Effective technologies in Custom Magnetics to reduce the losses in your High Frequency Power Converter

heynen prax

POWER ELECTRONICS

Power Electronics & Energy Storage event

27 juni 2023 | 1931 Congrescentrum 's-Hertogenbosch

ENERGY STORAGE

TRENDS IN POWER CONVERTERS TOPOLOGIES

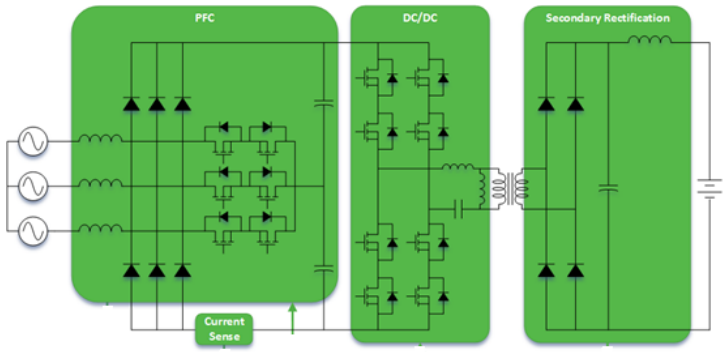
DC CONVERTERS

Resonant topologies are preferred for modern converters with well-known advantages

- ✓ Higher efficiency
- ✓ EMI reduction
- ✓ Higher power density
- ✓ Enhanced reliability
- ✓ Wide operating frequency

TOPOLOGIES

LLC Full Bridge
Dual Active Bridge
CLLC
…

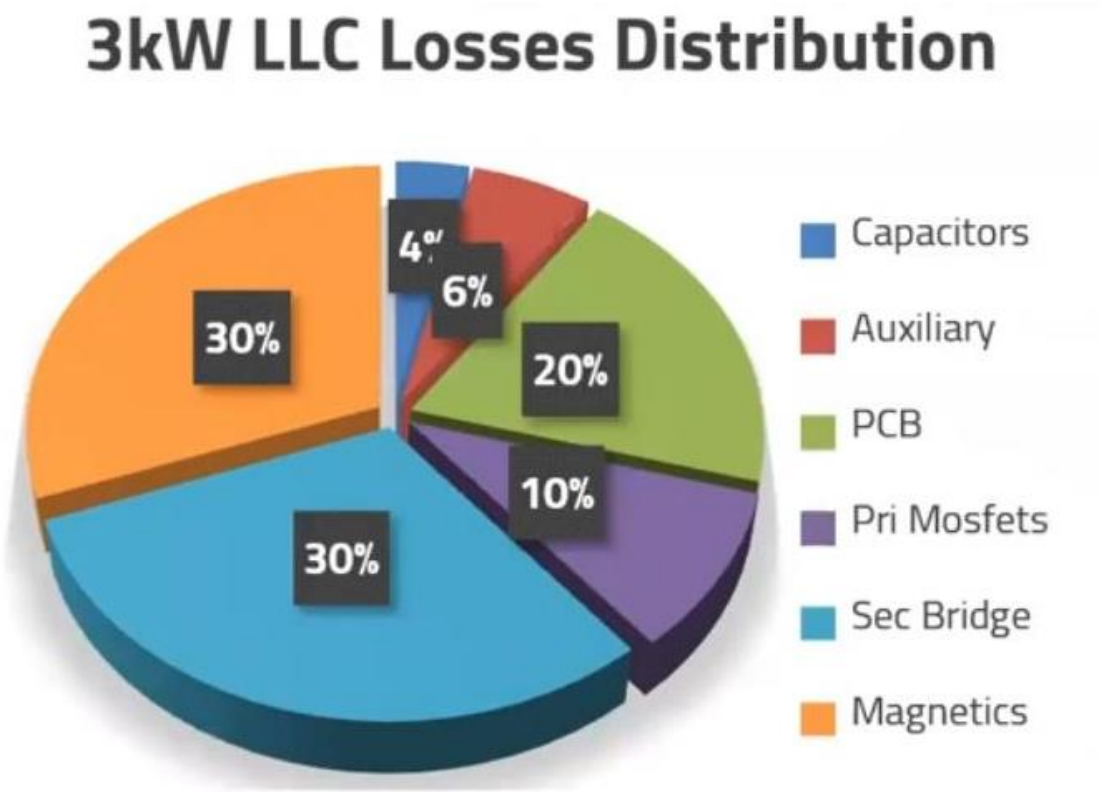


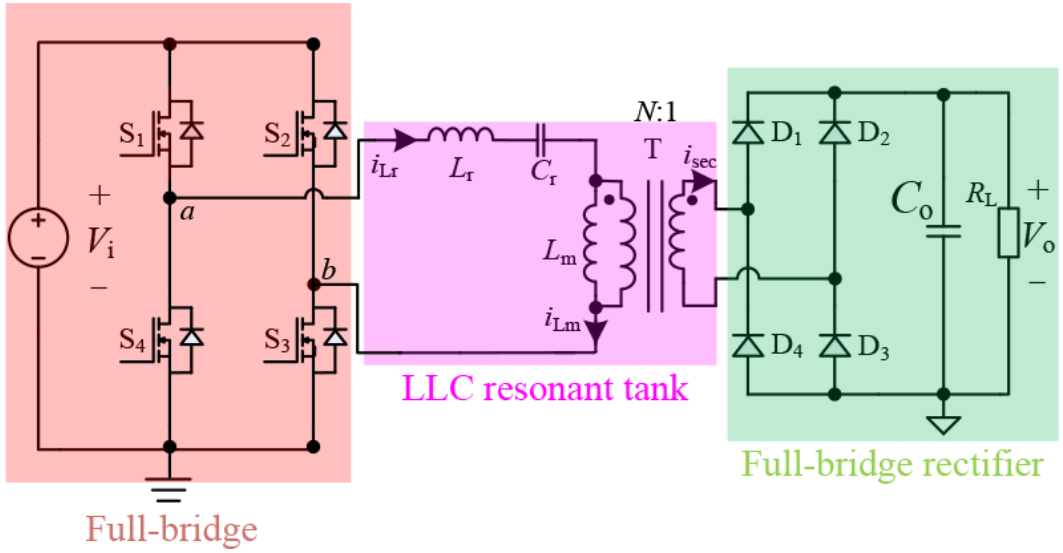
APPLICATIONS

EV Charging stations, OBCs, LED lighting drivers, photovoltaic systems, power supplies.

