Application Report

SNOA947A–March 2016–Revised February 2020

LDC0851 Quick-Start Guide

Varn Khanna

ABSTRACT

Texas Instruments introduced the first inductance to digital converter (LDC) in the industry in 2012. LDC100x revolutionized the world of proximity sensing by delivering increased reliability, high resolution, and lower total system cost.

The LDC100x was soon followed by second generation multi-channel LDC devices like the LDC161x and LDC131x. With up to four sensing channels and 28 bits of resolution, the second generation of LDC devices opened the technology up to a wider range of applications and simplified system design. However, TI firmly believed that Inductive sensing could be simplified further. The LDC0851 is a differential inductive switch with a push or pull output that does not require digital programming to enable simpler designs and lower system cost. This application note is a three-step guide to becoming a LDC0851 power user.

Contents

Trademarks

All trademarks are the property of their respective owners.

1 LDC0851 — The Working Principle

An AC current flowing through an inductor generates an AC magnetic field. If a conductive material, such as a metal object, is brought into the vicinity of the inductor, the magnetic field induces 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 a magnetic field that 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 free space inductance of the inductor.

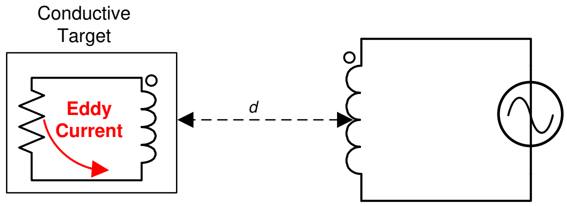

Figure 1. Conductor in AC Magnetic Field

An EM field appropriate for sensing can be generated using an L-C resonator. One topology for an L-C tank is a series R-L-C construction, as shown in Figure 2. To simplify the inductor amplitude calculations, the parallel electrical model is generally used. For inductive sensing applications, the resistive element is represents parasitic circuit losses and is not a discrete component.

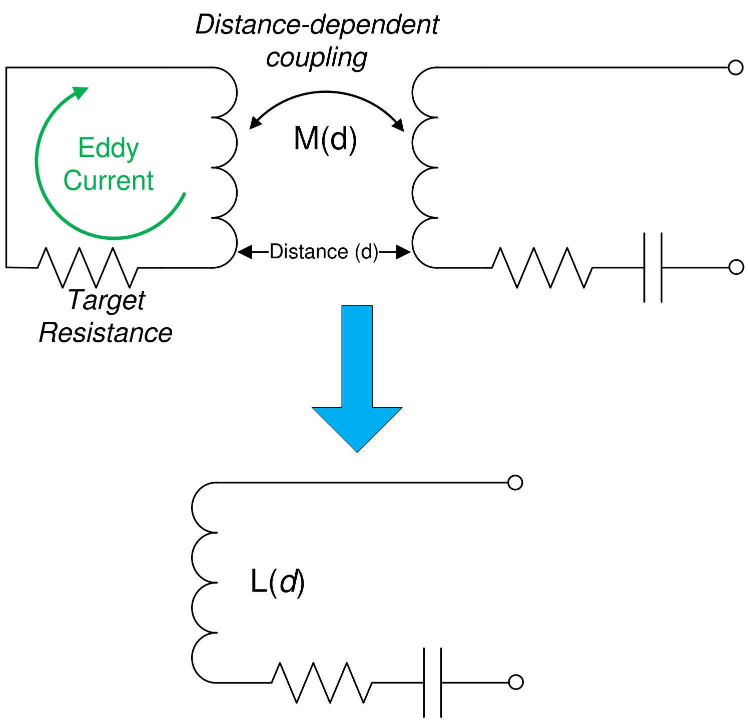

Figure 2. Electrical Model of Series Inductive Sensor

The decrease in the effective inductance of the LC resonator caused by a conductive target moving closer to the resonator can be observed as an increase in resonating frequency (f_{SENSOR}) given by Equation 1.

$$f_{SENSOR} = \left(\frac{1}{2\pi}\right) \times \sqrt{\frac{2}{L \times C}} \tag{1}$$

The LDC0851 measures the change in the inductance of the LC tank resonator (usually a PCB coil) as a conductive object moves closer to it. The LDC0851 comes in an eight-pin DFN package. A functional block diagram of the LDC0851 and pin out is shown in Figure 3.

