Overview

In the charger application area such as for electric bicycles and electric tools etc. manufacturers often have to make adjustments to the products before leaving the factory to ensure that the charger output voltage and current values are within specifications. The traditional way of doing this is by using calibration fixtures which use fixed value or variable resistors to determine the required resistance value. This method, in addition to the labour costs also results in increased production times which have a major influence on the product overall costs.

The HT45F5Q-2 charger ASSP MCU, which includes a fully integrated battery charger module and EEPROM, can be used together with an automatic calibration fixture to correct the charger output voltage and current values, whose parameters can then be stored in the device’s internal EEPROM. This application note will explain how to automatically correct the HOLTEK Charger ASSP MCU, such as the HT45F5Q-2, using such a calibration fixture. A suitable calibration fixture can be designed in consultation with this application note.

Functional Description

Charger Adjustment Reasons

During charger volume production, the actual output voltage and currents produced may result in the charger being out of spec due to the product components tolerances (R2, R5 and R6 in the figure below) as well as other reasons.

Charger Principles

The HOLTEK charger ASSP MCU has a fully integrated battery charger module. The example here uses the HT45F5Q-2 as an example. The internal DAC1 output is compared with the voltage divider output, or the internal DAC0 is compared with the R2 current signal. The internal OPA outputs will switch the opto-coupler which in turn will
change the Current Mode PWM IC output. In this way the required constant voltage or constant current can be obtained. When the charger is powered on, the MCU will first check whether it is connected to the calibration fixture through a 1-Wire communication method to confirm whether it should enter the calibration mode. If the connection is successful, the calibration will start and the correction value will be stored in the EEPROM. Then when the charger is powered up each time, the MCU will load the EEPROM updated calibration values.

Fig 1. HT45F5Q-2 Charger Application Circuit Diagram

Calibration Fixture Hardware Description
Holtek charger calibration fixture - uses the HT66F2390 as an example.
1. AC/DC power supply circuit: AC 110V to DC 12V and 5V for use by the calibration fixture, controls relay (K1) output to the charger AC power supply.
2. ADC reference voltage circuit: The external TL431 (D5) is used as the MCU A/D reference voltage (V_{REF}), with a variable resistor (VR2) added. Users can manually adjust the ADC reference voltage by 4.0V to reduce the error.
3. Charger voltage detection circuit: In the Normal Mode, this will detect the voltage of the charger and allow the LCM to display the voltage value. In the Test Mode, the voltage is applied to B+/B-, and allows the LCM to display the voltage value. Manually adjust the detection voltage using the variable resistor VR1 to ensure the measurement accuracy of the charger voltage.
4. Charger current detection circuit: Use the current sense IC (U1) to measure current and output voltage value to the MCU A/D.
5. Level Shift control circuit: The 5V signal is used to control the 12V relays (K1~K3) through the voltage converter IC (U4).
6. Load switching circuit: Use ceramic resistors (R1, R2) for the charger load.
7. Charger connection circuit: The charger's AC power input is provided by the calibration fixture (AC Output). The charger's DC power output is detected by the calibration fixture (DC IN). The charger's TRx and the calibration fixture communicate using single-wire communication.
Since the output voltage of the charger is charging C1, B+ and B- are equal to the high voltage potential. If there is no Zener D4 voltage regulation to 5.1V and an R3 current limit, the high voltage potential will be directly injected into the MCU A/D pin which will cause damage.

Calibration Fixture Circuit Diagram

Calibration Fixture and Charger Connection Instructions

During calibration, the charger needs to be connected to the calibration fixture using the communication pins (TRx and GND), the AC input interface and the DC output interface (B+, B-). This is shown in the accompanying diagram. The AC main power supply is provided by the calibration fixture. In actual production, the contacts D, E and F can be used to allow customers to design their preferred connection method.

<table>
<thead>
<tr>
<th>Charger</th>
<th>Calibration Fixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: DC Output B+, B-</td>
<td>D: DC Input B+, B-</td>
</tr>
<tr>
<td>B: Signal TRx, GND</td>
<td>E: Signal 1-Wire, GND</td>
</tr>
<tr>
<td>C: AC Input</td>
<td>F: AC Output</td>
</tr>
</tbody>
</table>

Connection Description

Charger and Calibration Fixture Wiring Diagram
Software Description

Users will have different requirements for the calibration protocol. The following is only a conceptual architecture but users can design the protocol format according to their own requirements. The following describes the software flow of the calibration fixture and the charger.

