MTCA-based Control System for Neutral Atom Quantum Computer

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WHO ARE WE?

Atom Computing

Neutral atom-based quantum computer

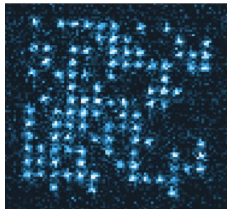
2018

Founding and build out of facility in Berkeley, CA

2018

100Q

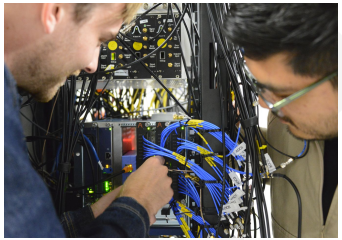
Neutral atom QC with 100 qubits demonstrated



Jul'21

MTCA

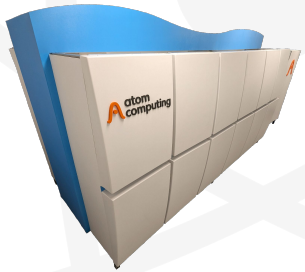
Integration of MTCA into 100Q system



Jul'22

Expansion

Start of development of new machines in Boulder



2022

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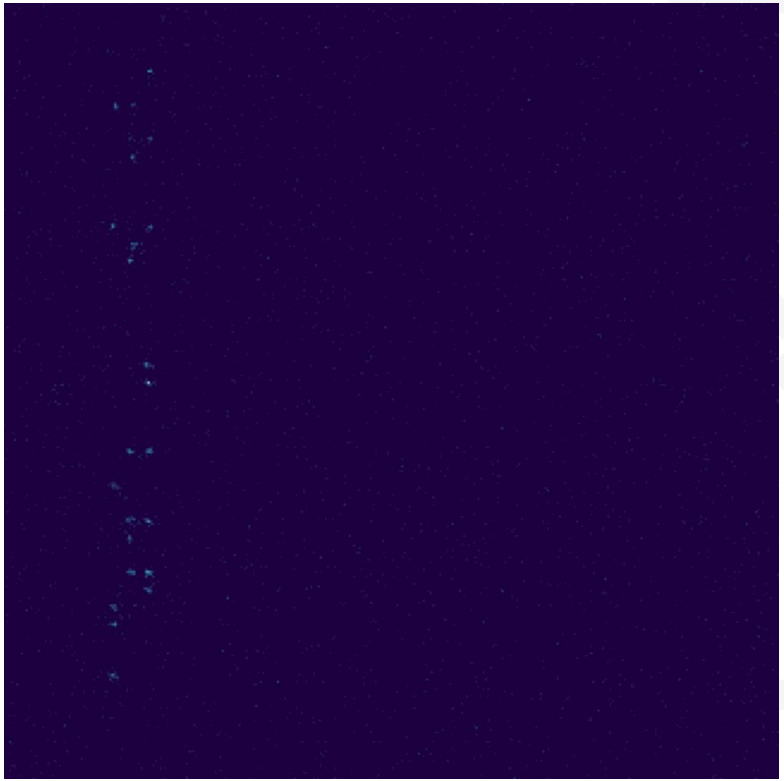
New Milestone

