Planar Magnetics for Auxiliary Power Supplies – A Case Study

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Power Magnetics - High Frequency Workshop

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Introduction

- On-board, low-power auxiliary power supplies provide operating power for a variety of electronic and industrial equipment
  - Appliances
  - Instruments
  - Metering
- Typical low-power AC-DC switching power supplies
  - Use integrated power supply controllers
    - Reduced component count
  - Use wire wound ferrite core transformers
  - Operating frequencies <150 kHz

Planar Magnetics for Auxiliary Power Supplies

- Planar magnetics – an advanced solution for auxiliary power supplies
- Limited adoption so far due to perception
  - Complex to design
  - High tooling costs
- Provide benefits for low- and high-volume designs
  - Dramatically simplify the transformer manufacturing process
  - Provide consistent electrical performance
  - Enable transformer manufacturing in the same flow as PCB assembly

Primary and secondary PCB winding separated by insulator

Advantages/Disadvantages of Wound Magnetics

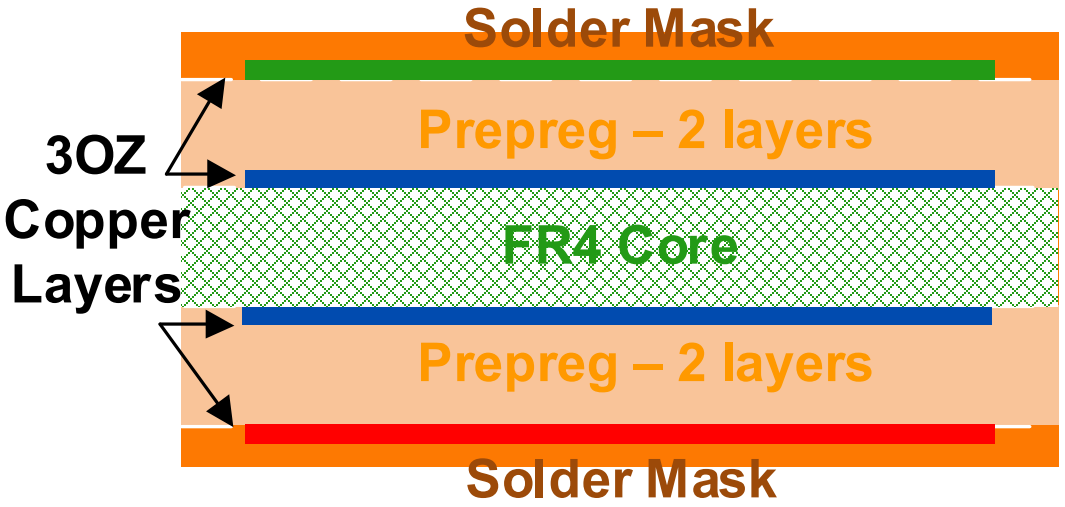
- Disadvantages
  - For low-volume design
  - Expensive manual labor
  - High parameter tolerances
  - Higher leakage due to limited splitting options (pins and connections)
- Advantages
  - Allows larger number of turns
  - Smaller inter-winding capacitance
  - Samples for testing quickly available

Advantages of Planar Magnetics

- Higher surface-to-volume ratio – more effective at conducting heat
- Height of planar magnetic device is typically 25% to 50% less than wire-wound
- Unrivalled parametric repeatability
- Easy interleaving
  - Allows reduction of leakage inductance
  - Reduces high-frequency winding losses
- Modularity

Market Shifts Making Planar Attractive

- Planar magnetics have become much more cost competitive
- PCB manufacturers are embracing PCB-based technology
- Simple rules ensure easy availability and low cost
  - Limit PCBs to four layers
  - ≤ 3-ounce copper
  - Uniform dielectric thickness throughout the stack
  - Use standard core or prepreg thickness options available from the PCB manufacturer
  - Minimize blind and buried vias



PCB vertical structure for four layers

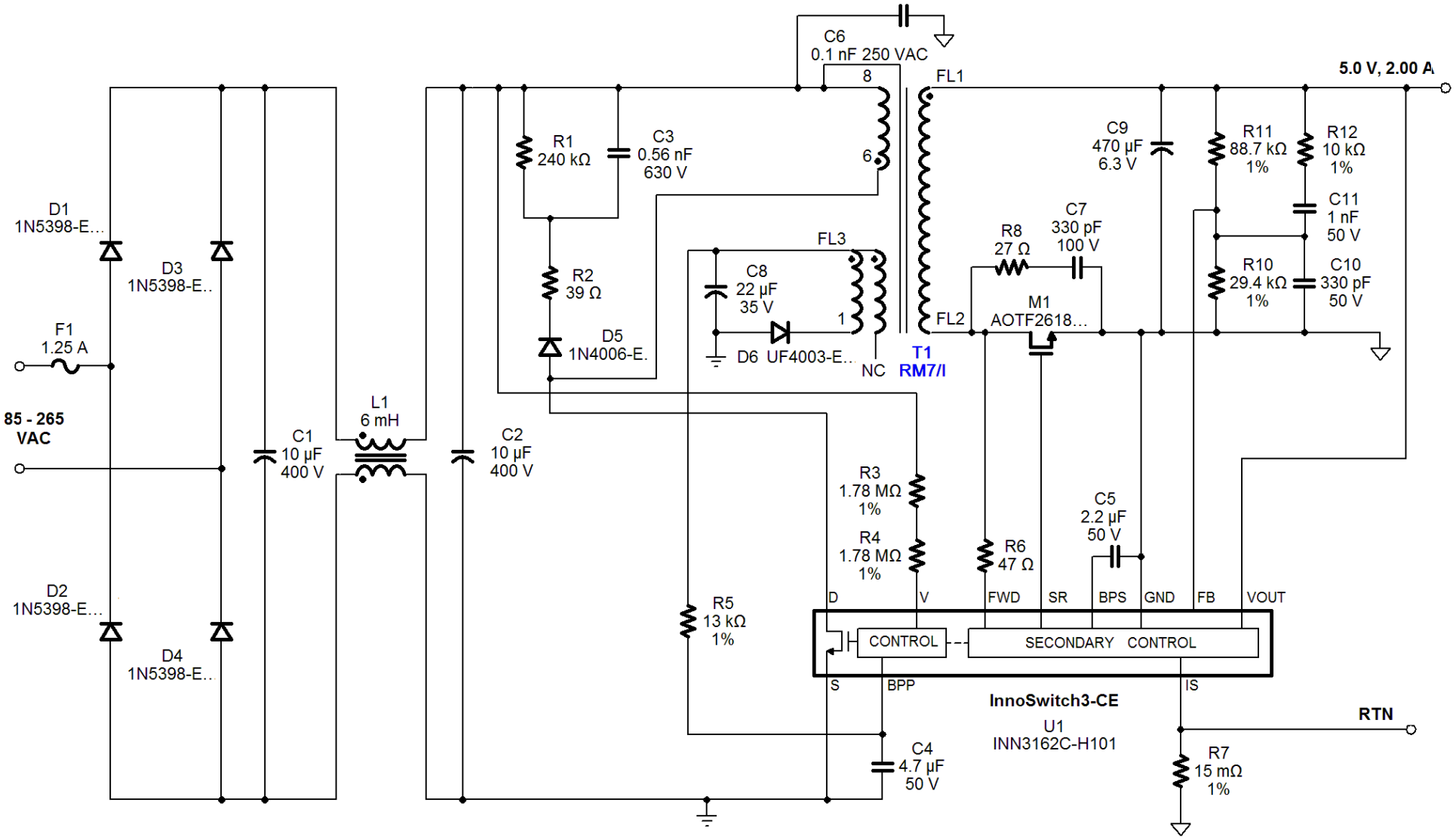
Case Study: Analysis, Considerations & Approach