Magnetic components, in particular MAIN TRANSFORMER and RESONANT INDUCTOR, play a key role for achieving the desired power efficiency and compact size

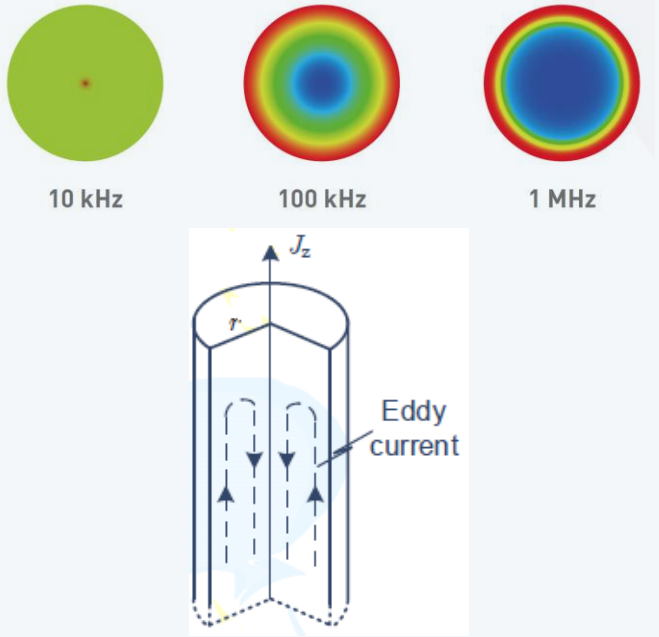
LLC RESONANT CONVERTER LOSSES DISTRIBUTION



