Application Note

Measuring Efficiency for a Switch-Mode Battery Charger

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ABSTRACT

The typical choice for a battery charger with higher charge current is a switch-mode battery charger. This is due to the higher efficiency available to a switch-mode charger over linear chargers, which dissipate the unneeded power from the input as heat. Accurate measuring of the efficiency is critical to evaluate the chosen battery charger, as incorrect measurements can lead to lower observed performance. Correctly prototyping a new battery charger depends on careful design of the Printed Circuit Board (PCB) to collect the required measurements.

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1 Introduction

In any given conduction path from one point to the other, there is resistance. Often in a battery charger, this can be the resistance in the cable from a wall adapter to the device, the contact resistance, and the trace to the battery charger. When the battery is attached, there is also the conduction path from the battery charger to the battery connector, and perhaps even cabling to the battery. What is the impact of this resistance in measurement?

Assuming the battery is charging from an adapter, the input voltage measured at the adapter and the battery voltage measured at the battery is different from the charger Integrated Circuit (IC) input voltage and battery voltage. This is due to the resistive loss in the cabling and traces to and from the IC. More specifically, the IC input voltage is lower than the adapter voltage and the IC battery voltage is higher than the measured battery voltage at the terminals. Either or both of these incorrect measurements lower efficiency. For a sample efficiency curve for the BQ25960H, see Figure 1-1.

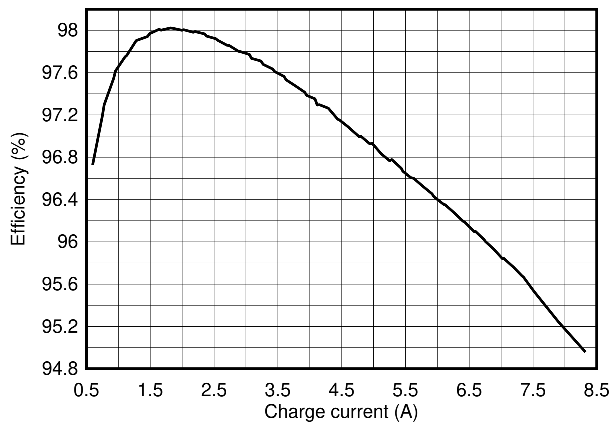

Figure 1-1. BQ25960H Battery Charge Efficiency vs. Charge Current, 2 x 22µF CFLY per Phase, VBAT = 4.0V, FSW = 500kHz

2 How to Measure Efficiency Correctly

First, users need to know how to calculate the efficiency for a battery charger. For the purposes of this example, assume there is no system load and that the only output from the battery charger is going to charge the battery. Efficiency is measured as the output power divided by the input power. For the case of the battery charger, the efficiency is the battery voltage multiplied by the battery current divided by the input voltage and input current. This is summarized in Equation 1.

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = \frac{V_{bat} \text{ x } I_{bat}}{V_{in} \text{ x } I_{in}} \tag{1}$$

The best place to measure any voltage that is also in a high current path, whether in a battery application or not, is through a Kelvin sense point. A Kelvin sense point is a thin trace that extends to a measurement point and goes directly to the pin on the IC that corresponds to the desired voltage. The trace cannot be in the conduction path of the voltage being measured. The trace also needs to be narrow and not meet the high current path except for at, or as close as possible, to the IC. Do not use the Kelvin sense path as the main power path for the power being routed, as the trace is not designed for the current being transferred. In general, the ADC of the charger IC must not be used to calculate the efficiency of the charger.

Another issue to keep in mind when measuring efficiency is how to measure the current. There are two ways to measure current, either with a sense resistor or with a direct current measurement from a sourcemeter or equivalent. There are tradeoffs to both, however the best way is to use a sourcemeter. When using a sense resistor, careful calibration is required to get accurate results. With multiple Printed Circuit Boards (PCBs), the calibration can be different from resistor to resistor. In addition, using a multimeter with even 1mV of error can make a huge difference for the efficiency. A sourcemeter is calibrated once and can work with multiple PCBs without additional steps.

