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Magnetics in the 800 VDC AI Data Center: A Teardown of the Renesas Power Architecture White Paper

What the 16:1 LLC DCX and its planar matrix transformer actually demand from a magnetics supplier

Item	Detail
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Document	Magnetics in the 800 VDC AI Data Center — A Teardown of the Renesas Power Architecture White Paper
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Summary & key takeaways

Bottom line

On the surface this white paper is about GaN and topology. For a magnetics supplier it is something else: a specification sheet with a disqualifying clause. The 16:1 conversion from 800 V to 48 V is implemented as an LLC DCX switching at 650 kHz–1 MHz; the transformer must be a planar matrix structure; and the core must use an equal airgap. The paper states outright that conventional transformers are not preferred for ultra-high-power-density applications — because of size, difficulty controlling leakage inductance, and the inability to integrate synchronous rectifiers and capacitors. That sentence is a structural filter, not a price negotiation.

Key takeaways — all quoted from the white paper:

- **Architecture is settled:** an 800 V DC bus (2- or 3-wire) replaces the OCP 48 V rack architecture, cutting copper weight by almost 50 %; a 16:1 isolated DC/DC steps 800 V down to 48 V so the existing ecosystem can be reused.
- **How the power is stacked:** a 12 kW system is two 6 kW units in parallel; each 6 kW unit is two 3 kW 400 V–48 V LLC DCX blocks stacked — inputs in series to hold 800 V, outputs in parallel. The 3 kW 400 V–48 V LLC DCX is the basic building block of the entire HV DC/DC system.
- **Frequency and efficiency:** switching frequency 650 kHz–1 MHz (the tested prototype runs at about 650 kHz); LLC DCX efficiency 98 %; the two-stage chain achieves 96 %; the 64:1 (800 V→12 V) variant simulates to about 96.7 %.
- **The matrix transformer is an enabling technology, not an option:** the paper names it as one of the two key system technologies that enable high efficiency and power density — the other being the LLC DCX itself.
- **Conventional transformers are explicitly ruled out:** they "are not preferred in applications requiring ultra-high-power density due to their large size, difficulty controlling the leakage inductance and inability to integrate SRs and capacitors as in the case of planar transformers."
- **Equal airgap is called out by name:** "The equal airgap on all parts of the core provides several advantages: flux and losses are spread out, the core is fully utilized and lower core losses are achieved." Verified by 3-D Ansys modelling of a two-limb structure.
- **Developed with Payton Group:** the paper discloses that the planar transformer was developed together with Renesas partner Payton Group, modelled in Ansys and analysed across several variations to minimise conduction and core losses.

Note This is an independent ProMagTech teardown, not a Renesas document. Every quotation is attributed; no white-paper figure is reproduced. All diagrams here are ProMagTech's own drawings. Read alongside the original — link in Section 9.

1. Why a "GaN white paper" deserves a line-by-line read from magnetics engineers

The authors are Renesas' power system architecture, GaN systems and GaN applications leads, and the narrative spine really is devices and topology. But if you build magnetics, the requirements are spread across four places: the matrix transformer section, the transformer design section, the 3 kW building-block description, and one sentence about the boost inductor in the Vienna front end.

Assembled, those four passages form a complete magnetics specification — one that includes an explicit disqualifier.

The industrial standing of the document matters as much as its content. The paper closes by stating that Renesas is collaborating with NVIDIA on the new 800 V architecture for data centers, and declares compliance with Open Compute Project tenets throughout. These are not one vendor's private experiments; they are candidates to become the industry default. A magnetics supplier that cannot read the structural requirements in this document will likely lose eligibility in the next round of AIDC power sourcing — before price is ever discussed.

