VICOR

The Power Behind Performance

3D Cooling of New High Density DC-DC Converters

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The Many Problems of Heat

- Lower reliability
- Lower power capability in elevated environmental temperatures
- Larger, heavier, more expensive systems
- Energy loss = more $/kWhr, more CO_2, more fossil fuel

The Two Challenges of Heat

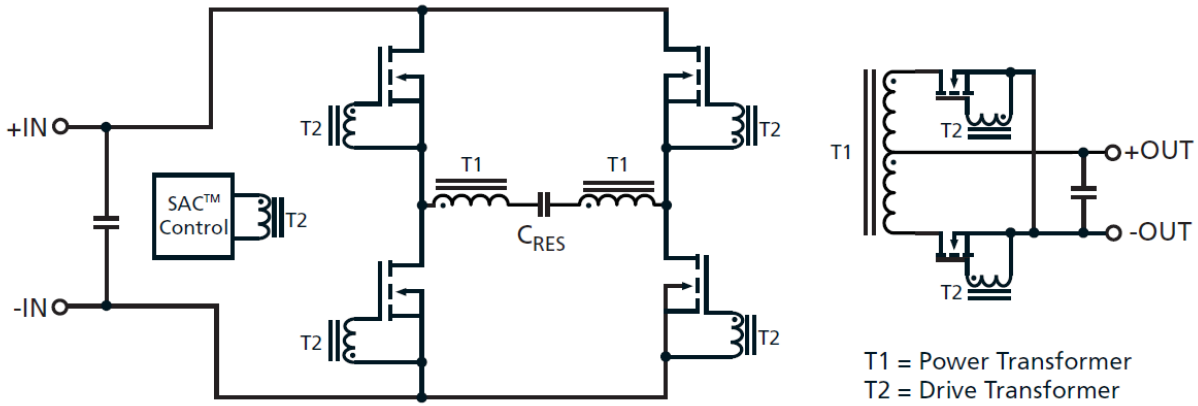
- 1) Avoiding it
- 2) Removing it

1) Avoiding Heat

- Choosing the right system architecture
  - Minimize I^2R loss
    - 400V DC distribution in datacenters, 270V DC in airborne systems
  - Minimize functions / conversion stages
    - 'Narrow' Telecom 48V enables use of high efficiency unregulated, fixed-ratio bus converters to 12V or 9.6V input buck converters
- Choosing the right power conversion topologies / components
  - Soft-switching (ZVS, ZCS)
  - Resonant systems
  - High frequency switching (>MHz)
  - High efficiency = less heat
    - $P_{DISSIPATION} = P_{OUT} \times (1 / EFFICIENCY – 1)$

Example topology: Sine Amplitude Converter (SAC)

- **Fixed-frequency, series resonant (LC) converter**
  - Resonant tank current is pure sinusoid
- **MHz switching, ZVS and ZCS**
- **Flexible topology**
  - Full-/half-bridge primary / secondary configurations
  - Stackable for higher input voltages
  - For further reading: http://cdn.vicorpower.com/documents/whitepapers/wp_sac.pdf
- **Thermal considerations:**
  - Maximum component junction temperature = 125°C
  - Maximum single-point case temperature = 100°C



T1 = Power Transformer
T2 = Drive Transformer

2) Removing Heat: Convection and / or Conduction

- **Convection**
  - Blow air across the device
    - Effectiveness = fn (inlet air temperature, theoretical air flow, impedance / disruption, device temperature)
- **Conduction**
  - Mechanical connection to draw heat to a cooler place
    - Effectiveness = fn (heatsink (size, material), interface (grease, pad, thickness), device temperature, external temperature)

Traditional Convection: Bus Converter

› **Intermediate Bus Converter (IBC)**
  – Traditional construction
  – SMT components
  – Open frame assembly
  – Industry-standard pin connections

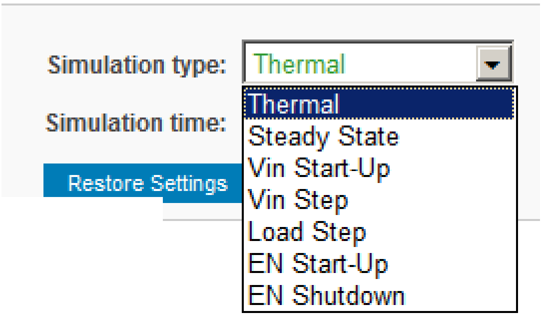
› **Thermal considerations:**
  – Majority convection cooling

