*TI Designs*

# *Thermostat Implementation with MSP430FR4xx User's Guide*

## TI Designs

TI Designs provide the foundation that you need including methodology, testing, and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

### Design Resources

| | |
|---|---|
| TIDM-FRAM-THERMOSTAT | Tool Folder Containing Design Files |
| MSP430FR4133 | Product Folder |
| TPS78228 | Product Folder |
| SN65HVD75 | Product Folder |
| TPD2E2U06 | Product Folder |

TI E2E™ Community

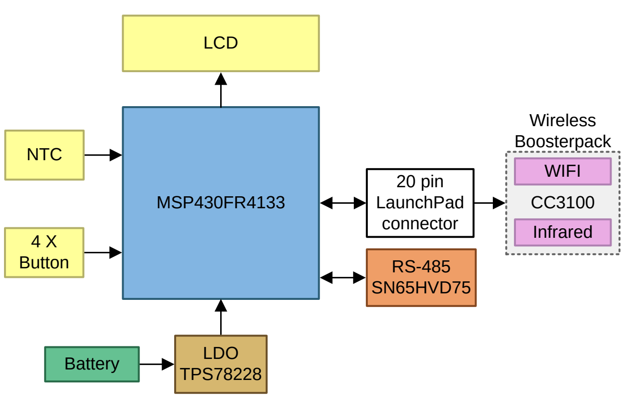
ASK Our E2E Experts
WEBENCH® Calculator Tools

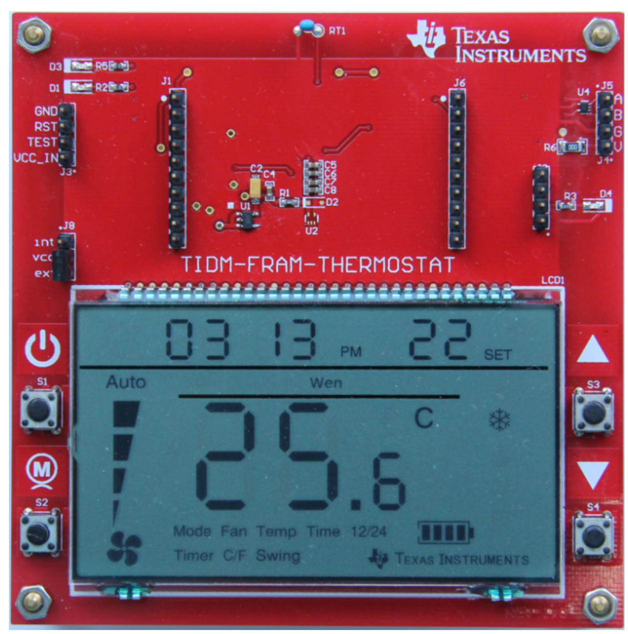
## Design Features

- 0°C to 35°C Temperature Measurement with 0.1°C Resolution
- 3.4 Inch 4×28 Segment LCD
- 1.8-µA Standby Current
- RS-485 Remote Control
- Capacitive Touch Buttons
- Battery Voltage Monitor

### Featured Applications

- Thermostat




An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

# 1 System Description

## 1.1 Thermostat

A thermostat is a component of a control system that senses the temperature of a system and maintains the temperature near a desired set-point. The thermostat maintains the temperature by switching heating or cooling devices on or off, or regulating the flow of a heat transfer fluid as needed, to maintain the correct temperature.

The history of thermostat development has included mechanical thermostats, electrical and analog electronic thermostats, and digital electronic thermostats. See Figure 1.

**Figure 1. Different Kinds of Thermostat**

The most popular thermostat is the digital electronic thermostat. This kind of thermostat has thermistors or other semiconductor temperature sensors to measure temperature. Typically one or more regular batteries are needed to be installed to operate it, or use common 24-V AC circuits as a power source. Each thermostat has an LCD showing the current temperature and the current setting. Most thermostats also have a clock, time-of-day, and even day-of-week settings for the temperature, which are used for comfort and energy conservation. Some advanced models have touch screens or the ability to work with home automation or building automation systems.

## 1.2 MSP430FR4133 in a Thermostat

MSP430FR4xx is a new ultra-low-power MSP430 FRAM-based microcontroller series. The abundant peripherals such as the FRAM, LCD_E, ADC module, and ultra-low-power features are very suitable in thermostat applications.

- Ultra-Low-Power: The MSP430FR4133 MCU has 5 low-power modes. The power consumption is under 1 µA when MSP430FR4133 is in LPM3.5 with RTC counter and LCD_E modules on, which is ideal for battery-powered thermostat applications.
- LCD_E: This new LCD module supports up to 4 × 36 or 8 × 32 LCD segments. The module allows the user to configure all LCD pins to be either SEG or COM via software settings, which makes PCB layout convenient and single-layer PCB possible. The LCD_E module also provides an internal charge pump with an adjustable contrast control, which can keep consistent contrast during battery life.
- FRAM: FRAM is a nonvolatile memory that combines the speed, ultra low power, high endurance, and flexibility of SRAM, and high reliability and stability of Flash. MSP430FR4133 contains 15.5 KB FRAM and 2 KB SRAM. With FRAM, no external nonvolatile memory is required to store setting data in programmable thermostat designs.
- CapTouch™ I/O: The MSP430FR4133 MCU supports up to 60 CapTouch I/Os with a validated touch solution and mature library to allow easy implementations of capacitive touch features in thermostats, even “Touch on LCD glass”.
- ADC: The sample rate of the ADC10 module in MSP430FR4133 is up to 200 ksps. The on-chip bandgap offers 1.2 V external reference and 1.5 V internal reference. With the ADC module, users can monitor VCC voltage without additional external components.
- For NTC thermistor temperature sensing, 1.2 V on-chip voltage reference output and 10-bit ADC can be used. For temperature-sensing IC, interfaces UART, SPI, and I2C are available for communication.

# 2 Getting Started

## 2.1 Introduction

The TIDM-FRAM-THERMOSTAT reference design, featuring the MSP430FR4133 FRAM-based ultra-low-power microcontroller, is a fully-functioning battery-powered platform for the thermostat that allows users to evaluate the MSP430FR4xx device in thermostat applications.

The reference board design provides everything necessary for a thermostat design, including a high accuracy temperature sensor, 3.4-inch LCD, and wired and wireless remote control interfaces. The out-of-box experience provides basic functions for thermostat applications such as temperature sensing, menu settings, and display settings. All hardware and software are available for developers to easily develop their own thermostat application.

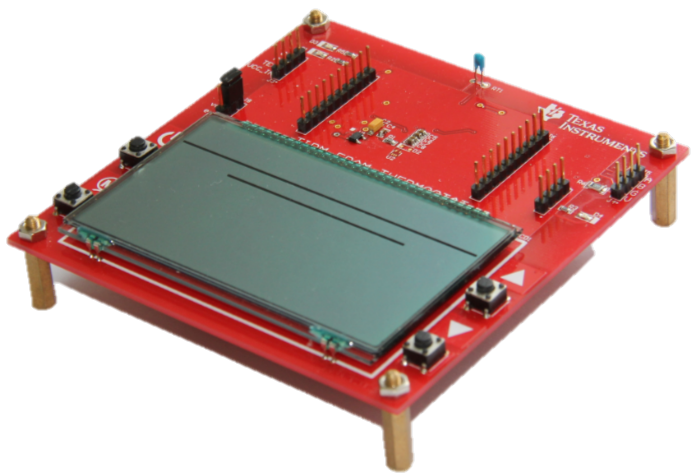


**Figure 2. TIDM-FRAM-THERMOSTAT**

## 2.2 Features

- High-accuracy temperature measurement
  - Temperature accuracy: 0°C to 35°C (±0.5°C)
  - Resolution 0.1°C
- 3.4 inch, 4×28 LCD segment
  - Mode of operation
  - Fan level setting
  - Temperature measurement (Celsius/Fahrenheit)
  - Temperature setting
  - Real-Time-Clock (RTC) (12/24 hour format) with days of the week
  - Timer
  - Battery status
- Ultra-Low-Power
  - 1.8-µA standby current
  - 10-µA average power consumption
- Support wired and wireless interface
  - RS-485 on board
  - Wireless BoosterPack connector
- Battery voltage monitor
- Four capacitive touch buttons

### 2.3 Kit Contents

- 1 × TIDM-FRAM-THERMOSTAT main board
- 1 × USB to RS-485 adapter
- 2 × AAA battery

### 2.4 Out-of-Box Experience

To become familiar with this reference design, use its pre-programmed User Experience Code. This code demonstrates key features from a user level.

