# DESIGN SOLUTIONS

## POWER

maxim integrated™

# Design a Cooler, Safer Smart-Home Hub—Using an Ideal Diode

## Introduction

Your customer has successfully launched a new smart-home hub with a design that wirelessly controls door locks, lights, thermostats, audio, and electrical appliances, all while sending notifications to the homeowner. The soap-bar sized gadget (Figure 1, lower left corner) powered by a wall adapter, is packed with electronics and includes backup batteries in case of a power outage. However, the sleek design is pushing the device's thermal limit, and now the customer is concerned that the heat generated by the hub may become a problem, compromising the product's success. The customer asks for help to seamlessly reduce the heat generated without compromising the overall design. This design solution will examine the best option for addressing this issue.



Figure 1. Smart-home Hub

## Power Management Implementation

Figure 2 shows a diagram of the customer's current smart hub system. It's powered by a 5V wall adapter and has a non-rechargeable backup battery. Three AA alkaline batteries (1.5V x 3, 2Ah) support the 200mA average load and the always-on buck converter outputs a nominal 2.5V.

The radio communicates with home appliances equipped with wireless protocols such as Z-Wave™ and ZigBee™. The ethernet connection ensures exchange of notifications and events with the cloud, but the device will still work locally provided there is power.
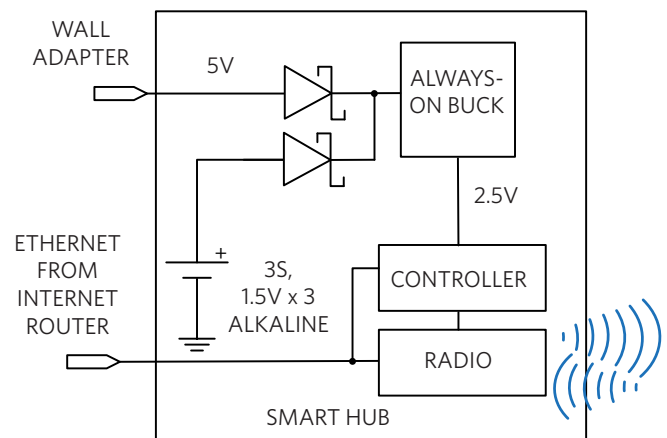


Figure 2. Your Customer's Smart Hub System

The active and passive components of the smart hub's power circuit are shown in Figure 3. The two diodes are housed in an SOT23-3 (2.6mm x 3mm) package, outlined in red.
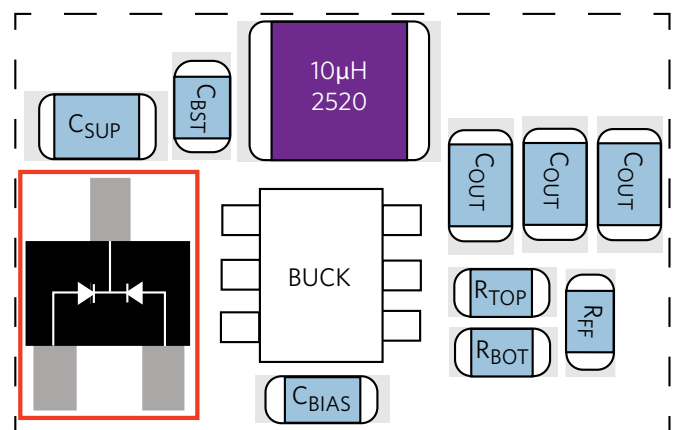


Figure 3. Smart Hub Power Circuit Footprint (46mm$^2$)

## Design Shortcomings

An initial thermal design analysis shows that the always-on buck regulator is operating quite efficiently. So, the focus quickly turns to the two Schottky diodes. At 200mA, these diodes develop a 600mV voltage drop, dissipating 120mW. The power delivered to the load is 2.5V x 0.2A = 500mW. This means that the diode adds a 24% power dissipation overhead.

Another concern in using Schottky diodes is leakage. In normal operation, the diode connected to the alkaline battery is reverse-biased, dumping a current of about 1µA into the load, with the leakage increasing over temperature. This leakage effectively acts like a trickle charge of the battery for an inordinately long time until a power outage comes along to discharge the battery. The problem is that these are non rechargeable batteries that carry a warning, "If recharged they may explode or leak and cause burn injury." This is not what we intended for the customer!

