



## LDC1000-Q1 Inductance to Digital Converter

### 1 Features

- Qualified for Automotive Applications
- AEC-Q100 Qualified With the Following Results:
  - Device Temperature Grade 0: –40°C to 150°C Ambient Operating Temperature Range E
  - Device Temperature Grade 1: –40°C to 125°C Ambient Operating Temperature Range Q
  - Device HBM ESD Classification Level 2
  - Device CDM ESD Classification Level C6
- Magnet-Free Operation
- Sub-Micron Precision
- Adjustable Sensing Range (through Coil Design)
- Lower System Cost
- Remote Sensor Placement (Decoupling the LDC from Harsh Environments)
- High Durability (by Virtue of Contact-Less Operation)
- Insensitivity to Environmental Interference (such as Dirt, Dust, Water, Oil)
- Supply Voltage, Analog: 4.75 to 5.25 V
- Supply Voltage, IO: 1.8 to 5.25 V
- Supply Current (Without LC Tank): 1.7 mA
- $R_p$  Resolution: 16-bit
- L Resolution: 24-bit
- LC Frequency Range: 5 kHz to 5 MHz

### 2 Applications

- Drive-by-Wire Systems
- Gear-Tooth Counting
- Flow Meters
- Push-Button Switches
- Rotational Position Sensor
- Linear Position Sensor
- Pedal Position Sensor
- Throttle Position Sensor

### 3 Description

Inductive sensing is a contactless, short-range sensing technology that enables low-cost, high-resolution sensing of conductive targets in the presence of dust, dirt, oil, and moisture, making this technology extremely reliable in harsh environments. Using a coil that can be created for example on a PCB as a sensing element, the LDC1000-Q1 device enables ultra-low cost system solutions.

Inductive sensing technology enables precise measurement of linear or angular position, displacement, motion, compression, vibration, metal composition, and many other applications in markets including automotive, consumer, computer, industrial, medical, and communications. Inductive sensing offers better performance and reliability at lower cost than other competitive solutions.

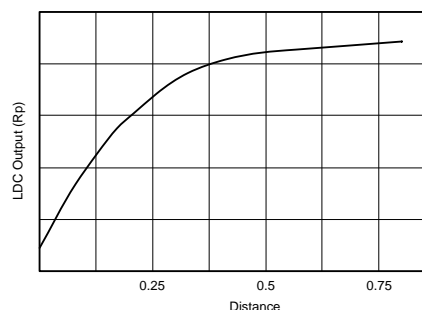
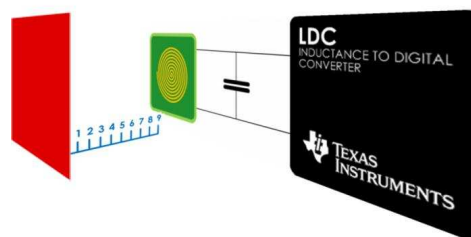
The LDC1000-Q1 device is the first automotive-qualified LDC, offering the benefits of inductive sensing in a low-power, small-footprint solution. The product is available in a 16-pin TSSOP package and offers several modes of operation. An SPI interface simplifies connection to an MCU.

#### Device Information<sup>(1)</sup>

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LDC1000-Q1	TSSOP (16)	5.00 mm x 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

#### Typical Application — Axial Distance Sensing



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## 4 Revision History

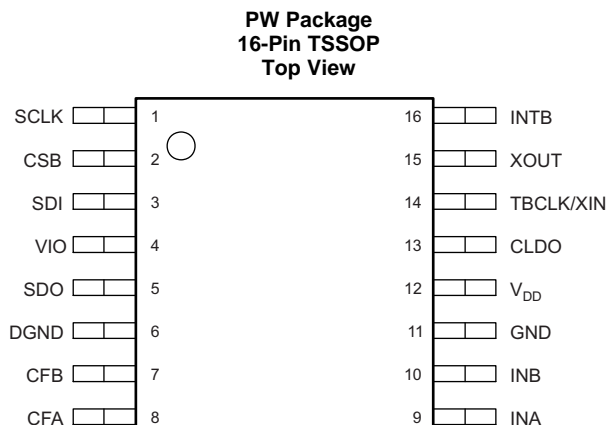
### Changes from Revision A (September 2014) to Revision B Page

- Changed pin configuration image and removed DAP from *Pin Functions* table ..... **3**

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

- Changed the device status from *Product Preview* to *Production Data* ..... **1**

## 5 Pin Configuration and Functions



### Pin Functions

PIN		TYPE <sup>(1)</sup>	DESCRIPTION
NO.	NAME		
1	SCLK	DI	SPI clock input. The SCLK pin is used to clock-out and clock-in the data from or into the chip
2	CSB	DI	SPI CSB. Multiple devices can be connected on the same SPI bus and the CSB pin can be used to select which device is communicated with.
3	SDI	DI	SPI Slave Data In (Master Out Slave In). This pin should be connected to the Master Out Slave In of the master device.
4	VIO	P	Digital IO Supply
5	SDO	DO	SPI Slave Data Out (Master In Slave Out). This pin is high-Z when the CSB pin is high.
6	DGND	P	Digital ground
7	CFB	A	LDC filter capacitor
8	CFA	A	LDC filter capacitor
9	INA	A	External LC Tank. Connect this pin to an external LC tank.
10	INB	A	External LC Tank. Connect this pin to an external LC tank.
11	GND	P	Analog ground
12	V <sub>DD</sub>	P	Analog supply
13	CLDO	A	LDO bypass capacitor. Connect a 56-nF capacitor from this pin to GND.
14	TBCLK/XIN	DI/A	External time-base clock and XTAL. This pin is either an external clock or is connected to a crystal.
15	XOUT	A	XTAL. Crystal out. Connecting an 8-Mhz crystal between the TBCLK/XIN pin and the XOUT pin with 20-pF capacitor from each pin to ground is recommended. This pin should be floating when an external clock is used.
16	INTB	DO	Configurable interrupt. This pin can be configured to function in three different ways (threshold detect, wakeup, or DRDYB) by programming the INT pin mode register.

(1) DO: Digital Output, DI: Digital Input, P: Power, A: Analog

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

		MIN	MAX	UNIT
Analog supply voltage	V <sub>DD</sub> – GND		5.5	V
IO supply voltage	V <sub>IO</sub> – GND		5.5	V
Voltage	On any pin	–0.3	V <sub>DD</sub> + 0.3	V
	On any digital pin	–0.3	V <sub>IO</sub> + 0.3	V
Input Current	INA and INB		8	mA
Junction Temperature, T <sub>J</sub>			150	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

### 6.2 Handling Ratings

			MIN	MAX	UNIT
T <sub>stg</sub>	Storage temperature range		–65	150	°C
V <sub>(ESD)</sub>	Electrostatic discharge	Human body model (HBM), per AEC Q100-002 <sup>(1)</sup>	–2000	2000	V
		Charged device model (CDM), per AEC Q100-011, all pins	–1000	1000	

- (1) AEC Q100-002 indicates HBM stressing is done in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

### 6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

			MIN	MAX	UNIT
V <sub>DD</sub>	Analog supply voltage (V <sub>DD</sub> – GND)		4.75	5.25	V
V <sub>IO</sub>	IO supply voltage (V <sub>IO</sub> – GND)		1.8	5.25	V
V <sub>DD</sub> – V <sub>IO</sub>			≥0		V
T <sub>A</sub>	Operating temperature (see the <a href="#">Mechanical, Packaging, and Orderable Information</a> section for package options)	Grade 0 (temperature range E)	–40	150	°C
		Grade 1 (temperature range Q)	–40	125	

### 6.4 Thermal Information

	THERMAL METRIC <sup>(1)</sup>	PW 16 PINS	UNIT
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	106.3	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	40.8	
R <sub>θJB</sub>	Junction-to-board thermal resistance	51.3	
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	3.6	
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	50.8	
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	—	

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

## 6.5 Electrical Characteristics

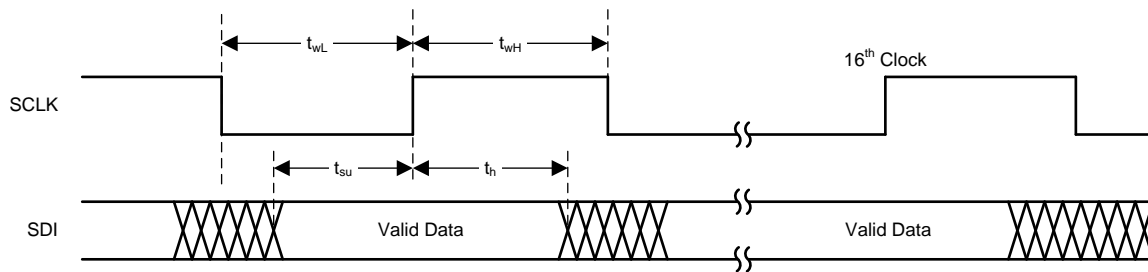
Unless otherwise specified, all limits ensured for  $T_A = 25^\circ\text{C}$ ,  $V_{DD} = 5\text{ V}$ ,  $V_{IO} = 3.3\text{ V}$

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>POWER</b>						
$V_{DD}$	Analog supply voltage		4.75	5	5.25	V
$V_{IO}$	IO supply voltage	$V_{IO} \leq V_{DD}$	1.8	3.3	5.25	V
$I_{DD}$	Supply current	Does not include the LC tank current		1.7	2.3	mA
$I_{IO}$	IO supply current	Static current			14	$\mu\text{A}$
$I_{DD(LP)}$	Low-power mode supply current	Without LC tank		250		$\mu\text{A}$
$t_{\text{(start)}}$	Start-up time	From POR to ready-to-convert. Crystal not used for frequency counter		2		ms
<b>LDC</b>						
$f_{\text{sensor\_min}}$	Minimum sensor frequency			5		kHz
$f_{\text{sensor\_max}}$	Maximum sensor frequency			5		MHz
$A_{\text{sensor\_min}}$	Minimum sensor amplitude			1		$V_{PP}$
$A_{\text{sensor\_max}}$	Maximum sensor amplitude			4		$V_{PP}$
$t_{\text{rec}}$	Recovery time	Oscillation start-up time after RP under-range condition		10		$1 / f_{\text{sensor}}$
$Z_{RP\_min}$	Minimum sensor RP range			798		$\Omega$
$R_{RP\_max}$	Maximum sensor RP range			3.93		M $\Omega$
$R_{RP\_res}$	RP measurement resolution			16		Bits
$t_{\text{res(min)}}$	Minimum response time	Minimum programmable settling time of digital filter		$192 \times 1 / f_{\text{sensor}}$		s
$t_{\text{res(max)}}$	Maximum response time	Maximum programmable settling time of digital filter		$6144 \times 1 / f_{\text{sensor}}$		s
<b>EXTERNAL CLOCK AND CRYSTAL FOR FREQUENCY COUNTER</b>						
$f_{\text{ref}}$	Crystal frequency			8		MHz
$t_{\text{xtalst}}$	Crystal startup time			30		ms
	External clock frequency				8	MHz
	External clock input high voltage				$V_{IO}$	V
<b>DIGITAL I/O CHARACTERISTICS</b>						
$V_{IH}$	Logic 1 input voltage		$0.8 \times V_{IO}$			V
$V_{IL}$	Logic 0 input voltage			$0.2 \times V_{IO}$		V
$V_{OH}$	Logic 1 output voltage	$I_{\text{(SOURCE)}} = 400\text{ }\mu\text{A}$		$V_{IO} - 0.3$		V
$V_{OL}$	Logic 0 output voltage	$I_{\text{(SINK)}} = 400\text{ }\mu\text{A}$			0.3	V
$I_{\text{IKglO}}$	Digital IO leakage current		–500		500	nA

