TI Designs
LDC0851 Event-Counting Design Guide

Design Overview

An event counting design that is inductive sensing-based provides a robust and low-cost interface for speed measurement and event counting applications. The TIDA-00851-LDC0851 design reliably operates in environments that have dirt, moisture, or oil, which usually pose challenges for alternate sensing technologies. This solution does not require magnets.

Design Resources

TIDA-00851-LDC0851	Design Folder
LDC0851	Product Folder
MSP430F5528	Product Folder
LP5951	Product Folder
LP38693	Product Folder
TPD2E001	Product Folder

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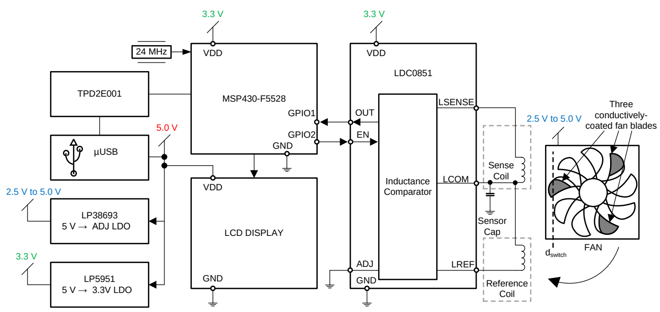
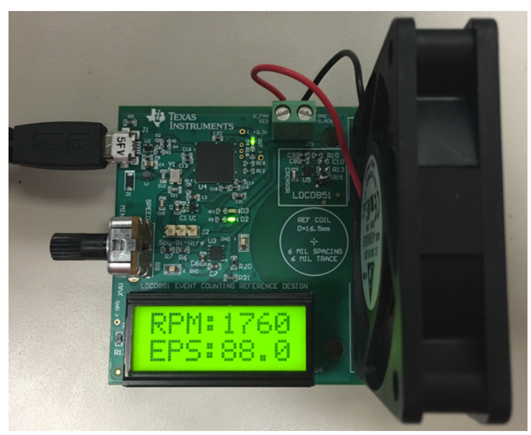
Design Features

- Highly Reliable, Contactless Event Counter Using LDC Technology
- No Calibration Required
- 1.71- to 3.6-V Operation
- Power Consumption < 1.5 mA (Excluding MCU, LDC, and Fan)
- Measurement > 300 Events per Second
- Minimal MCU Memory and Instructions:
  - 290 Bytes of RAM
  - 800 Bytes of ROM and Flash

Featured Applications

- Gear Tooth Counting
- Wheel Speed Sensing
- Flow Meters
- Fan Speed Sensing
- Motor Speed and Position Sensing





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1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
Module physical dimensions	90 mm × 68 mm × 68 mm
PCB dimensions	90 mm × 68 mm
Sensor geometry	Two PCB coils (side-by-side arrangement): Ø = 16.5 mm Layers = 2
Target	Copper tape: 9 mm × 17 mm at widest points
Measurement accuracy	> 99.9% at 260 events per second
Target to sensor distance	3 mm
Average LDC current consumption (including sensor current)	< 1.5 mA at 3.3 V
Total current consumption (including MCU, LCD, and fan at minimum fan speed setting)	130 mA at 5.0 V
Total current consumption (including MCU, LCD, and fan at maximum fan speed setting)	180 mA at 5.0 V
LDC operating temperature	–40°C to 125°C

2 System Description

Event counting solutions are used to detect the speed and calculate the position of motors, fans, flow meters, or gears. In the past, such event counting applications have been implemented using Hall effect or optical sensors. Hall effect-based systems are costly because of the material and assembly costs of the magnet. Alternate solutions using optical sensors can be affected by dirt and dust, which pose lifetime issues in many automotive and industrial applications.

Inductive sensing technology is also contactless, but does not require the use of magnets and is also unaffected by dirt or dust. Inductive sensing technology is a durable approach to event counting and offers many additional advantages such as repeatable switching thresholds and immunity to environmental factors such as humidity and temperature. Furthermore, this technology is extremely resistant to harsh environments and can even be implemented as a water-resistant solution. The TIDA-00851-LDC0851 design offers a low-cost and robust solution for such purposes as implementing gear tooth counting, motor speed detection, fan speed detection, or similar event counting applications in various industrial, consumer, and automotive applications.

Most inductive sensing designs use a sensor target that is arranged in parallel to the sensor coil. The TIDA-00851-LDC0851 reference design shows that the exceptional performance and sensitivity of the LDC0851 make it possible to design systems in which the target is perpendicular to the sense coil, thereby lowering the sensor coil exposure to the target by much lower than in traditional systems.

In inductive sensing applications, the sensor coil inductance increases or decreases with respect to the relative position of a conductive target. The sensor frequency increases when the target approaches the sensor coil and this increase is caused by a decrease in inductance. The targets consist of copper tape pieces, which have been secured to the fan blades and move over the coil as the fan rotates.

A 5-V USB connection supplies the power and is regulated to a 3.3-V supply for the microcontroller (MCU) and the LDC0851 device and to an adjustable voltage for the fan.

Figure 1 shows an overview of the TIDA-00851-LDC0851 printed-circuit board (PCB).

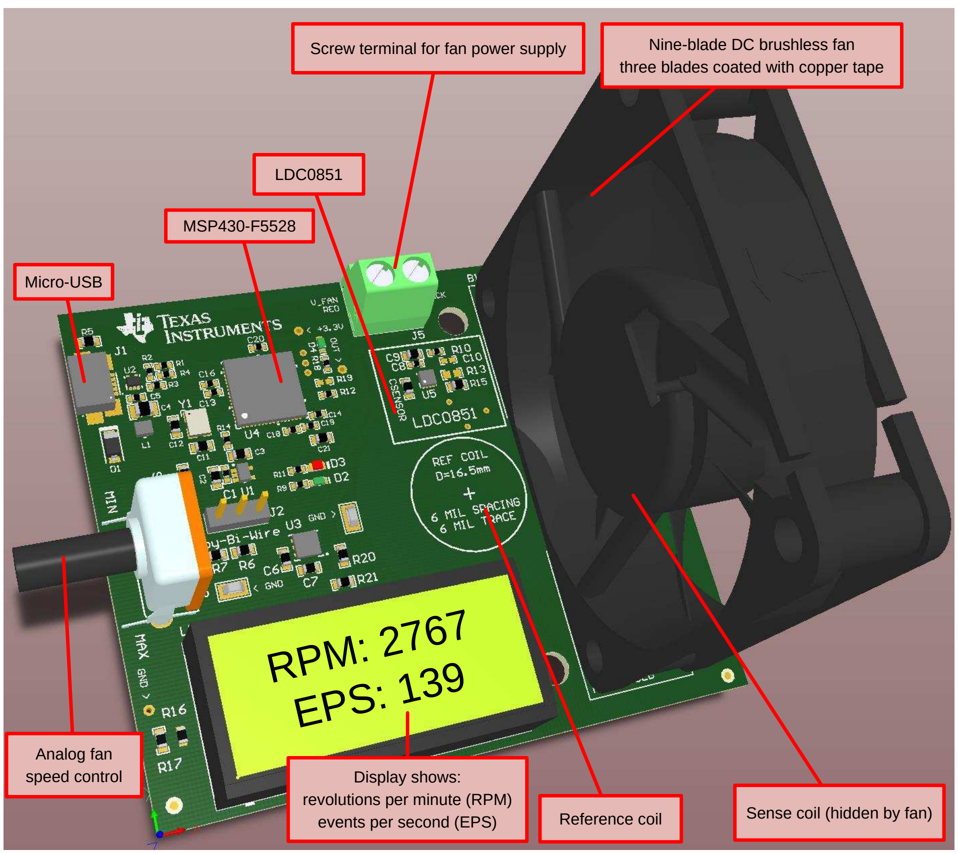

Figure 1. TIDA-00851-LDC0851 PCB Overview

The TIDA-00851-LDC0851 reference design comprises a sensor PCB (containing all of the electrical components), a liquid-crystal display (LCD), and a DC brushless PC fan.

Three of the nine fan blades (symmetrically spaced) have been coated with copper tape and function as targets for the inductive sensor.

2.1 LDC0851

The LDC0851 inductive switch compares the sensor coil inductance to the reference coil inductance to determine when a target comes into proximity of the sensor coil. When the difference in the inductances crosses a threshold, the LDC0851 signals that an event has occurred.

2.2 MSP430F5528

The MSP430F5528 MCU treats each high-low transition of the LDC0851 output as an interrupt and counts these events. This MCU calculates the speed at which the fan moves and displays the results in revolutions per minute and events per second. At one instance per second, the MCU updates the LCD as appropriate.

2.3 LP5951

The LP5951 is a low dropout (LDO) regulator that converts the 5 V provided from the USB interface to 3.3 V for use as the main supply for the TIDA-00851-LDC0851 reference design.

2.4 LP38693

The LP38693 is an adjustable LDO that provides a user-adjustable power supply between 2.5 V to 4.7 V to control fan speed. The LDO output voltage can be controlled through the potentiometer R8.

2.5 TPD2E001

The TPD2E001 is an electrostatic discharge (ESD) protection array that protects the digital inputs of the MSP430F5528 MCU that attach to the USB interface.

3 Block Diagram

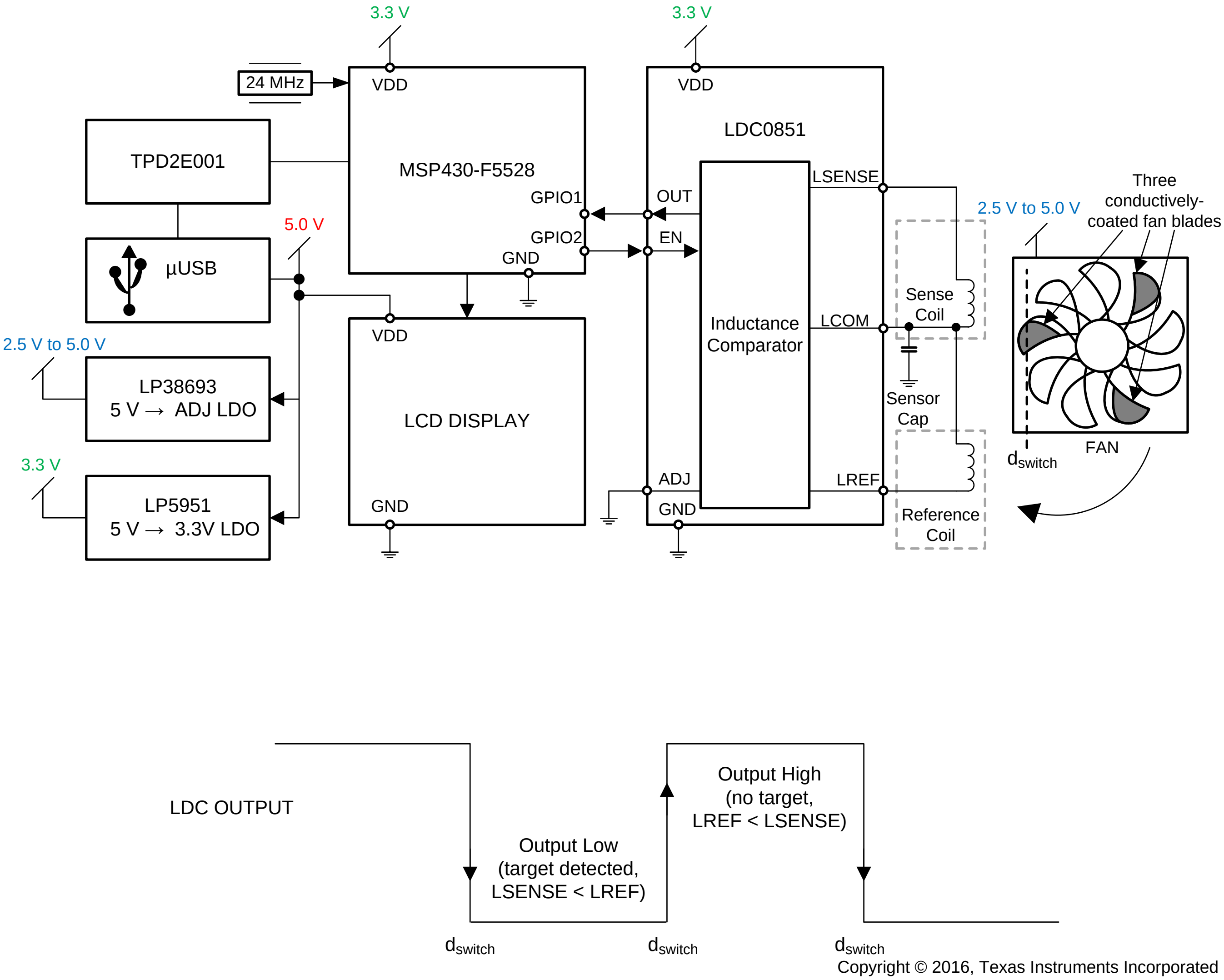

Figure 2. TIDA-00851-LDC0851 System Block Diagram

3.1 Highlighted Products

3.1.1 LDC0851

The LDC0851 is an inductive switch that is ideal for contactless and robust applications such as motion detection, event counting, and coarse position detection. A remote sensing coil and reference coil provide highly reliable and accurate switching over temperature without the requirement for calibration in production.

