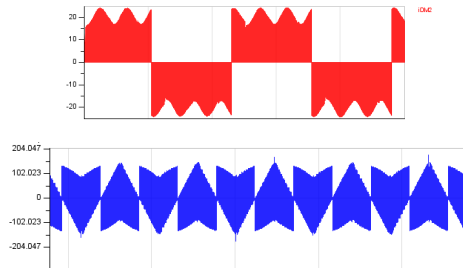


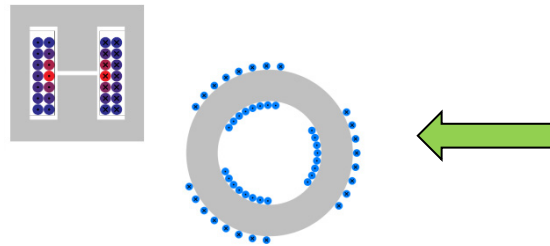
Gecko Three-Phase EMI Filter Optimizer

FREE Feature Demonstrator Application

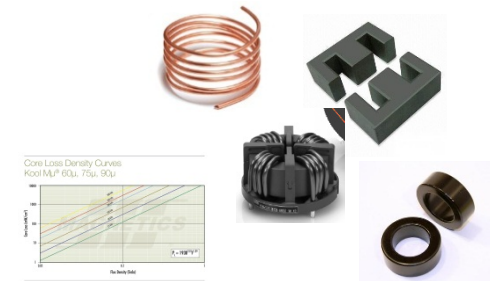
Download at <http://www.gecko-simulations.com/apec2015>



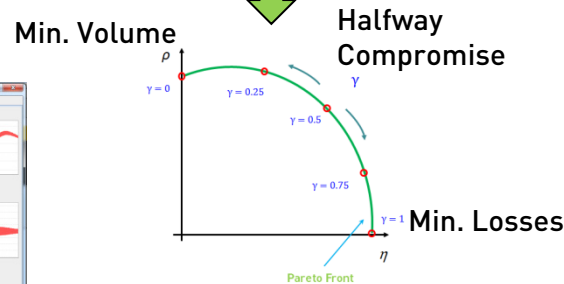
Circuit simulation
DM Current – DM Noise
CM Voltage – CM Noise



Magnetic simulation
(with thermal model)



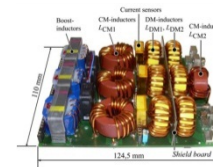
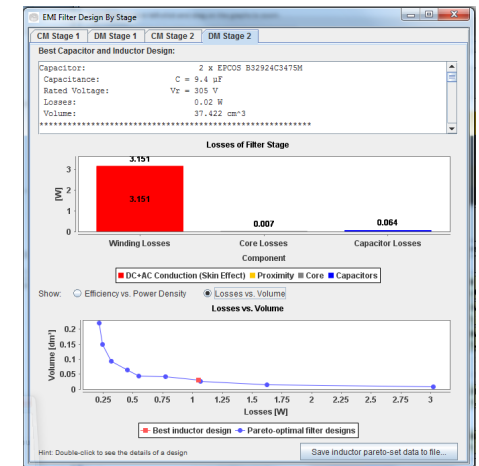
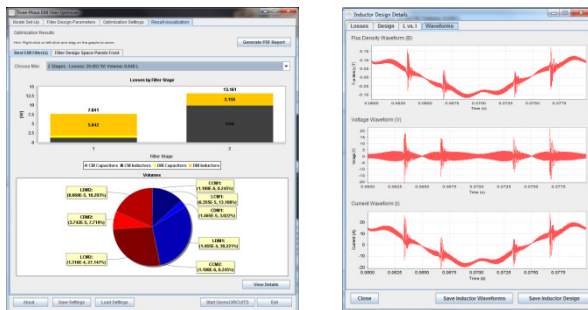
Component Design Space



Optimization Goal

Optimization Algorithm

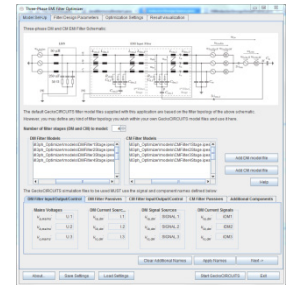
Multi-Objective Optimized Filter Design



Quick Introduction

The **Gecko Three-Phase EMI Filter Optimizer** is a **free, feature demonstrator** Java application build on top of **GeckoCIRCUITS** and **GeckoMAGNETICS** for finding the optimal EMI filter design with respect to **efficiency** and **power density** within a given design space:

- 1) It showcases **features in development** (e.g. filter 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.



