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Staple Detection with TI's Inductive Sensing Technology

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Design Resources

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[LDC1612](#)	Product Folder

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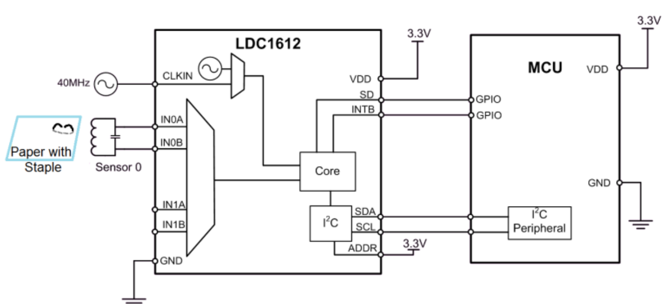
Block Diagram



Design Features

- Detects conductive foreign objects anywhere on a sheet of paper
- Scalable design – coil can be extended to cover desired scan width
- Insensitive to non-conductive environmental interferers (such as dirt, dust, oil etc.)
- Simple, low-cost system design
- Magnet-free operation

Featured Applications

- Staple detection
- Paper clip detection
- Metal foreign object detection
- Printers, Copiers, Scanners
- Bill counters, ATMs

Table of Contents

1 System Description

Many printers and scanners have automatic paper feeds for scanning a stack of documents. Alternatively, some people reuse paper for printing. Sometimes, there may be a staple or clip attached to the paper, which can cause severe damage to scanners and printers. The objective of this design is to use the LDC131x/161x EVM together with a customized PCB coil sensor to detect the presence of staples or paper clips. This design can be further integrated as part of the paper-feeding system in scanners and printers to prevent potential system damage.

1.1 LDC131x/161x EVM

The LDC131x/161x EVM demonstrates the use of inductive sensing technology to sense and measure the presence or position of conductive target objects. The LDC131x/161x chip is controlled by an MSP430, which interfaces to a host computer.

For details, please refer to the LDC131x/161x EVM User's Guide.

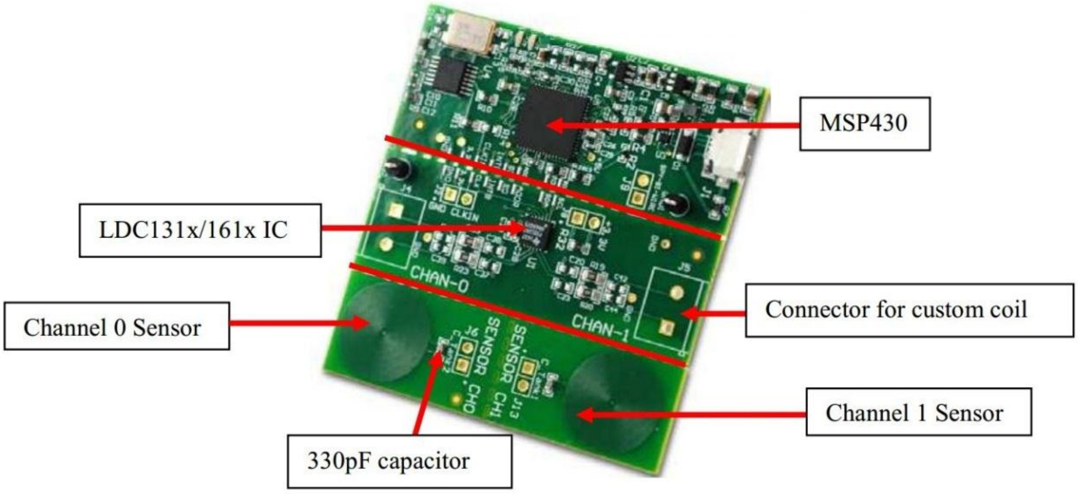


Figure 1: LDC1312/1612 Evaluation Module

1.2 PCB Coil Sensor

This design uses the 2-channel LDC1612. The LDC1612 EVM includes two circular PCB coil sensors. For this application, the two coils are replaced by another customized coil that spans across a sheet of paper. This coil is attached to the "Connector for custom coil" (J4 or J5), as labeled in Figure 1.

The size of this coil is about 21 x 0.8 cm. It is on both the top and bottom layers of the PCB, with seven turns on each layer. The low-frequency inductance of the coil is 23.5uH. Its self-resonant frequency is 5.24MHz. A capacitor of 4.7nF is placed in parallel with the inductor to form an LC oscillator with oscillation frequency about 480kHz.

Figure 2: Double-sided rectangular PCB coil sensor

2 System Design Theory

The Inductance-to-Digital Converter (LDC) measures the frequency of oscillation of an LC tank. As a conductive target, such as a staple or paper clip, approaches the coil, it results in a sharp negative reduction in the oscillation frequency response.

2.1 Coil Design

To maximize the sensor response to a staple or paper clip, it is recommended to maximize the *L* vs *Rs* ratio of the coil, where *L* is the inductance and *Rs* is the series resistance.

This seemingly simple task has its own challenges, mainly because *L* and *Rs* have a positive correlation for traces of the same size. As the trace gets narrower, both *L* and *Rs* increase. In addition, the width of the trace also limits the number of turns for a given PCB area. Although a wider trace helps to lower the resistance, it can lead to fewer turns which would degrade the inductance.

In this design, the length of the coil is set to 21 cm, which covers the width of an A4-sized paper. The width is set to about 0.8 cm, so that the entire system can fit into a compact space. The coil has a total of 14 turns, with 7 turns on either side of the PCB. The width of the copper trace is 10 mil and thickness is 3oz. The low-frequency inductance of the coil is about 23.5uH and resistance 5.1 Ohms.

