SHENZHEN PROMAGTECH CO.,LTD. | High-Performance Magnetic Solutions

Technical Application Note · www.promagtech.com

1 MHz / 3.3 kW Half-Bridge LLC 2-in-1 Matrix Planar Transformer

Design overview for 800 V HVDC AI-datacenter power (±400 V → 50 V DCX stage)

Item	Detail
Document	1 MHz 3.3 kW 2-in-1 Matrix Planar Transformer — Application Note
Application	800 V HVDC AI datacenter, in-rack DC-DC (±400 V → 50 V) DCX stage
Revision / Date	EN-1.0 / 2026-06-25
Classification	Public — Technical Resource
Website / Contact	www.promagtech.com · Zhang Yong · +86 135 3765 8938 · zyong@promagtech.cn

ProMagTech — flat-wire inductors & planar transformers for EV, energy storage, solar and AI-datacenter power.

0. Scope & Disclaimer

This application note describes ProMagTech's design approach for a 1 MHz, 3.3 kW half-bridge LLC main transformer built as a 2-in-1 matrix planar structure, intended for the in-rack DC-DC (DCX) stage of 800 V HVDC AI-datacenter power. It is a design overview for engineers and sourcing teams evaluating high-frequency, high-current planar magnetics.

> **Note** Figures and values shown are engineering design targets and estimates for illustration. Final loss, temperature rise, efficiency and AL tolerance are confirmed by sample test data for each project. Core geometry follows the ELP58/11/38 datasheet; material loss (Pv) is confirmed against the selected MHz-grade ferrite curve.

Key Takeaways

- A 1 MHz, 3.3 kW half-bridge LLC main transformer built as a 2-in-1 matrix planar structure for the in-rack ±400 V → 50 V DCX stage of 800 V HVDC AI-datacenter power.
- Turns ratio 4:1, realized as two ELP58-class cores — 2 primary turns in series, 1 secondary turn in parallel per core.
- Peak flux density ≈ 42 mT at 1 MHz by sizing core area Ae ≈ 300 mm²; windings are 2 oz, 8-layer, S-P-S-P interleaved.
- Sub-15 mm low-profile module via in-house ground ELP58 + PLT (core ≈ 10.6 mm, module ≈ 13–14 mm).
- Efficiency targets: transformer ≈ 99 %, module ≈ 97.5–98 % (design targets, confirmed by sample test data).

1. Application Overview

As AI-datacenter racks move toward 800 V HVDC, power is distributed as ±400 V and stepped down close to the load. A key building block is the in-rack DCX stage that converts one 400 V rail to ~50 V at multi-kW level, near-resonant at high frequency for fixed-ratio, soft-switched efficiency. The magnetic challenge is a low-profile, high-current transformer that stays efficient at 1 MHz — precisely the domain of flat-wire and planar magnetics.

When is 1 MHz the right choice? Higher frequency is not automatically better — for a general 3 kW / 800 V LLC transformer the practical frequency knee is often around 400 kHz, where 1 MHz would only add loss and thermal stress. This design targets the specific case where a sub-15 mm low-profile module for 800 V HVDC AI-datacenter racks makes 1 MHz worthwhile, managing the loss penalty with a 2-in-1 matrix planar structure, flat-wire/planar windings, S-P-S-P interleaving and a low flux density (≈ 42 mT).

2. Electrical Specifications

Parameter	Value	Note
Input bus Vin	400 VDC	one rail of a ±400 V bipolar bus; 650 V GaN
Topology	Half-bridge LLC + sync. rectification	primary square-wave amplitude = Vin/2 = 200 V
Output Vout	50 VDC	feeds downstream point-of-load VRMs
Rated power Pout	3.3 kW	
Rated output current	66 A	
Switching = resonant freq.	1 MHz	DCX near-resonant, fixed gain
Module height	< 15 mm	low-profile, board-embedded
Target eff. (transformer)	≥ 99%	core + copper; sample-confirmed
Target eff. (module)	≥ 97.5%	incl. GaN / SR / resonant tank

