Application Report

Inductive Sensing for LDC3114 Metal Proximity Detection

TEXAS INSTRUMENTS

Nicole Khoury *Current and Position Sensing*

ABSTRACT

This application report discusses the common use cases, benefits, and design flow for TI's LDC sensors when used in metal proximity sensing. It covers the specific considerations that must be addressed when designing a system for inductance-based metal detection, allowing the designer to achieve the optimal design.

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1 Introduction

Inductive sensing technology is a great choice for metal detection applications. In addition to detecting the presence of a metal target, the LDC3114 device is able to detect the proximity of the target with high precision.

1.1 Benefits of Inductive Proximity Sensing

Many applications require special care to ensure that system functionality is preserved in various situations and hazards. Inductive technologies offer unique benefits when compared to traditional metal detection designs:

- No magnets required
- Not affected by magnets
- Immunity against dust and dirt
- Simplicity and low cost of the PCB sensor

1.2 Common Applications

As a result of the benefits of inductive sensing, there are many applications that can be optimized with the addition of inductive metal detection. Immunity against dust and dirt makes inductive sensing a robust choice for household appliances or power tools that may be exposed to grease and other contaminants.

The following is an abbreviated list of applications in which inductive metal detection can be used:

- Spring compression detection
- Grip detection in power tools
- Stove top
- Rangehood display panels
- Pipe detection
- ATM interfaces

1.3 Human-Machine Interface Design Guide

Section 1.2 lists several examples of commonly-used applications that are appropriate for inductive metal proximity sensing. For stove displays or ATM interfaces where users may wear gloves when operating, inductive sensing allows for system functionality regardless of debris from normal operation. This is ideal for systems that are outside or in busy kitchens.

Figure 1-1 shows a common method to implement a layer stack for a touch button in a human-machine interface (HMI). The non-conductive layer can be a large, uninterrupted surface. By placing sensor PCBs at different points along the outside of this area, the deflection of the surface layer can be transmitted to the sensor.

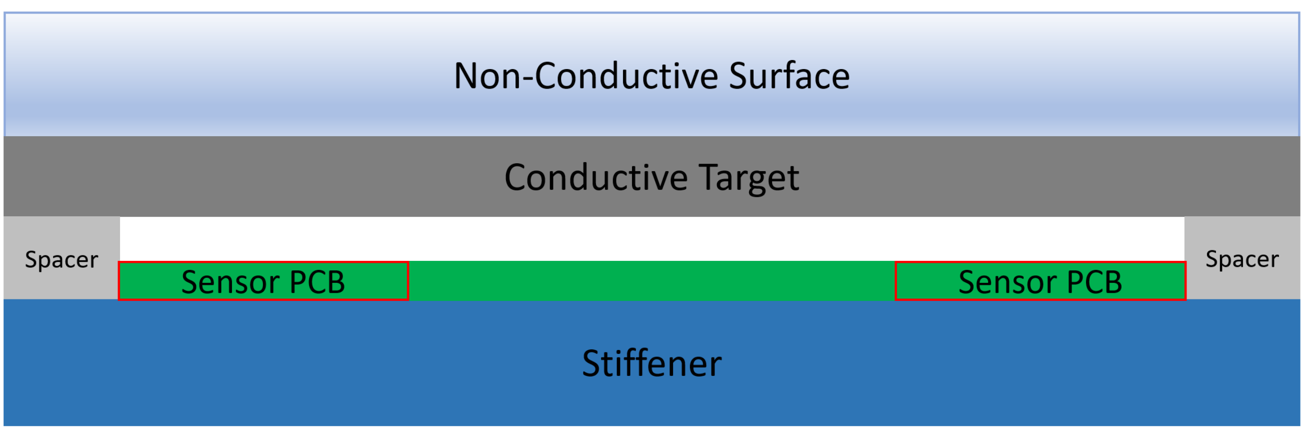

Figure 1-1. Example Layer Stack

In applications where the button press is experiencing a timeout or the baseline tracking has been reset, metal proximity sensing can be used to verify the target location. A micro-deflection is translated to the target when a user presses on the top non-conductive surface. This example mechanical stack up can be translated to work with many other types of material surfaces for different HMI designs. For detailed information regarding button construction and target material, as well as LDC3114 internal algorithms, see the *Inductive Touch System Design Guide for HMI Button Applications* and *LDC211x and LDC3114 Internal Algorithm Functionality* application reports.

2 System Considerations

There are several important criteria to enable, as well as optimize, metal proximity detection in a system. The following subsections discuss the factors that should be considered when designing an application for inductive metal proximity.

2.1 Target Properties

To achieve the best sensing response, the metal target should be at least the size of the sensing coil. It is also important to choose a highly conductive metal, such as copper or aluminum, because these have stronger inductive responses.

Figure 2-1 shows the sensor frequency shift of several common metals as a function of distance. Any discontinuities in the metal (gaps, voids, or indents) should be avoided, as they can cause disruptions in the current path and lead to measurement noise.

