Contents of the Lecture

- 1. Introduction
- 2. Methods for I/O Operations
- 3. Computer Buses
- 4. Expansion Modules for Embedded Systems
- 5. Computer Displays
- 6. Graphics Adapters
- 7. Optical Discs

4. Expansion Modules for Embedded Systems

- Requirements for Embedded Systems
- VME Modules
- CompactPCI Modules
- Mezzanine Modules
- COM Express Modules

Requirements for Embedded Systems (1)

- Embedded systems used in: industrial automation, transportation, defense
- Requirements: high reliability, simple maintenance
- Desktop systems use:
  - Connectors with blade contacts
  - Active backplanes or motherboards
- In an industrial or military environment, the backplane is exposed to mechanical stress

Requirements for Embedded Systems (2)

- High reliability:
  - Connectors with metallic pins and sockets
  - Front panels for fastening, guidance
  - Passive backplanes – only connectors
- Simple maintenance:
  - Short time required for repairs – failures of passive backplanes are rare
  - Simple module replacement
- Commonly, VME modules are used

4. Expansion Modules for Embedded Systems

- Requirements for Embedded Systems
- VME Modules
- CompactPCI Modules
- Mezzanine Modules
- COM Express Modules

VME Modules

- VME Modules
  - Parallel VME Bus Modules
  - VXS Modules
  - VPX Modules

Parallel VME Bus Modules (1)

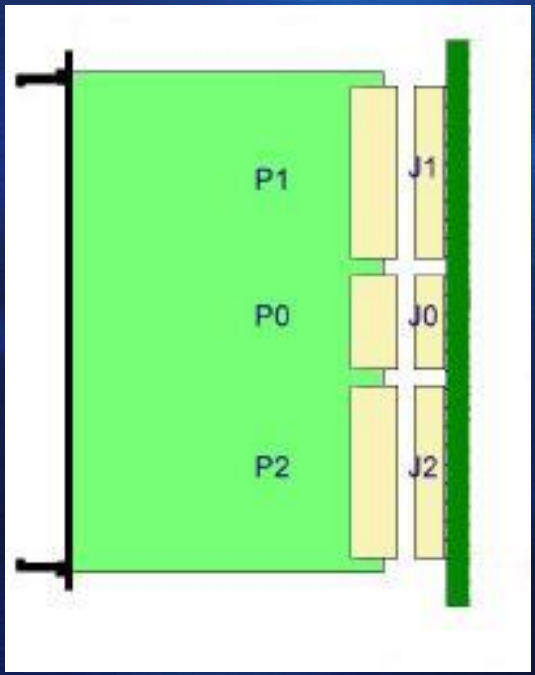
- Parallel VME module sizes
  - Single-height: 3U x 160 mm (U – unit of measure; 1U = 1.75 inch = 44.45 mm)
  - Double-height: 6U x 160 mm
  - Triple-height: 9U x 400 mm
- Conduction-cooled VME modules
  - Used in military and aerospace applications
  - Heat is conducted through the printed circuit board or through a conduction plate

Parallel VME Bus Modules (2)

- VME backplanes
  - Length of 19 inches; 1 .. 21 connectors
  - Standard: 3-row connectors
  - VME64x: 5-row connectors
  - VME320
- VME connector types
  - P (Plug): reside on the expansion modules
  - J (Jack): reside on the backplane
  - P1/J1, P2/J2: 96-pin or 160-pin connectors

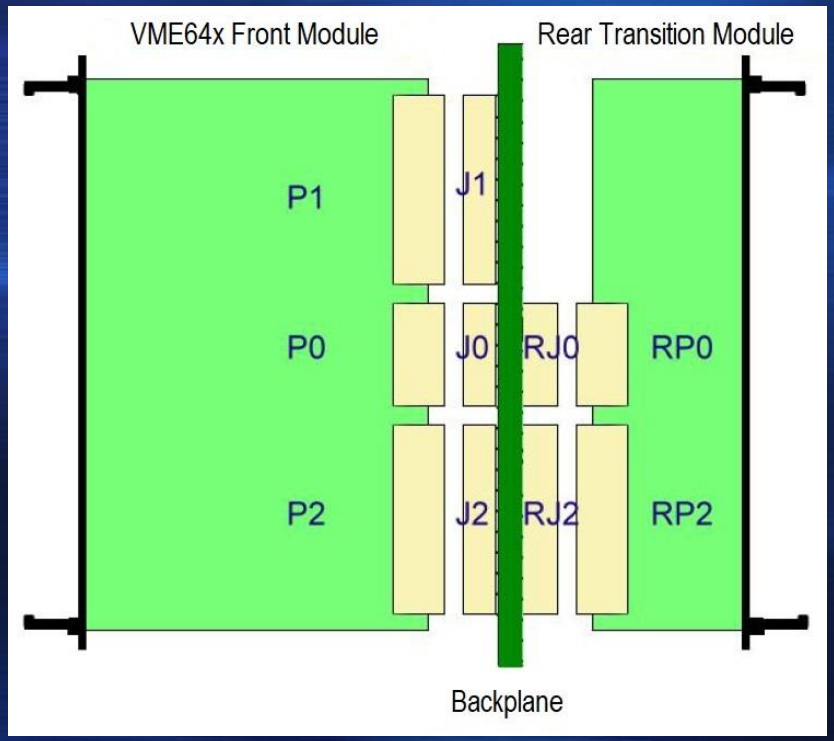
Parallel VME Bus Modules (3)

