EMI Filter Optimization Report

Global Parameters

Number of stages considered: 2

Ambient temperature: 25°C

Converter switching frequency: 36 kHz

Resulting design frequency: 180 kHz

Desired DM attenuation: 78 dB

CM attenuation: 88 dB

Mains voltage: 230.0 V (RMS)

Mains frequency: 50 Hz

Scaled converter inductance: 152.5 uH

Parasitics and Additional Components

Lumped stray capacitance Ceq: 600 pF

Lumped stray capacitance Cg: 2000 pF

Total volume is increased by 10% to account for the PCB.

Total volume is increased by 0% and total losses are increased by 0% to account for additional components.

Additional components (max. 10 displayed per category):

Single DM Additional Components			
Name (Unit)	*Min*	*Max*	*Increment*

Per-Stage DM Additional Components			
Name (Unit)	*Min*	*Max*	*Increment*

Single CM Additional Components			
Name (Unit)	*Min*	*Max*	*Increment*

Per-Stage CM Additional Components			
Name (Unit)	*Min*	*Max*	*Increment*

DM Filter Parameters

Maximum total DM capacitance per phase: 13 uF

DM attenuation is equally divided amongst the filter stages.

All filter stages are set to have the same range of inductance values.

All filter stages are set to use the same inductor and capacitor design space.

DM Stage 1

CDM1 is fixed to 2.5 uF

Attenuation of the first stage is not fixed to a separate constant value.

LDM range: 5 to 15 by 5 uH (applies to ALL filter stages)

Inductor design space single constraints	
Max. volume	1.0 L
Max. temperature	150.0 C
Core material	Micrometals -14
Core type	R (toroidal)
Wire material	Annealed Copper
Wire type	Round litz wire
Custom core	no
Custom wire	yes
Design approach	Parameter Variation
Ignore high freq. effects	yes
Ignore proximity effect	yes
Ignore leakage inductance	N/A

Core Parameters			
Name (Unit)	*Min*	*Max*	*Increment*
Number of Stacked Inductor Cores	1.0	3.0	1.0

Cores (max. 40 shown)			
T106	T124	T131	T14
T150	T16	T184	T20
T22	T32	T38	T60-D

Wire Parameters			
Name (Unit)	*Min*	*Max*	*Increment*
Inductor fill factor	0.5	0.5	0.1
Strand diameter (bare) di (m)	0.0002	0.0002	1.0E-5

Extra Wire Parameters	
Compact factor	1.3

Thermal Properties	
Core orientation	VERTICAL
Non-exposed sides	None

Capacitor Series (max. 40 shown)			
X1 B32911-6	X2 B32921-8	X2 B81130	

Above design space applies to ALL DM filter stages.

CM Filter Parameters

Maximum leakage current to earth: 3.5 mA Resulting maximum total CM capacitance: 35.228 nF

CM attenuation is equally divided amongst the filter stages.

All filter stages are set to have the same range of inductance values.

All filter stages are set to use the same inductor and capacitor design space.

CM Stage 1

CCM1 is not fixed to a constant value.

CCM1 is in series with CDM1.

LCM range: 500 to 1000 by 500 uH (applies to ALL filter stages)

Inductor design space single constraints	
Max. volume	1.0 L
Max. temperature	150.0 C
Core material	Vitroperm 500F-18k
Core type	R (toroidal)
Wire material	Annealed Copper
Wire type	Round solid wire
Custom core	no
Custom wire	yes
Design approach	Parameter Variation
Ignore high freq. effects	yes
Ignore proximity effect	yes
Ignore leakage inductance	yes

Core Parameters			
Name (Unit)	*Min*	*Max*	*Increment*
Number of Stacked Inductor Cores	1.0	3.0	1.0

Cores (max. 40 shown)			
T60006-L2020-W450+	T60006-L2025-W451+	T60006-L2040-W452+	T60006-L2040-W453+
T60006-L2045-V101#	T60006-L2050-W565#	T60006-L2063-V110#	T60006-L2160-V066#

Wire Parameters			
Name (Unit)	*Min*	*Max*	*Increment*
Inductor fill factor	0.4	0.4	0.1

Extra Wire Parameters	
s as % of d	0.05
Minimum s (mm)	0.001

Thermal Properties	
Core orientation	VERTICAL
Non-exposed sides	None

Capacitor Series (max. 40 shown)			
Y1 B81123	Y2 B32021-6		

Above design space applies to ALL CM filter stages.