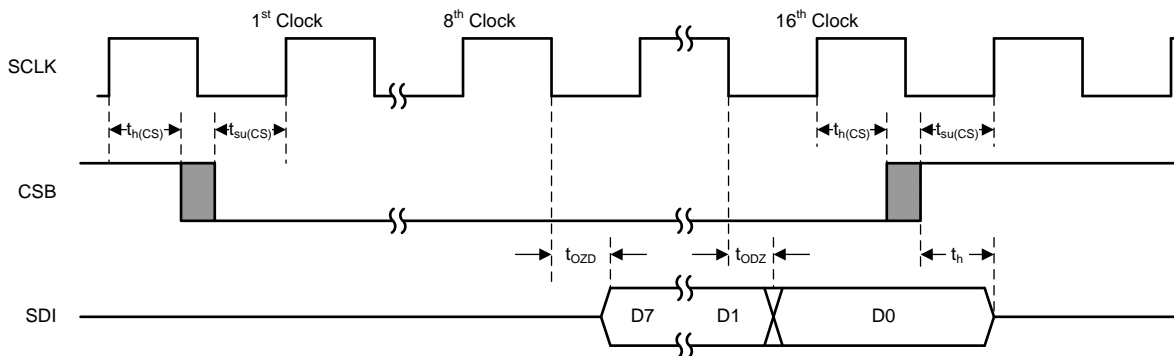
## 6.6 Timing Requirements

Unless otherwise noted, all limits specified at  $T_A = 25^\circ\text{C}$ ,  $V_{DD} = 5\text{ V}$ ,  $V_{IO} = 3.3\text{ V}$ , 10-pF capacitive load in parallel with a 10-k $\Omega$  load on the SDO. Specified by design; not production tested. See [Figure 1](#)

			MIN	NOM	MAX	UNIT
$f_{\text{SCLK}}$	Serial clock frequency	See <a href="#">Figure 1</a>			4	MHz
$t_{\text{WH}}$	SCLK pulse-width high	$f_{\text{SCLK}} = 4\text{ Mhz}$ , See <a href="#">Figure 1</a>	$0.4 / f_{\text{SCLK}}$			s
$t_{\text{WL}}$	SCLK pulse-width low	$f_{\text{SCLK}} = 4\text{ Mhz}$ , See <a href="#">Figure 1</a>	$0.4 / f_{\text{SCLK}}$			s
$t_{\text{SU}}$	SDI setup time	See <a href="#">Figure 1</a>	10			ns
$t_{\text{H}}$	SDI hold time		10			ns
$t_{\text{ODZ}}$	SDO driven-to-tristate time	Measured at 10% / 90% point, See <a href="#">Figure 2</a>			20	ns
$t_{\text{OZD}}$	SDO tristate-to-driven time	Measured at 10% / 90% point, See <a href="#">Figure 2</a>			20	ns
$t_{\text{d(OUTPUT)}}$	SDO output delay time	See <a href="#">Figure 2</a>			20	ns
$t_{\text{SU(CS)}}$	CSB setup time		20			ns
$t_{\text{H(CS)}}$	CSB hold time		20			ns
$t_{\text{IAG}}$	inter-access gap		100			ns
$t_{\text{W(DRDY)}}$	Data ready pulse width	Data ready pulse at every 1 / ODR if no data is read		$1 / f_{\text{sensor}}$		s

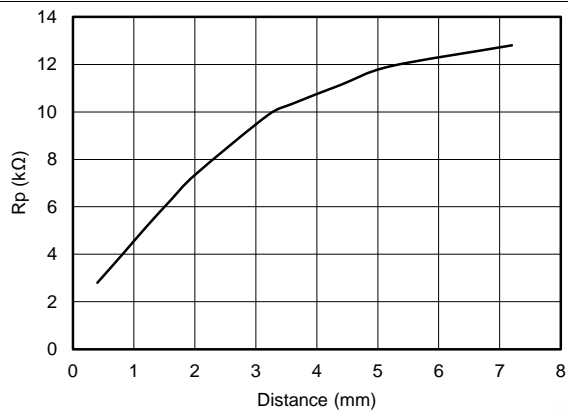


**Figure 1. Write Timing Diagram**



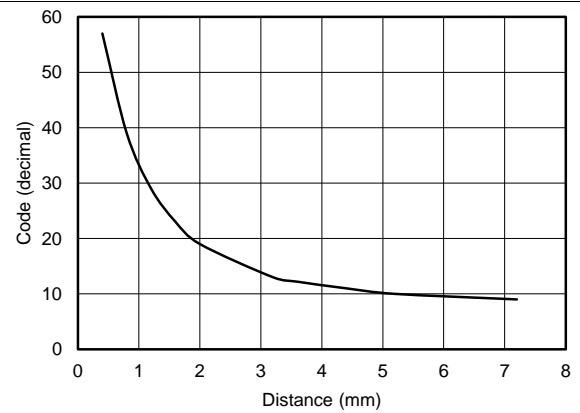
**Figure 2. Read Timing Diagram**

## 6.7 Typical Characteristics



Sensor Details: [Table 21](#) Rp\_MIN: 1.347 kΩ  
Target Material: Stainless Steel Rp\_MAX: 38.785 kΩ

**Figure 3. Rp vs Distance**



Sensor Details: [Table 21](#) Rp\_MIN: 1.347 kΩ  
Target Material: Stainless Steel Rp\_MAX: 38.785 kΩ

**Figure 4. Proximity Data vs Distance**

## 7 Detailed Description

### 7.1 Overview

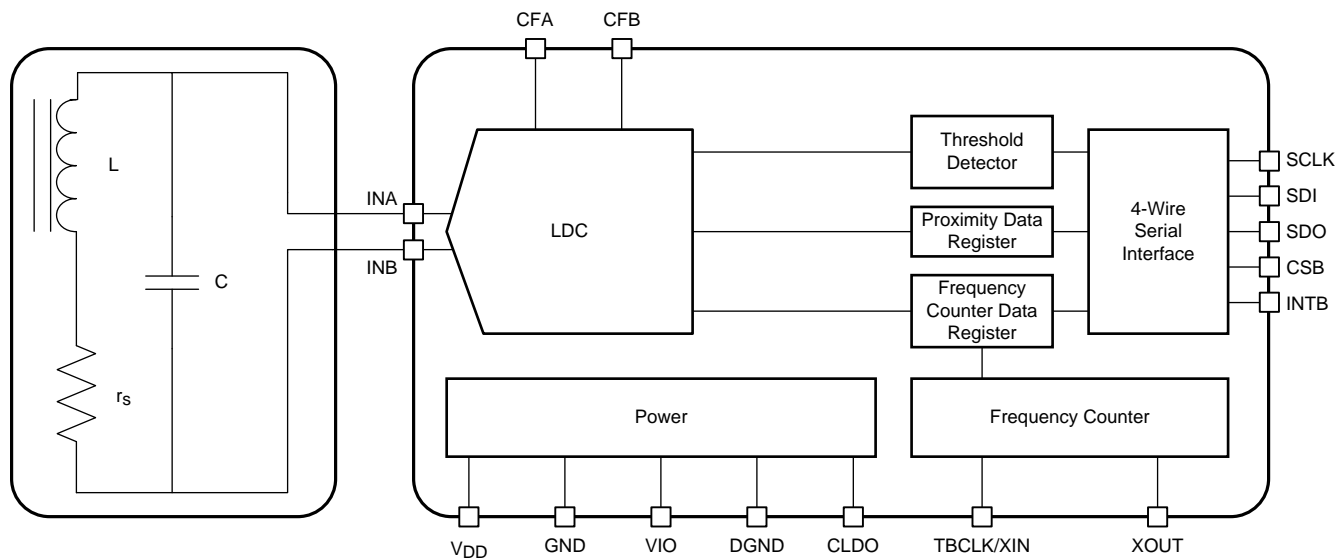
The LDC1000-Q1 device is an inductance-to-digital converter that simultaneously measures the impedance and resonant frequency of an LC resonator. The device accomplishes this task by regulating the oscillation amplitude in a closed-loop configuration to a constant level, while monitoring the energy dissipated by the resonator. By monitoring the amount of power injected into the resonator, the LDC1000-Q1 device can determine the value of  $R_p$ . When the value is determined, the device returns this as a digital value which is inversely proportional to  $R_p$ . In addition, the LDC1000-Q1 device 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 threshold detector block provides a comparator with hysteresis. With the threshold registers programmed and comparator enabled, the proximity data register is compared with threshold registers and INTB pin indicates the output.

The device has a simple 4-wire SPI interface. The INTB pin provides multiple functions which are programmable with SPI.

The device has separate analog and I/O supplies. The analog supply operates at 5 V and the I/O operates at 1.8 to 5 V. The integrated LDO requires a 56-nF capacitor connected from the CLDO pin to GND.

### 7.2 Functional Block Diagram



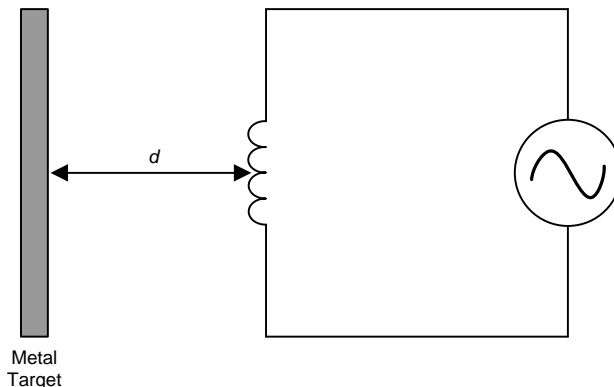
### 7.3 Feature Description

#### 7.3.1 Inductive Sensing

An alternating current (AC) flowing through a coil generates an AC magnetic field. If a conductive material, such as a metal target, is brought into the vicinity of the coil, this magnetic field induces circulating currents (eddy currents) on the surface of the target. These eddy currents are a function of the distance, size, and composition of the target. These eddy currents then generate a magnetic field that opposes the original field generated by the coil. This mechanism is best compared to a transformer, where the coil is the primary core and the eddy current is the secondary core. The inductive coupling between both cores depends on distance and shape. Hence the resistance and inductance of the secondary core (eddy current), shows up as a distant dependent resistive and inductive component on the primary side (coil). [Figure 5](#) through [Figure 8](#) show a simplified circuit model.

