TI Designs
Capacitive-Based Human Proximity Detection for System Wake-Up and Interrupt

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Design Resources

TIDA-00220	Design Page
FDC1004	Product Folder
MSP430FR5969	Product Folder
LP5907-33	Product Folder
LM3630A	Product Folder
TMP112	Product Folder
TPD1E10B06	Product Folder

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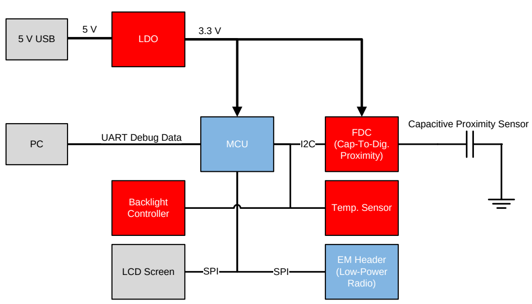
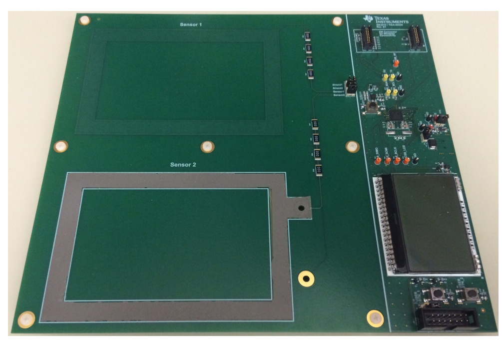
Design Features

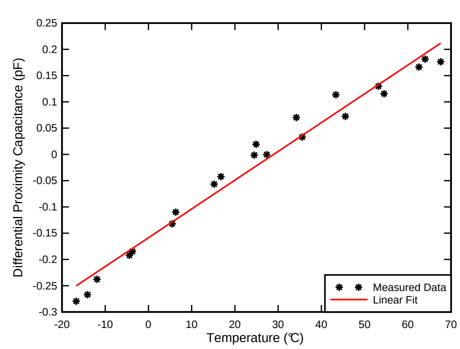
- Detects Human Proximity Using Conductive Nickel-Print Sensor, Enabling Flexible Industrial Design
- Sensor Itself Can Be Copper PCB Material or Other Conductive Materials
- Reduces Environmental Effects through Several Techniques
- Sensing Range is Dependent on Sensor Geometry (20 cm with Tested Hardware)
- Low Power Consumption of 6.2 mW

Featured Applications

- Building Automation
- Proximity Detection
- Smart Thermostat
- Control Panels
- Display Wake-Up
- Automotive Door and Kick Sensors
- Any Application Requiring Low Power Mode when User is Not Present







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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
Sensor type	Copper PCB sensor or conductive nickel print sensor	Section 2.1.1
Input voltage	5-V nominal (VBUS from USB)	Section 2.1.6
Sensing distance threshold	20 cm with tested hardware (Sensing range depends on sensor geometry)	Section 6.2
Sample rate	10 Hz for proximity detection	Section 4.5
Calibration method	User button for offset calibration	Section 5.1
Operating temperature	–20°C to 70°C (limited by LCD screen)	Section 6.4
Working environment	Indoor or outdoor	Section 4.1.1
Environmental compensation	Temperature and humidity	Section 4.1.1
IEC ESD testing	Contact discharge: ±4 kV Air discharge: ±8 kV	Section 6.7.1
IEC EFT testing	EFT: ±2 kV	Section 6.7.2
Radiated immunity testing	Tested from 25 to 300 kHz to determine motor and SMPS noise effects	Section 6.7.3
Debugging communication port	UART and EM connector	Section 4.5
Conductive nickel print	Nickel print from MG Chemicals	Section 4.1

2 System Description

Many industrial end-equipment systems must conserve power and component life through sleep or standby mode. If the system needs to wake up when a human is about to interact with it, the system requires some sort of proximity detection to acknowledge that human presence.

Enabled by Texas Instruments' capacitive-to-digital converter technology, capacitive sensing provides a high-precision method to wake up systems when human interaction occurs. The high-resolution capacitance measurements allow for an extended proximity sensing range as well as the use of non-standard sensing elements. In addition to copper-printed circuit board (PCB) sensors, this TI Design also demonstrates the use of a conductive print material that can be applied to many different surfaces. The flexibility in sensor design enables integrated and simple industrial design, because the proximity sensor can become part of a product's housing, eliminating unsightly sensing components.

This design guide addresses component selection, measurement theory, sub-system calibration, and environmental compensation. The scope of this design guide gives system designers a head-start in integrating TI's capacitance-to-digital converter technology into new applications that require high-resolution proximity detection for system wake-up.

2.1 Component Selection

2.1.1 Capacitance-to-Digital Converter

Using a capacitance-based proximity detection, a subsystem requires high resolution and low noise capacitance measurements to detect proximity using capacitance-to-digital technology. To determine if a person is close to the sensor, the proximity detection subsystem must be able to detect any capacitive changes above the baseline measurements. As the resolution for the capacitance measurement increases and the noise decreases, the proximity detection range and repeatability increases.

Another consideration for the selection of the capacitance-to-digital converter is the ability to handle measurement changes due to varying environmental conditions. This TI Design uses two methods to mitigate environmental variations: a separate environmental sensor (Section 4.1.1) and software filtering (Section 4.1.2).

The four-channel FDC1004 capacitance-to-digital converter combines unique features and functions with low power and 16-bit noise performance over a ±15-pF range to make it easy for designers to use capacitive sensing to increase the intelligence and awareness of their systems. The device can support an offset capacitance up to 100 pF, allowing for remote sensing in harsh environments or where electronics cannot be located. The device also includes a strong shield driver to help minimize interferers, to help focus the sensing direction, and to reduce the system performance impact of temperature variations. Finally, the FDC1004 allows an external offset capacitance to track environmental changes or to automatically correct for drift in the system over time.

2.1.2 Proximity and Environmental Sensor Design

The capacitance-to-digital converter technology from TI can operate with a wide variety of sensor geometries and conductive materials. This TI Design uses two rectangular bezel sensors: one made from copper PCB material and the other made from conductive nickel print. Since the FDC1004 device is simply measuring capacitance to ground of a sensor plate, and as long as the sensor material is conductive, there is no specific requirement for geometry or material. Therefore, this TI Design is an example for incorporating capacitance-to-digital technology for proximity detection into industrial end-equipments with a high degree of design flexibility.

The actual sensor geometry (rectangular bezel) selected emulates a small industrial control panel, which typically contains a display or control in the middle of the device housing. The range of proximity detection is correlated to the size of the capacitive sensor. As the sensor size increases, the distance at which proximity can reliably be detected also increases. The total area of each proximity sensor (copper PCB and conductive nickel print) is 36 cm^2. Both the copper PCB and the conductive nickel print sensors have a "shield" of an identical geometry. The purpose of these shields is to reduce effects of electromagnetic interference (EMI) and to direct the sensors to look in only one direction. The shield is also used to help minimize temperature and humidity effects on the measured capacitance due to PCB expansion or contraction.

To reduce the effects from environmental variations on the proximity measurements, this TI Design has an environmental sensor located on the design's backside. This environmental sensor also has a shield, which prevents it from seeing any capacitive changes due to human presence. Therefore, since the environmental sensor on the backside of the board and the proximity sensor on the topside of the board "see" the same environmental conditions, the FDC1004 measures the difference between the two, effectively eliminating the effects due to environmental variations. In this TI Design, the environmental sensor does not have an identical geometry to the proximity sensor, as shown in Figure 1. The active shields should be slightly wider than their corresponding sensors to better direct the electric field in the intended direction. The extended width of the shield is exaggerated for clarity in Figure 1.

This sensor requires characterization over environmental changes as well as firmware correction, since the different geometries do not respond in an identical manner. This characterization and correction is described in more detail in Section 6.4 and Section 4.5, respectively.

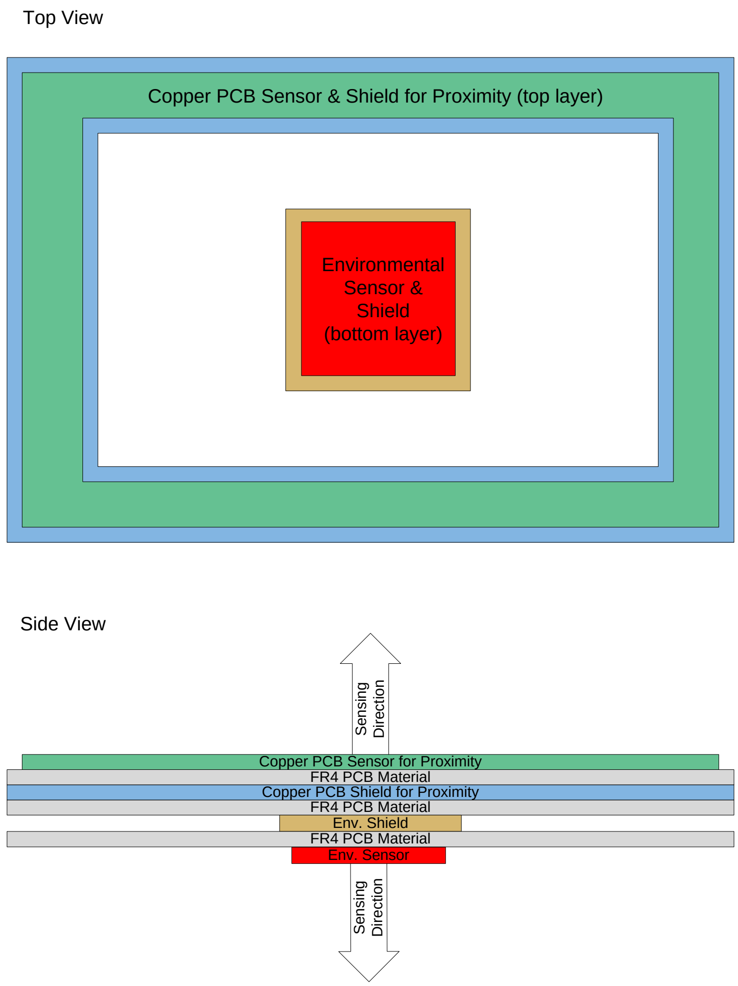

Figure 1. Capacitive Sensor Stackup

2.1.3 Microcontroller Selection

The MSP430FR5969 microcontroller was chosen as the central processor for the subsystem based on memory, processor power, and peripheral module requirements necessary to support the capacitance-to-digital converter, temperature sensor, backlight controller, and LCD screen. The MSP430FR5969 microcontroller uses FRAM memory instead of flash (SLAT151), which consumes less power for the entire system. In addition, the MSP430FR5969 device has eUSCI modules for I^{2}C, SPI, and UART, all used in this TI Design. Finally, the MSP430FR5969 device incorporates EnergyTrace++™ technology, which is helpful during system debugging.

EnergyTrace technology for MSP430 microcontrollers is an energy-based code analysis tool that measures and displays the application's energy profile and helps to optimize it for ultra-low-power consumption. This technology implements a new method for measuring MCU current consumption. Power is traditionally measured by amplifying the signal of interest and measuring the current consumption and voltage drop over a shunt resistor at discrete times.

In debuggers that support EnergyTrace technology, a software-controlled DC-DC converter generates the target power supply. The time density of the DC-DC converter charge pulses equals the energy consumption of the target microcontroller. A built-in calibration circuit in the debug tool defines the energy equivalent for a single charge pulse. The width of each charge pulse remains constant. The debug tool counts every charge pulse and the sum of the charge pulses are used in combination with the time elapsed to calculate an average current. Using this approach, even the shortest device activity that consumes energy contributes to the overall recorded energy.

EnergyTrace++™ technology, also known as EnergyTrace+[CPU States]+[Peripheral States], brings the capabilities of EnergyTrace to the next level. When debugging with devices that contain the built-in EnergyTrace++ support, the technology yields information about energy consumption as well as the internal state of the microcontroller. These states include the ON/OFF status of the peripherals and all system clocks (regardless of the clock source) as well as the low power mode (LPM) currently in use. This tool provides a means of directly verifying whether an application is demonstrating the expected behavior at the correct points in the code, such as ensuring that a peripheral is turned off after a certain activity.

2.1.4 Digital Temperature Sensor

The TMP112 digital temperature sensor enables temperature calibration in this TI Design. The TMP112 device is a digital output temperature sensor in a tiny, 6-pin, SOT563 package. The TMP112 device is capable of reading temperatures to 12-bit resolution with an accuracy of ±0.5°C. For minimal cost and board space, the addition of the TMP112 device to the subsystem allows for more accurate measurements through temperature calibration (see Section 6.4).

2.1.5 LCD Backlight Controller

The LM3630A high-efficiency LED driver drives the EA LED55X46-W LED backlight. The LM3630A has an I^2C interface, which easily interfaces with the MSP430FR5969 microcontroller.

2.1.6 Power Management

To best demonstrate the performance of the TI Design subsystem, the LP5907 low-dropout (LDO) regulator manages the input voltage down to 3.3 V. The design's hardware is configured to be powered from a standard USB port, which has a nominal voltage of 5 V. Also, the subsystem can be powered from the appropriate power rails if they already exist in an end-equipment.

One critical system design consideration is that of the power supply rejection ratio (PSRR). The PSRR of the FDC1004 device is specified at 11 fF/V. The input voltage is primarily supplied through USB and, per USB specifications, that voltage can only fluctuate by 0.25 V. The LP5907 LDO device has a specified PSRR of 60 dB at 100 kHz, which means that the output voltage variation that supplies the FDC1004 is only 0.25 mV. Therefore, the variation in capacitance reading due to power supply noise is only 0.00275 fF, which is far below the overall system noise.

Integrating the technology demonstrated in this TI Design into a end-equipment system may necessitate a different power management configuration. The choice of devices for power management could change, depending on existing input voltage rails. If lower voltage point-of-load rails already exist, then different TI devices for power management can be chosen to suit the conditions of the system (see www.ti.com/power). A low-noise power rail is necessary for optimal performance of the FDC1004, either by using a LDO linear regulator or by ensuring that the switching frequency of a DC-DC converter does not conflict with the FDC1004 nominal operating frequency of 25 kHz. WEBENCH Designer is an excellent tool to determine the appropriate devices.

2.1.7 EMI Protection Circuitry

The TPD1E10B06 Single-Channel ESD protection device guards the FDC1004 input channels, the USB power input, and the JTAG programming interface. The device offers over ±30-KV IEC air-gap, over ±30-KV contact ESD protection, and has an ESD clamp circuit with a back-to-back diode for bipolar or bidirectional signal support. The 10-pF line capacitance is suitable for a wide range of applications supporting data rates up to 400 Mbps. The line capacitance of the device does not exceed the input capacitance limits of the FDC1004 when added to the sensors already in place. The 0402 package is industry standard and convenient for component placement in space saving applications. The TPD1E10B06 is characterized for operation over ambient air temperature of –40°C to 125°C.

In addition to the TPD1E10B06 devices previously described, there is a protection network of discrete devices on the main power input net. This network consists of a transient voltage suppression (TVS) device and a Zener diode to clamp the input voltage. This network protects against transient voltages and currents on the main power input. This EMI protection circuitry can vary depending on the end-user system implementation.

2.2 FDC1004

Capacitive sensing with grounded capacitor sensors is a very low-power, low-cost, high-resolution contactless sensing technique that can be applied to a variety of applications ranging from detecting proximity and sensing gestures to analyzing materials and sensing remote liquid levels. The sensor in a capacitive-sensing system is any metal or conductor, allowing for a low-cost and highly flexible system.

The FDC1004 is a high-resolution, 4-channel capacitance-to-digital converter to implement capacitive sensing solutions. Each channel has a full-scale range of ±15 pF and can handle a sensor offset capacitance of up to 100 pF, which can be either programmed internally or can be an external capacitor for tracking environmental changes over time and temperature. The large offset capacitance capability allows for the use of remote sensors.

The FDC1004 also includes shield drivers for sensor shields, which can reduce EMI and help focus the sensing direction of a capacitive sensor. The small footprint of the FDC1004 allows use in space-constrained applications. The FDC1004 is available in a 10-pin WSON package and features an I^2C interface for interfacing to an MCU.

2.3 MSP430FR5969

The MSP430™ ultra-low-power (ULP) FRAM platform combines uniquely embedded FRAM and a holistic ULP system architecture, allowing innovators to increase performance at lowered energy budgets. FRAM technology combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash with much lower power.