Charger Fixture Single Line Communication Protocol

- **Host**: Calibration Fixture
- **Slave**: Charger
- Single-line communication definition: 1-bit total time of 1ms
  - Data 1: 700µs high-level, 300µs low-level
  - Data 0: 300µs high-level, 700µs low-level

Communication format:

<table>
<thead>
<tr>
<th>Instruction</th>
<th>01H</th>
<th>02H</th>
<th>03H</th>
<th>04H</th>
<th>05H</th>
<th>06H</th>
<th>07H</th>
<th>55H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
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<td></td>
<td></td>
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<tr>
<td>Confirm Connection</td>
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<td></td>
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<tr>
<td>Start</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increment Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrement Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confirm Power</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjustmen t Failed</td>
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<td></td>
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<tr>
<td>Complete</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear EEPROM</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Communication Timing Diagram

- **Normal Communication**
  - First the host sends a start signal which is to pull down the bus for 18ms, after which it sends the command
  - After the slave detects a start signal it starts receiving commands
  - After the host sends the command, it will change into a receiver state. If the slave receives the correct command, it will send a start signal first and then reply to the same host command after which the communication ends

- **Abnormal Condition – Example 1**
  - If the host send out an erroneous instruction, the slave will not respond
Abnormal Condition – Example 2

- After the host sends an instruction, if for unknown reasons the slave does not respond, the host will execute a delay and then send the command again. The delay time is controlled by the host (greater than 30ms) and the same command will be sent up to 15 times.

Calibration Fixture Software

After power-on, the calibration fixture waits for the user to press the start button and start communication. During communication, the fixture will switch on the charger power relay K1. After a 1 sec. charger stabilisation time, a communication command is sent for the charger to enter the calibration mode. If successful the charger will return a signal. If the communication has not been successful after the maximum permitted time is exceeded, it will be determined that the communication has failed or that the charger is not connected. The LCM will display a connection failure message and will then wait for the user to press the button again to re-communicate.

When the communication is successful, the calibration fixture displays the correction information and will start the calibration procedure. When the fixture is being calibrated, the load relays, K2 and K3, are sequentially turned on and the battery load is simulated by the cement resistors. Through the resistor voltage divider, R6 and VR1, and current measurement IC, U1, the charger voltage or current measurement is performed separately. After each measurement, an increment or decrement command is sent, after which the charger will adjust the DAC to change the output power. When the calibration requirements are met, the charger is instructed to store the DAC parameters to the EEPROM and perform the next stage of the calibration process until all calibrations have been completed. Then it will turn off all relays, K1–K3, and display a calibration completed message. Each calibration stage has a maximum number of corrections equal to 20 times. If the number of corrections exceeds this, the correction will be determined to have been unsuccessful.
Charger Software

For three seconds after power-on, the charger will continuously detect whether the calibration fixture requires calibration. If a communication command from the calibration fixture is not received within this time, it will enter the charger mode. If a communication command is received and communication command successfully returned, the calibration program will be started.

At the beginning of the calibration, the charger adjusts the integrated DAC (increment or decrement) according to the calibration fixture command, thereby adjusting the CV and CC values until the calibration is complete after which the DAC values are written into the EEPROM to complete the calibration program. Then wait for the charger to power up again but this time do not enter the calibration program. The charger will read the correction values in the EEPROM to update the DAC, and then start executing the normal charger program. Each calibration stage has a maximum number of corrections equal to 20 times. If the number of corrections exceeds this, the correction will be considered to be unsuccessful and no adjustment will take place until another correction command is received.
- **Calibration Fixture Step Description**
  - **Step 1**: After the fixture is powered on, select the charger type to be calibrated, press the start button, turn on the charger power relay (AC Output), and send a connection command.
  - **Step 2**: Wait for a return command and check that the time has not been exceeded and confirm that the charger has entered the calibration mode. If communication cannot be established with the calibration fixture then the calibration process will stop.
- Step 3: Connect the required load in the charging mode, measure the charger output status and the charger to adjust the DAC mode to fine tune the output voltage or current.

