TI Designs
Distance and Weight Measurement Using Inductive Sensing Reference Design

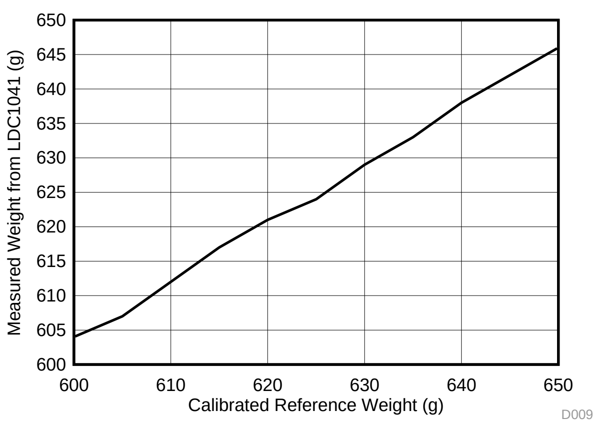
TI Designs

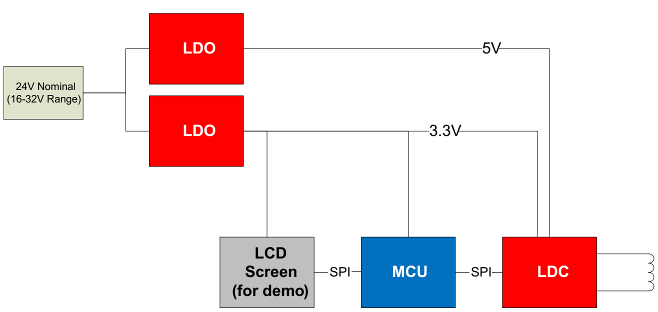
TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

TIDA-00215	Tool Folder Containing Design Files
LDC1041	Product Folder
MSP430F5232	Product Folder
TPS7A4101	Product Folder
TPD1E10B06	Product Folder

Measured vs Reference Weight





Design Features

The Distance and Weight Measurement subsystem is a reference design that uses Inductive Sensing to measure distance and weight at a high resolution.

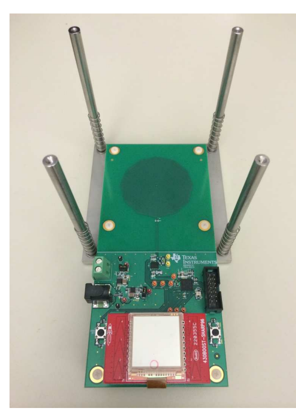
- Measures distance and weight without using expensive rare-earth magnet or materials
- Sensor coil input for inductive sensing customized for mechanical system from WEBENCH® Inductive Sensing Designer
- Calibrated sensor output from microcontroller
- Low power consumption of 37.8 mW
- Output resolution: 2 g
- Typical System Error: 9 g (100 g to 750 g)
- Typical System Error: 4.2 g (600 g to 650 g)
- IEC61000-4-2: ESD: Air Discharge: ±8 kV Class A
- IEC61000-4-4: EFT ±2 kV Class A

Featured Applications

- Building Automation
- Elevator Systems
- Weight Sensors
- Load Sensors

TI E2E™ Community

ASK Our Analog Experts
WEBENCH® Calculator Tools



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

1 Key Specifications

Parameter	Specifications and Features		Details
Sensor Type	PCB Inductor Coil		See Section 2.1.2
Weight Measurement Resolution	2 g		See Section 6.3
Characterized Weight Range	100 g to 750 g with MM-72 springs		See Section 6.2
System Accuracy or Maximum Measured Error	Maximum measured error: 9 g (100 g to 750 g)		Note: Error is dependent on mechanical set uo and configuration. See Section 6.4
	Maximum measured error: 4.2 g (600 g to 650 g)		
System Calibration	Best-fit 3rd order polynomial using regression analysis		See Section 6.2
Power Supply Range	7-40 Vdc, 24 V nominal		See Section 2.1.5
Power Consumption	37.8 mW		See Section 6.5
Power Supply Influence	0.602% from 7 V to 40 V		See Section 6.5
Reverse Polarity on Input Power	Supported		See Section 2.1.6
Ambient Temperature	–40°C to 125°C		See Section 2.1
IEC ESD on Input Power	IEC61000-4-2, ESD	Horizontal Coupling Plane: ±4 kV - Class A	See Section 6.7
		Air discharge: ±8 kV - Class A	
IEC EFT on Input Power	IEC61000-4-4	EFT: ±2 kV - Class A	See Section 6.7
Form Factor	3 x 6.5 inch rectangular PCB with stainless steel mechanical system		See Section 4.1

2 System Description

In many industrial end-equipment systems, there are many situations that require precise and accurate measurements of distance. One such scenario is the conversion of a distance measurement to a weight measurement, through the use of springs with well-known characteristics. Typical implementations of distance measurements use expensive rare-earth magnets. To lower overall system cost, this reference design walks through the implementation of TI's inductance-to-digital converters to measure distance (see Section 4.2), and therefore weight (see Section 4.1), without the use of any expensive rare-earth magnets.

This design addresses component selection, measurement theory, subsystem calibration, and temperature compensation. The scope of this reference design gives system designers a head-start integrating TI's family of inductance-to-digital converters into new applications requiring high-resolution distance and weight measurements.

The overall system-level challenges for this design were proper sensor coil design to achieve desired measurement resolution, proper conversion and calibration of inductance-to-digital converter output into usable data, and temperature compensation.

2.1 Component Selection

2.1.1 Inductance-to-Digital Converter

The LDC1041 is an Inductance-to-Digital Converter that simultaneously measures the impedance and resonant frequency of an LC resonator. It accomplishes this task by regulating the oscillation amplitude in a closed loop configuration to a constant level, while monitoring the energy dissipated by the resonator. By monitoring the amount of power injected into the resonator, the LDC1041 can determine the value of Rp; it returns this as a digital value which is inversely proportional to Rp. In addition, the LDC1041 also measure the oscillation frequency of the LC circuit; this frequency is used to determine the inductance of the LC circuit. The device outputs a digital value that is inversely proportional to frequency.

The LDC1041 inductance-to-digital converter is a high-resolution and low-cost device that enables contactless, short-range sensing, even in harsh environments. Using a printed circuit board (PCB) coil as a sensor, the LDC1041 provides system designers a way to achieve high performance and reliability at a lower system cost than other competing solutions. The LDC1041 was chosen because the device has the ability to measure inductance at a 24-bit resolution. The Distance and Weight Measurement Using Inductive Sensing Reference Design uses only the inductive measurement mode of the LDC family of parts; therefore, the LDC1041 represents the cost-optimized device for high-resolution inductance-only measurements.

2.1.2 Sensor Coil Design

The design of the sensor coil used with the LDC1041 is critical to achieve the desired distance measurement performance. In the Distance and Weight Measurement Using Inductive Sensing Reference Design, the WEBENCH® Inductive Sensing Designer was used to generate the appropriate sensor coil, based on the subsystem mechanical characteristics. The sensing coil design depends on the mechanical requirements for sensing distance, precision, and target size.

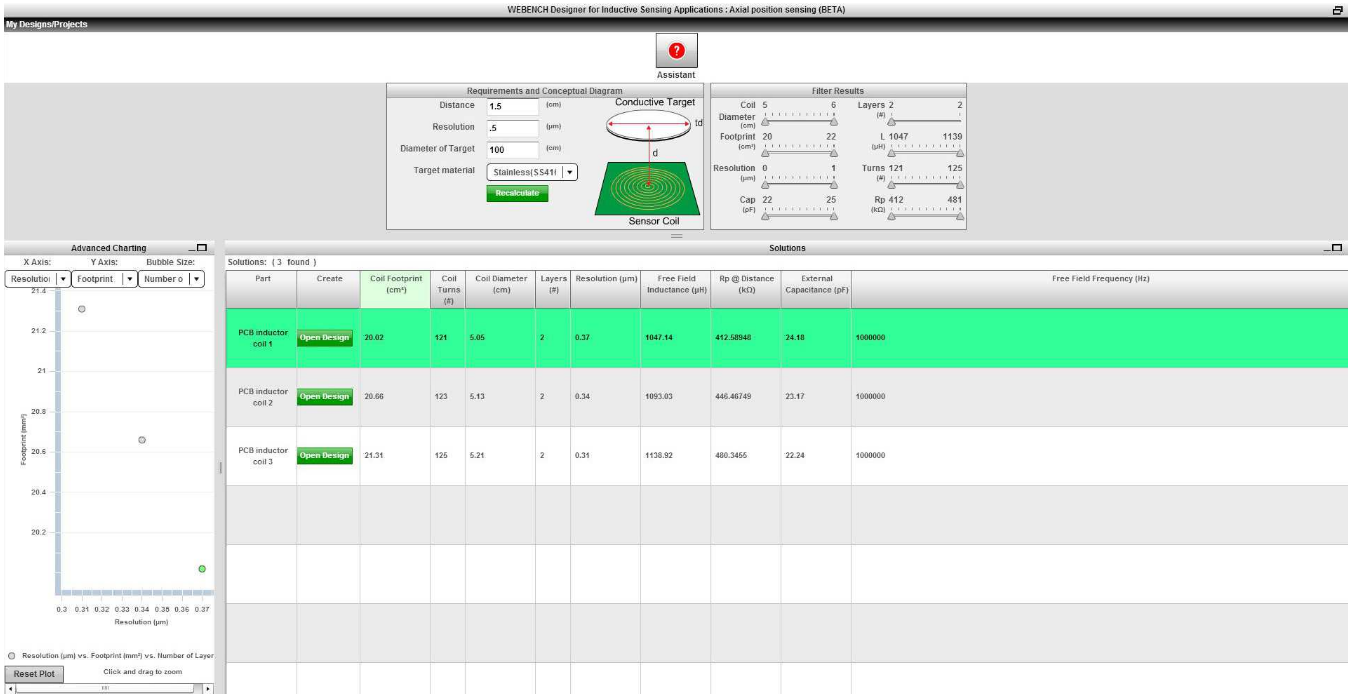


Figure 1. WEBENCH Coil Design

The available parameters for adjustment in the WEBENCH® Inductive Sensing Designer include distance, resolution, diameter of target, and target material. Sensor coil results can then be filtered by coil diameter, coil footprint, resolution, tank capacitance, PCB layers, inductance, number of turns, and Rp value. The Distance and Weight Measurement Using Inductive Sensing Reference Design uses a coil designed for 1.5 cm distance to target, 0.5 µm resolution, 100 cm target diameter, and filtered to achieve a 2-layer PCB coil design.

2.1.3 Microcontroller Selection

The MSP430F5232 microcontroller was chosen as the central processor for the subsystem, based on memory, processor power, and peripheral module requirements necessary to support the LDC1041 device, the TMP103 device, and the LCD Screen BoosterPack. The MSP430F5232 device contains two USCI_A communication modules, as well as two USCI_B communication modules. Two USCI_A modules was a requirement for the Distance and Weight Measurement Using Inductive Sensing Reference Design, as both the LDC1041 and the 430BOOST-SHARP96 LCD Screen BoosterPack communicate by way of a serial peripheral interface (SPI). In addition, the TMP103 temperature sensor communicates by way of I^2C, which uses the USCI_B module. In a final implementation of the Distance and Weight Measurement Using Inductive Sensing Reference Design, an LCD screen may not be desired. In this case, a smaller, more cost-optimized microcontroller may be utilized.

2.1.4 Digital Temperature Sensor

The TMP103 digital temperature sensor device was chosen to enable temperature calibration in the Distance and Weight Measurement Using Inductive Sensing Reference Design. The TMP103 device is a digital output temperature sensor in a four-ball wafer chip-scale package (WCSP). The TMP103 device is capable of reading temperatures to a resolution of 1°C. For minimal cost and board space, the addition of the TMP103 device to the subsystem allows for more accurate measurements through temperature calibration.

2.1.5 Power Management

The TPS7A4101 low-dropout (LDO) regulator devices were chosen as the power management devices for the subsystem for several reasons. The first reason is that this particular subsystem is designed to work from a nominal input voltage of 24 V. This requires a regulator that can handle an input voltage of at least 40 V to maintain sufficient margin to handle tolerances in the input voltage, as well as high transient voltage levels. The TPS7A4101 device has a current limit of 50 mA, which is significantly higher than the anticipated maximum total operating load of the subsystem. Two TPS7A4101 devices are used in this subsystem, one to regulate a 5-V output for the LDC1041, and another to regulate a 3.3-V output for all other devices.

When integrating the Distance and Weight Measurement Using Inductive Sensing Reference Design into a final system, different power requirements may exist. The choice of power management devices could change, depending on existing input voltage rails. If lower voltage point-of-load rails already exist, then different TI power management devices (www.ti.com/power) can be chosen to suit the conditions of the system. A low-noise power rail is necessary for optimal performance of the LDC1041, either by using a low-dropout linear regulator, or by ensuring that the switching frequency of a DC-DC converter does not conflict with the tank frequency of the sensing coil and capacitor. WEBENCH® Designer is an excellent tool to determine the appropriate devices.

2.1.6 ESD Protection

The TPD1E10B06 Single Channel ESD protection device was chosen to protect 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 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 that protect the JTAG programming interface, there is a protection network of discrete devices on the main power input net. This consists of a high-voltage (2 kV) shunt capacitor to ground, a transient voltage suppression (TVS) device, a common-mode choke, fast bypass capacitor, and a reverse voltage protection Schottky diode. This network protects against transient voltages and currents on the main power input, as well as reduces differential-mode and common-mode RF transients.

