

# TI Designs: TIDA-01626

## 低功耗、高精度温度计板参考设计



### 说明

这款温度计显示板为用户提供了易于读取的模块，方便测量环境空气温度。此参考设计展示了为带有集成温度感应能力的设备开发低功耗系统时主要关注的问题。该系统的尺寸为 1.83 英寸 × 1.45 英寸，可以满足小巧外形设备的需求，为在空间有限环境中使用提供了便利。板载微控制器 (MCU) 通过 I2C 通信协议与温度传感器进行通信，并将测量的结果通过 SPI 协议显示在 LCD 上。

### 资源

- TIDA-01626 设计文件夹
- TMP116 产品文件夹
- MSP430FR5969 产品文件夹



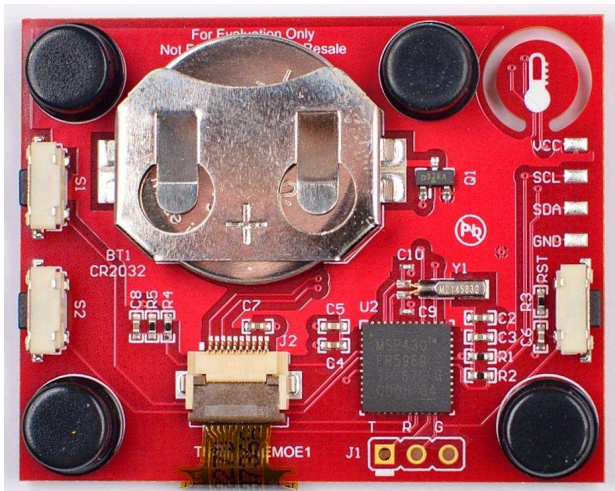
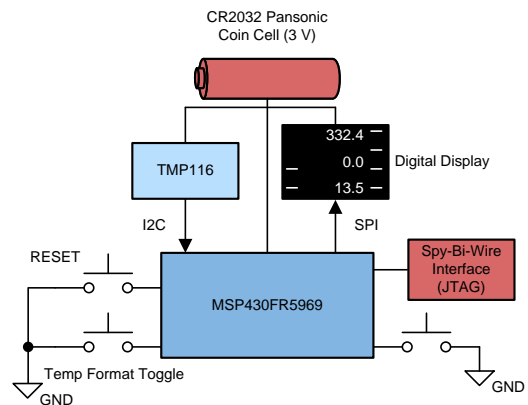
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### 特性

- 低功耗、高精度温度传感器
- 128x128 像素 LCD
- 超低功耗 MCU
- 电池供电
- 支持电池电压监控功能

### 应用

- 无线环境传感器
- 恒温器
- 个人电子产品



该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

## 1 System Description

The meter board comes pre-loaded with firmware that ensures successful operation upon connection of the coin cell battery. Because the MSP430™ MCU is flashed using JTAG protocol, the test, reset, and ground pins are broken out to a three-pin header for the user to have the option to flash the MSP430FR5969 MCU. The device features three push-buttons. Button S1 functions to perform RESET, S2 switches the temperature display format on the display (Celsius or Fahrenheit), and another button (S3) can be programmed by the user. Test points are provided for the user to probe the clock and data signal lines corresponding to I2C data transfer in addition to power and ground probe locations.

### 1.1 Key System Specifications

表 1. Key System Specifications

PARAMETER	PART NUMBER	KEY SPECIFICATIONS
Coin cell battery	CR2032	<ul style="list-style-type: none"> <li>• 3-V voltage output</li> <li>• 225-mAh nominal battery capacity</li> </ul>
Ultra-low-power MCU	MSP430FR5969	<ul style="list-style-type: none"> <li>• Wide supply voltage range (1.8 V to 3.6 V)</li> <li>• Active mode: 100 <math>\mu</math>A/MHz</li> <li>• Standby: 0.4 <math>\mu</math>A</li> <li>• Real-time clock: 0.25 <math>\mu</math>A</li> <li>• Shutdown: 0.02 <math>\mu</math>A</li> </ul>
Low-power, high-accuracy temperature sensor	TMP116	<ul style="list-style-type: none"> <li>• Temperature accuracy: <math>\pm 0.2^{\circ}\text{C}</math> (max) from <math>-10^{\circ}\text{C}</math> to <math>+85^{\circ}\text{C}</math></li> <li>• Shutdown current: 250 nA</li> <li>• 16-bit resolution at <math>0.0078^{\circ}\text{C}</math> (1 LSB)</li> </ul>
128x128-pixel LCD	LSO13B7DH03	Super low-power consumption TFT panel (50 $\mu$ W = no display update, 130 $\mu$ W = display update)