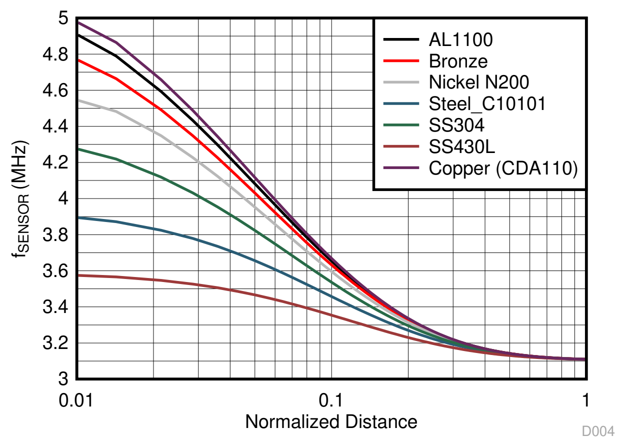

Figure 2-1. Sensor Frequency vs Distance of Common Targets

In regards to target thickness, it is a general guideline that it should be at least 3 skin depths. Skin depth, δ, is the distance where the eddy currents are reduced to approximately 37% of the density at the surface.

For further details on target design and calculating skin depth, refer to the *LDC Target Design* application report.

2.2 Sensing Distance

For inductive technology, 1 µm to 10 cm is a feasible sensing range. If an application requires high precision, a sensing range that is 50% of the coil diameter can be expected from most of the LDC devices. For example, a sensor with an outer diameter of 10 mm can be expected to have a sensing range of 5 mm. This range can be increased to 100% in low precision applications, such as a simple detection of metal presence.

It is important to note that sensitivity is greatest within 20% of the total sensing distance, and this should be considered when designing a system based on maximum required sensing distance.

Figure 2-2 illustrates the relative inductance shift versus distance and it can be seen that within 20% of the coil diameter, the shifts in inductance are stronger with respect to smaller distances. This allows for higher precision measurements, for example, an application with a sensor diameter of 10 mm could provide nanometer resolution within a target distance of 2 mm.

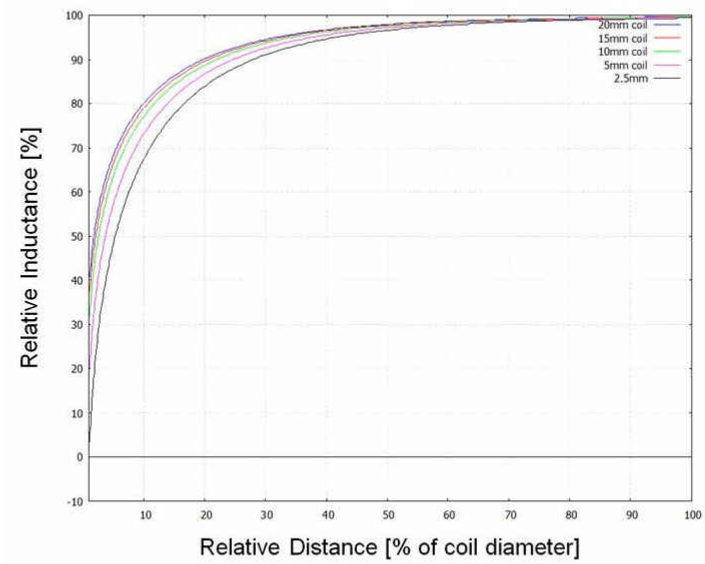

Figure 2-2. Relative Inductance vs Distance of Various Coil Sizes

2.3 LDC3114 Device Features

Table 2-1 provides a summary of device features for the LDC3114.

Table 2-1. LDC3114 Device Features

	LDC3114
Supply Voltage	1.71 V to 1.89 V
Typical Sleep Current	5 µA
Typical Shutdown Current	N/A
Maximum Sensor Frequency	30 MHz
Sensor Min R_P	350 Ω
Output L Measurement Resolution	12 bits
Maximum Reference Frequency	N/A
Internal Reference Oscillator	Yes
Number of Channels	4
Maximum Sample Rate	160 SPS
Switch Output	Yes, based on Sensor L
Interface	I^2C — 400 kbit Push-pull output
MCU Needed?	No

3 Design

Figure 3-1 describes the process of selecting sensor parameters for measurement optimization. It is important to make these design decisions with the desired sensing range in mind, because different applications may have different priorities.

To maximize resolution the sensing range should be within the linear region of the inductance versus distance response, as discucssed in Section 2.2. To help verify design, the Inductive Sensing Design Calculator Tool is a general purpose tool that allows sensor parameters to be entered in the Spiral Inductor Designer tab and checked against device specifications. There are also various device-specific tabs that allow further visualization of system performance.