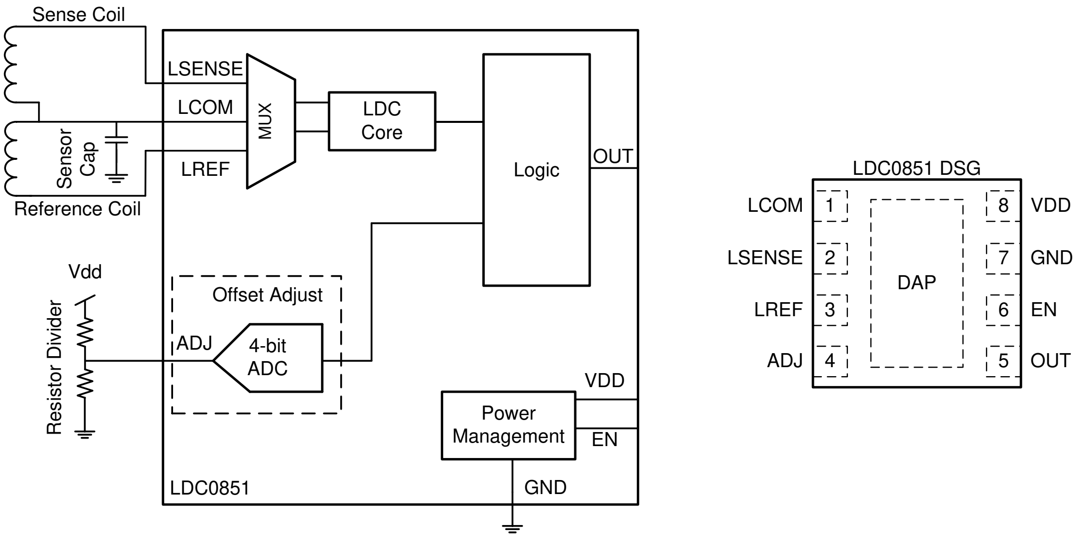

Figure 3. LDC0851 Functional Block Diagram and Pinout

The LDC0851 has two sensing channels: LREF and LSENSE. When the inductances on the LSENSE and LREF channels differ by a preconfigured ratio (ϰ , determined by the voltage level on the ADJ pin) the part toggles its digital output. A simplified view of the LDC0851 operation is shown in Figure 4.

