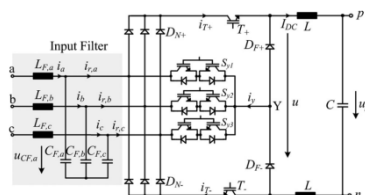


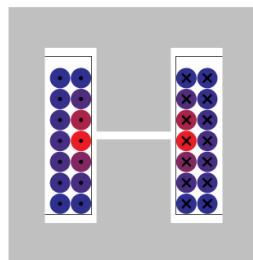
# Gecko Swiss Rectifier Optimizer

**FREE** Feature Demonstrator Application

Download at <http://www.gecko-simulations.com/apec2015>



**Circuit simulation**  
(electrical & thermal)



**Magnetic simulation**  
(with thermal model)

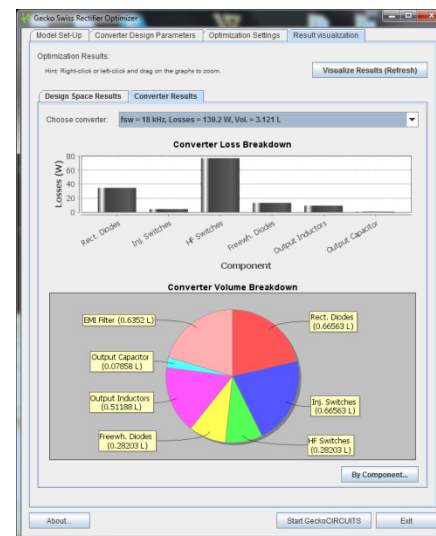
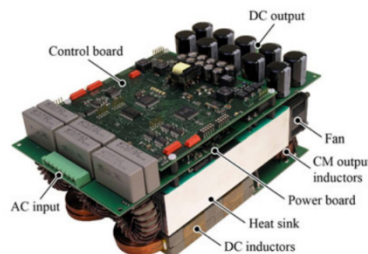
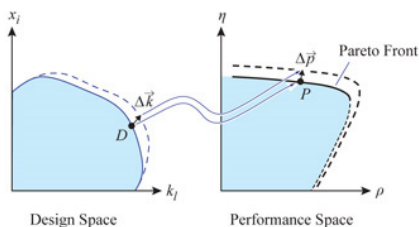


**Component Design Space**

**Optimization Algorithm**



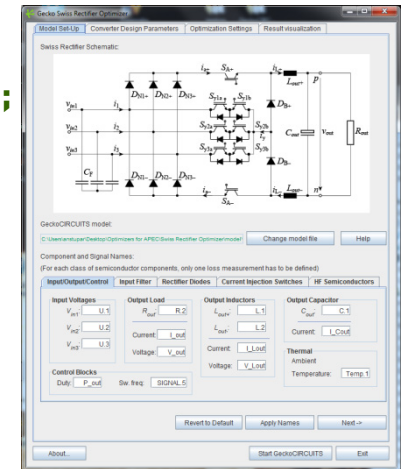
**Optimized Maximum-Efficiency Converter**



# Quick Introduction

The **Gecko PES Swiss Rectifier Optimizer** is a **free, feature demonstrator** Java application build on top of **GeckoCIRCUITS** and **GeckoMAGNETICS** for finding the highest efficiency Swiss Rectifier Design within a given design space:

- 1) It showcases **features in development** (e.g. converter optimization) that will become available in upcoming **Gecko-Simulations** products;
- 2) It demonstrates how custom applications can be built on top of **GeckoCIRCUITS** and **GeckoMAGNETICS**, to solve specific real-world problems in power electronics.



This is shown on the example of the **Swiss Rectifier**, a three-phase PFC rectifier topology developed at the Power Electronics Systems Laboratory at ETH Zurich:

The **Gecko PES Swiss Rectifier Optimizer** allows you to define a design space for each converter component, and then using evaluations through simulations and an optimization algorithm, it finds the maximum efficiency converter design.

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## IMPORTANT!

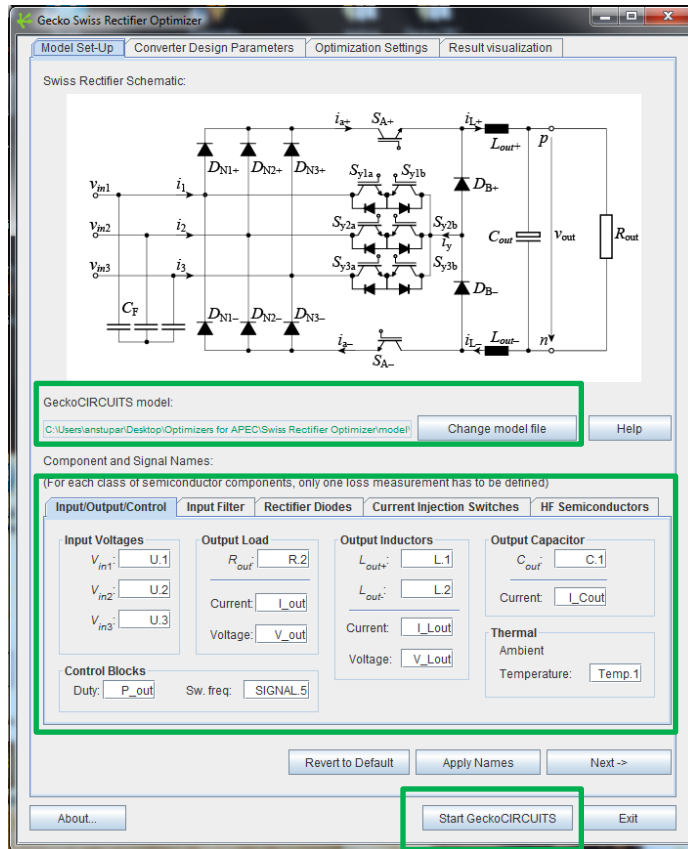
This presentation gives a Quick Introduction to using the Swiss Rectifier Optimizer. No detailed manual is supplied, since after this introduction using the program should be relative straight-forward and self-explanatory.

Also, “Help” buttons are available at almost every stage of the program’s interface, which give a more detailed explanation of the available options.

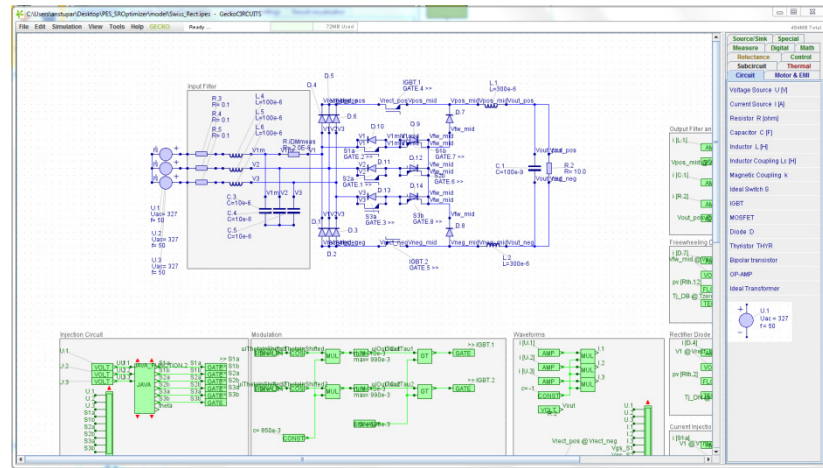
**BEFORE STARTING THE PROGRAM, please read the file README\_FIRST.txt**, supplied with the application and in the same directory as this presentation.