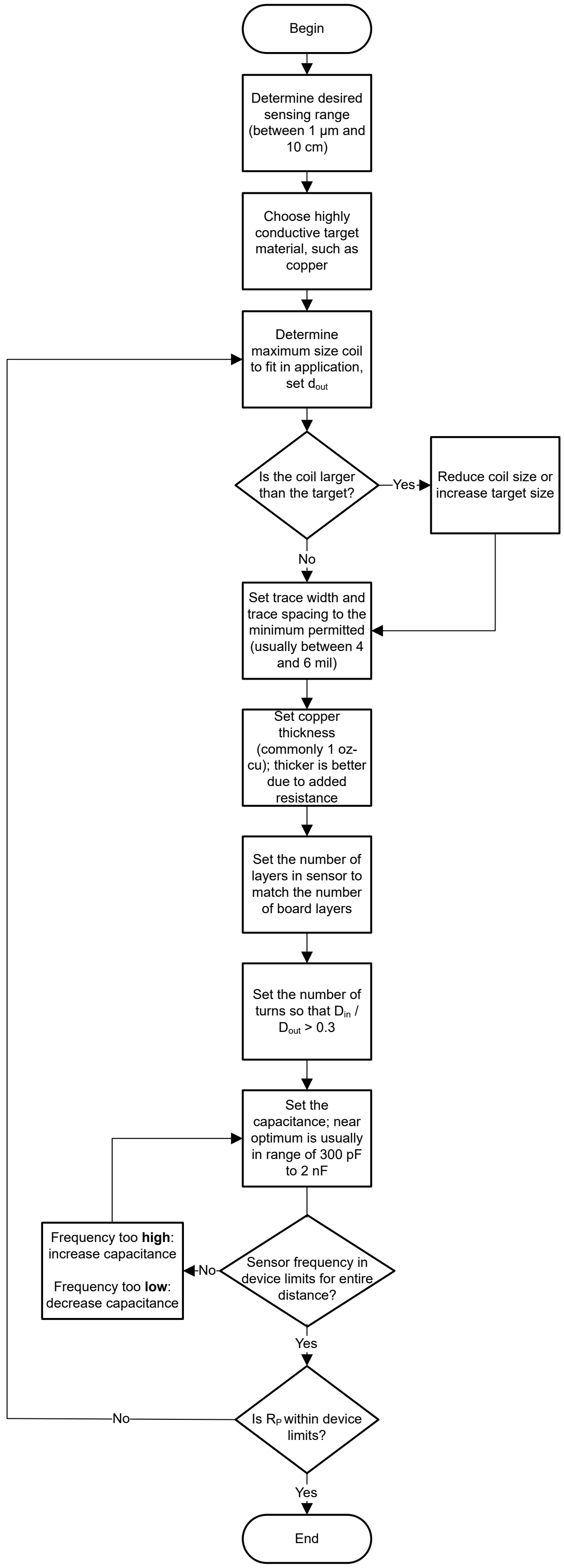

Figure 3-1. Sensor Design Flowchart

For a more detailed discussion on sensor design, see the *LDC Sensor Design* application note.

3.1 Sensor Size and Frequency

It is crucial to consider the operating conditions for the LDC3114 that will be designed into a system, making sure that the device specifications are not violated at any point in the desired target range. The sensor frequency is an important specification that shifts as the distance from the target changes. Sensor frequency is highest when the target is closest, and it is important to consider the entire desired distance range when designing a sensor.

For larger distances, choose a lower-frequency sensor. The inductance and capacitance determine the sensor frequency, and these can be controlled by the size and number of turns of the sensor, as well as the sensor capacitor. Figure 2-2 shows the relative inductance of a sensor as related to distance.

3.2 Linear Sensing Region

Section 2.2 discusses that the highest sensor sensitivity is within 20% of the total sensing range. The larger shift in inductance across distance means that target movement can be detected with nanometer resolution. Figure 3-2 is the approximate inductive response of the LDC3114 when used with a sensing coil from the LDC3114EVM. Calculate this graph for different sensor parameters and sensing distances using the Inductive Sensing Design Calculator Tool.

The red box indicates the closest and farthest desired target distance, and it was chosen to optimize the inductive response. Beyond 4.5 mm, the graph begins to level off and the measurement resolution is reduced. The higher resolution response begins to sharply decrease at a target distance of 1.8 mm. Therefore, design a sensor coil that has the largest change in slope within the desired distance range.

