Title: Multigap Toroidal Transformer and Inductors for Overcoming Fringing Losses in HF Resonant Converters.

Short description: This talk will provide an overview of how to achieve a reduction of fringing losses in high frequency magnetics for resonant converters applications. By using ferrite toroidal cores with split gap in several smaller gaps, generating a multi-gap ferrite toroidal core, fringing losses can be reduced considerably achieving higher efficiency or magnetics size reduction. The goal is showing engineers practical examples of multigap toroidal transformers and resonant inductors designs, number of gaps and gap size optimization with finite elements analysis, wire selection to minimize losses and comparable results versus an E or PQ format design.

Target audience: Power electronics professionals and systems engineers/architects for automotive and industrial applications designing DC/DC converters and Power supplies with resonant topologies.

Proposed content: Slide outline

1- <u>Introduction</u>

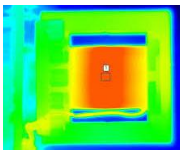
During past few years we have seen an increase of converters designed with resonant topologies like LLC, DAB, CLLC, etc.
In these topologies, magnetic components, in particular main transformer and resonant inductor, play a key for achieving the desired power efficiency and compact size.

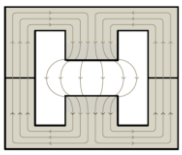
2- <u>Background</u>

Losses in magnetic components are divided in two main groups: core losses and winding losses. In this talk we will focus on the winding losses and specifically how to overcome the excess of losses in windings due to fringing effect.
Fringing effect appears because of the presence of the magnetic field circulation in the core, which is bent in the gap area and generates extra losses in windings.

3- <u>Understand</u>

Resonant topologies usually require the use of large air gap for both resonant inductor and main transformer, especially when use ferrite cores, which is the best option when increasing converter switching frequencies.
Such air gap generates extra losses in the windings which increases the heat in the magnetic component close to the gap area.



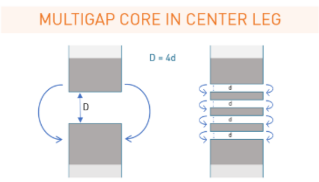


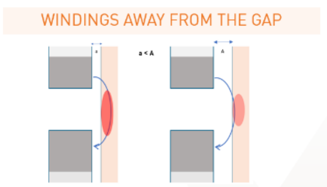
4- <u>Understand</u>

Most of current designs use ferrite PQ, PM or E formats. Traditionally fringing losses have been mitigated by two main techniques:

- Placing windings far away from the gap, which reduces effective winding area.
- Divide the length of the gap and use a multigap in the core center leg. Challenging when comes to iterations or design changes.

Both techniques hot spot is in the winding close to center legs, which still requires difficulties and challenges to get the heat out of the windings.



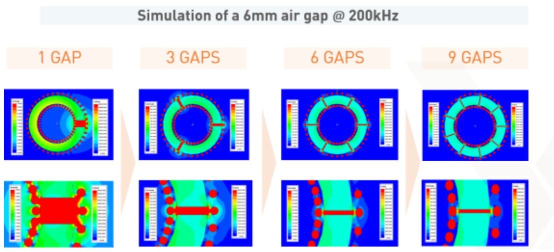


5- <u>Technique</u>

To improve tradition approach it is presented the use of a toroidal low loss ferrite core, splitting the gap between ferrite cores segments which will finally form a toroid.
The aim is to achieve a reduction of fringing losses as we increase the number of gaps.

6- <u>Technique</u>

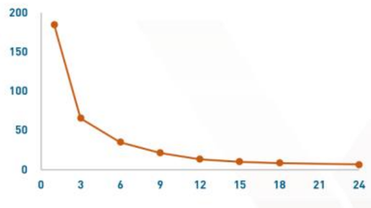
Show finite element analysis simulation of AC losses vs number of gaps.



7- <u>Technique</u>

Show AC resistance of the windings vs number of gaps. Define optimized gap number and size based on losses and manufacturability.

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



8- <u>Testing</u>

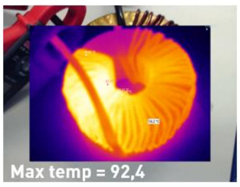
Example of a real inductor with multigap toroidal core: L=100uH, 10 Amps sinusoidal current at 150kHz.
Show design process, core selection, winding definition and Rac simulation.

9- <u>Testing</u>

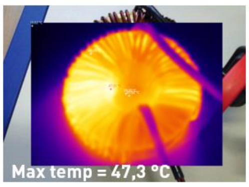
Show manufacturing process and samples build.

10- <u>Testing</u>

Show experimental results and compare with simulation. Measure temperature rise and hot-spot.
Show benefits of cooling capabilities for multigap toroidal technology comparing temperature rise with natural cooling and forced air.



Natural air

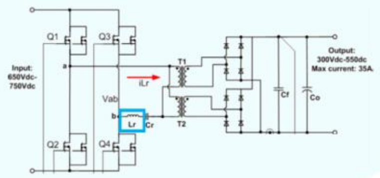


Forced Air

11- <u>Design example</u>

Show a design example of a resonant inductor for 22kW LLC commercial DC/DC converter for DC Charger applications.

Compare design results with traditional PQ format and toroidal multigap core.



Converter Detail	
Topology	LLC Resonant converter
Input Voltage	800 V
Output Voltage	300- 550V
Max Output power	20 kW
Frequency	150-400 kHz

	Base design 2x PQ 35/40	Multigap MXI	Multigap PQ 65/54
Description			
Core	PQ35/40 DMR44 G1380um x5	MXI 4000-0687 DMR44 G1200um x9	PQ65/54 3C97 G2490um x5
Wire	3// 14 turns Litz 825 * 0,05	2// 14 turns Litz 825 * 0,05	2// 15 turns Litz 1525 * 0,05
Size	36.1cm x39.7cm x32cm x2	56,2m x 56cm x 58,8cm	65cm x53,5cm x55cm
Final results			
Forced convection	3m/s	3m/s	3m/s
Core Losses	15,94 W x2	15,03 W	17,38 W
Winding losses	19,92 W x2	29,18 W	36,03 W

12- <u>Conclusion</u>

Summary of design considerations, test results and advantages of toroidal multigap core for magnetics designs in resonant converters.

Speaker bio

Pau Colomer is R&D Director in PRAX, Spanish company dedicated to design and manufacturing custom magnetics for Power Electronics applications. He has more than 20 years' experience in design of custom magnetics for a wide range of applications and sectors. He was also appointed as Professor of Master's degree in Power Electronics, for Design of Inductors and Transformers, by the University Politècnica of Catalonia, Spain.