Application Note

Implementing 2-V Charge Inhibition

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ABSTRACT

Lithium technology batteries provide an energy dense solution for portable power. The advantages lithium batteries provide come with added risk to final applications. To mitigate this risk, battery protection measures must be taken to reduce the possibility of battery failure. One such protection measure, 0 Volt Charging Inhibition, is implemented in many battery protection circuits. The protection is used to prevent the continual charging of an internally shorted battery.

Using a few techniques and features widely available on chargers, voltage based charging inhibition features can be approximated with only a host processor available. Using battery undervoltage detection as a basic battery voltage monitor, and some additional software logic, 2-V Charge Inhibition can be implemented in charging systems to add another layer of protection to the battery charging process.

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1 What is 0-V Charge Inhibition?

Lithium Ion and Lithium Polymer batteries represent the highest energy density among widely used battery technologies today. This type of battery, however, requires the additional protection features to make sure that their use and operation keep them within safe operating ranges. The risk of thermal runaway poses significant liability for any application that uses lithium-based batteries. As a result, battery chargers and battery protection IC's have developed more robust protection features for given battery-powered application.

One such feature that is increasingly found in battery protection ICs is a 0-V charge inhibiting feature. A battery that has depleted to 0 Volts can be indicative of a damaged battery with an internal short. In most applications, a device enters a very low power consumption state as the battery enters a deep discharge; in some cases, the battery is disconnected from the charging or discharging circuit. If battery voltage continues to fall despite the greatly reduced consumption, this can be due to an internal short. If the battery voltage drops below a certain voltage, the 0-V charge inhibit feature stops charging. For the BQ297x family of battery protection circuit, this voltage threshold can be as high as 0.75 V. Once this voltage threshold is crossed the battery is deemed unrecoverable, charging is inhibited completely.

A low battery voltage, however, is not necessarily indicate of an internally shorted cell. Normal battery self-discharge can cause battery voltage to drop over extended periods of time, but these cells can still be usable. If the battery has self-discharged, but voltage is still above the 0-V charging threshold (1.7 V for the BQ297x), then the battery cell can still be recoverable. This is not necessarily the case for all batteries, battery suppliers needs to be consulted to identify the lowest possible *recoverable* battery voltage. Recovering a deeply discharged battery requires charging at a low current due to the battery

This feature can be similarly approximated in a charging design with a host controller to provide logic. This can add a layer of protection to systems that can not have a protection circuit integrated into the battery pack. It is important to observe the implementation of this feature and how the design can affect the charger's interactions with a battery protection circuit.

2 Implement Charge Inhibition With a Charger

The 0-V battery charge inhibition feature is not directly implemented in most battery chargers, but in can be approximated for many battery chargers with an I2C interface in systems with a host controller. With most chargers it would be limited to a 2-V battery charge inhibition feature. To implement this protection feature, first battery voltage needs the ability to be monitored.

2.1 Measuring Battery Voltage using Battery Undervoltage Lockout

Some chargers, such as the BQ2515x family of Linear Charger BMUs, include an ADC; the BQ2515x's ADC directly reports battery voltage from 2 V to 5 V. Other chargers, such as the BQ25120 includes a battery voltage monitor which reports battery voltage as a percentage of battery regulation voltage. Almost all I2C chargers with power path management include a programmable Battery UnderVoltage Lock-out (BUVLO) protection feature which can be used for the purpose of getting an estimate of battery voltage.

The feature can first be triggered when a BUVLO fault is reported by the charger. This indicates that battery voltage has dipped below the BUVLO threshold, this is when one can begin to check for low voltage. If the BUVLO setting is not the lowest value, disabling charge then decreasing to the lowest BUVLO setting can allow the system to identify if the battery has fallen to a critically discharged level.

Most chargers are disabled if the battery drops below BUVLO. Because of this, it is important to note that using the BUVLO as a voltage monitor is requires an input adapter. Otherwise this may inadvertently disable the device. Note that the battery voltage can potentially be equal to the BUVLO voltage plus the BUVLO hysteresis value since a Battery UVLO flag can only be cleared once battery voltage rises above the hysteresis added voltage.

