# *TI Designs*
# *采用 MSP430™ 实现的空调遥控器用户指南*

## TI Designs

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| | |
|---|---|
| TIDU513 | 设计页面 |
| MSP430FR4133 | 产品文件夹 |

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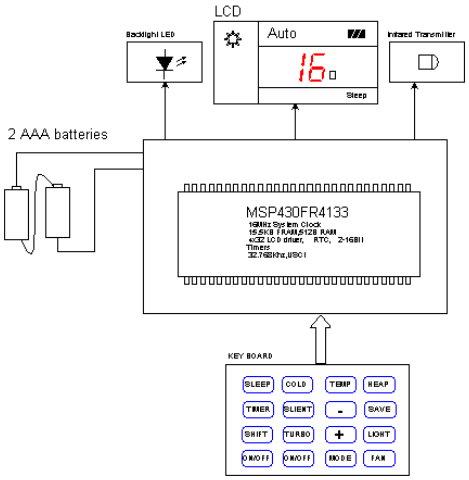
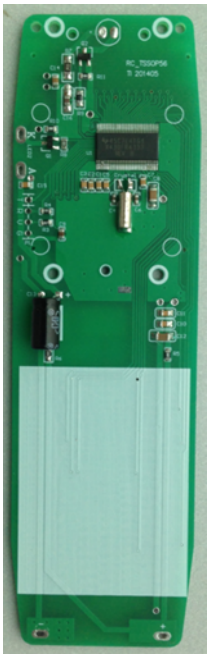
### 设计特性

- 采用 FRAM 技术实现超低功耗
- 通过优化的定时器发送红外编码
- 14 按键扫描矩阵键盘
- 段式 LCD

### 特色应用

- 红外 LCD 遥控器



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# 1 系统描述

该电路板演示了一种通用的超低功耗红外遥控器解决方案。 其采用基于 FRAM 的微控制器 (MCU) MSP430FR4133，支持实时时钟、按键扫描、红外编码、LED 背光和 LCD 显示等功能。

## 1.1 MSP430FR4133

MSP430FR4133 是一款基于 FRAM 的超低功耗混合信号 MCU。 MSP430FR4133 具有以下特性，非常适合便携式设备应用。

- 频率高达 16MHz 的 16 位精简指令集计算机 (RISC) 架构
- 宽电源电压范围：1.8V 至 3.6V
- 64/56/48 引脚薄型小外形尺寸 (TSSOP)/薄型四方扁平 (LQFP) 封装选项
- 集成带电荷泵的 LCD 驱动器，支持多达 4x36 或 8x32 的段式 LCD
- 优化的 16 位定时器，用于生成红外信号
- 实时时钟 (RTC) 使能时的低功耗模式 (LPM3.5)：0.77μA
- LCD 使能时的低功耗模式 (LPM3.5)： 0.936μA
- 激活模式：126μA/MHz
- 耐写次数高达 10^15 的低功耗铁电随机存取存储器 (FRAM)，可用于存储数据
- 内置 1.5V 参考电压的 10 通道、10 位模数转换器 (ADC)，适合电池供电类系统
- 所有 I/O 均为电容式触摸 I/O



