SmartNetics

Planar integrated inductor design

Tutorial - October 2026

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Introduction

SmartNetics is a software application for the design and analysis of magnetic devices: inductors and transformers. Our approach is not to offer a single one-size-fits-all solution, but to provide every possible design that matches a specification, along with an intuitive graphical interface. This combination allows the user to easily assess the impact of each variable in the design.

In previous tutorials (available at www.powersmartcontrol.com), we have shown how to design a dedicated magnetic component or how to analyze one that is already manufactured. In those tutorials, the magnetic device has always been designed as a single component, independent of the converter, built as a conventional magnetic, using wire wound around a core.

In this tutorial (that is also available as a webinar in our YouTube channel)), we will introduce a new approach. By means of a **planar design** we will allow the possibility of manufacturing the magnetic device as a part of the converter, by routing the turns in the same PCB the whole converter is built.

This tutorial aims to illustrate how to design a planar inductor for a power converter, using the PCB dimensions and properties as a restriction for the design, analyzing the different design possibilities with their opportunities and drawbacks, and validating the magnetic before including it in the converter. On top of the analytical calculations performed inside SmartNetics, this tutorial illustrates how to export the design to third-party tools, like KiCad for validation and how to automatically get your planar PCB magnetic ready for manufacture.

We are going to design the inductor for a buck converter with the following characteristics:

Avg current	Current ripple	Frequency	Inductance	Available area
1.5 A	1 A	50 kHz	100 µH	40 mm x 23 mm

Table 1: Main design parameters



Buck converter

1 Buck converter schematic

We are designing a very simple buck converter that matches the specification shown in Table 1, consisting of two MOSFET transistors driven by an IR2110 driver. The schematic of the buck converter, with the additional components needed to operate the IR2110 is shown in the next figure, with a missing inductor, which we are going to design.

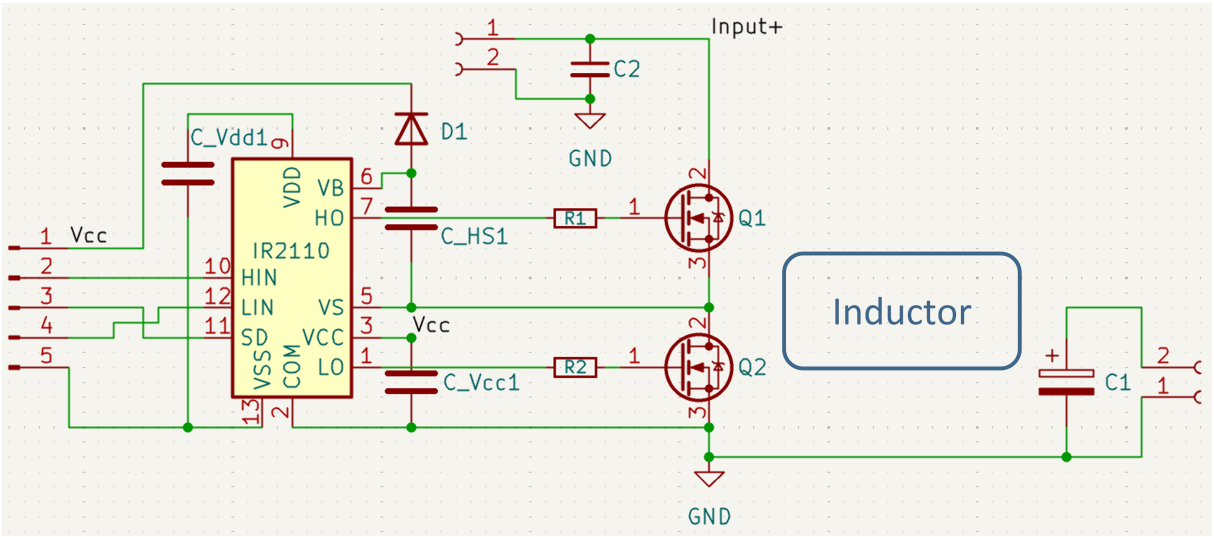


Figure 1: Buck schematic without inductor

The selection of the diodes, capacitors, and MOSFETs has been done following a design guide from the manufacturer. The values are not relevant for the present tutorial.

2 Buck converter PCB

The PCB for the buck converter has already been designed and routed, leaving space for the inductor that is yet to be designed. The PCB is shown in Figure 2, with the available area of 40mm x 23mm shown at the bottom-right corner.

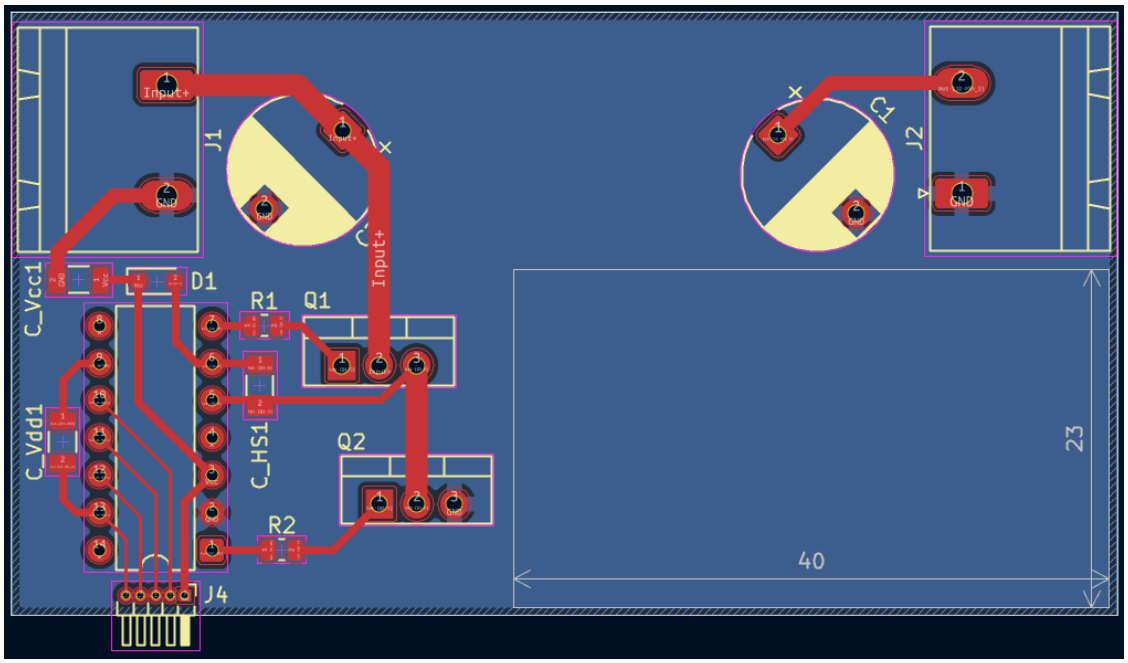


Figure 2: Buck PCB without inductor

The minimum number of layers is 2, since we are using the bottom layer as a ground plane. For the design, the total number of layers is a degree of freedom, so we will compare the solutions using 2, 4 or 6 layers for the inductor.

Inductor design

The first step is to configure the design restrictions in SmartNetics. This will be done in 3 steps:

1. **Set the input data**. This is the only mandatory step in SmartNetics, in which the user needs to provide information about the desired inductance and the current to handle.
2. **Databases**. In this step, we will restrict the design to only the items we want to use for this particular project. In this example, we will restrict the design to planar magnetics on PCB.
3. **Other restrictions**. Here, the user can set some restrictions that affect the design procedure. Some restrictions allow a faster design procedure in exchange for a loss in resolution while others can be used as a filter to reduce the number of available solutions.



1 Input data

Every electrical parameter given as a specification in Table 1 can be set in the first dialog "Input data", which will look as shown in Figure 3 after we have set:

- Current definition: Triangular.
- Average current (I avg (A)): 1.5.
- Current ripple (Peak-to-peak (A)): 1.

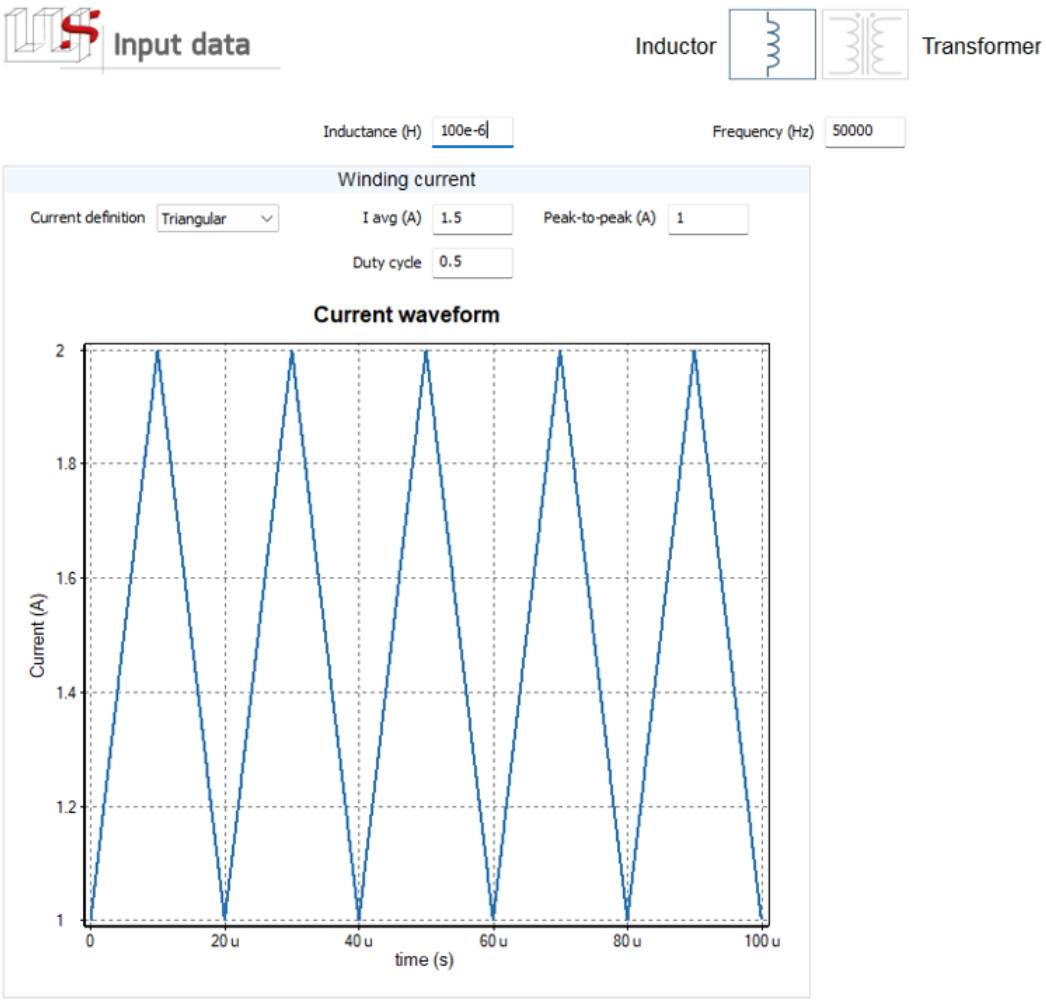


Figure 3: Electrical input data

This configuration is the only mandatory step in SmartNetics. Once done, the user can already get a magnetic design or, as we are going to do in this tutorial, the user can configure any part of the design process. This can be done in the second dialog, "Configuration".

2 Databases

To comply with the geometrical restrictions of the PCB, we can configure what items to use in the different databases, which can be configured in the first tab (“Databases”) of the second dialog, “Configuration”, which opens with some items selected by default, as shown in Figure 4.

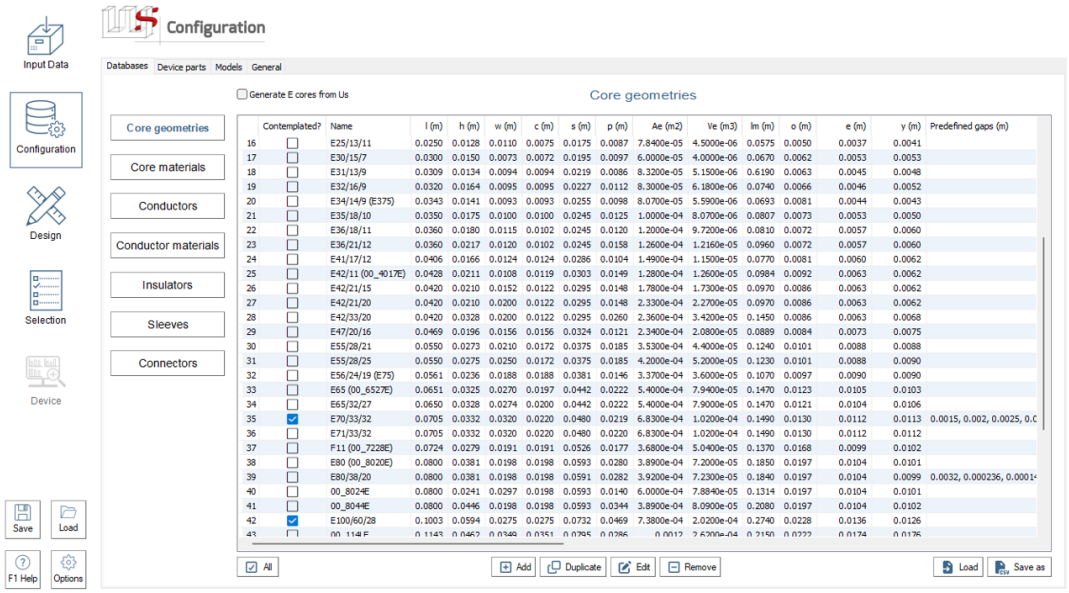


Figure 4: Default databases

2.1 Core geometry

First, we will restrict the design to planar cores with a length (“l (m)”) lower than the limit of 23 mm. The geometries that match that restriction are shown in Figure 5 (E14/3.5/5, E18/4/10 and E22/6/16).

