AN13864

基于LPC865带SMBus接口的智能电池充电器

第1版 — 2023年8月14日　　应用笔记

文档信息

信息	**内容**
关键词	智能充电器、PWM、电池
摘要	本应用笔记介绍了一个基于LPC865的智能充电器解决方案，包括硬件和软件设计及其性能数据。

1 介绍

电池的应用无处不在，如智能手机、笔记本电脑、可穿戴设备、手持电子产品和智能小家电等。关于电池状态的信息对用户来说是非常重要的，例如电池温度、电压、电流、容量，以及充放电的时间等。确保电池充电的安全性并提供一个平滑可控的充电曲线非常重要。上述要求有望通过智能充电器来实现。推荐一个基于LPC865的智能充电解决方案。

LPC86x是一个基于Arm Cortex-M0+的低成本32位MCU系列，其CPU频率高达48 MHz。LPC86x支持高达64 KB的闪存和8 KB的SRAM。LPC86x的外设包括一个CRC引擎、一个I2C总线接口、一个I3C-MIPI总线接口、最多3个USART、最多两个SPI接口、一个多速率定时器、自唤醒定时器、两个FlexTimer、一个DMA、一个12位ADC、一个模拟比较器、可通过开关矩阵进行功能配置的I/O端口、一个输入模式匹配引擎和多达54个的通用I/O引脚。

2 概述

本节提供了有关LPC865和智能电池之间的交互流程的基本信息。

2.1 功能框图

下图1所示为LPC865和智能电池之间的交互流程。

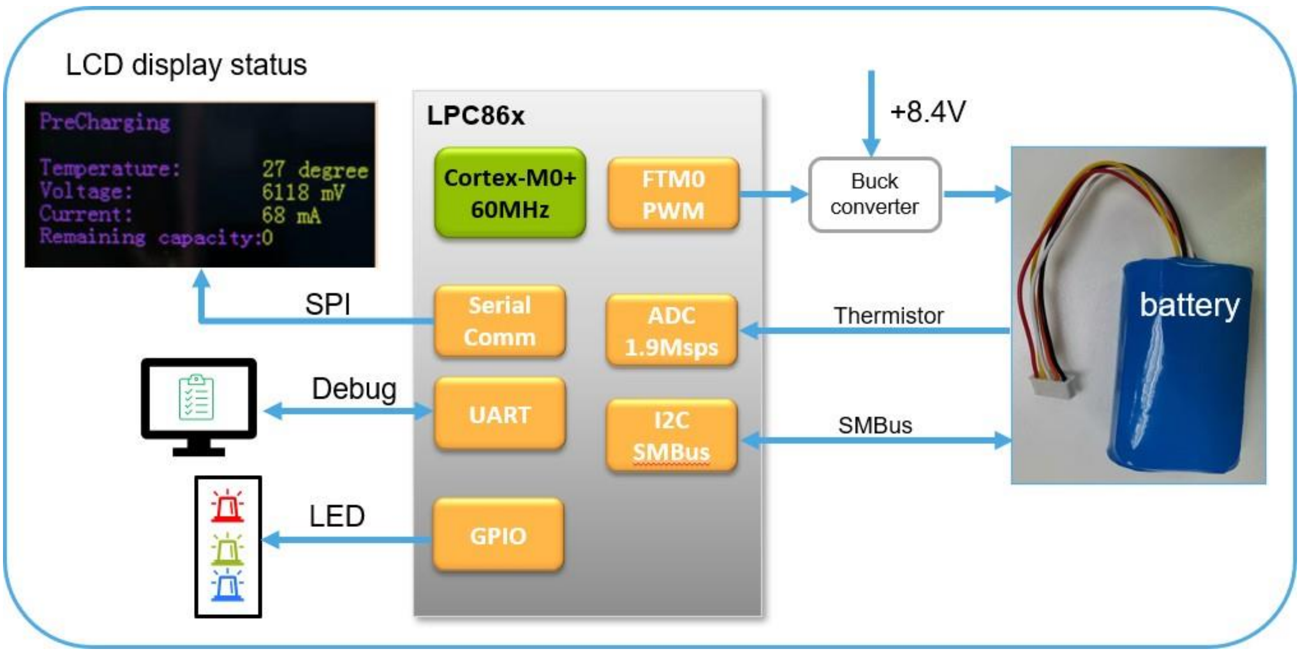

图1. 功能框图

LPC865通过SMBUS总线定期与智能电池进行通讯，获取电池信息，并动态调节PWM输出以调整充电电压。充电状态通过LED显示，且充电信息会显示在LCD屏幕上。

2.2 系统框图

下图2所示为主要的系统构建模块：NXP LPC865电池充电板、+12 V适配器、智能电池、LCD、仿真器。

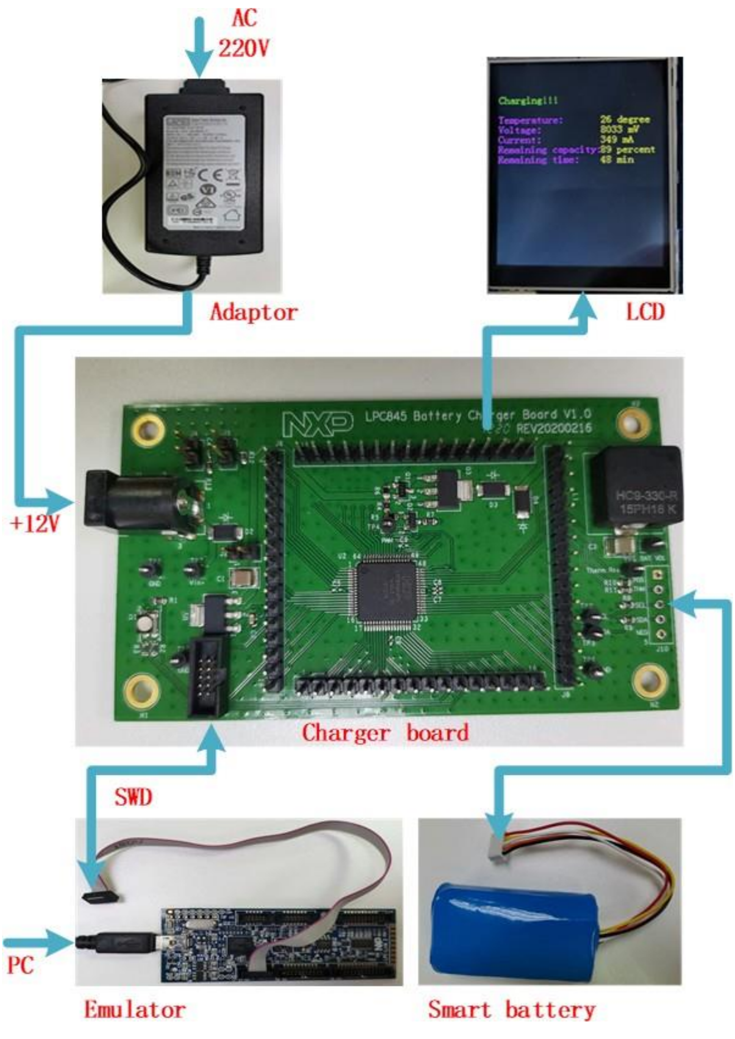

图2. 系统框图

注： *该应用使用与LPC845智能电池充电器解决方案相同的硬件。充电板上的芯片LPC845替换为LPC865。*

该系统可以用一个8.4 V的标称电压为智能电池充电。在充电过程中，电池电压、电流、温度和充电时间会实时显示在LCD屏幕上。在开发程序的过程中，使用LPC-link2仿真器将其下载到MCU中。可以使用任何其他的带有1.27'10脚SWD连接器的仿真器，如J-Link、U-Link。充电顺序也可以通过FreeMASTER软件实时绘制。在充电过程中，会经历预充、恒流充、恒压充和满充这4个阶段。