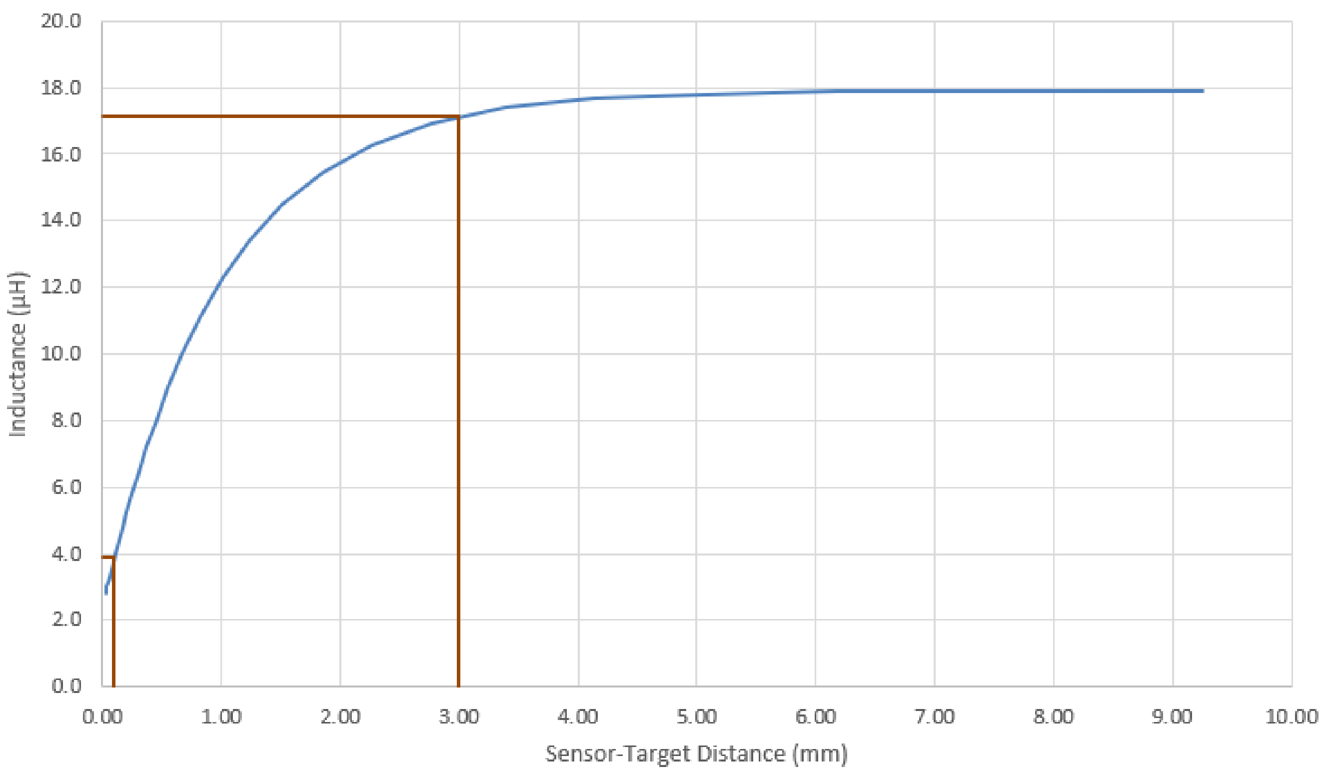

Figure 3-2. Calculated Inductive Response of LDC3114 With LDC3114EVM Coil

4 Measured Raw Data Output

Characterizing sensor response before designing a metal proximity application helps optimize target detection for a set distance and desired resolution. The sensor response can be measured and compared to the predicted behavior calculated from the Inductive Sensing Calculator Tool.

The coils included with the LDC3114EVM have a diameter of 9 mm. For prototyping purposes, a distance of up to 9.11 mm was measured to capture the entire sensor response. With no target present, the calculated inductance of this sensor is 3.458 µH. The LDC3114EVM sensors have the following physical properties:

- Outer diameter: 9 mm
- Number of turns (per layer): 14
- Number of layers: 2
- Trace spacing: 5 mil
- Trace width: 5 mil

These coils were used with the LDC3114EVM to measure the raw data output as distance from the target increased. Figure 4-1 shows the response of the sensor coil connected to Channel 0 of the LDC3114EVM, as well as a reference coil that did not have interaction with the target. It is helpful to include a reference coil to be able to track the sensor response to a target, allowing the user to measure the point at which the target becomes undetectable.

