

# Power efficiency and power losses estimation of Totem-Pole Converter based on IR thermography

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## Abstract

This paper presents a methodology for estimating the power loss of a Totem-Pole PFC (Power Factor Correction) converter using infrared thermography. The proposed approach enables contactless, real-time assessment of thermal behaviour during normal system operation without requiring circuit modifications or service interruption. Unlike conventional methods relying on datasheet parameters and pre-production characterization, IR thermography captures the thermal signature of the assembled PCB under realistic operating conditions, load profiles, and environmental factors. This work correlates thermal measurements with electrical power dissipation by establishing empirical relationships between surface temperature distributions and power losses considering PCB, ambient, and packaging effects.

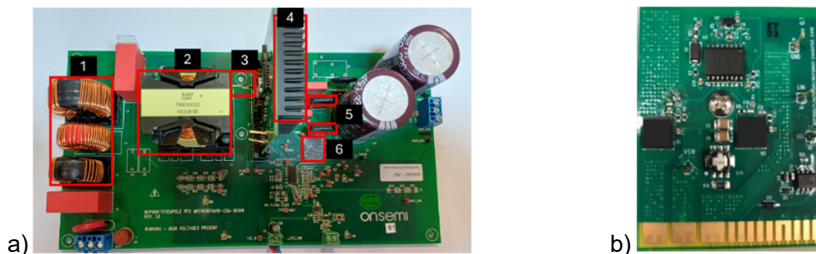
## 1. Introduction

Components with high heat generation, such as power MOSFETs, GaN transistors, inductors, power resistors, and high-current traces, require special attention when evaluating power dissipation [1, 2]. These elements often operate near their thermal limits and are susceptible to thermally accelerated aging. Traditional power loss estimation methods based on datasheets and simulations may not reliably reflect real operating conditions or manufacturing and aging effects.

Infrared thermography is a non-invasive diagnostic tool for estimating power loss in operational PCB assemblies. By capturing thermal signatures of components and circuit regions, IR imaging enables measurement of surface temperature distributions under real operating conditions. Combined with thermal modeling and heat transfer analysis, these measurements can be correlated with power dissipation, providing empirical validation of theoretical calculations and revealing discrepancies caused by aging, manufacturing variations, or suboptimal thermal design.

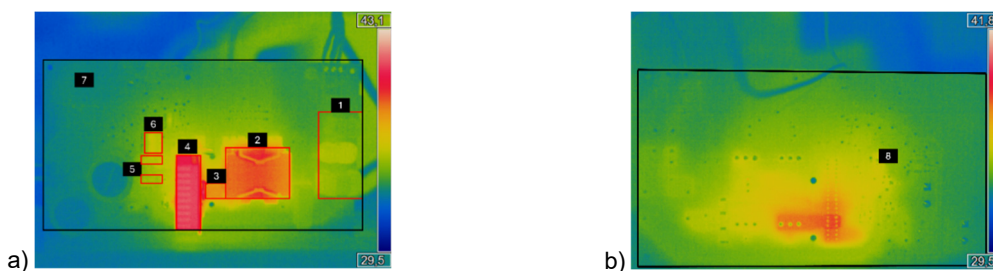
## 2. Thermal model

Evaluation Board NCP1681CCM1KWGEVB is modeled using a nodal thermal network. The board is divided into several thermal nodes: six represent heat sources, and two represent the PCB surfaces. Figure 1a presents the evaluation board with marked heat sources and Figure 1b the daughter board with GaN transistors (node 4).



**Figure 1.** Totem pole evaluation board with marked heat sources (a) and daughter board with GaN transistors (b)

Figure 2a shows the infrared image of the PCB top surface, while Figure 2b shows the bottom side. Red rectangles (nodes 1–6) indicate heat sources, and the black rectangle (node 7) represents the top surface excluding the marked heat sources. Node 8 represents the entire bottom area. All nodes are described in Table 1.



**Figure 2.** Infrared image of PCB board - top view (a), bottom view (b) with marked regions (black rectangles - PCB surface, white rectangles - heat sources)



Table 1 summarizes each node, including the mean temperature difference relative to ambient, the heat dissipation surface area, and the estimated power loss.

**Table 1. Description of the nodes and their parameter values**

Node (Fig2)	Description	$\Delta T_{power_i}, ^\circ C$		$S_i, m^2$	$P_{power_i}, W$		
		Mean temperature difference		Surface	Dissipated power		
		100W	200W		100W	200W	
1	Input filter inductors	2,33	3,13	0,006	0,1518	0,2105	
2	PFC inductor (choke)	case	5,41	6,83	0,003	0,4694	0,6291
		coil	6,47	8,55	0,0032		
3	PCB trace	5,64	6,18	0,00009	0,0084	0,0093	
4	GaN transistor daughter PCB with heatsink	9,11	9,28	0,0025	1,04	1,0961	
5	MOSFET transistors	2,82	3,59	-	0,0472	0,06	
6	Zero current detection resistors	2,96	3,96	0,00034	0,0136	0,019	
7	PCB - top side without heat sources	2,29	2,42	0,021	0,4954	0,5264	
8	PCB - bottom side	2,52	2,57	0,025	0,6341	0,6479	