The MSP430 ULP FRAM portfolio consists of a diverse set of devices featuring FRAM, the ULP 16-bit MSP430 CPU, and intelligent peripherals targeted for various applications. The ULP architecture showcases seven low-power modes, optimized to achieve extended battery life in energy-challenged applications.

2.4 LP5907-33

The LP5907 is a linear regulator capable of supplying a 250-mA output current. Designed to meet the requirements of RF and analog circuits, the LP5907 provides low noise, high PSRR, low quiescent current, and low line or load transient response figures. Using new and innovative design techniques, the LP5907 offers class-leading noise performance without a noise bypass capacitor and the ability to place remote output capacitors.

2.5 LM3630A

The LM3630A is a current-mode boost converter, which supplies the power and controls the current in up to two strings of 10 LEDs per string. Programming is done over an I^2C-compatible interface. The maximum LED current is adjustable from 5 to 28.5 mA. At any given maximum LED current, the LED brightness is further adjusted with 256 exponential or linear dimming steps. Additionally, pulsed width modulation (PWM) brightness control can be enabled, allowing for LED current adjustment by a logic level PWM signal.

The boost switching frequency is programmable at 500 kHz for low-switching loss performance or 1 MHz to allow the use of tiny low profile inductors. A setting for a 10% offset of these frequencies is available. Overvoltage protection is programmable at 16 V, 24 V, 32 V, or 40 V to accommodate a wide variety of LED configurations and Schottky diode or output capacitor combinations.

2.6 TMP112

The TMP112 is a 2-wire, serial output temperature sensor available in a tiny SOT563 package. Requiring no external components, the TMP112 is capable of reading temperatures to a resolution of 0.0625°C. The TMP112 slope-specification allows users to calibrate for higher accuracy.

The TMP112 features both SMBus and 2-wire interface compatibility and allows up to four devices on one bus. The TMP112 also features an SMBus alert function.

The TMP112 is ideal for measuring extended temperature in communication, computer, consumer, environmental, industrial, and instrumentation applications. The sensor operates over a temperature range of –40°C to 125°C.

2.7 TPD1E10B06

The TPD1E10B06 is a single-channel ESD protection device in a small 0402 package. The device offers over ±30KV IEC air-gap, over ±30KV contact ESD protection, and has an ESD clamp circuit with a back-to-back diode for bipolar or bidirectional signal support. The 10-pF line capacitance is suitable for a wide range of applications supporting data rates up to 400 Mbps. Typical application areas of the TPD1E10B06 include audio lines (microphone, earphone, and speaker phone), SD interfacing, keypad or other buttons, and VBUS pins of USB ports (ID).

3 Block Diagram

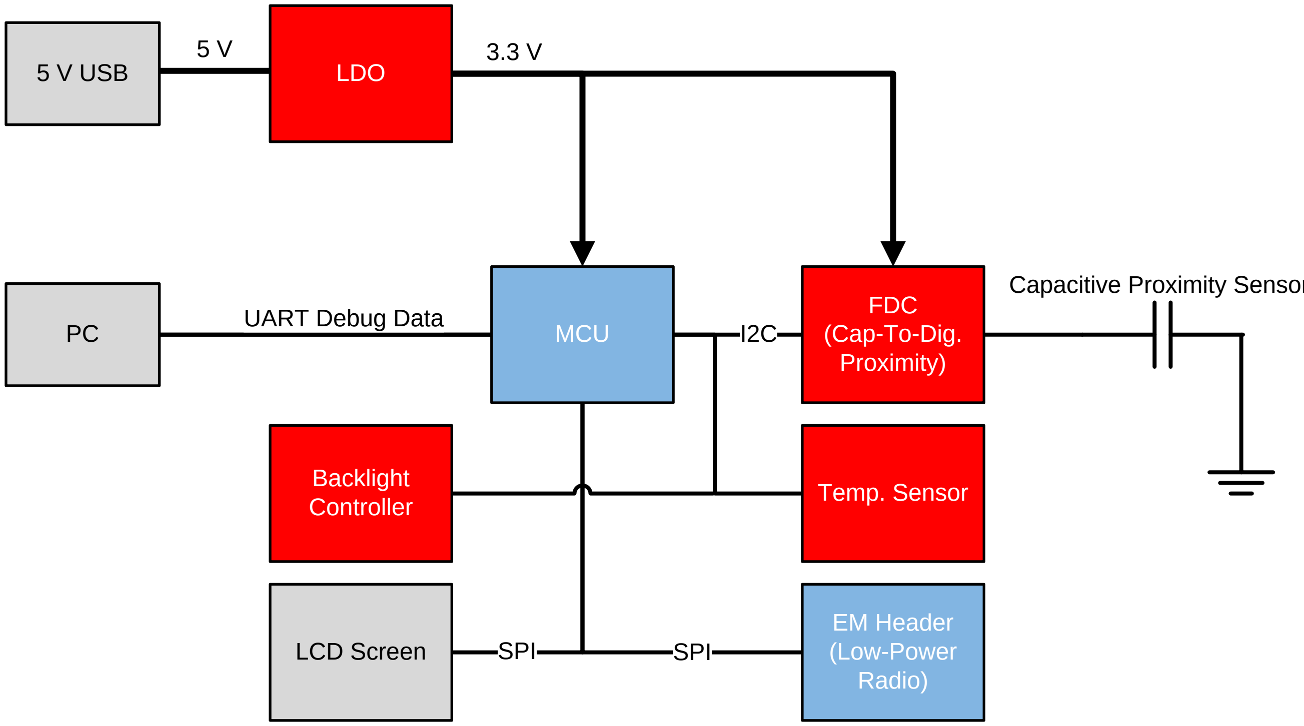

Figure 2. Capacitive-Based Human Proximity Detection System Block Diagram

3.1 Highlighted Products

The Capacitive-Based Human Proximity Detection for System Wake-Up and Interrupt design features the following devices:

- FDC1004: 4-channel capacitance-to-digital converter for capacitive sensing solutions
- MSP430FR5969: 16-MHz ULP microcontroller featuring 64-KB FRAM, 2-KB SRAM, 40 I/O
- LP5907: 250-mA, ultra-low noise LDO regulator
- LM3630A: High-efficiency dual-string white LED driver
- TMP112: High precision, low-power, digital temperature sensor
- TPD1E10B06: Single-channel ESD in 0402 package with 10-pF capacitance and 6-V breakdown

For more information on each of these devices, see the respective product folders at www.ti.com.

3.1.1 FDC1004

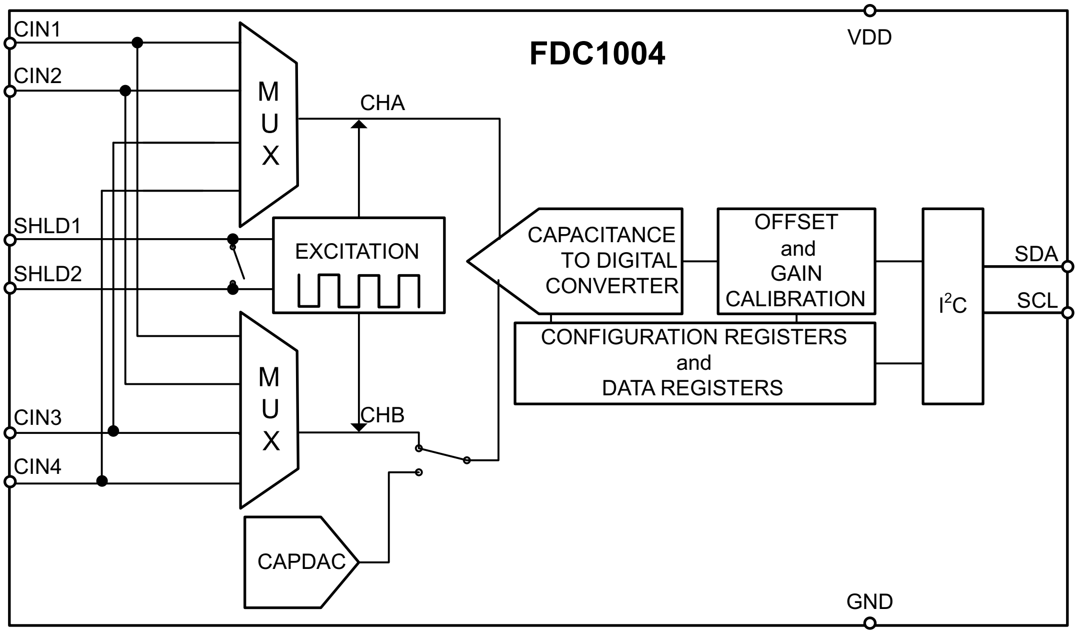

Figure 3. FDC1004 Functional Block Diagram

- Input range: ±15 pF
- Measurement resolution: 0.5 fF
- Maximum offset capacitance: 100 pF
- Programmable output rates: 100, 200, or 400 S/s
- Maximum shield load: 400 pF
- Supply voltage: 3.3 V
- Temperature range: –40°C to 85°C
- Current consumption:
  - Active: 750 µA
  - Standby: 29 µA
- Interface: I^2C
- Number of channels: 4

(Back to Section 3.1)

3.1.2 MSP430FR5969

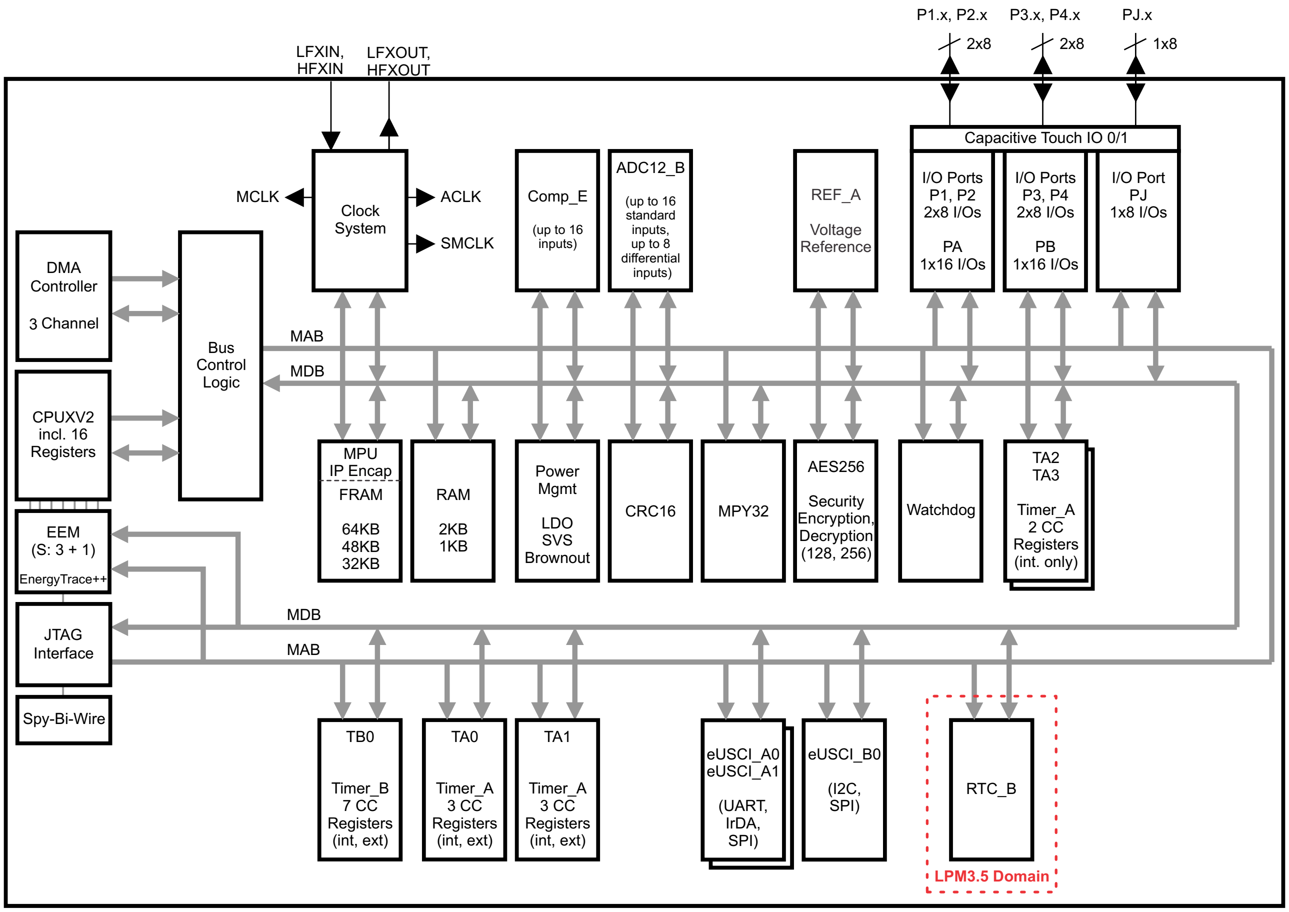

Figure 4. MSP430FR5969 Functional Block Diagram

- Embedded microcontroller
  - 16-bit RISC architecture up to 16-MHz clock
  - Wide supply voltage range
  - Code security and encryption (1.8 to 3.6 V) [(1)]
- Optimized ULP modes
  - Active mode: Approximately 100 µA/MHz
  - Standby (LPM3 With VLO): 0.4 µA (typical)
  - Real-time clock (LPM3.5): 0.25 µA (typical) [(2)]
  - Shutdown (LPM4.5): 0.02 µA (typical)
- ULP ferroelectric RAM (FRAM)
  - Up to 64KB of nonvolatile memory
  - ULP writes
  - Fast write at 125 ns per word (64KB in 4 ms)
  - Unified nemory = program + data + storage in one single space
  - 10^{15} write cycle endurance
  - Radiation resistant and nonmagnetic
- Intelligent digital peripherals
  - 32-bit hardware multiplier (MPY)
  - Three-channel internal DMA
  - Real-time clock with calendar and alarm functions
  - Five 16-bit timers with up to seven capture and compare registers each
  - 16-bit cyclic redundancy checker (CRC)
- High-performance analog
  - 16-channel analog comparator
  - 12-bit analog-to-digital converter (ADC) with internal reference, sample-and-hold, and up to 16 external input channels
- Multifunctional I/O ports
  - All pins support capacitive touch capability with no need for external components
  - Accessible bit-, byte-, and word-wise (in pairs)

(1) Minimum supply voltage is restricted by SVS levels.
(2) Real-time clock is clocked by a 3.7-pF crystal.