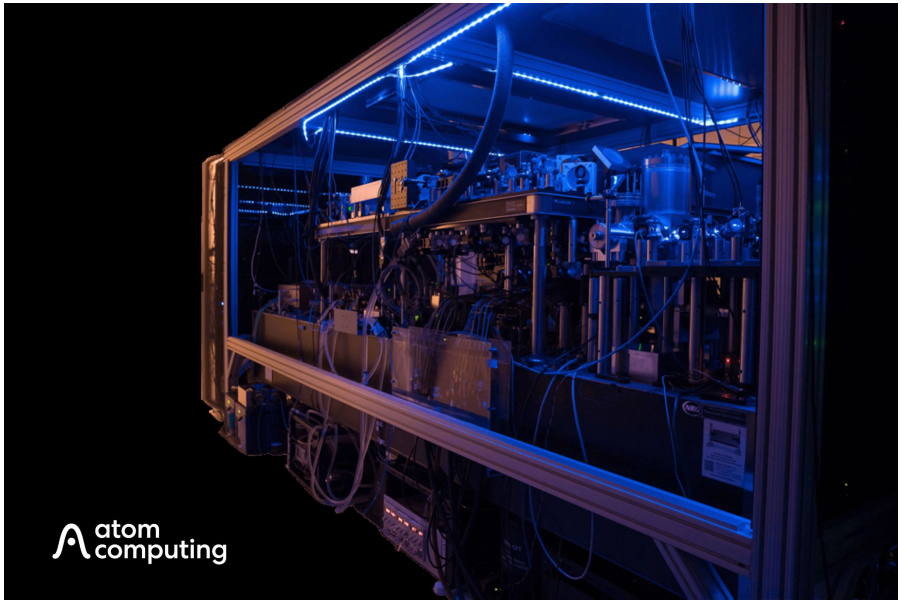
New Milestone

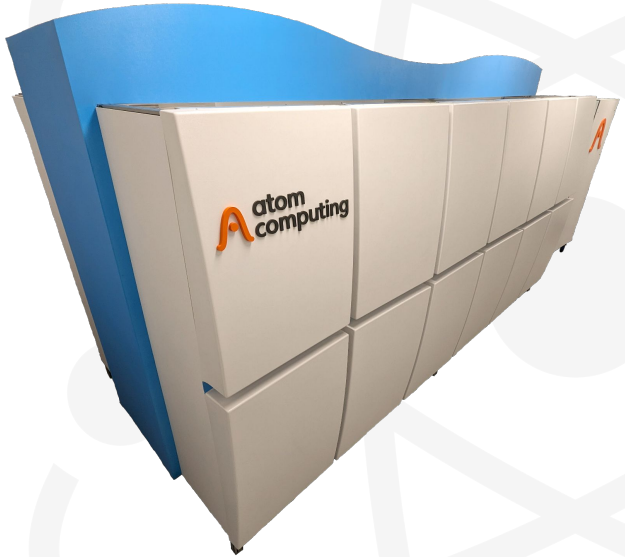
1000+ atoms!



Atom's Quantum Computers

Two generations across multiple sites





Phoenix

- 100 qubit prototype system
- Demonstrated coherence times >40s
- Located in Berkeley, California

Gen 2

- 1000+ qubit production system
- MCM, 1000+ atom trapping, and beyond!
- Located in Boulder, Colorado

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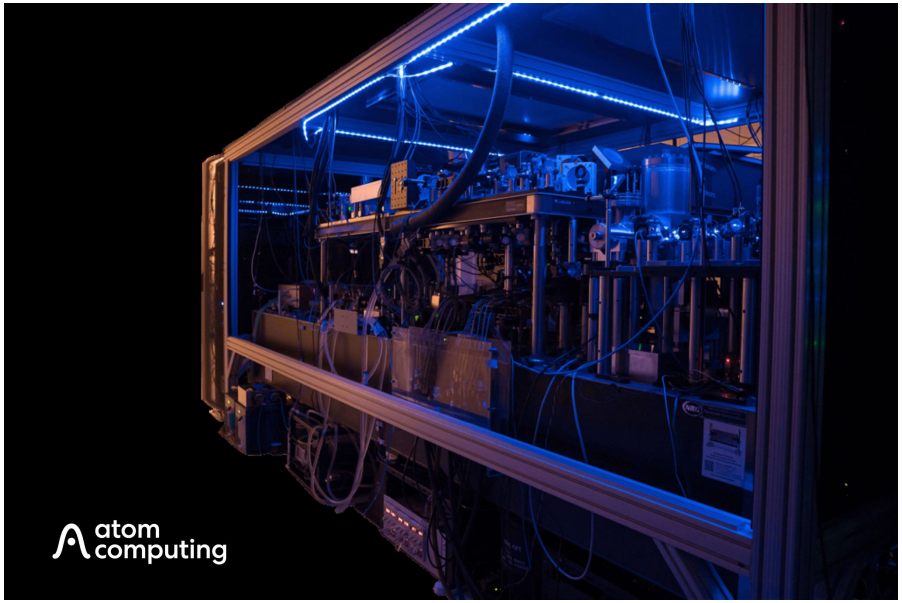
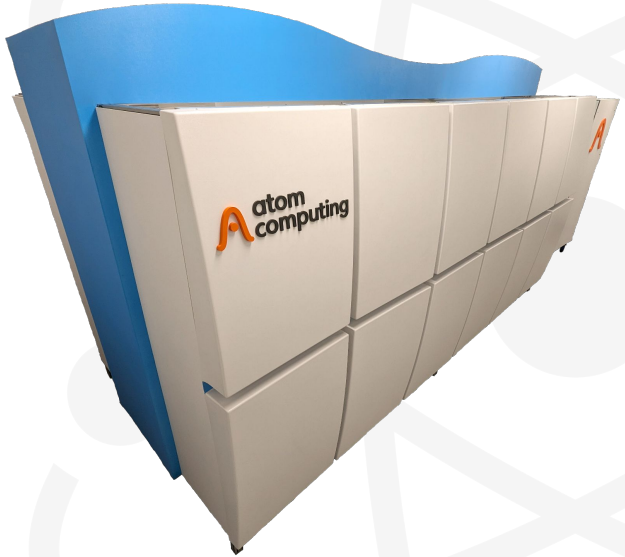
Atom's Quantum Computers