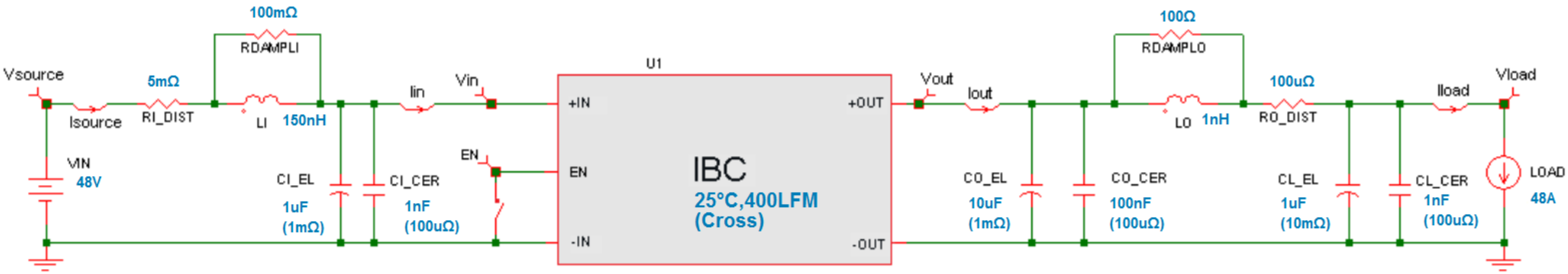
How much Air? Power? …?

› **Simulate for thermal design**

– IB048E096T48N1-00 bus converter

– 38-55V_{IN}, 9.6V_{OUT}, 500W, 98%

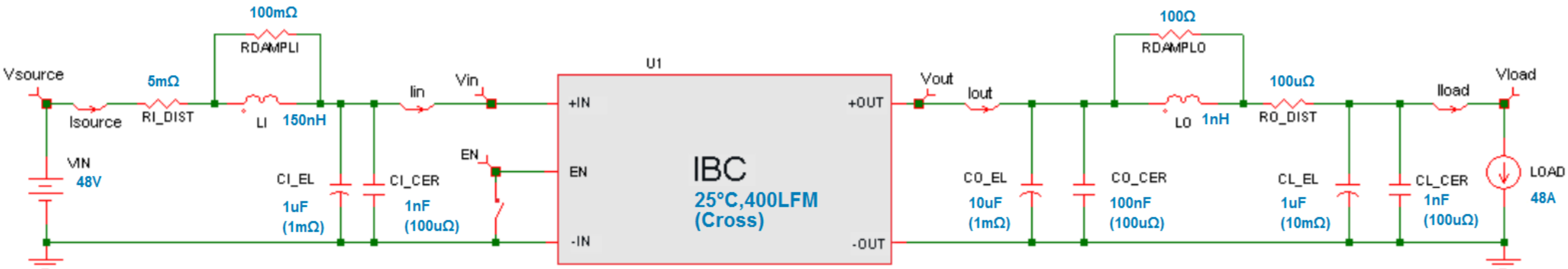




– Define electrical conditions, define airflow, temperatures, direction, etc.

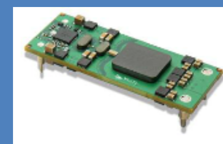
This much Air, Power, etc.