Optimization Parameters

Optimization Goal: 0.5

Optimization type: Exhaustive (brute force)

Converter output power: 7.5 kW

Converter switching frequency: 36 kHz

Optimization Results

Overall Best Filter Design: 2-Stage Filter

(See the pages for the best 2-stage filter for details)

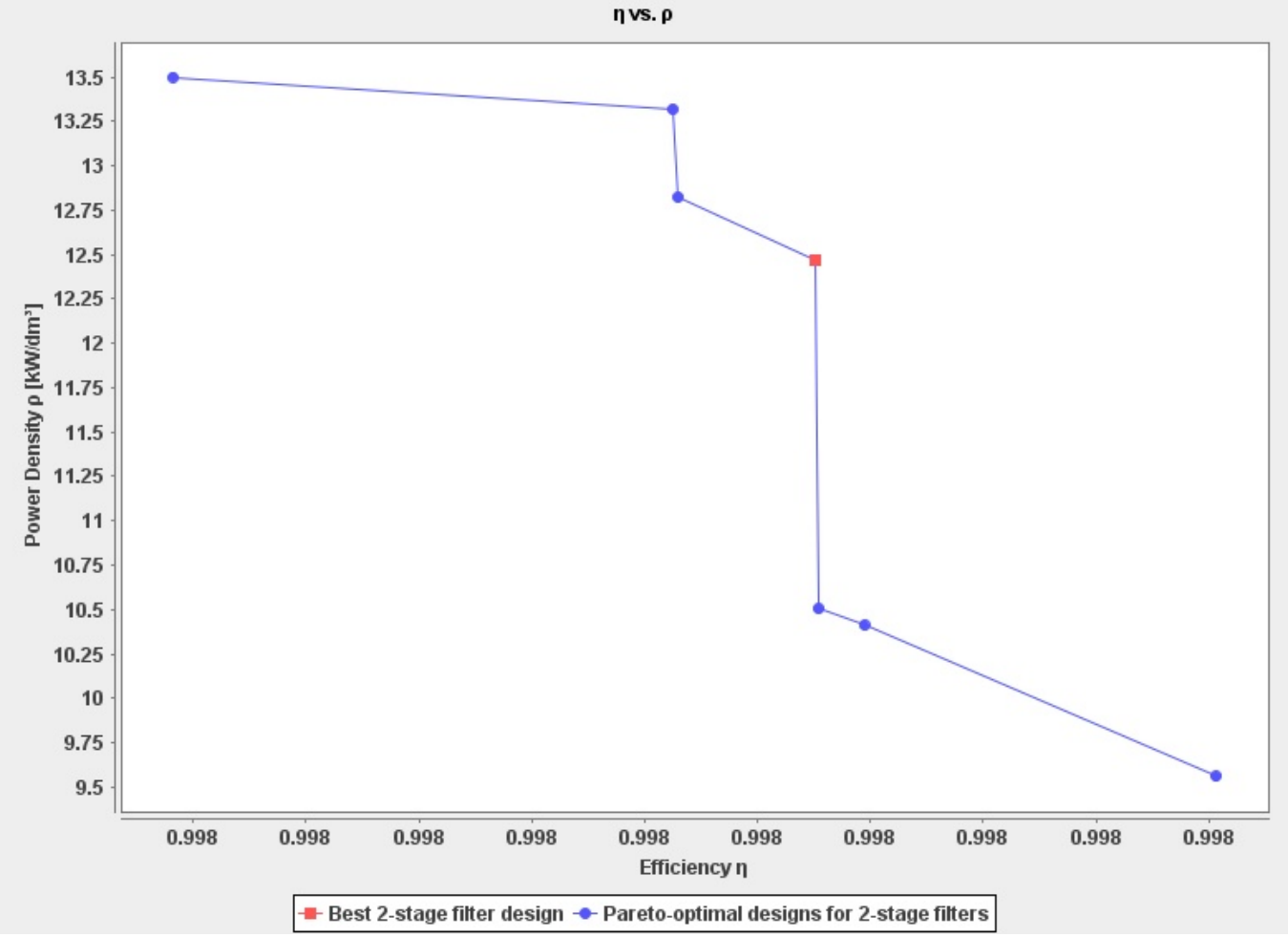
Total Losses: 13.706 W

Efficiency: 99.818%

Total Volume: 0.601 L

Power Density: 12.47 kW/L

EMI Filter Pareto-Optimal Designs:



