TI Designs: TIDA-01625
Low-Power, High-Accuracy Temperature and Humidity Meter Reference Design

Description

This humidity and temperature display meter board provides the user with an easy-to-read module to measure ambient air temperature and relative humidity. This reference design demonstrates the key considerations in developing a low-power system for devices with integrated temperature and humidity sense capability. It measures 1.83 in × 1.45 in, so the system is fitted to a small form factor for further convenience in space-constrained environments. The onboard microcontroller (MCU) communicates with the humidity sensor using I^2C communication protocol and displays the measurement onto an LCD through SPI protocol.

Resources

TIDA-01625	Design Folder
HDC2010	Product Folder
MSP430FR5969	Product Folder

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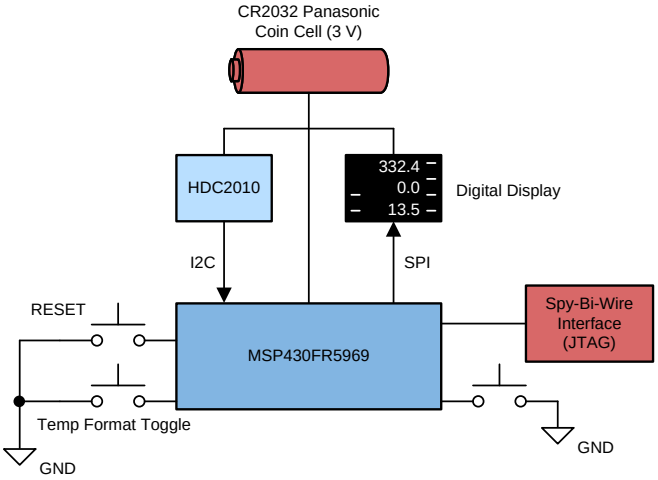
Features

- High-Accuracy, Low-Power Temperature and Humidity Sensor
- 128×128-Pixel LCD
- Ultra-Low-Power MCU
- Battery Powered
- Supports Battery Voltage Monitor Feature

Applications

- Wireless Environmental Sensor
- Thermostat
- Personal Electronics



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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

Table 1. Key System Specifications

PART DESCRIPTION	PART NUMBER	KEY SPECIFICATIONS
Coin cell battery	CR2032	• 3-V voltage output • 225-mAh nominal battery capacity
Ultra-low-power MCU	MSP430FR5969	• Wide supply voltage range (1.8 V to 3.6 V) • Active mode: 100 µA/MHz • Standby: 0.4 µA • Real-time clock: 0.25 µA • Shutdown: 0.02 µA
Low-power, high-accuracy humidity and temperature sensor	HDC2010	• Humidity accuracy: ± 2% • Sleep current: 50 nA • Average supply current (RH+ temperature): 550 nA
128×128 LCD	LSO13B7DH03	• Super low-power consumption TFT panel (50 µW = no display update, 130 µW = display update)

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2 System Overview

2.1 Block Diagram

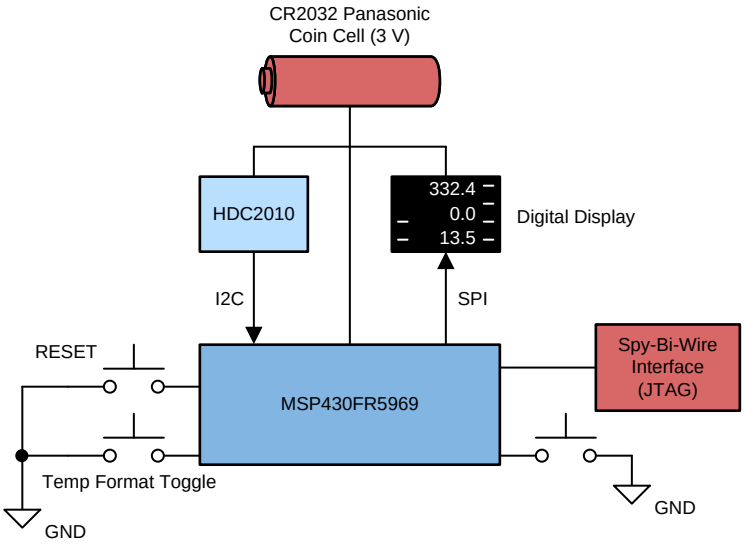

Figure 1. TIDA-01625 Block Diagram

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 and humidity measurement results; however, this requires firmware modification. $VCC_{Monitor}$ is calculated according to Equation 1:

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

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.