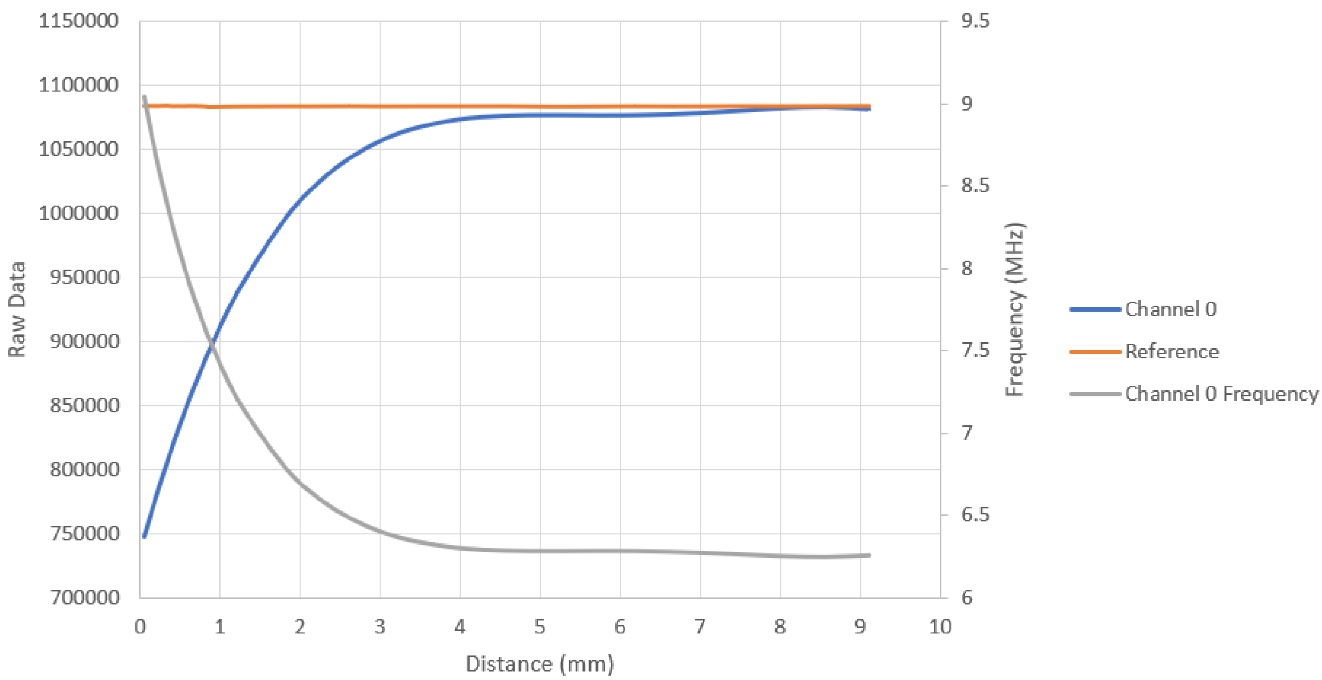

Figure 4-1. Measured Raw Data of LDC3114 With LDC3114EVM Coil

The average raw data output of the Channel 0 sensor approaches the output of the reference coil as distance increases. Within 1.8 mm of the target the sensor response is seen to be the strongest, and this correlates with 20% of the sensor diameter.

The frequency is calculated from the measured raw data as illustrated in Figure 4-1. Equation 1 shows the relationship between the raw data and sensor frequency.

$$f_{SENSOR} = (30 \times W \times f_{REF\_CLK}) / raw\_data \quad (1)$$

where:

- f_{REF_CLK} is the internal reference clock frequency of 44 MHz
- W can be calculated from Equation 1

$$W = 128 \times (1 + SENCYn) \times 2^{LCDIV} \quad (2)$$

See the *LDC3114-Q1 4-Channel Hybrid Inductive Touch and Inductance to Digital Converter* data sheet and register maps for more detailed information on using these equations.

4.1 Measured Response of LDCCOILEVM Sensor N

Different applications may require sensors other than what is included with the LDC3114EVM. For precise monitoring of short target distances, a smaller diameter sensor coil can be used.

The LDCCOILEVM includes 19 unique PCB coils that can be broken off and used as remote sensors with any TI inductive sensing device. Additional proximity testing was done using the LDC3114EVM with the 3-mm Sensor N from the LDCCOILEVM. Sensor N has the following physical properties:

- Outer diameter: 3 mm
- Number of turns (per layer): 3
- Number of layers: 4
- Trace spacing: 4 mil
- Trace width: 4 mil

The total calculated inductance of this sensor is 0.182 µH with no target present. As Figure 4-2 shows, the average raw data across distance for Sensor N increases steadily until leveling off with the reference coil. Starting from the closest target distance to approximately 0.6 mm the sensor response is the greatest. This relatively simple prototype helps determine the sensor combination that maximizes the desired inductive response for a given application.