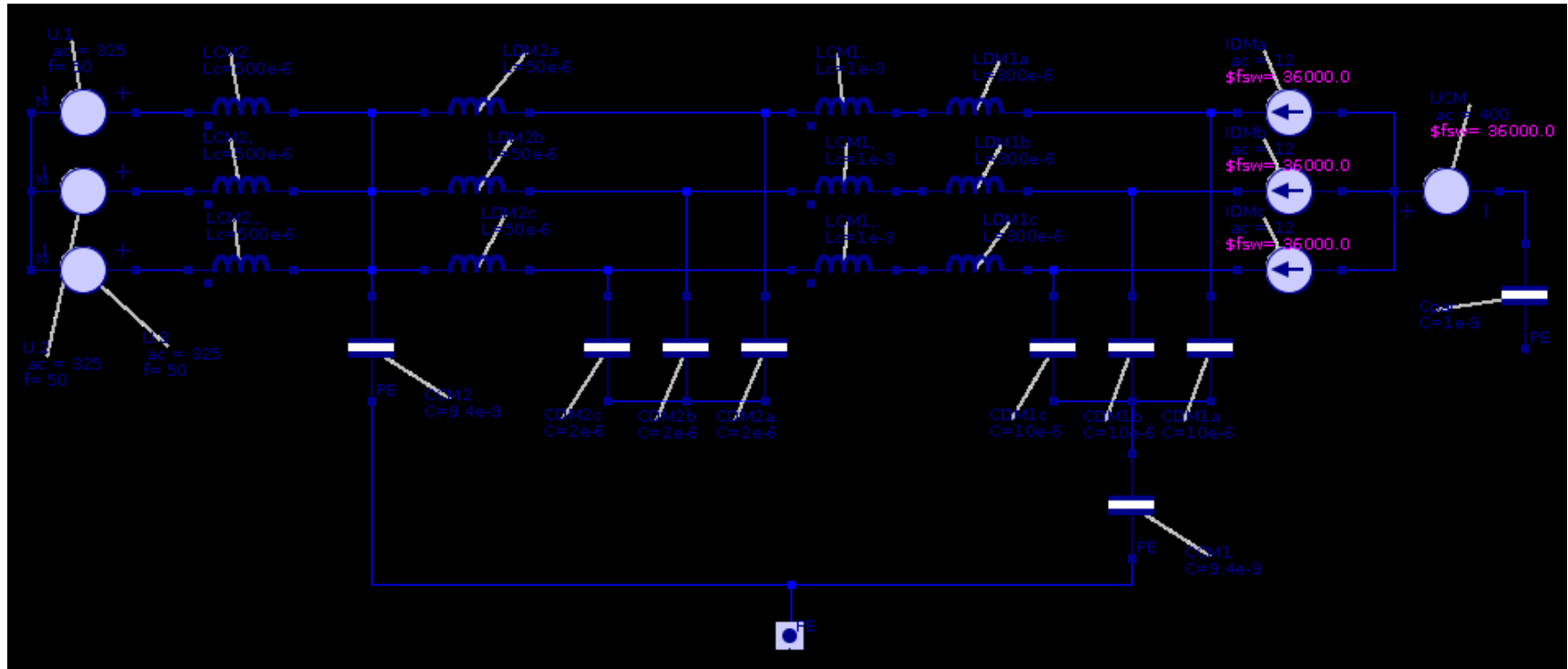
The **Gecko Three-Phase EMI Filter Optimizer** allows you to define a design space for each filter component, and then using evaluations through simulations and an optimization algorithm, it finds the best design according to your design goal, i.e. your defined compromise between efficiency and power density.

Optimizer Tool for Three-Phase EMI Filters

- ▶ Can be used for any three-phase converter topology (you must build appropriate noise models in GeckoCIRCUITS)
- ▶ Multiobjective optimization of an EMI filter for power density (volume) and efficiency (losses)
- ▶ Always calculates set of pareto-optimal designs, and then picks from this set based on optimization goal
- ▶ Gives LC values, attenuation distribution, and components to build inductors and capacitors from based from a list of real components in its database

EMI Filter Modeling

- The Optimizer uses a mostly fixed *LC-LC* filter topology:



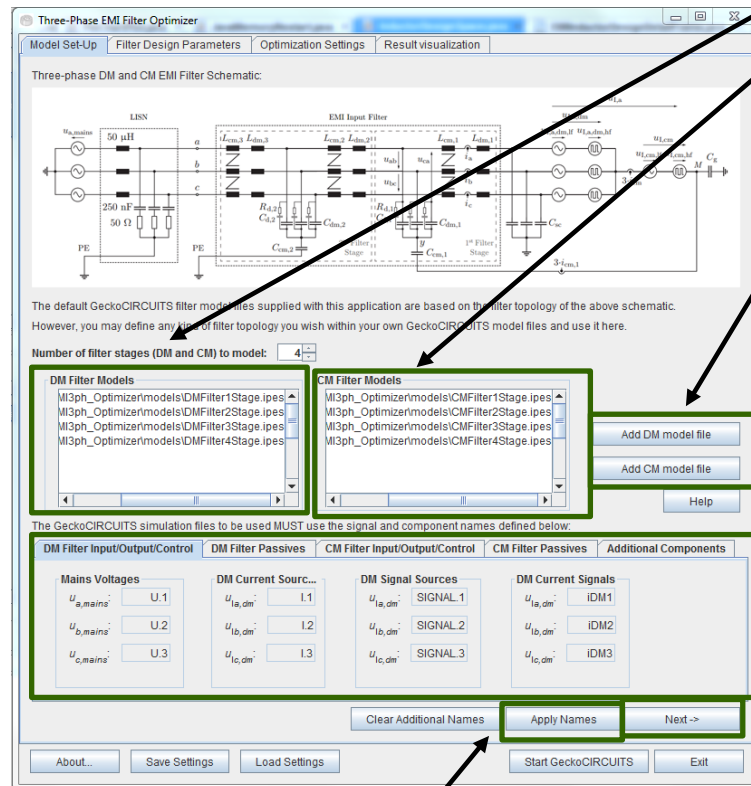
- You can select whether CM and DM capacitors are in series or not

Starting the Optimizer

1. Unzip the downloaded Optimizer package on your computer.
2. Open the newly created directory.
3. On Windows and Linux, double-clicking StartOptimizer.jar should start the program. IF this does not work, open a terminal (console), go to the directory and type `java -jar StartOptimizer.jar`
4. If you still have problems, please consult the **User's Manual** on how to start the program manually.
5. Within a few seconds, the main optimizer window should open.

EMI Filter Circuit Simulation Models

- First tab of window – model set up



Sample models up to 4 filter stages are provided

You can add your own models from GeckoCIRCUITS

Circuit simulation models for GeckoCIRCUITS must use the element names shown here

Click “Next” to see all required elements names in simulation models, and also to define additional components (see next slide)

Click “Apply Names” when finished with this screen

EMI Filter Circuit Simulation Models

- By default, the Optimizer considers only the filtering elements (inductor and capacitors)
- However, the user can define additional components to use in the models (e.g. **damping elements**)

DM Filter Input/Output/Control DM Filter Passives CM Filter Input/Output/Control CM Filter Passives **Additional Components**

Here you can define the names of components in your own custom filter models, if you are not using the supplied default models.