Best 2-Stage Filter Design

Total Losses: 13.706 W

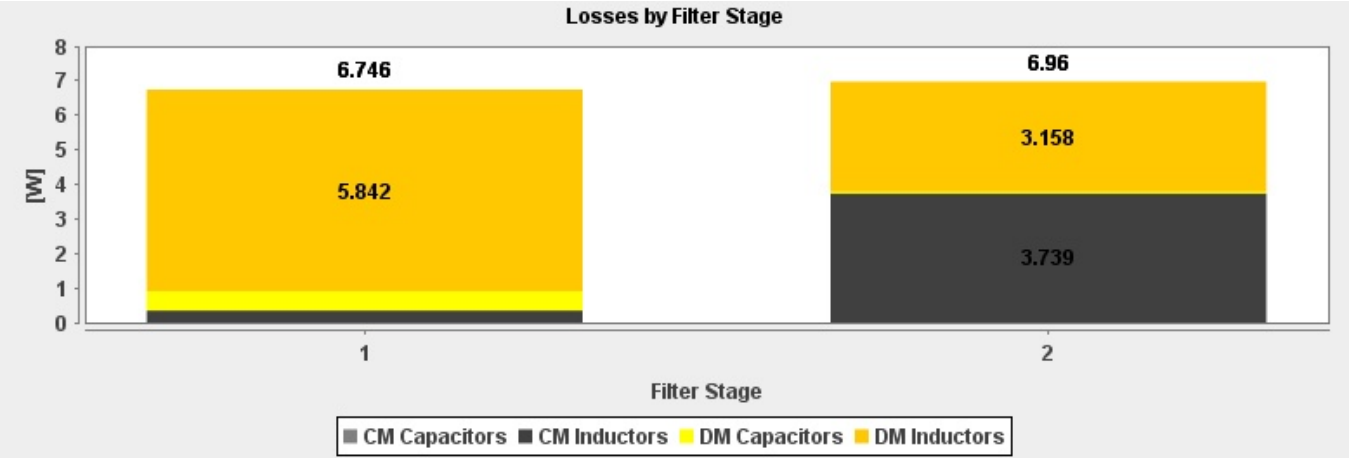
Efficiency: 99.818%

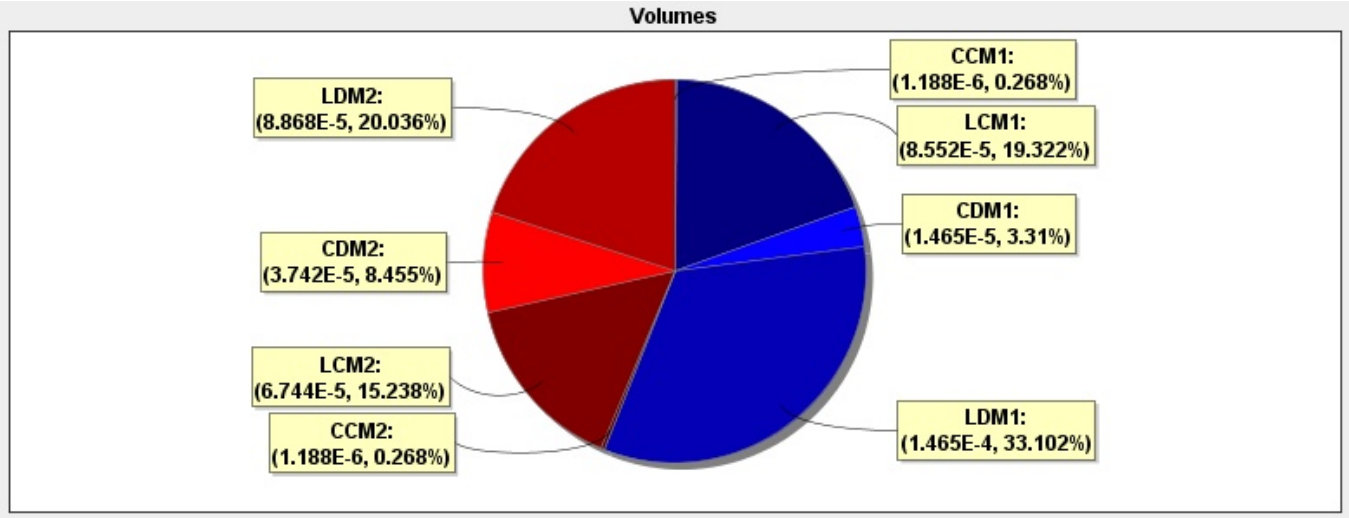
Total Volume: 0.601 L

Power Density: 12.47 kW/L

Stage 1	
LDM1	25.62 uH
CDM1	2.72 uF
LCM1	706.55 uH
CCM1	15 nF

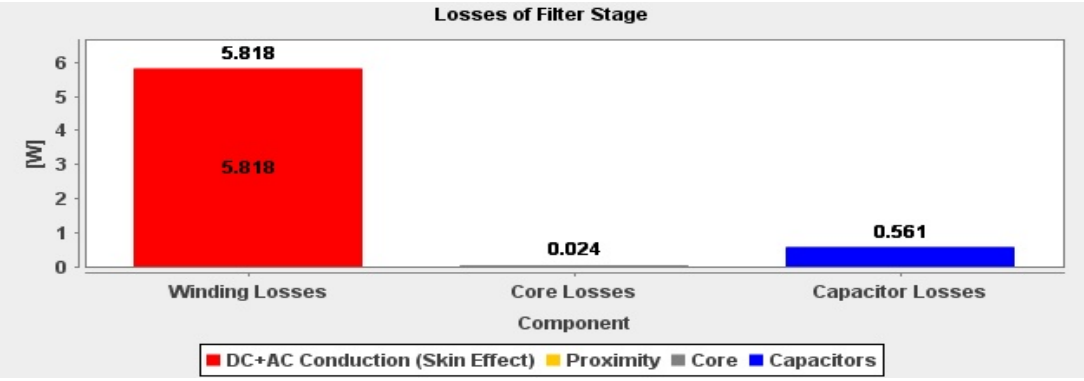
Stage 2	
LDM2	7.41 uH
CDM2	9.4 uF
LCM2	8.26 mH
CCM2	15 nF