Figure 3 in the next section shows the main parts of the board and the standard configuration for the out-of-box experience. A detailed hardware description is given in Section 3.

To start, install the battery to power on the system. A more detailed explanation of operating modes can be found in Section 4.

The User Experience Source code and more code examples are provided for download at http://www.ti.com/tool/TIDM-FRAM-THERMOSTAT. The code is licensed under BSD, and TI encourages reuse and modifications to fit specific needs.

In the User Experience Software section, all functions are described in detail, and a project structure is provided to help users become familiar with the code.

Details on the Integrated Development Environment (IDE) installation process are provided in the IDE user's guides for IAR (SLAU138) and CCS (SLAU157).

These user's guides also contain detailed step-by-step instructions on how to import projects into the workspace. Links to the latest versions of these documents are always part of the IDE installations in the Windows start menu.

Refer to www.ti.com/ccs for more details on Code Composer Studio (CCS) including getting started videos. CCS covers all basic aspects in great detail (project creation, browsing, debugging, breakpoints, and resource explorer).

## 3 Hardware

This section describes the hardware design of TIDM-FRAM-THERMOSTAT EVM board. Figure 3 and Figure 4 show an overview of the hardware.

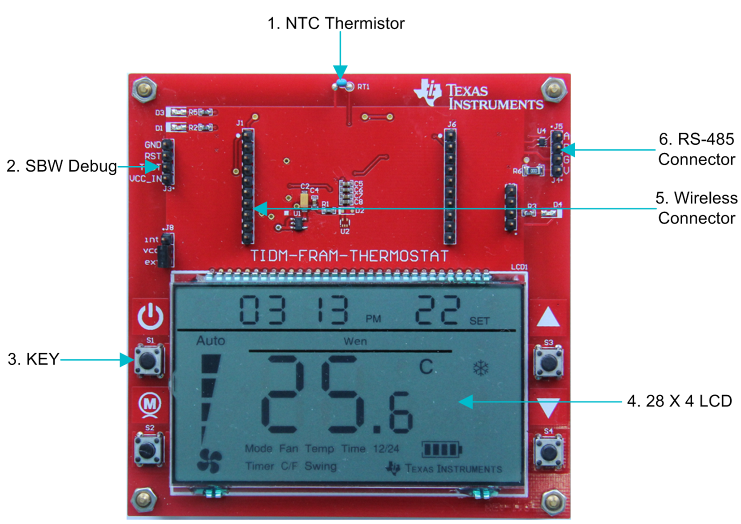



**Figure 3. EVM Board Top View**

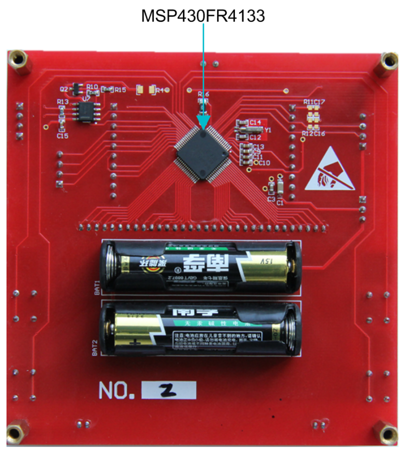



**Figure 4. EVM Board Bottom View**

## 3.1 Block Diagram

Figure 5 shows the block diagram.

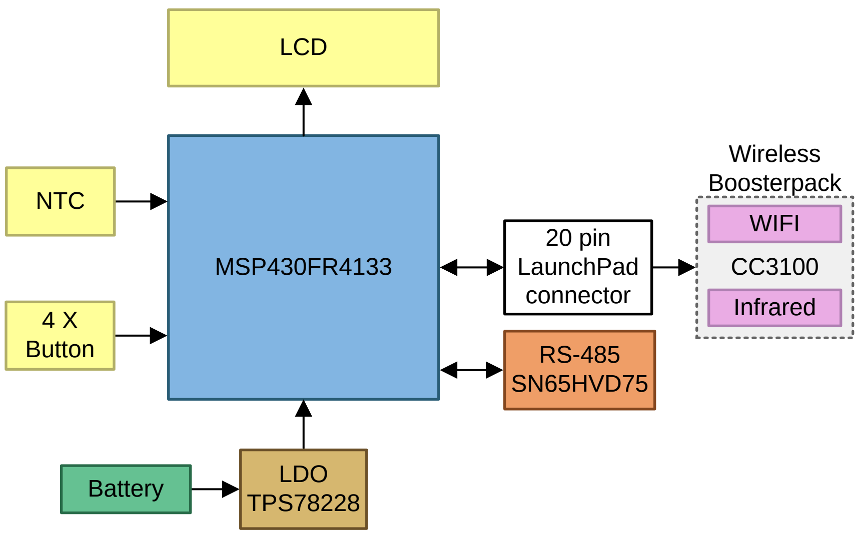



**Figure 5. Block Diagram**

**NOTE:** MSP430FR4133, TPS78228, SN65HVD75, CC3100 are Texas Instruments devices.

## 3.2 Hardware Features

### 3.2.1 MSP430FR3133

The MSP430FR4133 is a FRAM-based MCU with 15.5 kB of nonvolatile memory, 2 kB SRAM, and high-GPIO pin count including a segment LCD controller. To learn more about this device, visit www.ti.com/product/MSP430FR4133.

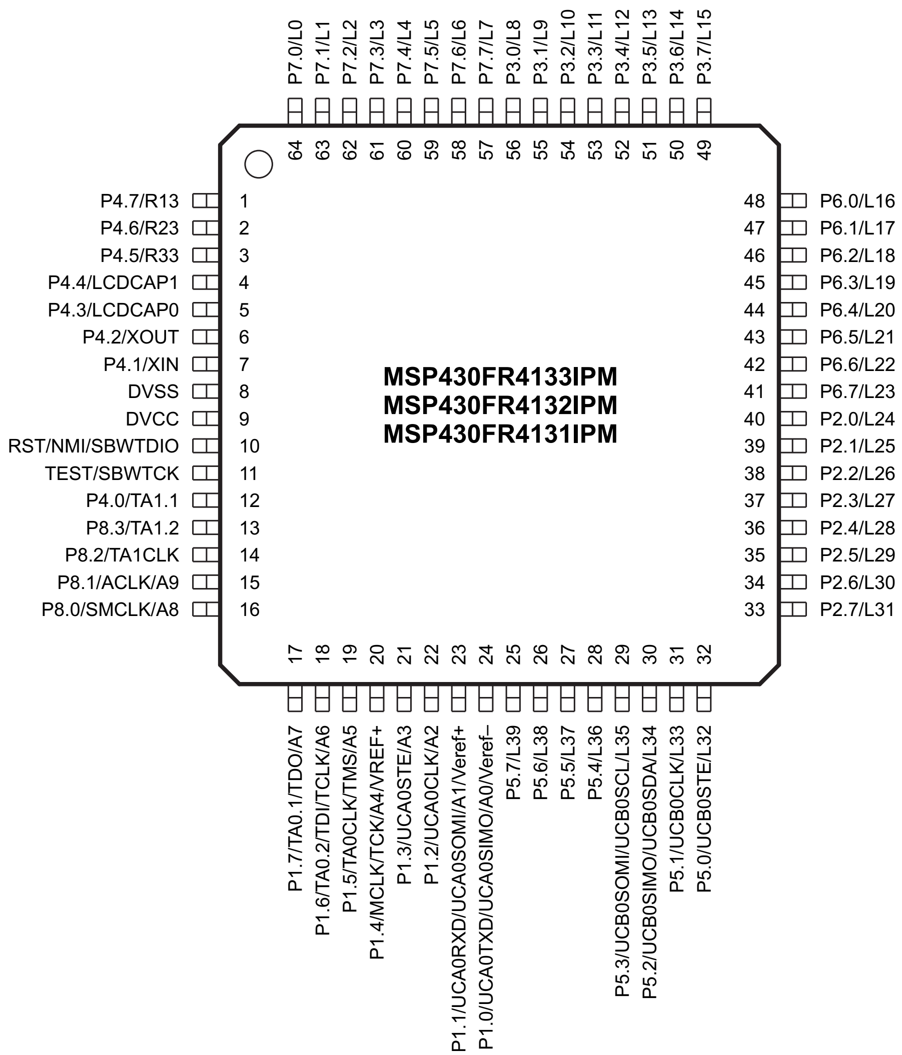



**Figure 6. MSP430FR4133 Pinout**

### 3.2.2 LCD

The LCD panel on the EVM board is 3.4 inches with 112 segments to provide all the information needed in thermostat applications such as time, temperature, operating mode, battery status, and so on.