DM Filter Single Elements	DM Filter Per Stage Elements	CM Filter Single Elements	CM Filter Per Stage Elements
LLISNa CLISNa RLISNb LLISNB	Rdamp Cdamp	Cxy	

The names of "per stage" elements are automatically appended by the stage number to get a particular name, e.g. Rdamp1.

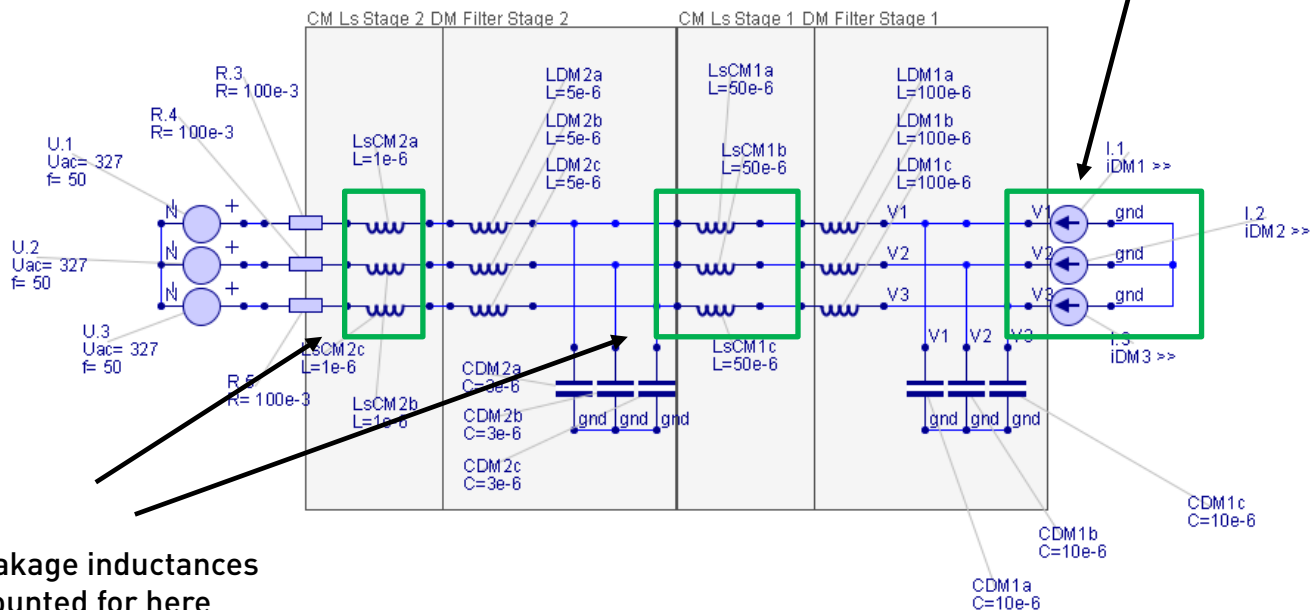
Clear Additional Names Apply Names Next ->

- This is done in the last sub-tab of the Model Set-Up screen
- For more details, see the [User's Manual](#)

EMI Filter Circuit Simulation Models

- Click “Start GeckoCIRCUITS” and the simulation models will open
- **DM noise** simulation model:

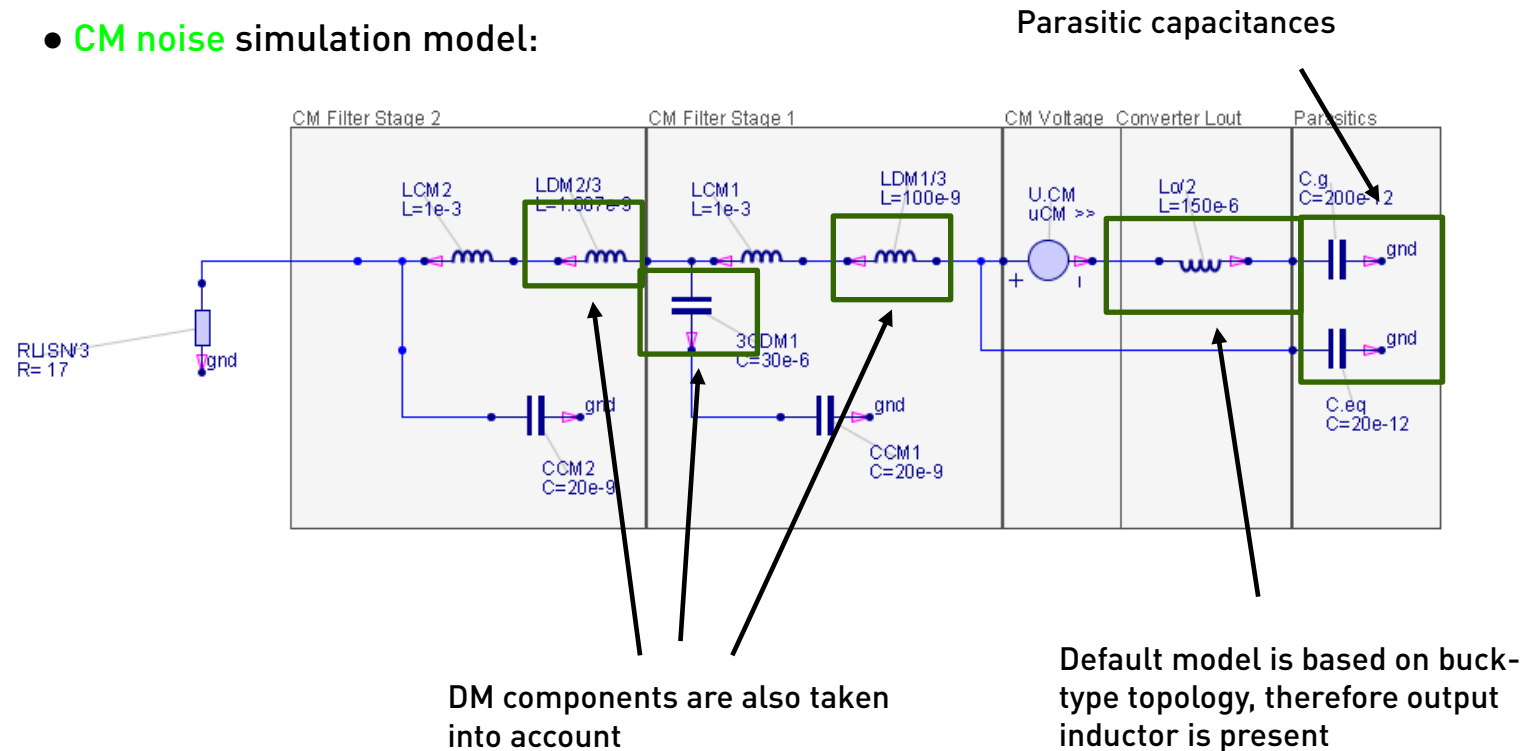
Converter modelled as current source (all three phases, properly phase shifted!)



