Introduction to LDC and its Technology

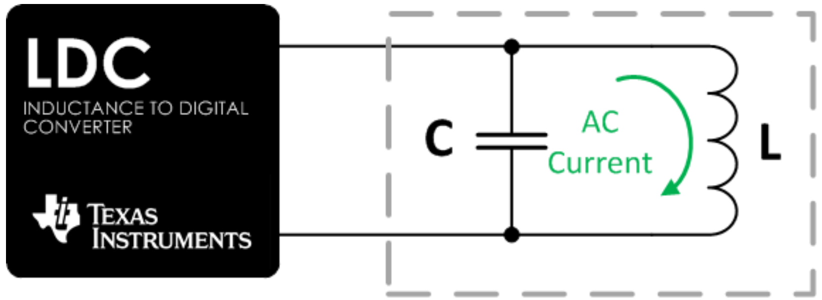
TI Precision Labs – Inductive Sensing

Presented by Justin Beigel

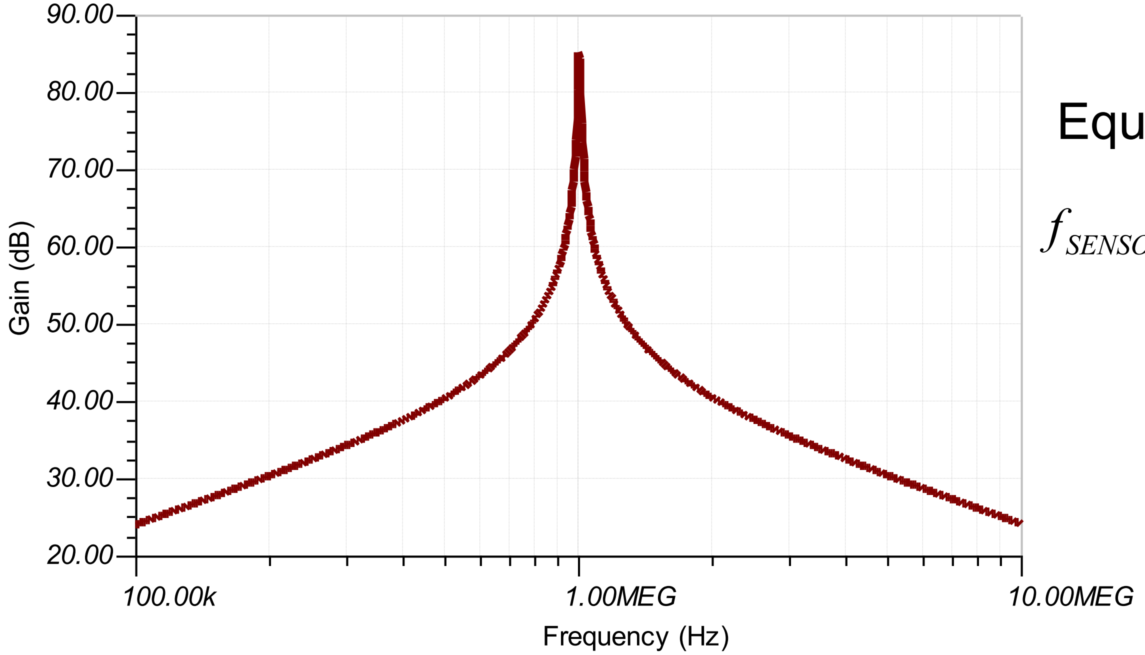
Prepared by Justin Beigel

Inductive Sensing

Basic concepts

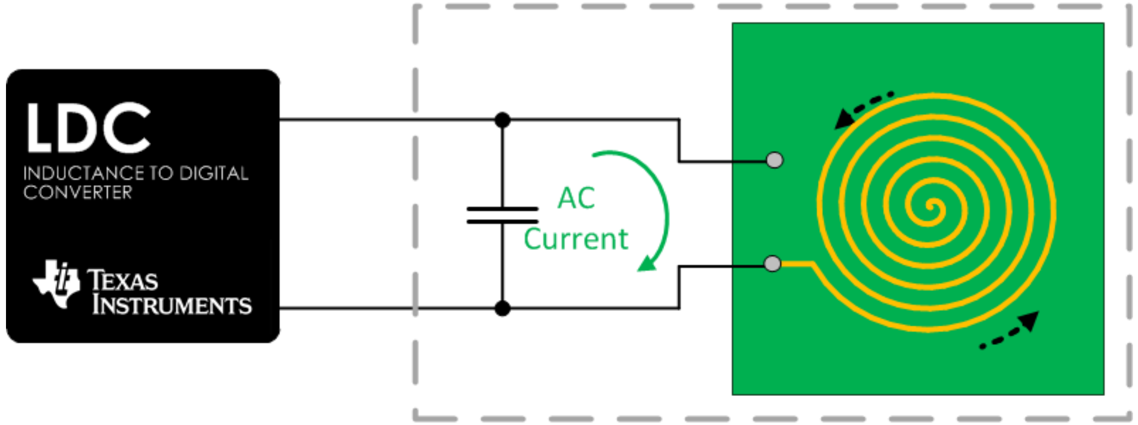


- Parallel inductor and capacitor form high Q resonant oscillator
- LDC converts fundamental frequency to high resolution digital value

