GeckoMAGNETICS is a tool that enables fast, accurate and user-friendly modelling and pareto-optimal design of inductive power components.

The key modelling features of Gecko-MAGNETICS are:

1) An easy-to-use GUI that guides through the design process. Based on the desired inductance, application, and cooling conditions GeckoMAGNETICS finds an optimal design with respect to losses or volume.

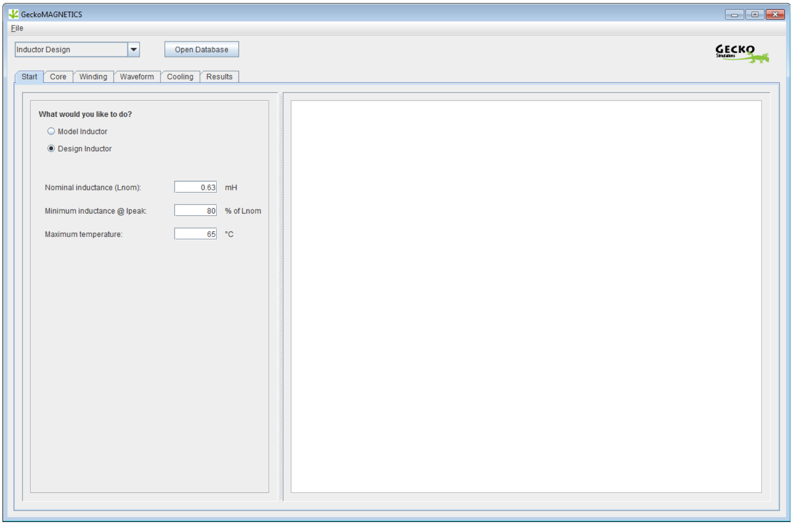
2) Sophisticated and accurate models for loss, thermal and inductance calculation, including:

- A very accurate inductance calculation based on a novel air gap reluctance calculation approach.
- Different winding loss effects, such as Skin effect, Proximity effects (including the influence of an air-gap fringing field).
- Many core loss effects such as a DC premagnetization, relaxation effects, etc. Neglecting a DC premagnetization, for example, may lead to a loss under-estimation by a factor of more than two.

3) A link to the circuit simulator GeckoCIRCUITS, enabling multi-domain modelling and extraction of waveforms from circuit simulations.

4) A material and core database, which is a part of the GeckoMAGNETICS tool, for accurate core loss modelling.

With an example of a buck type DC/DC converter, this tutorial shows how inductors can be pareto-optimally designed. The output of the tool is a so-called pareto-front from which the user can select loss and/or volumetric optimized designs, according to his needs.



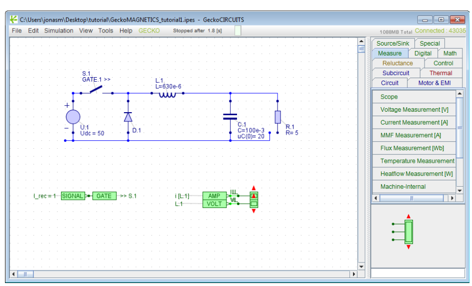
After starting GeckoMAGNETICS, the tab "Start" becomes active, as is illustrated in the figure above.

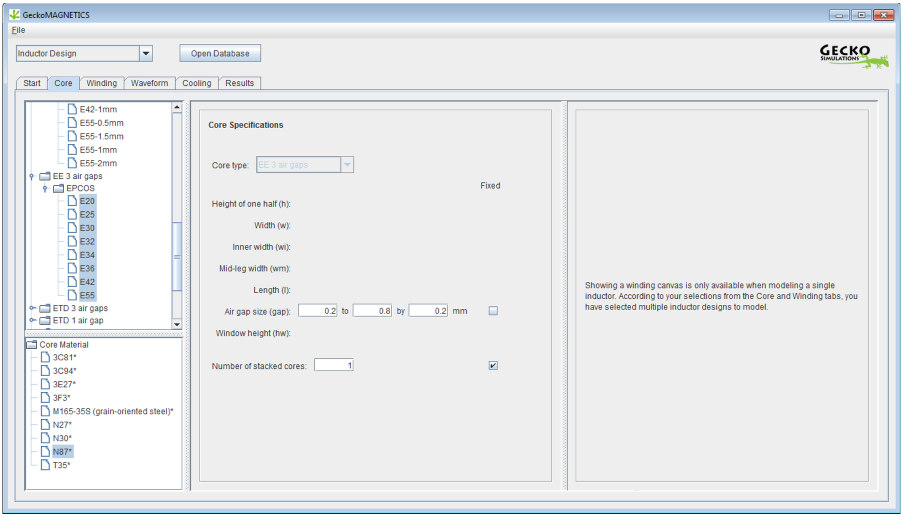
The user can model the losses and temperature of a single pre-defined inductor. Additionally, the tool can help in finding an optimum inductor for a particular design problem. In this tutorial, we would like to find the optimum design of an inductor for a buck-type DC/DC converter as shown on the right; **accordingly, please choose the "Design Inductor"** option in GeckoMAGNETICS.