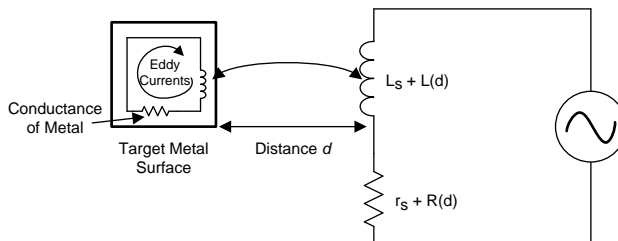


## Feature Description (continued)



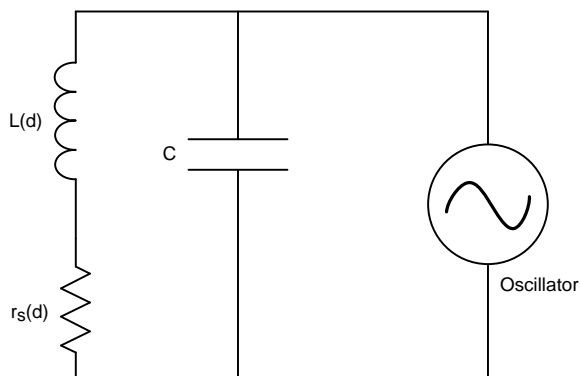
**Figure 5. Inductor with a Metal Target**

Eddy currents generated on the surface of the target can be modeled as a transformer as shown in [Figure 6](#). The coupling between the primary and secondary coils is a function of the distance and characteristics of the conductor. In [Figure 6](#), the inductance  $L_s$  is the inductance of the coil, and  $r_s$  is the parasitic series resistance of the coil. The inductance  $L(d)$ , which is a function of distance,  $d$ , is the coupled inductance of the metal target. Likewise,  $R(d)$  is the parasitic resistance of the eddy currents.



**Figure 6. Metal Target Modeled as L and R With Circulating Eddy Currents**

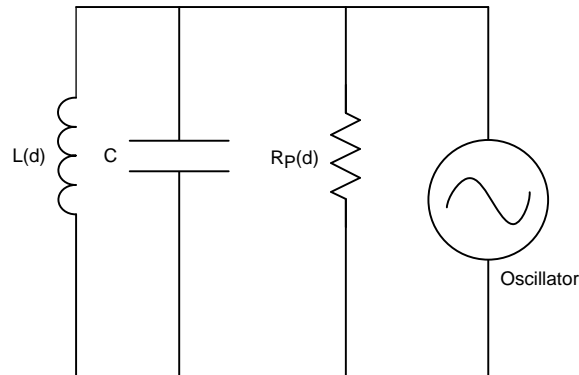
Generating an alternating magnetic field with just an inductor consumes a large amount of power. This power consumption can be reduced by adding a parallel capacitor, turning the right part of [Figure 6](#) into a resonator as shown in [Figure 7](#). In this manner the power consumption is reduced to the eddy and inductor losses  $r_s + R(d)$  only.



**Figure 7. LC Tank Connected to Oscillator**

The LDC1000-Q1 device does not directly measure the series resistance. Instead, the device measures the equivalent parallel resonance impedance  $R_p$  (see [Figure 8](#)). This representation is equivalent to the representation shown in [Figure 8](#), where the parallel resonance impedance  $R_p(d)$  is given by [Equation 1](#).

## Feature Description (continued)

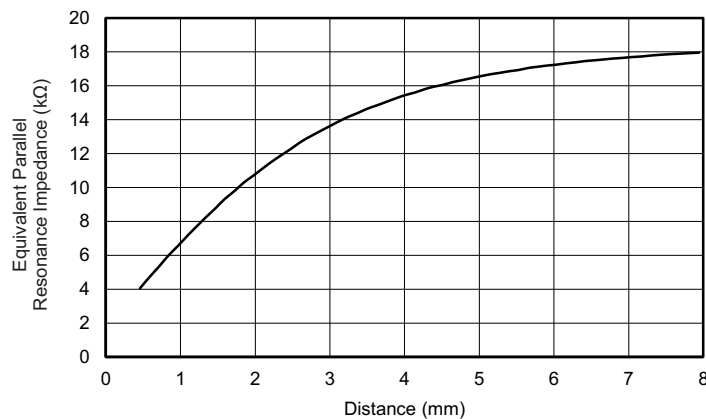


**Figure 8. Equivalent Resistance of  $r_s$  in Parallel With LC Tank**

$$R_p(d) = (1 / ([r_s + R(d)]) \times ([L_s + L(d)]) / C \quad (1)$$

$$R_p = (1 / r_s) \times (L / C) \quad (2)$$

Figure 9 shows the variation in  $R_p$  as a function of distance for a 14-mm diameter PCB coil (23 turns, 4-mil trace width, 4-mil spacing between trace, 1-oz copper thickness, FR4). The target metal used is a stainless steel 2-mm thick.



**Figure 9. Typical  $R_p$  versus Distance With a 14-mm PCB Coil**

### 7.3.2 Measuring Parallel Resonance Impedance and Inductance with LDC1000-Q1

The LDC1000-Q1 device is an inductance-to-digital converter that simultaneously measures the impedance and resonant frequency of an LC resonator. The device 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 LDC1000-Q1 device can determine the value of  $R_p$ . The device returns this value as a digital value which is inversely proportional to  $R_p$ . In addition, the LDC1000-Q1 device can also measure the oscillation frequency of the LC circuit. This frequency is used to determine the inductance of the LC circuit. The oscillation frequency is returned as a digital value.

The LDC1000-Q1 device supports a wide range of LC combinations with oscillation frequencies ranging from 5 kHz to 5 MHz and  $R_p$  ranging from 798  $\Omega$  to 3.93 M $\Omega$ . This range of  $R_p$  can be viewed as the maximum input range of an ADC. As shown in Figure 9, the range of  $R_p$  is typically much smaller than maximum input range supported by the LDC1000-Q1 device. To achieve better resolution in the desired sensing range, the LDC1000-Q1 device offers a programmable input range through the  $R_{p\_MIN}$  and  $R_{p\_MAX}$  registers. See the [Calculation of  \$R\_{p\\_Min}\$  and  \$R\_{p\\_Max}\$](#)  section for how to set these registers.

When the resonance impedance of the sensor,  $R_p$ , drops below the programed  $R_{p\_MIN}$ , the  $R_p$  output of the LDC will clip at the full scale output. An example occurrence of this situation is when a target comes too close to the coil.

## Feature Description (continued)



**Figure 10. Transfer Characteristics of LDC1000-Q1 With  $R_{P\_MIN} = 16.160\text{ k}\Omega$  and  $R_{P\_MAX} = 48.481\text{ k}\Omega$**

Use Equation 3 to calculate the resonance impedance from the digital output code.

$$R_P = (R_{P\_MAX} \times R_{P\_MIN}) / (R_{P\_MIN} \times (1 - Y) + R_{P\_MAX} \times Y), \text{ in } \Omega.$$

Where:

- $Y = \text{Proximity Data} / 2^{15}$
- Proximity data is the LDC output, register address 0x21 and 0x22. (3)

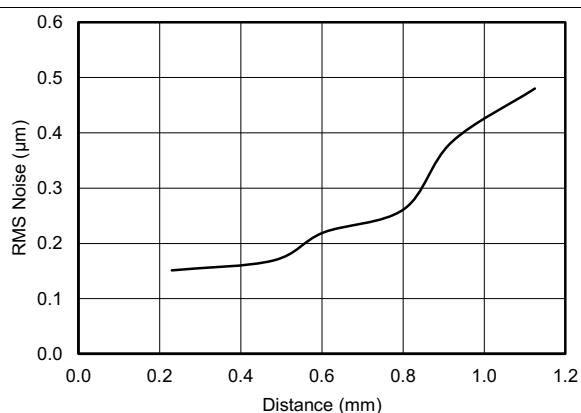
**Example:** If Proximity data (address 0x22 to 0x21) is 5000,  $R_{P\_MIN}$  is 2.394 kΩ, and  $R_{P\_MAX}$  is 38.785 kΩ, the resonance impedance is given by:

$$Y = 5000 / 2^{15} = 0.1526 \quad (4)$$

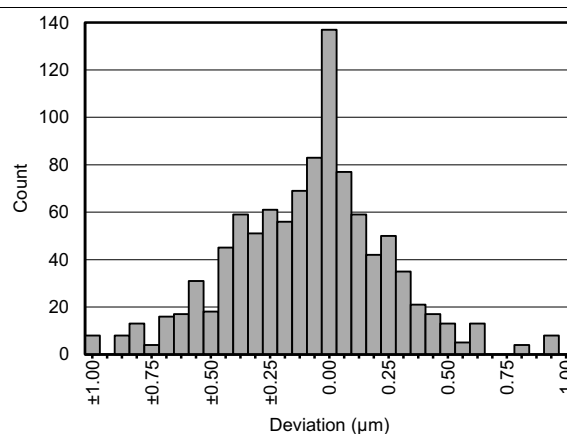
$$R_P = (38785 \times 2394) / (2394 \times (1 - 0.1526) + 38785 \times 0.1526) = (92851290) / (2028.675 + 5918.591) \quad (5)$$

$$R_P = 11.683\text{ k}\Omega \quad (6)$$

Figure 11 and Figure 12 show the change in RMS noise versus distance and a histogram of noise, with the target at an 0.8-mm distance from the sensor coil. Data was collected with a 14-mm PCB coil (23 turns, 4-mil trace width, 4-mil spacing between trace, 1-oz copper thickness, FR4) with a sensing range of 0.125 mm to 1.125 mm. At a distance of 0.8 mm, the RMS noise is approximately 250 nm.



**Figure 11. Typical RMS Noise versus Distance With PCB Coil**



**Figure 12. Histogram of Output Codes at 0.8-mm Distance**

### NOTE

Although the LDC1000-Q1 device has high resolution, the absolute accuracy depends on offset and gain correction which can be achieved by two-point calibration.