Feel free to send questions and comments to [andrija.stupar@gecko-simulations.com](mailto:andrija.stupar@gecko-simulations.com)

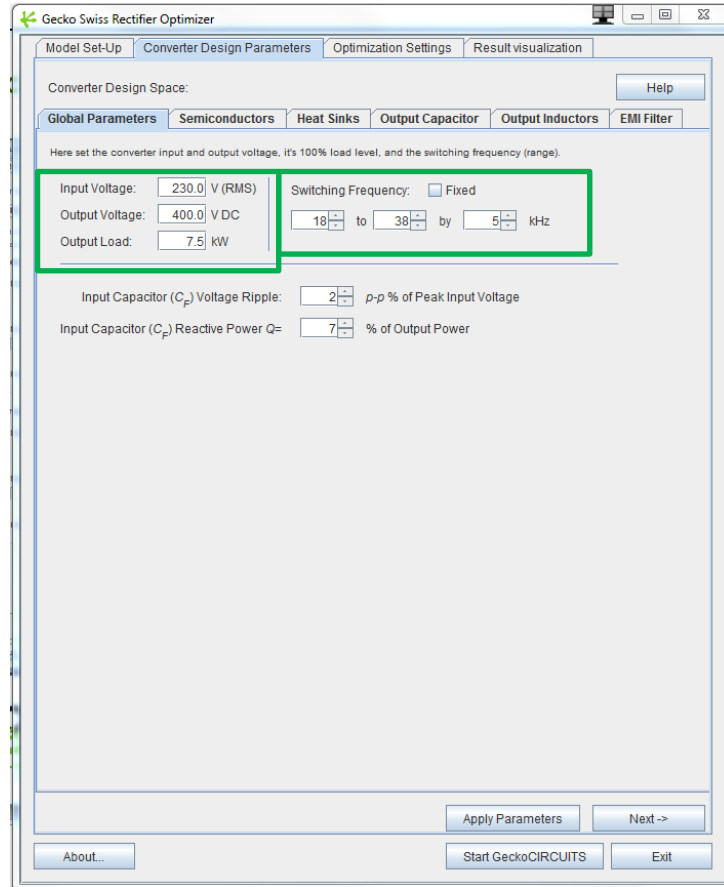
# Specifying the GeckoCIRCUITS Simulation Model



- The Optimizer uses a model of the Swiss Rectifier in **GeckoCIRCUITS** to extract electrical and thermal waveforms
- In the first tab (Model Set-Up), the names of the various **converter components** and **measurement signals** must be defined
- The default names work with the default supplied model – if using it, no change to the input field in this tab are necessary
- Click **“Start GeckoCIRCUITS”** to open the model



# Specifying the Design Space



- ▶ In the next tab (Converter Design Parameters), you are then guided, step-by-step, to define the design space of the converter
- ▶ Some parameters are fixed for each optimization (e.g. **input voltage**, **output load**, etc.)
- ▶ Most parameters (e.g. **switching frequency**) are variable, and you can specify a **range**, the **increment** for that range (e.g. frequencies from 18 to 50 kHz in increments of 2 kHz), or **fix** those parameters to one value

# Specifying the Design Space – Semiconductors

Gecko Swiss Rectifier Optimizer

Model Set-Up Converter Design Parameters Optimization Settings Result visualization

Converter Design Space: Help

Global Parameters Semiconductors Heat Sinks Output Capacitor Output Inductors EMI Filter

Here set the semiconductor devices to use, how many to parallel for each diode/switch, and the desired thermal resistance of the heat sink for each class of semiconductor device.

**Rectifier Diode Selection**

Device: DSEI30-12A View Properties

Number in parallel: 1 to 5 Fixed

Heat sink  $R_{th}$ : 2.5 K/W

**Current Injection Switch Selection**

Device: IHW40T120 View Properties

Number in parallel: 1 to 5 Fixed

Heat sink  $R_{th}$ : 2.5 K/W

**Freewheeling Diode Selection**

Device: C2D20120D View Properties

Number in parallel: 1 to 5 Fixed

Heat sink  $R_{th}$ : 1.9 K/W

**High-Frequency Switch Selection**

Device: IKW40T120 View Properties

Number in parallel: 1 to 5 Fixed

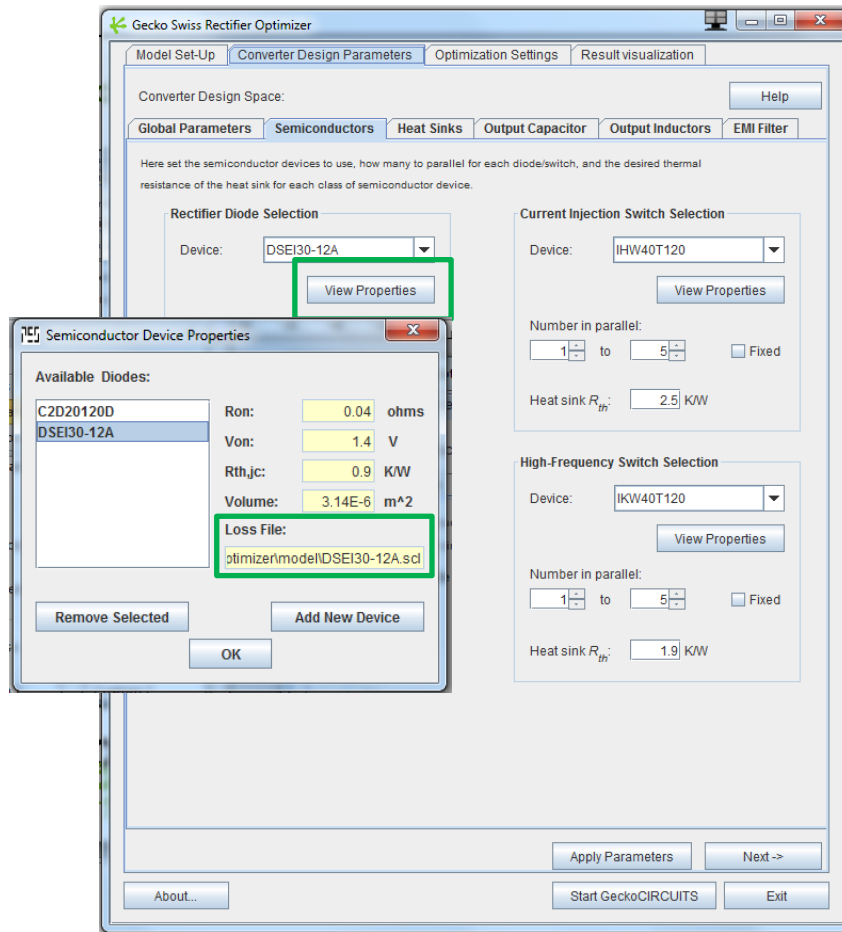
Heat sink  $R_{th}$ : 1.9 K/W

Apply Parameters Next ->

About... Start GeckoCIRCUITS Exit

- ▶ You can select from a list of available diodes or switches, for each class of semiconductor device in the rectifier
- ▶ The variable parameter is the number of devices used in parallel to implement each switch or diode (increment is by 1)
- ▶ You must specify a thermal resistance of the heat sink for each device. Note: this is the thermal resistance of the “piece of heat sink” under each particular device, i.e. if there are 5 switches in parallel, it is the thermal resistance under each of the five switches (so the total underneath all 5 is the single resistance divided by 5)

# Specifying the Design Space – Semiconductors



- ▶ You **must** give a **reasonable thermal resistance value**, otherwise temperatures (and losses) will be unrealistically high or unrealistically low
- ▶ By clicking on “**View Properties**”, the detailed properties of the selected semiconductor are shown – here you can examine all the devices available by default and compare their basic properties, and add new devices of your own
- ▶ **NOTE:** newly added devices are **not** saved to disk (when you close the program, they disappear)
- ▶ Each device **MUST** have a **GeckoCIRCUITS loss file (.scl)**

# Specifying the Design Space – Heat Sinks

Gecko Swiss Rectifier Optimizer

Model Set-Up Converter Design Parameters Optimization Settings Result visualization

Converter Design Space:

Global Parameters Semiconductors Heat Sinks Output Capacitor Output Inductors EMI Filter

Heat Sink Performance:

Cooling System Performance Index:

The CSPI is used, coupled with the desired heat sink thermal resistance, the heat sink volume, and from that, taking into account the material properties, the heat sink thermal capacitance.