4 Getting Started

The operation of TIDA-00851-LDC0851 reference design is simple: Connect a micro-USB cable into the J1 pin of the TIDA-00851-LDC0851 board and connect the other end of the cable to a PC or a powered-USB hub, as Figure 3 shows.

Place the PCB on a non-metallic table during operation and take care to avoid touching the sense coil or the reference coil.

The LCD indicates the speed of the fan. On the top line, the display shows the speed in revolutions per minute (RPM). The bottom line shows the detected events per second (EPS). The fan speed is controlled by the analog speed control knob (R8), which runs at approximately 900 RPM at the lowest speed position and 2900 RPM at the highest position.

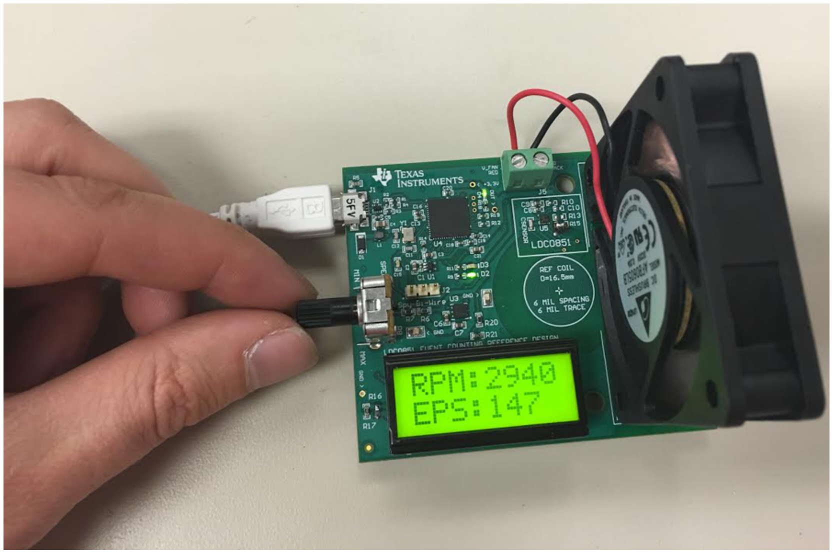

Figure 3. TIDA-00851-LDC0851 Powered by USB Connection

Three of the nine fan blades have been coated with conductive material and function as targets for the LDC0851 device (see Figure 4). The algorithm assumes that three events occur during one fan revolution. An event occurs whenever one of the targets (coated fan blade) passes the sense coil and triggers an interrupt. At speeds below 30 events per second, observing each event that has been detected by the LDC0851 is possible on the D4 light-emitting diode (LED).

Figure 4. Three Fan Blades Coated With Conductive Material (Copper Tape)

If the rotational speed drops below one event per second (20 RPM), then the display shows a “No event detected” message (see Figure 5). This drop in speed can occur if:

- The fan power supply cables are not connected to J5 or they are swapped around
- An object physically prevents the fan from moving
- Interfering metal is within two coil diameters away from either the sense coil or the reference coil
- The user is significantly changing the sensor capacitance by touching the PCB either near the sense coil or near the reference coil

Figure 5. Detected Speed After Dropping Below One Event per Second

5 System Design Theory

5.1 Inductive Sensing Theory of Operation

An AC current which flows through an inductor generates an AC magnetic field. If a conductive material, such as a metal object, is placed into the vicinity of an 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 its own magnetic field, which opposes the original field generated by the sensor inductor. By opposing the original field, the original field weakens, which produces a reduction in inductance compared to the free space inductance of the inductor.

This effect is equivalent to a set of coupled inductors, where the sensor inductor is the primary winding and the eddy current in the target object represents the secondary inductor. The coupling between the inductors is a function of the sensor inductor and the conductive material resistivity, distance, size, and shape. The resistance and inductance of the secondary winding caused by the eddy current can be modeled as a distance dependent resistive and inductive component on the primary side (coil). Figure 6 shows a simplified circuit model of the sensor and the target as coupled coils.

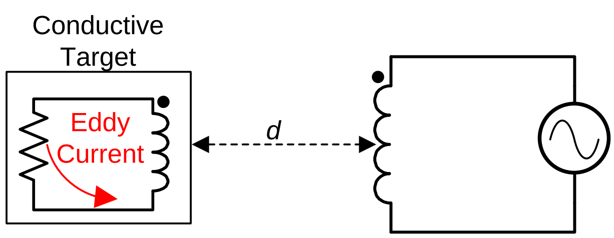

Figure 6. Conductor in AC Magnetic Field

An electromagnetic (EM) field appropriate for sensing can be generated using an LC resonator. Equation 1 approximately calculates the resonant frequency of a single-ended LC (inductor-capacitor) oscillator, such as the LDC0851:

$$f_{SENSOR} = \frac{1}{\pi \times \sqrt{2 \times L_{SENSOR} \times C_{SENSOR}}} \quad (1)$$

where

- f_{SENSOR} is the resonant sensor frequency in Hz
- L is the parallel inductance in H
- C is the parallel capacitance in F

As the conductive target approaches the sense coil, its inductance change causes a change in sensor frequency. This sensor frequency change can be measured by an inductance-to-digital converter or the change can be compared to the sensor frequency of a reference coil in an inductive switch, such as the LDC0851.

To learn more about inductive sensing, visit the following: www.ti.com/ldc.

5.2 LDC0851 Operation

The LDC0851 is an inductance comparator with a switch output (see Figure 7). The LDC0851 device utilizes a sensing coil and a reference coil to determine the relative inductance in a system. The push and pull output (OUT) switches low when the sense inductance drops below the reference and returns high when the reference inductance moves higher than the sense inductance. Hysteresis has been included to prevent false switching as a result of noise or mechanical vibration at the switching threshold. The switching threshold is set by the sensor characteristics and proximity to conductive objects. The LDC0851 also features a threshold adjust mode where an offset is subtracted from the reference inductance.

The sensing coil is connected across the LSENSE and LCOM pins and the reference coil is connected across the LREF and LCOM pins. A sensor capacitor is connected from LCOM to GND to set the sensor frequency.

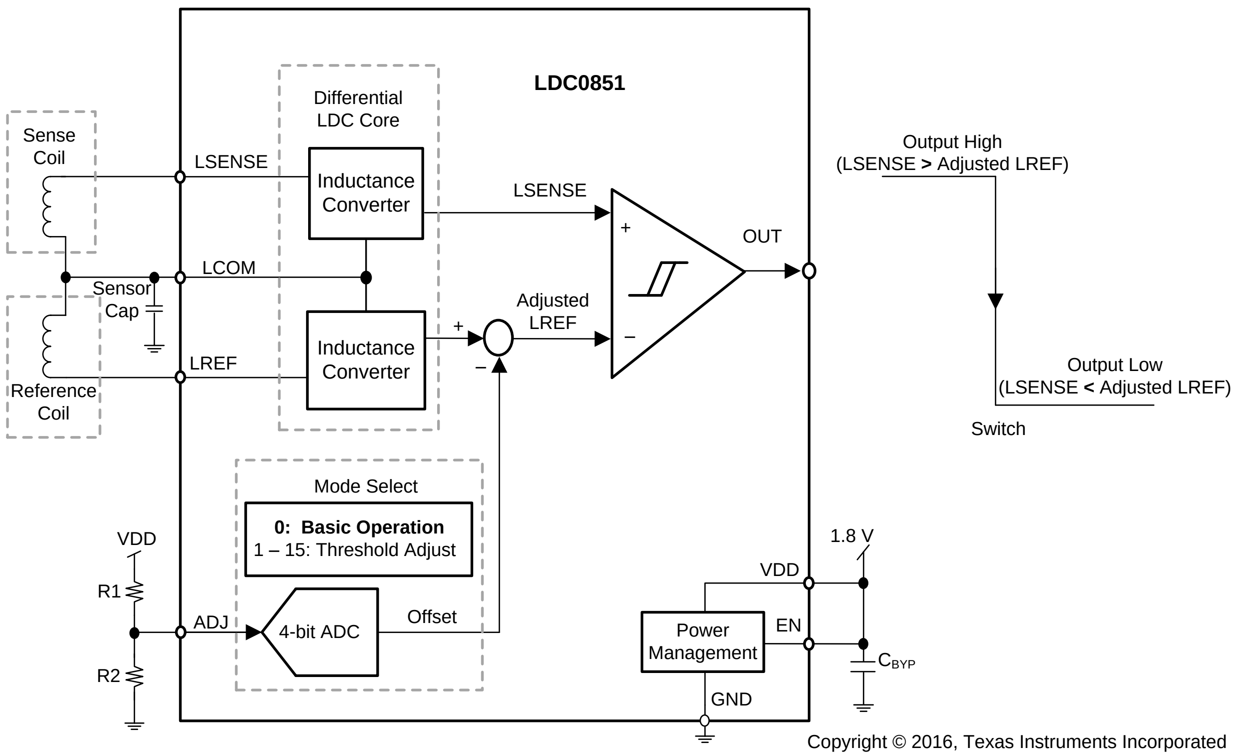

Figure 7. LDC0851 Functional Block Diagram

The LDC0851 has a built-in hysteresis. Without threshold adjustment, the output switches on when the sense coil inductance drops 0.4% below the reference coil inductance and returns to the off state if the sense coil inductance exceeds the reference coil inductance by at least 0.4%, as Figure 8 shows. The threshold adjustment can be disabled by tying the ADJ pin to GND, which sets the ADJ code to 0.