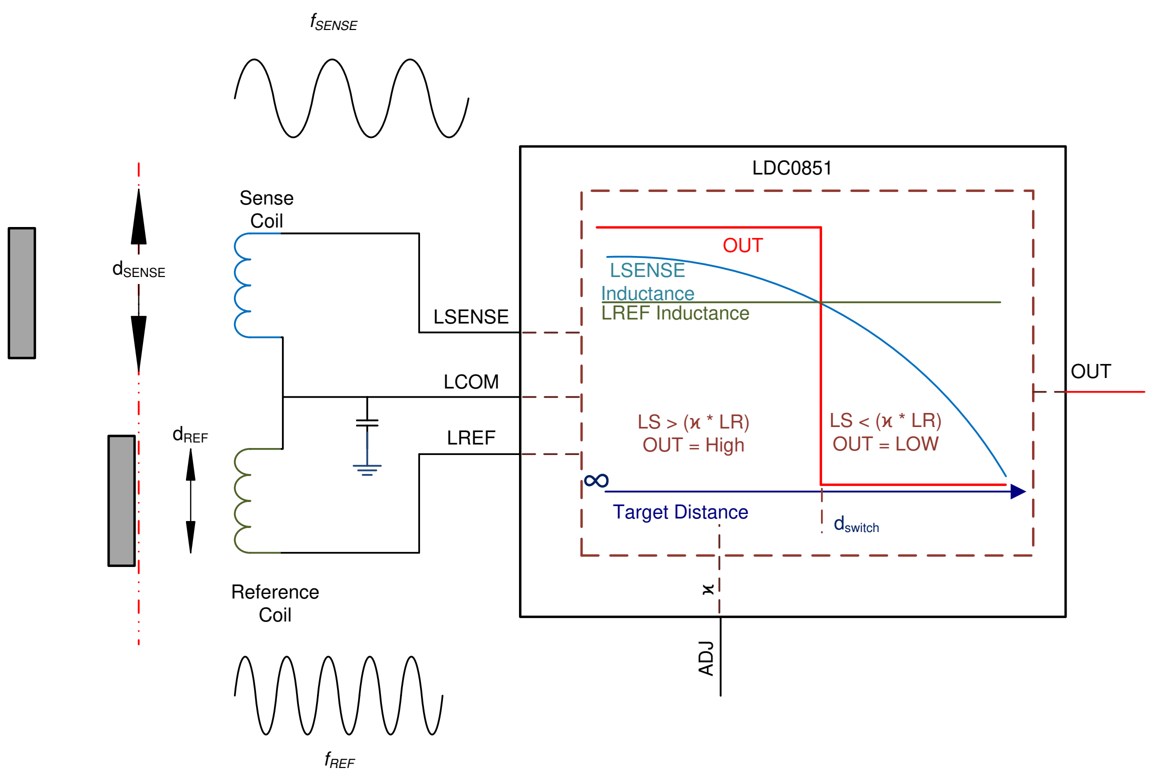

Figure 4. LDC0851 Operating Principle

2 Off to Prototyping – The Three Cs

The LDC0851 EVM is a great prototyping tool. It is available to order online and provides an excellent starting point for any LDC0851 application. A picture of the LDC0851 EVM is shown in Figure 5.

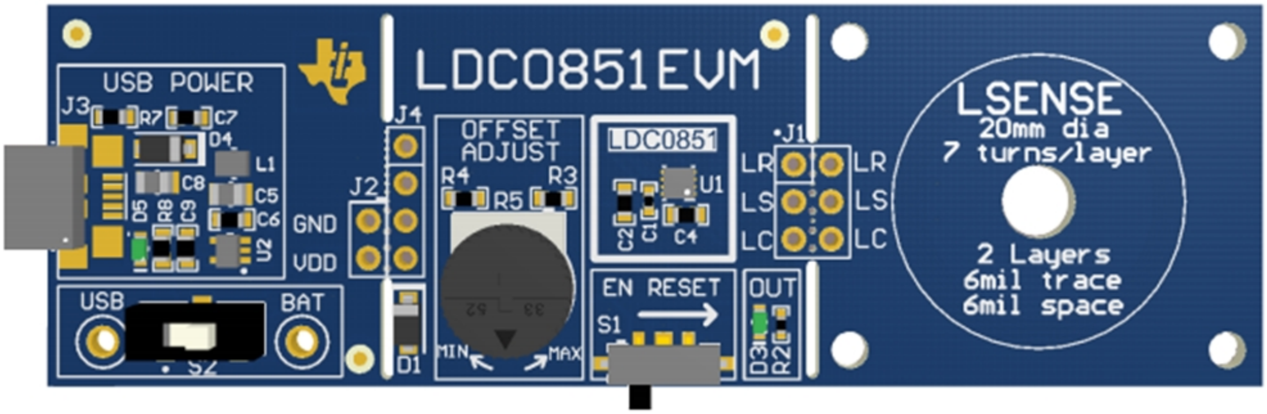

Figure 5. LDC0851 EVM

The LDC0851 EVM comes with a 20-mm diameter sensing coil in a stacked coil configuration (explained in Section 2.1) and an onboard potentiometer that can be used to set different switching thresholds (explained in Section 2.2). The stacked coil sensor can be snapped off and replaced with any other LDC0851 compatible sensor. For more information on the LDC0851 EVM, refer to the *LDC0851EVM User's Guide* (SNLU194).

The next few sections discuss designing and verifying a custom LDC0851 Proximity Sensing System.

