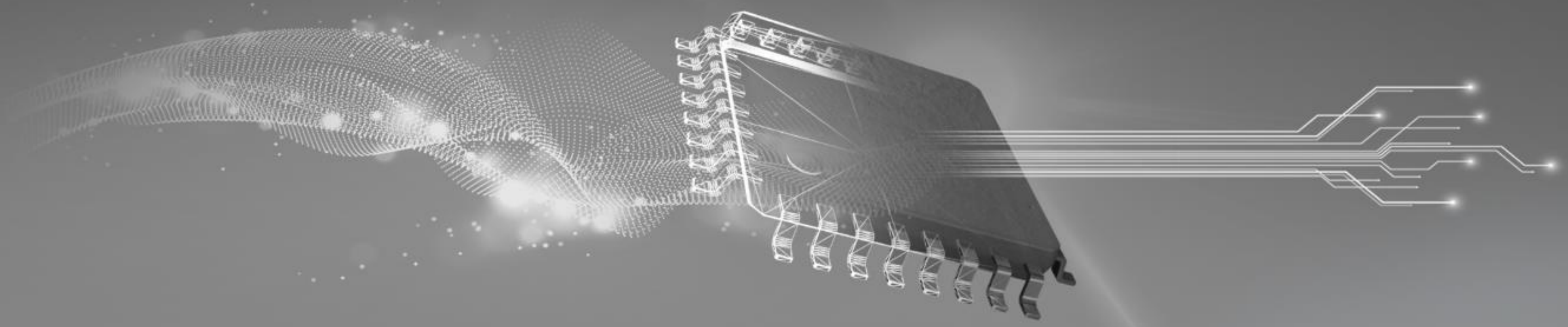
TI TECH DAYS



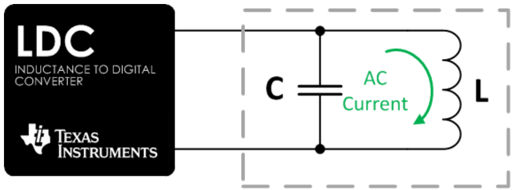
Introduction to inductive sensing technology:
Benefits of inductive sensing as a button replacement

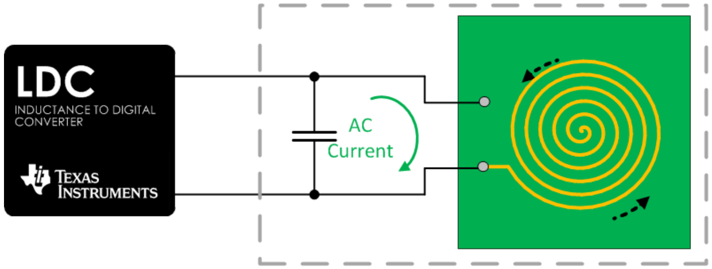
Justin Beigel

Position Sensing

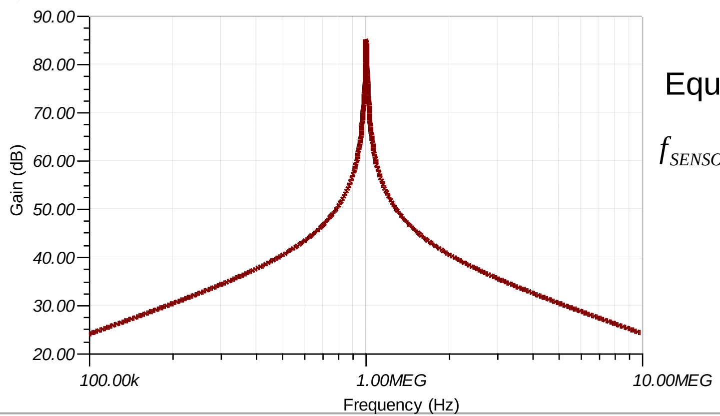
Inductive sensing

Basic concepts





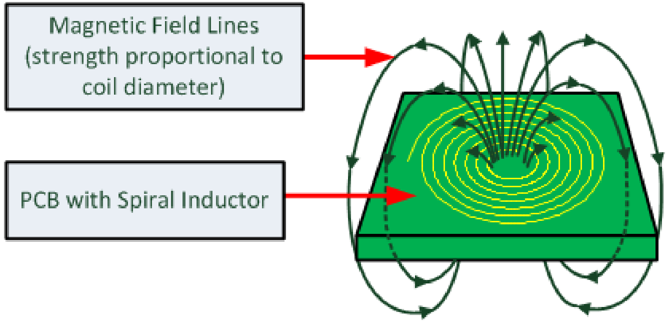
- Parallel inductor and capacitor form high Q resonant oscillator
- LDC converts fundamental frequency to high resolution digital value



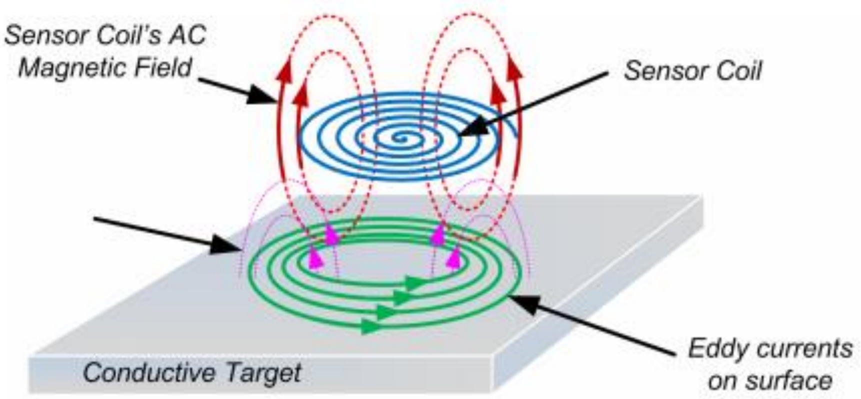
Equation 1:

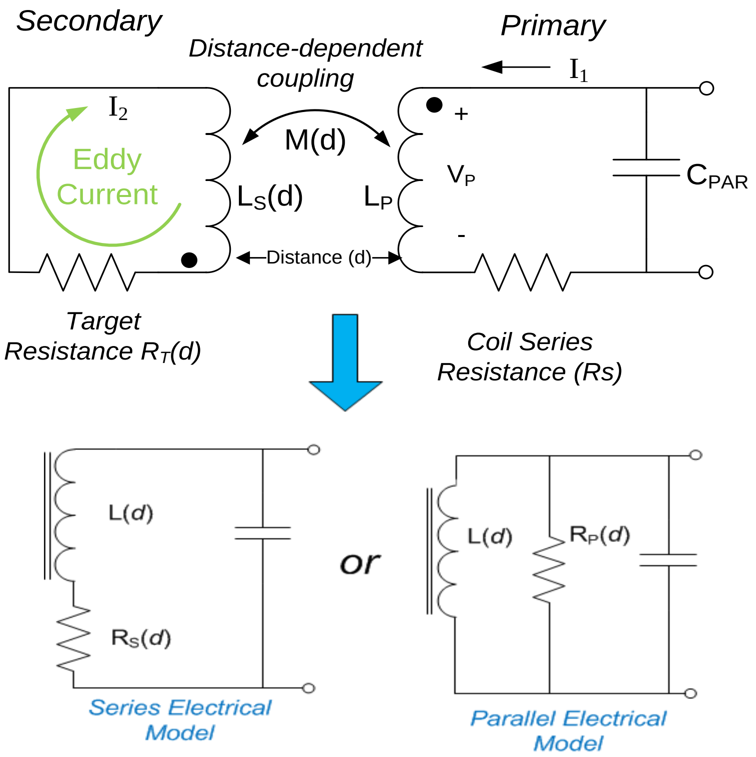
$$f_{SENSOR} = \frac{1}{2\pi\sqrt{L \cdot C}}$$