CM choke leakage inductances are also accounted for here

EMI Filter Circuit Simulation Models

- CM noise simulation model:



For more details on the CM model, please see the [User's Manual](#)

EMI Filter Global Parameters

- “Global Parameters” tab:

Three-Phase EMI Filter Optimizer

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

EMI Filter Design Space:

Global Parameters | DM Inductors and Capacitors | CM Inductors and Capacitors | Parasitics & Additional Components

Here set the filter design frequency, number of stages to consider, required attenuation or noise level and desired EMC standard.

Number of stages: to ☐ Fixed Ambient temperature: °C

Design Frequency

Specify: ☒ Design Frequency ☐ Converter Switching Frequency $f_D =$ kHz

Filter Design Goal

Specify: ☐ Desired Attenuation ☒ Noise and Limits

DM Attenuation: dB CM Attenuation: dB

DM Noise: dBuV CM Noise: dBuV

Emissions standard:

Given are Quasi-Peak worst-case values, generally valid for < 1 MHz. For exact values, especially for > 1 MHz, consult the relevant literature and use the "Custom" option to set the limits manually.

Standard Limit to 500 kHz: dBuV

Standard Limit > 500 kHz: dBuV

Safety Margin: dB

Here set the mains voltage and the converter (output) inductance. The mains voltage is used in the DM model, and the converter inductance in the CM model. Be careful to set the converter inductance correctly depending on your converter topology (for some topologies, it can be zero).

Mains voltage and frequency

$U_{mains} =$ V (RMS)

$f_{mains} =$ Hz

Scaled converter inductance

$K^*L_{out} =$ μ H

NOTE: The SCALED value should be specified - the default model is based on a buck topology and requires L_{out} divided by 2 - so this value should be entered here. That is, enter the value as needed by your model, not necessarily the exact value in your converter.

Powered by GeckoMAGNETICS (alpha version) **GECKO**

Apply Parameters Next ->

About... Save Settings Load Settings Start GeckoCIRCUITS Exit

Set **number of stages** to consider

Set **filter design frequency** directly or specify **converter switching frequency**

Required DM and CM **attenuation** can be specified directly, or instead calculated based on **noise and emissions standard**

Mains voltage and frequency are also input variables

CM and DM Filters

Set maximum CM and DM capacitance

First stage can be considered separately from the rest

Set how attenuation is distributed between stages

Set Inductor and Capacitor Design Spaces

Click here when finished setting all parameters



Defining an Inductor Design Space

3 different inductor design approaches (see next slide)

Model simplifications for faster simulation

Cores and wires from the database....

...or custom-defined by the user, with each dimension variable in a range

Thermal model considers natural convection only

Inductor Design for Stage 1 of Differential mode Filter

Core Material
Micrometals -14 (Micro...
View Properties

Constraints
Maximum volume: 1.0 L
Maximum temperature: 150 °C

Design Approach
☒ Parameter Variation
☐ Energy Based
☐ Hybrid

Model Simplifications
☐ Ignore Proximity Losses
☐ Ignore HF Effects
☐ Ignore Leakage Effects

Windings
Wire Material: Annealed Copper (N/A)
View Properties
☐ Filling Factor: ☒ Fixed
0.3 to 0.6 by 0.1
Wire Type: ☒ Solid ☐ Litz
Available Wires: AWG10
Multiple Selection Details
☐ Custom Wire: View Geometry

Conductor diameter (bare): ☒ Fixed
d: 2.6 to 10 by 0.5 mm
Isolation thickness: ☒ Fixed
s: 0.0444 to 0.5 by 0.01 mm
☐ As % of d:
s = 0.05 * d
Not less than: 0.1 mm

Core Dimensions
Available Cores: T106
Details
Multiple Selection
☐ Custom Core: View Geometry
Core Type: Toroid

Core dimensions (mm):
Inner core diameter di: ☒ Fixed
14.5 to 100 by 5 mm
Outer core diameter do: ☒ Fixed
26.9 to 150 by 5 mm
Core thickness t: ☒ Fixed
11.1 to 25 by 5 mm

Stacked cores: 3 to 4 ☐ Fixed

Thermal Model
Core Orientation: VERTICAL
Sides NOT exposed to air:
☐ FRONT ☐ BACK ☐ TOP ☐ BOTTOM
☐ LEFT ☐ RIGHT

OK Cancel

Defining an Inductor Design Space

- Toroid and EE cores (latter for DM inductors only)
- Round solid and litz wires
- Three design approaches for inductors:
 - **Parameter Variation**: tries all values of design parameters in user defined ranges
 - **Energy Based**: uses the core geometry coefficient and area product when selecting which core to use for the inductor design (quickly rejects cores which are too small, but does not necessarily explore the entire design space)
 - **Hybrid**: combines the two approaches above (searches with a subset of the user-defined ranges arrived at through the use of the energy-based approach) – combines quick rejection of very unsuitable designs with a more detailed search of the design space

Defining a Capacitor Design Space

Can select individual capacitors from the database....

