TEXAS INSTRUMENTS

LDC Spiral Inductor Designer Tool Instructions

These calculation tools are provided without any warranty. Users should verify any result.

The latest version of the LDC Tools Spreadsheet is available at http://www.ti.com/lit/zip/slyc137.

1 Overview

The Spiral Inductor Designer tool is a tab on an Excel worksheet which helps design spiral inductors for TI's LDC devices.

This worksheet is provided with modification protection to ensure that calculation cells are not changed. Only edit cells which have a Yellow background. Outputs are provided in the Orange background cells:

Enter values or select settings in yellow cells only.
Results provided in Orange cells. Do not edit these fields.
Intermediate Calculation cells. Do not edit.

The spreadsheet has several sections:

- Device Options
- Sensor Parameters
- Target Movement
- Sensor Drive
- Resolution and Sample Rate
- Register Configuration
- Duty Cycled Supply Current Estimator
- Output Code Calculation

LDC devices use inductors to sense the movement of conductive targets. Stable and consistent sensing inductors can be constructed from spiral traces routed on a printed circuit board (PCB) or flexible PCB. WEBENCH® Coil Designer is a useful online tool that can help you design a sensor inductor and also generate a layout.

The Spiral Inductor designer tool is another design tool in the LDC tools spreadsheet. While the Spiral inductor designer only calculates sensor parameters and does not generate a layout, it is quick to use. Simply click Spiral Inductor Designer on the

Contents tab of the LDC calculator tool, or click the **Spiral_Inductor_Designer** tab, as shown in Figure 1. You'll wind up on the tab shown in Figure 2.