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3.1.3 LP5907

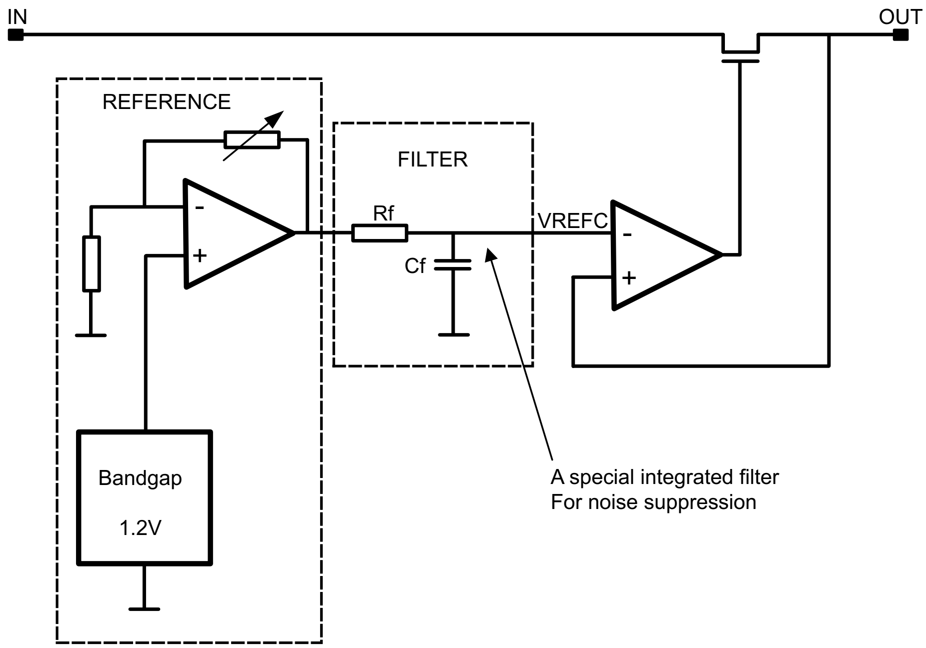

Figure 5. LP5907 Block Diagram

- Stable with 1-μF ceramic input and output capacitors
- No noise bypass capacitor required
- Remote output capacitor placement
- Thermal-overload and short-circuit protection
- –40°C to 125°C junction temperature range for operation

(Back to Section 3.1)

3.1.4 LM3630A

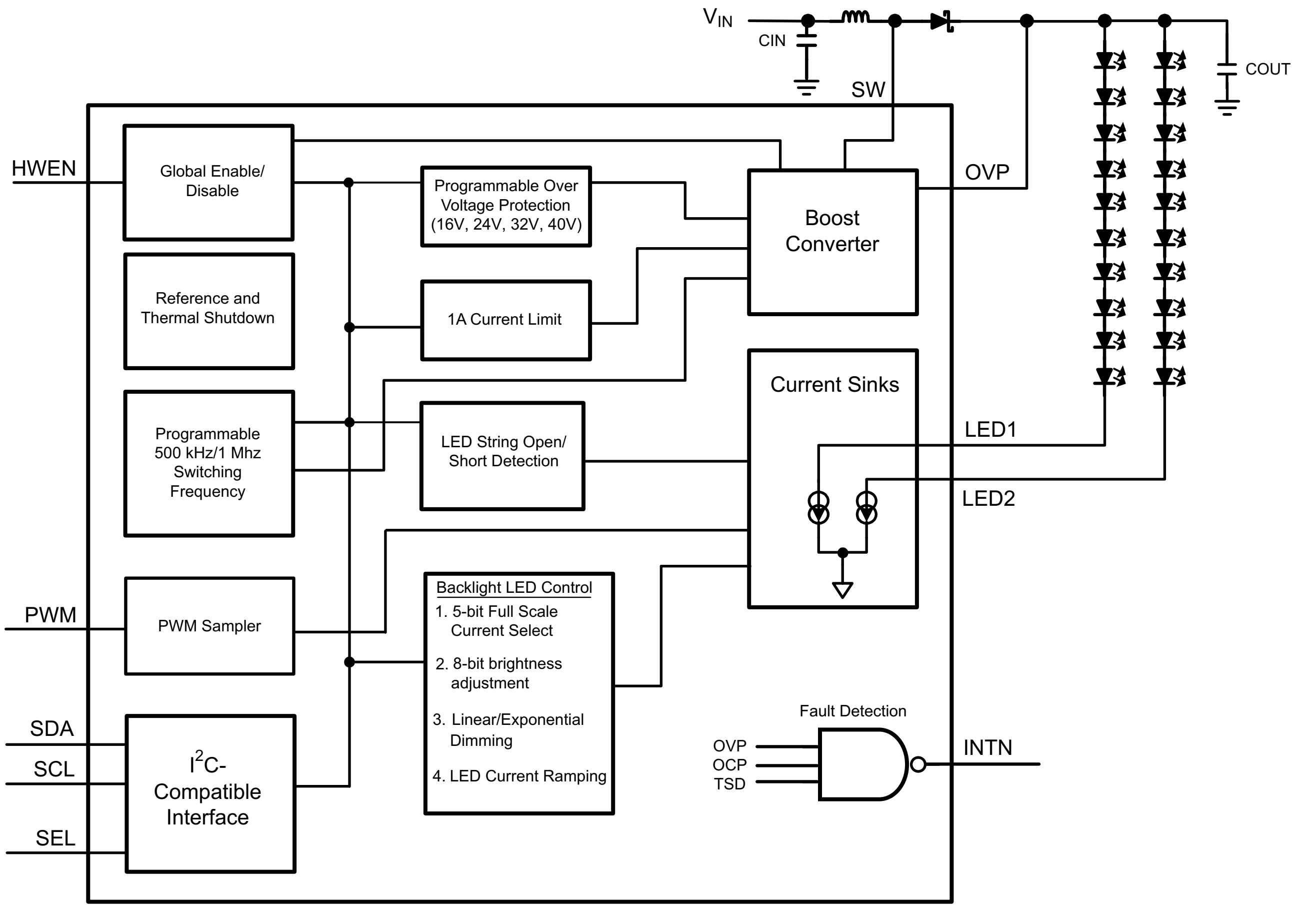

Figure 6. LM3630A Functional Block Diagram

- Drives up to two strings of 10 series LEDs
- Up to 87% efficient
- 8-bit I^2C-compatible programmable exponential or linear brightness control
- PWM brightness control for CABC operation
- Independent current control per string
- True shutdown isolation for LEDs
- Internal soft-start limits inrush current
- Wide 2.3-to-5.5-V input voltage range
- Adaptive headroom
- Programmable 16-V/24-V/32-V/40-V overvoltage protection
- Selectable boost frequency of 500 kHz or 1 MHz with optional additional offset
- Low profile 12-bump DSBGA package
- Solution size: 32 mm^2

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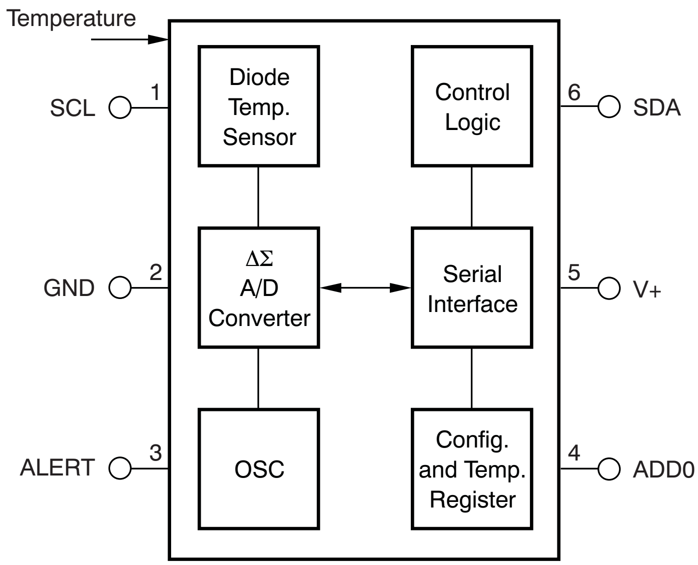
3.1.5 TMP112



TMP112

Figure 7. TMP112 Functional Block Diagram

- Tiny SOT563 package
- Accuracy:
  - 0.5°C (max) from 0°C to 65°C
  - 1.0°C (max) from –40°C to 125°C
- Low quiescent current: 10-µA active (max), 1-µA shutdown (max)
- Supply range: 1.4 to 3.6 V
- Resolution: 12 bits
- Digital output: 2-wire serial interface

(Back to Section 3.1)

3.1.6 TPD1E10B06

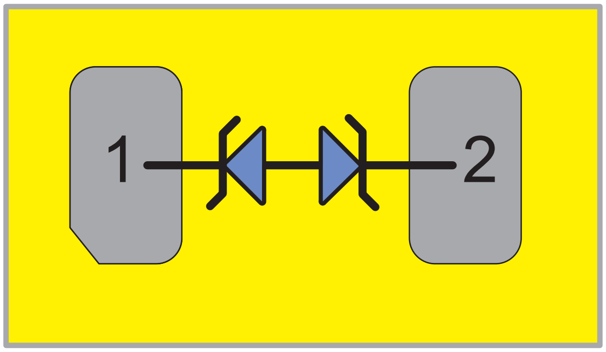


Figure 8. TPD1E10B06 Device Configuration

- Provides system-level ESD protection for low-voltage I/O interface
- IEC 61000-4-2 Level 4
  - >±30kV (air-gap discharge)
  - >±30kV (contact discharge)
- IEC 61000-4-5 (Surge): 6 A (8/20 µs)
- I/O capacitance: 12pF (typical)
- R_{DYN}: 0.4 Ω (typical)
- DC breakdown voltage: ±6 V (min)
- ultra low leakage current: 100 nA (max)
- 10-V clamping voltage (max at I_{PP} = 1 A)
- Industrial temperature range: –40°C to 125°C
- Space-saving 0402 footprint (1 × 0.6 × 0.5 mm)

(Back to Section 3.1)

4 System Design Theory

4.1 Proximity Detection Theory of Operation

This TI Design detects proximity using capacitive sensing technology from TI. The FDC1004 device measures the capacitance on a proximity sensor plate, which in this TI Design is a rectangular bezel shape of either copper PCB or conductive nickel print (nickel print 840 from MG Chemicals). When no human presence is in front of the proximity sensor, the FDC1004 device measures some baseline capacitance. When a human moves in proximity to the sensor, the FDC1004 device measures an increased capacitance. At this time, the system makes the decision to turn on the LCD backlight for a set period of time. Depending on the end-system requirements, a different action can occur, such as a general system interrupt or wake-up signal.

One major concern about using capacitance-to-digital converter technology is how to deal with a fluctuating baseline capacitance. If any of the environmental conditions vary, the system likely has a baseline capacitance measurement that fluctuates, which either causes a false triggering of the system wake-up or prevents the system from ever triggering.

An active shield, as implemented in this design, greatly reduces baseline fluctuations due to temperature and humidity changes that cause the PCB to expand and contract. This TI Design also uses two main techniques to deal with this problem: a differential measurement using an environmental sensor, and a slow-moving average threshold for the proximity detection decision.

4.1.1 Environmental Sensor for Differential Measurements

This TI Design makes use of the multiple input feature of the FDC1004 device. A separate capacitive sensor, called the environmental sensor, is located on the backside of the TI Design hardware. Since both the proximity sensor and the environmental sensor have corresponding shields, they only "see" capacitive changes on the side of the PCB where they are located.

To clarify, the proximity sensor "sees" a hand when placed over top, but the environmental sensor, located on the opposite side of the PCB, does not "see" that same hand. However, since the environmental sensor is still located close to the proximity sensor, both sensors are affected by environmental variations equally. In summary, the environmental sensor exists to zero out any changes due to environmental effects.

The FDC1004 device is configured in this TI Design to take a differential measurement between the proximity sensor and the environmental sensor. Therefore, whenever the difference between the two sensors rises above the baseline difference, the system can determine that there is a human or some other object present that was not previously there. By using the differential measurement, the system then does not need to rely on the absolute capacitance measured by each sensor, just the difference between the two.

4.1.2 Slow-Moving Average Threshold for Proximity Detection Decision

The other method that this TI Design uses to deal with a fluctuating baseline capacitance is a slow-moving average threshold. The differential measurement read by the FDC1004 device is averaged in firmware to reduce noise, and then this averaged value is compared against a threshold to determine if a proximate object is detected. However, this threshold is also an averaged value of the averaged values read by the FDC1004. Details on the specifics of this averaging scheme are found in Section 4.5.

The firmware adjusts to the new differential baseline measurement if a foreign object such as water drops or dust is placed on the proximity sensor but not the environmental sensor. In this case, the water drops has a short-term effect on the sensor that could activate the proximity threshold. However, once the water drop is stationary, the slow moving average threshold changes to reflect the new capacitance. The differential measurement is altered with the contaminant present, but because the firmware is comparing the differential reading to a slow moving average rather than a fixed value, the firmware eliminates the long-term effect from water drops, dust, or other contaminants on the proximity sensor.

The specific values of the slow-moving average threshold update rate, as well as the FDC1004 sample rate, can be adjusted, depending on end-product system requirements.

4.2 Temperature Compensation for Differential Measurements

In the TI Design hardware, the environmental sensor and the proximity sensor do not share the same geometry. During testing, the baseline differential measurement exhibited a linear rise as temperature increased (see Section 6.4). To eliminate this baseline drift, the TMP112 device, placed next to the FDC1004 device, adjusts the gain of the FDC1004 channel reading the environmental sensor. In the ideal end-product, the environmental sensor would have the same geometry as the proximity sensor, but this TI Design demonstrates the worst case scenario of differing geometries and how to compensate for temperature variations.

If the proximity and environmental sensors share the exact same geometry, there could still be a drift in the baseline differential measurement. In this case, temperature compensation can be implemented. However, the end-system could rely on the slow-moving average threshold because temperature changes are likely to be relatively slow. Additionally, as long as the system accurately makes decisions on proximity, there is no need to know or maintain a consistent capacitance value. Finally, the active shield feature of the FDC1004 device reduces baseline fluctuations due to temperature.

4.3 Humidity Compensation for Differential Measurements

Similar to temperature compensation, this TI Design exhibited changes in the baseline differential measurement over varying levels of relative humidity. However, the test results show that the relationship between the baseline drift and humidity is not as linear (see Section 6.5). This drift can be dealt with in two ways: install an active humidity sensor in the system (HDC1000, for example) or rely on the slow-moving average threshold.

If the end-product requires knowing the relative humidity of the system environment, then firmware compensation can be performed based on system characterization over humidity, similar to how this TI Design implements temperature compensation. Depending on how the system responds to humidity, linear compensation may suffice, or some multi-order polynomial may be necessary to achieve the best results.

Relying on the slow-moving average threshold is an acceptable solution for many customers, since in most systems humidity changes relatively slowly, even compared to the threshold refresh rate. In addition, the end-product likely does not need to know the actual differential capacitance between the proximity sensor and the environmental sensor; the end-product only needs to know when to wake up or generate an interrupt. Also, the active shield feature of the FDC1004 device reduces measurement fluctuations due to humidity changes.

Because the range of proximity detection using the conductive nickel-print sensor is equivalent to the copper PCB material, the proximity sensor can be printed or painted onto a surface that exhibits less susceptibility to humidity than FR4 PCB material. From a system-level perspective, this TI Design can be used to jump-start development in implementing an extremely, environmentally robust proximity detection solution into end-products.

4.4 C_{IN} Filtering

Another design aspect impacting the FDC1004 is the use of input filters on each capacitance input. Since the FDC1004 stimulates the capacitive sensor at approximately 25 kHz, have an input filter on each capacitive input with a cutoff frequency of 50 kHz. This filter reduces the effects of EMI on the capacitance measurement.

4.5 Software Control

The TI Design hardware is pre-loaded with firmware to control all the components in the subsystem. The MSP430FR5969 device is programmed to control the FDC1004, TMP112, and LM3630A devices using the eUSCI_B0 Enhanced Universal Serial Communication Interface in I^2C mode. The EA DOGM128W-6 LCD screen is controlled by the eUSCI_A0 module in SPI mode. The firmware initializes all the communication modules as well as the clock system of the MSP430FR5969.

The FDC1004 has several registers that need to be configured in order to operate properly in this TI Design, which can be found in Section 8.6 of SNOSCY5.

The FDC1004 is set to perform a software reset, then sets MEAS1 as ChA = CIN1, Chb = CIN2, and CAPDAC = 0 pF. The sample rate is set to 100 samples per second and sets the FDC1004 into single-shot mode. Once the FDC1004 is configured, the MSP430FR5969 samples the FDC1004 at approximately 80 Hz, which is clocked by the VLO clock source. This sample rate enables the MSP430FR5969 to enter low power modes when not sampling.

The samples from the FDC1004 are averaged eight times to yield an effective sample rate of 10 Hz. Therefore, the proximity detection decision is performed about ten times a second. This data from the FDC1004 is compared against the slow-moving average threshold. If the data is 10 fF above the threshold, then the MSP430FR5969 turns the LM3630A backlight controller on for approximately four seconds. The capacitance value that triggers the backlight turn-on is set in the software. That value can be adjusted to detect proximity at shorter ranges than the maximum and ensure the elimination of false proximity triggering.

This data is optionally outputted through UART to an external interface, enabling data-logging on a computer for a more detailed analysis. This method was the one used to collect the test data in Section 6.

The slow-moving average threshold is calculated by averaging the averaged FDC1004 data by another 32 samples, yielding a threshold update rate of approximately 0.3125 Hz.

The data on the LCD screen is set to update at about 2 Hz; any faster refresh rate would not be easily readable to human eyes.

5 Getting Started

5.1 Hardware Overview

The TI Design hardware is shown below in Figure 9. The copper PCB sensor (Sensor 1) is located in the upper-left corner of the board, and the conductive nickel print sensor (Sensor 2) is located in the lower right. All the electronics are located in the left two inches of the PCB. The environmental sensor is located in the middle of the copper PCB sensor but on the backside of the board.

