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

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Design Resources

- TIDA-00509 Design Folder
- LDC1314 Product Folder
- MSP430F5528 Product Folder
- LP2985AIM5-3.3 Product Folder
- TPD4E004 Product Folder

Design Features

- Robust Contactless Implementation
- Excellent Resistance to Harsh Environment
- Moisture and Dirt Proof
- Very Durable
- Standard Manufacturing Process

Featured Applications

- POS Terminals
- 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](image-url)
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.

![LDC1314 Functional Block Diagram](image)

**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:

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

(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.

![Figure 3. Electrical Model of the L-C Tank Sensor](image)
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

<table>
<thead>
<tr>
<th>серiес resonator</th>
<th>parallel resonator</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDUCTANCE</td>
<td>( L_s )</td>
</tr>
<tr>
<td></td>
<td>( L_p = L_s (1 + Q_s^2) )</td>
</tr>
<tr>
<td>RESISTANCE</td>
<td>( R_s )</td>
</tr>
<tr>
<td></td>
<td>( R_p = R_s (1 + Q_s^2) )</td>
</tr>
<tr>
<td>QUALITY FACTOR</td>
<td>( Q_s = \omega L_s / R_s )</td>
</tr>
<tr>
<td></td>
<td>( Q_p = R_p / \omega L_p )</td>
</tr>
</tbody>
</table>

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 \( 2\pi \) 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 \( F_{\text{SENSOR}} \) is given by:

\[
F_{\text{SENSOR}} = \frac{1}{2\pi \sqrt{L_p \times C}}
\]  

(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.

<table>
<thead>
<tr>
<th></th>
<th>Axial Proximity</th>
<th>Lateral Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Motion</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Angular Motion</td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>TARGET METAL</th>
<th>SENSOR FREQUENCY (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Copper</td>
<td>63</td>
</tr>
<tr>
<td>Silver</td>
<td>64</td>
</tr>
<tr>
<td>Gold</td>
<td>77</td>
</tr>
<tr>
<td>Aluminum</td>
<td>82</td>
</tr>
<tr>
<td>Aluminum alloy</td>
<td>99</td>
</tr>
<tr>
<td>Brass (yellow)</td>
<td>127</td>
</tr>
<tr>
<td>Solder</td>
<td>214</td>
</tr>
<tr>
<td>Non-ferritic stainless steel (3xx series)</td>
<td>421</td>
</tr>
</tbody>
</table>

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:

\[ D = \frac{F_{\text{SENSOR}}}{F_{\text{REF}}} \times 2^N \]

where

- \( N = 12 \) for LDC131x and 28 for LDC161x

The tank frequency is monotonically related to the proximity between the sensor coil and the target metal. Since \( F_{\text{REF}} \) 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:

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

where

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

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 NPO/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](image)

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

<table>
<thead>
<tr>
<th>TACTILE METAL DOME MANUFACTURER</th>
<th>WEBSITE</th>
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</thead>
<tbody>
<tr>
<td>Snaptron, Inc</td>
<td><a href="http://www.snaptron.com/">http://www.snaptron.com/</a></td>
</tr>
<tr>
<td>DS Click Dome Systems</td>
<td><a href="http://www.clik-domes.com/">http://www.clik-domes.com/</a></td>
</tr>
<tr>
<td>Memcon</td>
<td><a href="http://memcon.sitespherelive.com/">http://memcon.sitespherelive.com/</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MEMBRANE SWITCH MANUFACTURER</th>
<th>WEBSITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melrose</td>
<td><a href="http://www.melrose-nl.com/">http://www.melrose-nl.com/</a></td>
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<tr>
<td>Elecflex</td>
<td><a href="http://www.elecflex.com/">http://www.elecflex.com/</a></td>
</tr>
<tr>
<td>VIT International Group</td>
<td><a href="http://www.interfacetech.com.cn/">http://www.interfacetech.com.cn/</a></td>
</tr>
</tbody>
</table>
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 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.

Material: 0.005” textured polyester
Adhesive: 0.02” permanent

Layer stacking:
- Solder mask
- 1-oz. copper
- 0.01” FR4
- 1-oz. copper
- 0.04” FR4
- 1-oz. copper
- 0.01” FR4
- Solder mask

Coils:
- Double layer
- in layers 2 and 3
- 8-mm diameter
- 2.3 µH

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](image)