Figure 3: PCB layout of one end of the coil.

The inductance of a custom designed coil of similar geometry and size can be approximated with the following formula

$$L = L0 * N\char`^1.55 \qquad \text{Equation 1}$$

where *L0* is the inductance of the outermost turn and *N* is the total number of turns.

The low-frequency inductance for a single-turn rectangular loop of rectangular wire can be calculated with the following formula from F.E. Terman's "Radio Engineers' Handbook"

$$L0 = 0.02339\left[(s1+s2)\log\left(\frac{2s1s2}{b+c}\right) - s1*\log(s1+g) - s2*\log(s2+g)\right] + 0.01016\left[2g - \frac{s1+s2}{2} + 0.447(b+c)\right]\ uH \qquad \text{Equation 2}$$

where *s1* and *s2* are the length and width of the rectangular loop, and *b* and *c* are the width and thickness of the rectangular cross-section. The dimensions are in inches.

If space is less of a concern, you can use wider traces to reduce *Rs*, and a greater number of turns or larger loops to enhance *L*. This will further improve the sensitivity of the coil sensor.

2.2 Parallel Resonant Impedance

The LC tank can be modeled by the following schematic, where Rs is the parasitic series resistance of the inductor.

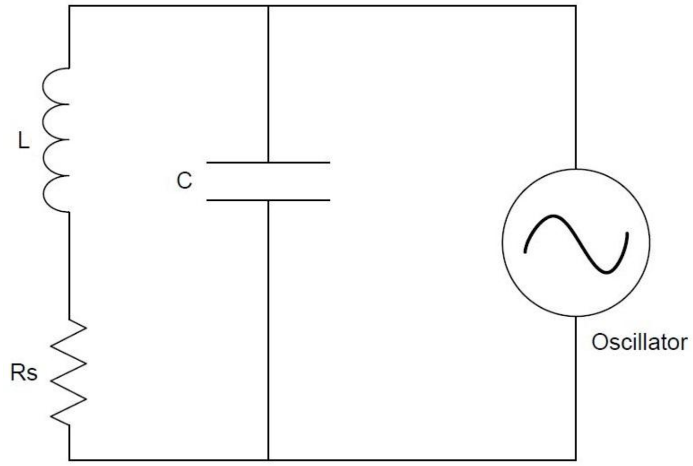


Figure 4: Schematic of an LC tank.

The series resistance can be more easily modeled as parallel resonance impedance (Rp), where Rp = 1/Rs*(L/C)

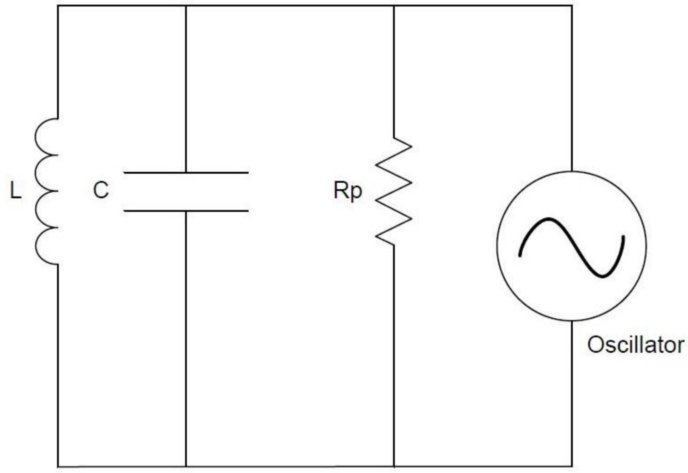


Figure 5: Schematic of an LC tank modeled with parallel resonant impedance Rp.

For optimal performance, the value of C should be chosen based on L and Rs, such that Rp is around 1k to 2k Ohms. For the coil used in this design, the optimal C is about 2.2 to 5nF. The test results below were taken with C=4.7nF.

The capacitor C is in parallel with the coil sensor L. It can be placed either on the coil PCB, or on the EVM. It is recommended to keep the traces connecting the coil to the LDC1612 EVM as short as possible to reduce parasitic resistance and capacitance, which would degrade the performance of the system.

3 Getting Started Hardware

This application utilizes two pieces of hardware, the LDC1612 EVM and the rectangular PCB coil sensor.

3.1 LDC1612 EVM

To get started, please refer to the LDC131x and LDC161x EVM User's Guide.

The EVM comes with two circular coils for initial evaluation. They need to be removed along the perforation.

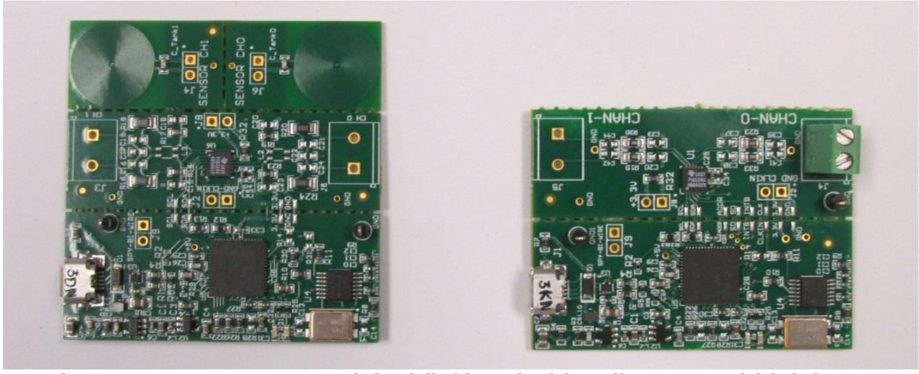


Figure 6: LDC1612 EVM, original (left) and with coils removed (right)

3.2 PCB Coil Sensor

After removing the EVM coils, the rectangular coil sensor can be attached to either channel through connector J4 (to Ch0) or J5 (to Ch1). For optimal performance, it is recommended to keep the wiring between coil sensor and EVM as short as possible.