2. Where magnetics sit in the architecture

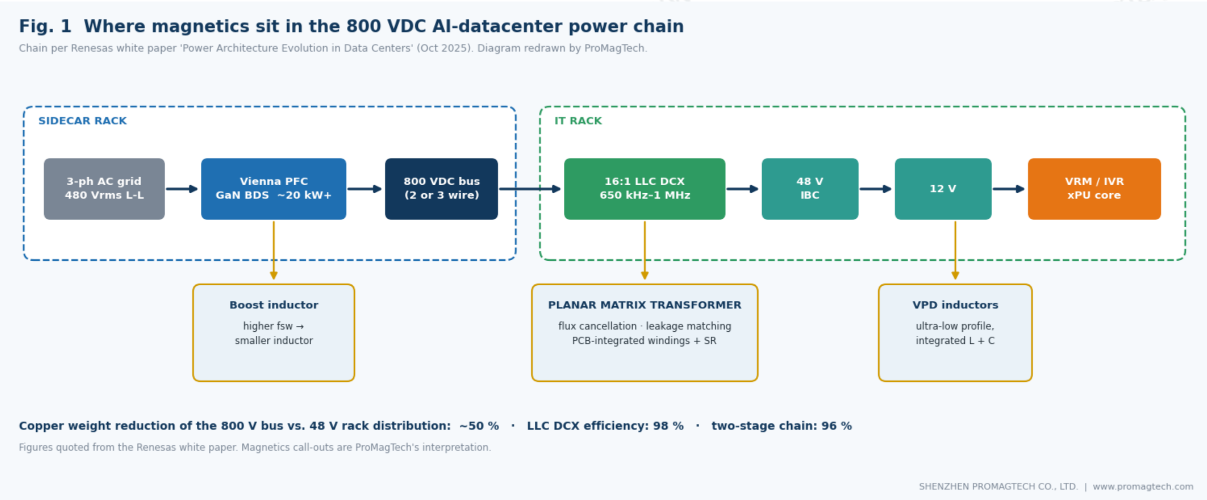

Fig. 1 — Magnetics call-outs along the 800 VDC power chain. Chain per the Renesas white paper; diagram redrawn by ProMagTech.

Stage	White paper description	Magnetics
Sidecar rack AC/DC front end	3-phase 480 Vrms line-to-line mains converted by a Vienna topology using GaN bi-directional switches (BDS) to generate the 800 V DC bus; power level trending to about 20 kW or higher (orig. Figure 4)	Vienna boost inductor
IT rack 16:1 DC/DC	800 V→48 V, LLC DCX topology, two stages stacked in series to support the full input voltage (orig. Figures 5 and 6)	Planar matrix transformer (core element)
64:1 extension	800 V→12 V, LLC DCX with an 8× secondary center-tap configuration (orig. Figure 12)	Matrix transformer with more secondary phases
Vertical power delivery / IVR	power delivered vertically from the opposite side of the SoC to cut distribution losses; inductors and capacitors combined with active elements in advanced packaging, all of extremely reduced height to fit the blade	Ultra-low-profile inductors, integrated magnetics

Table 1 — The four magnetics locations described in the white paper (figure numbers refer to the original document).

3. How 12 kW is assembled — and why it matters to the transformer

Fig. 2 How 12 kW is built: series-input / parallel-output stacking of a 3 kW block

Architecture described in the Renesas white paper. Diagram redrawn by ProMagTech.

