TRIGOPI
GROUP

Will you invest extra power

Concept Overview

“Will you invest extra power?” It’s a deceptively simple question that immediately invites a follow-up: “Invest for what?” Are we talking about squeezing an extra 7% range out of an electronic warfare (EW) radar, extending coverage from 300 km to 320 km? Or maybe boosting microwave digital link throughput by 15%? These incremental gains can be game changers in performance, but the catch is always heat. More power means more heat dissipation, and managing that heat effectively becomes critical to system reliability and longevity.

This article is Part #1 in a series where we explore the intricate balance of investing extra power in electronic systems, focusing here on the fundamentals of heat evacuation and thermodynamics within electronic enclosures. At TrigoPi, we love testing the edges of these challenges—it’s the kind of puzzle that keeps engineers awake at night, in a good way.

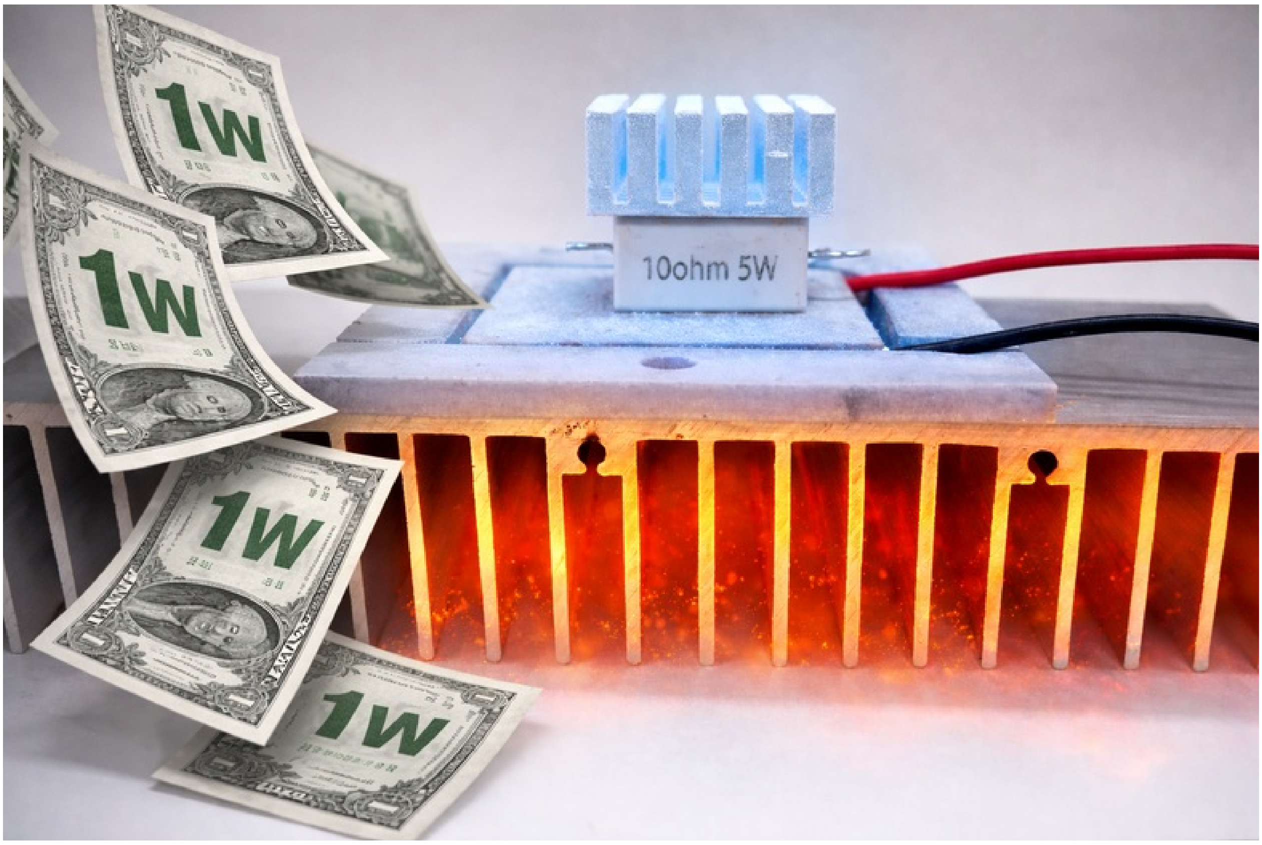

Figure 1: The classic question: Will you invest extra power? (Investing_extra_power.png)

Thought Process

In electronic board design, power dissipation and heat evacuation are inseparable. Electronic components convert electrical power into heat, which must be evacuated; otherwise, component temperatures rise until they exceed maximum ratings, risking failure. Heat leaves the system mainly through conduction, convection, and radiation. Our focus here is on conduction and convection, which dominate in typical enclosures.

