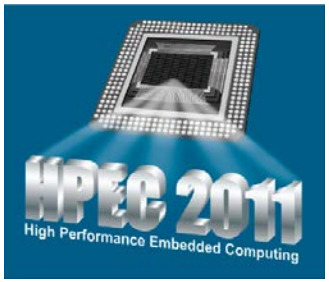
# Modular, Scalable Computing for Systems with Tight SWaP Constraints

**Prepared by**
**Colorado Engineering, Inc.**
**for HPEC 2011**
**September 21, 2011**



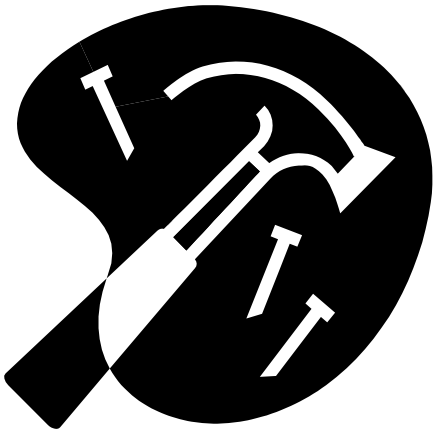

CΣi
COLORADO ENGINEERING, Inc.

# Outline

- Highlight considerations for meeting Size, Weight, and Power (SWaP) of embedded processing systems within constrained platforms
- Present an architecture developed under a Missile Defense Agency (MDA) SBIR facilitating SWaP-optimized solutions

# Meeting SWaP Challenges

- Suggests need for optimized system solutions
- Engineer should have flexibility to address size, weight, and power in trade space
- Ideal toolbox would be
  - Heterogeneous
    - ASICs
    - FPGAs
    - GPUs
    - General purpose / multi-core
  - Modular
  - Scalable



# Legacy Approach to Modularity and Scalability: Backplanes

- Add weight, size, and cost
- Constrain incremental scalability
  - Truly SWaP-optimized, backplane-centric solution should have zero empty slots
  - But zero available slots means system cannot incrementally scale to address fluid requirements
  - Solution then requires an additional backplane, or a new backplane with more slots
- Bottom line: backplanes are not SWaP friendly

*Image courtesy of Kontron*

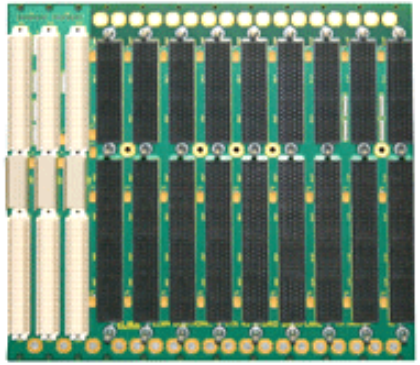
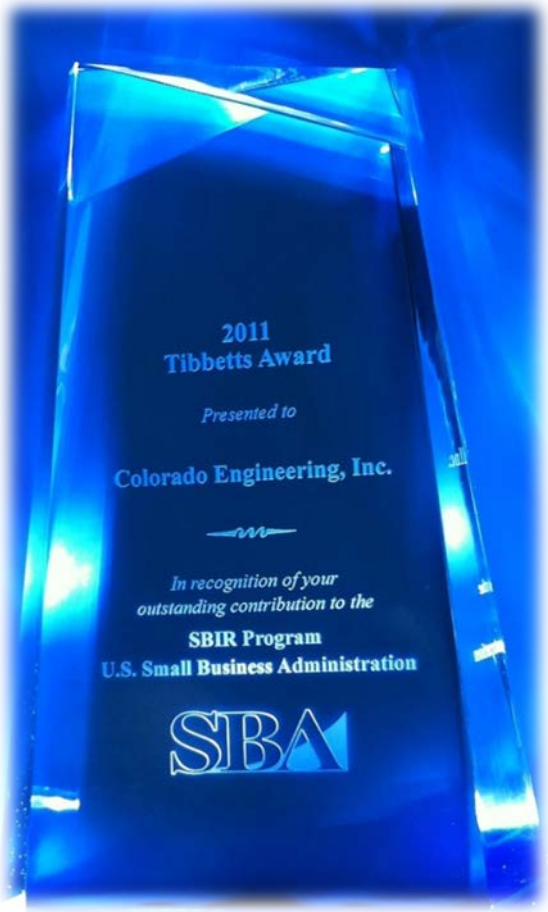


*Image courtesy of Elma Bustronic*

# Out-of-the-Box Approach to Embedded Computing for SWaP

- CEI and the Navy, sponsored by MDA, defined an open approach to SWaP-friendly embedded computing architectures
  - NRL
  - NSWC
  - ONR
- RARE: Reconfigurable Advanced Rapid-prototyping Environment
- SBIR Phase I & II
- Recipient of 2011 Tibbetts Award
- No backplane!