Figure 7 shows the full display. For the LCD-specification file, refer to the design file.

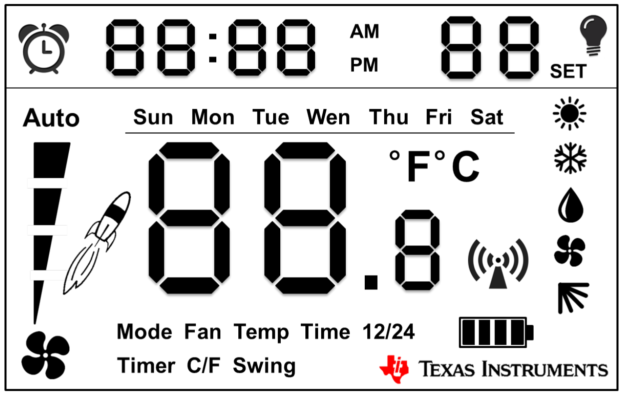



**Figure 7. Full LCD**

The LCD_E module in MSP430FR4133 supports up to 4 × 36 or 8 × 32 LCD segments. The module allows users to configure each LCD drive pin to be either SEG or COM via software settings, which is very convenient for the PCB layout. The LCD_E module also provides an internal charge pump with an adjustable contrast control.

### 3.2.3 RS-485

For wired control, the EVM supports an RS-485 interface. The transceiver part number is SN65HVD75. SN65HVD75 is a 3.3-V supply RS-485 with IEC ESD protection. For more information, please refer to http://www.ti.com/product/SN65HVD75.

In this interface circuit, only transmit and receive pins are used. The direction of data transmission is automatically controlled by the circuit. See Figure 8.

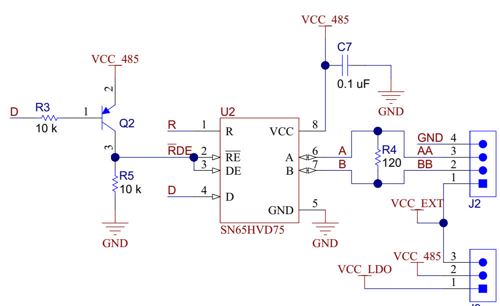



**Figure 8. RS-485 Circuit**

A PC-based GUI demonstrates communication between the thermostat EVM and the PC. For hardware support, a USB-to-RS-485 adapter is needed for protocol conversion.

### 3.2.4 Power Supply

TIDM-FRAM-THERMOSTAT can be powered from either the on-board battery or an external power supply. By default, the board is powered by two 1.5-V AAA batteries. Users can switch the power supply by switching the jumper on connector J8.

The LDO part number is TPS78228; its ultra-low IQ (500 nA) is ideal for battery-powered applications. For more information, please refer to http://www.ti.com/product/TPS78228/.

### 3.2.5 Battery Voltage Monitor

The battery voltage monitor solution in this design does not require additional external components. The MSP430FR4133 ADC module allows users to choose VCC as Vref+ reference, and measure 1.5 V on-chip voltage reference. Then, the VCC can be calculated with the following formula:

VCC 1.5 V × 1024 ÷ AD _result

### 3.2.6 Debug

The on-board connector J3 is a Spy-Bi-Wire debug interface. Spy-Bi-Wire is a serialized JTAG protocol developed by Texas Instruments for MSP430. In this protocol only two wires are used instead of the usual four pins for the general JTAG interface.

### 3.2.7 Buttons

Four mechanical buttons on board allow users to adjust the modes and settings. The EVM also supports four capacitive touch pads as well. With MSP430 PinOsc capacitive touch technology, no external components are needed in this design for the touch feature. For more information, please refer to www.ti.com/capacitivetouch and the MSP430FR413xx code examples on www.ti.com/tool/msp-exp430fr4133.

### 3.2.8 NTC Thermistor

NTC thermistors are thermally sensitive resistors whose resistance decreases with increasing temperature, so they can be used in temperature sensing by measuring their resistance.

**Figure 9. NTC Thermistor**

The NTC thermistor on board RT1 has a zero-power resistance of 100 k at 25°C. The NTC thermistor is from muRata part number NXRT15WF104FA1B040.

Table 1 shows the specification of NXRT15WF104FA1B040.

**Table 1. NXRT15WF104FA1B040**

| PART NUMBER | RESISTANCE (25°C) (ohm) | B-CONSTANT (25-50°C) (K) | B-CONSTANT (25-80°C) (REFERENCE VALUE) (K) | OPERATING CURRENT FOR SENSOR (25°C) (mA) | TYPICAL DISSIPATION CONSTANT (25°C) (mW/°C) |
|---|---|---|---|---|---|
| NXRT15WF104FA1 Bx | 100k ±1% | 4250 ±1% | 4303 | 0.04 | 1.5 |

For more information, please refer to http://www.murata.com/products/catalog/pdf/r44e.pdf

Because the resistance of the NTC Thermistor is high at low temperatures, even a small current flow causes the thermistor to generate heat. Therefore, when measuring the resistance, use a current level of 1/10th to 1/20th of the allowable operating current for reference.

On the EVM board, the NTC thermistor is connected in a series with a normal 100-k ohm resistor to form a voltage-divider circuit. The divider circuit is biased with the 1.2-V voltage reference from the MSP430FR4133. The ADC channel A8 measures the voltage across the NTC thermistor as seen in Figure 10. After calibration, a measurement accuracy of 0.5°C can be implemented.

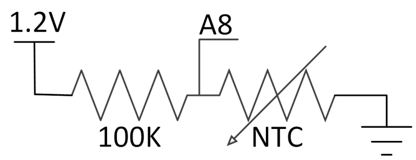



**Figure 10. NTC Voltage-divider Circuit**

### 3.3 Design Files

Schematics and Layout prints can be found in Section 8. All design files including Schematic and Layout in PDF and native format as well as Bill of Material, Gerber files and TI-TXT firmware images are made available in TIDM-FRAM-THERMOSTAT.

### 3.4 Hardware Change Log

**Table 2. Hardware Change Log**

| PCB REVISION | DATE | AUTHOR | DESCRIPTION |
|---|---|---|---|
| Rev 1.0 | 8/31/2014 | A0222632 | Initial release for first prototype run |

## 4 Software

This section describes the functionality and structure of the User Experience Software that is preloaded on the EVM.

### 4.1 Source Code File Structure

The project is split into multiple files as shown in Table 3. This split enables users to navigate and reuse parts of the project.

**Table 3. List of Source Files**

| NAME | DESCRIPTION |
|---|---|
| main.c | The user experience demo main function |
| msp_ts430fr4_global.c | Function file for system initialization |
| msp_ts430fr4_lcd.c | Function file for LCD |
| msp_ts430fr4_measure.c | Function file for temperature measurement |
| msp_ts430fr4_menu.c | Function file for menu |
| msp_ts430fr4_rs485.c | Function file for RS-485 communication |

## 4.2 Navigation and Menu

When the User Experience demo starts, it shows all the information on the LCD, such as time, temperature, and so on. The temperature updates every 10 seconds.

Users can configure settings with on-board buttons. Four buttons are on TIDM-FRAM-THERMOSTAT main board:

- S1 is the power on/off button that is used to turn on or turn off the system.
- S2 is the MODE button and used to switch the setting mode.
- S3 is the UP button.
- S4 is the DOWN button.