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## 2 电路设计

高度集成的混合信号处理器 MSP430FR4133 只需搭配少量组件即可实现一款全功能空调遥控器。

相关设计框图请参见图 1。

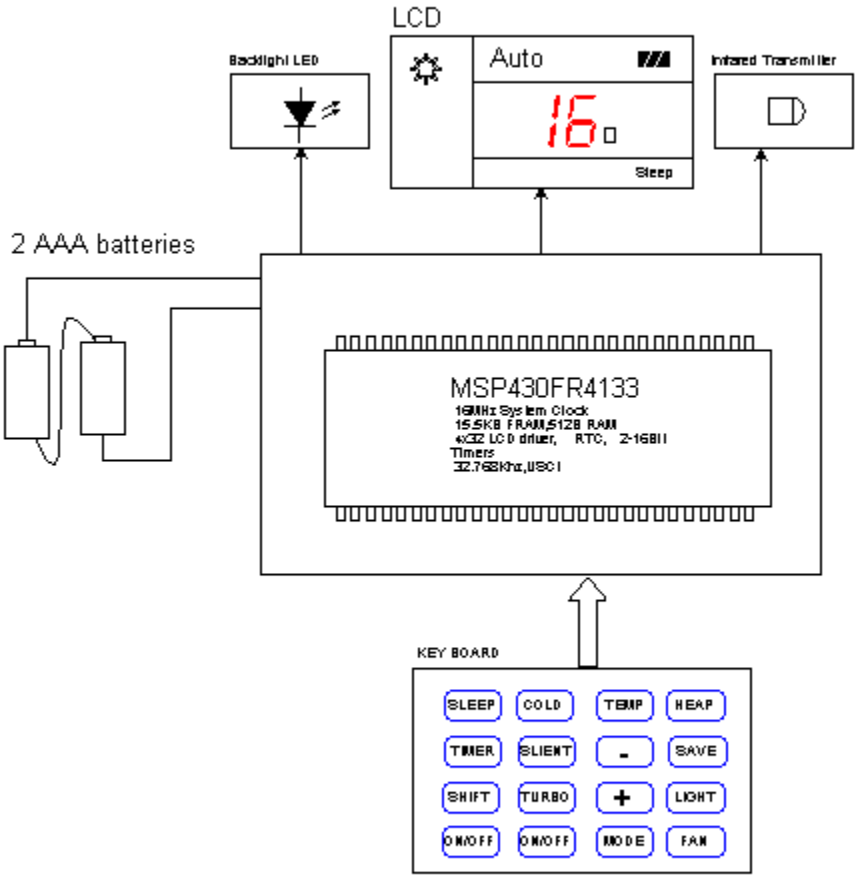


图 **1.** 遥控器框图

4x28 段式 LCD 直接与 MSP430FR4133 LCD 驱动器引脚相连。 设计者可以切换 COM 和 SEG 引脚来简化印刷电路板 (PCB) 布局布线。

4x4 矩阵键盘用于检测 15 个按键。 矩阵的列与中断使能的通用输入/输出 (GPIO) 引脚 (P1) 相连，用于将 MSP430FR4133 从低功耗模式中唤醒。 MCU 的内部上拉/下拉电阻用作按键扫描矩阵的上拉电阻。 无需外部电阻即可实现按键检测，而且无需外部电路即可实现电池电压检测。 MCU 的 ADC 模块在不使用任何外部组件的情况下也可实现该功能。



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32.768kHz 手表晶振用作 MCU 锁频环 (FLL) 和 RTC 时钟源。 两个贴片电容（C4 和 C6）用作晶振负载电容。 设计者必须根据晶振规格认真选择 C4 和 C6 的值。 强烈建议谨慎设计晶振的 PCB 布局，以便确保系统时钟的鲁棒性。图 2 给出了晶振的 PCB 设计示例。

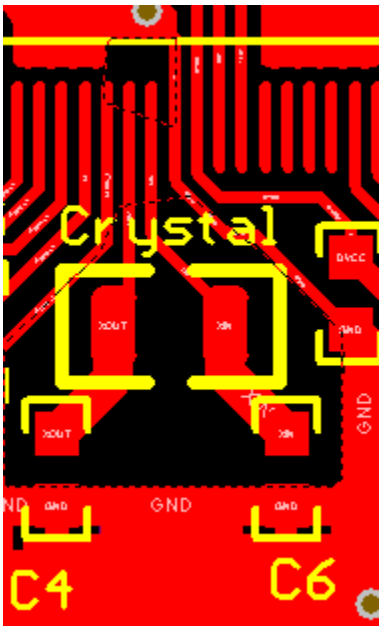


图 **2.** 晶振的 **PCB** 布局

有关详细的设计注意事项，请参见《SLAA322B-MSP430 32kHz 晶体振荡器》。



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## 3 软件描述

软件实现了一种中断驱动型结构。 在主循环中，MCU 保持 LPM3.5 模式。 按键、RTC 和定时器的相关中断会唤醒 MCU 以处理相应任务。 按键输入在 KeyProcess () 任务中进行处理，该任务将处理系统状态并生成 LCD 的显示内容和红外信号内容。 RTC 将生成 3S 间隔中断来通知系统进行电池电压测量。