3 The Impact of Incorrect Efficiency Measurement

Here are a few examples of how measuring input and output voltages incorrectly can affect the efficiency. If the applied input current to a battery charger is 2A, but the resistance from the adapter to the input pin of the battery charger is 100mΩ, then what is the impact? By Ohm's Law, this is a 200mV drop from the adapter to the input pin. Assume a 92% efficiency for example. If the input pin is actually 5V, with the adapter being 5.2V, and the battery is charging at 4V/2.3A, then the recorded efficiency is approximately 88.5% with the 5.2V adapter voltage, as shown in Equation 2. That has a huge impact on the evaluation of the thermal performance of the part. Second, take the same example (92% efficiency, 5V/2A input, 4V/2.3A battery), but now make the measured battery voltage 3.8V at the terminal of the battery. This presents a 87mΩ drop, making the calculated efficiency being 87.4%, as shown in Equation 3.

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = \frac{4.0\text{V x } 2.30\text{A}}{5.2\text{V x } 2.0\text{A}} = 88.5\% \tag{2}$$

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = \frac{3.8\text{V x } 2.30\text{A}}{5.0\text{V x } 2.00\text{A}} = 87.4\% \tag{3}$$

In both cases, there is an incorrect 200mV measure offset as seen by the adapter or terminal of the battery that lowers the efficiency by more than 3%. Proper care must be taken to accurately measure the efficiency and, thus verify the performance of a battery charger.

Having a significant digit off in a sense resistor voltage measurement can have a big impact on the efficiency, as mentioned in Section 2. Use the same example as before (92% efficiency, 5V/2A input, 4V/2.3A battery) but now with a 10mOhm sense resistor in the battery current path. The correct sense voltage for the battery current is 23mV for 2.3A of charge current, as shown in Equation 4. However, just 1mV off in the sense voltage leads to an observed current of 2.2A, as shown in Equation 5. This leads to an observed drop in efficiency to 88.0% as shown in Equation 6. Just 1mV off in a voltage measurement can lead to over 10% error in a current measurement and 4% drop in efficiency.

$$\text{Sense Current} = \frac{V_{sense}}{R_{sense}} = \frac{0.023\text{V}}{10\text{m}\Omega} = 2.3\text{ A} \tag{4}$$

$$\text{Sense Current} = \frac{V_{sense}}{R_{sense}} = \frac{0.022\text{V}}{10\text{m}\Omega} = 2.2\text{ A} \tag{5}$$

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = \frac{4.00\text{V x } 2.20\text{A}}{5.00\text{V x } 2.00\text{A}} = 88.0\% \tag{6}$$

4 Measuring Efficiency in a Buck Charger

A buck battery charger has an input voltage greater than the applied battery voltage. In a buck charger, the inductor is at the output of the switching converter, with the battery connection sometimes further down the line than the system connection due to Narrow Voltage DC Architecture (NVDC). Therefore, to measure the charging efficiency, users need to measure the Kelvin sense for the input voltage, the input current, the Kelvin sense for the battery voltage, and the battery current. Note that measuring the system efficiency in a NVDC charger with the Kelvin sense for the system voltage yields a slightly higher efficiency due to the exclusion of the BATFET on-resistance.

Take the BQ25638EVM as an example of a buck charger EVM. TP10 marks the Kelvin sense for the input voltage, or VBUS. TP13 marks the Kelvin sense for the battery voltage, or VBAT. While the input power is physically applied through J1 and the battery simulator is physically applied through J4, the input voltage for the efficiency measurement must be taken at TP10, and the battery voltage for the efficiency measurement must be taken at TP13. An example of how to connect the power supply, battery simulator, input voltage measurement, and battery voltage measurement for the BQ25638EVM as shown in Figure 4-1.