## 2 System Overview

### 2.1 Block Diagram

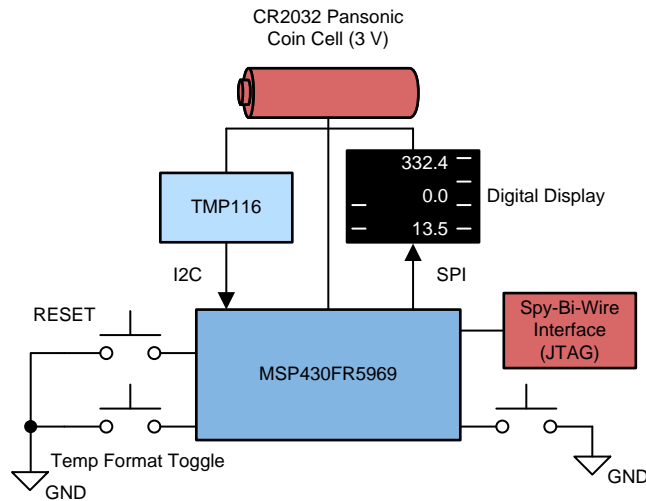


图 1. TIDA-01626 Block Diagram

### 2.2 Design Considerations

The primary design consideration in this reference design is the choice of low power-consumption devices.

A battery voltage monitoring system allows the user to implement in firmware. A potential divider serves to feed an ADC-enabled GPIO of the MSP430 MCU. That way, voltage sags intrinsic to battery operation over time can be monitored and optionally displayed along with temperature measurement results; however, this requires firmware modification.  $VCC_{Monitor}$  is calculated as follows:

$$VCC_{Monitor} = \frac{R5 * VCC}{R4 + R5} \quad (1)$$

Select R4 and R5 to provide appropriate drive current to the ADC. In addition, the system features a reverse polarity protection FET applied to the battery terminals. This FET acts as a load switch in the system. Looking at the schematic, the body diode of Q1 sits connected between the drain and source of Q1. The anode is connected to the drain, while the cathode is connected to the gate. When the battery is connected correctly, the body diode is forward biased and conducts current from the drain to the source. Because Q1 is a P-channel MOSFET, the gate voltage is brought below the source voltage, providing the correct turnon condition. When the battery is connected in reverse, the gate of Q1 is receiving a voltage above the source voltage. Therefore, Q1 does not turn on and current is not passed to the load through conduction of the body diode.

## 2.3 Highlighted Products

This reference design features the following TI devices:

- MSP430FR5969
- TMP116

For more information on these devices, see their respective product folders at [www.ti.com](http://www.ti.com).

### 2.3.1 MSP430FR5969 Mixed-Signal Microcontroller

The MSP430FR5969 is an ultra-low-power MCU that is optimized for lowered energy budgets in end equipment.

The device is a member of the MSP430FR59xx family of ultra-low-power mixed-signal MCUs featuring generous FRAM capabilities to enhance low-power designs in addition to intelligent peripherals to allow for varied application implementation. Updating FRAM takes 100× less time than DRAM, and there is no pre-erase required. In addition, FRAM includes faster write speeds, unified memory, and low-energy writes. Unified memory refers to program, data, and storage registers in one single place, which expedites the software run.

Because of its fast write speeds, FRAM has near infinite endurance. In a remote sensor, data could be written more often for improved data accuracy, or it could collect data for longer. Due to the lack of a charge pump, FRAM enables lower average and peak power during writes. FRAM is also nonvolatile (that is, retains its contents upon power loss). Using the MSP430 MCU with FRAM allows for on-the-fly writes, as opposed to buffered in RAM. The bitwise programmable memory can be used at the programmer's convenience for data or program storage. FRAM also offers advantages in security and is inherently more secure due to its makeup. Also, de-layering is not effective.