Ambient Temperature:

$T_{amb}$ : 25 °C

Heat Sink Material Volumetric Heat Capacity:

Default value is Aluminium

CSPI: 21

$C_v$ : 2.422 J/(cm<sup>3</sup>K)

The above values are common for all heat sinks in the system. The thermal resistance for each heat sink is set in the 'Semiconductors' tab. The default CSPI value is a theoretical near-maximum for aluminium heat sinks, see U. Drofenik, J. W. Kolar, "Thermal Density Barriers of Converter Systems," CIPS 2008.

Apply Parameters Next ->

About... Start GeckoCIRCUITS Exit

- ▶ For the **heat sink**, a **cooling system performance index (CSPI)** and a **volumetric heat capacity** of the material must be specified
- ▶ The **CSPI** is used to calculate the heat sink **volume** using the specified **thermal resistances** from the previous tab – therefore, a different (separate) heat sink is assumed for each class of semiconductors
- ▶ The **volumetric heat capacity** is then used with this calculated volume to calculate **the thermal capacitance** of the heat sink (which goes into the simulation model)
- ▶ Fans are not considered (i.e. their losses), the effect of the fan is assumed accounted for by the **CSPI**



# Specifying the Design Space – Output Capacitor

Gecko Swiss Rectifier Optimizer

Model Set-Up | Converter Design Parameters | Optimization Settings | Result visualization

Converter Design Space:

Global Parameters | Semiconductors | Heat Sinks | Output Capacitor | Output Inductors | EMI Filter

The output capacitor value is calculated based on the output voltage ripple requirements.  
For calculating losses, specify the parameters below. If there is no leakage current, set the coefficients to zero.

Maximum Output Voltage Ripple:  
 $V_{out,p-p} = 300 \text{ mV}$

Capacitor Losses:

ESR Characteristic:  
 $\tan(\delta) = 0.24$

Leakage Current Characteristic:  
 $I_{leak} (\mu A) = a * C_{out} (\mu F) * V_{out} + b$   
 $a = 0.02$   
 $b = 25$

Capacitor Volume:  
Capacitance per volume =  $2.338 \text{ F/m}^3$

To derive the above value, take the capacitor component you plan to use for the converter, and divide its capacitance by its total volume.

Apply Parameters | Next -> | About... | Start GeckoCIRCUITS | Exit

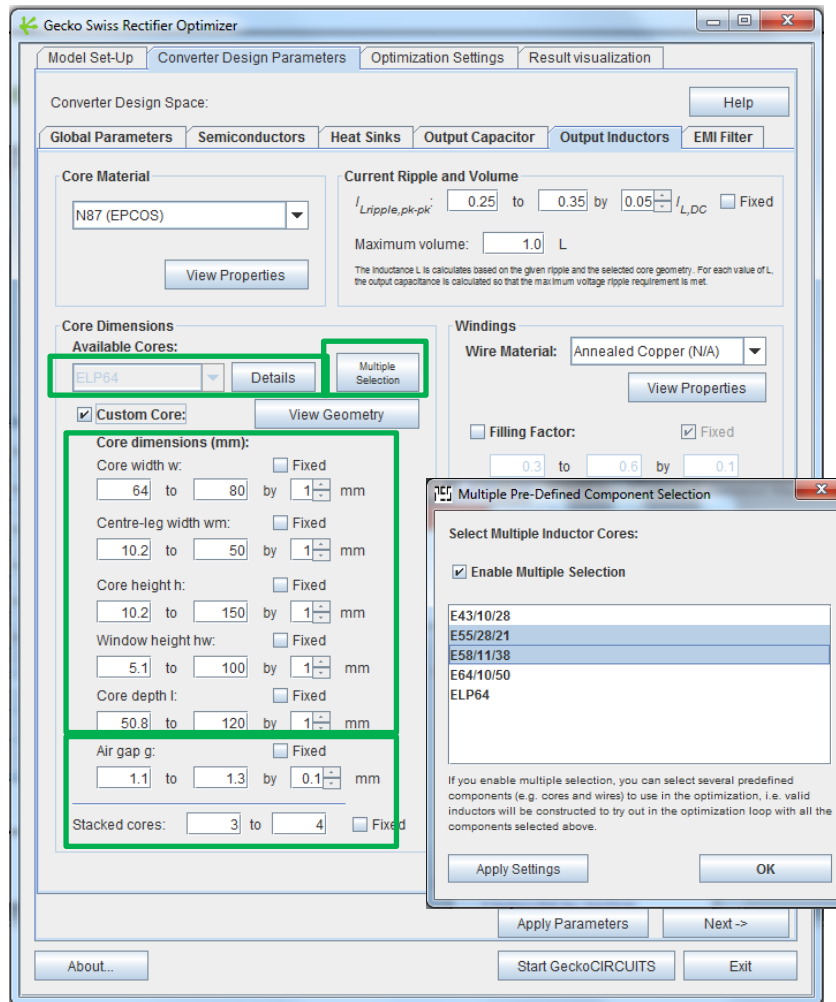
- ▶ Here a very important parameter is specified – **maximum output voltage ripple**
- ▶ Furthermore a **tan-delta factor** can be specified for **conduction losses**, and a simple (not really universal) model for **leakage current losses** is also specifiable
- ▶ A **volumetric constant** must be supplied in order to calculate the **volume** once the capacitance is calculated
- ▶ Capacitance is calculated from the voltage and current ripple specification

# Specifying the Design Space – Output Inductors

The screenshot shows the 'Gecko Swiss Rectifier Optimizer' window with the 'Output Inductors' tab selected. The 'Converter Design Space' section includes tabs for Global Parameters, Semiconductors, Heat Sinks, Output Capacitor, Output Inductors, and EMI Filter. The 'Core Material' dropdown is set to 'N87 (EPCOS)'. The 'Current Ripple and Volume' section shows a range for  $I_{L_{ripple, pk-pk}}$  from 0.25 to 0.35 by 0.05, with a fixed  $I_{L_{DC}}$  and a maximum volume of 1.0 L. The 'Core Dimensions' section lists available cores (ELP64) and core dimensions (mm) for width, height, and depth, all set to fixed values. The 'Windings' section shows 'Wire Material' as 'Annealed Copper (N/A)' and 'Type' as 'Solid Wire'. The 'Available Wires' section lists 'AWG10' and 'Custom Wire' options. The 'View/Set Thermal Properties' button is visible at the bottom.

