TI Designs
16-Button Keypad Using the LDC1314 Inductance-to-Digital Converter

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MSP430F5528	Product Folder
LP2985AIM5-3.3	Product Folder
TPD4E004	Product Folder

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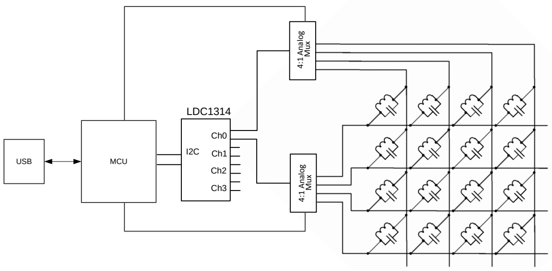
- Gas Station Pump Keypads
- Vending Machines
- ATMs
- Industrial Equipment
- HMI
- Building Automation
- Access Control Equipment



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1 Overview

Today, keypads are implemented using predominantly mechanical and electrical contact-based systems. Most of these systems are prone to breaking down and consequently expensive replacements over their lifetimes because of the moving parts and dependence on electrical contact.

Inductive sensing is a contactless sensing technology that offers a more durable keypad implementation. Furthermore, this technology is extremely resistant to harsh environments and is water and dirt proof. Using industry standard snap domes, the 16-button keypad offers a low-cost, robust, and scalable keypad implementation that can be used in various industrial, consumer, and automotive applications.

To learn more about inductive sensing, go to www.ti.com/ldc.

2 Key System Specifications

The 16-button keypad consists of the keypad assembly, the MCU board, and the GUI software. The key specifications include the following:

- Physical dimensions: 60.5 × 48.5 × 10 mm
- Number of keys: 16
- Simultaneous key press: Supported
- Sensor coil diameter: 8 mm
- Sensor coil inductance: 2.3 µH
- Key depression force: 340 g
- Keypad scan rate: 70 Hz
- Operating temperature: –20°C to 85°C
- Interface: USB on micro USB cable
- Power supply: 5 V (from USB)
- Power consumption: 30 mA

3 System Description

The 16-button keypad is an example of axial proximity sensing using TI's LDC1314 inductance-to-digital converter.

The basic principle of the position sensing used in the 16-button keypad is related to the phenomenon of eddy currents. When a metal is placed near the coil of an oscillating LC tank that is producing an AC magnetic field, the induced current in the metal produces an opposing field that reduces the effective inductance of the coil, thus changing the resonant frequency. Each printed coil in the 16-button keypad is covered by a metal snap dome switch. When a dome is pressed, the distance between it and the underlying coil is reduced, causing a decrease in the inductance. The LDC1314 detects the key press by measuring the change in inductance.

The keypad assembly is constructed using standard snap dome switch technology.

The firmware in the MCU connected to the LDC reads the 16-key data in a batch and sends the packet to the GUI software through the USB COM port. The GUI software displays the result in an animated graphic screen.

3.1 Block Diagram

The block diagram of the 16-button keypad system is shown in Figure 1. The system consists of an LDC1314 inductance-to-digital converter, an MSP430 microcontroller, two 4:1 analog multiplexers, and supporting electronics.

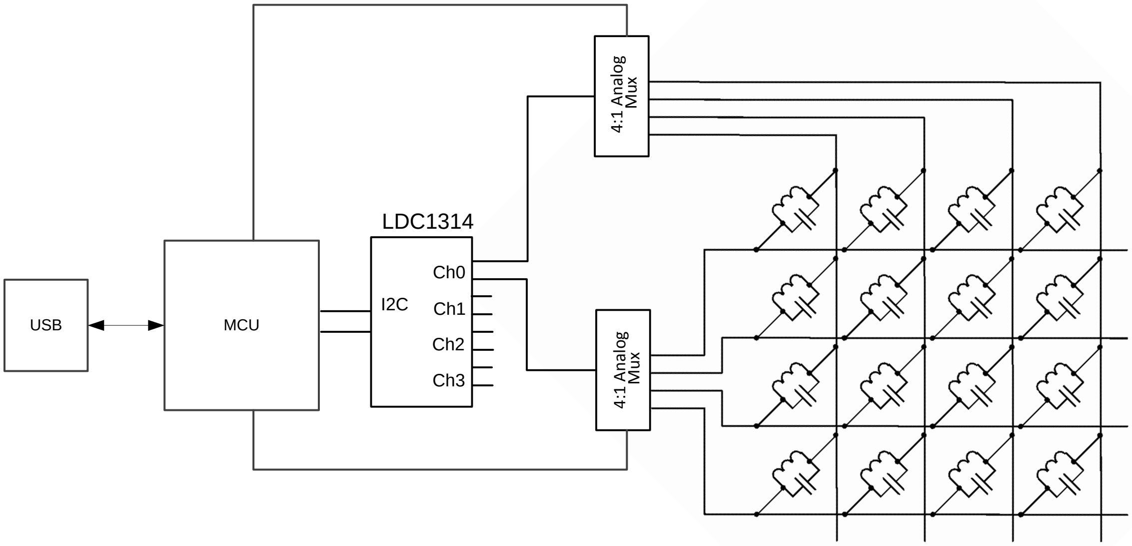


Figure 1. System Block Diagram

3.2 LDC1314

The LDC1314 is a 4-channel inductance-to-digital converter. An internal multiplexer connects the oscillator to one of the four channels per the register settings. In the keypad demo, only Channel 0 is used. The converter is set to the continuous conversion mode. This design can be expanded to 32 or 64 keys by using the rest of the channels. The internal clock reference source is used in this design, saving the cost of an external crystal oscillator.

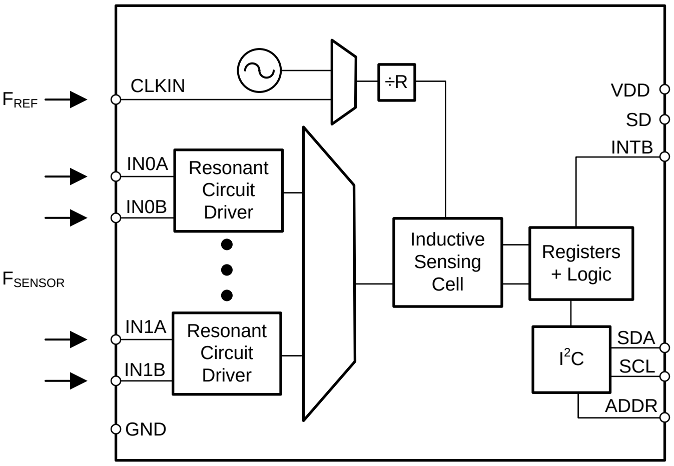


Figure 2. LDC1314 Functional Block Diagram

3.3 Other TI Parts

An MSP430 microcontroller is used as a bridge between the LDC1314 and the USB port. It also provides the non-volatile memory for the dial’s calibration data.

An LP2985 low-dropout linear regulator is used to step down the 5-V USB power to the 3.3 V required by the LDC1314 and the MSP430.

To protect the demo board circuit from possible ESD surge, the demo board uses a TPD4E004, the ESD protection circuit for high-speed data lines.

4 System Design Theory: General Guide for Inductive Sensing Using LDC1314

4.1 Working Principles

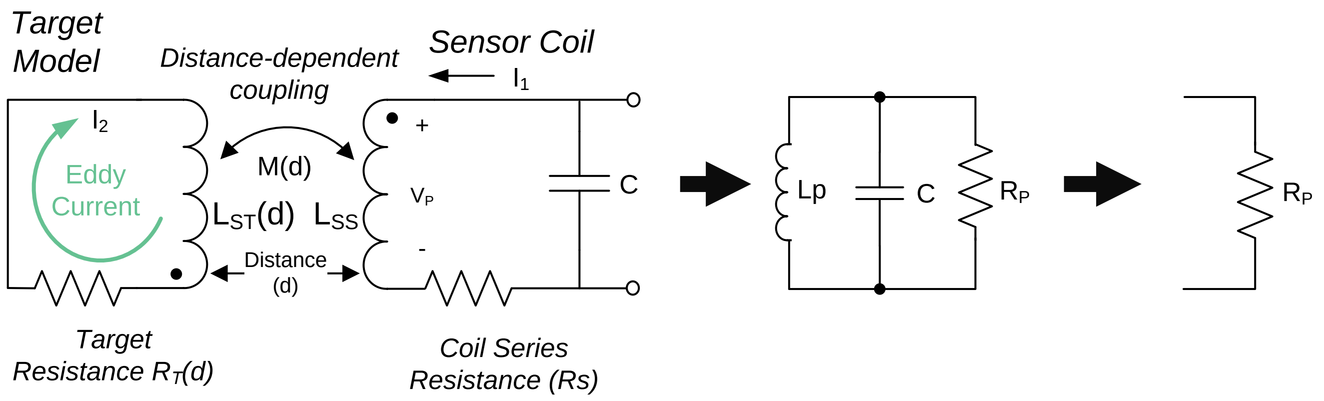
The working principle of the LDC1314 is based on the phenomenon that occurs when a conductive material, such as a metal, is placed in a magnetic field. An alternating current flowing through an inductor will generate an AC magnetic field. If a conductive material, such as a metal object, is brought into the vicinity of the inductor, the magnetic field will induce a circulating current (eddy current) on the surface of the conductor. The eddy current is a function of the distance, size, and composition of the conductor. The eddy current generates its own magnetic field, which opposes the original field generated by the sensor inductor. This effect is equivalent to a set of coupled inductors, where the sensor inductor is the primary winding and the eddy current in the target object represents the secondary winding. The coupling between the inductors is a function of the sensor inductor and the resistivity, distance, size, and shape of the conductive target. The resistance and inductance of the secondary winding caused by the eddy current can be modeled as distance dependent resistive and inductive components.