2.2 LDC1041

Inductive sensing is a contactless, short-range sensing technology enabling high-resolution and low-cost position sensing of conductive targets, even in harsh environments. Using a coil or spring as a sensor, the LDC1041 inductance-to-digital converter provides system designers a way to achieve high performance and reliability at a lower system cost than other competing solutions.

The LDC1041 device is pin compatible with the LDC1000 device (16-bit Rp/24-bit L) and the LDC1051 device (8-bit Rp). This family of devices offers system designers different resolution options based on their application and system requirements.

The LDC1041 is available in a 5 mm x 4 mm WSON-16 package. Device programming by way of SPI allows for easy configuration using a microcontroller. For the LDC1041 block diagram, see Figure 3.

2.3 MSP430F5232

The Texas Instruments MSP430 family of ultralow-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with extensive low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows the device to wake up from low-power modes to active mode in 3.5 µs (typical).

The MSP430F524x series are microcontroller configurations with four 16-bit timers, a high-performance 10-bit analog-to-digital converter (ADC), two universal serial communication interfaces (USCIs), a hardware multiplier, DMA, a comparator, and a real-time clock module with alarm capabilities.

The MSP430F523x series microcontrollers include all of the peripherals of the MSP430F524x series except for the ADC.

Typical applications include analog and digital sensor systems, data loggers, and various general-purpose applications. For the MSP430F5232 block diagram, see Figure 4.

2.4 TMP103

The TMP103 is a digital output temperature sensor in a four-ball wafer chip-scale package (WCSP). The TMP103 is capable of reading temperatures to a resolution of 1°C.

The TMP103 features a two-wire interface that is compatible with both I^2C and SMBus interfaces. In addition, the interface supports multiple device access (MDA) commands that allow the master to communicate with multiple devices on the bus simultaneously, eliminating the need to send individual commands to each TMP103 on the bus.

Up to eight TMP103s can be tied together in parallel and easily read by the host. The TMP103 is especially ideal for space-constrained, power-sensitive applications with multiple temperature measurement zones that must be monitored.

The TMP103 is specified for operation over a temperature range of –40°C to +125°C.

2.5 TPD1E10B06

The TPD1E10B06 is a single channel ESD protection device in a small 0402 package. 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. 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).

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.

2.6 TPS7A4101

The TPS7A41 is a very high voltage-tolerant linear regulator that offers the benefits of a thermally-enhanced package (MSOP-8), and is able to withstand continuous dc or transient input voltages of up to 50 V.

The TPS7A41 is stable with any output capacitance greater than 4.7 µF and any input capacitance greater than 1 µF (over temperature and tolerance). Therefore, implementations of this device require minimal board space because of its miniaturized packaging (MSOP-8) and a potentially small output capacitor. In addition, the TPS7A41 offers an enable pin (EN) compatible with standard CMOS logic to enable a low-current shutdown mode.

The TPS7A41 has an internal thermal shutdown and current limiting to protect the system during fault conditions. The MSOP-8 packages has an operating temperature range of T_J = –40°C to +125°C.

In addition, the TPS7A41 is ideal for generating a low-voltage supply from intermediate voltage rails in telecom and industrial applications; not only it can supply a well-regulated voltage rail, but it can also withstand and maintain regulation during very high and fast voltage transients. These features translate to simpler and more cost-effective electrical surge-protection circuitry for a wide range of applications. For the TPS7A4101 block diagram, see Figure 6.

3 Subsystem Block Diagram

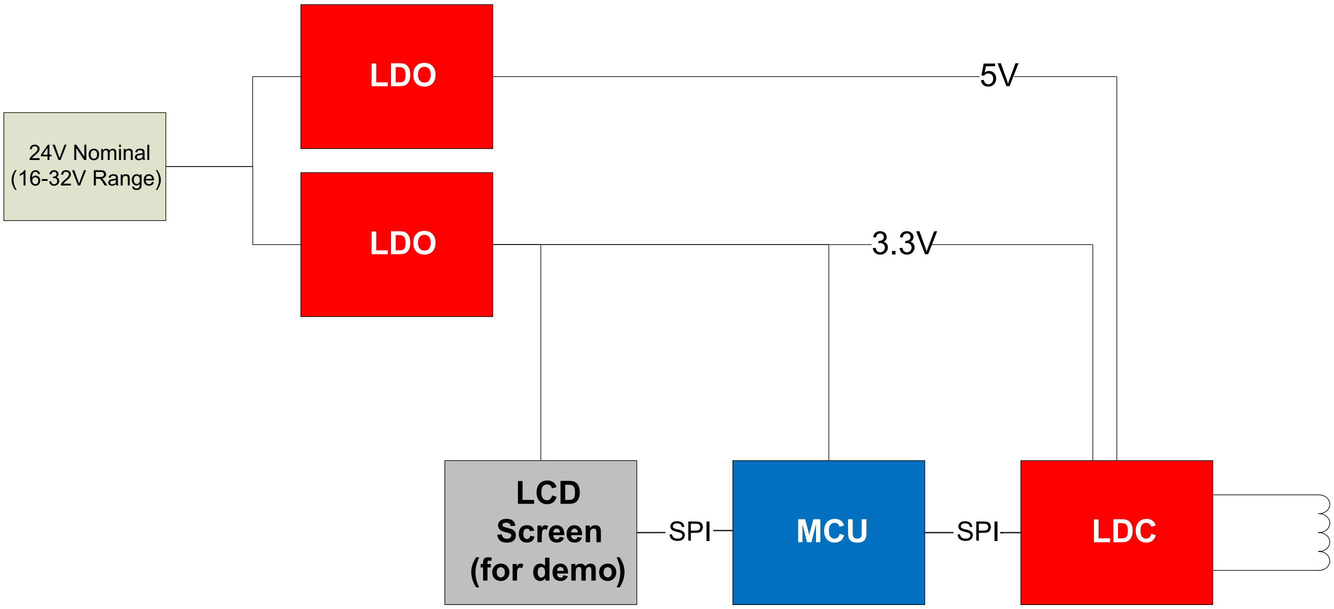


Figure 2. System Block Diagram

3.1 *Highlighted Products*

The Distance and Weight Measurement Using Inductive Sensing Reference Design features the following devices:

- **LDC1041**
  - Inductance-to-digital Converter with SPI Interface
- **MSP430F5232**
  - Ultra-Low Power MSP430 with 128 KB Flash
- **TMP103**
  - Digital Temperature Sensor with I^2C/SMBUS Expanded Interface
- **TPS7A4101**
  - 50 V Input, 50 mA, Single Output Low-Dropout Linear Regulator
- **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 LDC1041 Features

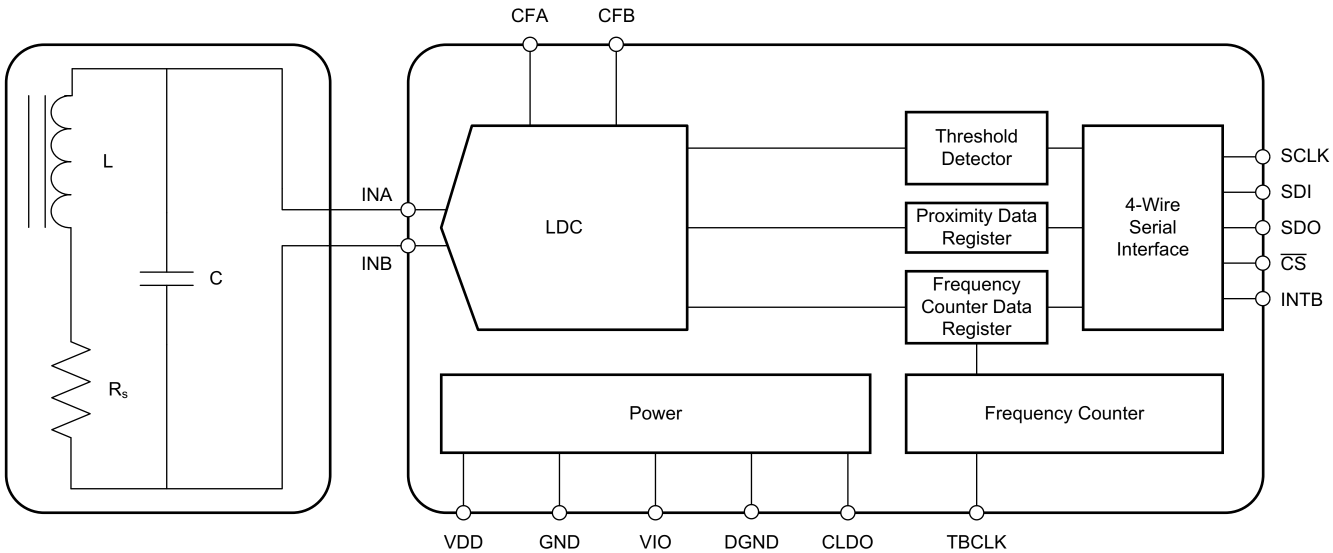


Figure 3. LDC1041 Block Diagram

- Remote sensor placement (decoupling the LDC from harsh environments)
- High durability (by virtue of contactless operation)
- Higher flexibility for system design (using coils or springs as sensors)
- Insensitive to non-conductive environmental interferers (such as dirt, dust, oil, and so on)
- Magnet-free operation
- Sub-micron precision
- Supply Voltage: 5 V, typ
- Supply voltage, IO: 1.8 V to 5.5 V
- Stand-by current: 250 µA, typ
- Rp resolution: 8-bit
- L resolution: 24-bit
- LC frequency range: 5 kHz to 5 MHz

3.1.2 MSP430F5232 Features

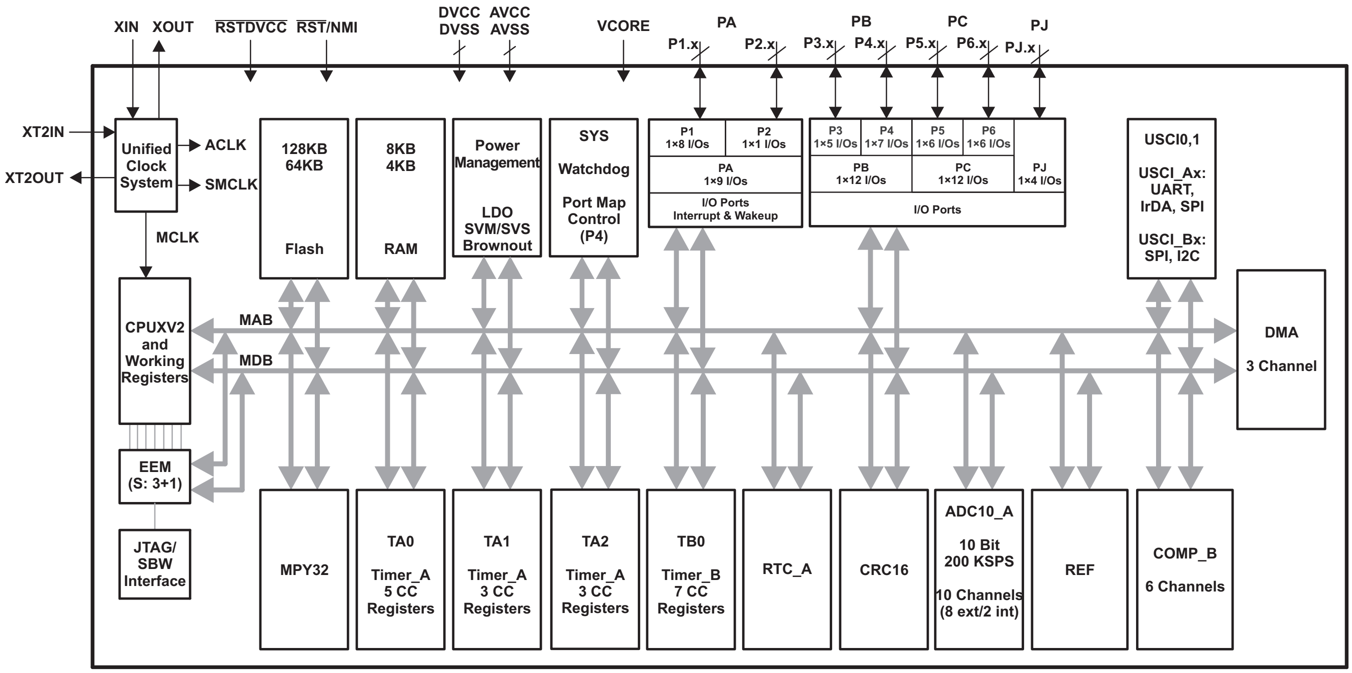


Figure 4. MSP430F5232 Block Diagram

- Low Supply-Voltage Range: 3.6 V Down to 1.8 V
- Ultralow-Power Consumption
  - Active Mode (AM):
    - All System Clocks Active
    - 290 µA/MHz at 8 MHz, 3.0 V, Flash Program Execution (Typical)
    - 150 µA/MHz at 8 MHz, 3.0 V, RAM Program Execution (Typical)
  - Standby Mode (LPM3):
    - Real-Time Clock With Crystal, Watchdog, and Supply Supervisor Operational, Full RAM Retention, Fast Wake Up:
    - 1.9 µA at 2.2 V, 2.1 µA at 3.0 V (Typical)
    - 1.4 µA at 3.0 V (Typical)
  - Off Mode (LPM4):
    - Full RAM Retention, Supply Supervisor Operational, Fast Wake Up:
    - 1.1 µA at 3.0 V (Typical)
  - Shutdown Mode (LPM4.5):
    - 0.18 µA at 3.0 V (Typical)
- Wake Up From Standby Mode in 3.5 µs (Typical)
- 16-Bit RISC Architecture, Extended Memory, up to 25-MHz System Clock
- Flexible Power Management System
  - Fully Integrated LDO With Programmable Regulated Core Supply Voltage
  - Supply Voltage Supervision, Monitoring, and Brownout