Generate E cores from Us

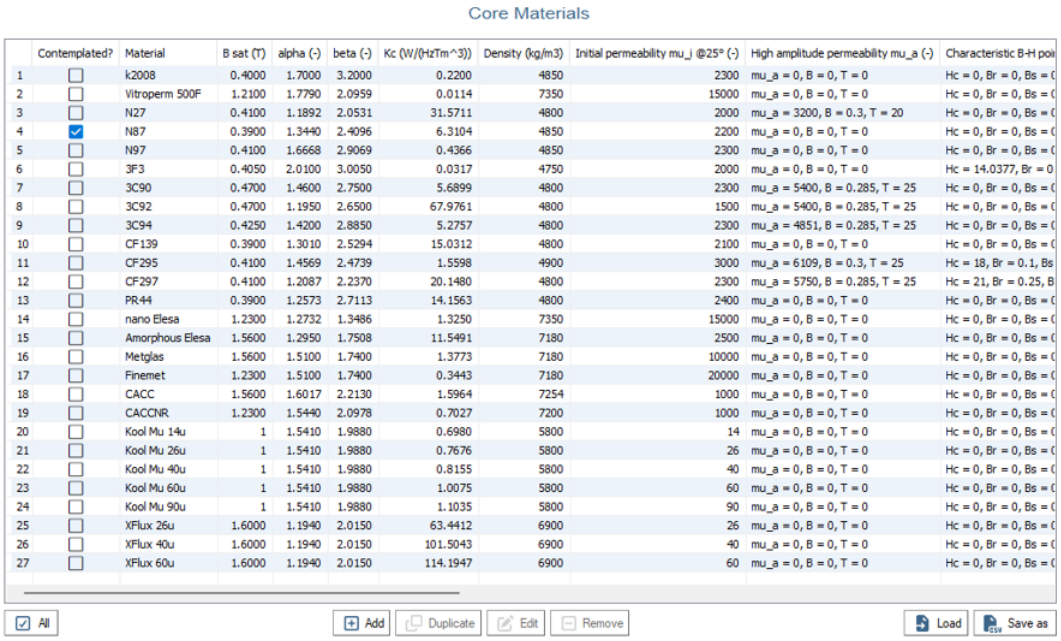
Core geometries

	Contemplated?	Name	l (m)	h (m)	w (m)	c (m)	s (m)	p (m)	Ae (m2)	Ve (m3)	lm (m)	o (m)	e (m)	y (m)	Predefined gaps (m)
29	☐	E47/20/16	0.0469	0.0196	0.0156	0.0156	0.0324	0.0121	2.3400e-04	2.0800e-05	0.0889	0.0084	0.0073	0.0075	
30	☐	E55/28/21	0.0550	0.0273	0.0210	0.0172	0.0375	0.0185	3.5300e-04	4.4000e-05	0.1240	0.0101	0.0088	0.0088	
31	☐	E55/28/25	0.0550	0.0275	0.0250	0.0172	0.0375	0.0185	4.2000e-04	5.2000e-05	0.1230	0.0101	0.0088	0.0090	
32	☐	E56/24/19 (E75)	0.0561	0.0236	0.0188	0.0188	0.0381	0.0146	3.3700e-04	3.6000e-05	0.1070	0.0097	0.0090	0.0090	
33	☐	E65 (00_6527E)	0.0651	0.0325	0.0270	0.0197	0.0442	0.0222	5.4000e-04	7.9400e-05	0.1470	0.0123	0.0105	0.0103	
34	☐	E65/32/27	0.0650	0.0328	0.0274	0.0200	0.0442	0.0222	5.4000e-04	7.9000e-05	0.1470	0.0121	0.0104	0.0106	
35	☑	E70/33/32	0.0705	0.0332	0.0320	0.0220	0.0480	0.0219	6.8300e-04	1.0200e-04	0.1490	0.0130	0.0112	0.0113	0.0015, 0.002, 0.0025, 0.0
36	☐	E71/33/32	0.0705	0.0332	0.0320	0.0220	0.0480	0.0220	6.8300e-04	1.0200e-04	0.1490	0.0130	0.0112	0.0112	
37	☐	F11 (00_7228E)	0.0724	0.0279	0.0191	0.0191	0.0526	0.0177	3.6800e-04	5.0400e-05	0.1370	0.0168	0.0099	0.0102	
38	☐	E80 (00_8020E)	0.0800	0.0381	0.0198	0.0198	0.0593	0.0280	3.8900e-04	7.2000e-05	0.1850	0.0197	0.0104	0.0101	
39	☐	E80/38/20	0.0800	0.0381	0.0198	0.0198	0.0591	0.0282	3.9200e-04	7.2300e-05	0.1840	0.0197	0.0104	0.0099	0.0032, 0.000236, 0.0001
40	☐	00_8024E	0.0800	0.0241	0.0297	0.0198	0.0593	0.0140	6.0000e-04	7.8840e-05	0.1314	0.0197	0.0104	0.0101	
41	☐	00_8044E	0.0800	0.0446	0.0198	0.0198	0.0593	0.0344	3.8900e-04	8.0900e-05	0.2080	0.0197	0.0104	0.0102	
42	☐	E100/60/28	0.1003	0.0594	0.0275	0.0275	0.0732	0.0469	7.3800e-04	2.0200e-04	0.2740	0.0228	0.0136	0.0126	
43	☐	00_114LE	0.1143	0.0462	0.0349	0.0351	0.0795	0.0286	0.0012	2.6200e-04	0.2150	0.0222	0.0174	0.0176	
44	☐	00_130LE	0.1303	0.0325	0.0539	0.0200	0.1085	0.0222	0.0011	2.3700e-04	0.2190	0.0442	0.0109	0.0103	
45	☐	00_160LE	0.1600	0.0381	0.0396	0.0198	0.1382	0.0281	7.7800e-04	2.1200e-04	0.2730	0.0592	0.0109	0.0100	
46	☑	E14/3.5/5	0.0140	0.0035	0.0050	0.0030	0.0110	0.0020	1.5000e-05	3.1100e-07	0.0207	0.0040	0.0015	0.0015	
47	☑	E18/4/10	0.0180	0.0040	0.0100	0.0040	0.0140	0.0020	4.0000e-05	9.7100e-07	0.0242	0.0050	0.0020	0.0020	
48	☑	E22/6/16	0.0218	0.0057	0.0158	0.0050	0.0168	0.0032	7.9000e-05	2.5600e-06	0.0325	0.0059	0.0025	0.0025	
49	☐	E32/6/20	0.0318	0.0063	0.0203	0.0063	0.0255	0.0032	1.2900e-04	5.3700e-06	0.0418	0.0096	0.0031	0.0032	
50	☐	E38/8/25	0.0381	0.0083	0.0254	0.0076	0.0308	0.0044	1.9100e-04	1.0100e-05	0.0528	0.0116	0.0037	0.0038	
51	☐	E43/10/28	0.0432	0.0095	0.0279	0.0081	0.0355	0.0054	2.2500e-04	1.3800e-05	0.0616	0.0137	0.0039	0.0041	
52	☐	E58/11/38	0.0584	0.0106	0.0381	0.0081	0.0511	0.0065	3.0200e-04	2.4500e-05	0.0813	0.0215	0.0037	0.0040	
53	☐	E64/10/50	0.0640	0.0102	0.0508	0.0102	0.0536	0.0051	5.2000e-04	4.1500e-05	0.0799	0.0217	0.0052	0.0051	
54	☐	E102/20/38	0.1020	0.0203	0.0375	0.0140	0.0868	0.0132	5.4000e-04	8.0000e-05	0.1480	0.0364	0.0076	0.0072	
55	☐	E153/31/55	0.1530	0.0310	0.0550	0.0220	0.1290	0.0210	0.0012	2.6019e-04	0.2237	0.0535	0.0120	0.0100	

Figure 5: Core geometries database

2.2 Core material

For these geometries, we will restrict the core material to only N87 by TDK, since we know they can supply those cores. The core material database then has a single active item, as shown in Figure 6.

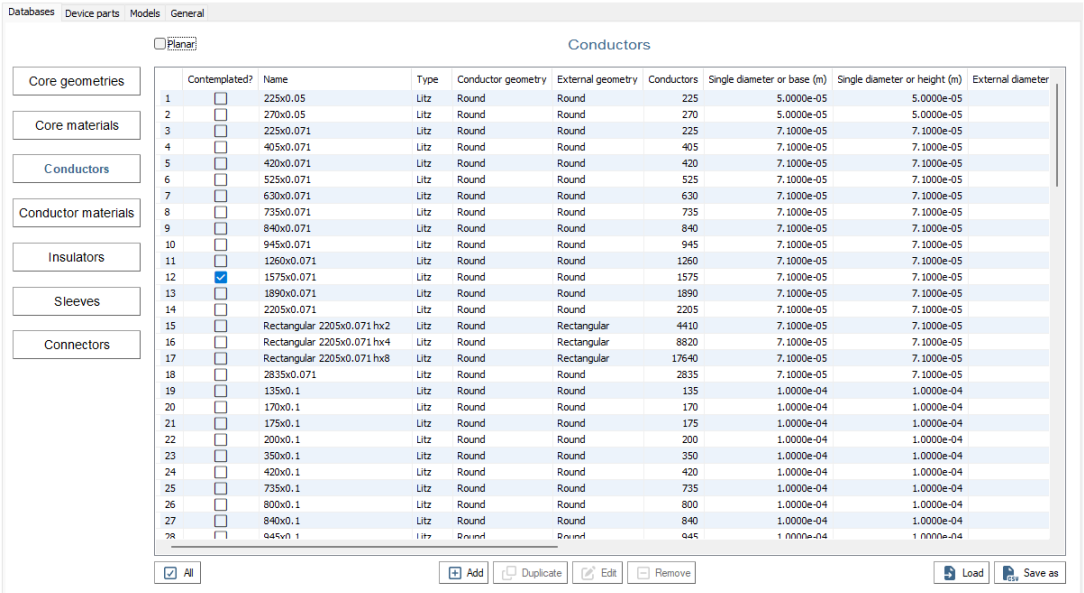


	Contemplated?	Material	B sat (T)	alpha (-)	beta (-)	Kc (W/(HzTm^3))	Density (kg/m3)	Initial permeability mu_i @25° (-)	High amplitude permeability mu_a (-)	Characteristic B-H poi
1	☐	k2008	0.4000	1.7000	3.2000	0.2200	4850	2300	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
2	☐	Vitroperm 500F	1.2100	1.7790	2.0959	0.0114	7350	15000	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
3	☐	N27	0.4100	1.1892	2.0531	31.5711	4800	2000	mu_a = 3200, B = 0.3, T = 20	Hc = 0, Br = 0, Bs = (
4	☑	N87	0.3900	1.3440	2.4096	6.3104	4850	2200	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
5	☐	N97	0.4100	1.6668	2.9069	0.4366	4850	2300	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
6	☐	3F3	0.4050	2.0100	3.0050	0.0317	4750	2000	mu_a = 0, B = 0, T = 0	Hc = 14.0377, Br = 0
7	☐	3C90	0.4700	1.4600	2.7500	5.6899	4800	2300	mu_a = 5400, B = 0.285, T = 25	Hc = 0, Br = 0, Bs = (
8	☐	3C92	0.4700	1.1950	2.6500	67.9761	4800	1500	mu_a = 5400, B = 0.285, T = 25	Hc = 0, Br = 0, Bs = (
9	☐	3C94	0.4250	1.4200	2.8850	5.2757	4800	2300	mu_a = 4851, B = 0.285, T = 25	Hc = 0, Br = 0, Bs = (
10	☐	CF139	0.3900	1.3010	2.5294	15.0312	4800	2100	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
11	☐	CF295	0.4100	1.4569	2.4739	1.5598	4900	3000	mu_a = 6109, B = 0.3, T = 25	Hc = 18, Br = 0.1, Bs
12	☐	CF297	0.4100	1.2087	2.2370	20.1480	4800	2300	mu_a = 5750, B = 0.285, T = 25	Hc = 21, Br = 0.25, B
13	☐	PR44	0.3900	1.2573	2.7113	14.1563	4800	2400	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
14	☐	nano Elesa	1.2300	1.2732	1.3486	1.3250	7350	15000	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
15	☐	Amorphous Elesa	1.5600	1.2950	1.7508	11.5491	7180	2500	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
16	☐	Metglas	1.5600	1.5100	1.7400	1.3773	7180	10000	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
17	☐	Finemet	1.2300	1.5100	1.7400	0.3443	7180	20000	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
18	☐	CACC	1.5600	1.6017	2.2130	1.5964	7254	1000	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
19	☐	CACCNR	1.2300	1.5440	2.0978	0.7027	7200	1000	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
20	☐	Kool Mu 14u	1	1.5410	1.9880	0.6980	5800	14	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
21	☐	Kool Mu 26u	1	1.5410	1.9880	0.7676	5800	26	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
22	☐	Kool Mu 40u	1	1.5410	1.9880	0.8155	5800	40	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
23	☐	Kool Mu 60u	1	1.5410	1.9880	1.0075	5800	60	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
24	☐	Kool Mu 90u	1	1.5410	1.9880	1.1035	5800	90	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
25	☐	XFlux 26u	1.6000	1.1940	2.0150	63.4412	6900	26	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
26	☐	XFlux 40u	1.6000	1.1940	2.0150	101.5043	6900	40	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (
27	☐	XFlux 60u	1.6000	1.1940	2.0150	114.1947	6900	60	mu_a = 0, B = 0, T = 0	Hc = 0, Br = 0, Bs = (

Figure 6: Core materials database

2.3 Conductor geometry

The next step is to configure what conductors can be used. By default, regular conductors are used (rigid or Litz), as shown in Figure 7.



	Contemplated?	Name	Type	Conductor geometry	External geometry	Conductors	Single diameter or base (m)	Single diameter or height (m)	External diameter
1	☐	225x0.05	Litz	Round	Round	225	5.0000e-05	5.0000e-05	
2	☐	270x0.05	Litz	Round	Round	270	5.0000e-05	5.0000e-05	
3	☐	225x0.071	Litz	Round	Round	225	7.1000e-05	7.1000e-05	
4	☐	405x0.071	Litz	Round	Round	405	7.1000e-05	7.1000e-05	
5	☐	420x0.071	Litz	Round	Round	420	7.1000e-05	7.1000e-05	
6	☐	525x0.071	Litz	Round	Round	525	7.1000e-05	7.1000e-05	
7	☐	630x0.071	Litz	Round	Round	630	7.1000e-05	7.1000e-05	
8	☐	735x0.071	Litz	Round	Round	735	7.1000e-05	7.1000e-05	
9	☐	840x0.071	Litz	Round	Round	840	7.1000e-05	7.1000e-05	
10	☐	945x0.071	Litz	Round	Round	945	7.1000e-05	7.1000e-05	
11	☐	1260x0.071	Litz	Round	Round	1260	7.1000e-05	7.1000e-05	
12	☑	1575x0.071	Litz	Round	Round	1575	7.1000e-05	7.1000e-05	
13	☐	1890x0.071	Litz	Round	Round	1890	7.1000e-05	7.1000e-05	
14	☐	2205x0.071	Litz	Round	Round	2205	7.1000e-05	7.1000e-05	
15	☐	Rectangular 2205x0.071 hx2	Litz	Round	Rectangular	4410	7.1000e-05	7.1000e-05	
16	☐	Rectangular 2205x0.071 hx4	Litz	Round	Rectangular	8820	7.1000e-05	7.1000e-05	
17	☐	Rectangular 2205x0.071 hx8	Litz	Round	Rectangular	17640	7.1000e-05	7.1000e-05	
18	☐	2835x0.071	Litz	Round	Round	2835	7.1000e-05	7.1000e-05	
19	☐	135x0.1	Litz	Round	Round	135	1.0000e-04	1.0000e-04	
20	☐	170x0.1	Litz	Round	Round	170	1.0000e-04	1.0000e-04	
21	☐	175x0.1	Litz	Round	Round	175	1.0000e-04	1.0000e-04	
22	☐	200x0.1	Litz	Round	Round	200	1.0000e-04	1.0000e-04	
23	☐	350x0.1	Litz	Round	Round	350	1.0000e-04	1.0000e-04	
24	☐	420x0.1	Litz	Round	Round	420	1.0000e-04	1.0000e-04	
25	☐	735x0.1	Litz	Round	Round	735	1.0000e-04	1.0000e-04	
26	☐	800x0.1	Litz	Round	Round	800	1.0000e-04	1.0000e-04	
27	☐	840x0.1	Litz	Round	Round	840	1.0000e-04	1.0000e-04	
28	☐	945x0.1	Litz	Round	Round	945	1.0000e-04	1.0000e-04	

Figure 7: Default conductor database

In this case, since we want to use the converter PCB to route the winding, we will activate the “Planar” option shown at the top-left corner of the screen.

We don’t have a strong restriction for the PCB technology, since it is not imposed yet for this project, so we will select a range of copper thicknesses (1, 2, or 3 ounces) and of PCB layers (2, 4 or 6 layers). The wire geometry configuration will look like the one shown in Figure 8.