The main menu shows all of the available settings in the demo. Use the MODE button to select a setting option and use the up and down buttons to adjust the settings. In the current firmware, Figure 11 shows the menu setting logic.

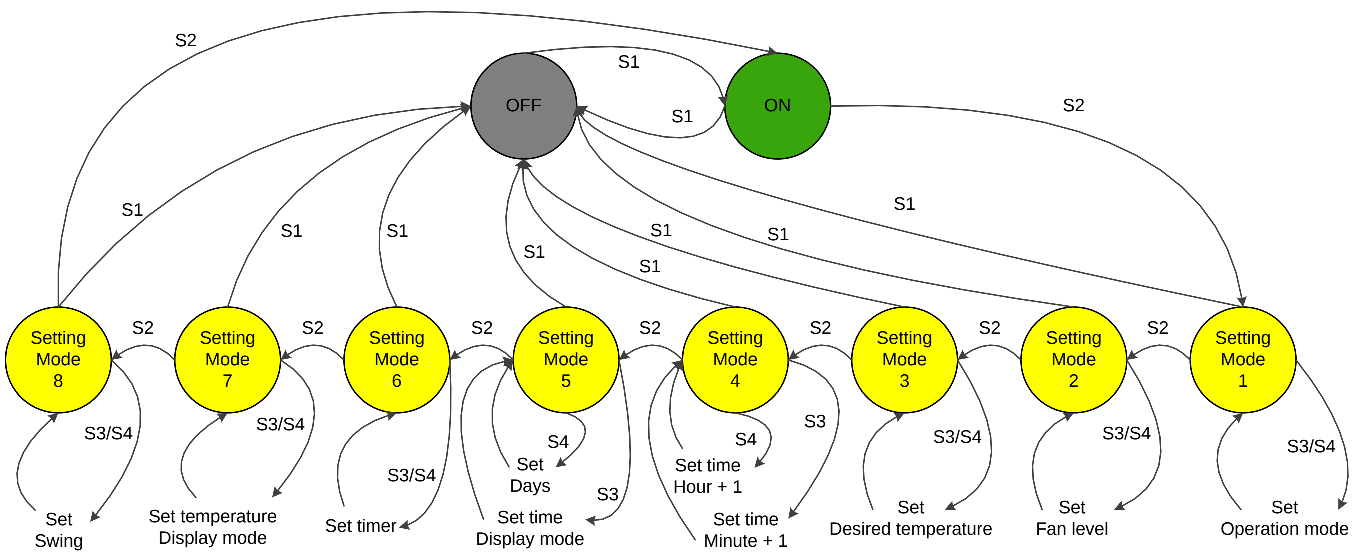



**Figure 11. State Machine**

- OFF: system standby, only RTC on. System is in standby (OFF) state at startup.
- ON: system active, RTC on, LCD on, temperature updates every 10 seconds.
- Setting Mode x: Eight setting modes are in the state machine. When users change these settings, each setting mode status will be displayed alone on the LCD.
  - Operation mode: Heat / Cool / Dehumidify / Fan
  - Fan level: Level 0 / 1 / 2 / 3 / 4 / Auto
  - Temperature setting: From 16°C to 32°C with 1°C step.
  - Time setting: S3 sets minute + 1; S4 sets hour + 1.
  - Time display format: S3 sets time display in 12-hour or 24-hour format; S4 sets days of week.
  - Timer setting: Default timer value is 1 hour; S3 timer adds 15 minutes; S4 timer subtracts 15 minutes.
  - Temperature display format: Set temperature display in format C or F.
  - Swing control: Turn on or turn off the swing.

# 5 Demo Example

The EVM supports the RS-485 remote control, remote turn on/off of the system, and temperature read back.

## 5.1 Installation

Before running the RS-485 remote control demo, users must install the provided USB-to-RS-485 adapter driver for data communication and Microsoft .NET Framework 4.0 for the GUI. The install file can be found in the Software\GUI folder of tidc669.zip.

The TIDM-FRAM-Thermostat GUI is a PC-based tool used to communicate with the thermostat via an RS-485 interface. This tool enables users to send commands to the thermostat, turn on/off the system, and read back the temperature.

## 5.2 Demonstration

1. Connect J2 to PC or laptop with a USB-to-RS-485 adapter.
2. Launch the TIDM-FRAM-Thermostat GUI in the Software\GUI folder of tidc669.zip. When the GUI runs, the screen shown in Figure 12 is displayed.

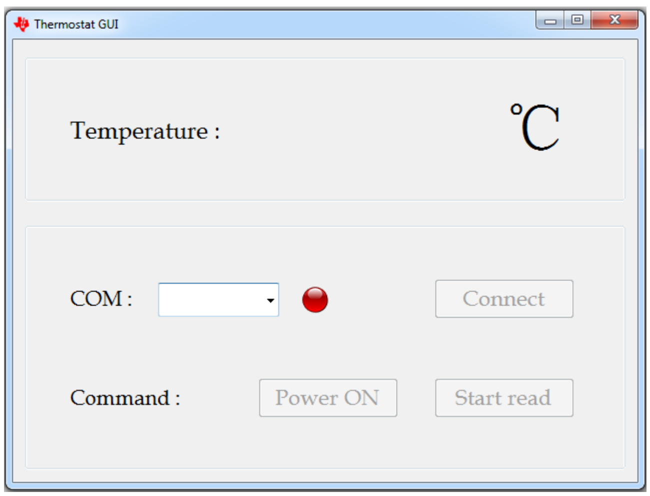



**Figure 12. Startup Screen**

3. To select the COM port to which the adapter is attached, click the Select COM button. In the drop-down menu, select the appropriate COM port for the adapter. More than one COM port may be listed in the COM window. To identify the appropriate COM port for the adapter, open Windows Device Manager and select the COM port with the name "Prolific USB-to-Serial Comm Port". Click connect; if the connection is successful, the connection light will turn green. The signal symbol on the LCD will indicate the connection status as well. Figure 13 shows the details.


**Figure 13. COM Port**

4. When the COM port is open, the Select COM port button is disabled, and the Command button is enabled. Users can then click the Power ON button to turn on the thermostat remotely, and can click the Start button to read back the current temperature.

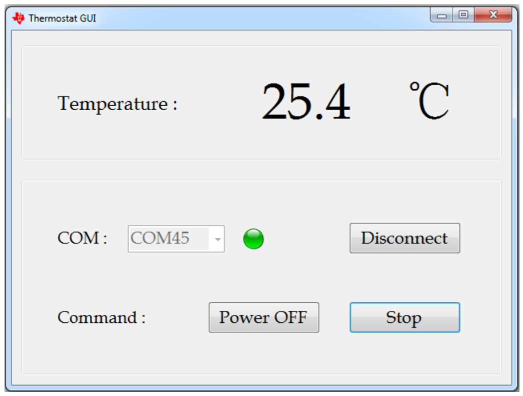



**Figure 14. Read Temperature**

# 6 Test Data

## 6.1 Temperature measurement

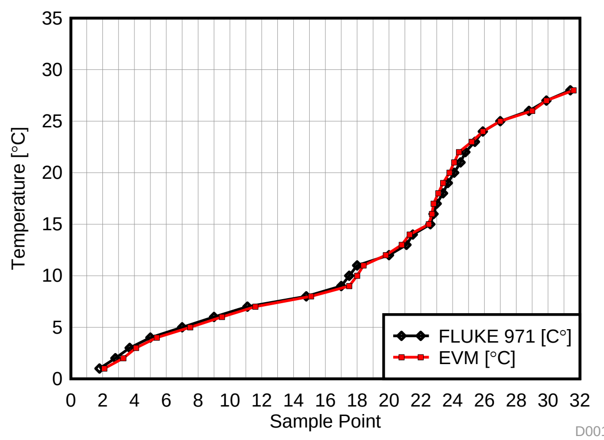



**Figure 15. Fluke 971 vs. EVM**

Figure 15 shows the temperature measurement by TIDM-FRAM-THERMOSTAT EVM and FLUKE 971 temperature humidity meter between 0°C to 35°C. The delta is within ±0.5°C.