- P3/J3: may be included on 9U modules
- P0/J0: for VME64x modules
  - 95-pin connectors
  - May be used for high-speed signals
- Custom connectors can be placed between the P1/J1 and P2/J2 pairs, e.g., for:
  - Coaxial cable
  - Fiber-optic cable



Parallel VME Bus Modules (4)

- Rear I/O transition modules
  - Optional feature of VME64x and later backplanes
  - Size: 6U x 80 mm
  - Contain the RP0 and RP2 connectors
  - Connect to the front module via feed-through pins of J0 and J2

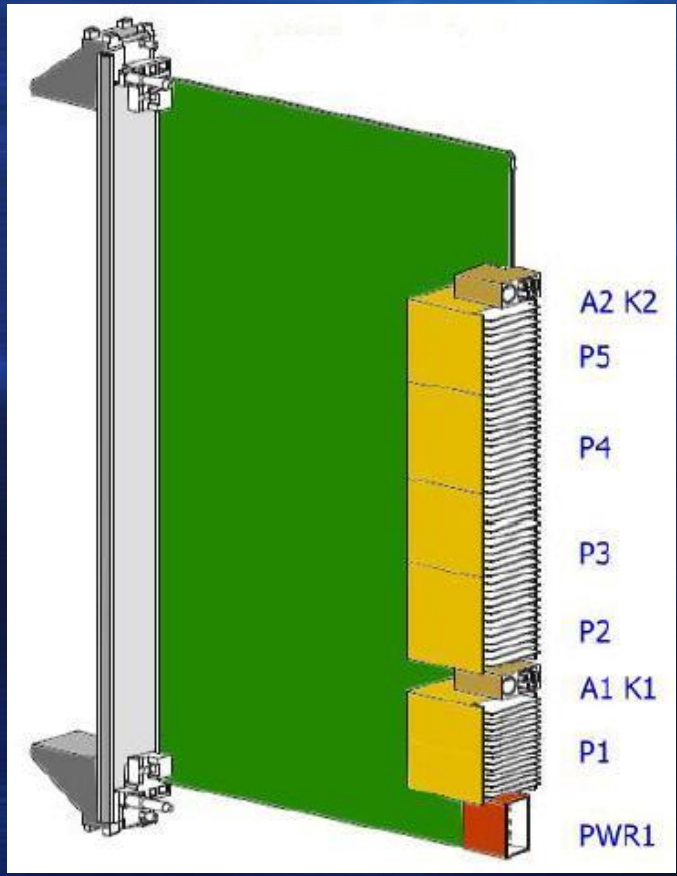


VME Modules

- VME Modules
  - Parallel VME Bus Modules
  - VXS Modules
  - VPX Modules

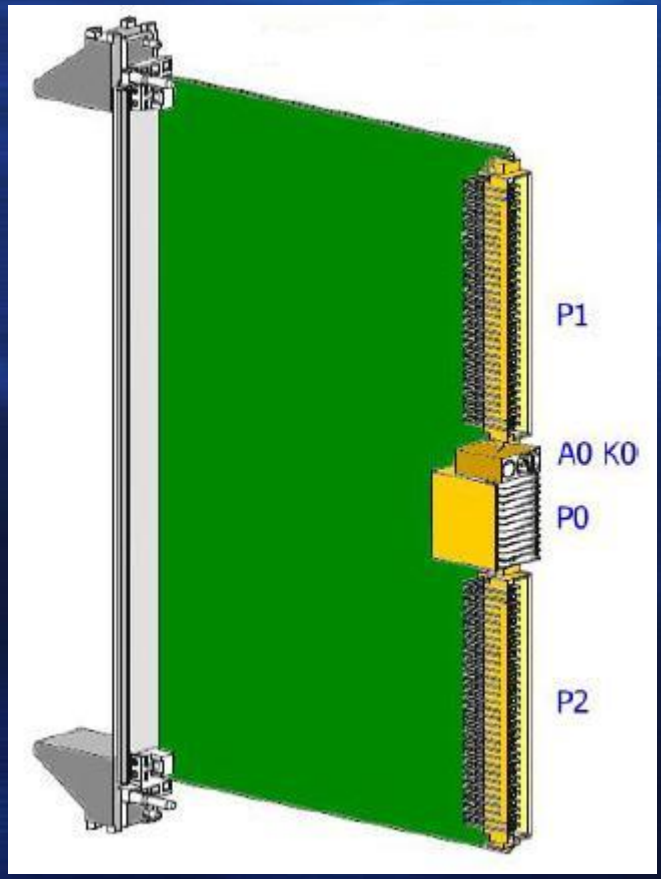
VXS Modules (1)