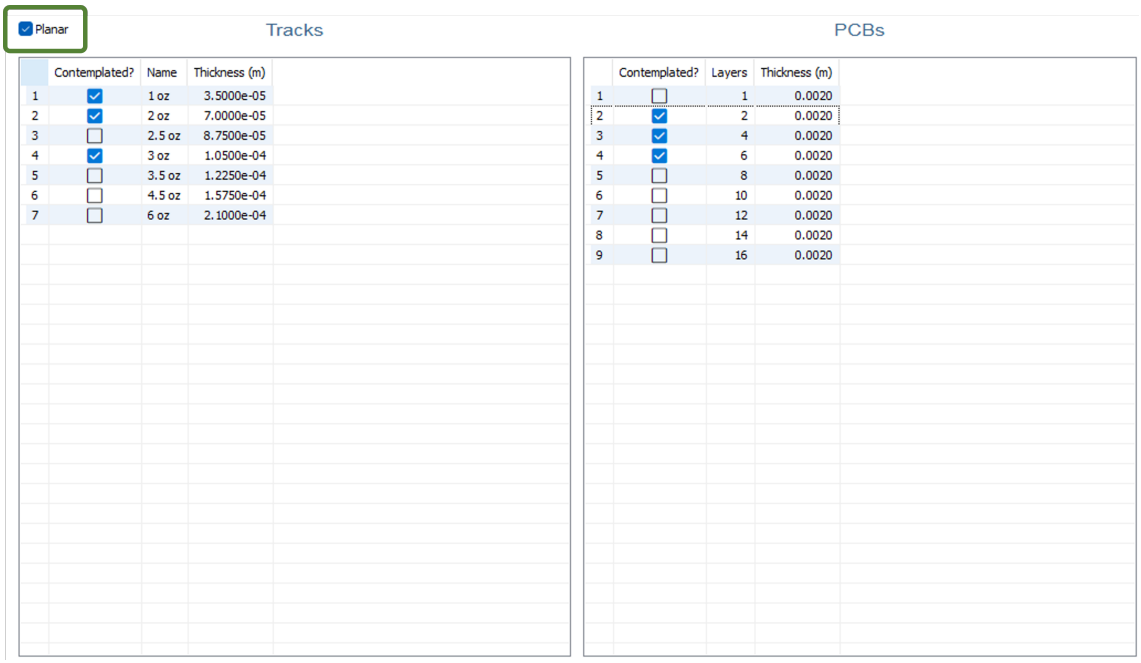


Figure 8: Planar conductor database

3 Other restrictions

We will leave the remaining configuration as is, since it matches most design cases with one exception. Since the inductor is going to be part of the PCB and it is going to strongly affect the rest of the circuit, we will set the maximum temperature to 100 ºC. This can be done in the third tab of this dialog: "Models", as shown in the next figure:

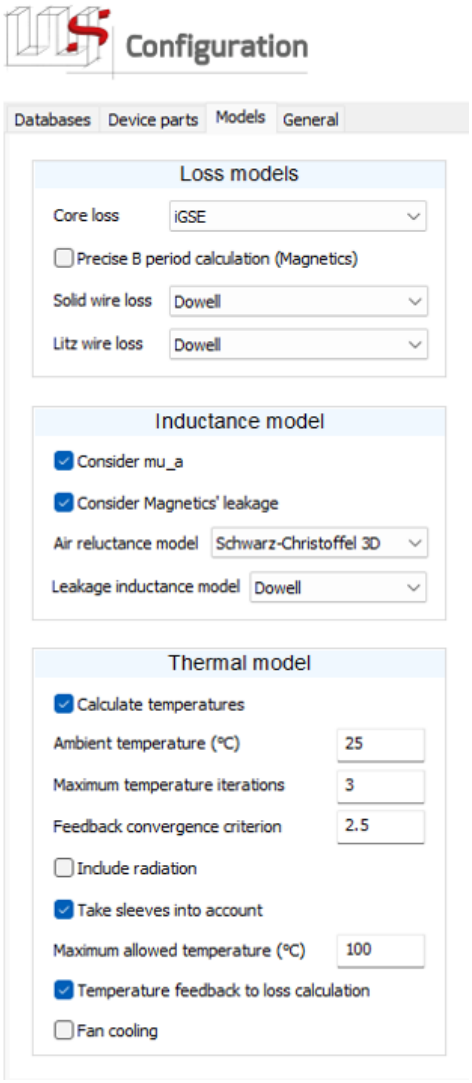


Figure 9: Temperature limitation

Once the input data has been set, we can proceed with the design.

4 Design procedure

The design procedure is started in the third dialog, “Design”, which will be empty until it starts:



Figure 10: Empty design space

The design procedure begins when clicking on the “begin magnetic design” button and, once it finishes, every possible combination of the parameters in the database that provides a valid solution is displayed in the plots, as shown in Figure 11.

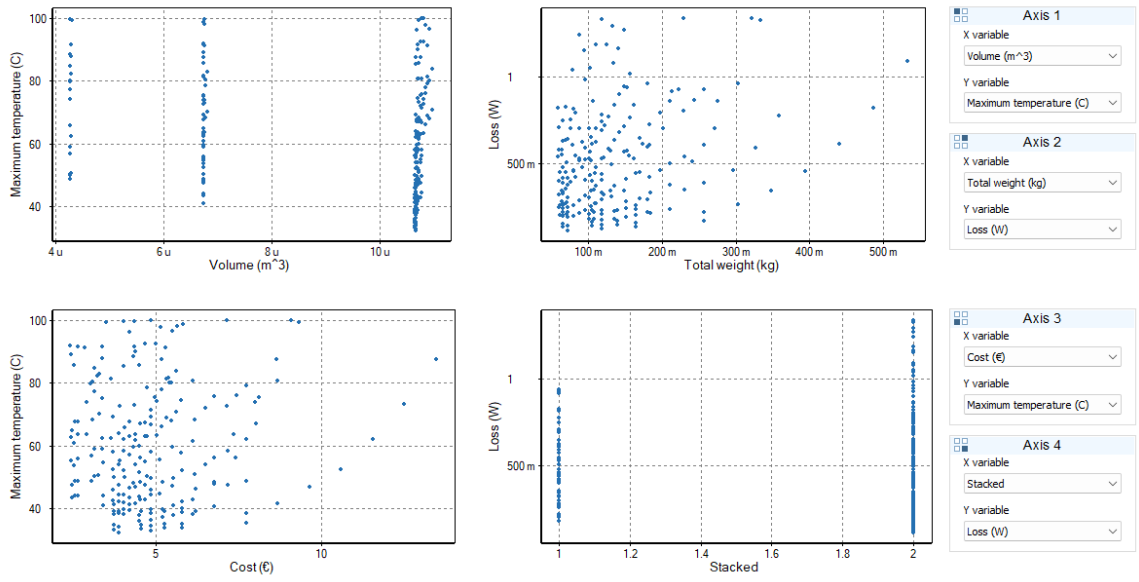


Figure 11: Design results with default axes

Any numerical variable that has any impact on the design can be used as X or Y axis for any of the graphs, thanks to the selectors on the right side. For this example, we will change some of them to use values more important for planar designs.

For this design, the variables of interest are:

- Axis 1: Temperature vs stacked cores
- Axis 2: Conductor height vs PCB layers
- Axis 3: Temperature vs cost
- Axis 4: PCB layers vs Number of turns

Once the desired variables have been selected, the results are automatically displayed again. Thanks to this, the user can use the metric that best suits their project for the selection.

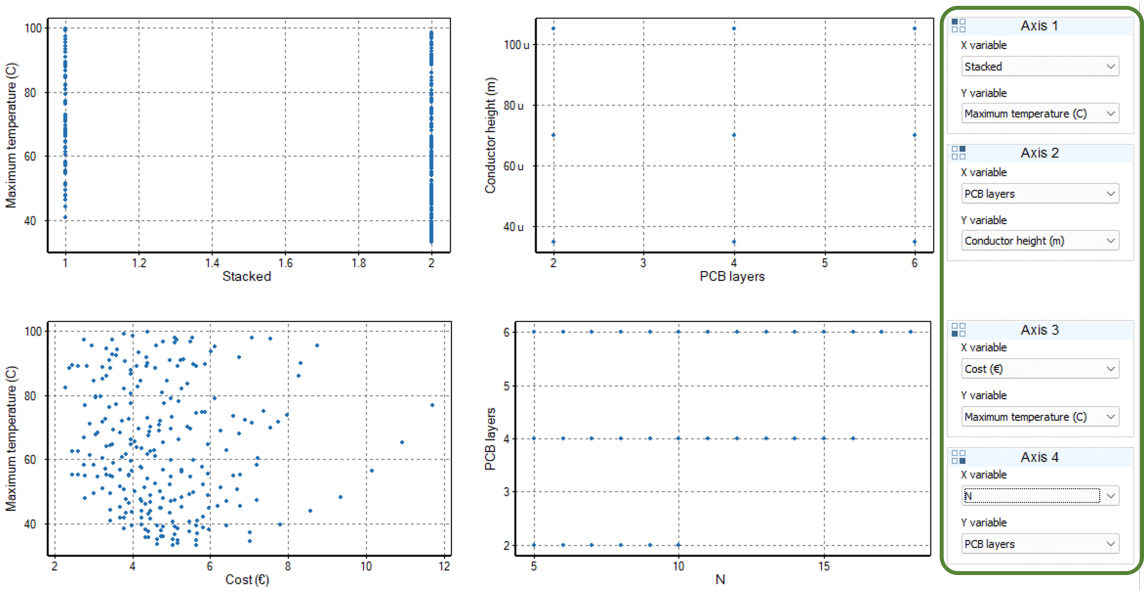


Figure 12: Design results

Once more convenient variables have been selected, the designs can be easily compared. The next step is to filter them and select a subset of possible candidates, from which we can select the desired inductor.

Inductor selection

1 Graphical selection

Every design displayed in the graphs is a valid design (one that matches specifications while complying with the imposed restrictions).

Once every valid solution is known, we can start by selecting the ones that are considered most convenient for this particular project. To do so, click and drag the cursor to select the desired devices in any graph; those designs will be highlighted in every other graph, enabling an easy comparison of up to 8 variables at the same time.

For example, we can get important information by selecting the subset of designs that allow a temperature lower than 65ºC and that only need a single stacked core. Those are the designs selected in Figure 13.

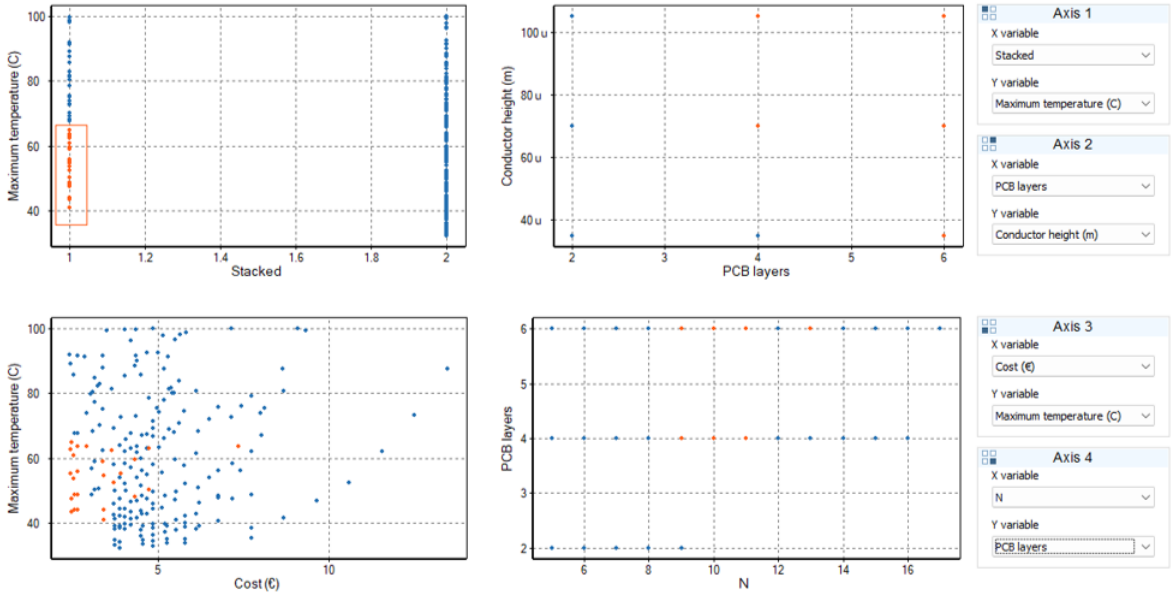


Figure 13: Design results. Single core

Thanks to the fact that the designs have been highlighted in the remaining graphs, we can get very important information about the design. If a single core is to be used (the core cross section area will be small) the needed number of turns to avoid satura-

tion must be relatively high (as seen in the bottom-right graph); if the number of turns is high (and so the wire length is high), the thickness of said turns or the number of layers in parallel have to increase to reduce the total resistance and wire loss (as can be seen in the top-right graph). This behavior is displayed in Figure 14.

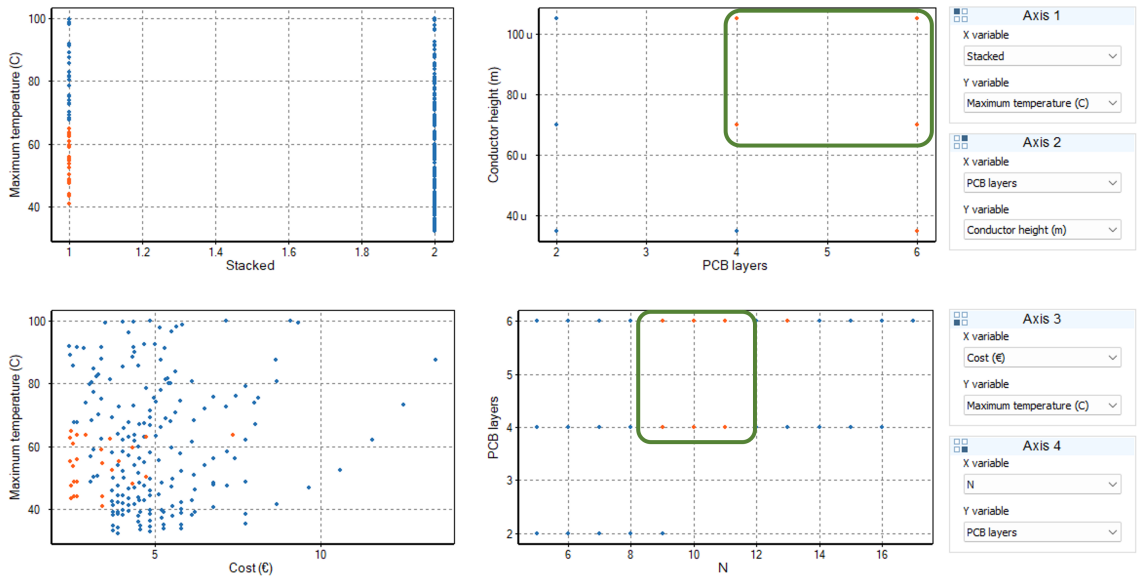


Figure 14: Design results. Single core (extrapolated)

On the other hand, we can see that, if we use 2 stacked cores (selected in the top-left graph) we can have designs with a lower number of turns (as seen in the bottom-right graph) and those turns do not need to be too thick or use several layers in parallel (as can be seen in the top-right graph). This analysis is seen in Figure 15.

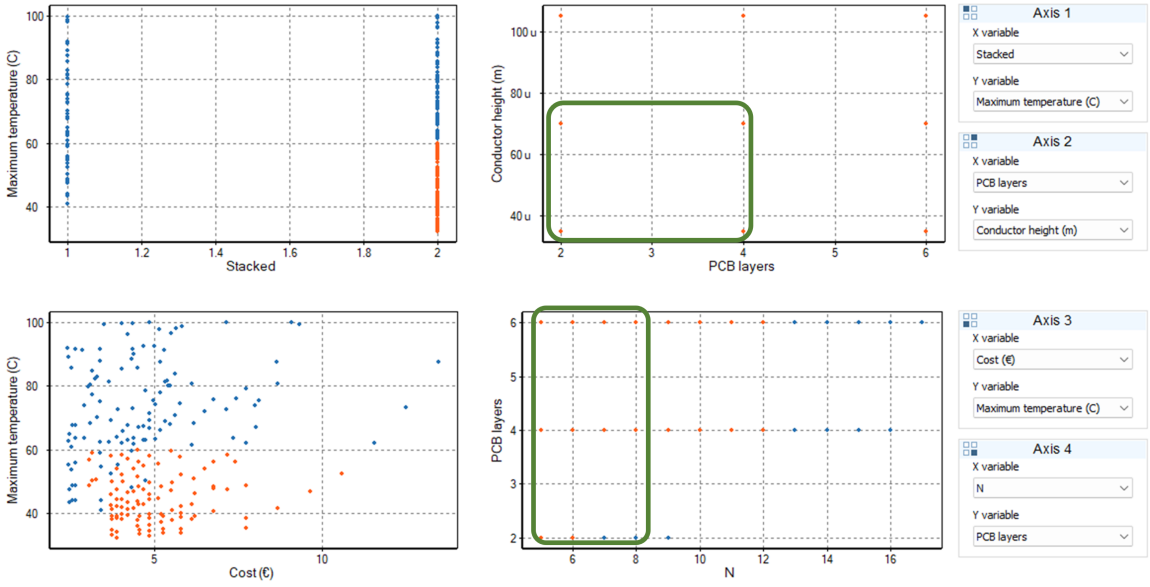


Figure 15: Design results. Double core (extrapolated)

Both approaches: more core, fewer turns, or less core, more turns are valid, since we have ensured they can fit the available space. In the general case of designing a magnetic device, this is the usual decision, and the user can take it by looking at other metrics, like total losses or temperature, since the magnetic device can be considered independent of the circuit.