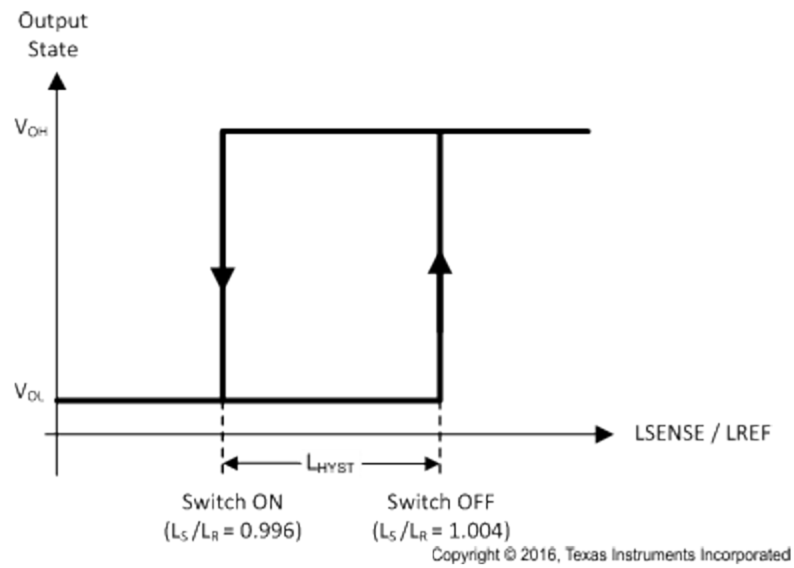

Figure 8. LDC0851 Hysteresis Levels

Alternatively, the hysteresis can be expressed in terms of sensor frequency:

- The output switches on when the sense coil frequency exceeds the reference coil frequency by at least 0.2%
- The output switches off if the sense coil frequency drops below the reference coil frequency by at least 0.2%

Table 2 summarizes the inductance and frequency requirements.

Table 2. Switching Levels Including Hysteresis for Systems Without Threshold Adjustment (Code 0)

OUTPUT SWITCHES TO	INDUCTANCE REQUIREMENT	FREQUENCY REQUIREMENT
GND (target detected)	≥ 0.4% below reference inductance	≥ 0.2% above reference frequency
V_{DD} (no target detected)	≥ 0.4% above reference inductance	≥ 0.2% below reference frequency

5.3 Sensor Design Procedure

The LDC0851 relies on two externally placed sensors for proper operation. Use the following procedure for sensor design:

1. Determine operating mode and set switching point
2. Determine the outer coil diameter
3. Determine coil inductance and sensor capacitor
4. Design sensor and reference coils

5.3.1 Determine Operating Mode and Set Switching Point

Because the LDC0851 has a built-in hysteresis, guaranteeing that the output releases when the target moves away from the sense coil is necessary. Use one of the three following approaching to set the switching point for proximity sensing:

1. Configure the LDC0851 device for basic operation mode by placing a conductive target at a fixed distance from the reference coil. The output switches when a conductive target approaches the sense coil (connected to the LSENSE pin) and reaches the same distance set by the fixed reference target. For reliable and repeatable switching, TI recommends to place the reference target at a distance less than 40% of the coil diameter from the reference coil. The basic operation mode can be used for a wide variety of applications including event counting or proximity sensing.
2. Configure the LDC0851 device for threshold adjust mode by setting a voltage (between V_{DD} / 16 to V_{DD} / 2) on the ADJ pin, which may be achieved through a simple resistor divider. In the threshold adjust mode, an inductance offset is subtracted from the LREF coil inductance, which effectively changes the switching threshold to LSENSE < (LREF – Offset).
3. Introduce a slight layout mismatch between the sense coil and the reference coil. The user must lay out the PCB such that LSENSE < LREF if no target is present and LREF < LSENSE if the target is present. For example, the layout designer can use shorter traces on LSENSE than on LREF or reduce the LSENSE coil by a half turn. This approach allows for a larger sensing range than if using the LDC0851 device in threshold adjust mode for a given target.

Sensing a target with small surface area such as the edge of a fan can be challenging because of the small amount of inductance shift produced as the target passes by the sensor. Targets with areas greater or equal to the sensor coil area produces the maximum frequency shift and drops 1:1 for ratios less than 100%. The TIDA-00851-LDC0851 design uses the third approach to ensure that a target with such a small surface area can still be sensed at a 3-mm distance in addition to tying the ADJ pin to GND. In the layout, an intentional layout mismatch between the sense coil and the reference coil is introduced.

5.3.2 Determine Outer Coil Diameter

The coil diameter (d_{coil}) must be at least three times larger than the sensing distance (d_{switch}) to ensure reliable operation. Larger coil diameters generally provide a better system design margin.

However, a limitation does exist on the coil diameter. If the coil diameter exceeds the target dimensions, then the relatively small target exposure limits the maximum frequency shift of the sensor. Figure 9 shows the effect of using a target that is smaller than the coil size where a 29-mm coil has been exposed to copper targets of varying sizes. The graph shows that not all target geometries produce the same response. Using larger targets produces significantly higher sensitivity, the effects of which result in either an increased sensing range or improved system accuracy. However, increasing the target diameter significantly past the coil geometries is not beneficial.

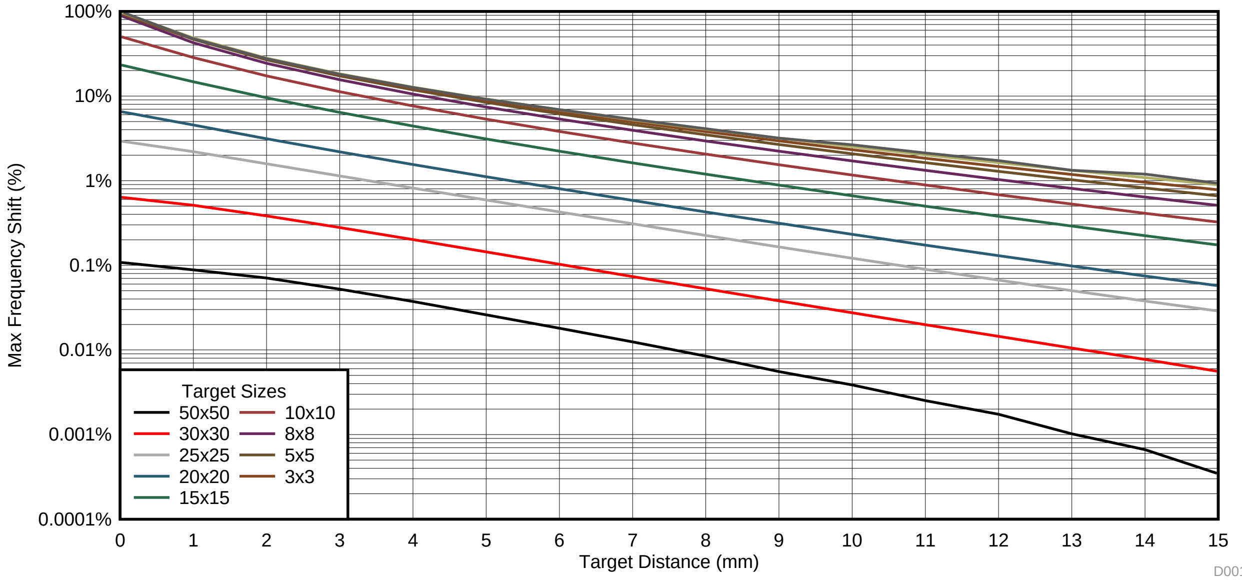

Figure 9. % Maximum Frequency Shift vs Target Distance (in mm)

The target distance in the TIDA-00851-LDC0851 design is 3 mm; therefore, the design requires a minimum coil diameter of 9 mm. The TIDA-00851-LDC0851 design uses a sensor coil with an outer diameter of 16.5 mm, which provides sufficient margin without exceeding the coil diameter or target ratio beyond which the target is too small to sense.

5.3.3 Determine Coil Inductance and Sensor Capacitor

Three restrictions exist on electrical sensor parameters, as taken from the datasheet:

1. The desired sensor frequency (f_{SENSOR}) must be between 300 kHz and 19 MHz. Equation 1 shows that the sensor frequency is determined from the total sensor capacitance (sensor capacitor and parasitic capacitances) and the coil inductance.
2. A minimum total sensor capacitance of 33 pF is required (refer to parameter C_{LCOM_MIN} in the LDC0851 electrical characteristics).
3. The sensor drive current must not exceed 6 mA at a supply voltage of V_{DD} = 3.3 V.

The graph in Figure 10 shows the design space following these requirements.

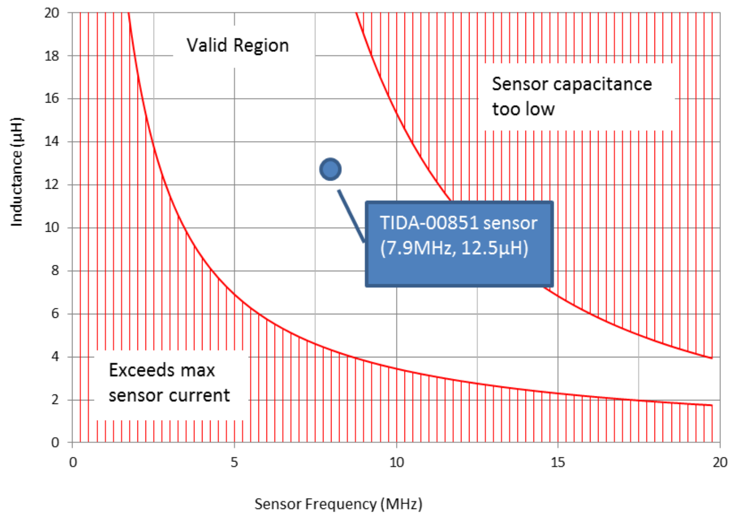

Figure 10. LDC0851 3.3-V Design Space

Estimate the LDC0851 coil inductance by using the LDC calculations tool spreadsheet, as Table 3 shows. The calculated values show that the expected coil inductance of a two-layer coil with an outer coil diameter of 16.5 mm, 6-mm trace feature size, 6-mm trace spacing, and a coil fill ratio of 0.3 is 13.6 µH, which lies in the center of the allowed design space. Note that the spreadsheet provides an estimate and that actual measured inductance is slightly less at 12.5 µH.

Table 3. Coil Inductance Estimate Based on LDC Tools Spreadsheet

LC TANK CALCULATIONS				
PARAMETER	SYMBOL	VALUE	UNIT	DESCRIPTION
Operating temperature	T	25	ºC	Enter operating temperature
Sensor capacitance	C	47.0	pF	Select LC tank capacitance
Layers	M	2	Layers	Number of layers on PCB board (1 ≤ M ≤ 8)
Turns	N	19	Turns	Number of turns per layer
Outer diameter of the inductor	D_{OUT}	16.50	mm	Outer diameter of the spiral inductor
Spacing between traces	s	6.000	mil	Space between traces (mm or mil)
Width of trace	w	6.000	mil	Width of the trace (mm or mil)
PCB thickness between first layer and second layer	h12	58.000	mil	Space between layer 1 and layer 2 (mm or mil)
Copper thickness	t	1.000	Oz-Cu	Copper layer thickness (mm, Oz-Cu, or mil)
Conductor resistivity (at 20°C)	pr	1.68E-08	Ωm	—
Conductor resistivity temperature coefficient	pr_tc	0.393	%/°C	—
Conductor relative permeability	ur	1.00	—	—
Copper resistivity at operating temperature	pr_t	1.713E-08	Ωm	—
Coil fill ratio	D_{IN} / D_{OUT}	0.3	—	0.3 > 0.8 is recommended
Inductor inner diameter	D_{IN}	4.918	mm	—
Self inductance per layer	L	4.491	µH	—
Total inductance	L_{TOTAL}	13.577	µH	—
Coil length per layer	l	639.21	mm	—
DC resistance	R_{DC}	4.141	Ω	—

The next step is to choose the sensor capacitor to obtain an oscillation frequency that is comfortably within the design space requirements. Using Equation 1, the designer can calculate that a 47-pF capacitor, together with a 12-pF L_{COM} pin capacitance and additional PCB trace capacitances, places the expected oscillation frequency into the middle of the design space.

