_{\overline{\text{CHG}}}$  is a maximum of 0.4V. Rearranging the equation above to solve for  $R_{\text{LED}}$ :

$$R_{\text{LED}} = \frac{5\text{V} - V_{\text{LED}} - V_{\overline{\text{CHG}}}}{I_{\text{LED}}}$$

$$R_{\text{LED}} = \frac{5\text{V} - 1.8\text{V} - 0.4\text{V}}{5\text{mA}} = 560\Omega$$

A 560Ω, 0603 surface-mount resistor was chosen.

### Step 9: USB Charger Detector Selection

For whichever USB host is connected to the MAXREFDES1214, the MAX8808X battery charger must be set so that its maximum charge current does not exceed the maximum current capability of the host. To do this, two possible charge currents are allocated: 1A for Apple 1A chargers, DCPs, and CDPs; 0.5A for SDPs.

The MAX14636 was chosen for its CHG\_DET digital output and its capability to detect both Apple and BC 1.2 compliant chargers. The CHG\_DET output is used to drive a logic-level MOSFET, which switches in a

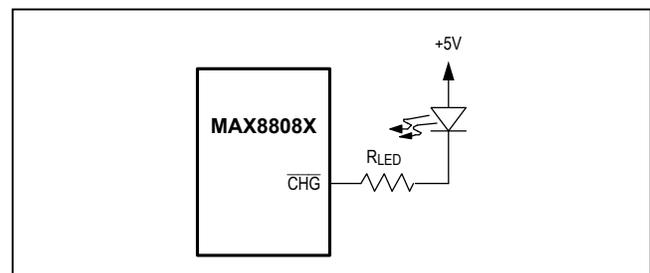


Figure 10. MAX8808X CHG LED configuration.

parallel resistor to the ISET resistor, as shown in Figure 3. The change in resistance at the ISET pin changes the maximum charge current that the MAX8808X battery charger will draw.

### Step 10: MAX8808X ISET Resistor Selection

To set the maximum charge current for the MAX8808X battery charger, use the following equation:

$$R_{ISET} = \frac{1302V}{I_{FAST-CHG}}$$

A 2.7kΩ resistor is used to set the charge current to approximately 500mA. When an additional 2.7kΩ resistor is switched in when CHG\_DET is high, the equivalent resistance from ISET to ground is half of 2.7kΩ, or 1.35kΩ. This sets the charge current to roughly 1A, as shown in Figure 2.

### Step 11: Logic-Level MOSFET Selection

A logic-level MOSFET is used to change the maximum charge current of the MAX8808X. The MAX14636's CHG\_DET output has a maximum logic-low value of 0.4V and a minimum logic-high value of 2V. Select a MOSFET with a gate-source threshold voltage between 0.4V and 2V to ensure that the MOSFET will be in the correct state when CHG\_DET is driven.

The NXP® 2N7002PW logic-level MOSFET was chosen for this design. This MOSFET has a gate-source threshold

voltage of 1.75V, which is in the range of the MAX14636 CHG\_DET drive voltage.

### Step 12: I<sup>2</sup>C Level Translator Selection

The MAX77816C has an I<sup>2</sup>C bus that can be used for configuration of the part, fault detection, and status monitoring. The I<sup>2</sup>C bus operates with a maximum logic high of the battery voltage, while the logic-high threshold is 1.4V. When the battery voltage drops below 3.3V, a 3.3V I<sup>2</sup>C master can no longer be used. To combat this problem, an I<sup>2</sup>C level translator is used to translate 3.3V logic to 1.8V logic for the MAX77816C.

The MAX14595 was chosen due to its open-drain capability for I<sup>2</sup>C bus. It can also translate voltages between 5V and 1.8V. See Figure 11 for a schematic of the I<sup>2</sup>C level translator circuit.

### Step 13: LDO Selection

A 1.8V LDO is used to power the MAX77816C side of the MAX14595 level translator. This is required so that the I<sup>2</sup>C master can operate with a logic level of 1.8V to 5.0V. If the battery voltage had been used instead, the I<sup>2</sup>C master would be forced to use a logic voltage above 4.2V, the maximum battery voltage. This is because the MAX14595 requires that its V<sub>L</sub> voltage be less than or equal to its V<sub>CC</sub> voltage.

The MAX8891 was chosen as the LDO. This part is available in a fixed 1.8V output version to reduce component count.