A capacitor, whose value was determined in Section 2.2, must be soldered in parallel with the coil. There is a place holder C1 on the coil PCB for this capacitor. This forms the LC tank oscillator. If longer wiring is necessary, it is better to solder the capacitor on the EVM (e.g. underneath the J4 connector). In this case, the parasitic resistance will cause some degradation in the Q-factor of the coil, but not to such a point that it would significantly dampen the change in the oscillation frequency.

4 Getting Started Software

To test this system, you can use either a LabVIEW-based GUI, or the LDC131x/161x EVM GUI.

4.1 LabVIEW-based GUI

To run the LabVIEW executable, you will first need to install the LabVIEW Run-Time Engine 2014 or later, and NI-VISA Run-Time Engine 5.4 or later.

After installing those two run-time engines, you will be able to run the Staple Detection Demo executable. The interface is shown in Figure below.

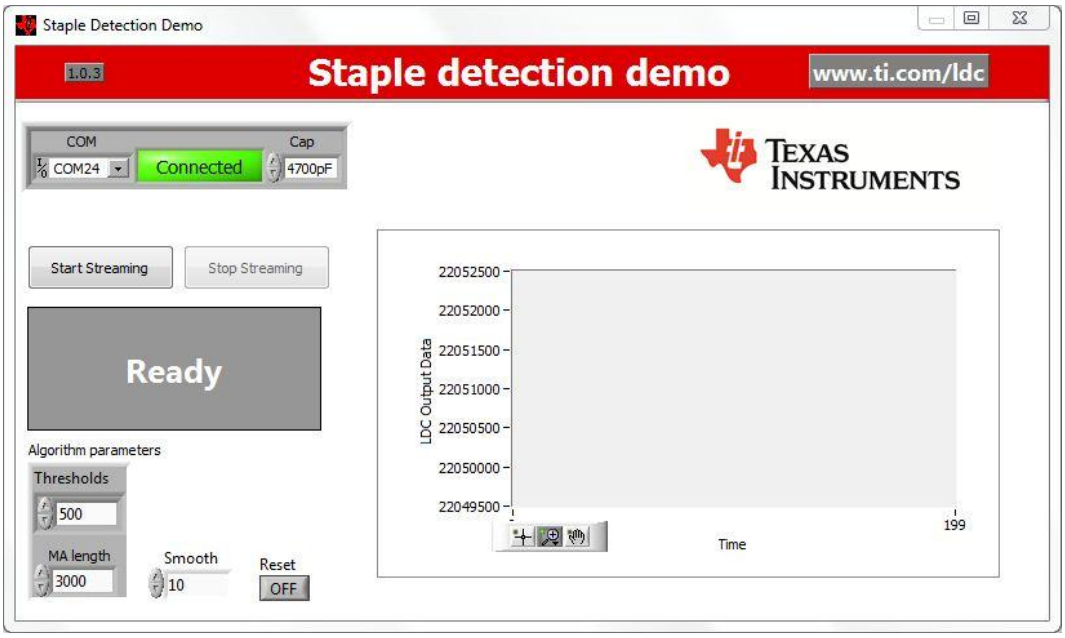


Figure 7: LabVIEW GUI

The GUI contains a dynamic plot window, which displays the LDC output data. The "threshold" is the amount of change in the output data that will be considered as a positive detection. To determine an appropriate threshold, you may first slide the paper with a staple or clip across the coil once, to see how much the output data changes. The amount of change will depend on your particular setup.

After the EVM is connected to a computer, the green "Connected" indicator will confirm communication with the EVM. After clicking the "Start Streaming" button, the LDC Output Data will start streaming. As a staple is passed over the coil, the output data will look like the figure below.

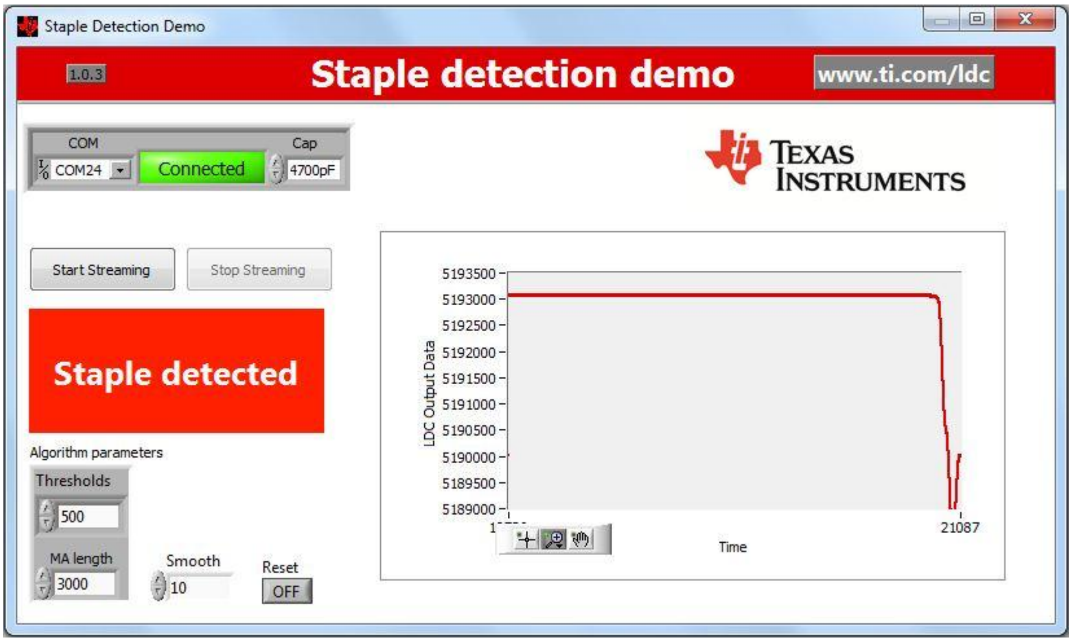


Figure 8: LabVIEW GUI when a staple is being detected.