...or can select capacitor series from the database, where each series contains capacitors of various capacitance values

Alternatively, a custom capacitor model can be defined

Capacitor Design for Stage 1 of Differential mode Filter

☐ Select individual capacitor(s)

Available Capacitors

463I2330(1)01(2)

Details

Multiple Selection

☒ Select capacitor series

Available Capacitor Series

X2 R46

Details

Multiple Selection

☐ Custom capacitor: Help

Volume model: $Vol_C = k_1 * C U_n^2 + k_2 * C U_n + k_3 * U_n + k_4$

$k_1 = 6.274e-3$ L(V²F) $k_2 = 4.540$ L(VF) $k_3 = 0.011e-3$ LV $k_4 = 1.44e-3$ L

Loss model:

ESR Characteristic: $\tan(\delta) = 0.002$

Lekage Current Characteristic: $I_{leak} (\mu A) = a * C(\mu F) * U_n + b$

$a = 0$ $b = 0$

Rated voltage:

☐ Multiple capacitors of rated voltage: $U_n = 350$ V

☒ Single capacitor of voltage with closest multiple of 5 V to the required U_n

Rated capacitance:

☐ Multiple capacitors of capacitance: $C = 10$ μF

☒ Single capacitor of capacitance with closest multiple of 5 μF to the required C

OK Cancel

Parasitics and Additional Components

Three-Phase EMI Filter Optimizer

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

EMI Filter Design Space: Help

Global Parameters | DM Inductors and Capacitors | CM Inductors and Capacitors | **Parasitics & Additional Components**

Here set the values of the default parasitic capacitances and any other components you have defined in your filter models.

Parasitic Capacitances

Lumped stray capacitance C_{eq} = pF Lumped stray capacitance C_g = pF

In the default model, C_{eq} represents the stray capacitances from the common mode terminals to earth, while C_g represents the capacitances from the negative and positive power rails (busbars) and the load to earth.

Additional Components

For per-stage components, the defined range is the same for each stage.

DM Filter Single Components:	<input type="text" value="LLISNa"/>	<input type="text" value="10.0"/> to <input type="text" value="10.0"/> by <input type="text" value="10"/>	<input type="text" value="μH"/>	<input checked="" type="checkbox"/> Fixed
DM Filter Per Stage Components:	<input type="text" value="Rdamp"/>	<input type="text" value="10.0"/> to <input type="text" value="50.0"/> by <input type="text" value="10"/>	<input type="text" value="mΩ"/>	<input type="checkbox"/> Fixed
CM Filter Single Components:	<input type="text" value="Cxy"/>	<input type="text" value="10.0"/> to <input type="text" value="20.0"/> by <input type="text" value="10"/>	<input type="text" value="μF"/>	<input type="checkbox"/> Fixed
CM Filter Per Stage Components:	<input type="text" value=""/>	<input type="text" value="10"/> to <input type="text" value="50"/> by <input type="text" value="10"/>	<input type="text" value="mΩ"/>	<input type="checkbox"/> Fixed

Additional components are not designed by the optimizer, and their losses and volume are not computed individually. However, below you can set an approximate percentage to increase the total volume and losses by, in order to roughly account for the effect of these additional components.

Increase total filter volume by % and the total filter losses by % to account for additional components' impact

PCB and Interconnections

Increase total filter volume by % to account for the volume added by the PCB and the interconnections

Powered by **GeckoMAGNETICS** (alpha version) **GECKO** SIMULATIONS

Apply Parameters Next ->

About... Save Settings Load Settings Start GeckoCIRCUITS Exit

Specify value of parasitic capacitances for CM noise model

Specify value ranges of user-defined additional components, if any

Approximately account for volume of PCB and interconnections

Optimization Settings

Three-Phase EMI Filter Optimizer

Model Set-Up | Filter Design Parameters | **Optimization Settings** | Result visualization

Simulation and Optimization Criterion Settings:

Simulation Settings

Differential Mode Filter Simulations

Time step dt: 100E-9 s
Periods to simulate: 2
DM Current files: ☐ Embedded in model files

Phase 1: /models/DMcurrent1.dat Change...
Phase 2: /models/DMcurrent2.dat Change...
Phase 3: /models/DMcurrent3.dat Change...

Network port: 43055

Common Mode Filter Simulations

Time step dt: 100E-9 s
Periods to simulate: 2
CM Voltage file: ☐ Embedded in model files

/models/CMvoltage.dat Change...

Network port: 43056

Optimization Goals

Optimization type: ☐ Exhaustive ☒ Genetic algorithm Configure...

Optimize for: **Power Density (Volume)** 0.0 0.25 0.5 0.75 1.0 **Efficiency (Losses)**

Converter Output Power: 10 kW
Converter Switching Frequency: 50 kHz

Hard constraints:

☒ Maximum allowed volume: 5.0 L
☒ Maximum allowed losses: 500 W

Output file: /C:/gecko-git/EMI3ph_Optimizer/build/classes/output.txt Change... Apply Settings Start Optimization

Here, set the simulation time step and the number of mains periods to simulate. Make sure the simulation models reach steady state during the whole simulation time (number of periods). You can also choose whether to optimize for maximum efficiency (minimum losses) by setting the slider to 1, maximum power density (minimum volume) by setting the slider to 0, or some compromise in between (the slider position signifying whether you favour efficiency or power density more). You can also specify hard limits, i.e. maximum overall filter losses and minimum overall filter volume. If you set these constraints, any designs which fail to meet them will be rejected.

For the simulation files, if the noise waveforms are not embedded in/generated by the simulation files, you must specify the files from which they are loaded. For the DM model, there must be three phase-shifted waveforms, one for each phase. You must also specify the output file where the optimization results will be saved.