- VXS switch boards
  - Have point-to-point connections to other boards
  - 6U x 160 mm
  - Replace the parallel P1 and P2 connectors with 5 serial connectors (P1 .. P5)
  - MultiGig RT connectors
  - A1 K1, A2 K2: alignment and keying connectors
  - PWR1: power connector



VXS Modules (2)

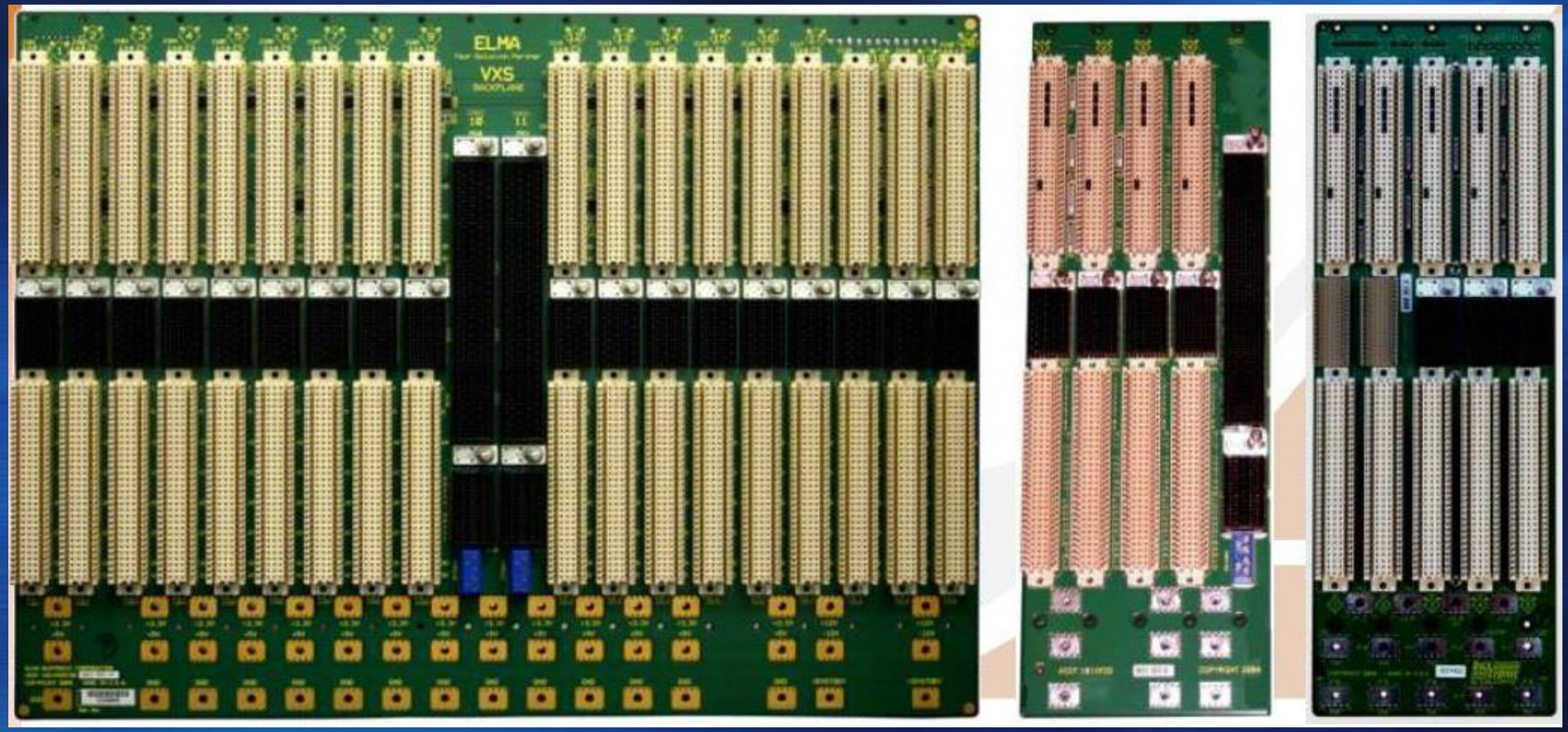
- VXS payload boards
  - P1, P2: VME64x parallel connectors; 5 rows
  - P0: high-speed serial connector; 7 rows
  - The P0 connector provides eight full-duplex serial links (up to 2.5 GB/s or 5 GB/s in each direction)
  - A0 K0: alignment and keying connector