Thermal resistance is the key concept, analogous to electrical resistance but for heat flow. It’s defined as the temperature difference divided by power flow:

$$R_{th} = \frac{\Delta T}{P}$$

For conduction, thermal resistance is:

$$R_{cond} = \frac{L}{k \times A}$$

where L is the thickness of the material, k is its thermal conductivity, and A is the cross-sectional area.

For natural convection (no forced airflow), thermal resistance is:

$$R_{conv} = \frac{1}{h \times A}$$

where h is the heat transfer coefficient, a flow-dependent property describing how well air carries heat away, and A is the surface area.

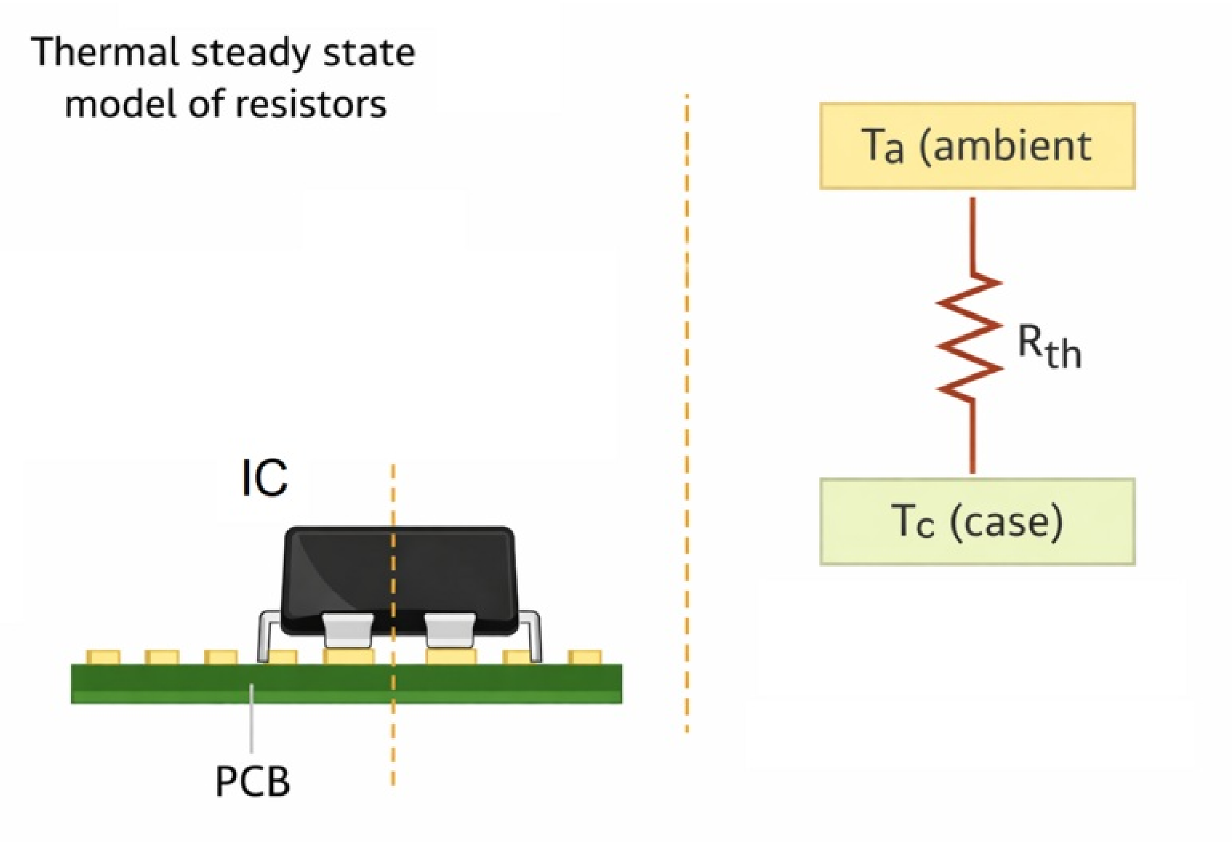

Figure 2: Thermal steady state model of IC on PCB illustrating thermal resistance analogy (Thermal_steady_state_model_of_IC_on_PCB.png).

The heat transfer coefficient h is derived from the Nusselt number Nu, which relates convective to conductive heat transfer in the fluid:

$$h = \frac{Nu \times k_{air}}{L_c}$$

where L_c is the characteristic length and $k_{air} \approx 0.026 \ W/(m \cdot K)$ is air's thermal conductivity.