Table 1 Electrical specifications

3. Topology & Turns Ratio

Two low-profile planar cores (A and B) are combined into a 2-in-1 matrix: primaries in series, secondaries in parallel. This splits the high output current between two cores for balanced current sharing and a low-profile footprint.

```
Half-bridge LLC gain at resonance  M = 1  ->  Vout = (Vin/2) / N
N = (Vin/2) / Vout = 200 V / 50 V = 4   ->   Np : Ns = 4 : 1
Matrix split: cores A & B each 2 primary turns (series), 1 secondary turn
(parallel)
```

Winding	Connection	Result
Primary	A & B, 2 turns each, in series	total Np=4, 200 V, 100 V per core
Secondary	A & B, 1 turn each, in parallel	total Ns=1, 66 A, 33 A per core
Overall ratio	(2+2) : 1	4 : 1

Table 2 2-in-1 matrix connection

4. Flux-Density Design

Volts-per-turn are fixed by the ratio (200 V across 4 turns = 50 V/turn). Peak flux and flux density follow directly; core cross-section Ae is sized to keep 1 MHz core loss in check.

```
Peak flux per turn  Phi_pk = (V per turn) / (4 · fs) = 50 / (4×10^6) = 12.5 uWb
Peak flux density   Bpk = Phi_pk / Ae
With Ae = 300 mm² (ELP58 class):
Bpk = Vcore / (4 · fs · Ncore · Ae) = 100 / (4×10^6 × 2 × 300×10^-6) = 41.7 mT
```

Target Bpk	Required Ae / core	Note
50 mT	≥ 250 mm²	upper bound
42 mT	≥ 300 mm²	design point

Table 3 Flux density vs. core cross-section (50 V/turn, 1 MHz)

4.1 Core & Material

Parameter	Value	Note
Core	ELP58/11/38 (E58/11/38)	planar E, per datasheet
Effective area Ae	308–310 mm²	-> Bpk ≈ 40.6 mT at 2 turns/core
Effective volume Ve	25,000 mm³ / set	two cores = 50,000 mm³
Center leg	8.1 × 38.1 mm	= 308 mm²
Material	MHz-grade low-loss MnZn (e.g. 3F46 class)	nanocrystalline not used at 1 MHz
Gap / AL	center-leg ~0.2 mm -> AL ≈ 1500 nH	gapped on center leg only

Table 4 ELP58/11/38 key data (per Ferroxcube / EPCOS datasheet)

5. Resonant Tank (Lm / Lr / Cr)

Element	Value	Basis / note
Lm magnetizing	12 µH	set by ZVS; Im,pk ≈ 4.2 A
Lr resonant	2 µH	Ln = Lm/Lr = 6, Q ≈ 0.3–0.5
Cr resonant	≈ 12.7 nF	from fr = 1 MHz; C0G/NP0, ≥ 630 V

Table 5 Resonant tank parameters

```
Cr = 1 / ((2π·fr)² · Lr) = 1 / ((2π×10^6)² × 2×10^-6) ≈ 12.7 nF
Im,pk = (Vin/2)·(T/2)/Lm = 200 × 0.5×10^-6 / 12×10^-6 ≈ 4.2 A  (ZVS)
```

Because strong interleaving minimizes leakage, the resonant inductor Lr is realized as a dedicated low-profile planar inductor (2 µH, ~18.5 A rms, 1 MHz), not integrated leakage.

6. PCB Winding Stack-up

The winding is an 8-layer planar sub-board embedded in the main board. The generous ELP58 window (≈ 21 mm width) allows wide copper, so 4 parallel secondary layers carry the 37 A/core with balanced current density.

```
Skin depth at 1 MHz  δ = 66/√f(Hz) ≈ 0.066 mm (66 μm)
-> 2 oz copper (≈ 70 μm ≈ 1δ); carry current by parallel layers, not thicker copper
-> Strong S-P-S-P interleaving to break the MMF staircase and cut proximity loss
```

