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Remote Controller of Air Conditioner Using MSP430 User's Guide

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MSP430FR4133	Product Folder

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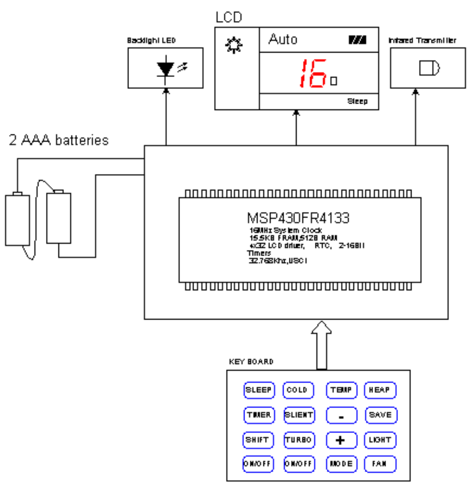
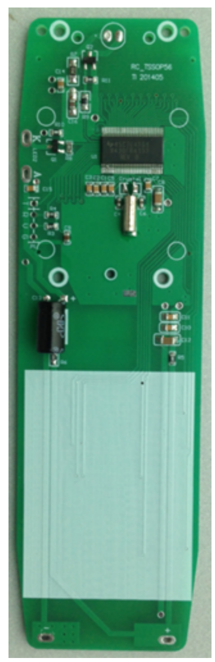
Design Features

- Ultra Low Power with FRAM Technology
- Infrared Code Sending with Optimized Timer
- Matrix Key Scan for 14 Buttons
- Segment LCD

Featured Applications

- Infrared LCD Remote Controller





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1 System Description

This board demonstrates an ultra-low power, general purpose, infrared remote controller solution. The board uses a FRAM-based MCU MSP430FR4133, which supports features such as real time clock, button scan, infrared encoding, LED backlight, and LCD display.

1.1 MSP430FR4133

The MSP430FR4133 is a FRAM-based ultra-low power mixed signal MCU. With the following features, the MSP430FR4133 is highly suitable for portable device applications.

- 16-bit RISC architecture up to 16 Mhz
- Wide supply voltage range from 1.8 V to 3.6 V
- 64-Pin/56-Pin/48Pin TSSOP/LQFP package options
- Integrated LCD driver with charge pump can support up to 4x36 or 8x32 segment LCD
- Optimized 16-bit timer for infrared signal generation
- Low power mode (LPM3.5) with RTC on:0.77 uA
- Low power mode (LPM3.5) with LCD on: 0.936 uA
- Active mode: 126 uA/MHz
- 10^15 write cycle endurance low power ferroelectric RAM (FRAM) can be used to store data
- 10-channel, 10-bit analog-to-digital converter (ADC) with built-in 1.5 V reference for battery powered system
- All I/Os are capacitive touch I/O

2 Circuit Design

The highly-integrated mixed signal processer MSP430FR4133 has a small amount of components necessary to realize a fully-functional air conditioner remote controller.

Refer to Figure 1 for the design block diagram.