## What are the Options?

Clearly, it's critical to drastically reduce the power dissipation. One option is to use a low $R_{DSON}$ n-channel DMOS-based solution such as the one shown in Figure 4. The diodes intrinsic to the MOSFETs are indicated with dashed lines. In this configuration, the control IC biases the GATE according to the voltage sensed across the MOSFET. A positive source-to-drain voltage turns the MOSFET "on" with current flowing in reverse mode (source to drain). A negative source-to-drain voltage turns the MOSFET "off", with the intrinsic diode reverse-biased. This solution requires two MOSFETS and two control ICs, making it bulky and expensive. This is a drastic solution that would require the redesign of the entire PCB.
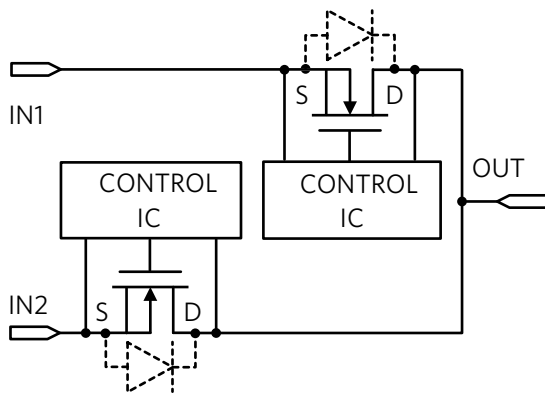


*Figure 4. A Discrete Solution to the Diode OR-ing Problem*

## The Ideal Solution

The best solution would be a small, "ideal" diode with dramatically lower losses than a Schottky diode and no or minimal reverse current. Fortunately for your customer, such a device is available.

## An Ultra-Tiny, Micropower, 1A Ideal Diode with Ultra-Low Voltage Drop

The MAX40200 is an ideal diode that drops a voltage about an order of magnitude lower than that of Schottky diodes. Looking at the functional diagram in Figure 5, the "ideal" diode is based on a low $R_{DSON}$ p-channel DMOS. The internal circuitry senses the MOSFET drain-to-source voltage and, in addition to driving the gate, keeps the body diode reverse-biased. This additional step allows the device to behave like a true open switch when EN is pulled low, or when hitting its thermal limit. A positive drain-to-source voltage turns the MOSFET "on", with current flowing in normal mode while the body diode is reverse-biased. A negative drain-to-source voltage turns the MOSFET "off", with the intrinsic diode again reverse-biased. If EN is low then the device is "off" independently of the $V_{DD}$-OUT polarity.
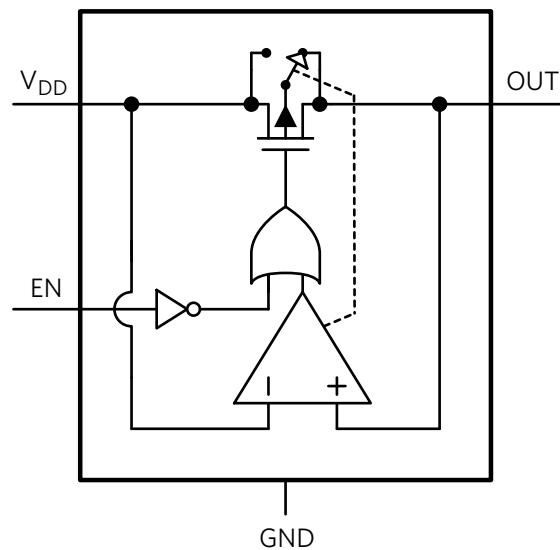


*Figure 5. Ideal Diode Functional Diagram*

When forward-biased and enabled, the MAX40200 conducts with less than 100mV of voltage drop while carrying currents as high as 1A. The typical voltage drop is 43mV at 500mA, with the voltage drop increasing linearly at higher currents. Figure 6 shows the ideal diode's forward voltage vs. forward current and temperature. The MAX40200 thermally protects itself and any downstream circuitry from overtemperature conditions. It operates from a supply voltage of 1.5V to 5.5V and is housed in a tiny, 0.73mm x 0.73mm, 4-bump wafer-level package (WLP).
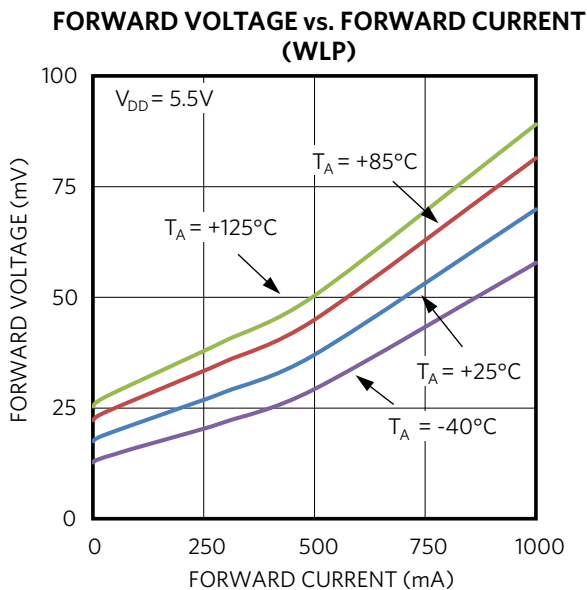
## FORWARD VOLTAGE vs. FORWARD CURRENT (WLP)