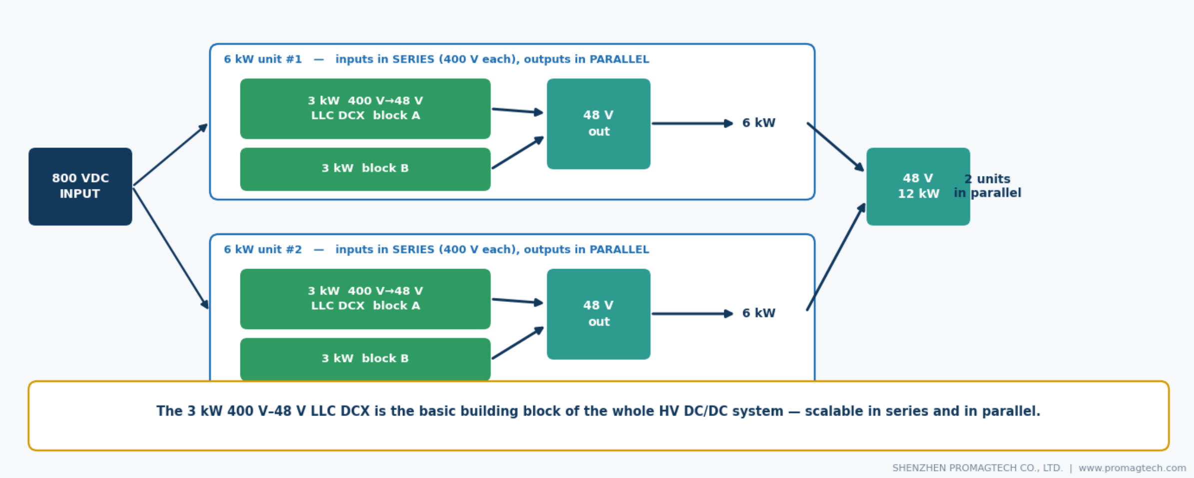

Fig. 2 — Series-input / parallel-output stacking of the 3 kW building block. Architecture per the white paper; diagram redrawn by ProMagTech.

The scaling scheme is stated plainly: two 6 kW converters are built separately and their inputs and outputs paralleled to handle 12 kW; each 6 kW unit is itself two 3 kW 400 V–48 V LLC DCX units with inputs in series (to hold 800 V) and outputs in parallel. The paper calls this "a scalable architecture supporting multiple blocks in parallel or in series."

> **Why this matters for magnetics** Series-input stacking means each transformer's primary sees 400 V while the assembly withstands 800 V — so insulation coordination must be evaluated at the stack level, not the block level. Parallel outputs mean current sharing between blocks becomes a system requirement, and current sharing is set largely by leakage inductance matching. Both consequences land on the transformer designer.

4. The matrix transformer: six stated advantages, decoded

The white paper defines the matrix transformer this way: unlike traditional transformers where different windings use separate magnetic components, it is designed and built as an array of elements inter-wired and sharing the same magnetic components so that the whole functions as a single transformer. The windings can be integrated into the main power PCB, combining synchronous rectification (SR) and output capacitors into a compact co-designed structure essential to the PCB layout and fabrication (orig. Figure 8).