- Step 4: When the charger output voltage or current meets requirements, the charger is instructed to save the correction value to the EEPROM and displays a calibration success. If the calibration has not completed within the maximum correction time, the charger is instructed to skip this calibration item and display a calibration failure.

- Step 5: Repeat steps 3 and 4 until all voltage and current calibration items have been corrected.

- Charger Step Description

- Step 1: Initialise the settings after the charger is powered on and receive the connection command.

- Step 2: The charger establishes communication with the calibration fixture and enters the calibration mode. If communication cannot be established with the calibration fixture, the default value in the EEPROM will be kept and returned to the charger operating mode.

- Step 3: Start the calibration process.

- Step 4: Send a correction command according to the calibration fixture to adjust the DAC mode and fine tune the output voltage or current.

- Step 5: Send the completion command according to the calibration fixture to complete the point correction at this stage. If successful, the DAC value is stored in the EEPROM. If it fails, the point correction is skipped and the next calibration item will be executed.

- Step 6: Repeat steps 4 and 5 until the calibration fixture sends a calibration end command to end the calibration process.

**Select Type Display**

**Calibration Display**

**Calibration Complete Display**

**Connection Failed Display**
Calibration fixtures are preset to four calibration points: floating voltage charging, constant voltage charging, trickle current charging and constant current charging. Taking a 48V lead-acid battery as an example, note the following process:

- Floating voltage charging (FV): Constant voltage charging, used for self-discharge maintenance after the battery has been fully charged, and can also be trickle charged.
- Constant voltage charging (CV): Constant voltage charging, supplementing the part that has not been fully charged after constant current charging.
- Trickle charge (TC): Constant small current charging for when the battery has been deep-discharged, a small current can re-activate the battery.
- Constant current charging (CC): Constant current charging to prevent rapid battery temperature rise which can reduce battery life and charging efficiency

The correction fixture voltage and current AD value calculation formula is as follows:

- AD voltage value calculation: \( AD_{V_{BAT}} = \frac{4096}{V_{REF}} \times \left( V_{BAT} \times \frac{V_{R1}}{R_6+V_{R1}} \right) \)
  - Example: 59V AD voltage value: \( AD_{V_{BAT}} = \frac{4096}{4} \times \left( 59 \times \frac{1k}{20k+1k} \right) = 2876 = \text{B3CH} \)
  - Note: Demo Board \( R_6=20k \), \( V_{R1}=1kk \), \( V_{REF}=4.0V \cdot V_{BAT}= \text{charging voltage} 59V \)

- AD current value calculation: \( AD_{I_{BAT}} = \frac{4096}{V_{REF}} \times (0.185 \times I_{BAT}) \)
  - Example: 0.2A AD current value: \( AD_{I_{BAT}} = \frac{4096}{4} \times (0.185 \times 0.2A) = 37 = \text{25H} \)
  - Note: Demo Board \( R_6=20k \), \( V_{R1}=1kk \), \( V_{REF}=4.0V \), \( I_{BAT}= \text{Charging Current} 0.2A \)

Correct the calibration fixture data, register setup values are shown below:

<table>
<thead>
<tr>
<th>Calibration Steps</th>
<th>Setup Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating Voltage Charging (FV)=55V</td>
<td>2681 0A79H</td>
</tr>
<tr>
<td>Constant Voltage Charging (CV)=59V</td>
<td>2876 0B3CH</td>
</tr>
<tr>
<td>Trickle Current Charging (TC)=0.2A</td>
<td>37 0025H</td>
</tr>
<tr>
<td>Constant Current Charging (CC)=2.0A</td>
<td>378 017AH</td>
</tr>
</tbody>
</table>

