

LDC Device Selection Guide

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ABSTRACT

Texas Instruments revolutionized inductive sensing when it introduced the LDC1000. Since then, TI has released an entire portfolio of devices using LDC technology, providing devices with extended capabilities and more features. This application note reviews the currently available LDC devices, summarizes their capabilities, and provides device recommendations for various applications.

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1 LDC Applications

Inductive sensing provides contactless sensing of conductive objects using only an AC magnetic field. This approach has many compelling features, including low cost, high reliability, low power consumption, and robust operation even in challenging environments experiencing high temperatures or in the presence of moisture, dirt, or oil. In addition, TI's LDC devices do not require permanent magnets, and are not affected by permanent magnets. LDC technology can measure a wide range of target movement configurations, as shown in [Figure 1](#).

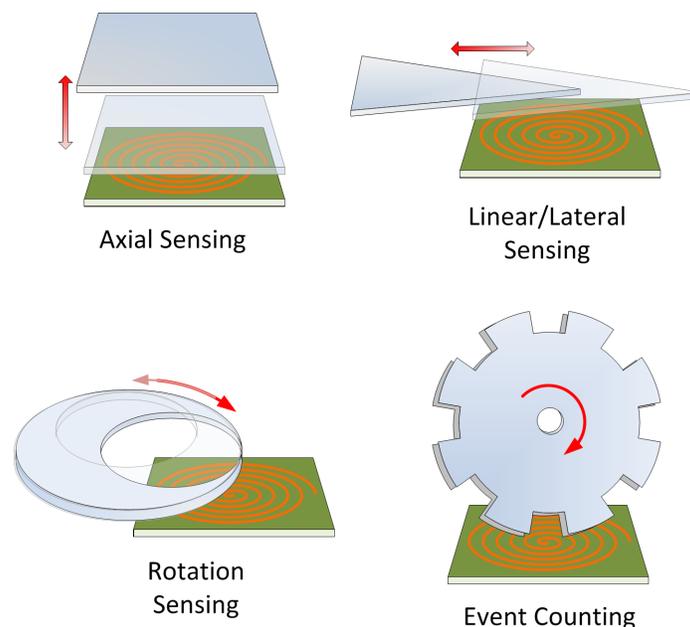


Figure 1. LDC Sensing Configurations

1.1 Axial Sensing

An axial sensing configuration is where the conductive target moves along an axis that is perpendicular to the plane of the coil, as shown in the upper left of [Figure 1](#). The LDC sensor measures the change of inductance caused by the movement of the target. The target is constrained so that it only moves in one axis. As the target distance from the sensor varies, the LDC output will correspond to the target distance.

This common configuration can be used for a wide variety of systems, from measuring extruded material to sensing whether a door is open or closed.

1.1.1 Buttons and Keypads

The axial sensing configuration can be used for human-machine interface (HMI) applications such as buttons or keypads using continuous metal surfaces. By attaching a metal film as thin as 10 μm to the inside surface, Inductive touch buttons can be constructed with non-conductive materials such as glass, plastic, and even wood. This type of implementation can be used for rugged, waterproof, long-life interfaces which can work in harsh environments where other technologies fall short. Details on one implementation of this capability can be found at [Touch on Metal Buttons Reference Design](#), which uses the LDC1614.

Some LDC devices, such as the LDC2114, include algorithms and output features making them drop-in replacements for currently existing mechanical implementations.

Another example which uses LDC sensing to create more reliable snap-dome switches can be found at [16-Button Inductive Keypad](#).

1.2 Linear Sensing

In a linear sensing configuration, a target of varying width (such as a triangular shape) is held at a constant distance from the sensor, as shown in the upper right area of [Figure 1](#). As the target is moved laterally over the sensor, more or less of the target area is exposed to the sensor, causing the sensor inductance to vary. The LDC response can be used to determine the horizontal position of the target. The application note [LDC1612/LDC1614 Linear Position Sensing \(SNOA931\)](#) provides more information on this sensing configuration.

1.3 Rotation and Angular Sensing

The rotation of a target can also be measured, using a variation of the linear sensing configuration. This is illustrated in the lower left area of [Figure 1](#). By using multiple sensors, both the absolute angle and direction of rotation can be measured. The [LDC 1° Dial](#) reference design documents an implementation of angular measurement using the LDC1314.