## 6.2 Power consumption

**Table 4. Power Consumption**

| WORKING MODE | CURRENT |
|---|---|
| Standby | 1.8 µA (LDO IQ 0.5 µA) @25°C |
| Active | Average 10 µA (LCD 7.3 µA, LDO IQ 0.5 µA) @25°C |

IQ: Quiescent current.

# 7 References

1. MSP430FR4133 Datasheet
2. MSP430FR4xx User's Guide
3. http://en.wikipedia.org/wiki/Thermostat

# 8 Design Files

## 8.1 Schematics

To download the schematics, see the design files at TIDM-FRAM-THERMOSTAT.

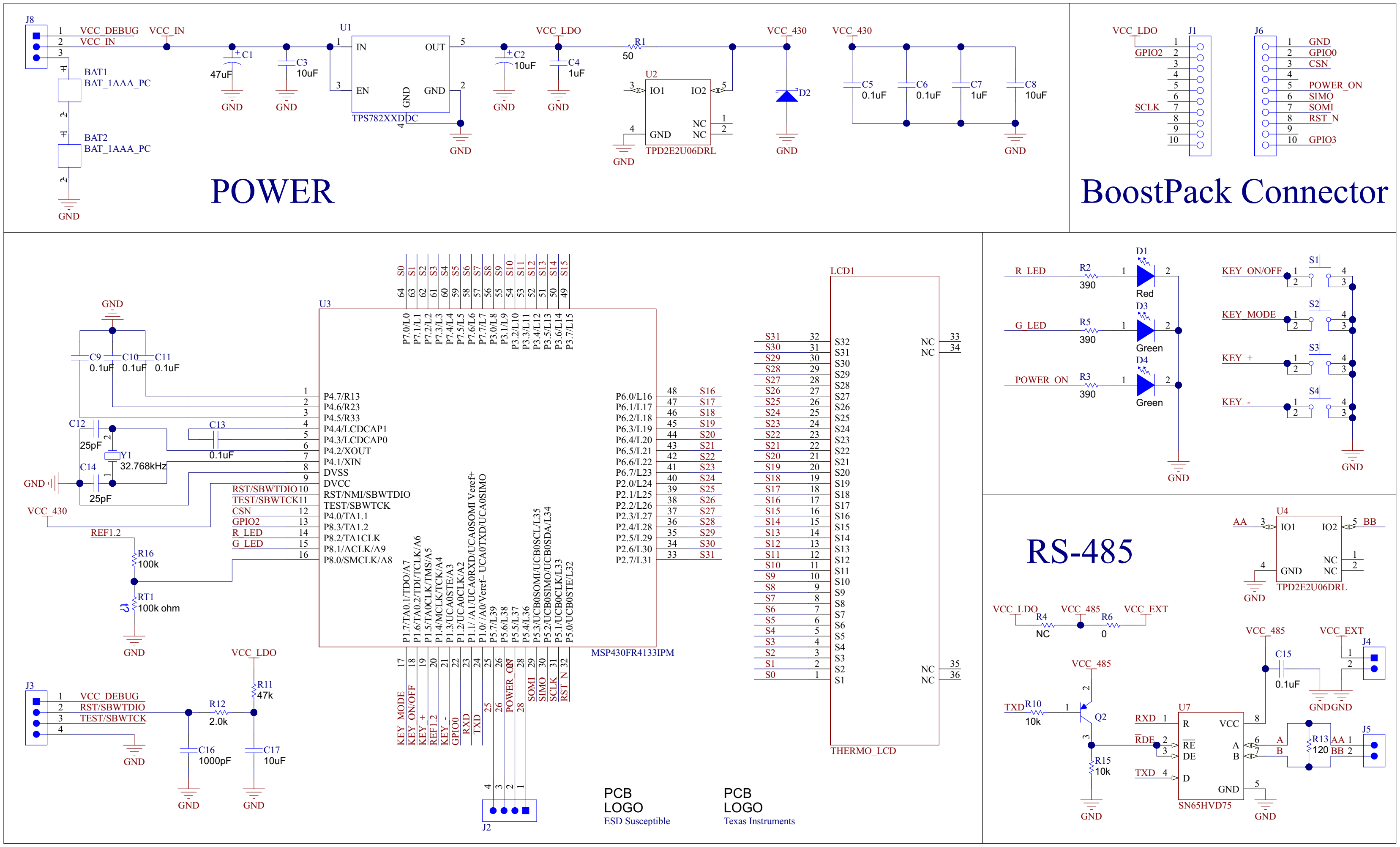


**Figure 16. Schematics Page 1**

## 8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDM-FRAM-THERMOSTAT.

**Table 5. BOM**

| ITEM | DESIGNATOR | QTY | VALUE | PART DESCRIPTION | MANUFACTURER | MANUFACTURER PART NUMBER | DIGIKEY PART NUMBER | PCB FOOTPRINT |
|---|---|---|---|---|---|---|---|---|
| 1 | BAT1, BAT2 | 2 | AAA | Battery Holder, 1 AAA Cells, PC-mount | Keystone | 2466 | 2466K-ND | BC1AAAPC |
| 2 | C1 | 1 | 47uF | CAP, TA, 47uF, 6.3V, +/-10%, 0.8 ohm, SMD | AVX | TPSA476K006R0800 | 478-3079-1-ND | 3216-18 |
| 3 | C2 | 1 | 10uF | CAP, TA, 10uF, 16V, +/-10%, 3 ohm, SMD | Vishay-Sprague | 293D106X9016A2TE3 | 718-1123-1-ND | 3216-18 |
| 4 | C3, C8, C17 | 3 | 10uF | CAP, CERM, 10uF, 6.3V, +/-20%, X5R, 0603 | Kemet | C0603C106M9PACTU | 399-5504-1-ND | 603 |
| 5 | C4, C7 | 2 | 1uF | CAP, CERM, 1uF, 16V, +/-10%, X5R, 0603 | Kemet | C0603C105K4PACTU | 399-5090-1-ND | 603 |
| 6 | C5, C6, C9, C10, C11, C13, C15 | 7 | 0.1uF | CAP, CERM, 0.1uF, 16V, +/-5%, X7R, 0603 | Kemet | C0603C104J4RACTU | 399-1097-1-ND | 603 |
| 7 | C12, C14 | 2 | 25pF | CAP, CERM, 25pF, 50V, +/-11%, C0G/NP0, 0603 | AVX | 06035A2R2CAT2A | 478-1155-1-ND | 603 |
| 8 | C16 | 1 | 1000pF | CAP, CERM, 1000pF, 100V, +/-5%, X7R, 0603 | AVX | 06031C102JAT2A | 478-3698-1-ND | 603 |
| 9 | D1 | 1 | Red | LED, Red, SMD | Lite-On | LTST-C170KRKT | 160-1415-1-ND | LED_LTST-C170 |
| 10 | D2 | 1 | Diode | Diode, Schottky, 40V, 0.03A, SOD-323 | Diodes Inc. | SDMK0340L-7-F | SDMK0340LDICT-ND | sod-323 |
| 11 | D3, D4 | 2 | Green | LED, Green, SMD | Lite-On | LTST-C171GKT | 160-1423-1-ND | LED_LTST-C171 |
| 12 | J1, J6 | 2 | 10x1 | Receptacle 100mil 10x1, Tin, TH | Sullins Connector Solutions | PPTC101LFBN-RC | S7008-ND | CONN_PPTC101LFBN-RC |
| 13 | J2, J3 | 2 | 4x1 | Header, TH, 100mil, 4x1, Gold plated, 230 mil above insulator | Samtec | TSW-104-07-G-S | SAM1029-04-ND | TSW-104-07-G-S |
| 14 | J4, J5 | 2 | 2x1 | Header, TH, 100mil, 2x1, Gold plated, 230 mil above insulator | Samtec | TSW-102-07-G-S | SAM1029-02-ND | TSW-102-07-G-S |
| 15 | J8 | 1 | 3x1 | Header, TH, 100mil, 3x1, Gold plated, 230 mil above insulator | Samtec | TSW-103-07-G-S | SAM1029-03-ND | TSW-102-07-G-S |
| 16 | LCD1 | 1 | LCD | Custom THERMOSTAT LCD | Provided by TI | N/A | N/A | TH_LCD |
| 17 | Q2 | 1 | PNP | Transistor, PNP, 40V, 0.2A, SOT-23 | Diodes Inc. | MMBT3906-7-F | MMBT3906-FDICT-ND | SOT-23 |
| 18 | R1 | 1 | 50 | RES, 50 ohm, 0.5%, 0.1W, 0603 | Yageo America | RT0603DRE07150RL | RT0603DRE07150RL-ND | 603 |
| 19 | R2, R3, R5 | 3 | 390 | RES, 390 ohm, 0.1%, 0.1W, 0603 | Susumu Co Ltd | RG1608P-391-B-T5 | RG16P390BCT-ND | 603 |
| 20 | R4, R6 | 2 | 0 | RES, 0 ohm, 5%, 0.25W, 1206 | Panasonic | ERJ-8GEY0R00V | P0.0ECT-ND | 1206 |