As the staple continues to slide across the coil, a negative spike in the output data is observed, as shown in the following figure.

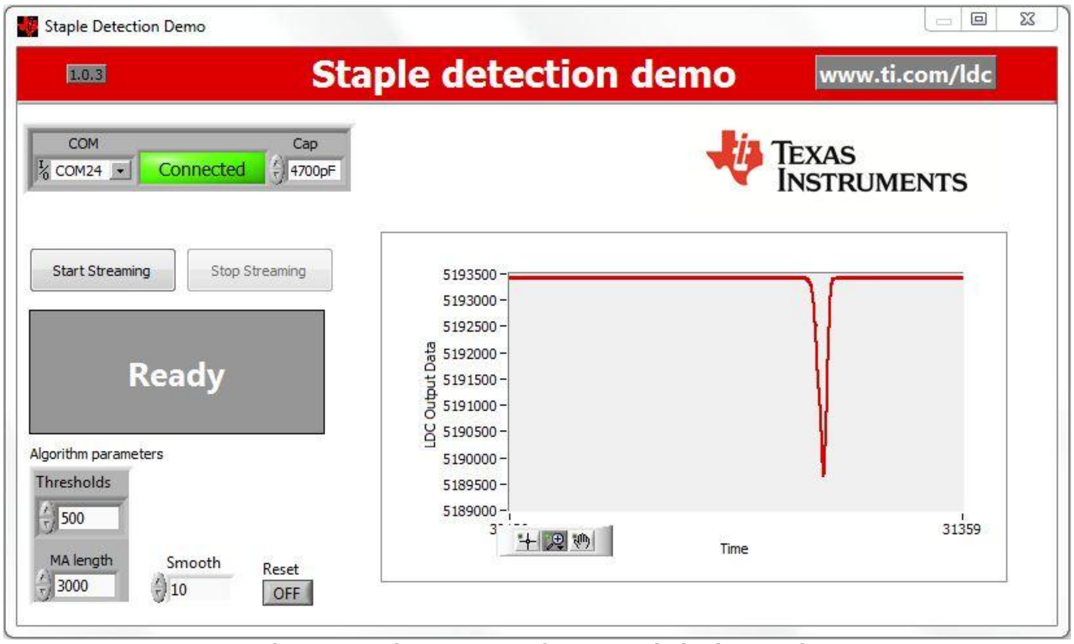


Figure 9: LabVIEW GUI after a staple is detected.

4.2 LDC131x/161x EVM GUI

The EVM GUI provides graphical configuration and streaming support for the LDC131x/161x. The GUI package includes drivers for use with the EVM. The EVM provides a device abstraction layer for the GUI to communicate with the LDC131x/161x through I2C, and includes other extended functionality.

Details on how to install, configure, and operate the GUI can be found in Section 3 of the LDC131x/161x EVM User's Guide.

After the GUI is installed and started, right-click on the appropriate channel plot, then choose "Toggle Data Type" to change the plot from inductance to frequency counter. To start real time plotting of the output data, click on the "Start" button.

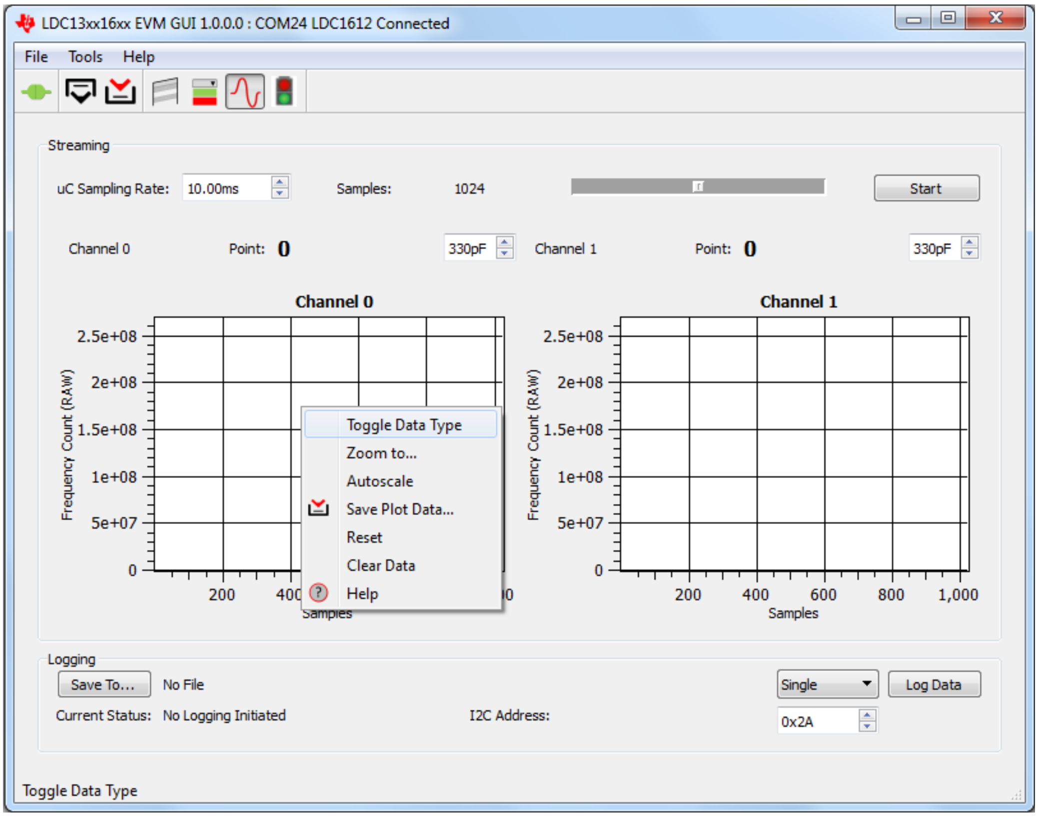


Figure 10: EVM GUI – toggle data type.