1.3.1 Event Counting

A special case of rotation sensing can be referred to as event counting, which usually is intended to measure rotational rate. This is illustrated in the lower right section of [Figure 1](#). By monitoring periodic target interactions, such as interactions with gear teeth, the rotation rate of motor can be measured. The [LDC0851 Event Counting Reference Design](#) is an example of an LDC measurement of this type of configuration.

LDC-based event counting can also be used for control knobs for HMI; refer to [32 Position Encoder Knob](#) for one such implementation using the LDC0851.

1.4 Other Types of Sensing

LDC technology is not limited to these configurations. For example, proximity detection of a conductive object can be implemented. LDC technology can also be used to identify metal composition.

LDC technology can use a wide variety of sensors in addition to spiral trace PCB inductors. One example is using LDC technology to measure a spring's extension and contraction.

2 Inductive Sensing Theory of Operation

An AC 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. By opposing the original field, the original field is weakened; this produces a reduction in inductance compared to the inductor's free space inductance.

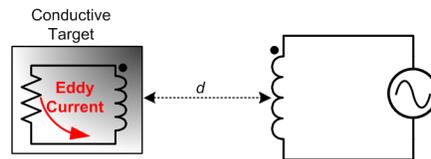


Figure 2. Conductor in AC Magnetic Field

An EM field appropriate for sensing can be generated using an L-C resonator. One topology for an L-C tank is a parallel R-L-C construction, as shown in Figure 3. To simplify the inductor amplitude calculations, the parallel electrical model is generally used. For inductive sensing applications, the resistive element represents parasitic circuit losses and is not a discrete component.

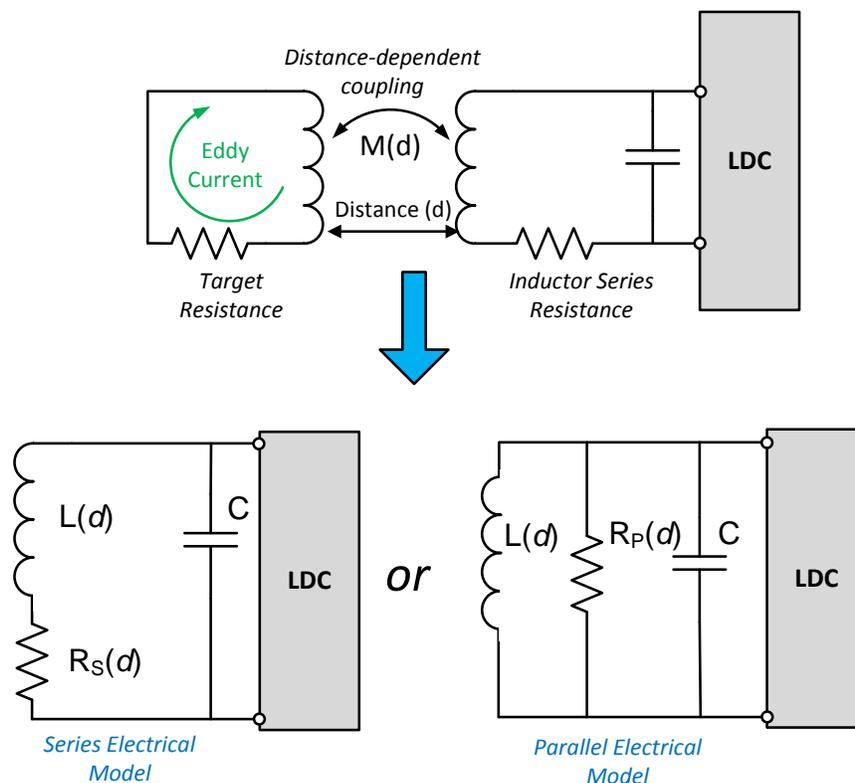


Figure 3. Electrical Model of Parallel Inductive Sensor

The circuit resonates at a frequency given by Equation 1:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Any shift in the target position causes the inductance value, $L(d)$, to change, which in turn causes the resonant frequency to change. Hence, measuring the frequency change can be used to determine the inductance change, and therefore is based on the target position. In addition, by monitoring the amount of energy injected into the LC circuit, the $RS(d)$ can be measured. TI's various LDC devices use one or both of these two principles to determine the change in position of the target, depending on the specific device.

The Analog Wire blog post [Inductive sensing: Should I measure L, \$R_p\$ or both?](#) compares the two different measurement techniques and recommends the more appropriate parameter to monitor.