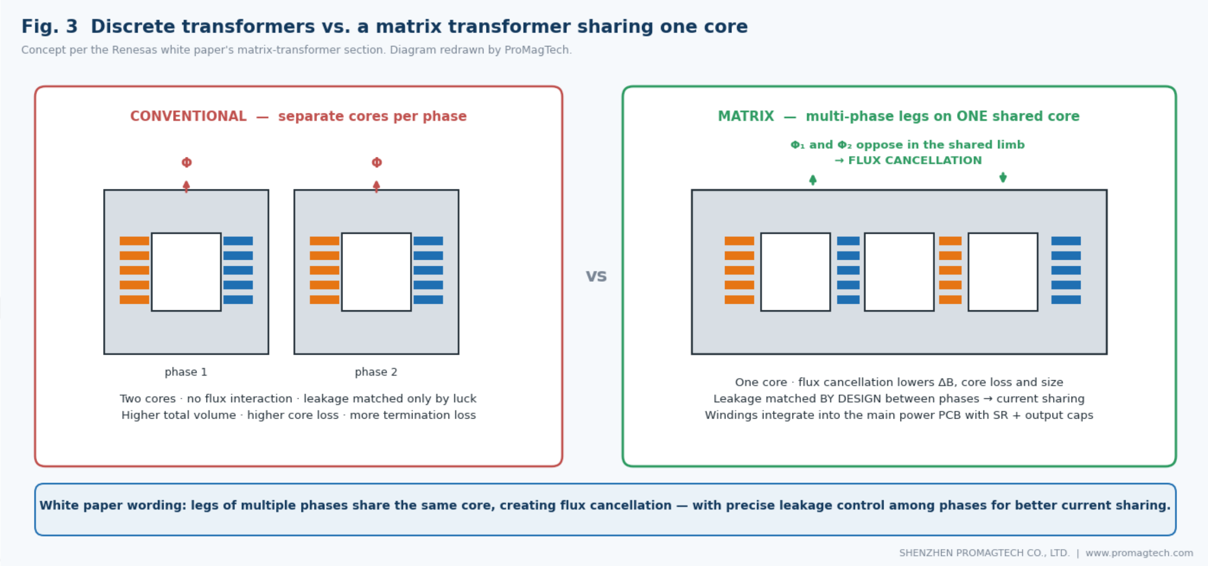

Fig. 3 — Discrete transformers versus a matrix transformer sharing one core. Concept per the white paper; diagram redrawn by ProMagTech.

Stated advantage (white paper)	Engineering meaning	What it demands of the supplier
Legs of multiphases sharing the same core creating flux cancellation	Adjacent phase fluxes partially cancel in the shared magnetic path, lowering effective flux swing	Winding direction must be designed to the phase relationship — not simply paralleled
Precise leakage control among phases for better current sharing	Phase-to-phase leakage sets phase impedance; leakage mismatch is current mismatch	Leakage consistency must be repeatable in production, not achieved by selection
Inter-phase winding configuration to create flux cancellation and reduce core loss and size	Core loss falls with ΔB to a power; volume follows	Requires design and simulation capability for flux-cancelling structures
Multiphase small transformers merge into a single core, optimizing size and minimizing magnetic losses	Integration traded for density — the fundamental value of the matrix approach	One part is now multi-phase: process and test complexity rise sharply
No need to parallel devices compared to single phase transformer	Secondary current is split across phases, lowering per-phase current	Transformer structure directly drives the semiconductor BOM — co-design is mandatory
Less termination loss compared to single phase transformer	Termination is a significant loss term on the low-voltage high-current side	PCB-integrated winding terminations are part of the design, not an afterthought

Table 2 — The six matrix-transformer advantages listed in the white paper, with engineering interpretation (advantage column quoted from the source).

Key Note the second item. The paper ties "precise leakage control among phases" directly to "better current sharing." That reframes leakage inductance: it is no longer only a parasitic to minimise, it is a controlled parameter that must be matched between phases. Without that matching, multi-phase paralleling loses current sharing — and the thermal margin goes with it.

5. Why conventional transformers are ruled out — three stated reasons

In the transformer design section the paper is unambiguous. Traditional transformers used in LLC applications typically require a separate ferrite core with windings, but are "not preferred in applications requiring ultra-high-power density" for three reasons:

- **Large size —** a discrete core-plus-winding assembly cannot be compressed into brick or blade dimensions at this power level.
- **Difficulty controlling leakage inductance —** conventional winding structures leave leakage exposed to process spread, which is fatal in a topology whose behaviour depends on resonant-parameter accuracy.
- **Inability to integrate SRs and capacitors as planar transformers can —** the most fundamental of the three, since integration capability determines whether SR devices, output capacitors and windings can be built as one co-designed structure.

The paper's conclusion: planar-based matrix transformers are preferable for LLC DCX applications. It further contrasts the two structures directly — with a non-integrated structure the flux distribution is not uniform, which results in higher core loss; with the integrated structure the flux is uniformly distributed, ensuring minimum core loss.