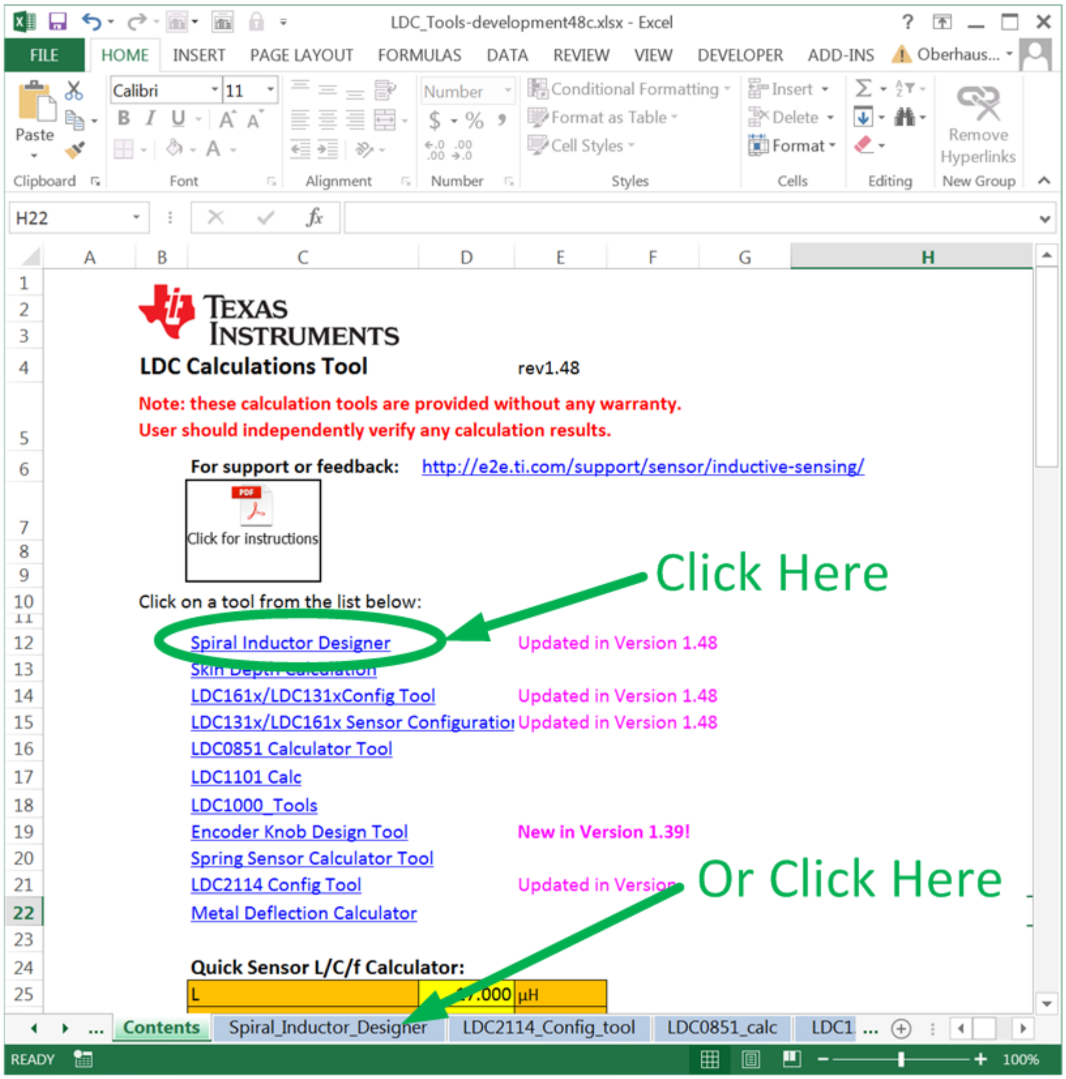

Figure 1: Accessing the Spiral Inductor Designer

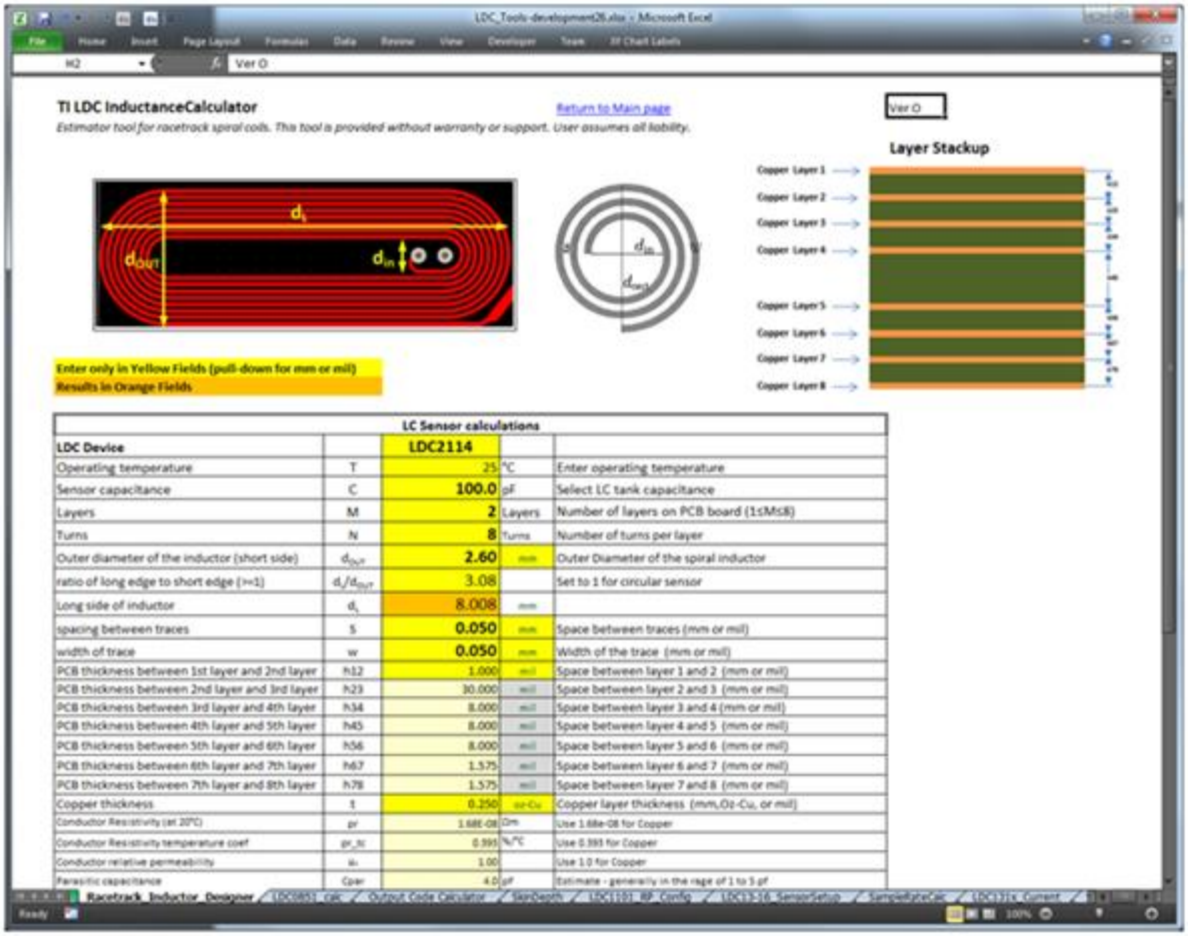

Figure 2: Racetrack coil designer tool

The LDC calculator tool is pretty accurate – typically a physical sensor will be within 10% of the calculations. For racetrack-shaped sensors, however, the accuracy may degrade when the ratio of the long side to the short side is greater than 4.

The first step in the process to design a sensor is to determine the PCB manufacturing limitations. Table 1 shows an example of limits from one PCB manufacturer.

Table 1: Sensor fabrication parameters

Sensor parameter	Value	Comments
PCB minimum trace width/space	0.125 mm (5 mil)	Fabrication limitation
Via minimum pad size	0.6 mm (24 mil)	Fabrication limitation
Via minimum hole size	0.25 mm (10 mil)	Fabrication limitation
Sensor minimum inner diameter	0.825 mm (21 mil)	0.6 mm + 2 × 0.125 mm One via pad + two trace spaces

Stack-up thickness between layers	0.80 mm (32 mil)	Desired PCB thickness
Copper thickness	0.5-2.0 oz-Cu	Thicker is better

Next, we need to know a few system limitations – what is the maximum possible size of the sensor, and how close the target can be to the sensor. Refer to a summary of the values for the example system designed in Table 2. For more information on how the physical parameters should be set, refer to http://www.ti.com/lit/snoa930 and http://www.ti.com/lit/an/snoa957/snoa957.pdf.

Table 2: Sensor Physical Parameters

Sensor parameter	Value	Comments