3 LDC Device Feature Overview

Determining the appropriate LDC device for a specific application is based on a few device parameters. [Table 1](#) provides a comparison for the various LDC devices.

Table 1. Comparison of LDC Devices

	LDC2112/4	LDC1312/4 LDC1612/4	LDC0851	LDC1101	LDC1000/ LDC1041/ LDC1051
Supply Voltage	1.71 to 1.89 V	2.7 to 3.6 V	1.71 to 3.46 V	1.71 to 3.46 V	4.75 to 5.25 V
Typical Sleep Current	5 μ A	35 μ A	N/A	135 μ A	250 μ A
Typical Shutdown Current	N/A	0.2 μ A	0.14 μ A	1.4 μ A	N/A
Sensor Frequency Range (wider is better)	1 MHz to 30 MHz	1 kHz to 10 MHz	300 kHz to 19 MHz	500 kHz to 10 MHz	5 kHz to 5 MHz
Sensor Min R_p (lower is better)	350 Ω	1 k Ω /Ch0 = 250 Ω	N/A	1.25 k Ω	1 k Ω
Output R_p Measurement Resolution	N/A	N/A	N/A	16 bits	LDC1000:15 bits LDC1041:8 bits LDC1051:8 bits
Output L Measurement Resolution	12 bits	LDC131x: 12 bits (16 bits effective with output gain) LDC161x: 28 bits	N/A	16 bits or 24 bits	LDC1000:24 bits LDC1041:24 bits LDC1051:N/A
Maximum Reference Frequency (higher is better)	N/A	40 MHz	N/A	16 MHz	8 MHz
Internal Reference Oscillator	Yes	Yes	N/A	No	No
Number of Channels	LDC2112: 2 LDC2114: 4	LDC1312/LDC1612: 2 LDC1314/LDC1614: 4	1 (uses 2nd sensor for reference comparison)	1	1
Maximum Sample Rate	80 SPS	LDC1312/4: 13.3 kSPS LDC1612/4: 4.1 kSPS	4 kSPS	180 kSPS	78 kSPS
Automotive Version	N/A	LDC1312-Q1 LDC1314-Q1 LDC1612-Q1 LDC1614-Q1	N/A	N/A	LDC1000-Q
Switch Output	Yes, based on Sensor L	No	Yes, based on Sensor L	Yes, based on Sensor R_p or L	Yes – based on Sensor R_p
Interface	I2C – 400 kbit Push-pull Output	I2C – 400 kbit	Push-pull Output	SPI – 8 MHz	SPI – 4MHz
Stand-alone operation (No MCU needed)	Yes	No	Yes	No	No

3.1 Sample Rate

LDC devices have a maximum sample rate between 4 kSPS and 180 kSPS. 4 kSPS is sufficient for a wide range of applications, as physical movement is typically much slower than electronic signals. For example, a car traveling at 100 kph will move less than 7 mm in the 250- μ s sample time interval of a 4-kSPS LDC.

In general, LDC devices have a tradeoff between sample rate and effective resolution. The TI application notes [Optimizing L Measurement Resolution for the LDC161x and LDC1101](#) (SNOA944) and [Optimizing L Measurement Resolution for the LDC131x](#) (SNOA945) cover this topic in detail.

3.2 Sensor L Measurement and Reference Frequency

LDC devices determine the sensor inductance by measuring the sensor frequency with the relationship in [Equation 1](#). A reference frequency of some source is needed.

Some LDC devices, such as the LDC1314, provide the choice of using either an internal oscillator or an external reference oscillator, while others such as the LDC1101 require an external oscillator. For a given sample frequency, devices that are able to use a higher reference frequency can provide higher measurement resolution.

If the LDC requires an external oscillator, it should be a square wave with low jitter ($<100 \text{ ps}_{\text{RMS}}$), frequency stable, and have a 50% duty cycle.

Note that the LDC1051 does not measure L – it only measures R_p .

3.3 Sensor R_p Measurement

Some of TI's LDC devices can measure the parallel resonant impedance (R_p) of a sensor. This R_p measurement can be scaled to match the range of sensor R_p for an optimized measurement.