**Table 5. BOM (continued)**

| ITEM | DESIGNATOR | QTY | VALUE | PART DESCRIPTION | MANUFACTURER | MANUFACTURER PART NUMBER | DIGIKEY PART NUMBER | PCB FOOTPRINT |
|---|---|---|---|---|---|---|---|---|
| 21 | R10, R15 | 2 | 10k | RES, 10k ohm, 5%, 0.1W, 0603 | Vishay-Dale | CRCW060310K0JNEA | 541-10KGCT-ND | 603 |
| 22 | R11 | 1 | 47k | RES, 47k ohm, 5%, 0.1W, 0603 | Vishay-Dale | CRCW060347K0JNEA | 541-47KGCT-ND | 603 |
| 23 | R12 | 1 | 2.0k | RES, 2.0k ohm, 5%, 0.1W, 0603 | Vishay-Dale | CRCW06032K00JNEA | 541-2.0KGCT-ND | 603 |
| 24 | R13 | 1 | 120 | RES, 120 ohm, 5%, 0.1W, 0603 | Vishay-Dale | CRCW0603120RJNEA | 541-120GCT-ND | 603 |
| 25 | R16 | 1 | 100k | RES, 100k ohm, 1%, 0.25W, 1206 | Vishay-Dale | CRCW1206100KFKEA | 541-100KFCT-ND | 1206 |
| 26 | RT1 | 1 | 100k | THERMISTOR 100K OHM 40MM L NTC | Murata | NXRT15WF104FA1B040 | 490-7169-ND | THROUGH HOLE |
| 27 | S1, S2, S3, S4 | 4 | key | SWITCH TACTILE SPST-NO 0.02A 15V, TH | Panasonic | EVQ-PAD04M | P8007S-ND | SW_EVQ-PAD04M |
| 28 | U1 | 1 | TPS78228 | Ultra-Low Quiescent Current, IQ 500nA LDO | Texas Instruments | TPS78228DDCR | 296-23826-1-ND | TSOT-23-5[DDC] |
| 29 | U2, U4 | 2 | TPD2E2U06 | DUAL CHANNEL HIGH SPEED ESD PROTECTION DEVICE, DRL0005A | Texas Instruments | TPD2E2U06DRL | 296-38361-1-ND | DRL0005A |
| 30 | U3 | 1 | MSP430FR4133 | 16-bit Ultra-Low-Power MCU | Texas Instruments | MSP430FR4133IPM | N/A | PM0064A_M |
| 31 | U7 | 1 | SN65HVD75 | High Temperature 3.3 V RS-485 Transceiver | Texas Instruments | SN65HVD75DGKR | 296-35070-1-ND | D0008A_N |
| 32 | Y1 | 1 | 32.768k | Crystal, 32.768kHz, 12.5pF, SMD | Abracon Corporation | AB26TRQ-32.768KHZ-T | 535-12051-1-ND | XTAL_MS3V-T1R |

### 8.3 Layer Plots

To download the layer plots, see the design files at TIDM-FRAM-THERMOSTAT.

