Thermal tests & simulations with CMS "Serenity" ATCA boards

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• Thermal measurements with an ATCA mock up board
  • on a Comtel shelf
  • on the LHC-customized Schroff shelf

• Thermal simulations with Ansys Icepak
  • LHC-custom Schroff shelf simulation
  • Mock up board simulation
  • Heat sinks optimization
Test stand @ building 14

- PC blade
- ATCA shelf 14 slots
- 3 PSU 2 channels 60V-7A connected to the PC via Ethernet
- Front and rear fillers (with plastic baffles)
- 1 mockup board
- 2 heater boards
- S7 system for temperature probe (pt1000) reading
- LAN connecting the shelf manager, PSUs, and the PC

- Temperature measurements accessible using Simatic GUI and via Python-snap7 interface
Serenity board

- ATCA development platform
  - Provide a rapid-prototyping platform for different project needs
- Carrier Card
  - Services: power, clocks, optics, interconnects, IPMC & CPU
- Daughter Cards
  - Data processing FPGAs
  - Samtec Z-RAY custom socket

- Tested:
  - Ethernet connection
  - COM-Express with Centos Linux
  - PCIe connections
  - 25 Gbps links daughter-daughter
  - 25 Gbps Firefly links
  - Clock distribution
Board mock up

- Heat sink
- Conductive film
- Heater (Cu, Kapton)
- Conductive film
- FPGA mockup (Al)
- Daughter board
- Interposer mockup
- Main board

Kapton heaters made at CERN Atelier

FPGA mock up

Optic block mock up

All components provided by Imperial College
Temperature sensors

12 Pt1000 temperature sensors: 4 for FPGAs and 8 for Optics, glued into small holes in the aluminum blocks

- Max FPGA temperature = 100 °C for a ku115 "-e" part
- Optics “safe” limit temperature = 50 °C

Legend
XyFwww = FPGA temperatures,
XyOFwww = Optics Front temperatures,
XyORwww = Optics Rear temperatures.
Thermal meas.: Comtel shelf

Comtel Shelf specs:
- 4x RiCool3 on top of the shelf
- Air flow: front-inlet back-outlet
- For each fan:
  - Airflow: 320 m$^3$/h (188 CFM)
  - Static Pressure: 897 Pa
  - Noise: 59 dB(A)@70% speed
- cooling 300W/board

Summary of the measurement outcomes:
- Power: 90W/FPGA and 10W/Optics
- Inlet air temp 19 Celsius
- Fan at max speed
- Cooling is not optimal (see picture)
- Tested the cross board heating with sandwiching the board with another two with same power injection:
  - negligible effect: ~1 Celsius difference
- Filler effects, removed the baffles at the end of the fillers:
  - temperature increase of 1-3 Celsius at the bottom sensors, marginal for the others
Schroff shelf

- 2 fan trays, each fan tray contains 6 fans
- Air flow: bottom->top
- For each fan:
  - Airflow: 336 CFM
  - Power: 120 W
  - RPMs: 11000
  - Noise: 78 dbA
  - cooling 450W/board

Summary of the measurement outcomes:

- Power: 90W/FPGA and 10W/Optics
- At fan speed 10/15 similar to Comtel at max speed (see picture)
- At max fan speed cooling is fairly ok (see picture)
- Increased the injected power per optic block to 20 W (25 Gbps firefly)
- Tested a heat sink with fins instead of pins (see next slides), better performance obtained
- Effect of baffles
Schroff cooling

- **Setup:**
  - heater-boards off
  - top fan tray off
  - bottom fan tray on

- For high fan speed level we observe the injection of heat inside the shelf (4 Celsius w.r.t. to resting condition)
Crate noise and power (2 fan trays)

- **Setup:**
  - heater-boards off
  - top and bottom fan trays activated

- **Comments:**
  - noise reaching 90 dBA at maximum fan speed (single shelf)
  - 2 kW power consumption at maximum fan speed
Thermal meas.: Schroff shelf

- Fan speed setting from 10 to 15 (maximum) level
- Higher fan settings produce only a limited reduction in temperature, but do result in significant additional noise and power consumption.
Schroff simulation in IcePak

- A simplified Schroff geometry has been created in IcePak:
  - Crate with bottom air inlet and top air outlet
  - 6 inlet fans and 6 outlet fans
    - configured for the max speed
    - 10500 RPMs, 150 W/fan, pressure/cfm curve
  - front/rear panel
  - vertical board panels
  - horizontal panel emulating power supply unit

Inlet flow from simulation: 0.93 m³/s = 1970 CFM

Front view
Comparison between measurements and simulations: fair compatibility; the goal of the simulation is to have a tool for the heatsink optimization.
Fins heatsink cross check

**FINS**
- Fan speed: 10/15
- 90 W/FPGA 10W/Optics
- Optics heat sink: Al, fins,
- FPGA new heat sink:
  - Commercial hs
  - Cu
  - 28 fins, 0.45 mm wide
  - H.: base 2.9mm, total 10.1mm

**PINS**
- Same shelf conditions
- FPGA old pins HS:
  - Cu
  - 26 pins per row
  - Pin diameter: 1.7mm
  - H.: base 4.4mm, total 12.7mm