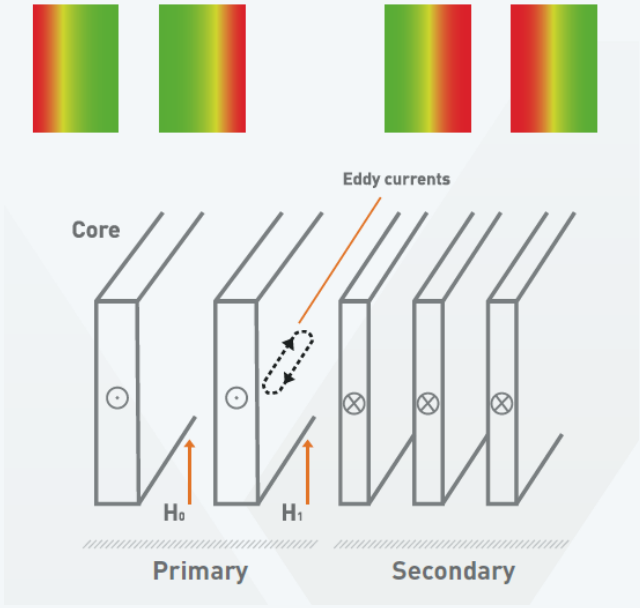


MAIN EFFECT GENERATING LOSSES IN WINDINGS

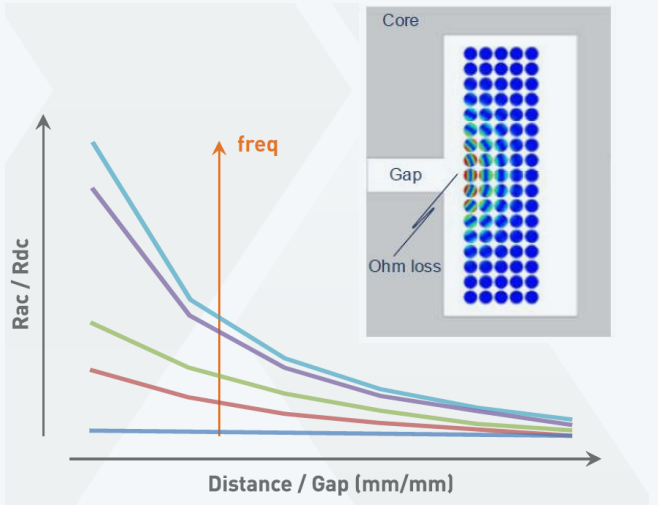
SKIN EFFECT



PROXIMITY EFFECT

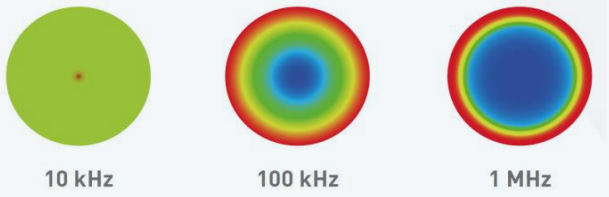


FRINGING EFFECT



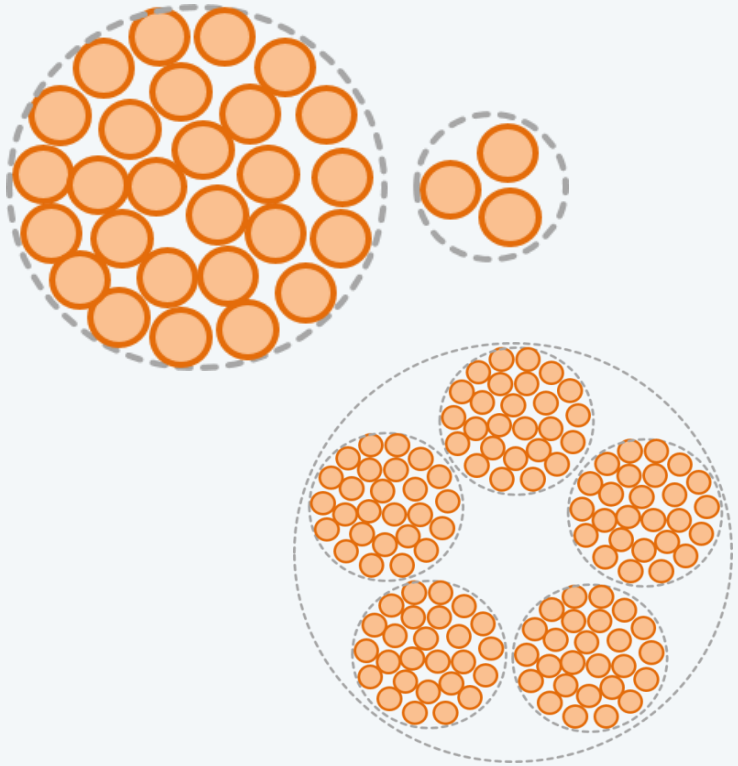
SKIN EFFECT

An isolated round conductor carrying AC current generates a concentric alternating magnetic field which induces Eddy Currents.
These currents oppose to normal current flow in the center of the conductor increasing the effective current closer to the conductor surface.
The overall effect is that total current flows in a smaller perimetral area. This intensifies as frequency increases. Current flow concentrates in an equivalent perimetral cylinder at the surface of the conductor. This cylinder thickness is known as skin depth.



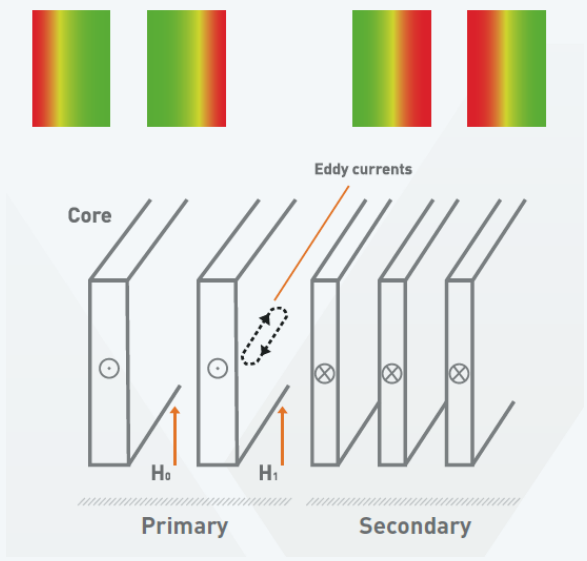
LITZ WIRE

Litz wire is the best option to reduce skin effect. It consists of multiple single wires electrically isolated from each other.



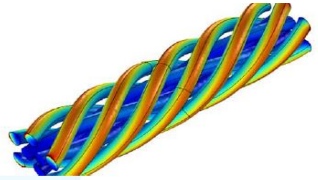
PROXIMITY EFFECT

Proximity effect appears when the distribution of current of a winding in one-layer influences current distribution in another layer, always in the same winding.
Such proximity effect, therefore, increases winding resistance (Rac).



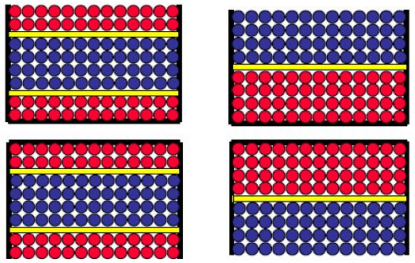
LITZ WIRE

Magnetic field created by proximity effect in conductors in parallel is compensated by the twisted bunching construction of litz wire.



INTERLEAVING LAYERS

Interleaving layers of different windings ensures magnetic field cancelation. Oversize of component is required.

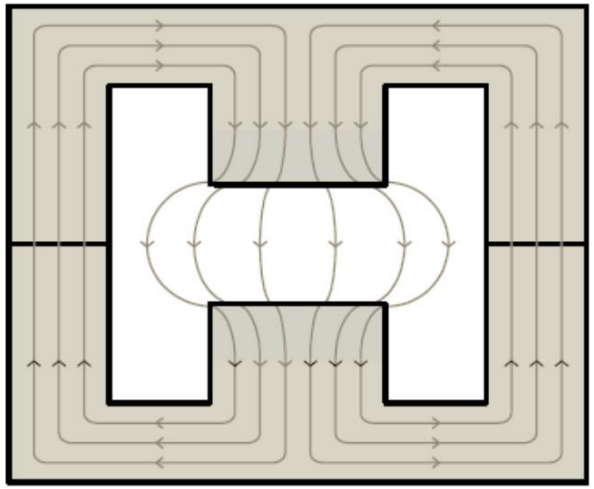


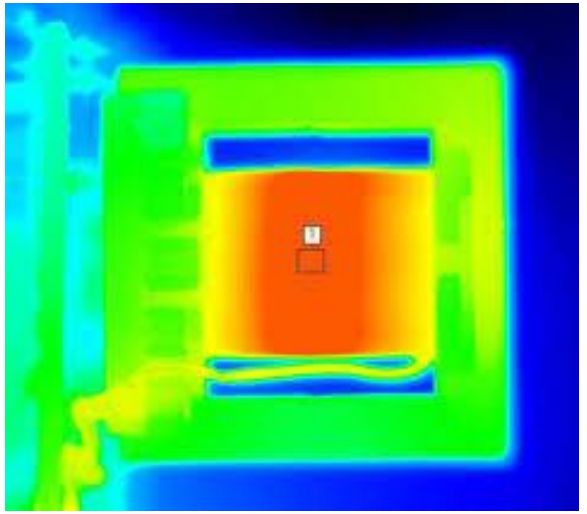
TOROIDAL FORMAT

Toroidal shape is the one with larger winding window. This ensures that all turns are wound in one layer reducing extremely proximity effects.