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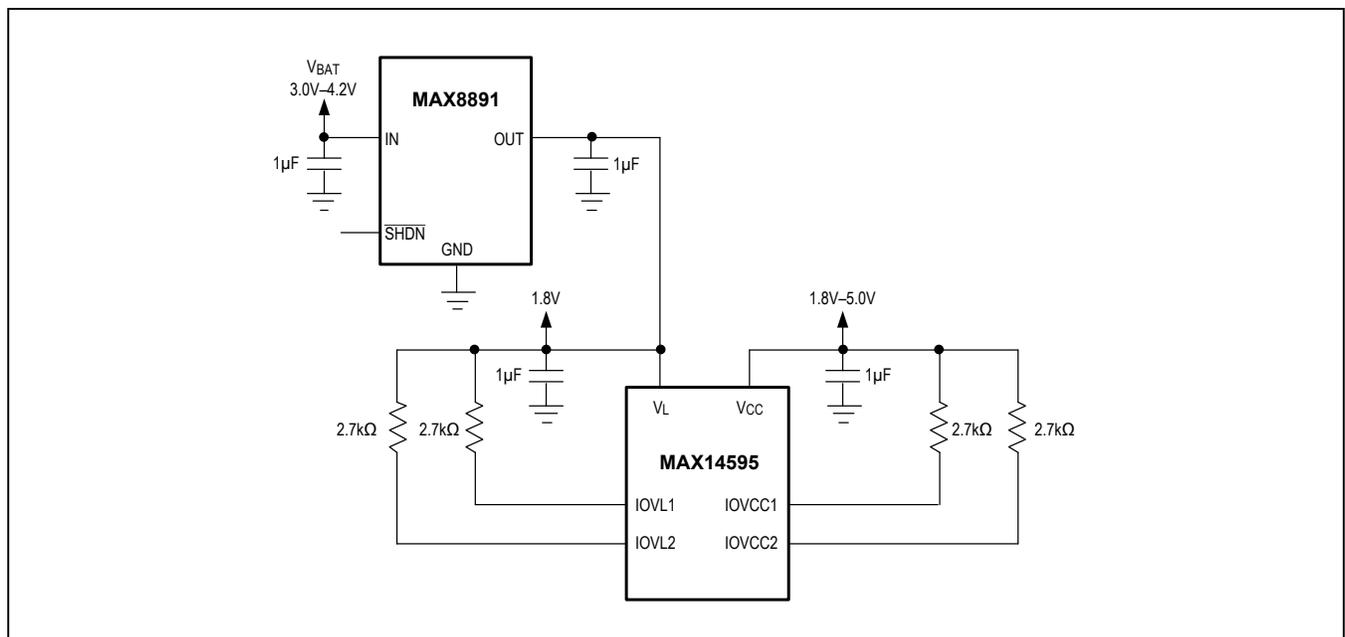


Figure 11. I<sup>2</sup>C level translator circuit with the MAX14595 and MAX8891.

## Step 14: Pullup Resistor Selection

For I<sup>2</sup>C lines, 1kΩ to 10kΩ is the general recommendation. Larger pullup resistors consume less power, but they create larger rise and fall times. They also drop more voltage when the open-drain I<sup>2</sup>C MOSFET leaks current in the high-impedance state. This voltage drop could lead to a false logic-low. For this design, 2.7kΩ resistors were chosen as the I<sup>2</sup>C pullups. This solution offers a good compromise between data rate and power consumption.

The CHG\_AL\_N also needs a pullup resistor. Because this is a simple digital output that does not require high speed, a 10kΩ resistor was chosen.

## Layout Guidelines

The MAXREFDES1214 uses a four-layer board. A description of the layers is shown in [Table 2](#).

For all ICs, follow the data sheet guidelines for proper bypassing on the power rails. Keep all bypass capacitors as close to the device as possible and ensure that the current loops for the capacitors are very small. This is especially critical for the MAX77816C, as its input and output capacitors filter high-frequency switching noise.

The MAX77816C and its inductor are placed on the top layer. For the inductor, use the bottom layer to route the LX traces. Put vias directly on the inductor pads for a simple connection from the bottom layer to the top layer. This makes it easy to lay out the input and output capacitors with small current loops back to the IC. Make the LX traces as short as possible and sufficiently wide

to carry the higher current. Longer traces add parasitic inductance that can cause the LX node to ring. Wider traces add parasitic capacitance, which can cause excessive peak currents.

The MAX77816C's output capacitor should be as close to the device as possible to minimize trace length and parasitic inductance. Because the output capacitor experiences a high di/dt (see [Figure 9c](#)), short trace lengths are crucial to reduce voltage spikes at the output.

Give the battery a power plane on an internal layer to provide more copper for heat dissipation. Do the same for the Micro-USB input. Provide a ground plane on another internal layer as a reference for the whole board. Most of the heat will be dissipated on this large plane of copper.

**Table 2. Layer Stackup**

LAYER	DESCRIPTION
Top	Signal
Inner 1	Ground
Inner 2	Power
Bottom	Signal

## Design Resources

Download the complete set of [Design Resources](#), including the schematics, bill of materials, PCB layout, and test files.

## Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	03/19	Initial release	—

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