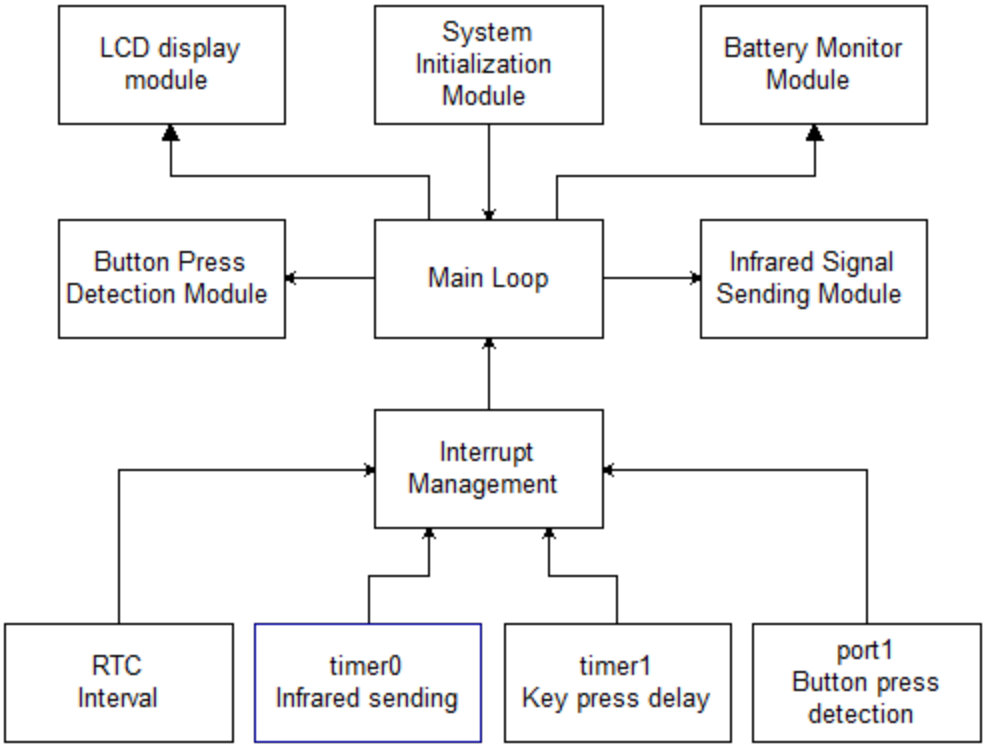


图 **3.** 软件结构

### *3.1 红外信号生成*

目前业内有多种红外调制协议。 本设计采用的是脉冲距离协议，以及空调遥控器最常用的数据帧格式。 如图 4 所示，每个位由载波调制脉冲和空白部分组成。 通过不同的空白部分宽度来分别表示逻辑 1 和逻辑 0。 载波调制脉冲的宽度是恒定的。 在本设计中，数字 1 和数字 0 所对应的空白部分长度分别为 1690μs 和 560μs。调制脉冲的宽度为 560μs。

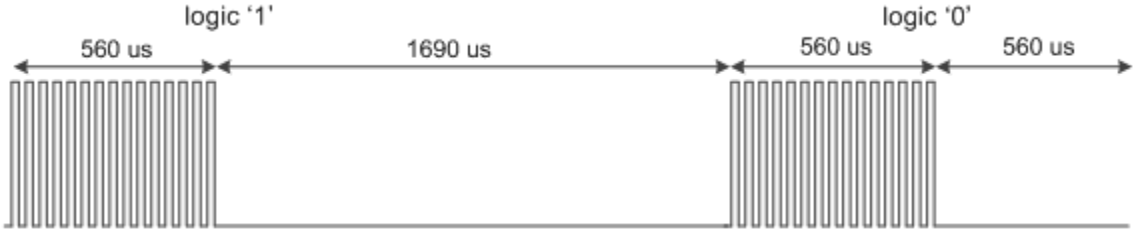


图 **4.** 脉冲距离协议，位编码



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图 5 显示了完整的数据帧格式。

图 **5.** 脉冲距离协议，数据帧格式

包络波形取决于帧格式。 表 1 列出了上述所有项基于最短时隙 (0.56ms) 的量化值。

表 **1.** 表 **1.**脉冲距离协议，数据编码量化表

| 项目 | 帧头 | | 逻辑“1” | | 逻辑“0” | | 尾码 | |
|---|---|---|---|---|---|---|---|---|
| | 载波调制脉冲 | 空白部分 | 载波调制脉冲 | 空白部分 | 载波调制脉冲 | 空白部分 | 载波调制脉冲 | 空白部分 |
| 长度 | 9ms | 4.5ms | 0.56ms | 1.69ms | 0.56ms | 0.56ms | 0.56ms | 0ms |
| 量化 | 16 | 8 | 1 | 3 | 1 | 1 | 1 | 0 |