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](image)
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:

```assembly
.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

<table>
<thead>
<tr>
<th>REGISTER ADDRESS</th>
<th>REGISTER NAME</th>
<th>REGISTER VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x08</td>
<td>RCOUNT_CH0</td>
<td>01A5</td>
</tr>
<tr>
<td>0x09</td>
<td>RCOUNT_CH1</td>
<td>02B0</td>
</tr>
<tr>
<td>0x0A</td>
<td>RCOUNT_CH2</td>
<td>02B0</td>
</tr>
<tr>
<td>0x0B</td>
<td>RCOUNT_CH3</td>
<td>02B0</td>
</tr>
<tr>
<td>0x0C</td>
<td>OFFSET_CH0</td>
<td>2800</td>
</tr>
<tr>
<td>0x0D</td>
<td>OFFSET_CH1</td>
<td>20A4</td>
</tr>
<tr>
<td>0x0E</td>
<td>OFFSET_CH2</td>
<td>20A4</td>
</tr>
<tr>
<td>0x0F</td>
<td>OFFSET_CH3</td>
<td>20A4</td>
</tr>
<tr>
<td>0x10</td>
<td>SETTLECOUNT_CH0</td>
<td>8</td>
</tr>
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<tr>
<td>0x1C</td>
<td>RESET_DEV</td>
<td>400</td>
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<tr>
<td>0x1D</td>
<td>DRIVE_CURRENT_CH0</td>
<td>E800</td>
</tr>
<tr>
<td>0x1E</td>
<td>DRIVE_CURRENT_CH1</td>
<td>E800</td>
</tr>
<tr>
<td>0x20</td>
<td>DRIVE_CURRENT_CH2</td>
<td>E800</td>
</tr>
<tr>
<td>0x21</td>
<td>DRIVE_CURRENT_CH3</td>
<td>200</td>
</tr>
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</table>
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](image-url)
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 to 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](image)

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.

![Figure 13. USB Screen](image)
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

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>PART REFERENCE</th>
<th>VALUE</th>
<th>DESCRIPTION</th>
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<th>MFG1_PN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>C1</td>
<td>2.2u</td>
<td>2.2uF 10V X7R 0603 +/-10% -55~125C</td>
<td>muRata</td>
<td>GRM188R71A225KE15D</td>
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<tr>
<td>2</td>
<td>1</td>
<td>C2</td>
<td>10u</td>
<td>CAP,1206,X5R,10uF, +/- 10%, 35V, -55~85C</td>
<td>Taiyo Yuden</td>
<td>GMK316BJ106KL-T</td>
</tr>
<tr>
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<td>1</td>
<td>C3</td>
<td>0.01uF</td>
<td>CAP,0402,X7R,0.01uF, +/- 10%, 25V -55~125C</td>
<td>muRata</td>
<td>GRM155R71E103KA01D</td>
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<td>C4 C8 C12 C13</td>
<td>0.1uF</td>
<td>CAP,0402,X7R,0.1uF, +/- 10%, 16V, -55~125C</td>
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<td>C5</td>
<td>2200pF</td>
<td>CAP,0402,X7R,2200pF, +/- 10%, 50V</td>
<td>Yageo</td>
<td>CC0402KRX7R9BB222</td>
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<td>C6 C7</td>
<td>18pF</td>
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<td>TDK</td>
<td>LMK105BJ224KV-F</td>
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<td>C9 C10</td>
<td>0.22uF</td>
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<td>D1</td>
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<td>Diodes</td>
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<td>LED Green</td>
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<td>Osram</td>
<td>LG L29K-G2J1-24-Z</td>
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<td>11</td>
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<td>D3</td>
<td>RED LED</td>
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<td>Lumex</td>
<td>SML-LX0603SRW-TR</td>
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<td>12</td>
<td>1</td>
<td>FB1</td>
<td>1k/300mA</td>
<td>FER 1K @ 100MHz, 0603 300mA 0.6 Ohm</td>
<td>TDK</td>
<td>MMZ1608B102C</td>
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<td>13</td>
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<td>MICRO USB-B</td>
<td>CON, USB, Micro, Type B</td>
<td>FCI</td>
<td>10118193-0001LF</td>
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<td>14</td>
<td>2</td>
<td>J2 J3</td>
<td>Header 2X8 F</td>
<td>2MM Header Female SMD BOTTOM ENTRY w. Peg, H=2.8MM</td>
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<td>NPPN082GFNS-RC</td>
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<td>15</td>
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<td>J4</td>
<td>HEADER 7X2</td>
<td>Heater 7X2,.1X.1, SMD, pin=6.1MM, base-to-pcb=3.56mm</td>
<td>Molex</td>
<td>15912140</td>
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<td>JP2</td>
<td>SOLDER-JUMPER3</td>
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<td>17</td>
<td>2</td>
<td>R1 R2</td>
<td>33</td>
<td>RES,0402,33 OHMS, +/- 5%, 1/16 W</td>
<td>RHOM</td>
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<td>1.5k</td>
<td>RES,0402,1.5K OHMS, +/- 5%, 1/16W</td>
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<td>19</td>
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<td>R4</td>
<td>1M</td>
<td>RES,0402,1M OHMS, +/- 5%, 1/16 W</td>
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<td>ERJ-2GEJ105X</td>
