

Simulation-Based Investigation of PCB Thickness Effects on DC–DC Buck Converter Performance in Laptop Motherboard Voltage Regulator Modules at Elevated Temperatures

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ABSTRACT

Laptops are getting smaller and more powerful, putting a lot of heat stress on motherboard parts, especially voltage regulator modules. As these devices shrink, their temperatures go up during heavy use, causing excess heat to build up. This trapped heat makes the power system unstable, leading to power loss and crashes. Because of this, cooling the system is no longer just about adding fans; we must rethink how the motherboard is built. This study looks at how printed circuit board thickness affects heat control and electrical performance in a buck converter running at high temperatures. To do this, the study used a physics-based AI assisted simulation instead of building physical prototypes. A multiphase buck converter (12 V input, 0.5–2.0 V output, 35 A total load) was modelled. The evaluation varied PCB thickness (0.8–4.0 mm) and ambient temperature (35–100 °C). The results indicate that conversion loss increased consistently with ambient temperature across all board thicknesses. Thicker boards, particularly near 4.0 mm, trapped heat, causing a drop in efficiency to approximately 81% at 100 °C. Conversely, thinner boards exhibited lower thermal resistance and maintained higher conversion efficiency. Based on the electro-thermal simulation, board thicknesses between 1.2 mm and 1.6 mm offered a favorable thermal baseline for high-performance laptop VRMs.

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INTRODUCTION

The ongoing advancement of portable computing systems has substantially increased thermal demands in modern electronic hardware, as laptops pack high-performance processors, power modules, and memory into compact enclosures with elevated power densities and limited dissipation pathways (Perdigones & Quero, 2022; Wang et al., 2025). The motherboard, a multilayer PCB, functions as both an electrical interconnection platform and a primary heat-conduction path; as devices shrink, thermal stress from CPUs and voltage regulator modules (VRMs) increasingly limits reliability and performance (Zhang & Chen, 2024; Intel, 2022). Elevated ambient temperature further reduces convective dissipation and raises steady-state board temperature (Wang et al., 2025), while repeated thermal cycling induces thermomechanical fatigue, solder-joint degradation, and board warpage (Hu et al., 2023; Samavatian et al., 2020).

MATERIALS AND METHODS

Existing mitigation strategies emphasize active, passive, and environmental cooling (Lasance & Poppe, 2014) and layout optimization such as thermal vias and copper redistribution. However, the role of PCB thickness itself as an independent structural thermal variable has not been systematically established for high-current, laptop-scale VRMs. Previous thermal studies often treat PCB thickness as a secondary parameter tied to layer count (Alade & Adewole, 2026). This gap motivates the present study.

This research systematically analyses the relationship between PCB thickness, temperature, and output voltage to evaluate conversion loss and efficiency in laptop VRM power delivery (Erickson & Maksimović, 2020; Rashid, 2017). By isolating PCB thickness as the primary variable, this study aims to evaluate the direct electro-thermal effects on converter efficiency without reliance on costly, time-consuming experimental procedures (Goodfellow et al., 2016).



Plate 1: Dell Latitude 5490 i5-4th Gen Laptop Motherboard (Source: Dell Inc.)

AI simulation-based analytical approach was used to evaluate the influence of PCB thickness on the performance and thermal stability of a laptop VRM DC–DC buck converter, modelled on the Dell Latitude 5490

(LA-F391P) platform (Intersil ISL95855-type) as shown in plate 1 above. The system was modeled as a 4-phase interleaved synchronous buck architecture to accurately represent the 35 A total load (8.75 A per phase).

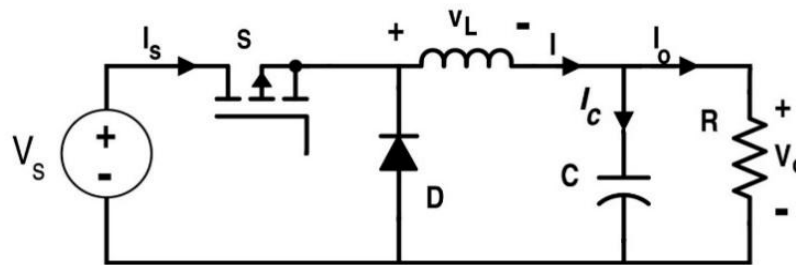


Figure 1: Basic DC–DC Buck Converter Circuit Topology (Source: IJSRP, 2021 and standard power electronics literature)

A typical buck converter as shown in figure 1 above, comprises a high-side and synchronous low-side MOSFET switch, an inductor, and an output capacitor. During the switch-ON state the input voltage is applied across the inductor and energy is stored in its magnetic field; during the switch-OFF state the inductor releases this stored energy to the load, sustaining continuous conduction. Converter behaviour is governed by the

relationships $V_{out} = D \cdot V_{in}$ (duty-cycle-controlled voltage conversion), inductor ripple $\Delta I_L = \frac{(V_{in}-V_{out})D}{Lfs}$ and output ripple $\Delta V_{out} = \frac{\Delta I_L}{8fsc}$ with conduction and switching losses in MOSFETs and inductors manifesting as heat concentrated near the CPU socket (Erickson & Maksimović, 2020; Rashid, 2017).