TA1 用于生成包络波形，每一对载波调制脉冲和空白部分都必须更新一次 CCR0 和 CCR2。 CCR0 取决于载波调制脉冲周期和空白周期，而 CCR2 取决于载波调制脉冲周期。 例如，如果 TA1 源自 4MHz 的 SMCLK 且使用默认的分频器配置，则将 CCR0 和 CCR2 分别配置为 54000 和 36000 来生成帧头（9ms 的载波调制脉冲搭配 4.5ms 的空白部分），并将 CCR0 和 CCR1 分别更新为 9000 和 2240 来表示逻辑 1（请参见图 6）。 要发送一个完整的数据帧，必须将 CCR0 和 CCR2 更新 34 (1+8*2+8*2+1) 次（在 TA1 中断程序中实现）。

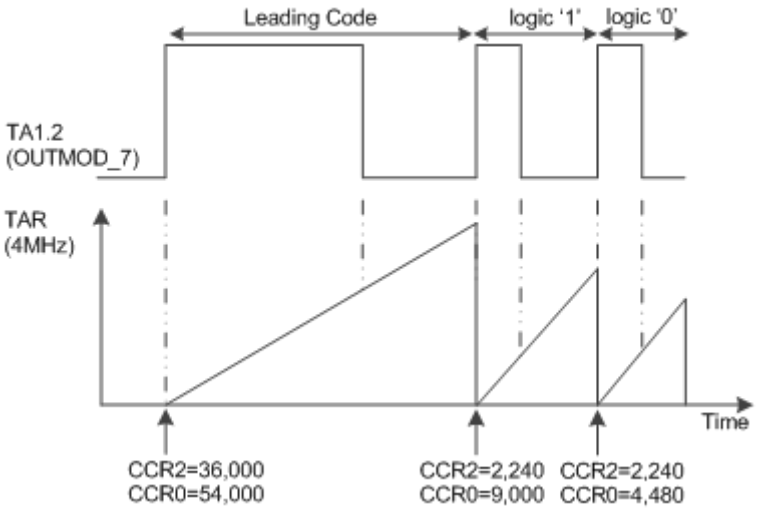


图 **6.** 脉冲距离协议，使用 **TA1** 生成包络



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如要生成占空比为 ¼ 的 38kHz 载波，则可以根据 SMCLK 来配置 TA0 的 CCR0 和 CCR2。 例如，当 SMCLK 为 4MHz 时，CCR0 和 CCR2 分别配置为 105 (4000 / 38) 和 26 (4000 / 38 / 4)。图 7 显示了占空比设置的作用。

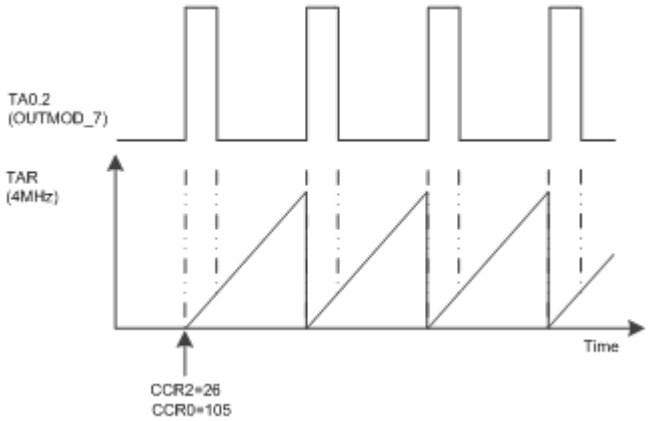


图 **7.** 脉冲距离协议，使用 **TA0** 生成载波

## 4 测试的设置和结果

### *4.1 电源和红外编码测试*

使用 2 节 AAA 电池为电路板供电。 用户可通过按下按键来查看 LCD 上的内容。 可以配置典型的空调工作模式和参数。 可在供电路径中接入一个微安表来监视电路板功耗，如图 8 所示。表 2 列出了示例电路板的测试结果。 要观察红外信号，请在 P1.0 引脚上连接示波器。图 9 显示了红外驱动信号，通常为 38KHz 的脉宽调制 (PWM) 载波，占空比为 30%。