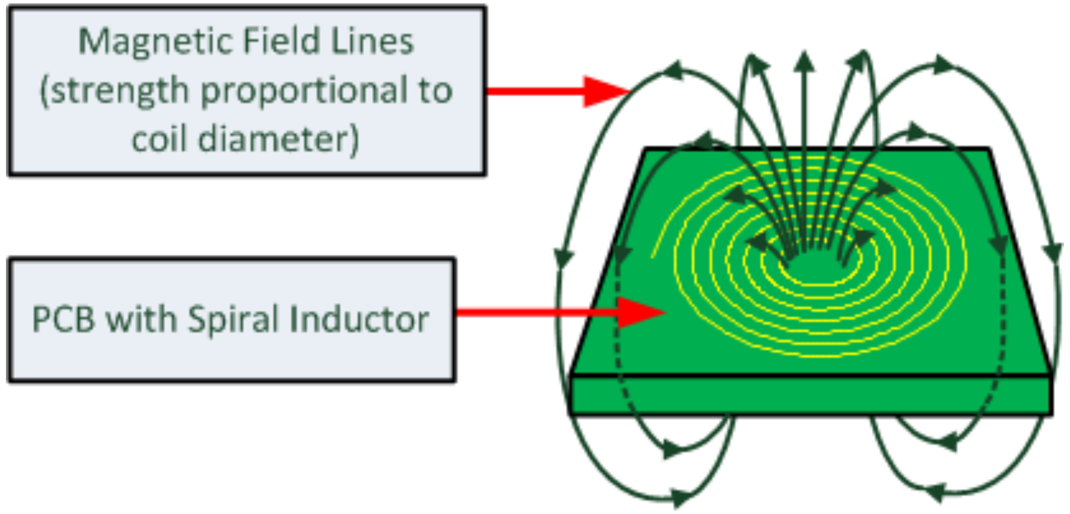


Equation 1:

$$f_{SENSOR} = \frac{1}{2\pi\sqrt{L \cdot C}}$$

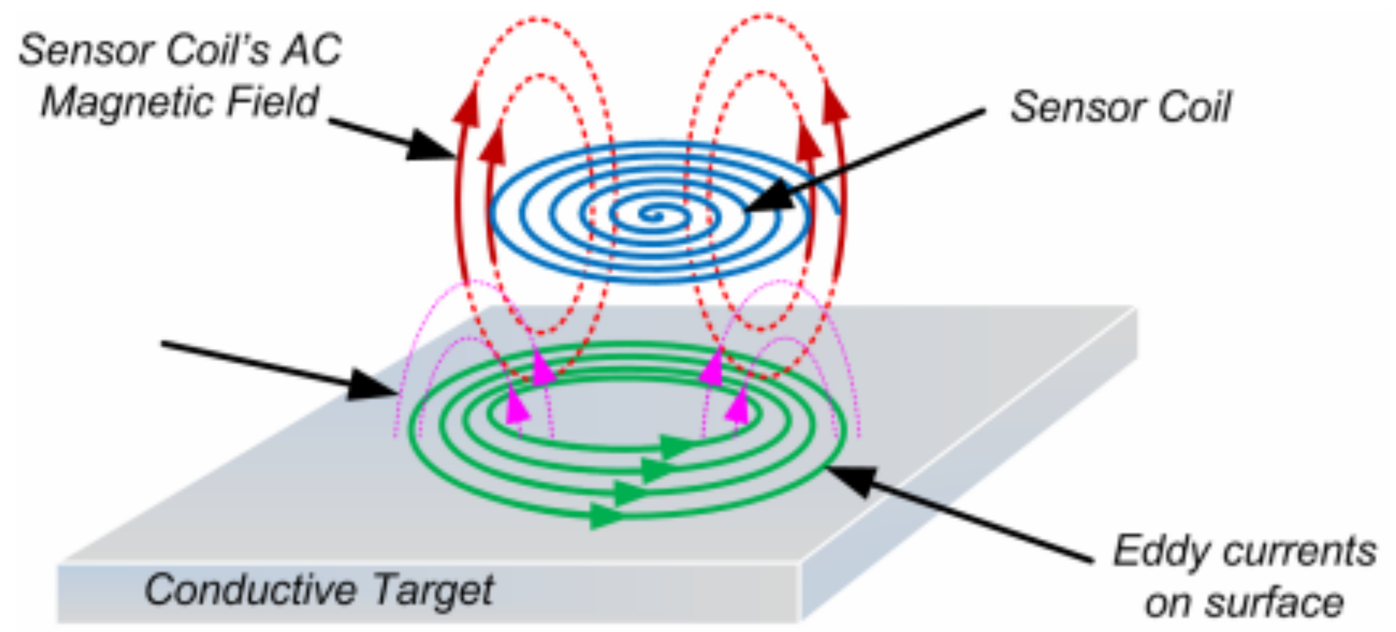


- Inductor typically constructed on PCB which radiates an AC magnetic field
- Discrete capacitor typically NP0/C0G