The user can now select the nominal inductance, the maximum allowed hot spot temperature, as well as the minimum inductance at the peak current in the "Start" tab.

The "Minimum Inductance @ Ipeak" allows controlling the reduced inductance at higher current levels in comparison to the nominal inductance at zero current. Here, the user can specify to which percentage the inductance is allowed to drop at the peak current.

In the example at hand, please choose a nominal inductance of **0.63 mH**, a minimum inductance of **80 %**, and a maximum temperature of **65 °C**.





The design space is specified in the tabs "Core" and "Winding". For instance, the user specifies a group of cores from which the program then finds the optimum one.

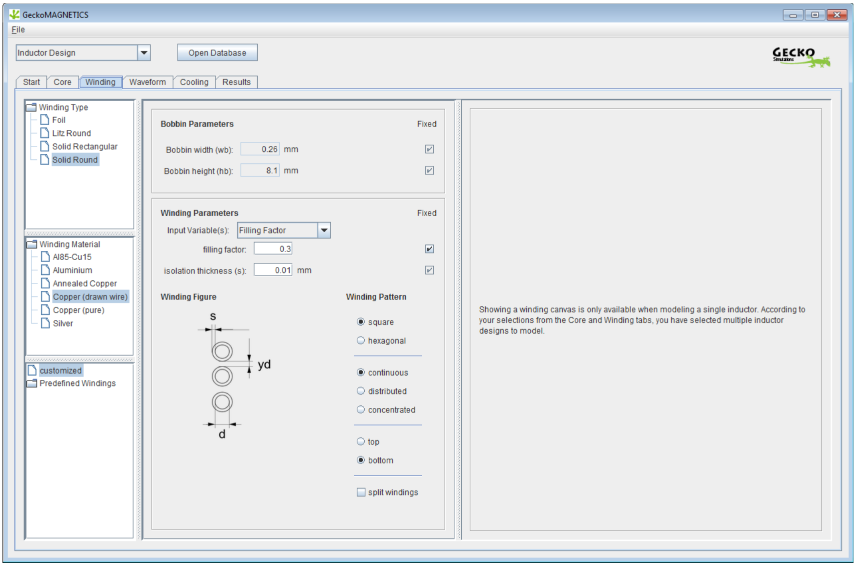
A typical design approach is to preselect the core shape. For instance, a pot core is taken in order to reduce the stray field; or, an EE core nicely fills the available space, etc. In the example, we go for EE cores; however, since we do not know the needed size yet, we simply choose **all EPCOS "EE 3 air gaps"** cores from the database. A multiple selection is done by pressing **SHIFT** to choose a range, or by pressing **CTRL** to add a core to the previously made selection.

A core of type "EE 3 air gaps" has three air gaps of the same size. Thus, the tool is asking for this air gap size. Since we want the tool to select the optimal air gap size, we define a range: Un-select the according "fixed" check box and choose **"0.2 to 0.8 by 0.2 mm"**.

Different materials can be selected; the tool then finds the best possible material. The characteristics to a material are stored in a database that can be viewed by pressing the button "Open Database". Details of the database are given in a separate tutorial. Here, we select just one material, the EPCOS material "**N87**".

For each core material marked with a cross (+), a core loss database has been set up by Gecko-Simulations. The loss database stores losses per unit volume of a particular material at different operating points defined by the flux density ΔB, frequency f, temperature T, and DC bias H_{DC} at which the measurement is made. From these measurements, GeckoMAGNETICS interpolates the losses for an operating point simulated by the user.

Instead of selecting predefined cores, it is possible to select "customized" cores. In this case, ranges for dimensions can be defined, which allows finding the optimized dimension of one particular core shape.