In the particular case of magnetics integrated in the converter PCB, there is a direct impact of this decision in the rest of the converter. If the whole circuit is going to be made in the same PCB, the number of layers or the copper thickness is going to be the same for everything. Taking this into account, the decision in this case is to increase the copper thickness, since it allows reducing conduction losses not only in the inductor, but in every part of the converter as well.

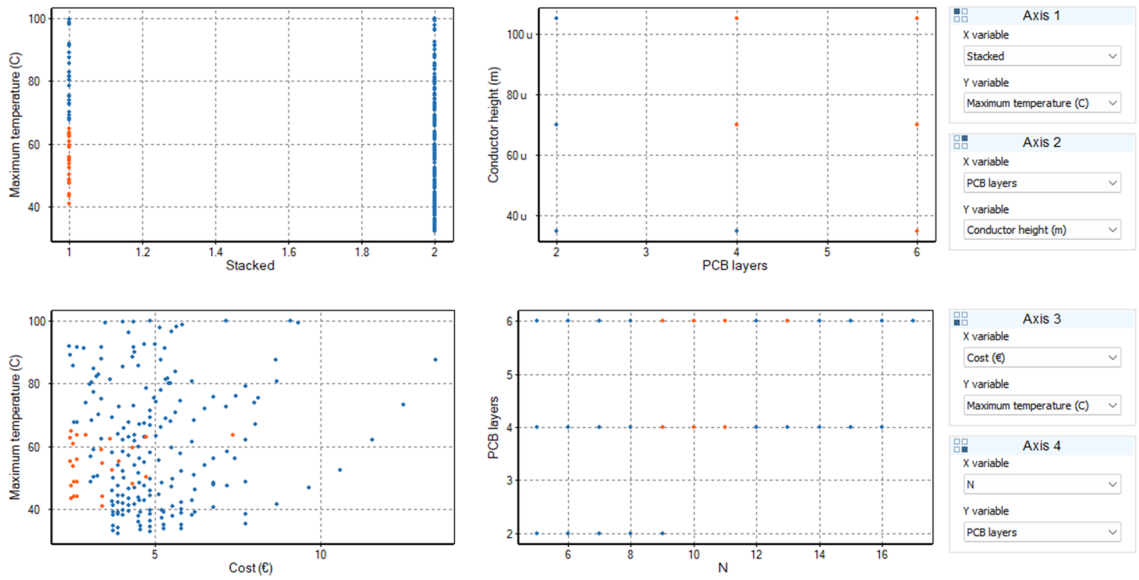


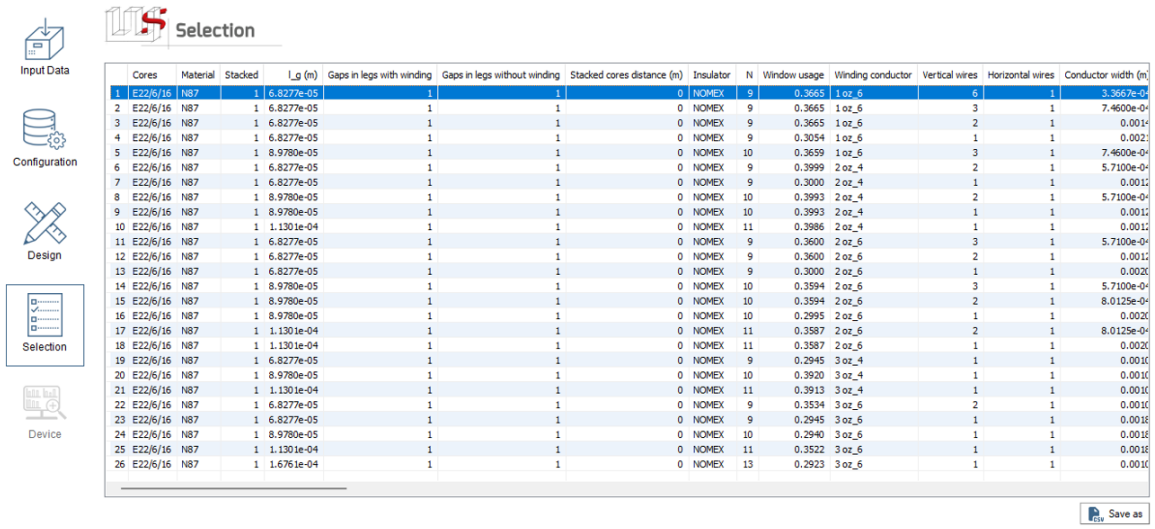
Figure 16: Selected designs

Once a subset of all the possible combinations has been selected, a detailed description of the remaining designs can be used for a finer selection. That can be done in the next dialog: “Selection”, which is now available in the lateral menu.

2 Table selection

In this dialog, the selected devices can be inspected in detail to choose the one that best fits the needs of the current project. The definition of every parameter can be consulted in the provided help (accessed by pressing *'F1'* or clicking in the corresponding button, always available at the bottom-left corner).

The devices shown in the figure are the ones selected in the previous step, so all of them comply with the imposed restrictions. In this case, we selected 26 designs in the previous step, that are now displayed in the table, as shown in Figure 17.



	Cores	Material	Stacked	l_g (m)	Gaps in legs with winding	Gaps in legs without winding	Stacked cores distance (m)	Insulator	N	Window usage	Winding conductor	Vertical wires	Horizontal wires	Conductor width (m)
1	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	6	1	3.3667e-0
2	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	3	1	7.4600e-0
3	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	2	1	0.001
4	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3054	1 oz_6	1	1	0.002
5	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3659	1 oz_6	3	1	7.4600e-0
6	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3999	2 oz_4	2	1	5.7100e-0
7	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3000	2 oz_4	1	1	0.001
8	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	2	1	5.7100e-0
9	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	1	1	0.001
10	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3986	2 oz_4	1	1	0.001
11	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3600	2 oz_6	3	1	5.7100e-0
12	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3600	2 oz_6	2	1	0.001
13	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3000	2 oz_6	1	1	0.002
14	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3594	2 oz_6	3	1	5.7100e-0
15	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3594	2 oz_6	2	1	8.0125e-0
16	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.2995	2 oz_6	1	1	0.002
17	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3587	2 oz_6	2	1	8.0125e-0
18	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3587	2 oz_6	1	1	0.002
19	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.2945	3 oz_4	1	1	0.001
20	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3920	3 oz_4	1	1	0.001
21	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3913	3 oz_4	1	1	0.001
22	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3534	3 oz_6	2	1	0.001
23	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.2945	3 oz_6	1	1	0.001
24	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.2940	3 oz_6	1	1	0.001
25	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3522	3 oz_6	1	1	0.001
26	E22/6/16	N87	1	1.6761e-04	1	1	0	NOMEX	13	0.2923	3 oz_6	1	1	0.001

Figure 17: Table with selected designs

Since all of them were selected from a cluster of designs that were very close to each other in the graphs, they are all very similar. Every design selected uses the same core geometry and core material, and the main differences are the copper thickness and the number of layers.

In this case, to reduce cost we will select only those that use a 4-layer PCB. They are the ones with a value of 4 in the "PCB layers" column (the columns can be navigated with the scroll bar at the bottom of the table). There are now 8 designs left, as highlighted in Figure 18.

egs with winding	Gaps in legs without winding	Stacked cores distance (m)	Insulator	N	Window usage	Winding conductor	Vertical wires	Horizontal wires	Conductor width (m)	Conductor height (m)	Layers	PCB layers	PCB thickne
1	1	0	NOMEX	9	0.3665	1 oz_6	6	1	3.3667e-04	3.5000e-05	1	6	0.
1	1	0	NOMEX	9	0.3665	1 oz_6	3	1	7.4600e-04	3.5000e-05	2	6	0.
1	1	0	NOMEX	9	0.3665	1 oz_6	2	1	0.0014	3.5000e-05	3	6	0.
1	1	0	NOMEX	9	0.3054	1 oz_6	1	1	0.0021	3.5000e-05	5	6	0.
1	1	0	NOMEX	10	0.3659	1 oz_6	3	1	7.4600e-04	3.5000e-05	2	6	0.
1	1	0	NOMEX	9	0.3999	2 oz_4	2	1	5.7100e-04	7.0000e-05	2	4	0
1	1	0	NOMEX	9	0.3000	2 oz_4	1	1	0.0012	7.0000e-05	3	4	0
1	1	0	NOMEX	10	0.3993	2 oz_4	2	1	5.7100e-04	7.0000e-05	2	4	0
1	1	0	NOMEX	10	0.3993	2 oz_4	1	1	0.0012	7.0000e-05	4	4	0
1	1	0	NOMEX	11	0.3986	2 oz_4	1	1	0.0012	7.0000e-05	4	4	0
1	1	0	NOMEX	9	0.3600	2 oz_6	3	1	5.7100e-04	7.0000e-05	2	6	0.
1	1	0	NOMEX	9	0.3600	2 oz_6	2	1	0.0012	7.0000e-05	3	6	0.
1	1	0	NOMEX	9	0.3000	2 oz_6	1	1	0.0020	7.0000e-05	5	6	0.
1	1	0	NOMEX	10	0.3594	2 oz_6	3	1	5.7100e-04	7.0000e-05	2	6	0.
1	1	0	NOMEX	10	0.3594	2 oz_6	2	1	8.0125e-04	7.0000e-05	3	6	0.
1	1	0	NOMEX	10	0.2995	2 oz_6	1	1	0.0020	7.0000e-05	5	6	0.
1	1	0	NOMEX	11	0.3587	2 oz_6	2	1	8.0125e-04	7.0000e-05	3	6	0.
1	1	0	NOMEX	11	0.3587	2 oz_6	1	1	0.0020	7.0000e-05	6	6	0.
1	1	0	NOMEX	9	0.2945	3 oz_4	1	1	0.0010	1.0500e-04	3	4	0
1	1	0	NOMEX	10	0.3920	3 oz_4	1	1	0.0010	1.0500e-04	4	4	0
1	1	0	NOMEX	11	0.3913	3 oz_4	1	1	0.0010	1.0500e-04	4	4	0
1	1	0	NOMEX	9	0.3534	3 oz_6	2	1	0.0010	1.0500e-04	3	6	0.
1	1	0	NOMEX	9	0.2945	3 oz_6	1	1	0.0018	1.0500e-04	5	6	0.
1	1	0	NOMEX	10	0.2940	3 oz_6	1	1	0.0018	1.0500e-04	5	6	0.
1	1	0	NOMEX	11	0.3522	3 oz_6	1	1	0.0018	1.0500e-04	6	6	0.
1	1	0	NOMEX	13	0.2923	3 oz_6	1	1	0.0010	1.0500e-04	5	6	0.

Figure 18: Designs with 4 PCB layers

To reduce the cost even further, we will also discard those that use a 3 oz copper thickness, leaving only 5 possible designs:

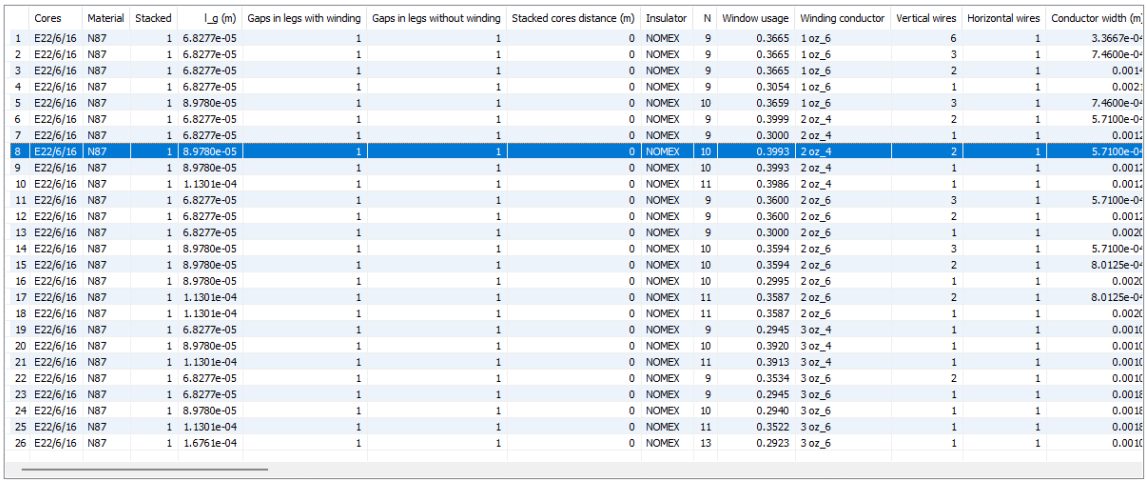
	Cores	Material	Stacked	l_g (m)	Gaps in legs with winding	Gaps in legs without winding	Stacked cores distance (m)	Insulator	N	Window usage	Winding conductor	Vertical wires	Horizontal wires	Conductor width (m)
1	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	6	1	3.3667e-0
2	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	3	1	7.4600e-0
3	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	2	1	0.001
4	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3054	1 oz_6	1	1	0.002
5	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3659	1 oz_6	3	1	7.4600e-0
6	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3999	2 oz_4	2	1	5.7100e-0
7	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3000	2 oz_4	1	1	0.001
8	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	2	1	5.7100e-0
9	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	1	1	0.001
10	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3986	2 oz_4	1	1	0.001
11	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3600	2 oz_6	3	1	5.7100e-0
12	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3600	2 oz_6	2	1	0.001
13	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3000	2 oz_6	1	1	0.002
14	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3594	2 oz_6	3	1	5.7100e-0
15	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3594	2 oz_6	2	1	8.0125e-0
16	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.2995	2 oz_6	1	1	0.002
17	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3587	2 oz_6	2	1	8.0125e-0
18	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3587	2 oz_6	1	1	0.002
19	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.2945	3 oz_4	1	1	0.001
20	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3920	3 oz_4	1	1	0.001
21	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3913	3 oz_4	1	1	0.001
22	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3534	3 oz_6	2	1	0.001
23	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.2945	3 oz_6	1	1	0.001
24	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.2940	3 oz_6	1	1	0.001
25	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3522	3 oz_6	1	1	0.001
26	E22/6/16	N87	1	1.6761e-04	1	1	0	NOMEX	13	0.2923	3 oz_6	1	1	0.001

Figure 19: Designs with 2 oz thickness

All the remaining designs are very similar. These similarities highlight the advantages of the SmartNetics approach. As can be seen, a device with approximately the same value in a given parameter can be built in many different ways, and sometimes allowing a slight increase in a parameter can allow for a much better design in every other aspect. In a different approach, only one of these devices would be available, for example, the one with the lowest losses. This illustrates the disadvantages of that approach, where designs that are very similar in a given parameter could be discarded by a small difference that wouldn't even have any impact on the converter, without considering the big improvement they could provide in other metrics.

In this case, from the remaining designs, we will select the one that best uses the PCB, using a higher filling and ensuring that every layer is symmetrical. Of these designs, the one that best matches that, is design number 8, which we will select, as shown in Figure 20.