In Figure 3(a), an electrical model is shown. The primary side represents the electrical model of a coil with series resistance (R_S), parasitic capacitance (C_{PAR}), and current I_1. The secondary side represents the target model with eddy current I_2. The mutual inductance [M(d)] between the primary and secondary sides is a function of the distance between the two. Based on the dot convention, the voltage across the primary coil, V_P, is given by Equation 1:

$$V_P(d) = L_S \frac{dI_1}{dt} - M(d)\frac{dI_2}{dt} \tag{1}$$

As the distance between the sensor coil and the target decreases, the mutual inductance M(d) increases, and the magnetic field strength at the surface of the target increases, increasing I_2. Because both M and I_2 increase, the total voltage across the primary side decreases. *Looking into the terminals of the primary side, this appears as a reduction in the effective inductance.*

An equivalent, parallel R-L-C model of the sensor and target can be constructed, as shown in Figure 3(b). Both the inductance and resistance vary with the distance between the target and sensor coil. The parallel equivalent circuit becomes a parallel resistor at parallel resonance when the impedance of the parallel inductance is equal to that of the parallel capacitance in value at the parallel resonant frequency.



(a) Model for sensor and target

(b) Parallel resonator model

(c) Model at resonance

Figure 3. Electrical Model of the L-C Tank Sensor

The conversions from the series inductance and resistance into their parallel counterpart are listed in Table 1.

Table 1. Converting Series Resonator into Parallel Resonator

	SERIES RESONATOR → PARALLEL RESONATOR	
INDUCTANCE	L_S	$L_P = L_S (1 + Q_S^{-2})$
RESISTANCE	R_S	$R_P = R_S (1 + Q_S^2)$
QUALITY FACTOR	$Q_S = \omega L_S / R_S$	$Q_P = R_P / \omega L_P$

An EM field can be generated using an L-C resonator, or L-C tank. One topology for an L-C tank is a parallel R-L-C construction, as shown in Figure 3(b). A parallel LC oscillator can be constructed by combining a frequency selective circuit with a gain block in a closed loop. The criteria for oscillation are: 1) loop gain > 1, and 2) closed loop phase shift of 2π radians. In the context of an oscillator, the R-L-C resonator provides the frequency selectivity and contributes to the phase shift. At resonance, the parallel impedance of the reactive components (L and C) cancels, leaving only R_P, the lossy (resistive) element in the circuit (Figure 3(c)). L and R are modeled as distance dependent components, and C includes both a parallel capacitance and the parasitic capacitance between the windings of the inductor.

The sensor oscillation frequency F_{SENSOR} is given by:

$$F_{SENSOR} = \frac{1}{2\pi\sqrt{L_P \times C}} \tag{2}$$

Because the effective parallel inductance, L_P, decreases as the target moves closer to the sensor coil, Equation 2 tells us that the resonant frequency of the sensor increases.

Various position sensing techniques have been developed based on this phenomenon.

4.2 Sensor-Target Configuration

To design an inductive sensing application, the first step is to convert the measurement goal into the amount of exposure of a metal target in the electromagnetic field generated by the coils. The commonly used methods include axial proximity and lateral proximity, as depicted in Figure 4. When the metal target is placed closer to the coil, or more of the metal target overlaps with the coil, more electromagnetic field is intercepted at the target surface. The eddy current increases as more electromagnetic field flux is intercepted, decreasing the effective inductance of the coil that generates the field and increasing the LC tank oscillation frequency. This makes a greater digital output value of the LDC131x or LDC161x.

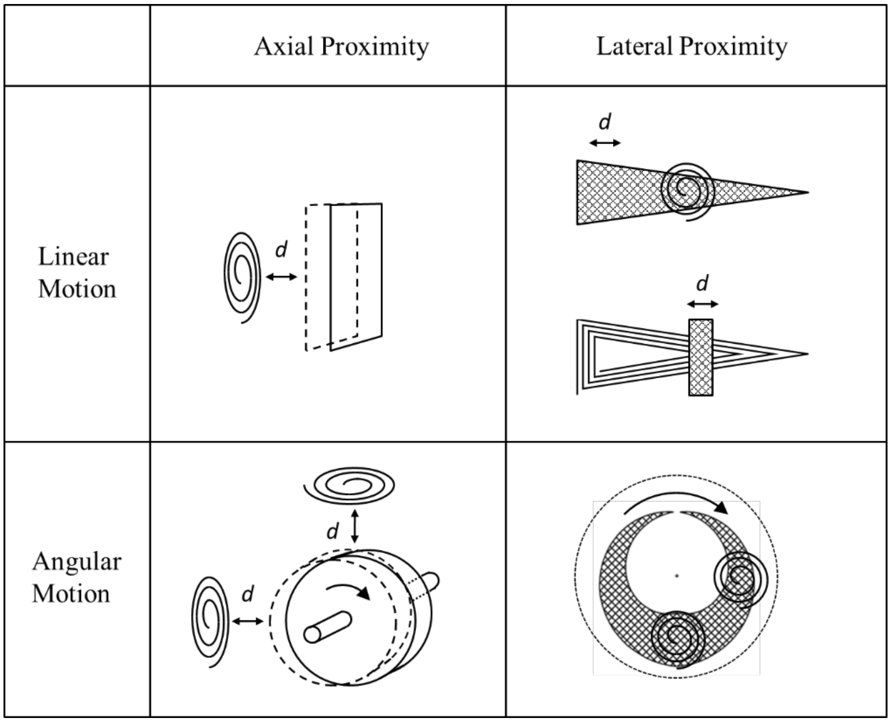


Figure 4. Commonly Used Sensor-Target Configurations

In some position sensing cases, a single coil is sufficient. Multiple coils can be used to for differential data to cancel certain unwanted changes in the output. In rotational sensing, the use of multiple coils enables continuous 360-degree angular position sensing and increases the sensing accuracy.

4.3 Target Metal and Thickness

Certain metal types perform better than other types, in terms of creating greater sensor output change. These metals are high conductivity, low magnetic permeability metals, including the common aluminum (alloys) and copper (alloys). The 300 series, non-ferritic stainless steel materials (that is, they cannot be picked up by a magnet) also work well.

Because an alternating current (such as the eddy current) tends to concentrate in the metal surface facing the sensor coil (known as the "skin effect"), a thin layer of metal usually works well enough. Table 2 shows the recommended minimum thickness for several commonly used metals, based on the sensor oscillation frequency.

Table 2. Recommended Minimum Target Metal Thickness

TARGET METAL	SENSOR FREQUENCY (MHz)		
	1	3	10
Copper	63	37	20
Silver	64	37	20
Gold	77	45	24
Aluminum	82	47	26
Aluminum alloy	99	57	31
Brass (yellow)	127	73	40
Solder	214	123	68
Non-ferritic stainless steel (3xx series)	421	243	133

4.4 Coil Design Information

The wide range of oscillation frequency and the driving current of the LDC131x and LDC161x gives the user great flexibility in selecting the dimensions of the coil that best suits their mechanical system configuration. However, certain rules must be followed to ensure the proper operation of the IC.

- *LC tank resonant frequency* — The recommended sensor frequency range for LDC131x and LDC161x devices is 1 kHz to 10 MHz
- *Inductance of the sensor coil* — There is no absolute requirement on the value of the inductance as long as the range of the resonant frequency and R_P (the parallel loss resistance) are not violated.
- *Sensor oscillation amplitude* — The maximum allowable sensor oscillation amplitude must not exceed 1.8 V. The maximum operating amplitude occurs when the target is either at its maximum distance from the sensor coil (axial sensing) or the least amount of target area overlaps the coil (lateral sensing). The minimum amplitude occurs when the target is at its closest point to the sensor (axial), or when is achieves maximum overlap with the coil (lateral). Maintain the minimum operating amplitude above 500 mV. As already explained, the sensor voltage is proportional to $R_P(d)$, which will vary as the target moves. Therefore, the coil must be carefully designed to maintain a sufficient range of R_P over the operating range to ensure that the sensor oscillation does not collapse.
- *R_P (Parallel Loss Resistance) of the LC tank* — As described in Section 4.1, the LC tank is "lossy" due to the inductor's loss and the energy dissipated by the target metal. This loss can be modeled by a parallel equivalent resistance R_P. The more the energy loss in the LC tank, the smaller the value of R_P. The range of R_P values that the LDC131x and LDC161x devices can handle is from 150 Ω to 100 kΩ, with gradually degrading S/N as it decreases below 1 kΩ. Although it is possible for R_P to exceed 100 kΩ, the minimum R_P value is more important in a majority of applications. Higher "open-air" R_P (that is, R_P value measured with no target metal) helps increase the S/N of the output. To increase the open-air R_P, use thick trace size for the printed sensor coil. Appendix A described three methods for measuring R_P value of an inductor.

4.5 Interpreting and Using the Output Data

The digital output of the LDC131x and LDC161x is a number proportional to the LC tank's oscillating frequency:

$$D = \frac{F_{SENSOR}}{F_{REF}} \times 2^N$$

where

- N is 12 for LDC131x and 28 for LDC161x (3)

The tank frequency is monotonically related to the proximity between the sensor coil and the target metal. Since FREF and N are constant, D can be directly used to indicate the target position.

D is a monotonic function of the proximity. In axial sensing, D increases as the distance decreases. In lateral sensing, D increases as the overlap between the target and the coil increases. In almost all cases, D is not a linear function of the proximity distance.

4.6 Resolution of Position Measurement

The resolution of a position sensing system is defined as the number of discreet position values that the sensor can resolve within the measurement range. In the LDC131x and LDC161x, the resolution is directly related to how fine the LC tank frequency can be resolved. Suppose the LC tank frequency increases from F_1 to F_2 as a result of moving the target from position P_1 to P_2. The position resolution is then:

$$\text{Steps between } P_1 \text{ and } P_2 = 32 \times \text{REFCNT} \times \frac{\Delta F_{TANK}}{\text{mean}\left(F_{TANK}\right)} = 64 \times \text{REFCNT} \times \frac{\left|F_1 - F_2\right|}{F_1 + F_2}$$

where

- REFCNT = reference clock count used to measure F_{TANK} (see the LDC1314 datasheet) (4)

Do not confuse this resolution with the number of bits of the output sample. In the case of LDC161x, the output samples will always have enough bits to represent the effective resolution shown above. In the case of LDC131x, because its output samples have only 12 bits, the internally available resolution is sometimes under-represented by the output sample, and the effective resolution can decrease. If this is the case, use the GAIN and OFFSET registers of the LDC1314 to restore the resolution. Altering the reference frequency (including setting the REFDIV register) can also help recover the resolution. The ratio of the effective reference frequency to tank frequency must be greater than 4 for both LDC131x and LDC161x.