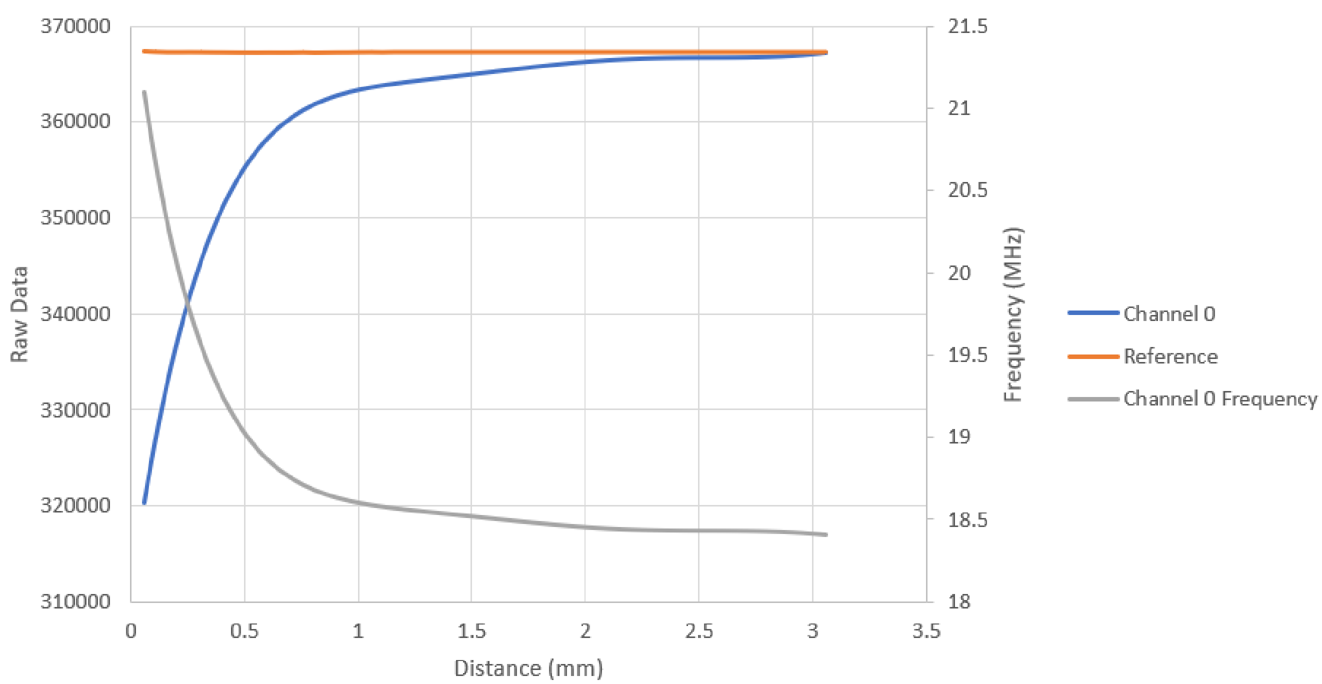

Figure 4-2. Measured Raw Data of LDC3114 With Sensor N

Sensor N has a smaller diameter than the LDC3114EVM sensor coil, reducing the effective sensing distance as discussed in Section 2.2. The target movements were in increments of 0.05 mm to capture the entire sensor response. As the target distance approaches the diameter of Sensor N, the frequency and raw data responses show minimal changes between target positions. A higher frequency sensor, such as Sensor N, is a good choice for applications that require high resolution at small distances.

4.2 Measured Response of LDCCOILEVM Sensor R

To present a wide range of sensor resonant frequencies, an additional sensor that was used to prototype with the LDC3114EVM was Sensor R. The inductance of this sensor is a midpoint between the EVM sensor and Sensor N, at 1.026 µH with no target present. Sensor R has the following physical properties:

- Outer diameter: 4 mm
- Number of turns (per layer): 3
- Number of layers: 6
- Trace spacing: 4 mil
- Trace width: 4 mil

Figure 4-3 shows the raw data and frequency response of Sensor R. After the target reaches 20% of the sensor diameter, 0.8 mm, the frequency response begins to level off.