5.3.4 Design Sensor and Reference Coils

The coils have been arranged such that the center of the copper target moves over the center of the sense coil (see Figure 11).

A ground fill keep-out area around the coils ensures that the coils do not sense the ground flood, which can otherwise act as a secondary target and decrease sensitivity. Adding ground traces on either side of the LSENSE and LREF traces improves capacitive matching between coils.

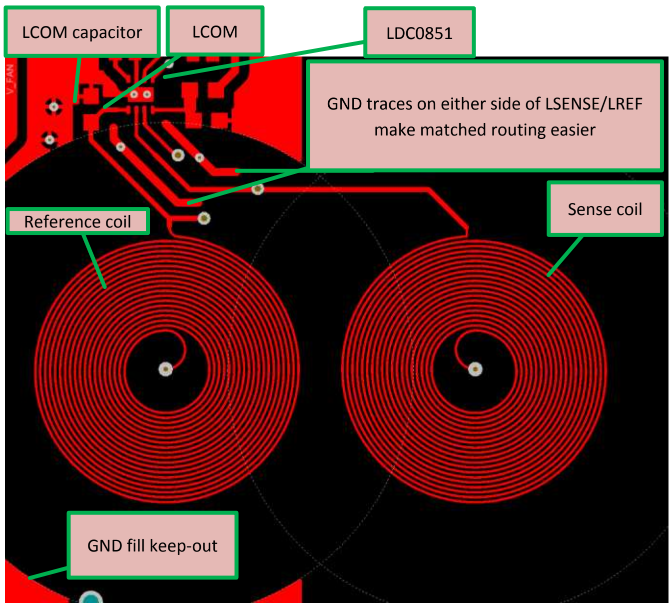

Figure 11. Sensor Configuration

To increase the coil inductance and meet design space limitations, the coil turns have been doubled by using a second PCB layer. To ensure that the inductance increases after adding coil layers are added, the coil has been constructed as shown in Figure 12. Refer to the *LDC Sensor Design* application report for further information on how to design sensor coils (SNOA930).

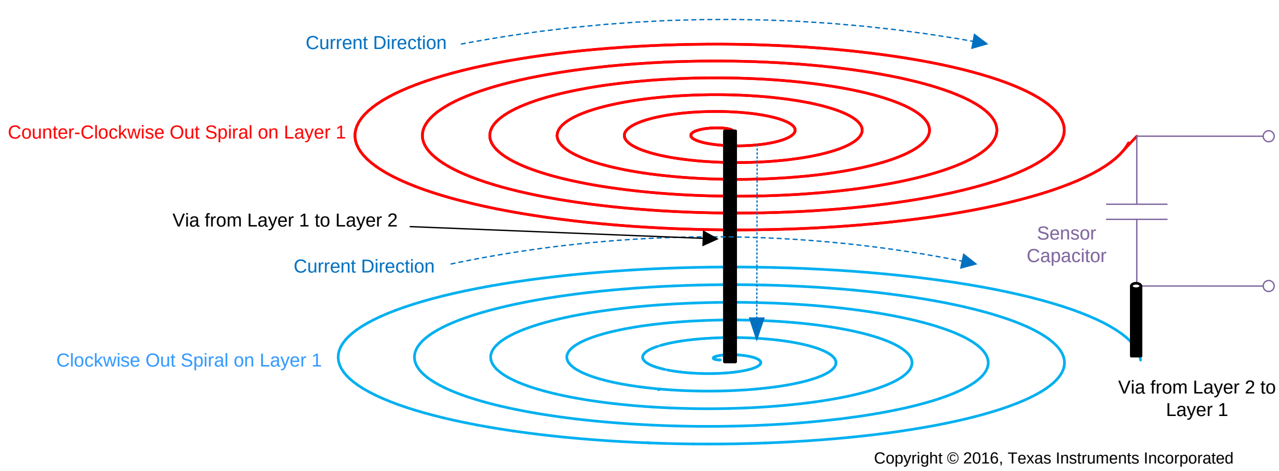

Figure 12. Two-Layer Inductor Physical Construction

5.4 System Electrical Characteristics

5.4.1 Sensor Electrical Characteristics

An impedance analyzer was used in this design to measure the sensor characteristics of inductance, quality factor, and series AC resistance over the frequency range of 0.1 MHz to 14 MHz (see Table 4 and Figure 13).

Table 4. Sensor Electrical Characteristics

PARAMETER	SENSOR VALUE (REFERENCE COIL)
Outer diameter	16.5 mm
Inner diameter	5.2 mm
Number of turns per layer	19
Number of layers	2
Trace width	6 mils (0.152 mm)
Trace spacing	6 mils (0.152 mm)
Trace thickness	1 Oz-Cu (35 µm)
Inductance at 0.1 MHz	12.5 µH
Sensor capacitance (including trace, pin)	65 pF
Sensor capacitance (discrete)	47 pF
f_{SENSOR} (no target)	7.9 MHz
R_p at 8 MHz (no target)	45.3 kΩ
Q at 8 MHz	92
Self-resonant frequency (SRF)	13.8 MHz

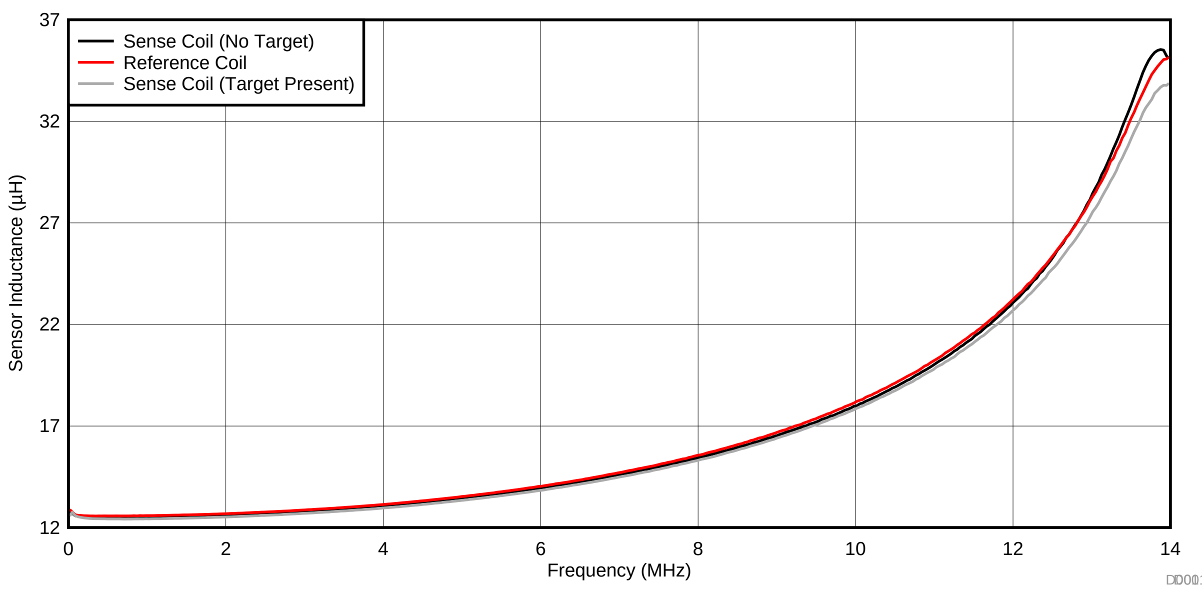

Figure 13. Coil Inductance vs Frequency

5.4.2 Verification of Switching Operation

The switching point occurs when a nearby metal target causes the sense coil inductance to drop below the reference coil inductance, as Figure 14 shows.

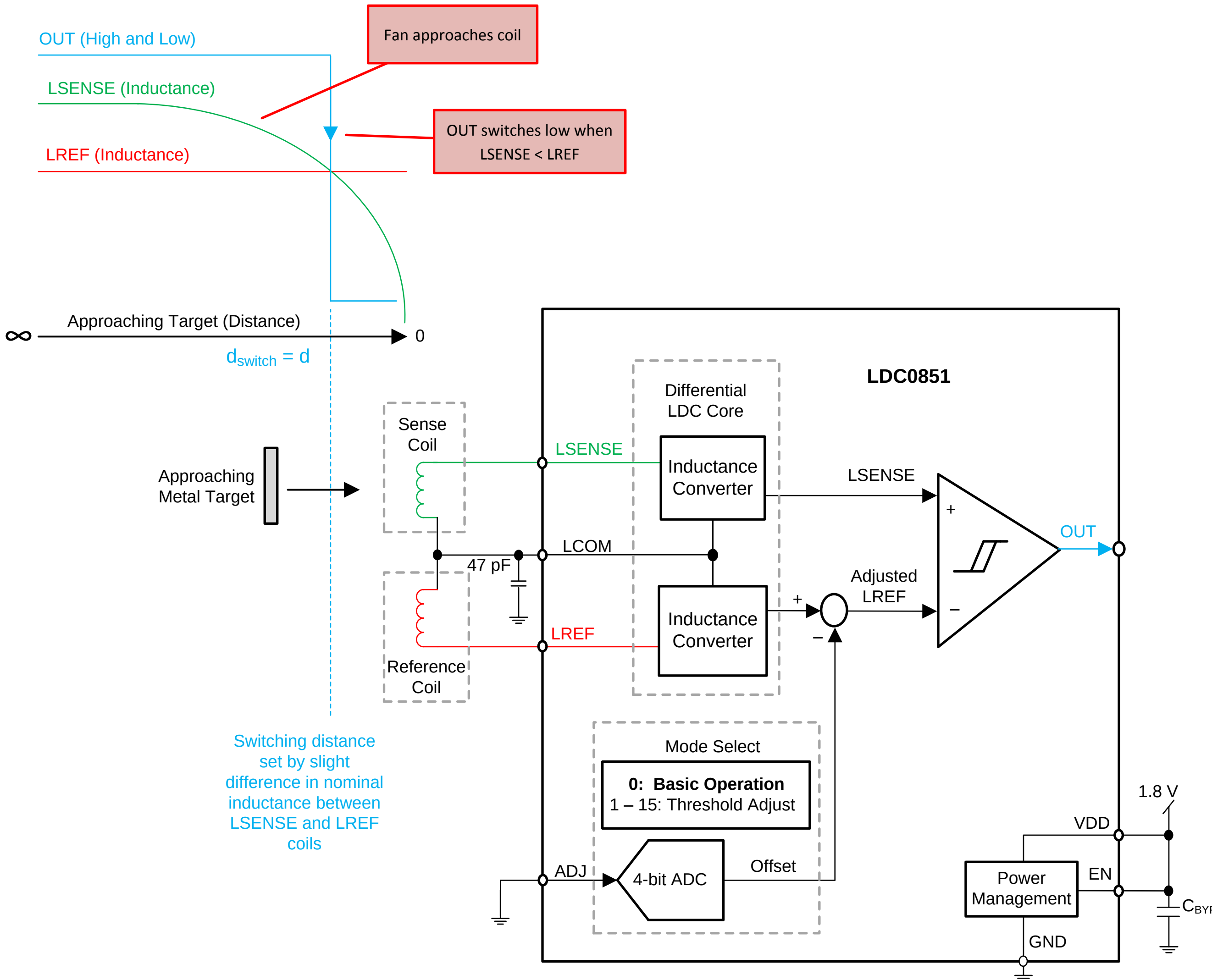

Figure 14. Diagram—Basic Operation Mode for Distance Sensing

With a 47-pF, 1% C0G (NP0) capacitor and PCB parasitics, the coils oscillate at the frequencies as shown in Table 5. The oscillation frequency can be measured with an active oscilloscope probe. The oscillation frequency can also be measured using a passive probe with a series resistor (1 kΩ for example), which isolates the probe capacitance from affecting the sensor oscillation frequency.