4.7 System-to-System Variation and System Calibration

System-to-system variations in practical applications do exist. These variations are mainly due to the component tolerances. The capacitance of the capacitors and the inductance of the coils are the main contributor of the system-to-system variation. Good quality capacitors are recommended, such as the **NP0/CG0** ceramic capacitor or film capacitors with a tolerance of 1% to 5%. A non-printed circuit sensor coil should also have a tolerance of 5% or less.

For sensing systems that require high accuracy, a system calibration will be necessary. Most common calibration involves offset and gain calibration. In many systems, on-the-fly calibration is a good choice because it does not require permanent calibration data storage.

5 Inductive Snap Dome Key Sensing

The LDC1314 senses the key press by detecting the inductance change of the printed coil as the proximity to the metal dome surface changes, as shown in Figure 5. The snap domes have long been used as way to implement low-cost keypads, widely used in handsets, vending machines, ATMs, POS, and industrial and medical equipment. An inductive keypad can also be constructed with the snap domes. The principle of an inductive dome switch is depicted in Figure 5.

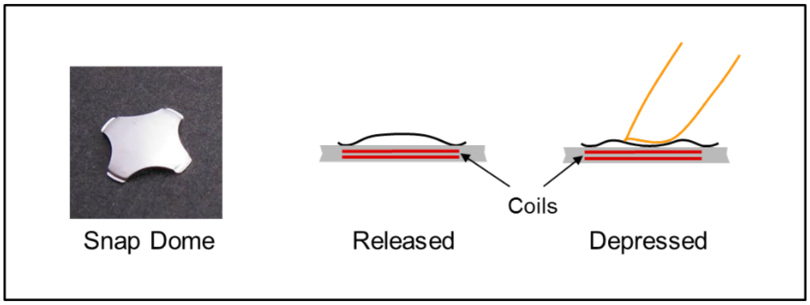


Figure 5. Inductive Key Using Snap Dome

When the dome is depressed, the distance between the dome metal and the coils is decreased. The small displacement (usually about a fraction of a millimeter) causes change in the inductance, which is converted to a digital value in the LDC1314. An algorithm that runs either in the microcontroller or the application software can then detect the key press.

Because there is no electrical contact between the column and row circuits, the inductive snap dome keypad offers these advantages over a traditional keypad:

- It is much more durable. It does not wear out over time, and is moisture and dust proof.
- It has longer operating life.
- It can detect arbitrary simultaneous key press.

In the 16-button keypad reference design, there is approximately a 0.25-mm mechanical displacement as the result of a key press. This displacement approximately causes about a 2% increase in the resonant frequency of the selected LC tank, allowing the LDC1314 to detect the action of the key press.

The resonant frequencies of the 16 LC tanks may have tolerance errors greater than the detectable frequency change of the key press. Temperature change also creates frequency drift. For reliable key press detection, the 16-button keypad reference design employs a self-adapting algorithm to determine the switching threshold (see Section 7.3).

The microcontroller is responsible for controlling the multiplexers and collecting sensor data. The GUI software processes the data and displays the result graphically. Although this processing is done in the GUI, the data can be easily ported into a microcontroller for stand-alone applications.

Although the LDC1314 has four channels, the 16-button keypad reference design only uses one. The key selection is done by the two 4:1 analog switches that are connected to the 16 keys in a column-row manner. The design can be easily expanded to implement 32 or 64 keys through the remaining LDC1314 channels. Note that each of the 4:1 multiplexer IC's has two identical multiplexers. When designing a 32-key keypad, no additional multiplexer ICs are needed.

6 Mechanical Construction

The keypad assembly uses the standard, tactile metal dome technology. The metal dome pieces can be ordered from the switch dome manufacturers in the form of a dome array sheet with adhesive on the bottom side. The top graphic overlay sheet can be ordered from many label and name plate companies. Figure 6 shows the mechanical construction of the keypad assembly of the 16-button keypad reference design.

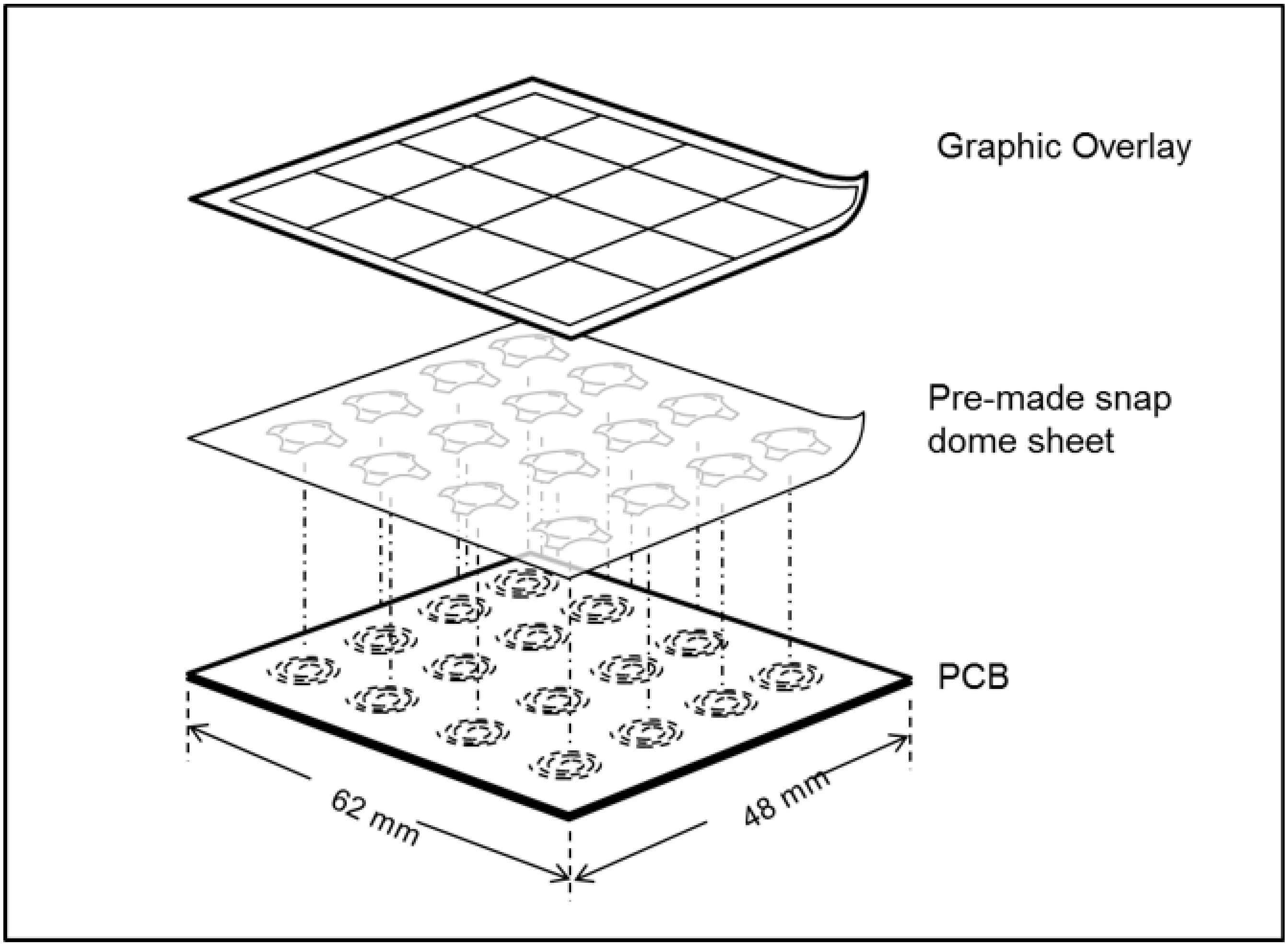


Figure 6. Mechanical Construction of Keypad Assembly

Some of the snap switch dome and label manufacturers are listed in Table 3.

Table 3. Title

TACTILE METAL DOME MANUFACTURER	WEBSITE
Snaptron, Inc	http://www.snaptron.com/
Best Hardware Co., Ltd.	http://www.metal-domes.com/products.htm
DS Click Dome Systems	http://www.clik-domes.com/
Memcon	http://memcon.sitespherelive.com/
MEMBRANE SWITCH MANUFACTURER	**WEBSITE**
Melrose	http://www.melrose-nl.com/
Elecflex	http://www.elecflex.com/
VIT International Group	http://www.interfacetech.com.cn/
Dyna-Graphics Corp.	http://www.dyna-graphics.com/

7 Hardware Design

The LDC1314 uses an inductor as the sensor. It excites the LC tank circuit, senses the proximity between the sensor and target metal by measuring the oscillating frequency. In the 16-button keypad reference design, there is a coil for each snap dome. The coils are printed in the inner two layers of a four-layer PCB, providing maximum protection from wear and tear and external environment. A center hole is fabricated in the middle of each coil that provides an air passage to ensure free movement of the dome under the sealed top graphic membrane.

7.1 Sensor Design

The diameter of the each coil is 8 mm, matching the size of the snap dome. The nominal inductance of the coil is around 2.3 μH. Each coil contains 16 turns on each side. The tank capacitor value is 150 pF. The average resonance frequency is around 9.5 MHz after the keypad is assembled. The 43-MHz internal reference oscillator of the LDC1314 is used, saving the cost of an external crystal oscillator.

The keypad PCB and graphic overlay designs are shown in Figure 7.