- Unified Clock System
  - FLL Control Loop for Frequency Stabilization
  - Low-Power Low-Frequency Internal Clock Source (VLO)
  - Low-Frequency Trimmed Internal Reference Source (REFO)
  - 32-kHz Watch Crystals (XT1)
  - High-Frequency Crystals up to 32 MHz (XT2)
- 16-Bit Timer TA0, Timer_A With Five Capture/Compare Registers
- 16-Bit Timer TA1, Timer_A With Three Capture/Compare Registers
- 16-Bit Timer TA2, Timer_A With Three Capture/Compare Registers
- 16-Bit Timer TB0, Timer_B With Seven Capture/Compare Shadow Registers
- Two Universal Serial Communication Interfaces
  - USCI_A0 and USCI_A1 Each Support:
    - Enhanced UART Supports Auto-Baudrate Detection
    - IrDA Encoder and Decoder
    - Synchronous SPI
  - USCI_B0 and USCI_B1 Each Support:
    - I^2C
    - Synchronous SPI
- 10-Bit Analog-to-Digital Converter (ADC) With Internal Reference, Sample-and-Hold Comparator
- Hardware Multiplier Supports 32-Bit Operations
- Serial Onboard Programming, No External Programming Voltage Needed
- Three-Channel Internal DMA
- Basic Timer With Real-Time Clock Feature

For complete module descriptions, see the MSP430x5xx and MSP430x6xx Family User's Guide (SLAU208)

3.1.3 TMP103 Features

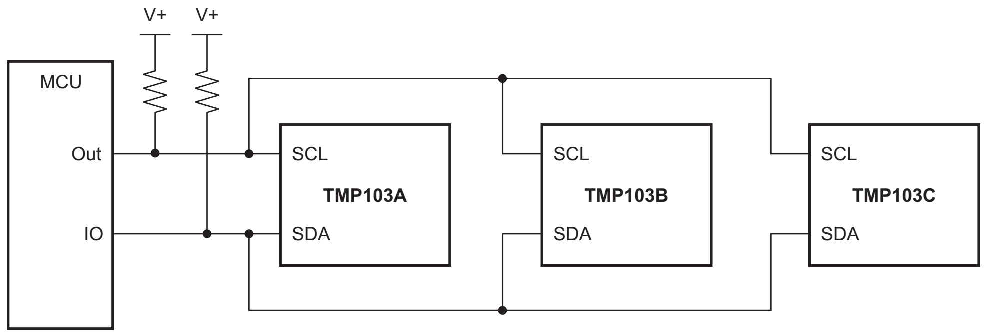


Figure 5. TMP103 Block Diagram

- Multiple Device Access (MDA):
  - Global Read/Write Operations
- I^2C™-/SMBus™-Compatible Interface
- Resolution: 8 Bits
- Accuracy: ±1°C Typ (–10°C to +100°C)
- Low Quiescent Current:
  - 3 µA Active IQ at 0.25 Hz
  - 1 µA Shutdown
- Supply Range: 1.4 V to 3.6 V
- Digital Output
- Package: 4-Ball WCSP (DSBGA)

3.1.4 TPS7A4101 Features

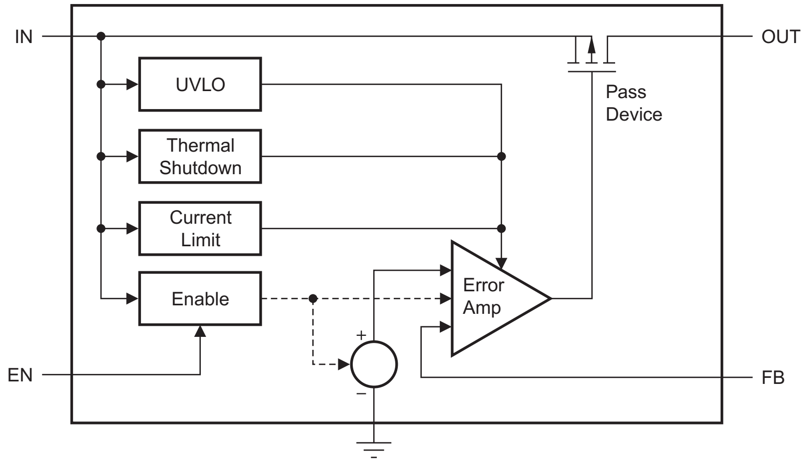


Figure 6. TPS7A4101 Block Diagram

- Wide Input Voltage Range: 7 V to 50 V
- Accuracy:
  1. Nominal: 1%
  2. Over Line, Load, and Temperature: 2.5%
- Low Quiescent Current: 25 µA
- Quiescent Current at Shutdown: 4.1 µA
- Maximum Output Current: 50 mA
- CMOS Logic-Level-Compatible Enable Pin
- Adjustable Output Voltage: ~1.175 V to 48 V
- Stable with Ceramic Capacitors:
  1. Input Capacitance: ≥ 1 µF
  2. Output Capacitance: ≥ 4.7 µF
- Dropout Voltage: 290 mV
- Built-In Current-Limit and Thermal Shutdown Protection
- Package: High Thermal Performance MSOP-8 PowerPAD™
- Operating Temperature Range: –40°C to +125°C

3.1.5 TPD1E10B06 Features

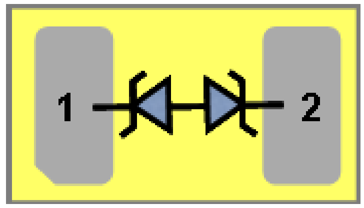


Figure 7. TPD1E10B06 Block Diagram

- Provides System Level ESD Protection for Low-voltage IO Interface
- IEC 61000-4-2 Level 4
  - ±30 kV (Air-Gap Discharge)
  - ±30 kV (Contact Discharge)
- IEC 61000-4-5 (Surge): 6A (8/20µs)
- IO Capacitance 12 pF (Typ)
- RDYN 0.4 Ω (Typ)
- DC Breakdown Voltage ±6 V (Min)
- Ultra Low Leakage Current 100 nA (Max)
- 10 V Clamping Voltage (Max at IPP = 1A)
- Industrial Temperature Range: –40°C to 125°C
- Space Saving 0402 Footprint (1.0 mm × 0.6 mm × 0.5 mm)

4 System Design Theory

4.1 Weight Measurement Theory of Operation

The Distance and Weight Measurement Using Inductive Sensing Reference Design uses a small mechanical setup to convert linear distance into weight. The method uses four identical springs, with characteristics shown in Table 1.

Table 1.

SPRING PARAMETER	MM-72 VALUE
Outer Diameter (OD) (in) [mm]	0.328 [8.331]
Inner Diameter (ID) (in) [mm]	0.288 [7.315]
Free Length (in) [mm]	1.5 [38.1]
Rate (lbs/in) [kg/cm]	0.87 [0.155]
Sugg. Max Defl. (in) [mm]	1.1 [27.94]
Sugg. Max Load (lbs) [kg]	0.98 [0.445]
Solid Length (in) [mm]	0.22 [5.588]
Wire Dia. (in) [mm]	0.02 [0.508]
Total Coils	10
Material	Stainless
Ends	Closed
Finish	None

These springs, model number MM-72, were sourced from the Century Spring Corp. (http://www.centuryspring.com). The diameter of the spring was chosen to fit properly around a ¼" diameter stainless steel round standoff. The primary spring parameter of interest is the Rate, which is a measure of how much weight will deflect the spring a known amount, given above in pounds per inch. The spring was chosen with a Rate, such that a 4" x 4" x 1/4" plate of grade 304 stainless steel (the top mechanical plate) would deflect all four springs by at least 15%. According to the SMI Handbook of Spring Design, normal compression springs have a linear load deflection curve between 15% and 85% deflection. Therefore, in order to approximate the spring response as linear, the Distance and Weight Measurement Using Inductive Sensing Reference Design ensures that the springs are only ever operated between 15% and 85% deflection.

The top plate of the mechanical setup is 4" x 4" x 1/4" with four holes of diameter 17/64" drilled out of the corners. Because the well-known density of grade 304 stainless steel is 0.289 lb/in³ (8000 kg/m3), the weight of the top plate is shown by Equation 1.

$$\text{Top Plate Weight} = 0.289\,\frac{\text{lb}}{\text{in}^3} \times \left(4\,\text{in} \times 4\,\text{in} - 4 \times \pi \times \left(\frac{17}{64 \times 2}\right)^2\right) \times 0.25\,\text{in} = 1.140\,\text{lbs} = 0.517\,\text{kg} \quad (1)$$

Using a kitchen scale with 1 g resolution and 2 g accuracy, the top plate has an actual measured mass of 499 g, indicating that the top plate weight was within 4% of the estimated value.

The SMI Handbook of Spring Design states, "When compression springs are used in parallel, the composite rate is the sum of the rates for individual springs." Because the mechanical setup in the Distance and Weight Measurement Using Inductive Sensing Reference Design uses four springs in parallel, the combined spring rate is shown by Equation 2:

$$\text{Combined Rate} = 4 \times 0.87\,\frac{\text{lbs}}{\text{in}} = 3.48\,\frac{\text{lbs}}{\text{in}} \quad (2)$$

Therefore, the total deflection when the top plate is placed on the four springs is shown by Equation 3:

$$\text{Deflection} = \frac{1.156\,\text{lbs}}{3.48\,\frac{\text{lbs}}{\text{in}}} = 0.332\,\text{in} \quad (3)$$

Because the length of the uncompressed spring is given by the Free Length (in) parameter above, it is possible to show in Equation 4 that the top plate alone compresses all four springs in the Distance and Weight Measurement Using Inductive Sensing Reference Design by at least 15%, which ensures linear operation of the mechanical setup.

$$\frac{\text{Deflection}}{\text{Free Length}} = \frac{0.332\,\text{in}}{1.5\,\text{in}} \times 100\% = 22.13\% \tag{4}$$

The actual free length of the springs as measured with calipers (0.01” Resolution and 0.01” Accuracy) is 1.52 in. The actual compressed length of the springs as measured with calipers is 1.21 in. Therefore, the actual spring deflection over free length is shown by Equation 5:

$$\frac{\text{Deflection}}{\text{Free Length}} = \frac{1.52 - 1.21}{1.52} \times 100\% = 20.39\% \tag{5}$$

The free length, combined rate of the four springs in parallel, and suggested maximum deflection can also be used to calculate the maximum recommended weight that can be placed on top of the top plate of the mechanical system. This calculation is shown in Equation 6 and Equation 7:

$$\text{Max. Weight} = \text{Combined Rate} \times \text{Sugg. Max. Deflection} - \text{Top Plate Weight} \tag{6}$$

$$\text{Max. Weight} = 3.48\,\frac{\text{lbs}}{\text{in}} \times 1.1\,\text{in} - 1.156\,\text{lbs} = 2.672\,\text{lbs} = 1.212\,\text{kg} \tag{7}$$

To ensure good performance of the mechanical system, the Distance and Weight Measurement Using Inductive Sensing Reference Design was characterized over a weight range of 0 to 750 grams.

The LDC1041 is an Inductance-to-Digital Converter that simultaneously measures the impedance and resonant frequency of an LC resonator. It accomplishes this task by regulating the oscillation amplitude in a closed loop configuration to a constant level, while monitoring the energy dissipated by the resonator. The Distance and Weight Measurement Using Inductive Sensing Reference Design uses only the resonant frequency information from the LDC1041 device by way of using the inductance-only measurement mode.

To convert the output of the LDC1041 into useful, real-world data, a system calibration is necessary to implement an accurate look-up table. In the Distance and Weight Measurement Using Inductive Sensing Reference Design, a known, calibrated set of weights was used to calibrate the subsystem from 0 to 750 grams. The output of the LDC1041 at each data point was recorded, and regression method was used to generate a 3rd order polynomial curve to best fit the data. The coefficients of the polynomial are incorporated into the MSP430 microcontroller. When a weight is placed on the system, the MSP430 receives the data from the LDC1041 and runs it through the 3rd order polynomial, using the programmed coefficients, which then generates the weight in grams. Figure 16 shows the measured data, as well as the 3rd order polynomial best-fit line and equation for a sample test setup.

In end-user systems that require different weight ranges, different springs with higher rates can be used. Likewise, different mechanical setups that do not necessarily use four springs, but still require linear distance measurements can still be used. To ensure proper operation with the LDC1041 device, it is necessary to characterize the resonant frequency data over the entire operating distance range of the mechanical setup. Calibration by way of a look-up table or best-fit polynomial curve can then be implemented, similarly to the Distance and Weight Measurement Using Inductive Sensing Reference Design.

4.2 Distance Measurement Theory of Operation

In the Distance and Weight Measurement Using Inductive Sensing Reference Design, the desired information is ultimately the weight placed on the mechanical setup. Therefore, the distance data is not specifically calculated in the MSP430 firmware. If the mechanical setup is such that actual distance is the desired information, a similar procedure as the weight measurement calibration is required to derive the appropriate look-up table or best-fit polynomial curve. The Distance and Weight Measurement Using Inductive Sensing Reference Design would need to be calibrated by determining the LDC1041 device output at a series of well-known distances between the top plate and the sensor coil, similar to how well-known weights were used to derive the weight look-up table or best-fit polynomial curve.