2.1 Step 1: Choose the Sensors

Before beginning to prototype with the LDC0851, there are some key system considerations that need to be kept in mind. Starting off, it is important to know the switching distance — this is the distance between the sensor and the conductive target where one wants the LDC0851 to switch. The switching distance dictates the Sensor Coil Diameter, which needs to be at least 2.5 times greater than the switching distance for reliable performance. Generally speaking, it is always a good idea to choose the biggest sensor dimensions an application allows. In a few applications, sensor design is restricted by space constraints and smaller sensors are preferred. How small of a sensor a user can use with the LDC0851 is defined by the Maximum Sensor Current listed in the *Electrical Characteristics* table in the *LDC0851 Differential Inductive Switch* data sheet (SNOSCZ7). The Maximum Sensor Current value differs for the 1.8-V and 3.3-V domain, the value being higher at 3.3 V which equates to the LDC0851 being able to support a smaller sensors at higher supply levels.

A LDC0851-compatible sensor can be easily selected by keeping the sensor minimum inductance in mind. At 1.8 V, the minimum sensor inductance is typically around 2.5 µH, while at 3.3 V is around 1.8 µH. **Additionally, it is important to note that the inductance of the sensor goes down to half of the original value when the target is almost touching the sensor.**

Table 1 provides a handy list of small LDC0851 compatible spiral PCB coils sizes and their inductance values in free space.

Table 1. LDC0851 Small Sensor Coil Examples(1)

1.8 V			3.3 V		
PCB LAYERS	SENSOR DIAMETER	SENSOR INDUCTANCE	PCB LAYERS	SENSOR DIAMETER	SENSOR INDUCTANCE
2	10.5 mm	5.2 µH	2	9.5 mm	3.8 µH
4	7.5 mm	5.7 µH	4	6.5 mm	3.6 µH
6	7 mm	5 µH	6	6.5 mm	4.3 µH

(1) The values specified in the table above were calculated with the LDC_Tools Excel spreadsheet using 5-mil trace and space width and a 30% coil fill ratio. There are multiple factors, like number of turns and trace thickness, that affect coil inductance and sensitivity. For more information, refer to sections 2.2, 2.3, and 2.4 of the *LDC Sensor Design* application note (SNOA930).

Matched coils for both LSENSE and LREF channels are recommended for better switching accuracy. Matched coils also increase temperature stability and make it easier to calculate switching thresholds.

After choosing the correct sensing coil, the minimum sensor capacitor required on LCOM can be calculated using Equation 2:

$$C_{TOTAL} = \frac{1}{7126 \times 10^{12} \times L_{SENSOR}}$$

where

- C_{TOTAL} is the sum of the sensor capacitance, the board, and the pin parasitic capacitances on the LCOM channel. (2)

A smaller cap results in a higher resonating frequency and is usually preferred as it enables faster sampling rates. The LDC0851 sampling rate is given by Equation 3:

$$\text{Sampling Rate} = 231 \times 10^{-6} \times f_{Sensor} \tag{3}$$

A subtle point to note here is that higher sensor frequency results in a slight increase in power consumption. A user can accurately estimate LDC0851 power consumption by walking through steps defined in the *Device Functional Modes* section of the *LDC0851 Differential Inductive Switch* data sheet (SNOSCZ7).

Sensor configuration and placement in an application are also very important. LREF and LSENSE coils are usually placed next to each other in a side-by-side configuration. For a cleaner mechanical design or for applications that are space constrained, consider using a stacked coil configuration. A stacked coil configuration places the reference coil right underneath the sense coil, which results in a smaller and more compact sensor footprint.

Figure 6 shows a comparison of the side-by-side and stacked coil configurations:

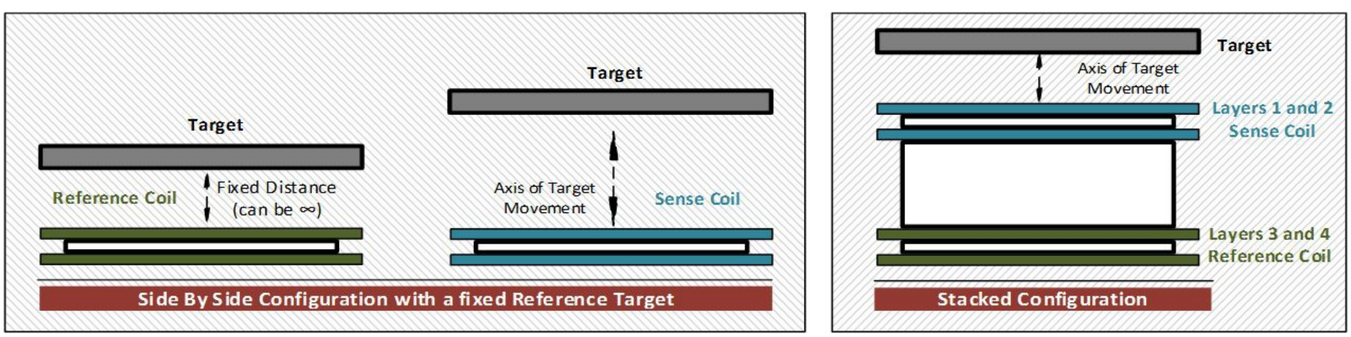

Figure 6. Side-by-Side and Stacked Coil Configurations (PCB Side View)

This section highlighted key considerations for choosing the correct sensor for an LDC0851 application. Before moving to the next step, ensure that the reference and sense sensors, along with the sensor capacitor, are connected correctly as highlighted in Figure 3. The pins VDD and GND should be connected to an appropriate voltage source.

2.2 Step 2: Configure the LDC0851

The LDC0851 can be configured in two operational modes, detailed in the following sections.

2.2.1 Basic Operation Mode

Physical Object used to define Switching Threshold

This is by far the simplest method of configuring the LDC0851, and works well in applications like door open and close and event counting. This configuration is also recommended for applications requiring precise switching performance over temperature.

For this mode, ensure that the ADJ pin is grounded before enabling the part.

Select a metal target and place it in front of the LREF sensor separated by a distance d_{REF}. The fixed metal target results in a fixed inductance for the LREF channel. When the movable metal target comes close enough to the LSENSE coil such that the LSENSE channel inductance drops below the fixed inductance of the LREF channel, the output of the LDC0851 switches low.

In this configuration, the d_{REF} is the switching distance for the LDC0851.