- **Simulation result**
  - 25°C air at 400LFM means:
    - 97% efficiency
    - <14W of loss
    - A safe operating temperature of 69°C



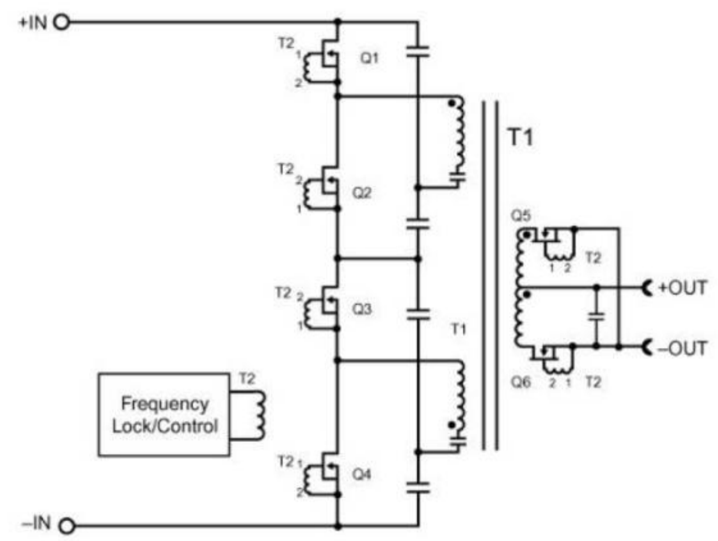
Vin (V)	Iin (A)	Vout (V)	Iout (A)	Rout (mΩ)	Pin (W)	Pout (W)	Power Loss (W)	Efficiency (%)	Operating Temp (°C)
47.95	9.64	9.34	48.00	4.79	462.42	448.55	13.87	97.00	69

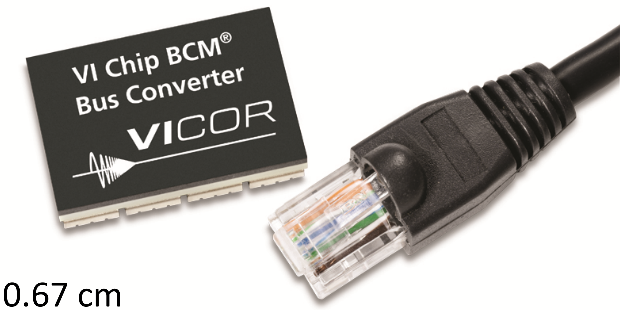
Converter Construction Considerations

	Open frame: 	**Over-molded** 
Convection cooling:	Irregular ‘city-skyline’ surface makes it difficult to reduce case-ambient resistance by increasing surface area (i.e. adding a heatsink). Soft / thick flexible pads have poor thermal resistance	Regular, flat surface allows simple, effective heatsink attach
Conduction cooling:	Conduction cooling: Negligible (through pins to main board)	Regular, flat surface allows simple, effective path to cold-plate / application case
Component ‘hot-spots’ (may vary over application conditions e.g. “High line, no load” vs. “low line, full load”)	Isolated / insular	‘Averaged’ (lowered) across a wider surface area of the converter by low thermal impedance mold material
High voltages		Over-molding overcomes creepage / clearance challenges to enable higher input voltage inputs in smaller converter packages

Over-molded Converter: ‘VI Chip’

- **Sine Amplitude Converter**
- **Input voltages up to 400V DC**
  - ‘Stacked-cell primary’ SAC variant shown
  - Transformer ratios from 1/1 to 1/40
- **‘Thermally’ not ‘electrically’ power limited**
  - Power capability increased if T_{CASE} can be maintained
    - 330W at T_{CASE} 100°C → 375W at T_{CASE} 85°C