- Evaluation of 10 W auxiliary switch mode power supply (SMPS) using planar magnetics
- Four different transformers compared for this study
- One wire wound transformer used for reference
- Three different transformer constructions tested for planar

Design Example – Technical Specification

- Prototype specification and controller
  - Output: 5 V / 2 A
  - Input: 85 VAC to 265 VAC
  - 65 - 75 kHz operation
- InnoSwitch™3-CE INN3163C IC from Power Integrations
  - Flyback circuit switcher
  - Integrated 650 V MOSFET
  - Synchronous rectification
  - $I_{P(MAX)}$ = 550 mA

Schematic for 5 V / 2 A PSU Used in Case Study



Magnetics Design – Wound Transformer

Expert PI Expert Online

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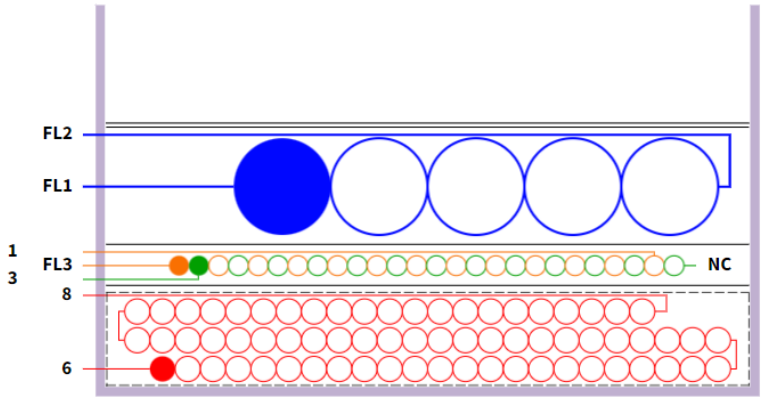
File Edit View Active Design Tools Help

Design Passed (No Optimization)

Schematic | Design Results | Board Layout | BOM | Magnetics Designer | Design Evaluation | Design Notes

Mechanical Diagram



Winding Info

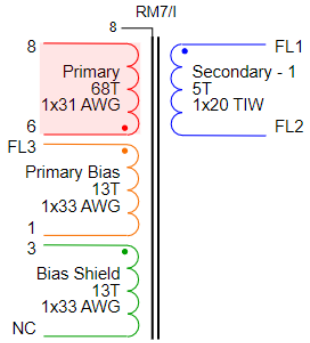
Stack Fill Factor: 66.76%;
Total Copper Weight: 2.03g
Copper Loss: 0.265W; Total Transformer Loss: 0.298W

33.51%H; Secondary - 1; IRMS = 3.31A;
1L; 5T; 1x20 TIW; CMA = 309.37 Cmils/A; LENw = 21.6 cm;
RDC = 9.16 mΩ; RAC = 17.12 mΩ; WeightCU = 1 g; Pw = 175.82 mW;

7.51%H; Primary Bias;
0.87L; 13T; 1x33 AWG; LENw = 48.6 cm;
Bias Shield;
0.9L; 13T; 1x33 AWG; LENw = 48 cm;

25.74%H; Primary; IRMS = 0.23A;
2.88L; 68T; 1x31 AWG; CMA = 348.89 Cmils/A; LENw = 223.7 cm;
RDC = 1227.86 mΩ; RAC = 1362.15 mΩ; WeightCU = 0.8 g; Pw = 89.09 mW;

Electrical Diagram



Core / Coil Former Parameters

Core	RM7/I
Core Part Number	RM7/I-3F3
Ferrite Material	PC95
Coil Former Part Number	RM7/I - (P4 + S4)
Orientation	Vertical
Available Pins	8
Bobbin Window Length, mm	6.6
X-Tolerance, %	0
Maximum Stack Height, mm	3.175

Winding Parameters

Type	Power
Name	Primary
Turns	68
Layers	2.88
Color	Red
Wire Type	Single Core
Wire Size	31
Wire Grade	Heavy Build
Filar	1
Wire Tolerance, %	0

Building instructions

LIST OF MATERIALS

Item	Description
[1]	Core: RM7/I, PC95, gapped for ALG of 281 nH / T^2
[2]	Bobbin: Generic, 4 pri. + 4 sec.
[3]	Tinned copper wire 0.5mm
[4]	Varnish
[5]	Single core wire: 31 AWG (0.26 mm), insulation Heavy Build
[6]	Separation Tape: Polyester film [1 mil (25.4 micrometers) base thickness], 6.6 mm wide
[7]	Single core wire: 33 AWG (0.21 mm), insulation Heavy Build
[8]	Triple Insulated Wire: 20 AWG (1 mm)

SHOW

Design of Planar Transformer

- Safety requirement for reinforced insulation
  - Minimum internal distance through isolation (DTI)

    $DTI_{min} = 0.4\ mm$ & $DTAir_{min} = 6.4\ mm$
- Tracks width – from current density
  - For boundary operation, assume initial current density is

    $CD_{init} = 8.5 \frac{A}{mm^2}$ $(230CMA)$

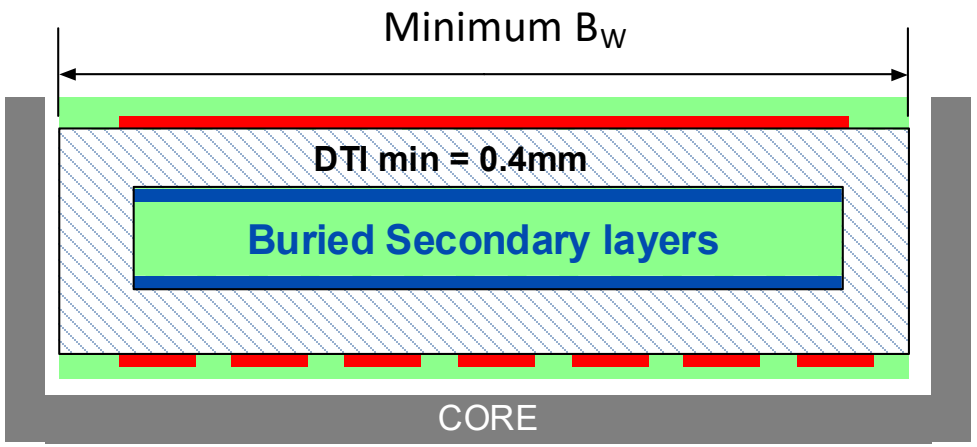
    and track thickness for 3 ounces is $TT_{3OZcopp} = 108\ \mu m$
  - Secondary: For $IRMS_{sec} = 4\ A$

    $TWsec = \frac{IRMS_{sec}}{CD_{init}\ TT_{3OZcopp}} = 4.53\ mm$
  - Considering single track in a layer, horizontal space of required is

    $$BW_{min} = TWsec + 2 * DTImin = 5.4\ mm$$
  - Primary: For $IRMSprm = 0.25\ A$ single primary track width is $TW_{prm} = 0.29\ mm$
  - Assuming the same BW, the maximum primary turns in layer (TIL) possible are

    $TIL_{prm} = 11$ (with 0.2mm reserved between turns and core)