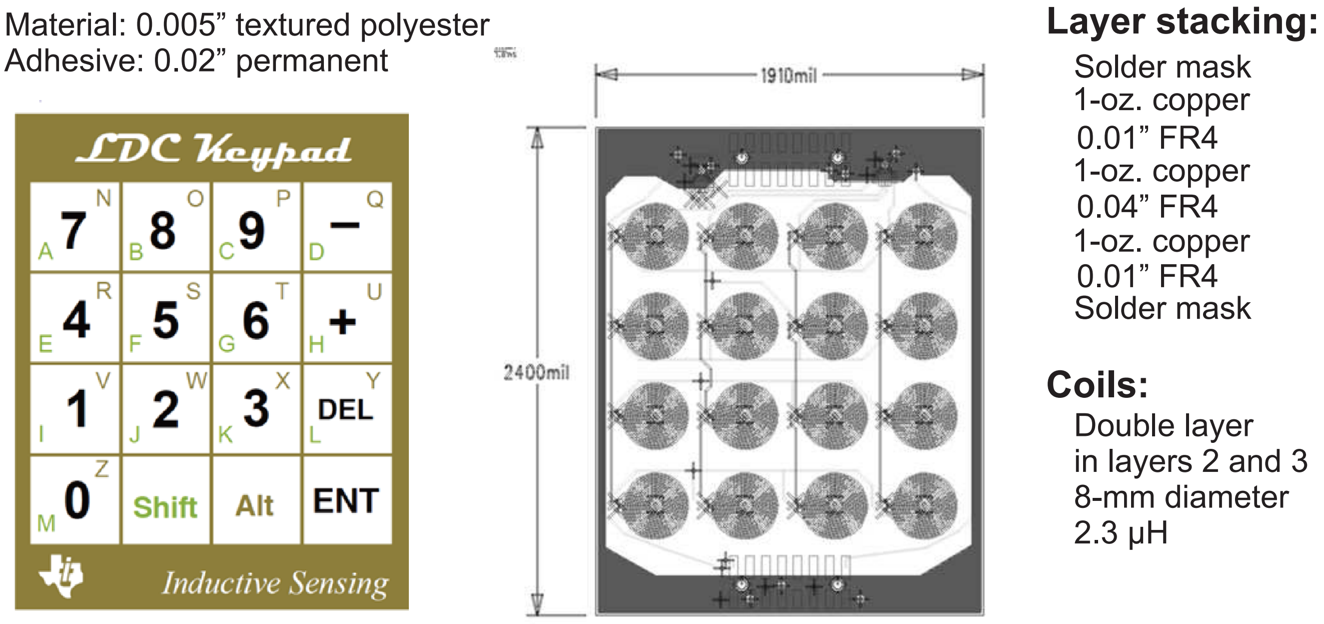


Figure 7. Keypad PCB and Graphic Overlay Designs

7.2 Scan Loop

The scan loop is driven by the GUI software, which requests the microcontroller to send the data for the 16 keys in a block. The data is then processed to identify the key presses and the result is displayed on the GUI screen. Figure 8 illustrates the scan loop flowchart.

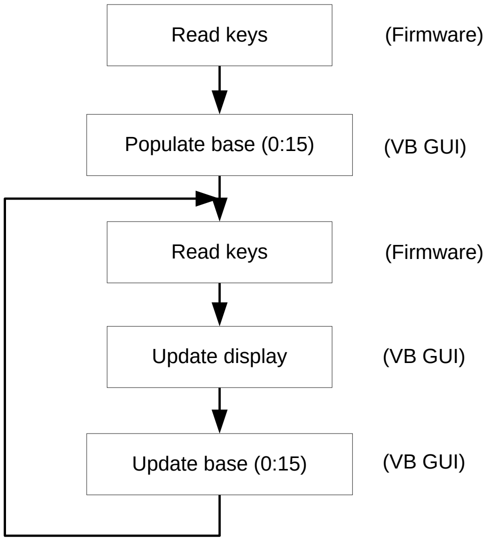


Figure 8. Key Scan Loop

7.3 Key Press Identification

As mentioned in Section 5, a self-adapting algorithm is used in the 16-button keypad reference design to reliably detect the key presses. This is done in the GUI software. The algorithm keeps an array of the "unpressed" values, referred to as the "base value", of each key by slowly tracking the change of the key values. The "slow tracking" is done by incrementing the base value when the most recent key data is greater than the base value, and decrementing the base value if the most recent key data is smaller than the current value. With this action, fast changes (from a key press, for example) are effectively ignored. The base value is kept unchanged otherwise. The slow changes, such as those due to temperature drift, are tracked continuously. A fixed threshold above the base value is used to judge if the key is depressed. The self-adapting algorithm is shown in Figure 9.

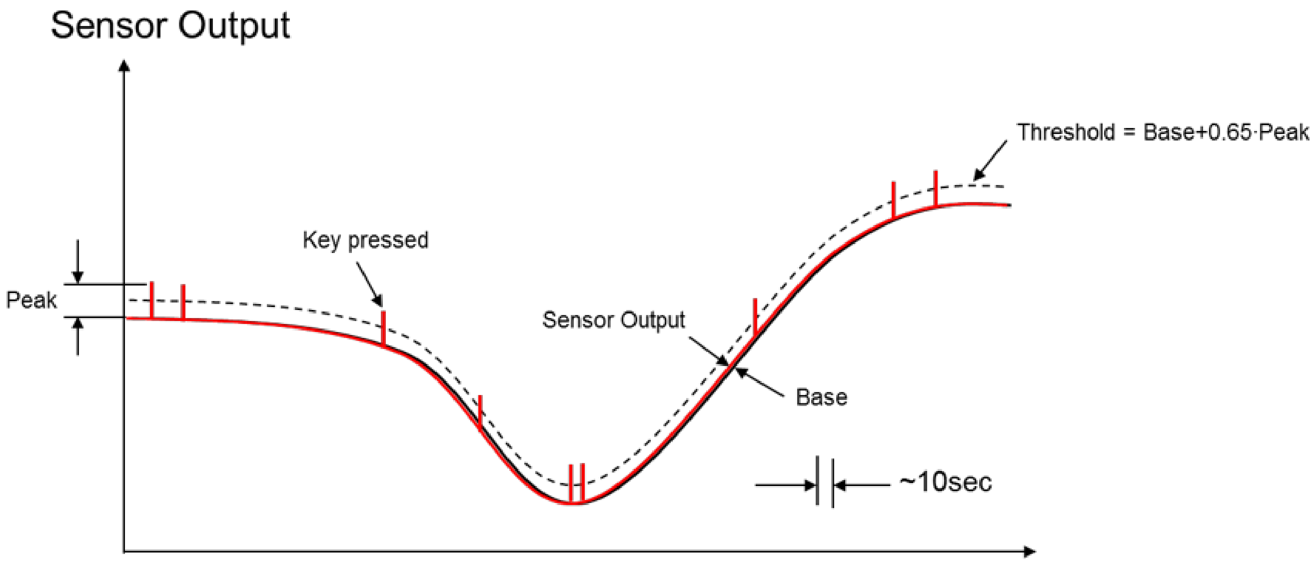


Figure 9. Self-Adapting Key Detection

8 Firmware

8.1 Com Port Commands

The MSP430 firmware of the keypad bridges between the I^{2}C interface of the LDC1314 and the virtual COM port of the GUI. The baud rate is 912.6k. There are seven commands:

- RK n: This command requests the firmware to send the sensor output data, each 16 bits long, in the following sequence: Ch0, Ch1, Ch2, Ch3
- FB n: Set flash block
- BW w w: Block-writes the 16-bit values that follow to the flash storage of the MCU, starting from address 0
- BR n: Requests the firmware to send *n* 16-bits values in the flash storage from address 0
- IW addr reg w: Writes the 16-bit value w into the reg register of the I^{2}C device having address addr
- IR addr reg: Requests the firmware to send the 16-bit content of register reg of the I^{2}C device having address addr
- LR: Loads the default register values into the LDC1314 registers (with an I^{2}C address of 2 A)

8.2 Flash Storage Data Format

The flash memory dedicated to the keypad firmware has the following assignment:

```
.equ      Flash_1614_R08,    0     ; Register 08
.equ      Flash_1614_R09,    2     ; Register 09
.equ      Flash_1614_R0A,    4     ; Register 0A
.equ      Flash_1614_R0B,    6     ; Register 0B
.equ      Flash_1614_R0C,    8     ; Register 0C
.equ      Flash_1614_R0D,    10    ; Register 0D
.equ      Flash_1614_R0E,    12    ; Register 0E
.equ      Flash_1614_R0F,    14    ; Register 0F
.equ      Flash_1614_R10,    16    ; Register 10h
.equ      Flash_1614_R11,    18    ; Register 11h
.equ      Flash_1614_R12,    20    ; Register 12h
.equ      Flash_1614_R13,    22    ; Register 13h
.equ      Flash_1614_R14,    24    ; Register 14h
.equ      Flash_1614_R15,    26    ; Register 15h
.equ      Flash_1614_R16,    28    ; Register 16h
.equ      Flash_1614_R17,    30    ; Register 17h
.equ      Flash_1614_R19,    32    ; Register 19h
.equ      Flash_1614_R1A,    34    ; Register 1Ah
.equ      Flash_1614_R1B,    36    ; Register 1Bh
.equ      Flash_1614_R1C,    38    ; Register 1Ch
.equ      Flash_1614_R1D,    40    ; Register 1Dh
.equ      Flash_1614_R1E,    42    ; Register 1Eh
.equ      Flash_1614_R1F,    44    ; Register 1Fh
.equ      Flash_1614_R20,    46    ; Register 20h
.equ      Flash_1614_R21,    48    ; Register 21h
```

Upon power up, these values are written into the intended LDC1314 registers. The LDC1314 registers can also be reloaded by the LR command. The actual register contents are shown in Table 4.