3 硬件

本节对包括充电板、LCD、智能电池、电源适配器在内的硬件给出了概述。

3.1 硬件概述

图3所示为一个完整的演示系统，包括充电板、LCD、智能电池和电源适配器。

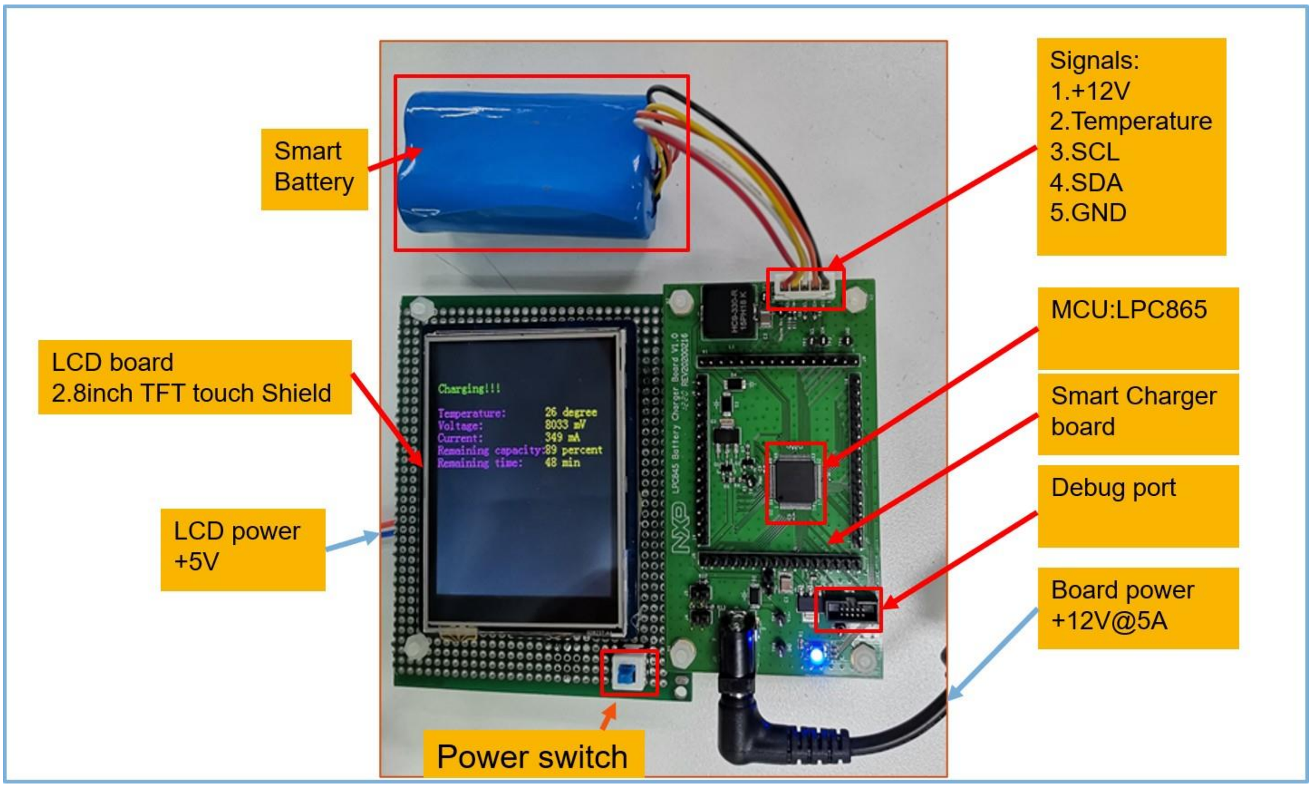

图3. 硬件概述

***注：** 该应用使用与LPC845智能电池充电器解决方案相同的硬件。充电板上的芯片LPC845替换为LPC865。*

使用一个12 V、5 A的适配器作为电源，不仅为该充电板供电，还为充电电池提供电压和电流。智能电池的标准电压为8.4 V。该LCD是一个320x240分辨率的TFT显示屏。