Because R_p measurements are based on the resistivity of target, the measurement will vary with the temperature of the target; many metals have significant resistivity temperature coefficients (temp-co) which can introduce a change into the measurement based on the system temperature. For example, copper has a temp-co of 4300ppm/°C. If the target temperature changes by 20°C, the LDC would see an R_p shift of >8%, which could be too large an error for the application.

Due to the large temp-co, R_p measurements are better suited for applications which have a very limited temperature range, or where the target temperature is monitored, or where there is a need to measure the sensor energy loss, or for material composition.

TI devices that can measure R_p are the LDC1000, LDC1041, LDC1051, and the LDC1101. The LDC1101 provides the highest R_p measurement accuracy, and is recommended for any R_p measurement where the sensor frequency is above 500 kHz.

The LDC1000, LDC1041, and LDC1051 require the use of an external compensation capacitor for R_p measurement; the LDC1101 has an internal configurable capacitor.

3.4 Sensor R_p (Current) Drive Capability

As the target gets closer to the sensor, more energy is dissipated in the target eddy currents. This energy loss needs to be replaced by the LDC device in order to maintain the sensor oscillation. Each LDC has a minimum sensor R_p which it can drive; where a lower R_p is a sensor with more loss. Being able to drive a higher loss sensor is desirable and provides more system design flexibility. The R_p drive is a consideration even for L measurement applications.

Terminology for the sensor drive varies with device – on the LDC1101, the RPMIN setting is used for to control the sensor drive. With the LDC1312, LDC1314, LDC1612, and LDC1614 devices, the sensor drive is configured by the IDRIVE setting.

An application using the LDC0851, as long as the sensor inductance and capacitance are within the operating range specified in the data sheet, does not need to consider the sensor R_p due to the sensor driver circuit design.

3.5 Switch Output Functionality

The LDC0851 is an inductive comparator with a single-pin switched output. The LDC1000/1041/1051 devices can be configured to toggle the INTB pin based on a threshold for the R_p conversion result. The LDC1101 can toggle the SDO output pin based on either the R_p or the L conversion result, and the threshold can even be dynamically changed.

If this feature is needed, the LDC0851 is recommended for all applications when the maximum sample rate is less than 4 kSPS. If the application requires a higher sample rate, then the LDC1101 is recommended.

3.6 Sensor Frequency Range

The sensor frequency is correlated to the physical size of the inductor. While both the inductance and capacitance of the sensor determine its frequency, higher frequencies are usually associated with smaller inductances (coils), and vice versa.

Sensing range is also correlated to inductor (coil) size; larger coils have longer sensing range. Hence, larger, lower frequency sensors can usually be located farther away from the target than smaller, higher frequency sensors.

3.7 Multi-Channel Sensing

Multi-channel LDCs offer the capability to design multi-sensor systems using a single LDC device. The multiple sensors may be configured with a dedicated reference sensor or in a differential sensor configuration to compensate for environmental variations.

The LDC1612/4 and LDC1312/4 sequentially sample their active sensor channels using an internal switching multiplexer which provides excellent matching between channels. Multiple LDC1101 devices can be configured for synchronized L sampling by gating the external reference.

3.8 Power Management

When actively converting, LDC devices typically consume approximately 3 mA, depending mainly on the sensor R_p and supply voltage. Some LDC devices have inactive modes in which they consume minimal currents, making them more suitable for power limited applications.

The LDC0851 has a typical shutdown current draw of only 140 nA, and the LDC1312/4 and LDC1612/4 have a typical shutdown current 200 nA, making these devices optimum choices for battery powered systems. Since many applications do not require a very high sample rate, duty-cycling the LDC into an inactive mode whenever possible can provide significant current savings. For example, with an LDC1312 application sampling at 20 sps, the current consumption would be approximately 140 μ A. For more information on managing the power consumption of an LDC device, refer to the TI application note [Power Reduction Techniques for the Multichannel LDCs in Inductive Sensing Applications](#) (SNOA949).

Inductive Touch LDC devices such as the LDC2114 can periodically sample all active channels at a selected scan rate, and then automatically return to an ultra-low power mode without any MCU interaction.