Magnetics in Resonant Topologies

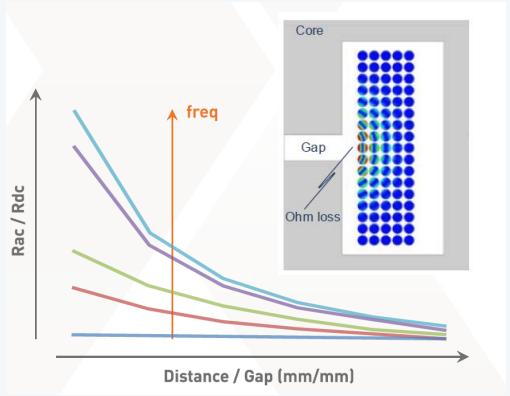
Need of large air gaps for the main transformer and resonant inductor, and the associated fringing losses challenge the converter efficiency, size and cooling management

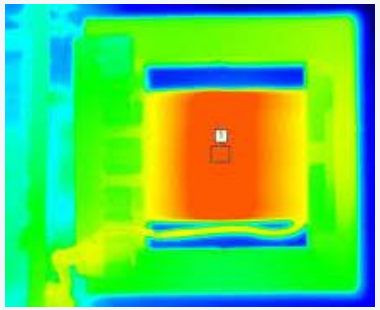


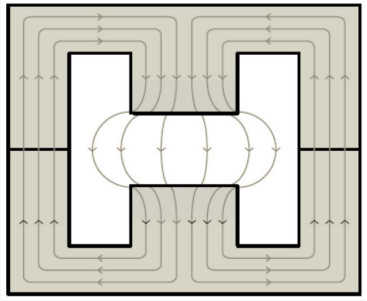


FRINGING EFFECT

Fringing effect happens when a magnetic flux near a core airgap bends out.
The distance over which these flux fringes out is basically proportional to the length of the airgap.

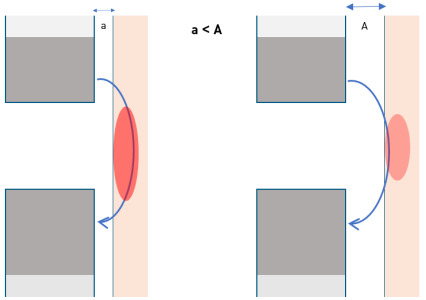






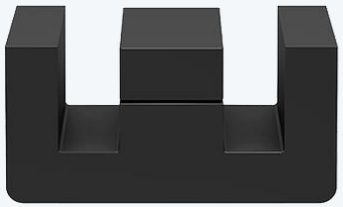
WINDING AWAY

Increasing distance between gap and windings reduces fringing effect. Main drawback is that component needs to be oversized to ensure enough distance between them.

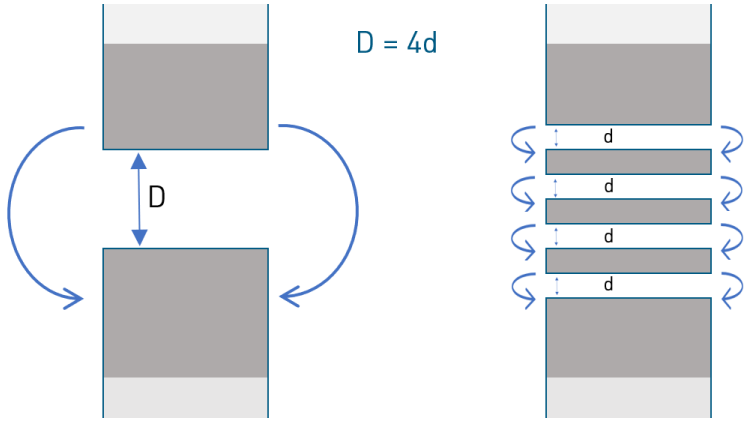


MULTIGAP SOLUTION

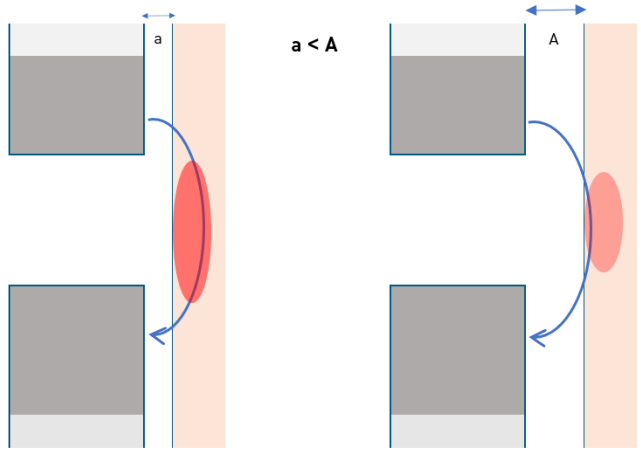
Splitting the gap in several parts reduces fringing effects as the magnetic flux outside the core is reduced dramatically.