- 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

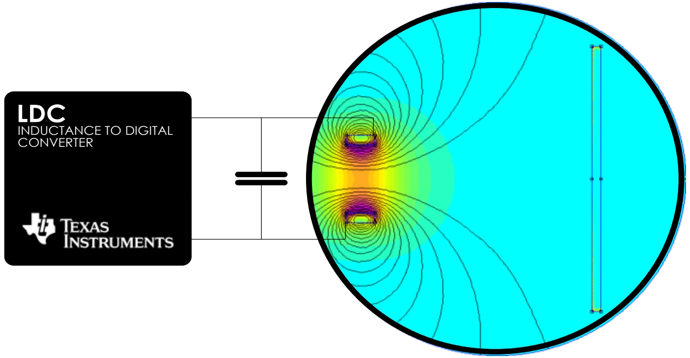
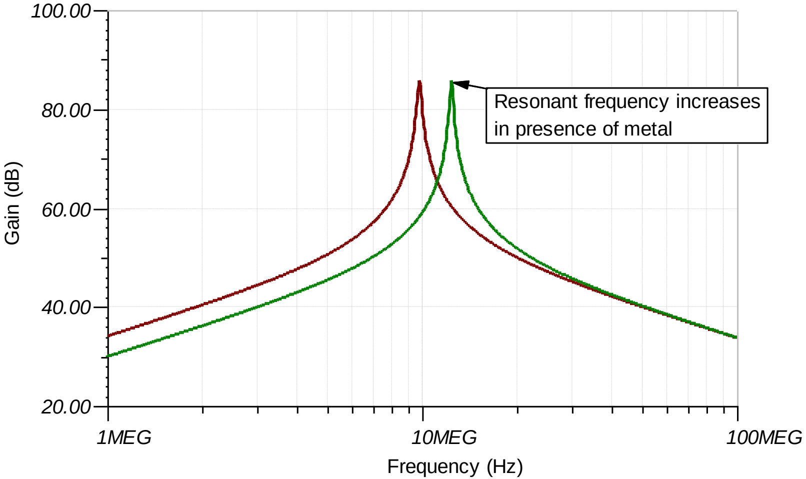


Figure 1:



- 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.

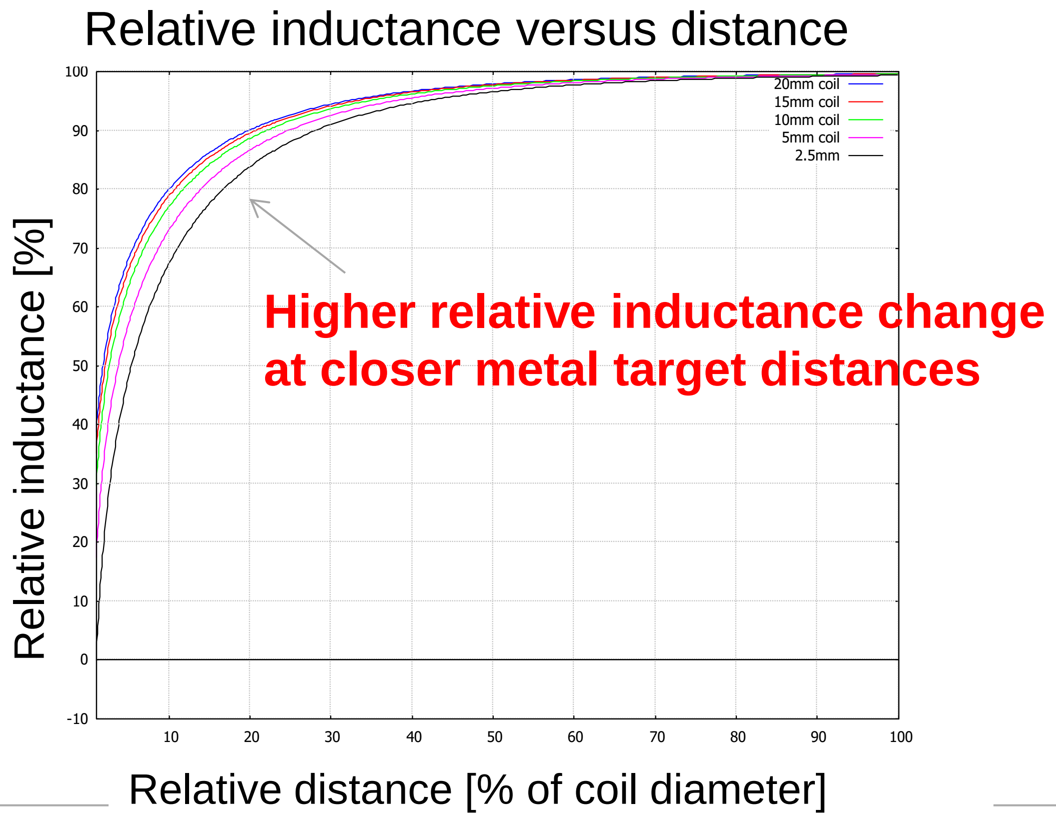
- Based on the properties of the metal and proximity to the sensor, the eddy currents generate an opposing magnetic field that varies in strength and reduces the inductance of the LC sensor.

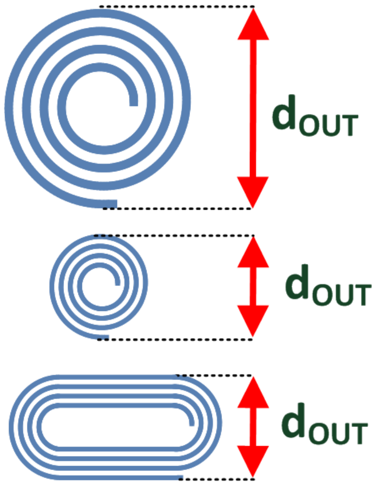
- A decrease in inductance of the LC sensor causes an increase in resonant frequency which the LDC converts into a new digital value.