Table 4. LDC1314 Register Values

REGISTER ADDRESS	REGISTER NAME	REGISTER VALUE
0x08	RCOUNT_CH0	01A5
0x09	RCOUNT_CH1	02B0
0x0A	RCOUNT_CH2	02B0
0x0B	RCOUNT_CH3	02B0
0x0C	OFFSET_CH0	2800
0x0D	OFFSET_CH1	20A4
0x0E	OFFSET_CH2	20A4
0x0F	OFFSET_CH3	20A4
0x10	SETTLECOUNT_CH0	8
0x11	SETTLECOUNT_CH1	8
0x12	SETTLECOUNT_CH2	8
0x13	SETTLECOUNT_CH3	8
0x14	CLOCK_DIVIDERS_CH0	0
0x15	CLOCK_DIVIDERS_CH1	0
0x16	CLOCK_DIVIDERS_CH2	0
0x17	CLOCK_DIVIDERS_CH3	0
0x19	ERROR_CONFIG	1
0x1A	CONFIG	1C01
0x1B	MUX_CONFIG	02FF
0x1C	RESET_DEV	400
0x1E	DRIVE_CURRENT_CH0	E800
0x1F	DRIVE_CURRENT_CH1	E800
0x20	DRIVE_CURRENT_CH2	E800
0x21	DRIVE_CURRENT_CH3	200

8.3 Application Specific Command

The RK command is designed specifically for this inductive keypad. It handles the multiplexing and reading of the data from the 16 keys and transmits it to the GUI. To ensure reliable reading of the correct key values, certain timing requirement must be observed, as shown in Figure 10.

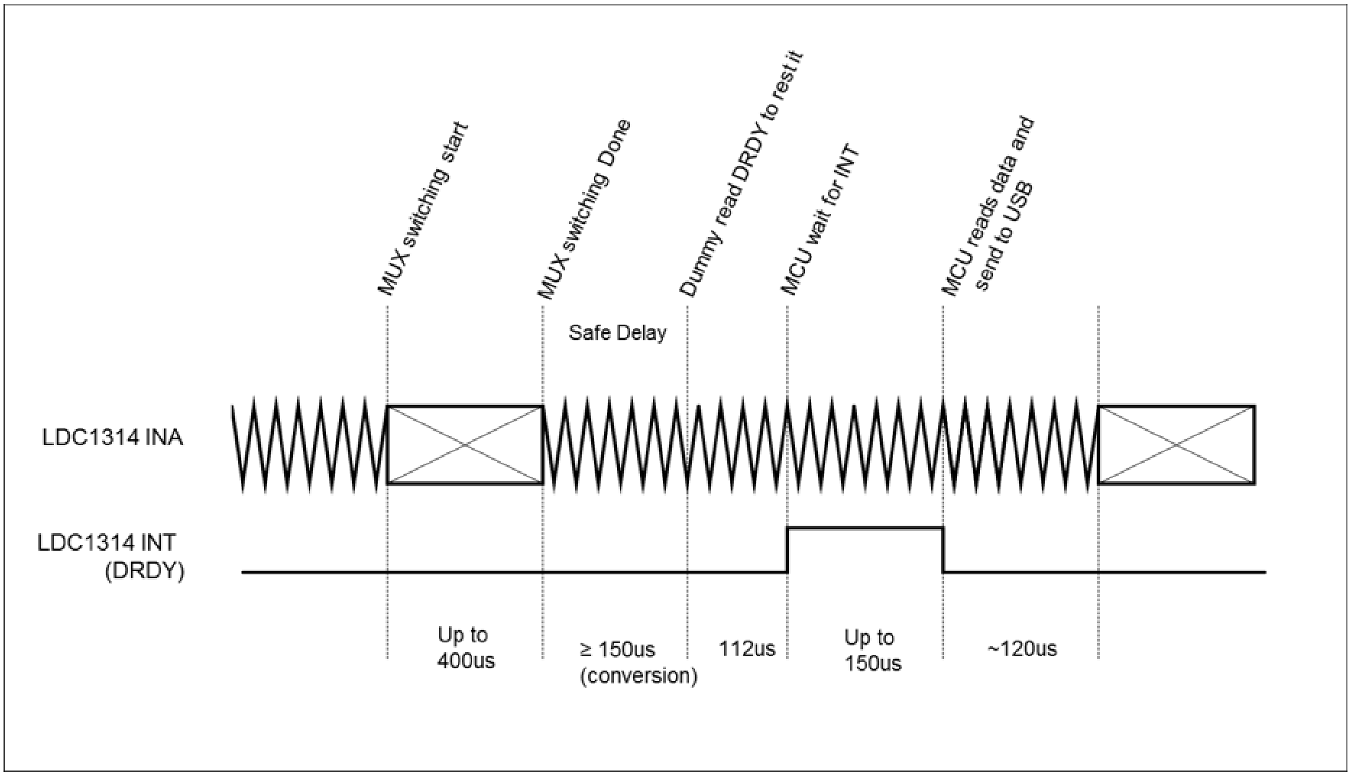


Figure 10. Timing Requirement for a Single Key Read

The flowchart of the RK command is shown in Figure 11.

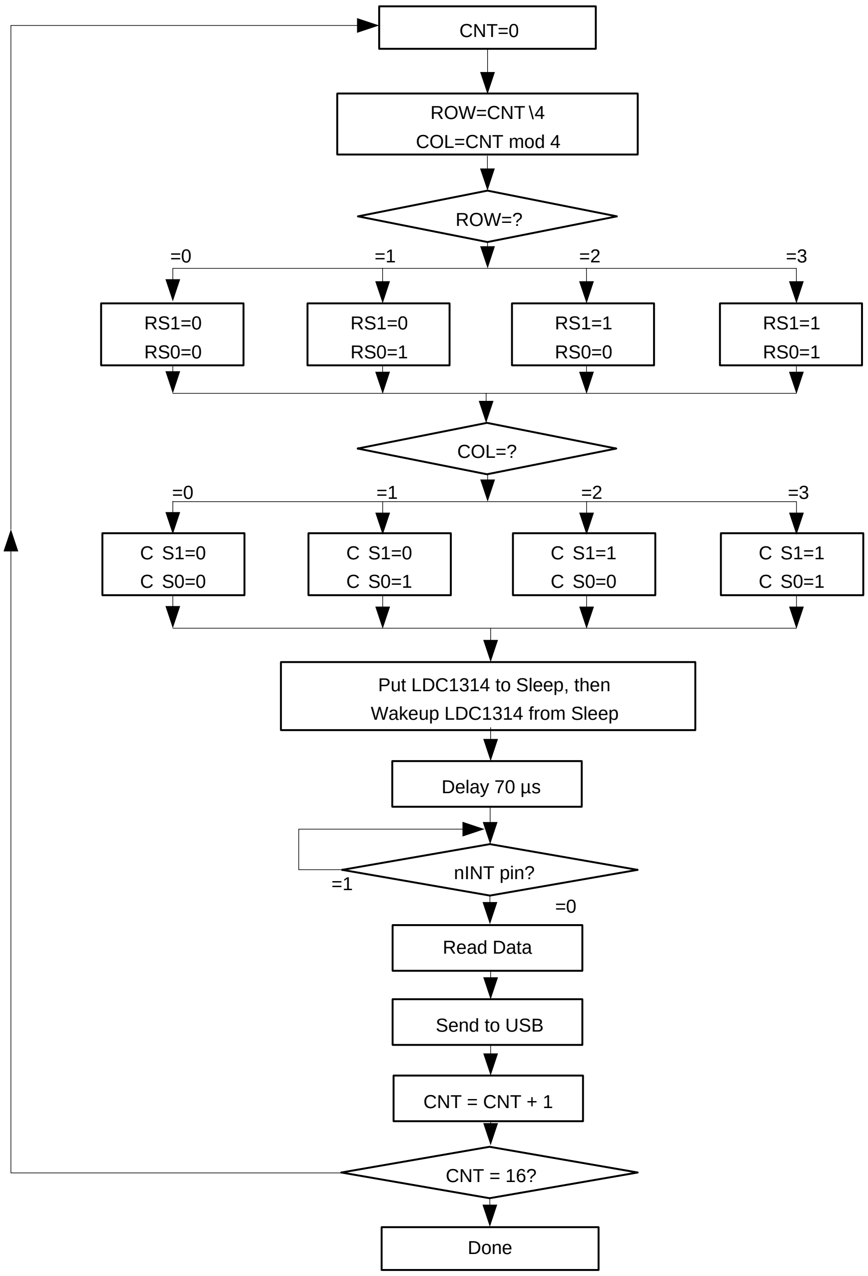


Figure 11. RK Command Flowchart

9 GUI Software

The GUI software is written in Visual Basic® 2012. The main screen is the graphic animation of the keypad. Use the USB tab select the COM port used to communicate with the keypad.

9.1 Main Screen

The main screen is shown in Figure 12 with the pressed keys highlighted.

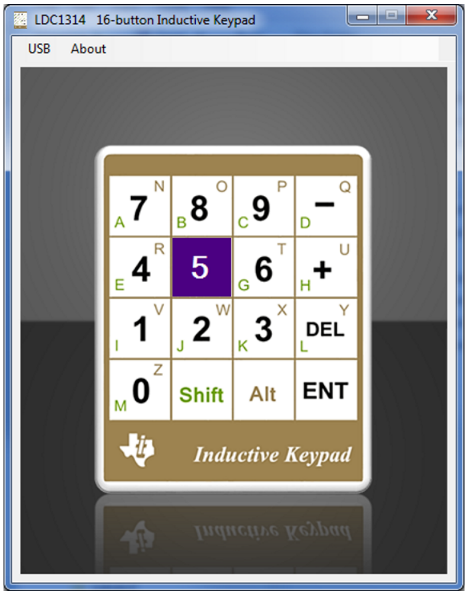
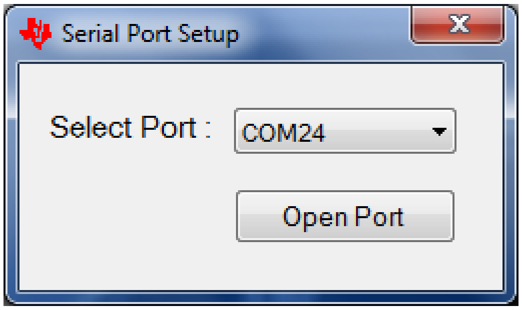


Figure 12. Main Screen

9.2 USB Screen

The COM port is selected in the USB screen. The COM port must be first selected for the proper operation of the 16-button keypad. The USB screen is shown in Figure 13.