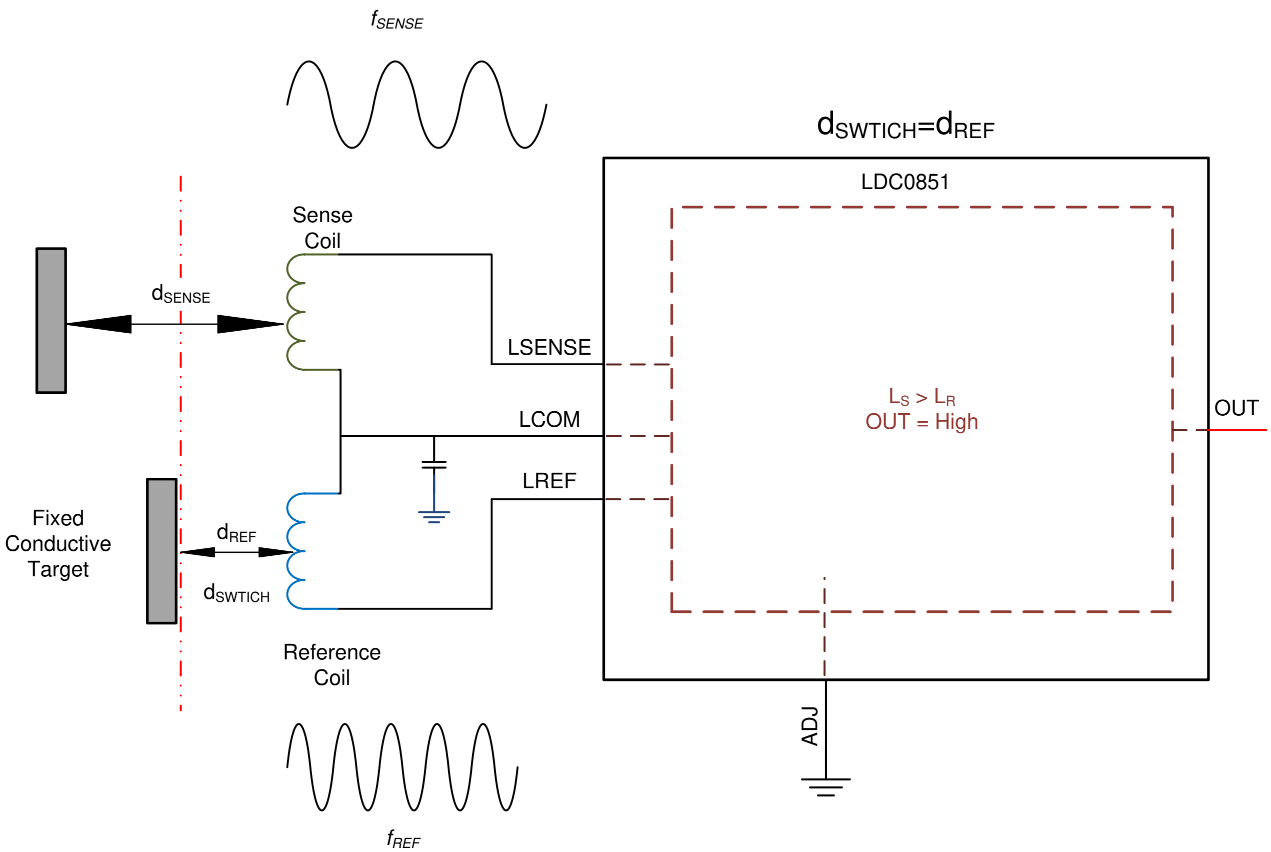

Figure 7. Basic Operation Mode

2.2.2 Threshold Adjust Mode

ADJ pin used to define Switching Threshold

This mode is useful when placing a fixed physical object in front of LREF is impractical, or if there are space constraints in the application. Stacked coil configurations are primarily used in Threshold Adjust Mode.

For this mode, ensure that the LREF is not obstructed by any conducting object.

Choose an appropriate switching distance and calculate the ADJ code (ζ, $1 \le \zeta < 16$) needed from Equation 4:

$$d_{SWITCH} = d_{COIL} \times 0.4 \times \left(1 - \frac{\zeta}{16}\right) \tag{4}$$

where

- d_{COIL} is the diameter of the sensing coil

Set the ADJ level to the voltage corresponding to the ADJ code (ζ, $1 \le \zeta < 16$), which can be calculated from Equation 5:

$$ADJ_{LEVEL} = \frac{V_{DD}}{32}(\zeta + 1) \tag{5}$$

It is important to remember that Equation 5 gives the center of the voltage range for each code ($1 < \zeta < 16$).