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

Inductive sensing

Relative inductance vs. distance





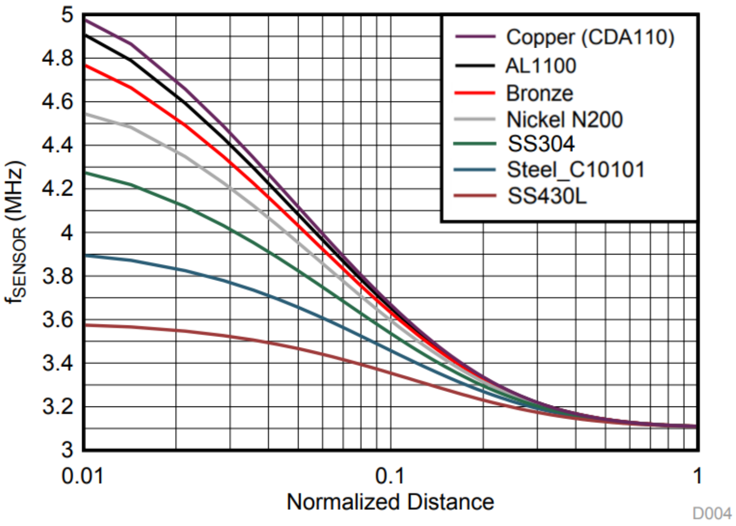
- Relative inductance shift determined by outer diameter or critical dimension of coil shape
- **Note: More inductance does not mean more sensing range**

Inductive sensing

Material options – conductivity/Eddy currents/Skin depth



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




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

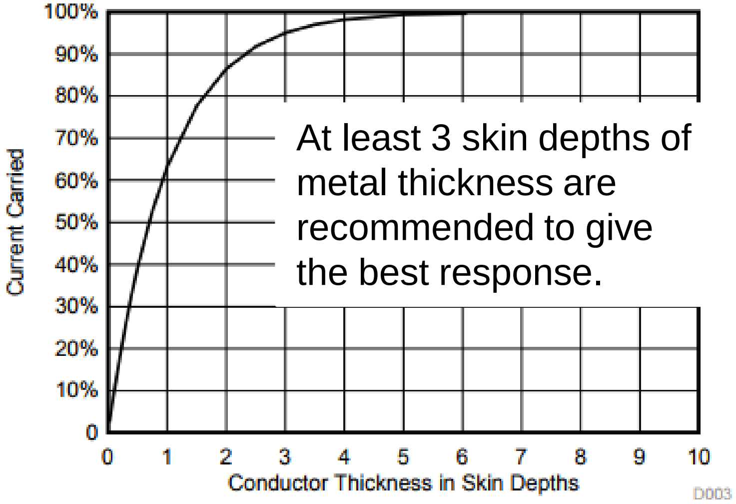
- Materials that have a higher conductivity produce more of an inductance shift because there are less losses in the material for the eddy currents to form

Inductive sensing
Thin materials and skin depth

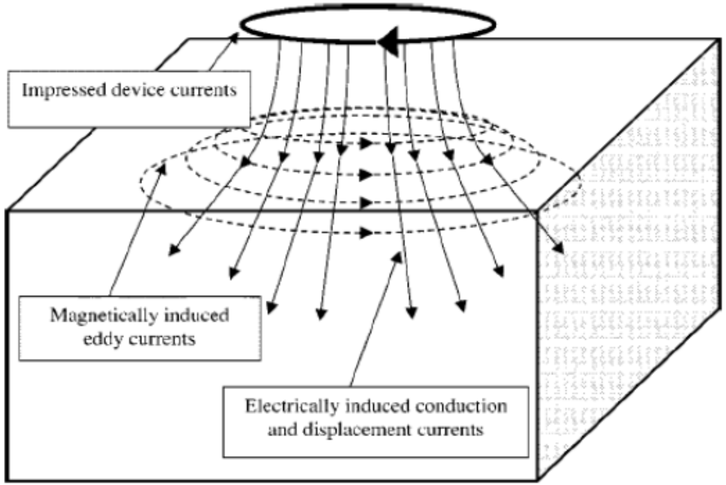
- Skin depth specifies how deep into the conductive surface that the eddy currents will form
- Eddy currents that form closer to the surface produce a more concentrated opposing magnetic field to our sensor

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

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:

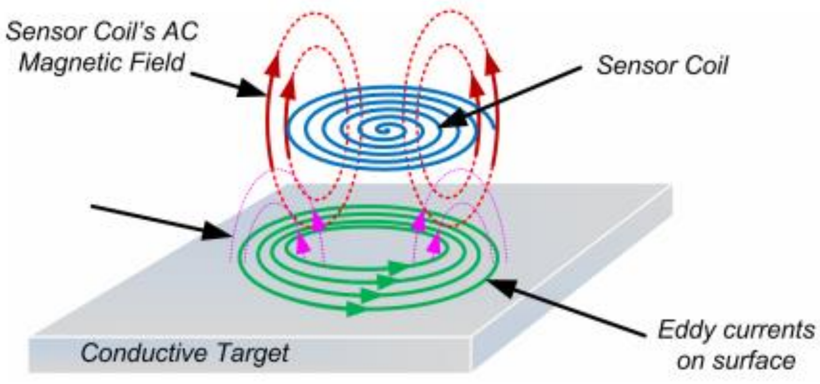
- Reduce the inductor's magnetic field reducing the inductance of the sensor.
- Lower inductance results in:
    - Higher sensor frequency which reduces the skin depth.
    - Shallower skin depth increases R_s losses, resulting in higher power consumption.

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

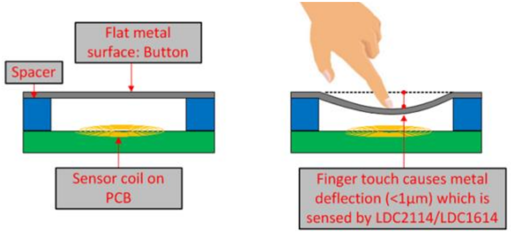
δ = skin depth
μ = permeability
f = sensor frequency
σ = conductivity

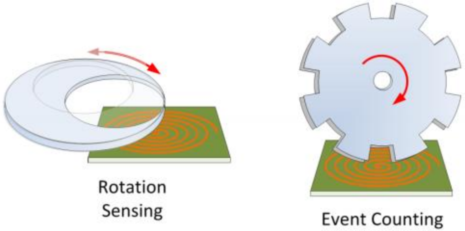
$$f_{sensor} = \frac{1}{2\pi\sqrt{L * C}}$$

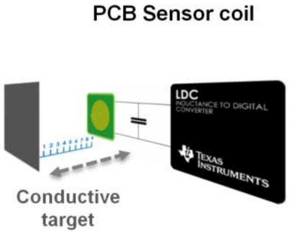
f_{sensor} = sensor frequency
L = sensor coil inductance
C = fixed sensor capacitance