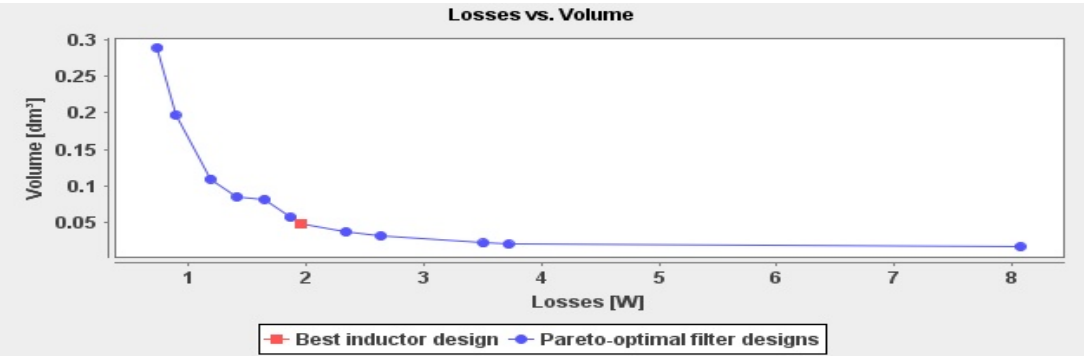




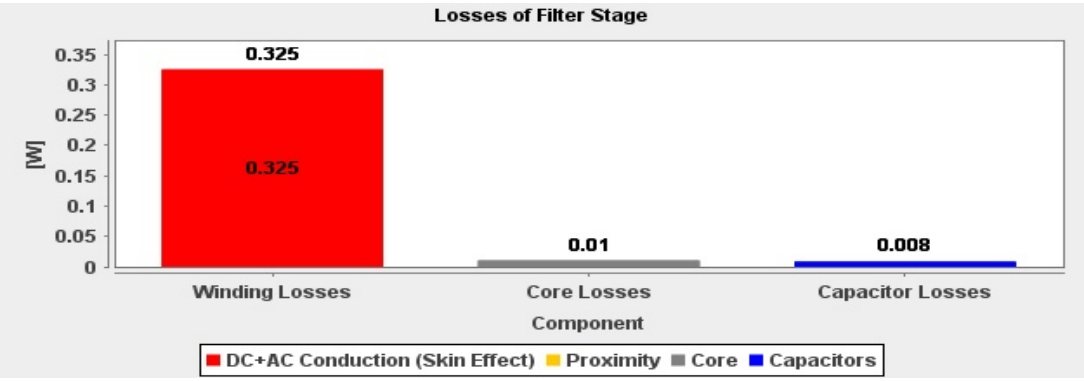
Filter Stage 1

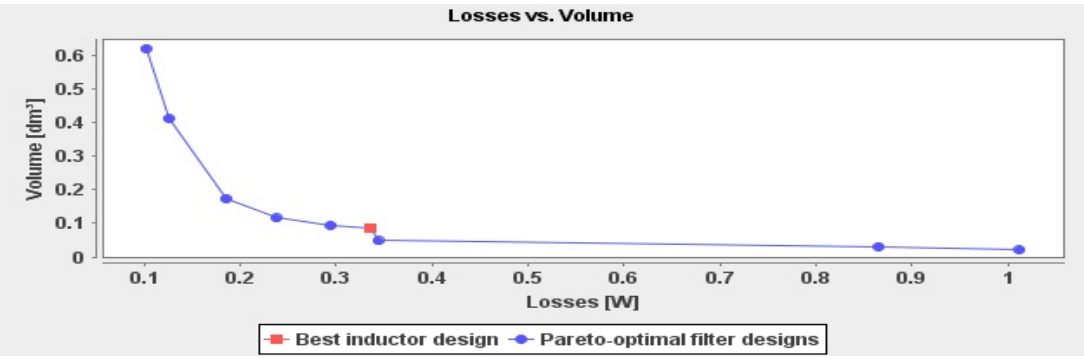
Differential mode:





Common mode:





DM Capacitor and Inductor Design For Stage 1

```
Capacitor:                          4 x EPCOS B32922C3684
 Capacitance:                C = 2.72 µF
 Rated Voltage:             Vr = 305 V
 Losses:                         0.19 W
 Volume:                         14.652 cm^3
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Toroid-Inductor:              L = 26.0303 µH

Core:                               T150
Type:                               R (toroidal)
Core Material:                      Micrometals -14
Number stacked:                     1

Dimensions (mm):
 Outer Diameter:             do = 38.4
 Inner Diameter:             di = 21.5
 Thickness:                   t = 11.1

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Winding:                            Custom Litz (fill factor)
Type:                               Round litz wire
Material:                           Annealed Copper
Number of turns:              N = 38

Dimensions (mm):
 Total diameter:              d = 2.466
 Strand diameter:            di = 0.25
 Number of strands:           n = 58
 Wire spacing:               yd = 0.0

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Losses (W):
 Core Losses:                       0.01
 Winding losses DC:                 2.2618466771159446E-8
 Winding losses skin effect:        1.94
 Winding losses prox. effect:       0.0
 TOTAL:                             1.95

Winding temperature:                44.31 C
Core Temperature:                   44.36 C
Inductor Orientation:               VERTICAL
Convection:                         NATURAL

Total Boxed Volume:                 48.8376 cm^3
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CM Capacitor and Inductor Design For Stage 1

```
Capacitor:                          1 x EPCOS B32022A3153
 Capacitance:                C = 15.0 nF
 Rated Voltage:             Vr = 300 V
 Losses:                         0.01 W
 Volume:                         1.188 cm^3
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Toroid CM 3ph-Inductor:       L = 814.027 µH
                             Ls = 629.376 µH

Core:                           T60006-L2040-W453+
Type:                           R (toroidal)
Core Material:                  Vitroperm 500F-18k
Number stacked:                 2

Dimensions (mm):
 Outer Diameter:             do = 40.0
 Inner Diameter:             di = 25.0
 Thickness:                   t = 30.0

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Winding:                        Custom SR (fill factor)
Type:                           Round solid wire
Material:                       Annealed Copper
Number of turns:         3 x  N = 4

Dimensions (mm):
 Conductor diameter:          d = 3.48
 Isolation thickness:         s = 0.174
 Wire spacing:               yd = 0.0