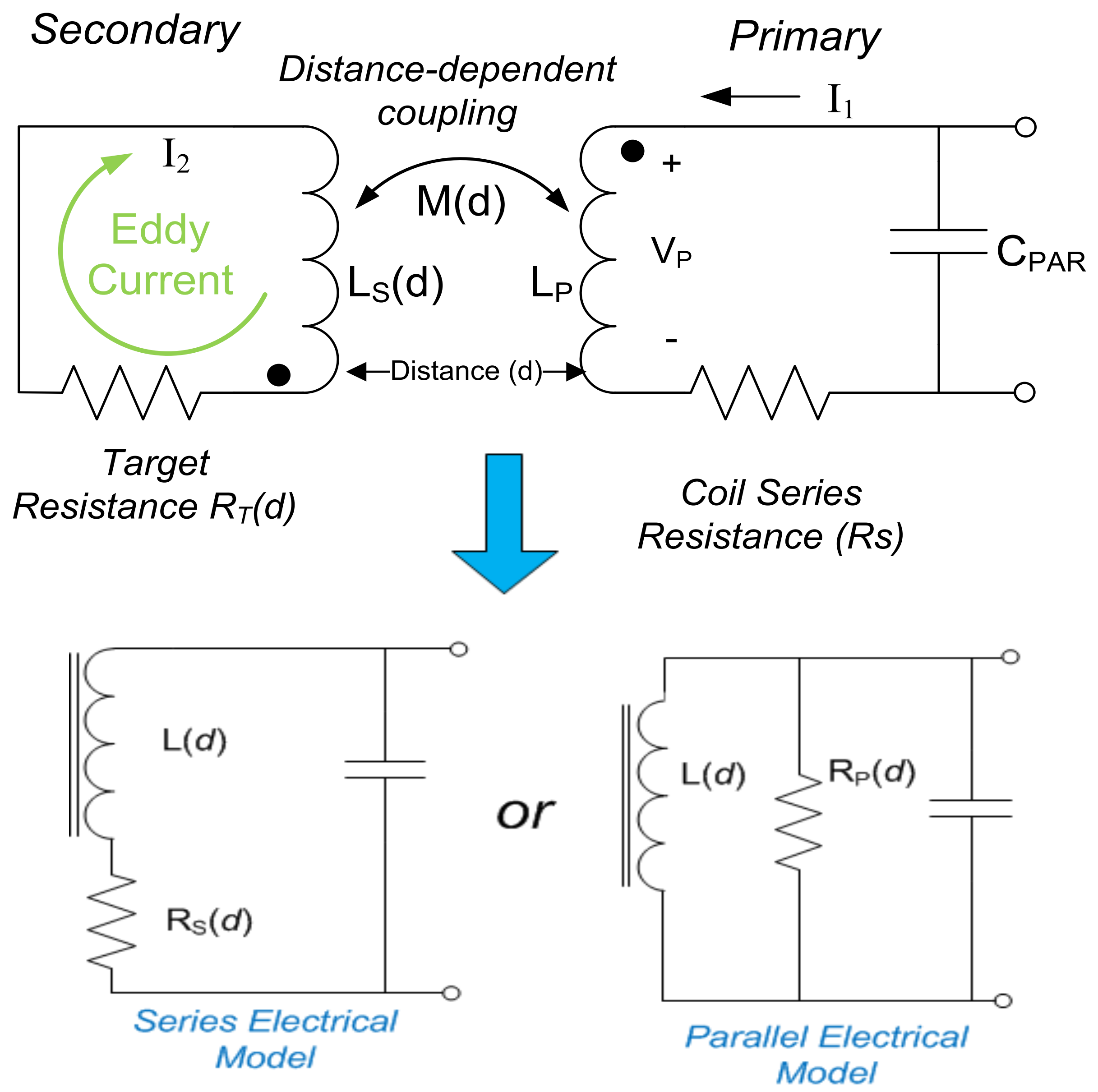
Inductive Sensing

Eddy Currents and Inductance Coupling



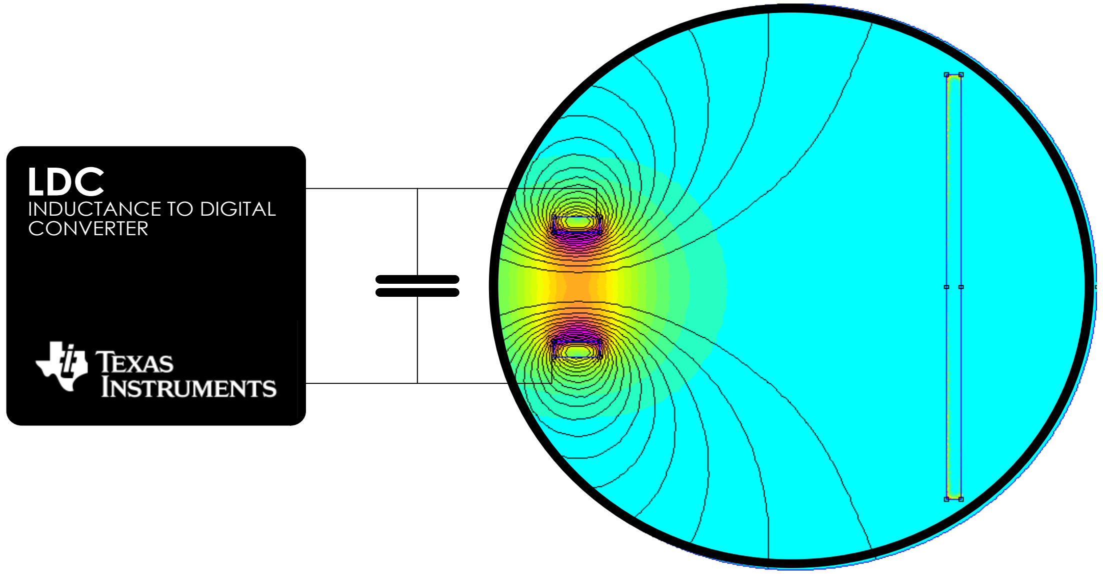
- The AC magnetic field from the LC sensor causes eddy currents to form on the surface of the conductor.