Inductive sensing
Common applications







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

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

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

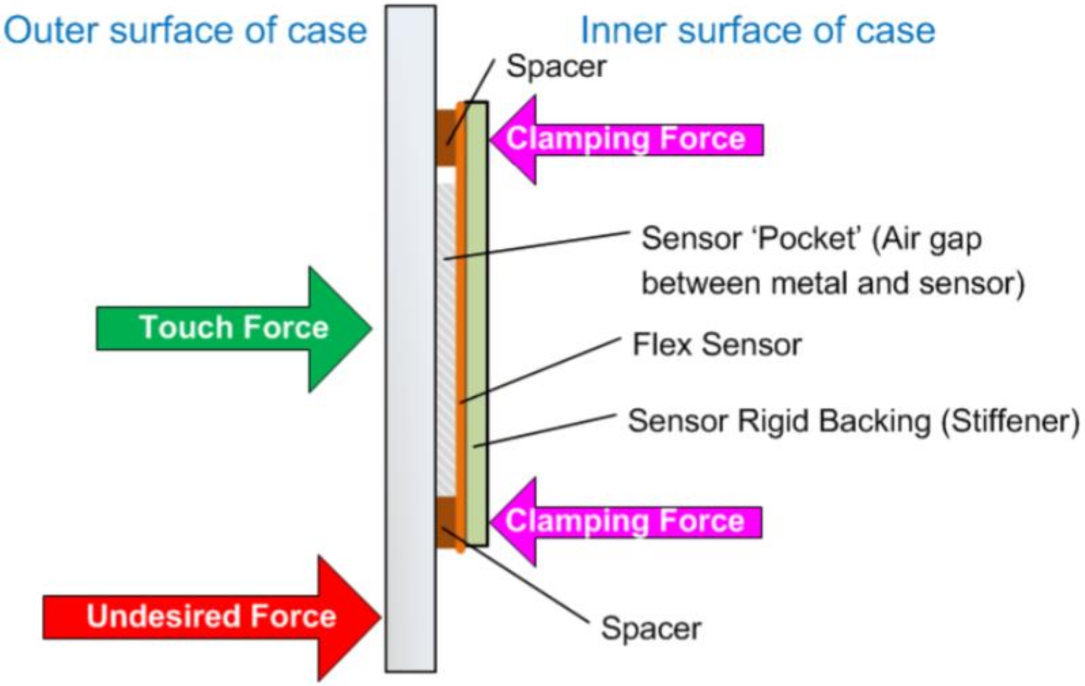
Design considerations
- Resolution
- Target distance (min and max)
- Lateral or Axial
  - Target design for lateral
- Coil size
- Mechanical stack-up
- Automotive applications
- Power requirements

Inductive sensing buttons

Inductive touch
Key advantages

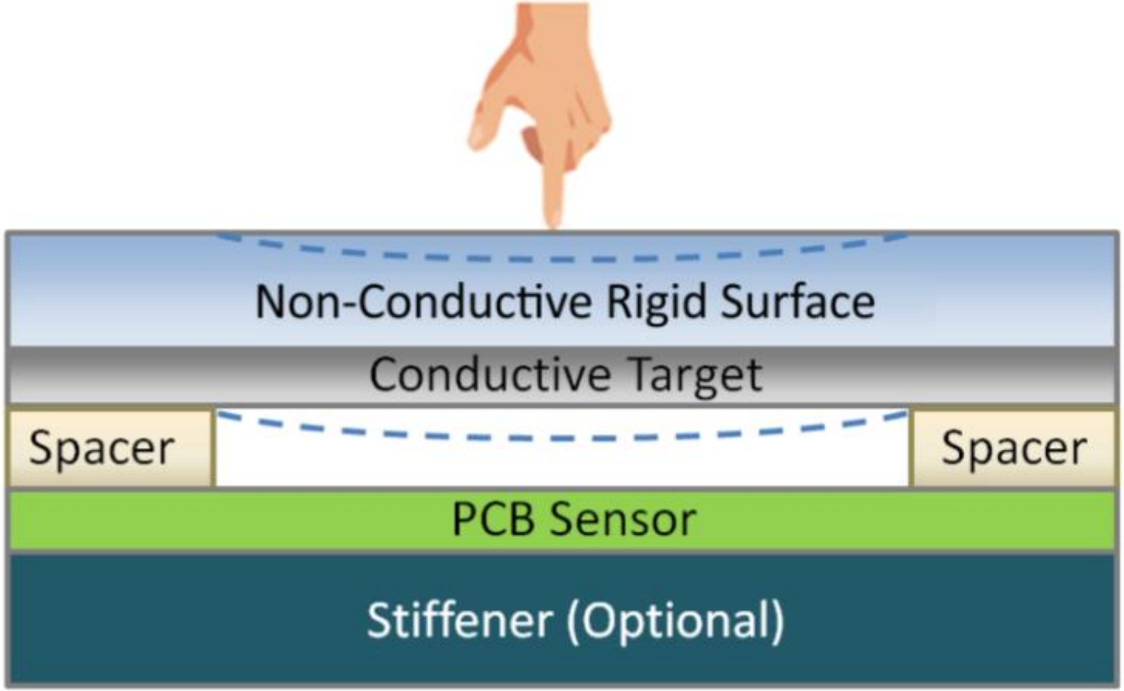
- **Simplified design approach** :
  - **Doesn’t require cutouts or holes** in the button surface
  - Button surface **doesn’t need to be grounded**
  - **Customizable** sensor design and shape.
  - More button placement options
  - Sensor fabrication **uses existing manufacturing processes** and materials
- **Senses** actual **mechanical deflection** of the button surface :
  - Provides a **force response**
  - **Works with gloves**
  - **Immune to false button response**
- **Rugged functionality** – Highly resistant to environmental factors like dust, dirt, oil, and water.
- **High reliability and extended life span** - does not include any moving components or contacts

Inductive touch mechanical structure

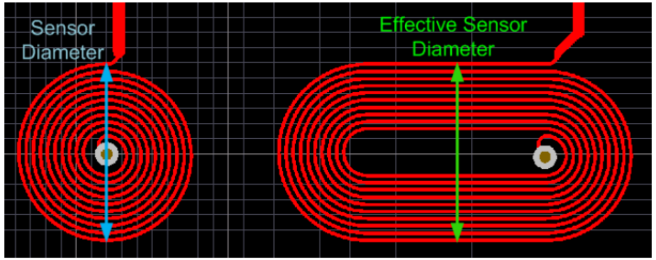


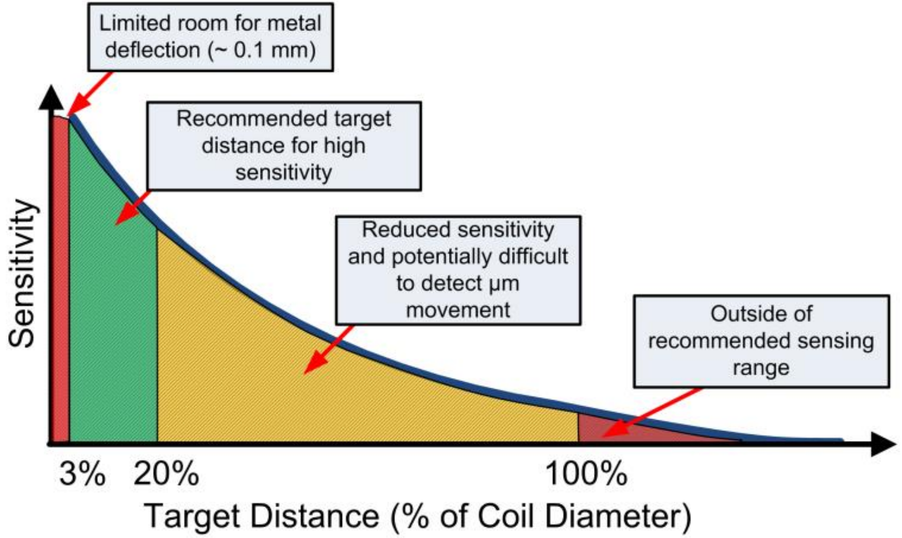
Mechanical structure for non-conductive cases

For non-conductive case materials such as plastic, a metal insert can be added to create a conductive target.