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Losses (W):
 Core Losses:                   0.01
 Winding losses DC:             1.5164060032857921E-18
 Winding losses skin effect:    0.32
 Winding losses prox. effect:   0.0
 TOTAL:                         0.34

Winding temperature:            28.92 C
Core Temperature:               29.02 C
Inductor Orientation:           VERTICAL
Convection:                     NATURAL

Total Boxed Volume:             85.5221 cm^3
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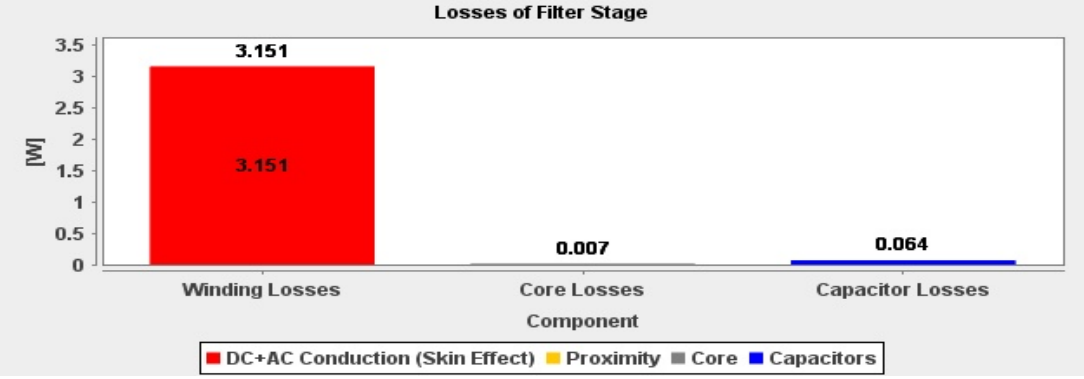
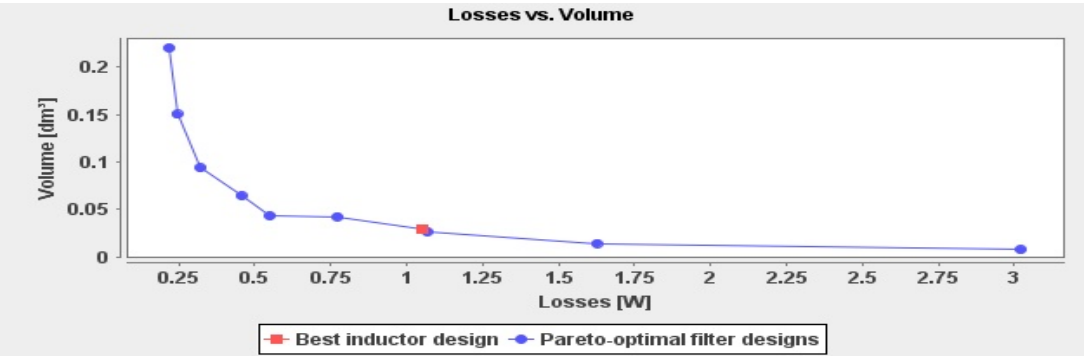
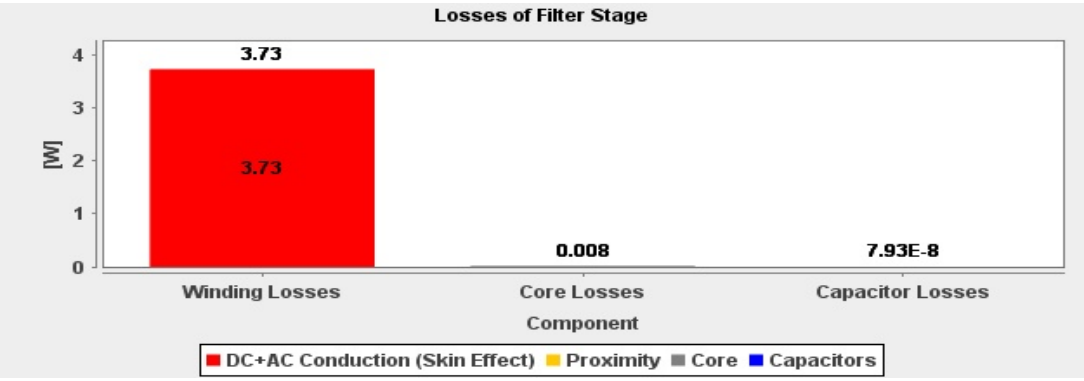
Filter Stage 2