Two generations across multiple sites



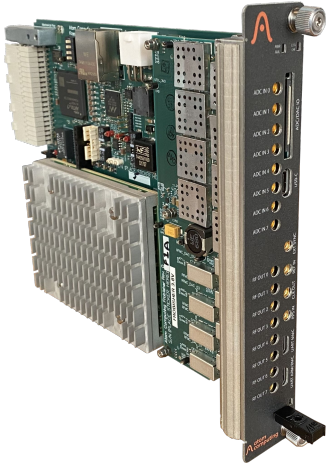


Both use MTCA!

MICROTCA HARDWARE

AMC + RTM Cards

Across all systems



SDR

- Custom AMC card
- RF Generation in MHz - GHz range
- Controls sequencing and triggering

DC Volt. + Camera

- Custom FMC card + ZUP + EasiIC FMC
- Precise DC voltage control
- Coaxpress interface with cameras

Triggers

- Custom RTM card
- Responsible for physically driving individual trigger lines to external components

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MicroTCA crates

Phoenix system

- Single Native-R5 chassis (5U)
  - 4x double full-size custom AMC cards
    - 32 RF-DAC channels
    - 32 RF-ADC channels used for active RF feedback and monitoring
    - Backplane triggering and 10MHz clock distribution
  - 1x custom RTM for external triggering
- 2x Native-mini-R1 chassis (1U)
  - 2x ZUP boards
    - custom DAC FMC for DC voltages
    - Coaxpress FMC for cameras
  - 1x double full-size custom AMC for diagnostics
    - Phase locking, CW RF generations