Button design considerations

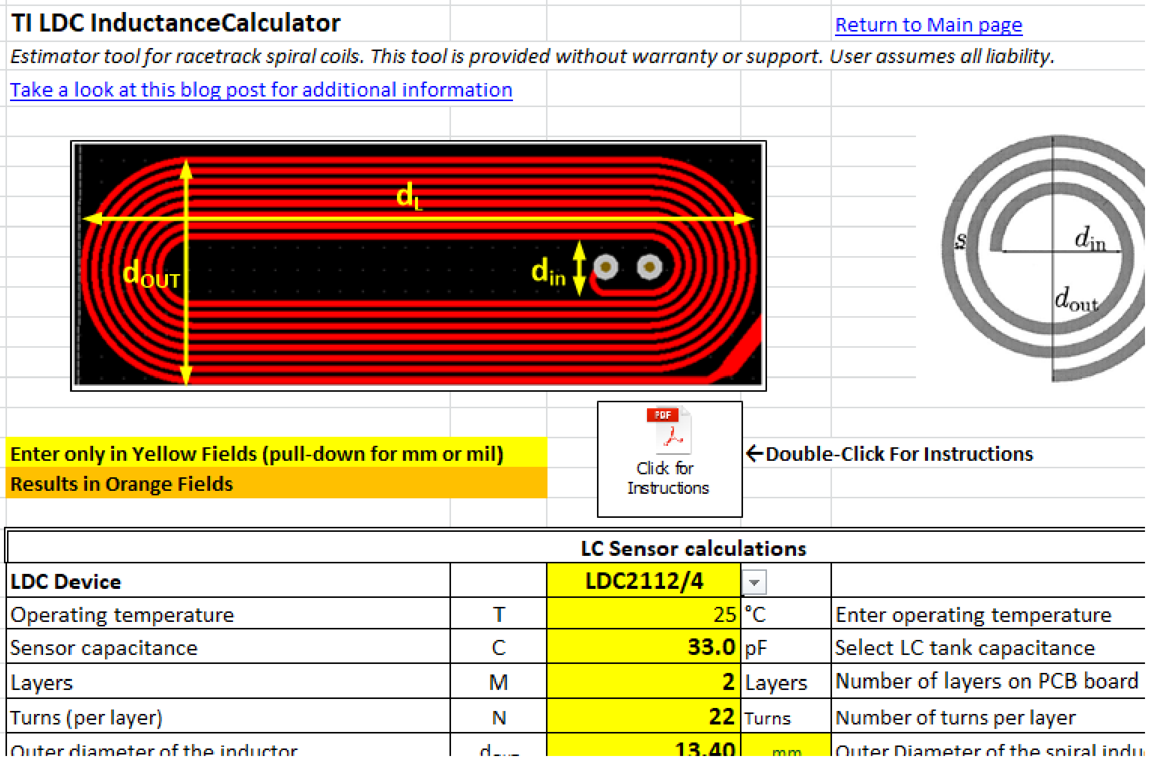




- Target
  - Height, width, skin depth
- Coil
  - Circular vs racetrack
  - Diameter
  - Inductance
- Target distance vs. coil diameter

Design tools

- Excel calculation spreadsheet
  - Calculate sensor parameters
  - Device specific calculations
- FEMM simulation
  - 2D magnetic field simulation
- Webench coil designer
  - Online coil design tool


TI LDC InductanceCalculator Return to Main page

Estimator tool for racetrack spiral coils. This tool is provided without warranty or support. User assumes all liability.

Take a look at this blog post for additional information

Enter only in Yellow Fields (pull-down for mm or mil)

Results in Orange Fields

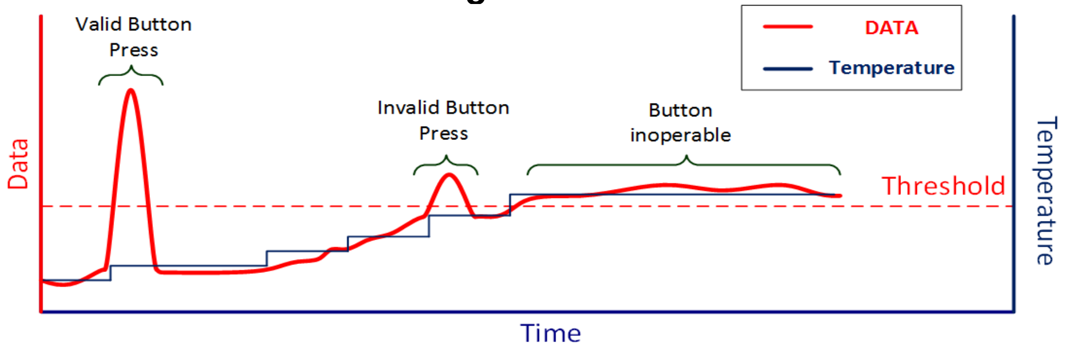
←**Double-Click For Instructions**

LC Sensor calculations				
LDC Device		**LDC2112/4**		
Operating temperature	T	25	°C	Enter operating temperature
Sensor capacitance	C	**33.0**	pF	Select LC tank capacitance
Layers	M	**2**	Layers	Number of layers on PCB board
Turns (per layer)	N	**22**	Turns	Number of turns per layer
Outer diameter of the inductor	d_{OUT}	13.40	mm	Outer Diameter of the spiral indu

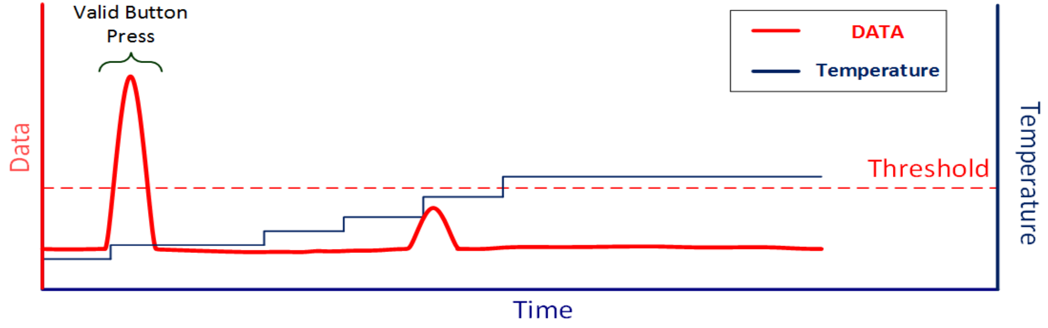
Baseline tracking

Baseline tracking for environmental factors

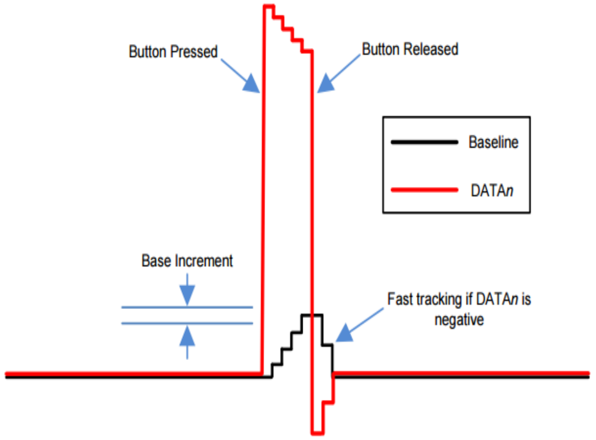
Environmental shifts degrade measurements



Baseline tracking compensation



Implementation



Compensates for:

- Environmental factors
- Permanent deformation of button surface (drops, dents etc.)