In comparison to MCUs with flash, FRAM:

- Is very easy to use
- Requires no setup or preparation such as unlocking of control registers
- Is not segmented and each bit is individually erasable, writable, and addressable
- Does not require an erase before a write
- Allows low-power write accesses (does not require a charge pump)
- Can be written to across the full voltage range (1.8 V to 3.6 V)
- Can be written to at speeds close to 8MBps (maximum flash write speed including the erase time is approximately 14 kBps)
- Does not require additional power to write to FRAM when compared to reading from FRAM

表 2 summarizes the MSP430 FRAM advantages:

**表 2. MSP430™ FRAM Advantages**

SPECIFICATION	FRAM	SRAM	FLASH
Write speed per word	125 ns	< 125 ns	85 μs
Erase time	No pre-erase required	No pre-erase required	23 ms for 512 bytes
Bitwise programmable	Yes	Yes	No
Write endurance	10 <sup>15</sup> writes	N/A	10 <sup>5</sup> writes per erase cycle
Nonvolatile	Yes	No	Yes
Internal write voltage	1.5 V	1.5 V	12 V to 14 V (charge pump required)

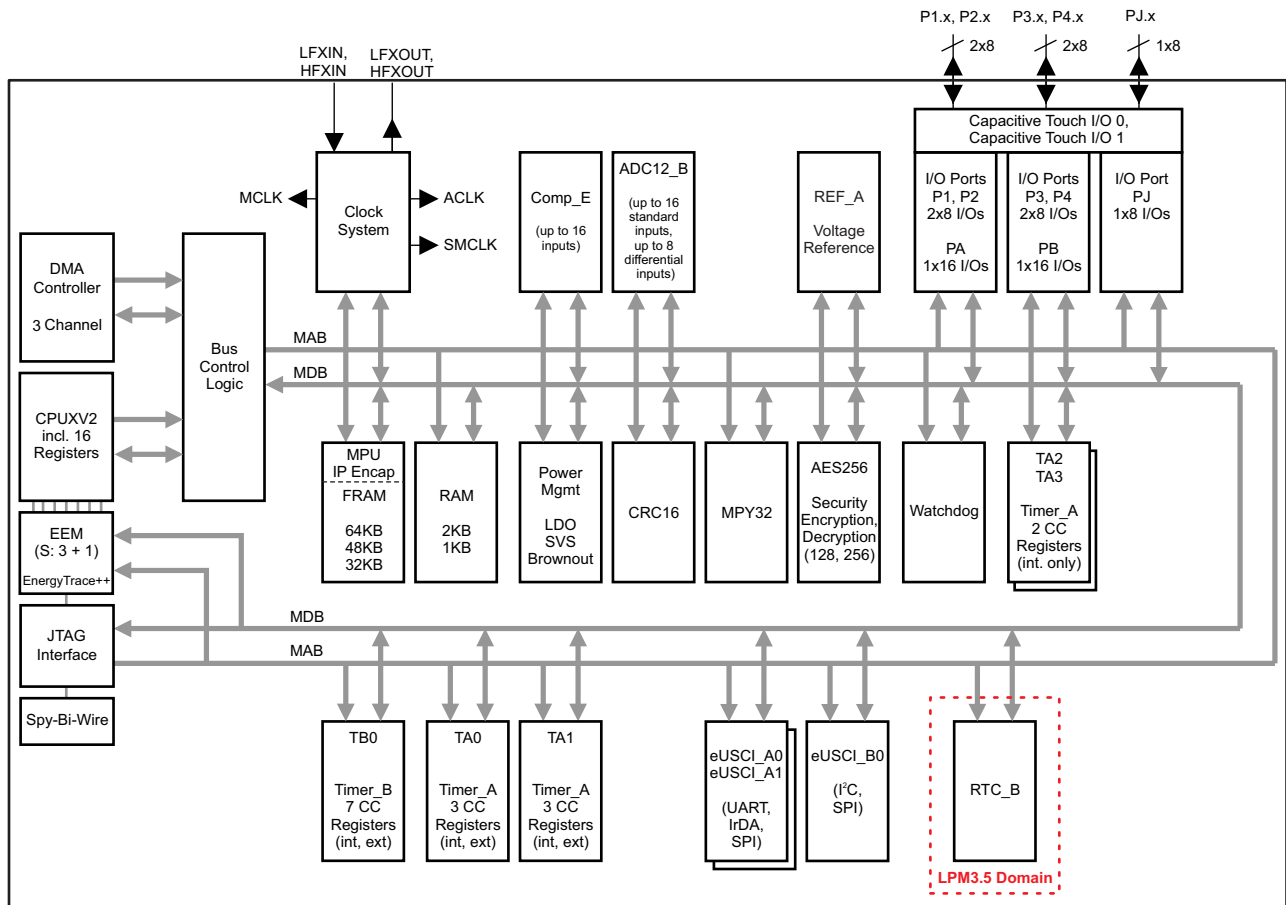


图 2. MSP430 Functional Block Diagram

### 2.3.2 TMP116 Temperature Sensor

The TMP116 sensor measures the ambient air temperature with high precision and low power consumption. This device provides a 16-bit temperature result with a resolution of 0.0078°C without calibration. The TMP116 units are 100% tested on a production setup that is NIST traceable and verified with equipment calibrated to ISO and IEC 17025 