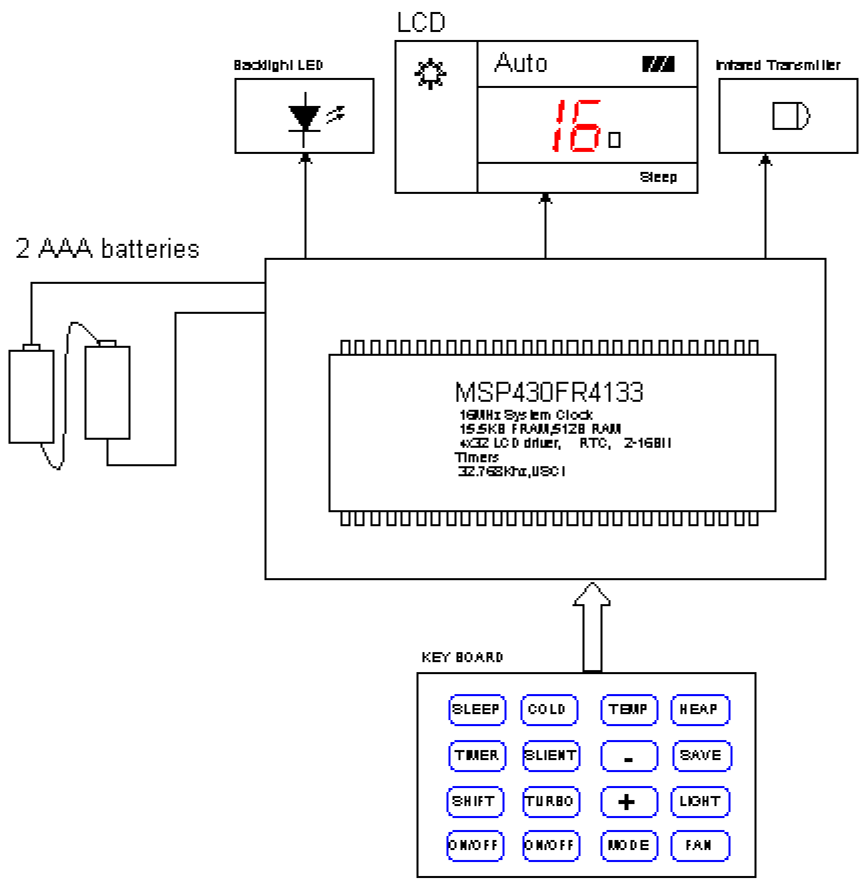

Figure 1. Remote Controller Block Diagram

A 4x28 segment LCD is directly connected to the MSP430FR4133 LCD driver pins. Designers can swap the COM and SEG pins to simplify the PCB layout.

A 4x4 matrix is used to detect 15 buttons. The matrix columns are connected to interrupt-enabled GPIOs (P1) to wake up the MSP430FR4133 from low power mode. MCU internal pull up/pull down resistors are used as button scan matrix pull up resistors. No external resistor is needed for button detection, and no external circuit is needed for battery voltage detection. The function is also realized by the MCU ADC module without any external component.

A 32.768 KHz watch crystal serves as the MCU FLL and RTC clock source. Two chip capacitors, C4 and C6, are used as the crystal loading capacitor. Designers must choose C4 and C6 values carefully according to crystal specification. Cautious PCB layout design for the crystal is strongly recommended, to secure system clock robustness. Figure 2 illustrates an example of the crystal PCB design.

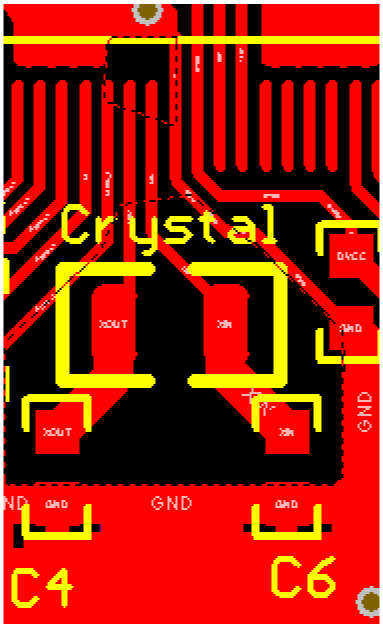

Figure 2. Crystal PCB Layout

Refer to SLAA322B-MSP430 32-kHz Crystal Oscillators for detailed design considerations.

3 Software Description

The software implements an interrupt-driven structure. In the main loop, the MCU stays in LPM3.5 mode. Interrupts from the button, RTC, and timer wake up the MCU for task processing. Inputs from the button are processed in task KeyProcess (), which handles system status and generates the content for the LCD display and infrared signal. RTC generates a 3S interval interrupt to inform the system of battery voltage measurement.