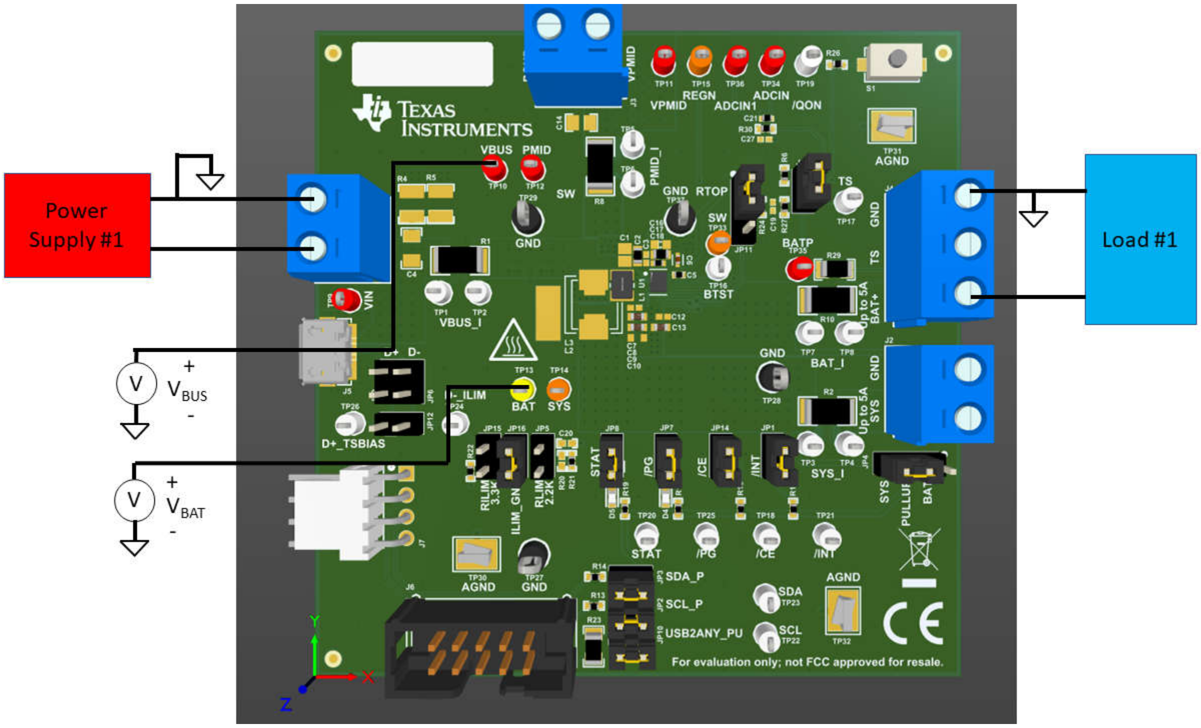

Figure 4-1. BQ25638EVM Efficiency Measurement Setup

5 Measuring Efficiency in a Switch-Cap Charger

A switch-cap charger has a ratio of input to output voltage that must be maintained for the converter to work. In a 2:1 switch-cap charger, the input voltage is always slightly higher than 2x the battery voltage. For a switch-cap charger or inductor-less charger, there is usually not a system rail as the output is not regulated. Switch-cap chargers run open-loop, entirely dependent on the input voltage applied, the battery voltage applied, the resistance between the power supply and the converter, and the resistance between the converter and the battery simulator. However, like the buck charger, in addition to input and output current being measured, the Kelvin sense for the input voltage and output voltage need to be measured. The issue of efficiency accuracy is even higher for switch-cap chargers due to the high current output. The BQ25960H can power up to 8A with a single charger, and there can be a significant drop from the output of the converter to the edge of the EVM or the battery. Therefore, this is critical to measure the output voltage of the converter to accurately represent the efficiency of a switch-cap charger.

Take the BQ25960HEVM as an example of a switch-cap charger EVM. The BQ25960H is a 2:1 switch-cap charger, meaning the input voltage is twice the output voltage. TP2 marks the Kelvin sense for the input voltage, or VBUS_M. TP5 marks the Kelvin sense for the output voltage, or VOUT_M. While the input power is physically applied through J1 and the battery simulator is physically applied through J2, the input voltage for the efficiency measurement must be taken at TP2 and the output voltage for the efficiency measurement must be taken at TP5. An example of how to connect the power supply, battery simulator, input voltage measurement, and output voltage measurement for the BQ25960HEVM is shown in Figure 5-1.