3.2 系统连接

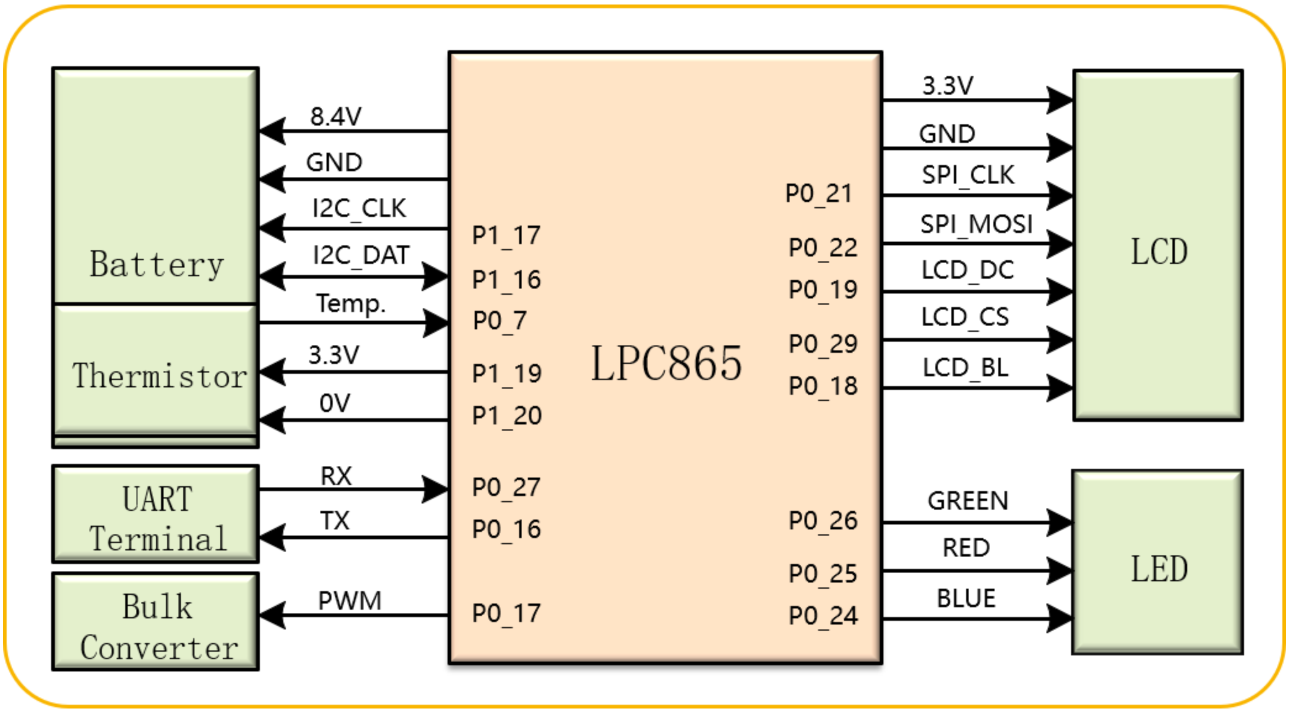

图4. 系统连接

3.3 充电板

充电板中的一些模块如图5所示，将它们列出如下：

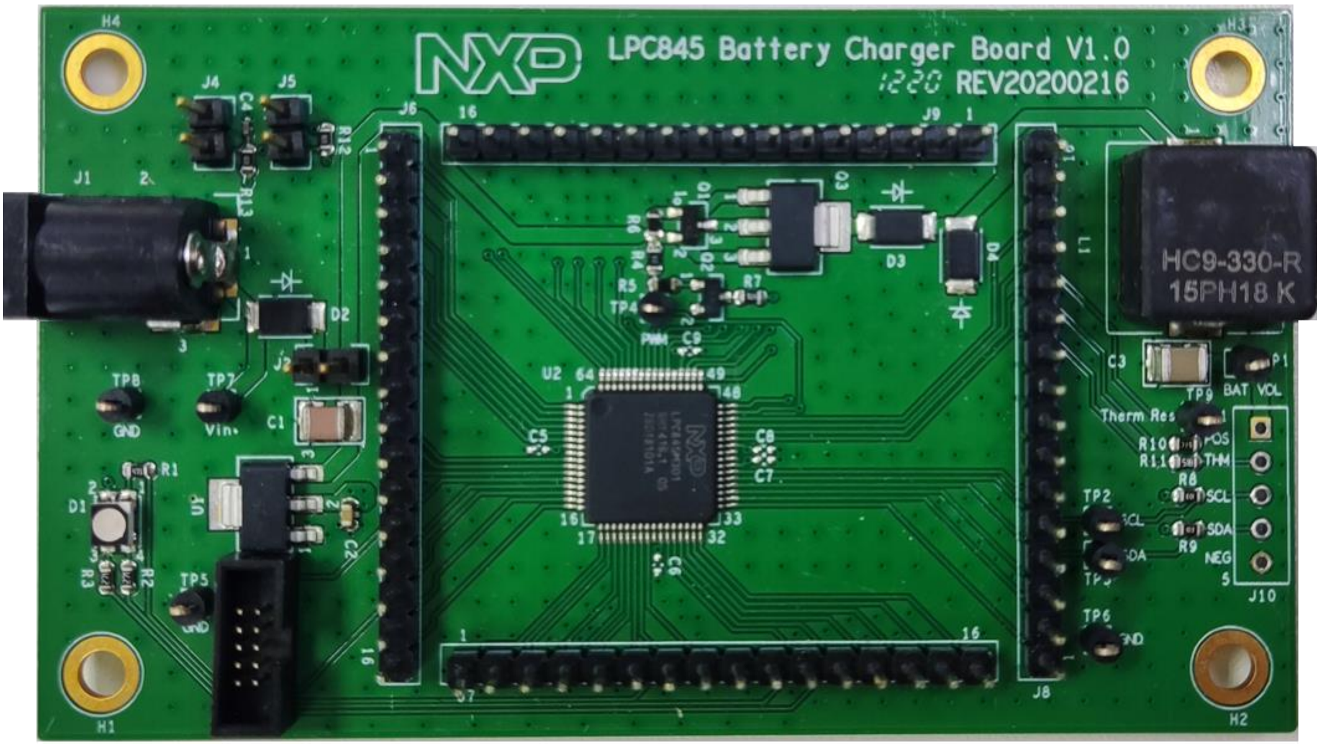

图5. 充电板

***注：**该应用使用与LPC845智能电池充电器解决方案相同的硬件。充电板上的芯片LPC845替换为LPC865。*

- +12 V电源插座用于连接12 V的电源适配器。
- MCU的64个引脚为LED的输出信号，提供SPI等信号来驱动LCD显示屏。
- 智能电池接口用于连接智能电池。
- 仿真器接口用于连接MCU调试器。
- 板载LDO用于提供3.3 V电源。
- 板载buck降压电路用于为电池提供可调电压。
- MCU控制器——LPC865

3.4 智能电池

图6. 智能电池

该电池组是一款由两节标准电压为8.4 V的锂离子电池组成的智能电池。电池组内包含一颗名为bq40z50的锂离子电池组管理芯片。该电池组支持双线SMBus v1.1，带有可以与MCU进行交互的接口。此外，电池组还包含一个10 k欧姆的PTC热敏电阻。MCU可以通过ADC对电压进行采样来计算其温度。

3.5 LCD显示板

图7. LCD模块

该LCD板由Waveshare提供，它是一款针对Arduino的2.8英寸触摸式LCD扩展板。

它具有以下特性：

- 2.8英寸TFT LCD电阻式触摸屏，320x240分辨率
- Arduino标准接口，兼容Arduino UNO等开发板
- 通过SPI控制，使用多个Arduino引脚