Maximum sensor diameter	9mm (315mil)	Mechanical constraint
Target closest distance	1.8mm	Based on system mechanicals

This example will use the LDC1612 and comply with the limitations from Tables 1 and 2. Figure 3 shows the calculating region of the racetrack coil designer. The number to the left of each parameter corresponds to the step in the usage model.

	LC Sensor calculations			
1	**LDC Device**		**LDC1312/4**	
	Operating temperature	T	25	°C
11	Sensor capacitance	C	**330.0**	pF
5	Layers	M	**2**	Layers
9	Turns (per layer)	N	**12**	Turns
7	Outer diameter of the inductor	d_{OUT}	**7.00**	mm
6	Sensor Shape		**Circular**	
	Long side of inductor	d_L	**12.00**	mm
2	spacing between traces	S	**5.000**	mil
	width of trace	w	**5.000**	mil
3	PCB thickness between 1st layer and 2nd layer	h12	40.000	mil
4	Copper thickness	t	1.000	oz-Cu
	Copper resistivity at operating temperature	pr_t	1.713E-08	Ωm
	Coil Fill Ratio	din/dout	**0.13**	
	Inductor inner diameter	din	**0.904**	mm
	Self inductance per layer	L	0.457	µH
	Total Inductance with no target	L_{TOTAL}	**1.788**	**µH**
	Sensor Operating Frequency no target	f_{RES}	**6.513**	**MHz**
	Rp with no Target	R_P	**2.56**	**kΩ**
	Q factor	Q	**34.56**	
	Self resonant frequency (estimated)	SRF	59.515	MHz
10	**Target Distance**	D	**2.000**	mm
	Sensor Inductance from Target Interaction	L'	**1.583**	**µH**
	Sensor Frequency with Target Interaction	f_{RES}'	**6.922**	**MHz**
	Rp with Target Interation	R_P'	**2.23**	**kΩ**
	Q Factor with target	Q'	**32.2**	