Select Port : COM24

Figure 13. USB Screen

10 Design Files

10.1 Schematics

To download the schematics for each board, see the design files at TIDA-00509.

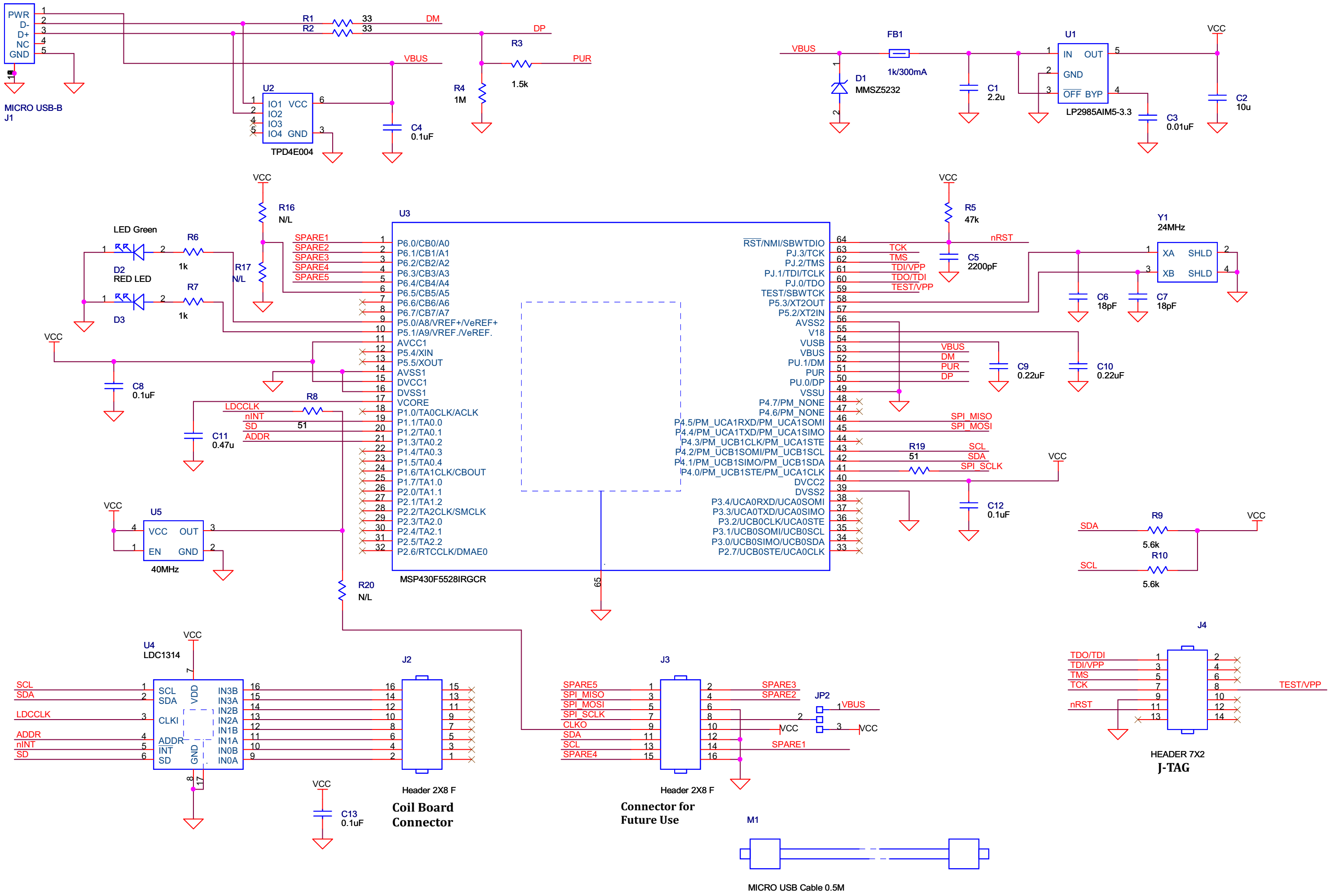


Figure 14. MCU Board Schematic

10.2 Schematics — Keypad Board

To download the schematics for each board, see the design files at TIDA-00509.

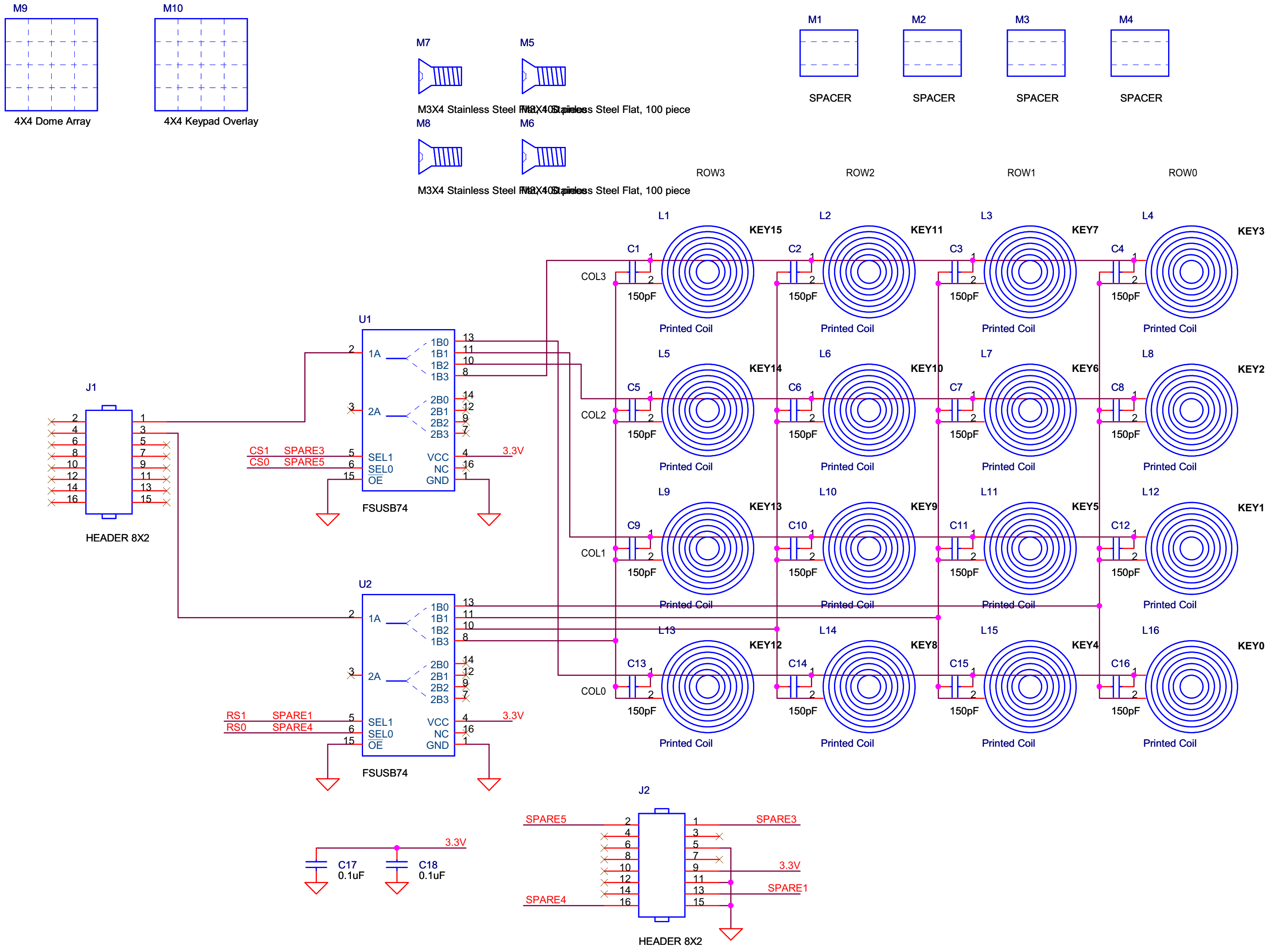


Figure 15. Keypad Board Schematic

10.3 Bill of Materials — MCU Board

To download the bill of materials (BOM), see the design files at TIDA-00509.