There are test points located on the PCB for all the communication lines as well as the power nodes. The JTAG programming port is located in the lower-right corner of the board, and the EM connector for adding in low-power radio modules is located in the upper right.

J5 is the header that allows the selection of the copper PCB sensor or the conductive nickel print sensor as well as the corresponding shields. J2 allows current measurements of the entire subsystem. J3 and J9 are used to select the power source: either the USB jack or the JTAG programming port.

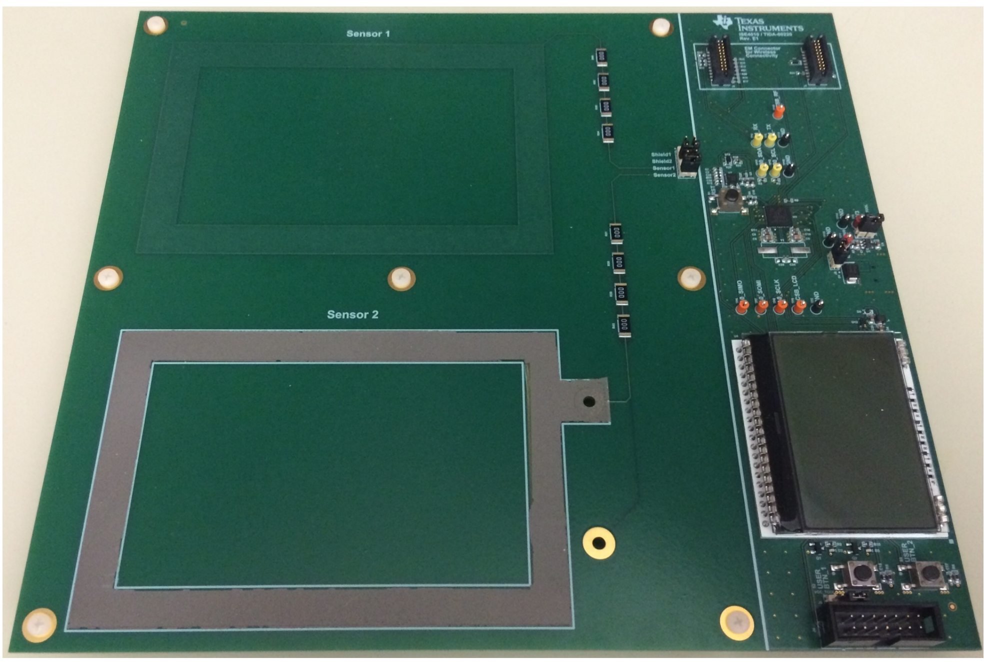


Figure 9. TI Designs Hardware

To power the system from a standard mini-USB cable, set J9 to short pins 2 and 3 (labeled VCC_TARGET) and to short J3.

To power the system from the MSP-FET programming and debugging tool, set J9 to short pins 1 and 2 (labeled VCC_TOOL) and to remove jumper from J3.

By default, the LCD screen shows three lines of data, as shown in Figure 10: the proximity capacitance [the differential measurement between proximity and environmental sensor (*Prox*)], the slow-moving average threshold capacitance (*Thld*), and the temperature reading from the TMP112 device (*Temp*).

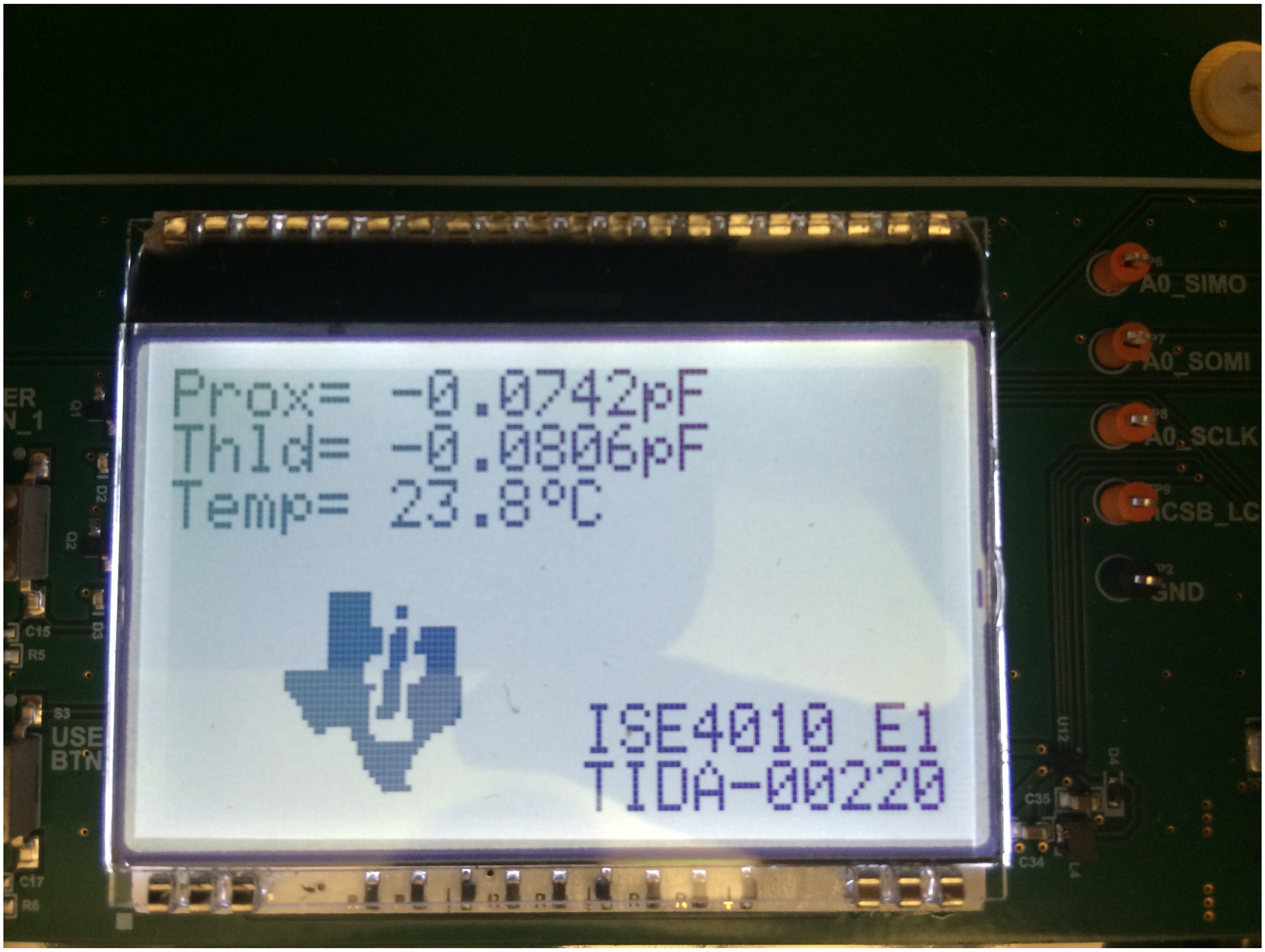


Figure 10. LCD Screen

When first powering up the TI Design hardware, perform an offset calibration. With nothing present in front of the sensor, press USER_BTN_1 (S2), which will zero out the differential capacitance reading.

5.2 Loading the Software

For MSP430 firmware updates, use Code Composer Studio (v6 or newer), along with the MSP-FET USB Debugging Interface. For programming setup, supply the TI Design hardware with power. Either USB power or debugger power is suitable as a power source for programming, assuming J3 and J9 are configured properly.

6 Test Data

NOTE: Unless otherwise noted, the test data in the following sections was measured with the system at room temperature.

NOTE: All of the measurements in this section were measured with calibrated lab equipment.

6.1 Overview

This TI Design has been characterized for both functional usage (proximity detection range and power consumption) as well as the impact of environmental variations and electromagnetic interference.

6.2 Proximity Detection Range

The primary purpose of the TI Design is to provide proximity detection for a system wake-up or interrupt generation. The primary characteristic of the TI Design is the detection range, using both the copper PCB sensor and the conductive nickel print sensor. Table 2 summarizes the range results. Note that sensing range is proportional to the sensor area. Therefore, if a larger sensor area is acceptable, then the sensing range can be extended. In addition, there is a tradeoff between the sensing range and refresh rate of the system; if the refresh rate is slower (that is, more averaging of the FDC1004 data), then the threshold can be set somewhat closer to the baseline, yielding a longer proximity sensing distance.

The tradeoff of the final sensor design is between the proximity detection range and EMI protection. The addition of an RC filter and ESD protection device to reduce EMI also reduces the effective proximity sensing range of the system. Furthermore, if a shorter proximity detection range is required, the system can be calibrated to use a higher threshold value to intentionally decrease the sensing range, thus preventing all but the most deliberate of proximity activations.

Table 2. Sensing Range Summary

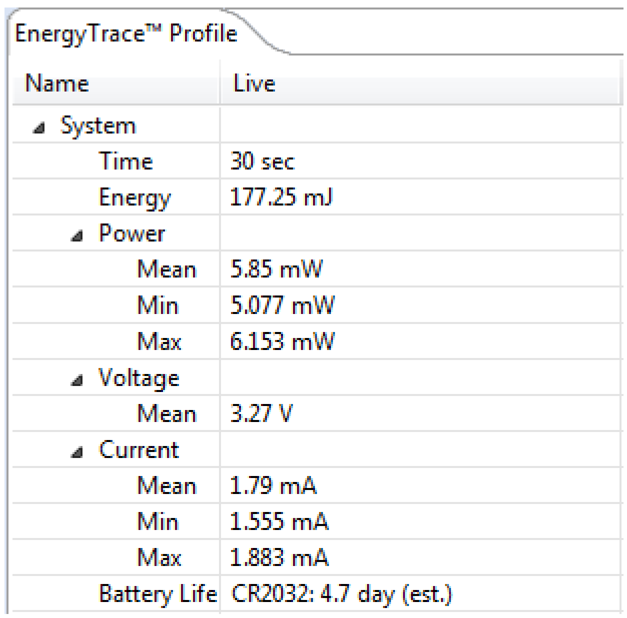
MEASUREMENT	WITHOUT C_{IN} FILTER		WITH C_{IN} FILTER	
	PCB	PAINT	PCB	PAINT
Noise standard deviation (fF)	0.9	1.2	0.8	1.0
$Noise_{PP}$ (fF)	4.4	11.1	5.1	3.9
Range (in)	7.5	8	4.5	8
Range (cm)	19.05	20.32	11.43	20.32

6.3 Power Consumption

The components chosen for this TI Design are all extremely low power; in addition, the firmware takes advantage of the various low-power modes of the MSP430FR5969. The total current provided to the TI Design at a 5-V input voltage is 1.869 mA with the backlight off and 12.831 mA with backlight on. This current yields a power consumption of 9.345 mW when in proximity detection mode. If a 3.3-V rail is already present, then the power consumption is 6.168 mW.

When debugging with the MSP430FR5969 that contains the built-in EnergyTrace++ support, the technology yields information about energy consumption as well as the internal state of the microcontroller. These states include the ON/OFF status of the peripherals and all system clocks (regardless of the clock source) as well as the low power mode (LPM) currently in use. This tool provides a means of directly verifying whether an application is demonstrating the expected behavior at the correct points in the code, such as ensuring that a peripheral is turned off after a certain activity.

As shown in Figure 11, the debugging code used in this TI Design is low power, only consuming 5.85 mW, when measured with the MSP-FET debugging tool. However, as shown in Figure 12 and Figure 13, this system spends much of the time in Active Mode, polling the FDC1004 for data. Therefore, with proper firmware optimization, the power consumption of this system can be further reduced.


EnergyTrace™ Profile

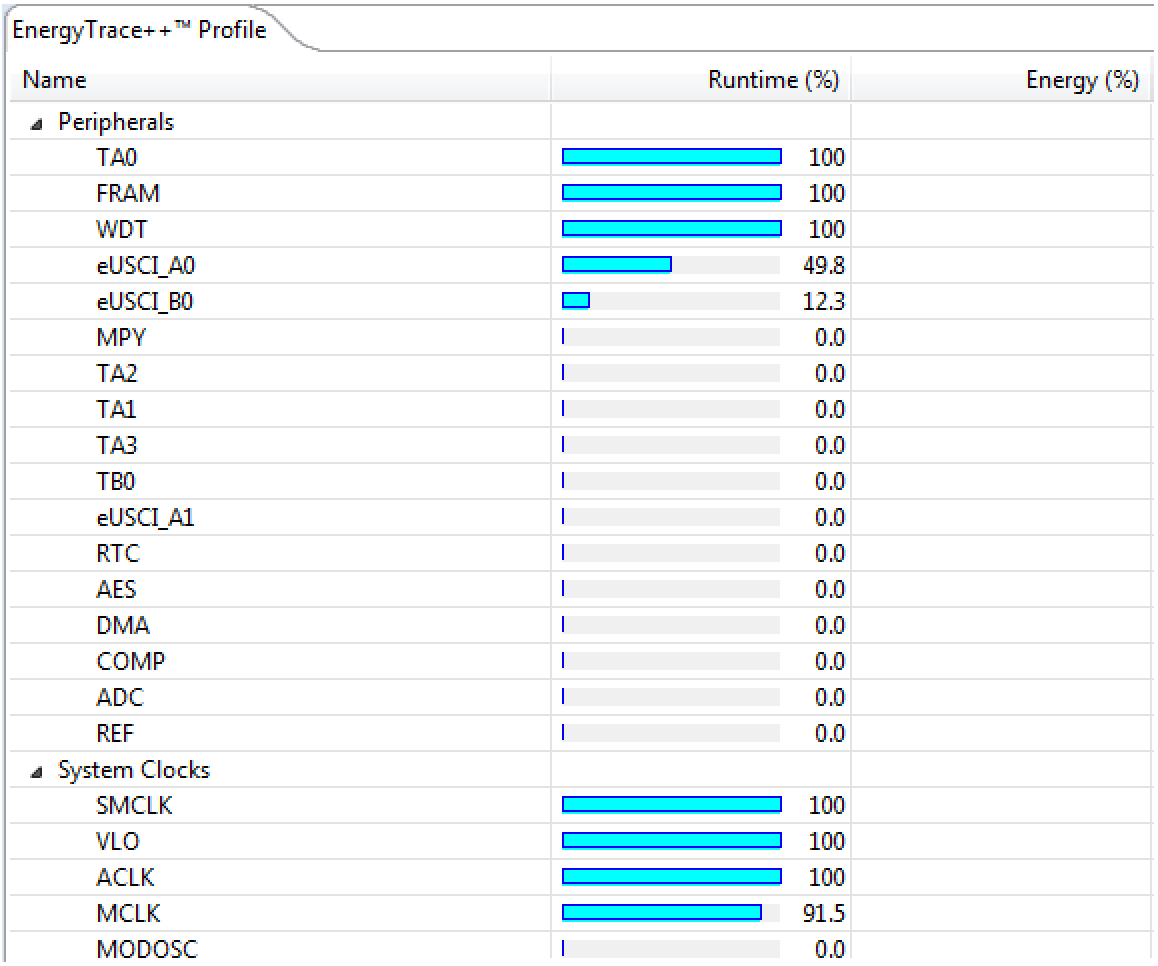
Name	Live
System	
Time	30 sec
Energy	177.25 mJ
Power	
Mean	5.85 mW
Min	5.077 mW
Max	6.153 mW
Voltage	
Mean	3.27 V
Current	
Mean	1.79 mA
Min	1.555 mA
Max	1.883 mA
Battery Life	CR2032: 4.7 day (est.)