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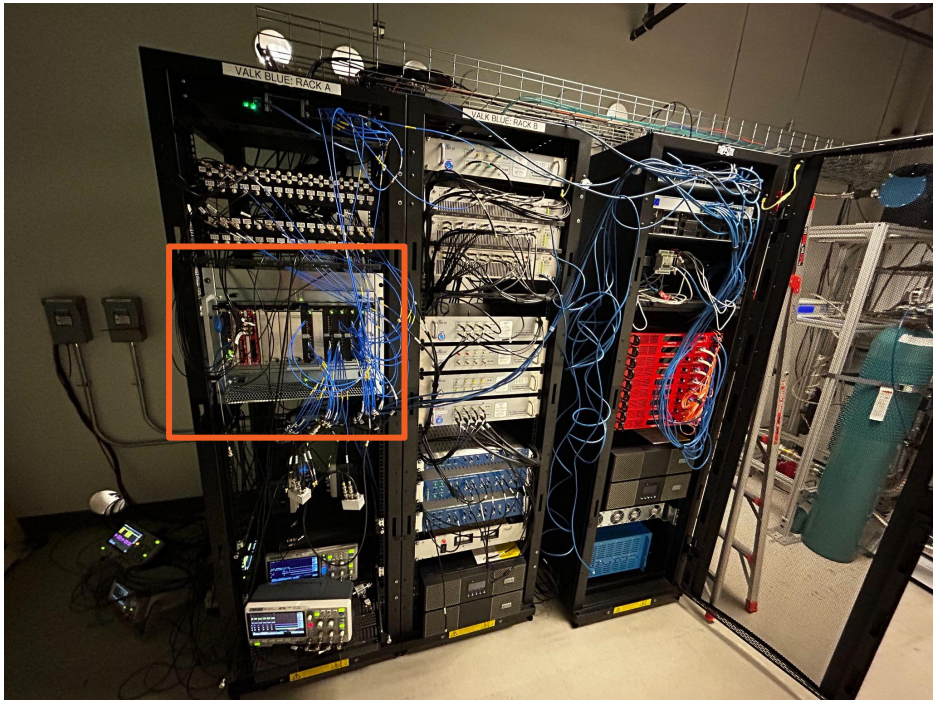
MicroTCA crates

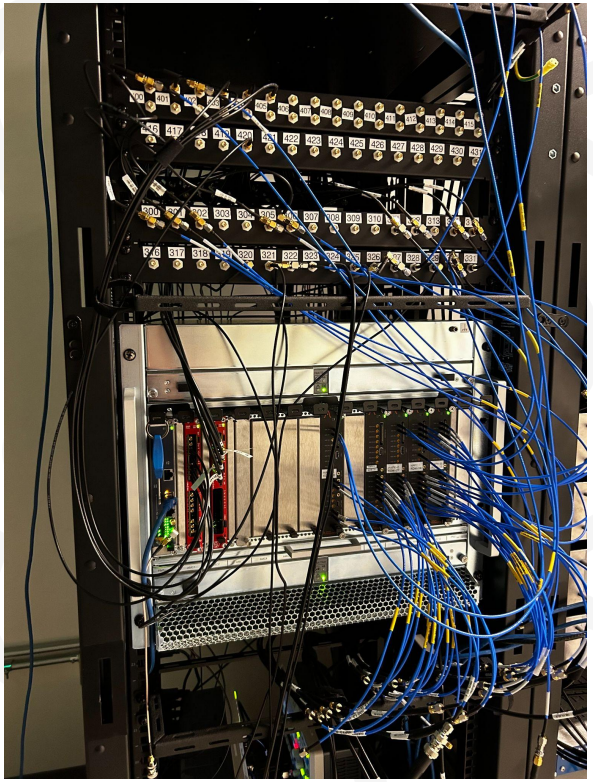
Gen 2 systems

- 1x custom nVent Schroff 9U chassis per machine
  - 9x double full-size custom AMC cards
    - 72 RF-DAC channels
      - RF Generation
      - Laser and cavity locking
    - 72 RF-ADC channels used for active RF feedback and monitoring
    - Backplane triggering and 10MHz clock distribution
  - 1x custom RTM for external triggering
- 2x Native-mini-R1 (1U) per machine