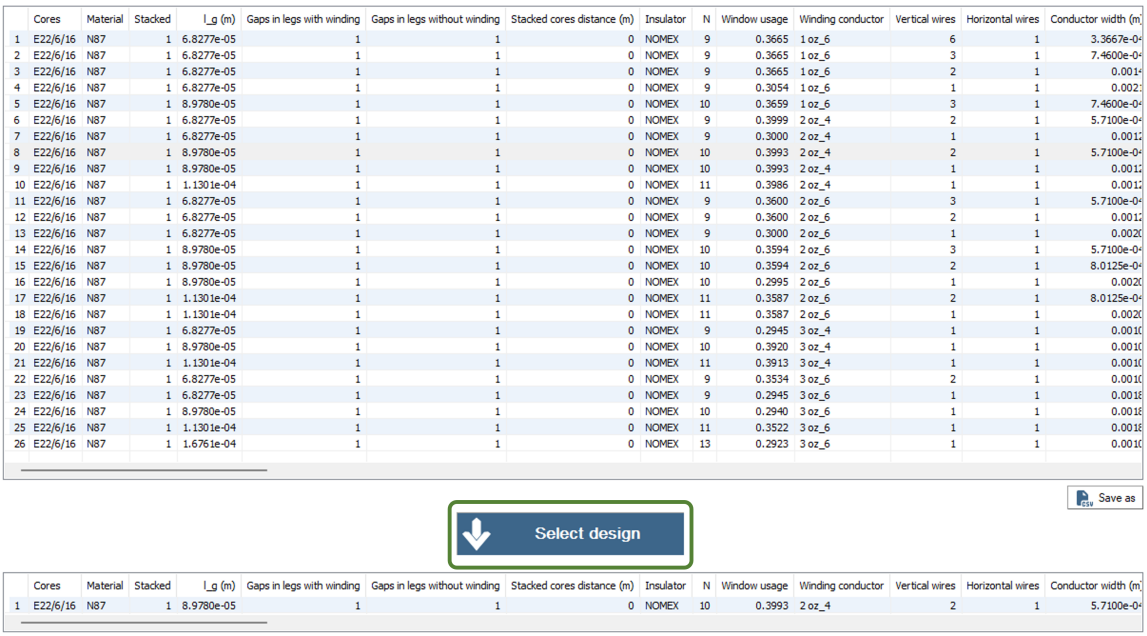




	Cores	Material	Stacked	l_g (m)	Gaps in legs with winding	Gaps in legs without winding	Stacked cores distance (m)	Insulator	N	Window usage	Winding conductor	Vertical wires	Horizontal wires	Conductor width (m
1	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	6	1	3.3667e-0
2	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	3	1	7.4600e-0
3	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3665	1 oz_6	2	1	0.001
4	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3054	1 oz_6	1	1	0.002
5	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3659	1 oz_6	3	1	7.4600e-0
6	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3999	2 oz_4	2	1	5.7100e-0
7	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3000	2 oz_4	1	1	0.001
8	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	2	1	5.7100e-0
9	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	1	1	0.001
10	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3986	2 oz_4	1	1	0.001
11	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3600	2 oz_6	3	1	5.7100e-0
12	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3600	2 oz_6	2	1	0.001
13	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3000	2 oz_6	1	1	0.002
14	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3594	2 oz_6	3	1	5.7100e-0
15	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3594	2 oz_6	2	1	8.0125e-0
16	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.2995	2 oz_6	1	1	0.002
17	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3587	2 oz_6	2	1	8.0125e-0
18	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3587	2 oz_6	1	1	0.002
19	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.2945	3 oz_4	1	1	0.001
20	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3920	3 oz_4	1	1	0.001
21	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3913	3 oz_4	1	1	0.001
22	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.3534	3 oz_6	2	1	0.001
23	E22/6/16	N87	1	6.8277e-05	1	1	0	NOMEX	9	0.2945	3 oz_6	1	1	0.001
24	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.2940	3 oz_6	1	1	0.001
25	E22/6/16	N87	1	1.1301e-04	1	1	0	NOMEX	11	0.3522	3 oz_6	1	1	0.001
26	E22/6/16	N87	1	1.6761e-04	1	1	0	NOMEX	13	0.2923	3 oz_6	1	1	0.001

Figure 20: Selected device

Now that a single design is selected, the user can click on the "Select design" button at the bottom. That will mark the device as selected and replicate its data in the bottom table, as shown in Figure 21.



	Cores	Material	Stacked	l_g (m)	Gaps in legs with winding	Gaps in legs without winding	Stacked cores distance (m)	Insulator	N	Window usage	Winding conductor	Vertical wires	Horizontal wires	Conductor width (m
1	E22/6/16	N87	1	8.9780e-05	1	1	0	NOMEX	10	0.3993	2 oz_4	2	1	5.7100e-0

Figure 21: Selected device (Button clicked)

Once a single device has been selected, the last dialog, "Device", becomes available. The user can go to that dialog to analyze in depth the selected device.

Inductor analysis

The first tab of this dialog, “Geometry”, allows the validation of the device measures, as shown in Figure 22. At the bottom-right corner, the user can check the distances between layers and tracks. In the current SmartNetics release, those distances are calculated based on IPC-2221b standard.

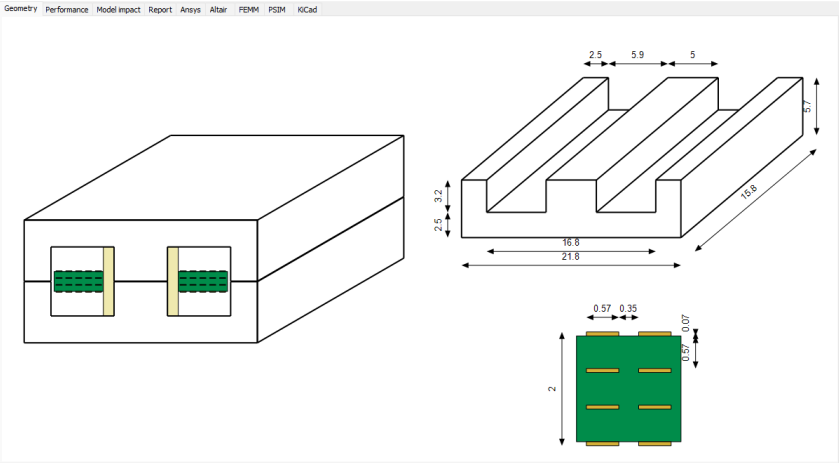


Figure 22: Device geometry

In the next tab, “Performance”, the user can check the expected temperature distribution for the device, as shown in the next figure.

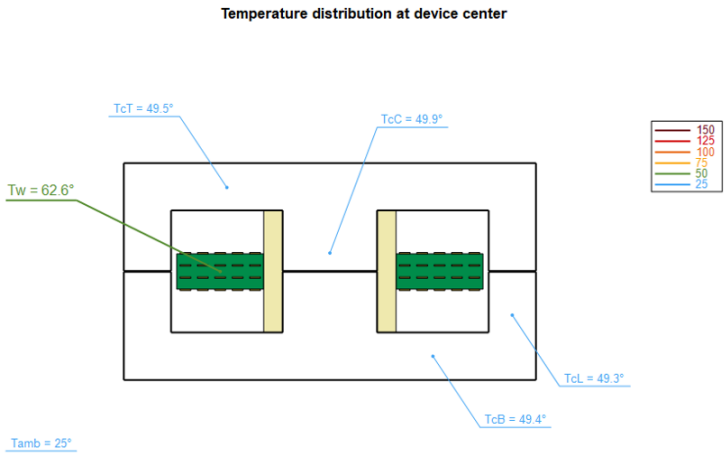


Figure 23: Expected temperature distribution

If everything is considered valid, the user can generate a full report of the device, in which they can include the desired properties of the device. This can be done in the "Report" tab, which is displayed in Figure 24.

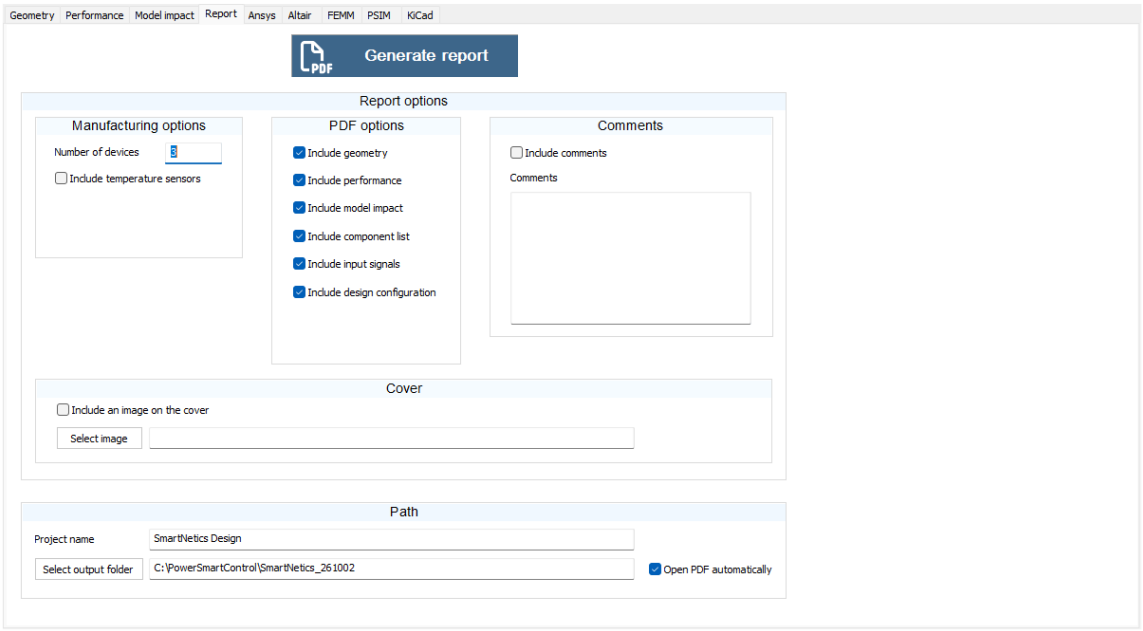


Figure 24: Report configuration

Once the design has been analyzed and is expected to match specifications, SmartNetics provides an additional step. The user can export the design to third-party tools to validate the calculations.

Inductor validation

The best way to accurately achieve that validation is by means of a Finite Element simulation. SmartNetics provides a direct export to: Ansys (Maxwell for electromagnetic simulation and Icepak for temperature), Altair-Flux (for 3D or 2D electromagnetic simulation) and FEMM (for a free 2D electromagnetic simulation).

1 FEMM

In the "FEMM" tab, the user can configure the model export to that software.

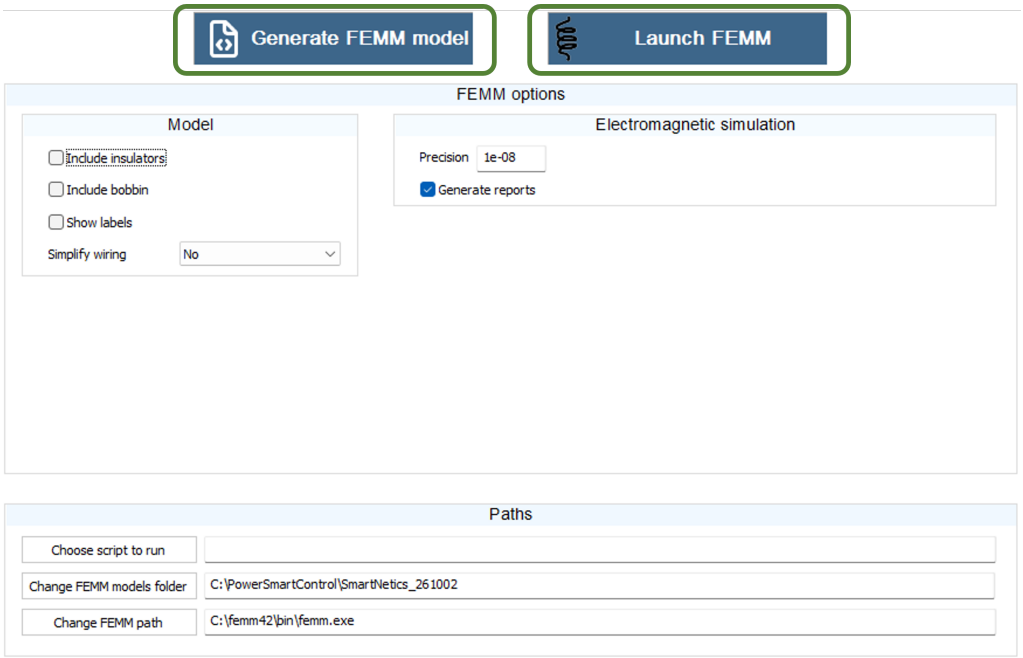


Figure 25: FEMM configuration

The user can replicate the design selected in SmartNetics by clicking on the "Generate FEMM model" button. Once generated, it can be simulated on the same computer (if FEMM is installed) or on any other. If installed, the user can click on "Launch FEMM" to automatically launch the software, run the simulations, and display the results, as shown in Figure 26.

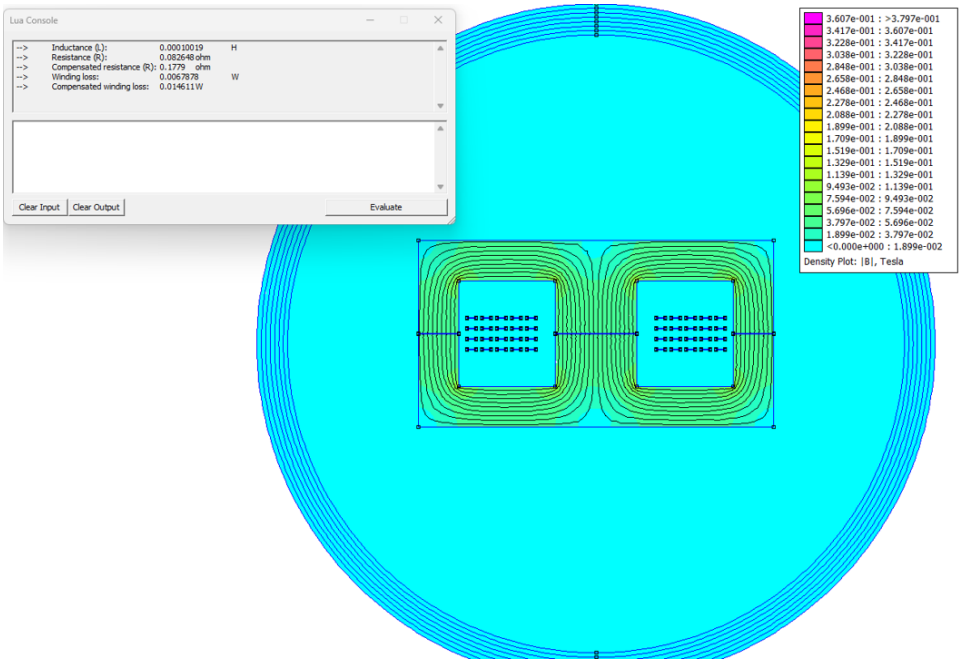


Figure 26: FEMM simulation

In this screen the user can check the inductance and resistance obtained in the simulation, after compensating for the fact that it is a 2D simulation, in the fields "Inductance (L)" and "Compensated resistance (R)":

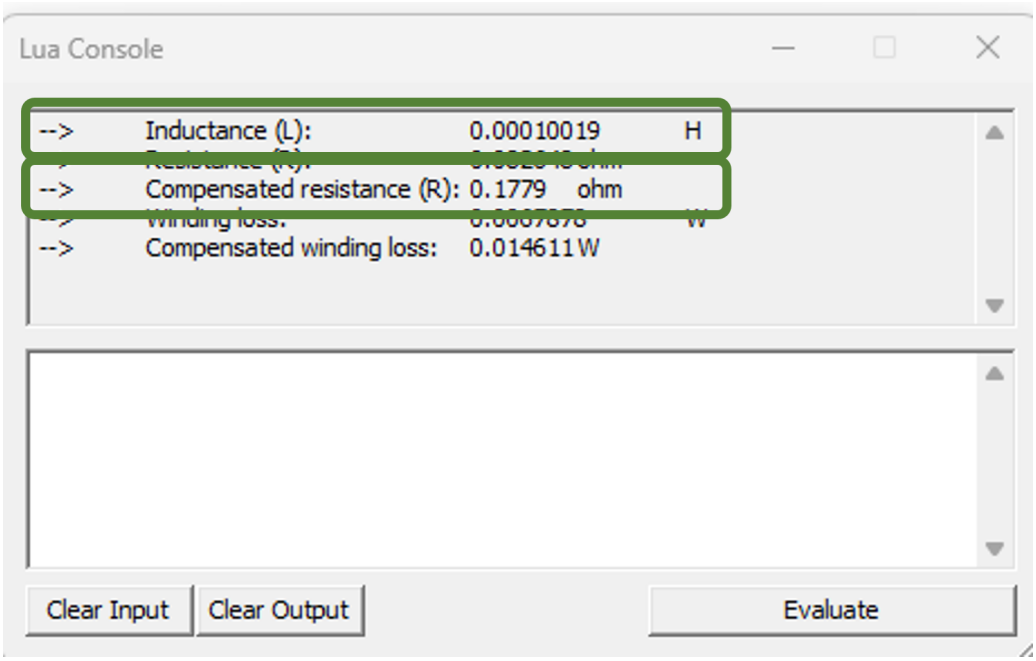


Figure 27: FEMM results

* Notice that, since the FEMM simulation was carried out for a single frequency using a sinusoidal current, the total losses do not match the expected ones for the triangular waveform used.