Figure 11. EnergyTrace Profile

EnergyTrace++™ Profile

Name	Runtime (%)	Energy (%)
System	100	100
CPU		
Active Mode	91.5	91.7
FDC1004_singleRead_MEAS1	75.7	76.2
main	4.9	4.4
RTS	4.8	4.9
__mspabi_divul	4.7	4.8
__mspabi_divli	0.1	0.1
DOGS128x6_writeData	1.1	1.1
memcpy	1.0	1.0
DOGS128x6_charDraw	0.5	0.4
_IQ19toa	0.5	0.5
EUSCI_B_I2C_masterInit	0.4	0.4
EUSCI_B_I2C_initMaster	0.4	0.4
USCIB0_ISR	0.4	0.4
DOGS128x6_writeCommand	0.4	0.4
EUSCI_A_SPI_isBusy	0.3	0.3
EUSCI_B_I2C_setSlaveAddress	0.2	0.2
EUSCI_B_I2C_masterMultiByteSendStop	0.2	0.2
privateCSAComputeCLKFrequency	0.2	0.2
privateCSASourceClockFromDCO	0.1	0.1
i2c_read_byte	0.1	0.1
EUSCI_A_SPI_transmitData	0.1	0.1
i2c_write	0.1	0.1
EUSCI_B_I2C_setMode	0.1	0.1
TIMER0_A1_ISR	0.0	0.0
EUSCI_B_I2C_masterIsStopSent	0.0	0.0
EUSCI_A_UART_queryStatusFlags	0.0	0.0
EUSCI_A_UART_transmitData	0.0	0.0
EUSCI_A_SPI_receiveData	0.0	0.0
Low Power Mode	8.5	8.3
LPM0	7.9	7.9
<Undetermined>	0.5	0.5

Figure 12. EnergyTrace++ Profile: CPU States



EnergyTrace++™ Profile

Name	Runtime (%)	Energy (%)
Peripherals		
TA0	100	
FRAM	100	
WDT	100	
eUSCI_A0	49.8	
eUSCI_B0	12.3	
MPY	0.0	
TA2	0.0	
TA1	0.0	
TA3	0.0	
TB0	0.0	
eUSCI_A1	0.0	
RTC	0.0	
AES	0.0	
DMA	0.0	
COMP	0.0	
ADC	0.0	
REF	0.0	
System Clocks		
SMCLK	100	
VLO	100	
ACLK	100	
MCLK	91.5	
MODOSC	0.0	

Figure 13. EnergyTrace++ Profile: Peripherals and System Clocks

6.4 Temperature Characterization

As mentioned in Section 4.2, the differential measurement between the proximity sensor and the environmental sensor changes linearly with temperature. Figure 14 shows the test setup for both temperature and humidity testing. Figure 15 shows the baseline change from –20°C to 70°C. The result has minimal hysteresis, which indicates that a firmware correction is simple to implement.

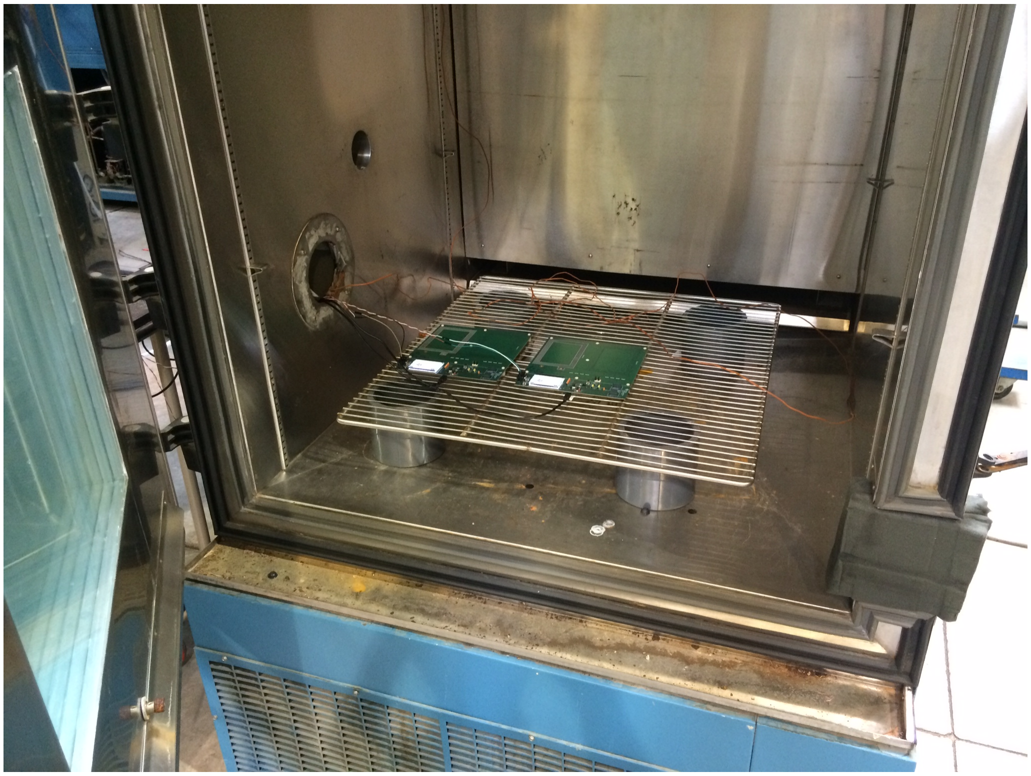


Figure 14. Environmental Testing Setup

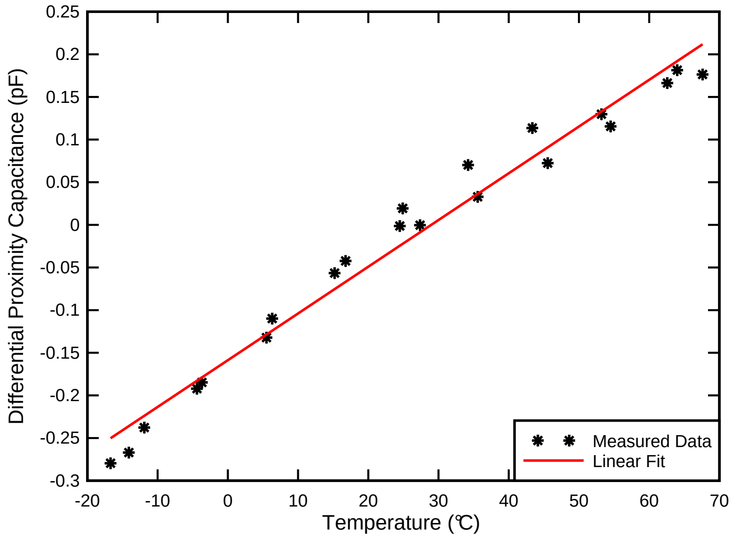


Figure 15. FDC1004 Baseline Capacitance versus Temperature

Figure 16 shows the baseline capacitance that has been corrected for temperature variation overlaid on top of the original data. The baseline drift due to temperature is now much reduced.

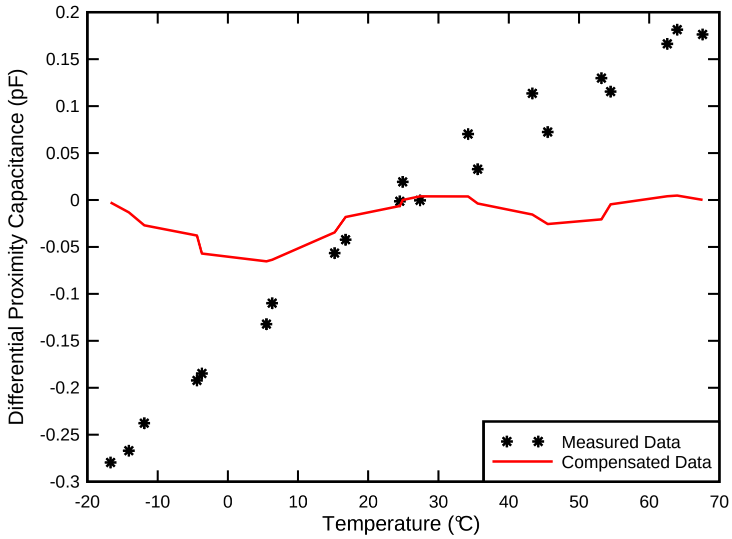


Figure 16. Corrected FDC1004 Baseline Capacitance versus Temperature

6.5 *Humidity Characterization*

As mentioned in Section 4.3, the differential measurement between the proximity sensor and the environmental sensor changes with humidity. Figure 17 shows the baseline change from 10 to 90% RH. The result has some hysteresis, which occurs due to the absorptive characteristics of FR4 PCB material. Since the range of the conductive nickel print sensor is greater than or equal to the copper PCB sensor, place the conductive nickel print sensor on a different dielectric that has different properties when exposed to varying humidity levels.

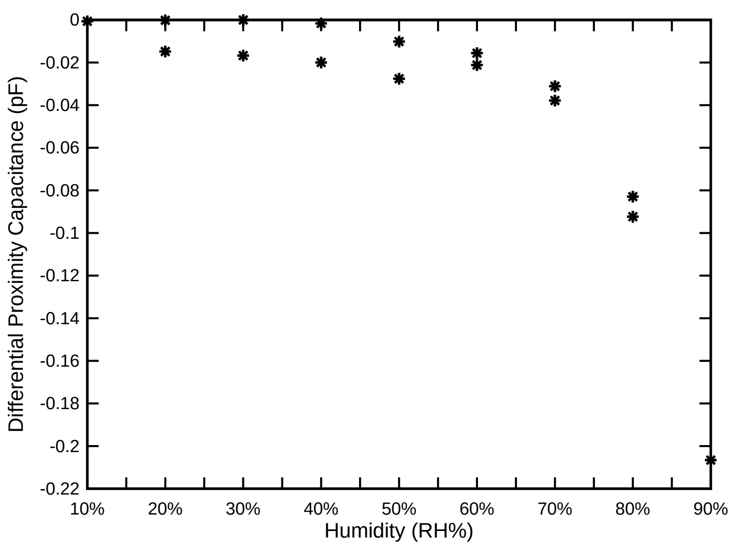


Figure 17. Baseline Capacitance versus Humidity

No correction for humidity changes has been implemented in this TI Design because there is no need to measure humidity directly on the hardware. However, if the end-product uses a humidity sensor, such as the HDC1000 from TI, it is simple to characterize the system response to humidity and then correct that in firmware, similar to correcting for temperature changes.

6.6 Water Droplet Characterization

Figure 18 shows the response of both the differential measurement and the slow-moving threshold to water droplets on the proximity sensor. The five downward spikes on the differential measurement curve correspond to five water droplets placed on the copper PCB sensor. The slow-moving threshold moves down due to the influence of the water droplet spikes, which causes the LCD backlight to turn on. However, after the slow-moving threshold adjusts to the new offset caused by the water droplets, the LCD backlight deactivates, and the system continues to perform normally. As seen by this behavior, the system does not have the ability to screen out transient events such as water droplets hitting the sensor, but it does have the ability to compensate for those same water droplets after they have come to rest on the sensor.

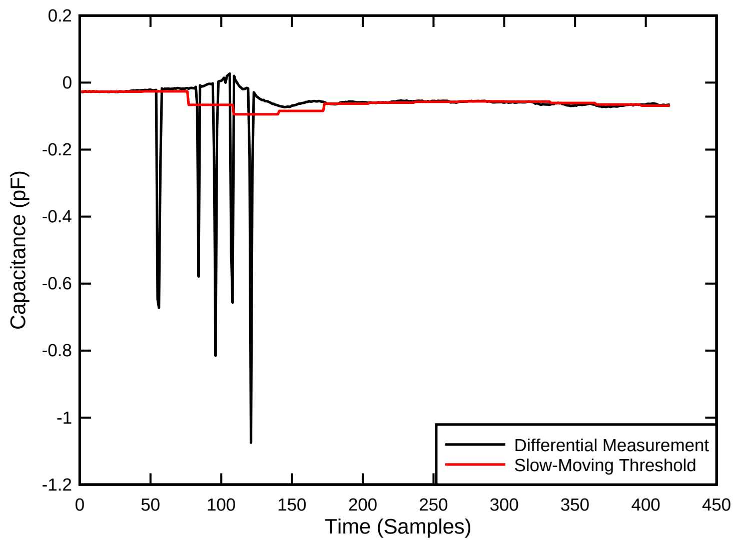


Figure 18. Response of Differential Measurement and Slow-Moving Threshold to Water Droplet Testing on Proximity Sensor

6.7 EMI Protection

This TI Design was characterized through pre-compliance and engineering tests for ESD, EFT, and radiated immunity.

Table 3. Criteria and Performance as Per IEC61131-2

CRITERIA	PERFORMANCE (PASS) CRITERIA
A	The system shall continue to operate as intended with no loss of function or performance even during the test.
B	Temporary degradation of performance is accepted. After the test, the system shall continue to operate as intended without manual intervention.
C	During the test, loss of functions accepted, but no destruction of hardware or software. After the test, the system must continue to operate as intended automatically, after a manual restart, powering off, or powering on.

6.7.1 IEC 61000-4-2 (ESD)

For the IEC 61000-4-2 pre-compliance test, the system was powered and the differential proximity capacitance was recorded via UART stream before, during, and after test conditions were applied. For the test conditions that received a Class B rating, the FDC1004 device registered a full-scale reading. However, the firmware can be recovered in this condition if the appropriate logic is implemented. The FDC1004 can be re-initialized in the firmware, which prevents a required manual power reset to the system. Figure 19 shows the setup for ESD testing.

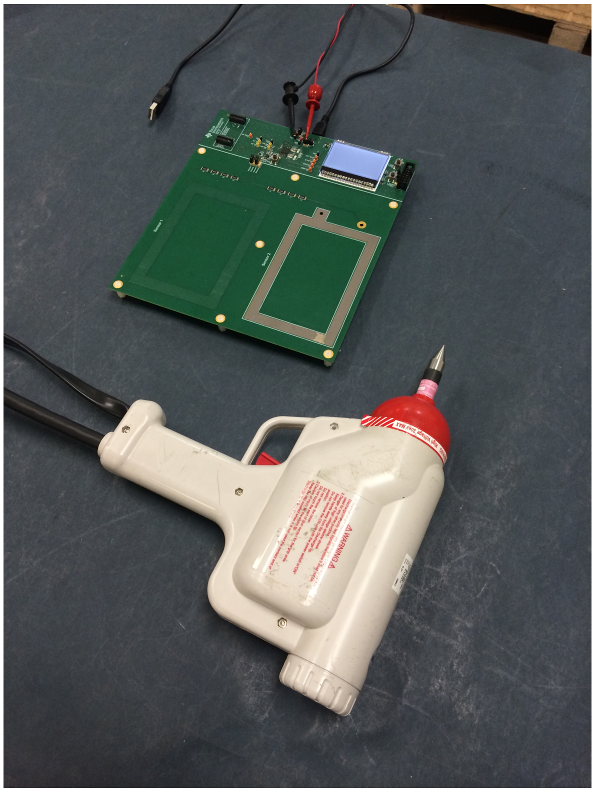


Figure 19. ESD Test Setup

Table 4. Test Results for the ESD Test

IEC 61000-4-2 (ESD) TEST CONDITION	RESULT (SEE Table 3 FOR DETAILS)
±2-kV air discharge on USB power connector	Class A
±4-kV air discharge on USB power connector	Class A
8-kV air discharge on USB power connector	Class A
–8-kV air discharge on USB power connector	Class B
2-kV contact discharge on USB power connector	Class A
–2-kV contact discharge on USB power connector	Class B
±4-kV contact discharge on USB power connector	Class A
±2-kV air discharge on copper PCB sensor	Class A
4-kV air discharge on copper PCB sensor	Class B
–4-kV air discharge on copper PCB sensor	Class A
8-kV air discharge on copper PCB sensor	Class B
–8-kV air discharge on copper PCB sensor	Class A
±2-kV contact discharge on copper PCB sensor	Class A
±4-kV contact discharge on copper PCB sensor	Class B

6.7.2 IEC 61000-4-4 (EFT)

For the IEC 61000-4-4 pre-compliance test, the system was powered and the differential proximity capacitance was recorded via UART stream before, during, and after test conditions were applied. Figure 20 shows the setup for the EFT testing. During the EFT test, the FDC1004 output was varying by ±200 fF, which causes false triggers. However, as soon as the EFT test concluded, the system fully recovered and did not require any manual power reset.