3.6 仿真器

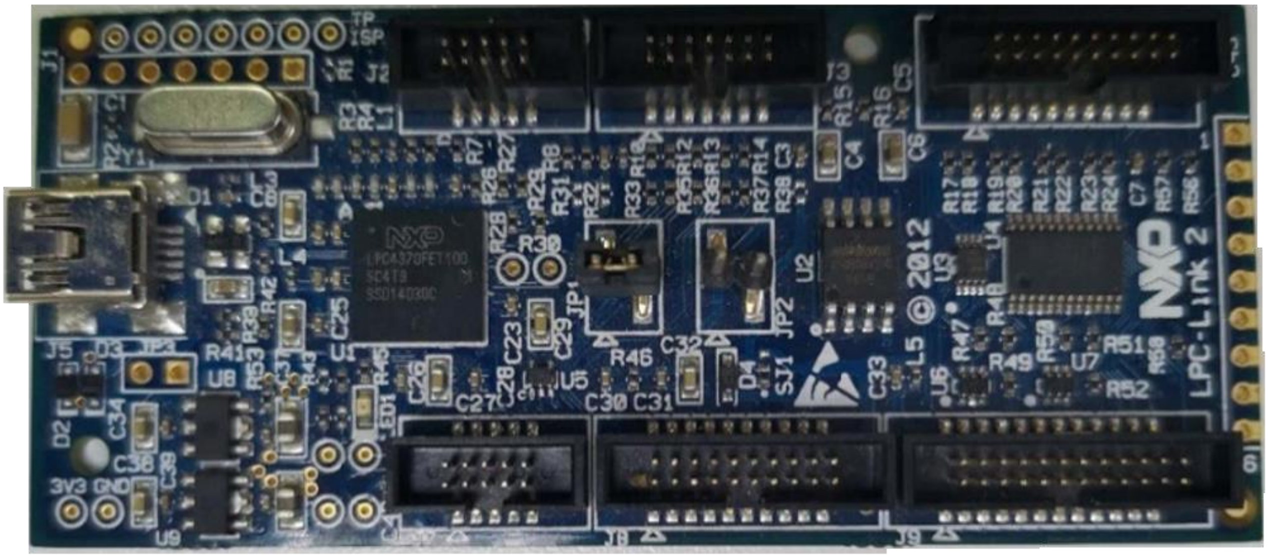

图8. 仿真器

LPC-Link 2是恩智浦和Embedded Artists开发的一款可扩展的独立调试器，它可以通过配置，使用各种可下载的固件映像来支持开发工具和IDE。它可以用作恩智浦LPC4370三核MCU的一个独立评估板。

3.7 交流适配器

该适配器将220 V交流电转换为12 V 5A的直流电，为开发板和电池供电。也可以使用任何其他直流电源。

图9. 交流适配器

4 软件

本节提供了有关软件的详细信息。

4.1 源代码

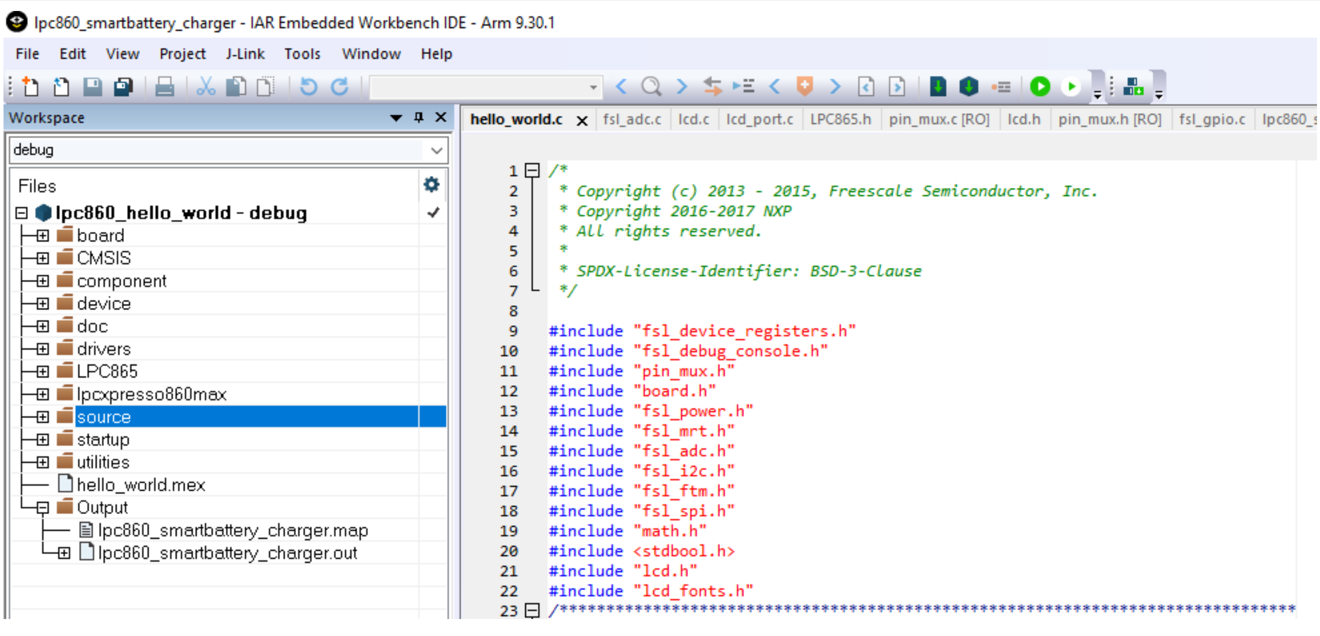

图10. 代码工程

该代码是在IAR 9.30.1 IDE平台上开发的，使用了最新的官方SDK软件开发包（SDK2.12.0）。根据功能要求，使用了UART、SPI、I2C、FTM、Multimer、ADC等外设。

它们的功能如下：

- UART用于驱动串行输出。
- SPI用于驱动LCD屏幕。
- I2C负责与电池组进行通信。
- FTM定时器生成PWM波，以控制Buck降压电路。
- Multimer生成周期性中断以进行周期性采样和调制。
- ADC用于采集热敏电阻电压并计算温度。
- 使用了4.9 KB的RAM。
- 使用了26 KB的闪存。

4.2 程序流程图

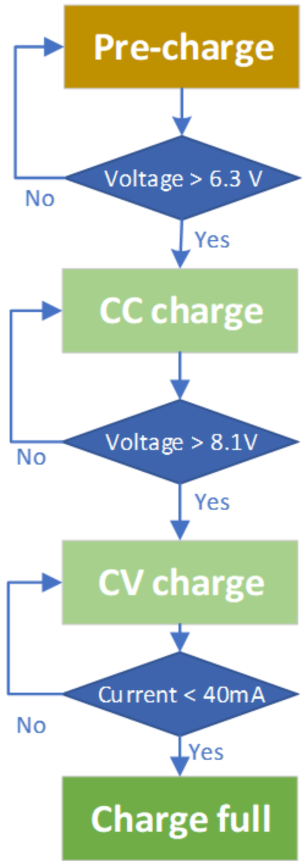

图11. 程序流程图

电池充电的过程主要包括四个阶段：预充阶段、恒流阶段、恒压阶段和满充阶段。预充阶段主要是为了防止在电压过低时由于灌入大电流而损坏电池。只有当它超过一定的电压时，才会切换到恒流充。恒流充是电池充电的主要阶段。电池在恒流阶段获得大部分电力。在这个阶段，电池电压持续上升。当达到相对较高的电压时，进入恒压充阶段。恒压阶段是最后的工作阶段。电池已接近满容量。此阶段，不适合提供一个大电流，而应提供稳定的电压。充电电流会继续减小。当电流达到一个较小的值时，可以认为电池已充满。