4.3 Temperature Compensation

The LDC1000 Temperature Compensation Application Report (SNAA212) provides details about the theory and implementation of temperature compensation for Rp measurements with the LDC10xx family of inductance-to-digital converters. Because the Distance and Weight Measurement Using Inductive Sensing Reference Design uses the inductance-only mode of the LDC1041, it is necessary to expand on temperature compensation theory.

To achieve maximum accuracy while performing inductance-only measurements with the LDC1041, it is also necessary to account for changes over temperature in the mechanical setup, and changes in the parasitic ESD capacitors internal to the LDC1041, particularly if those capacitors are significant compared to the sensor coil tank capacitor value. Although not implemented in the Distance and Weight Measurement Using Inductive Sensing Reference Design firmware, the advised method of temperature compensation involves recording resonant frequency data over the calibrated weight range at the minimum, nominal, and maximum operating temperatures of the system. If the real-time temperature is known (by way of the TMP103 temperature sensor), it is possible to use linear interpolation to derive the actual resonant frequency data. However, if the internal ESD capacitor is the main source of temperature variation, an exponential-type interpolation may be required. Temperature compensation is system specific, and will require experimental data to determine the appropriate method of compensation.

4.4 Software Control

The Distance and Weight Measurement Using Inductive Sensing Reference Design is pre-loaded with firmware to control all the components in the subsystem. The MSP430 device is programmed to control the LDC1041 using SPI with the USCI_A0 Universal Serial Communication Interface. The 430BOOST-SHARP96 LCD BoosterPack is controlled by the MSP430 device using SPI with the USCI_A1 module. The TMP103 device is controlled by way of I^2C using the USCI_B0 module. The firmware initializes all three of the required communication modules.

The LDC1041 device is configured by way of Table 2 and Table 3:

RpMin and RpMax are both set to 0.798 to essentially disable Rp measurements, and put the LDC1041 into an inductance-only measurement mode.

Table 2. Rp_MAX

Address = 0x01, Default=0x0E, Direction=R/W		
Bit Field	**Field Name**	**Description**
7:0	Rp Maximum	Maximum Rp that LDC1041 needs to measure. Configures the input dynamic range of LDC1041.

Table 3. Rp_MIN

Address = 0x02, Default=0x14, Direction=R/W		
Bit Field	**Field Name**	**Description**
7:0	Rp Minimum	Minimum Rp that LDC1041 needs to measure. Configures the input dynamic range of LDC1041. See [(1)]

(1) This Register needs a mandatory write as it defaults to 0x14.

Because the resonant frequency of the sensor coil tank is approximately 1 MHz, the Watchdog Timer Frequency is set to 179, as shown in Table 4.

Table 4. Watchdog Timer Frequency

Address = 0x03, Default=0x45, Direction=R/W		
Bit Field	**Field Name**	**Description**
7:0	Min Sensor Frequency	Sets the watchdog timer. The Watchdog timer is set based on the lowest sensor frequency. $N = 68.94 \times \log_{10}\left(\frac{F}{2500}\right)$ where • F is the sensor frequency (8) Example: If Sensor frequency is 1Mhz Min Sensor Frequency=68.94*log10(1M/2500)=Round to nearest integer(179.38)=179

The LDC Configuration register is set to have an oscillation amplitude of 2 V, and a response time of 6144.

Table 5. LDC Configuration

Address = 0x04, Default=0x1B, Direction=R/W		
Bit Field	**Field Name**	**Description**
7:5	Reserved	Reserved to 0
4:3	Amplitude	Sets the oscillation amplitude 00:1V 01:2V 10:4V **11:Reserved**
2:0	Response Time	000: Reserved 001: Reserved 010: 192 **011: 384** 100: 768 101: 1536 110: 3072 111: 6144

The INTB pin is configured to enable the DRDY interrupt, which the MSP430 uses to signal the start of a data read sequence on the SPI bus.

Table 6. INTB Terminal Configuration

Address = 0x0A, Default=0x00, Direction=R/W		
Bit Field	**Field Name**	**Description**
7:3	Reserved	Reserved to 0
2:0	Mode	**000: All modes disabled** 001: Wake-up Enabled on INTB terminal 010: INTB terminal indicates the status of Comparator output 100: DRDYB Enabled on INTB terminal All other combinations are Reserved

5 Getting Started

5.1 Mechanical Setup Configuration

The mechanical setup used for the Distance and Weight Measurement Using Inductive Sensing Reference design is comprised of several simple mechanical components:

- (1) Top Plate
- (1) Bottom Plate
- (4) 4-40 ½” Male/Female nylon standoffs
- (4) 4-40 ½” nylon screws
- (4) 4-40 3/8” stainless steel machine screws
- (4) 4-40 4” stainless steel round standoff (1/4” diameter)
- (4) MM-72 springs from Century Spring Corp

The bottom plate has holes drilled for the nylon standoffs, which hold the PCB in place, and the stainless steel round standoffs, which provide a guide for the support springs and top plate. Figure 8 shows the bottom plate with both sets of standoffs installed, along with the four support springs.

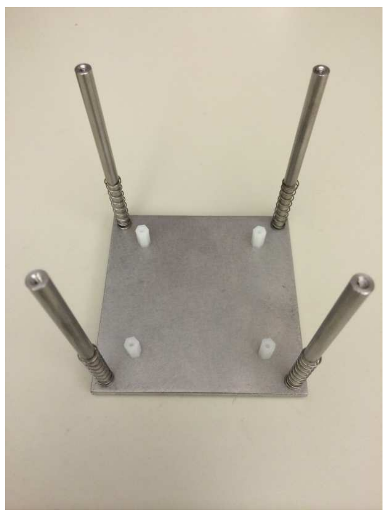


Figure 8. Mechanical Setup without Reference Design PCB

The Distance and Weight Measurement Using Inductive Sensing Reference Design PCB is then mounted on the nylon standoffs, as seen in Figure 9.

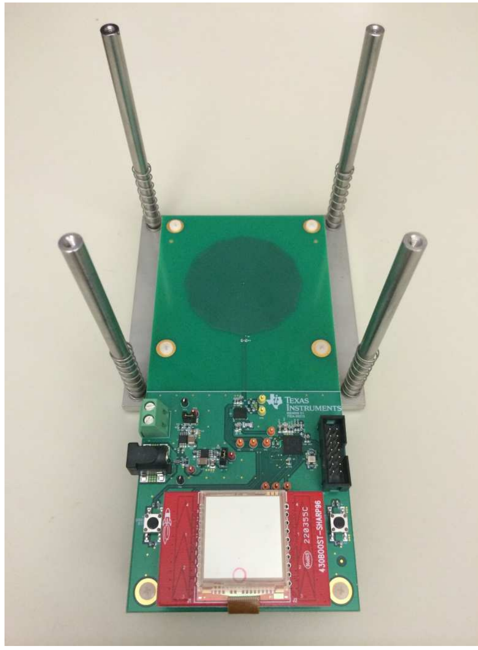


Figure 9. Mechanical Setup with Reference Design PCB

The top plate is then placed on the stainless steel round standoffs until it rests on the four support springs. This represents the setup of the mechanical configuration of the Distance and Weight Measurement Using Inductive Sensing Reference Design.

Figure 10. Mechanical Setup with Reference Design PCB and Top Plate

Getting Started Steps

1. A power supply with 20 to 24-V (typical) range can power the system as shown in Figure 11

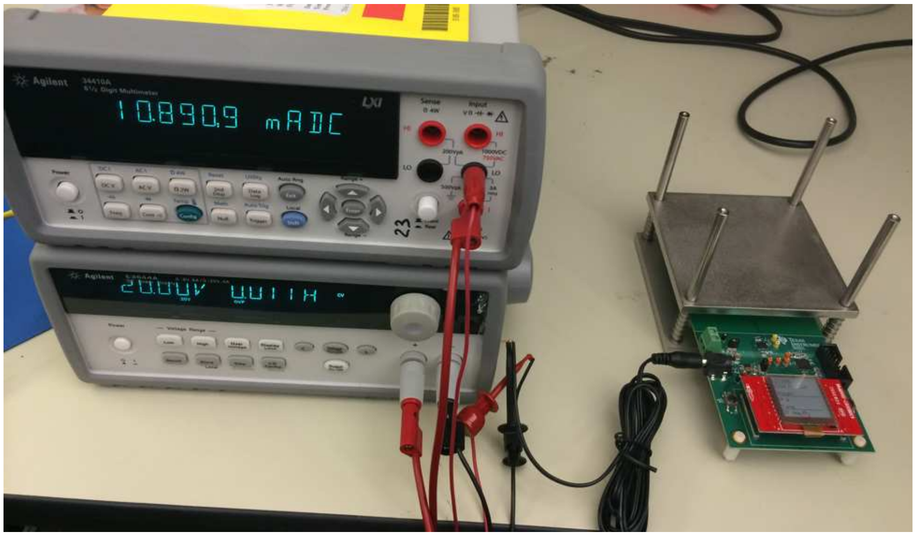


Figure 11. Power Supply and Multimeter Connected in Series

2. The current-limit of the power supply is set to 50 mA as recommended. 10 mA is the typical power supply current draw seen in testing.
3. The power leads can be connected to either the J1 terminal block, or the J2 barrel connector.
4. If the test setup has not been previously calibrated, then proper care must be taken to update the firmware with appropriate calibration data.
5. By default, the LCD screen will show three lines of data, as shown in Figure 12: FreqCnt, Weight, and Temp. The FreqCnt data over a range of well-known weights must be recorded and put into Excel or some other tool to generate a third-order, best-fit regression curve. Figure 16 shows an appropriate plot of FreqCnt versus Weight with the best-fit line and equation shown.

Figure 12. LCD Screen

5.2 Firmware

For MSP430 firmware updates, *Code Composer Studio* is recommended, along with the MSP-FET430UIF USB Debugging Interface. For programming setup, 24 V must be supplied to either J1 or J2; no power is provided from the programmer in the Distance and Weight Measurement Using Inductive Sensing Reference Design.

The previously determined coefficients of the best-fit curve must be stored in the firmware in order for the 'Weight' readout on the LCD to be accurate. These coefficients are brought out as firmware variables, as seen in Figure 13. Each test setup will have unique coefficients, due to differences in mechanical tolerances and part-to-part variation of the electronic devices.

```
//Hardware Setup #1 Coefficients
#if 0
#define C3 0.00000010506f
#define C2 -0.00049841f
#define C1 0.94608f
#define C0 6.1096f
#define Cz 12228
#endif

// Hardware Setup #2 Coefficients
#if 0
#define C3 0.00000018063f
#define C2 -0.00074818f
#define C1 1.13670f
#define C0 22.8580f
#define Cz 12455
#endif

// Hardware Setup #3 Coefficients
#if 1
#define C3 0.00000003304f
#define C2 -0.00020012f
#define C1 0.61898f
#define C0 9.4833f
#define Cz 12491
#endif

```

Figure 13. Hardware Calibration Coefficient Code Snippet

The firmware initializes all the system modules (clocks, SPI, I^2C, and so on) and then the main 'while' loop is entered, which continuously reads in data from the LDC1041 device. If the system has been calibrated as described above, then the proper coefficients will convert the LDC1041 output, which is time-averaged, into a weight, which is then displayed on the LCD screen. Figure 14 shows the algorithm used to convert the LDC1041 device code into a weight.

```
res = -1*(answer2 - Cz);

res = (((((C3 * res) + C2) * res) + C1) * res) + C0;

LCD_displayLDC1000(answer2, (unsigned long)res, tempData);
```

Figure 14. Weight Calibration Algorithm Code Snippet

Temperature data is read from the TMP103 device to establish the current temperature of the LDC1041 device. However, the current version of firmware does not implement temperature compensation. If real-time temperature compensation is a desired system feature, refer to Section 4.3, *Temperature Compensation*.

6 Test Data

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

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

6.1 Overview

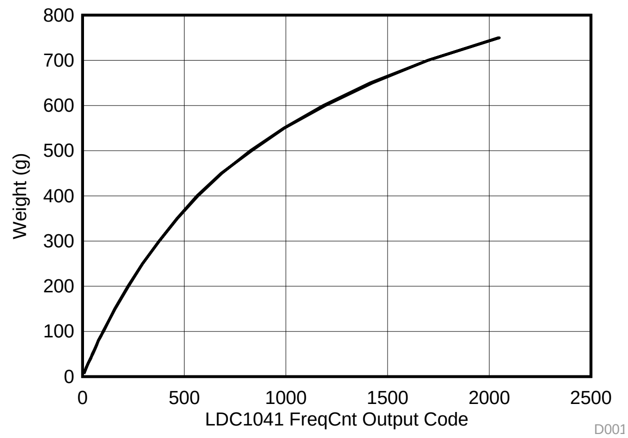
Because the overall system performance is governed by the LDC1041 device accuracy, as well as the mechanical setup stability, Section 6.2 characterizes the system through a best-fit regression curve model, described before, but in more detail. Also, power supply performance is characterized, to show minimal impact on measurements.

6.2 Overall System Calibration and Best-Fit Regression Curve Modeling

The Distance and Weight Measurement Using Inductive Sensing Reference Design is a sensor-based electromechanical system, and thus requires system calibration. As described briefly in the Section 5.2 section, the Reference Design relies on a full range calibration using known weights. Figure 15 shows the known weights used for system calibration. The Troemner Metric Stainless Steel Calibration Weight Set is classified as an ASTM Class 7 set, and also includes an ISO9001 Statement of Accuracy. If higher accuracy of calibration is required, weight sets of higher ASTM Class can be purchased, albeit at higher expense.