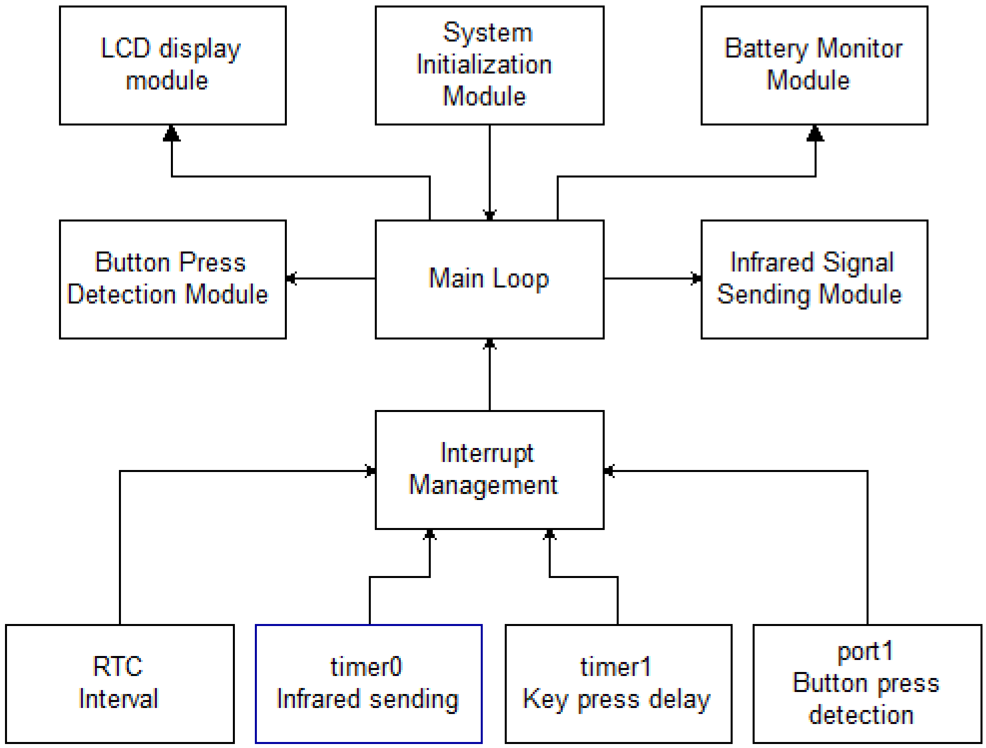

Figure 3. Software Structure

3.1 Infrared Signal Generation

There are several kinds of infrared modulation protocols in the industry. This design illustrates pulse distance protocol with data frame format, the most commonly-used format for air conditioner remote controllers. As shown in Figure 4, each bit is composed of a carrier-modulated pulse and a space. The space's width distinguishes logic 1 and logic 0 respectively. The carrier-modulated pulse width is constant. In this design, space length for 1 is 1690 uS, and 560 uS for digit 0. Modulated pulse width is 560 uS.

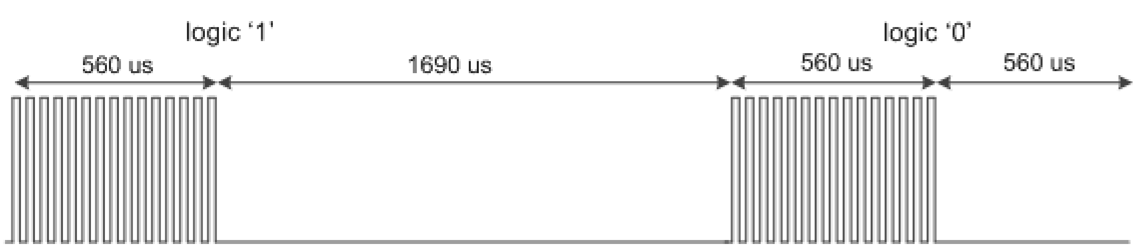

Figure 4. Pulse Distance Protocol, Bit Encoding

A complete data frame format is shown in Figure 5.

Figure 5. Pulse Distance Protocol, Data Frame Format

The envelope waveform depends on the frame format. Quantize all of the above items with a minimum time slot of 0.56 ms, as shown in Table 1.

Table 1. Table 1. Pulse Distance Protocol, Data Encoding Quantization Table

Items	Leading Code		Logic ‘1’		Logic ‘0'		Tail Code	
	Carrier Modulated Pulse	Space	Carrier Modulated Pulse	Space	Carrier Modulated Pulse	Space	Carrier Modulated Pulse	Space
Length	9 ms	4.5 ms	0.56 ms	1.69 ms	0.56 ms	0.56 ms	0.56 ms	0 ms
Quantization	16	8	1	3	1	1	1	0

TA1 is used to generate an envelope waveform, and each pair of carrier-modulated pulse and space must update the CCR0 and CCR2 once. The CCR0 depends on the carrier-modulated pulse period plus the space period, while the CCR2 depends on the carrier-modulated pulse period. For instance, if TA1 sources from SMCLK of 4 MHz and uses default divider configuration, CCR0 and CCR2 are individually configured as 54,000 and 36,000, to generate the leading code (9 ms carrier modulated pulse paired with 4.5 ms space), and updated to 9,000 and 2,240 for logic 1 (see Figure 6). To send one full data frame, CCR0 and CCR2 must be updated 34 (1+8*2+8*2+1) times, which is achieved in the TA1 interrupt routine.