When a staple is detected, the frequency counter shows a negative spike as in the following figure.

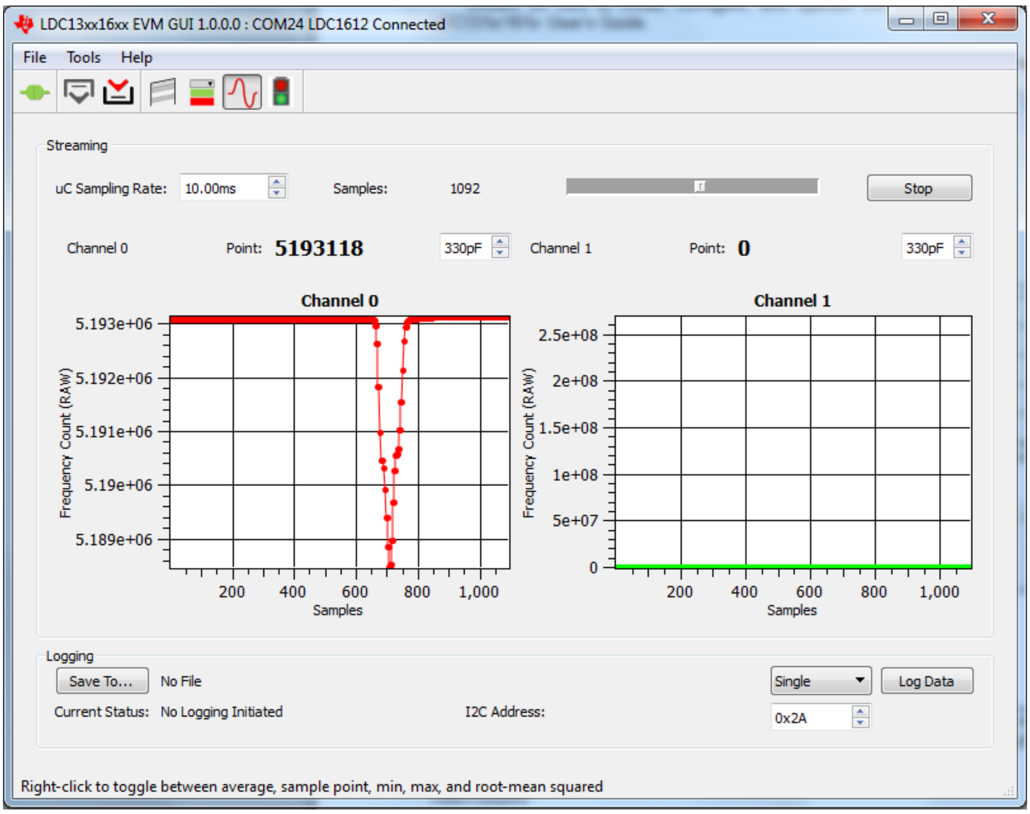


Figure 11: EVM GUI after a staple is detected.

5 Test Setup

To test this design, the EVM and coil should be attached to a flat surface (e.g. a desk). You may also put a thin stack of paper next to the coil as a platform to facilitate sliding the paper and staple. Among common metal foreign objects on paper, e.g. staples, paper clips, binders, etc., staples are the smallest in size and therefore most difficult to detect.

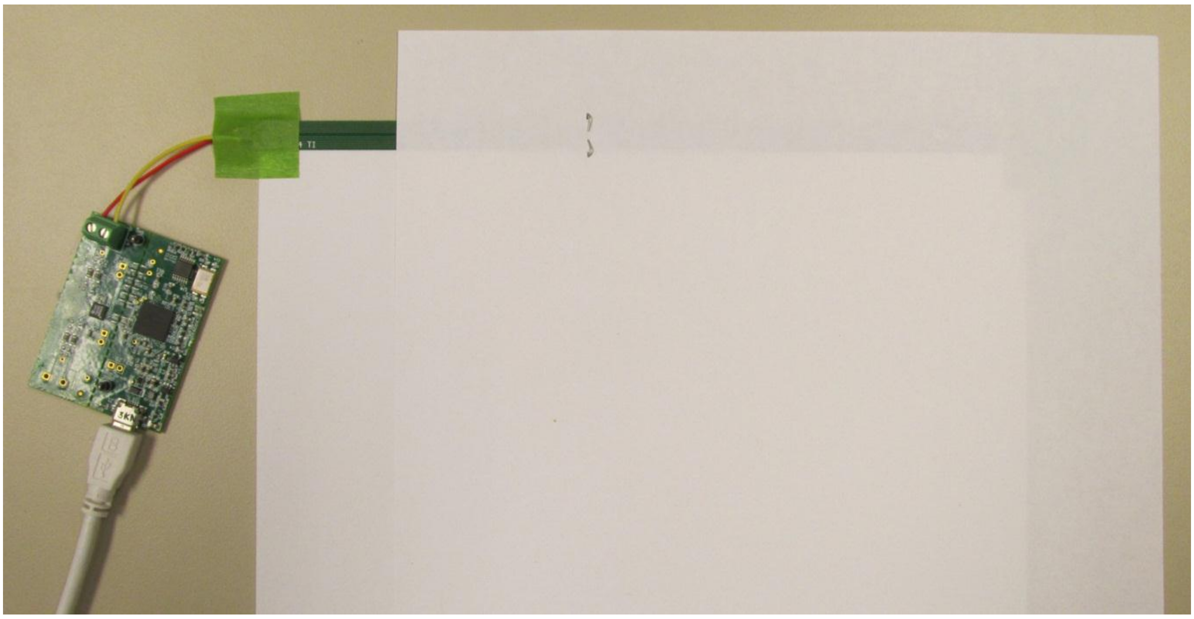


Figure 12: Test setup of the staple detection application.