4.3 PWM信号的生成

PWM信号用于调节Buck降压电路的输出电压，它由FlexTimer生成。计数器/定时器模块用于对系统时钟或外部供应时钟的周期进行计数，并且可以选择性地通过匹配输出生成脉宽调制器。在此应用中，60 MHz的系统时钟用作FlexTimer的时钟源。PWM的频率为70 kHz。最小占空比数为857。通过产生具有不同占空比的PWM波可以产生不同的充电电压和充电电流。

```
uint32_t FTM_Init_Config(void){

    ftm_config_t ftmInfo;
    ftm_chnl_pwm_signal_param_t ftmParam;
    ftm_pwm_level_select_t pwmLevel = FTM_PWM_ON_LEVEL;

    /* Fill in the FTM config struct with the default settings */
    FTM_GetDefaultConfig(&ftmInfo);
    /* Calculate the clock division based on the PWM frequency to be obtained */
    ftmInfo.prescale = FTM_CalculateCounterClkDiv(BOARD_FTM_BASEADDR, DEMO_PWM_FREQUENCY, FTM_SOURCE_CLOCK);
    /* Initialize FTM module */
    FTM_Init(BOARD_FTM_BASEADDR, &ftmInfo);

    /* Configure ftm params with frequency 24kHZ */
    ftmParam.chnlNumber            = BOARD_FTM_CHANNEL;
    ftmParam.level                 = pwmLevel;
    ftmParam.dutyCyclePercent      = 0;
    ftmParam.firstEdgeDelayPercent = 0U;
    ftmParam.enableComplementary   = false;
    ftmParam.enableDeadtime        = false;
    if (kStatus_Success !=
        FTM_SetupPwm(BOARD_FTM_BASEADDR, &ftmParam, 1U, kFTM_EdgeAlignedPwm, DEMO_PWM_FREQUENCY, FTM_SOURCE_CLOCK))
    {
        PRINTF("\r\nSetup PWM fail, please check the configuration parameters!\r\n");
        return -1;
    }

    FTM_StartTimer(BOARD_FTM_BASEADDR, kFTM_SystemClock);

    return kStatus_Success;
}
```

图12. 生成PWM的代码

4.4 SMbus通信

LPC865有一个支持SMBus的I2C模块。选择I2C作为MCU和电池之间的通信总线。从给定的器件地址读取电池相关的寄存器的值，以获取如电压、电流、温度等充电信息。

```
uint16_t Information_Read_From_Battery(uint32_t address){

    status_t reVal  = kStatus_Fail;
    uint8_t deviceAddress;
    uint8_t  RxData[2];
    uint16_t ReturnData;
    i2c_master_transfer_t masterXfer = {0};

    deviceAddress = address;

    i2c_master_config_t masterConfig;

    /*
     * masterConfig.debugEnable = false;
     * masterConfig.ignoreAck = false;
     * masterConfig.pinConfig = kI2C_2PinOpenDrain;
     * masterConfig.baudRate_Bps = 100000U;
     * masterConfig.busIdleTimeout_ns = 0;
     * masterConfig.pinLowTimeout_ns = 0;
     * masterConfig.sdaGlitchFilterWidth_ns = 0;
     * masterConfig.sclGlitchFilterWidth_ns = 0;
     */
    I2C_MasterGetDefaultConfig(&masterConfig);

    /* Change the default baudrate configuration */
    masterConfig.baudRate_Bps = I2C_BAUDRATE;

    /* Initialize the I2C master peripheral */
    I2C_MasterInit(EXAMPLE_I2C_MASTER, &masterConfig, I2C_MASTER_CLOCK_FREQUENCY);

    /* Create the I2C handle for the non-blocking transfer */
    I2C_MasterTransferCreateHandle(EXAMPLE_I2C_MASTER, &g_m_handle, i2c_master_callback, NULL);
```

图13. Smbus的代码

4.5 温度采样

GPIO输出一个高电平电压为热敏电阻供电，然后根据热敏电阻上的电压计算智能电池的实际温度。如果温度发生变化，热敏电阻的电阻值也会随之改变。则热敏电阻上的电压就会发生变化，这种变化可以通过MCU上的ADC采样来捕获。

LPC865带有一个12位ADC，多达12个输入通道，采样率高达1.2 Msamples/s。ADC通道0负责对热敏电阻的电压进行采样，并计算出相应的温度。如果出现温度过高的情况，就立即关闭PWM信号。

```
ADC_DoSoftwareTriggerConvSeqA(DEMO_ADC_BASE);
/* Wait for the converter to be done. */
while (!ADC_GetChannelConversionResult(DEMO_ADC_BASE, DEMO_ADC_SAMPLE_CHANNEL_NUMBER, &adcResultInfoStruct))
{
}
g_Voltage_NTC = (float)adcResultInfoStruct.result/4096*3.3;
Rt = (33200*g_Voltage_NTC)/(3.3 - g_Voltage_NTC);
g_Temperature_NTC = (1/(log(Rt/Rp)/Bx+(1/T2)))-273.15;
```

图14. ADC的代码

4.6 周期中断

```
void MRT0_IRQHandler(void)
{
    /* Clear interrupt flag.*/
    MRT_ClearStatusFlags(MRT0, kMRT_Channel_0, kMRT_TimerInterruptFlag);
    g_mrtCountValue++;

    if((g_mrtCountValue% 2) == 0){ //every 500ms
      g_Voltage = Information_Read_From_Battery(Voltage_Add);
      g_Current = Information_Read_From_Battery(Current_Add);
```

图15. 多速率定时器的代码

LPC865带有一个四通道多速率定时器（MRT），能够按4个可编程的固定速率重复生成中断。通过配置，可以每100毫秒执行一次轮询任务。检查充电状态并进行相关的PWM信号调整，并在充电的所有阶段都保持这种操作。

4.7 LCD驱动器

```
gpio_pin_config_t   gpioPinConfig;
// Select the function clock source for the master, SPI0 (slave will be clocked by the master's SCK)
SYSCON->FCLKSEL2[0] = 1;
SYSCON->SYSAHBCLKCTRL0 |= (1<<11);
SYSCON->PRESETCTRL0 &= ~(1<<11);
SYSCON->PRESETCTRL0 |= (1<<11);
EXAMPLE_SPI_MASTER->DIV = 5;
EXAMPLE_SPI_MASTER->CFG = SPI_CFG_ENABLE_MASK | SPI_CFG_MASTER_MASK |SPI_CFG_CPOL_MASK | SPI_CFG_CPHA_MASK  ;
EXAMPLE_SPI_MASTER->DLY = 0;
EXAMPLE_SPI_MASTER->TXCTL = SPI_TXCTL_EOT_MASK | SPI_TXCTL_LEN(7);
```

图16. SPI的代码

LPC865上有两个SPI模块，可以使用30 MHz时钟作为波特率时钟。排除外部设备和PCB引入的时延，SPI主机模式支持的最大比特率为30 Mbit/s。这样的速度可以提高屏幕的刷新率。

4.8 FreeMASTER

FreeMASTER是一款用户友好的实时调试监视器和数据可视化工具，可实现嵌入式软件应用的运行时配置和调整。在此应用笔记中，可通过FreeMASTER显示系统信息，且充电阶段的设置也可以在FreeMASTER中完成。