Table 5. Relative Frequency Values

CONDITION	FREQUENCY (MHz, MEASURED)	FREQUENCY CHANGE RELATIVE TO REFERENCE COIL
Sense coil (target present)	7.93651	0.32%
Reference coil	7.91139	—
Sense coil (no target)	7.88644	–0.32%

Including hysteresis, the following conditions must be met for systems without threshold adjustment (code 0):

1. To ensure detection of the target, the sense coil (target present) frequency must be at least 0.2% above the reference coil oscillation frequency
2. To ensure release of the output when the target moves away from the sense coil, the sense coil (without target) frequency must be at least 0.2% below the reference coil oscillation frequency

The relative frequency changes from Table 5 satisfy both conditions. Figure 15 shows the switching points of the LDC0851 device for ADJ = 0.

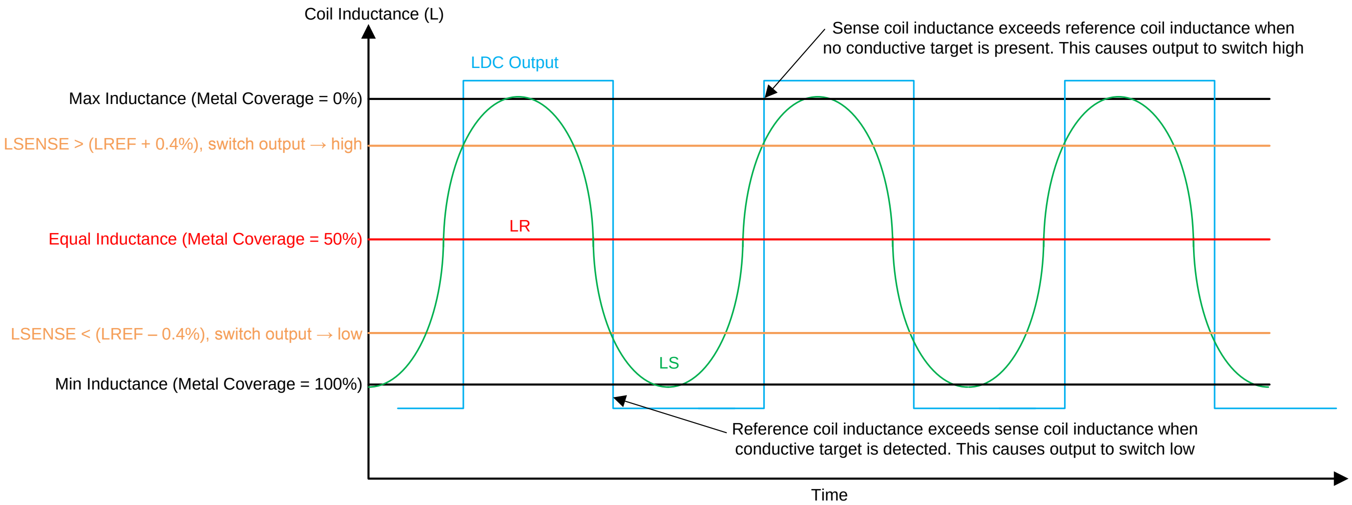

Figure 15. LDC0851 Switching Points (ADJ = 0)

An alternative but equivalent approach is to work out the inductances in each case and ensure to meet the following conditions:

1. To ensure detection of the target, the sense coil (target present) inductance must be at least 0.4% below the reference coil inductance
2. To ensure release of the output when the target moves away from the sense coil, the sense coil (without target) inductance must be at least 0.4% above the reference coil inductance

Measuring the reference coil inductance with an impedance analyzer shows that it is 12.5 µH near DC. With this result, the user can determine the total sensor capacitance, which consists of the LCOM input pin capacitance (from datasheet: 12 pF nominal), the discrete sensor capacitor, and the capacitance of any wires or PCB traces as Figure 16 shows.

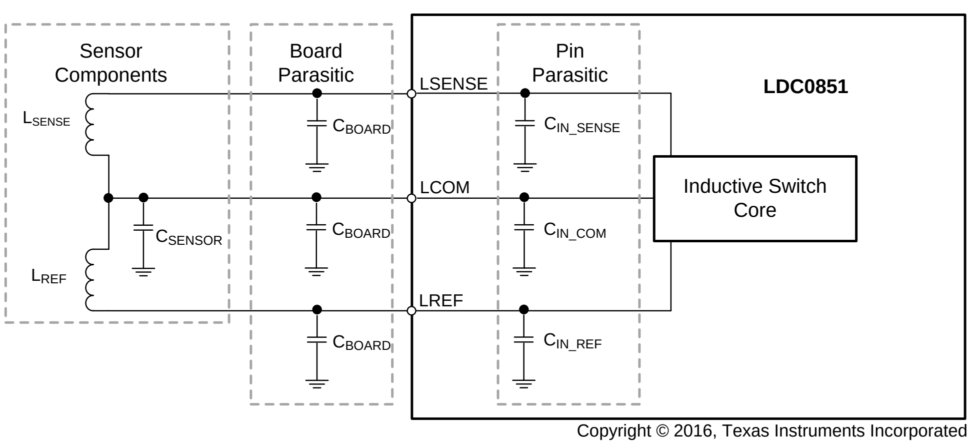

Figure 16. Sensor Capacitance

Measure or calculate the total sensor capacitance using Equation 2:

$$C_{TOTAL} = \frac{2}{(2 \times \pi \times f_{SENSOR})^2 \times L_{SENSOR}} = 64.6\ \text{pF} \quad (2)$$

The user can calculate the precise inductance values for the sense coil with and without target using the value of the total sensor capacitance by plugging the measured frequency values and calculated sensor capacitance into the following Equation 3:

$$L_{SENSOR} = \frac{2}{(2 \times \pi \times f_{SENSOR})^2 \times C_{TOTAL}} \quad (3)$$

The relative inductances in Table 6 meet the criteria of a ±0.4% inductance shift from the reference coil and are therefore adequate for reliable detection.

Table 6. Relative Inductance Values

CONDITION	INDUCTANCE (µH, CALCULATED)	INDUCTANCE CHANGE RELATIVE TO REFERENCE COIL (L_{SENSOR} / L_{REF} %)
Sense coil (target present)	12.45	–0.63%
Reference coil	12.53	—
Sense coil (no target)	12.61	0.63%

5.5 Measurement Accuracy

Two methods were used to verify the accuracy of the TIDA-00851-LDC0851 design: optical verification and Hall-effect verification.

5.5.1 Optical Verification

Rotational speed can be measured with an external digital laser tachometer, such as the CyberTech DT2234A (see Figure 17). During the optical verification test, the tachometer optically measures the speed of the reflective tape adhering to the fan.

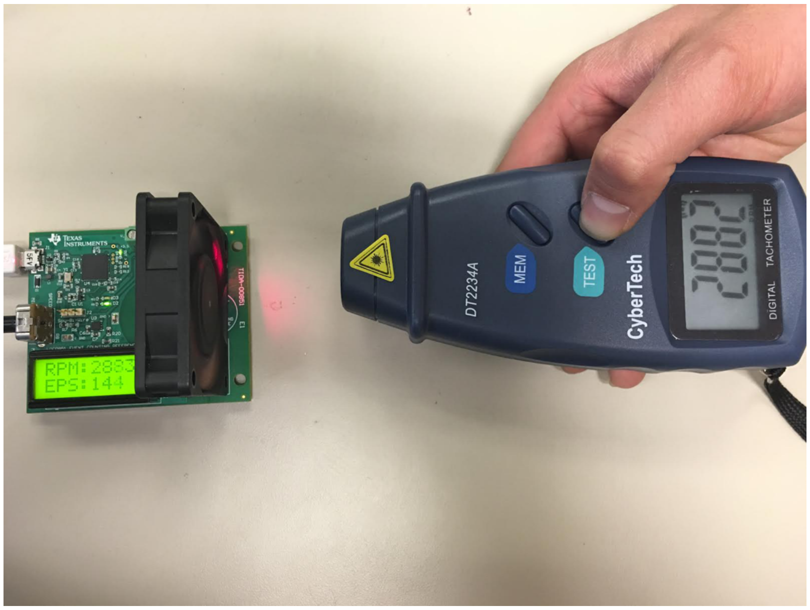

Figure 17. Verification With Optical Tachometer

This measurement provides a quick and reliable way of verifying the rotational speed as it is detected by the LDC0851. However, because the speed of the DC fan fluctuates slightly, a single-point measurement cannot accurately be used to verify the speed.

5.5.2 Hall-Effect Verification

To measure rotational speed accurately with another independent measurement technique, the 5-V fan was replaced with a different model (Delta AFB0612HHB-F00). The AFB0612HHB-F00 is mechanically equivalent to the 5-V fan, but spins faster and also has a built-in Hall-effect based tachometer. The built-in tachometer produces two pulses per revolution, which can be captured on an oscilloscope, as Figure 18 and Figure 19 show.