**Simulation**

**Measurement**
Sim: heat sink param optimization

- 90 W/FPGA - 20 W/Optics
- 10/15 Schroff equivalent fan speed
- Procedure:
  - Optimization of fins
  - Fixed 25 fins, optimization of the thickness of the fins
  - Fixed 0.5 thickness, optimization of the base height
Sim: optimized heat sink design

- Fan speed: 10/15
- 90 W/FPGA 20W/Optics
- Copper
- 25 fins/90 mm
- 3 mm base
- 14.2 mm total height
- 0.4 mm fin thickness

Possible real heat sink

- Aluminum (cheaper and lighter)
- 25 fins/90 mm
- 4 mm base (to increase rigidity)
- 14.2 mm total height
- 1 mm fin thickness (extrudable)
Conclusions I

• A **thermal simulation** of a Phase-2 ATCA card and shelf has been performed and compared against a thermal mock-up of the card, with good agreement

• New ATCA designs and heat sinks can now be **quickly simulated** to determine whether thermal performance is satisfactory

• Two shelves have been tested: Comtel and LHC-customized Schroff, along with **different configuration aspects** (e.g. impact of adjacent cards and fillers with/without baffles)

• The **cooling performance**, **power consumption** and **fan noise** as a function of fan speed have been measured. As a consequence, our new ATCA designs will be designed with a maximum fan setting of **10 out of 15**, significantly reducing fan power & fan noise to more manageable levels.
• **Heat sinks were optimized**, leading to significant performance improvement. For reasonably large FPGAs (90W) and 16Gbps optical modules there is now significant margin in the thermal design, albeit with significant board real estate used for heatsinks.

• Despite the thermal headroom, the heat sink area will not be reduced, allowing the card to accommodate larger, pin compatible FPGAs and 28Gbps optical modules, both of which dissipate more power.

• **Future work.** In simulation aluminium has shown comparable performance to copper and thus a switch to lower cost, lighter weight heatsinks may be possible.
Testing boards

Board mock-up: heaters+temperature sensors

x2 heater boards: only heaters

Graphical view: No power
Measurements Vs. Simulations

Fan speed: 100%
Power: 90W/FPGA - 10W/Optics block
No Heater boards on

Thomas’ simulations - FloTherm
Power: 85 W/FPGA - 10W/Optics bloc
Air speed: 6m/s, 28mm deep tunnel

Not matching, large delta between top and bottom FPGA
Air speed

Anemometer: testo 425
Accuracy: ~5%
Measured inside the ATCA shelf
Board setup: like picture

Air speed [m/s] Vs. Fan speed for bottom part

Front
Middle
Rear

Bottom line: fairly linear, reproducible measurements
Measurements with increased power

Schroff - Power: 95W/FPGA - 20W/Optics block  No Heater boards on

Fan speed 10/15

Fan speed 11/15

Fan speed 12/15

Fan speed 13/15

Fan speed 14/15

Fan speed 15/15
New heatsink simulation

- New heatsinks were designed, most important improvements done on the optics heatsinks:
  - Larger area
  - Different material: it was aluminum, it is copper
  - Increased pin density
- Simulation done using the same shelf conditions
- 6-10 Celsius improvement on the optics temperatures

Max temperatures reported

Current heatsinks  New heatsinks
Pins Vs Fins comparison

- For the FPGA heatsinks, fins were tested instead of pins
  - 26 fins 1 mm width 90/26 mm pitch
  - same material

Max temperatures reported

Current heatsinks

Fins heatsinks
Simulation of 10/15 fan level

- Default
  - FPGA HS: Pins

- FPGA heat sinks with fins
  - FPGA HS: 37 fins 0.35 mm width
  - 90/37 mm pitch

- New Design, all pins
  - FPGA HS: Pins
  - Optics HS: Pins,
    - larger and denser
• Fan Speed: 10/15

- FPGA HS: Pure copper
  - 44°C
  - 47°C
  - 38°C
  - 39°C
  - 65°C
- FPGA HS: Extruded aluminium
  - 44°C
  - 47°C
  - 38°C
  - 39°C
  - 68°C
  - 51°C
Fins heat sinks

- FPGA heat sink: Cu, fins
- Optics heat sink: Al, pins

- FPGA heat sink: Cu, fins
- Optics heat sink: Al, fins

- FPGA heat sink: Cu, fins
- Optics heat sink: Al, fins, 4 cm width
Increased power - 20W optics

- FPGA heat sink: Cu, fins
- Optics heat sink: Al, fins,
  - 4 cm width
  - 20 W instead of 10 W

- FPGA heat sink: Cu, fins
- Optics heat sink: Cu, fins,
  - 4 cm width
  - 20 W instead of 10 W
Fins heatsink test

- Optics heat sink: Al, fins,
- FPGA new heat sink:
  - Commercial hs
  - Cu
  - 28 fins, 0.45 mm wide
  - Height: base 2.9mm, total 10.1 mm

- Same config but:
  - Height: base 4.4mm, total 12.7 mm

![Diagram showing temperature distribution for different heatsinks.](image-url)
Sim: optimized heat sinks

copper - 25 fins/90 mm - 3 mm base - 14.2 mm total height - 0.4 mm fin thickness

FPGA heat sink 9 cm

FPGA heat sink 7 cm
Sim: deflector

W/o deflector

36°C  39°C

31°C  32°C

59°C

W/ deflector

33°C  35°C

31°C  33°C

58°C

47°C  48°C