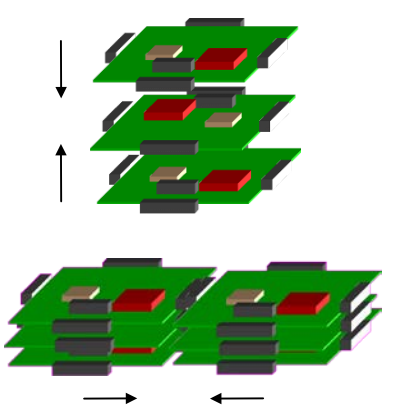


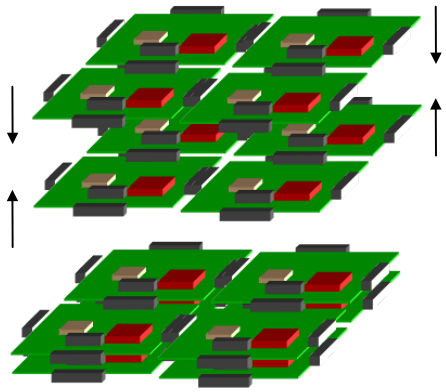
# RARE: MOSA-Inspired Technology

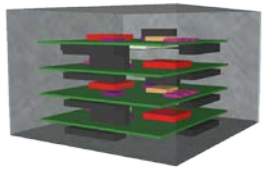
- Decomposes a general sensor system into functional COTS building blocks
- Blocks provide a modular way to achieve loosely coupled common operational subsystem components
- When tied together using well defined interfaces, blocks form a complete, scalable processing and control system
- Addresses systems for small UAVs to large manned aircraft
- Applicable to radar, -INT, EW, and digital communications

# Modularity, Scalability, and Flexibility

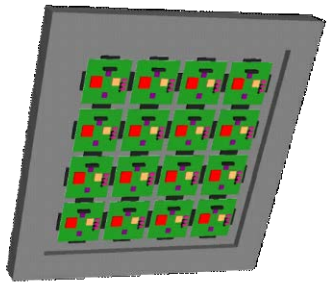
- RARE modules are 6.25” x 6.25” cards with interface connections in all three dimensions (x, y, z)
  - PCIe fabric, LVDS, and SerDes for data and control plane communications
  - Provide combined I/O bandwidth of 39 GB/sec per module
- Allows integrators to stack and/or tile modules in x, y, or z to scale performance while simultaneously addressing processing load, I/O bandwidth, and physical installation footprint
  - Systems can be physically reconfigured to address different footprints while maintaining common hardware, firmware, and software across platforms
  - RARE modules can implement solutions in a fraction of the volume of traditional 20-slot 6U style backplanes



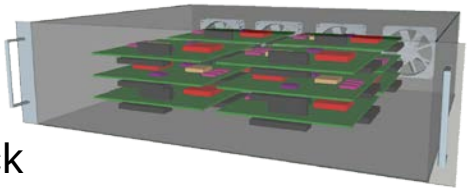




Cube

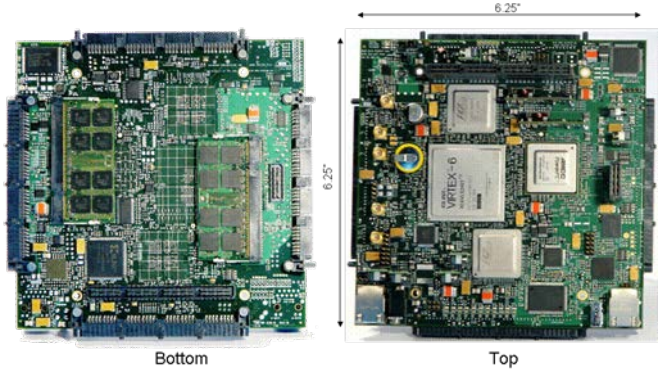


Tiled



19”
Rack

# Module Examples




**Processor Module**
- AMCC 460SX PowerPC
- Xilinx Virtex-6 FPGA
- Dual 1Gb Ethernet
- USB, RS-232
- Short range wireless

Architecture easily incorporates other technologies (GPUs, multicore, ASICs, ADCs, DACs, I/O…)

**ADC+Processor Module**
- 10 ADC channels
- 16b @ 160MSPS
- Xilinx Virtex-6 FPGA

**DAC+Processor Module**
- 2 DAC channels
- 16b @ 1GSPS
- Xilinx Virtex-6 FPGA

**Other Modules**
- Dual 10Gb Ethernet
- Adapter for commercial PCIe cards
- Tailored interfaces
- High performance LO synthesis and clock distribution
- RF functions (up/down conversion)

Modules Stacked

Modules Tiled

# Heterogeneous Processing

## XILINX VIRTEX 6 HIGH LEVEL STATS

| Part Number: | XC6VLX240T | XC6VLX550T | XC6VSX475T (DSP optimized part) |
|---|---|---|---|
| CLBs | 18,840 | 42,960 | 37,200 |
| Block Memory | 14.976Mbits | 22.752Mbits | 38.304Mbits |
| Clock Managers (DLL/PLL) | 12 | 18 | 18 |
| Multiplier Accumulators | 768 | 864 | 2,016 |
| Configuration Memory | 70.4Mbits | 1.374Gbits | 149.4Mbits |


**CLB= Configuration Logic Block: 8 x 6 input LUTs and 16 Flip-Flops**
**Multipliers = 18 to 40 bit inputs with 48bit output (much more functionality – 50 page data sheet)**

## AMCC PPC460SX


- 1.2GHz
- Three Gen 2 PCI Express interfaces
- On-chip DDR2 SRAM controller
- Storage and network encryption engines
- 1Gb Ethernet, full duplex MACs with TCP/IP assist and Quality of Service support