    Primary AC factors $\varphi_{AC} = \frac{TT_{3OZcopp}}{\sqrt{\frac{TIL_{prm}\ TW_{prm}}{BW_{min}}}\ D_{skin\ 75\ kHz}} = 0.31$; $\varphi_{prox2L} = 1.5$; $\varphi_{prox4L} = 3$



Planar Design – Core Selection E22/6/16

- Check for the minimum required bobbin width

$$BW_{min} = 5.45\ mm$$

$$\boldsymbol{BW\_E22 = \frac{Bmin - Cmax}{2} = 5.65\ mm}$$

- Primary inductance is

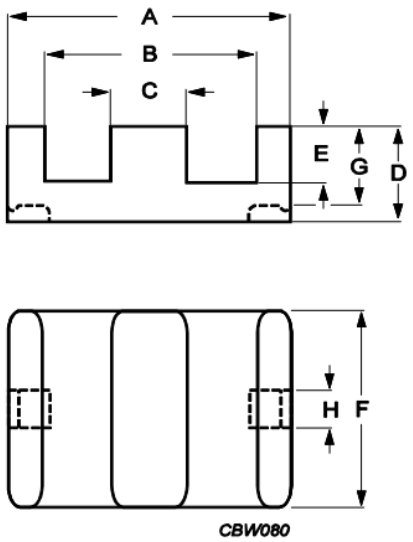
$$\boldsymbol{Lp = \frac{Vinmin}{Ip\ Fnop}} = 1.3\ \text{mH}$$

- 44 turns are required for

$$Bm = 0.32\ T$$

  - With $TILprm = 11$ turns, four layers are needed to complete the primary winding

E22/6/16/R

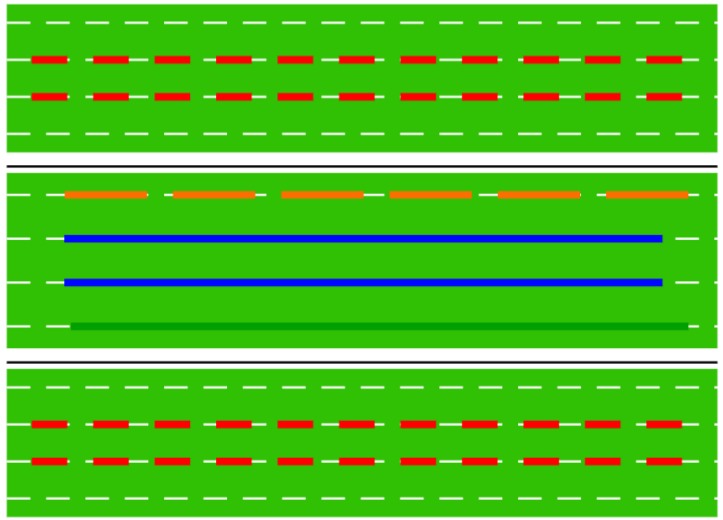


Effective parameters			
	Parameter	**Value**	**Unit**
Σ(I/A)	*core factor (C1)*	0.324	mm^{-1}
Ve	*effective volume*	2100	mm^3
Le	*effective length*	26.1	mm
Ae	*effective area*	78.5	mm^2
Amin	*minimum area*	72.6	mm^2
m	*E22/6/16/R*	≈ 6.5	g/pcs
m	*PLT22/16/2.5/S*	≈ 4	g/pcs

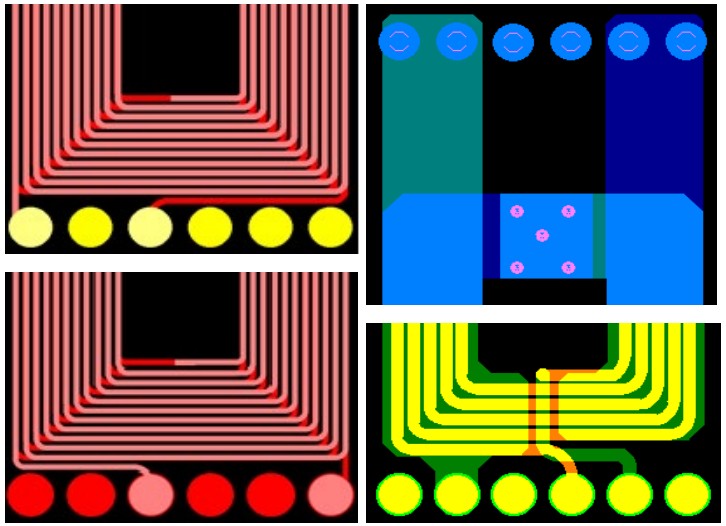
Dimensions for product: E22/6/16/R						
	Nom	**Tol +**	**Tol -**	**Max**	**Min**	**Unit**
A	21.80	0.40	0.40	22.20	21.40	mm
B	16.80	0.40	0.40	17.20	16.40	mm
C	5.00	0.10	0.10	5.10	4.90	mm
D	5.70	0.10	0.10	5.80	5.60	mm
E	3.20	0.10	0.10	3.30	3.10	mm
F	15.80	0.30	0.30	16.10	15.50	mm
G	4.70	0.15	0.15	4.85	4.55	mm
H	2.80	0.20	0.00	3.00	2.80	mm

Split Primary Planar Transformer – Design Constraints

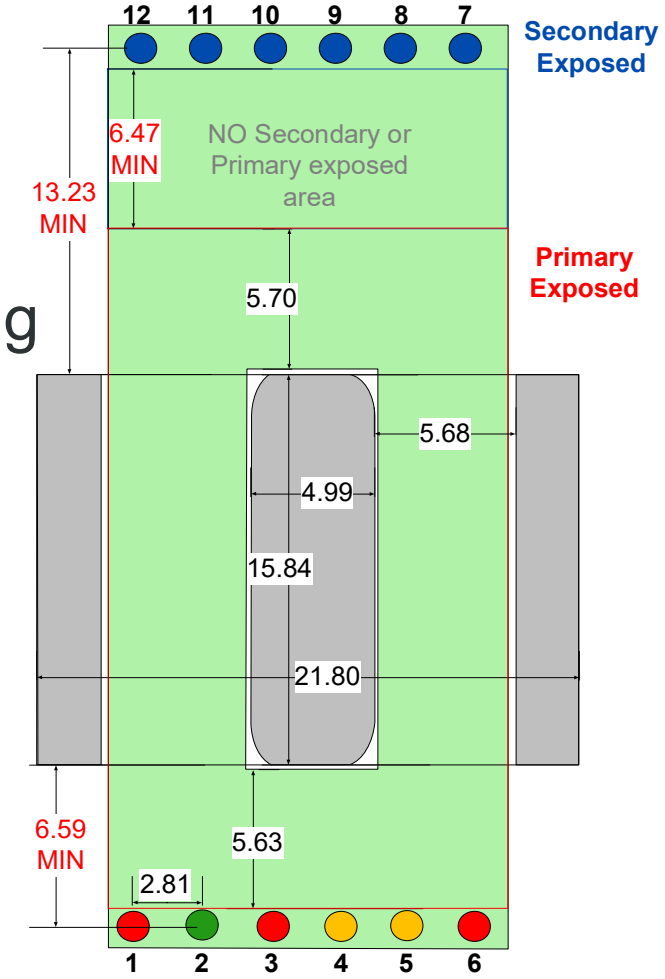
- Split primary construction
  - PCB1: Two layers 22 turns – first half primary winding
  - PCB2: Screen, two layers secondary, bias
  - PCB3: Two layers 22 turns – second half primary winding