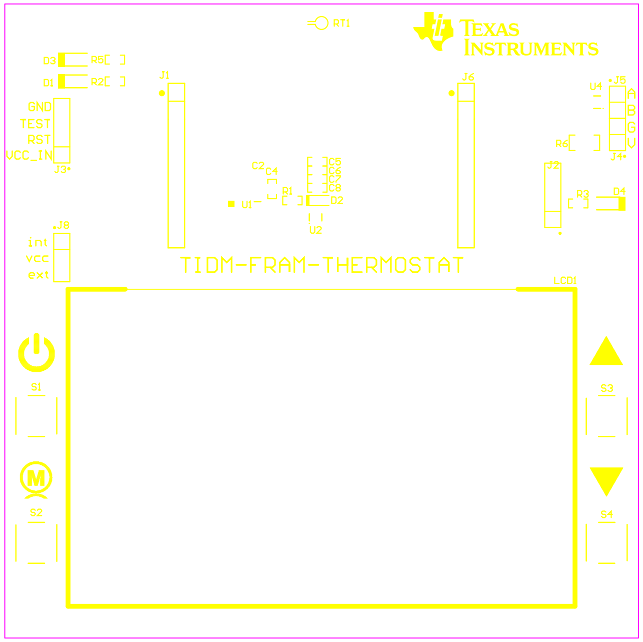



**Figure 17. Top SilkScreen Overlay**

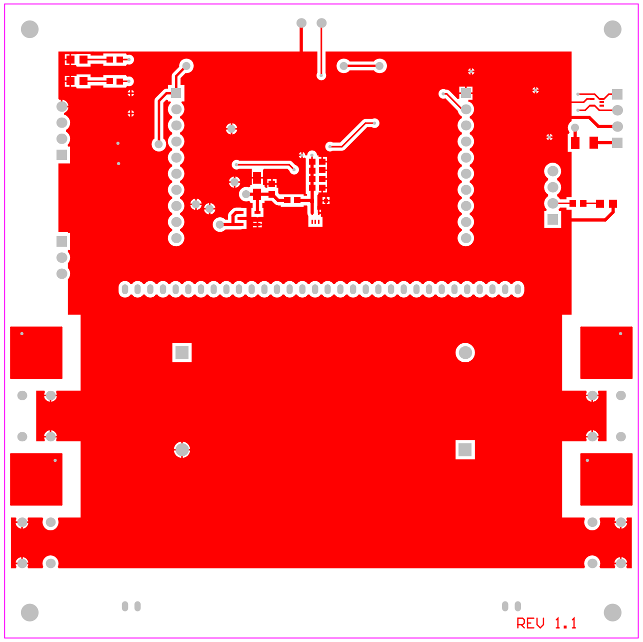



**Figure 18. Top Layer**

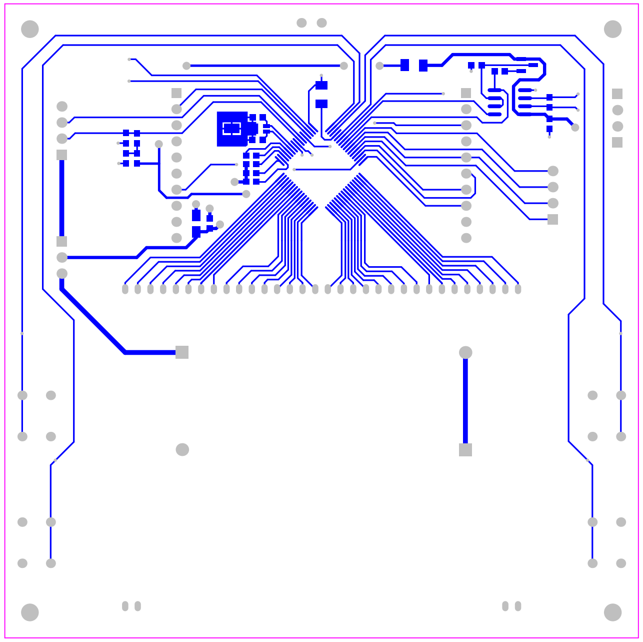


Figure 19. Bottom Layer

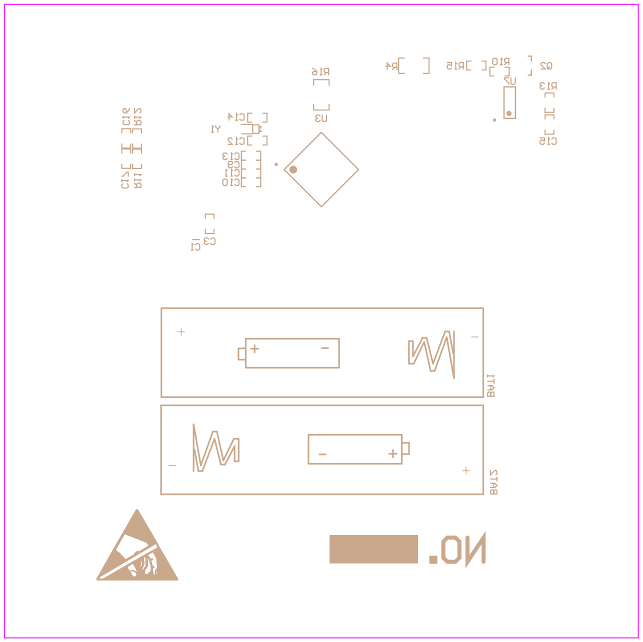


Figure 20. Bottom Silkscreen Overlay

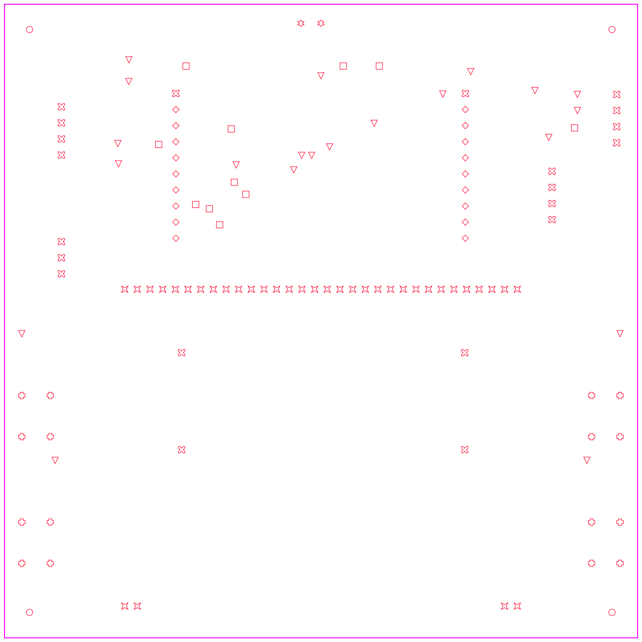


Figure 21. Drill Drawing for Top and Bottom Layers

### 8.4 Altium Project

To download the Altium project files, see the design files at TIDM-FRAM-THERMOSTAT.