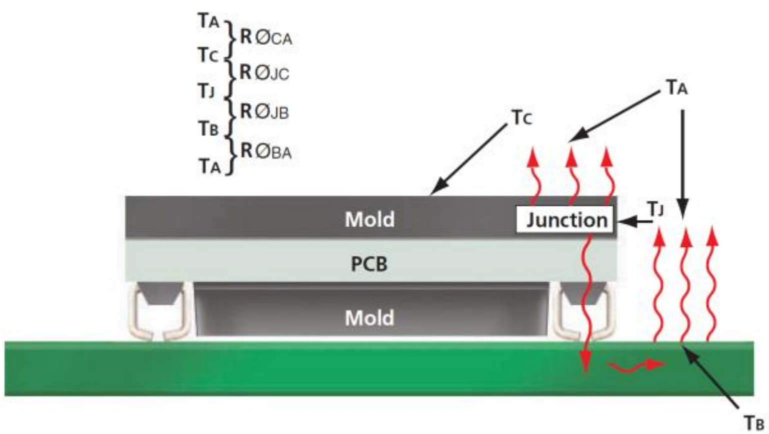


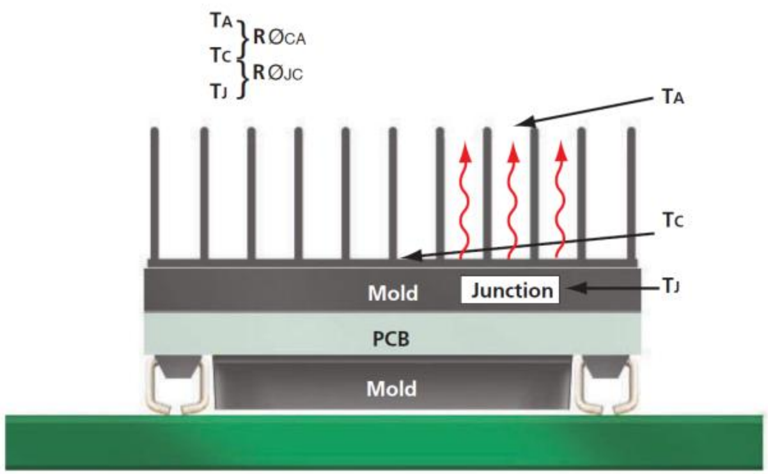
3.25 x 2.2 x 0.67 cm
(1.28 x 0.87 x 0.265 in)

Over-molded: Convection & Conduction

- **Convection:**
  - Simple application of heatsink (vary height, orientation)
  - Thin, effective path (grease, phase-change material, tape, etc.)

- **Conduction:**
  - Lower lead/pin impedance to main board
  - Power components located close to leads
  - Simple attachment to cold-plate





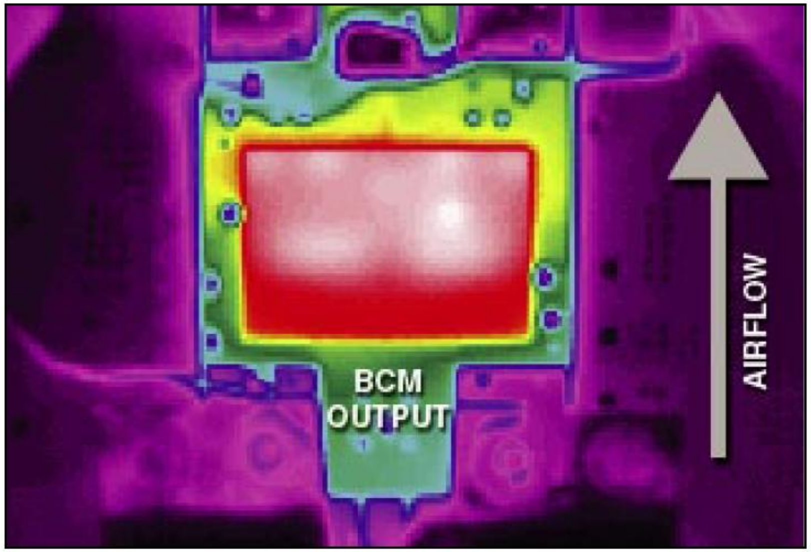
Convection:

Power vs. air, temp

48:12V bus converter

- **Output Power**
  - Fn (T_{AMB}, heatsink, airflow)
    - More air
    - Lower temperature
    - More heatsink

  … = more power



IR image, 0° airflow; Full load, 200 LFM, no heat sink

- **Notes**
  - "0° Airflow" refers to air direction, *not* air temperature
  - See Application Note AN:008: http://cdn.vicorpower.com/documents/application_notes/vichip_appnote8.pdf for more details