Winding cross-section illustration

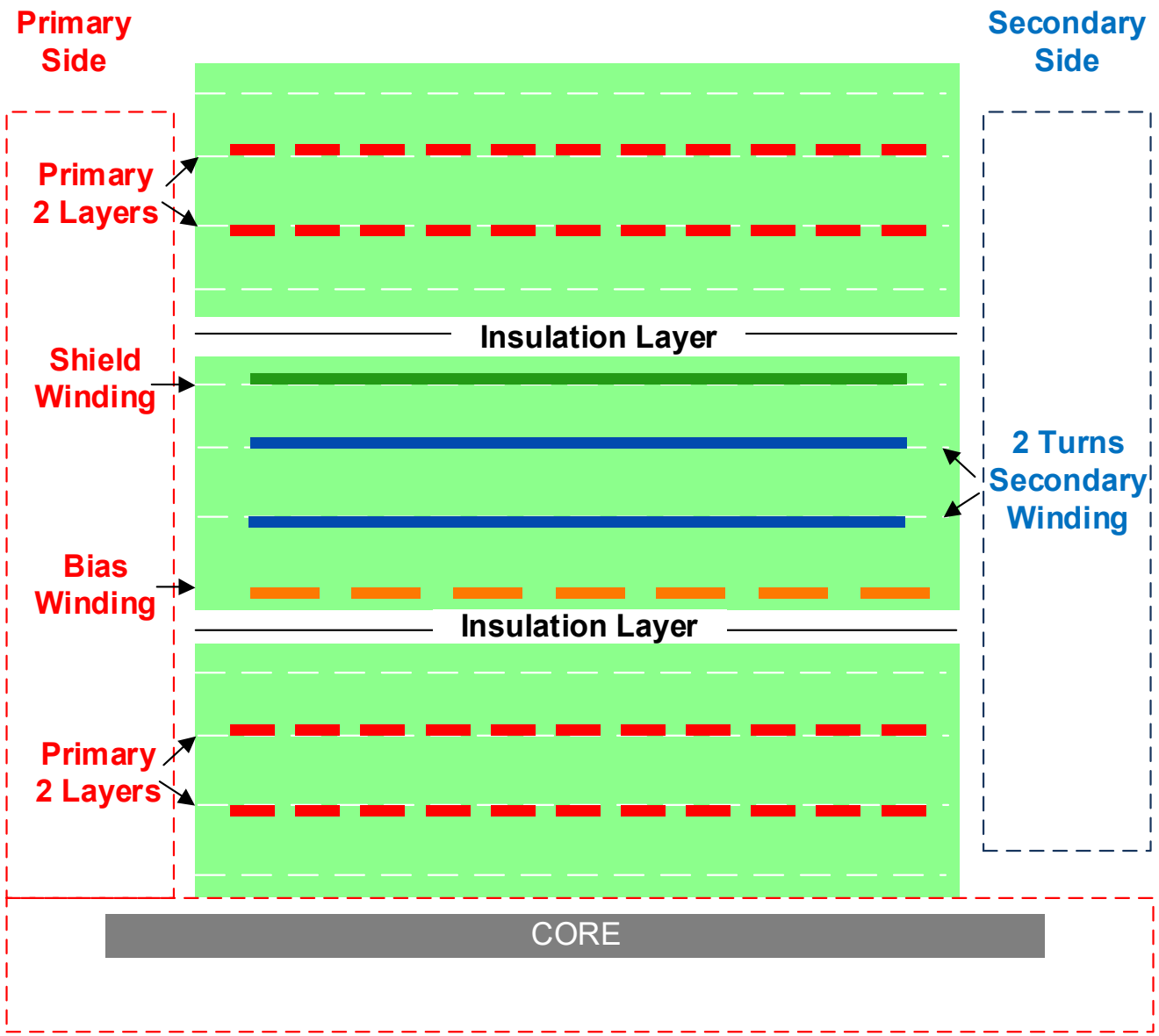


Gerbers snapshot



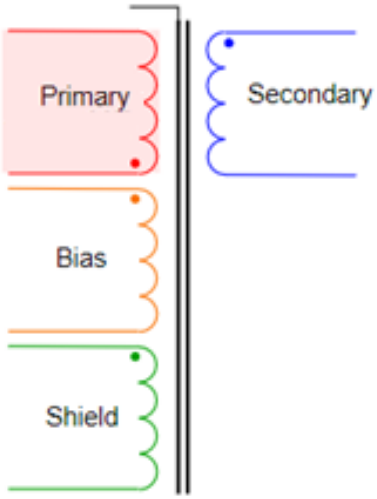
Construction and dimension overview

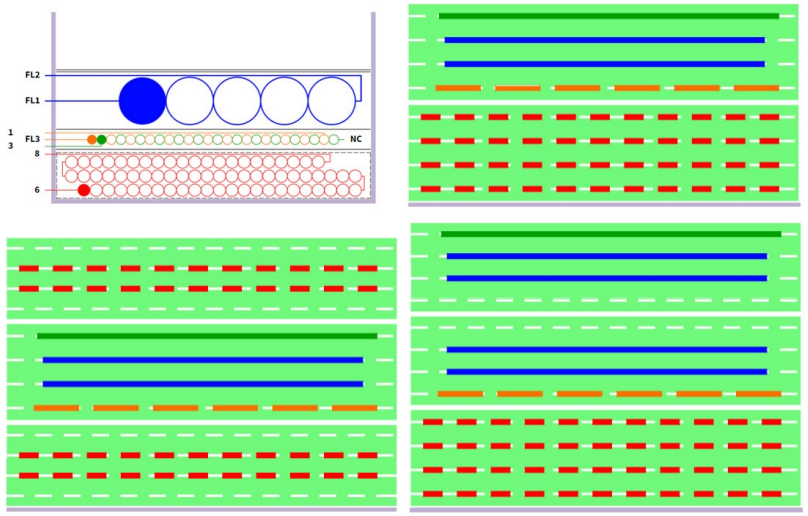
Construction Details – Expanded View



Solution – Transformer Construction

- All transformers have four windings as shown in the electrical diagram
- Differences are:
  1. Core
  2. Winding technology
  3. Stack organization
  4. Number of turns

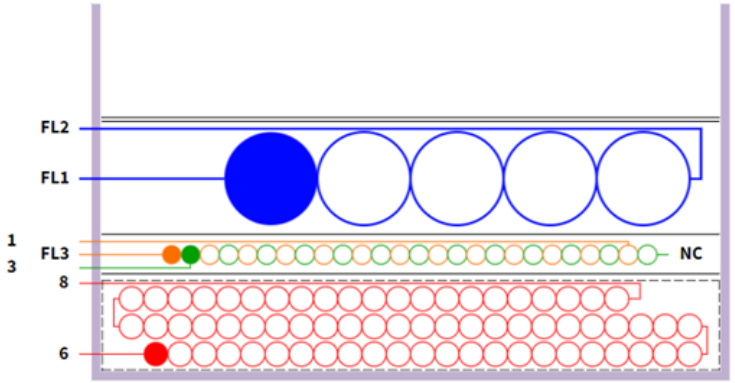




TRF	Core	NP	Primary Conductor	Primary Construction	NS	Secondary Conductor	Winding Technology	N_{BIAS}	N_{SCREEN}
RM7	2xRM7	66	1x32AWG	None-split	5	1x20AWG	Wire Wound	13	13
E22 v1	2xE22/6/16	44	0.274mm 3OZ	None-split	2	4.48mm 3OZ	Planar	6	1
E22 v2	2xE22/6/16	44	0.274mm 3OZ	Split	2	4.48mm 3OZ	Planar	6	1
E22 v3	2xE22/6/16	44	0.274mm 3OZ	None-split	4	4.48mm 3OZ	Planar	6	1