- Eddy currents create an opposing magnetic field which effectively reduces the inductance of the inductive sensor. The inductance changes as a function of distance.



Inductive Sensing

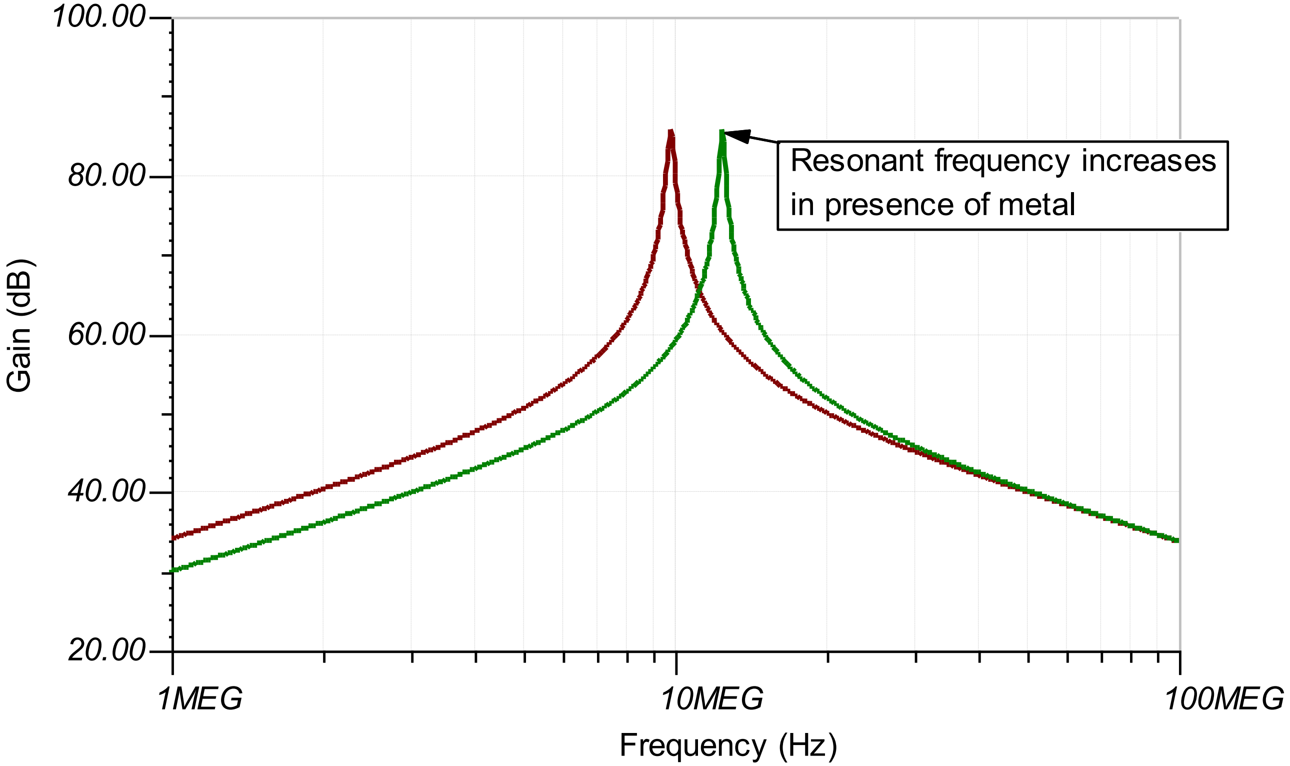
Metal Target Interaction



- Approaching conductive target forms greater density of eddy currents on its surface as it interacts with more of the magnetic field generated by the inductive sensor

- Based on the properties of the metal and proximity to the sensor, the eddy currents generate an opposing magnetic field that varies in strength and reduces the inductance of the LC sensor

Figure 1:

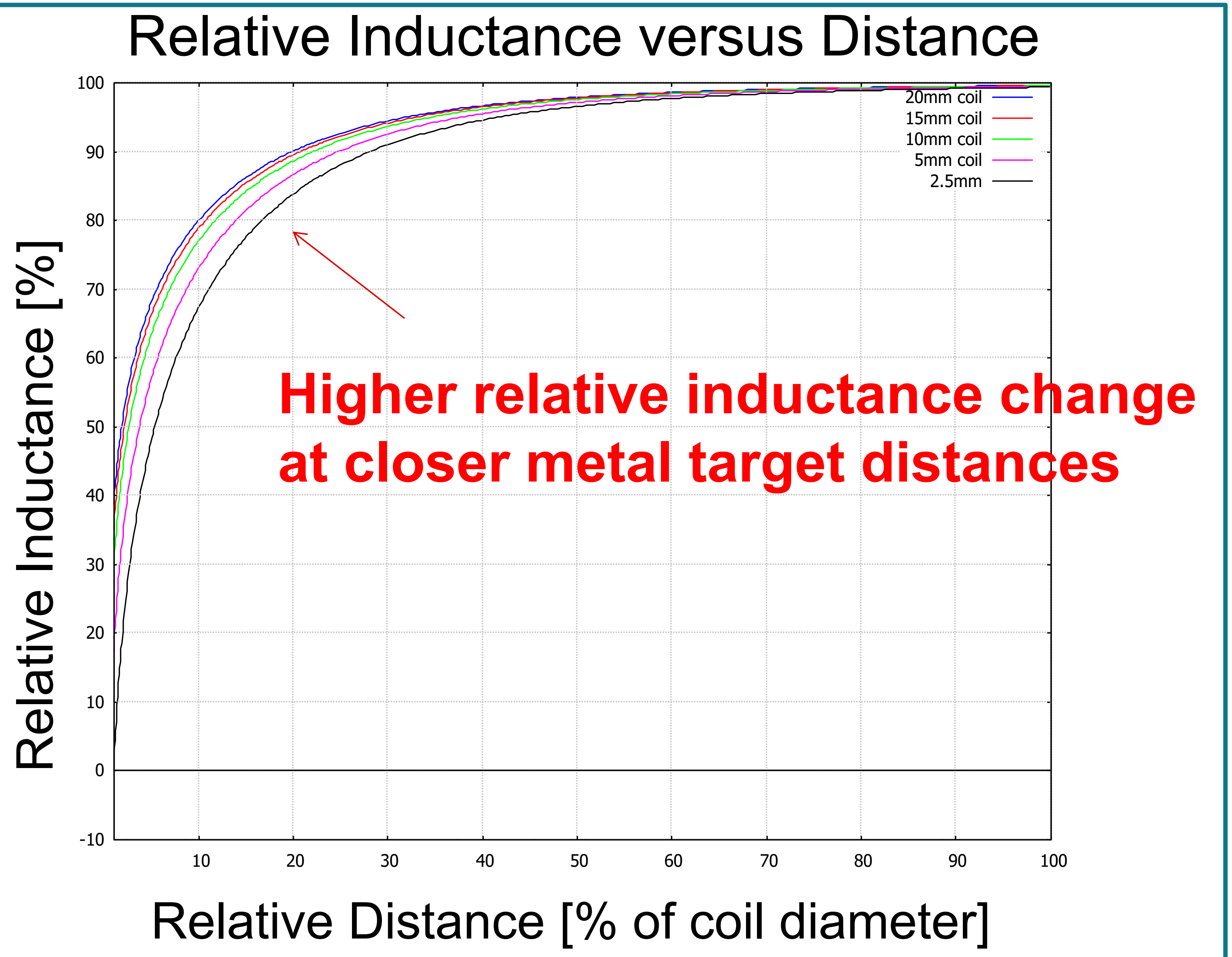


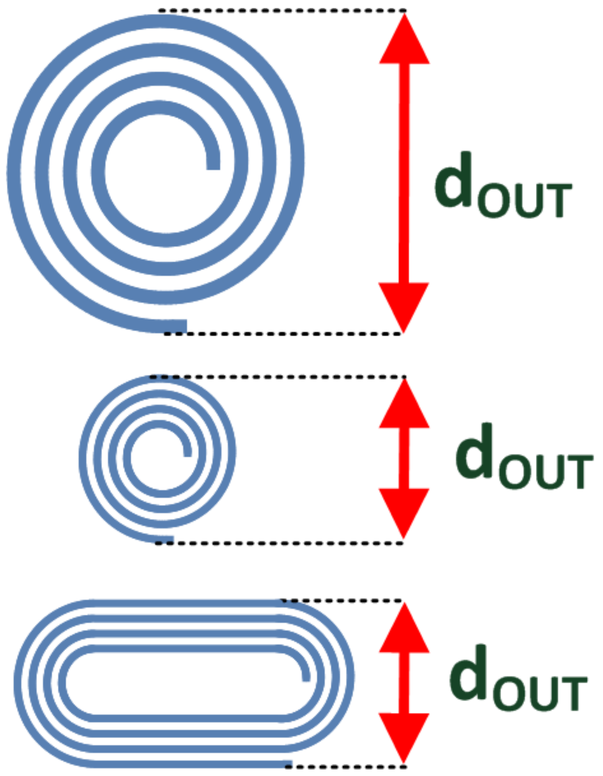
- A decrease in inductance of the LC sensor causes an increase in resonant frequency which the LDC converts into a new digital value

$$f_{SENSOR} = \frac{1}{2\pi\sqrt{L \cdot C}}$$

Inductive Sensing

Relative inductance vs distance





- Relative inductance shift determined by outer diameter or critical dimension of coil shape
- **Note: More inductance does not mean more sensing range**