Table 5. MCU Board BOM

ITEM	QTY	PART REFERENCE	VALUE	DESCRIPTION	MFG1	MFG1_PN
1	1	C1	2.2u	2.2uF 10V X7R 0603 +/-10% -55~125C	muRata	GRM188R71A225KE15D
2	1	C2	10u	CAP,1206,X5R,10uF,+/- 10%, 35V, -55~85C	Taiyo Yuden	GMK316BJ106KL-T
3	1	C3	0.01uF	CAP,0402,X7R,0.01uF,+/- 10%, 25V -55~125C	muRata	GRM155R71E103KA01D
4	4	C4 C8 C12 C13	0.1uF	CAP,0402,X7R,0.1uF,+/- 10%, 16V, -55~125C	Taiyo Yuden	EMK105B7104KV-F
5	1	C5	2200pF	CAP,0402,X7R,2200pF,+/- 10%, 50V	Yageo	CC0402KRX7R9BB222
6	2	C6 C7	18pF	CAP,0402,NPO,18pF,+/- 5%, 50V	TDK	LMK105BJ224KV-F
7	2	C9 C10	0.22uF	CAP,0402,X7R,0.22uF,+/- 10%, 10V, -55~125C	muRata	GRM155R71H222KA01
8	1	C11	0.47u	CAP CER .47UF 25V X7R 0603	muRata	GRM188R71E474KA12D
9	1	D1	MMSZ5232	ZENER 5.6V 500mW	Diodes	MMSZ5232B-7-F
10	1	D2	LED Green	LED Diffused Green High Efficinecy	Osram	LG L29K-G2J1-24-Z
11	1	D3	RED LED	LED 660NM SUPER RED DIFF 0603SMD	Lumex	SML-LX0603SRW-TR
12	1	FB1	1k/300mA	FER 1K @ 100MHz, 0603 300mA 0.6 Ohm	TDK	MMZ1608B102C
13	1	J1	MICRO USB-B	CON, USB, Micro, Type B	FCI	10118193-0001LF
14	2	J2 J3	Header 2X8 F	2MM Header Female SMD BOTTOM ENTRY w. Peg, H=2.8MM	Sullins	NPPN082GFNS-RC
15	1	J4	HEADER 7X2	Heater 7X2,.1X.1, SMD, pin=6.1MM, base-to-pcb=3.56mm	Molex	15912140
16	1	JP2	SOLDER-JUMPER3	Solder Jumper 0201	TBD	TBD
17	2	R1 R2	33	RES,0402,33 OHMS, +/- 5%, 1/16 W	RHOM	MCR01MRTJ330
18	1	R3	1.5k	RES,0402,1.5K OHMS, +/- 5%, 1/16W	Panasonic ECG	ERJ-2GEJ152X
19	1	R4	1M	RES,0402,1M OHMS, +/- 5%, 1/16 W	Panasonic ECG	ERJ-2GEJ105X
20	1	R5	47k	RES,0402,47K OHMS, +/- 5%, 1/16 W	Panasonic ECG	ERJ-2GEJ473X
21	2	R6 R7	1k	RES,0402,1K OHMS, +/- 5%, 1/16 W	Panasonic ECG	ERJ-2GEJ102X
22	2	R8 R19	51	RES,0402,51 OHMS, +/- 5%, 1/16W	Panasonic ECG	ERJ-2GEJ510X
23	2	R9 R10	2.7k	RES,0402,2.7K OHMS, +/- 5%, 1/16W	Stackpole Electronics Inc	RMCF0402JT2K70
24	2	R16 R17	N/L	RES,0402	DO NOT	STUFF
25	1	R20	100	RES,0402,100 OHMS, +/- 5%, 1/16W	Panasonic - ECG	ERJ-2GEJ101X

Table 5. MCU Board BOM (continued)

ITEM	QTY	PART REFERENCE	VALUE	DESCRIPTION	MFG1	MFG1_PN
26	1	U1	LP2985AIM5-3.3	LDO 3.3V 0.15A, VINmax=16V	TI	LP2985AIM5-3.3/NOPB
27	1	U2	TPD4E004	4CH ESD-PROT ARRAY	TI	TPD4E004DRYR
28	1	U3	MSP430F5528IRGCR	MCU 16BIT 128KB FLASH 64VQFN	TI	MSP430F5528IRGCR
29	1	U4	LDC1314	INDUCTANCE TO DIGITAL CONVERTER 4CH	TI	LDC1314
30	1	U5	40MHz	CMOS,40 MHz,SMD 4pin,1.6-3.3V, 50ppm, 5mA	AVX	KC2520B40.0000C10E00
31	1	Y1	24MHz	CRYSTAL 24.000 MHZ 10PF SMD	CTS	403C11A24M00000

10.4 Bill of Materials — Keypad

To download the bill of materials (BOM), see the design files at TIDA-00509.

Table 6. Keypad Board BOM

ITEM	QTY	DIGIKEY PN	PART REFERENCE	VALUE	DESCRIPTION	MFG1	MFG1_PN
1	16	490-3229-1-ND	C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16	150pF	CAP,0402,NPO,150pF,+/-5%, 50V -55~125C	muRata	GRM1555C1H151JA01D
2	2	587-1451-1-ND	C17 C18	0.1uF	CAP,0402,X7R,0.1uF,+/-10%, 16V, -55~125C	Taiyo Yuden	EMK105B7104KV-F
3	2	S6008-08-ND	J1 J2	HEADER 8X2	8X2 2MM SMD HEADER H=2.2MM Peg=1.2MM	Sullins	NRPN082MAMP-RC
5	4	952-2179-ND	M1 M2 M3 M4	SPACER	HEX STANDOFF M3 Brass/Nickle 5MM F-F	Harwin Inc	R30-1000502
6	4		M5 M6 M7 M8	M3X4 Stainless Steel Flat, 100 piece	M3x4mm Stainless Steel Flat Head Machine Screw, 100-piece	www.laptopscrews.com/M3x4.htm	Item #10109
7	2	FSUSB74UMXCT-ND	U1 U2	FSUSB74	Analog SW 2X4:1 -40~85C 2.7-4.4V 6.5 Ohm 7.5p/2p	Fairchild Semi	FSUSB74UMX

10.5 Layer Plots

The LDC1314 has a nominal minimum requirement of 2.3 µH for coil inductance. This inductance can be achieved by a 2-layer coil with a 8-mm diameter using 4-mil trace and spacing. The composite view of PCB layout image is shown in Figure 16. The coils are printed in the layer 2 and 3 of the 4-layer board.

To download the layer plots, see the design files at TIDA-00509.

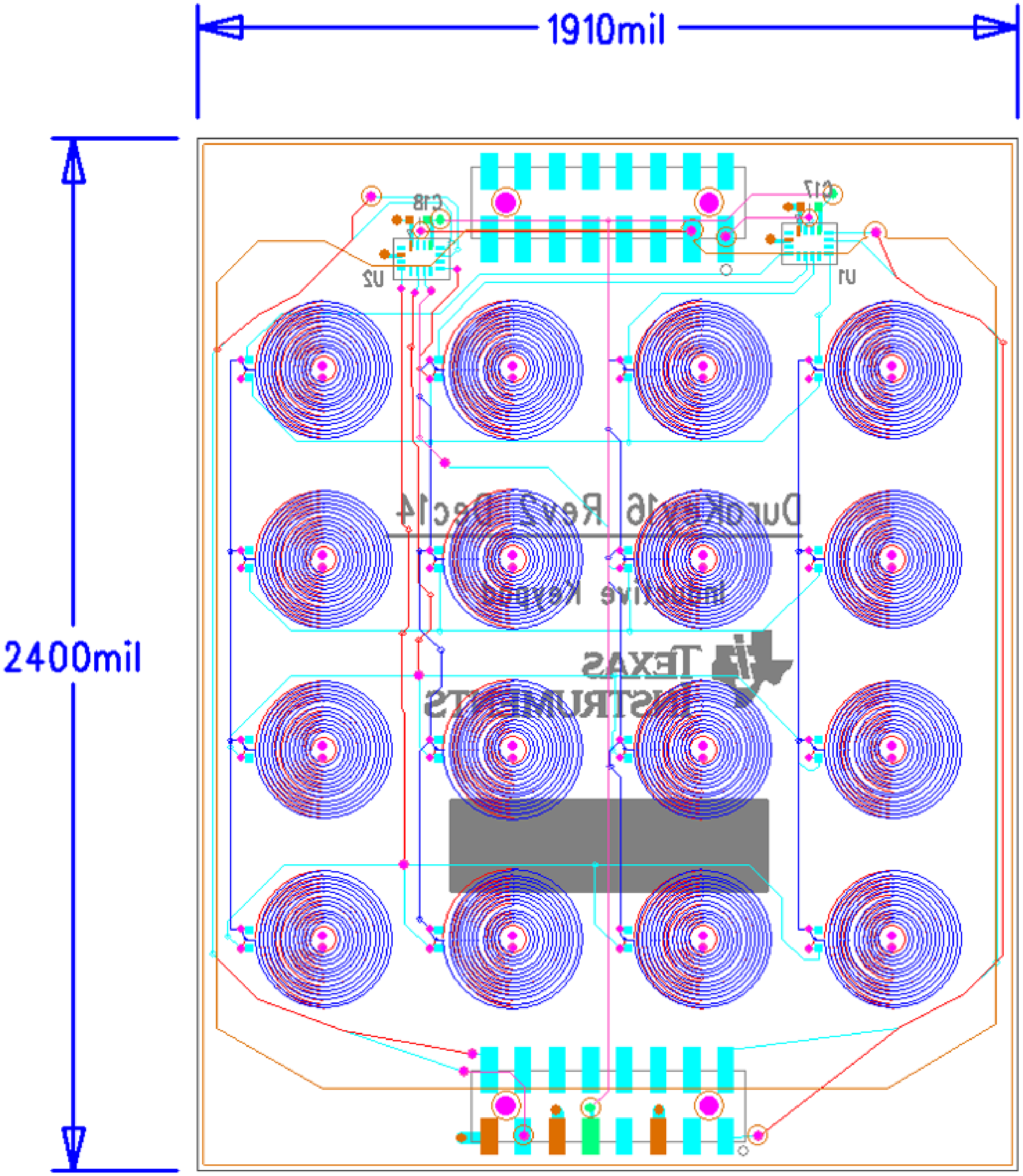


Figure 16. Keypad PCB Layout

Figure 17 shows the PCB layout of the MCU board.