## Feature Description (continued)

### 7.3.2.1 Measuring Inductance

The LDC1000-Q1 device measures the frequency of the oscillation of the sensor by a frequency counter. The frequency counter timing is set by an external clock or crystal. Either the external clock (8 MHz typical) from a microcontroller can be provided on the TBCLK/XIN pin or a crystal can be connected on the TBCLK/XIN and XOUT pins. The clock mode is controlled through clock configuration register (address 0x05). The sensor resonance frequency is derived from the frequency-counter register value (see the [Frequency Counter LSB \(offset = 0x23\) \[reset = NA\]](#) section through the [Frequency Counter MSB \(offset = 0x25\) \[reset = NA\]](#) section) as shown in [Equation 7](#).

$$f_{\text{sensor}} = (1/3) \times (f_{\text{ext}} / f_{\text{count}}) \times t_{\text{res}}$$

where

- $f_{\text{sensor}}$  is the sensor frequency
- $f_{\text{ext}}$  is the frequency of the external clock or crystal
- $f_{\text{count}}$  is the value obtained from the Frequency Counter Data register (see the [Frequency Counter LSB \(offset = 0x23\) \[reset = NA\]](#) section through the [Frequency Counter MSB \(offset = 0x25\) \[reset = NA\]](#) section)
- $t_{\text{res}}$  is the programmed response time (see the [LDC Configuration \(offset = 0x04\) \[reset = 0x1B\]](#) section) (7)

The inductance in H can be calculated with [Equation 8](#).

$$L = 1 / [C \times (2 \times \pi \times f_{\text{sensor}})^2]$$

where

- C is the parallel capacitance of the resonator (8)

#### 7.3.2.1.1 Example

If the following values are selected,  $f_{\text{ext}} = 6 \text{ MHz}$ ,  $t_{\text{res}} = 6144$ ,  $C = 10 \text{ pF}$ , and measured  $f_{\text{count}} = 3000$  (decimal) (see the [Frequency Counter LSB \(offset = 0x23\) \[reset = NA\]](#) section through the [Frequency Counter MSB \(offset = 0x25\) \[reset = NA\]](#) section) then:

$$f_{\text{sensor}} = 1/3 \times (6000000 / 3000) \times (6144) = 4.096 \text{ MHz} \quad (9)$$

Now use [Equation 10](#).

$$L = 1 / [C \times (2 \times \pi \times f_{\text{sensor}})^2]$$

where

- $L = 15.098 \text{ } \mu\text{H}$  (10)

The accuracy of measurement largely depends upon the choice of the external time-base clock (TBCLK) or the crystal oscillator (XIN and XOUT).

## 7.4 Device Functional Modes

### 7.4.1 INTB Pin Modes

The INTB pin is a configurable output pin which can be used to drive an interrupt on an MCU. The LDC1000-Q1 device provides three different modes on the INTB pin which include:

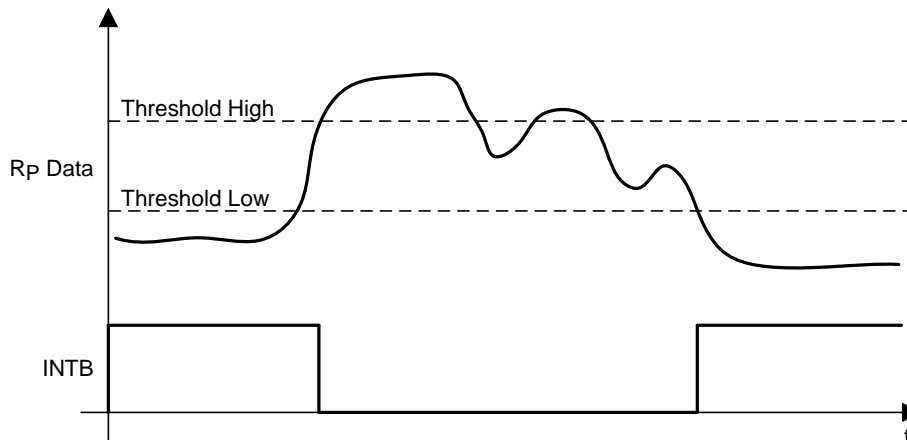
1. Comparator mode
2. Wake-up mode
3. DRDY mode

The LDC1000-Q1 device has a built-in high trigger and low trigger threshold registers that can be a comparator with programmable hysteresis or a special mode that is used to wake-up an MCU. The following sections describe these modes in detail.

#### 7.4.1.1 Comparator Mode

In the comparator mode, the INTB pin is asserted or de-asserted when the proximity register value increases above the threshold high registers or decreases below the threshold low registers respectively. In this mode, the function of the LDC1000-Q1 device is a proximity switch with programmable hysteresis.

## Device Functional Modes (continued)

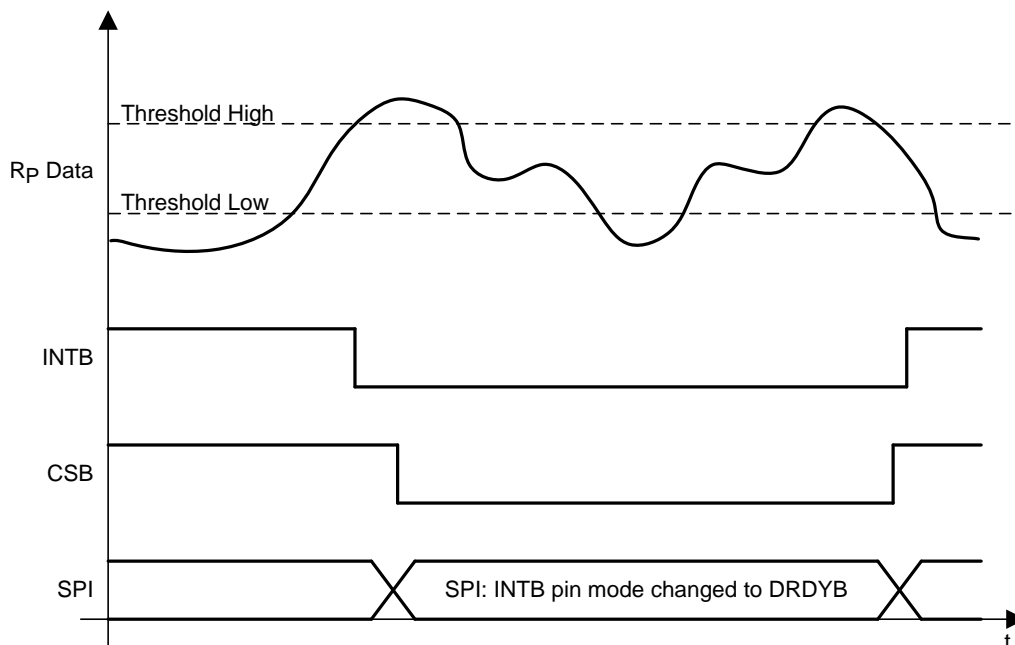


**Figure 13. Behavior of the INTB Pin in Comparator Mode**

### 7.4.1.2 Wake-Up Mode

In wake-up mode, the INTB pin is asserted when proximity register value increases above the threshold high registers and is deasserted when wake-up mode is disabled in the INTB pin mode register.

This mode can wake-up an MCU that is in sleep mode to conserve power.

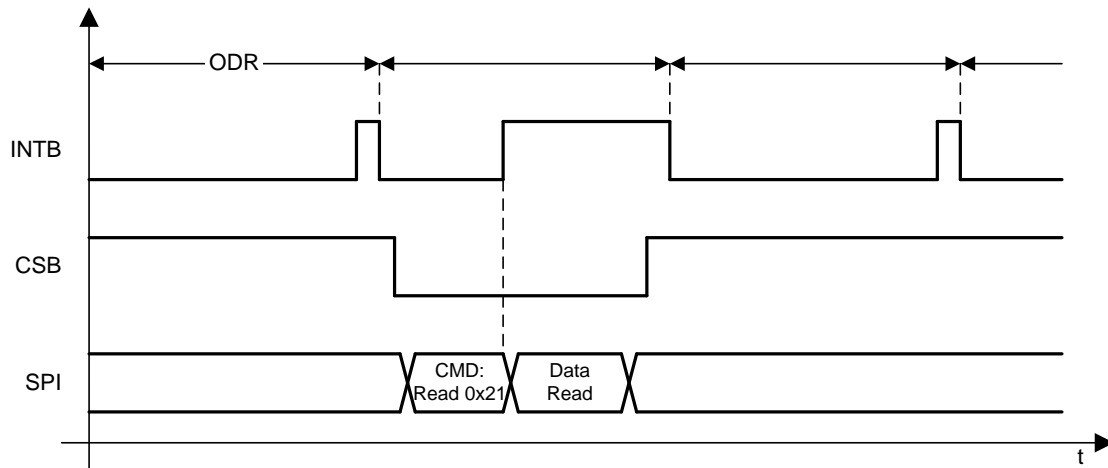


**Figure 14. Behavior of the INTB Pin in Wake-Up Mode**

### 7.4.1.3 DRDYB Mode

In DRDY mode (default), the INTB pin is asserted every time the conversion data is available and is deasserted when the read command on register 0x21 is registered internally. If the read command is in progress, the pin is pulsed instead.

## Device Functional Modes (continued)



**Figure 15. Behavior of the INTB Pin in DRDYB Mode**

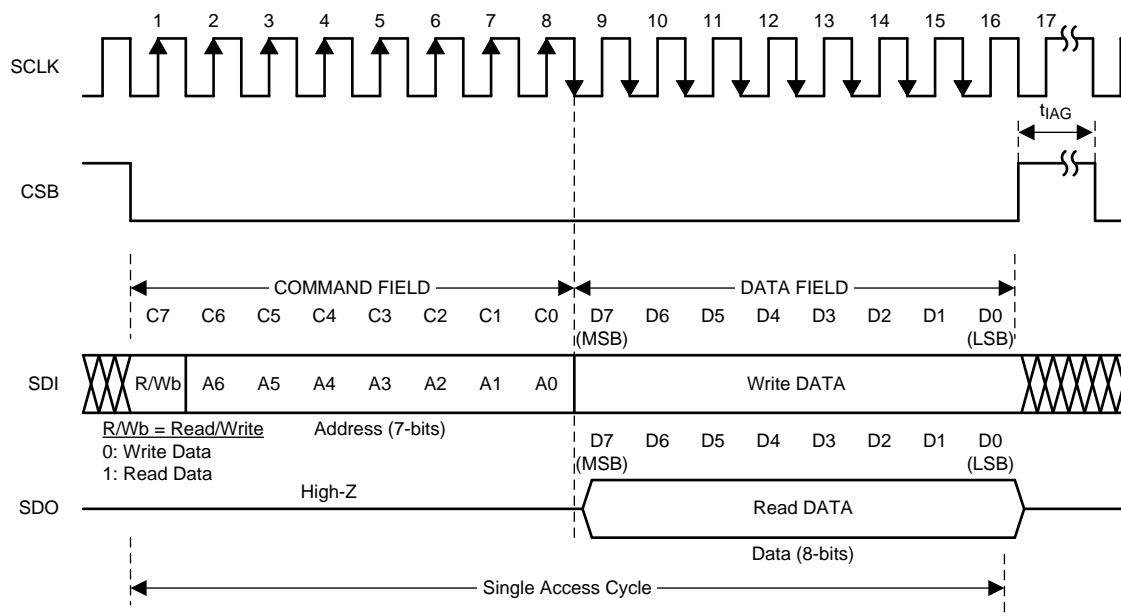
## 7.5 Programming

### 7.5.1 Digital Interface

The LDC1000-Q1 device uses a 4-wire SPI interface to access control and data registers. The LDC1000-Q1 device is an SPI slave device and does not initiate any transactions.