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图 **8.** 电流测试设置



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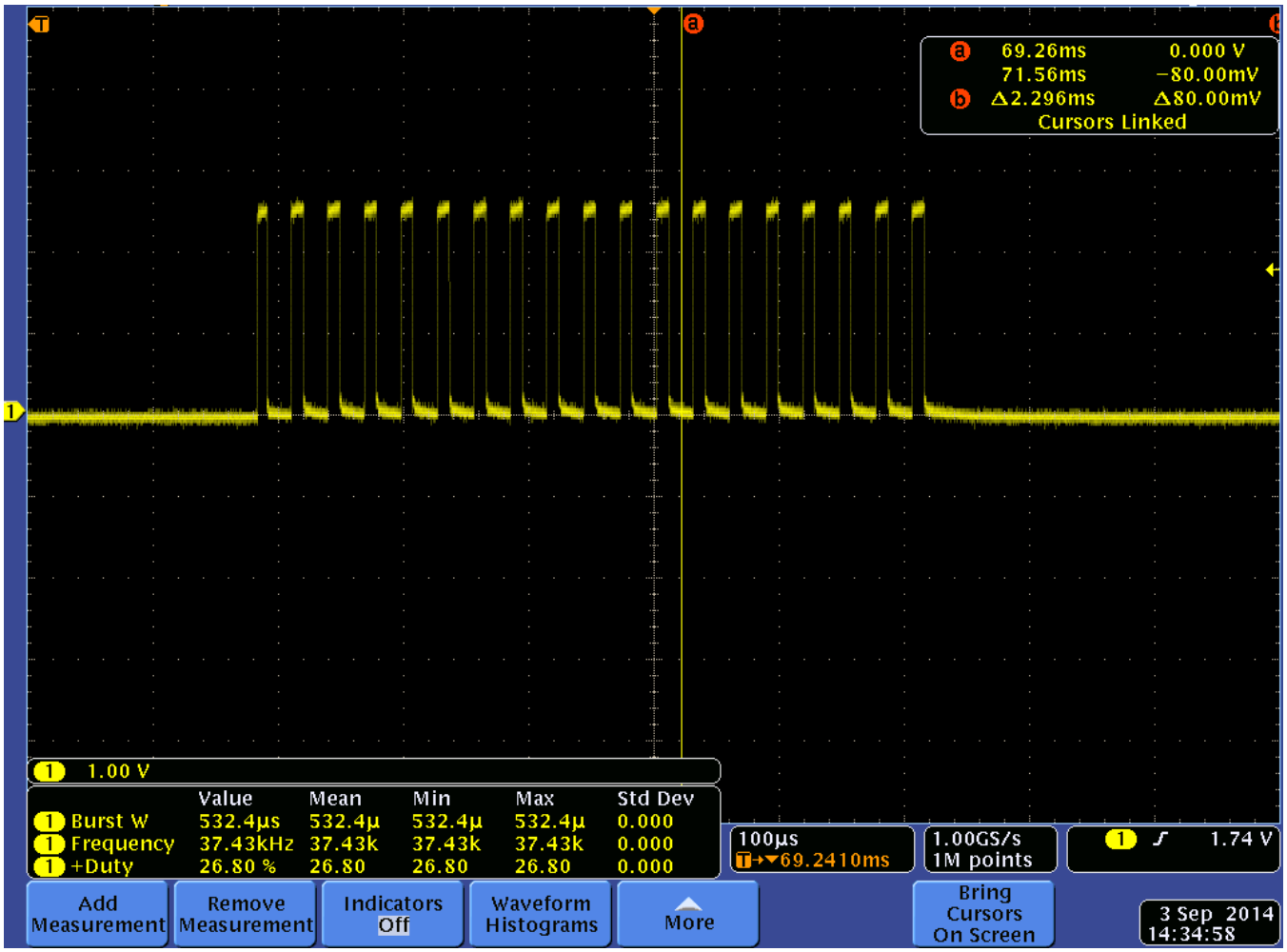


图 **9.** 来自 **MCU** 的红外发送器驱动信号

表 **2.** 功耗测试结果（**VCC = 3.0V**，**RTC** 和 **LCD** 均使能，**LPM3.5** 模式）

| 电路板编号 | Vcc (V) | 低功耗模式（RTC 和 LCD 均使能） | 待机电流 (µA) |
|---|---|---|---|
| 1 | 3.0 | LPM3.5 | 2.6 |
| 2 | 3.0 | LPM3.5 | 3.4 |
| 3 | 3.0 | LPM3.5 | 3.6 |
| 4 | 3.0 | LPM3.5 | 2.8 |



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## 4.2 振荡器频率、峰峰值电压和容差测试

MCU RTC 时钟源和 FLL 参考时钟源为 32.768kHz 超低功耗晶振。 确保稳健的抗噪声性能是至关重要的。 根据《SLAA322B-MSP430 32kHz 晶体振荡器》，用户可测试振荡频率和容差以计算 SF（安全系数），从而评估系统时钟的稳健性。 如 SLAA322B 中所述，SF 应大于 3。