MicroTCA crates

Gen 2 systems



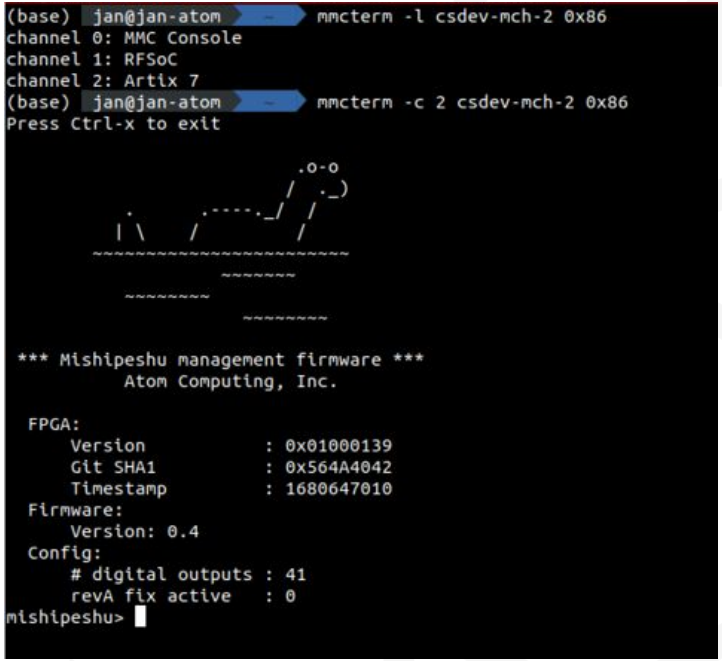


OPERATIONAL EXPERIENCE

Remote operation

Multi-site coordination

- Deployment of updates across sites
- Active coordination of MTCA maintenance between sites
  - #microtca-in-boulder
- Real-time inventory
- UART-over-IPMI
  - MMC update to reroute UART communication from front panel to allow data transfer over backplane
  - Greatly increased productivity!

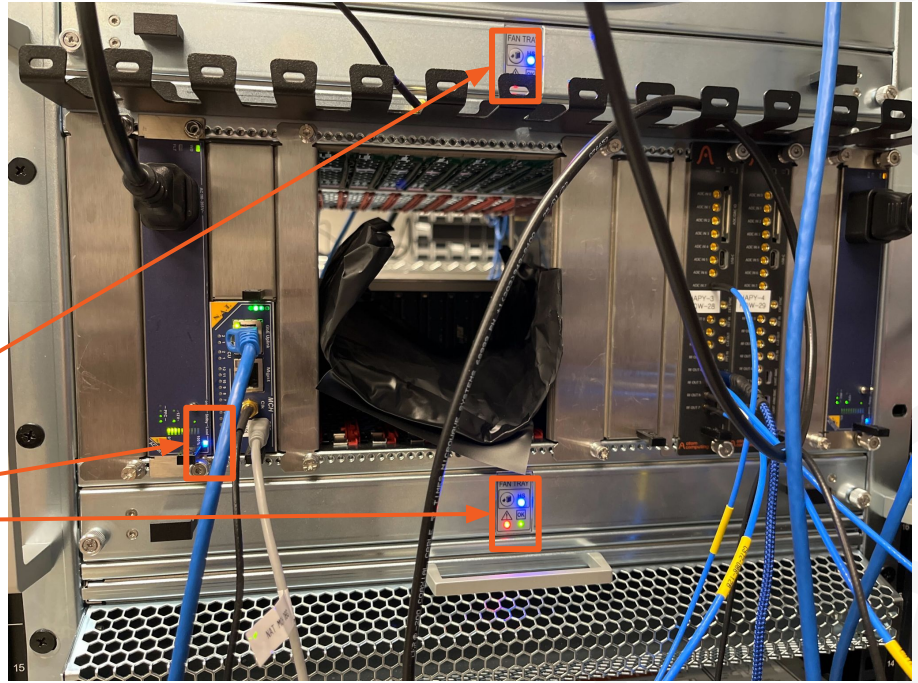


Name	Date created	Total membership	Messages posted
# microtca-in-boulder	2023-03-06	19	1,180

Remote operation

What can go wrong?

- One of our chassis stopped responding
  - Fans roaring, LEDs were in incorrect states



Remote operation

What can go wrong?