Table 1: System Tools and Resources

Tool	Resource/Description
High-Performance Laptop	Data processing
DC–DC Buck Converter Model	A specialized VRM topology modeled for low-voltage, high-current laptop applications (12Vdc input to 0.5Vdc-2.0Vdc output).
Data Processing Software	Used for tabulation and graphical analysis
Python Analytical Script	Parameter generation and physics-based equation solving

AI Simulation Procedure

Fixed parameters were input voltage $V_{in} = 12.0V$, output current $I_{out} = 35.0A$, and switching frequency $F_{sw} = 500kHz$. Two independent variables were varied: PCB thickness (0.80–4.00mm, step 0.40mm; 9 levels) and ambient temperature (35–100°C, step 1°C; 66 levels), with target output voltage stepped from 0.50–2.00V (step 0.10V; 16 levels). The thermal boundary conditions

assumed standard FR-4 dielectric material (thermal conductivity $k = 0.25 \text{ W/m}\cdot\text{K}$) operating in a natural convection environment. Tools used are listed in Table 1 above.

For every permutation, conduction loss, switching loss, total conversion loss and efficiency were computed as:

$$R_{th} = \frac{d}{k \cdot A} \quad (1)$$

$$P_{cond} = I^2 R_{DS(on)} \quad (2)$$

$$P_{sw} = \frac{1}{2} V_{in} I (t_r + t_f) f_s \quad (3)$$

$$P_{loss} = P_{cond} + P_{sw} \quad (4)$$

$$\eta = \left(\frac{V_{out} I_{out}}{V_{out} I_{out} + P_{loss}} \right) * 100\% \quad (5)$$

where R_{th} , is the thermal resistance, d is the PCB thickness, k is thermal conductivity, and A is the effective dissipation area, $R_{DS(on)}$ is MOSFET on-resistance and P_{loss} is total conversion loss; both $R_{DS(on)}$ and inductor DC resistance (DCR) were scaled with junction temperature from base values $R_{DS(on)} = 0.003\Omega$ and $DCR = 0.001\Omega$, using copper and MOSFET temperature

coefficients of $0.00393/^\circ\text{C}$ and $0.004/^\circ\text{C}$ respectively. The AI simulation specification fixed the device as a Dell Latitude 5490 (LA-F391P) multiphase synchronous buck architecture with an Intersil ISL95855-type PWM controller, and the permutation matrix as PCB thickness 0.80–4.00mm (step 0.40mm), ambient temperature 35–100°C (step 1°C), and target Vout 0.50–2.00V (step 0.10V). The generated datasets were processed with AI-assisted tools to identify non-linear trends between thickness and thermal dissipation, quantify the rate of performance degradation with temperature, and derive an optimal PCB thickness range balancing efficiency and thermal stability.

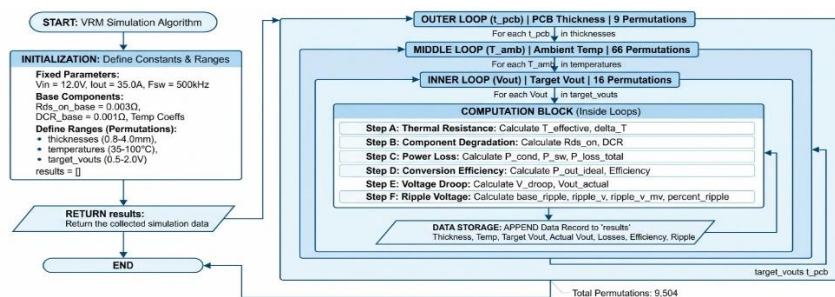


Figure 2: Flowchart Showing the Process Simulation and Analysis

RESULTS AND DISCUSSION

From table 3 below, Simulation results indicate that conversion loss increased consistently with ambient temperature across all nine PCB thicknesses (as shown in the illustrated graph in figure 3). At nominal Vcore = 1.10 V, the 0.80 mm board exhibited the lowest thermal resistance, while the 4.00 mm board severely restricted

vertical heat transfer. As temperature approached 100°C , the thick FR-4 material trapped heat at the MOSFET junctions, driving losses up sharply. Total conversion loss also increased steadily with target Vout at fixed temperature, as duty-cycle expansion shifted thermal burden onto the high-side MOSFET.