accredited standards. The sensor comes in a WSON (2.00 mm × 2.00 mm) package and consumes minimal current that, in addition to providing power savings, minimizes self-heating and improves measurement accuracy. The TMP116 operates from 1.9 V to 5.5 V and typically consumes 3.5  $\mu$ A.

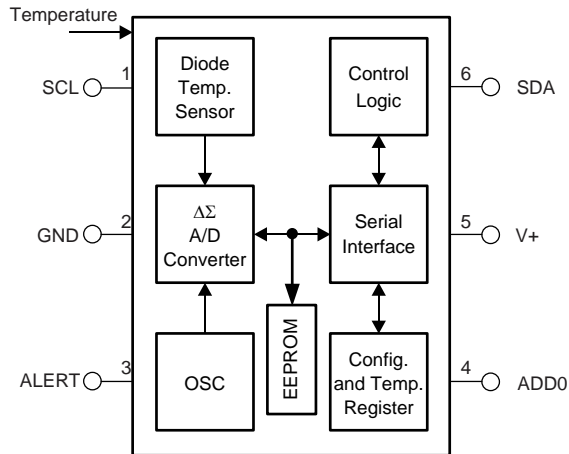


图 3. TMP116 Functional Block Diagram

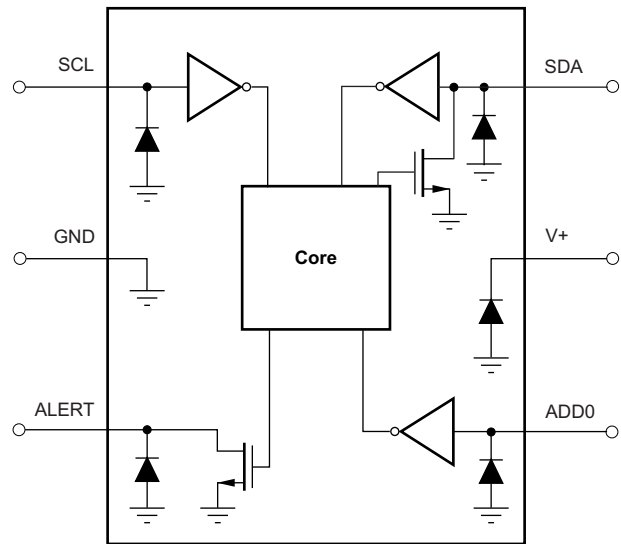


图 4. TMP116 Equivalent Internal ESD Protection Circuitry

## 3 Hardware, Software, Testing Requirements, and Test Results

### 3.1 Required Hardware and Software

The meter board kit includes everything needed to get started. Simply ensure that the battery is placed correctly in its holder and the TMP116 will perform its measurements to be displayed on the LCD.

#### 3.1.1 Hardware

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注: The TMP116METER-EVM requires a Panasonic CR2032 coin cell battery which is not included.

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The meter kit includes:

- MSP430FR5969 MCU
- Three push-button switches
- TMP116 temperature sensor
- LSO13B7DH03 LCD
- 32-kHz FC-135 32.7680KA-A3 crystal
- Associated discrete components

#### 3.1.2 Software

This reference design ships pre-loaded with software for its MSP430FR5969 MCU. When the battery is loaded, the display shows a Texas Instruments splash screen and then proceeds to display the current temperature and humidity. The rest of this section details the operation of the software.