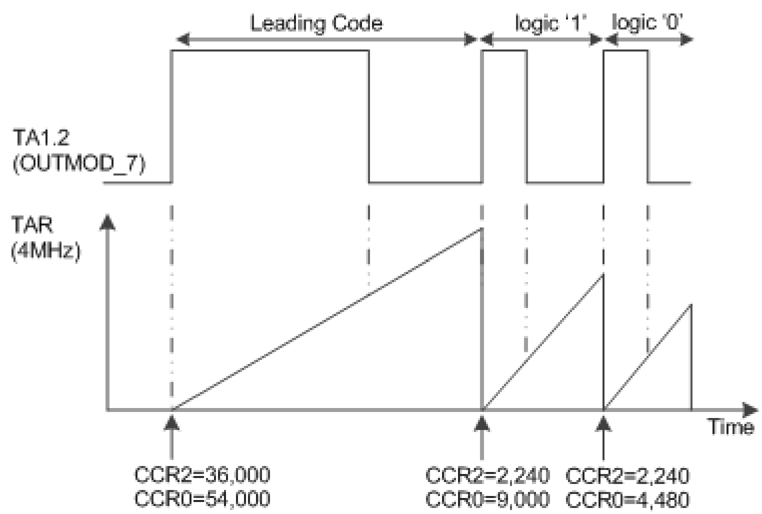

Figure 6. Pulse Distance Protocol, TA1 in Envelope Generation

To generate 38 kHz carrier with ¼ duty, CCR0 and CCR2 of TA0 are configured according to SMCLK. For example, with a 4 MHz SMCLK, CCR0 and CCR2 are individually configured to be 105 (4,000/38) and 26 (4,000/38/4). Figure 7 shows how the duty setting works.

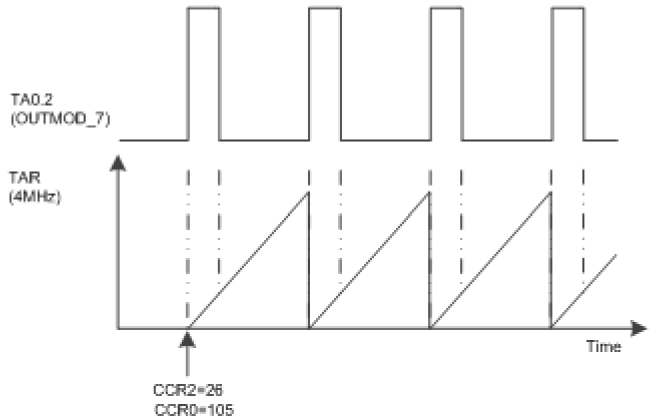

Figure 7. Pulse Distance Protocol, TA0 in Carrier Generation

4 Test Setup and Results

4.1 Power and Infrared Code Test

2 AAA batteries power the board. By pressing the button pads with conductors, the user can observe the contents on the LCD. Typical air-conditioner working modes and parameters can be configured. A micro-ampere meter is inserted in the power path to monitor the board power consumption as shown in Figure 8. Table 2 shows the sample board test results. To observe the infrared signal, use P1.0 with an oscilloscope. Figure 9 shows the infrared driving signal, typically 38 KHz PWM carriers, 30% duty.