MULTIGAP CORE IN CENTER LEG



WINDINGS AWAY FROM THE GAP



This approach is far from ideal…

- Multigap center leg requires **customized ferrites** with the associated ferrite molds
- Each format is valid only for the **application under design**
- Gap size dimensioning requires **challenging iterations**
- Winding away from gap **reduces winding area**, leading to inefficient design
- **Hot-spot** winding temperature is still always in the **inner-layer** with associated cooling challenges

THE TOROIDAL MULTIGAP APPROACH

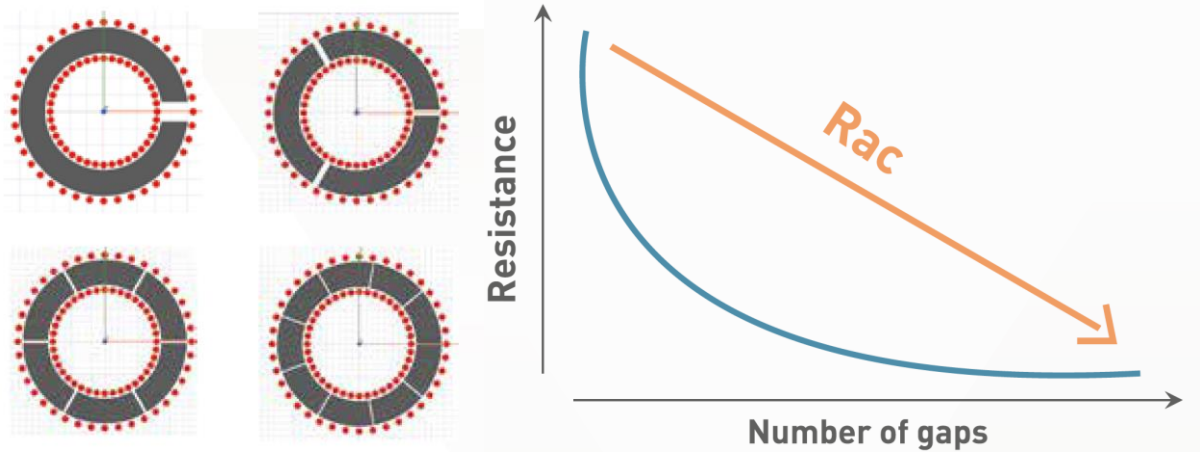
Toroidal multigap technology developed by PRAX to reduce winding AC losses

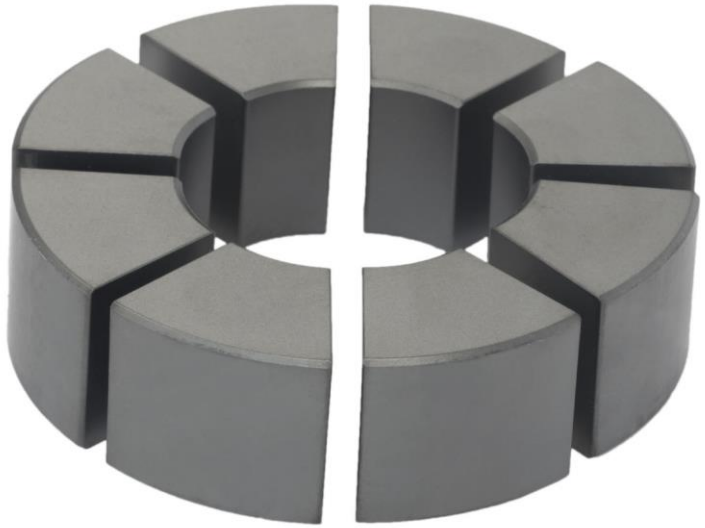
Allows a large airgap to be evenly distributed on a toroid to minimize fringing effect

Splits the gap into smaller gaps (up to 12 or 15 segments)

Losses are reduced exponentially because of the Rac reduction

Cost-effective solution improving power density

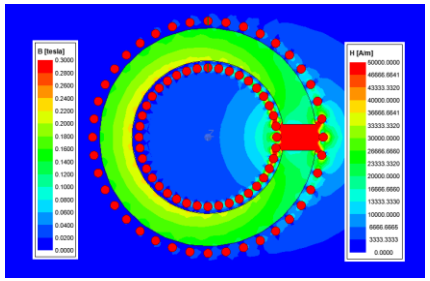
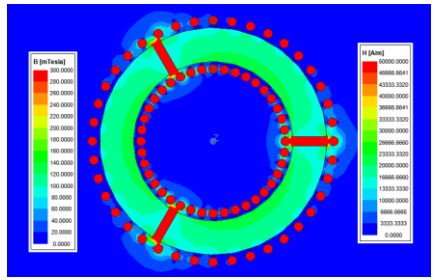
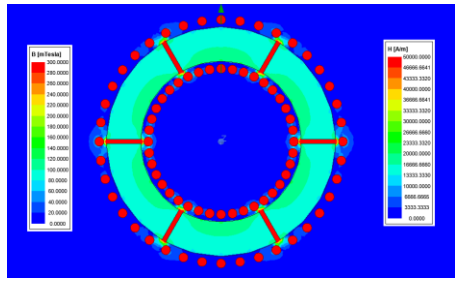
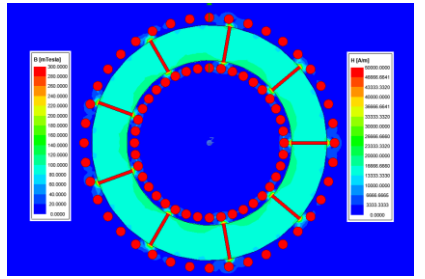
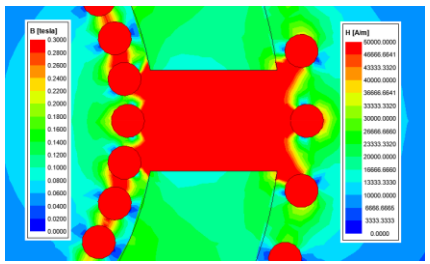
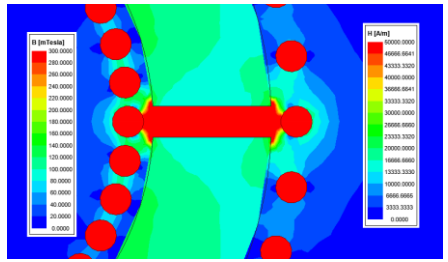
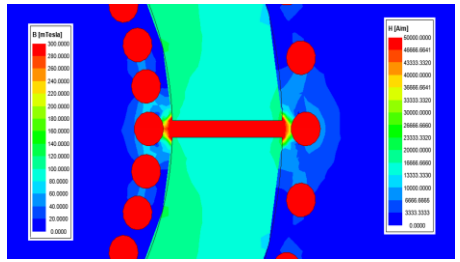
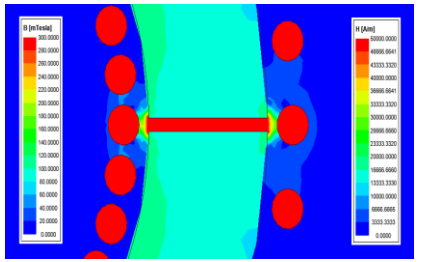