要执行振荡频率测试，请将 FR4133CrystalTest.c 下载到电路板中。 然后在 P1.4 引脚上观察 MCLK 频率，即晶体振荡频率。

要执行振荡峰峰值电压测试，请使用低电容 (<2pF) 探针观察 XOUT 引脚上的信号。 要执行振荡容差测试，请为晶振串联一个电阻 (Rq)，如图 10 所示。

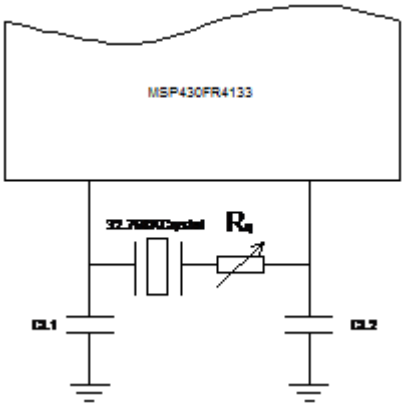


图 **10.** 振荡容差测试（添加电阻 **Rq**）

表 3 列出了采用不同 Rq 值时示例电路板的测试结果。

表 **3.** 振荡测试（**VCC = 3.0V**，温度 **= 25**℃，晶振等效串联电阻 **(ESR) = 35kΩ**）

| 电路板 | Rq = 0Ω | | Rq=100kΩ | | Rq=200kΩ | | SF |
|---|---|---|---|---|---|---|---|
| | 频率(kHz) | Vp-p(mV) | 频率(kHz) | Vp-p(mV) | 频率(kHz) | Vp-p(mV) | |
| 1 | 32.769 | 512 | 32.770 | 616 | 32.770 | 560 | >6.7 |
| 2 | 32.769 | 504 | 32.770 | 624 | 32.770 | 568 | >6.7 |
| 3 | 32.770 | 448 | 32.770 | 536 | 32.771 | 488 | >6.7 |
| 4 | 32.769 | 488 | 32.770 | 560 | 32.770 | 520 | >6.7 |
| 5 | 32.770 | 512 | 32.770 | 600 | 32.771 | 584 | >6.7 |
| 6 | 32.769 | 472 | 32.770 | 568 | 32.771 | 528 | >6.7 |
| 7 | 32.770 | 630 | 32.768 | 608 | 32.769 | 520 | >6.7 |
| 8 | 32.767 | 480 | 32.770 | 576 | 32.770 | 536 | >6.7 |