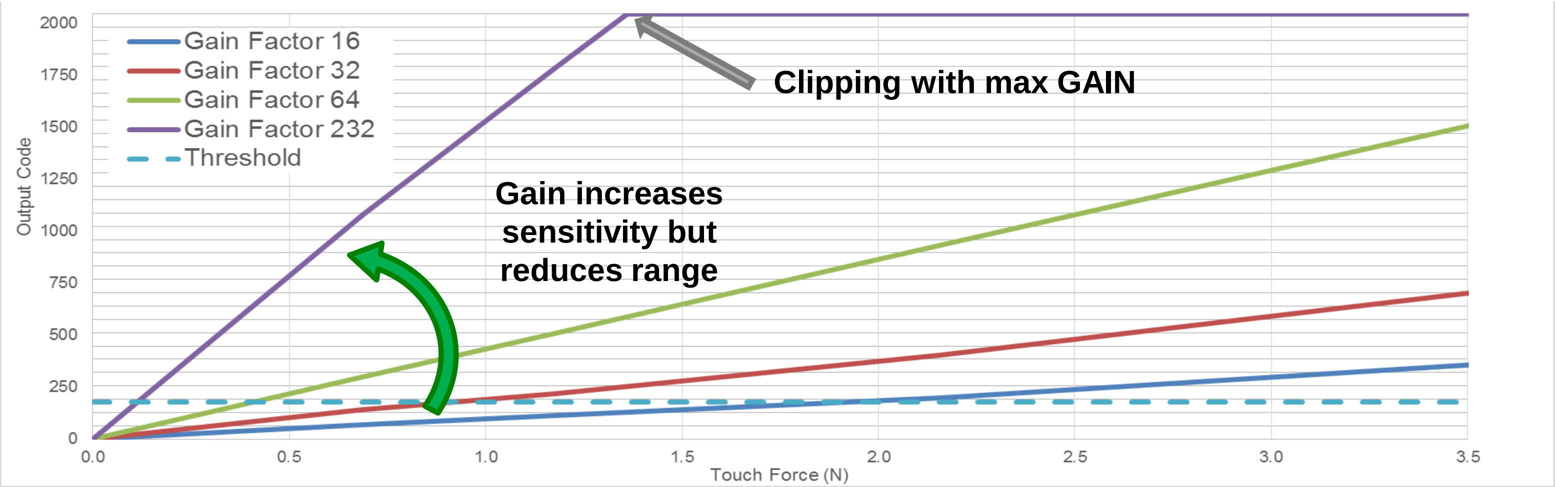
Button gain/sensitivity

GAINn configuration

The digital IO toggles when the DATA level crosses the button threshold.

- Gain factor sets desired button trigger force.
- Gain factor adjusted from 1 to 232.

Force vs LDC Net Data Response



Button sensitivity can be easily adjusted by GAIN:

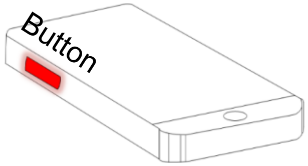
- The GAIN scales the normalized 12 bit DATA output value.
- A higher GAIN value results in a higher sensitivity.

Button examples

Personal electronics

- Smart watches
- Cell Phones

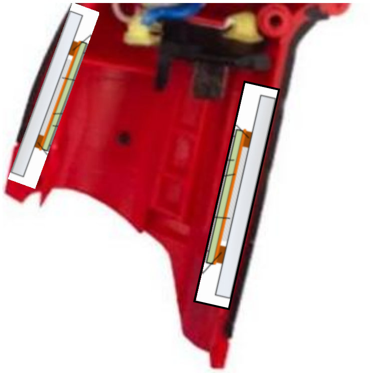
Smartwatch



Smartphone

Industrial

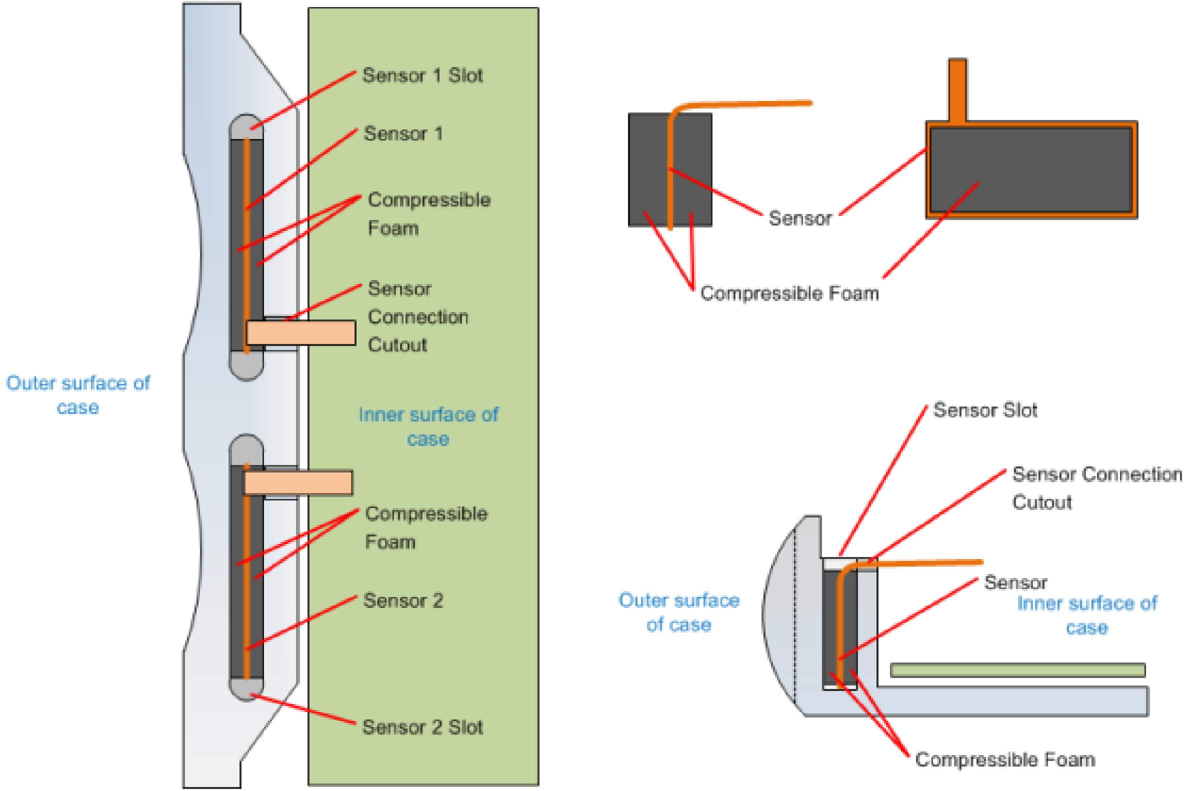
- HMI
- Grip Detection



Personal electronics button

Key features

- Low power
- Sealed button design
- Small button form factor
- False button rejection
- Baseline tracking can account for dents to the outer surface