FINITE ELEMENTS ANALYSIS SIMULATIONS

Simulation of a 6mm air gap @ 200kHz

1 GAP	3 GAPS	6 GAPS	9 GAPS

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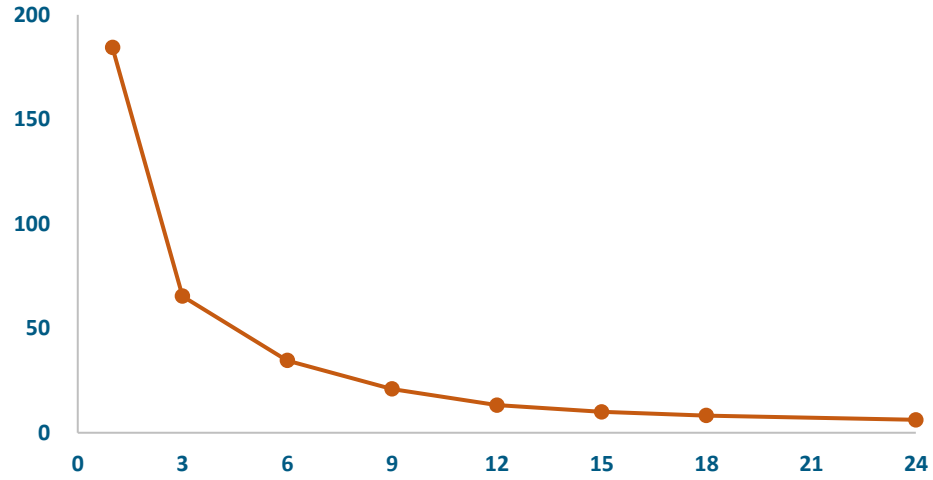
SUMMARY OF SIMULATIONS

Finite Elements Analysis Simulation (Simulated up to 24 gaps)

SIM	GAP (mm)	# GAPS	L/GAP (mm)	# TURNS	Rac (Ω)
1	6	1	6,00	40	184,40
2	6	3	2,00	40	65,40
3	6	6	1,00	40	34,60
4	6	9	0,67	40	21,00
5	6	12	0,50	40	13,23
6	6	15	0,40	40	9,99
7	6	18	0,33	40	8,28
8	6	24	0,25	40	6,23

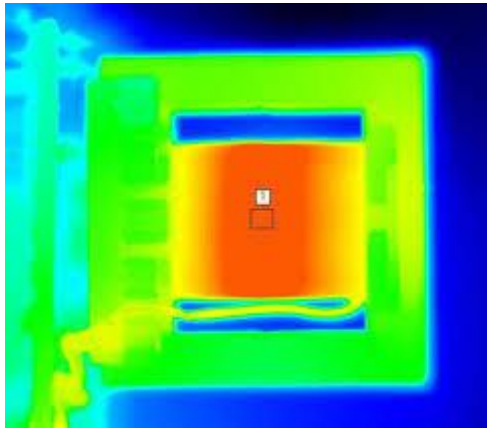


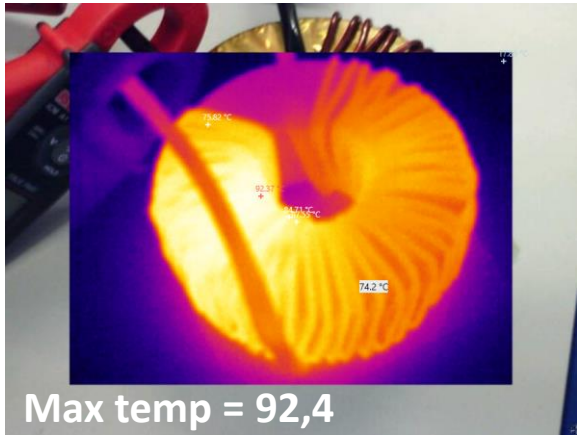
Up to 12-15 gaps Rac, and therefore losses, reduction decrease exponentially

Large number of gaps does not reduce losses significantly, not compensating the increase of manufacturing cost