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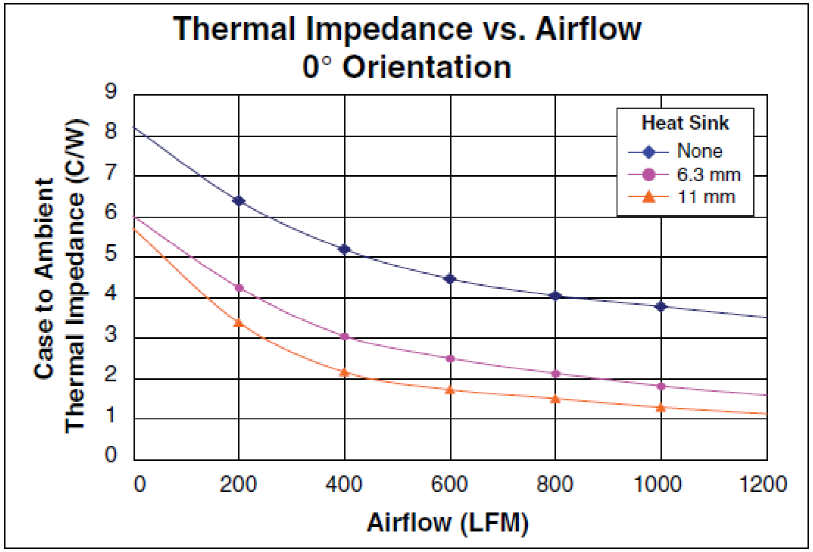
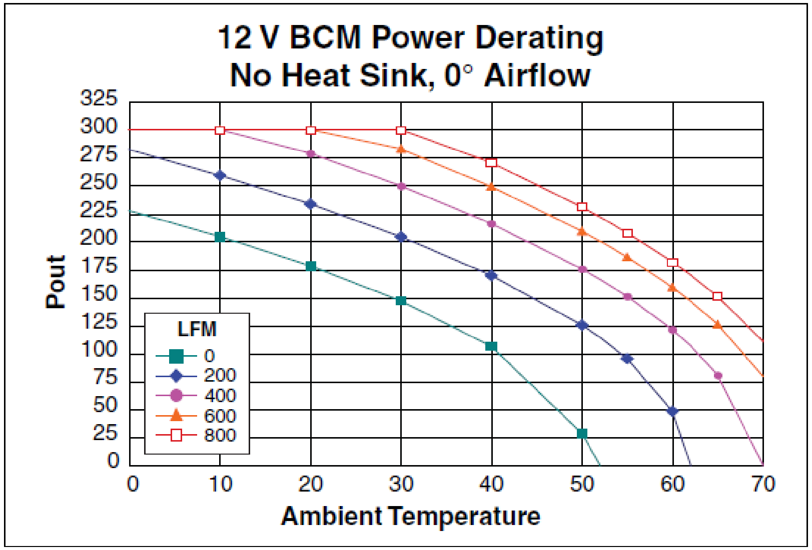
Convection: Effect of Heatsinking

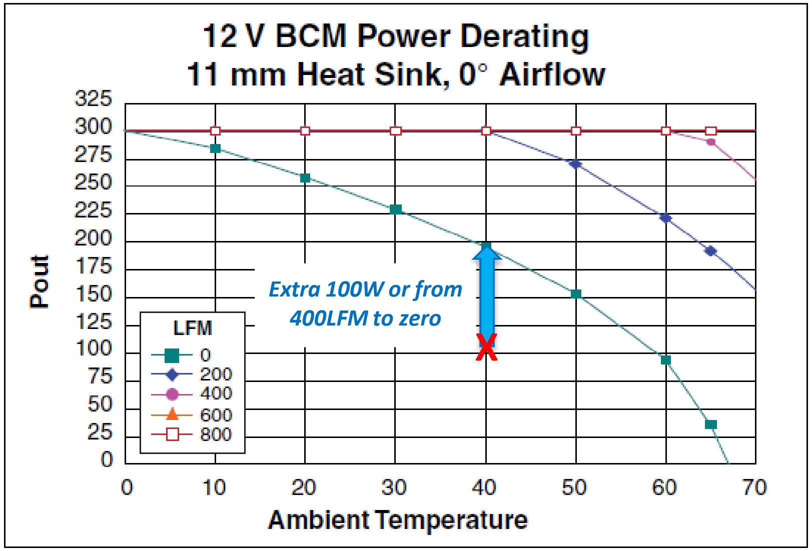
- Increased surface area exposed to air
- Thermal impedance reduced