2 Ansys

Once inductance and losses have been validated, we can proceed to export the model to Ansys-Icepak for temperature validation, since we can check the temperature distribution for the full volume of the device.

To provide a good depiction of the real problem, we will include every component in the simulation. Apart from the core and winding, we will use the check-boxes to include insulators, wire sleeves, and bobbin, as shown in the next figure:

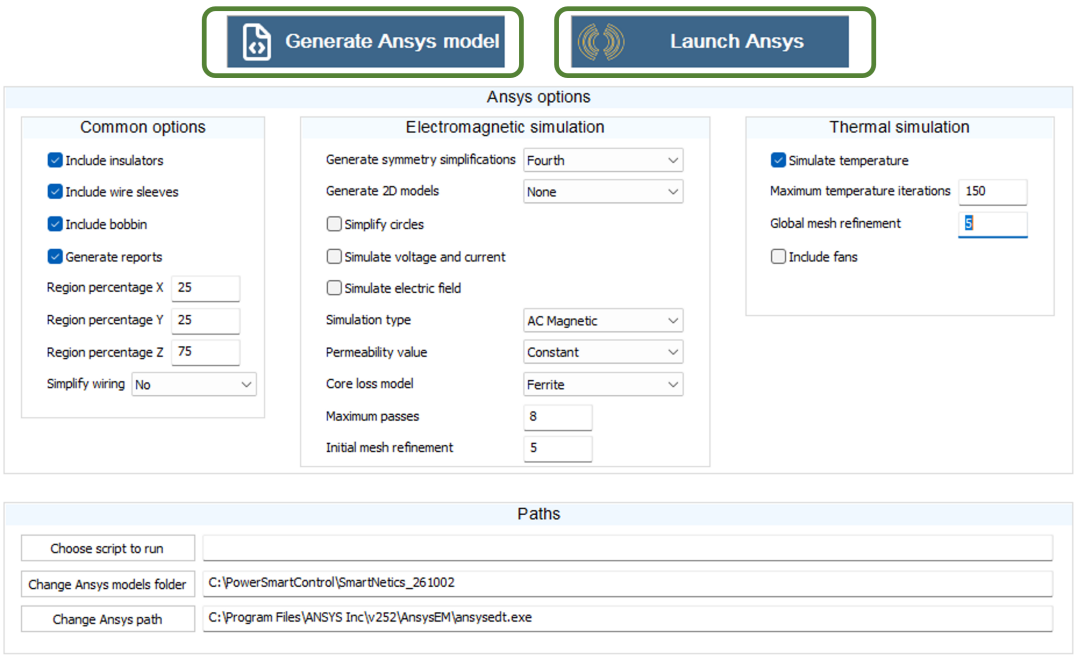


Figure 28: Ansys configuration

As in FEMM, the user can generate the Ansys model by clicking on the "Generate Ansys model" button. Once generated, it can be simulated on the same computer (if Ansys is installed) or on any other. If installed, the user can click on "Launch Ansys" to automatically launch the software and build the model.

Several symmetry simplifications can be used to reduce the simulation time, with every simplified model coming from the full 3D representation of the device, shown in Figure 29.



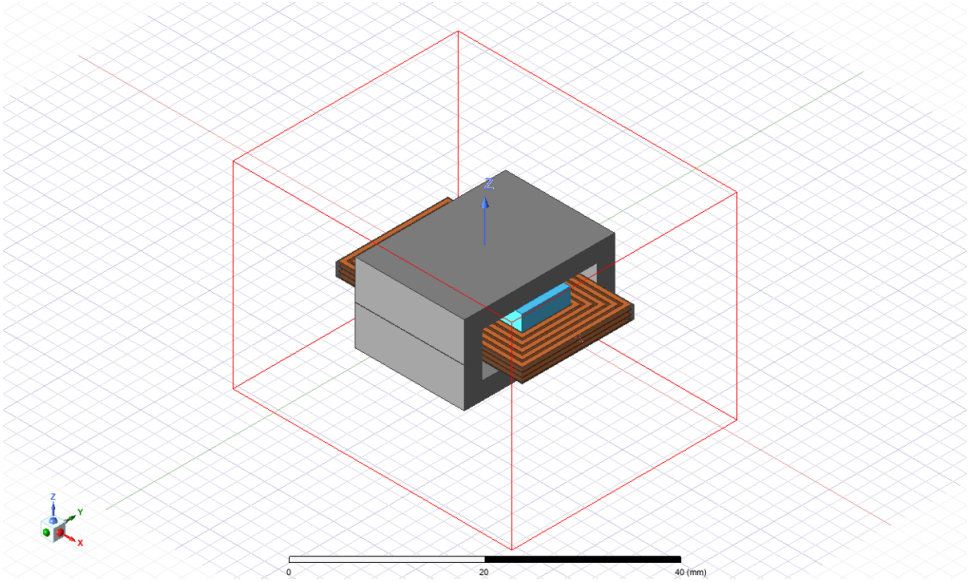


Figure 29: Ansys 3D model

Once in Ansys-Icepak, the user can click on "Analyze All" to run the simulation:

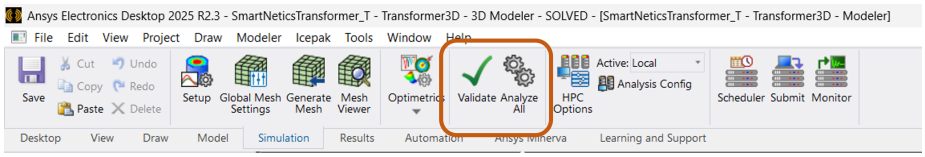


Figure 30: Ansys run button

After the simulation finishes, we can check the temperature distribution, shown in Figure 31, that matches the expected temperature shown in Figure 23.

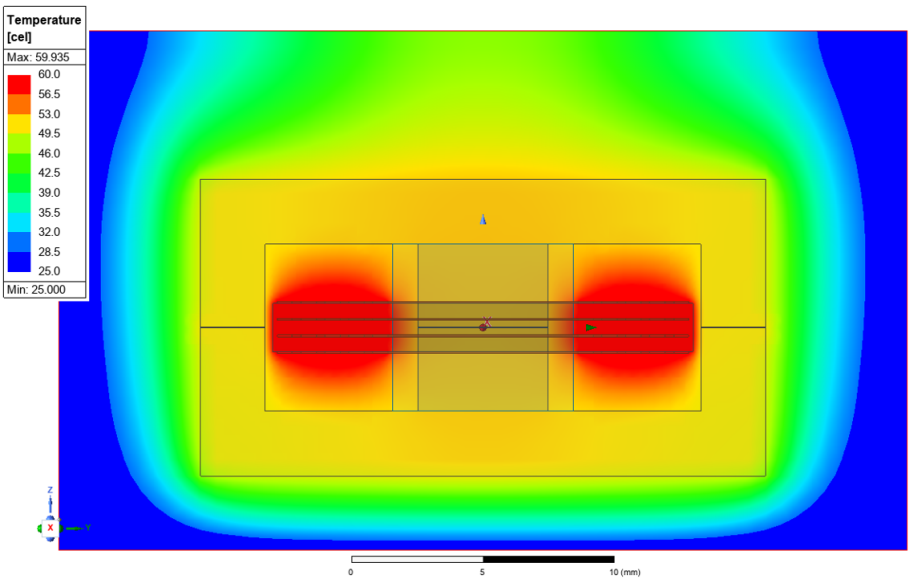


Figure 31: Ansys temperature

Once the desired design has been selected and validated, we can proceed to the last step: generate its PCB and include it in the converter.

PCB generation

The user can automatically generate the PCB in KiCad, including the magnetic device, the layer stackup, the vias, etc. This is done in the last panel of the dialog, "KiCad" and the PCB is generated by pressing on "Generate KiCad model".

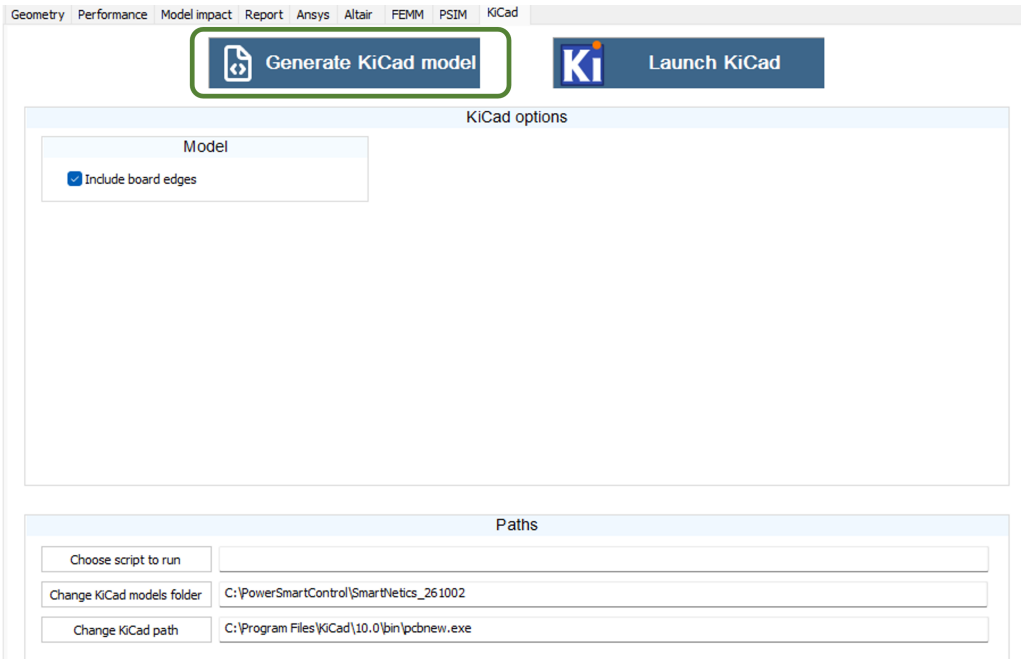


Figure 32: KiCad export panel

As in FEMM or Ansys, the user can generate the PCB model by clicking on the "Generate KiCad model" button. Once generated, it can be opened on the same computer (if KiCad is installed) or on any other.

If installed, the user can click on "Launch KiCad" to automatically launch the software and view or edit the PCB. Once done, KiCad opens, and the device is displayed, as shown in Figure 33.

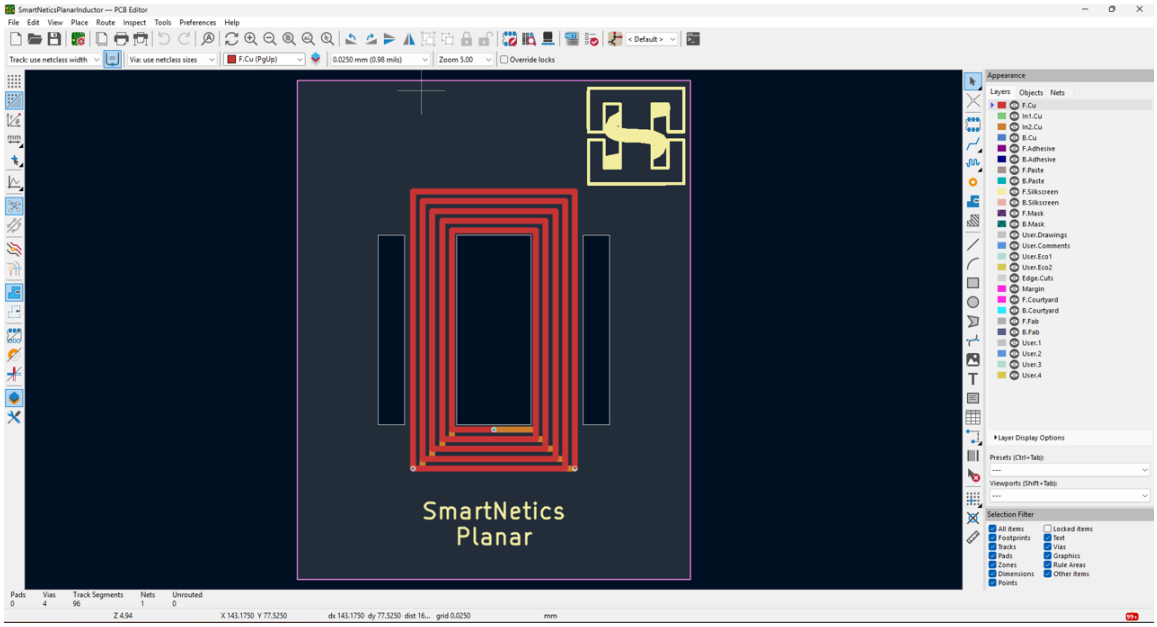


Figure 33: KiCad export result

The design can be checked in 3D by the shortcut Alt+3:

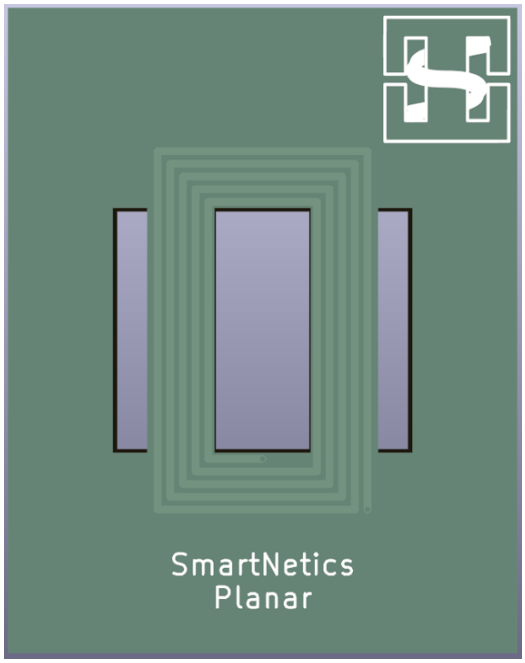


Figure 34: KiCad 3D view

Although it does not have an impact on the PCB routing, if the user has the 3D model of the core, it can be added to the component. To do so, add a dummy small component (for example, a PinHeader_1x01_P1.00mm_Vertical) to the center of the device (in coordinates 150, 100) as shown in Figure 35.