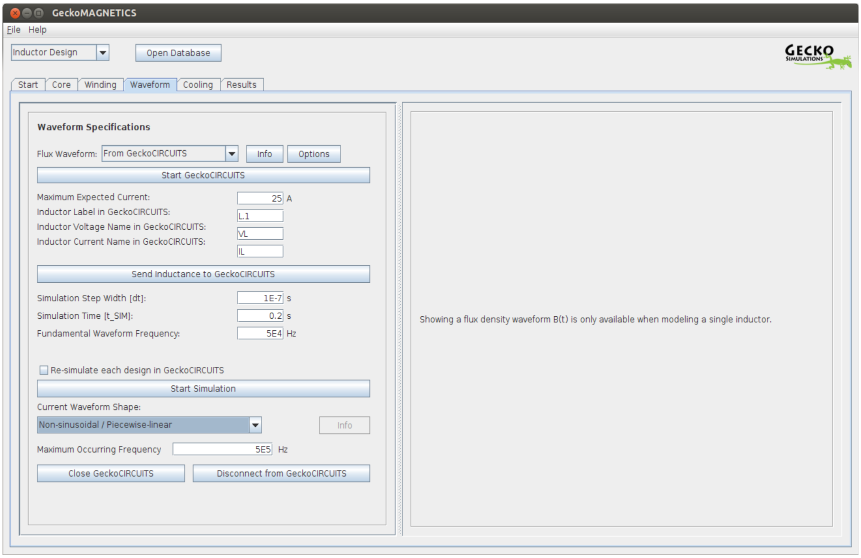


In a next step, we define the winding design space. First, one winding type is selected; in this example we choose “**Solid Round**”.

Winding materials are specified similar as core materials in the previous tab. Here, we select “Copper (drawn wire)”, which is the standard winding material in inductive components.

The number of turns is calculated by GeckoMAGNETICS in order to reach the (nominal) inductance given. The user has to specify the diameter of the windings or, as an alternative option, the tool can compute the diameter via a specified filling factor. Furthermore, a database with pre-manufactured windings is available. Again, with CTRL and SHIFT multiple selections are possible.

For our example, we use a fixed **filling factor of 0.3** which is a reasonable value.

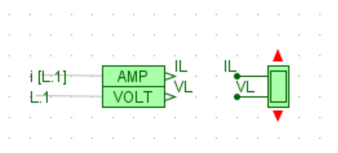


The user can choose between different standard waveforms, such as sinusoidal, triangular, or trapezoidal flux waveforms. However, the highest accuracy is achieved by setting up a link between Gecko-MAGNETICS and GeckoCIRCUITS (or any other circuit simulator).

GeckoCIRCUITS is a circuit simulator that allows a power electronic system to be described on a system level. GeckoCIRCUITS is distributed as an open-source project for free use without additional cost (for more information, visit us at www.gecko-simulations.com).

In the tab “Waveform”, we select “From GeckoCIRCUITS” and then press the button “Start GeckoCIRCUITS”. After GeckoCIRCUITS is started, we open the model “**GeckoMAGNETICS_buck.ipes**”.

The inductor as well as its current and voltage label has to be specified in the “Waveform” tab. For this, it is very important to have the scope labels specified properly in GeckoCIRCUITS, as shown below.



Note: to select more than one inductor in GeckoCIRCUITS, enter e.g. “L.1;L.2;L.3”.

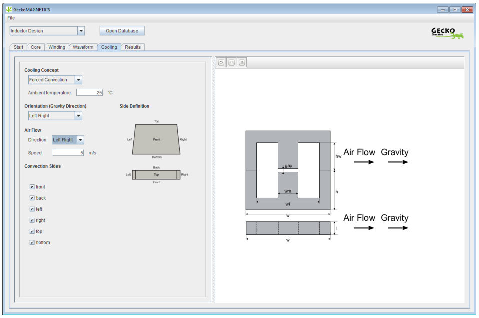
The maximum expected current is an important value in case a non-linear inductance is sent to GeckoCIRCUITS. The non-linear inductance within Gecko-CIRCUITS is then characterized up to this current. By default in design mode, the inductance that will be transferred to GeckoCIRCUITS is constant (linear); its value was specified before via the nominal inductance within the "Start" tab.

After the button "Send Inductance to GeckoCIRCUITS" has been pressed, some parameters that are related to the GeckoCIRCUITS settings have to be defined. In the case at hand, we are interested in the steady state behavior of our inductor. Steady state is reached after approximately 0.2 s; hence, we set the **simulation time to 0.2 s**. A **waveform frequency of 50 kHz (i.e. 50e3 Hz)** should be selected (since this is our switching frequency). The **simulation time step of 1e-7 s** is a good choice for this model. In case this value is too low, GeckoMAGNETICS becomes slow. On the other hand, if the value is too big, the results of GeckoCIRCUITS might become inaccurate.

The maximum occurring frequency defines up to which frequency the tool is taking current harmonics into account for the winding loss calculation. A frequency that is a factor ten higher than the switching frequency is a good choice in order to take the most important harmonics into account. Thus, the maximum occurring frequency is set to **5E5 Hz**.