Figure 15. Weight Set

System calibration was performed by placing a series of calibrated weights, from 10 g up to 750 g onto the Distance and Weight Measurement Using Inductive Sensing Reference Design and recording the FreqCnt value on the LCD display. This value represents the time-average output from the LDC1041 device. This data is plotted in Microsoft Excel, and then a best-fit regression curve is fitted to the data using Excel's Trendline feature. Excel generates the equation describing the line, along with the R2 value. The coefficients of the line are programmed into the Distance and Weight Measurement Using Inductive Sensing Reference Design firmware. The FreqCnt data from the LDC1041 is then processed through the equation, which produces the appropriate weight value. Figure 16 shows an example plot of calibration data, along with the best-fit regression curve and equation.



$y = 1.0506E{-}07x^3 - 4.9841E{-}04x^2 + 9.4608E{-}01x + 6.1096E{+}00$ $R^2 = 9.9965E{-}01$

Figure 16. Weight vs LDC Output with Best-Fit Regression Curve Equation

6.3 System Weight Resolution

For this test, a known weight of 200 g was placed on the Distance and Weight Measurement Using Inductive Sensing Reference Design, and the minimum and maximum weights displayed over time were 195 g and 197 g respectively, and thus the output weight resolution was 2 g.

6.4 Complete System Maximum Measured Error

For this test, after the system was calibrated as described above, the same known weights were placed on the Distance and Weight Measurement Using Inductive Sensing Reference Design. This test measures the complete system maximum measured error, which accounts for both mechanical setup tolerances, and electrical part-to-part tolerances.

The results from three different test setups are shown in Figure 17. As evidenced by these results, the setup-to-setup variation is relatively large. This is attributed to the mechanical variances of the setup, which include friction between the top plate and the four stainless steel round standoffs, as well as rate differences in the four support springs. Obviously, integration of TI's inductive sensing technology into an end-user system will require calibration to that specific mechanical setup, which is likely to be different from the Distance and Weight Measurement Using Inductive Sensing Reference Design. Therefore, maximum measured error of the system is largely dependent on the consistency and accuracy of the mechanical design. In this mechanical implementation, the maximum measured error over 100 g to 750 g was 9 g on the first test setup. The errors for weights less than 100 g were not recorded because the LDC1041 device inherently loses resolution as the target moves further from the sensor coil. Care must be taken in both sensor coil design and mechanical design to ensure that the desired error levels are maintained to the lightest weight required.

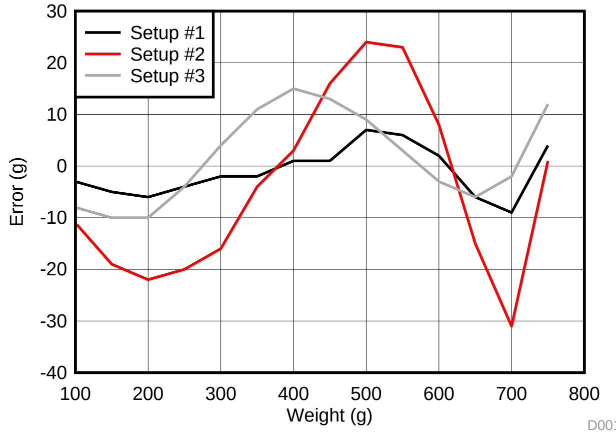


Figure 17. Maximum Measured Error of the System (g)

The Distance and Weight Measurement Using Inductive Sensing Reference Design exhibits a slight hysteretic effect with the current mechanical setup. The weight in grams was recorded from the LCD screen as weights were being increased as well as decreased. The absolute difference between the readings of the same calibrated weight is shown in Figure 18.

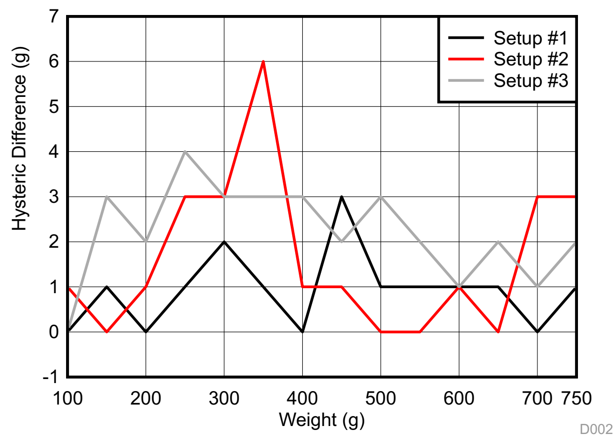


Figure 18. Hysteretic Difference in Maximum Measured Error of the System

A specific application of the Reference Design is to determine whether the weight on the top plate is above or below a certain value (in this case, 625 g). To know with a high degree of certainty, typical system error must be defined. As shown in Figure 19, well-known weights from 600 g to 650 g in 5 g increments were placed on the Distance and Weight Measurement Using Inductive Sensing Reference Design.

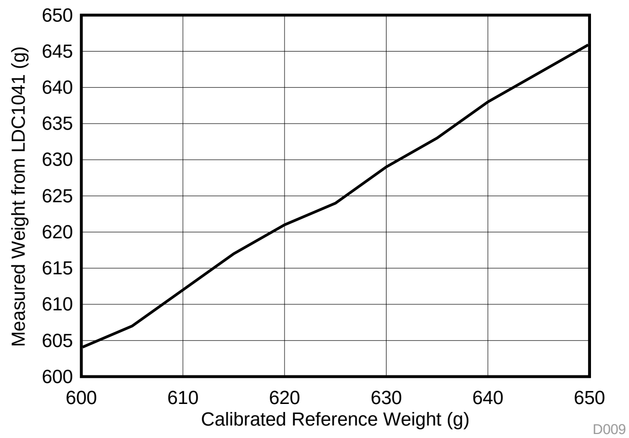


Figure 19. Measured vs Reference Weight

Table 7. Measured vs Reference Weight Data

Actual Weight (g)	Displayed Weight (g)
600	604
605	607
610	612
615	617
620	621
625	624
630	629
635	633
640	638
645	642
650	646

The root sum of squares method is used, along with the results of system resolution and power supply influence, to calculate the typical system error. The equation for root sum of squares in this application is shown in Equation 9.

$$\text{Typical Error} = \sqrt{(\text{system resolution error})^2 + (\text{power supply error})^2 + (\text{average inaccuracy})^2} \quad (9)$$

Over the range of 600 g to 650 g, the average inaccuracy is 2.18 g, the system resolution from above is 2 g, and the power supply error is 3 g. Therefore, the Typical Error over 600 g to 650 g is shown in Equation 10.

$$\text{Typical Error} = \sqrt{2.18^2 + 2^2 + 3^2} = 4.213 \text{ g} \quad (10)$$

For a set threshold of 625 g, the Distance and Weight Measurement Using Inductive Sensing Reference Design has the ability to detect a high weight at 629.213 g, or 0.674% over the desired set point.

6.5 Power Supply Influence and Consumption

For the power supply influence testing, the input voltage supply was varied from 7 V to 40 V and the corresponding weight output values were recorded. These measurements were taken with a 500 g weight on the Distance and Weight Measurement Using Inductive Sensing Reference Design. The total observable deviation in weight value over the power supply range was 3 g.

For the power supply consumption testing, the input voltage supply was stepped from 7 V to 40 V and the corresponding rail currents (3.3 V and 5 V) were recorded. Varying the weights on the Distance and Weight Measurement Using Inductive Sensing Reference Design were found to have no impact on these measurements. The results are shown in Figure 20 and Table 8.

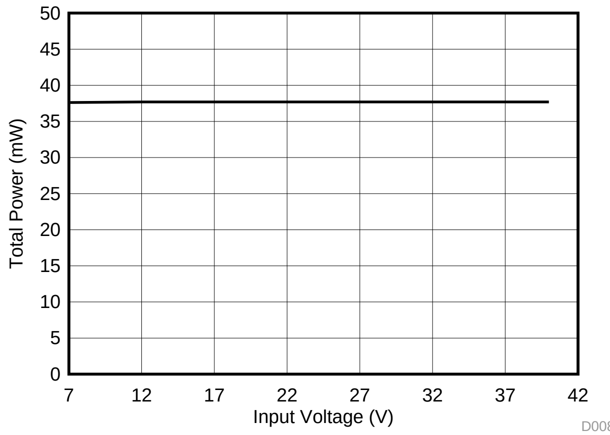


Figure 20. Total Power vs Input Voltage

Table 8.

3.3 V Rail Voltage (V)	3.3 V Rail Current (mA)	3.3 V Rail Power (mW)	5 V Rail Voltage (V)	5 V Rail Current (mA)	5 V Rail Power (mW)	Total Power (mW)
3.296	7.32	24.12672	4.99	2.71	13.5229	37.6
3.297	7.33	24.16701	4.992	2.71	13.52832	37.7
3.297	7.33	24.16701	4.992	2.71	13.52832	37.7
3.297	7.33	24.16701	4.992	2.71	13.52832	37.7
3.297	7.33	24.16701	4.992	2.71	13.52832	37.7
3.297	7.33	24.16701	4.992	2.72	13.57824	37.7

6.6 Reverse Polarity Test

For the reverse polarity test, the power leads are connected to J1 in reverse. The leakage current of the system is only 19.3 μA with reverse polarity applied, as shown in Figure 21.

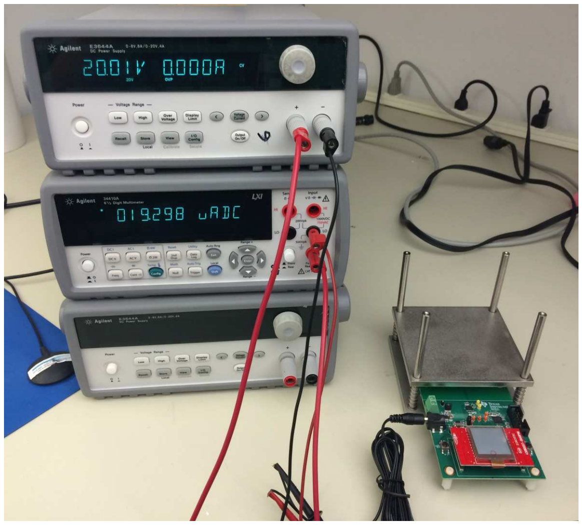


Figure 21. Reverse Polarity Test Setup

6.7 IEC 61000-4-2 (ESD) and IEC 61000-4-4 (EFT) Protection

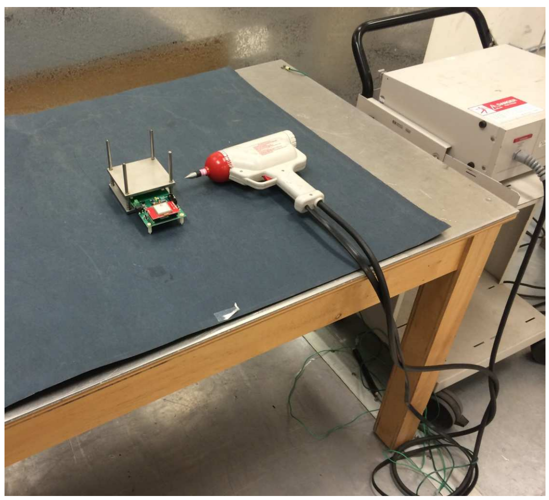


Figure 22. IEC61000-4-2 ESD Setup

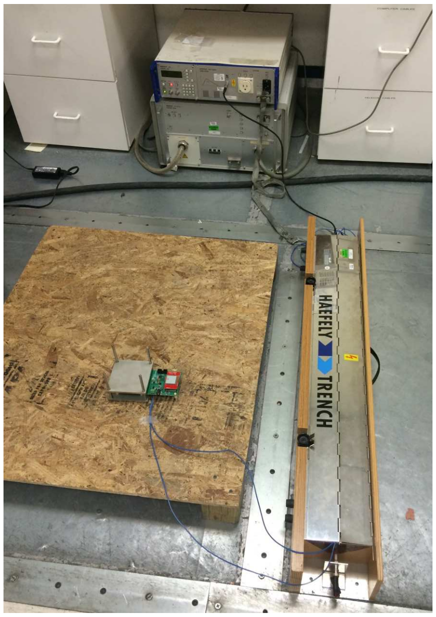


Figure 23. IEC61000-4-4 EFT Setup

For both IEC61000-4-4 and IEC61000-4-2 tests, the system was powered and weight measurement and LDC1041 FreqCnt was observed before, during, and after the strike. Also, the firmware was programmed to keep an LED lit during the main code routine. If the CPU was reset, the LED would flash. During the ESD test, the maximum deviation of the LDC1041 FreqCnt data was less than 3 g, and no LED flash was observed, meaning that the CPU did not reset.

The Electrical Fast Transients (EFT) test is designed to simulate interference from inductive sources. Because the Distance and Weight Measurement Using Inductive Sensing Reference Design is sensing changes in inductance, the EFT test pulses are picked up by the sensor coil and converted into measurement deviation by the LDC1041 device. In an end system, care must be taken to design the sensor coil to reject inductive noise to achieve the desired level of performance in the expected operating environment. During the EFT test, the maximum deviation of the LDC1041 FreqCnt data was ±50 codes, and no LED flash was observed, meaning that the CPU did not reset.

NOTE: IEC61000 tests were only performed on power inputs, or the J1 connector.

Table 9. IEC61000 Test Data

IEC61000 TEST	RESULTS
IEC ESD on Loop Power	IEC61000-4-2, ESD: Horizontal Coupling Plane. Vertical Coupling Plane: ±4 kV — Class A
	IEC61000-4-2, ESD: Air Discharge: ±8 kV — Class A
IEC EFT on Loop Power	IEC61000-4-4: EFT ±2 kV — Class A

7 Schematics

To download the schematics for each board, see the design files at TIDA-00215. Figure 24 shows the schematic for the Distance and Weight Measurement Using Inductive Sensing Reference Design.