#### 7.5.1.1 SPI Description

A typical serial interface transaction begins with an 8-bit instruction that is comprised of a read-write (R/W) bit (MSB, R = 1) and a 7-bit address of the register followed by a data field that is typically 8 bits. However, the data field can be extended to a multiple of 8 bits by providing sufficient SPI clocks. See the [Extended SPI Transactions](#) section.



**Figure 16. Serial Interface Protocol**

## Programming (continued)

Each assertion of the chip select bar (CSB) begins a new register access. The R/W bit in the command field configures the direction of the access. A value of 0 indicates a write operation and a value of 1 indicates a read operation. All output data is driven on the falling edge of the serial clock SCLK, and all input data is sampled on the rising edge of the serial clock SCLK. Data is written into the register on the rising edge of the 16th clock. Deasserting the CSB pin after the 16th clock is required. No data write occurs if the CSB pin is deasserted before the 16th clock.

### 7.5.1.2 Extended SPI Transactions

A transaction can be extended to multiple registers by keeping the CSB pin asserted beyond the stated 16 clocks. In this mode, the register addresses increment automatically. The CSB pin must be asserted during  $8 \times (1 + N)$  clock cycles of SCLK, where  $N$  is the amount of bytes to write or read during the transaction.

During an extended read access, the SDO pin outputs register contents every 8 clock cycles after the initial 8 clocks of the command field. During an extended write access, the data is written to the registers every 8 clock cycles after the initial 8 clocks of the command field.

Extended transactions can be used to read 16-bits of proximity data and 24-bits of frequency data all in one SPI transaction by initiating a read from register 0x21.

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## 7.6 Register Map

**Table 1. Register Map<sup>(1)(2)</sup>**

REGISTER NAME	ADDRESS	TYPE <sup>(3)</sup>	DEFAULT	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Device ID	0x00	R	0x80	Device ID							
Rp_MAX	0x01	R/W	0x0E	Rp Maximum							
Rp_MIN	0x02	R/W	0x14	Rp Minimum							
Sensor Frequency	0x03	R/W	0x45	Min Resonating Frequency							
LDC Configuration	0x04	R/W	0x1B	Reserved(000)			Amplitude		Response Time		
Clock Configuration	0x05	R/W	0x01	Reserved(000000)						CLK_SEL	CLK_PD
Comparator Threshold High LSB	0x06	R/W	0xFF	Threshold High LSB							
Comparator Threshold High MSB	0x07	R/W	0xFF	Threshold High MSB							
Comparator Threshold Low LSB	0x08	R/W	0x00	Threshold Low LSB							
Comparator Threshold Low MSB	0x09	R/W	0x00	Threshold Low MSB							
INTB Pin Configuration	0x0A	R/W	0x00	Reserved(00000)					INTB_MODE		
Power Configuration	0x0B	R/W	0x00	Reserved(0000000)							PWR_MODE
Status	0x20	R		OSC Dead	DRDYB	Wake-up	Comparator	Don't Care			
Proximity Data LSB	0x21	R		Proximity Data[7-0]							
Proximity Data MSB	0x22	R		Proximity Data[15-8]							
Frequency Counter Data LSB	0x23	R		ODR LSB							
Frequency Counter Data Mid-Byte	0x24	R		ODR Mid Byte							
Frequency Counter Data MSB	0x25	R		ODR MSB							

(1) Values of bits which are unused should be set to default values only.

(2) LEGEND R/W = read/write. R = read only. W = write only

(3) When the device is in active mode (the PWR\_MODE bit is SET), registers 0x01 through 0x05 are read only (R).



## 7.6.1 Register Description

### 7.6.1.1 Revision ID (offset = 0x00) [reset = 0x80]

**Figure 17. Revision ID Register**

7	6	5	4	3	2	1	0
Revision ID							
R							

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 2. Revision ID Field Descriptions**

Bit	Field	Type	Reset	Description
7-0	Revision ID	R	0x080	Revision ID of silicon.

**7.6.1.2 Rp\_MAX (offset = 0x01) [reset = 0x0E]**
**Figure 18. Rp\_MAX Register**

7	6	5	4	3	2	1	0
Rp Maximum							
R/W							

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 3. Rp\_MAX Field Descriptions**

Bit	Field	Type	Reset	Description
7-0	Rp Maximum	R/W	0x0E	<p>Maximum <math>R_p</math> that the LDC1000-Q1 device must measure. Configures the input dynamic range of the LDC1000-Q1 device. Register setting for Rp_MAX (k<math>\Omega</math>):</p> <p>0x00 = 3926.991  0x01 = 3141.593  0x02 = 2243.995  0x03 = 1745.329  0x04 = 1308.997  0x05 = 981.748  0x06 = 747.998  0x07 = 581.776  0x08 = 436.332  0x09 = 349.066  0x0A = 249.333  0x0B = 193.926  0x0C = 145.444  0x0D = 109.083  0x0E = 83.111  0x0F = 64.642  0x10 = 48.481  0x11 = 38.785  0x12 = 27.704  0x13 = 21.547  0x14 = 16.16  0x15 = 12.12  0x16 = 9.235  0x17 = 7.182  0x18 = 5.387  0x19 = 4.309  0x1A = 3.078  0x1B = 2.394  0x1C = 1.796  0x1D = 1.347  0x1E = 1.026  0x1F = 0.798</p>

### 7.6.1.3 Rp\_MIN (offset = 0x02) [reset = 0x14]

**Figure 19. Rp\_MIN Register**

7	6	5	4	3	2	1	0
Rp Minimum							
R/W							

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 4. Rp\_MIN Field Descriptions**

Bit	Field	Type	Reset	Description
7-0	Rp Minimum	R/W	0x014	<p>Minimum <math>R_P</math> that the LDC1000-Q1 device must measure. Configures the input dynamic range of the LDC1000-Q1 device.</p> <p>Register setting for Rp_MIN (k<math>\Omega</math>):</p> <p>0x20 = 3926.991</p> <p>0x21 = 3141.593</p> <p>0x22 = 2243.995</p> <p>0x23 = 1745.329</p> <p>0x24 = 1308.997</p> <p>0x25 = 981.748</p> <p>0x26 = 747.998</p> <p>0x27 = 581.776</p> <p>0x28 = 436.332</p> <p>0x29 = 349.066</p> <p>0x2A = 249.333</p> <p>0x2B = 193.926</p> <p>0x2C = 145.444</p> <p>0x2D = 109.083</p> <p>0x2E = 83.111</p> <p>0x2F = 64.642</p> <p>0x30 = 48.481</p> <p>0x31 = 38.785</p> <p>0x32 = 27.704</p> <p>0x33 = 21.547</p> <p>0x34 = 16.16</p> <p>0x35 = 12.12</p> <p>0x36 = 9.235</p> <p>0x37 = 7.182</p> <p>0x38 = 5.387</p> <p>0x39 = 4.309</p> <p>0x3A = 3.078</p> <p>0x3B = 2.394</p> <p>0x3C = 1.796</p> <p>0x3D = 1.347</p> <p>0x3E = 1.026</p> <p>0x3F = 0.798</p>

### 7.6.1.4 Sensor Frequency (offset = 0x03) [reset = 0x45]

**Figure 20. Sensor Frequency Register**

7	6	5	4	3	2	1	0
Min Resonating Frequency							
R/W							

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 5. Sensor Frequency Field Descriptions**

Bit	Field	Type	Reset	Description
7-0	Min Resonating Frequency	R/W	0x45	<p>Sets the minimum resonating frequency to approximately 20% below the lowest resonating frequency of the sensor with no target in front. Use the formula below to determine the value of register.</p> $N = 68.94 \times \log_{10}(f / 2000)$ <p>where</p> <ul style="list-style-type: none"> <li>N = Register Value. Round to nearest value.</li> <li>f = 20% below resonating frequency, Hz</li> </ul> <p>(11)</p> <p><b>Example:</b> Sensor frequency (<math>f_{\text{sensor}}</math>) = 1 MHz</p> $f = 0.8 \times 1 \text{ MHz} = 800 \text{ KHz}$ <p>(12)</p> $N = 68.94 \times \log_{10}(800 \text{ KHz} / 2000) = \text{Round to nearest whole number } (179.38) = 179 \text{ (Value to be programmed in the sensor frequency register)}$ <p>(13)</p>

### 7.6.1.5 LDC Configuration (offset = 0x04) [reset = 0x1B]

**Figure 21. LDC Configuration Register**

7	6	5	4	3	2	1	0
Reserved			Amplitude		Response Time		
—			R/W		R/W		

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 6. LDC Configuration Field Descriptions**

Bit	Field	Type	Reset	Description
7-5	Reserved	—	—	Reserved to 0
4-3	Amplitude	R/W	0x1B	<p>Sets the oscillation amplitude</p> <p>00: 1 V</p> <p>01: 2 V</p> <p>10: 4 V</p> <p>11: Reserved</p>
2-0	Response Time	R/W	0x1B	<p>Sets the response time</p> <p>000: Reserved</p> <p>001: Reserved</p> <p>010: 192</p> <p>011: 384</p> <p>100: 768</p> <p>101: 1536</p> <p>110: 3072</p> <p>111: 6144</p>

### 7.6.1.6 Clock Configuration (offset = 0x05) [reset = 0x01]

**Figure 22. Clock Configuration Register**

7	6	5	4	3	2	1	0
Reserved						CLK_SEL	CLK_PD
R/W						R/W	R/W

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 7. Clock Configuration Field Descriptions**

Bit	Field	Type	Reset	Description
7-2	Resrved	—	—	Reserved to 0
1	CLK_SEL	R/W	0x01	1:External crystal used for frequency counter (XIN or XOUT). 0:External time-base clock used for frequency counter (TBCLK).
0	CLK_PD	R/W	0x01	1:Disable external time base clock. Crystal oscillator power down. 0:Enable External time base clock.

### 7.6.1.7 Comparator Threshold High LSB (offset = 0x06) [reset = 0xFF]

**Figure 23. Comparator Threshold High LSB Register**

7	6	5	4	3	2	1	0
Threshold High[7:0]	Threshold High[6]	Threshold High[5]	Threshold High[4]	Threshold High[3]	Threshold High[2]	Threshold High[1]	Threshold High[0]
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 8. Comparator Threshold High LSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	Threshold High LSB Threshold High[7:0]	R/W	0xFF	Least Significant byte (LSB) of the threshold high register. This register is a buffer. A read reflects the current value of the threshold high[7:0] register. See the <a href="#">Comparator Threshold High MSB (offset = 0x07) [reset = 0xFF]</a> section for details on updating the threshold high register.