Measurements were performed using an OPRIS PI450 non-cooled IR camera to estimate heat losses and power efficiency in the circuit based on PCB topology and IR thermography. The input voltage was 230 V, and efficiency was evaluated at 100 W and 200 W output power. Heat loss from each node occurs via convection and radiation. For each surface node, convection and radiation are treated as parallel heat transfer mechanisms acting simultaneously.

$$h_c = C \left( \frac{\Delta T}{L} \right)^n = \frac{C}{L^n} \left( \frac{\Delta T}{\Delta T_0} \right)^n \cdot (\Delta T_0)^n = \frac{C \Delta T_0^n}{L^n} \left( \frac{\Delta T}{\Delta T_0} \right)^n = h_0 \left( \frac{\Delta T}{\Delta T_0} \right)^n \quad (1)$$

where  $C$  is an empirical constant dependent on the surface geometry,  $\Delta T$  denotes the temperature difference between the surface and the ambient environment,  $\Delta T_0$  represents the reference temperature difference,  $L$  is the characteristic length of the surface, and  $n$  is an empirical exponent, typically taken as 0,25 [3] for natural convection.

The radiative heat transfer coefficient is estimated using the Stefan–Boltzmann law. After a few transformations of Stefan-Boltzmann equation and approximations, the heat flux [4] is expressed as:

$$q \approx \sigma \cdot 4T_a^3(T - T_a) = h_r \Delta T \quad (2)$$

For  $T_a = 300K$ , the radiative heat transfer coefficient is  $h_r=6,23 W/(m^2 K)$ . The total heat flux from a node to the ambient is therefore expressed as the sum of the convective and radiative heat fluxes. This allows the definition of a total heat transfer coefficient to be defined as the sum of the convection and radiation coefficients.

$$q = h_r \Delta T S + h_c \Delta T S = (h_r + h_c) \Delta T S \quad (3)$$

Based on the PCB topology and the dimensions of the heat sources, we estimate the heat fluxes for each node in a manner similar to that shown above. Total power loss is the sum of the power losses in each of the nodes. Based on the obtained values, the power efficiency was estimated. The results are shown in table 2.

**Table 2. Description of the nodes and with the parameter's values**

Output power:		100W	200W
Power loss obtained from the IR measurement	$P_{loss}$	2,86W	3,20W
Power efficiency obtained from the IR measurement	$\eta_{IR\_measurement}$	97,22%	98,42%
Power efficiency obtained from the electrical power measurement	$\eta_{electrical\_measurement}$	96,90%	98,19%
Power efficiency taken from the datasheet	$\eta_{datasheet}$	97,48%	98,43%

The presented method estimates power efficiency and power losses based on thermographic measurements. The obtained results agree with documentation values. Inaccuracies may arise from limited thermal camera precision, estimation of average temperatures and surface areas, and varying PCB component emissivity. Nevertheless, the results indicate the method is suitable for estimating power losses and monitoring heat loss changes due to component aging. The methodology requires no circuit modification, allows measurements during normal operation, provides sufficient spatial resolution to identify hotspots, and enables longitudinal studies tracking thermal performance degradation over the product's lifetime. The proposed IR thermography-based approach facilitates both initial design validation and ongoing condition monitoring, supporting predictive maintenance strategies and enhancing overall system reliability.

### Acknowledgments

This research was carried out as part of a project funded by the National Centre for Research and Development (Polish: NCBR—Narodowe Centrum Badań i Rozwoju) under the LIDER XV program, in accordance with the contract for the execution and financing of project No. LIDER15/0205/2024.

## References

- [1] J. L. R. Martínez, H. C. Sariol, M. M. Pérez de la Parte, B. Sáenz-Diez Pérez, E. Jiménez Macías, J. Yperman e D. Vandamme, «Heat-loss measurement using infrared thermography by multi-threshold analysis,» *Applied Thermal Engineering*, vol. 279A, 2025.
- [2] G. Langer, M. Leitgeb, J. Nicolics, M. Unger, H. Hoschopf e F. Wenzl, «Advanced thermal management solutions on PCBs for high power applications,» *Journal of Microelectronics and Electronic Packaging*, vol. 11, pp. 104-114, 2014.
- [3] Cranfield University Electronics Cooling, «Simplified formula for estimating natural convection heat transfer coefficient on a flat plate,» *Electronics Cooling Magazine*, 2001. [Online]. Available: <https://www.electronics-cooling.com/2001/08/simplified-formula-for-estimating-natural-convection-heat-transfer-coefficient-on-a-flat-plate/>. [Accessed: 27-Apr-2026].
- [4] Więcek, B., & De Mey, G. (2011). *Termowizja w podczerwieni: Podstawy i zastosowania*. Wydawnictwo PAK.