- ▶ The most different parameters to set are for the output inductor design
- ▶ Here you can select a **core material** – several are offered – this choice is a fixed parameter
- ▶ The main parameter for inductor design is the **current ripple** – this can be specified as a range, and in turn determines the required inductance  $L$
- ▶ A **maximum allowed volume** must also be specified

# Specifying the Design Space – Output Inductors



- **Cores:** Only EE-Cores with three air gaps are available
- You can select a **predefined core** from the drop-down list, or define a **custom core** by defining a value range for each core dimension parameter
- Besides setting ranges for a custom EE-Core geometry, you can also do a **multiple selection of predefined cores**, so that the program tries out all of them
- Whether using predefined cores or a custom core, you must define the **air gap range and the number of stacked cores** (also variable)

Gecko Swiss Rectifier Optimizer

Model Set-Up Converter Design Parameters Optimization Settings Result visualization

Converter Design Space: Help

Global Parameters Semiconductors Heat Sinks Output Capacitor Output Inductors EMI Filter

**Core Material**

N87 (EPCOS) View Properties

**Current Ripple and Volume**

$I_{Lripple, pk-pk}$ : 0.25 to 0.35 by 0.05  $I_{DC}$  ☐ Fixed

Maximum volume: 1.0 L

The inductance L is calculated based on the given ripple and the selected core geometry. For each value of L, the output capacitance is calculated so that the maximum voltage ripple requirement is met.

**Core Dimensions**

Available Cores:

ELP64 Details Multiple Selection

☐ Custom Core: View Geometry

**Core dimensions (mm):**

Core width w: ☒ Fixed  
64 to 80 by 1 mm

Centre-leg width wm: ☒ Fixed  
10.2 to 50 by 1 mm

Core height h: ☒ Fixed  
10.2 to 150 by 1 mm

Window height hw: ☒ Fixed  
5.1 to 100 by 1 mm

Core depth l: ☒ Fixed  
50.8 to 120 by 1 mm

Air gap g: ☐ Fixed  
1.1 to 1.3 by 0.1 mm

Stacked cores: 3 to 4 ☐ Fixed

**Windings**

Wire Material: Annealed Copper (N/A) View Properties

☐ Filling Factor: ☒ Fixed  
0.3 to 0.6 by 0.1

Type:

☐ Solid Wire ☒ Litz Wire

Available Wires: PF AWG38 10 Multiple Selection Details

☒ Custom Wire: View Geometry

Conductor diameter: Total diameter:  
d: 2.6 mm d: 0.5 mm

Isolation thickness: Strand diameter:  
s: 0.0444 mm di: 0.1 mm

Number of strands:  
n: 10

View/Set Thermal Properties

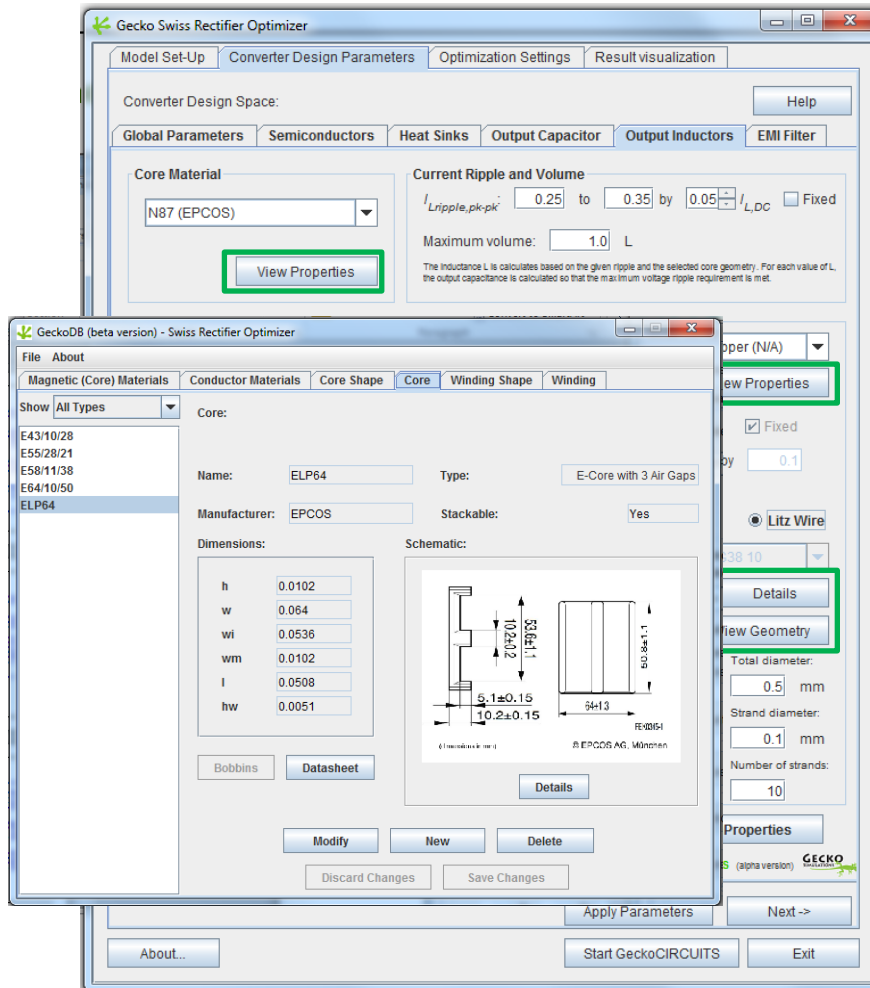
Powered by **GeckoMAGNETICS** (alpha version)

Apply Parameters Next ->

About... Start GeckoCIRCUITS Exit

- GECKO**  
SIMULATIONS
- 

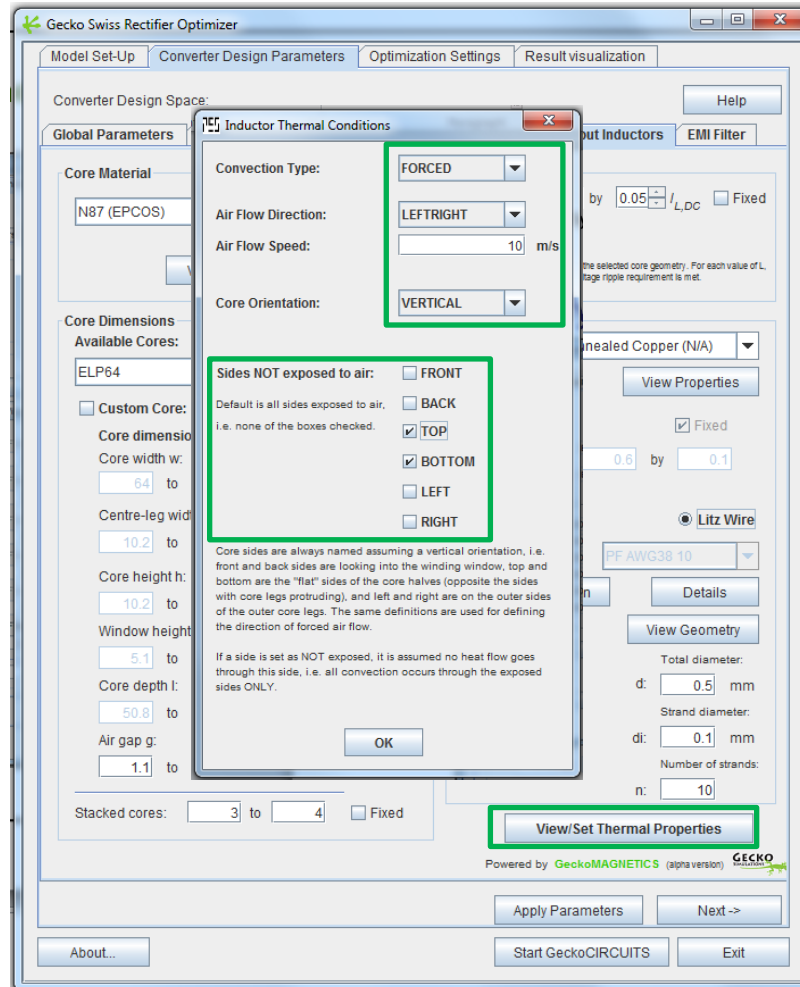
# Specifying the Design Space – Output Inductors