> **Reminder** Of the three reasons, the first two are matters of degree — a good design can improve them. The third is structural: a wire-wound transformer cannot, in principle, place its windings inside the main power PCB. The screening this imposes on magnetics suppliers is therefore structural, not incremental. A supplier without planar / PCB-integrated winding capability is not a weaker candidate; it is not a candidate.

6. Equal airgap — the most specific magnetics instruction in the paper

The white paper discloses that this transformer was developed together with Renesas partner Payton Group, that a 3-D model with a two-limb structure was built in Ansys (orig. Figure 10), and that several variations were analysed to minimise conduction and core losses. On the airgap it is explicit:

> "The equal airgap on all parts of the core provides several advantages:"
> (1) flux and losses are spread out
> (2) the core is fully utilized
> (3) lower core losses are achieved

Fig. 4 Concentrated gap vs. equal airgap — why the white paper calls it out

Concept per the Renesas white paper's transformer-design section. Diagram redrawn by ProMagTech.

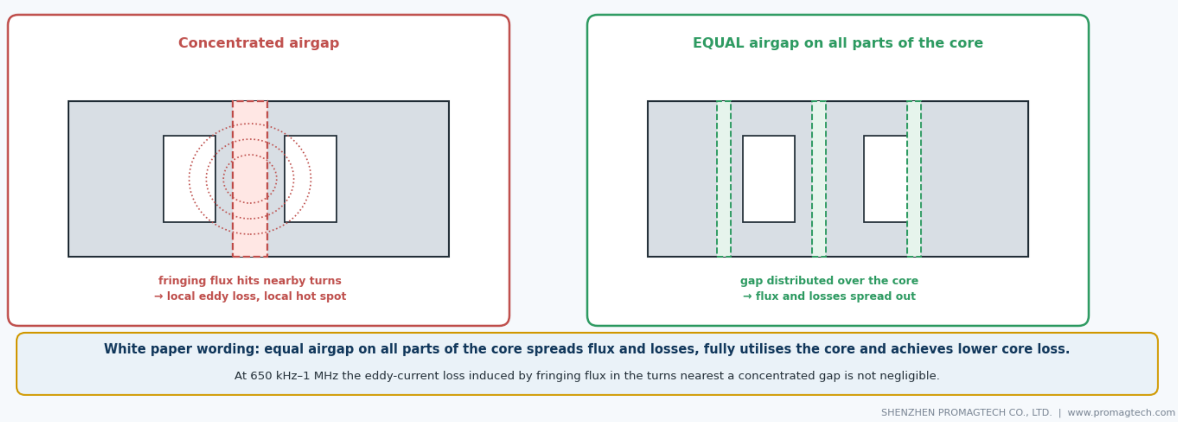

Fig. 4 — Concentrated gap versus equal airgap. Concept per the white paper; diagram redrawn by ProMagTech.

Engineering reading An equal airgap prevents flux from concentrating in one limb. A concentrated gap raises local flux density and local core loss, and it generates fringing flux that cuts perpendicularly through the nearest turns, inducing additional eddy-current loss. In the 650 kHz–1 MHz band that added loss is not negligible — and it is exactly the mechanism that makes a 1-D winding-loss model unreliable near a gap. The practical difficulty is process consistency: core grinding tolerance, assembly pressure and adhesive thickness all perturb the gap.

7. The 3 kW building block: the transformer's role in the circuit

The white paper gives a full design for the 3 kW 400 V–48 V LLC DCX (orig. Figure 9). The transformer-relevant content:

Design element	White paper content
Topology	Half-bridge LLC, designed and controlled as a DCX; always operates at the resonant frequency, achieving ZVS over the entire operating range
Primary devices	2 × Renesas TP65H030G4PRS, 650 V / 30 mΩ GaN FET, TOLT package (top-side cooling)
Secondary	Two phases of full-bridge SR, each using four RBE024N08R1SZN6 (80 V / 2.4 mΩ MOSFET, BSC package); each phase handles about 1.5 kW
Transformer structure	A matrix transformer structure is used: the two secondary-side windings of the 2-phase SR circuits are wound on two legs of the same transformer core, to optimise core size and minimise magnetic losses
Switching frequency	650 kHz – 1 MHz, to enable high power density (measured prototype ≈ 650 kHz)
Controller	Renesas RA6T2 MCU; open-loop control, no output voltage regulation and no real-time control loop required
Auxiliary supply	Renesas iW1825 flyback (integrated 700 V MOSFET, primary-side sensing, no optocoupler)
12 V variant	For a 12 V output the number of secondary phases increases and a center-tapped configuration with a low-side driver is used

Table 3 — Transformer-relevant elements of the 3 kW 400 V–48 V LLC DCX building block (content quoted from the white paper).

One sentence in this section deserves particular attention. The paper states that the primary consideration for using two-phase SR circuits is the ease of managing power loss, thermal, parasitic effects and gate driving at high power and high current — and to avoid the need to parallel devices and the associated difficulties on leakage control.

What that means The multi-phase structure of the transformer is not chosen only for the transformer's own size and loss. It simultaneously determines whether the secondary power devices must be paralleled. Magnetics structure is driving the semiconductor BOM and the thermal design — which is the operative meaning of "co-design" in this white paper.

8. Isolation, creepage and form factor: the conflict the paper admits

In the test results section the paper concedes a real difficulty: "Reinforced isolation requirements together with clearance and creepage requirements generate significant challenges to the form factor of the converter in the form of an onboard converter." The stated goal is to fit the entire 12 kW system into a size only slightly larger than a standard full-brick module.

> **ProMagTech's view** This is the most painful sentence in the document for a magnetics engineer. On one side, an 800 V input demands reinforced insulation, with clearance and creepage scaled per IEC 60664-1 lookup. On the other, power density demands the whole 12 kW fit a full brick. The two pull in opposite directions, and the collision happens inside the planar stack-up: insulation margin consumes interlayer spacing, interlayer spacing consumes window area, and window area consumes copper. There is no way to satisfy both without an explicit trade — which is why the insulation target must be set at design input, not discovered at sample stage.

9. The Vienna front end: one sentence about the boost inductor

Listing the advantages of GaN bi-directional switches in the Vienna rectifier, the paper cites three: low conduction loss, the need for only three floating HV drivers, and — the relevant one here — "reduction in boost inductor size due to higher switching frequency, enabling higher power density."

For an inductor supplier the implication is direct: for the roughly 20 kW-class Vienna front end in the sidecar rack, the dominant selection variable is migrating from "low frequency, high current" toward a loss-versus-volume balance at elevated switching frequency. As frequency rises, the frequency term in the Steinmetz relation gains weight and core loss climbs relative to copper loss — so a loss split derived from a low-frequency design cannot be carried over. It has to be recalculated.

10. Sources

All quotations in this article are drawn from the following public document. Readers are encouraged to consult the original:

- [Renesas Electronics, "Power Architecture Evolution in Data Centers", October 2025, Doc No. R30WP0013EU0100]

Figures in the original relevant to this teardown: Figure 4 (Vienna front end), Figures 5–6 (HV DC/DC architecture), Figure 8 (LLC DCX with matrix transformer), Figure 9 (3 kW building block), Figure 10 (Ansys equal-airgap 3-D view), Figure 12 (12 V output configuration). Those figures are copyright Renesas and are not reproduced here; all diagrams in this article were drawn by ProMagTech.

11. Frequently asked questions (FAQ)

Q Is a matrix transformer the same thing as a planar transformer?

A No. "Planar" describes how the windings are realised — as PCB or copper-foil layers. "Matrix" describes the architecture — multiple transformer elements sharing one magnetic component and inter-wired so the whole functions as a single transformer. The white paper combines both: it specifies a planar-based matrix transformer.

Q Why does the paper stress leakage matching rather than simply low leakage?