"Start Optimization" will commence the full search for the optimum efficiency converter in the specified design space.

NOTE: If you are having trouble starting GeckoCIRCUITS, change the network ports above until a connection to GeckoCIRCUITS can be established. Make sure you have allowed this application network access when prompted to do so.

About... Save Settings Load Settings Start GeckoCIRCUITS Exit

Simulation length and time-step

Files with noise waveforms (DM current and CM voltage)

Choice between two optimization algorithms (see Manual for details)

Select optimization goal:

0 – max. power density

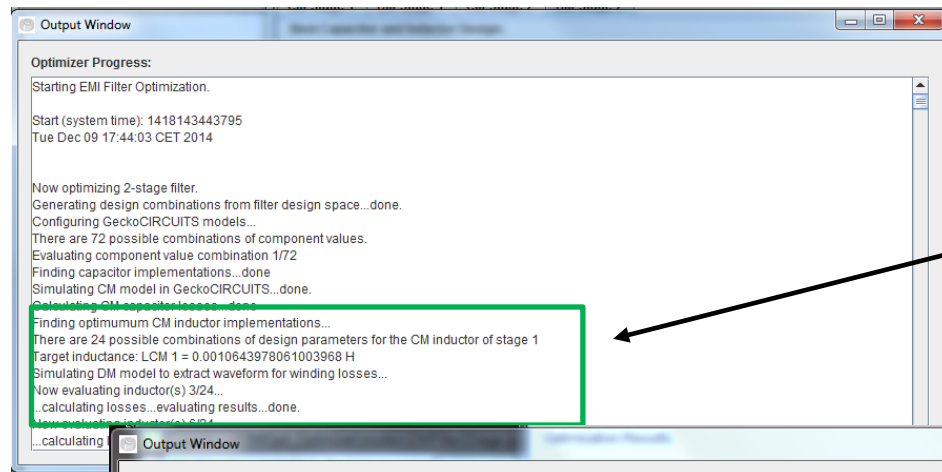
1 – max. efficiency

0.5 – half-way compromise

(values from 0 – 1 are possible in increments of 0.01)

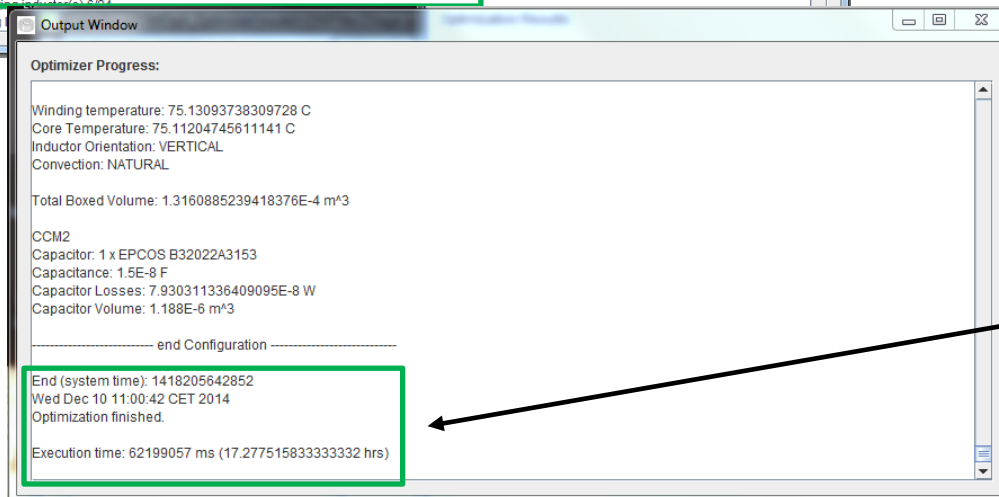
This button starts the optimization process

Optimization Progress



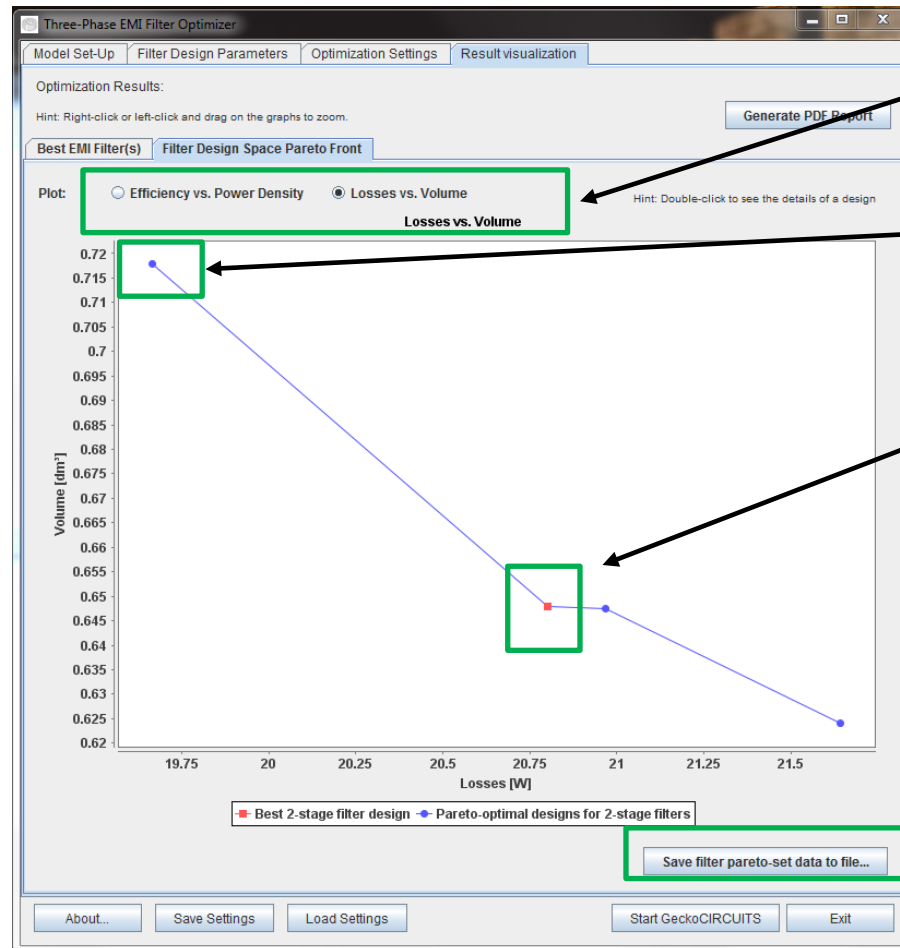
Output Window opens

Shows progress...