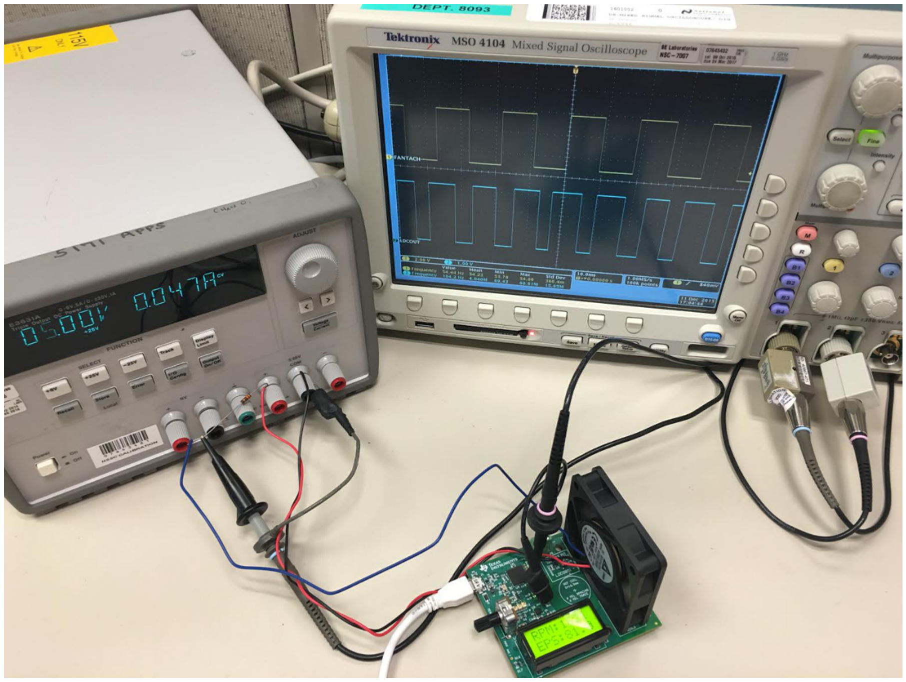

Figure 18. Verification With Hall-Effect-Based Tachometer

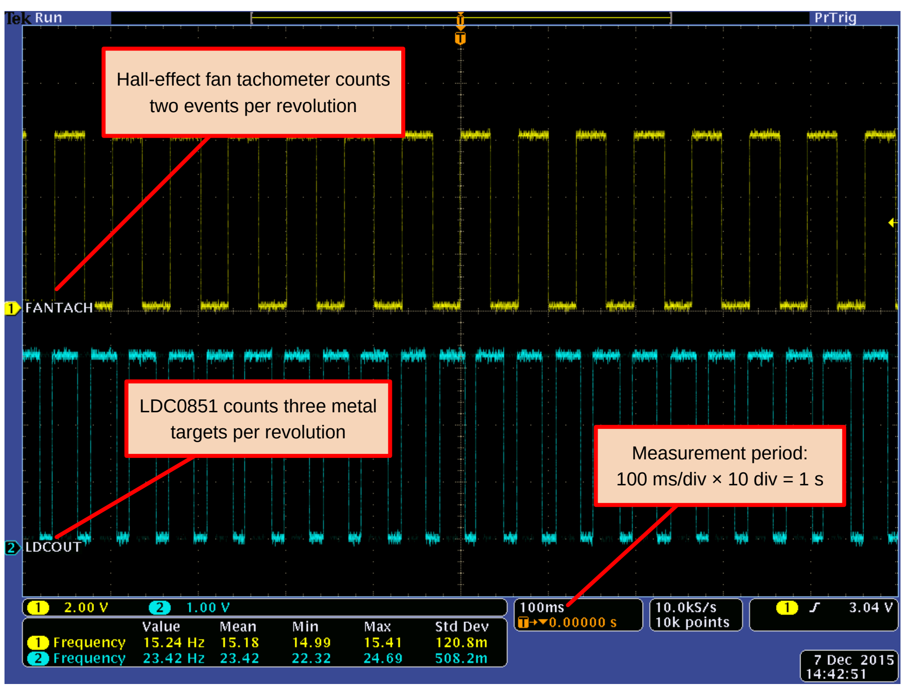

Figure 19. 460 RPM (23 Events per Second) With Hall-Effect Based Verification

Table 7 shows the system accuracy of the design over different rotational speeds. For this measurement, the event count of the LDC0851 output (over a 100-s period) was compared with the event count of the fan tachometer.

Table 7. Measurement Accuracy

PARAMETER	FAN V = 3.0 V	FAN V = 5.0 V	FAN V = 15.0 V	FAN V = 18.0 V	UNIT
Measurement setup					
Measurement period	100	100	100	100	s
Samples captured	0.1	0.1	1.0	1.0	Msamples
LDC0851 output					
Events per revolution	3	3	3	3	—
Events detected	2412	7815	26300	29510	—
Rotational speed	24.1	78.2	263.0	295.1	eps[(1)]
	482.4	1563.0	5260.0	5902.0	RPM
Fan tachometer					
Events per revolution	2	2	2	2	
Events detected	1608	5210	17549	19834	
Rotational speed	482.4	1563.0	5264.8	5950.2	RPM[(2)]
Accuracy					
System accuracy (difference between fan tachometer measurement and LDC0851 measurement)[(3)]	> 99.9	> 99.9	> 99.9	99.2	%

(1) eps = Events per second: events detected / measurement period
(2) RPM = 60 × Events detected / (events per revolution × measurement period)
(3) System accuracy = 1 – (Rotational speed (LDC OUTPUT) / rotational speed (FAN TACHOMETER))

The data shows that an accuracy of greater than 99.9% can be achieved with up to 263 events per second (equivalent to 5260 revolutions per minute if three fan blades have been conductively coated). Above this speed, events can still be detected, but accuracy decreases. To further increase the maximum rotation speed, the designer must employ the following techniques:

1. Improve the manufacturing tolerances for the size and placement of the targets.
2. Increase the width of the targets so that during a full rotation the total target exposure is 50%.
3. Decrease the number of targets to one or two. This decrease does not increase the maximum events per second, but does increase the maximum number of revolutions per measurement period that can be measured.

5.6 *Target Optimization*

The target used in the TIDA-00851 design is a piece of copper tape that is attached to the fan blades. The effect that the target has on the magnetic field is dominated by the closest point of the target that moves laterally across the coil surface, which is located at the bottom of the fan blade. The area measures approximately 15 mm × 1 mm and is 3 mm away from the coil surface.

The target choice demonstrates the possibility of sensing targets with minimal sense coil exposure, which are relatively far away from the sense coil surface. System designs can benefit from one or both of the following mechanical setup modifications to achieve greater frequency shifts:

1. Design the mechanical system such that a higher percentage of the sensor coil may be exposed to the target. For more information on how target size affects measurement, consult the following blog post: *Inductive sensing: target size matters* [1].
2. Reduce the distance between the target and the sense coil. For more information on measurements and how target distance affects inductive sensors, consult the following blog post: *Inductive sensing: How far can I sense?* [2].

For the sake of comparison, the sensor frequency shift introduced by the TIDA-00851-LDC0851 has been compared to a 20×20-mm piece of copper tape fully covering the sensor area at a distance of 0.5 mm. Table 8 shows that the sensor frequency changes by 88.29%, which is a significant improvement over the frequency change of the standard target.

Table 8. Relative Frequency Values

CONDITION	FREQUENCY (MHz, MEASURED)	FREQUENCY CHANGE RELATIVE TO FREE SPACE INDUCTANCE ($f_{SENSOR\_NO\_TARGET}$ / $f_{SENSOR\_WITH\_TARGET}$ %)
Sense coil (no target)	7.88644	—
Sense coil (target present, closest point is 3 mm away from the coil surface)	7.93651	0.63%
Sense coil (>100% sensor coverage at 0.5-mm distance)	14.85387	88.29%

The target choice is not restricted to conductive tape; some alternative, common target choices are:

- A solid piece of metal (such as the teeth of a metal gear)
- Conductive paint or coating on a non-metallic object

6 Signal Processing

6.1 Microcontroller Requirements

The TIDA-00851 design uses a MSP430F5528 microcontroller as its central processor. The primary consideration for this selection was to maintain build environment consistency with other LDC EVMs. The MSP430F5528 has more than the sufficient memory, processor power, and peripherals necessary to support the event counting design and also provides a USB interface to a PC.

Because most systems do not require a USB peripheral, the MCU requirements can be reduced significantly. The minimum MCU requirements are:

1. Flash memory used: 800 bytes (display operation not included)
2. RAM/FRAM used: 290 bytes (display operation not included)
3. Execution time:
   (a) Interrupt service routine: 840 ticks
   (b) Convert event timestamp deltas to events per second and revolutions per minute (float operations): 1477 ticks

6.2 Algorithm

The primary goal for the algorithm used in the TIDA-00851-LDC0851 design is to require as little memory and calculation power as possible. The LDC0851 device continuously samples the sense and reference coils; if a target has been detected, the device triggers an interrupt in the MSP430F5528 MCU. The algorithm compares timestamps of the current and the previous event to determine the speed of rotation. To compensate the jitter from minor fan speed variations, the timestamps pass through a moving average filter (see Table 9).

Table 9. Variables List

VARIABLE	TYPE	FUNCTIONALITY
TIDA00851_EVENTCOUNTING_EVENTS_PER_FAN_REVOLUTION	Float	Constant: stores how many events occur in one fan revolution
eventsPerSecond	Float	Calculated events per second
revolutionsPerSecond	Float	Calculated RPM
isFanRotating	bool	Flag if events were detected within last second
TIDA00851_EventCounting_timestampDeltas[16]	uint32_t[16]	Buffer for moving average
TIDA00851_EventCounting_timestampPrevious	uint32_t	Timestamp of previous event
TIDA00851_EventCounting_timestampCurrent	uint32_t	Timestamp of current event
TIDA00851_EventCounting_timestampDelta	uint32_t	Difference between current timestamp and previous timestamp

Figure 20 shows the flow chart of the algorithm.

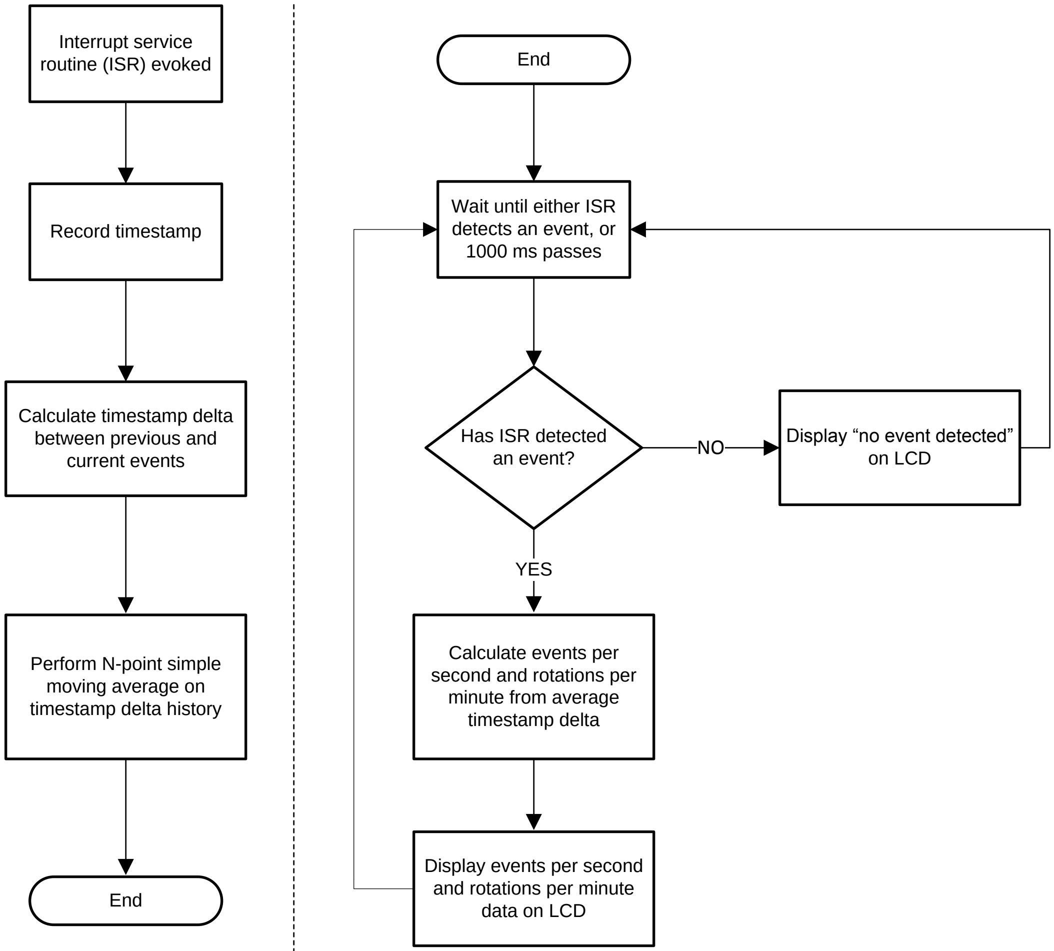

Figure 20. Algorithm Flow Chart

7 Design Files

7.1 Schematics

To download the schematics, see the design files at TIDA-00851-LDC0851.