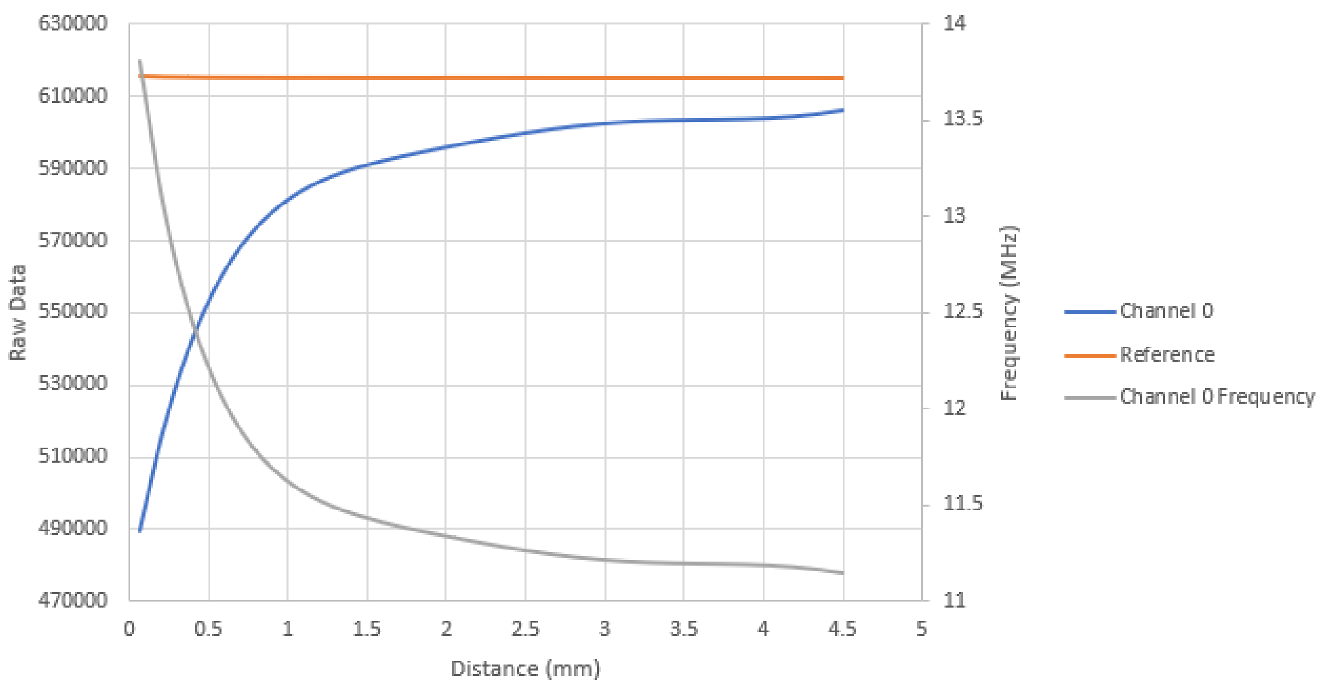

Figure 4-3. Measured Raw Data of LDC3114 With Sensor R

5 Observed Effects of Ambient Temperature

The variation of inductance and R_P over temperature can result in measurement variations, a concept that is further explored in the *Temperature Compensation* application report. To observe this change with the setup that was previously characterized (see Section 4), a fixed distance was set between the copper target and the LDC3114EVM sensor coil. In addition to the coil and target, a reference coil was placed on Channel 1 of the EVM. Systems that are expected to operate over a set temperature range may need to calibrate the sensors accordingly. This dual sensor prototyping setup illustrated in Figure 5-1 can be used to observe the behavior of both sensors with a controlled environment and with a stationary target.

The copper target was secured in place over the Channel 0 sensor coil with rubber housing, to ensure that the target placement would not be affected by the chamber fan controls.