Layer	Function	Turns / parallel	Current	Note
L1 (Top)	Secondary S	1T / 1 of 4 parallel	~9.3 A/layer	top bus, near SR FET
L2	Primary P·turn1 (a)	turn1 / 1 of 2	~9.3 A/layer	HV input
L3	Secondary S	parallel	~9.3 A/layer	
L4	Primary P·turn2 (a)	turn2 / 1 of 2	~9.3 A/layer	t1→t2 buried-via series
L5	Primary P·turn2 (b)	turn2 // L4	~9.3 A/layer	
L6	Secondary S	parallel	~9.3 A/layer	
L7	Primary P·turn1 (b)	turn1 // L2	~9.3 A/layer	
L8 (Bot)	Secondary S	1T / 1 of 4 parallel	~9.3 A/layer	bottom bus

Table 6 8-layer transformer sub-board (per core window; A/B identical)

Summary: secondary = L1/3/6/8 (4 parallel = 1 turn, 37 A → ~9.3 A/layer); primary turn1 = L2//L7, turn2 = L4//L5, in series (2 turns). Copper is 2 oz throughout; board ≈ 1.4–1.8 mm. Design target Rac/Rdc ≤ 1.4 at 1 MHz (FEA-verified). Secondary bus vias are placed symmetrically for even current sharing.

7. Loss Budget (design targets)

7.1 Transformer

Item	Estimate	Note
Core loss	~12–15 W	MHz ferrite @ ~40 mT / 1 MHz / 100°C, Ve = 50 cm^3 (two cores)
Primary copper	~7–10 W	Ip,rms ≈ 18.5 A
Secondary copper + vias	~8–12 W	~37 A rms per core, 4-layer parallel
Transformer total	**~27–37 W**	**→ ~99% (target, sample-confirmed)**

Table 7 Transformer loss budget

7.2 Module

Item	Estimate	Note
Transformer	~30 W	see 7.1
Resonant inductor + Cr ESR	~6–8 W	
Primary GaN (cond. + 1 MHz sw.)	~10–20 W	
Secondary SR (66 A)	~15–25 W	
Module total	**~65–90 W**	**→ ~97.5–98% (target)**

Table 8 Module loss budget

8. Thermal Design

Double-sided conduction: the core bottom couples through a ≥ 6 W/m·K gap pad to a cold plate; the top face and secondary SR FETs are covered by an aluminium heatsink for forced-air cooling.

```
Gap-pad resistance  θ = t/(k·A) = 1×10^-3 / (6 × 44×10^-4) ≈ 0.04 K/W
-> ~1.2 K rise for 30 W; hot-spot governed by core interior and secondary copper
```

- Symmetric via placement on the paralleled secondary layers ensures even current sharing and avoids local hot spots.
- With a 60°C cold plate, transformer hot-spot stays within ferrite and high-Tg PCB limits (confirmed by IR/thermocouple on samples).

9. Low-Profile Core — In-House Ground ELP58 + PLT

To meet the < 15 mm module envelope, ProMagTech grinds the ELP58 core legs in-house to the required window height while keeping the yoke and outer-leg cross-sections intact — so flux density and 1 MHz core loss are unchanged. A standard PLT58/38/4 plate closes the magnetic path.

Item	Value	Note
Ground E-core half	≈ 6.55 mm	yoke retained + leg ground to window ~2.5 mm
PLT58/38/4 plate	≈ 4.0 mm	standard closing plate
Core height (E + PLT)	≈ 10.6 mm	low-profile
8-layer sub-board	≈ 1.8 mm	fits window with ~0.7 mm clearance for potting/tolerance
Module height	≈ 13–14 mm	incl. gap pad + heatsink → < 15 mm
Footprint	≈ 60 × 80 mm	two cores + resonant inductor + SR

Table 9 Low-profile stack (ground ELP58 + PLT)