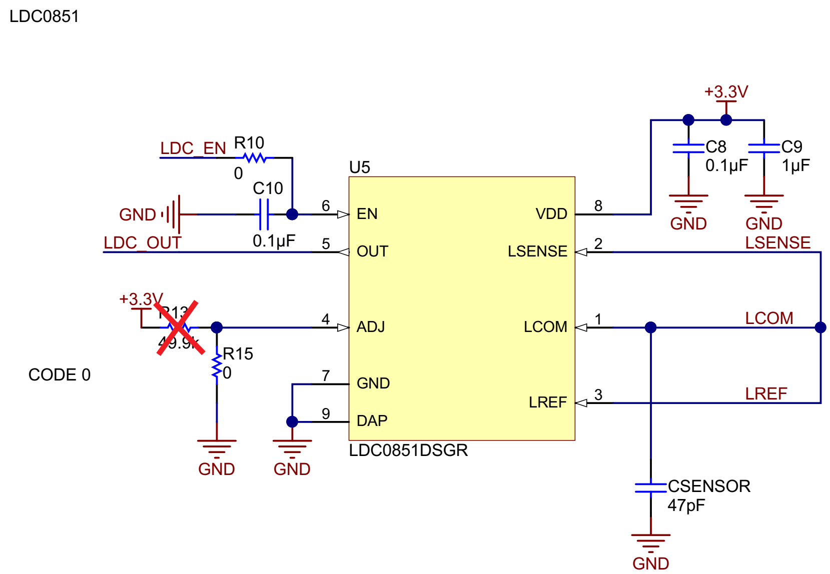

Figure 21. LDC0851 and Sensor Schematics (1)

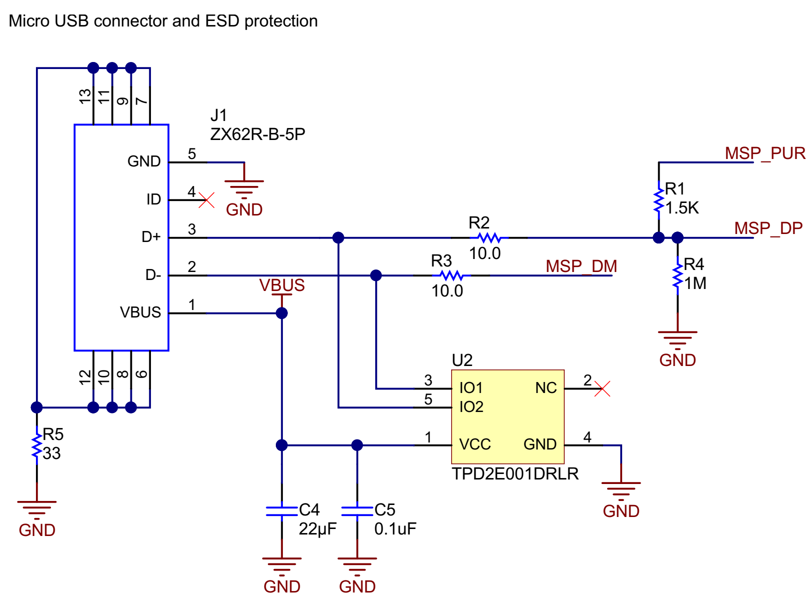

Figure 22. Micro USB Connector and ESD Protection Schematics

(1) Note that the sense coil and the reference coil appear as shorts in the schematics

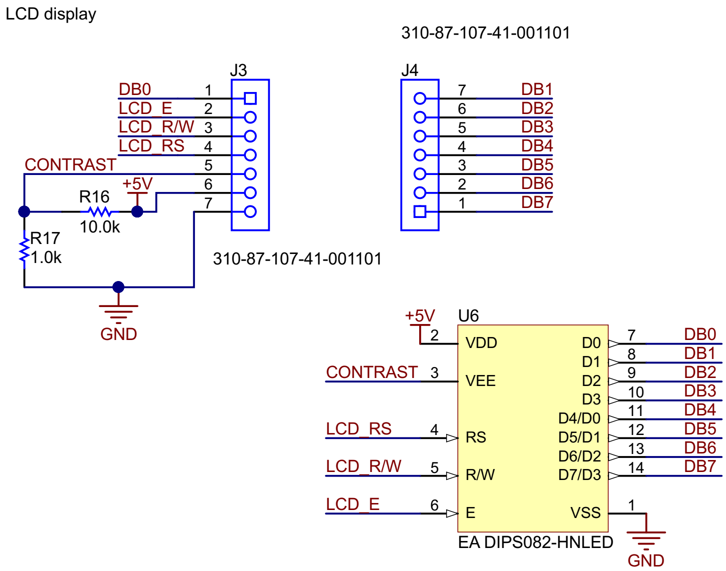

Figure 23. LCD Display Schematics

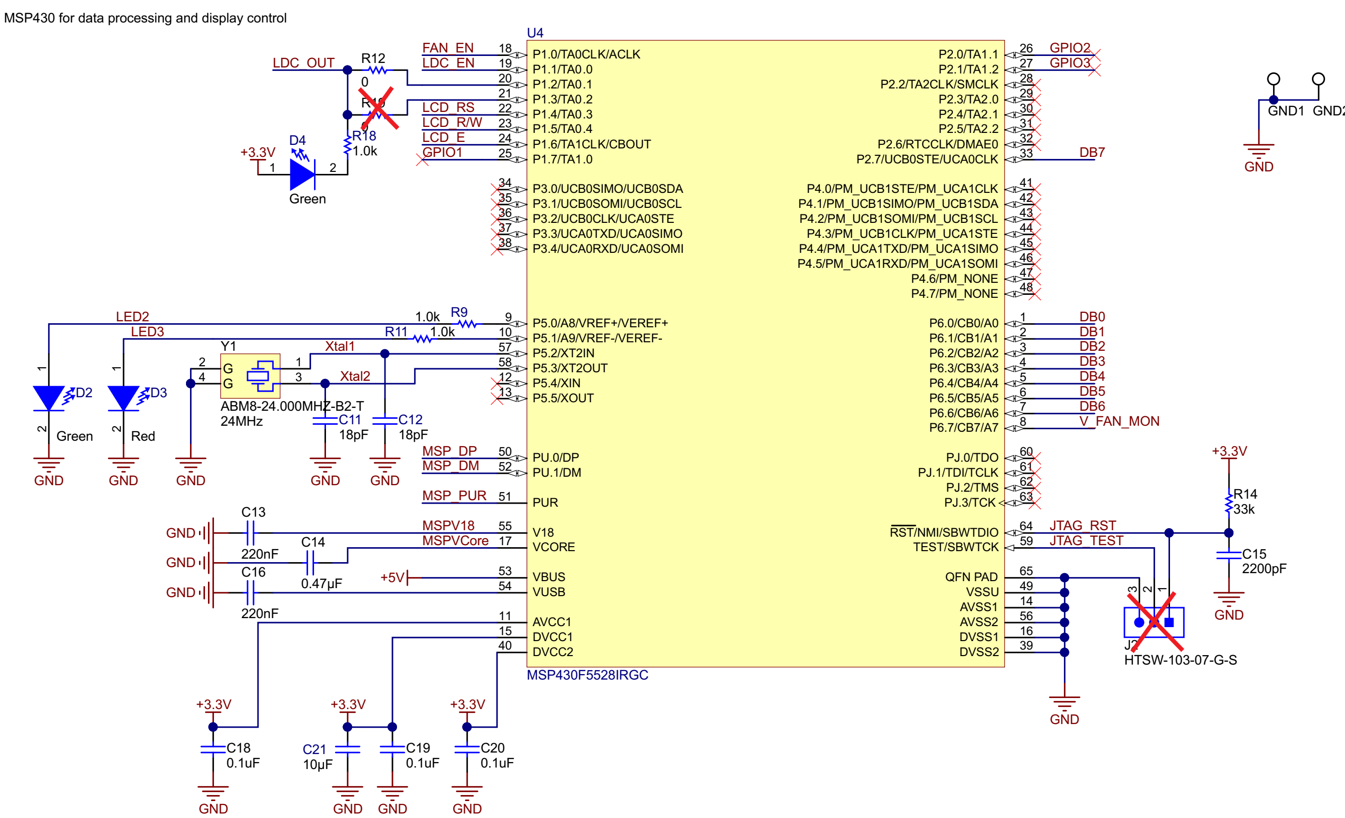

Figure 24. MSP430F5528 MCU for Data Processing and Display Control Schematics

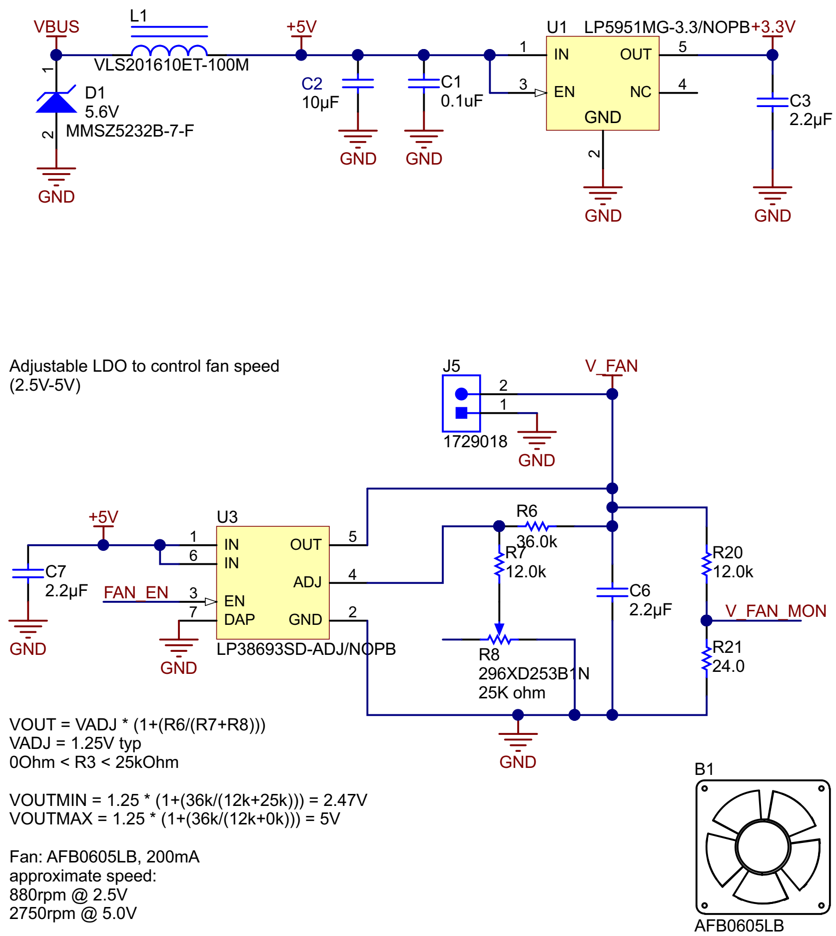

Figure 25. Power Management Schematics

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00851-LDC0851.

7.3 PCB Layout Recommendations

7.3.1 Layout Guidelines

The TIDA-00851-LDC0851 design has the following layout guidelines:

- For an inexpensive PCB manufacturing cost, the TIDA-00851-LDC0851 sensor routing uses a 6-mil (0.15 mm) trace width and spacing. In space-constrained applications with smaller sensor diameter, decreasing the feature size to a 4-mil trace width and spacing may be advantageous.
- Minimize the amount of traces and board fills near the sensor.

7.3.2 PCB Stackup

Table 10. Sensor PCB Layer Usage

LAYER	FUNCTIONALITY
Top	Signals, components, and ground-fill
Bottom	Signals and ground-fill

Table 11. Sensor PCB Stackup

LAYER	NAME	MATERIAL	THICKNESS	CONSTANT
1	Top overlay	—	—	—
2	Top solder	Solder resist	0.40 mil	3.5
3	Top layer	Copper	1.40 mil	—
4	Dielectric1	FR-4	59.20 mil	4.8
5	Bottom layer	Copper	1.40 mil	—
6	Bottom solder	Solder resist	0.40 mil	3.5
7	Bottom overlay	—	—	—

7.3.3 Mechanical Assembly Sequence

The following sequence details the PCB assembly as shown in (Figure 26):

1. The fan with the copper tape targets is attached to the PCB using double-sided adhesive tape (for example: 3M™ 300LSE adhesive transfer tape). Note that accurately placing along the silkscreen markings is required, and that the fan sticker faces towards the center of the PCB.
2. The fan is secured to the PCB with the cable ties provided.
3. The fan power supply wires are connected to the screw terminal J5.
4. The display is connected to J3 and J4 (note correct orientation: pin 8 of the LCD connects to pin 7 of J4)
5. The PCB is connected to a PC, wall adapter, or power bank through the supplied micro USB cable.