Thermal impedance vs. airflow, 0° orientation



Power derating with no heat sink, 0° airflow



Power derating with 11 mm heat sink, 0° airflow

- Get more power and/or use less air

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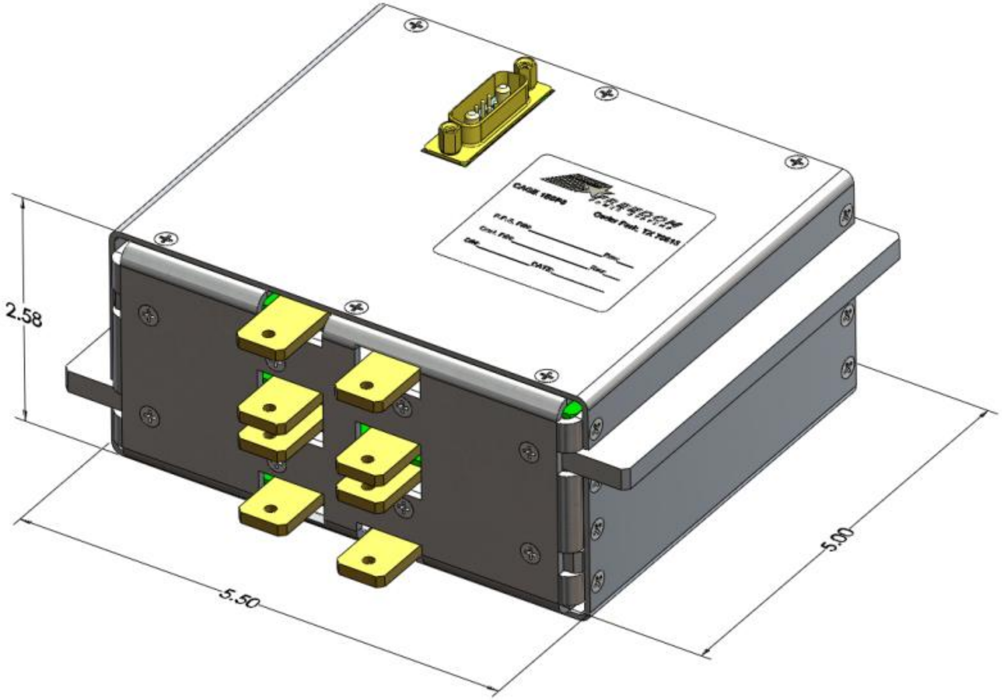
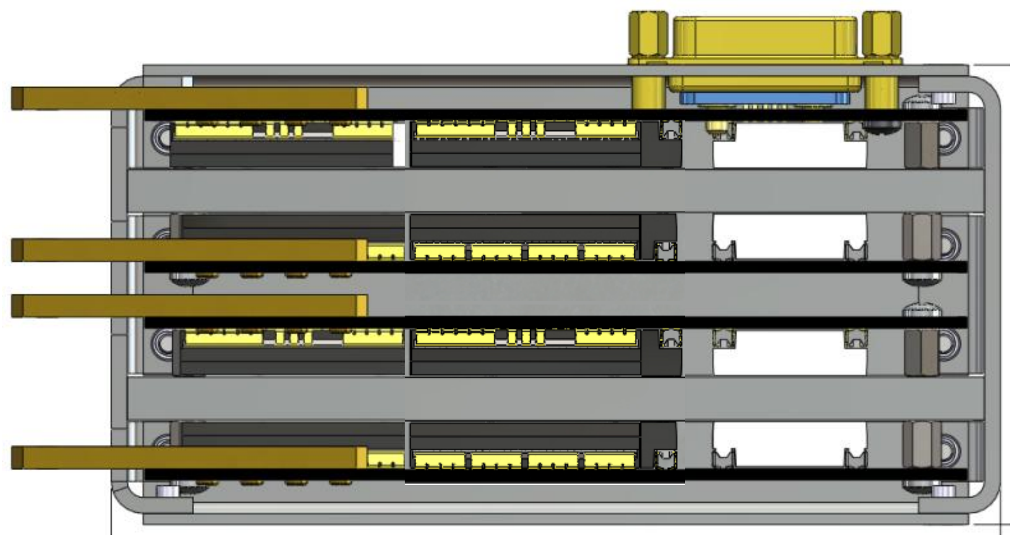
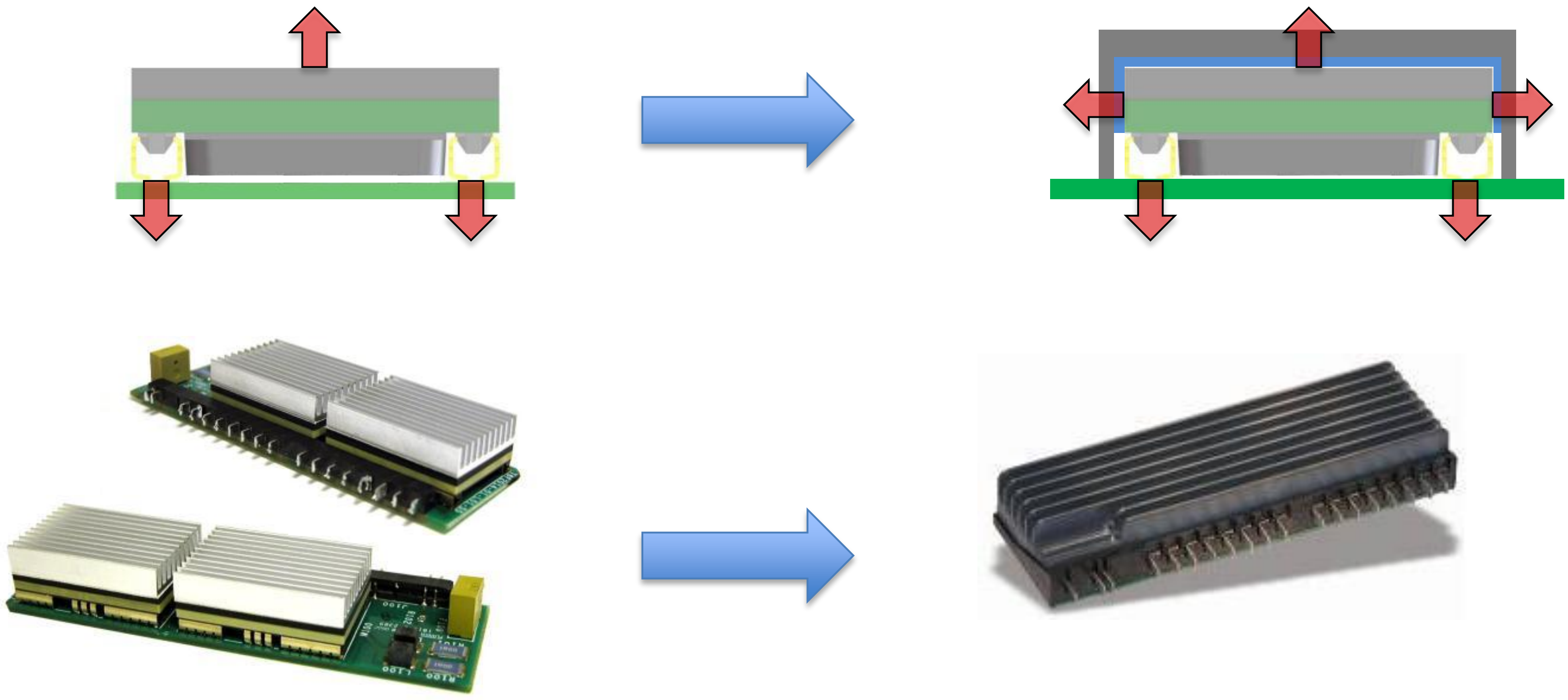
Conduction:
270V Airborne