Personal electronics example

- Using the LDC2112
- Spiral inductance calculator
  - Device
  - Temperature
  - Capacitance
  - # of Layers
  - Racetrack
  - Diameter
  - Trace width
  - Trace spacing

LC Sensor calculations				
LDC Device		**LDC2112/4**		
Operating temperature	T	22	°C	Enter operating temperature
Sensor capacitance	C	**350.0**	pF	Select LC tank capacitance
Layers	M	**2**	Layers	Number of layers on PCB board (1≤M≤8)
Turns (per layer)	N	**9**	Turns	Number of turns per layer
Short Side of inductor	d_{OUT}	**4.00**	mm	Outer Diameter of the spiral inductor
Sensor Shape		**Racetrack**		
Long side of inductor	d_L	**8.00**	mm	
spacing between traces	S	**4.000**	mil	Space between traces (mm or mil)
width of trace	w	**4.000**	mil	Width of the trace (mm or mil)
PCB thickness between 1st layer and 2nd layer	h12	0.040	mm	Space between layer 1 and 2 (mm or mil)
PCB thickness between 2nd layer and 3rd layer	h23	30.000	mm	Space between layer 2 and 3 (mm or mil)
PCB thickness between 3rd layer and 4th layer	h34	8.000	mm	Space between layer 3 and 4 (mm or mil)
PCB thickness between 4th layer and 5th layer	h45	8.000	mm	Space between layer 4 and 5 (mm or mil)
PCB thickness between 5th layer and 6th layer	h56	8.000	mm	Space between layer 5 and 6 (mm or mil)
PCB thickness between 6th layer and 7th layer	h67	1.575	mm	Space between layer 6 and 7 (mm or mil)
PCB thickness between 7th layer and 8th layer	h78	1.575	mm	Space between layer 7 and 8 (mm or mil)
Copper thickness	t	0.500	oz-Cu	Copper layer thickness (mm,Oz-Cu, or mil)

Personal electronics example - continued

- Outputs:

Copper resistivity at operating temperature	pr_t	1.693E-08	Ωm	
Coil Fill Ratio	din/dout	**0.09**		0.2> din/dout >0.8 is recommended for highest Q
Inductor inner diameter	din	**0.342**	mm	Inner diameter of the spiral inductor (mm or mil)
Self inductance per layer	L	0.305	µH	
Total Inductance with no target	L_{TOTAL}	**1.111**	**µH**	
Sensor Operating Frequency no target	f_{RES}	**8.024**	**MHz**	
Rp with no Target	R_P	**0.87**	**kΩ**	
Q factor	Q	**15.36**		
Self resonant frequency (estimated)	SRF	75.488	MHz	SRF should be >1.25*Fsensor
Target Distance	D	**0.500**	mm	For aluminum target of at least 5 skin depths
Sensor Inductance from Target Interaction	L'	**0.504**	**µH**	
Sensor Frequency with Target Interaction	f_{RES}'	**11.920**	**MHz**	
Rp with Target Interation	R_P'	**0.37**	**kΩ**	
Q Factor with target	Q	**9.7**		
Ccom Value (with Target)	Ccom	**3.6< C <45.2**	nF	

$\frac{0.5\ (mm)}{4\ (mm)}$ = 12.5% of the coil diameter

Sensor Properties

Personal electronics example - continued

LDC2112/4 Configuration Tool — Return to Main Pag

Device : LDC2112

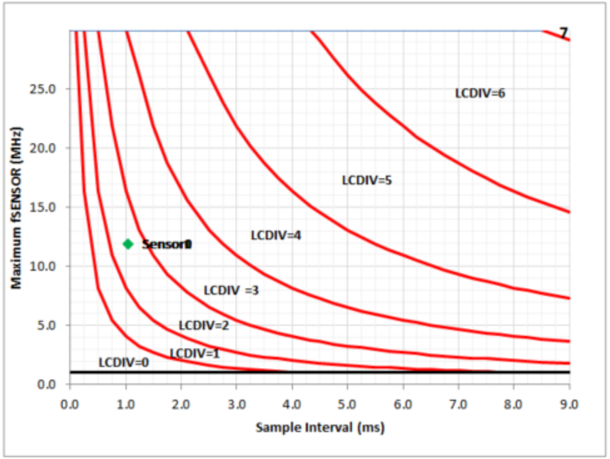
	Sensor 0		Sensor 1	
Enabled Buttons:	☑ Enable Ch0		☑ Enable Ch1	
Enabled in LP mode:	☑ Ch0 Low Power		☐ Ch1 Low Power	
Sensor R_P	0.37	kΩ	0.37	k
Sensor R_P Range	350Ω ≤ RP ≤ 4kΩ		350Ω ≤ RP ≤ 4kΩ	
f_{SENSOR} (with target)	11.92	MHz	11.92	M
Target Sample Time interval	1.00	ms	1.00	r
LCDIV	2		2	
Sensor Cycle Count	22		22	
Actual Sample Time Interval	1.038	ms	1.038	r
CNTSC	0		0	
Gain Setting Register Value	40		40	
Gain Scale	32.0		32.0	
Sensor Frequency Shift (ppm)	500.0		500.0	
NET code shift	208		208	
NP Baseline Inc (Δcode/sample)	3.65		3.65	
LP Baseline Inc (Δcode/sample)	29.23		29.23	

Low Power Scan Rate	1.25	SPS
Normal Power Scan Rate	10	SPS
Estimated Current in LP	9.46	µA
Estimated Current in NP	78.95	µA

Low Power Base Increment	3	
Normal Power Base Increment	3	
INTB pin polarity	Active Low	
HYST setting (Default = 8)	8	
Hysteresis	32	codes
Low Detect Threshold	96	codes
High Detect Threshold	160	codes

Partial List of Register Settings

Name	Address	Value
EN	0x0C	0x13
NPSCAN_RATE	0x0D	0x03
GAIN0	0x0E	0x28
LP_SCAN_RATE	0x0F	0x02
GAIN1	0x10	0x28
INTPOL	0x11	0x01
GAIN2	0x12	0x28
LP_BASE_INC	0x13	0x03
GAIN3	0x14	0x28
NP_BASE_INC	0x15	0x03
LC_DIVIDER	0x17	0x02
HYST	0x18	0x08
CNTSC	0x1E	0x00
SENSOR0_CONFIG	0x20	0x56
SENSOR1_CONFIG	0x22	0x56
SENSOR2_CONFIG	0x24	0x53
SENSOR3_CONFIG	0x26	0x53