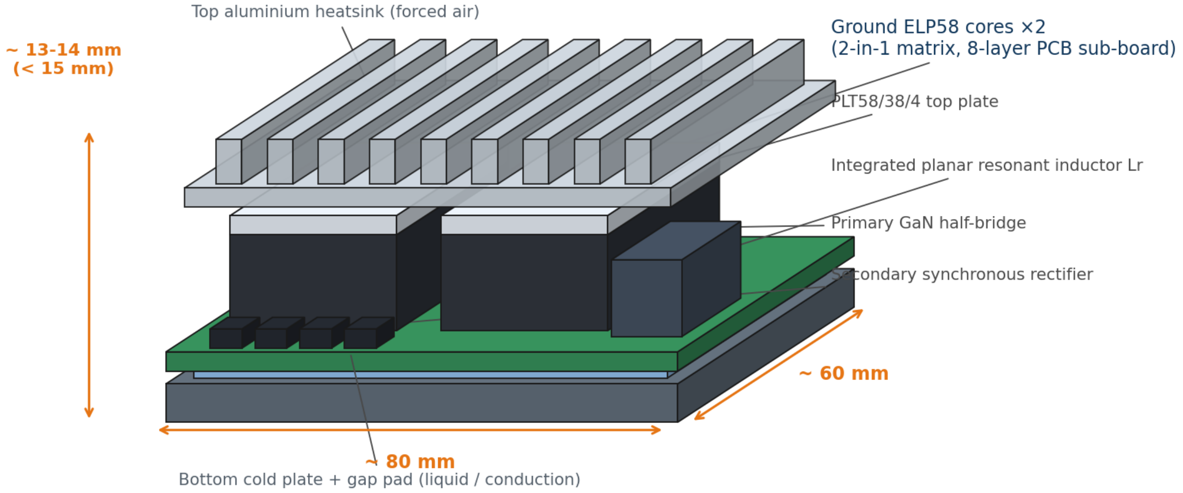
> **Process advantage** In-house core grinding lets ProMagTech tune both the low-profile height and the center-leg gap (AL) with tight, repeatable tolerance — the ground face is also the gap/mating face, controlling AL spread (target ±5%) batch to batch.

10. Module Views

Renderings below show the assembled module, the side stack-up and the top layout. Illustrative; final mechanical drawings govern.

Fig. 1 Module rendering - 2-in-1 Matrix Planar Transformer (800 V HVDC DCX stage)

Illustration; Z-axis exaggerated for clarity - actual is a low-profile module.



Illustration; Z-axis exaggerated for clarity — actual is a low-profile module.

Fig. 2 Side stack-up

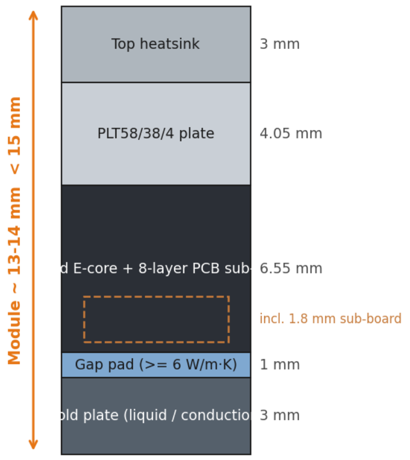
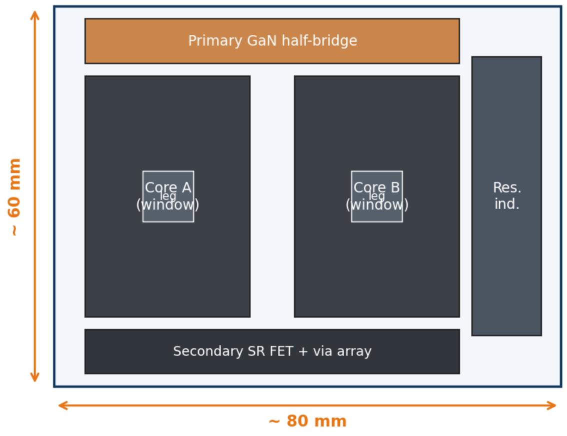


Fig. 3 Top layout (footprint ~ 60 x 80 mm)



Left: side stack-up (ground E + PLT, module ~13–14 mm). Right: top footprint ≈ 60 × 80 mm.

11. Validation & Test

Every design passes a structured validation flow before sample release. Simulation confirms the magnetic and thermal design; measurement confirms real performance on hardware.