Inductive Sensing

Material Options – Conductivity/Eddy Currents/Skin depth

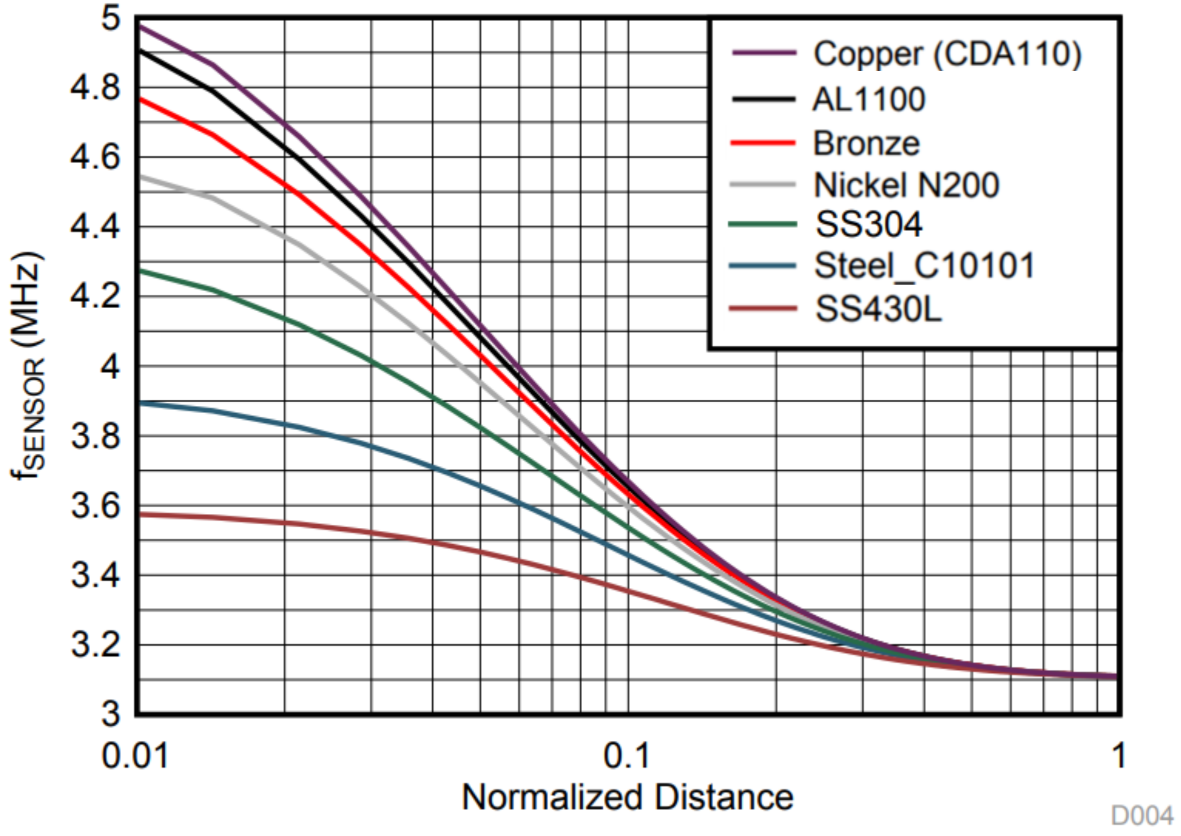
Conductive Materials

- Stainless Steel (med σ) ✓
- Bronze (med σ) ✓✓
- Aluminum (high σ) ✓✓✓
- Copper (high σ) ✓✓✓

Non-Conductive Materials

- Plastic ✗
- Glass ✗
- Plastic with metal film ✓
- Glass with metal film ✓

Inductance Shift



- Materials that have a higher conductivity produce more of an inductance shift because there are less losses in the material for the eddy currents to form