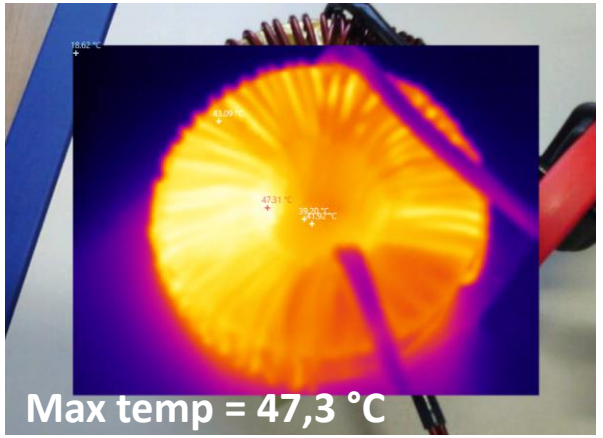
XGAP DISSIPATION BENEFITS

- Windings and core are completely touching the air. No hot spot in internal areas.
- Better heat distribution. All component is heated uniformly.
- Most of the losses are in the windings ensuring a better dissipation.
- With any kind of cooling, temperature can be reduced more due to excellent dissipation.





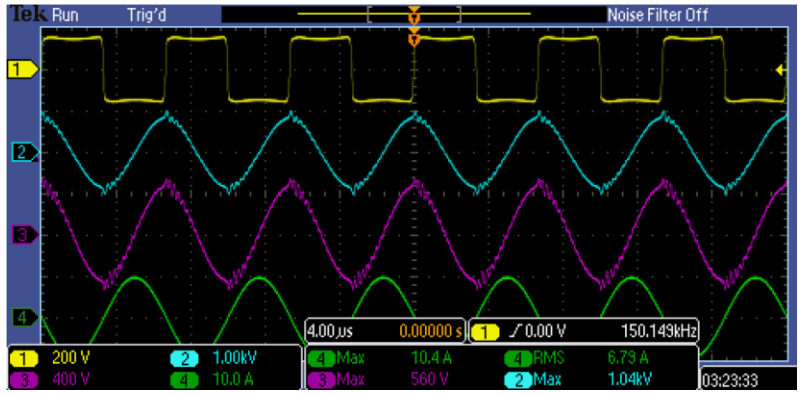
Natural air

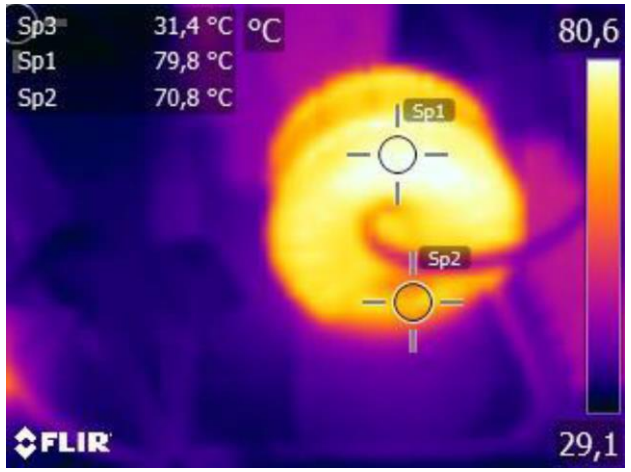


Forced Air

WE LIKE TO VALIDATE OUR CALCULATIONS…

Multigap Inductor 100uH 10A 150kHz





Prax off-the-shelf inductor
MXI-10010

Actual waveforms
of current and voltage

Actual component temperature
No hot spots
Temperature stays in operative limits

ADVANTAGES OF THE TOROIDAL MULTIGAP APPROACH

The Toroidal Multigap solves the challenges of the Traditional Approach…

- Increases winding area by using toroid formats
- No need to keep winding away from the gap
- Allows handling of high current and high frequencies by means of using low losses ferrite material
- Best dissipation of windings in any type of cooling system

… and offers Additional Features

- Reduction of component overall size around 20%
- Tighter tolerances for the inductance value (as low as ± 8%)
- Flexibility in inductance value design by adjusting separator thickness between segments easily
- Cost-effective solution compared to usual PQ / E /PM formats

SOME REAL TOROIDAL MULTIGAP MARKETS DESIGNS…

LLC Transformer + Resonant Inductor Set for On Board Charger

Rated Power 11kW

Working Voltage 800V

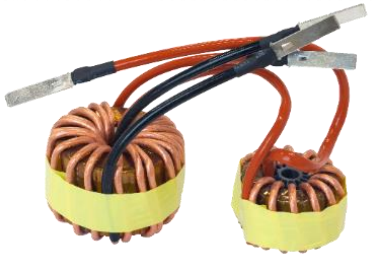
1st generation

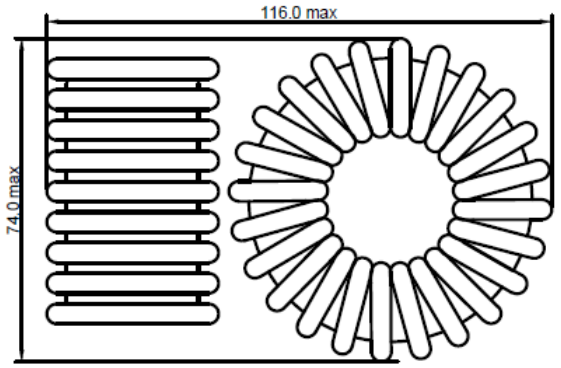
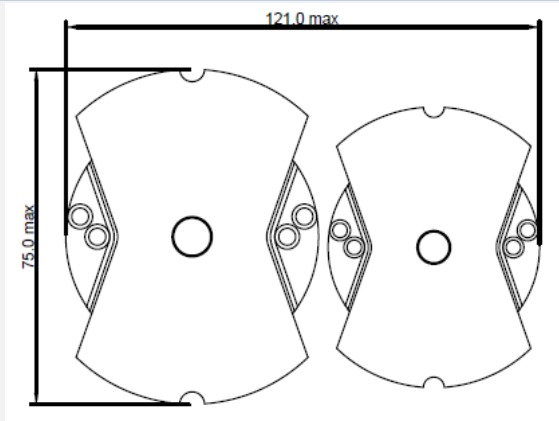
Interconnection made with same wire