Figure 6. Ideal Diode Forward Voltage

## ANODE CURRENT AT REVERSE OPERATION



Figure 8. Leakage Current Into $V_{DD}$

The tiny MAX40200 WLP package is about one order of magnitude smaller than the SOT23-3 housing the two Schottky diodes in Figure 3. Two MAX40200s fit easily in place of the SOT23-3 position on the PCB with additional room to spare. The MAX40200 application footprint is shown in Figure 7.
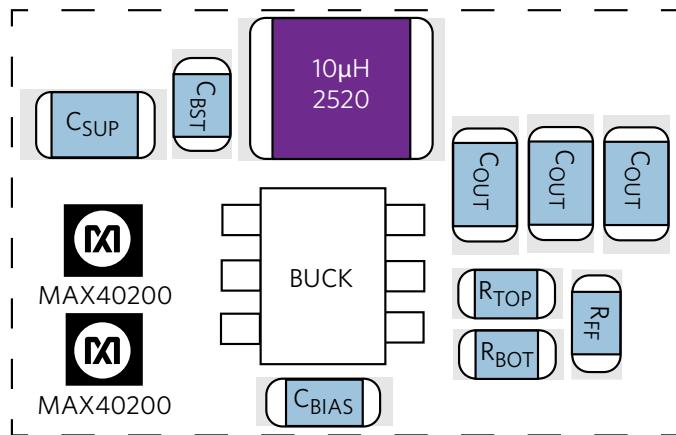


Figure 7. Integrated Smart Hub Power Solution with Two MAX40200s

With a 20mV drop at 200mA, the device consumes only 20mV x 200mA = 4mW of power, greatly reducing the thermal load. Additionally, the MAX40200 reverse leakage current is mostly from Cathode/OUT to ground, while the Anode/$V_{DD}$ reverse current is practically null (Figure 8). This effectively eliminates the unwanted trickle charge of the non-rechargeable battery. The MAX40200-based solution, easily and quickly implemented by the relieved customer, solves both the heat and leakage problems in the smart-home hub device.
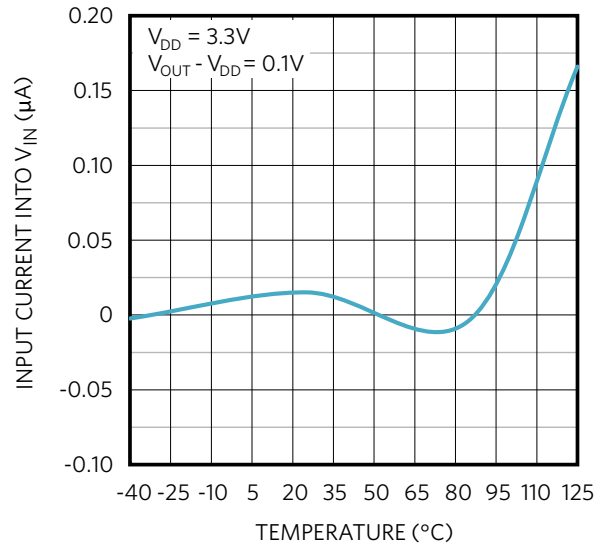
## Conclusion

We discussed the constraints of a smart hub's power management system in the context of a customer problem case study. The customer's smart hub had severe problems directly related to the classic shortcomings of Schottky diodes, namely the high forward voltage drop and high reverse leakage current caused by these diodes. The smart-home hub generated too much heat and the reverse leakage current was unwittingly trickle-charging the non rechargeable battery. To address this, two MAX40200 ideal diodes were used to seamlessly replace the two Schottky diodes with little modification of the PCB. This practically eliminated the leakage current into the battery and reduced the power dissipation overhead by a factor of thirty, making for a happy, satisfied customer.

Learn more:

MAX40200 Ultra-Tiny Micropower, 1A Ideal Diode with Ultra-Low Voltage Drop

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