* Shield treated as separate winding

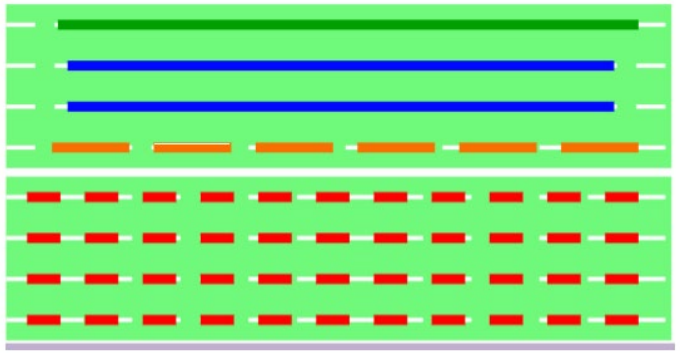
Comparison of Transformers in Case Study



1

RM7

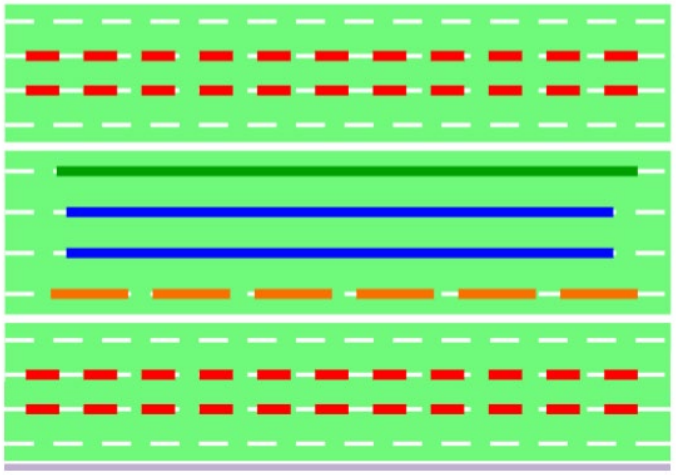
Conventionally wound transformer



2

EE22 V1

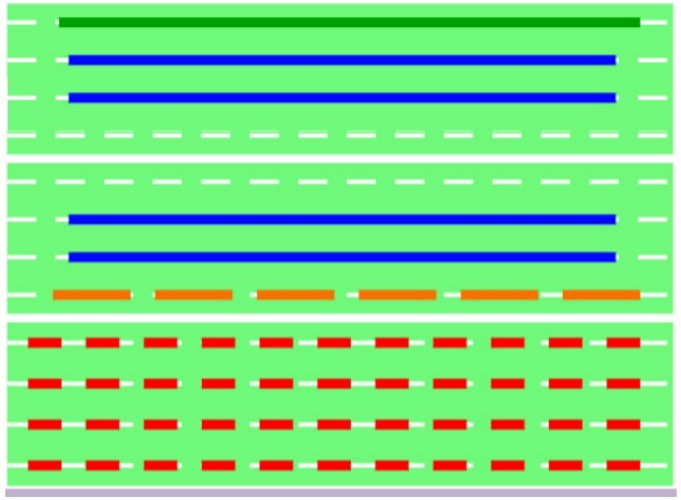
Planar transformer none-split primary configuration, two turns secondary