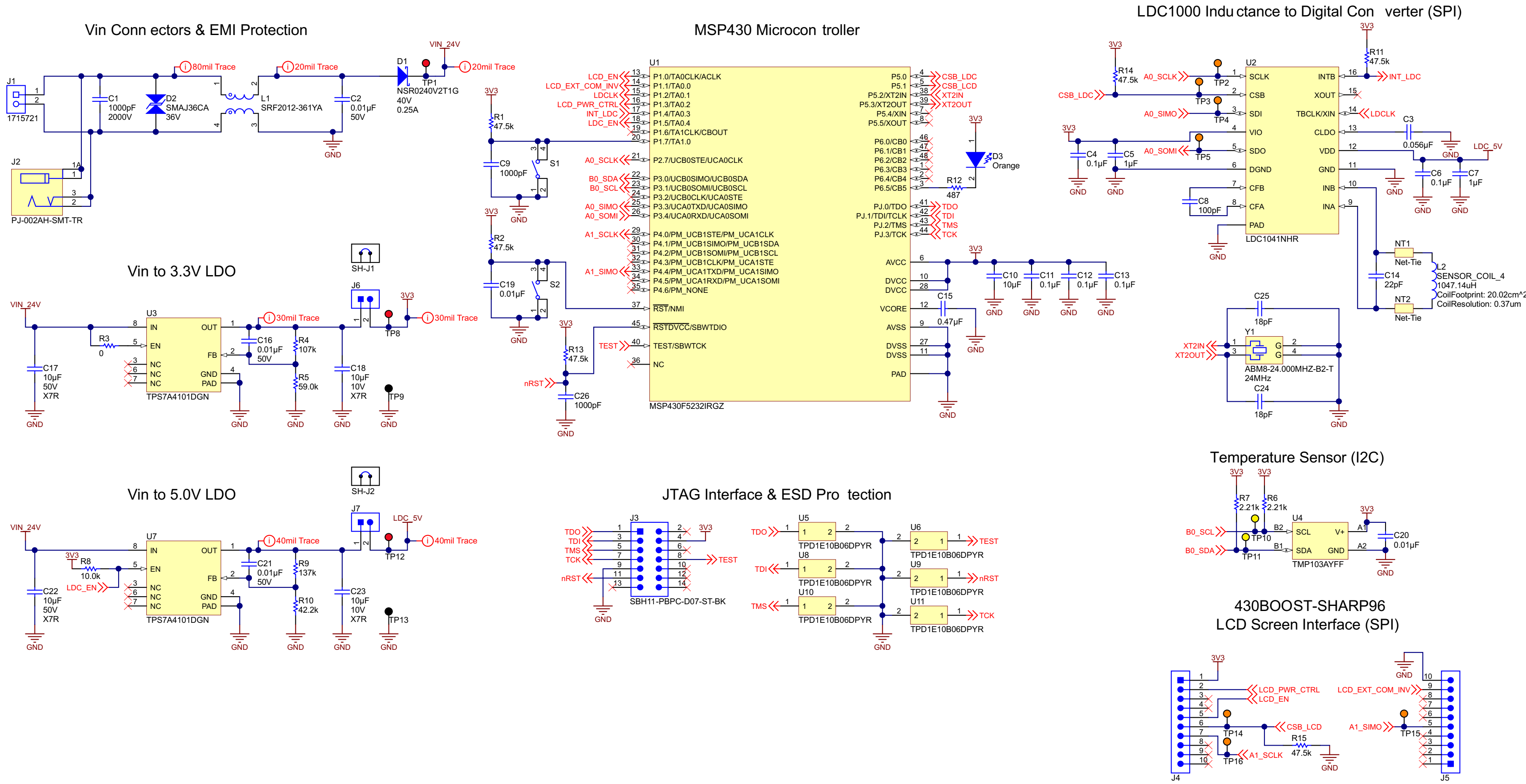


Figure 24. Distance and Weight Measurement Using Inductive Sensing Reference Design

8 Bill of Materials

To download the bill of materials (BOM) for the referenece design, see the design files at TIDA-00215. Table 10 shows the BOM for the Distance and Weight Measurement Using Inductive Sensing Reference Design.

Table 10. BOM

Designator	Quantity	Value	Description	Package Reference	PartNumber	Manufacturer
!PCB1	1		Printed Circuit Board		ISE4008	Any
C1	1	1000pF	CAP, CERM, 1000pF, 2000V, +/-10%, X7R, 1210	1210	C1210C102KGRACTU	Kemet
C2, C16, C21	3	0.01uF	CAP, CERM, 0.01uF, 50V, +/-10%, C0G/NP0, 0402	0402	GCM155R71H103KA55D	MuRata
C3	1	0.056uF	CAP, CERM, 0.056uF, 16V, +/-10%, X7R, 0402	0402	GRM155R71C563KA88D	MuRata
C4, C6, C11, C12, C13	5	0.1uF	CAP, CERM, 0.1uF, 16V, +/-10%, X7R, 0402	0402	GRM155R71C104KA88D	MuRata
C5, C7	2	1uF	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0603	0603	C1608X7R1C105K	TDK
C8	1	100pF	CAP, CERM, 100pF, 50V, +/-5%, C0G/NP0, 0805	0805	08055A101JAT2A	AVX
C9, C26	2	1000pF	CAP, CERM, 1000pF, 16V, +/-10%, X7R, 0402	0402	GRM155R71C102KA01D	MuRata
C10, C18, C23	3	10uF	CAP, CERM, 10uF, 10V, +/-10%, X7R, 0805	0805	GRM21BR71A106KE51L	MuRata
C14	1	22pF	CAP, CERM, 22pF, 50V, +/-5%, C0G/NP0, 0402	0402	GRM1555C1H220JA01D	MuRata
C15	1	0.47uF	CAP, CERM, 0.47uF, 16V, +/-10%, X7R, 0603	0603	C0603C474K4RACTU	Kemet
C17, C22	2	10uF	CAP, CERM, 10uF, 50V, +/-10%, X7R, 1210	1210	GRM32ER71H106KA12L	MuRata
C19	1	0.01uF	CAP, CERM, 0.01uF, 16V, +/-10%, X7R, 0402	0402	GRM155R71C103KA01D	MuRata
C20	1	0.01uF	CAP, CERM, 0.01uF, 10V, +/-10%, X7R, 0201	0201	GRM033R71A103KA01D	MuRata
C24, C25	2	18pF	CAP, CERM, 18pF, 100V, +/-5%, C0G/NP0, 0603	0603	GRM1885C2A180JA01D	MuRata
D1	1	40V	Diode, Schottky, 40V, 0.25A, SOD-523	SOD-523	NSR0240V2T1G	ON Semiconductor
D2	1	36V	Diode, TVS, Bi, 36V, 400W, SMA	SMA	SMAJ36CA	Littelfuse
D3	1		Orange LED, Orange, SMD Orange	LED	SML-P12DTT86	Rohm
H1, H2, H3, H4, H9, H10	6		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
H6, H8	2		Standoff, Hex, 0.5"L #4-40 Nylon	Standoff	1902C	Keystone
J1	1	2x1	Conn Term Block, 2POS, 5.08mm, TH	2POS Terminal Block	1715721	Phoenix Contact
J2	1		Power Jack, SMT	14.8x11x12.6mm	PJ-002AH-SMT-TR	CUI Inc.
J3	1		Header (shrouded), 100 mil, 7x2, Gold plated, TH	7x2 Shrouded Header	SBH11-PBPC-D07-ST-BK	Sullins Connector Solutions
J4, J5	2		Header, TH, 100mil, 10x1, Gold plated, 230 mil above insulator	10x1 Header	TSW-110-07-G-S	Samtec
J6, J7	2		Header, TH, 100mil, 2x1, Gold plated, 230 mil above insulator	2x1 Header	TSW-102-07-G-S	Samtec
L1	1		Inductor, Wirewound, Ferrite, , 0.3A, 0.45 ohm, SMD	2.0x1.2x1.2mm	SRF2012-361YA	Bourns
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650"H x 0.200"W	THT-14-423-10	Brady
R1, R2, R11, R13, R14, R15	6	47.5k	RES, 47.5k ohm, 1%, 0.063W, 0402	0402	CRCW040247K5FKED	Vishay-Dale
R3	1	0	RES, 0 ohm, 5%, 0.063W, 0402	0402	ERJ-2GE0R00X	Panasonic
R4	1	107k	RES, 107k ohm, 1%, 0.063W, 0402	0402	CRCW0402107KFKED	Vishay-Dale
R5	1	59.0k	RES, 59.0k ohm, 1%, 0.063W, 0402	0402	CRCW040259K0FKED	Vishay-Dale
R6, R7	2	2.21k	RES, 2.21k ohm, 1%, 0.063W, 0402	0402	CRCW04022K21FKED	Vishay-Dale
R8	1	10.0k	RES, 10.0k ohm, 1%, 0.063W, 0402	0402	CRCW040210K0FKED	Vishay-Dale
R9	1	137k	RES, 137k ohm, 1%, 0.063W, 0402	0402	CRCW0402137KFKED	Vishay-Dale
R10	1	42.2k	RES, 42.2k ohm, 1%, 0.063W, 0402	0402	CRCW040242K2FKED	Vishay-Dale
R12	1	487	RES, 487 ohm, 1%, 0.063W, 0402	0402	CRCW0402487RFKED	Vishay-Dale

Table 10. BOM (continued)

Designator	Quantity	Value	Description	Package Reference	PartNumber	Manufacturer
S1, S2	2		Switch, Tactile, SPST-NO, 0.05A, 12V, SMT	SW, SPST 6x6 mm	4-1437565-1	TE Connectivity
SH-J1, SH-J2	2	1x2	Shunt, 2mm, Gold plated, Black	2mm Shunt, Closed Top	2SN-BK-G	Samtec
TP1, TP8, TP12	3	Red	Test Point, Miniature, Red, TH	Red Miniature Testpoint	5000	Keystone
TP2, TP3, TP4, TP5, TP14, TP15, TP16	7	Orange	Test Point, Miniature, Orange, TH	Orange Miniature Testpoint	5003	Keystone
TP9, TP13	2	Black	Test Point, Miniature, Black, TH	Black Miniature Testpoint	5001	Keystone
TP10, TP11	2	Yellow	Test Point, Miniature, Yellow, TH	Yellow Miniature Testpoint	5004	Keystone
U1	1		Mixed Signal MicroController, RGZ0048A	RGZ0048A	MSP430F5232IRGZ	Texas Instruments
U2	1		8-bit Rp, 24-bit L Inductance-to-Digital Converter with SPI, NHR0016B	NHR0016B	LDC1041NHR	Texas Instruments
U3, U7	2		50-V Input Voltage, 50-mA, Very High Voltage LINEAR REGULATOR, DGN0008B	DGN0008B	TPS7A4101DGN	Texas Instruments
U4	1		Low-Power, Digital Temperature Sensor with Two-Wire Interface in WCSP, YFF0004AAAA	YFF0004AAAA	TMP103AYFF	Texas Instruments
U5, U6, U8, U9, U10, U11	6		ESD in 0402 Package with 10 pF Capacitance and 6 V Breakdown, 1 Channel, -40 to +125 degC, 2-pin X2SON (DPY), Green (RoHS & no Sb/Br)	DPY0002A	TPD1E10B06DPYR	Texas Instruments
Y1	1		Crystal, 24.000MHz, 18pF, SMD	3.2x0.8x2.5mm	ABM8-24.000MHZ-B2-T	Abracon Corportation

9 Layer Plots

To download the layer plots for the reference design, see the design files at TIDA-00215. Figure 25 through Figure 26 show the layer plots for the Distance and Weight Measurement Using Inductive Sensing Reference Design.