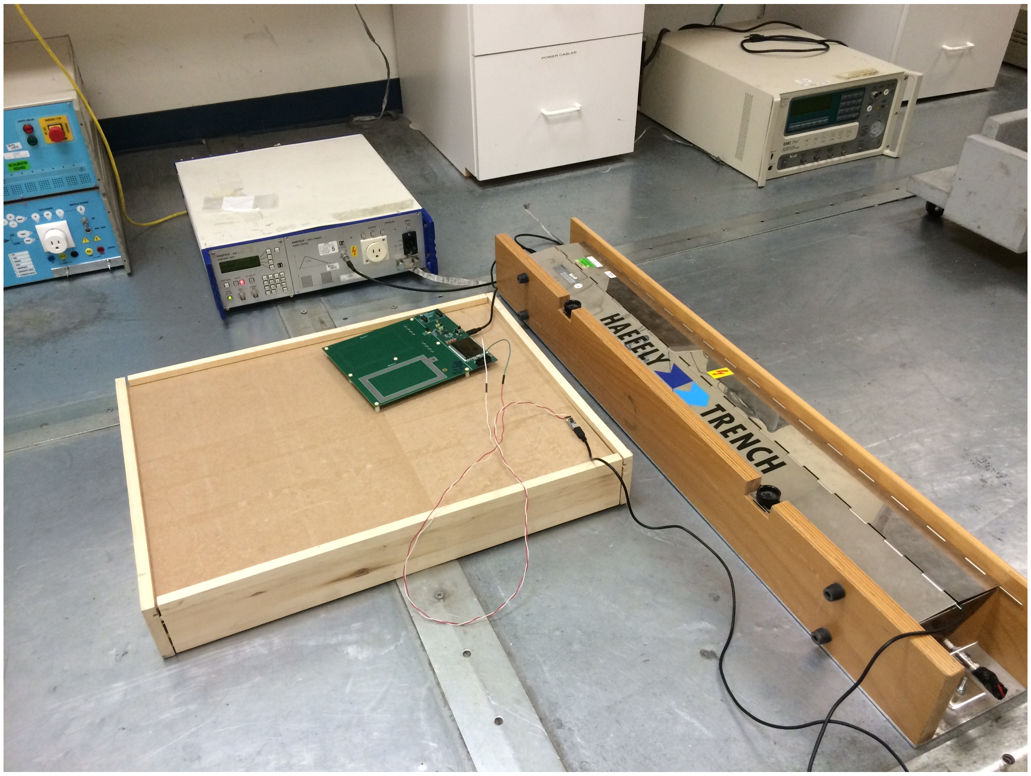


Figure 20. EFT Test Setup

Table 5. Test Results for the EFT Test

IEC 61000-4-4 (EFT) TEST CONDITION	RESULT (SEE Table 3 FOR DETAILS)
±0.5 kV on USB power cable	Class B
±1 kV on USB power cable	Class B
±2 kV on USB power cable	Class B

6.7.3 Radiated Immunity

Because the FDC1004 device excites the capacitive sensor at approximately 25 kHz, engineering tests for radiated immunity were performed at low frequencies on the system. The system was powered and the differential proximity capacitance was recorded through UART stream before, during, and after test conditions were applied. The radiated interference was varied from 25 to 300 kHz at the harmonics of 25 kHz with a field strength of 3 V/m. The results of peak-to-peak noise on the system are shown in Figure 21. The presence of the simple RC filter with a cutoff frequency of 50 kHz does much to reduce the noise in the system due to these frequencies. In a real system, several sources of noise could generate this sort of interference (for example, electrical motors and switching power supplies).

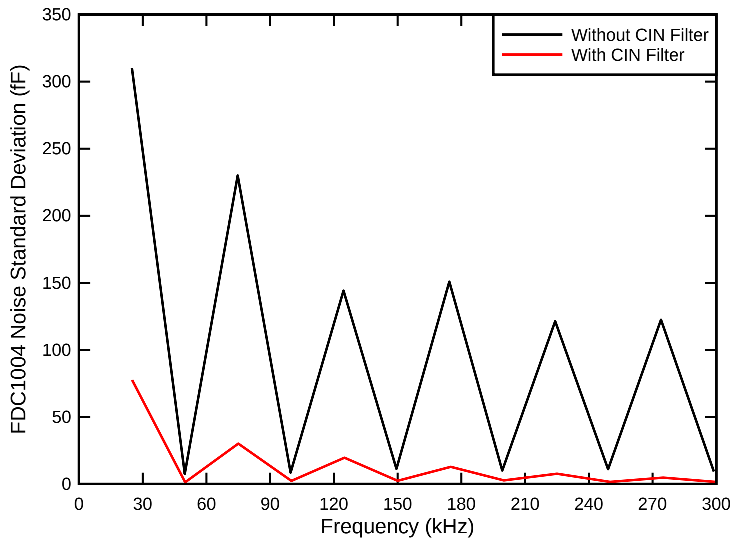


Figure 21. FDC1004 Noise versus Frequency of Radiated Interference

To provide the best performance of the system, ensure that any sources of noise in this frequency range are suppressed or eliminated.

The system was tested over the standard high-frequency range of 80 MHz to 1 GHz at a field strength of 3 V/m. The system output data during this test is shown in Figure 22. The standard deviation of the system output was 1.1 fF, and the peak-to-peak noise was 4.8 fF. A slow drift in the data built as the noise frequency swept from 80 MHz to 1 GHz. However, the slow-moving average feature of the TI Design eliminates any false triggering of the system. Thus, the TI Design is resilient to radiated immunity effects.

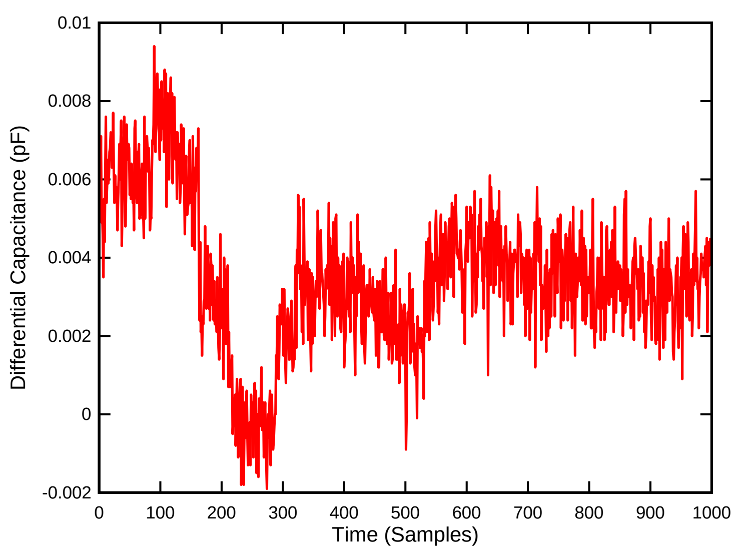


Figure 22. FDC1004 Output During High-Frequency Radiated Immunity Test

7 Design Files

7.1 Schematics

To download the schematics, see the design files at TIDA-00220.

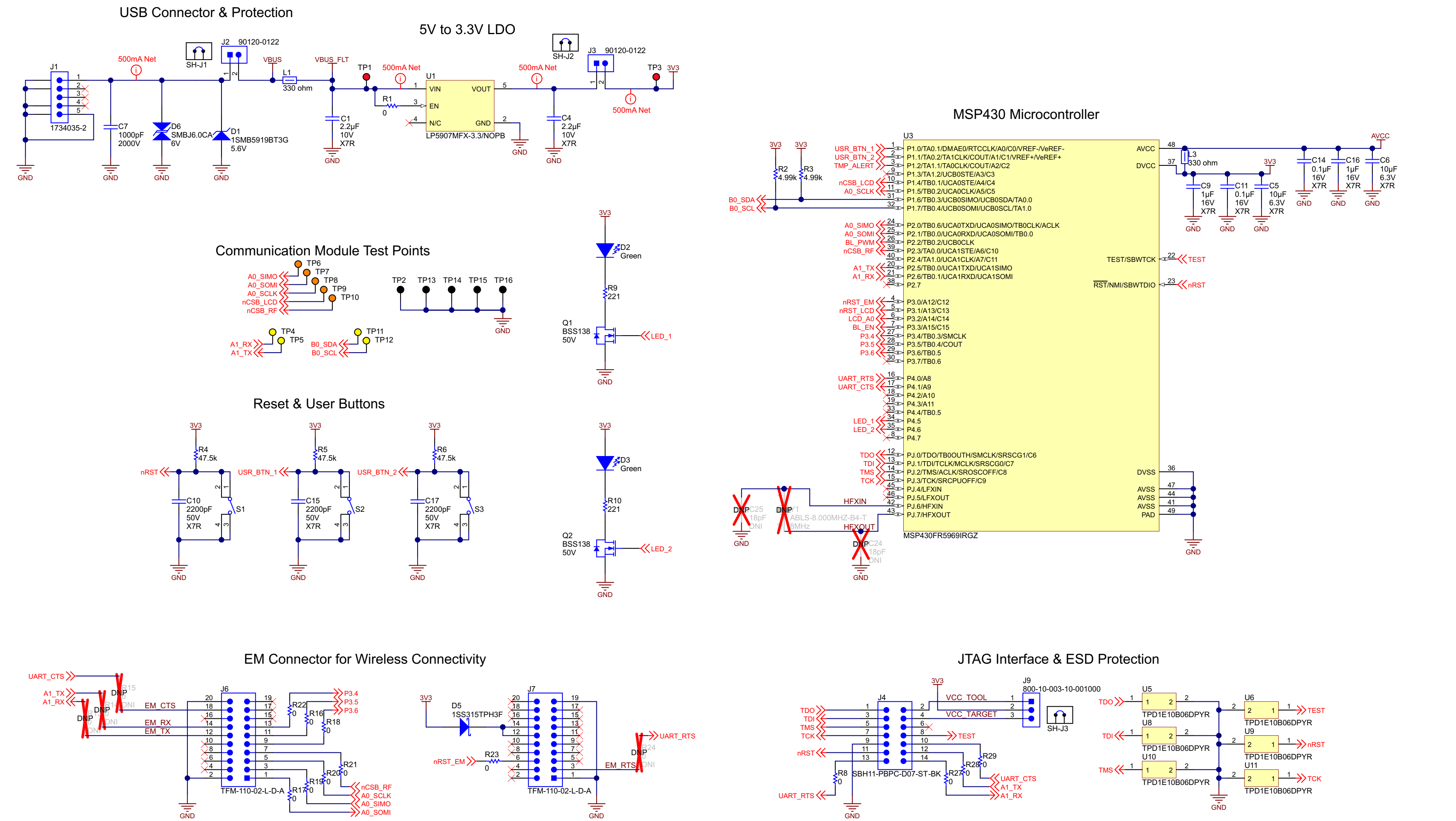


Figure 23. MSP430 Schematic

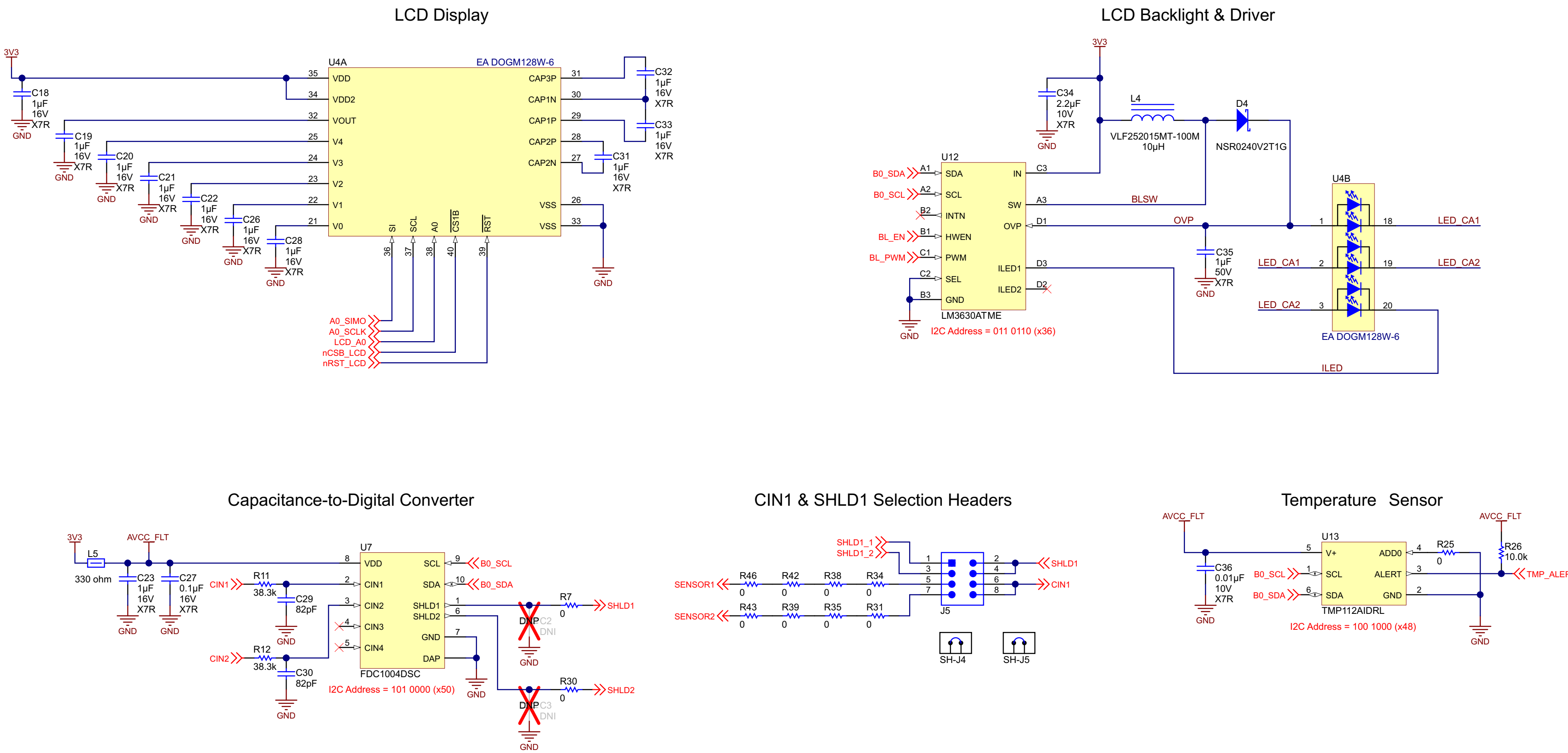


Figure 24. LCD Display Schematic

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00220.