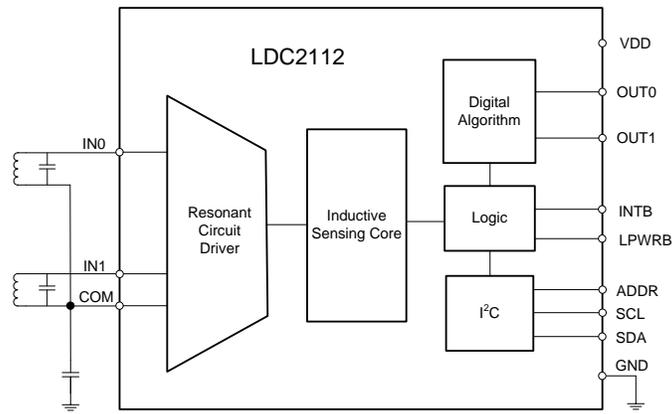
3.9 Internal Algorithms

Inductive Touch LDC devices such as the LDC2114 include internal algorithms can automatically process sensor measurements and indicate when button presses have occurred without any MCU resources. These algorithms provide compensation for environmental shifts, variations in button actuation force, and configurable scan rates to provide faster button response to presses or to minimize supply current.

4 Device Families

4.1 Inductive Touch Devices

The Mobile Inductive Touch LDC Devices, the 2 channel LDC2112 and the 4 channel LDC2114, are high-resolution LDCs with internal algorithms optimized for Inductive Touch applications. The internal algorithms extract inductance shifts corresponding to button presses and can report the event through dedicated output pins. A dedicated sensor per channel can detect sensor frequency shifts corresponding to metal deflection smaller than 200 nm. The sensor frequency can go up to 30 MHz, which enables circular buttons as small as 2.4 mm and rectangular buttons smaller than 2.0 mm by 7.0 mm. LDC2112/LDC2114 sensors can be constructed on PCBs or flex PCBs.



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Figure 4. LDC2112 Block Diagram

The main features of this family of LDCs are:

1. Multiple buttons supported with a single device – up to 4 buttons
2. Low Standby current of <5 μA and average operation currents lower than 10 μA
3. Wide range of sensor frequencies - from 1 MHz to 30 MHz
4. Dedicated output pins to emulate mechanical button operation
5. Scan rates of up to 80 SPS
6. Supply voltage range of 1.71 V to 1.89 V
7. I2C interface for configuration and data readback

4.1.1 Inductive Touch LDC Recommended Applications

The Inductive Touch devices are suitable for a wide range of button replacement applications, from mobile and wearable systems, to industrial and white goods.

4.2 Multichannel LDC Devices

The Multichannel LDC family consists of the LDC1312, LDC1314, LDC1612, and the LDC1614. While these devices only measure the sensor inductance, they incorporate significant improvements over the first-generation LDC1000.

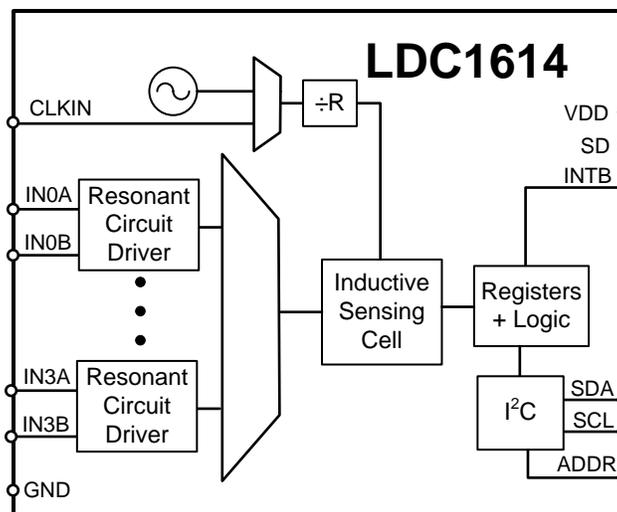


Figure 5. LDC1614 Block Diagram

The main features of this architecture are:

1. Multiple sensors on a single device – multiplexed 2 or 4 channels conversion, with excellent channel-channel matching
2. Supply voltage range of 2.7 V to 3.6 V
3. Deterministic sample rate of 40 SPS to 4.1 kSPS for the LDC1612/4
4. Deterministic sample rate of 40 SPS to 13.3 kSPS for the LDC1312/4
5. The widest sensor frequency range of 1 kHz to 10 MHz
6. The highest maximum reference frequency of 40 MHz
7. Two low power inactive modes – Sleep (typical < 35 μ A) and Shutdown (typical < 200 nA) make this family suitable for battery powered applications

The LDC161x devices feature 28 bits of resolution, while the LDC131x has an effective 16 bits of resolution.