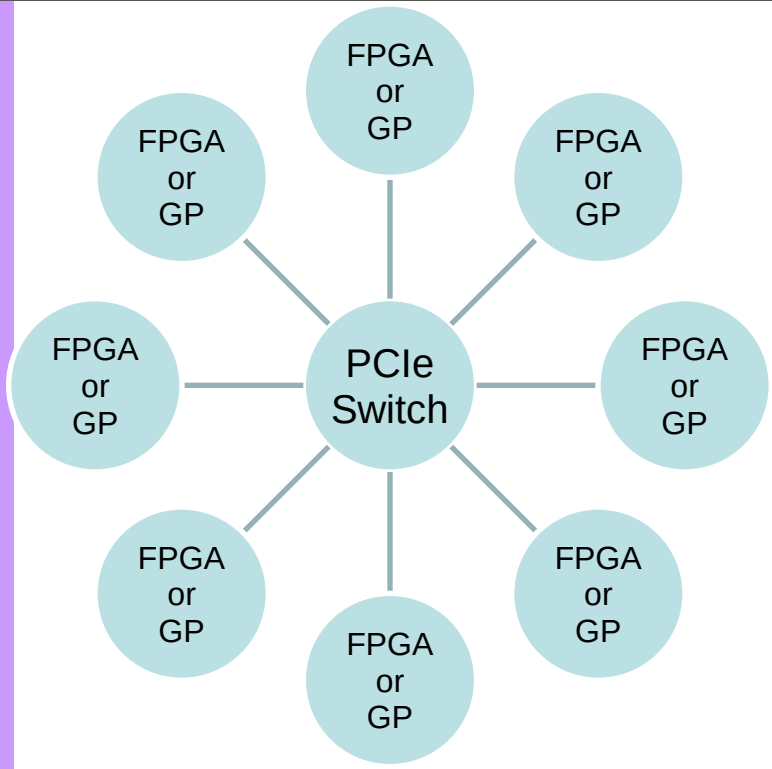
# RARE Inter-Module I/O Bandwidths

| RARE Connector | Half Duplex (FPGA LVDS @ 1GHz) | | | | Full Duplex | | | Bandwidth (per Connector) |
|---|---|---|---|---|---|---|---|---|
| | # of Clusters | # of LVDS Pairs | LVDS Total (Gb/s) | LVDS Total (MB/s) | PCIe FPGA (MB/s) | PCIe PPC (MB/s) | SerDes FPGA (MB/s) | |
| X | 3 | 7 | 21,000 | 2,625 | 2,000 | 2,000 | 0 | 6.625 GB/s |
| Y | 3 | 7 | 21,000 | 2,625 | 0 | 2,000 | 0 | 4.625 GB/s |
| Z | 2 | 13 | 26,000 | 3,250 | 2,000 | 2,000 | 1,000 | 8.250 GB/s |

| RARE Connector | Total Bandwidth (Dual Connectors per Direction) | Total Bandwidth per RARE Module |
|---|---|---|
| **X** | **13.25 GB/s** | **39.00 GB/s** |
| **Y** | **9.25 GB/s** | |
| **Z** | **16.50 GB/s** | |

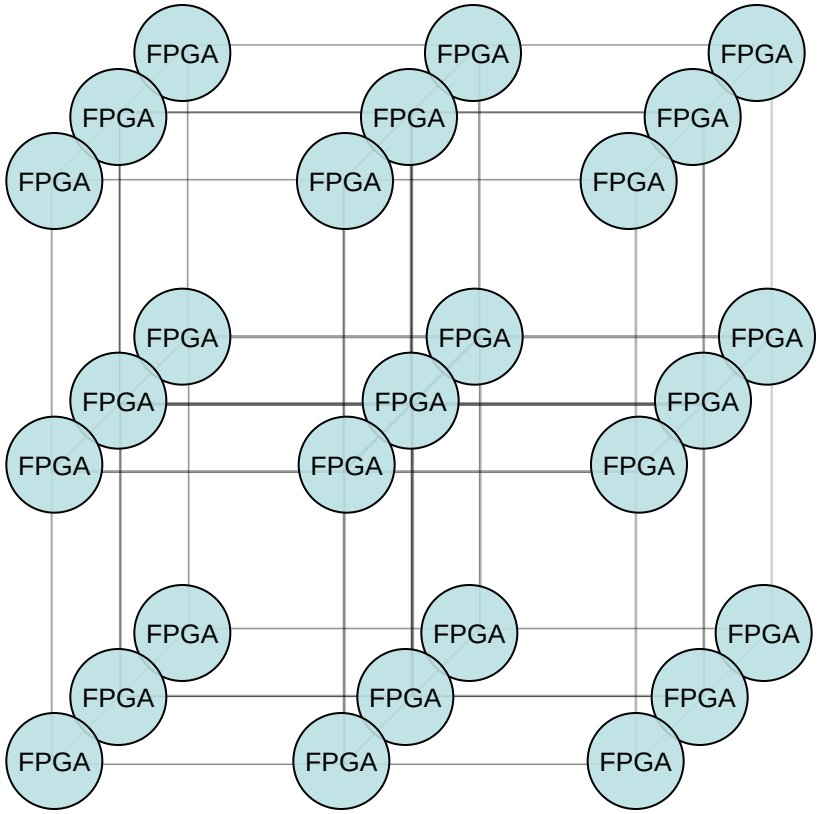
**RARE Modules Balance High Bandwidth Cross-Channel I/O with Processing to Maximize Performance.**