FreeMASTER的安装包可以从恩智浦网站获取。

显示信息：

- 充电电压，
- 充电电流，
- 剩余电池容量，
- 剩余充电时间。

设置：

- 预充到恒流充阶段的跨电压；
- 从恒流充到恒压充阶段的跨电压；
- 从恒压充到满充阶段的跨电流。

电池的充电电压、电流和剩余容量如图17所示：

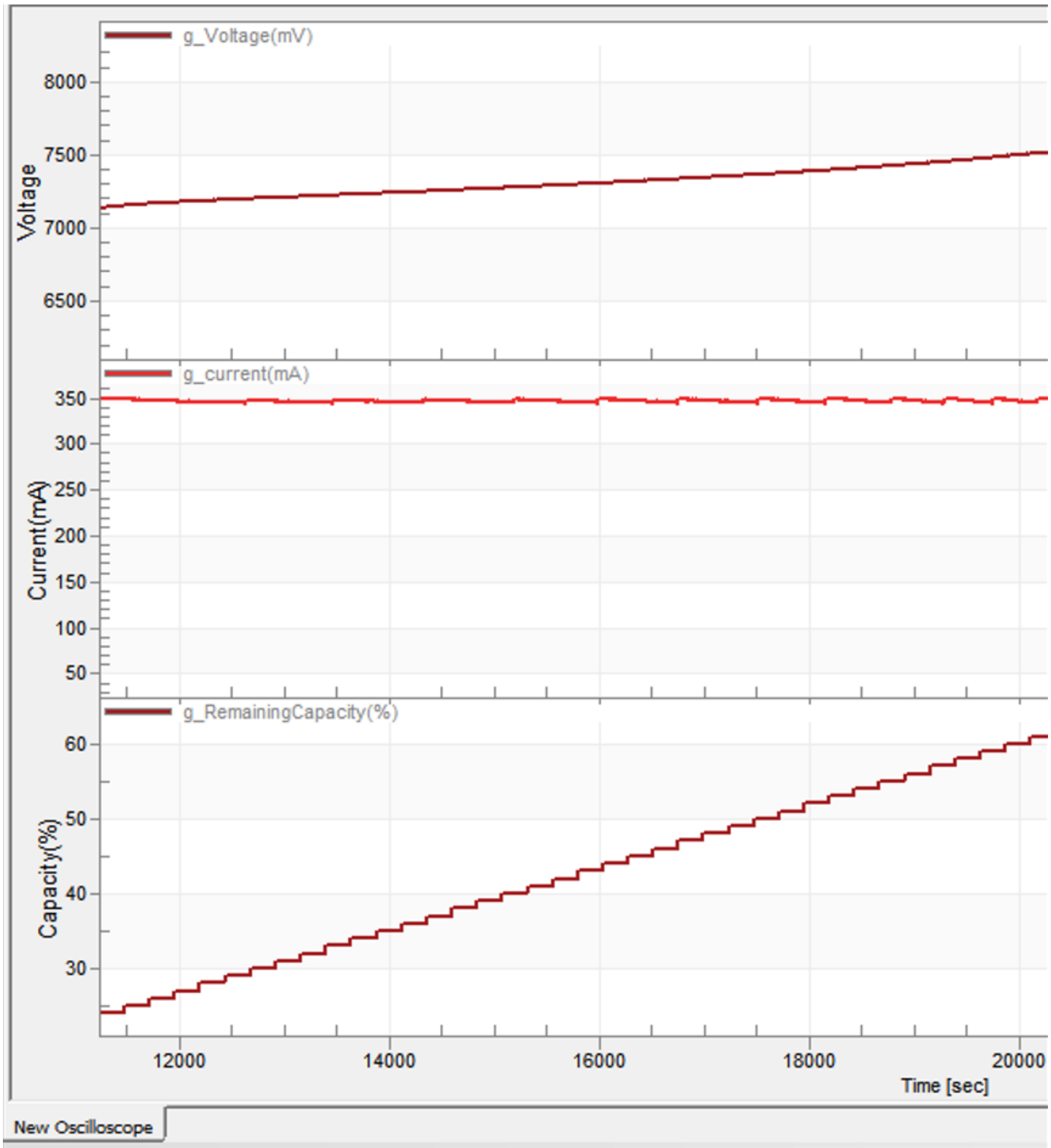

图17. FreeMASTER的监视器

注： *变量`g_PreChargeMaxVoltage`、`g_CCChargeMaxVoltage`和`g_CVChargeMinCurrent`的值可由用户修改。变量`g_Voltage`、`g_Current`和`g_RemainingCapacity`的值只能供用户读取，而不能修改。*

5 分步演示

1. 将适配器、LCD、仿真器连接到充电板。
2. 按下电源开关，编译并将代码下载到MCU中。
3. 向上推动电源开关，将电池连接到充电板。
4. 如果电池电压低于`g_PreChargeMaxVoltage`，则进入预充模式。当电池电压超过`g_PreChargeMaxVoltage`时，进入恒流充模式。当电池电压达到`g_CCChargeMaxVoltage`时，进入恒压充模式。此时电压保持在`g_CCChargeMaxVoltage`，直到电流下降到`g_CVChargeMinCurrent`。然后充电完成。这4个充电阶段的状态如图18所示：