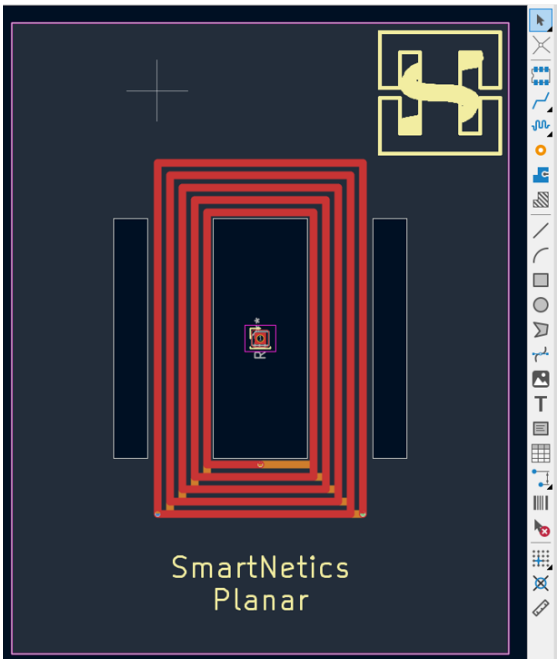


Figure 35: KiCad. Include dummy device

Then, by double-clicking on the component, its model can be included in the "3D Models" tab. The model can also be moved or rotated depending on the original orientation of the step file, as shown in Figure 36.

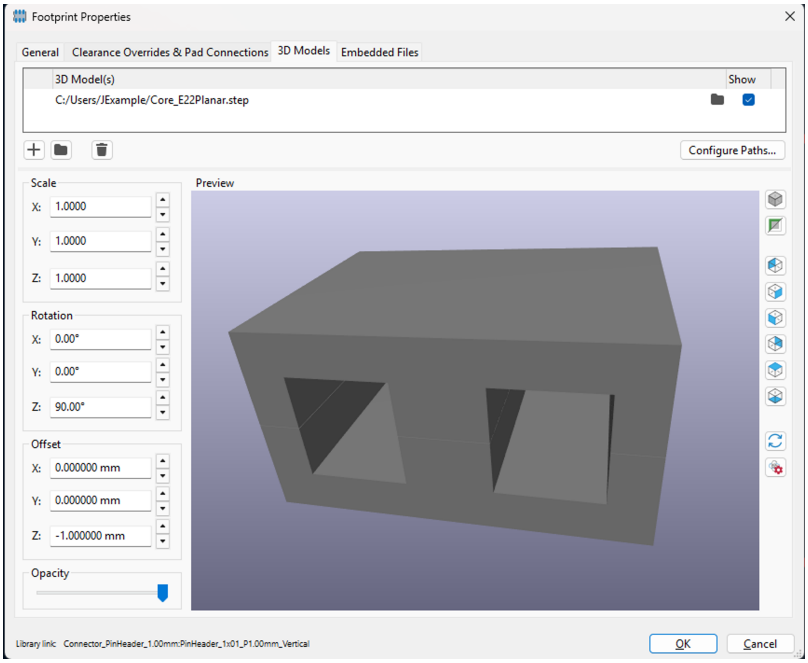


Figure 36: KiCad. Add 3D model

Once added, the full component can be displayed in 3D (by the Alt+3 shortcut). The complete device, including the core and PCB winding, is shown in Figure 37.

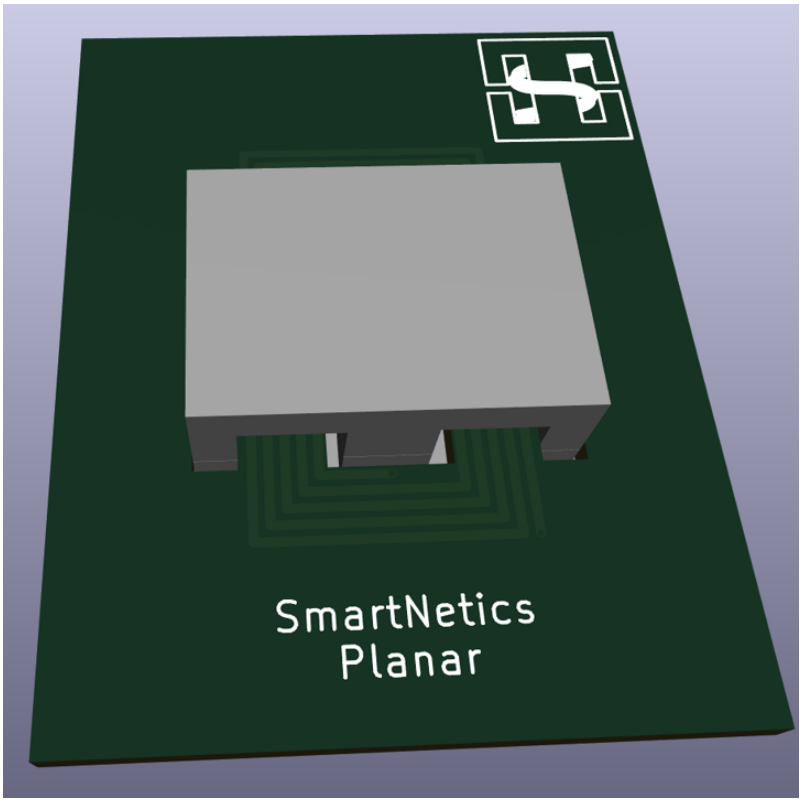


Figure 37: KiCad. Inductor 3D model

Now that the device is completed, save the PCB with the desired name so it can be included in the PCB of the converter. This is done by clicking on "File" - "Save", on the top-left corner.

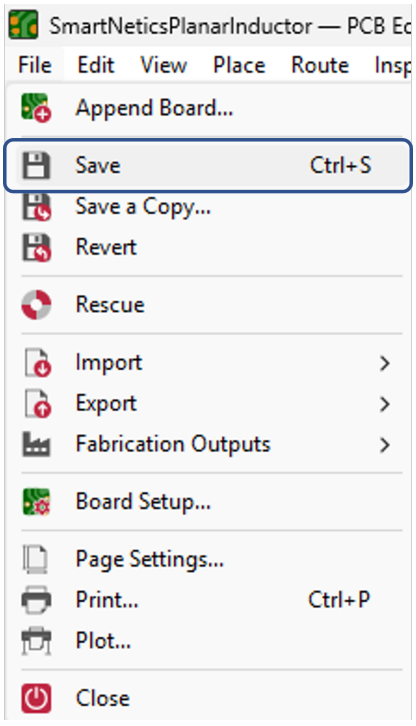


Figure 38: KiCad. Save inductor PCB

Now you can close the inductor PCB and reopen the converter one.

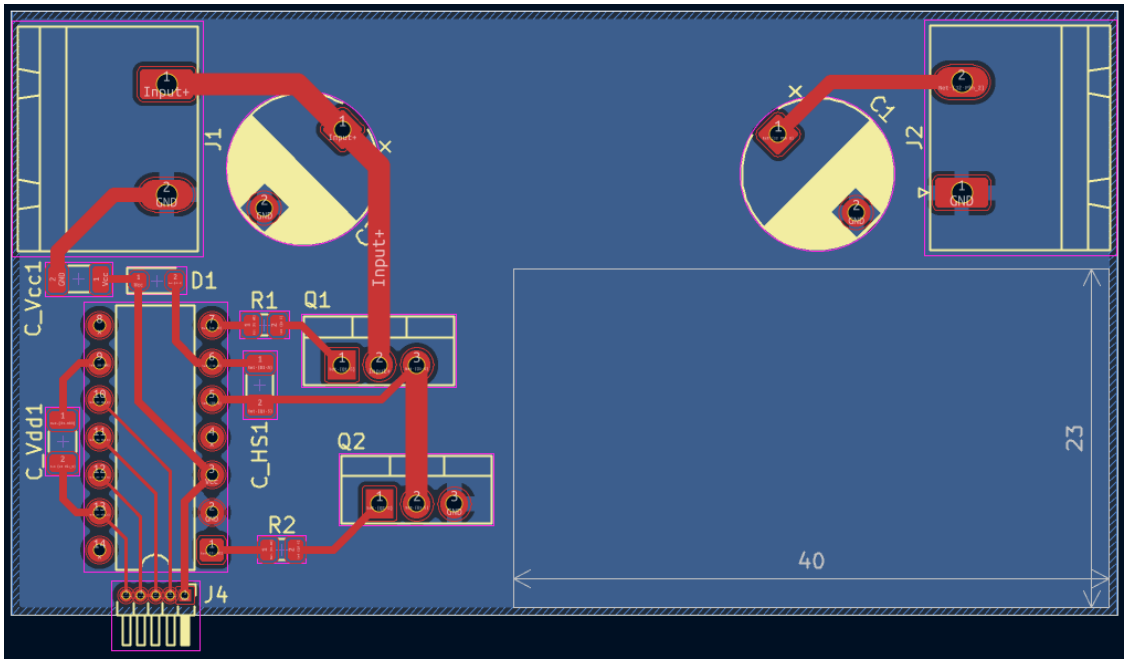


Figure 39: Buck PCB without inductor

Once opened, you can add the inductor to it with the "Append board" control, on the top-left corner.

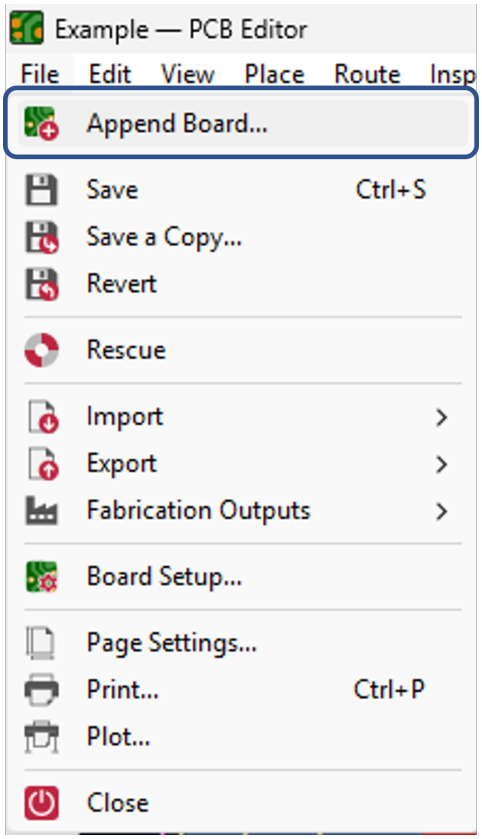


Figure 40: KiCad. Append board

First, place the inductor alongside the converter PCB, as shown in the next figure.

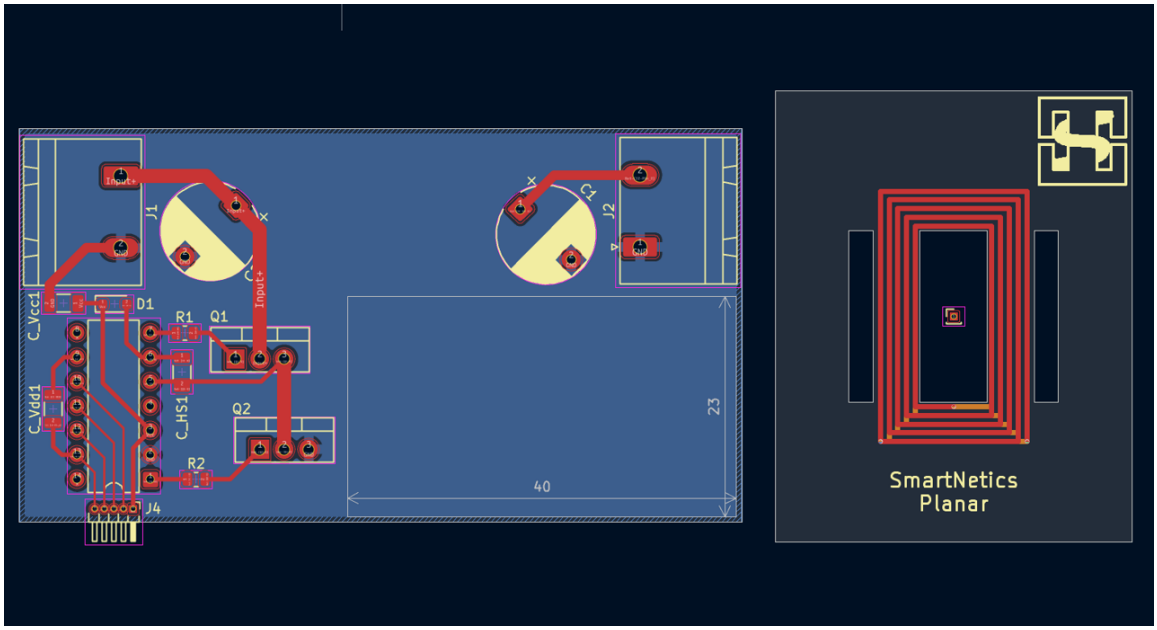


Figure 41: KiCad. Converter and inductor

Now, the converter schematic has to be modified to include the inductor. This is done by including a short circuit in place of the inductor and assigning a name to the net, that has to match the one of the desired inductor: "Winding". The schematic will now look as shown in Figure 42.

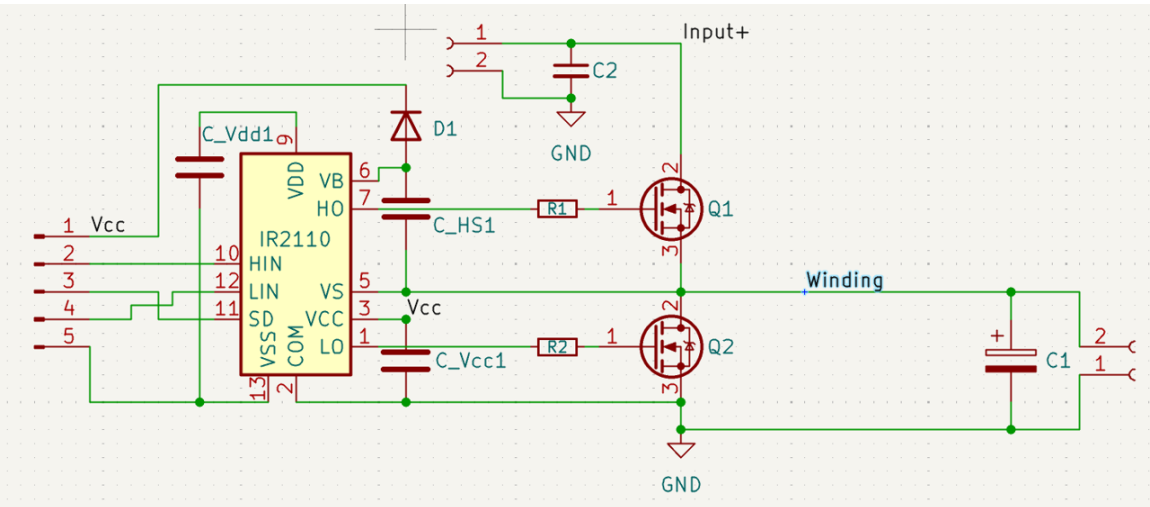


Figure 42: KiCad. Schematic modification

Now, back to the PCB, apply the changes and check that the new connections have been created. A ratsnest line can now be seen displaying a remaining connection, as shown in Figure 43.