VXS Modules (3)

- VXS Backplanes
  - Maximum configuration: 18 payload boards; 2 switch boards; 1 VME64x board
  - Single star topology: each payload board connects to a single switch board
  - Dual star topology: each payload board connects to both switch boards (redundancy)
  - Mesh topology: up to 3 payload boards directly connected without a switch board
  - Daisy-chain topology: each payload board connects to its nearest neighbors

VXS Modules (4)



VXS topologies: dual star; single star; mesh

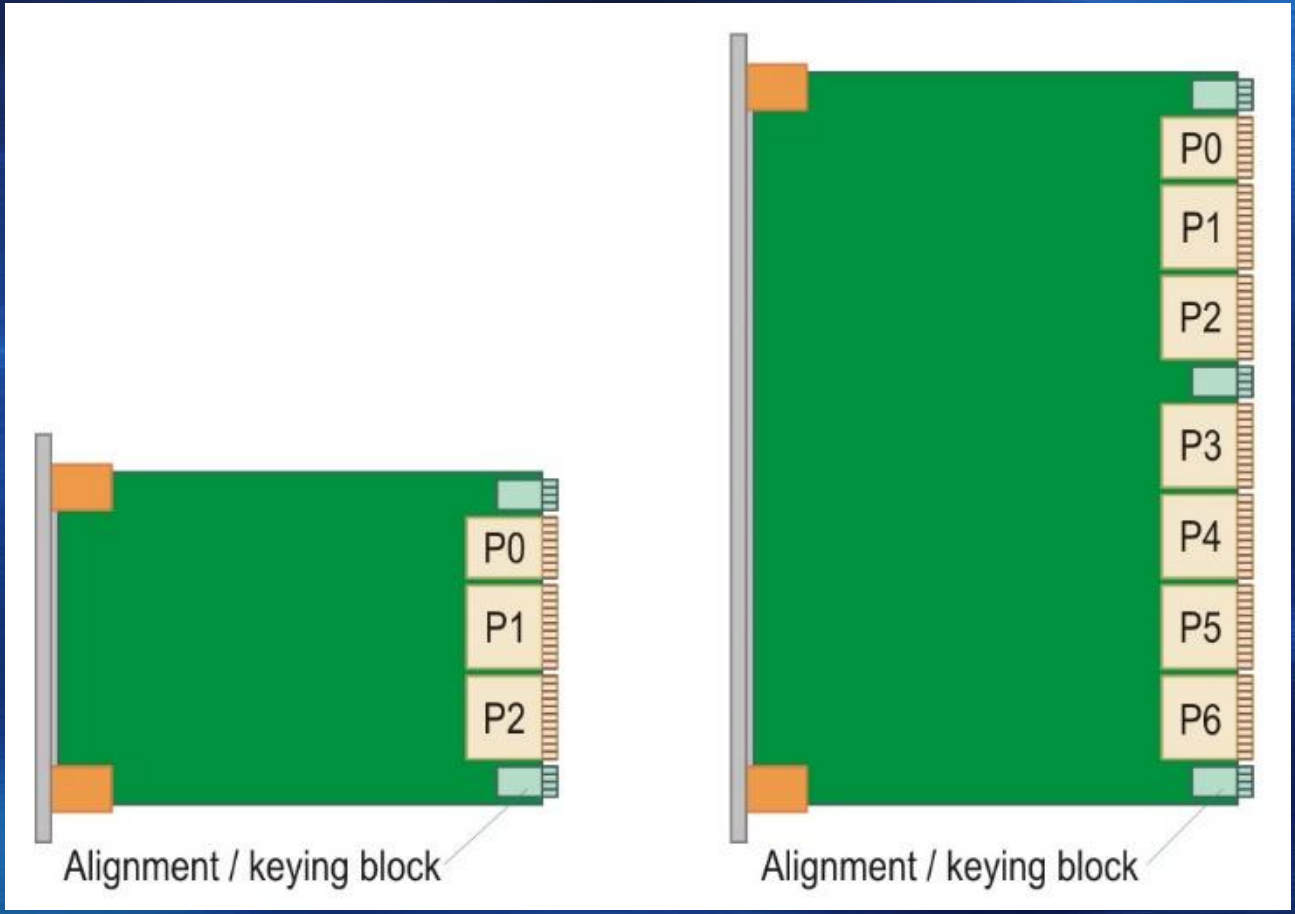
VME Modules

- VME Modules
  - Parallel VME Bus Modules
  - VXS Modules
  - VPX Modules

VPX Modules (1)