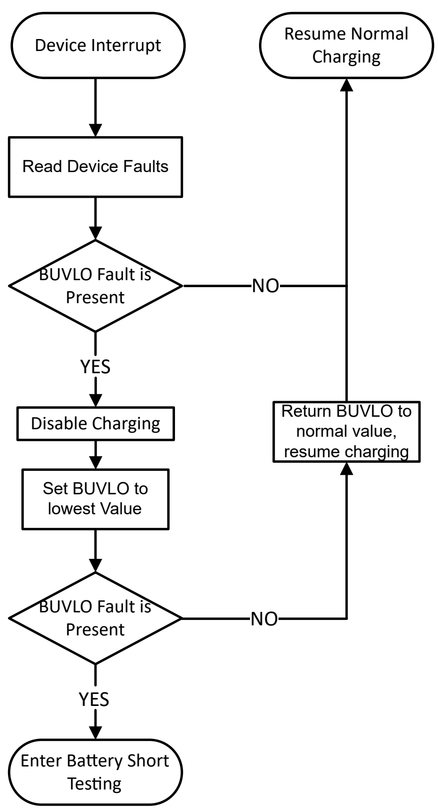

Figure 2-1. Battery Monitoring Flow

2.2 Executing a Battery Short Test

If the battery has fallen below to a critically discharged level, the system can enter a battery short identification process. A battery that is sufficiently discharged can be recovered if a low charge current is applied, however a battery with an internal short will not rise in voltage. We can take advantage of this behavior to help the identification of a battery short by monitoring the rise in voltage via BUVLO. A pre-charge current, specified by the battery manufacturer, can be applied to slowly charge the severely discharged battery. After a period of time charging can again be halted and a similar battery voltage check can be applied. If battery is still below the BUVLO threshold, this can be tried again. After a number of retries without the battery voltage rising above BUVLO, it is likely the cause of an internal battery short leaking the charge current. The system needs to be made aware of the behavior and charge needs to be disabled.

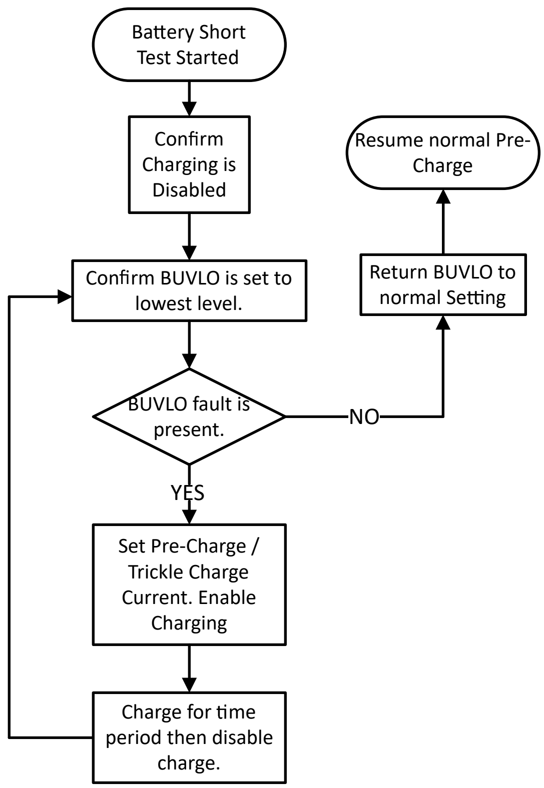

Figure 2-2. Short Test Flow

2.3 Example Implementation

To demonstrate one possible implementation of the 2-V charge inhibition, the following example is provided. The set up for this example consists of an MSP430F5529 connected to a BQ25120A. For a broader example that applies to most chargers, the BUVLO setting is used to measure battery voltage rather than the Voltage Based Monitor function that is available on the BQ2512x family of devices.

A BAT_UV fault can be used as a trigger to begin the process of identifying that a battery is internally shorted. This test can be disruptive to charging, so it is best to confirm that a battery is critically discharged first before the test is run. In this case, the Charger_getBatteryCriticallyDischarged function is used to identify that battery voltage is low enough for a test to be run.

```
void Charger_handleBatUVFault(void){
    //Charge is Disabled
    Charger_disableCharge();

    //Check if battery is critically discharged
    if(Charger_getBatteryCriticallyDischarged()){

        //Run battery short test
        if(Charger_runBatteryShortTest()){

            //If Battery is Shorted set global flag
            Charger_BatteryShorted = true;
            return;
        }
    }

    //enable Charging
    Charger_enableCharge();
    return;
}
```