Figure 8. Current Test Setup

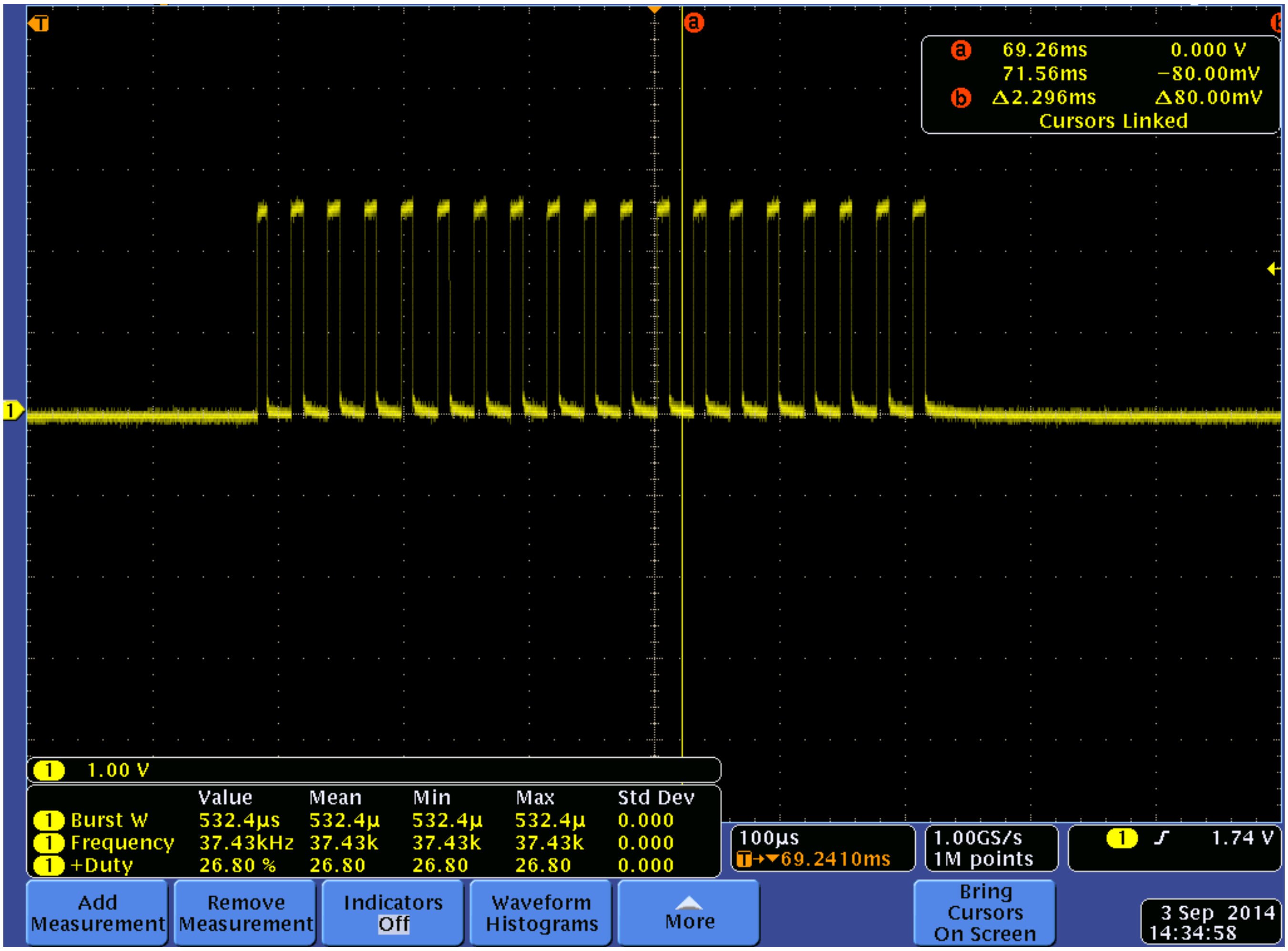

Figure 9. Infra Transmitter Driving Signal from MCU

Table 2. Power Consumption Test Result (VCC = 3.0 V with RTC ON and LCD ON, LPM3.5)

Board NO#	Vcc(V)	Low Power Mode with RTC and LCD ON	Standby Current (uA)
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

4.2 Oscillation Frequency, Peak-Peak Voltage and Allowance Test

The ultra-low power 32.768 KHz crystal is the MCU RTC clock source and FLL reference clock source. It is essential to secure the robustness from noises. According to SLAA322B-MSP430 32-kHz Crystal Oscillators, the user can test the oscillation frequency and allowance to calculate the SF (Safety Factor), and evaluate system clock robustness. As described in SLAA322B, the SF should be greater than 3.