- Noticed in the logs that the MCH switched to from IPMB-A to IPMB-B

```
ipmiMsgSender(52): REQ(I2C=0xc6) failed on bus 13, result -9
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R(52,13,1)ipmiMsgSender(52): REQ(I2C=0xc6) failed on bus 13, result -9
R(52,13,2)ipmi_SwitchBus(52): WARN - switch IPMB-A(13) -> IPMB-B(14)
MsgAge(chan=14) = 0
ipmiMsgSender(50): REQ(I2C=0xc2) failed on bus 13, result -9
ipmiMsgSender(52): REQ(I2C=0xc6) failed on bus 14, result -10
R(52,14,4)ipmiMsgSender(50): REQ(I2C=0xc2) failed on bus 13, result -9
R(50,13,1)ipmiMsgSender(52): REQ(I2C=0xc6) failed on bus 14, result -10
R(52,14,5)ipmiMsgSender(50): REQ(I2C=0xc2) failed on bus 13, result -9
R(50,13,2)ipmi_SendFru(52): timeout - no response for REQ: 0x20->0xc6, Seq=57
PM_HEARTBEAT_REQ
PM(52): heartbeat command completed with code = 0xffffffff
PM(52): Board has been removed !
```
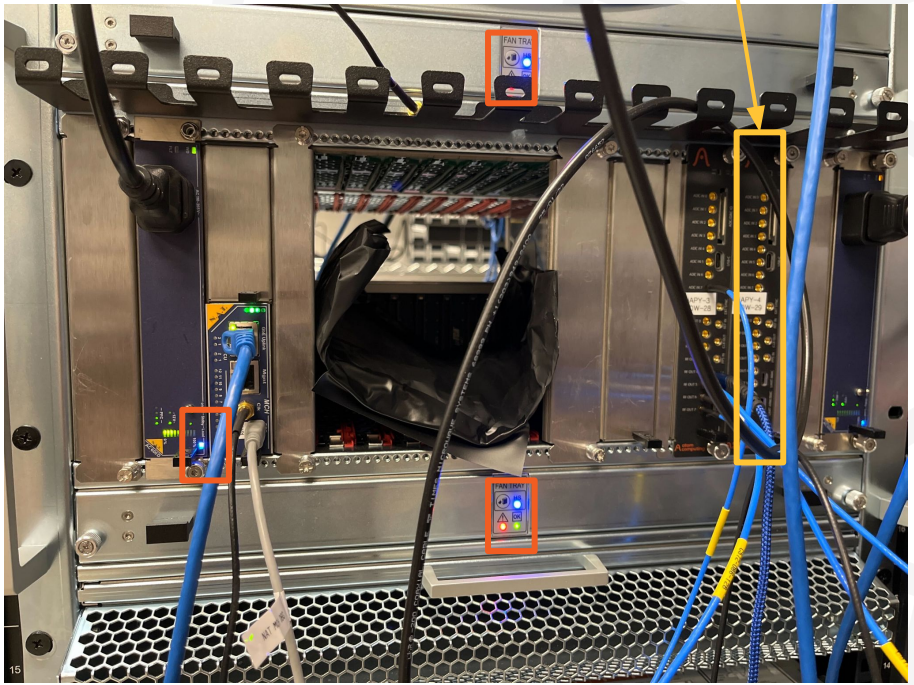

Remote operation

What can go wrong?