# Cross Channel Communication without Dedicated Switch Cards



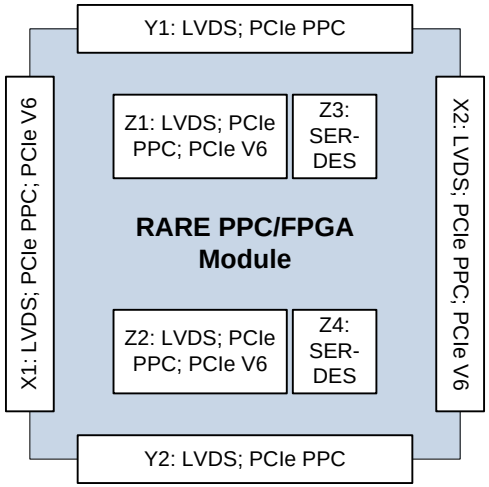

- PCIe switches built into modular architecture
- End points can be FPGAs or General Purpose Processors

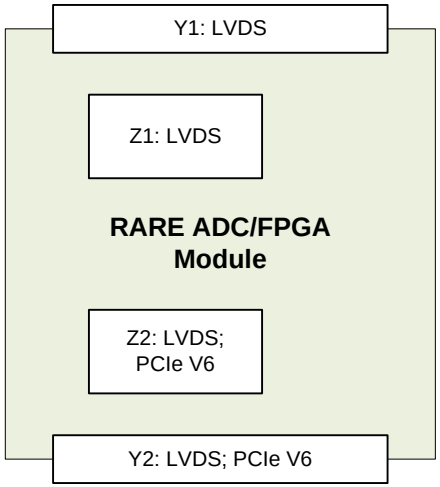
- FPGAs also interconnect with low latency, high bandwidth across the 3D topology
  - LVDS
  - SerDes

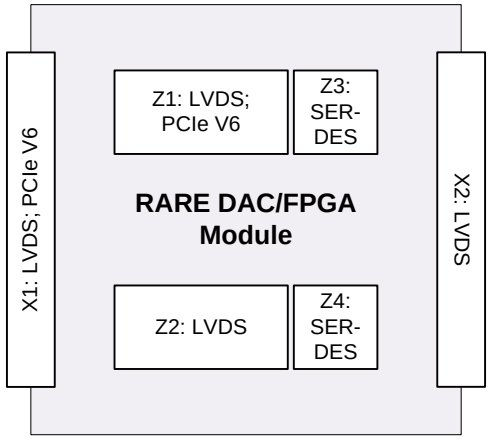


# X and Y Interfaces per Module

| | | X & Y "1" Style Module Connectors (Plug into "2" Style) | | | |
|---|---|---|---|---|---|
| | | **Processor X1**<br>**- LVDS**<br>**- PCIe PPC**<br>**- PCIe FPGA** | **Processor Y1**<br>**- LVDS**<br>**- PCIe PPC** | **ADC Y1**<br>**- LVDS** | **DAC X1**<br>**- LVDS**<br>**- PCIe FPGA** |
| **X & Y "2" Style Module Connectors (Plug into "1" Style)** | **Processor X2**<br>**- LVDS**<br>**- PCIe PPC**<br>**- PCIe FPGA** | supports LVDS, PCIe (PPC), and PCIe (FPGA) | supports LVDS and PCIe (PPC) | supports LVDS | supports LVDS and PCIe (FPGA) |
| | **Processor Y2**<br>**- LVDS**<br>**- PCIe PPC** | supports LVDS and PCIe (PPC) | supports LVDS and PCIe (PPC) | supports LVDS | supports LVDS |
| | **ADC Y2**<br>**- LVDS**<br>**- PCIe FPGA** | supports LVDS and PCIe (FPGA) | supports LVDS | supports LVDS | supports LVDS (please call CEI for PCIe support) |
| | **DAC X2**<br>**- LVDS** | supports LVDS | supports LVDS | supports LVDS | supports LVDS |