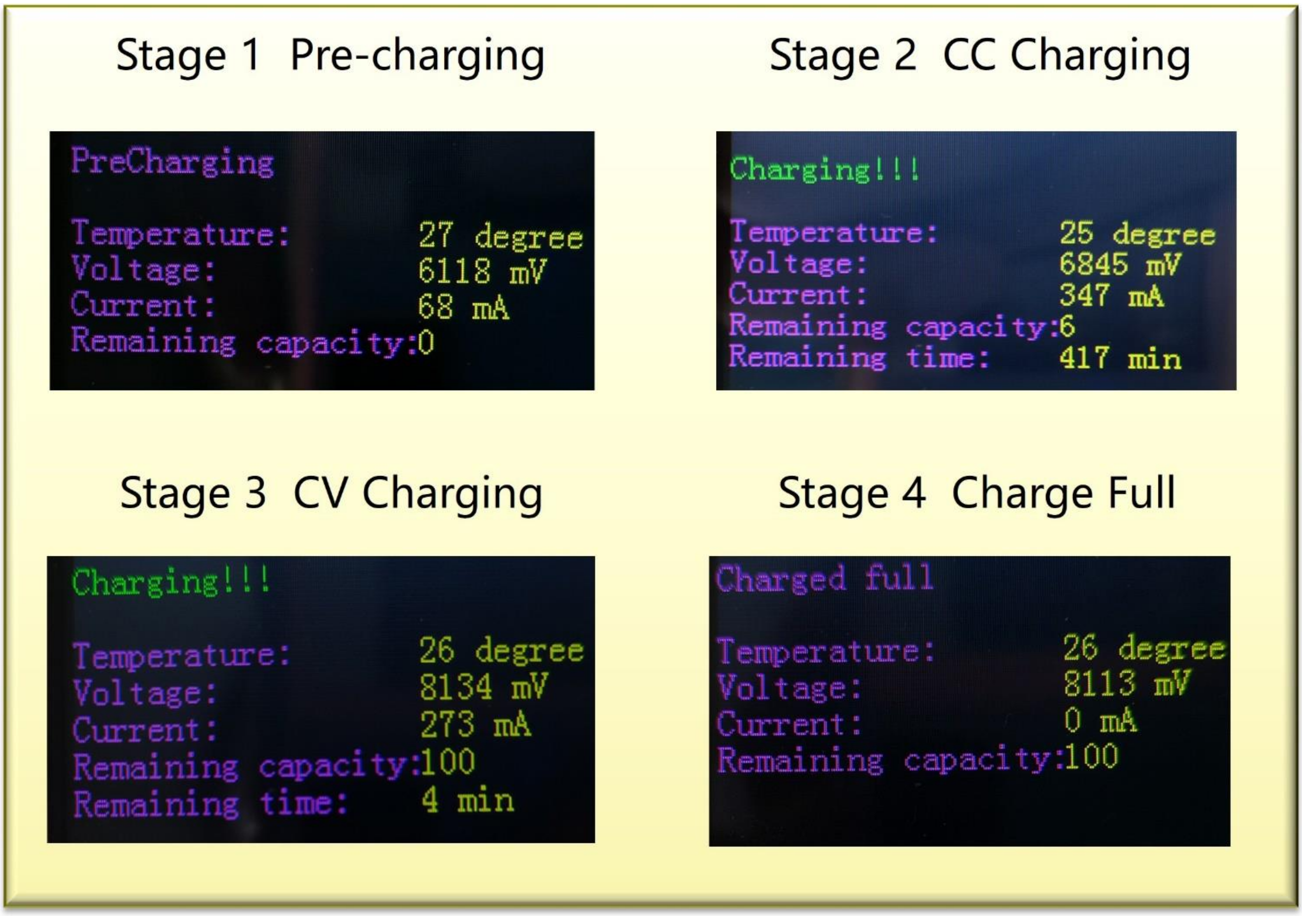
Stage 1 Pre-charging
PreCharging
Temperature: 27 degree
Voltage: 6118 mV
Current: 68 mA
Remaining capacity:0
Stage 2 CC Charging
Charging!!!
Temperature: 25 degree
Voltage: 6845 mV
Current: 347 mA
Remaining capacity:6
Remaining time: 417 min
Stage 3 CV Charging
Charging!!!
Temperature: 26 degree
Voltage: 8134 mV
Current: 273 mA
Remaining capacity:100
Remaining time: 4 min
Stage 4 Charge Full
Charged full
Temperature: 26 degree
Voltage: 8113 mV
Current: 0 mA
Remaining capacity:100

图18. 4个充电阶段

6 充电的时序及规格

图19. 充电时序

图19为通过FreeMASTER捕获的实际充电电压和电流的曲线。在整个充电过程中，电池容量在94%到100%之间。从左到右依次为预充、恒流充、恒压充和满充四个阶段，它们用四种颜色标记。

规格：

1. 充电电压范围：6 V ~ 8.4 V
2. 充电电压（CV充电模式）：由`g_CCChargeMaxVoltage`设置，默认值为8.15 V
3. 充电电流范围：0m A ~ 385m A
4. 充电电流（CC充电模式）：350 mA
5. 从空到充满所需的充电时间：约7小时
6. 过充电压警报：8.5 V
7. 过充电流警报：500 mA
8. 过热警报：50度

6.1 附录A：原理图

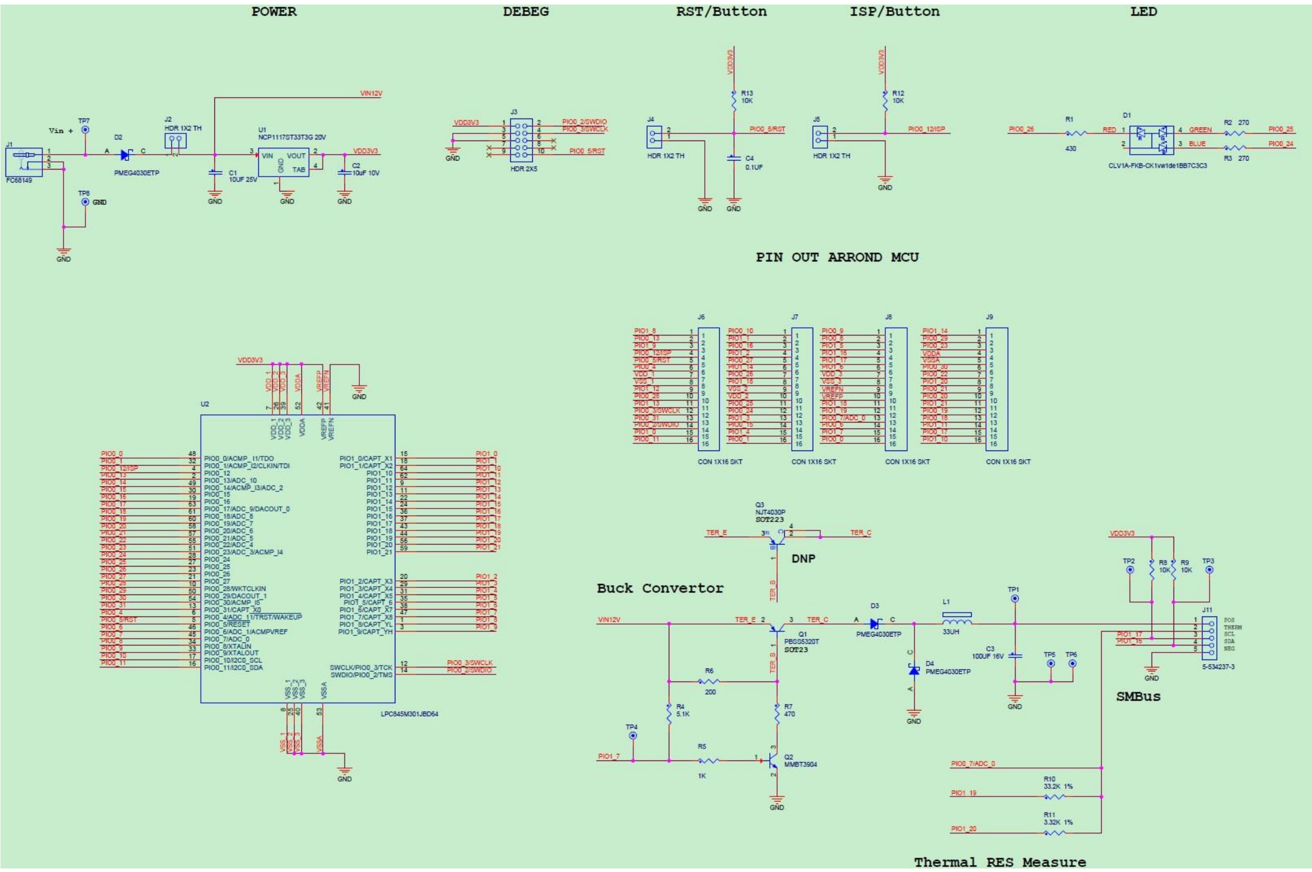

图20. 原理图

***注：**该应用使用与LPC845智能电池充电器解决方案相同的硬件。充电板上的芯片LPC845替换为LPC865。*

7 关于本文中源代码的说明

本文中所示的示例代码具有以下版权和BSD-3-Clause许可：

2023年恩智浦版权所有。在满足以下条件的情况下，可以源代码和二进制文件的形式重新分发和使用本源代码（无论是否经过修改）：

1. 重新分发源代码必须保留上述版权声明、这些条件和以下免责声明。
2. 以二进制文件形式重新分发时，必须在文档和/或随分发提供的其他材料中复制上述版权声明、这些条件和以下免责声明。
3. 未经事先书面许可，不得使用版权所有者的姓名或参与者的姓名为本软件的衍生产品进行背书或推广。