Natural convection is like a heater on a heatsink with still air; forced convection adds a fan to push air, increasing h and reducing thermal resistance.

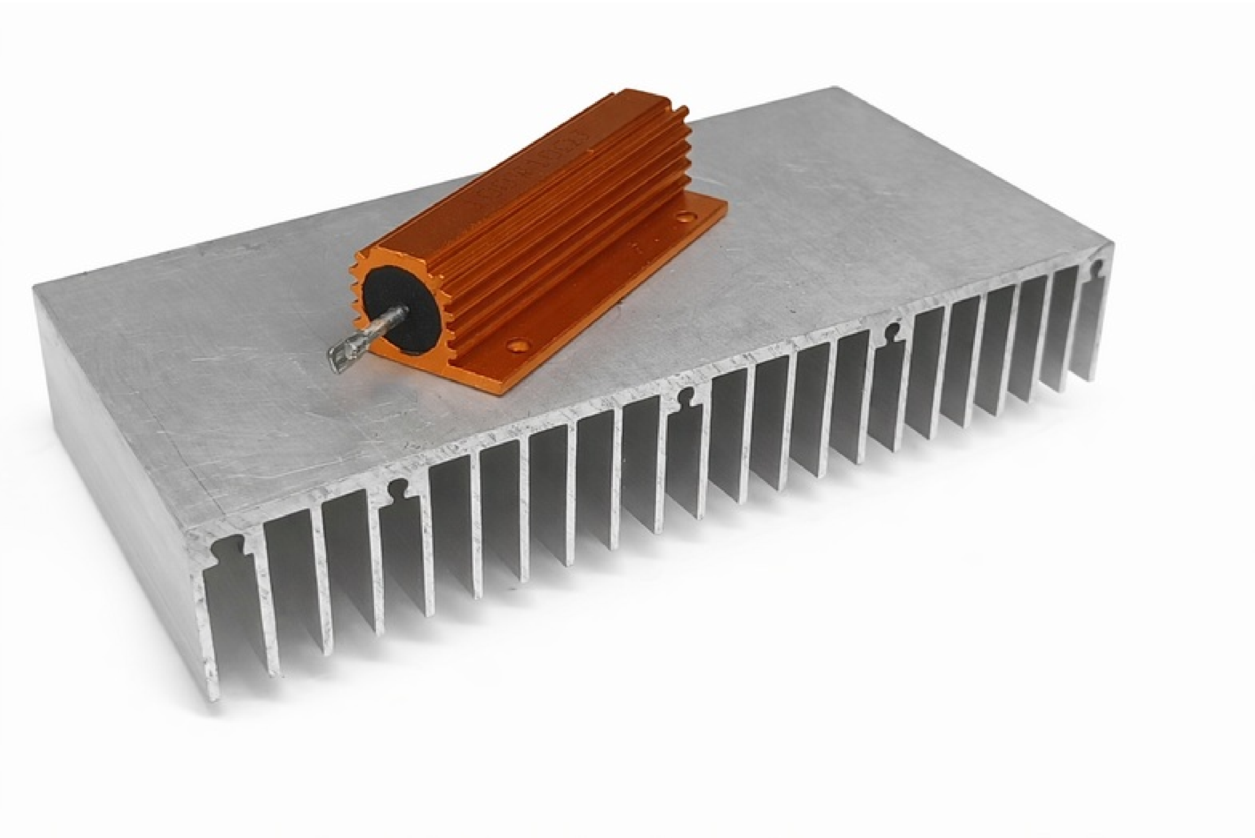

Figure 3: Heat evacuation by natural convection where warm air rises from the surface (Heat_evacuation_natural_convection.png).