The battery monitoring flow can be demonstrated by the following line of code. For the purpose of low voltage charge inhibition, monitoring flow only requires that the battery is tested against the lowest voltage level. Using the other voltage levels can give an idea of what the battery voltage is for other purposes.

```
bool Charger_getBatteryCriticallyDischarged(void){
    uint8_t currentBuvlo, faultRegisterValue;
    bool batteryIsCriticallyDischarged;
    uint16_t ERR_NO;

    //Store Current BUVLO Setting
    currentBuvlo = Charger_getBUVLO();

    //Set BUVLO to Lowest Value
    Charger_setBUVLO(CHARGER_BUVLO_2p2V);

    //Read Fault Register
    StdI2C_P_RX_Single(CHARGER_I2C_ADDR,CHARGER_REG_FAULT    ,&faultRegisterValue   ,&ERR_NO);

    //Get BAT_UVLO Status
    batteryIsCriticallyDischarged = (faultRegisterValue & CHARGER_FAULT_BATUV_MASK);

    //Restore BUVLO Setting
    Charger_setBUVLO(currentBuvlo);

    return batteryIsCriticallyDischarged;
}
```

After identifying that the battery is critically discharged, a battery short test is run during which a low charge current is used and for a short period of time with the battery being periodically re-tested at various intervals. The current for this test, duration of this test, and intervals for re-testing can vary from battery to battery and application to application.

```
bool Charger_runBatteryShortTest(void){
    uint8_t pretermCurrent;
    uint8_t maxRetries = 5;

    //Store PreTerm current settings
    pretermCurrent = Charger_getPreTermCurrent();

    //Set PreTerm to 10mA
    Charger_setPreTermCurrent(CHARGER_PRETERM_10mA);

    for(int try = 0; try < maxRetries; try++){
        //Enable Charging for test
        Charger_enableCharge();

        //Start Periodic Retest timer
        Charger_startShortTestTimer();

        //Await timer elapse
        while(Charger_ShortTestTimerRunning);

        //Disable charging for Critical Discharge test
        Charger_disableCharge();

        //Test if critically discharged
        if (!Charger_getBatteryCriticallyDischarged()){

            //Return PreTerm current to previous setting
            Charger_setPreTermCurrent(pretermCurrent);

            //Report no short on battery
            return false;
        }
    }

    //Return PreTerm current to previous setting
    Charger_setPreTermCurrent(pretermCurrent);

    //Report Shorted battery
    return true;
}
```

Ultimately, if the charging does not result in the battery voltage increasing above the critically discharged threshold, a global flag indicating the battery short is set and charging is not allowed to resume. This is a flag that is checked upon charge enable, while set charging cannot be started.

```
void Charger_enableCharge(void){
    uint8_t registerValue;
    uint16_t ERR_NO;

    //Check if Battery is Shorted before enabling charge
    if(Charger_BatteryShorted){
       return;
    }

    //Clear Charge Disable Bit
    StdI2C_P_RX_Single(CHARGER_I2C_ADDR,    CHARGER_REG_ICHG,   &registerValue, &ERR_NO);
    registerValue &= ~(CHARGER_ICHG_DISABLE_MASK);
    StdI2C_P_TX_Single(CHARGER_I2C_ADDR,    CHARGER_REG_ICHG,  registerValue,  &ERR_NO);
    return;
}
```

The results of the implementation is shown in Figure 2-3 and Figure 2-4. In these tests, a battery simulator is used to demonstrate how a battery that is at a low voltage is prevented from charging if it stays low. A battery that recovers voltage during the short testing is allowed to resume charging.

After multiple battery voltage measurements without BAT recovering, charge is disabled indicated by INT going high and IBAT going to 0 mA.