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2.3 Highlighted Products

This reference design features the following TI devices:

- MSP430FR5969
- HDC2010

For more information on these devices, see their respective product folders at 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 microcontrollers, 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 the sensor 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

Table 2 summarizes the MSP430 FRAM advantages:

Table 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^{15} writes	N/A	10^{5} writes per erase cycle
Nonvolatile	Yes	No	Yes
Internal write voltage	1.5 V	1.5 V	12 to 14 V (charge pump required)

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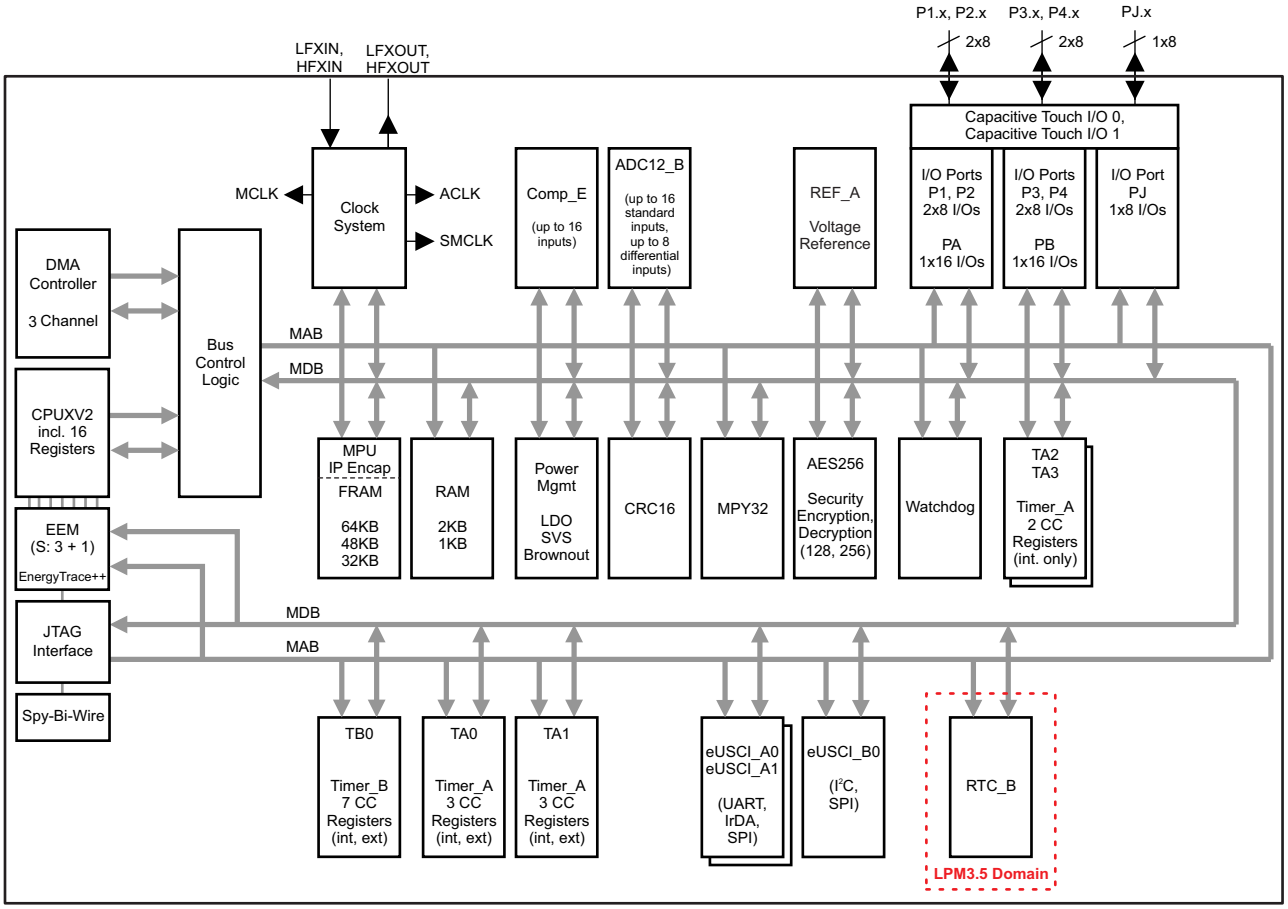