If the check-box "Re-simulate each design in GeckoCIRCUITS" is active, each inductor design is simulated with its own non-linear current characteristics. This makes the modeling more accurate but slow. Normally it is sufficient to simulate with a constant inductance over the full current range.

The current waveform in the example should be defined as **"Non-sinusoidal / Piecewise-linear"**. After the button "**Start Simulation**" is pressed, GeckoCIRCUITS simulates the active model and the waveforms are read by GeckoMAGNETICS.



Another important aspect in the design phase of inductive components is the expected temperature of the component. This is not only important to avoid overheating; it is also of significance for the correct calculation of losses. Since losses are influenced by the temperature, a thermal model is indispensable for an accurate loss model.

In the tab "Cooling", the thermal boundary conditions can be defined. The user can choose between different options, here: natural convection, forced convection, and a fixed temperature (hence there is no thermal model included). Additionally, the inductor orientation, i.e. the gravity direction, as well as the air stream direction can be specified here.

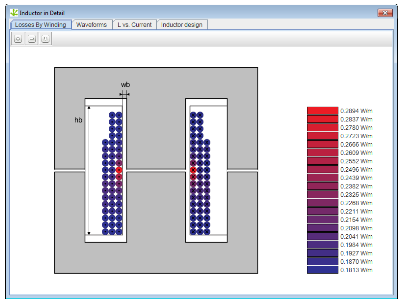
Please select "Forced Convection" with air speed of 5 m/s; the air flow direction and orientation are set to "Left-Right".

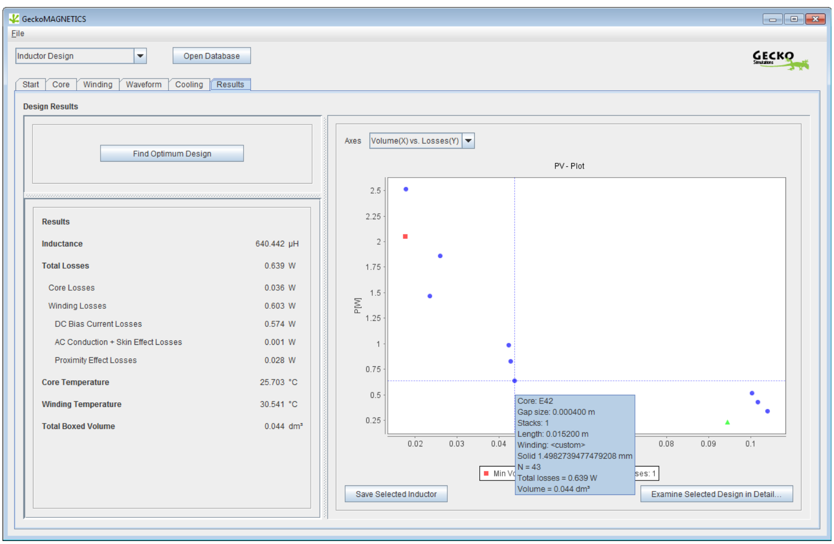
Now, all required information for a proper inductor design is defined and GeckoMAGNETICS can search for an optimized design.

Please press the button "**Find Optimum**" in the "Result" tab and wait until the calculation is finished.

In the graph "PV – Plot", all calculated designs are visualized in an "inductor power loss" vs. "inductor volume" graph (i.e. a pareto-plot). Depending on whether the aim of the optimization is more on reducing the volume or the losses, one would select a different design. A good compromise with moderate volume and losses is highlighted in the figure below.

By holding the mouse over of a design in the PV - Plot, a blue tooltip appears. The tooltip gives more detailed information about a specific inductor. Furthermore, by **double-clicking on a design**, more information shows up. For instance, the losses per winding, as shown in the figure below, are displayed. The increased losses due to the air gap stray field are clearly evident.





This tutorial has given a step-by-step introduction to the tool GeckoMAGNETICS. It has been demonstrated how a pareto-optimal inductor can be designed.

A particular focus was put on how to couple GeckoMAGNETICS with the Gecko-CIRCUITS power electronics simulator.

This tutorial example gives the reader a good starting point to GeckoMAGNETICS. Generally, the tool is designed to be as self-explanatory as possible. Nevertheless, if anything is unclear, or you would like to have a feature which is not available at the moment, please do not hesitate to contact us. Please also consider visiting our bug reporting platform

www.bugs.gecko-simulations.org

Contact Information / Feedback

Dr. Jonas Mühlethaler

Gecko-Simulations AG
Physikstrasse 3
CH-8092 Zürich, Switzerland

Phone +41-44-632 6576
Fax +41-44-632 1212

www.gecko-simulations.com
contact@gecko-simulations.com

Document version: March 2014