Validation item	Method / instrument	Acceptance
Flux density Bpk	Magnetic FEA + AL from sample	≤ 50 mT
AC winding resistance	FEA + impedance analyzer	Rac/Rdc ≤ 1.4 @ 1 MHz
Resonant Lm / Lr / Cr	Precision LCR / network analyzer	fr = 1 MHz ±3%
Ground-core AL consistency	Sampled LCR	AL 1500 nH ±5%
ZVS	Oscilloscope + HV differential probe	ZVS across load range
Efficiency	Precision power analyzer	meets target at full load
Temperature rise / hot-spot	Thermocouple + IR, cold plate	within core & PCB limits
Secondary current sharing	IR imaging / per-layer probing	no local over-heating
Insulation / hi-pot	Hi-pot + insulation resistance	pass per specification
Dimensions / assembly	Measured stack height	< 15 mm

Table 10 Validation checklist

12. Manufacturing & Quality

- **Winding technology:** flat-wire (edge-wound) and multilayer planar PCB windings for low DCR, low AC loss and high current density.
- **In-house core grinding:** low-profile core shaping and center-leg gapping with controlled AL tolerance.
- **Materials:** MHz-grade low-loss MnZn ferrite, high-Tg PCB, C0G/NP0 resonant capacitors, 650 V GaN-compatible layout.
- **Inspection scope:** inductance, DCR, DC bias, leakage inductance, turns ratio, hi-pot and insulation resistance per approved sample record.

13. Frequently Asked Questions

What is a 2-in-1 matrix planar transformer?

It uses two low-profile planar cores with primaries in series and secondaries in parallel, splitting the high output current between two cores for balanced current sharing, low DCR and a low-profile footprint — ideal for high-frequency LLC / DCX converters.

Why run the 800 V HVDC DCX transformer at 1 MHz?

Near 1 MHz the magnetics shrink and the module becomes low-profile, while near-resonant ZVS keeps efficiency high. The trade-off — higher AC winding and core loss — is managed with flat-wire / planar windings, interleaving and a low flux density.

How is flux density controlled at 1 MHz?

Volts-per-turn are fixed by the ratio, so peak flux per turn is fixed; Bpk = flux / Ae depends only on core cross-section. Ae ≈ 300 mm² (ELP58 class) gives Bpk ≈ 42 mT, keeping 1 MHz core loss in check.

How is the module kept under 15 mm tall?

ProMagTech grinds the ELP58 legs in-house to the needed window height while keeping the yoke and outer-leg cross-sections intact, then closes with a standard PLT plate — a core of ≈ 10.6 mm and a module of ≈ 13–14 mm, with flux density and core loss unchanged.

What efficiency can a 1 MHz 3.3 kW LLC planar transformer reach?

Design targets are ≈ 99 % for the transformer and ≈ 97.5–98 % for the full module — engineering estimates confirmed by sample test data per project.

Does ProMagTech make custom planar transformers and flat-wire inductors?

Yes. ProMagTech (Shenzhen, since 2013) designs and manufactures flat-wire inductors, planar transformers, common-mode chokes and PFC inductors, with in-house core grinding and a defined inspection scope. Samples and engineering review are available on request.

14. Glossary

800 V HVDC — High-voltage DC distribution (±400 V bipolar or 800 V monopolar) used in AI-datacenter racks to cut current and copper loss.

DCX — A fixed-ratio DC transformer stage, usually an LLC converter near resonance for high, load-independent efficiency.

Planar transformer — A transformer whose windings are PCB copper layers around a flat ferrite core, giving low profile, repeatable AC resistance and good thermal coupling.

Flat-wire (edge-wound) winding — Rectangular copper wound on edge for high copper fill, low DCR and low temperature rise at high current.

ZVS — Zero-voltage switching — soft switching that lowers switching loss, enabled in LLC by the magnetizing current.

15. References

- Open Compute Project — Power architecture evolution for 800 V DC data centers (opencompute.org).

- Ferroxcube — E58/11/38 planar core and 3F46 material datasheets (ferroxcube.com).
- ProMagTech — Flat-wire vs round-wire inductors, planar transformer and 800 V platform selection guides (promagtech.com/technical-resources).

16. About ProMagTech

SHENZHEN PROMAGTECH CO.,LTD (founded 2013, Guangming District, Shenzhen) designs and manufactures power magnetic components — flat-wire inductors, planar transformers, common-mode chokes and PFC inductors — for EV on-board chargers and DC charging stations, energy-storage PCS, solar inverters, industrial power and AI-datacenter power.

Contact: Zhang Yong · +86 135 3765 8938 · zyong@promagtech.cn · www.promagtech.com