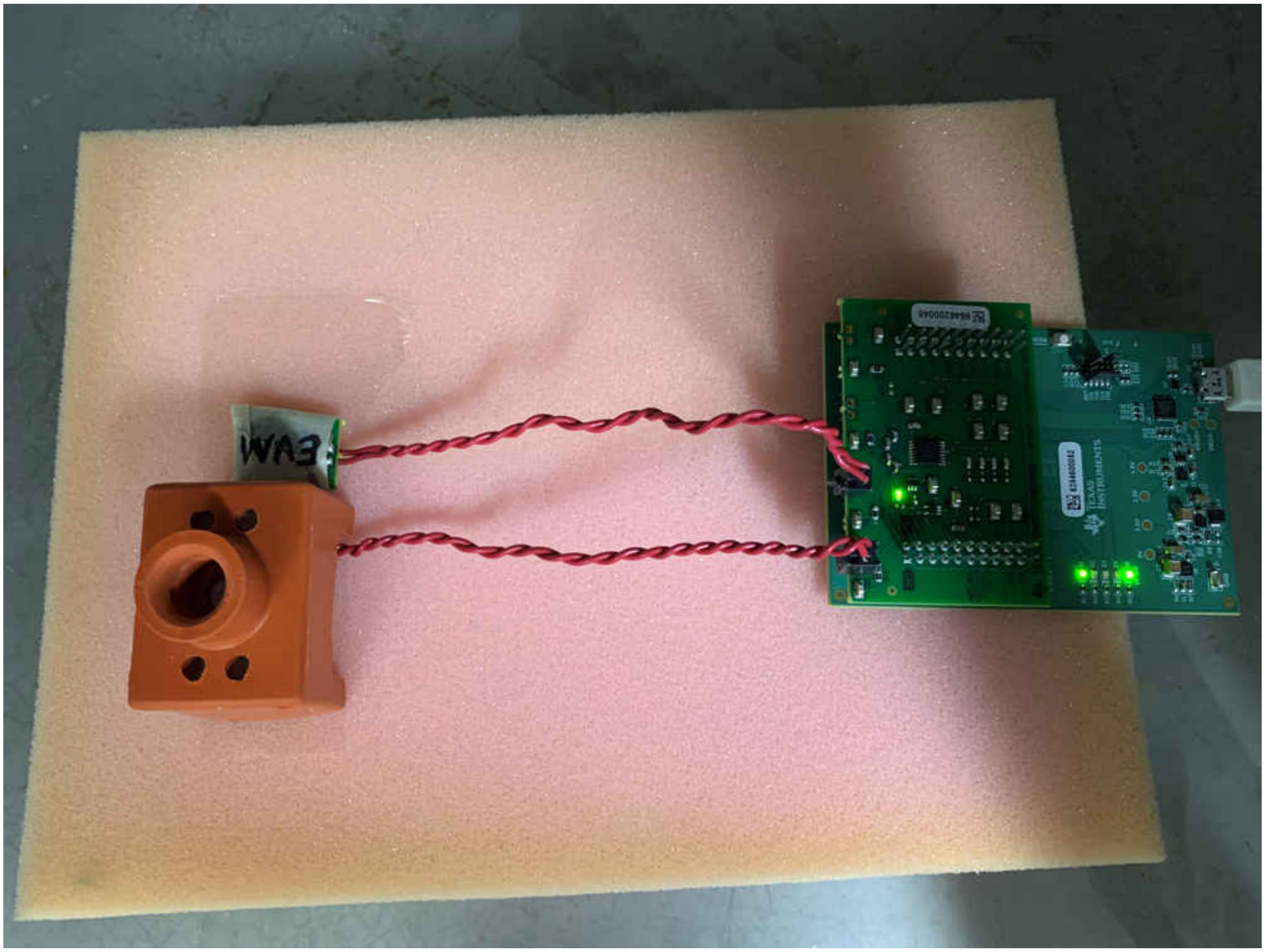

Figure 5-1. LDC3114EVM Temperature Chamber Setup

Figure 5-2 illustrates the change in raw data across the operating temperature of the LDC3114. The raw data was collected and averaged across temperatures of –40°C to 125°C. This temperature range was chosen because it aligns with the recommended ambient operating temperature listed in the LDC3114 data sheet. The behavior of both the Channel 0 and Channel 1 sensors was first observed without any metal target present. Once it was confirmed that both sensors had the same response to the temperature sweep, a copper target was added to Channel 0.

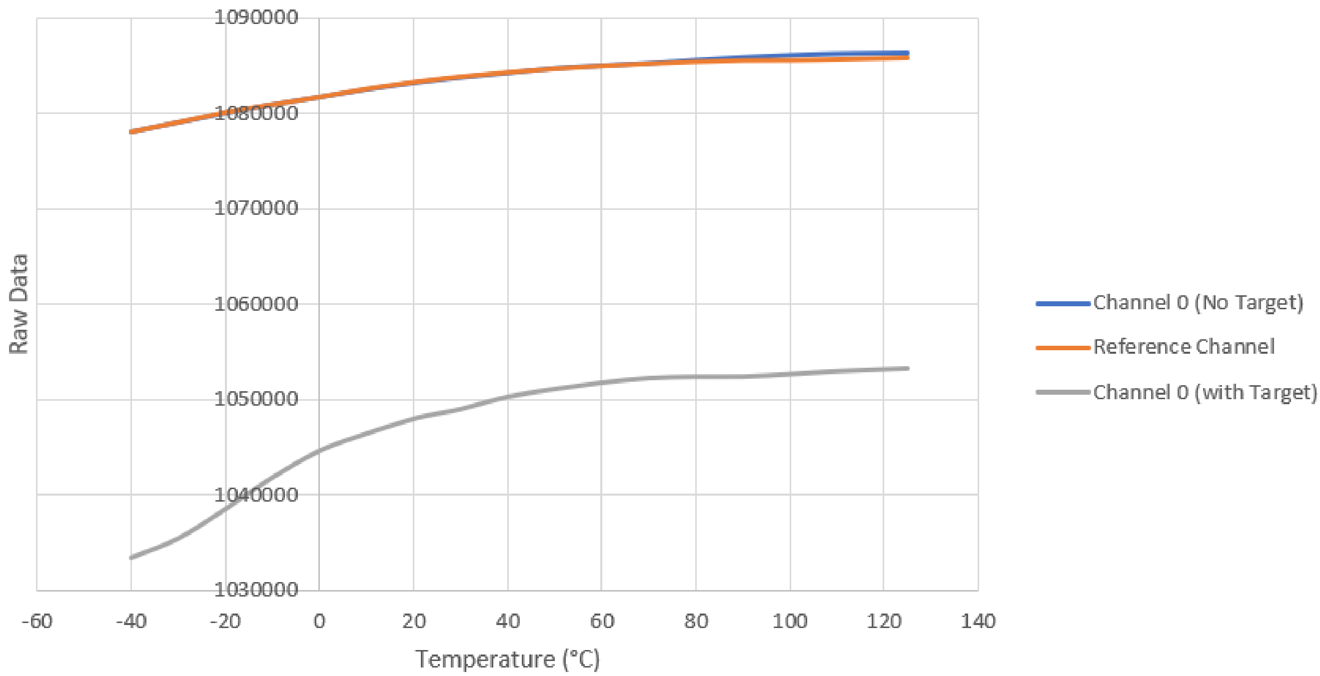

Figure 5-2. Observed Effect of Ambient Temperature on LDC3114 With LDC3114EVM Coil

The resistance of a typical PCB coil increases as a function of temperature, mainly dependent on the resistivity of the metal. For a copper coil, the resistive temperature coefficient is 3900 ppm/°C. Additionally, the proportionality of R_P to inductance means that as the R_P value changes over temperature, so will the inductance.

Measurement drifts due to temperature can be corrected if the operating temperature range is known and the system behavior has been characterized. A reference coil that is not exposed to any varying target parameters can be placed in the same environment as the main sensor, and the reference sensor output can be used to calibrate the system for a specific temperature range.

6 References

- Texas Instruments, *Inductive Touch System Design Guide for HMI Button Applications*
- Texas Instruments, *LDC211x and LDC3114 Internal Algorithm Functionality*
- Texas Instruments, *LDC Target Design*
- Texas Instruments, Inductive Sensing Design Calculator Tool
- Texas Instruments, *Sensor Design for Inductive Sensing Applications Using LDC*
- Texas Instruments, *LDC100x Temperature Compensation*

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