- Whenever you click on a “View Geometry” or “View Properties” button, the magnetic component database - **GeckoDB** - opens up

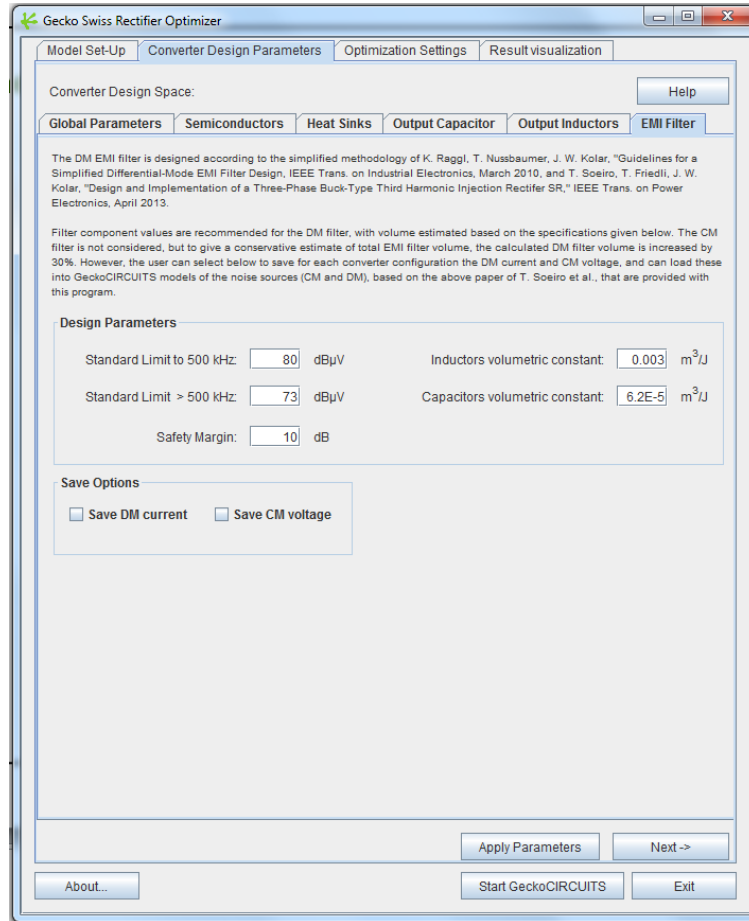
- Here you can define **your own core and wire sizes and core materials** – any changes or additions to make are **saved to disk** and are available next time you start the program

# Specifying the Design Space – Output Inductors



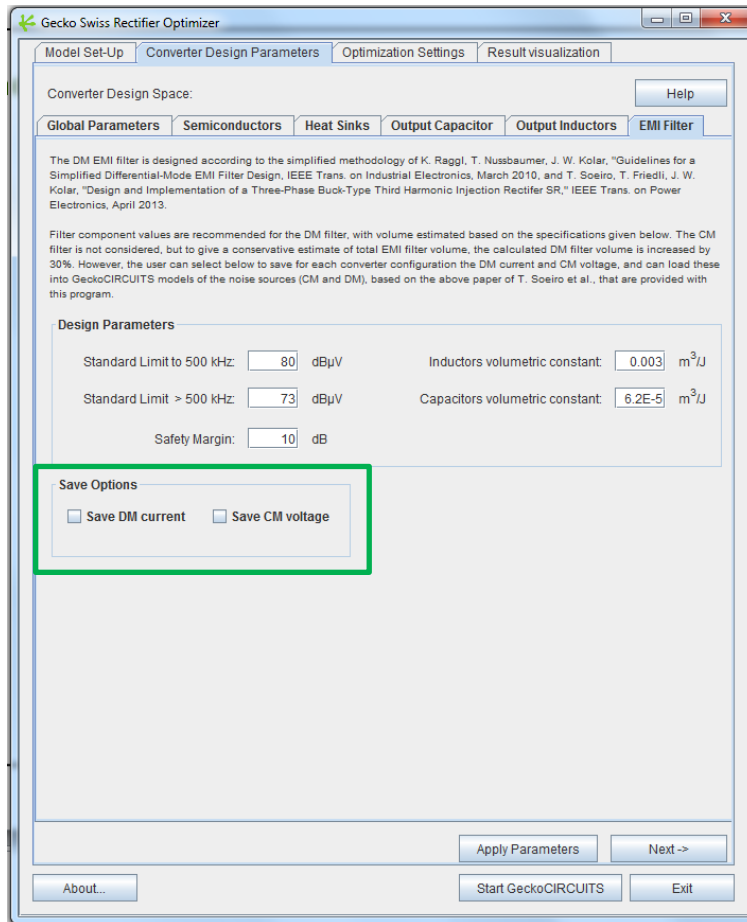
- ▶ The **thermal properties** are set in a separate window by clicking on the lower-right button
- ▶ You can select the **type of convection** (**natural** or **forced** – and if forced, at which **air speed** and in which **direction of airflow**), the **orientation** of the core with respect to gravity, and which of the sides are **exposed** to air flow
- ▶ Thermal model is only stationary (resistances, no capacitances)
- ▶ Sides not exposed to air are assumed to transfer no heat
- ▶ Volume or losses of the fan blowing if forced convection is selected are not taken into account at this point

# Specifying the Design Space – EMI Filter



- ▶ For the **EMI filter**, you can specify the **limits** of the standard being used, the **safety margin** for the attenuation, and the **volumetric constants** of the inductors and capacitors that are to be used for the filter
- ▶ After a converter is **optimized at a certain switching frequency**, from simulation data of the **differential mode current** the required **attenuation** is calculated
- ▶ From this attenuation, a **two-stage LC input DM** EMI filter is calculated, with the volume calculated based on the volumetric constants
- ▶ **CM filter** is **not** calculated; volume of DM filter is increased by 30% to approximate the effect of the CM filter on total volume
- ▶ **DM filter LC values (1<sup>st</sup> and 2<sup>nd</sup> stage)** are given in the Output Window and in the output file at the end of the optimization