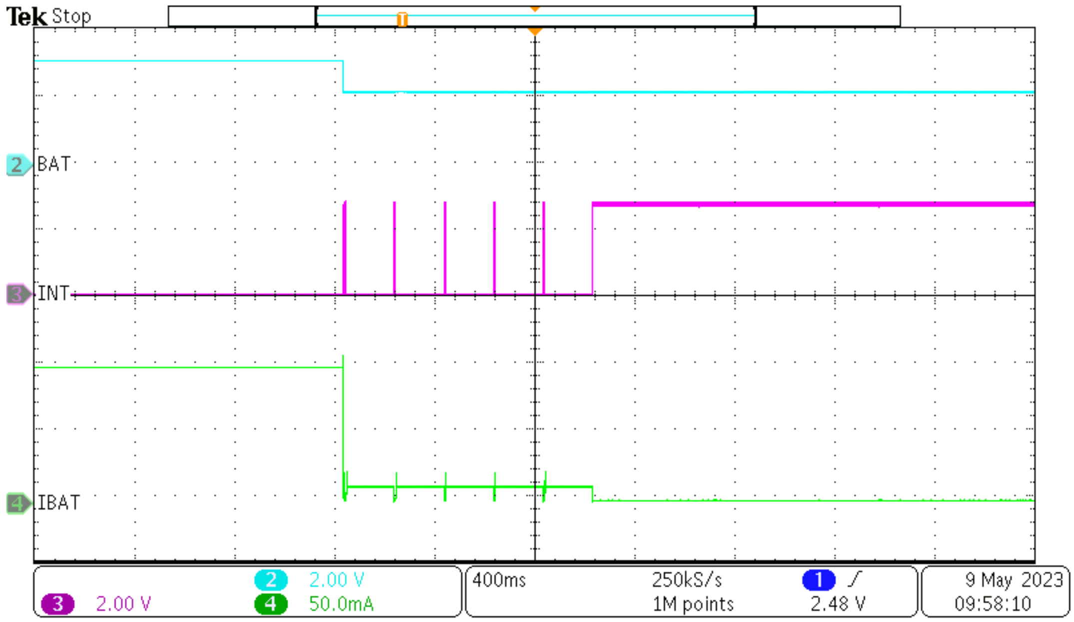

Figure 2-3. Shorted Battery Simulation

BAT voltage rising after a couple re-attempts allows the device to exit the test and resume charging the battery.

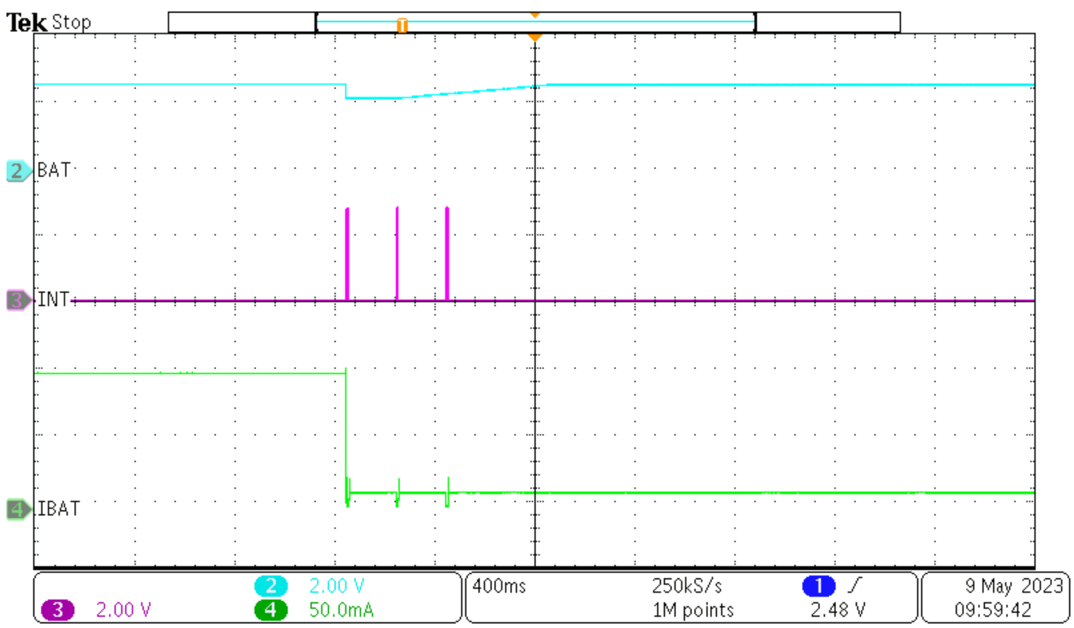

Figure 2-4. Recovered Battery Simulation

3 Summary

Although it is not a direct replacement for a Protection IC, battery charges can be used to implement protections against charging internally-shorted batteries. The BUVLO feature can be used as an improvised voltage monitor, if other monitors are not available, to identify low voltages. Using this voltage monitor, a small current can be used to test for battery shorts. A host processor can implement this logic to add a layer of redundancy to a charging system's protection measures.

4 References

- Texas Instruments, *BQ25180 I2C Controlled, 1-Cell, 1-A Linear Battery Charger with Power Path and Ship Mode*, data sheet.
- Texas Instruments, *BQ25150 I2C Controlled 1-Cell 500-mA Linear Charger with 10-nA Ship Mode, Advanced Power Path Management and Control, ADC, and LDO*, data sheet.
- Texas Instruments, *bq25120A Low IQ Highly Integrated Battery Charge Management Solution for Wearables and IoT*, data sheet.
- Texas Instruments, *BQ25970, BQ25971 I2C Controlled Single Cell High Efficiency 8-A Switched Cap Fast Chargers With ADC*, data sheet.
- Texas Instruments, *Why 0-V Charge Inhibition?*, E2E™ Design Support Forum.

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