6 Test Results

The amount of change in the frequency counter will depend on a number of factors. These include the orientation of the staple, the relative position of staple to the paper, and which side of the staple is facing the coil. However, as long as a suitable threshold is selected, all these scenarios can be detected.

Figure 13: Possible orientations of a staple. From left to right: horizontal, slanted, and vertical.

The following figure shows the measured response to each of these orientations.

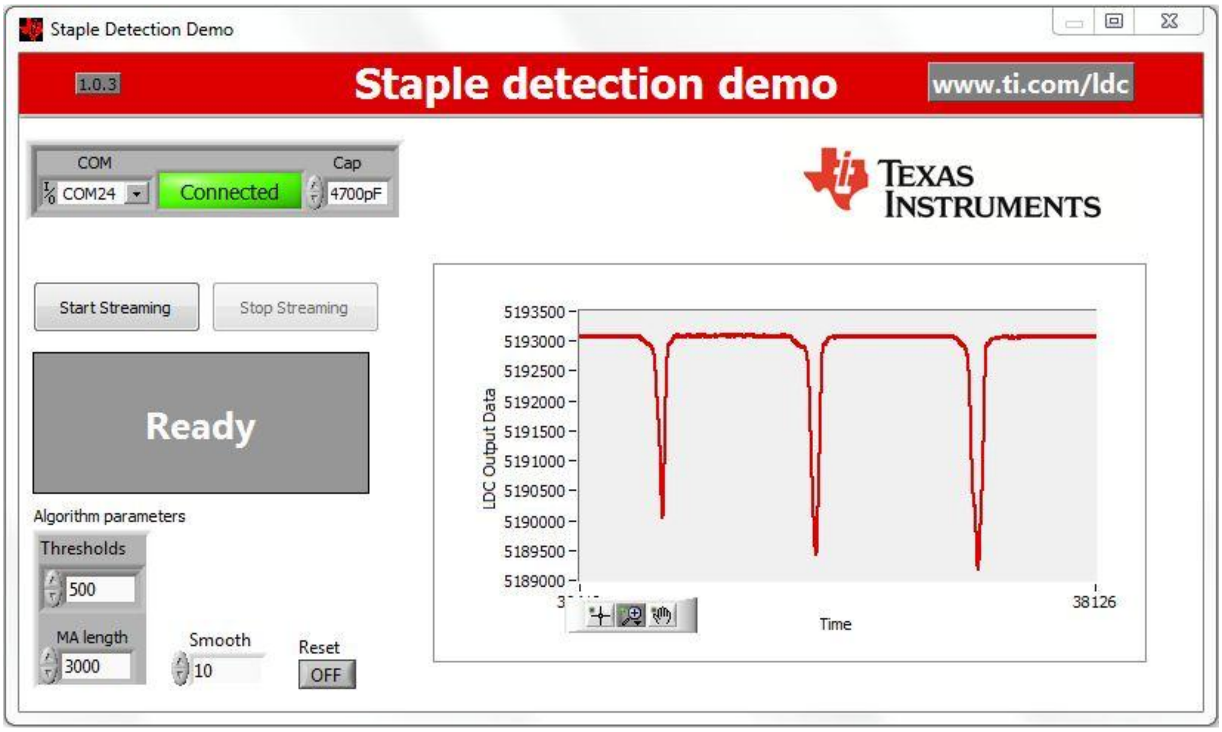


Figure 14: Frequency response due to a staple. From left to right: Horizontal, Diagonal, and Vertical.