Figure 2. MSP430FR5969 Functional Block Diagram

2.3.2 HDC2010—Humidity and Temperature Sensor

The HDC2010 sensor measures the ambient air temperature and humidity with very low power consumption. The sensor comes in an ultra-compact Wafer Level Chip Scale Package (WLCSP) with the sensing element placed on the bottom part of the device, making it more robust against dirt, dust, and other environmental contaminants. One of the key features of the HDC2010 is its low power consumption, a key requirement for this coin cell based design. The device consumes a mere 50 nA of current in sleep mode, which is the default mode upon startup and is the mode it immediately returns to following a measurement.

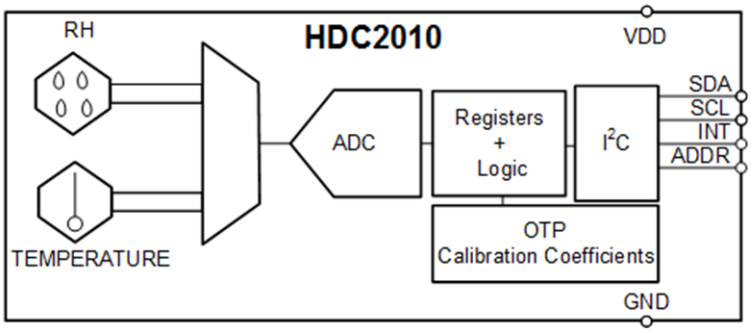

Figure 3. HDC2010 Functional Block Diagram

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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 HDC2010 will perform its measurements to be displayed on the LCD.

3.1.1 Hardware

NOTE: The HDC2010METER-EVM requires a Panasonic CR2032 coin cell battery which is not included.

The meter kit includes:

- MSP430FR5969 MCU
- Three push-button switches
- HDC2010 humidity and 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 the 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 HDC2010 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 HDC2010 to begin a temperature and humidity measurement. This measurement takes a few milliseconds (for conversion time, see *HDC2010 Low Power Humidity and Temperature Digital Sensors*), so the MSP430FR5969 is configured for LPM4 during the down time. After TIMER A interrupts and resumes, the temperature and humidity data is retrieved from the HDC2010. The values for temperature and humidity are converted to characters using the tmpdecode.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 and humidity strings update the display, and the MSP430FR5969 returns to LPM4 for 2 seconds before looping.

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3.1.2.1 Programming

The HDC2010 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*.

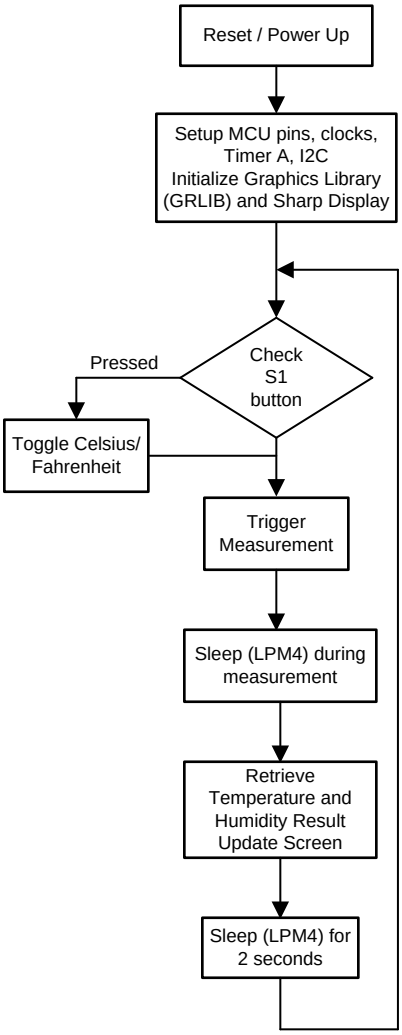

Figure 4. Software Flow Chart

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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