Table 6. BOM

DESIGNATOR	QTY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PARTNUMBER	MANUFACTURER	ALTERNATE PARTNUMBER	ALTERNATE MANUFACTURER
!PCB1	1		Printed Circuit Board		ISE4010	Any		
BL1	1		LED Backlight, White		EA LED55X46-W	Electronic Assembly		
C1, C34	2	2.2 µF	CAP, CERM, 2.2 µF, 10 V, ±10%, X7R, 0603	0603	GRM188R71A225KE15D	MuRata		
C4	1	2.2 µF	CAP, CERM, 2.2 µF, 10 V, ±10%, X7R, 0603	0603	GRM188R71A225KE15D	MuRata		
C5, C6	2	10 µF	CAP, CERM, 10 µF, 6.3 V, ±20%, X7R, 0805	0805	C2012X7R0J106M125AB	TDK		
C7	1	1000 pF	CAP, CERM, 1000 pF, 2000 V, ±10%, X7R, 1210	1210	C1210C102KGRACTU	Kemet		
C9, C16, C18, C19, C20, C21, C22, C23, C26, C28, C31, C32, C33	13	1 µF	CAP, CERM, 1 µF, 16 V, ±10%, X7R, 0603	0603	C1608X7R1C105K	TDK		
C10, C15, C17	3	2200 pF	CAP, CERM, 2200 pF, 50 V, ±10%, X7R, 0402	0402	C1005X7R1H222K	TDK		
C11, C14, C27	3	0.1 µF	CAP, CERM, 0.1 µF, 16 V, ±10%, X7R, 0402	0402	GRM155R71C104KA88D	MuRata		
C29, C30	2	82 pF	CAP, CERM, 82 pF, 50 V, ±5%, C0G/NP0, 0402	0402	GRM1555C1H820JA01D	MuRata		
C35	1	1 µF	CAP, CERM, 1 µF, 50 V, ±10%, X7R, 0603	0603	UMK107AB7105KA-T	Taiyo Yuden		
C36	1	0.01 µF	CAP, CERM, 0.01 µF, 10 V, ±10%, X7R, 0201	0201	GRM033R71A103KA01D	MuRata		
D1	1	5.6 V	Diode, Zener, 5.6 V, 550 mW, SMB	SMB	1SMB5919BT3G	ON Semiconductor		
D2, D3	2	Green	LED, Green, SMD	LED, 1 × .2 × .6 mm	SML-P12PTT86	Rohm		
D4	1	40 V	Diode, Schottky, 40 V, 0.25 A, SOD-523	SOD-523	NSR0240V2T1G	ON Semiconductor		
D5	1	5 V	Diode, Schottky, 5 V, 0.03 A, SOD-323	SOD-323	1SS315TPH3F	Toshiba		
D6	1	6 V	Diode, TVS, Bi, 6 V, 600 W, SMB	SMB	SMBJ6.0CA	Littelfuse		
H1, H2, H5, H7, H8, H11, H13	7		Standoff, Hex, 0.5"L #4-40 Nylon	Standoff	1902C	Keystone		

Table 6. BOM (continued)

DESIGNATOR	QTY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PARTNUMBER	MANUFACTURER	ALTERNATE PARTNUMBER	ALTERNATE MANUFACTURER
H3, H4, H6, H9, H10, H12, H14	7		Machine Screw, Round, #4-40 × 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply		
J1	1		Connector, Receptacle, Mini-USB Type B, R/A, Top Mount SMT	USB Mini Type B	1734035-2	TE Connectivity		
J2	1		Header, 100 mil, 2×1, Tin plated, TH	Header 2×1	90120-0122	Molex		
J3	1		Header, 100 mil, 2×1, Tin, TH	Header 2×1	90120-0122	Molex		
J4	1		Header (shrouded), 100 mil, 7×2, Gold plated, TH	7×2 Shrouded Header	SBH11-PBPC-D07-ST-BK	Sullins Connector Solutions		
J5	1		Header, 100 mil, 4×2, Gold, TH	4×2 Header	TSW-104-07-G-D	Samtec		
J6, J7	2		Straight Low Profile Header, 10×2 Position,1.27-mm Pitch, SMT	10×2 SMT, 15.88 × 6.35 × 5.72 mm	TFM-110-02-L-D-A	Samtec		
J9	1		Header, 3×1, 100 mil, SMT	Header, 3×1, 100 mil, TH	800-10-003-10-001000	Mill-Max		
L1, L3, L5	3	330 Ω	1.5-A Ferrite Bead, 330 Ω at 100 MHz, SMD	0603	BLM18SG331TN1 D	MuRata		
L4	1	10 µH	Inductor, Shielded, Ferrite, 10 µH, 0.47 A, 0.24 Ω, SMD	IND_2.5 × 1.5 × 2 mm	VLF252015MT-100M	TDK		
LBL1	1		Thermal Transfer Printable Labels, 0.650" W × 0.200" H - 10,000 per roll	PCB Label 0.650"H × 0.200"W	THT-14-423-10	Brady	—	—
Q1, Q2	2	50 V	MOSFET, N-CH, 50 V, 0.22 A, SOT-23	SOT-23	BSS138	Fairchild Semiconductor		None
R1, R8, R16, R17, R18, R19, R20, R21, R22, R23, R25, R27, R28, R29	14	0	RES, 0 Ω, 5%, 0.063 W, 0402	0402	CRCW04020000Z 0ED	Vishay-Dale		
R2, R3	2	4.99 k	RES, 4.99 kΩ, 1%, 0.063 W, 0402	0402	CRCW04024K99F KED	Vishay-Dale		
R4, R5, R6	3	47.5 k	RES, 47.5 kΩ, 1%, 0.1 W, 0603	0603	CRCW060347K5F KEA	Vishay-Dale		
R7, R30	2	0	RES, 0, 5%, 0.063 W, 0402	0402	CRCW04020000Z 0ED	Vishay-Dale		
R9, R10	2	221	RES, 221 Ω, 1%, 0.063 W, 0402	0402	CRCW0402221RF KED	Vishay-Dale		
R11, R12	2	38.3 k	RES, 38.3 k, 1%, 0.063 W, 0402	0402	CRCW040238K3F KED	Vishay-Dale		
R26	1	10.0 k	RES, 10.0 kΩ, 1%, 0.063 W, 0402	0402	CRCW040210K0F KED	Vishay-Dale		

Table 6. BOM (continued)

DESIGNATOR	QTY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PARTNUMBER	MANUFACTURER	ALTERNATE PARTNUMBER	ALTERNATE MANUFACTURER
R31, R34, R35, R38, R39, R42, R43, R46	8	0	RES, 0 Ω, 5%, 1 W, 2512	2512	CRCW25120000Z0EG	Vishay-Dale		
S1, S2, S3	3		Switch, Tactile, SPST-NO, 0.05 A, 12 V, SMT	SW, SPST 6×6 mm	4-1437565-1	TE Connectivity		
SH-J1, SH-J2, SH-J4, SH-J5	4	1×2	Shunt, 2 mm, Gold plated, Black	2-mm Shunt, Closed Top	2SN-BK-G	Samtec		
SH-J3	1		Shunt, 100 mil, Gold plated, Black	Shunt 2 pos. 100 mil	881545-2	TE Connectivity		
TP1, TP3	2	Red	Test Point, Miniature, Red, TH	Red Miniature Testpoint	5000	Keystone		
TP2, TP13, TP14, TP15, TP16	5	Black	Test Point, Miniature, Black, TH	Black Miniature Testpoint	5001	Keystone		
TP4, TP5, TP11, TP12	4	Yellow	Test Point, Miniature, Yellow, TH	Yellow Miniature Testpoint	5004	Keystone		
TP6, TP7, TP8, TP9, TP10	5	Orange	Test Point, Miniature, Orange, TH	Orange Miniature Testpoint	5003	Keystone		
U1	1		Ultra-Low-Noise, 250-mA Linear Regulator for RF and Analog Circuits Requires No Bypass Capacitor, DBV0005A	DBV0005A	LP5907MFX-3.3/NOPB	Texas Instruments		None
U3	1		Mixed Signal Microcontroller, RGZ0048B	RGZ0048B	MSP430FR5969IRGZ	Texas Instruments		None
U4	1		Module, 128×64-pixel graphics display	LCD Module	EA DOGM128W-6	Electronic Assembly		
U5, U6, U8, U9, U10, U11	6		ESD in 0402 Package with 10-pF Capacitance and 6-V Breakdown, 1 Channel, –40°C to 125°C, 2-pin X2SON (DPY), Green (RoHS and no Sb/Br)	DPY0002A	TPD1E10B06DPYR	Texas Instruments	Equivalent	None
U7	1		4-Channel Capacitance-to-Digital Converter for Capacitive Sensing Solutions, DSC0010B	DSC0010B	FDC1004DSC	Texas Instruments		None
U12	1		LM3630A High-Efficiency Dual-String White LED Driver, YFQ0012AKAR	YFQ0012AKAR	LM3630ATME	Texas Instruments		None
U13	1		High-Accuracy, Low-Power, Digital Temperature Sensor With SMBus(TM)/Two-Wire Serial Interface, DRL0006A	DRL0006A	TMP112AIDRL	Texas Instruments		None
C2, C3	0		CAP, CERM, xxxF, xxV, [TempCo], xx%, [PackageReference]	Used in PnP output	Used in BOM report	Used in BOM report	—	—

Table 6. BOM (continued)

DESIGNATOR	QTY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PARTNUMBER	MANUFACTURER	ALTERNATE PARTNUMBER	ALTERNATE MANUFACTURER
C24, C25	0	18 pF	CAP, CERM, 18 pF, 100 V, ±5%, C0G/NP0, 0603	0603	GRM1885C2A180JA01D	MuRata		
FID1, FID2, FID3, FID4, FID5, FID6	0		Fiducial mark. There is nothing to buy or mount.	Fiducial	N/A	N/A		
R13, R14, R15, R24	0	0	RES, 0 Ω, 5%, 0.063 W, 0402	0402	CRCW04020000Z0ED	Vishay-Dale		
Y1	0		Crystal, 8 MHz, 18 pF, SMD	Crystal, 11.4 × 4.3 × 3.8 mm	ABLS-8.000MHZ-B4-T	Abracon Corportation		

NOTE: Unless otherwise noted in the Alternate PartNumber or Alternate Manufacturer columns, all parts may be substituted with equivalents.

7.3 Layer Plots

To download the layer plots, see the design files at TIDA-00220.