- The 3U and 6U Eurocard form factors of the VME specifications are maintained
  - 6U hybrid backplanes can also be used to accommodate VME64, VXS, and VPX modules
- Gen 4 VPX: MultiGig RT2 connectors
  - Data rates up to 16 Gbits/s
  - 3U modules: three connectors (P0 .. P2)
  - 6U modules: seven connectors (P0 .. P6)
  - Provided with robust alignment/keying blocks

VPX Modules (2)

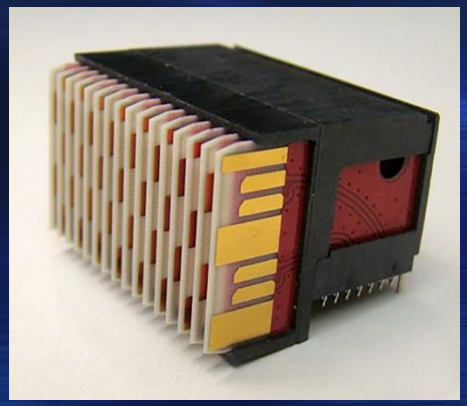


VPX Modules (3)

- P0 connector
  - 8 x 7 contacts
  - Power, system reset, reference clock, bus management, other utility signals
- P1 connector
  - 16 x 7 contacts
  - 32 differential pairs, 8 single-ended signals
- P2 .. P6 connectors
  - Physically identical with P1
  - A total of 128 differential pairs for user I/O

VPX Modules (4)

- Gen 5 VPX: MultiGig RT3 connectors
  - Data rates up to 25.8 Gbits/s
  - Compatible with MultiGig RT2 connectors
  - Contacts: small printed circuit boards with gold plates



Left: MultiGig RT2; right: MultiGig RT3 (© Tyco Electronics)

VPX Modules (5)

6U VPX Module (© Extreme Engineering Solutions)

4. Expansion Modules for Embedded Systems

- Requirements for Embedded Systems
- VME Modules
- CompactPCI Modules
- Mezzanine Modules
- COM Express Modules

CompactPCI Modules

- CompactPCI Modules
  - CompactPCI Overview
  - CompactPCI Express Modules
  - CompactPCI PlusIO Modules
  - CompactPCI Serial Modules

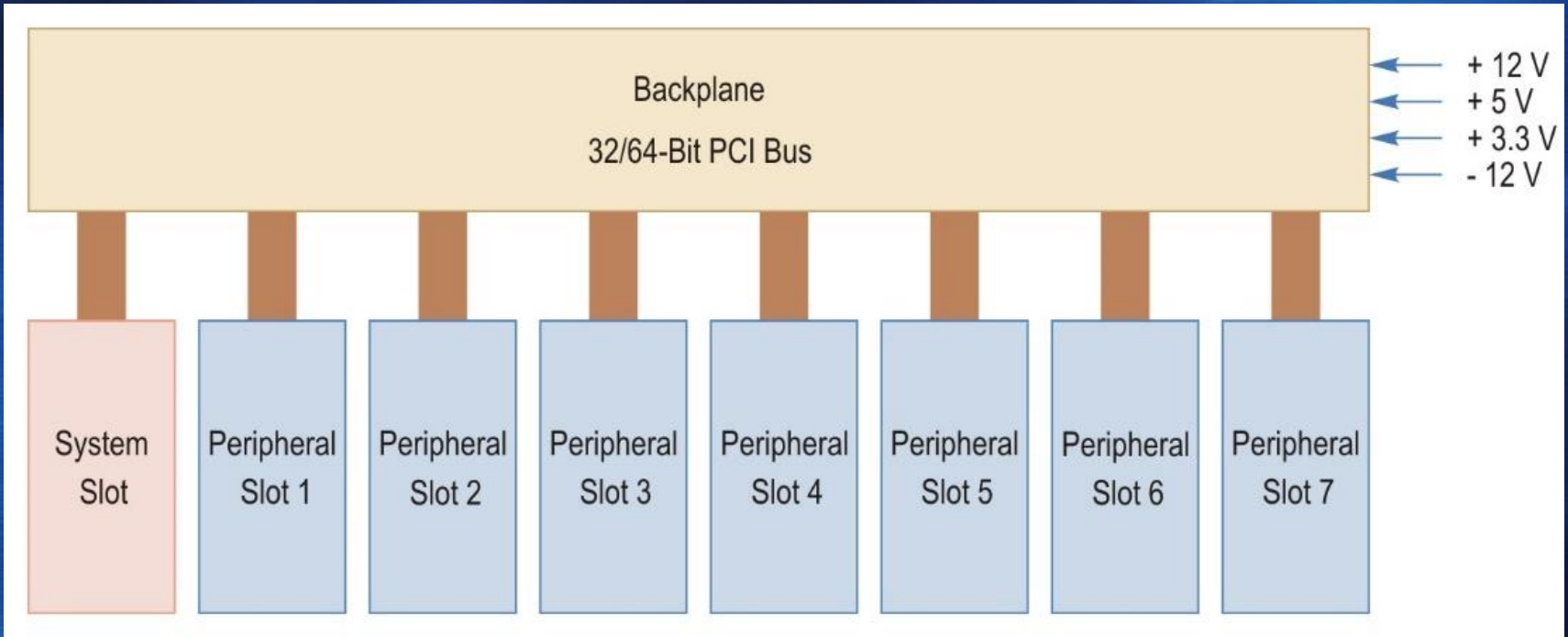
CompactPCI Overview (1)