To perform the oscillation frequency test, download FR4133CrystalTest.c to the board. Then observe the MCLK frequency on P1.4, which indicates crystal oscillation frequency.

For an oscillation peak-peak voltage test, observe the signal on XOUT with a low capacitor (<2 pF) probe. For an oscillation allowance test, add a resistor (Rq) in series with the crystal, as shown in Figure 10.

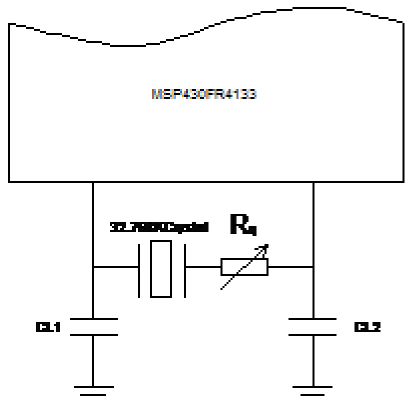

Figure 10. Oscillation Allowance Test with Added Resister Rq

Table 3 shows the test results of sample boards with different value Rq.

Table 3. Oscillation Test with VCC = 3.0 V, Temperature = 25℃，Crystal ESR = 35 KOhm

Board	Rq = 0Ohm		Rq=100KOhm		Rq=200KOhm		SF
	Freq.(Khz)	Vp-p(mV)	Freq.(Khz)	Vp-p(mV)	Freq.(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

As shown in Table 3, even with a 200 KOhm resistor added in series with the crystal, the crystal works normally, which indicates the SF is greater than 6.7.

5 Design Files

5.1 Schematics

To download the schematic, see the design files at http://www.ti.com/tool/TIDU513