3

EE22 V2

Planar transformer with split primary configuration, two turns secondary



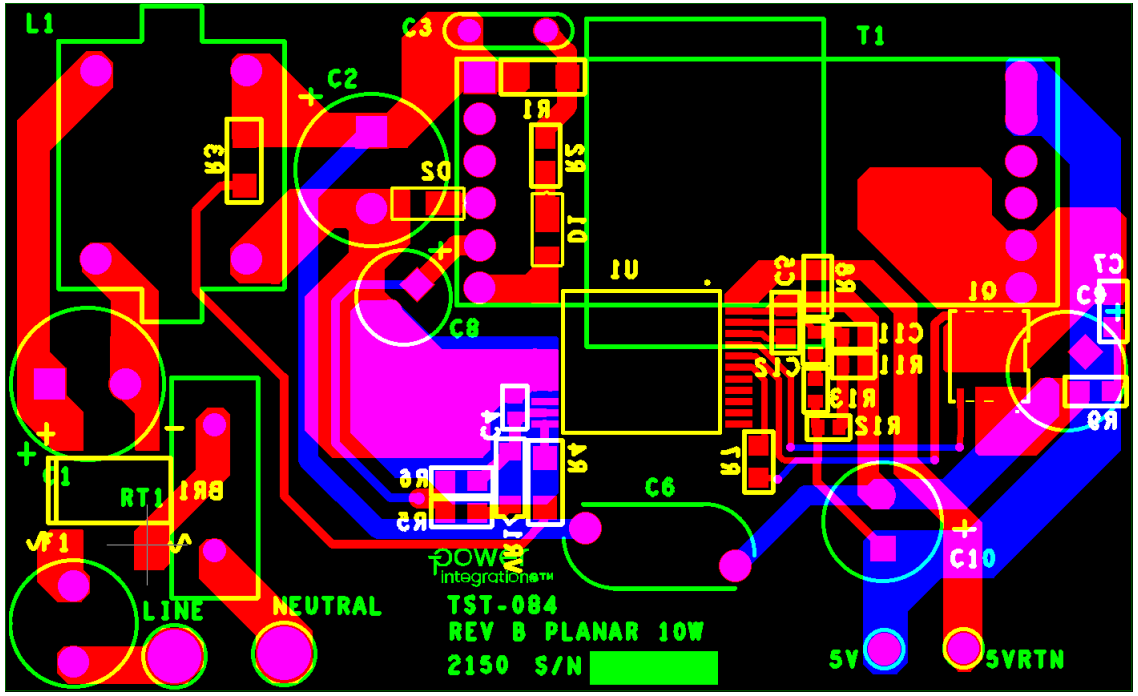
4

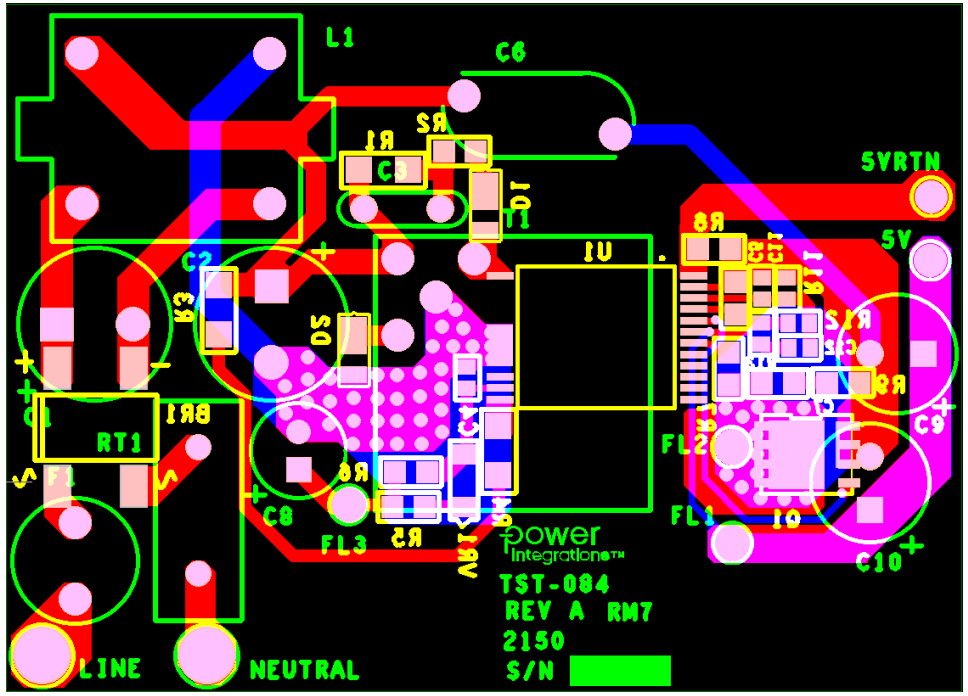
EE22 V3

Planar transformer none-split primary configuration, four turns secondary

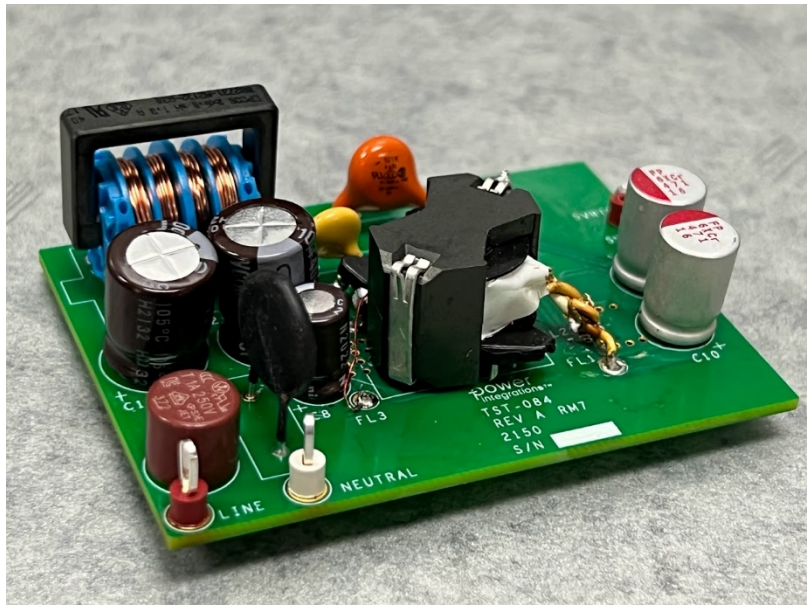