Included with this reference design is a software package that contains a Code Composer Studio™ (CCS) project designed for the MSP430FR5969 mCU. For proper evaluation, import the CCS project into CCS v7.3 or later with TI Compiler v16.9.4.LTS or later.

After reset or power-on, several hardware initializations take place. All GPIO pins are configured as outputs and driven to logic low to save power. The pins that are used are then reconfigured for their intended purpose. The MSP430 MCU's internal oscillator, known as DCO, is configured for 8 MHz and connected to the internal signals SMCLK and MCLK. The external 32-kHz real-time crystal (RTC) is connected to the low-frequency clock inputs (LFXT), so the LFXT is configured as the source of the internal signal ACLK (Aux Clock). TIMER A is configured as a counter with ACLK as source. Conveniently, a count of 32768 ( $2^{15}$ ) is equivalent to 1 second, a count of 16384 ( $2^{14}$ ) is equivalent to a half second, and so on. The eUSCI B0 peripheral is configured for I2C communication with the TMP116 device. Finally, the eUSCI A1 peripheral is configured for SPI use with the Sharp® display, and the Sharp display is initialized. The next step in the software is to begin the loop.

On each iteration, the MSP430 MCU begins by checking the state of the button S1 and setting the Celsius and Fahrenheit variable. An I2C Write transaction is then performed to instruct the TMP116 to begin a temperature measurement. This measurement takes a few milliseconds (for conversion time, see [TMP116x High-Accuracy, Low-Power, Digital Temperature Sensor With SMBus- and I2C-Compatible Interface](#)), so the MSP430 MCU is configured for LPM4 during the down time. After TIMER A interrupts

and resumes, the temperature data is retrieved from the TMP116. The values for temperature are converted to characters using the tmp-decode.c library. This library is designed to provide string conversion without loss of 16-bit precision, but it can be adjusted for less precision. Finally, the temperature string updates the display and the MSP430 MCU returns to LPM4 for 2 seconds before looping.



### 3.1.2.1 Programming

The TMP116 meter can be flashed or debugged using the Spy-By-Wire (SBW) interface. The MSP430FR5969's SBW interface is available at header J1 pins TEST and RST. Connect these pins, and GND/VCC as appropriate, to an MSP430 LaunchPad™ or a standalone debugger such as MSP-FET. For more information, see [MSP Debuggers](#).

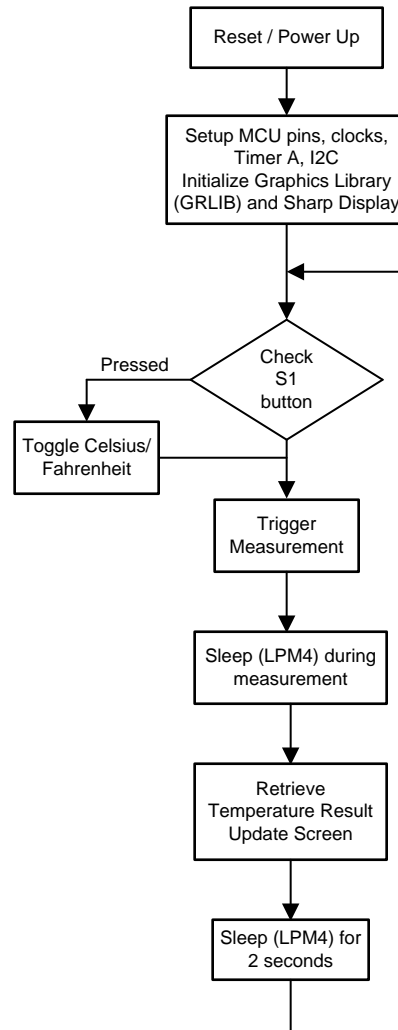


图 5. Software Flow Chart

## 3.2 Testing and Results

### 3.2.1 Test Setup

Although the current consumption of the system in its inactive mode is clearly defined by summing each inactive mode current specification in device data sheets, it is not so clear when the devices are active. Therefore, this test is set up to measure the current consumption of the system in active mode. The measurement is taken using a small series resistor connected to a simple instrumentation amplifier to perform a differential measurement across the resistor. This arrangement is used because the standard probes of an oscilloscope can only take single-ended measurements.