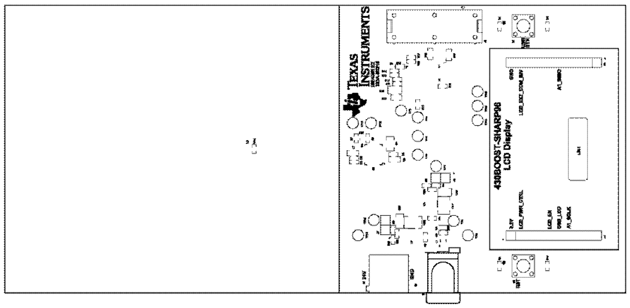


Figure 25. Top Overlay

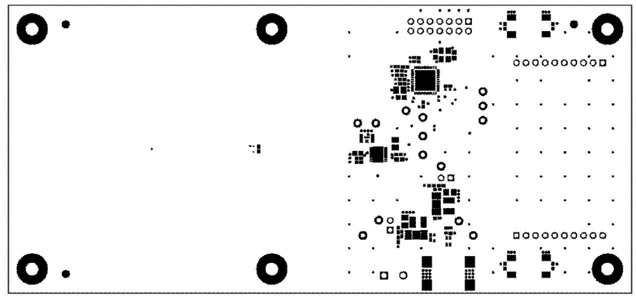


Figure 26. Top Solder Mask

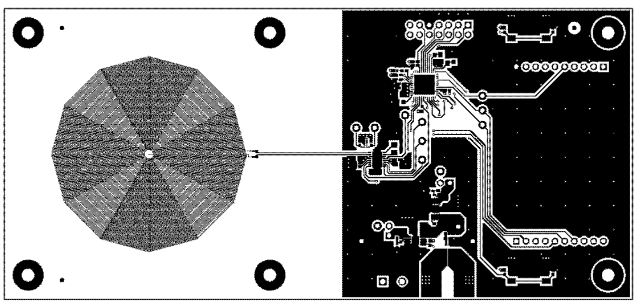


Figure 27. Top Layer

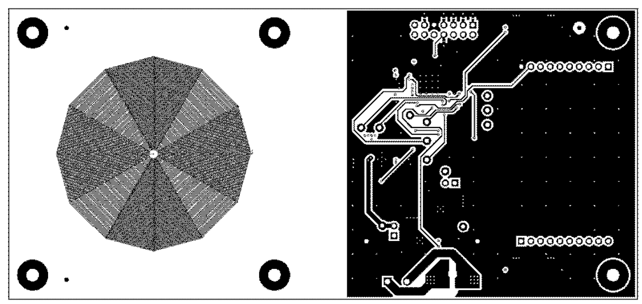


Figure 28. Bottom Layer

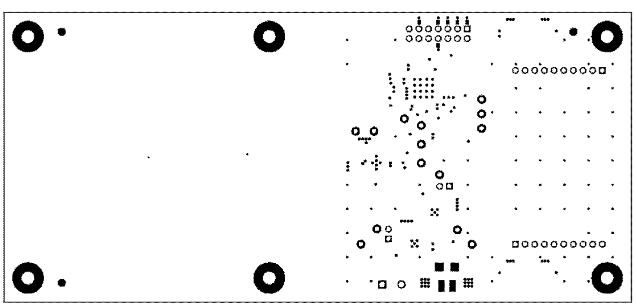


Figure 29. Bottom Solder Mask

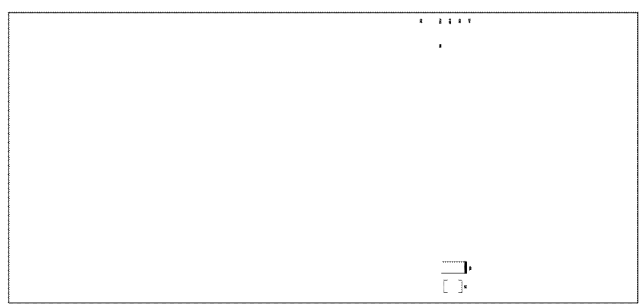
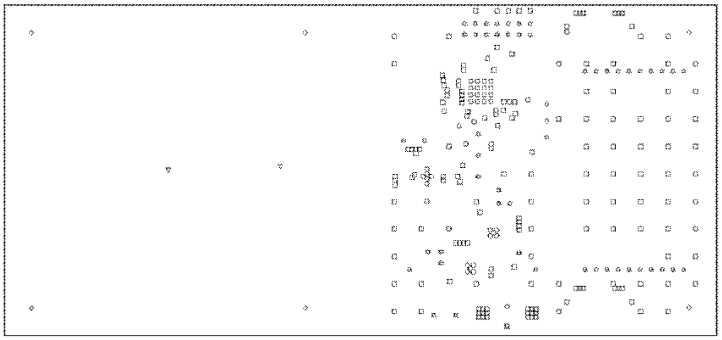


Figure 30. Bottom Overlay



Symbol	Hit Count	Tool Size	Plated	Hole Type
	2	6mil (0.152mm)	PTH	Round
	32	7.874mil (0.2mm)	PTH	Round
	174	10mil (0.254mm)	PTH	Round
	52	40mil (1.016mm)	PTH	Round
	2	51.181mil (1.3mm)	PTH	Round
	1	62.992mil (1.6mm)	NPTH	Round
	1	70.866mil (1.8mm)	NPTH	Round
	6	125.984mil (3.2mm)	PTH	Round
	270 Total			

Drill Table

Figure 31. Drill Drawing

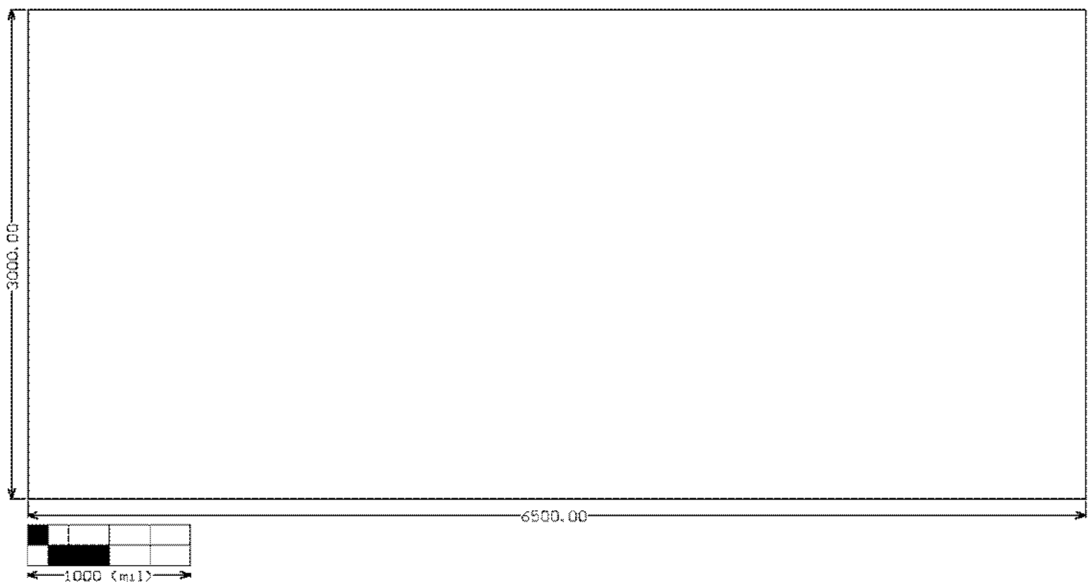


Figure 32. Board Dimensions

10 Altium Project

To download the Altium project files for the reference design, see the design files at TIDA-00215. Figure 33, Figure 34, Figure 35, Figure 36, and Figure 37 show the layout for the Distance and Weight Measurement Using Inductive Sensing Reference Design.