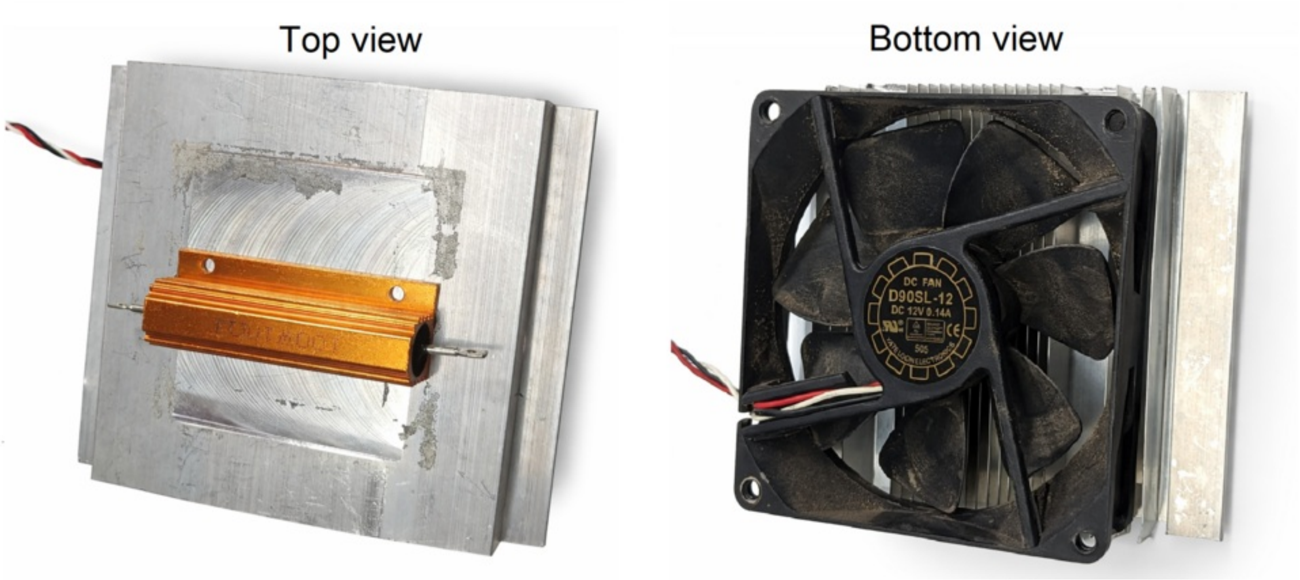

Figure 4: Heat evacuation by forced convection with airflow enhancing heat transfer (Heat_evacuation_forced_convection.png).

Consider an aluminum flat heatsink 3 mm thick with 200,000 mm² surface area. Aluminum's thermal conductivity is about 205 W/(m·K). The conduction resistance is:

$$R_{cond} = \frac{0.003}{205 \times 0.2} = 0.00007\ K/W$$

With natural convection heat transfer coefficient $h = 5\ W/(m^2 \cdot K)$, convection resistance is:

$$R_{conv} = \frac{1}{5 \times 0.2} = 1.0\ K/W$$

Total thermal resistance is approximately 1.0 K/W, meaning each watt dissipated causes about a 1°C temperature rise above ambient.

Potential Applications

This understanding is crucial when deciding to invest extra power for improved EW radar coverage or microwave link throughput. More power means more heat, and without effective heat evacuation, components risk overheating and failure, negating performance gains.

At TrigoPi, we enjoy exploring these trade-offs through experiments and modeling. It's a balancing act between pushing performance and managing thermal budgets to ensure reliability and longevity.

Challenges & Next Steps

Neither natural nor forced convection cooling can reduce case temperature below ambient temperature. For example, a heatsink with 14,400 mm² area and heat transfer coefficient of 15 W/(m²·K) has a total thermal resistance of about 8.68 K/W, limiting cooling effectiveness.

Increasing heatsink area reduces thermal resistance—for instance, a 500,000 mm² area heatsink may achieve about 0.44 K/W total resistance, while a 42,120 mm² heatsink with 24 fins may have 5.3 K/W.

Conduction cooling alone cannot cool below the cold plate temperature. These fundamental limits mean passive cooling methods have ceilings.

In Part #2, we'll explore active cooling using thermoelectric coolers (Peltier effect) that can push case temperatures below ambient, breaking passive cooling limits.

Key Insights

- Natural and forced convection cooling cannot reduce case temperature below ambient temperature.
- Conduction cooling cannot reduce case temperature below cold plate temperature.
- Thermal resistance depends on heatsink area, material conductivity, and heat transfer coefficient.
- Large heatsinks with high surface area reduce thermal resistance but have practical size limits.
- Effective thermal design is critical when investing extra power to avoid overheating.

Practical Considerations

- Always calculate combined thermal resistance (conduction + convection) to estimate temperature rise.
- Don't expect forced convection to cool below ambient without active cooling.
- Design enclosures to maximize heatsink surface area and airflow paths.
- Use thermal interface materials to minimize contact resistance.
- Early thermal modeling and testing save costly redesigns and improve reliability.

Investing extra power is tempting for performance gains, but it must be balanced with thermal management to ensure system reliability. Stay tuned for Part #2, where we'll dive into active cooling solutions.

If you want to discuss how these principles apply to your projects or explore innovative cooling strategies, reach out to us. At TrigoPi, we love pushing the edges of thermal management challenges to find practical solutions.

For more information, call us at info@trigopi.com or visit www.trigopi.com.