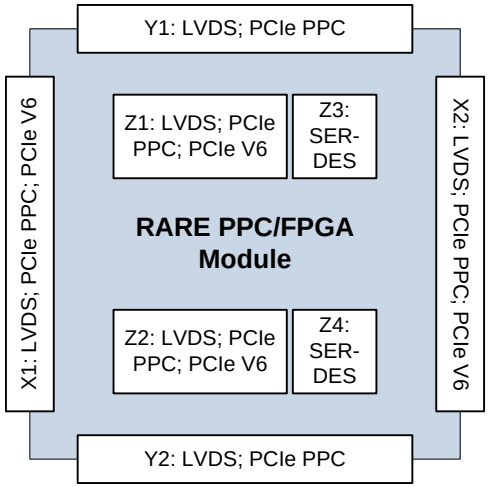


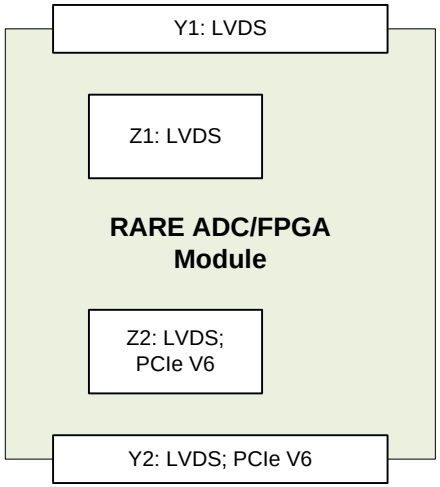



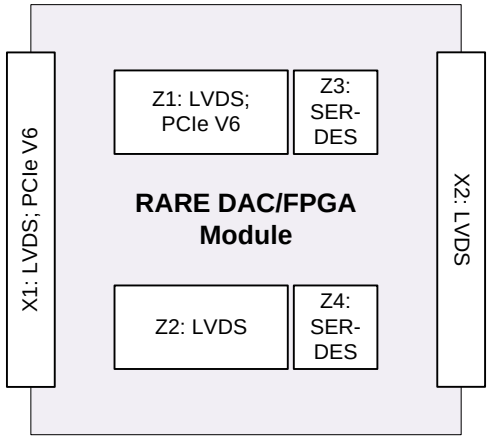



# Z Interfaces per Module

| | | "Z" Style Module Connectors (1 ↔ 2; 3 ↔ 4) | | | | |
|---|---|---|---|---|---|---|
| | | **Processor Z1**<br>**- LVDS**<br>**- PCIe PPC**<br>**- PCIe FPGA** | **Processor Z3**<br>**- SERDES** | **ADC Z1**<br>**- LVDS** | **DAC Z1**<br>**- LVDS**<br>**- PCIe FPGA** | **DAC Z3**<br>**- SERDES** |
| **"Z" Style Module Connectors (1 ↔ 2; 3 ↔ 4)** | **Processor Z2**<br>**- LVDS**<br>**- PCIe PPC**<br>**- PCIe FPGA** | supports LVDS, PCIe (PPC), and PCIe (FPGA) | n/a | supports LVDS | supports LVDS and PCIe (FPGA) | n/a |
| | **Processor Z4**<br>**- SERDES** | n/a | supports SERDES | n/a | n/a | supports SERDES |
| | **ADC Z2**<br>**- LVDS**<br>**- PCIe FPGA** | supports LVDS and PCIe (FPGA) | n/a | supports LVDS | supports LVDS (please call CEI for PCIe support) | n/a |
| | **DAC Z2**<br>**- LVDS** | supports LVDS | n/a | supports LVDS | supports LVDS | n/a |
| | **DAC Z4**<br>**- SERDES** | n/a | supports SERDES | n/a | n/a | supports SERDES |



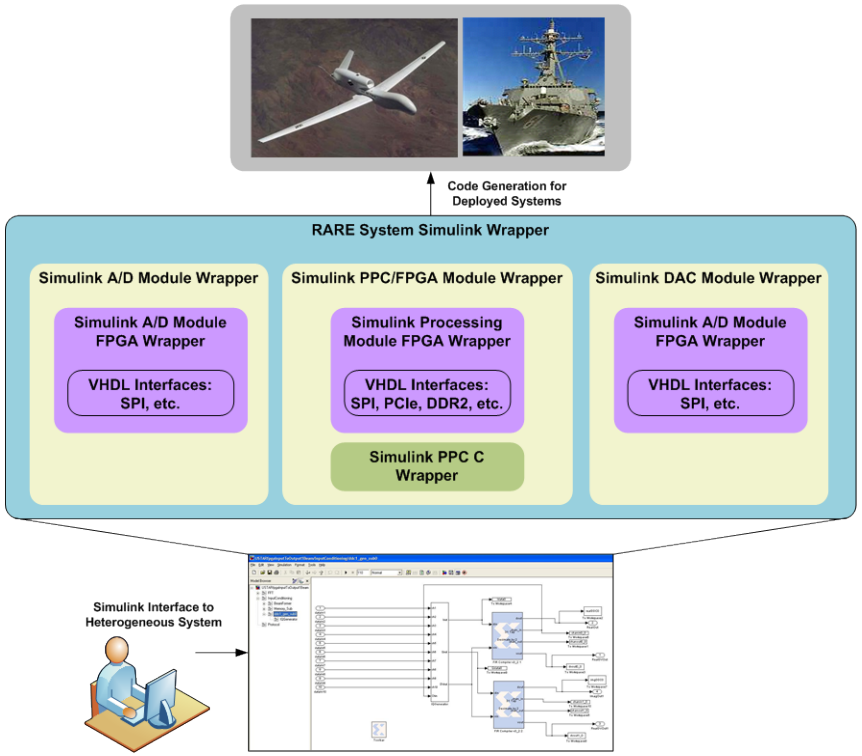



# Integrated Health and Status Monitoring

- $I^2C$ network of microcontrollers distributed throughout architecture for health and status
  - ADCs built into microcontrollers monitor voltages, currents, and temperatures
  - Used to sequence power supplies and protect modules in event of supply issues or overheating
  - Microcontrollers can shut down modules or system when tolerances are not within defined limits
- Fully programmable and tailorable
- More information available in poster session