Table 3: Conversion Loss (W) against Output Voltage (Vout) for Various PCB Thicknesses at 35°C

Vout (V)	0.80 mm	1.20 mm	1.60 mm	2.00 mm	2.40 mm	2.80 mm	3.20 mm	3.60 mm	4.00 mm
0.50	6.86	6.93	6.99	7.07	7.14	7.21	7.28	7.36	7.43
0.60	6.89	6.96	7.03	7.10	7.17	7.25	7.32	7.40	7.47
0.70	6.93	7	7.07	7.14	7.21	7.29	7.36	7.44	7.52
0.80	6.96	7.03	7.10	7.18	7.25	7.32	7.40	7.48	7.56
0.90	6.99	7.07	7.14	7.21	7.29	7.36	7.44	7.52	7.60
1.00	7.03	7.10	7.17	7.25	7.32	7.40	7.48	7.56	7.64
1.10	7.06	7.14	7.21	7.29	7.36	7.44	7.52	7.60	7.68
1.20	7.10	7.17	7.25	7.32	7.40	7.48	7.56	7.64	7.72
1.30	7.13	7.21	7.28	7.36	7.44	7.52	7.60	7.68	7.76
1.40	7.17	7.24	7.32	7.40	7.48	7.56	7.64	7.72	7.81
1.50	7.20	7.28	7.35	7.43	7.51	7.60	7.68	7.76	7.85
1.60	7.23	7.31	7.39	7.47	7.55	7.64	7.72	7.80	7.89
1.70	7.27	7.35	7.43	7.51	7.59	7.67	7.76	7.85	7.93
1.80	7.30	7.38	7.46	7.55	7.63	7.71	7.80	7.89	7.98
1.90	7.34	7.42	7.50	7.58	7.67	7.75	7.84	7.93	8.02
2.00	7.37	7.45	7.54	7.62	7.71	7.79	7.88	7.97	8.06

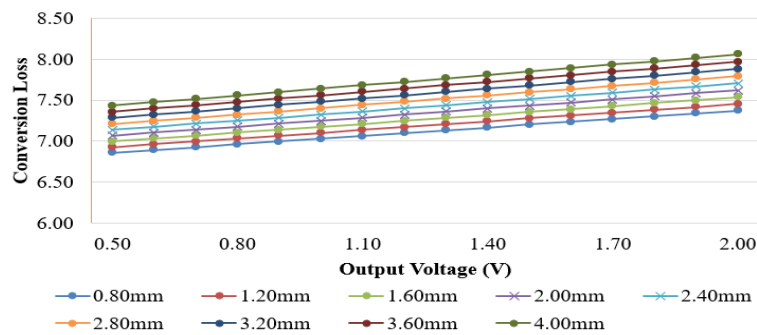


Figure 3: Showing Variations of Conversion Loss against Output Voltage at Temp=35°C

Table 4: Conversion Efficiency (%) against Output Voltage (Vout) for Various PCB Thicknesses at 35°C

Vout (V)	0.80 mm	1.20 mm	1.60 mm	2.00 mm	2.40 mm	2.80 mm	3.20 mm	3.60 mm	4.00 mm
0.50	71.85	71.65	71.44	71.24	71.03	70.82	70.61	70.40	70.19
0.60	75.29	75.11	74.92	74.73	74.54	74.34	74.15	73.95	73.75
0.70	77.96	77.79	77.61	77.44	77.26	77.08	76.90	76.71	76.53
0.80	80.09	79.93	79.77	79.60	79.43	79.27	79.09	78.92	78.75
0.90	81.83	81.68	81.53	81.37	81.21	81.05	80.89	80.73	80.57
1.00	83.28	83.13	82.99	82.84	82.69	82.54	82.39	82.24	82.08
1.10	84.50	84.36	84.23	84.09	83.95	83.80	83.66	83.51	83.37
1.20	85.55	85.42	85.29	85.15	85.02	84.88	84.75	84.61	84.47
1.30	86.45	86.33	86.20	86.08	85.95	85.82	85.69	85.56	85.42
1.40	87.24	87.13	87.01	86.88	86.76	86.64	86.51	86.39	86.26
1.50	87.94	87.83	87.71	87.60	87.48	87.36	87.24	87.12	86.99
1.60	88.56	88.45	88.34	88.23	88.12	88.00	87.89	87.77	87.65
1.70	89.11	89.01	88.90	88.80	88.69	88.58	88.46	88.35	88.24
1.80	89.61	89.51	89.41	89.30	89.20	89.09	88.98	88.87	88.76
1.90	90.06	89.96	89.87	89.76	89.66	89.56	89.45	89.35	89.24
2.00	90.47	90.38	90.28	90.18	90.08	89.98	89.88	89.78	89.67