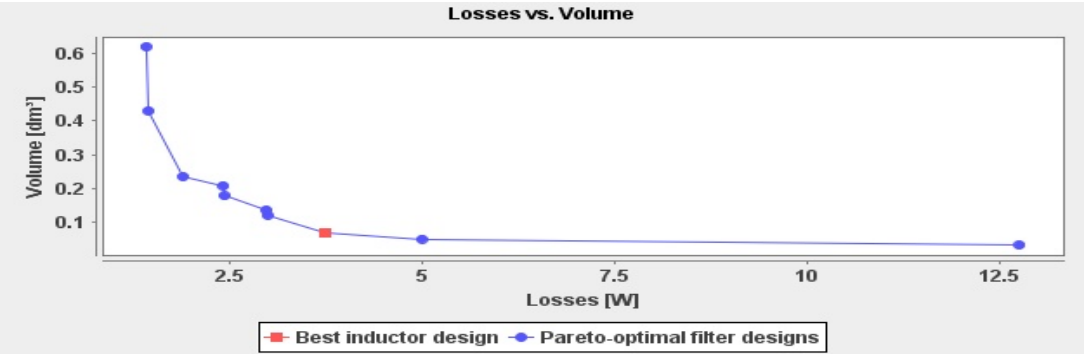
Differential mode:





Common mode:





DM Capacitor and Inductor Design For Stage 2

```
Capacitor:                          2 x EPCOS B32924C3475M
 Capacitance:                C = 9.4 µF
 Rated Voltage:             Vr = 305 V
 Losses:                         0.02 W
 Volume:                         37.422 cm^3
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Toroid-Inductor:              L = 7.5739 µH

Core:                               T124
Type:                               R (toroidal)
Core Material:                      Micrometals -14
Number stacked:                     1

Dimensions (mm):
 Outer Diameter:             do = 31.6
 Inner Diameter:             di = 18.0
 Thickness:                   t = 7.11

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Winding:                            Custom Litz (fill factor)
Type:                               Round litz wire
Material:                           Annealed Copper
Number of turns:              N = 26

Dimensions (mm):
 Total diameter:              d = 2.496
 Strand diameter:            di = 0.25
 Number of strands:           n = 59
 Wire spacing:               yd = 0.0

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Losses (W):
 Core Losses:                       0.0022951423223659157
 Winding losses DC:                 3.3477543250024525E-8
 Winding losses skin effect:        1.05
 Winding losses prox. effect:       0.0
 TOTAL:                             1.05

Winding temperature:                40.25 C
Core Temperature:                   40.27 C
Inductor Orientation:               VERTICAL
Convection:                         NATURAL

Total Boxed Volume:                 29.5613 cm^3
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CM Capacitor and Inductor Design For Stage 2

```
Capacitor:                          1 x EPCOS B32022A3153
 Capacitance:                C = 15.0 nF
 Rated Voltage:             Vr = 300 V
 Losses:                         7.930311336409095E-8 W
 Volume:                         1.188 cm^3
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Toroid CM 3ph-Inductor:       L = 7.9195 mH
                             Ls = 5.3858 mH

Core:                           T60006-L2045-V101#
Type:                           R (toroidal)
Core Material:                  Vitroperm 500F-18k
Number stacked:                 1

Dimensions (mm):
 Outer Diameter:             do = 45.0
 Inner Diameter:             di = 30.0
 Thickness:                   t = 15.0

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Winding:                        Custom SR (fill factor)
Type:                           Round solid wire
Material:                       Annealed Copper
Number of turns:         3 x  N = 19

Dimensions (mm):
 Conductor diameter:          d = 1.939
 Isolation thickness:         s = 0.097
 Wire spacing:               yd = 0.0

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Losses (W):
 Core Losses:                   0.01
 Winding losses DC:             1.2042714641655947E-14
 Winding losses skin effect:    3.73
 Winding losses prox. effect:   0.0
 TOTAL:                         3.74

Winding temperature:            54.42 C
Core Temperature:               54.51 C
Inductor Orientation:           VERTICAL
Convection:                     NATURAL

Total Boxed Volume:             67.4445 cm^3
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