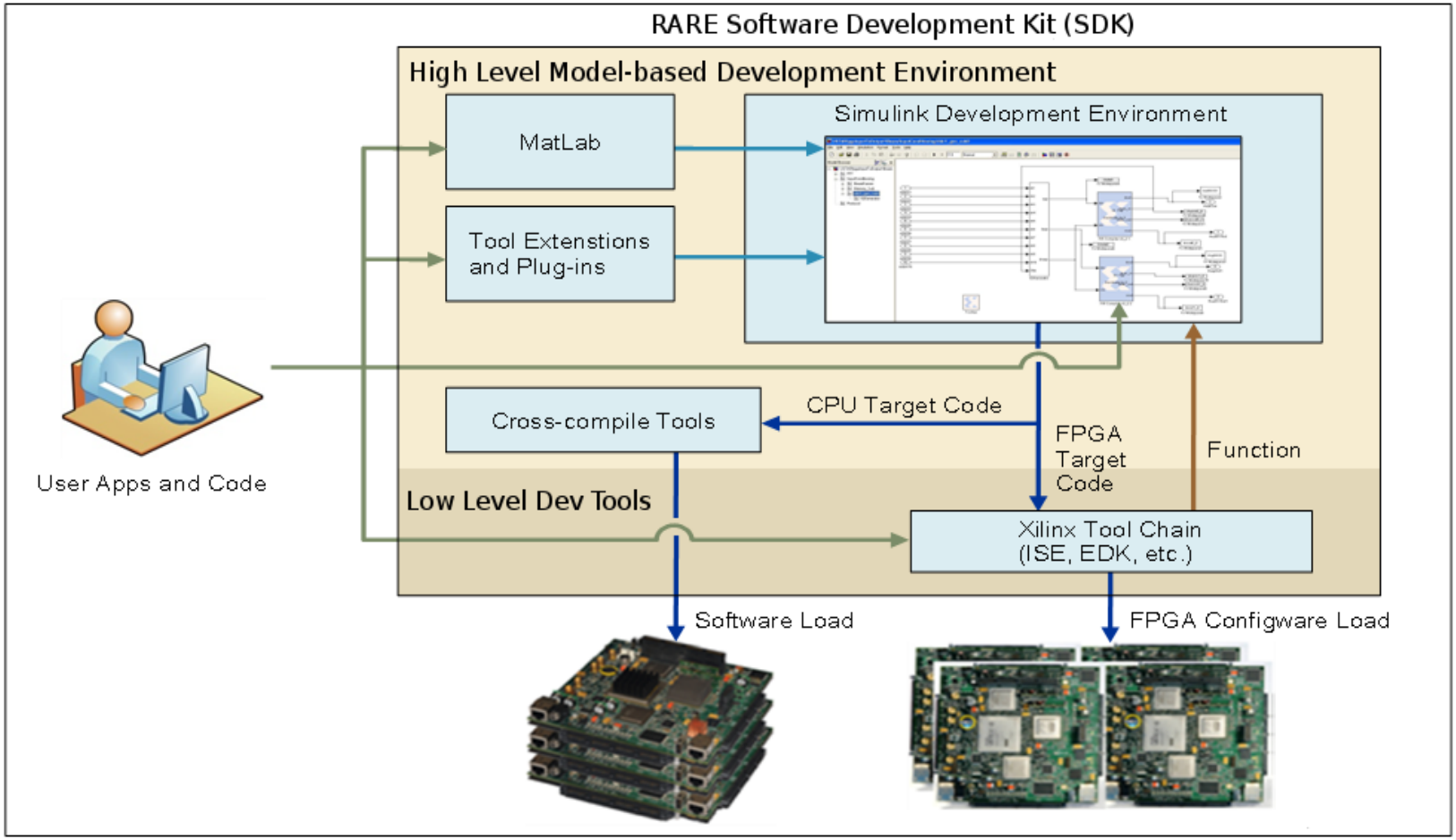
# Software and High Level Programming Model

- Leverages open source
  - Avoids sole source proprietary operating systems
  - Lower TOC
  - Can be tailored by user
- SDK handles module communications protocols and data movement between processors and FPGAs
  - Linux kernel
  - Fedora x86-64 gcc cross compiler tool chain
  - U-Boot boot loader
  - Core root file system




- Code wrappers encapsulate modules and enable MATLAB™ / Simulink™ tool flows for code development
- Enables quick turn from algorithms concept and simulation to implementation

# SDK Encompasses CPUs and FPGAs

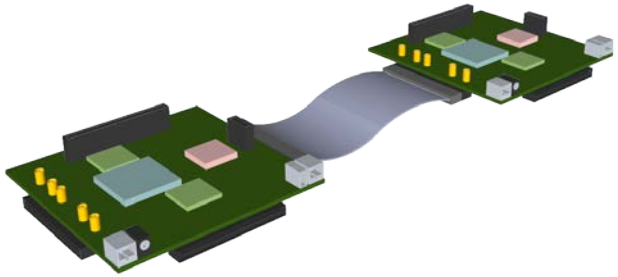


# Packaging Strategies

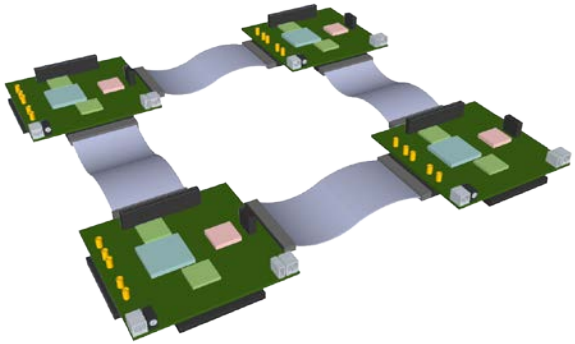
- RARE flexibility opens up packaging trade space to systems integrator
  - Physical enclosure
  - Thermal management
- Enables solutions that are truly optimized for C-SWaP on the deployment platform
  - Standard 19” rack mount enclosure
  - Tailored box-level solutions
  - Platform-ready deployment