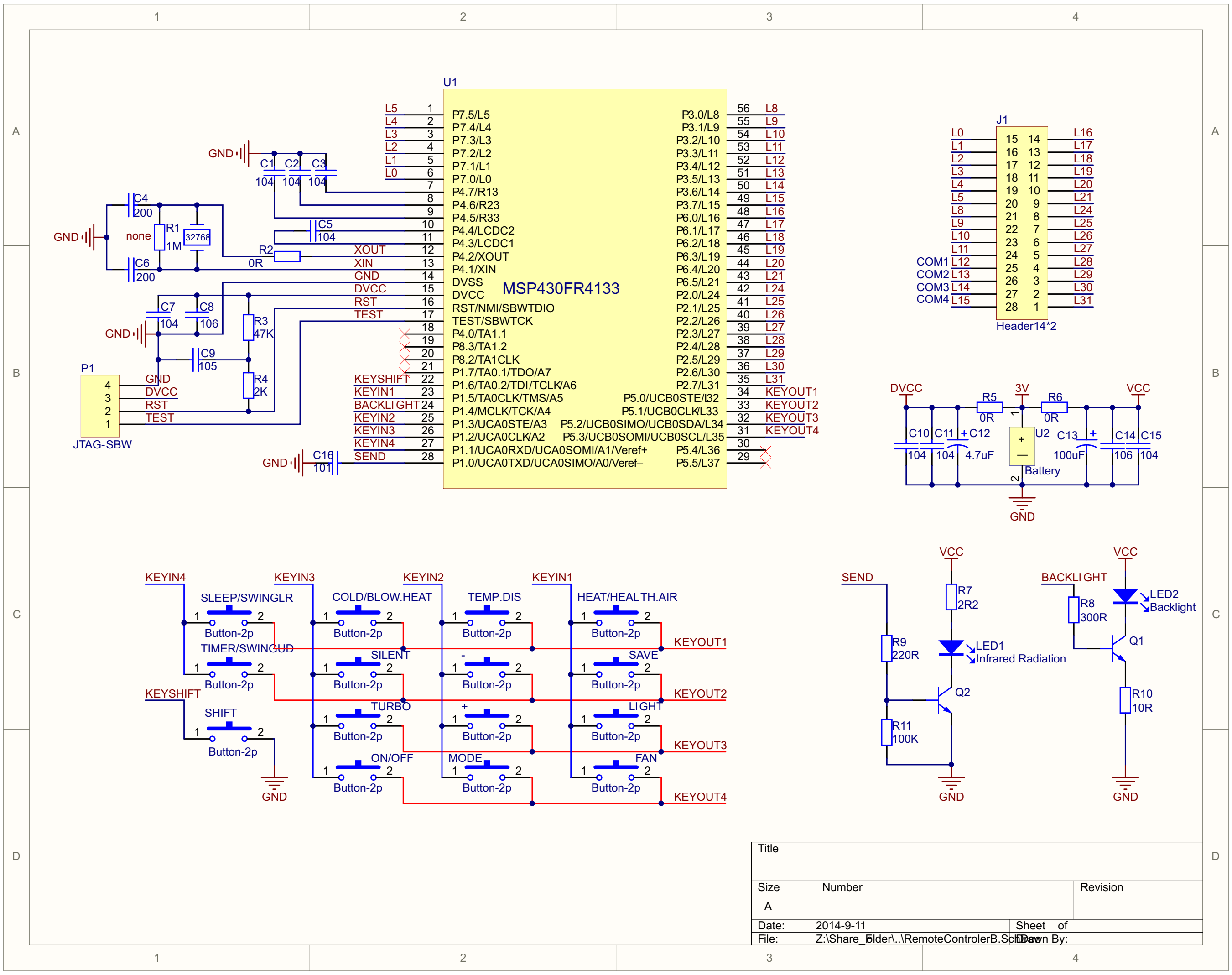

Figure 11. Schematic

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at http://www.ti.com/tool/TIDU513.

Table 4. BOM

Designator	Description	Quantity
+, -, COLD/BLOW.HEAT, FAN, HEAT/HEALTH.AIR, LIGHT, MODE, ON/OFF, SAVE, SILENT, SLEEP/SWINGLR, TEMP.DIS, TIMER/SWINGUD, TURBO	Buttons	14
C1, C2, C3, C5	0805, Chip Capacitor, X7R,16 V, +-10%	4
C4, C6	0805, Chip Capacitor Chip Capacitor 200 X7R,16 V, +-10%	2
C7, C10, C11, C14	0805, Chip Capacitor 104 X7R, 16 V, +-10%	4
C8, C16	0805, Chip Capacitor 106 X7R,16 V, +-10%	1
C9	0805, Chip Capacitor 105 X7R,16 V, +-10%	1
C12	0805, Chip Capacitor Cap Pol1 X7R,16 V, +-10%	1
C13	0805, Chip Capacitor Cap Pol1 X7R,16 V, +-10%	1
C15	0805, Chip Capacitor 102 X7R,16 V, +-10%	1
Crystal	32.768 Khz crystal	1
J1	Header14*2	1
LED1	Infrared Radiation transmitter	1
LED2	Backlight LED	1
P1	JTAG-SBW	1
Q1, Q2	Transistor	2
R1, R2, R3, R4, R5, R6, R8, R9, R10, R11	0805 Chip Resistor	10
R7	0805 Chip Resistor	1
SHIFT	Button	1
U1	MSP430F4133	1
U2	Battery	1

5.3 PCB Layout

To download the layer plots, see the design files at http://www.ti.com/tool/TIDU513.