Parameter Calculation

The charger output voltage and current are measured and assessed by the MCU ADC on the calibration fixture. The output voltage signal is read from the 20kΩ and 1kΩ resistors voltage divider. The preset resistors are \( R_6 \) and \( V_{R1} \), which are used to convert the voltage signal. The formula is:

\[
AD_{V_{BAT}} = \frac{4096}{V_{REF}} \times \left( V_{BAT} \times \frac{V_{R1}}{R_6+V_{R1}} \right)
\]
The charger output current is measured by the current sensing IC (ACS712ELCTR-05B-T) and supports a maximum current measurement of 5A, the detailed specifications are shown below. The current conversion voltage formula is

\[ AD_{IBAT} = \frac{4096}{V_{REF}} \times (0.185 \times I_{BAT}) \]  

(as shown in the following red frame)

Using the HT66F2390 12-Bit A/D with a reference voltage of 4.00V gives the following resolution:

\[ I_{Resolution} = \frac{4}{0.185} \approx 5.3\,mA \]

**ACS712ELCTR-05B-T Specification Table**

**Correction Error Calculation**

The corrected ADC value is compared with the tolerance maximum and minimum values. The error is corrected to achieve an accurate measurement of to achieve with the current sensing IC. However, the correction is still limited by each DAC. If the corresponding voltage or current has exceeded the specification, the calibration fixture will not have met the calibration requirements even if the measurement accuracy is accurate.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Theoretical Value</th>
<th>R_e</th>
<th>VR_v</th>
<th>Permitted Error</th>
<th>ADC Conversion Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FV</td>
<td>55V</td>
<td>20k</td>
<td>1k</td>
<td>+1%</td>
<td>2709</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1%</td>
<td>2655</td>
</tr>
<tr>
<td>CC</td>
<td>2A</td>
<td></td>
<td></td>
<td>+5%</td>
<td>398</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-5%</td>
<td>360</td>
</tr>
</tbody>
</table>

- Using FV=55V as an example, the AD conversion value is 2655~2709 so a value between this can be taken
- Using CC=2A as an example, the AD conversion value is 360~398 so a value between this can be taken
Correction fixture load component selection

The calibration fixture uses cement resistors to simulate the battery load. The resistor voltage is used to measure the charger output voltage, and a current sensing IC measures the charger output current. The choice of cement resistance should pay attention to the resistance and power ratings. For example, if the output voltage of the charger is 60V and the output current is 2A, the resistance value should be 30Ω (R=V/I), and the rated power must be 120W (P=I^2 R). However, when taking into account the loading time during the calibration process, the power should be multiplied by the ratio of the use time. If the time ratio is 1/5, the resistance power can be reduced to about 24W.

Comparison of advantages and disadvantages between automatic calibration fixture and traditional calibration fixture

<table>
<thead>
<tr>
<th></th>
<th>Automatic Calibration Fixtures</th>
<th>Traditional Calibration Fixtures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration Type</td>
<td>Single Click Calibration – saves time</td>
<td>Manual Calibration – time consuming</td>
</tr>
<tr>
<td>People required</td>
<td>1 person</td>
<td>2 or more people</td>
</tr>
<tr>
<td>Calibration Accuracy</td>
<td>Internal DAC provides accurate calibration</td>
<td>Limited due to external components</td>
</tr>
<tr>
<td>Calibration Time</td>
<td>Less than 10 sec./fixture</td>
<td>Greater than 60 sec./ fixture</td>
</tr>
</tbody>
</table>

Conclusion

After the charger has been manufactured, due to external component tolerances or due to long-term component depreciation, the charging parameters may experience inaccuracies. For this reason a charger calibration tool is required to make the necessary adjustments. This application note has provided a hardware description, software description, calibration parameter register names and parameter calculation formulas, supplemented by program flow charts and program step descriptions to allow users to understand the causes, principles, methods and points to note in a charger calibration fixture. The fixture uses cement resistors as charger loads, however this can be changed to different load types by the user. The above can help users to quickly understand the design and which can be modified according to their own needs, or directly use the calibration fixture provided by HOLTEK to reduce any difficulties due to manual correction and improve the overall efficiency.

Reference Material

Reference documents: HT66F2390 Datasheet

For more information consult the Holtek website: www.holtek.com

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Version and Modification Information

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<th>Date</th>
<th>Author</th>
<th>Issue Release and Modification</th>
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