- CompactPCI, cPCI
- Industrial standard for modular computer systems
- Developed by the *PCI Industrial Computer Manufacturers Group* (PICMG)
- Aim: replacing the VME bus with the PCI bus
  - Combining the electrical specifications of the parallel PCI bus with the 3U and 6U Eurocard form factors

CompactPCI Overview (2)

- Original CompactPCI modules: 32-bit or 64-bit parallel PCI bus
  - Socket connectors
  - 3U: J1 (32-bit bus), J2 (64-bit bus or user-defined I/O pins)
  - 6U: J1, J2, and up to three optional connectors (J3, J4, J5) for I/O pins
- CompactPCI backplanes
  - Plug (pin) connectors: P1, P2 (3U backplanes); P1 .. P5 (6U backplanes)

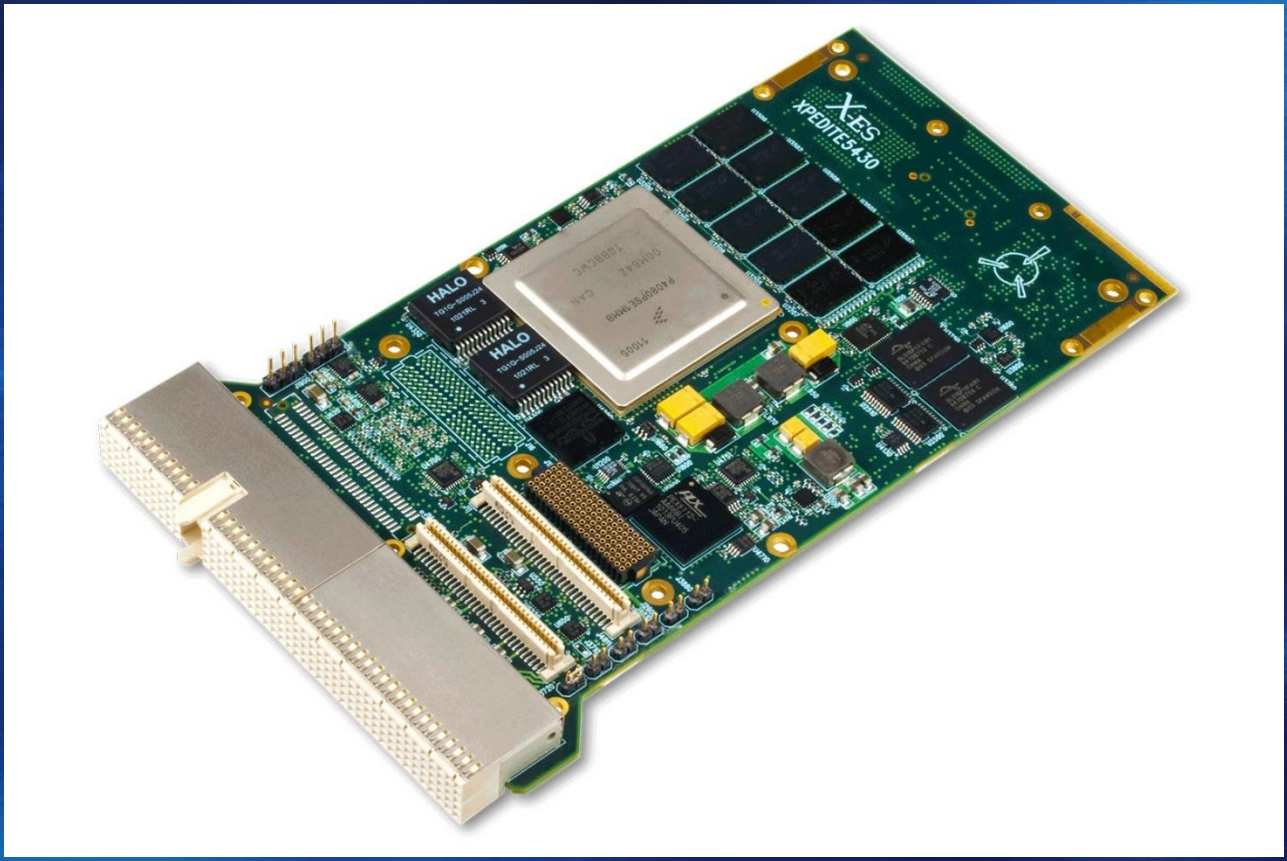
CompactPCI Overview (3)