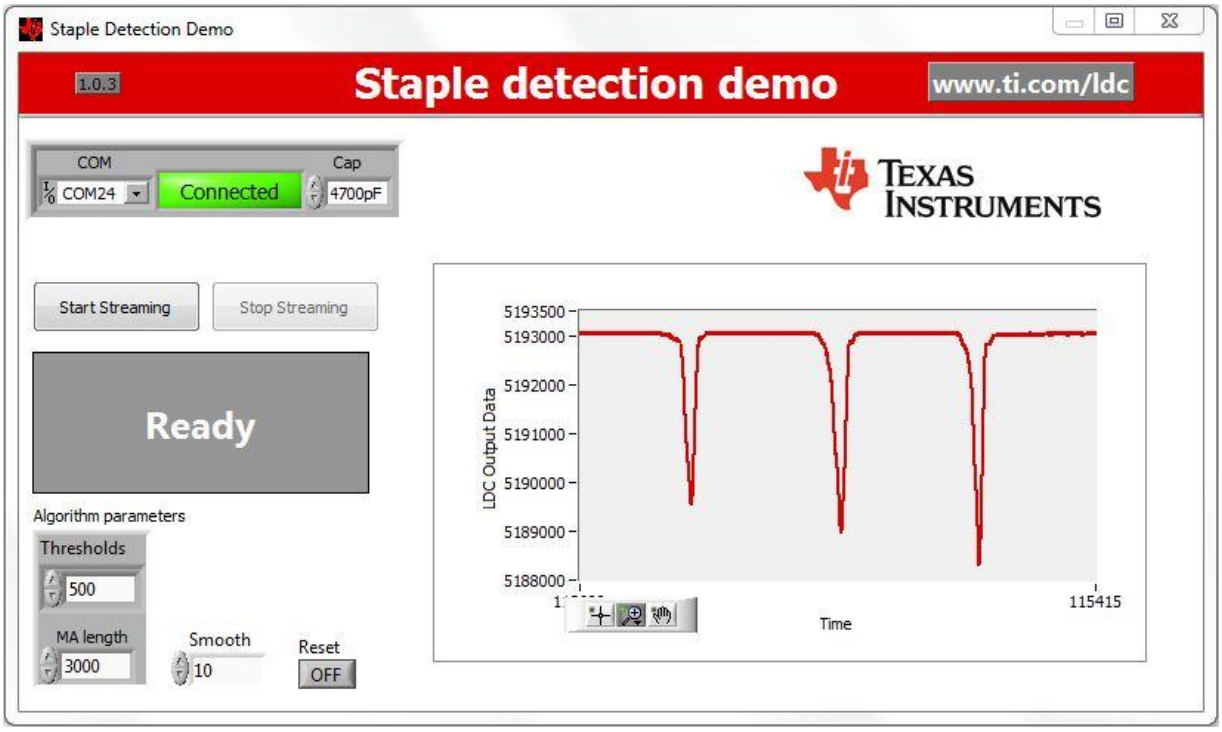


Figure 15: Frequency response due to a vertical staple at different positions on paper. From left to right: side, quarter width, center of paper.

Figure 15: Two sides of a staple; open (left) and closed (right).

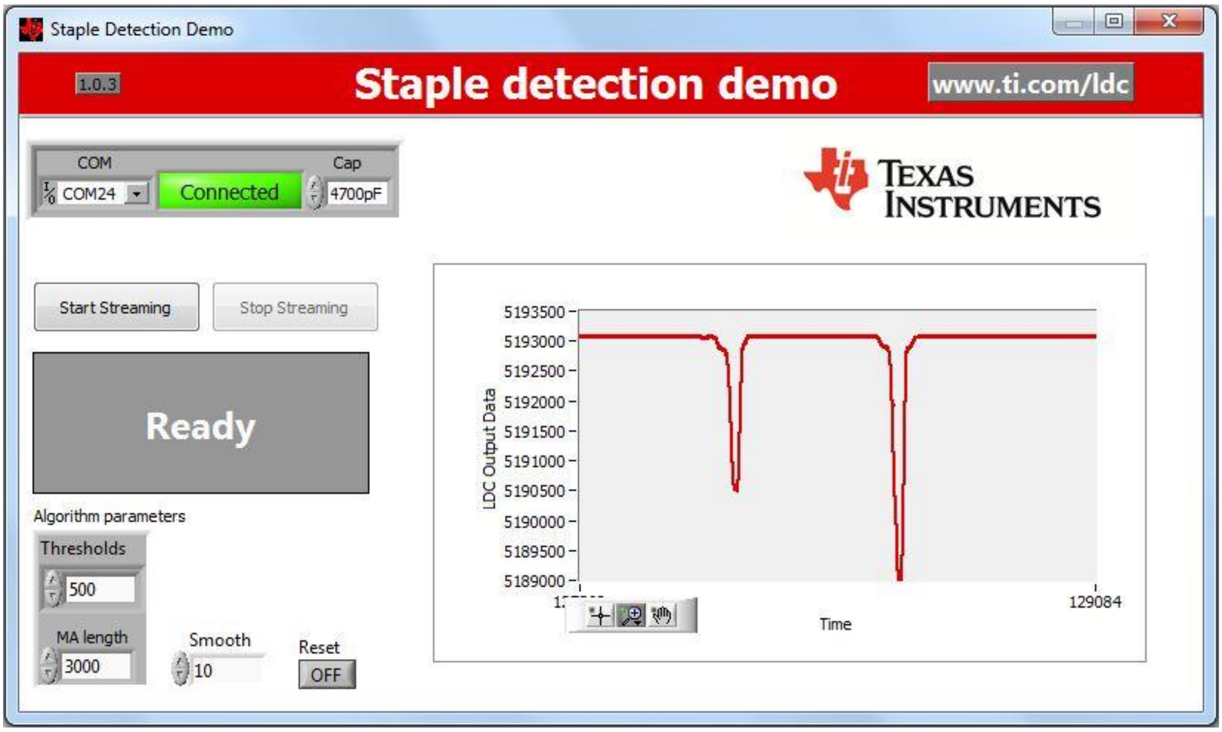


Figure 16: Frequency response due to a vertical staple with different side facing the coil, open side facing the coil (left) and closed side facing the coil (right).