- AMC card was inserted into MCH slot

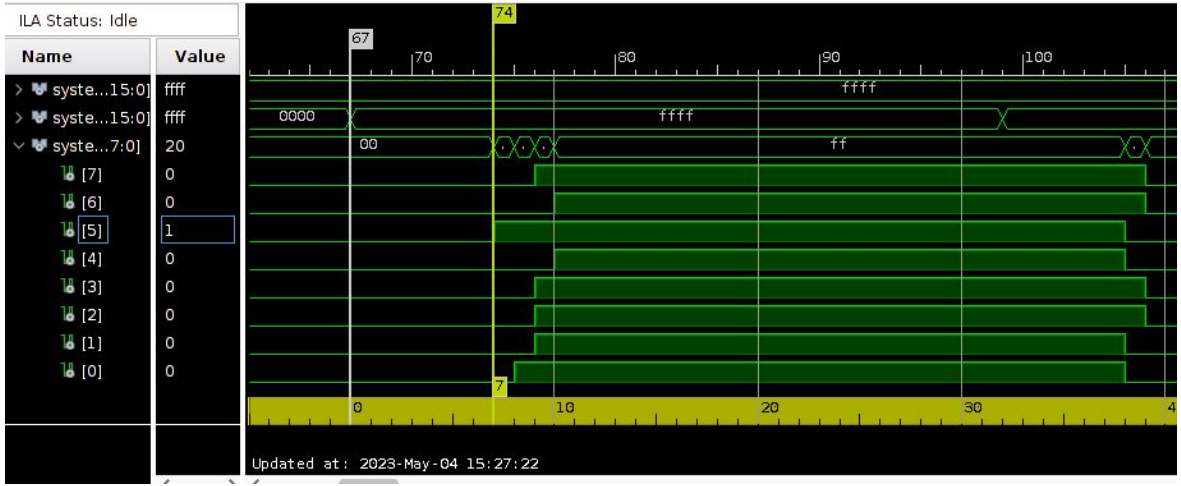


NEW HARDWARE

Native-mini-R1 Issue

Backplane termination

- Mini-R1 chassis missing 100Ω termination resistors on backplane
  - MTCA .4 spec calls for these termination resistors to be populated
- Caused signal integrity issues
  - Long propagation delays and significant channel to channel skew
- Interfered with our ability to utilize backplane in this chassis



ILA with 125MHz clock

- **56ns of propagation delay**
- **Max channel skew of 24ns**

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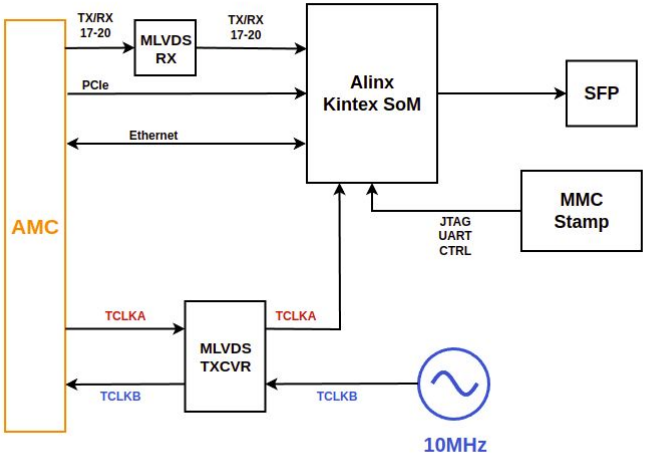
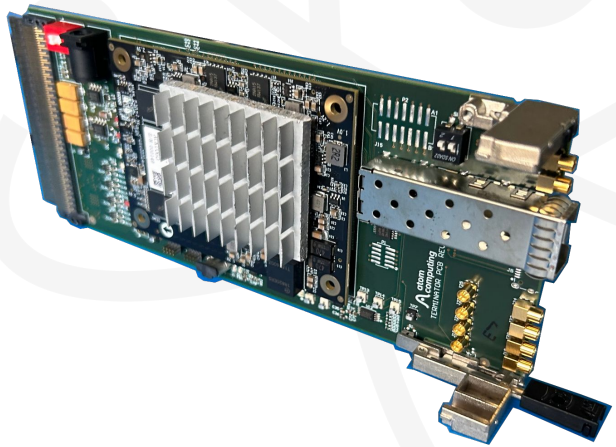
The Terminator Board

Backplane termination and monitoring

- Single-width AMC board
  - MMC stamp to implement management
- Provides termination for NATIVE-mini-R1 chassis on MLVDS trigger lines
- 10MHz oscillator to drive TCLKB
- Monitoring of backplane signals
  - TCLKA
  - Port 17-20 MLVDS backplane triggers
- Evaluation platform for Kintex Ultrascale FPGA
  - Also works standalone with no FPGA SoM mounted
- Seamless bringup





FUTURE OUTLOOK

Future Outlook

For next generation control system

- Scaling up number of RF channels per chassis
  - Improvements to SDR AMC card
  - RF over Zone3
- Integrating fast, complex classical control flow logic into system
  - PCIe uplink to chassis
  - Error correction and logical qubit encoding
  - Board-to-board communication
- Multi-chassis synchronization

Thank you!