Shows message when finished

Results: EMI Filter Designs Pareto Front



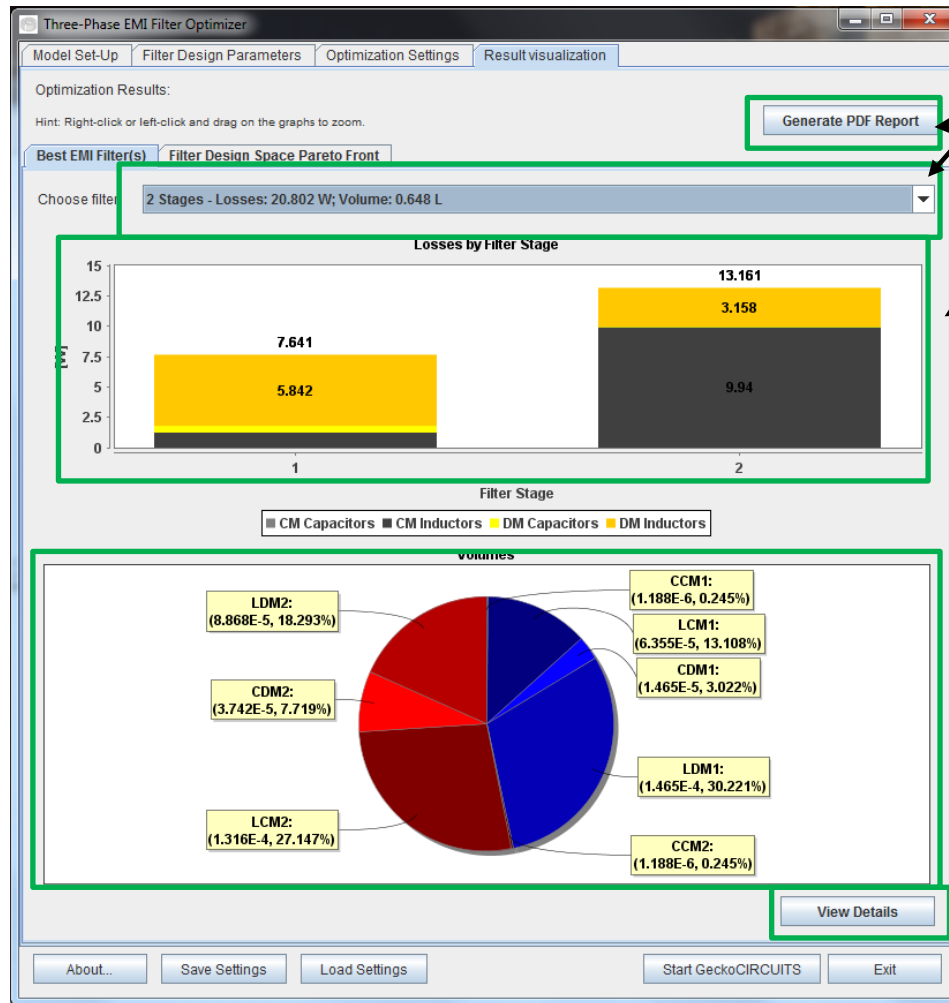
Can select how to display the plot

Move mouse over any point to see summary of design, double-click to open a window showing detailed results

Best filter design with respect to the selected design goal is highlighted

The pareto front data can be saved to a file

Results: Best EMI Filter Designs



Best design (based on optimization goal) for each number of stages is given here

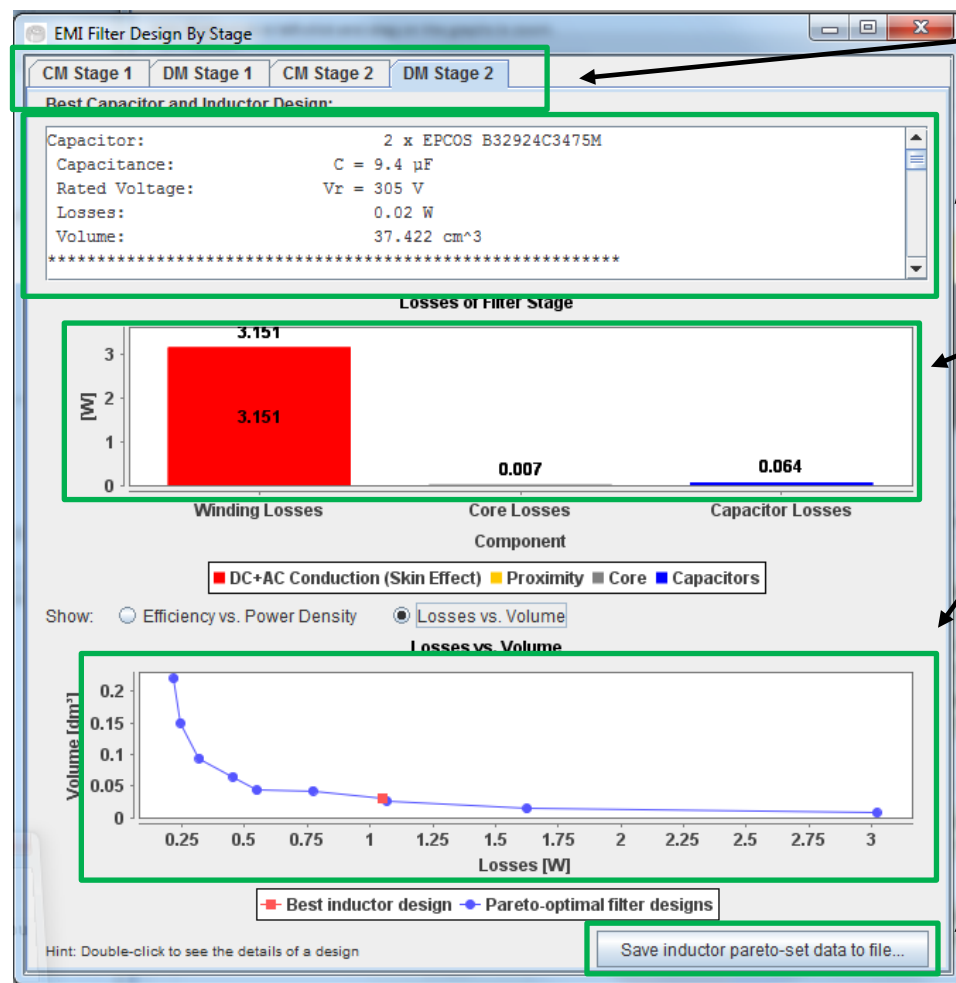
Can **save** the optimization results as a **PDF file**