CompactPCI Overview (4)

- Passive backplane → simple maintenance
- Larger number of peripheral slots than in conventional PCI systems
  - High-quality pin-and-socket connectors
  - Large number of ground pins
- Connectors
  - HM (*Hard Metric*), step of 2 mm
  - 22 rows x 5 pins, keying area on J1
  - 6U module with 5 connectors: 535 pins

CompactPCI Overview (5)



3U CompactPCI module (© Extreme Engineering Solutions)

CompactPCI Overview (6)

6U CompactPCI chassis (© Kontron S&T AG)

CompactPCI Overview (7)

- CompactPCI Extensions
  - Enable to use CompactPCI systems in various applications
- Hot Swap (PICMG 2.1)
  - Defines additional requirements for adding and removing modules during operation
  - Pins of multiple lengths are provided
- Ethernet Connectivity (PICMG 2.16)
  - Enables to create a local area network between multiple expansion modules
  - Up to 2 Gbits/s for each CompactPCI slot

CompactPCI Overview (8)

- CompactPCI Advantages
  - Modularity, ruggedness
  - Scalability
  - Processor-independent
  - Wide OS and software support, compatibility with existing drivers and applications
  - Low cost of PCI and PCIe chips
  - Extensions of the base specification enable to transition to serial interconnections

CompactPCI Modules

- CompactPCI Modules
  - CompactPCI Overview
  - CompactPCI Express Modules
  - CompactPCI PlusIO Modules
  - CompactPCI Serial Modules

CompactPCI Express Modules (1)

- PICMG EXP.0 extension
  - The use of PCIe technology by CompactPCI backplanes
  - Revision 2.0: support for Gen 2 and Gen 3 of the PCIe bus
- CompactPCI Express system:
  - System slot and board
  - Peripheral slots and boards
  - Switch slot and board
  - Hybrid peripheral slots

CompactPCI Express Modules (2)

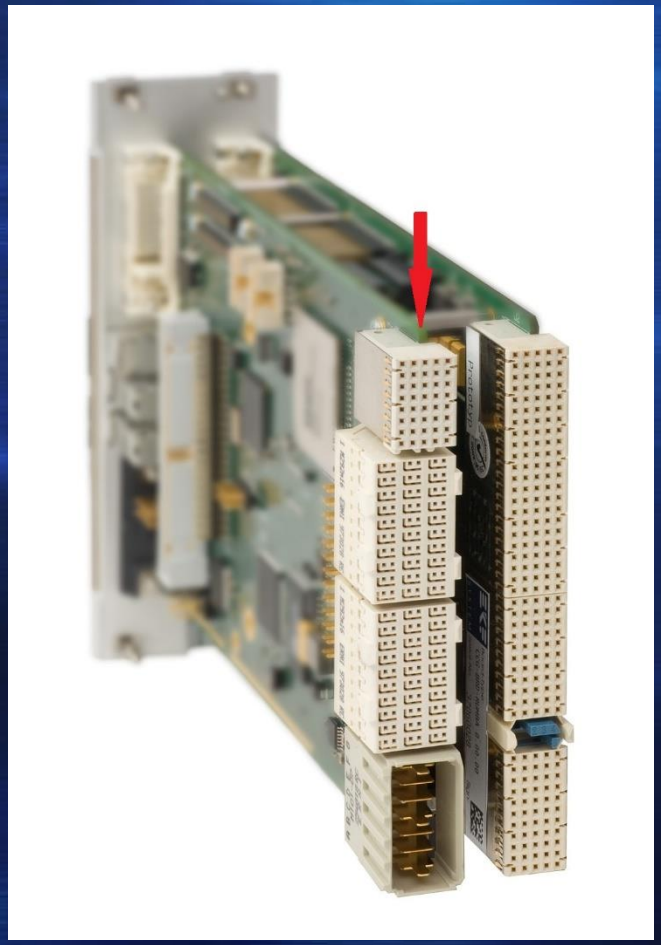
- System slot and board
  - Include up to 24 PCIe lanes, 2 or 4 PCIe links
- Peripheral slots and boards: Type 1, Type 2
  - Type 1 peripheral boards
    - Same pin definitions as the system board
    - Up to 16 PCIe lanes
  - Type 2 peripheral boards
    - Can be inserted into Type 1, Type 2, or hybrid peripheral slots
    - Up to 8 PCIe lanes

CompactPCI Express Modules (3)