### 7.6.1.8 Comparator Threshold High MSB (offset = 0x07) [reset = 0xFF]

**Figure 24. Comparator Threshold High MSB Register**

7	6	5	4	3	2	1	0
Threshold High[15]	Threshold High[14]	Threshold High[13]	Threshold High[12]	Threshold High[11]	Threshold High[10]	Threshold High[9]	Threshold High[8]
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 9. Comparator Threshold High MSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	Threshold High MSB Threshold High[15:8]	R/W	0xFF	Most significant byte (MSB) of the threshold high register. A write to this register copies the contents of the 0x06 register and writes to the threshold high register[15:0]. A read returns the threshold high [15:8] register. To update the threshold high register write register 0x06 first and then 0x07.

### 7.6.1.9 Comparator Threshold Low LSB (offset = 0x08) [reset = 0x00]

**Figure 25. Comparator Threshold Low LSB Register**

7	6	5	4	3	2	1	0
Threshold Low[7:0]	Threshold Low[6]	Threshold Low[5]	Threshold Low[4]	Threshold Low[3]	Threshold Low[2]	Threshold Low[1]	Threshold Low[0]
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 10. Comparator Threshold Low LSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	Threshold Low LSB Threshold Low[7:0]	R/W	0x00	Least significant byte of the threshold low value. This register is a buffer. A read reflects the current value of the threshold low [7:0] register. See the <a href="#">Comparator Threshold Low MSB (offset = 0x09) [reset = 0x00]</a> section for details on updating the threshold low register.

### 7.6.1.10 Comparator Threshold Low MSB (offset = 0x09) [reset = 0x00]

**Figure 26. Comparator Threshold Low MSB Register**

7	6	5	4	3	2	1	0
Threshold Low[15]	Threshold Low[14]	Threshold Low[13]	Threshold Low[12]	Threshold Low[11]	Threshold Low[10]	Threshold Low[9]	Threshold Low[8]
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 11. Comparator Threshold Low MSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	Threshold Low MSB Threshold Low[15:8]	R/W	0x00	Most significant byte of the threshold low register. A write to this register copies the contents of the 0x08 register and writes to the threshold low register[15:0]. A read returns the threshold low [15:8] register. To update the threshold low register write register address 0x08 first and then 0x09.

### 7.6.1.11 INTB Pin Configuration (offset = 0x0A) [reset = 0x00]

**Figure 27. INTB Pin Configuration Register**

7	6	5	4	3	2	1	0
Reserved					Mode		
—					R/W		

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 12. INTB Pin Configuration Field Descriptions**

Bit	Field	Type	Reset	Description
7:3	Reserved	—	—	Reserved to 0
2:0	Mode	R/W	0x00	100: DRDYB enabled on the INTB pin 010: The INTB pin indicates the status of the comparator output 001: Wake-up enabled on the INTB pin <b>000: All modes disabled</b> All other combinations are reserved

### 7.6.1.12 Power Configuration (offset = 0x0B) [reset = 0x00]

**Figure 28. Power Configuration Register**

7	6	5	4	3	2	1	0
Reserved							PWR_MODE
—							R/W

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 13. Power Configuration Field Descriptions**

Bit	Field	Type	Reset	Description
7:1	Reserved	—	—	Reserved to 0
0	PWR_MODE	R/W	0x00	<b>0: Stand-by mode</b> 1: Active mode. Conversion is enabled

### 7.6.1.13 Status (offset = 0x20) [reset = NA]

**Figure 29. Status Register**

7	6	5	4	3	2	1	0
OSC status	Data Ready	Wake-up	Comparator	Don't Care			
R	R	R	R	R			

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 14. Status Field Descriptions**

Bit	Field	Type	Reset	Description
7	OSC status	R	NA	1: Indicates that the oscillator is overloaded and has stopped 0: Oscillator is working
6	Data Ready	R	NA	0: Data is ready to be read 1: No new data is available
5	Wake-up	R	NA	0: Wake-up triggered. Proximity data is more than the threshold high value. 1: Wake-up is disabled
4	Comparator	R	NA	0: Proximity data is more than the threshold high value 1: Proximity data is less than the threshold low value
3:0	Don't Care	R	NA	

### 7.6.1.14 Proximity Data LSB (offset = 0x21) [reset = NA]

**Figure 30. Proximity Data LSB Register**

7	6	5	4	3	2	1	0
Proximity Data[7]	Proximity Data[6]	Proximity Data[5]	Proximity Data[4]	Proximity Data[3]	Proximity Data[2]	Proximity Data[1]	Proximity Data[0]
R	R	R	R	R	R	R	R

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 15. Proximity Data LSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	Proximity Data[7:0]	R	NA	Least significant byte of proximity data

### 7.6.1.15 Proximity Data MSB (offset = 0x22) [reset = NA]

**Figure 31. Proximity Data MSB Register**

7	6	5	4	3	2	1	0
Proximity Data[15]	Proximity Data[14]	Proximity Data[13]	Proximity Data[12]	Proximity Data[11]	Proximity Data[10]	Proximity Data[9]	Proximity Data[8]
R	R	R	R	R	R	R	R

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 16. Proximity Data MSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	Proximity data[15:8]	R	NA	Most significant byte of proximity data

### 7.6.1.16 Frequency Counter LSB (offset = 0x23) [reset = NA]

**Figure 32. Frequency Counter LSB Register**

7	6	5	4	3	2	1	0
ODR[7]	ODR[6]	ODR[5]	ODR[4]	ODR[3]	ODR[2]	ODR[1]	ODR[0]
R	R	R	R	R	R	R	R

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 17. Frequency Counter LSB Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	ODR LSB ODR[7:0]	R	NA	LSB of output data rate. Sensor frequency can be calculated using the output data rate. See the <a href="#">Measuring Inductance</a> section.

### 7.6.1.17 Frequency Counter Mid-Byte (offset = 0x24) [reset = NA]

**Figure 33. Frequency Counter Mid-Byte Register**

7	6	5	4	3	2	1	0
ODR[15]	ODR[14]	ODR[13]	ODR[12]	ODR[11]	ODR[10]	ODR[9]	ODR[8]
R	R	R	R	R	R	R	R

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 18. Frequency Counter Mid-Byte Field Descriptions**

Bit	Field	Type	Reset	Description
7:0	ODR Mid byte ODR[15:8]	R	NA	Middle byte of output data rate



### 7.6.1.18 Frequency Counter MSB (offset = 0x25) [reset = NA]

**Figure 34. Frequency Counter MSB Register**

7	6	5	4	3	2	1	0
ODR[23]	ODR[22]	ODR[21]	ODR[20]	ODR[19]	ODR[18]	ODR[17]	ODR[16]
R	R	R	R	R	R	R	R

LEGEND: R/W = Read/Write; R = Read only; -n = value after reset

**Table 19. Frequency Counter MSB Field Descriptions<sup>(1)</sup>**

Bit	Field	Type	Reset	Description
7:0	ODR MSB ODR[23:16]	R	NA	MSB of Output data rate

- (1) Care must be taken to ensure that the proximity data[15:0] and Frequency Counter[23:0] registers are all from same conversion. Conversion data is updated to these registers only when a read is initiated on 0x21 register. If the read is delayed between subsequent conversions, these registers are not updated until another read is initiated on 0x21.

## 8 Application and Implementation

### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 8.1 Application Information

#### 8.1.1 Calculation of Rp\_Min and Rp\_Max

Different sensing applications may have a different ranges of the resonance impedance  $R_p$  to measure. The LDC1000-Q1 measurement range of  $R_p$  is controlled by setting two registers:  $Rp\_MIN$  and  $Rp\_MAX$ . For a given application,  $R_p$  must never be outside the range set by these register values, otherwise the measured value will be clipped. For optimal sensor resolution, the range of  $Rp\_MIN$  to  $Rp\_MAX$  should not be unnecessarily large. The following procedure is recommended to determine the  $Rp\_MIN$  and  $Rp\_MAX$  register values.

##### 8.1.1.1 Rp\_MAX

$Rp\_MAX$  sets the upper limit of the LDC1000-Q1 resonant impedance input range.

- Configure the sensor such that the eddy-current losses are minimized. As an example, for a proximity sensing application, set the distance between the sensor and the target to the maximum sensing distance.
- Measure the resonant impedance  $R_p$  using an impedance analyzer.
- Multiply  $R_p$  by 2 and use the next higher value from the register settings listed in [Table 3](#).

For example, if  $R_p$  is measured at 18 k $\Omega$ ,  $18000 \times 2 = 36000$ . Referring to [Table 3](#), 38.785 k $\Omega$  is the smallest value larger than 36 k $\Omega$ ; therefore  $Rp\_MAX$  should be set to 0x11.

Setting  $Rp\_MAX$  to a value not listed in [Table 3](#) can result in indeterminate behavior.

##### 8.1.1.2 Rp\_MIN

$Rp\_MIN$  sets the lower limit of the LDC1000-Q1 resonant impedance input range.

- Configure the sensor such that the eddy current losses are maximized. As an example, for a proximity sensing application, set the distance between the sensor and the metal target to the minimum sensing distance.
- Measure the resonant impedance  $R_p$  using an impedance analyzer.
- Divide the  $R_p$  value by 2 and then select the next lower  $R_p$  value from the register settings listed in [Table 4](#).

For example, if  $R_p$  at 1 mm is measured to be 5 k $\Omega$ ,  $5000 / 2 = 2500$ . Referring to [Table 4](#), 2.394 k $\Omega$  is the smallest value smaller than 2.5 k $\Omega$  which corresponds to an  $Rp\_MIN$  value of 0x3B.

Setting  $Rp\_MIN$  to a value not listed on [Table 4](#) can result in indeterminate behavior. In addition,  $Rp\_MIN$  powers on with a default value of 0x14 which must be set to a value from [Table 4](#) prior to powering on the LDC.

#### 8.1.2 Output Data Rate

The output data rate of the LDC1000-Q1 device depends on the sensor frequency,  $f_{\text{sensor}}$  and the Response Time[2-0] field in the LDC configuration register (address: 0x04).

$$\text{Output data rate} = f_{\text{sensor}} / (\text{Response Time}[2-0] / 3) \text{ in SPS (samples per second)} \quad (14)$$

##### 8.1.2.1 Example

If the following values are selected,  $f_{\text{sensor}} = 5 \text{ Mhz}$  and Response Time[2-0] = 192, then:

$$\text{Output data rate} = 5 \text{ MHz} / (192 / 3) = 78.125 \text{ KSPS} \quad (15)$$

## Application Information (continued)

### 8.1.3 Selecting a Filter Capacitor (CFA and CFB Pins)

The filter capacitor is critical to the operation of the LDC1000-Q1 device. The capacitor should be low leakage, temperature stable, and it must not generate any piezoelectric noise (the dielectrics of many capacitors exhibit piezoelectric characteristics and any such noise is coupled directly through  $R_p$  into the converter). The optimal capacitance values range from 20 pF to 100 nF. The value of the capacitor is based on the time constant and resonating frequency of the LC tank.