Loss breakdown by stage and component

Volume breakdown by stage and component

Click this button to view details of the filter design stage-by-stage

Detailed EMI Filter Results



Detailed results for each filter stage

Details for the capacitor and inductor design for this stage (components used, dimensions, exact losses and volumes)

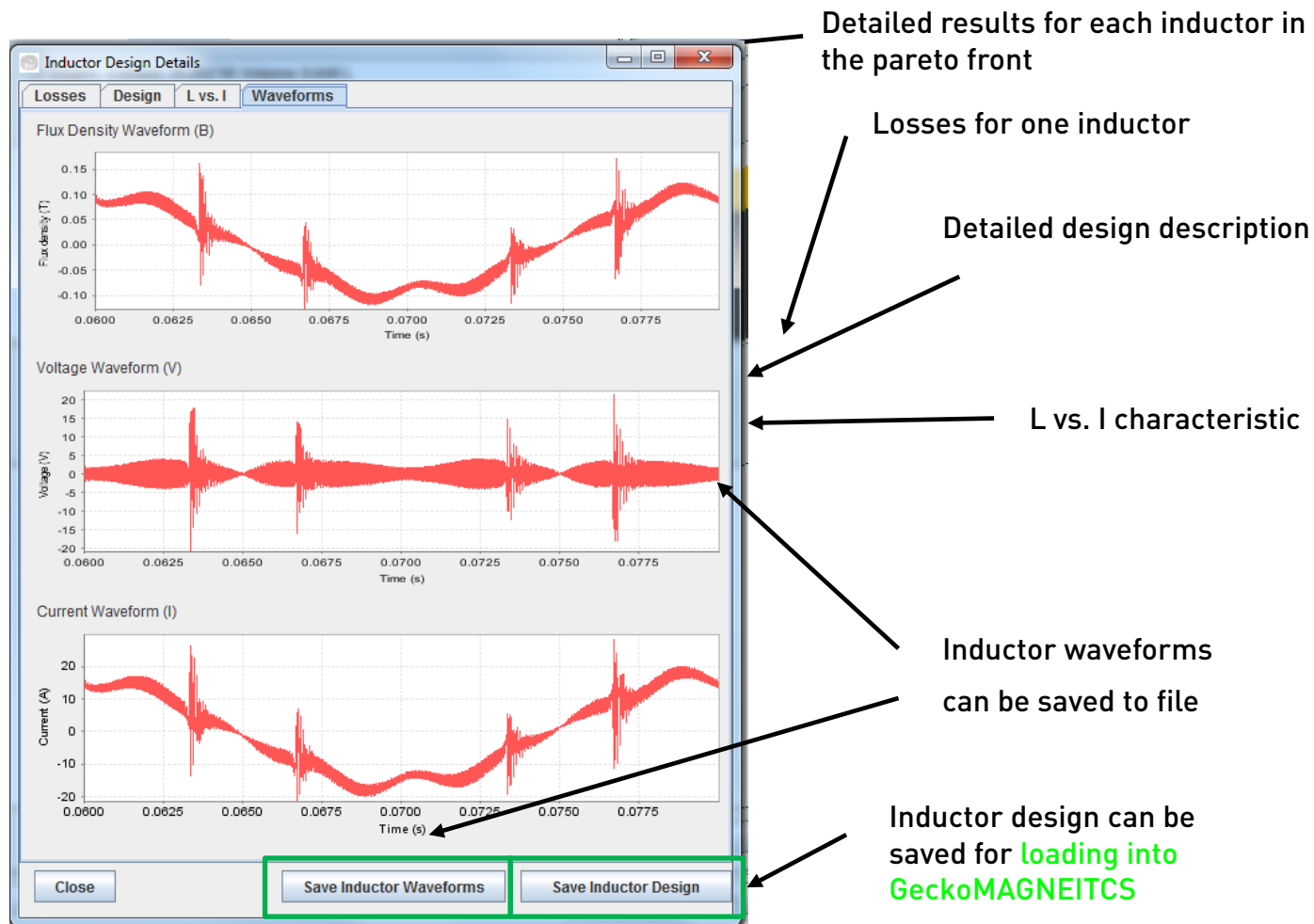
Loss breakdown for this stage

Pareto front of the design space for this stage's inductor, showing highlighted the selected inductor design (according to the set optimization goal)

Double-click on a point to see the details of the inductor design

Inductor pareto front data can be saved to a file

Detailed Inductor Results



User's Manual

Before using the program, and for all other details, please read the **User's Manual!**

Gecko-Simulations AG

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