7 Design Files

7.1 Gerber

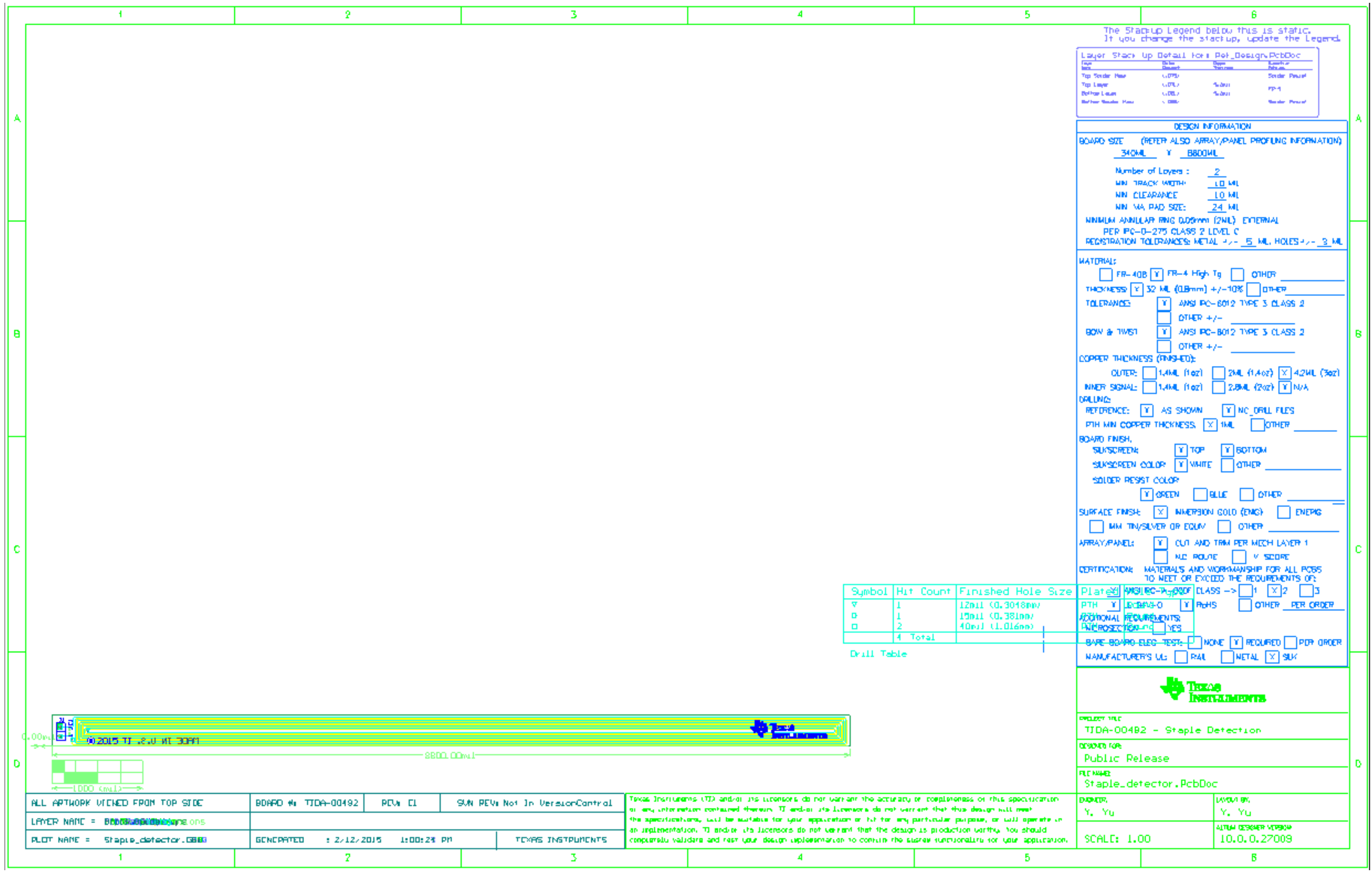


Figure 17: Gerber of the staple detection coil.

7.2 Layer Plots

The coil sensor is on the top and bottom layers of the PCB.

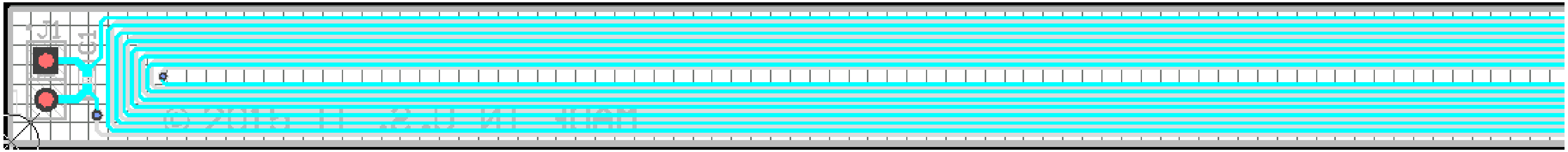


Figure 18a: Top layer of the PCB coil sensor.

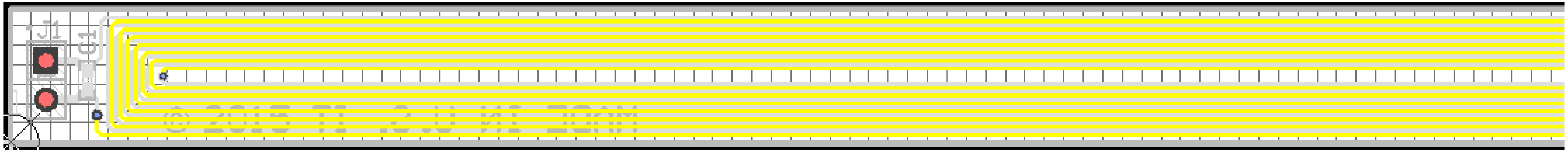


Figure 18b: Bottom layer of the PCB coil sensor.

8 Software Files

To download the software files for this reference design, please see the link at http://www.ti.com/tool/tida-00492

9 References

1. Frederick Emmons Terman, “Radio Engineers’ Handbook”, First Ed., McGraw-Hill Book Company, Inc., 1943

10 About the Author

Yibo Yu is a Systems Architect at Texas Instruments, where he is responsible for developing system solutions and reference designs for inductive and capacitive sensing technologies. Yibo earned his Master of Science degree in Electrical Engineering at Stanford University, and Bachelor of Science in Electrical Engineering and Computer Sciences at University of California, Berkeley.

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