如表 3 所示，即使串联一个 200kΩ 的电阻，晶振也能正常工作（SF 大于 6.7）。



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# 5 设计文件

## 5.1 电路原理图

要下载电路原理图，请参见 http://www.ti.com.cn/tool/cn/TIDM-REMOTE-CONTROLLER-FOR-AC 的设计文件

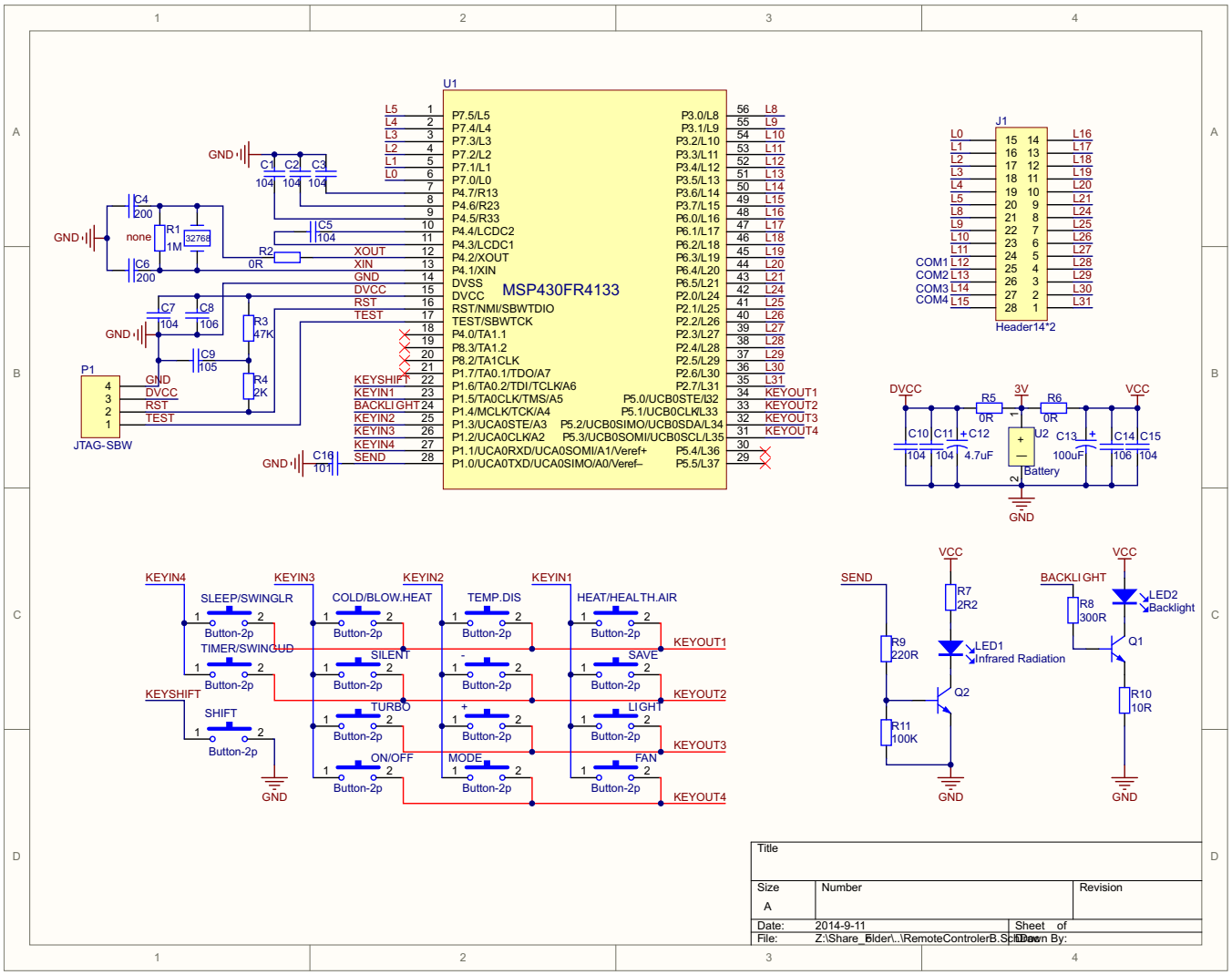


图 **11.** 电路原理图



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## 5.2 物料清单

要下载物料清单 (BOM)，请参见 http://www.ti.com.cn/tool/cn/TIDM-REMOTE-CONTROLLER-FOR-AC 的设计文件。

**表 4. BOM**

| 标号 | 描述 | 数量 |
|---|---|---|
| +、-、COLD/BLOW.HEAT、FAN、HEAT/HEALTH.AIR、LIGHT、MODE、ON/OFF、SAVE、SILENT、SLEEP/SWINGLR、TEMP.DIS、TIMER/SWINGUD、TURBO | 按键 | 14 |
| C1、C2、C3、C5 | 0805，贴片电容，X7R，16V，+-10% | 4 |
| C4, C6 | 0805，贴片电容 200 X7R，16V，+-10% | 2 |
| C7、C10、C11、C14 | 0805，贴片电容 104 X7R，16V，+-10% | 4 |
| C8、C16 | 0805，贴片电容 106 X7R，16V，+-10% | 1 |
| C9 | 0805，贴片电容 105 X7R，16V，+-10% | 1 |
| C12 | 0805，贴片电容 Cap Pol1 X7R，16V，+-10% | 1 |
| C13 | 0805，贴片电容 Cap Pol1 X7R，16V，+-10% | 1 |
| C15 | 0805，贴片电容 102 X7R，16V，+-10% | 1 |
| 晶体 | 32.768kHz 晶振 | 1 |
| J1 | 接头 14*2 | 1 |
| LED1 | 红外辐射发送器 | 1 |
| LED2 | 背光 LED | 1 |
| P1 | JTAG-SBW | 1 |
| Q1、Q2 | 晶体管 | 2 |
| R1、R2、R3、R4、R5、R6、R8、R9、R10、R11 | 0805 贴片电阻 | 10 |
| R7 | 0805 贴片电阻 | 1 |
| SHIFT | 按键 | 1 |
| U1 | MSP430F4133 | 1 |
| U2 | 电池 | 1 |