- **Electrical Specification:**
  - Input = 270V
  - Output = 4V, 800 A (regulated, 3.2 kW)
- **Mechanical Specification:**
  - Size = 5 x 5.5 x 2.58”
  - Weight = ~4x less than typical solution
- **Power density**
  - => 40 W/in3
- **Thermal design**
  - Mount converters either side of cooling plates, brought out to airframe
  - No airflow allowed within case





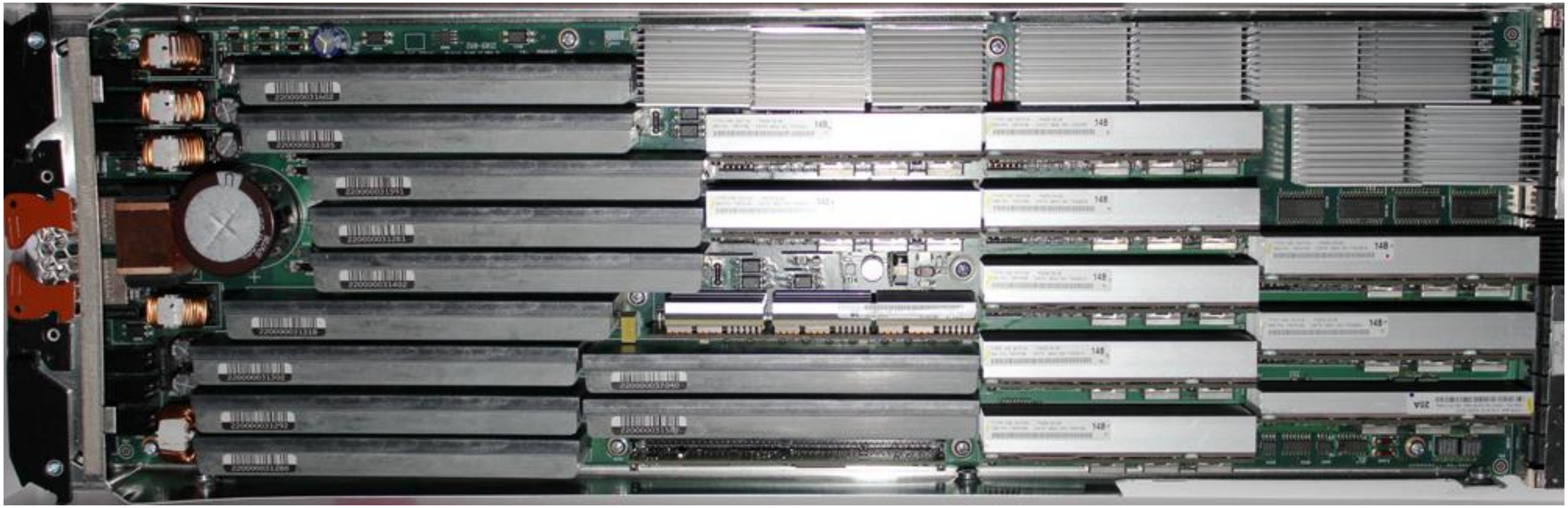
Minimizing Conductive Impedance: ‘3D’ Approach



- **‘VI Brick Arrays’**
  - Additional heat extraction through *sides* of VI Chip enables increase of power capability up to 10%
  - 2-up and 3-up high voltage bus converter arrays in thermally-enhanced, ruggedized solutions simplify thermal management and minimizes board space
  - Integrated vertical package orientation also provides better exposure of the heatsink to system airflow.

Conduction, then Convection:
IBM POWER7 Disk Enclosure (9 kW)

- **Electrical Specification:**
  - Input = 350V
  - Outputs = 12V, 600A and 5V, 558A(pk)
  - Efficiency = 94% (to 12V)
- **Mechanical Specification:**
  - Size = 21 x 6.25 x 1.75in
- **Power density**
  - = 39 W/in3
- **Thermal design**
  - Air-cooled (longitudinal)
  - VI Chips plus standard heatsinks
  - VI Chips in VI Brick arrays



Summary: Efficient thermal design

- **Take a holistic look at the whole system**
  - Electrical, mechanical and thermal
- **Select heat path (direction(s) and method) early**
  - Maximize chance of reliable, competitive system
- **Use the tools (electrical simulators linked to thermal results)**
  - Reduce time to market
  - Avoid excessive ‘sand-bagging’ / tolerances in designs
- **Good news: lots of options available!**

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…and thank you!

- ***For further information, please:***
  - *Visit us at booth #731*
  - *Visit us at www.vicorpower.com*
  - *Call or email: Stephen Oliver: soliver@vicorpower.com, +1-978-749-3526*