PCB Comparison

- Planar and wire wound transformer PCBs

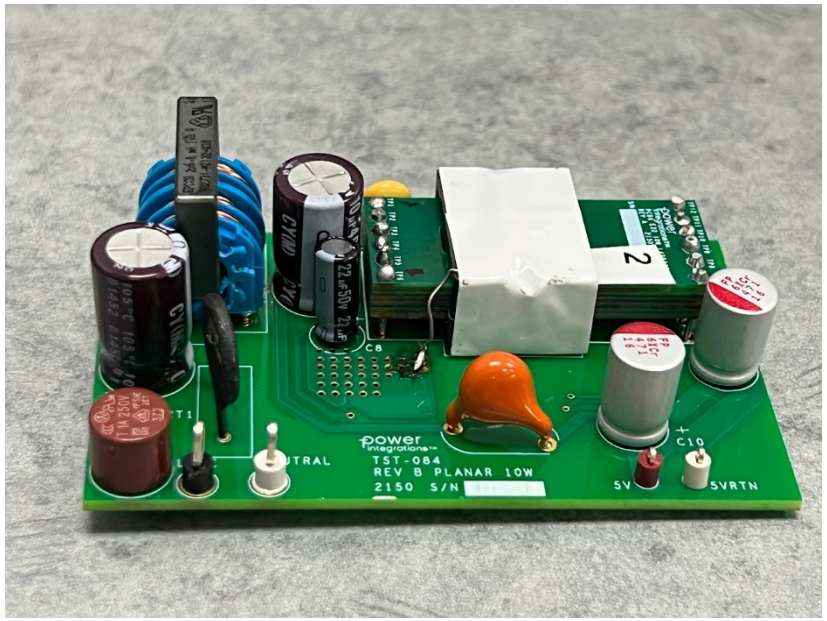




Prototypes Used for Study

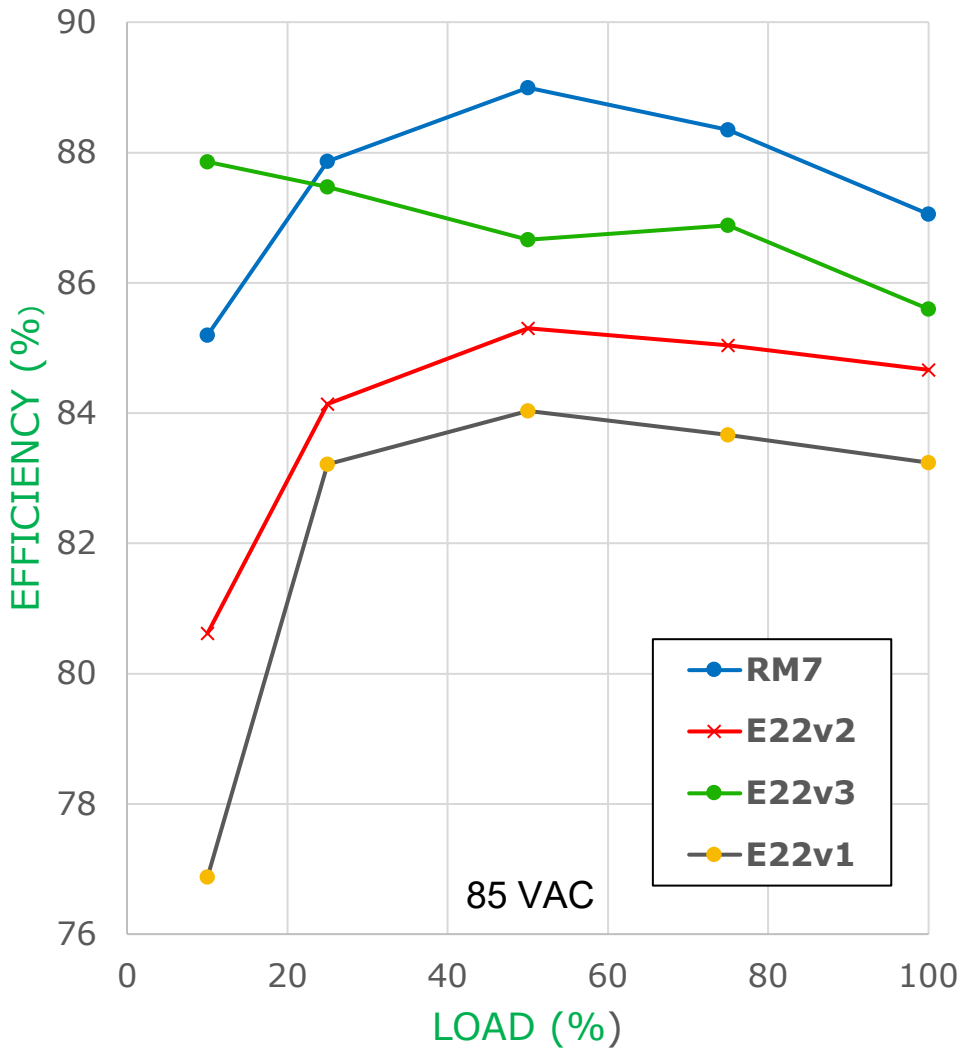


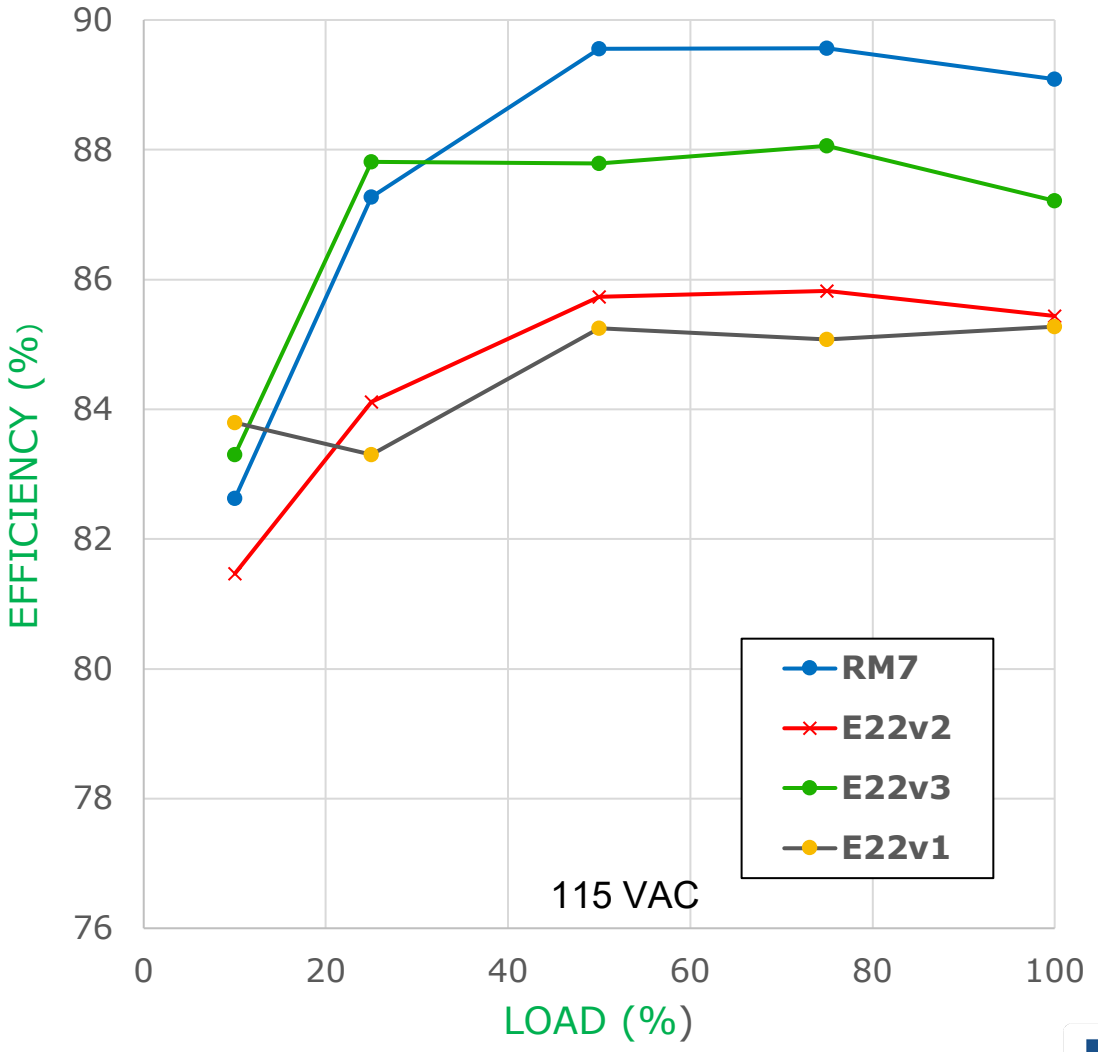
Prototype with RM7 Wound Transformer Used as Baseline