### 3.2.2 Test Results

图 6 yields the current consumption of the system while it is in its active mode:



图 6. System Current Consumption

Because the gain of the instrumentation amplifier is programmed to 1000, the 1.65-V measurement highlighted by cursor B corresponds to 1.02 mA consumed by the system. The transactions taking place during the system's active mode cycle are as follows:

1. MSP430 MCU wakes up due to interrupt by Timer A.
2. MSP430 MCU communicates with the TMP116 through I2C.
3. MSP430 MCU decodes information provided by TMP116.
4. MSP430 MCU communicates with the LCD through SPI to update the display.

These transactions are reflected in the oscilloscope capture whenever the voltage signal steps up. After these transactions take place, the MSP430 MCU returns to standby mode (LPM4), the TMP116 sensor returns to sleep mode, and the LCD returns to its low power consumption mode. During the active mode transactions, the system consumes between 0.2 mA to 1.02 mA. Because the active mode cycle is occurring about every 2 seconds, this active mode occurs 1800 times per hour. The active mode transactions each take about 100 ms to perform, so for 6.65% of an hour, the system is in active mode.

The blue arrow indicates the system current consumption in LPM4 (shutdown). Shutdown current consumption includes the MSP430 MCU, TMP116, and LCD in shutdown modes. A typical system shutdown current consumption is about 130  $\mu$ A.

公式 2 yields an estimate for the expected battery life of the CR2032:

$$\text{Battery Life (hours)} = \frac{\text{Nominal Battery Capacity (mAh)} \times \% \text{ of the hour spent active}}{\text{Active Mode Current Consumption (mA)}} + \frac{\text{Nominal Battery Capacity (mAh)} \times \% \text{ of the hour spent inactive}}{\text{Inactive Current Consumption (mA)}} \quad (2)$$

## 4 Design Files

### 4.1 Schematics

To download the schematics, see the design files at [TIDA-01626](#).

### 4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01626](#).

### 4.3 PCB Layout Recommendations

#### 4.3.1 Layout Considerations for MSP430-MCU

Ensure the following layout considerations for the MSP430 MCU:

- Ground and short traces for the external crystal to reduce parasitic capacitance.
- Bypass capacitors on DVCC, AVCC, and the reference pins if used.
- Avoid routing any high-frequency signals close to an analog signal line. For example, keep digital switching signals like a PWM or JTAG signals away from the oscillator circuit.
- For a detailed description of PCB layout considerations, see [Circuit Board Layout Techniques](#). This document is written primarily about op amps, but the guidelines are generally applicable for all mixed-signal applications.
- Consider proper ESD level protection to protect the device from unintended high-voltage electrostatic discharge. For more guidelines, see [MSP430™ System-Level ESD Considerations](#).