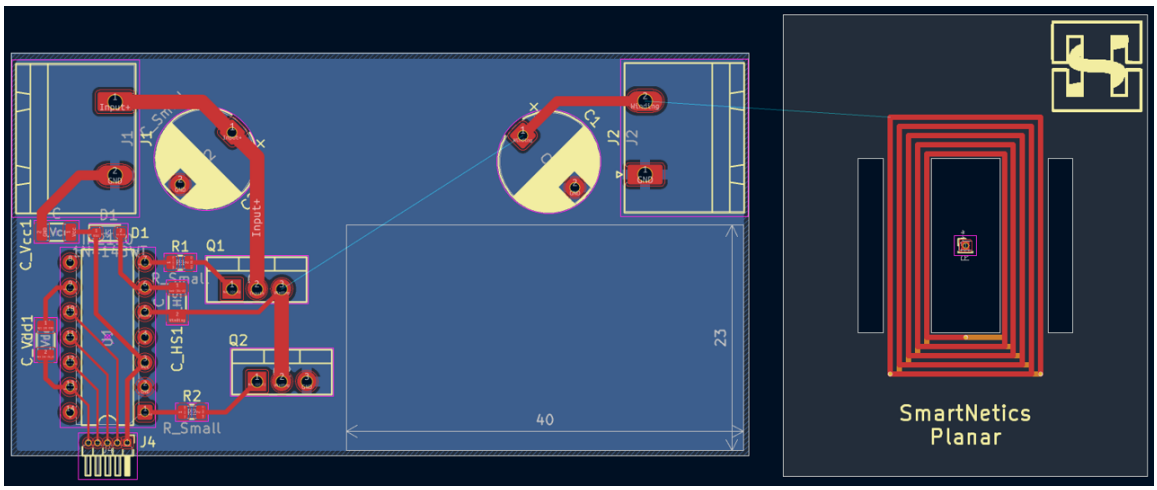


Figure 43: KiCad. Schematic check

The inductor PCB still has its own margins, which should be removed to avoid interfering with the converter's PCB. To do so, select the inductor group by clicking on any of its parts. It will become highlighted:

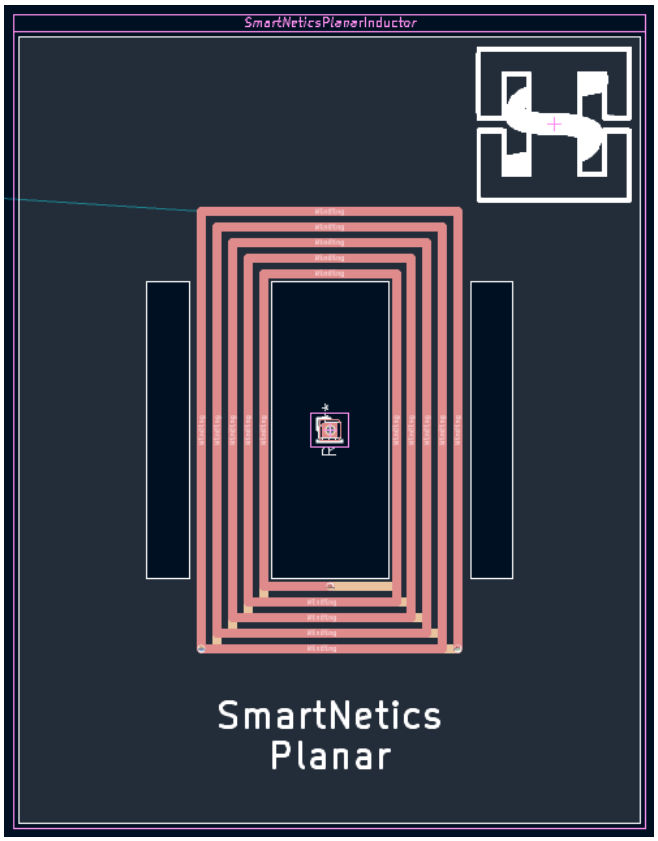


Figure 44: KiCad. Select the whole inductor

Now, right-click on it and press Grouping - Ungroup items, as shown in Figure 45.

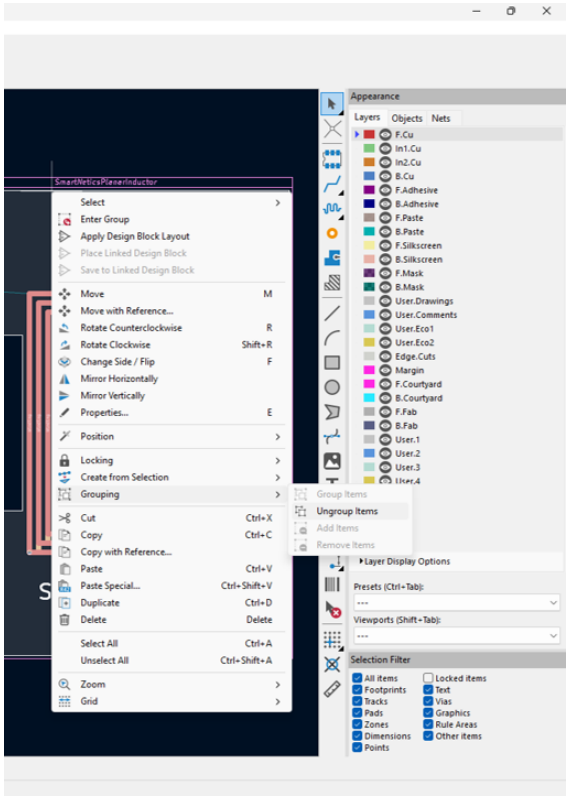


Figure 45: KiCad. Ungroup inductor

And then select the borders and delete them by pressing the "Delete" key or with right-click - "Delete".

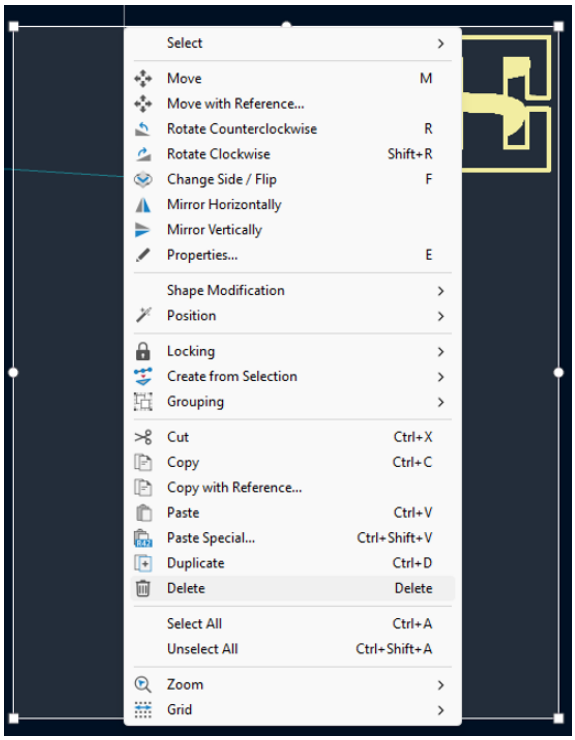


Figure 46: KiCad. Delete borders

Once they are deleted, group the items back together by selecting them right-clicking - “Grouping” - “Group items”, as shown in Figure 47.

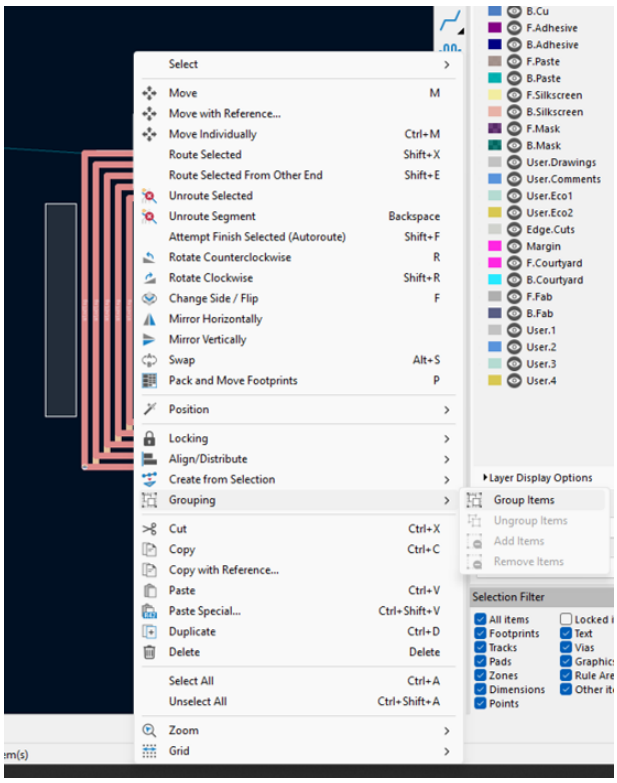


Figure 47: KiCad. Regroup inductor

Now move and rotate the inductor and place it in its desired spot (you can also move the text and icon of SmartNetics). The full converter, including the now placed inductor, is shown in Figure 48.

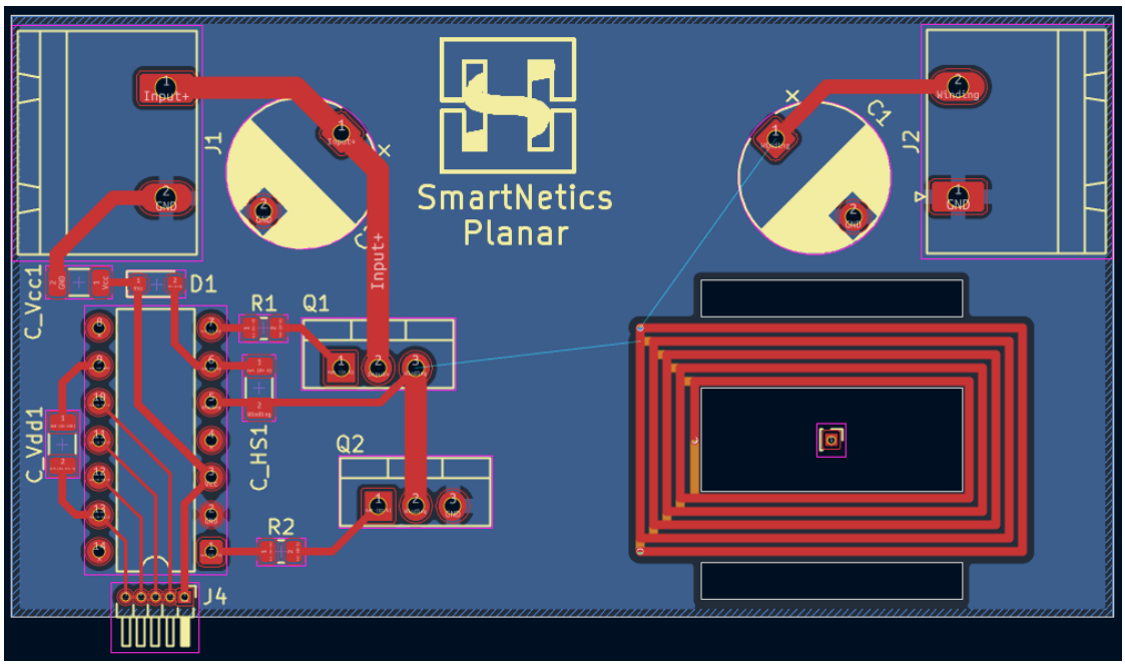


Figure 48: KiCad. Arranged circuit

The last step is to route the input and output of the inductor. Once done, the whole converter, including the inductor integrated in the PCB, is finished and ready for production.

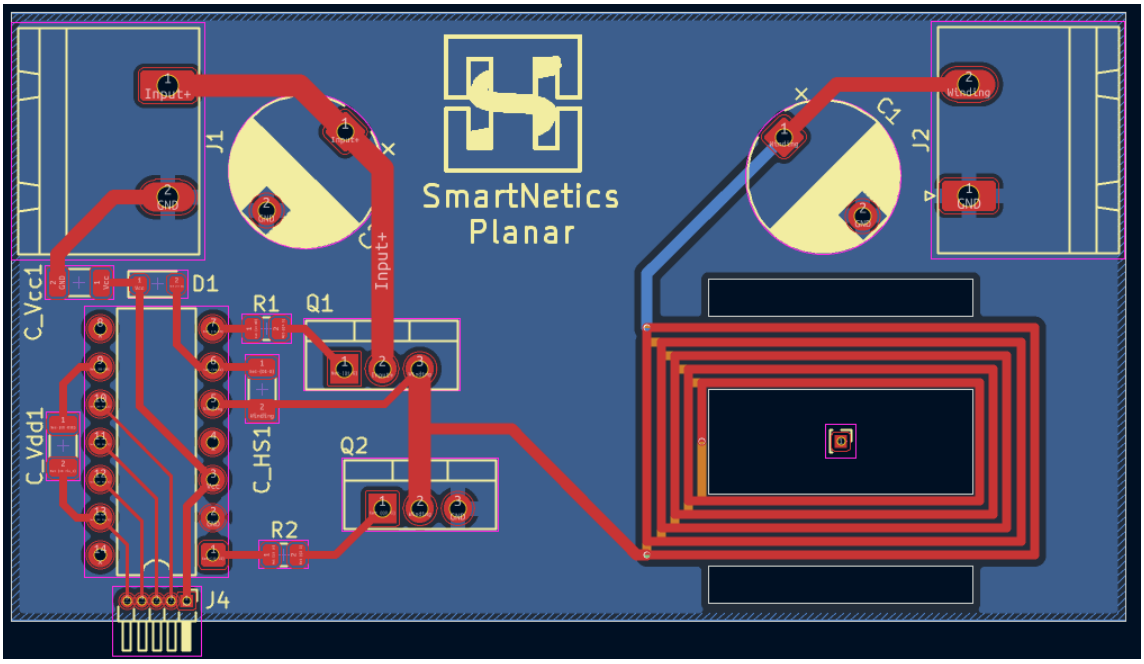


Figure 49: KiCad. Routed circuit

Finally, the end design can be previewed in 3D to ensure everything is arranged as expected:

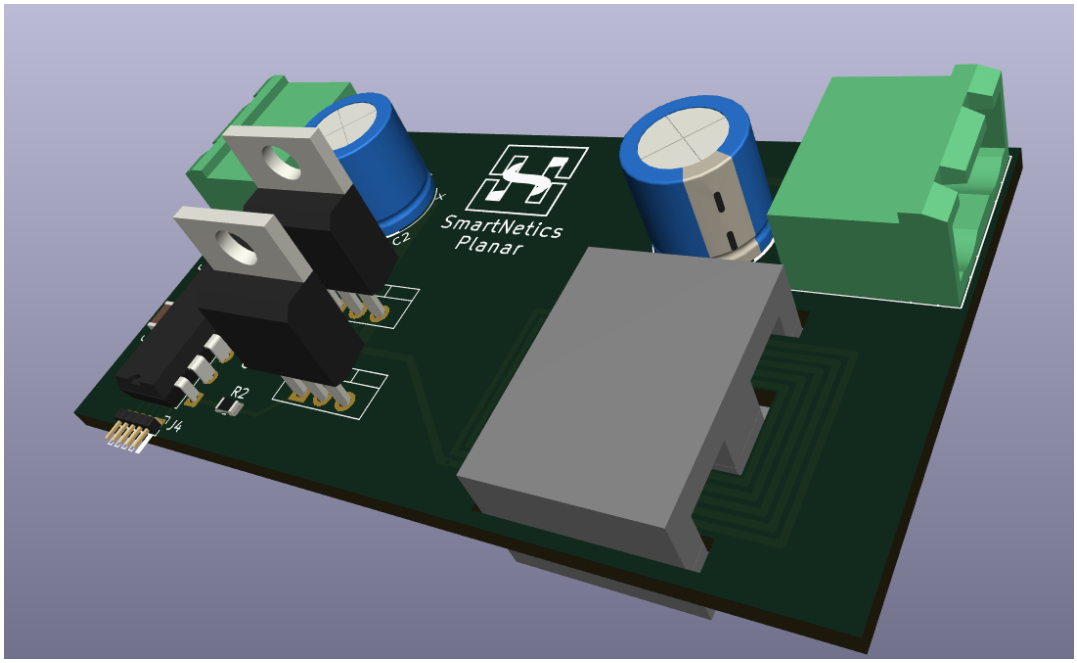


Figure 50: KiCad. Converter 3D view

Conclusions

In this tutorial, we have shown how to design an integrated planar inductor for a given specification and how to include it in the PCB of a power converter. Thanks to SmartNetics' capabilities, on top of the analytical calculations, the user can automatically export the full model to third-party tools for its simulation, including Ansys (Maxwell or Icepak), Altair-Flux, FEMM, and PSIM.

Once the design is validated, the user can automatically get a fully routed PCB device in KiCad, which can be used standalone or included in the PCB of a power converter, to achieve complete integration.

This tutorial is intended as an example, so the user is encouraged to try different configurations to find the one that is best suited for their particular project. Please keep in mind that the images shown in this document may not exactly match the options and distribution shown in the application, since different updates may result in slight changes.