Inductive Sensing

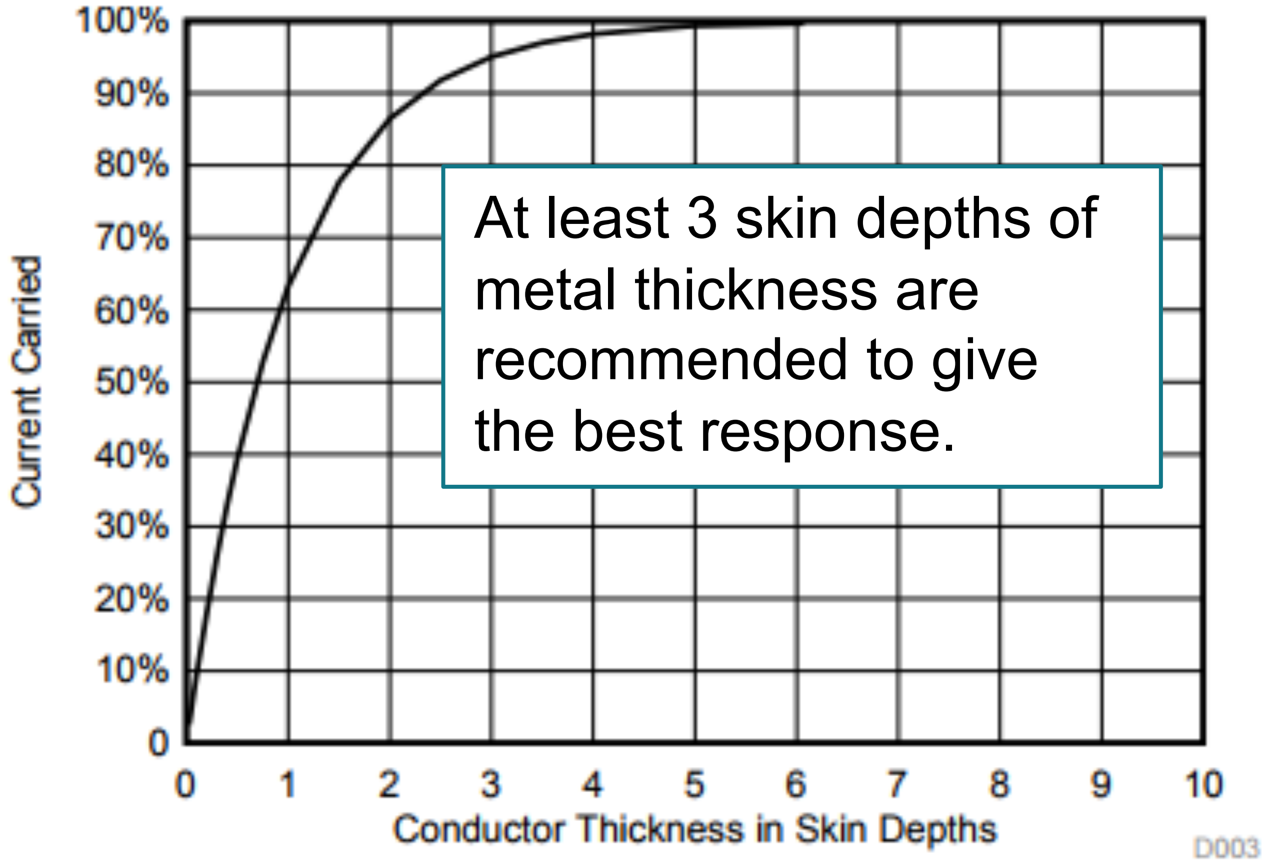
Thin Materials and Skin Depth

Skin Depth and Conductive Materials

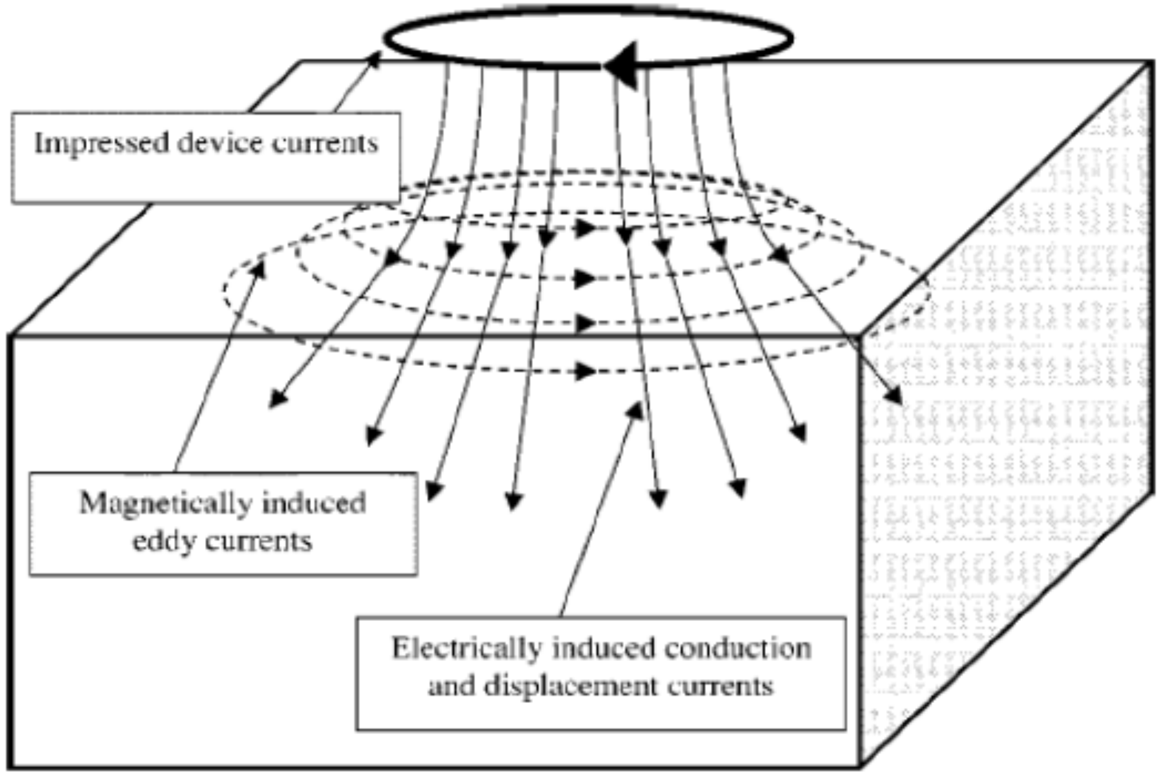
- Skin depth specifies how deep into the conductive surface that the eddy currents will form
- Eddy currents that form closer to the surface produce a more concentrated opposing magnetic field to our sensor

$$\delta = \sqrt{\frac{1}{\pi \mu f \sigma}}$$

δ = skin depth
μ = permeability
f = sensor frequency
σ = conductivity



At least 3 skin depths of metal thickness are recommended to give the best response.



Inductive Sensing

Target Properties Affecting Power Consumption

An inductive sensor generates an AC magnetic field which induces eddy currents on the conductor's surface.

Generated eddy currents:

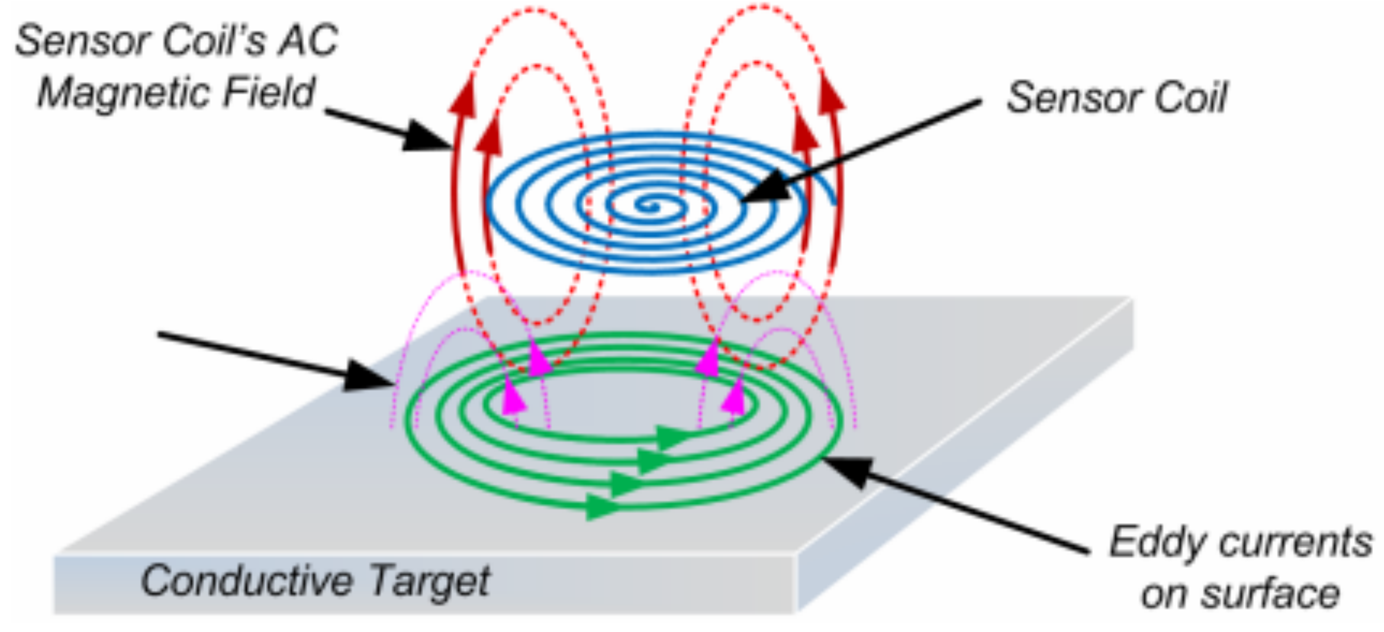
- Reduce the inductor's magnetic field reducing the inductance of the sensor.
- Lower inductance results in:
  - Higher sensor frequency which reduces the skin depth.
  - Shallower skin depth increases R_s losses, resulting in higher power consumption.

$$\delta = \sqrt{\frac{1}{\pi \mu f_{sensor} \sigma}}$$

δ = skin depth
μ = permeability
f = sensor frequency
σ = conductivity

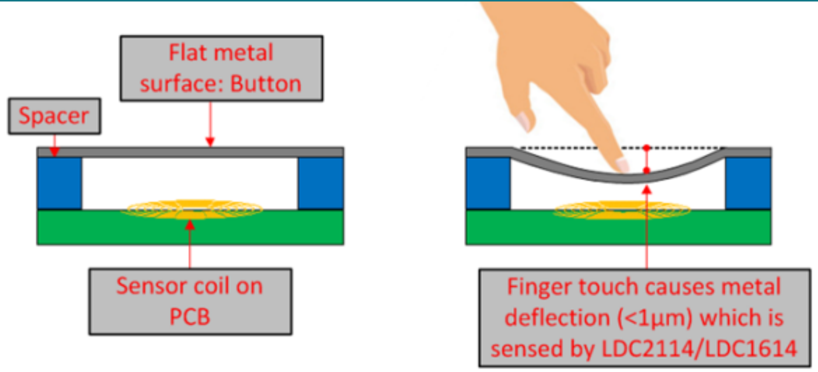
$$f_{sensor} = \frac{1}{2\pi\sqrt{L * C}}$$

f_{sensor} = sensor frequency
L = sensor coil inductance
C = fixed sensor capacitance



Inductive Sensing
Common Applications

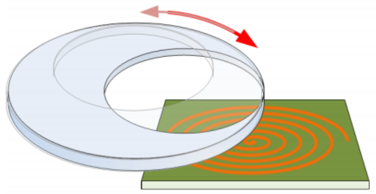
Buttons



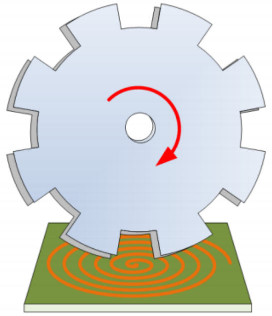
Benefit
- No cutouts or holes needed
- No moving parts
- Force detection for multi-level button
- Not affected by debris, liquids, magnets
- Works with gloves

Design Considerations
- Resolution
- Coil size
- Mechanical stack-up
- Automotive applications
- Power requirements

Encoder/Knob



Rotation Sensing

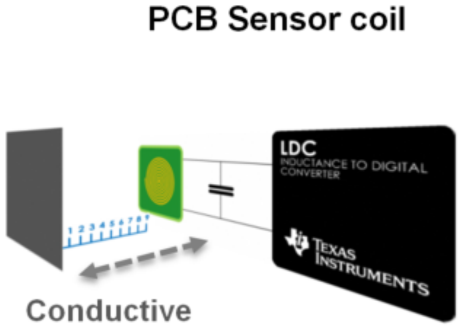


Event Counting

Benefit
- No calibration required
- No magnets required and not affected by them
- Immune against dirt and dust
- Can measure > 300 events per second
- Minimal MCU memory and instructions required

Design Considerations
- Resolution
- Coil size
- Target design
- Automotive applications
- Power requirements

Metal Proximity



Benefit
- Immune against dirt and dust
- No magnets required and not affected by them
- Sensor is simply a PCB coil and the target is any conductive material

Design Considerations
- Resolution
- Target distance (min and max)
- Lateral or Axial
    - Target design for lateral
- Coil size
- Mechanical stack-up
- Automotive applications
- Power requirements

To find more current sense amplifier technical resources and search products, visit ti.com/inductive