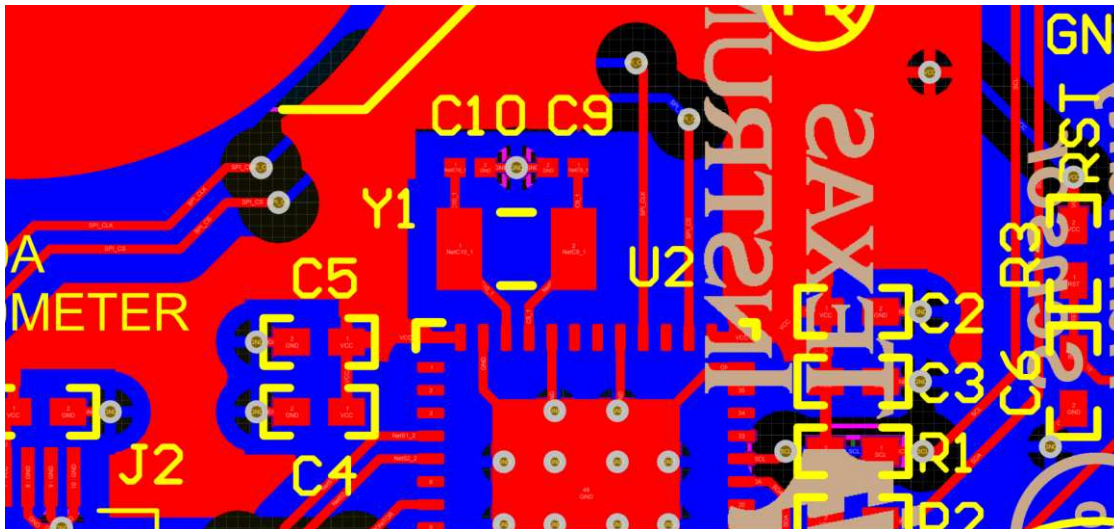


图 7. External Crystal Consideration

### 4.3.2 Layout Considerations for TMP116 Temperature Sensor

Isolate the temperature sensor from the rest of the PCB by eliminating copper layers below the device (GND, VDD) and creating a slot into the PCB around the sensor to enhance thermal isolation.

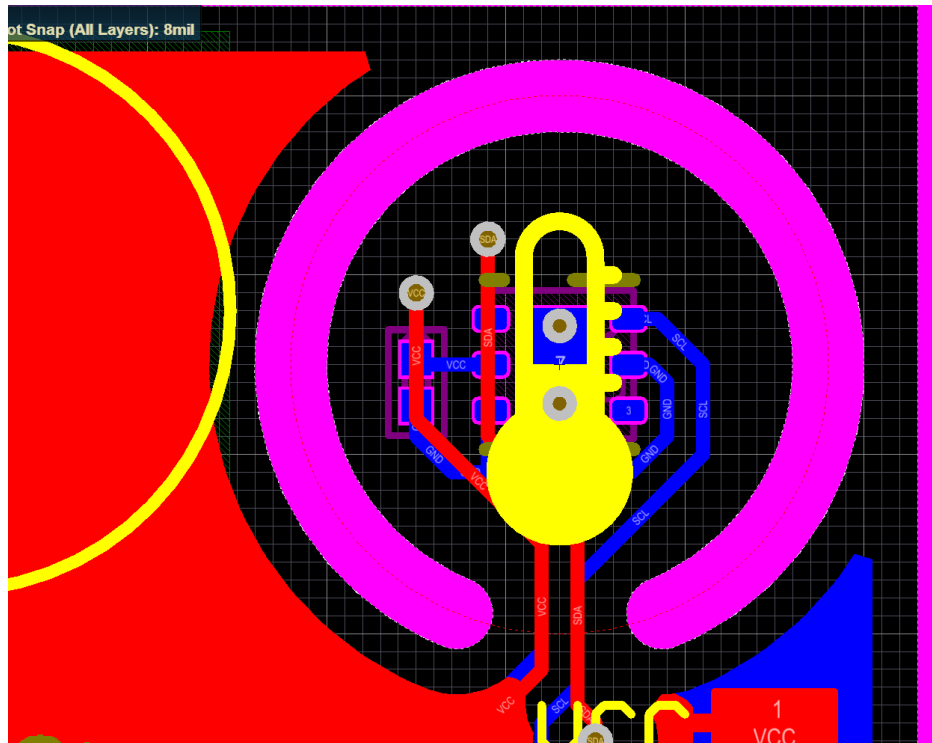


图 8. TMP116 Sensing Island

### 4.3.3 Layout Prints

To download the layer plots, see the design files at [TIDA-01626](http://www.ti.com.cn/TIDA-01626).

### 4.4 Altium Project

To download the Altium project files, see the design files at [TIDA-01626](http://www.ti.com.cn/TIDA-01626).

### 4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-01626](http://www.ti.com.cn/TIDA-01626).

### 4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01626](http://www.ti.com.cn/TIDA-01626).

## 5 Software Files

To download the software files, see the design files at [TIDA-01626](http://www.ti.com.cn/TIDA-01626).

## 6 Related Documentation

1. Texas Instruments, [TMP116x High-Accuracy, Low-Power, Digital Temperature Sensor With SMBus- and I2C-Compatible Interface Data Sheet](#)
2. Texas Instruments, [MSP430FR59xx Mixed-Signal Microcontrollers Data Sheet](#)
3. Texas Instruments, [Load Switches: What Are They, Why Do You Need Them And How Do You Choose The Right One? Application Report](#)
4. Texas Instruments, [TIDA-00461 IO-Link Firmware Update Reference Design Leveraging MSP430™ FRAM Technology Design Guide](#)

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