本软件由版权所有者和参与者“按原样”提供，不承担任何明示或暗示的担保责任，包括但不限于对适销性和特定用途适用性的暗示保证。在任何情况下，无论因何种原因或根据何种法律条例，版权所有者或参与者均不对因使用本软件而导致的任何直接、间接、偶然、特殊、惩戒性或后果性损害（包括但不限于采购替代商品或服务；使用损失、数据损失或利润损失或业务中断）承担责任，无论是因合同、严格责任还是侵权行为（包括疏忽或其他原因）造成的，即使事先被告知有此类损害的可能性也不例外。

8 修订历史

表1对本文档的修订情况进行了汇总。

表1. 修订历史

版本号	发布日期	说明
第1版	2023年8月14日	首次公开发布

9 Legal information

9.1 Definitions

Draft — A draft status on a document indicates that the content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included in a draft version of a document and shall have no liability for the consequences of use of such information.

9.2 Disclaimers

Limited warranty and liability — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information. NXP Semiconductors takes no responsibility for the content in this document if provided by an information source outside of NXP Semiconductors.

In no event shall NXP Semiconductors be liable for any indirect, incidental, punitive, special or consequential damages (including - without limitation - lost profits, lost savings, business interruption, costs related to the removal or replacement of any products or rework charges) whether or not such damages are based on tort (including negligence), warranty, breach of contract or any other legal theory.

Notwithstanding any damages that customer might incur for any reason whatsoever, NXP Semiconductors' aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the Terms and conditions of commercial sale of NXP Semiconductors.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Customers are responsible for the design and operation of their applications and products using NXP Semiconductors products, and NXP Semiconductors accepts no liability for any assistance with applications or customer product design. It is customer's sole responsibility to determine whether the NXP Semiconductors product is suitable and fit for the customer's applications and products planned, as well as for the planned application and use of customer's third party customer(s). Customers should provide appropriate design and operating safeguards to minimize the risks associated with their applications and products.

NXP Semiconductors does not accept any liability related to any default, damage, costs or problem which is based on any weakness or default in the customer's applications or products, or the application or use by customer's third party customer(s). Customer is responsible for doing all necessary testing for the customer's applications and products using NXP Semiconductors products in order to avoid a default of the applications and the products or of the application or use by customer's third party customer(s). NXP does not accept any liability in this respect.

Terms and conditions of commercial sale — NXP Semiconductors products are sold subject to the general terms and conditions of commercial sale, as published at http://www.nxp.com.cn/profile/terms, unless otherwise agreed in a valid written individual agreement. In case an individual agreement is concluded only the terms and conditions of the respective agreement shall apply. NXP Semiconductors hereby expressly objects to applying the customer's general terms and conditions with regard to the purchase of NXP Semiconductors products by customer.

Suitability for use in automotive applications — This NXP product has been qualified for use in automotive applications. If this product is used by customer in the development of, or for incorporation into, products or services (a) used in safety critical applications or (b) in which failure could lead to death, personal injury, or severe physical or environmental damage (such products and services hereinafter referred to as "Critical Applications"), then customer makes the ultimate design decisions regarding its products and is solely responsible for compliance with all legal, regulatory, safety, and security related requirements concerning its products, regardless of any information or support that may be provided by NXP. As such, customer assumes all risk related to use of any products in Critical Applications and NXP and its suppliers shall not be liable for any such use by customer. Accordingly, customer will indemnify and hold NXP harmless from any claims, liabilities, damages and associated costs and expenses (including attorneys' fees) that NXP may incur related to customer's incorporation of any product in a Critical Application.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from competent authorities.

Translations — A non-English (translated) version of a document, including the legal information in that document, is for reference only. The English version shall prevail in case of any discrepancy between the translated and English versions.

Security — Customer understands that all NXP products may be subject to unidentified vulnerabilities or may support established security standards or specifications with known limitations. Customer is responsible for the design and operation of its applications and products throughout their lifecycles to reduce the effect of these vulnerabilities on customer's applications and products. Customer's responsibility also extends to other open and/or proprietary technologies supported by NXP products for use in customer's applications. NXP accepts no liability for any vulnerability. Customer should regularly check security updates from NXP and follow up appropriately.

Customer shall select products with security features that best meet rules, regulations, and standards of the intended application and make the ultimate design decisions regarding its products and is solely responsible for compliance with all legal, regulatory, and security related requirements concerning its products, regardless of any information or support that may be provided by NXP.

NXP has a Product Security Incident Response Team (PSIRT) (reachable at PSIRT@nxp.com) that manages the investigation, reporting, and solution release to security vulnerabilities of NXP products.

NXP B.V. - NXP B.V. is not an operating company and it does not distribute or sell products.

9.3 Trademarks

Notice: All referenced brands, product names, service names, and trademarks are the property of their respective owners.

NXP — wordmark and logo are trademarks of NXP B.V.

AMBA, Arm, Arm7, Arm7TDMI, Arm9, Arm11, Artisan, big.LITTLE, Cordio, CoreLink, CoreSight, Cortex, DesignStart, DynamIQ, Jazelle, Keil, Mali, Mbed, Mbed Enabled, NEON, POP, RealView, SecurCore, Socrates, Thumb, TrustZone, ULINK, ULINK2, ULINK-ME, ULINK-PLUS, ULINKpro, μVision, Versatile — are trademarks and/or registered trademarks of Arm Limited (or its subsidiaries or affiliates) in the US and/or elsewhere. The related technology may be protected by any or all of patents, copyrights, designs and trade secrets. All rights reserved.

目录

1 介绍 2
2 概述 2
2.1 功能框图 2
2.2 系统框图 3
3 硬件 4
3.1 硬件概述 4
3.2 系统连接 4
3.3 充电板 5
3.4 智能电池 6
3.5 LCD显示板 8
3.6 仿真器 9
3.7 交流适配器 9
4 软件 10
4.1 源代码 11
4.2 程序流程图 12
4.3 PWM信号的生成 12
4.4 SMbus通信 13
4.5 温度采样 14
4.6 周期中断 15
4.7 LCD驱动器 15
4.8 FreeMASTER 16
5 分步演示 17
6 充电的时序及规格 19
6.1 附录A：原理图 19
7 关于本文中源代码的说明 20
8 修订历史 21
9 法律声明 22

Date of release: 14 August 2023
Document identifier: AN13864