Figure 3: Sequence to enter parameters

Follow these steps to calculate a basic sensor design:

1. Select the appropriate LDC device – for this example, the LDC1612/4 (the LDC1612 and LDC1614 share the same limitations on sensor drive).

2. Set the spacing between traces and the width of traces to the 0.125 mm (5 mil) manufacturer's minimum (as presented in Table 1).
3. Set the spacing between layers to 32 mil – also from Table 1.
4. Use 1oz-CU, which is the thickest copper available from the PCB manufacturer (Table 1), for lower R_P, a critical sensor parameter.
5. Set the number of layers – typically 2 or 4 layers. Since this PCB is going to be two layers, set the number of layers to 2.
6. Set the shape of the inductor – Circular or Racetrack, based on the system physical constraints. Circular Spirals have a better Q, but for smaller sensors, a Racetrack may be needed to increase the R_P.
7. Enter the outer diameter of the inductor – 9mm is the size for this design, from Table 2.
8. Set the ratio to 1.0 for a circular-shaped sensor. Values larger than 1 will have a racetrack shape. The racetrack shape has higher inductance but a lower Q than a circular sensor. For many applications like Inductive Touch buttons, a racetrack shape fits the available area better and enables smaller buttons than a circular sensor.
9. Set the number of turns. The maximum number of turns for this design is 16 turns; if more turns are entered the sensor will be below the minimum inner diameter of 0.825mm from Table 1. Settings number of turns to 13 gives a coil fill ratio close to the optimum value of ~0.3. (The 0.3 coil fill ratio is optimal for most applications, although Inductive Touch applications perform better with lower values.)
10. Calculate the effect of the target on the sensor by setting the distance to the target. Set the target distance to 1.80mm, which is the spacing between the sensor and the metal surface – this is from Table 2.
11. Adjust the sensor capacitor to so that f_{RES}', R_P', and Q' are within the LDC1614's design space constraints. The calculator tool will indicate any parameters that are outside the operating region of the selected space with a red warning label on the appropriate parameter, as shown in Figure 4.

Target Distance	D	1.800	mm	For aluminum target of at least 5 skin depths
Sensor Inductance from Target Interaction	L'	2.291	µH	
Sensor Frequency with Target Interaction	f_{RES}'	10.027	MHz	Fsensor is too high - increase L or C
Rp with Target Interation	R_p'	5.57	kΩ	
Q Factor with target	Q'	38.6		

Figure 4: Example error warning generated by the calculator tool

After entering the parameters, you may need to adjust the number of turns or the sensor capacitance. After trying several settings, I wound up with the values shown in Table 3. I chose 130 pF for the sensor capacitor so that I could safely use a 10% tolerance part.

Table 3: Resulting parameters

Sensor parameter	Value
Sensor capacitance	130 pF
Layers	2
Turns	14
Outer diameter	9.0 mm

Ratio of long edge to short edge	1
Spacing between traces	5 mil
Width of trace	5 mil
PCB thickness	32 mil
Copper thickness	1.0 oz-Cu

Because the sensor's electrical parameters change when the target is close, you need to verify that the sensor is still within the valid operating range of the LDC when this occurs. With the closest target distance of 1.8 mm, my sensor has the electrical specifications shown in Table 4, which are within the LDC1614's operating region.