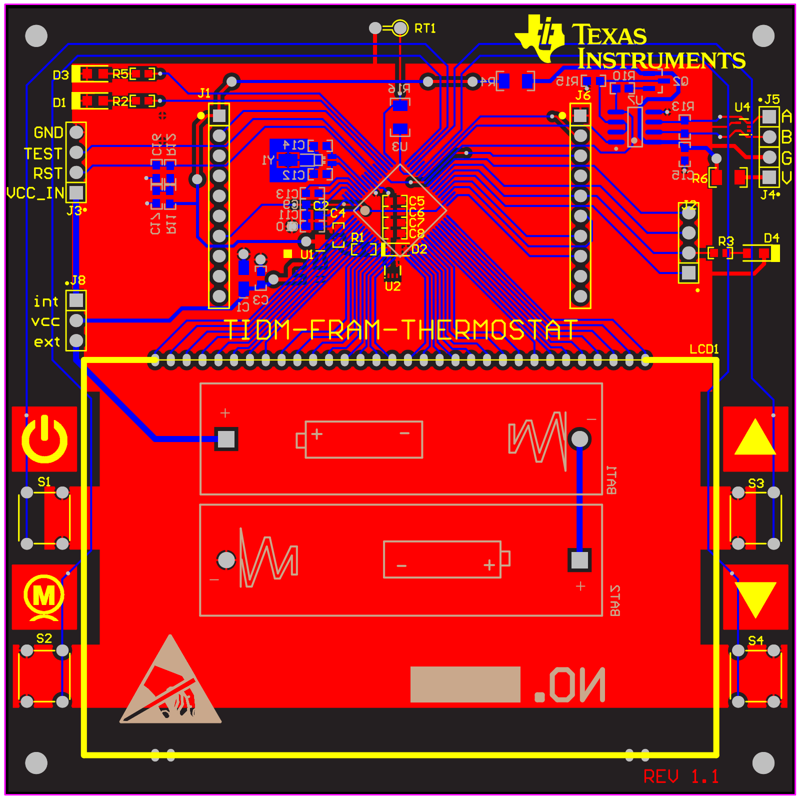



Figure 22. Altium Image 1

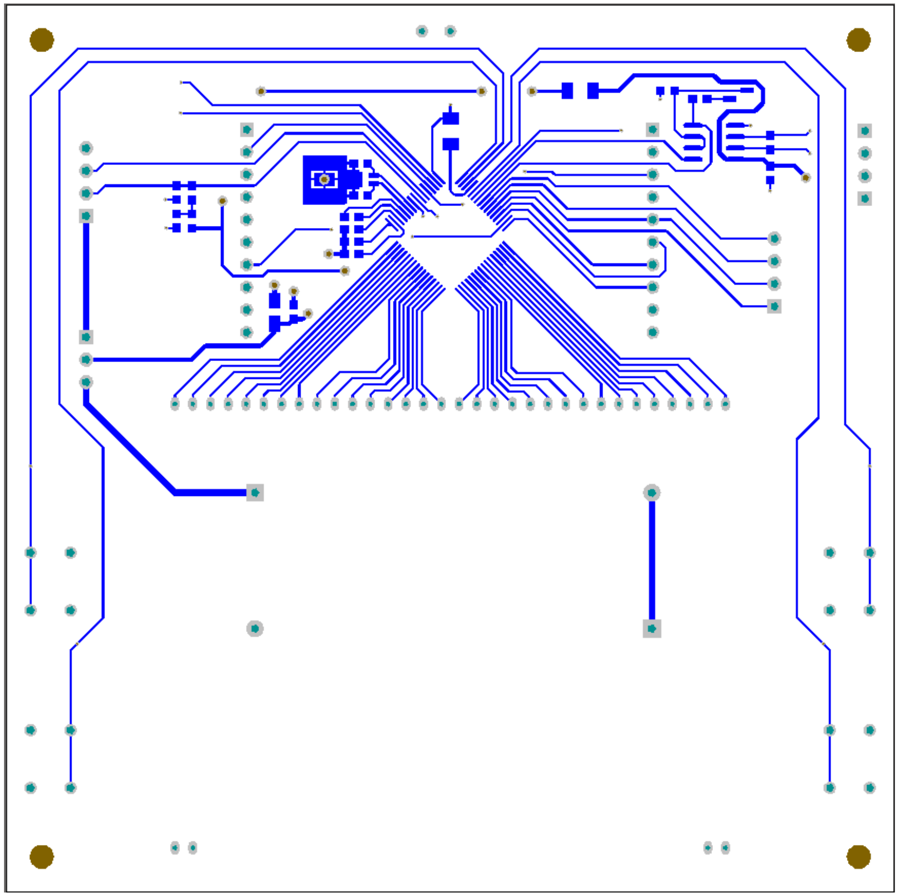


Figure 23. Altium Image 2

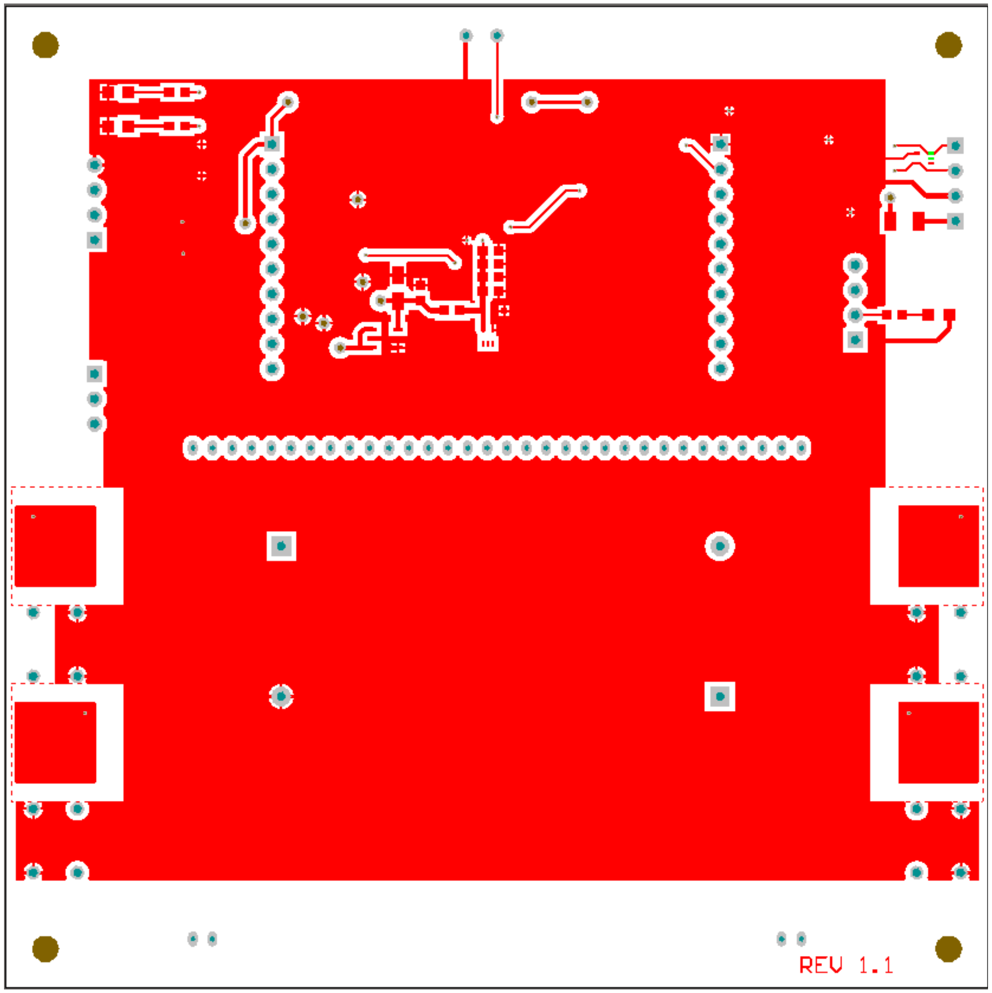



**Figure 24. Altium Image 3**

### 8.5 Assembly Drawings

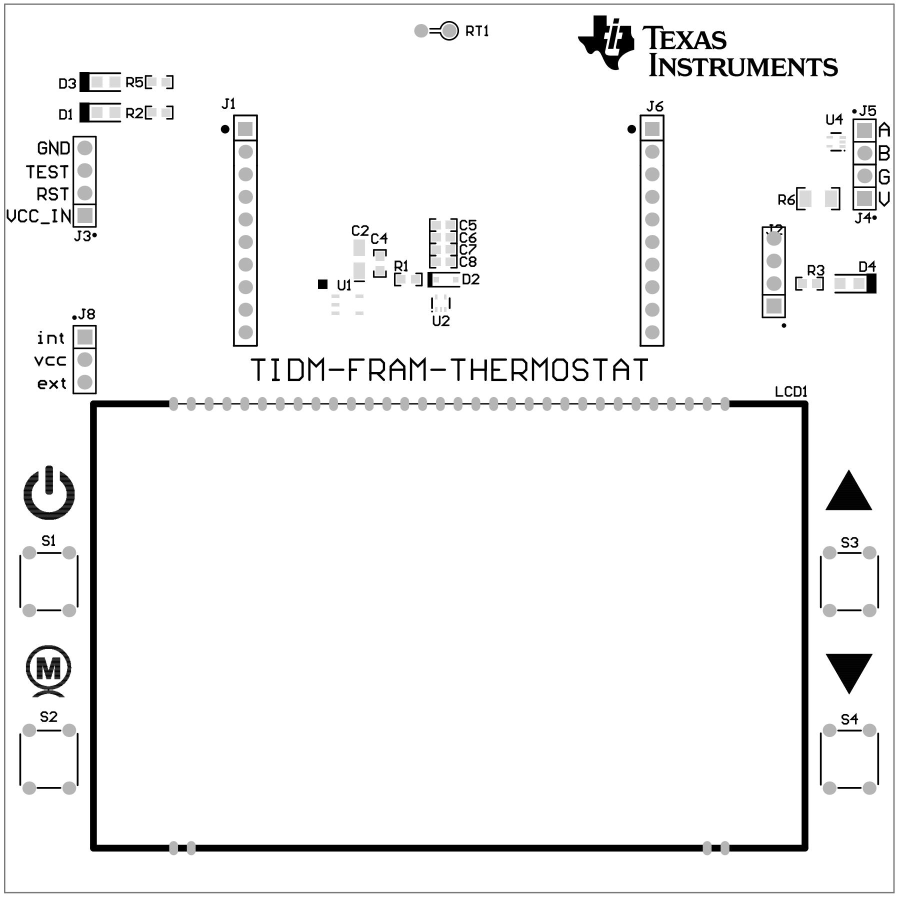



**Figure 25. Top Assembly Drawing**

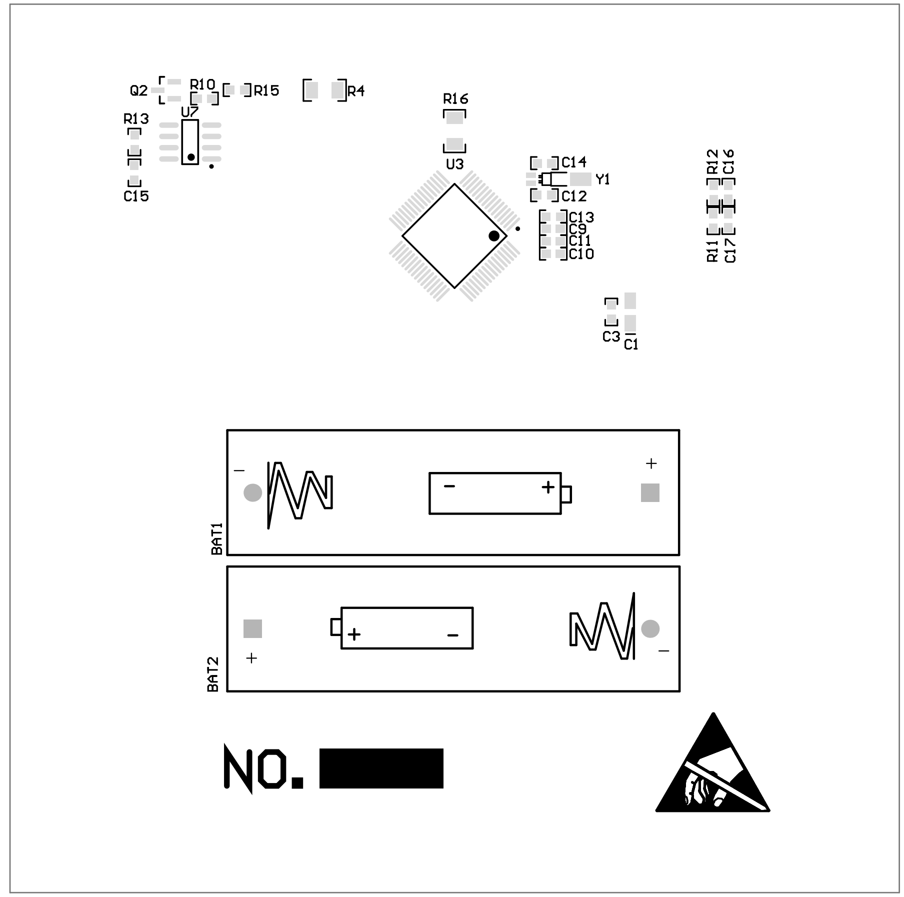



**Figure 26. Bottom Assembly Drawing**

## 9 About the Author

**LING ZHU** is an MSP430 applications engineer at Texas Instruments where he is responsible for developing reference design solutions and customer support for MSP430 value line devices. Ling earned his master of Measure & Control Technology from XIDIAN University in China.

## IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have ***not*** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265