A Because in a multi-phase paralleled secondary, each phase's leakage sets its impedance, and leakage mismatch translates directly into current mismatch. The paper explicitly links "precise leakage control among phases" to "better current sharing." For a supplier this means both batch-to-batch and phase-to-phase leakage consistency belong in the DVP — a typical value alone is not sufficient.

Q What makes equal airgap difficult in production?

A Process consistency. Core grinding tolerance, assembly pressure and adhesive layer thickness all perturb the local gap, and at 650 kHz–1 MHz the fringing flux and local core-loss amplification caused by gap deviation are significant. Achieving it requires the grinding process and the assembly tooling to hold tolerance together.

Q What does the 650 kHz–1 MHz band mean for core material?

A It narrows the material window considerably. Powder cores and general-purpose power ferrites used at low frequency have excessive loss in this band; ferrite grades optimised for high frequency are required. Core loss also rises as a share of the total, so a loss split derived from a copper-loss-dominated low-frequency design no longer applies and must be recomputed.

Q How should a magnetics supplier read this white paper?

A As an eligibility list rather than a marketing document. Five capabilities are implied: planar / PCB-integrated windings; multi-phase matrix structure design; phase-to-phase leakage consistency control; equal-airgap process capability; and the ability to balance 800 V reinforced insulation against a full-brick form factor. A supplier missing any of these is filtered out on structure, before price is considered.

Q What is ProMagTech's experience in this chain?

A ProMagTech has published a 1 MHz / 3.3 kW matrix planar transformer application note (a half-bridge LLC 2-in-1 matrix planar transformer for 800 V HVDC AI datacenter power), alongside an IBC DCX transformer loss analysis and a 48 V AI server PSU flat transformer design guide. Feasibility for any specific project is confirmed through a design review against the customer's topology and specification.

12. Glossary

- **LLC DCX —** An LLC converter run open-loop at a fixed frequency at or near resonance, with near-unity gain, behaving as a DC transformer whose ratio is set by the turns ratio.
- **Matrix transformer —** Multiple transformer elements sharing one magnetic component, inter-wired so the assembly functions as a single transformer.
- **Equal airgap —** A design in which the gap is distributed uniformly across the core, spreading flux and losses and fully utilising the core.
- **Flux cancellation —** Partial cancellation of adjacent-phase fluxes in a shared magnetic path, reducing effective flux swing and core loss.
- **Termination loss —** Loss at the interface between winding terminations and the external circuit; significant on the low-voltage high-current side.
- **VPD (vertical power delivery) —** Delivering power to the SoC from the opposite side of the package to shorten the path and cut distribution loss.
- **GaN BDS —** Gallium-nitride bi-directional switch, realising an ideal four-quadrant switch and replacing two back-to-back series devices in a Vienna topology.

13. Further reading (ProMagTech)

- 1 MHz / 3.3 kW Matrix Planar Transformer Application Note
- 800 VDC Bus to 48 V — Magnetics Division of Labor in the AIDC Power Architecture
- AIDC Magnetic Components Full Power-Chain Applications (Pillar)
- IBC DCX Transformer Loss Analysis (48 V–12 V stage)
- 48 V AI Server PSU Flat Transformer Design Guide
- Insulation Design & Partial Discharge Testing — 800 V Platform Methodology
- SiC/GaN High dv/dt Switching — 800 V Platform EMI Co-Design
- 20–60 kW PFC Inductor Selection & Design Guide
- Thermal Design & Temperature-Rise Testing for High-Current Magnetics
- 800 V Power Magnetics Selection Reference (Pillar)

14. About ProMagTech

SHENZHEN PROMAGTECH CO.,LTD (founded 2013, Guangming District, Shenzhen) designs and manufactures planar transformers, matrix planar transformers, flat-wire inductors and common-mode chokes for AI-datacenter power, 800 V EV OBC, PV inverters and energy-storage PCS.

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