Table 4: Sensor parameters due to Target Interaction

Sensor parameter	Symbol	Value
Sensor Inductance from Target Interaction	L'	2.380 µH
Sensor Frequency with Target Interaction	f_{RES}'	9.049 MHz
R_P with Target Interaction	R_P'	4.90 kΩ
Q Factor with target	Q'	36.3

It is important that the sensor is still within the LDC operating region when the target is at the closest position.

A useful tip – after designing a sensor using this tool, paste the values into the schematic or layout of the system, as shown below:

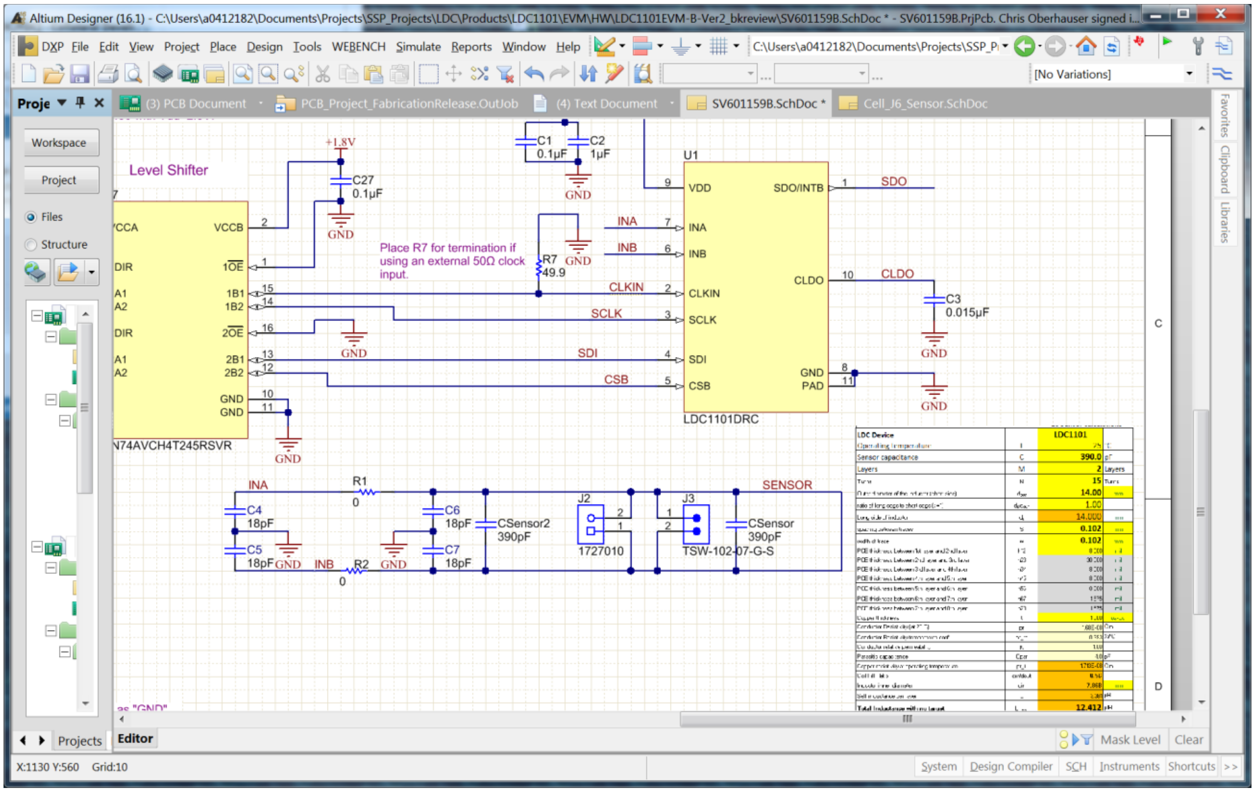

Figure 4: Pasting Sensor Information into Schematic