2nd generation

Resonant inductor integrated within transformer leakage inductance

SOME REAL TOROIDAL MULTIGAP MARKETS DESIGNS…



	Xgap core	Traditional PM core
Total losses	25,6 W	27,3 W
Core	H58x27x38	PM74 Core
Gap	6 x 0,9	2 x 2,5
Transformer size	68 x 65 x 51 mm (LxDxH)	73 x 58 x 63 mm (LxDxH)
Weight	734 gram	1072 gram
Volume	62571 mm³	101000 mm³
Set dimensions		

38% volume reduction

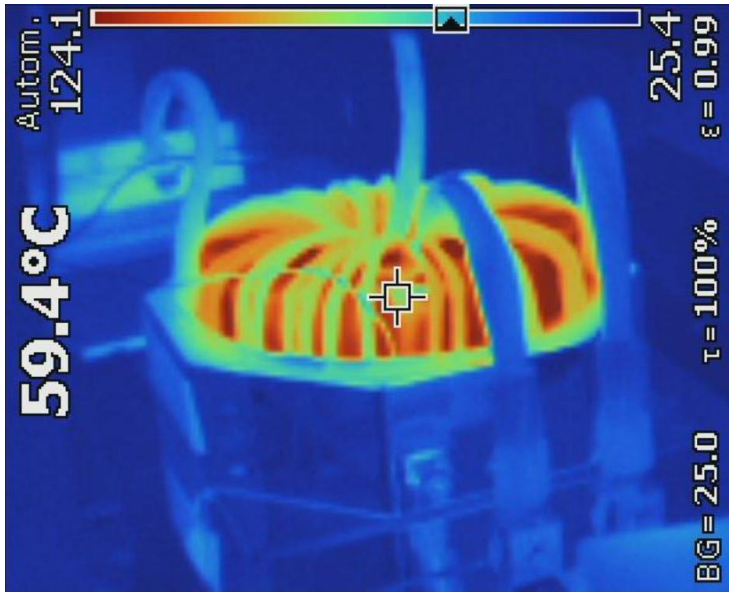
15% total component size reduction

SOME REAL TOROIDAL MULTIGAP MARKETS DESIGNS…

30kW Main Transformer for Fast DC-Charger

Rated Power 30kW

Working Voltage 1000V



Excellent cooling capabilities

DAB Topology

Custom housing

Small footprint (150x150mm)

SOME REAL TOROIDAL MULTIGAP MARKETS DESIGNS…

OnSemi reference design for Fast DC-Charger

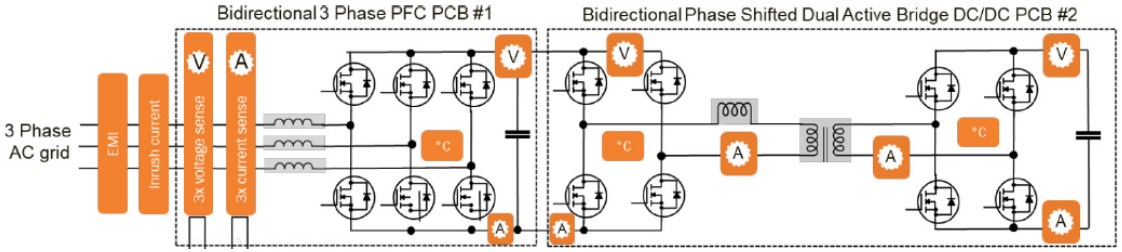
Rated Power 25kW

Working Voltage 1000V

onsemi

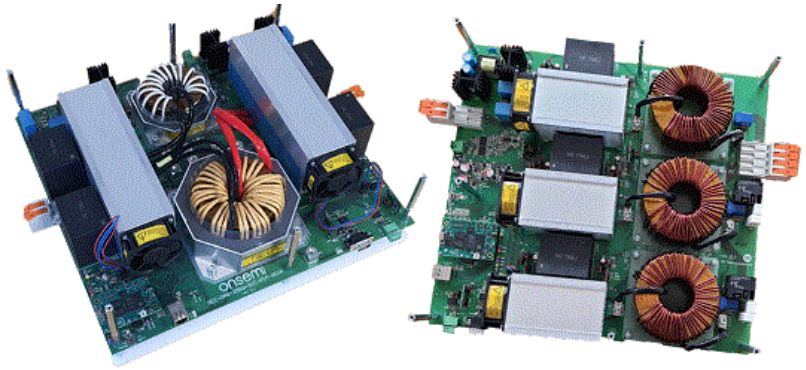
Main Transformer

DAB Topology 100kHz



Resonant Inductor

15uH 85A 100kHz



PFC Choke

150uH 64A 210kHz

SOME REAL TOROIDAL MULTIGAP MARKETS DESIGNS…

Resonant Inductors

Suitable for HF ripple current applications

Nominal current 9 to 65A

Working Voltage 1000V

Typical frequency ranges from 50 to 250kHz

Litz wire winding, minimizing Rac

Flat inductance vs current

Multigap ferrite core design minimizing fringing losses

Nominal inductance from 10µH to 250µH

Aluminum diecast enclosure

High thermal conductivity potting material

CONTACT DETAILS

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