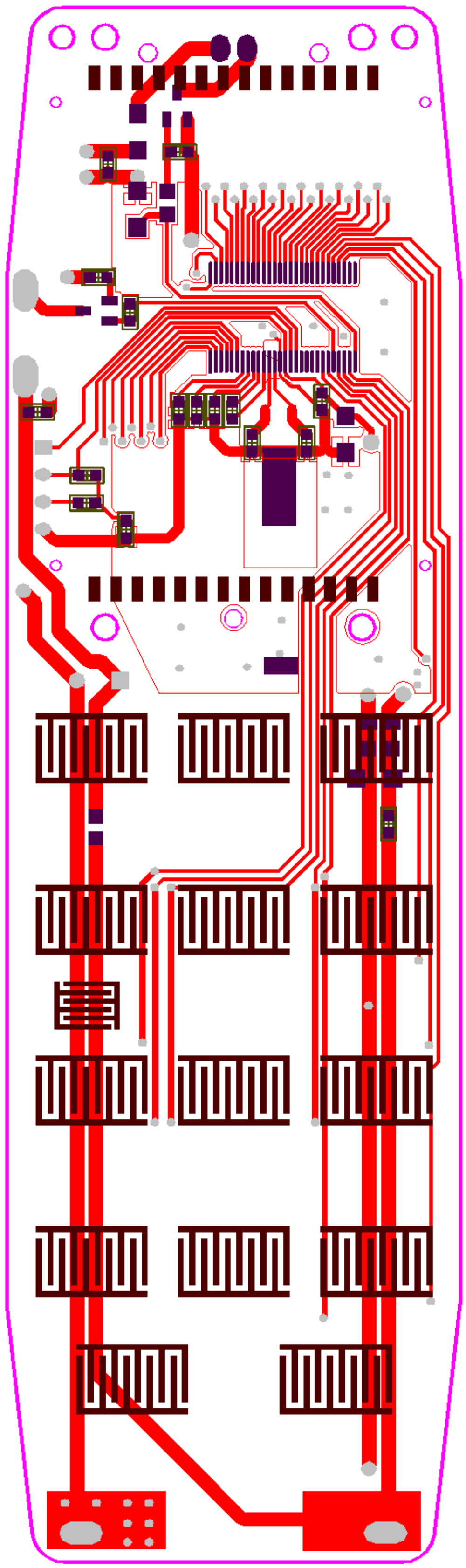

Figure 12. PCB Layer 1

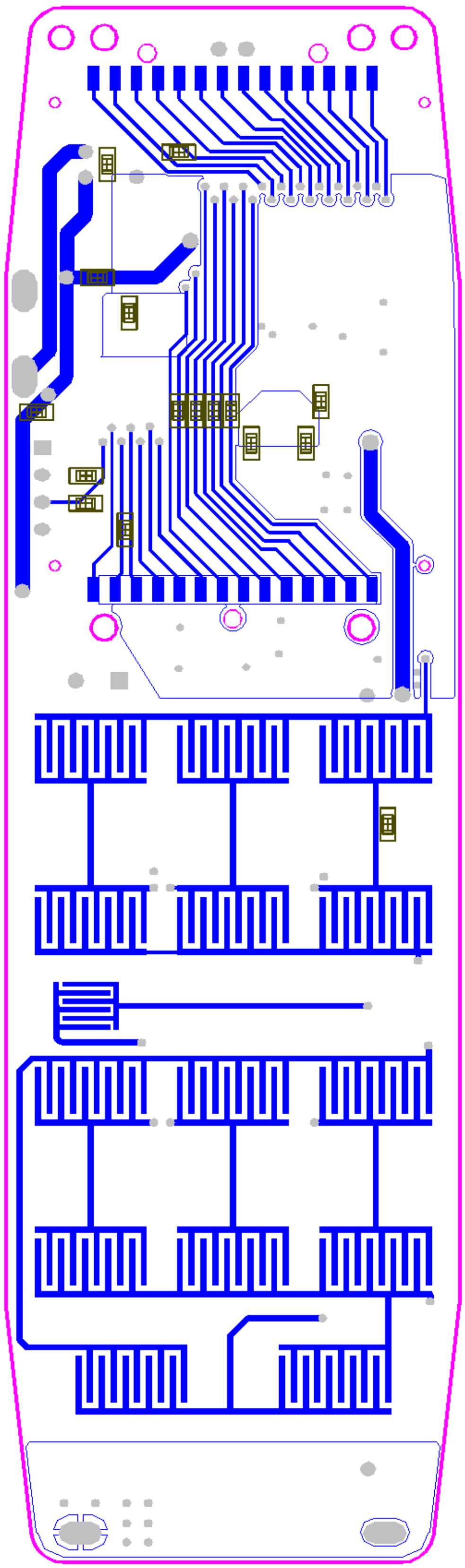

Figure 13. PCB Layer 2

5.4 Gerber Files

To download the Gerber files, see the design files at http://www.ti.com/tool/TIDU513.

6 Software Files

To download the software files, see the design files at http://www.ti.com/tool/TIDU513

7 About the Author

JASON GUO is a system application engineer at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Jason earned his Engineering Master of Integrated Circuits Design from Peking University, and Bachelor of Electronic Engineering from Shanghai Jiaotong University.

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