# Specifying the Design Space – EMI Filter

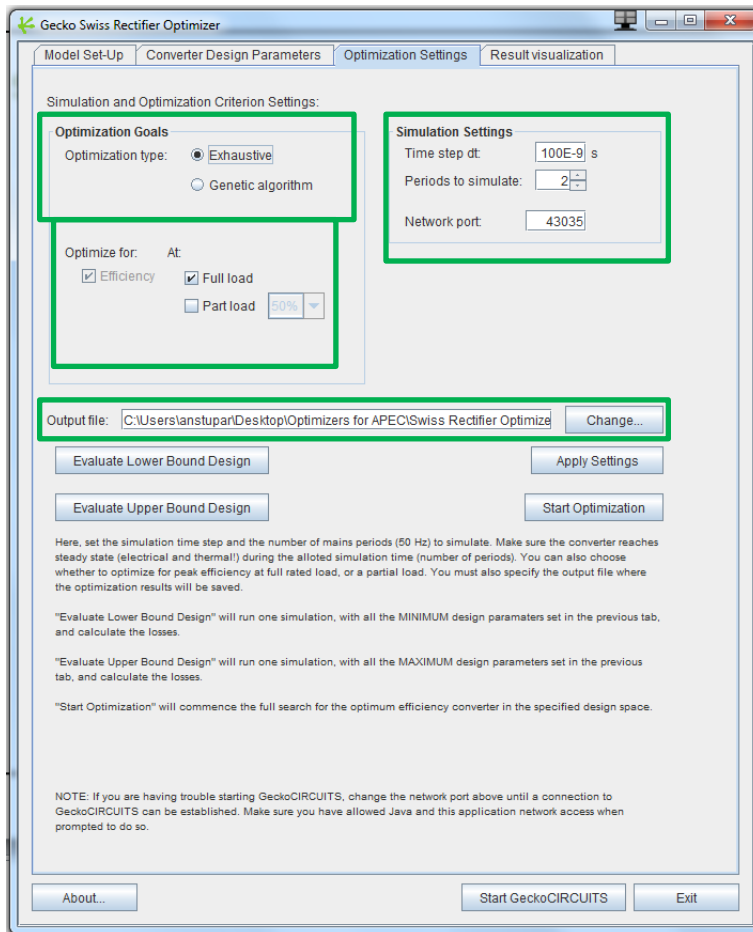


- To perform a **detailed optimization of the EMI filter** for a particular efficiency optimized converter design, including all losses and the **CM filter** design, select the options to **save the DM current and CM voltage**

- Then load these saved waveforms into the Swiss Rectifier CM and DM noise models supplied with this program and load them into the **Gecko Three-Phase EMI Filter Optimizer**



# Optimization Settings



► Here you must specify:

The **output file** to which the optimization results will be written

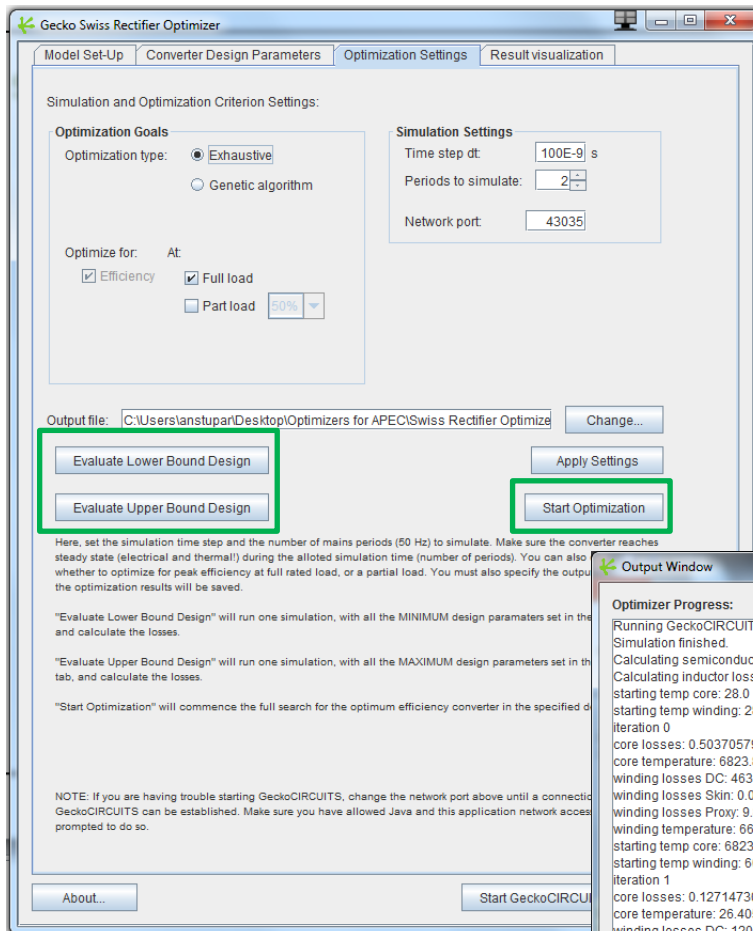
**Simulation settings:** the time-step and the number of periods to simulate (make sure the circuit is in **steady-state** in the last simulated period)

Whether to optimize for **full** or **partial** output load

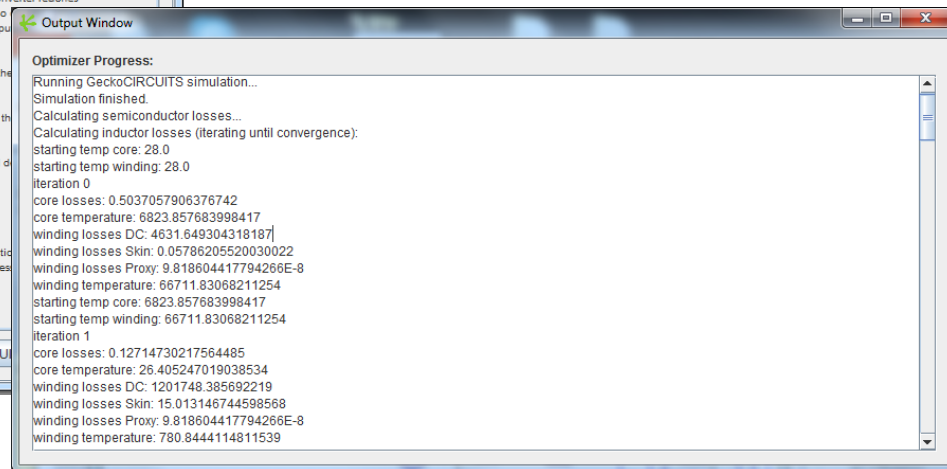
**Optimization algorithm:** exhaustive (brute-force) or genetic

The usage of the **genetic algorithm** is recommended for large design spaces

# Optimization Settings

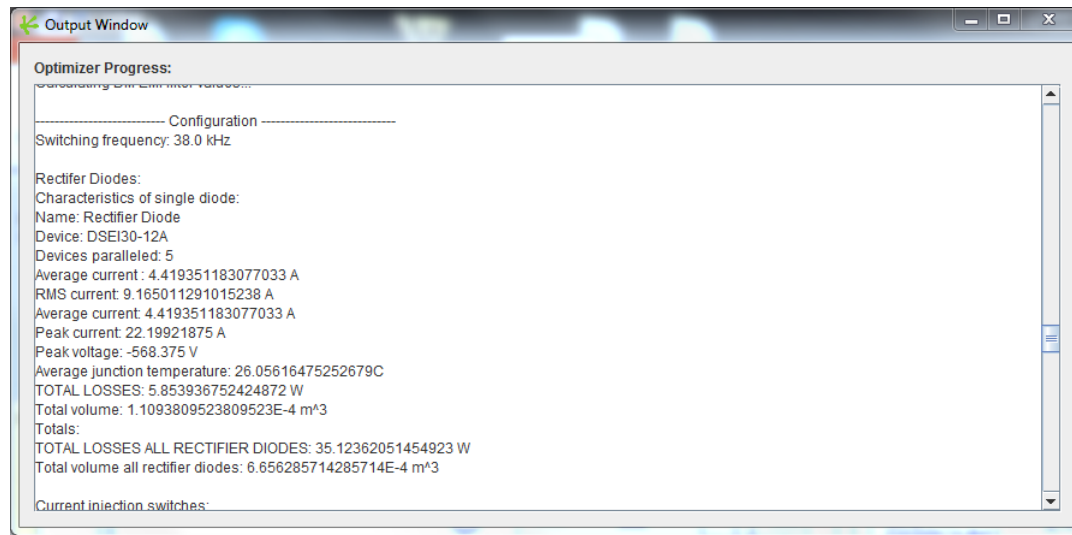


- “Evaluate Upper/Lower Bound Design” runs **one** simulation, and gives the breakdowns of the losses and volume – the **upper bound** takes all the **maximum** defined values of the variable parameters, and the **lower bound** all the **minimum** defined values of those parameters
- “Start Optimization” will start the full optimization and open the **Output Window** in which you can monitor the Optimizer’s progress