Figure 5 yields the current consumption of the system while it is in its active mode:

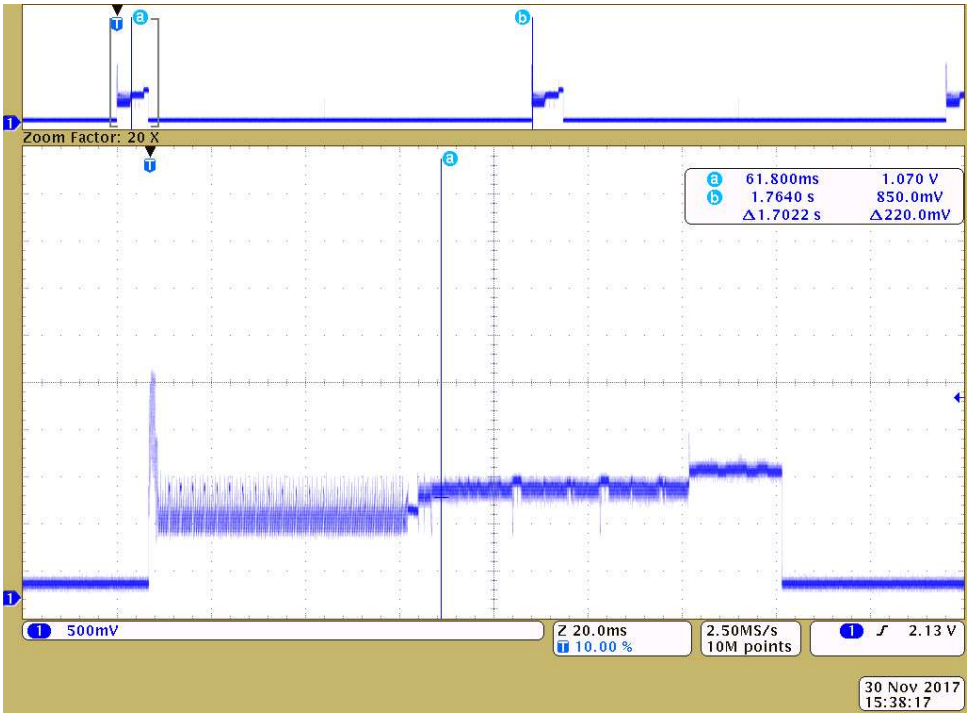

Figure 5. System Current Consumption

Because the gain of the instrumentation amplifier is programmed to 1000, the 1.07-V measurement highlighted by cursor A corresponds to 1.07 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 from Timer A.
2. MSP430 MCU communicates with the HDC2010 through I2C.
3. MSP430 MCU decodes information provided by HDC2010.
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 operations take place, the MSP430 MCU returns to standby mode (LPM4), the HDC2010 returns to sleep mode, and the LCD returns to its low power consumption mode. During the active mode transactions, the system consumes between 0.80 mA to 1.40 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.

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The blue arrow indicates the system current consumption in LPM4 (shutdown). Shutdown current consumption includes the MSP430 MCU, HDC2010, and LCD in shutdown modes. The current consumption of a typical system shutdown is about 130 µA.

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

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

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01625.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01625.

4.3 PCB Layout Recommendations

4.3.1 Layout Considerations for MSP430FR5969 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 form unintended high-voltage electrostatic discharge. For more guidelines, see *MSP430™ System-Level ESD Considerations*.