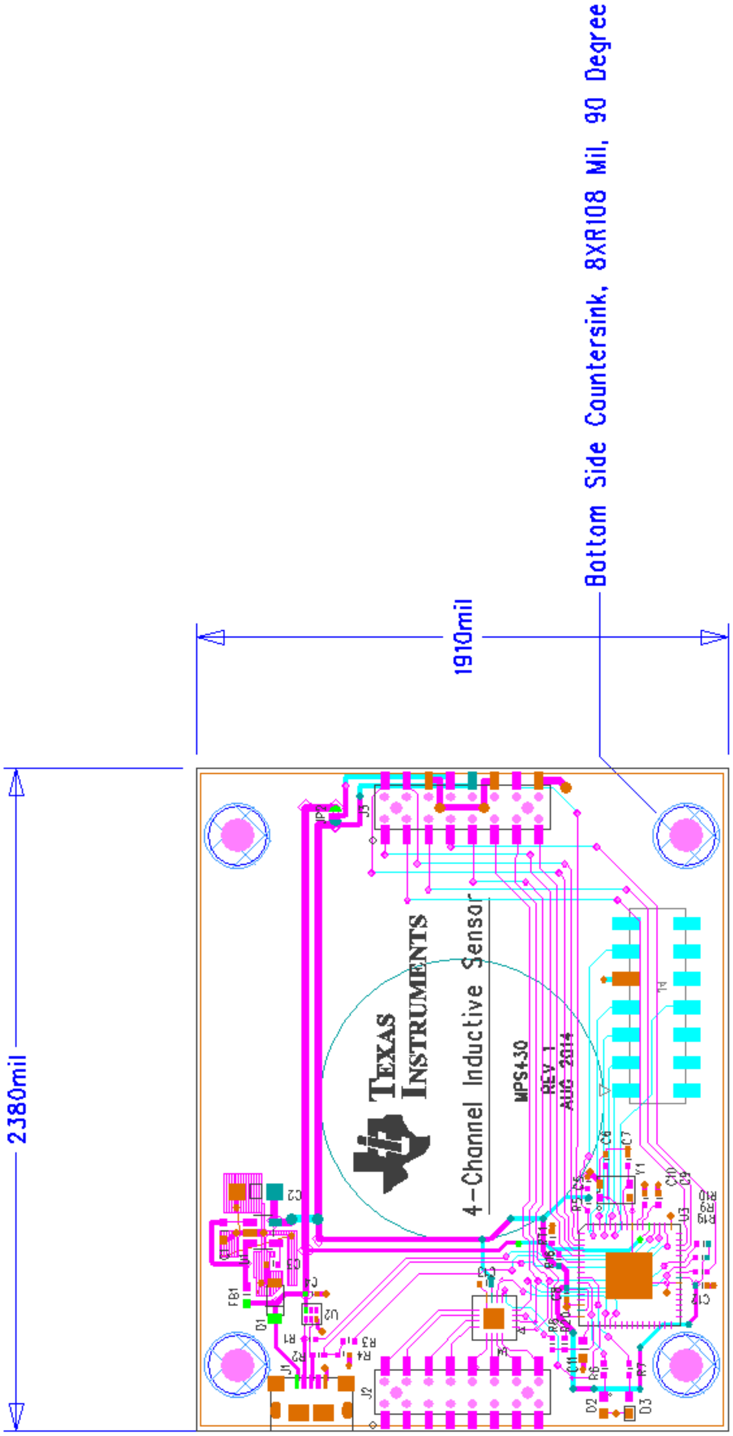


Figure 17. MCU Board Composite View

10.6 Software Files

To download the software files, see the design files at TIDA-00509.

11 References

1. Texas Instruments, *1º Dial Using the LDC1314 Inductance-to-Digital Converter*, Design Guide (TIDU953).
2. Texas Instruments, *Touch on Metal Buttons With Integrated Haptic Feedback Reference Design*, Design Guide (TIDU613).

12 About the Author

DON LIU a system architect in TI's Precision Signal Path group, located in Santa Clara, California.

Appendix A Measuring R_P of an Inductor

There are several ways to determine the R_P of an inductor, as illustrated in the following figures. Make sure to place the target metal at the closest distance to the coil as required by the application when measuring R_P, for this represents the case of "minimum R_P".

- R_P Measurement Method 1 — Use a network analyzer to measure the complex impedance of the coil (coil only, without the capacitor). The X_L (reactance) and R_S (series loss resistance) values are displayed at a selected frequency. Then use the formula shown in Figure 18 to calculate the R_P.

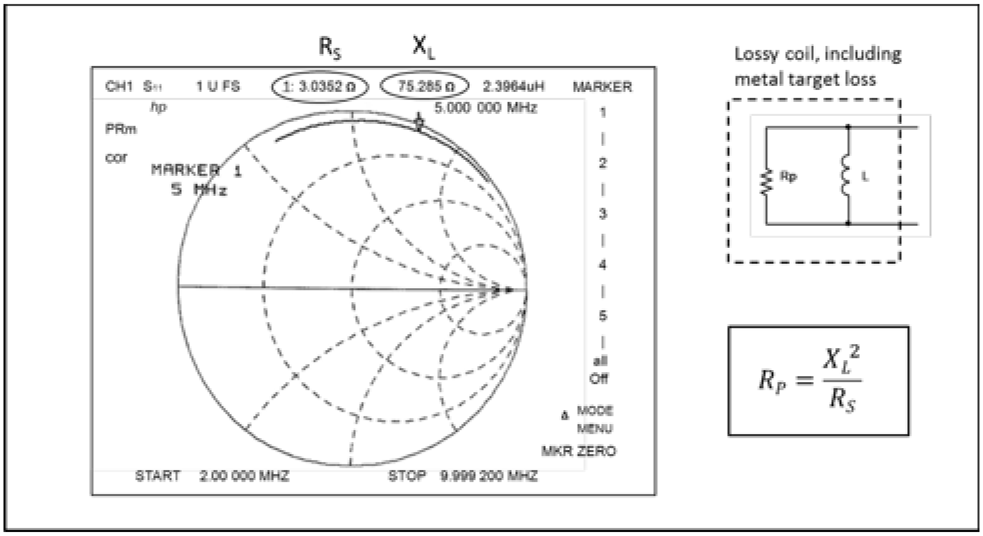


Figure 18. Using a Network Analyzer to Find R_P

- RP Measurement Method 2 — Use an impedance analyzer to measure the inductance and series resistance of the coil (coil only, without the capacitor). The L_S (Inductance) and R_S (series loss resistance) values are displayed at a selected frequency. Then use the formula shown in Figure 19 to calculate the R_P.

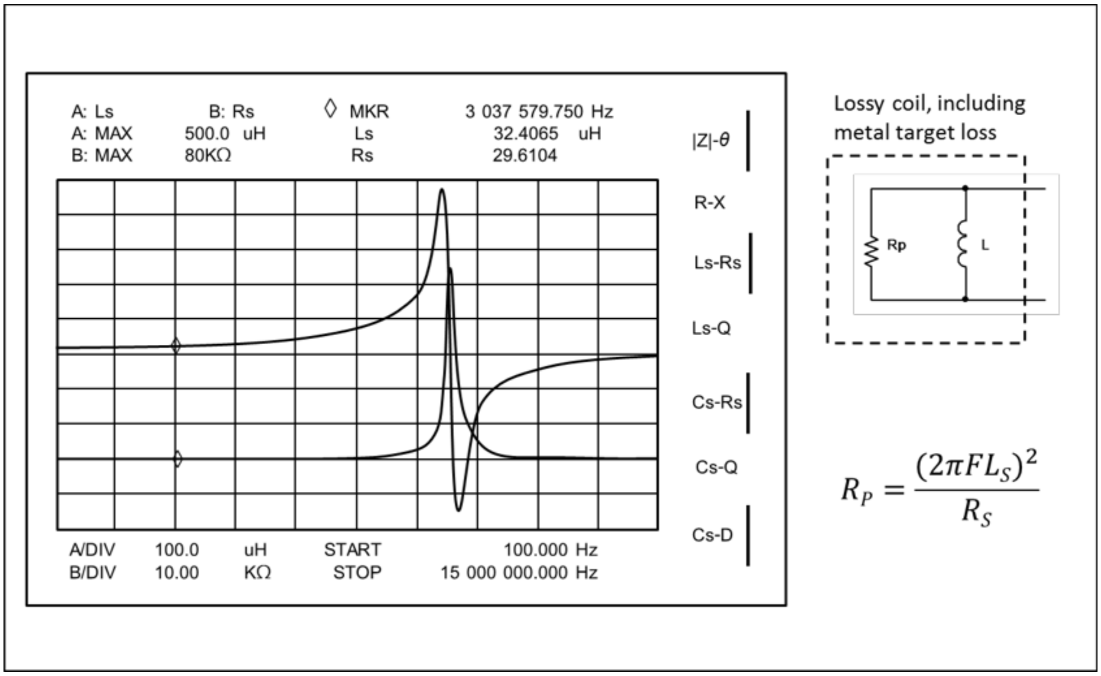
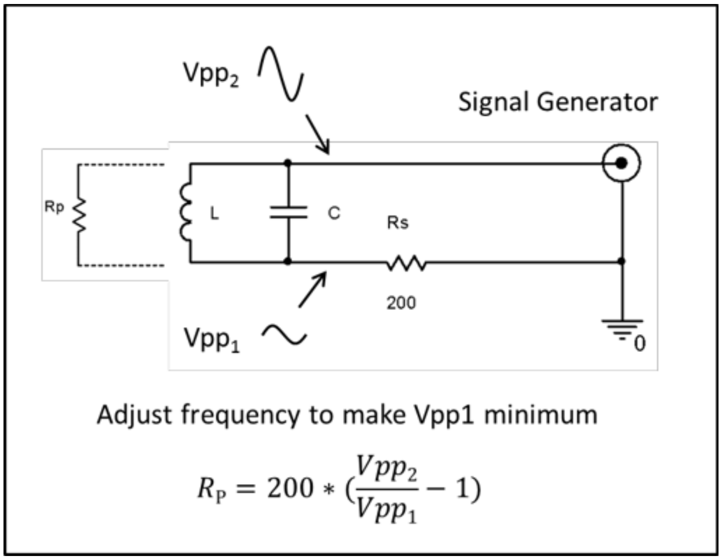


Figure 19. Using an Impedance Analyzer to Find R_P

- R_P Measurement Method 3 — Use a signal generator and oscilloscope, as illustrated in Figure 20. The LC tank capacitor is required for this method.



Adjust frequency to make Vpp1 minimum

$$R_P = 200 * (\frac{Vpp_2}{Vpp_1} - 1)$$

Figure 20. Using a Signal Generator and Oscilloscope to Find R_P

Revision A History

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

Changes from Original (July 2015) to A Revision	**Page**
• Changed Equation 2 content from "LPC" to "L_P × C"	6

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