If a ceramic capacitor is used, then a C0G (or NP0) grade dielectric is recommended. The voltage rating should be 10 V or higher. The traces connecting the CFA and CFB pins to the capacitor should be as short as possible to minimize any parasitics.

For optimal performance, the selected filter capacitor, connected between the CFA and CFB pins, must be as small as possible but large enough such that the active filter does not saturate. The size of this capacitor depends on the time constant of the sense coil, which is given by  $L / r_s$  ( $L$  = inductance,  $r_s$  = series resistance of the inductor at oscillation frequency). The larger this time constant, the larger filter capacitor is required. Therefore the time constant reaches the maximum when there is no target present in front of the sensing coil.

Use the following procedure to find the optimal filter capacitance:

1. Use with a large filter capacitor. For a ferrite core coil, a value of 10 nF is generally large enough. For an air coil or PCB coil, a value of 100 pF is generally large enough.
2. Power on the LDC and set the desired register values.
3. Minimize the eddy currents losses by ensuring maximum clearance between the target and the sensing coil.
4. Observe the signal on the CFB pin using a scope. Because this node is very sensitive to capacitive loading, the use of an active probe is recommended. As an alternative, a passive probe with a 1-k $\Omega$  series resistance between the tip and the CFB pin can be used.
5. Vary the values of the filter capacitor until the signal observed on the CFB pin has an amplitude of approximately 1  $V_{pp}$ . This signal scales linearly with the reciprocal of the filter capacitance. For example, if a 100-pF filter capacitor is applied and the signal observed on the CFB pin has a peak-to-peak value of 200 mV, the desired 1- $V_{pp}$  value is obtained using a filter capacitor value that is calculated with [Equation 16](#).

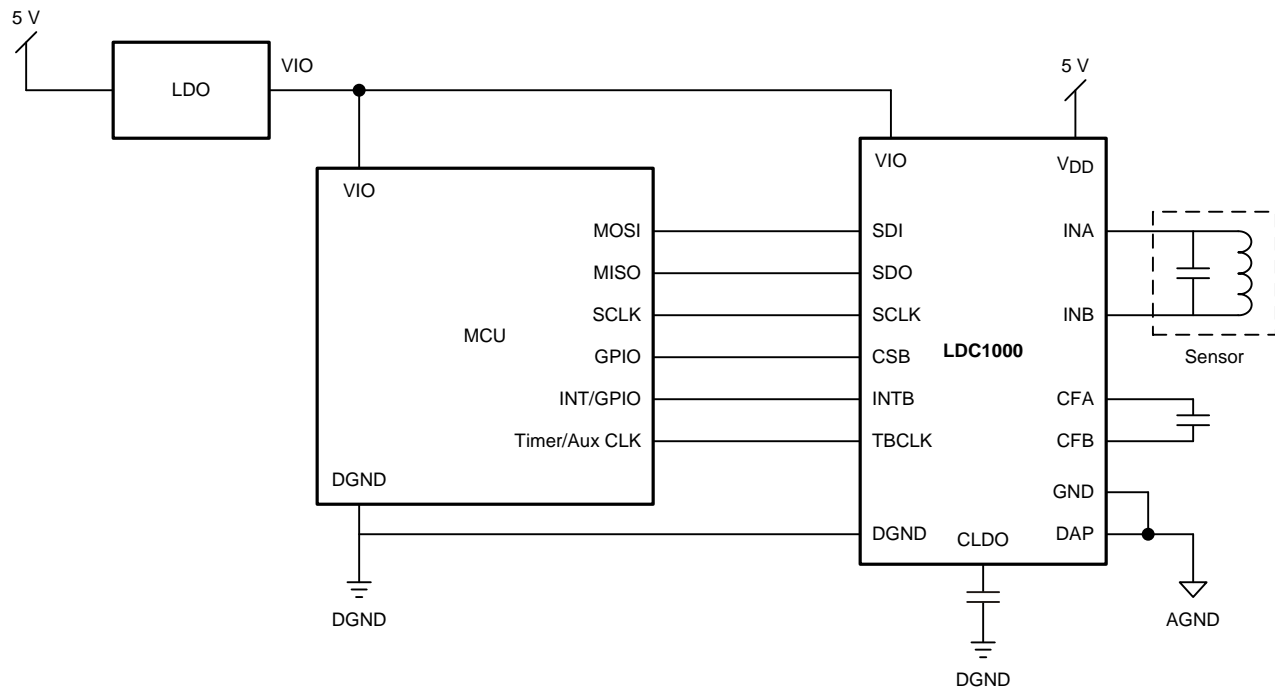
$$200 \text{ mV} / 1 \text{ V} \times 100 \text{ pF} = 20 \text{ pF} \quad (16)$$

## LDC1000-Q1

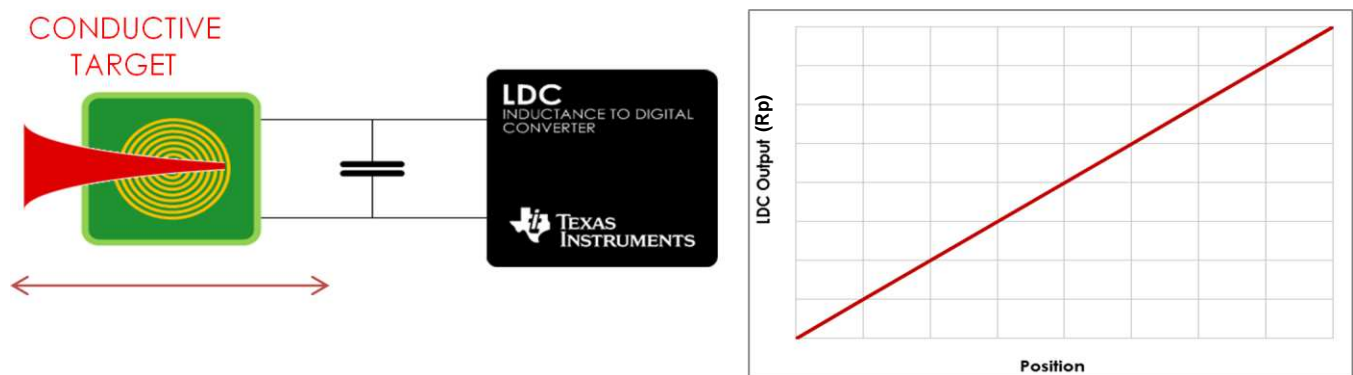
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### 8.2 Typical Application

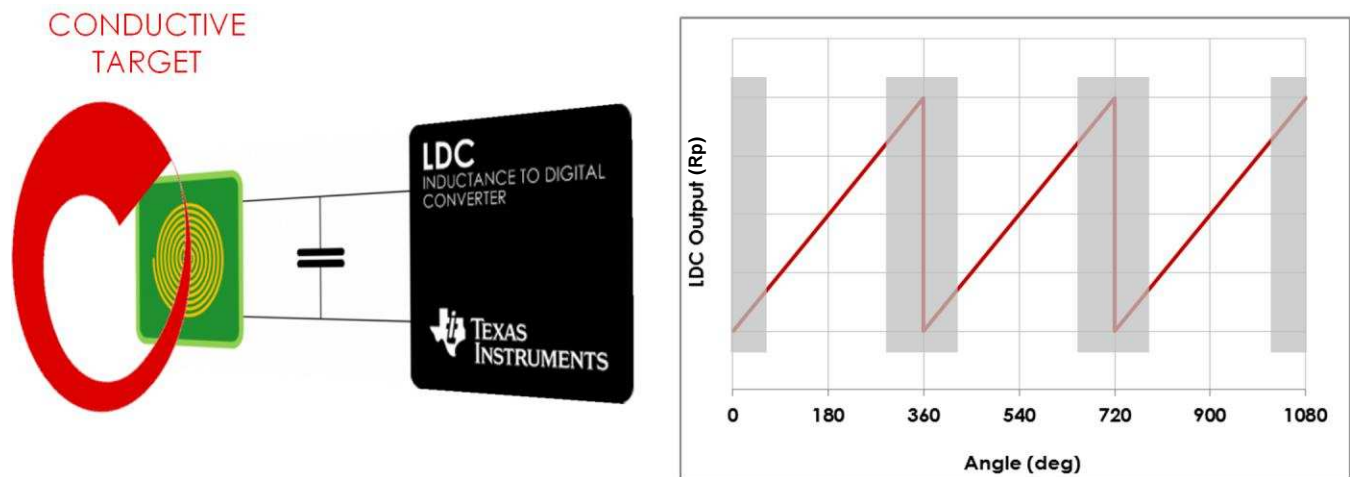


**Figure 35. Typical Application Schematic**



**Figure 36. Linear Position Sensing**

## Typical Application (continued)



**Figure 37. Angular Position Sensing**

### 8.2.1 Design Requirements

For this design example, use the following as the input parameters.

**Table 20. Design Parameters**

DESIGN PARAMETER	EXAMPLE VALUE
Minimum sensing distance	1 mm
Maximum sensing distance	8 mm
Output data rate	78 KSPS (Max data rate with LDC10xx series)
Number of PCB layers for sensor	2 layers

### 8.2.2 Detailed Design Procedure

#### 8.2.2.1 Sensor and Target

In this example, consider a sensor with the characteristics listed in [Table 21](#).

**Table 21. Sensor Characteristics**

PARAMETER	VALUE
Layers	2
Thickness of copper	1 oz
Coil shape	Circular
Number of turns	23
Trace thickness	4 mil
Trace spacing	4 mil
PCB core material	FR4
R <sub>P</sub> at 1 mm	5 kΩ
R <sub>P</sub> at 8 mm	12.5 kΩ
Nominal Inductance	18 μH

The target material used is stainless steel.