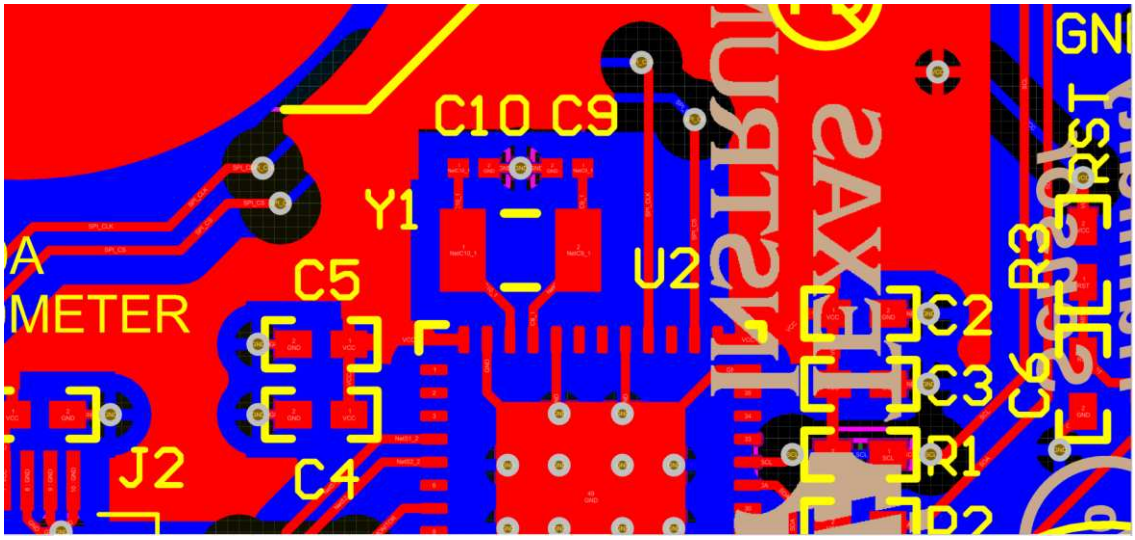

Figure 6. External Crystal Consideration

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4.3.2 Layout Considerations for HDC2010 Humidity Sensor

Isolate the humidity 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.

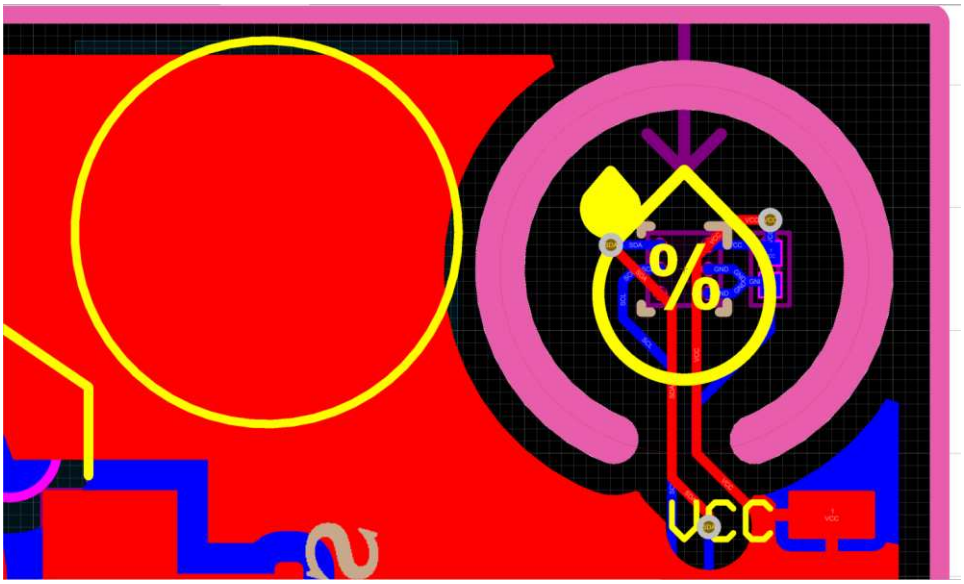

Figure 7. HDC Sensing Island

4.3.3 Layout Prints

To download the layer plots, see the design files at TIDA-01625.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01625.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01625.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01625.

5 Software Files

To download the software files, see the design files at TIDA-01625.

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6 Related Documentation

1. Texas Instruments, *HDC2010 Low Power Humidity and Temperature Digital Sensors 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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