# Extreme Packaging Flexibility to Address Size: FlexRARE

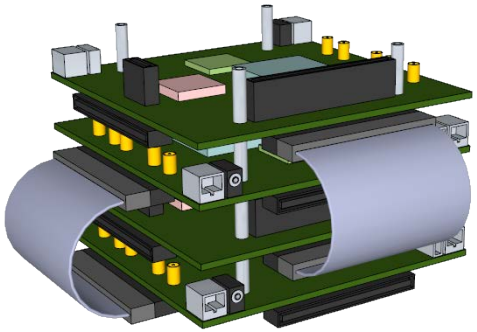
- Increases system “morphability,” flexibility, and out-of-the-box installations (literally!)
- Increases bandwidth for stacked systems
- No performance degradation
- Fully customizable cable lengths available (SamTec)
- Right angle or straight connectors available
- Promotes straight-forward board level replacement in mesh structure



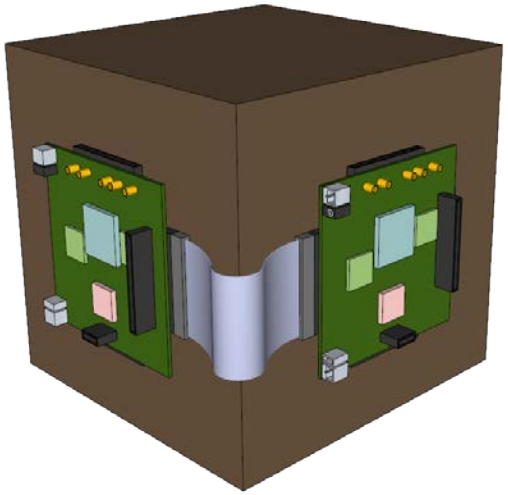
Ex: FlexRARE Basic Option



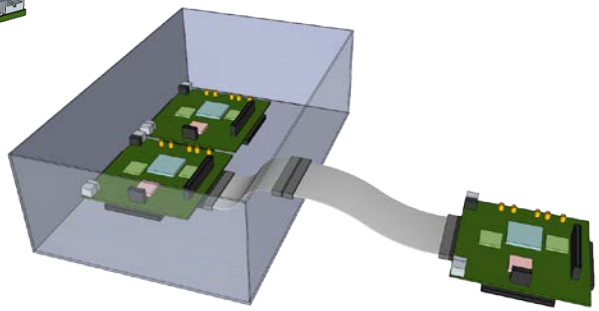
Ex: FlexRARE Mesh Option



Ex: FlexRARE Stackable Option



Ex: FlexRARE Corner-Turn Option



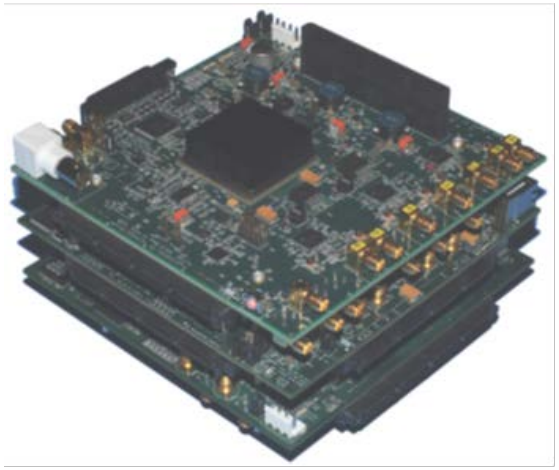
Ex: FlexRARE Through-Wall Option

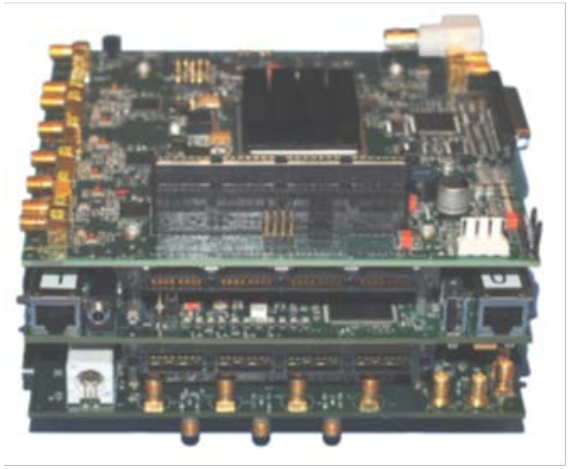
# Example Applications

- RARE architecture is being utilized by multiple DoD agencies to meet C-SWaP while adhering to MOSA philosophies
- Two examples
  - Programmable MIMO radar transmit / receive system
  - Sense and Avoid radar for UAVs