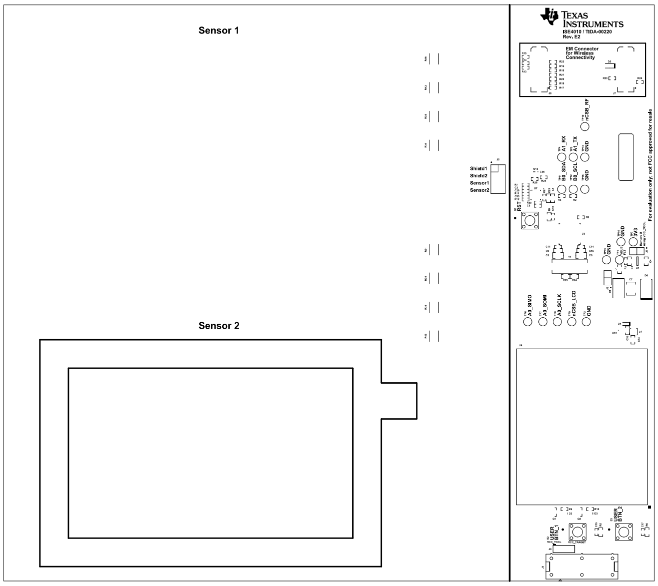


Figure 25. Top Overlay

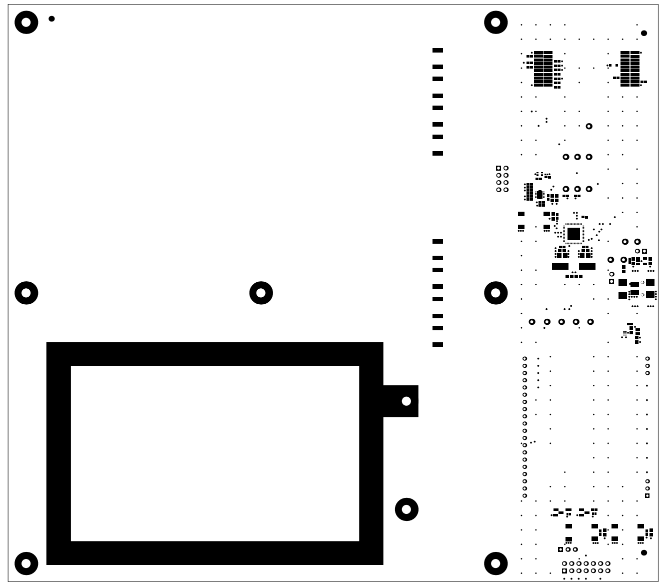


Figure 26. Top Solder Mask

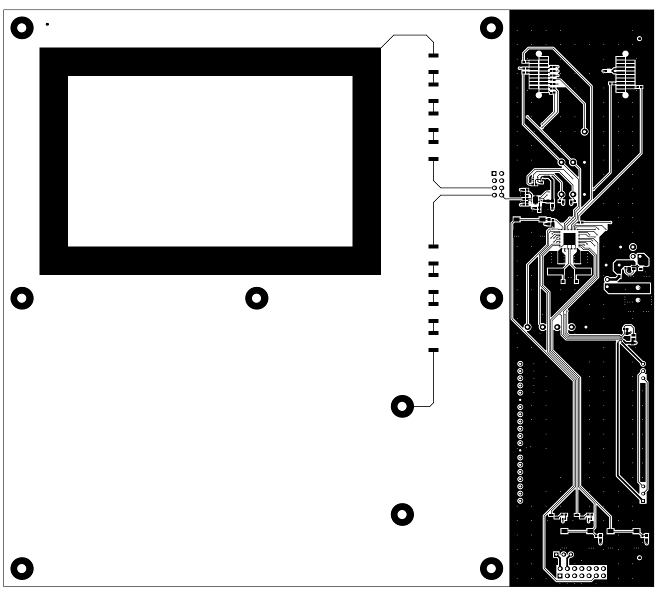


Figure 27. Top Layer

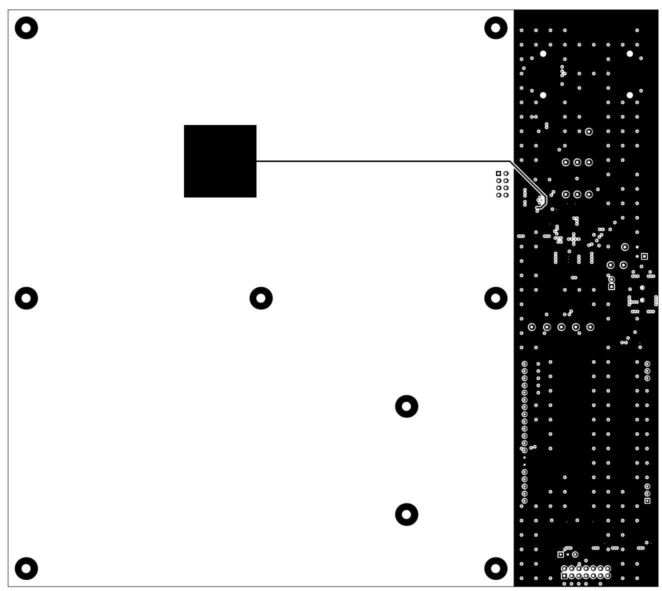


Figure 28. Mid Layer 1

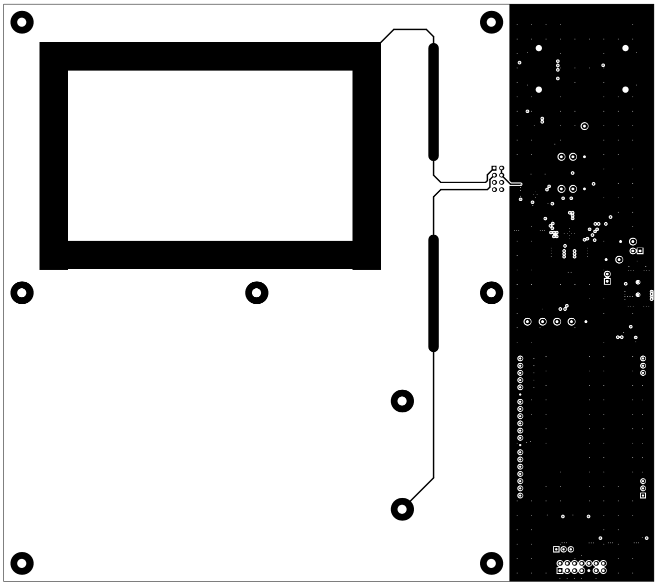


Figure 29. Mid Layer 2

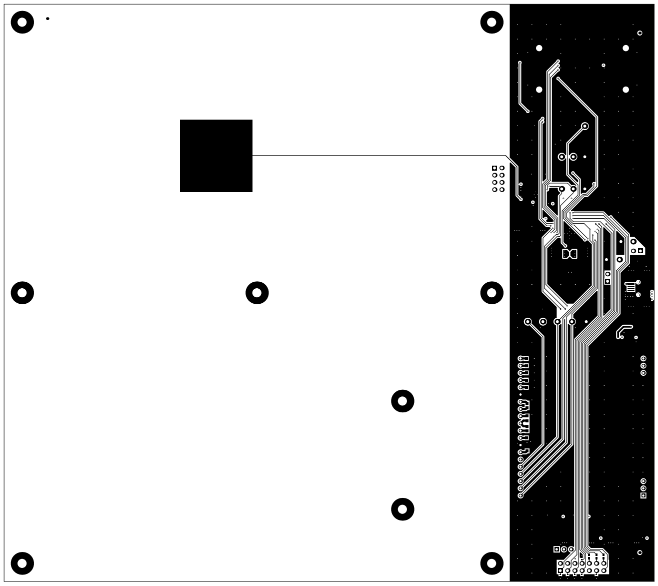


Figure 30. Bottom Layer

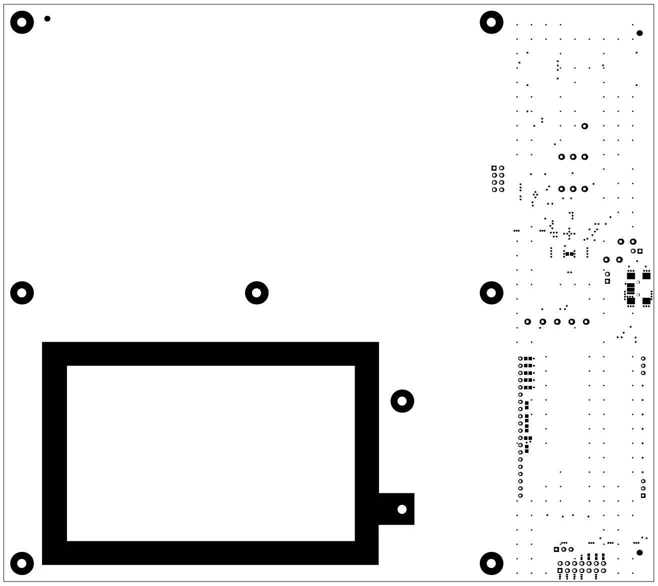


Figure 31. Bottom Solder Mask

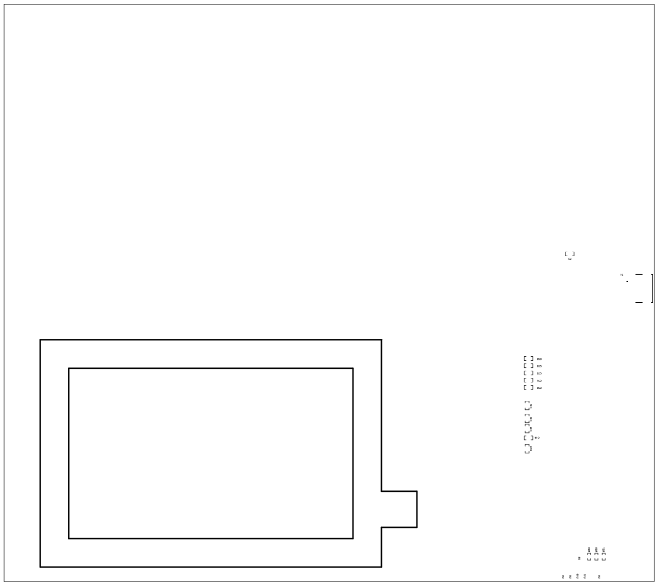
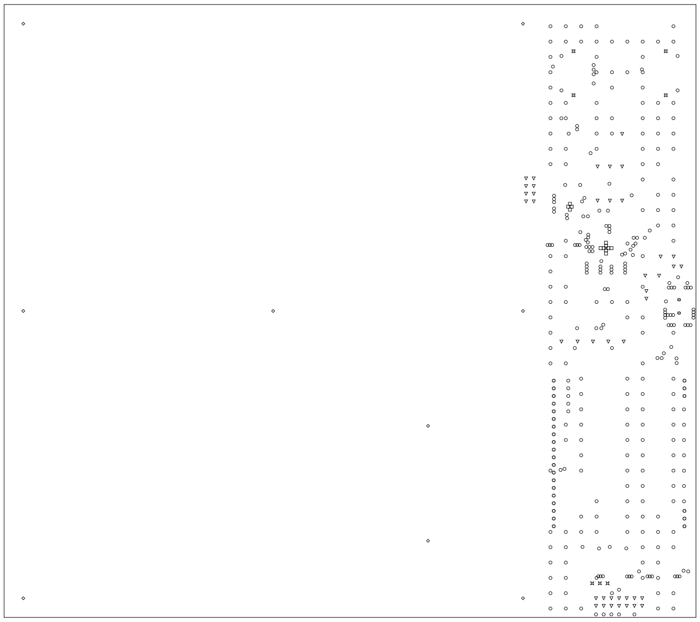


Figure 32. Bottom Overlay



Symbol	Hit Count	Tool Size	Plated	Hole Type
□	12	7.874mil (0.2mm)	PTH	Round
○	320	10mil (0.254mm)	PTH	Round
⌬	26	31.496mil (0.8mm)	PTH	Round
⌑	3	33.465mil (0.85mm)	PTH	Round
✡	2	35.433mil (0.9mm)	NPTH	Round
▽	42	40mil (1.016mm)	PTH	Round
⌧	4	57.087mil (1.45mm)	NPTH	Round
◇	9	125.984mil (3.2mm)	PTH	Round
	418 Total			

Drill Table

Figure 33. Drill Drawing

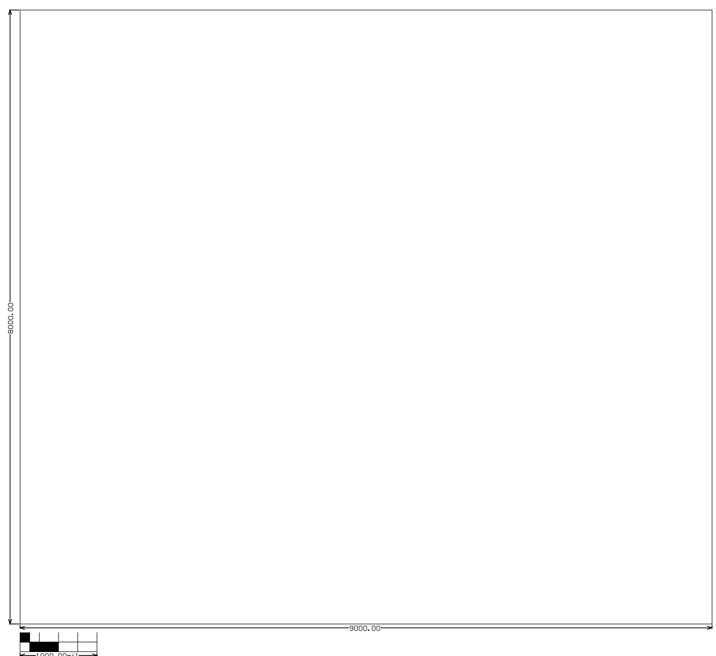


Figure 34. Board Dimensions

7.4 Altium Project

To download the Altium project files, see the design files at TIDA-00220.

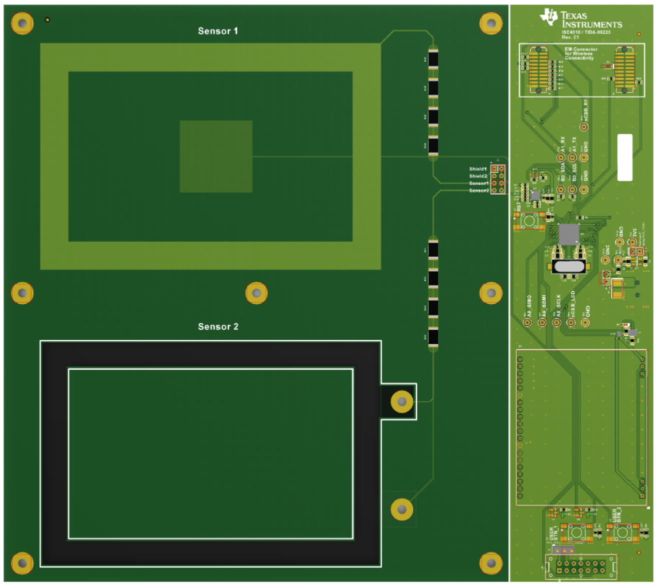


Figure 35. Top Side

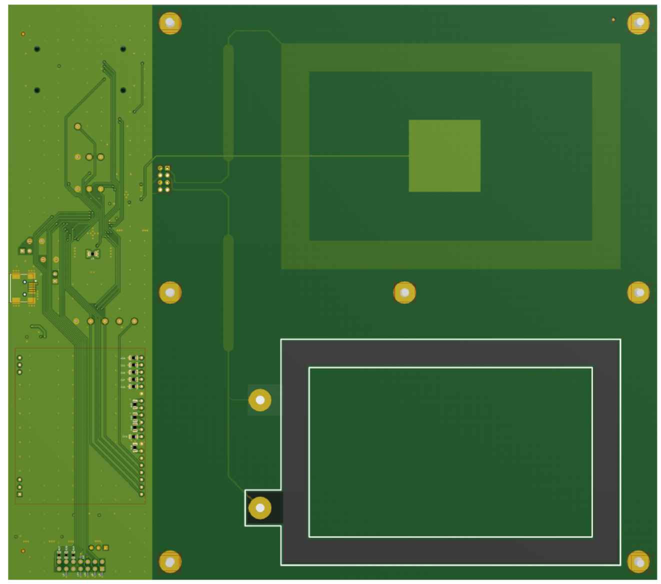


Figure 36. Bottom Side

7.5 Layout Guidelines

The following layout guidelines are recommended for implementing this TI Design into end-products:

- Keep input filters as close as possible to FDC1004.
- Ensure shield traces are slightly larger than proximity sensor traces; this 'directs' the electric field slightly.
- Ensure that shield traces for proximity sensor and shield traces for environmental sensor do not cross.
- Follow general layout guidelines for FDC1004, LM3630A, and LP5907 for best results.

7.6 Gerber Files

To download the Gerber files, see the design files at TIDA-00220.

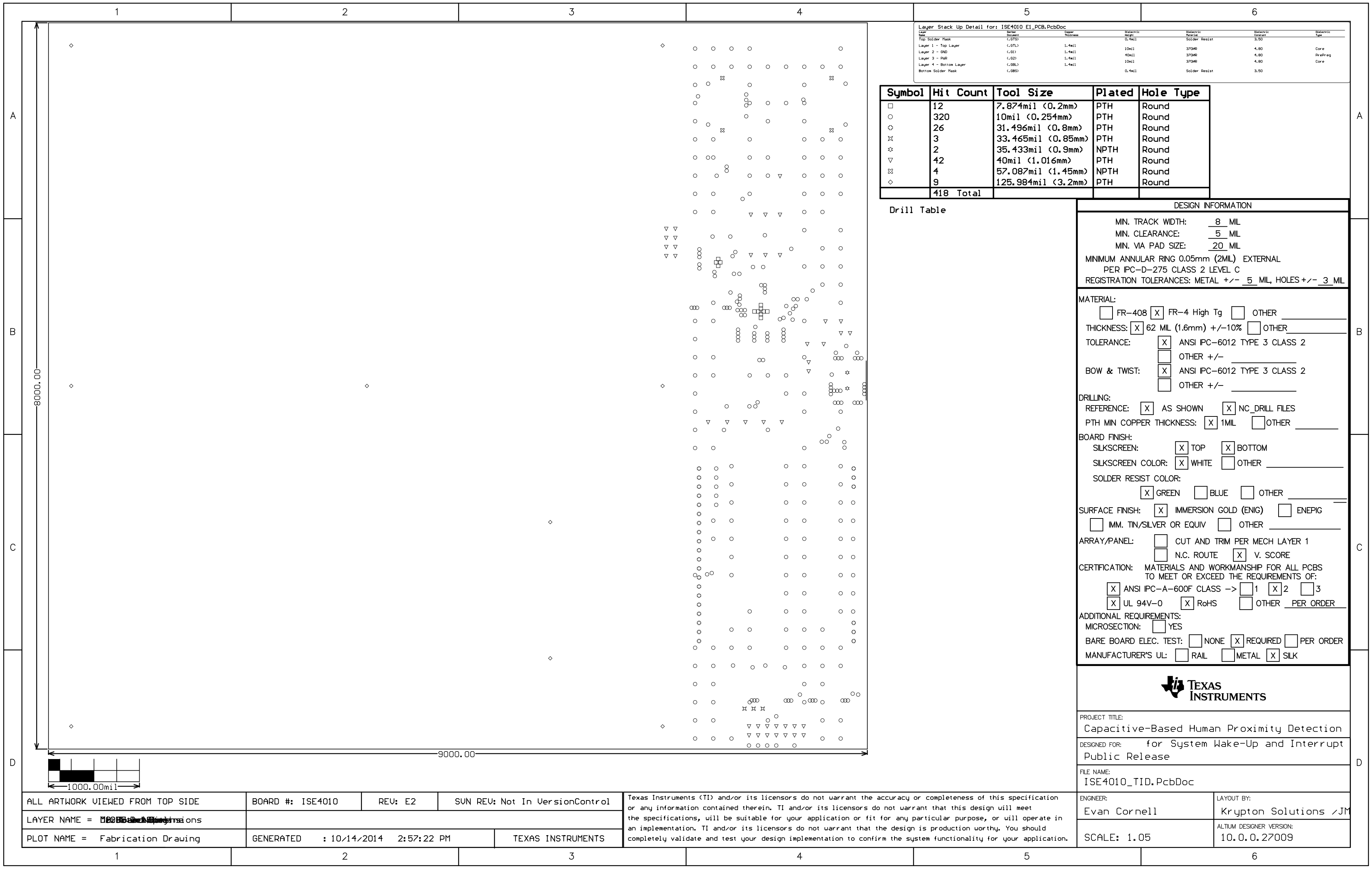


Figure 37. Fabrication Drawing

7.7 Assembly Drawings

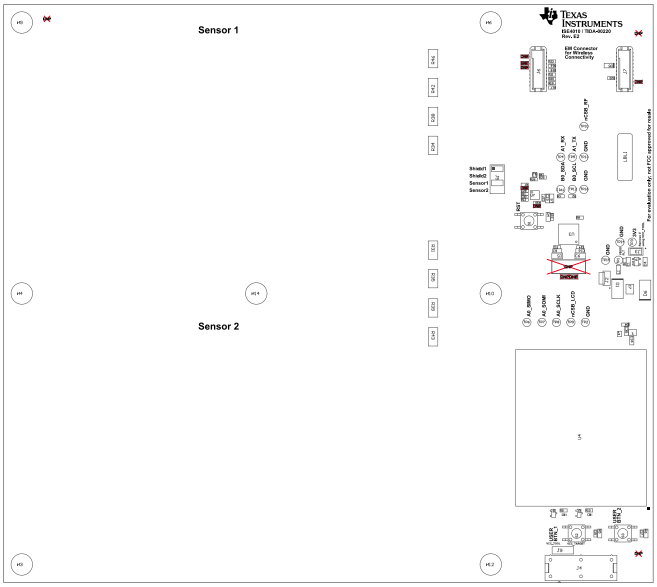


Figure 38. Top Assembly Drawing

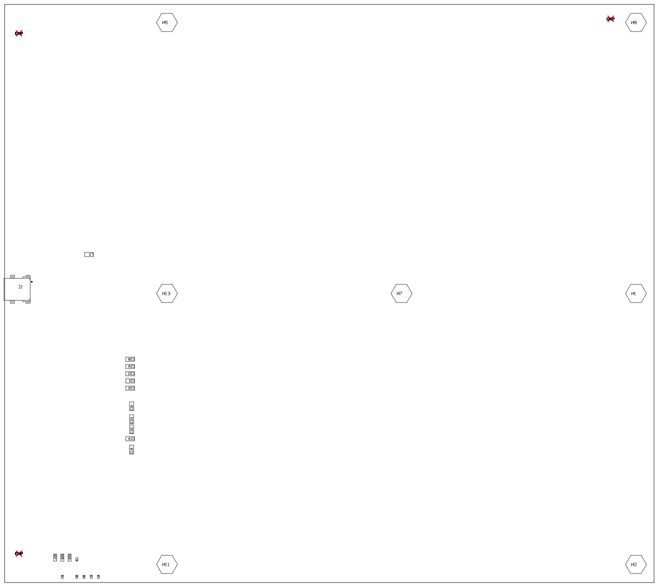


Figure 39. Bottom Assembly Drawing

7.8 Software Files

To download the software files, see the design files at TIDA-00220.

8 References

For additional references, see the following:

1. FDC1004 Datasheet (SNOSCY5)
2. MSP430FR5969 Datasheet (SLAS704D)
3. LP5907-33 Datasheet (SNVS798G)
4. LM3630A Datasheet (SNVS974A)
5. TMP112 Datasheet (SBOS473B)
6. TPD1E10B06 Datasheet (SLLSEB1B)

9 About the Author

EVAN D. CORNELL is a systems architect at Texas Instruments where he is responsible for developing reference design solutions for the industrial segment. Evan brings to this role experience in system-level analog, mixed-signal, and power management design. Evan earned his master of electrical and computer engineering (M.Eng.) and bachelor of science (BS) in electrical engineering from the Rose-Hulman Institute of Technology in Terre Haute, IN. Evan is a member of the Institute of Electrical and Electronics Engineers (IEEE).

TIDA-00220 Revision A History

Changes from Original (September 2014) to A Revision **Page**

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

TIDA-00220 Revision B History

Changes from A Revision (October 2014) to B Revision **Page**

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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