The main limitation of these devices comes from the I2C bus bandwidth – while a single channel conversion can be read at up to 4 kSPS, when multiple channels are used the maximum retrievable sample rate decreases proportionally. One nice feature about this family of devices is the common register settings and common footprint – the programming and settings are compatible across all the devices in this family. In addition, the LDC1312 and LDC1612 share a 12 pin WSON package, and the LDC1314 and LDC1614 share a 16 pin WQFN package.

4.2.1 Multi-Channel LDC Recommended Applications

The multi-channel devices are highly versatile and recommended for the majority of applications. The multi-channel capability is useful for systems requiring absolute measurements, or for systems which need to monitor several sensors.

The LDC1612/4 provides the highest resolution and is optimum for applications such as high resolution differential sensor configurations and can also support touch-on-metal buttons.

The lower resolution, higher sample rate LDC1312/4 are good choices for rotation measurement and lower resolution applications.

4.2.2 LDC1101

The LDC1101 is an improved version of the LDC1000 – it has the highest R_p measurement resolution of any LDC and significantly better device-to-device matching. In addition to the improved LDC1000 features, it includes the same measurement core (the High Res L Measurement block) as the LDC1612, however with 24 bits of measurement resolution.

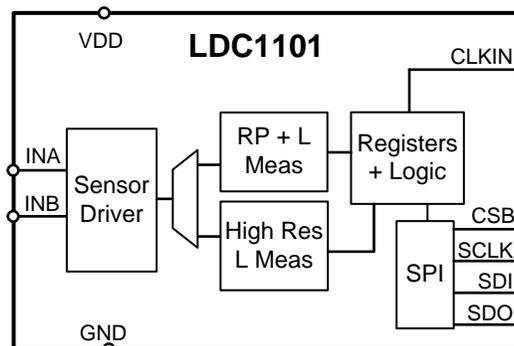


Figure 6. LDC1101 Block Diagram

The main features of this device are:

1. Highest R_p measurement resolution of 16 bits
2. Supply voltage range of 1.71 V to 3.46 V
3. Highest LDC sample rates of up to 180 kSPS

4. Sensor frequency range of 500 kHz to 10 MHz
5. Maximum reference frequency of 16 MHz
6. Switch output functionality on SDO pin
7. Small 10-pin DFN footprint with reduced external passive component count
8. Two low power inactive modes – Sleep (<math><135 \mu\text{A}</math>) and Shutdown (<math><1.4 \mu\text{A}</math>)

4.2.2.1 LDC1101 Recommended Applications

The LDC1101 provides the highest R_p measurement resolution and accuracy, and has many significant improvements on the LDC1000 family of devices. It is the recommended device for any application where R_p measurements are needed.

The LDC1101 is recommended for any LDC application where the sample rate requirement exceeds 13.3 ksp/s (which is the highest speed the LDC1312/4 can attain). One application which can use this speed is motor rotation speed sensing.

The 1.8V supply operation and small footprint make the LDC1101 suitable for many portable applications.

4.2.3 LDC0851

The LDC0851 is a low-cost inductive comparator, generating an output based on the difference between a sense inductor and a reference inductor. A pair of resistors on the ADJ pin can be used to adjust the sensitivity or switching distance; no other configuration is necessary. The LDC0851 uses one capacitor for both sensors, which improves the matching of the two sensors and also reduces system cost. The LDC0851 does not have any registers and therefore does not require any MCU configuration for operation.

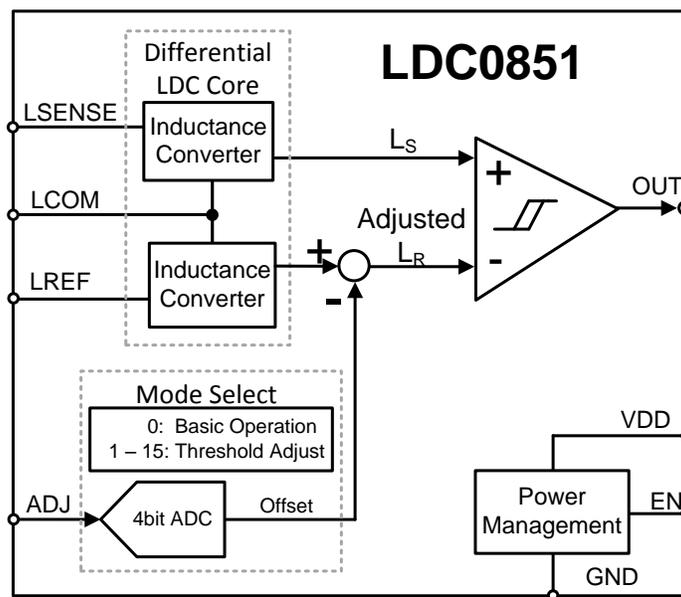


Figure 7. LDC0851 Block Diagram

The main features of this device are:

1. Simple operation
2. Configured by only two resistors on the ADJ pin
3. Intrinsic temperature and system compensation
4. Supply voltage range of 1.71 V to 3.46 V
5. Sensor frequency range of 300 kHz to 19 MHz
6. Small 8-pin DFN footprint

The sensor drive design of the LDC0851 makes it able to drive nearly any sensor within its design requirements (based on the sensor L and the sensor C), without needing to consider the sensor R_p .

4.2.3.1 Recommended Applications

The LDC0851 is recommended for applications that currently use Hall sensors, such as proximity switches and rotational speed measurements. It can also be used in rotational encoder applications as a replacement for optical sensors, where it offers the advantage that it is immune to dust and dirt which can interfere with optical solutions.

4.2.4 LDC1000 Family

The first generation LDC devices, the LDC1000 family contains 4 devices – the LDC1000, LDC1000-Q1, LDC1041, and the LDC1051.

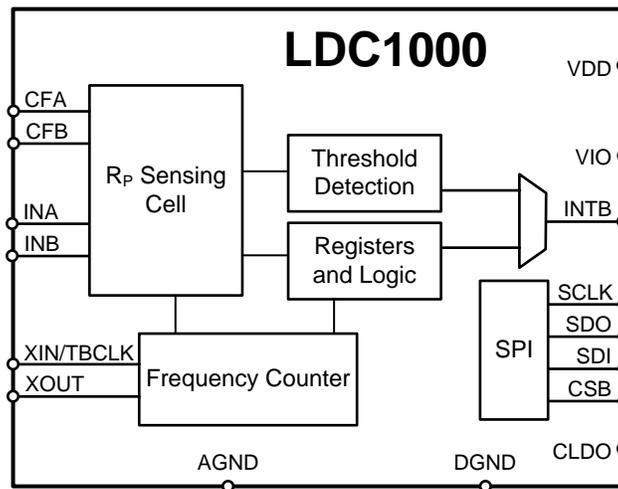


Figure 8. LDC1000 Block Diagram

The main features of this family are:

1. R_p measurement capability
2. Sensor frequency range of 5 kHz to 5 MHz
3. High sample rates of up to 78 ksps
4. Low power Sleep mode
5. Switch output functionality based on R_p measurement

Table 2. LDC10xx Devices

	LDC1000	LDC1000Q	LDC1041	LDC1051
R_p Measurement Resolution	15 bits	15 bits	8 bits	8 bits
L Measurement Resolution	24 bits	24 bits	24 bits	N/A
Reference Input	Oscillator or Crystal	Oscillator or Crystal	Oscillator	N/A
Package	DFN-16	TSSOP-16	DFN-16	DFN-16

Note that the sample rate for this family of devices is a function of the device's RESP_TIME setting and the sensor frequency.

4.2.4.1 Recommended Applications

The LDC1000 devices are advised for applications which require R_p measurement with low frequency sensors ($f_{\text{SENSOR}} < 500$ kHz), such as metal identification. For most other applications, a different LDC would be more suitable.

The lower cost, lower resolution LDC1041 and LDC1051 members of the family provide LDC solutions in price conscious applications, but the LDC0851 is usually a better choice.

5 Summary

LDC sensing is an excellent solution for a wide range of applications. Based on the application and system needs, selection of the appropriate LDC device needs to only consider a few factors; primarily switch functionality, sample rate, and device resolution.

Revision History

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

Changes from A Revision (February 2017) to B Revision	Page
• Added table entry for LDC2112/4	4
• Changed Column to contain both LDC1612/4 and LDC1312/4 for space considerations	4
• Added Added section on Internal Algorithms	6
• Added Added section on LDC2112/4	6
• Changed multichannel LDC package options to be clearer	8

Changes from Original (July 2016) to A Revision	Page
• Corrected typos to reflect datasheet parameters	4

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