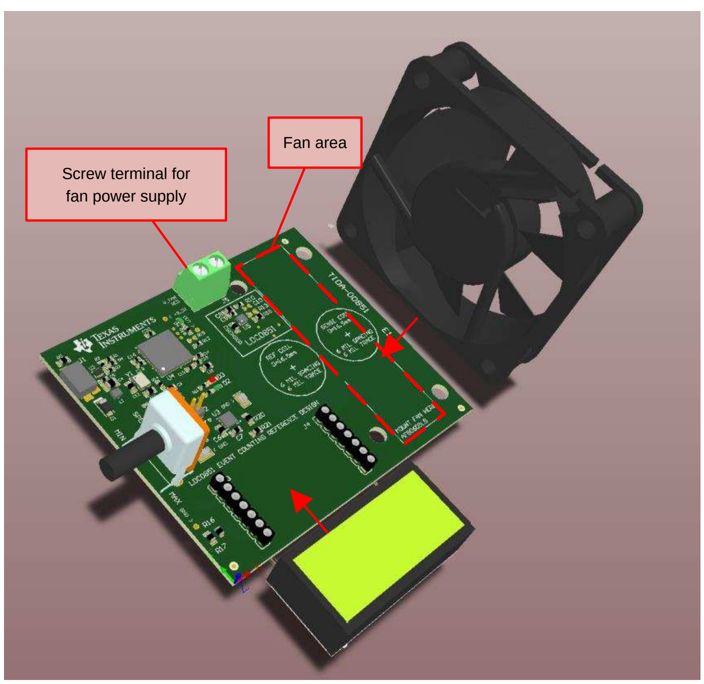

Figure 26. System Assembly

7.3.4 Layout Prints

To download the layer plots, see the design files at TIDA-00851-LDC0851.

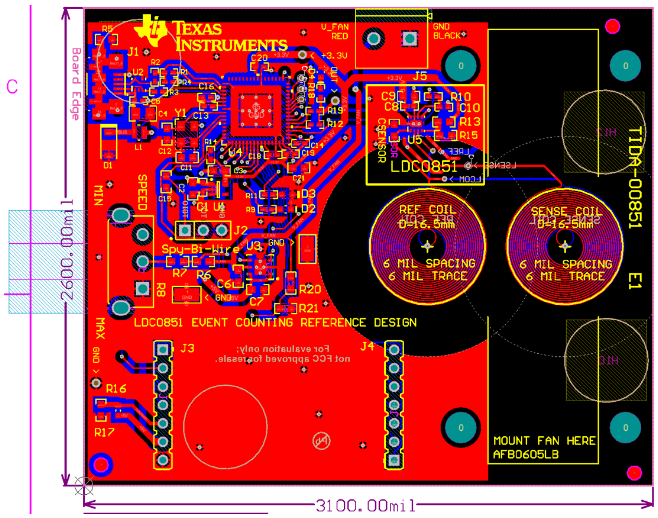

Figure 27. Multi-Layer

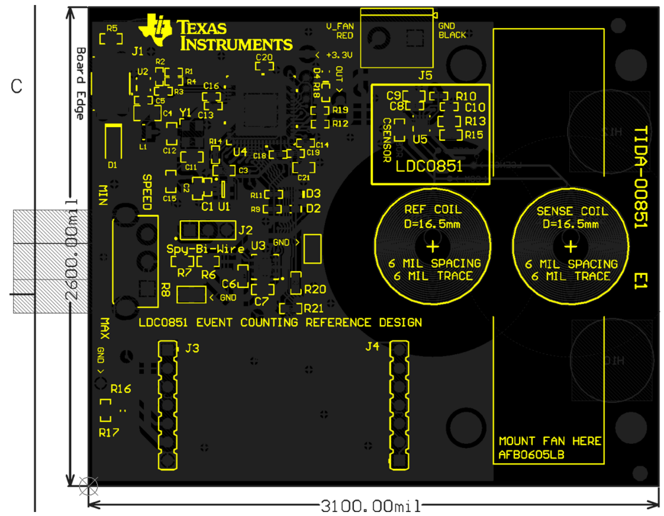

Figure 28. Top Silkscreen

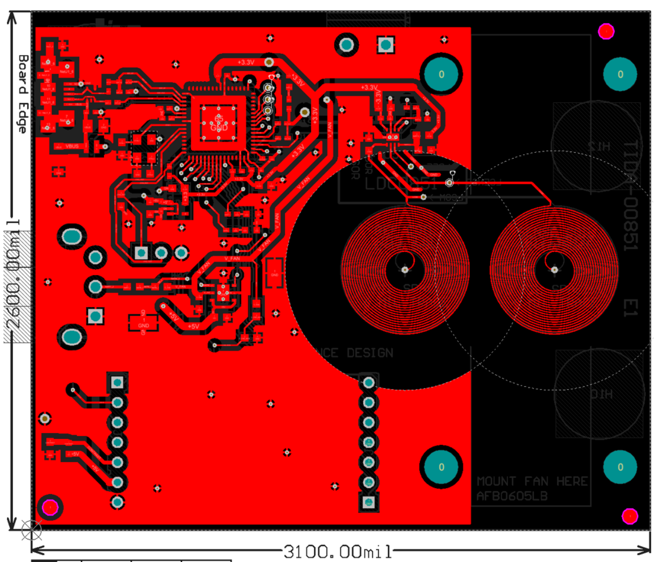

Figure 29. Top Layer Routing

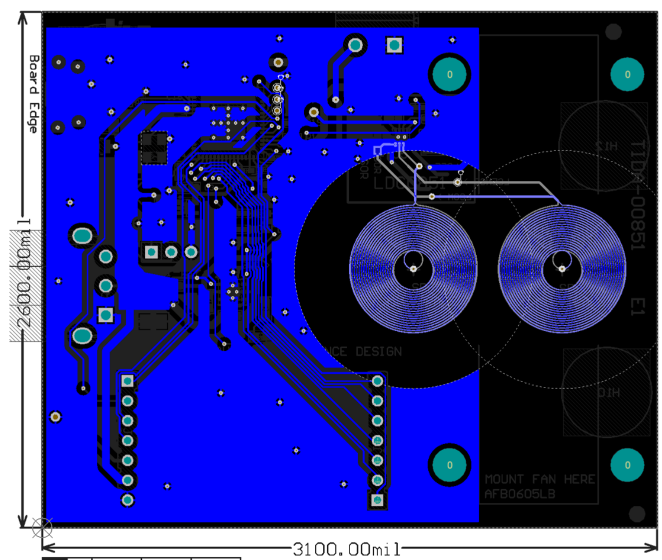

Figure 30. Bottom Layer Routing

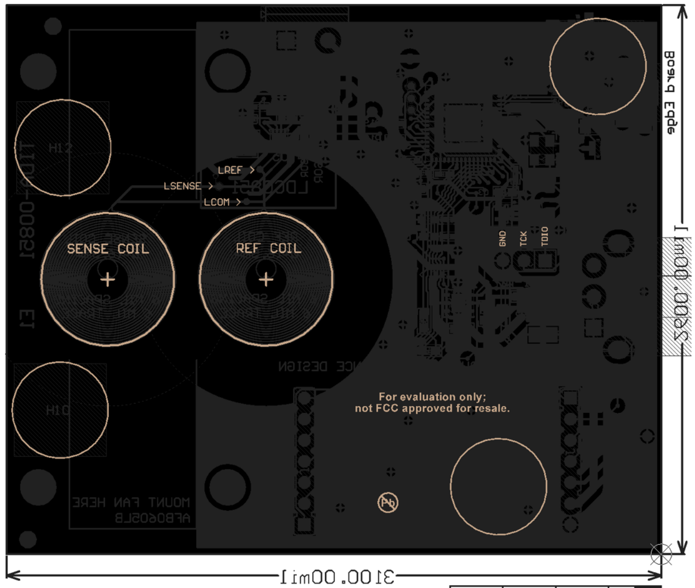

Figure 31. Bottom Silkscreen

7.4 Altium Project

To download the Altium project files, see the design files at TIDA-00851-LDC0851.

7.5 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00851-LDC0851.

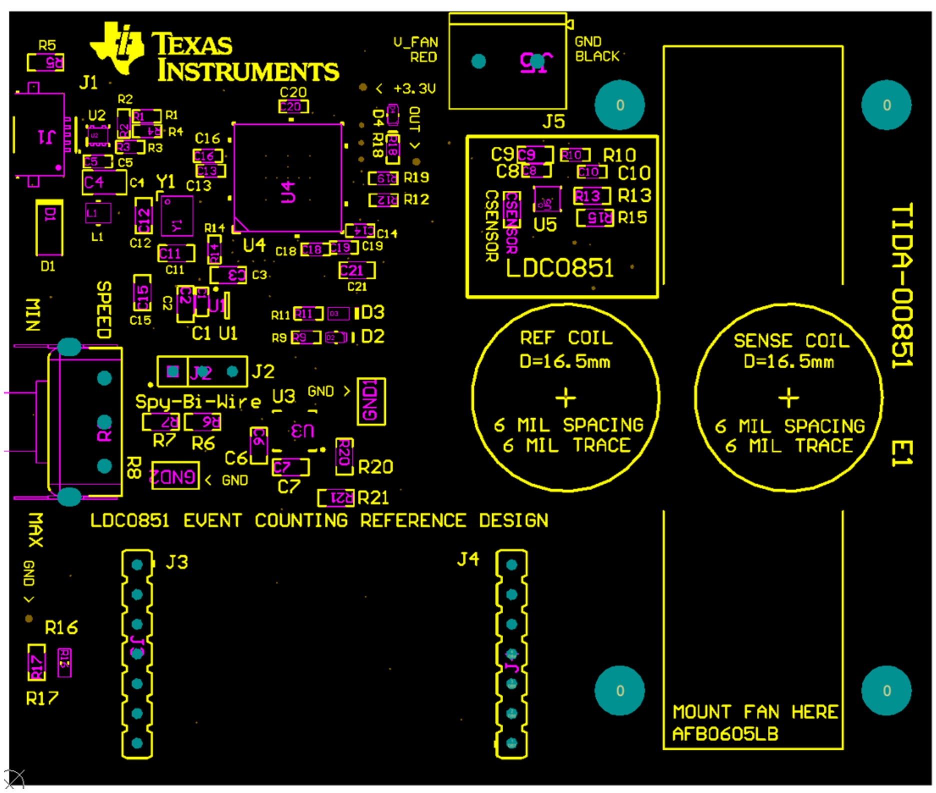

Figure 32. Assembly Drawing

8 Software Files

To download the software files, see the design files at TIDA-00851-LDC0851.

9 References

1. Texas Instruments, *LDC Sensor Design*, Application Report (SNOA930)
2. Texas Instruments, *Inductive sensing: target size matters*, TI E2E™ Online Community Blog (https://e2e.ti.com/blogs_/b/analogwire/archive/2015/11/16/inductive-sensing-target-size-matters)
3. Texas Instruments, *Inductive sensing: How far can I sense?*, TI E2E™ Online Community Blog (https://e2e.ti.com/blogs_/b/analogwire/archive/2015/06/17/inductive-sensing-how-far-can-i-sense)

10 About the Author

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