Industrial button

Key features

- Can use with gloves on
- Sealed design
- Robust
- Dents in the metal can be ignored using baseline tracking

Industrial button example

- Using the LDC1614 for this design

Sensor input parameters

LC Sensor calculations				
LDC Device		LDC1612/4		
Operating temperature	T	22	°C	Enter operating temperature
Sensor capacitance	C	350.0	pF	Select LC tank capacitance
Layers	M	2	Layers	Number of layers on PCB board (1≤M≤8)
Turns (per layer)	N	20	Turns	Number of turns per layer
Outer diameter of the inductor	d_{OUT}	14.00	mm	Outer Diameter of the spiral inductor
Sensor Shape		Circular		
Long side of inductor	d_L	8.00	mm	
spacing between traces	S	5.000	mil	Space between traces (mm or mil)
width of trace	w	5.000	mil	Width of the trace (mm or mil)
PCB thickness between 1st layer and 2nd layer	h12	0.040	mm	Space between layer 1 and 2 (mm or mil)

Sensor output parameters

Coil Fill Ratio	din/dout	0.27		0.2> din/dout >0.8 is recommended for highest Q
Inductor inner diameter	din	3.840	mm	Inner diameter of the spiral inductor (mm or mil)
Self inductance per layer	L	3.426	µH	
Total Inductance with no target	L_{TOTAL}	13.522	µH	
Sensor Operating Frequency no target	f_{RES}	2.300	MHz	
Rp with no Target	R_P	3.69	kΩ	
Q factor	Q	18.67		
Self resonant frequency (estimated)	SRF	21.641	MHz	SRF should be >1.25*Fsensor
Target Distance	D	0.500	mm	For aluminum target of at least 5 skin depths
Sensor Inductance from Target Interaction	L'	5.440	µH	
Sensor Frequency with Target Interaction	f_{RES}'	3.627	MHz	
Rp with Target Interation	R_P'	1.42	kΩ	
Q Factor with target	Q'	11.4		

Even with a larger coil, we are still using the 0.5mm target distance

TEXAS INSTRUMENTS

Industrial button example - continued

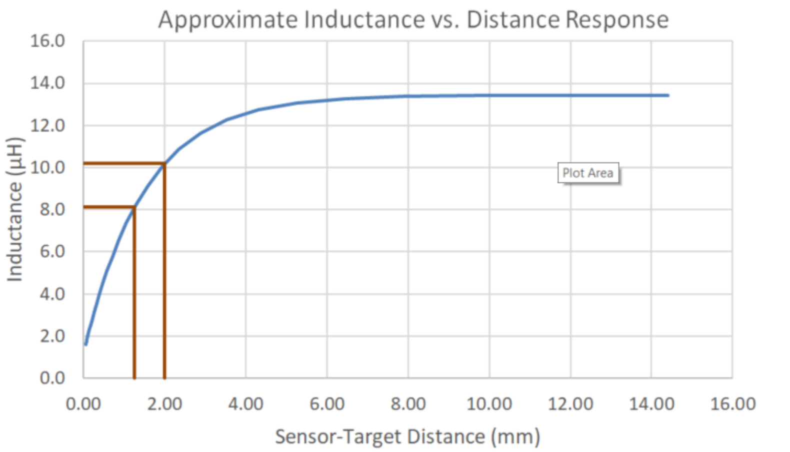
Sensor Parameters (this tool assumes all channels have matching sensors)			
Is Spiral Designer tool set to LDC131x/LDC161x?	TRUE		
Use Spiral Designer Tool Values checked	TRUE		

☑ Use Settings from Spiral Inductor Designer

Reuse design from previous slide

Sensor Inductance for calculations	13.52	µH	this value used for subsequent calculations
Sensor Capacitance for calculations	350.00	pF	this value used for subsequent calculations
f_{SENSOR} Minimum	0.001	MHz	
f_{SENSOR} Maximum	10.00	MHz	
Free-space Sensor Frequency	2.313	MHz	

Axial Target Movement Calculations		
Farthest Target Distance	2.00	mm
Closest Target Distance	1.25	mm
distance1/diameter	0.14	
L adjust factor for distance 1	0.7543	
f_{SENSOR} at farthest target Distance	2.6638	MHz
skin depth of Alumium at f1	0.0502	mm
R_P at Distance 1	2.7840	kΩ
distance2/diameter	0.09	
L adjust factor for distance 2	0.6001	
f_{SENSOR} at Closest Target Distance	2.9864	MHz
Sensor Frequency shift	322.58	kHz
Maximum Distance between LDC & sensor:	36.84	cm



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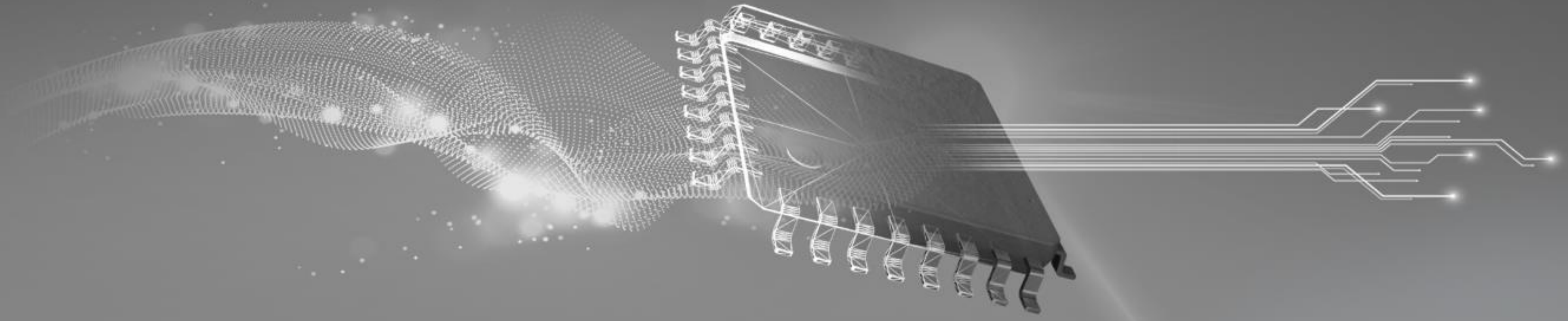

Backup Slides

TEXAS INSTRUMENTS

Design Tools and Resources

Research	Evaluate/Demo	Design	Debug
LDC Training Videos	LDC Device EVMs	LDC Sensor Design (Rev. B) App Note	E2E – Inductive Sensing FAQ
Common Inductive and Capacitive Sensing Applications (Rev. A)	LDC Coil EVMs	LDC1xxx LDC Target Design (Rev. A) App Note	E2E Forum
LDC Device Selection Guide (Rev. C)		LDC Calculator Spreadsheet	
		FEMM Tool	
		Device Datasheets	
		EMI App Note	

LDC Demos/Reference Designs (TIDAs)