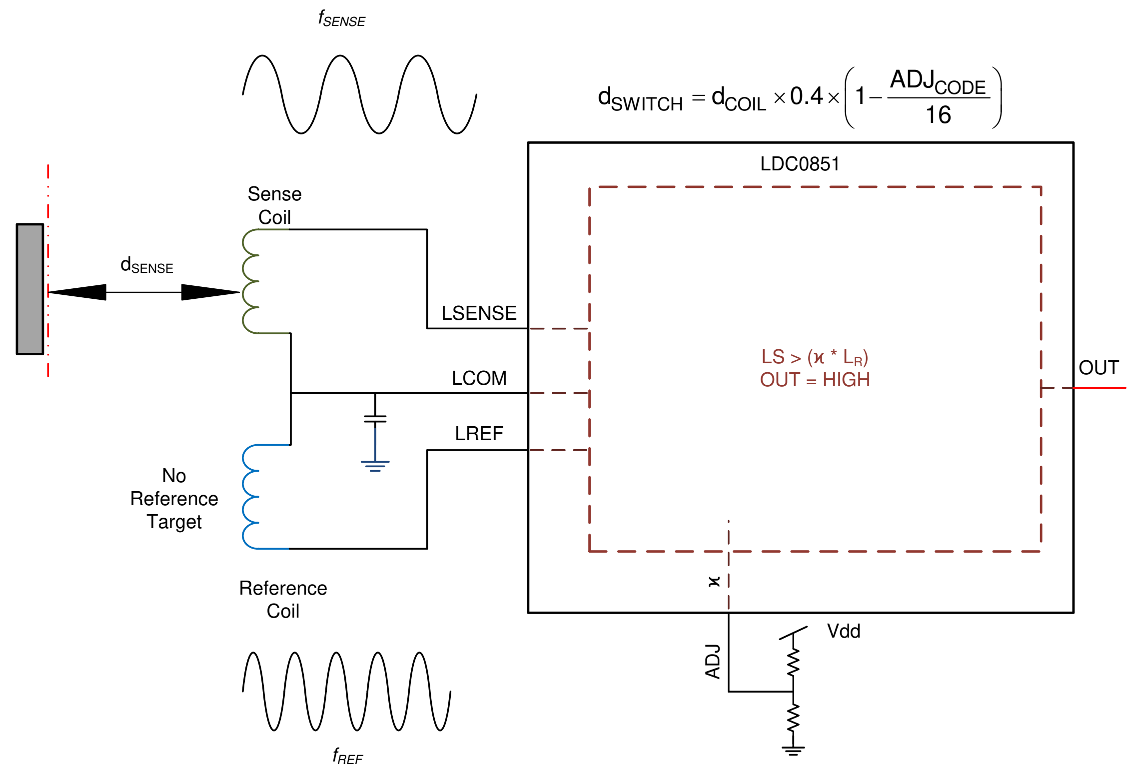

Figure 8. Threshold Adjust Mode

2.3 Step 3: Calibrate and Verify the Setup

The previous two sections talked about choosing the correct sensor and the appropriate operational mode for an application. If the directions were followed correctly, the remaining steps are trivial.

Enabling the part and bringing a conductive target close to the LSENSE coil beyond the switching threshold now makes the OUT pin toggle low. Rarely, due to small mismatches in the sensors on LREF and LSENSE or the cables/traces connecting them to the LDC0851, the switching threshold may vary slightly. To tweak the switching threshold, users can try different ADJ levels while taking into account the following:

- The farthest switching distance is obtained with ADJ code 0 (ADJ pin grounded), while the closest switching distance is obtained with ADJ code 15.
- The max sensing distance must always be limited to 0.4x the sensor coil diameter. The enable pin needs to be toggled every time the ADJ level is changed.

Equation 4 must provide a good estimation of the switching thresholds for verification purposes. Figure 9 below shows an example of switching characteristics with a plot of switching distance versus ADJ code for a 10-mm spiral PCB inductor. The data was collected using the LDC0851 EVM and a custom PCB coil in Threshold Adjust mode with the LREF and LSENSE sensors in a side-by-side configuration. During the measurement, no target was present in front of the LREF sensor and the threshold was adjusted using the EVM's onboard potentiometer.

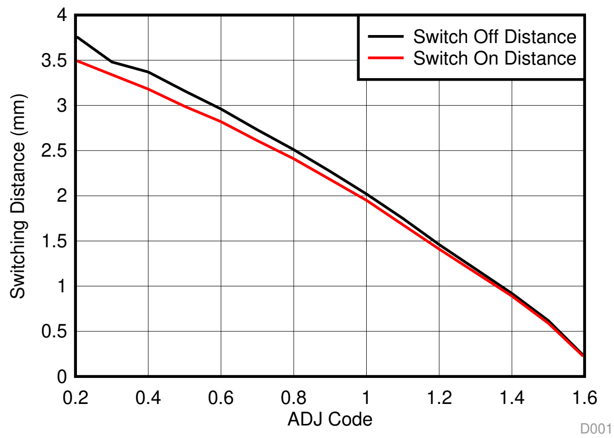

Figure 9. Threshold Adjust Mode Switching Performance

3 Summary

This document highlighted the simplicity of prototyping a proximity sensing solution with the LDC switch. The LDC0851 can support an enormous amount of applications some of which may require a little more effort. Detailed design procedures and all the necessary information about the switching characteristics of the LDC0851 are included in the data sheet.

4 References

1. Texas Instruments, *LDC Sensor Design* Application Report
2. Texas Instruments, *LDC0851 Differential Inductive Switch* Data Sheet
3. Texas Instruments, *Inductive Sensing Design Calculator Tool*
4. Texas Instruments, *LDC0851EVM User's Guide*

Revision History

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

Changes from Original (March 2016) to A Revision **Page**

- Changed LDC1000 to LDC100x throughout 1
- Removed references to the webench tool now unavailable on ti.com 1
- Fixed equation 2
- Changed equation 2........ 5
- Added the *LDC0851EVM User's Guide* to the *References* section 8

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265