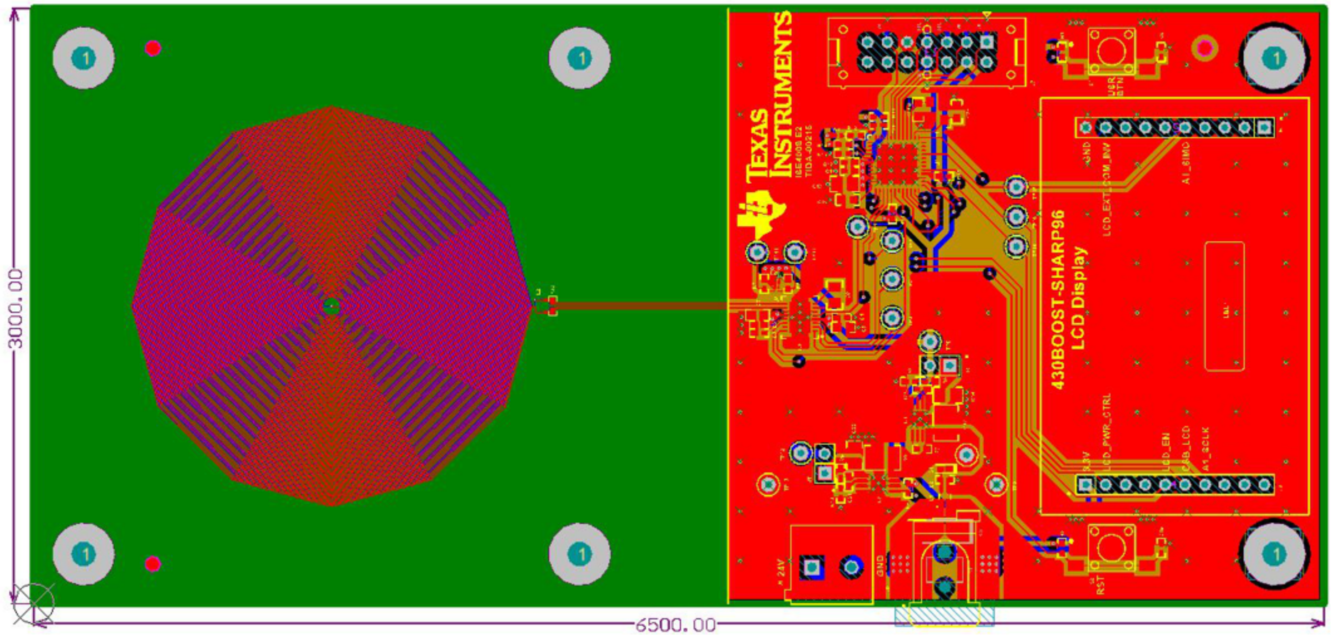


Figure 33. All Layers

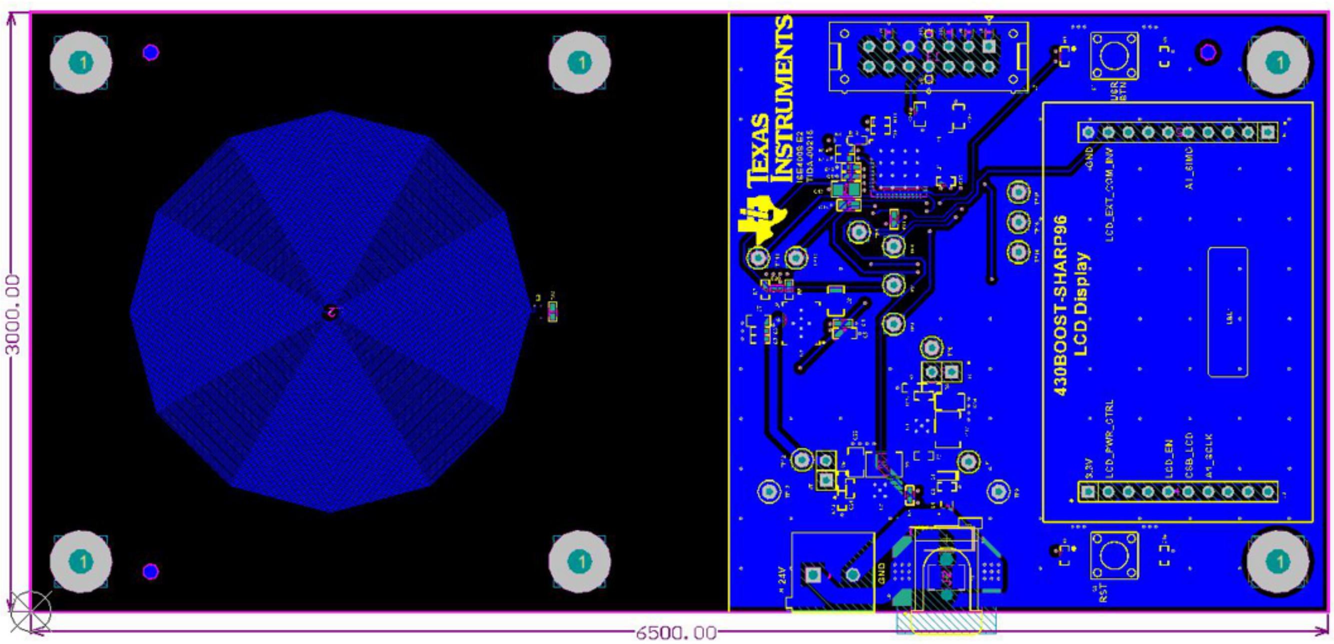


Figure 34. Bottom Layer

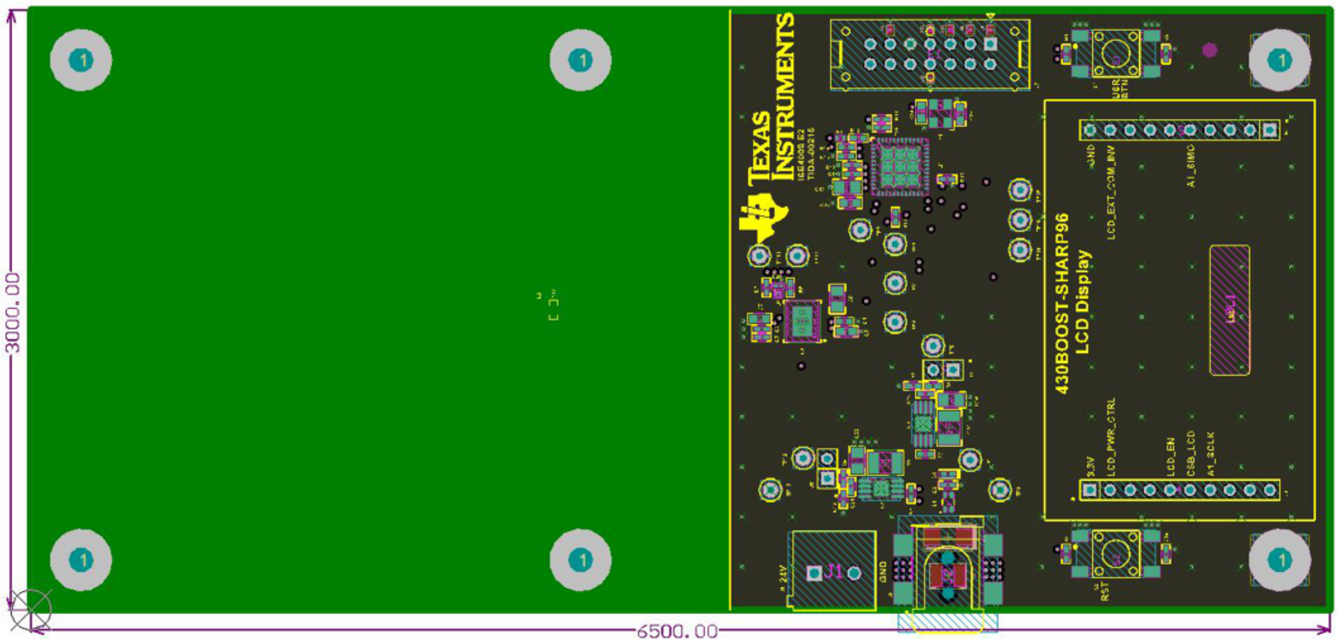


Figure 35. Ground Layer

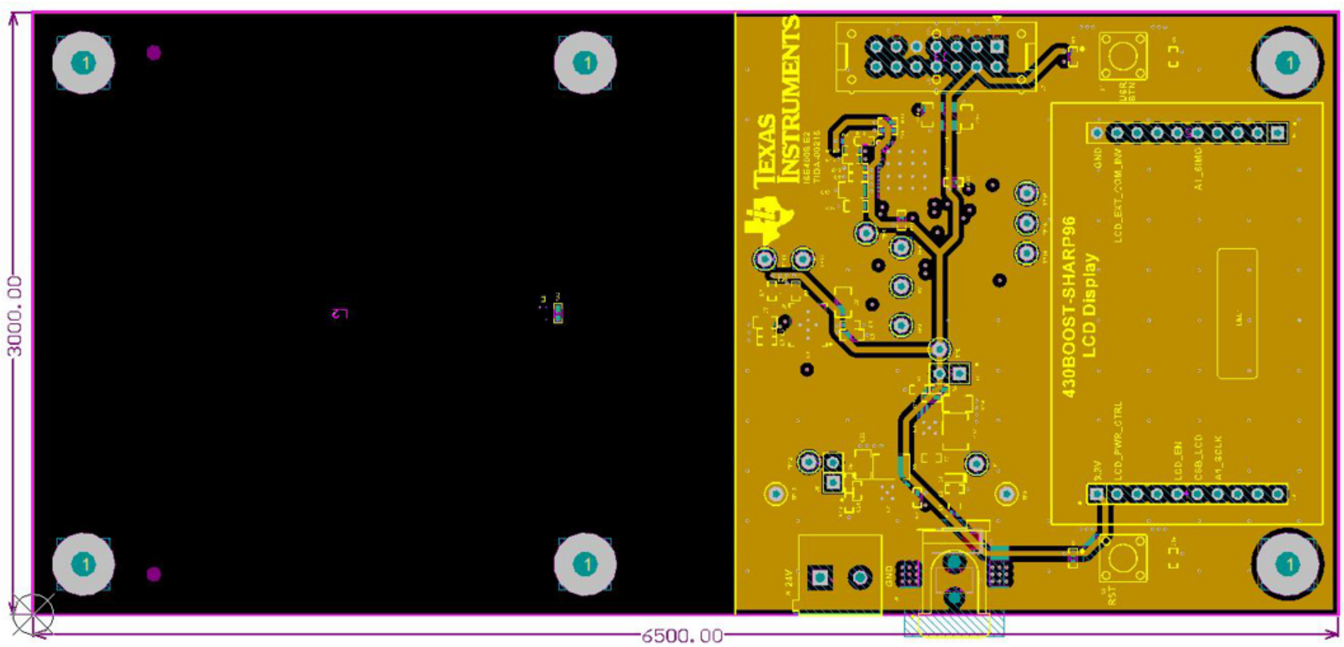


Figure 36. Inner Layer

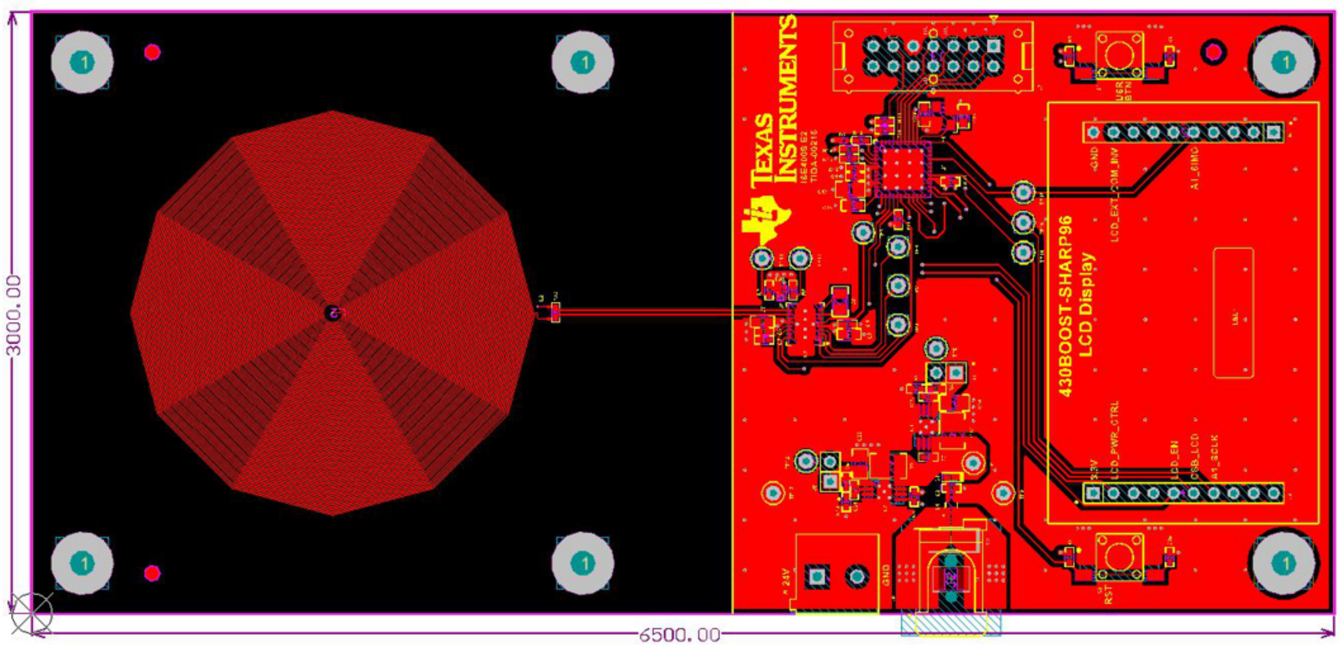


Figure 37. Top Layer

11 Layout Guidelines

To ensure high performance analog design, the sensor coil is designed from the top and bottom PCB layers. No planes are poured in the vicinity of the sensor coil. The tank capacitor is placed next to the coil connections to the LDC1041. No routes cross the sensor coil connections on any layer to reduce noise.

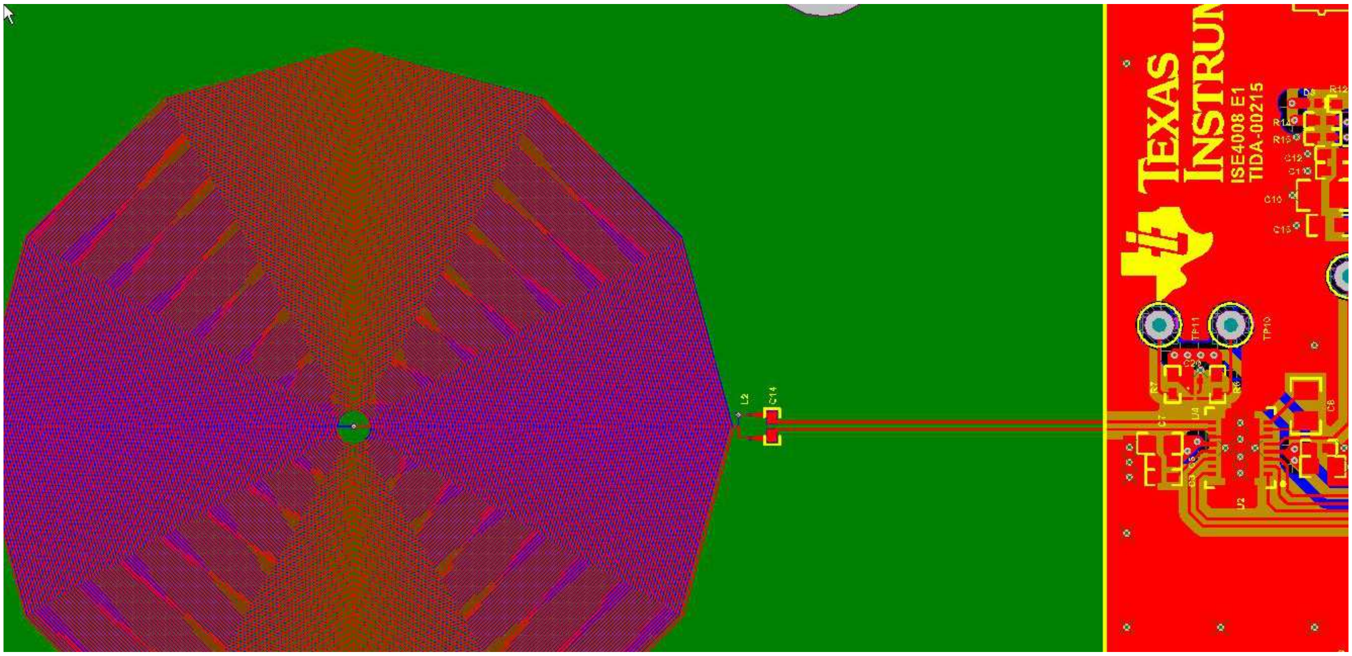


Figure 38. Sensor Coil Example Layout

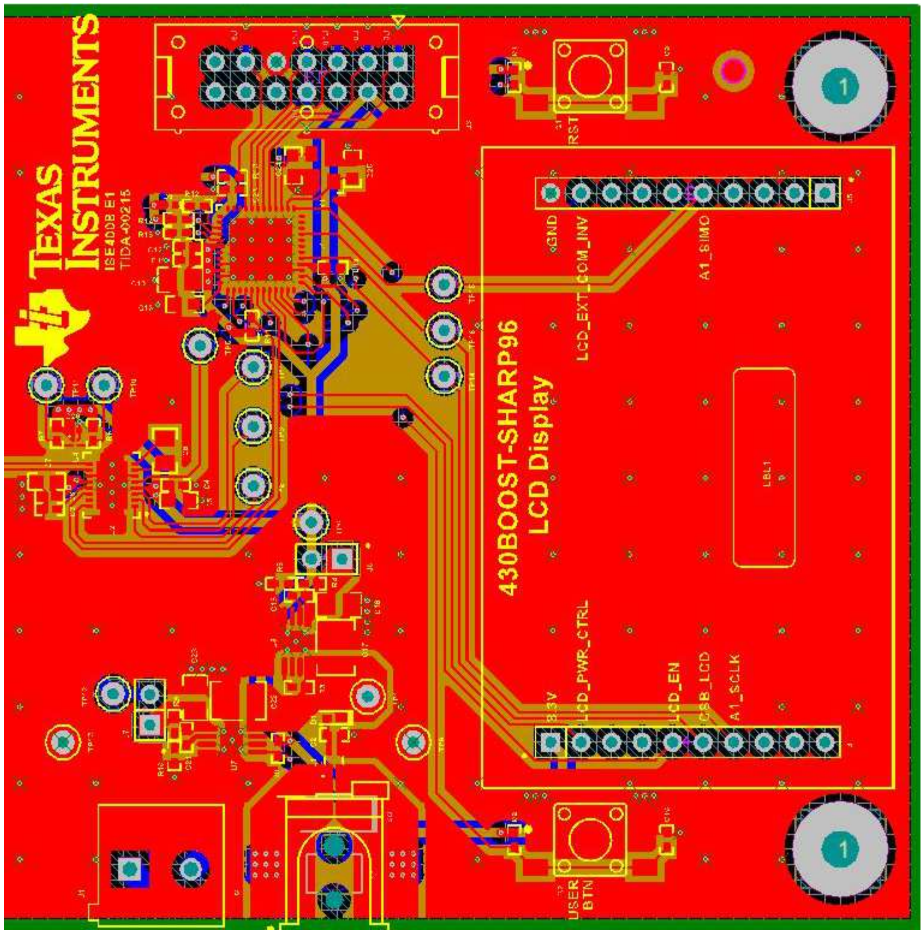


Figure 39. Noise Reduction Layout Example

The MSP430 MCU, LDC1041, and LDOs were placed as far away from each other as possible to reduce noise.

Via stitching was used throughout the PCB on ground planes to help ensure high performance analog design.

For more specific layout guidelines, please consult *LDC1041 8-Bit Rp, 24-bit L Inductance-to-Digital Converter with SPI*, (SNOSCY1).

12 Gerber Files

To download the Gerber files for the reference design, see the design files at TIDA-00215

13 Software Files

To download the software files for the reference design, see the design files at TIDA-00215

14 References

For additional references, refer to the following:

1. *Application Report, LDC1000 Temperature Compensation,* (SNAA212)
2. *Handbook of Spring Design* (Spring Manufacturers Institute)
3. *LDC1041 8-Bit Rp, 24-bit L Inductance-to-Digital Converter with SPI*, (SNOSCY1)
4. *MSP430F524x and MSP430F523x Mixed Signal Microcontrollers*, (SLAS897)
5. *TMP103 Low-Power, Digital Temperature Sensor with Two-Wire Interface in WCSP*, (SBOS545)
6. *TPS7A4101 50-V Input Voltage, 50-mA, Very High Voltage Linear Regulator*, (SBVS183)
7. *TPD1E10B06 Single Channel ESD Protection Device in 0402 Package*, (SLLSEB1)

15 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).

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