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<td>20</td>
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<td>R5</td>
<td>47k</td>
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<td>ERJ-2GEJ473X</td>
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<tr>
<td>21</td>
<td>2</td>
<td>R6 R7</td>
<td>1k</td>
<td>RES,0402,1K OHMS, +/- 5%, 1/16 W</td>
<td>Panasonic ECG</td>
<td>ERJ-2GEJ102X</td>
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<tr>
<td>22</td>
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<td>R8 R19</td>
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<td>RES,0402,51 OHMS, +/- 5%, 1/16W</td>
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<td>ERJ-2GEJ510X</td>
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<tr>
<td>23</td>
<td>2</td>
<td>R9 R10</td>
<td>2.7k</td>
<td>RES,0402,2.7K OHMS, +/- 5%, 1/16W</td>
<td>Stackpole Electronics Inc</td>
<td>RMCF0402JT2K70</td>
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<td>24</td>
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<td>STUFF</td>
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<td>RES,0402,100 OHMS, +/- 5%, 1/16W</td>
<td>Panasonic - ECG</td>
<td>ERJ-2GEJ101X</td>
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Table 5. MCU Board BOM (continued)

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<tr>
<th>ITEM</th>
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<td>U2</td>
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<td>4CH ESD-PROT ARRAY</td>
<td>TI</td>
<td>TPD4E004DRVR</td>
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<td>U3</td>
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<td>U4</td>
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<td>TI</td>
<td>LDC1314</td>
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<td>30</td>
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<td>U5</td>
<td>40MHz</td>
<td>CMOS,40 MHz,SMD 4pin,1.6-3.3V, 50ppm, 5mA</td>
<td>AVX</td>
<td>KC2520B40.0000C10E00</td>
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<td>31</td>
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<td>Y1</td>
<td>24MHz</td>
<td>CRISTAL 24.000 MHZ 10PF SMD</td>
<td>CTS</td>
<td>403C11A24M00000</td>
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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

<table>
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<tr>
<th>ITEM</th>
<th>QTY</th>
<th>DIGIKEY PN</th>
<th>PART REFERENCE</th>
<th>VALUE</th>
<th>DESCRIPTION</th>
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<tr>
<td>1</td>
<td>16</td>
<td>490-3229-1-ND</td>
<td>C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16</td>
<td>150pF</td>
<td>CAP,0402,NPO,150pF,+//- 5%, 50V -55~125C</td>
<td>muRata</td>
<td>GRM1555C1H151JA01D</td>
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<tr>
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<td>2</td>
<td>587-1451-1-ND</td>
<td>C17 C18</td>
<td>0.1uF</td>
<td>CAP,0402,X7R,0.1uF,+//-10%, 16V, -55~125C</td>
<td>Taiyo Yuden</td>
<td>EMK105B7104KV-F</td>
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<td>3</td>
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<td>S6008-08-ND</td>
<td>J1 J2</td>
<td>HEADER 8X2</td>
<td>8X2 2MM SMD HEADER H=2.2MM Peg=1.2MM</td>
<td>Sullins</td>
<td>NRP082MAMP-RC</td>
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<td>4</td>
<td>952-2179-ND</td>
<td>M1 M2 M3 M4</td>
<td>SPACER</td>
<td>HEX STANDOFF M3 Brass/Nickel 5MM F-F</td>
<td>Harwin Inc</td>
<td>R30-1000502</td>
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<tr>
<td>6</td>
<td>4</td>
<td>M5 M6 M7 M8</td>
<td>M3X4 Stainless Steel Flat, 100 piece</td>
<td>M3x4mm Stainless Steel Flat Head Machine Screw, 100-piece</td>
<td><a href="http://www.laptopscrews.com/M3x4.htm">www.laptopscrews.com/M3x4.htm</a></td>
<td>Item #10109</td>
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</tr>
<tr>
<td>7</td>
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<td>FSUSB74UMXCT-ND</td>
<td>U1 U2</td>
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<td>Analog SW 2X4:1 -40~85C 2.7-4.4V 6.5 Ohm 7.5p2p</td>
<td>Fairchild Semi</td>
<td>FSUSB74UMX</td>
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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.

10.6 Software Files

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


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 $R_p$.

- $R_p$ 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 18. Using a Network Analyzer to Find $R_p$

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.

![Diagram of signal generator and oscilloscope](image)

Adjust frequency to make $V_{pp1}$ minimum

$$R_p = 200 \times \left( \frac{V_{pp2}}{V_{pp1}} - 1 \right)$$

*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.

<table>
<thead>
<tr>
<th>Changes from Original (July 2015) to A Revision</th>
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<tr>
<td>• Changed Equation 2 content from “LPC” to “L_p x C”</td>
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