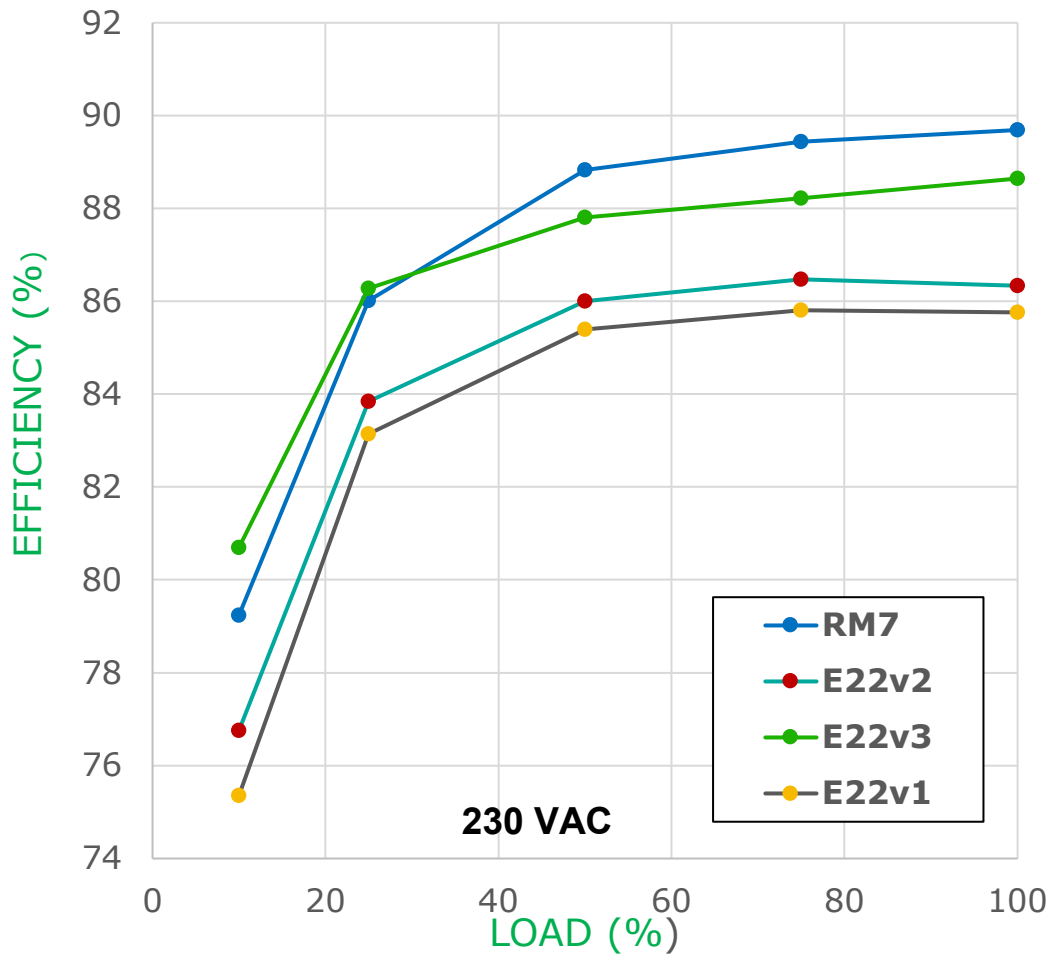
Prototype with Planar Transformer

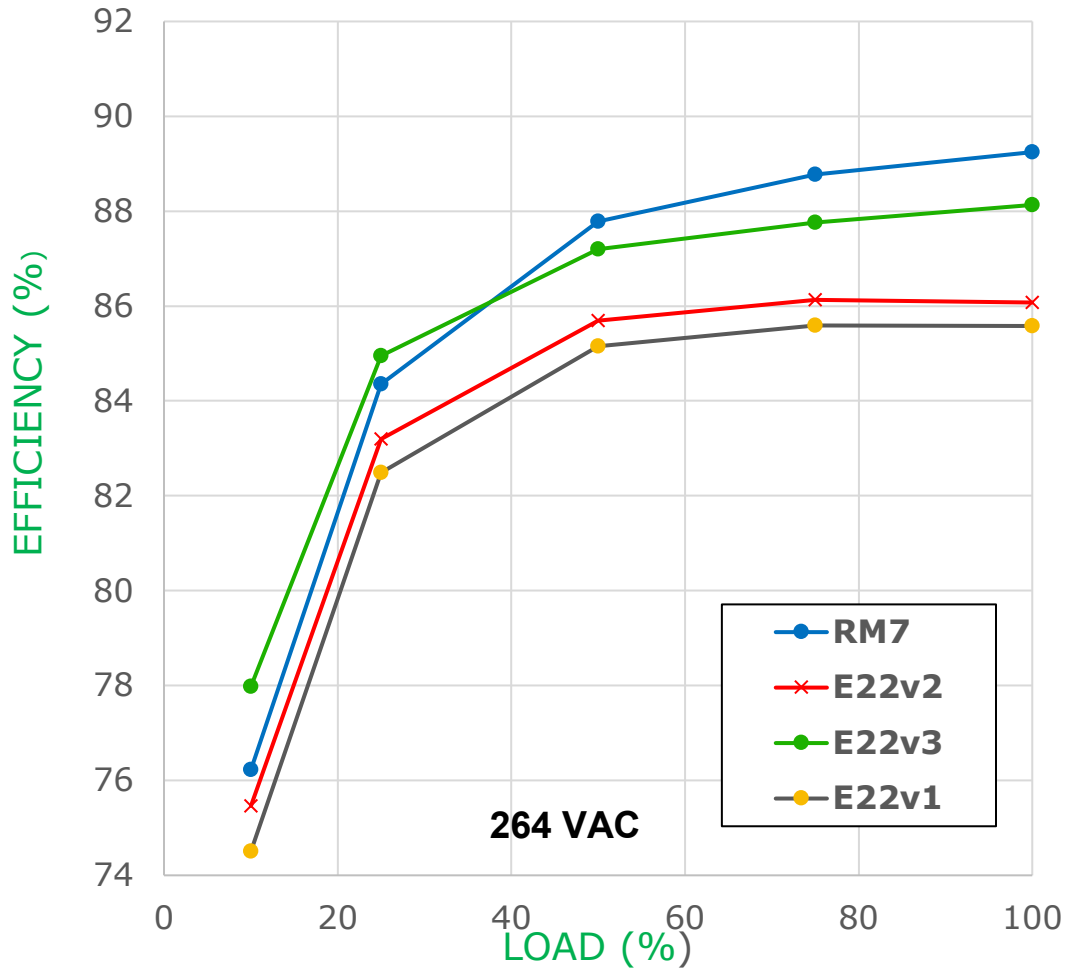
Efficiency Comparison at 85 VAC & 115 VAC





Efficiency Comparison – 230 VAC & 265 VAC





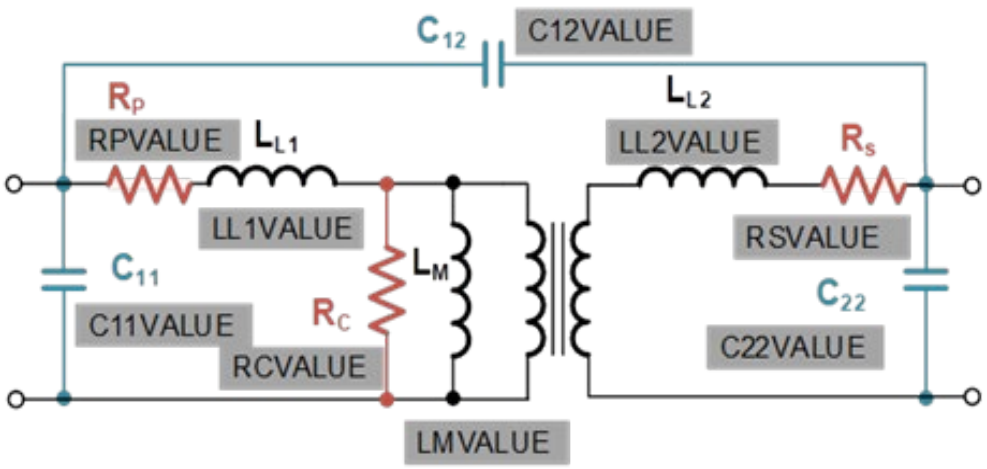
Solution – Transformer Windings Results

- Winding parameter simulation results

Core/ Ver.	R_{DC} [Ω]	R_{AC} 75 kHz [Ω]	R_{AC}/R_{DC} 75 kHz	L_{MAG} [mH]	Llk [μH]	Self Cap [pf]	Prim-Sec Cap [pF]
PRIMARY							
RM7	1.03	11.1	10.73	1.30	8.60	7.29	3.79
E22v1	2.22	6.29	2.84	1.23	17.0	7.90	26.5
E22v2	2.22	8.17	3.69	1.22	8.59	7.11	26.7
E22v3	2.22	7.53	3.40	1.22	17.4	7.78	27.7
SECONDARY							
RM7	503 E-3	505 E-3	1.09				
E22v1	5.6 E-3	13.6 E-3	2.44				
E22v2	5.6 E-3	17.4 E-3	3.13				
E22v3	11.1 E-3	62.7 E-3	5.65				

Solution – Transformer Windings Results

- Winding parameters
  - Comparison of simulated and measured values



Core /Ver.	[R_P] R_{DC}, [Ω]		[R_P] R_{AC} @75 kHz	[R_P] R_{AC}/R_{DC}	L_M [mH]		L_{L1}[L_{L1}], [uH]		[C_{11}] Self Capacitance (pF)		[C_{12}] Prim-Secondary Capacitance (pF)	
	Measured	Simulated	Simulated	Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated
RM7	0.86	1.03	11.1	10.7	1.30	1.30	18.6	8.60	12.1	7.29	10.1	3.79
E22v1	2.40	2.22	6.29	2.84	1.21	1.23	56.3	17.0	13.7	7.90	36.2	26.5
E22v2	2.76	2.22	8.17	3.69	1.20	1.22	24.0	8.59	11.5	7.11	31.4	26.7
E22v3	2.53	2.22	7.53	3.40	1.27	1.22	42.9	17.4	13.3	7.78	29.9	27.7

Questions Remaining & Other Issues to Address

- Effects of self-capacitance and construction techniques to reduce it
  - Minimizing overlapping of top and bottom side traces
    - Results in poor space utilization
- Effects of inter-winding capacitance and construction techniques to reduce it
  - Shielding is effective
- Reducing the voltage gradient between overlapping turns
  - Requires construction complexity and simplifies interlayer connections
- Interleaving with shielding is often impractical
  - Increases losses
- Passive cancellation (noise-balancing techniques)

Conclusion

- Planar magnetics for auxiliary power supplies simplifies manufacturing
  - Simplifies supply chain for transformers
  - Enables use of PCB assembly infrastructure for transformer build
- Suitable for low- and high-volume designs
- No significant performance disadvantage compared to wound transformers
- Important to understand process limitations of PCB vendors
- Limit designs to four layers and 3-ounce copper for easy availability

Thank you for your interest.

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