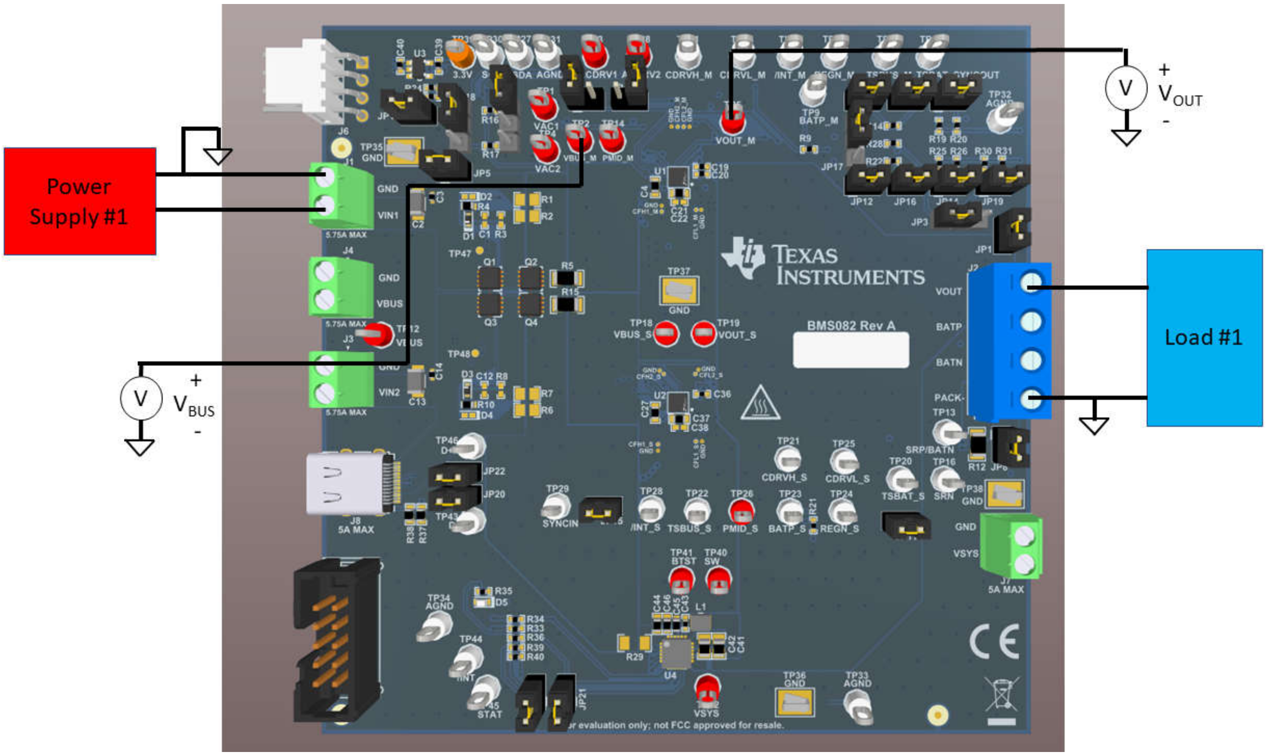

Figure 5-1. BQ25960HEVM Efficiency Measurement Setup

6 Summary

Careful measurement of the input voltage and output voltage of buck chargers and switch-cap chargers are needed to accurately measure the efficiency of these chargers. Measuring the input voltage at the terminal of the adapter and measuring the output voltage at the battery terminal can lead to lower efficiency measurements for a battery charger. Sensing these voltages through a Kelvin sense is needed to make these measurements correctly.

7 References

1. Texas Instruments, BQ25960H I 2C Controlled, Single Cell 8A Switched Cap Parallel Battery Charger with Integrated Bypass Mode and Dual-Input Selector, data sheet
2. Texas Instruments, BQ25638x Evaluation Module User's Guide (Rev. A)
3. Texas Instruments, BQ25960HEVM (BMS082) Evaluation Module User's Guide

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