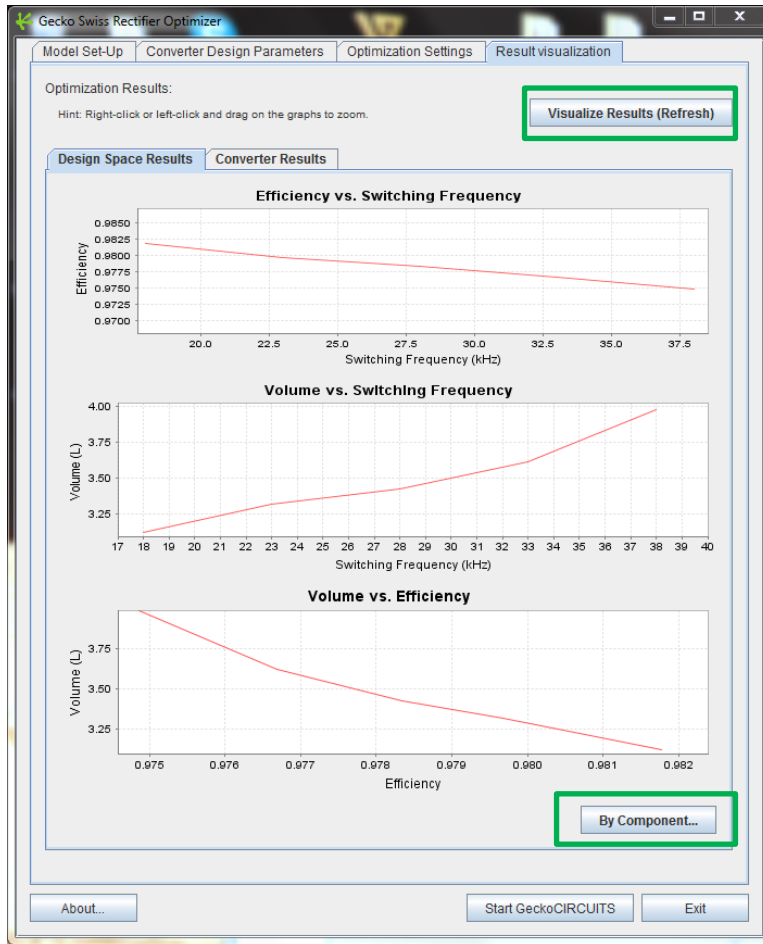
# Optimization Results

- At the end, for each switching frequency, the maximum efficiency design is specified in the Output Window
- Given are all the component values, which components to use and how many (how many diodes and switches to place in parallel, how many cores of which size, turns of which wire, etc).



- The same information is written to the output file you have previously specified

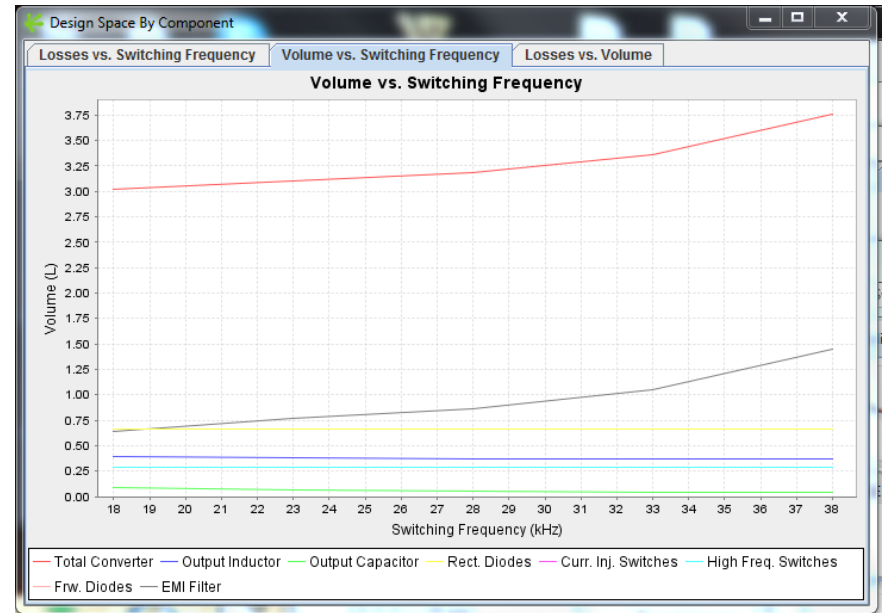
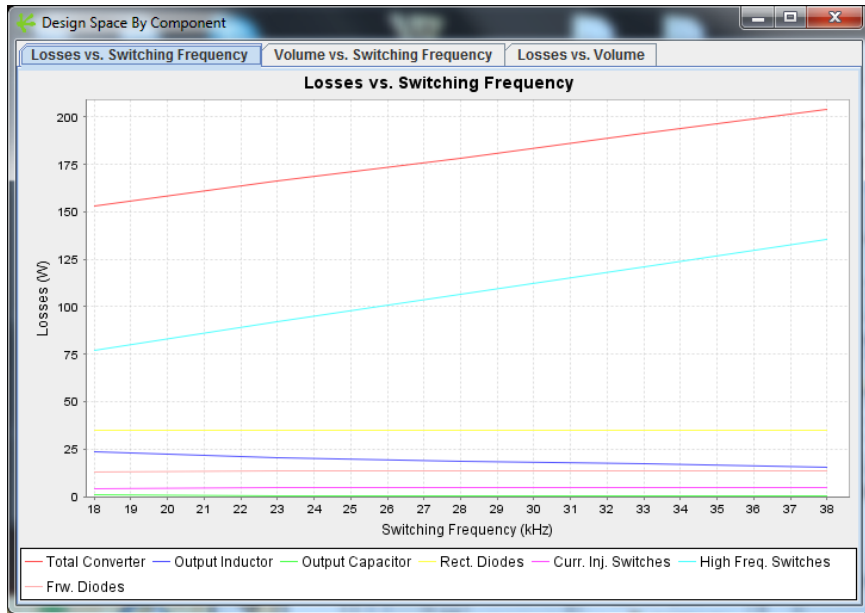
# Visualization of Results – Design Space



- ▶ When the optimization finishes, click **“Visualize Results (Refresh)”** in the Result visualization tab to see plots and graphs of the resulting designs
- ▶ The **“Design Space”** visualization gives the key characteristics of the efficiency-optimized converters over the switching frequency range
- ▶ Clicking **“By Component”** ...