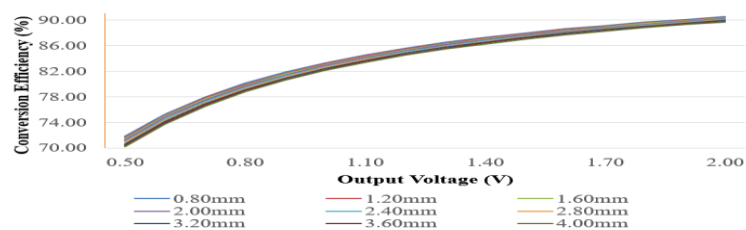
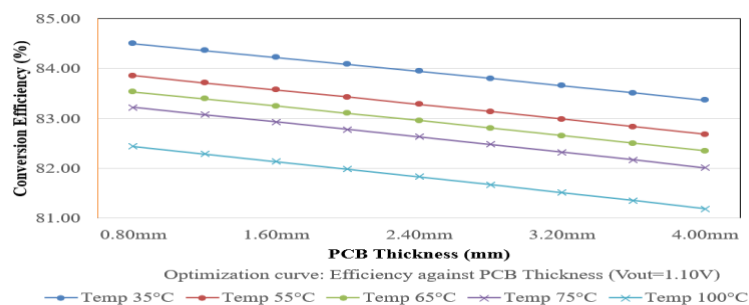


Figure 4: Showing Variations of Conversion Efficiency against Output Voltage at 35°C

Table 5: Optimization: Efficiency against PCB Thickness at Output Voltage 1.10V

PCB Thickness	Temp 35°C	Temp 55°C	Temp 65°C	Temp 75°C	Temp 100°C
0.80mm	84.50	83.85	83.54	83.22	82.44
1.20mm	84.36	83.71	83.39	83.07	82.29
1.60mm	84.23	83.57	83.25	82.93	82.14
2.00mm	84.09	83.43	83.10	82.78	81.98
2.40mm	83.95	83.28	82.96	82.63	81.83
2.80mm	83.80	83.14	82.81	82.48	81.67
3.20mm	83.66	82.99	82.66	82.33	81.51
3.60mm	83.51	82.84	82.50	82.17	81.35
4.00mm	83.37	82.68	82.35	82.01	81.19

**Figure 5: Optimization curve: Efficiency against PCB Thickness (Vout=1.10V)**

Conversion efficiency mirrored these loss trends (Table 4). At 35 °C, the converter maintained efficiency above 83% for nominal voltages across all thicknesses; as ambient temperature rose toward 100 °C, efficiency fell for every thickness, with the 4.00 mm board dropping to 81.19% at 100 °C due to severe thermal blanketing. Efficiency against Vout followed a saturating trend (shown in figure 4), as low Vout (0.50 V) suffered disproportionately from fixed switching losses, while efficiency climbed and stabilized in the 1.10–1.50 V range.

Synthesizing these results (Table 5 and illustrated Figure 5), extremely thin boards (0.80–1.00 mm) yielded the highest electrical efficiency due to low thermal resistance. However, determining their viability requires external mechanical and routing capacity assumptions outside this simulation. Thicknesses exceeding 2.40 mm exhibited severe thermal blanketing and precipitous efficiency drops under high thermal load. From a purely electro-thermal standpoint, the data establishes an optimal PCB thickness baseline of 1.20–1.60 mm.

CONCLUSION

This study investigated how PCB thickness affects the power loss and efficiency of a DC–DC buck converter across ambient temperatures of 35–100 °C using a physics-based analytical simulation approach. Results demonstrate that PCB thickness plays a substantial role in thermal handling and power efficiency: thinner boards (0.80–1.00 mm) sustain lower loss and higher efficiency due to reduced thermal resistance, while thicker boards

(> 2.40 mm) trap heat and lose efficiency sharply at 100 °C. From a strictly electro-thermal perspective, the 1.20–1.60 mm range provides a highly favorable efficiency baseline. Future research should apply multi-objective optimization, incorporating finite-element structural analysis and experimental testing to definitively balance thermal efficiency with mechanical stiffness.

Based on the findings, designers should utilize analytical simulation tools to evaluate the electro-thermal impacts of PCB thickness before hardware fabrication, particularly for high-power devices like laptop motherboards.

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