### 8.2.2.2 Calculating a Sensor Capacitor

Sensor frequency depends on various factors in the application. In this example, use Equation 17 to calculate the sensor frequency in order to achieve an output data rate of 78 KSPS per the design parameter.

$$\text{Output Data Rate} = \frac{f_{\text{sensor}}}{\left( \frac{\text{Response time}}{3} \right)} \quad (17)$$

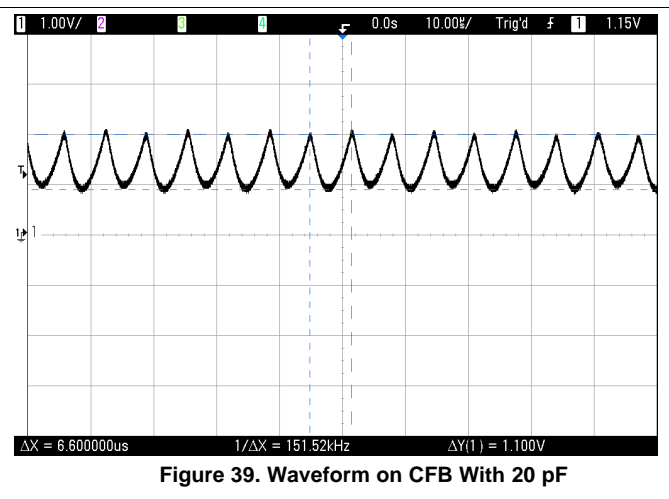
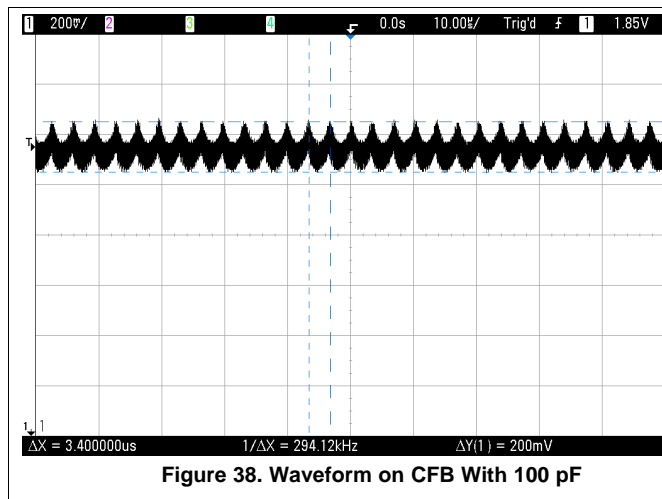
With the lowest response time ( $t_{\text{res}}$ ) of 192 and output data rate of 78 KSPS, the calculated sensor frequency using Equation 17 is 4.99 MHz.

Use Equation 18 to calculate the sensor capacitor as 55 pF with a sensor inductance of 18  $\mu\text{H}$ .

$$L = \frac{1}{C \times (2\pi \times f_{\text{sensor}})^2} \quad (18)$$

### 8.2.2.3 Selecting a Filter Capacitor

Use the steps listed in the [Selecting a Filter Capacitor \(CFA and CFB Pins\)](#) section to calculate a filter capacitor. For this example, the selected capacitor value is 20 pF. The following waveforms were taken on the CFB pin with a 14-mm, 2-layer PCB coil (23 turns, 4-mil trace width, 4-mil spacing between trace, 1-o.z copper thickness, FR4).



### 8.2.2.4 Setting Rp\_MIN and Rp\_MAX

To calculate the value for the Rp\_MAX register, use the following value: Rp at 8 mm is 12.5 k $\Omega$ , 12500  $\times$  2 = 25000. Then 27.704 k $\Omega$  is the nearest value larger than 25 k $\Omega$ . Referring to Table 3, this value corresponds to a Rp\_MAX value of 0x12.

To calculate the value for the Rp\_MIN register, use the following value: Rp at 1 mm is 5 k $\Omega$ , 5000 / 2 = 2500. Then 2.394 k $\Omega$  is the nearest value lower than 2.5 k $\Omega$ . Referring to Table 4, this value corresponds to Rp\_MIN value of 0x3B.

### 8.2.2.5 Calculating Minimum Sensor Frequency

Use Equation 19 to calculate the minimum sensor frequency.

$$N = 68.94 \times \log_{10} \left( \frac{F}{2500} \right)$$

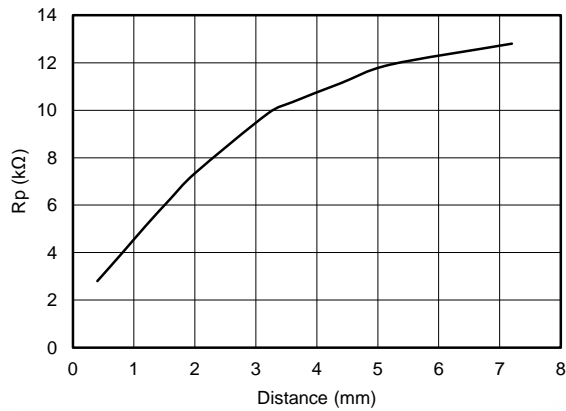
where

- N is 227.51

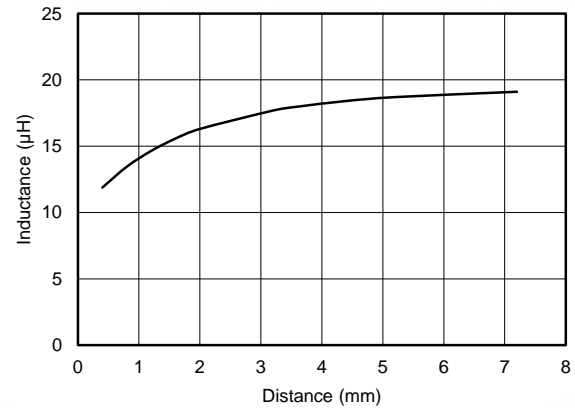
(19)

For this example, round the value of N up to 228. This value must be written into the watchdog timer register, which is used to wake up the internal circuit when the sensor is saturated.

### 8.2.3 Application Curves



**Figure 40. R<sub>p</sub> vs Distance**



**Figure 41. Inductance vs Distance**

## 9 Power Supply Recommendations

The LDC1000-Q1 device is designed to operate from an analog supply range of 4.75 to 5.25 V and digital I/O supply range of 1.8 to 5.25 V. The analog supply voltage should be greater than or equal to the digital supply voltage for proper operation of the device. The supply voltage should be well regulated. If the supply is located more than a few inches from the LDC1000-Q1 device, additional bulk capacitance may be required in addition to the ceramic bypass capacitors.

## 10 Layout

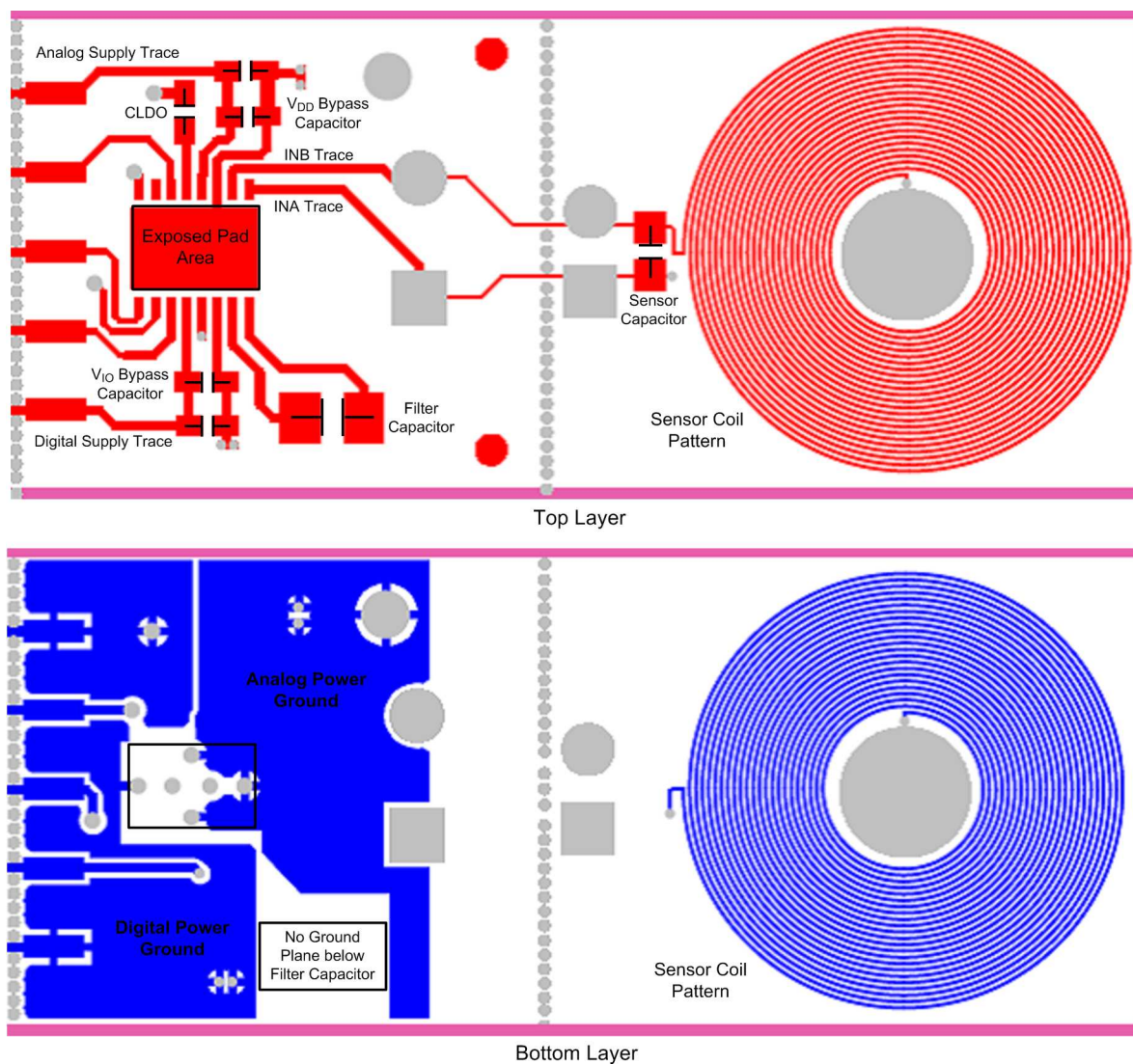
### 10.1 Layout Guidelines

Use the following guidelines:

- Bypass the  $V_{DD}$  and VIO pin to ground with a low ESR ceramic bypass capacitor. A ceramic X7R dielectric capacitor with a value of 0.1  $\mu$ F is recommend.
- Place the VDD, VIO, GND, and DGND pins as close to the device as possible. Take care to minimize the loop area formed by the bypass capacitor connection and the  $V_{DD}$ , VIO, GND, and DGND pins of the IC. See [Figure 42](#) for a PCB layout example.
- Bypass the CLDO pin to the digital ground (DGND) with a ceramic bypass capacitor with a value of 56 nF.
- Connect the filter capacitor that is selected using the procedure listed in the [Selecting a Filter Capacitor \(CFA and CFB Pins\)](#) section between the CFA and CFB pins. Place the capacitor close to the CFA and CFB pins. Do not use any ground or power planes below the capacitor and the trace connecting the capacitor and the CFx pins.
- Use two separate ground planes for the ground (GND) and digital ground (DGND) for a star connection as recommended. See [Figure 42](#) for a PCB layout example.



## 10.2 Layout Example



**Figure 42. LDC10xx Board Layout**

## 11 Device and Documentation Support

### 11.1 Trademarks

All trademarks are the property of their respective owners.

### 11.2 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### 11.3 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

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