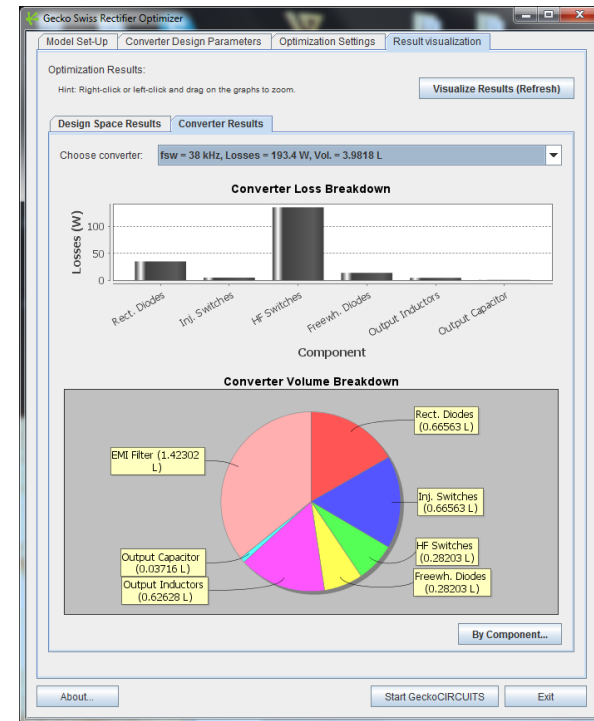
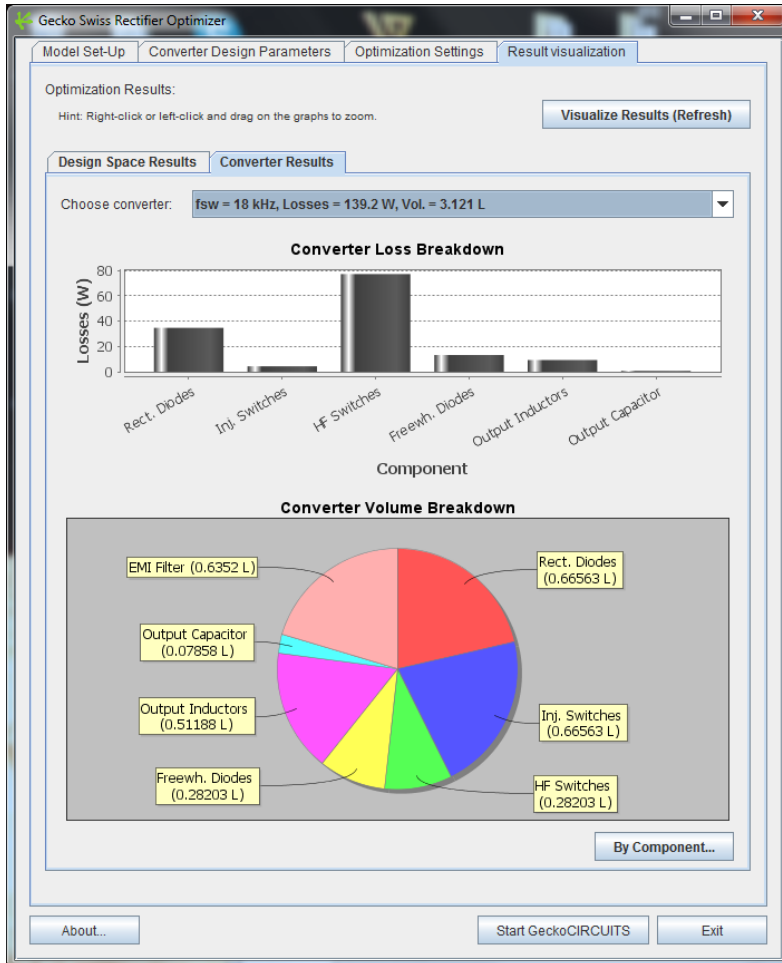
## Visualization of Results – Design Space

... will show the same plots, but broken down by component type, so you can see how the design of e.g. the inductor moves over frequency



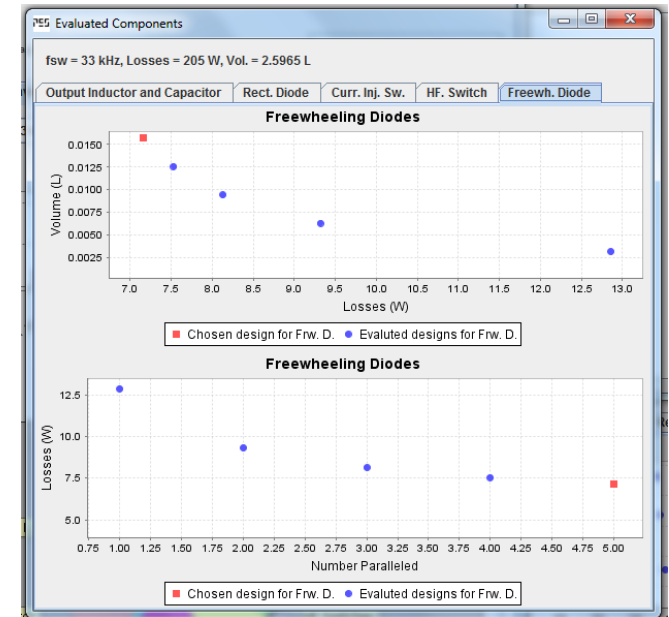
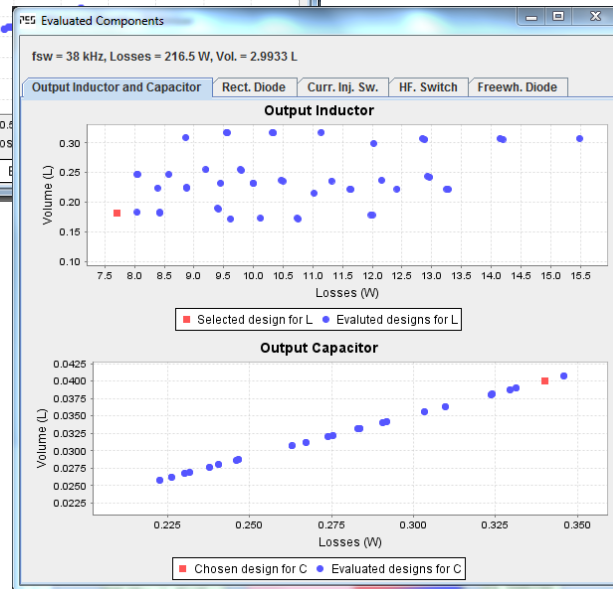
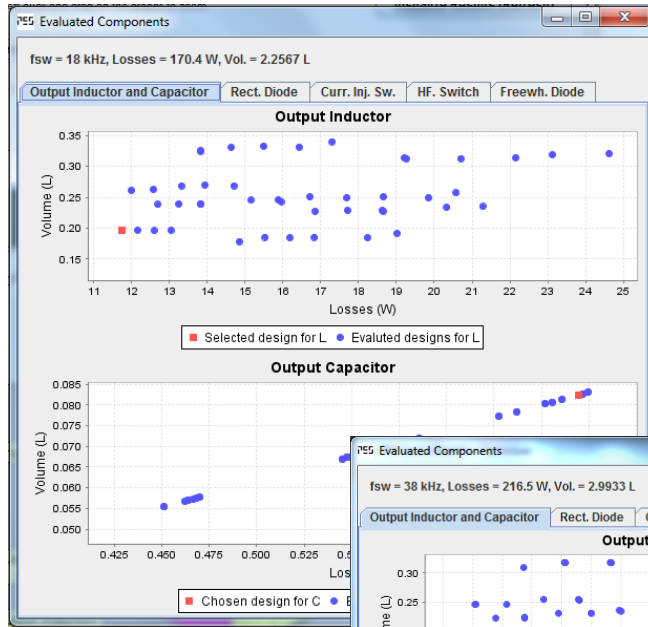
# Visualization of Results – Converter Results

- The “**Converter Results**” visualization gives **loss and volume breakdown by component** for the optimum-efficiency converter **at each frequency**



# Visualization of Results – Converter Results

- ▶ Clicking “By Component” gives, for that switching frequency, all the designs evaluated for a particular component (e.g. all inductors simulated) in a loss vs. volume plot, and shows also the selected (optimum) design



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