# Example 1: Multichannel DREX

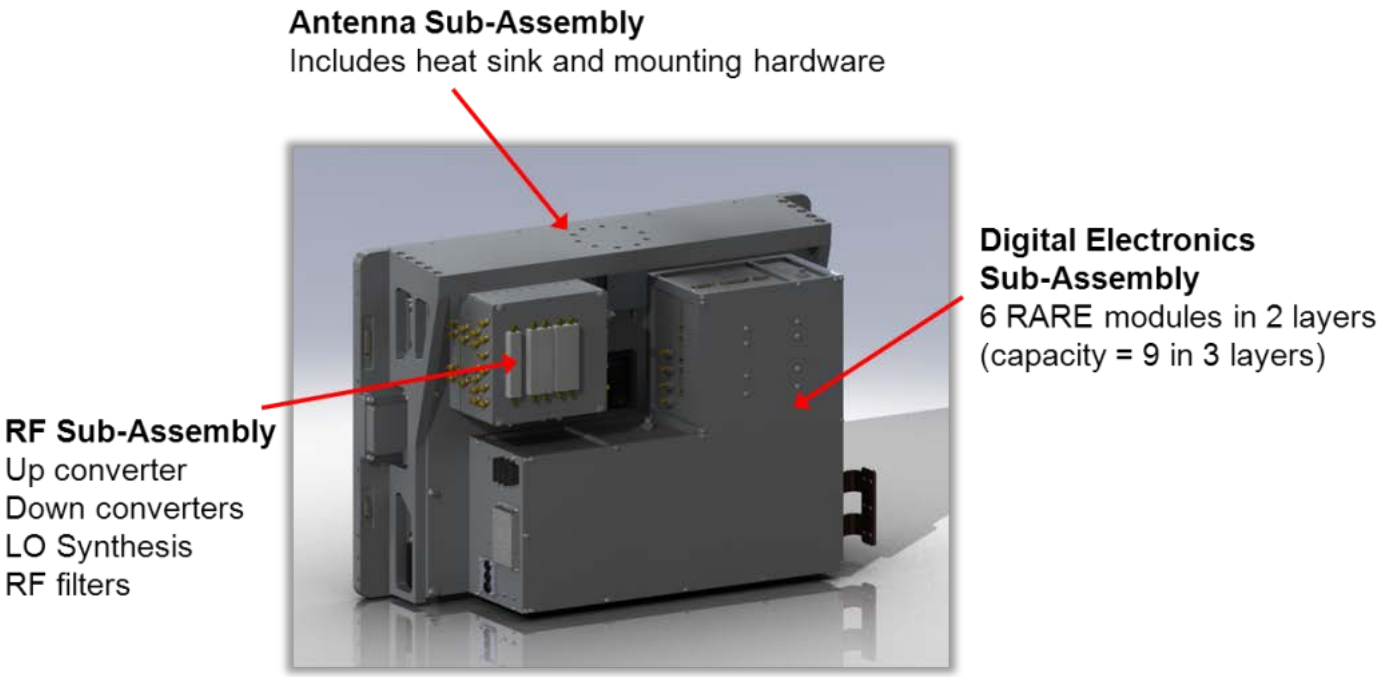
- Programmable MIMO radar transmit / receive system
- Uses three COTS RARE modules
  - 2x exciter channels (1 GHz)
  - 10x receive channels (160 MSPS)
  - 3x Virtex-6 FPGAs
  - 1x PPC
  - 2x 1GbE
- Electronics: 6.25” x 6.25” x 4”
- Dual 10GbE can be supported through the addition of one more module





# Example 2: Sense and Avoid Radar

- Turnkey search & track capability
- 21.25” x 16” x 5.5”
- 400W input power (28VDC)
- < 45 lbs.



# Summary

- RARE facilitates embedded processing solutions for SWaP-constrained applications
  - Heterogeneous technology helps balance processing capability with power consumption
  - Solutions are not backplane constrained thus maximizing flexibility within SWaP trade space
  - Architecture enables integrators to simultaneously address processing capacity, I/O bandwidth, and physical installation footprint while eliminating the cost and impact of backplane and dedicated switch card architectures
  - Model-based software development accelerates transition from algorithmic concept to deployment
- MOSA approach facilitates the realization of common subsystem building blocks and lowers total ownership costs
- Award winning technology being utilized in multiple DoD programs

# Thank You!

For more information please contact:

Michael J. Bonato
Colorado Engineering, Inc.
michael.bonato@coloradoengineeringinc.com
719-388-8582 (office)

www.coloradoengineeringinc.com

# About Colorado Engineering

- Provides engineered solutions for high performance computing and sensor systems
  - Hardware: FPGA design and multi-layer high speed digital and analog circuit card designs for C-SWaP
  - Software: high performance computing and system management at real-time embedded and enterprise levels
  - Systems: radar, -INT, EW, digital communications, DSP, grid computing, situational awareness, THz technologies
- Recognized industry leaders in MOSA applications
- Cross discipline experience of engineering staff
- Woman-Owned small business located in Colorado Springs
- TS facility clearance (in process)
- Recent recipient of Tibbetts and Nunn-Perry awards
- 23 Phase I/II SBIR & STTR awards with over 37 technologies deployed in DoD and Government systems
- For more information
  - www.coloradoengineeringinc.com
  - 719-388-8582