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### 5.3 PCB 布局

要下载板层图，请参见 http://www.ti.com/tool/TIDM-REMOTE-CONTROLLER-FOR-AC 的设计文件。



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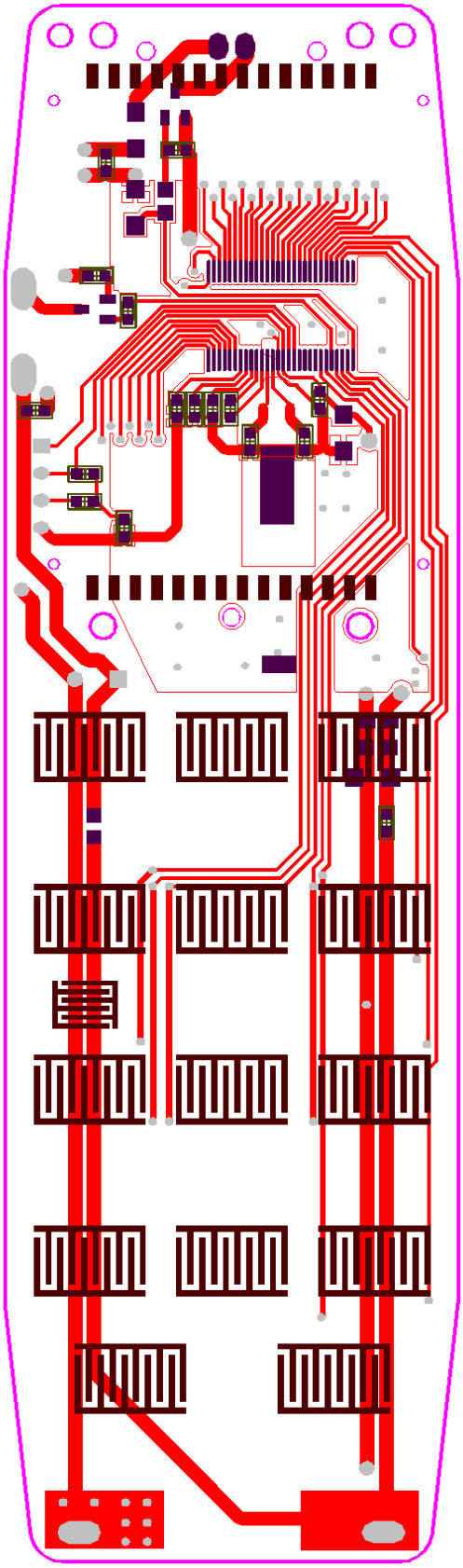

图 **12. PCB** 层 **1**



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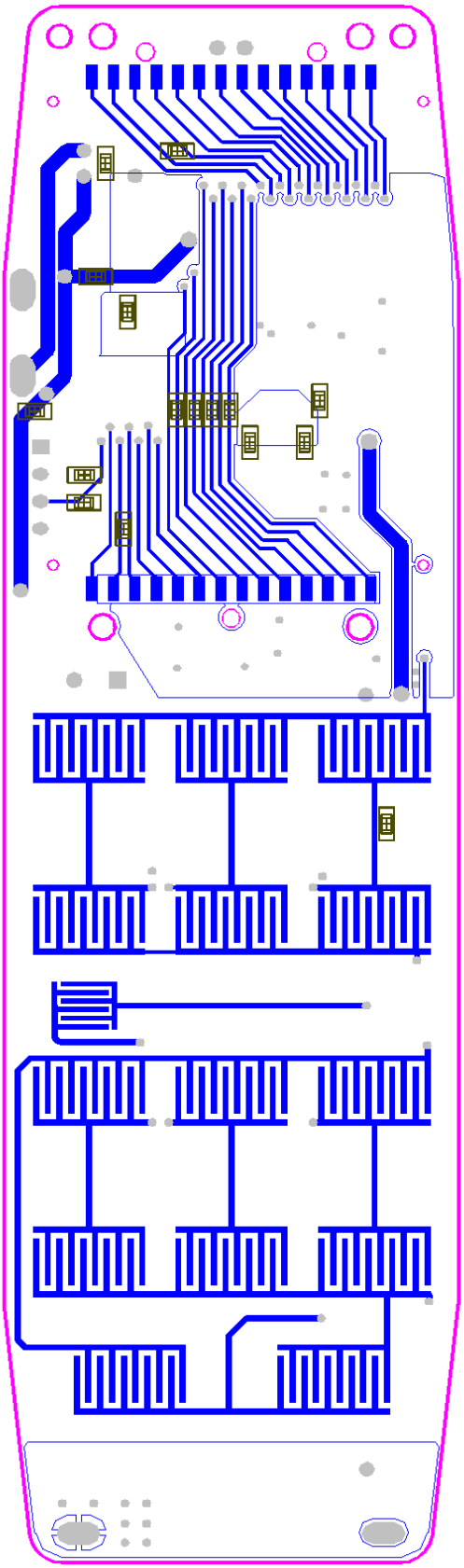

图 **13. PCB** 层 **2**



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### 5.4 光绘文件

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## 6 软件文件

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