- Connectors
  - J1/P1 and J2/P2 connectors replaced with improved connectors
  - Connectors on system boards and Type 1 peripheral boards: XP1 (power); XJ2, XJ3 (differential signals); XJ4 (user I/O pins)
  - Connectors on Type 2 peripheral boards: XJ3, XJ4
  - The J3, J4, and J5 connectors on 6U boards are the same as in standard CompactPCI

CompactPCI Express Modules (4)

- XJ4/XP4 connector (top)
  - eHM (*enriched Hard Metric*)
- XJ3/XP3, XJ2/XP2 connectors (middle)
  - ADF (*Advanced Differential Fabric*)
- XP1/XJ1 connector (bottom)
  - UPM (*Universal Power Module*)
  - Power of 400 W



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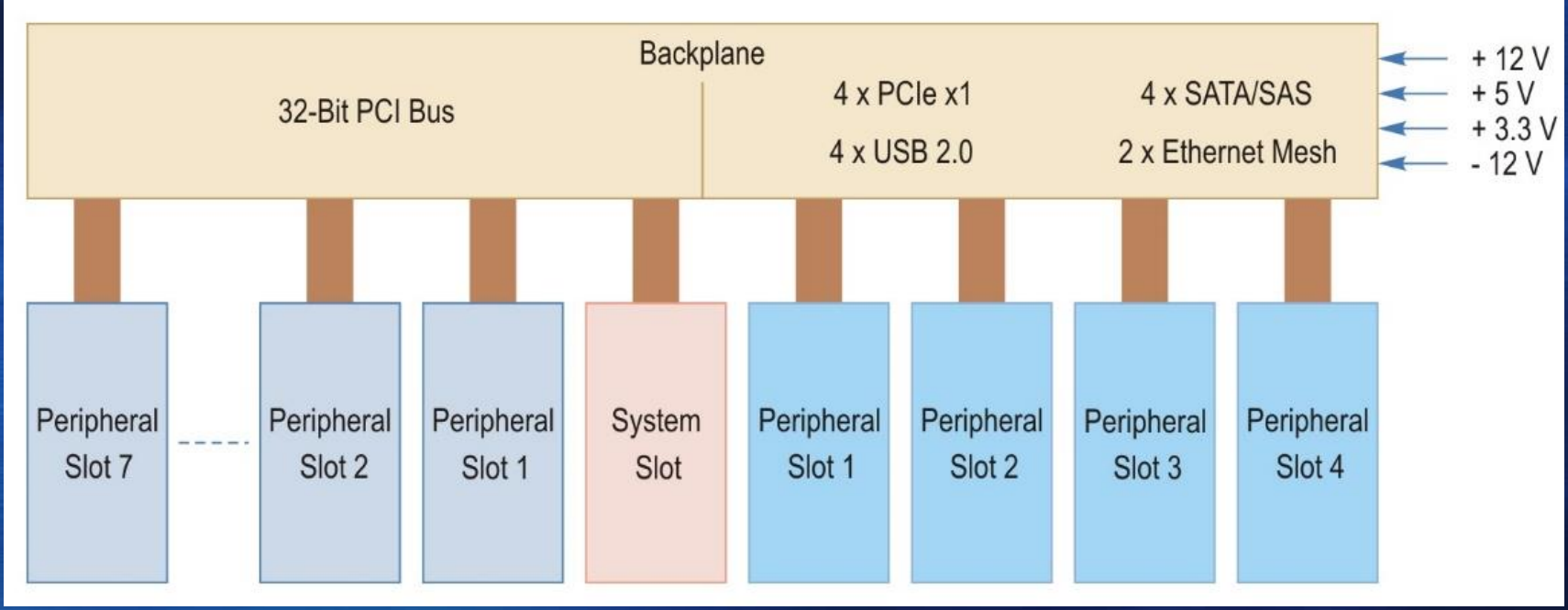
CompactPCI Modules

- CompactPCI Modules
  - CompactPCI Overview
  - CompactPCI Express Modules
  - CompactPCI PlusIO Modules
  - CompactPCI Serial Modules

CompactPCI PlusIO Modules (1)

- PICMG 2.30 extension
  - Enables to add fast serial connections and serial interfaces in a standard way
  - Specifies the pin assignment and function of user pins on the J2 connector
  - Maintains the parallel PCI bus
    - Limited to 32 bits → J2 is used for serial interconnects
  - Serial links/interfaces: 4 x PCIe (x1), 2 x Gigabit Ethernet, 4 x USB 2.0, 4 x SATA/SAS

CompactPCI PlusIO Modules (2)



CompactPCI PlusIO Modules (3)

- Full compatibility with 32-bit CompactPCI 3U and 6U expansion modules
  - A system slot can control up to 7 CompactPCI and up to 4 CompactPCI PlusIO peripheral boards
  - Hybrid backplanes: include CompactPCI, CompactPCI PlusIO, and CompactPCI Serial slots
  - Hybrid systems enable to migrate to fully serial connections

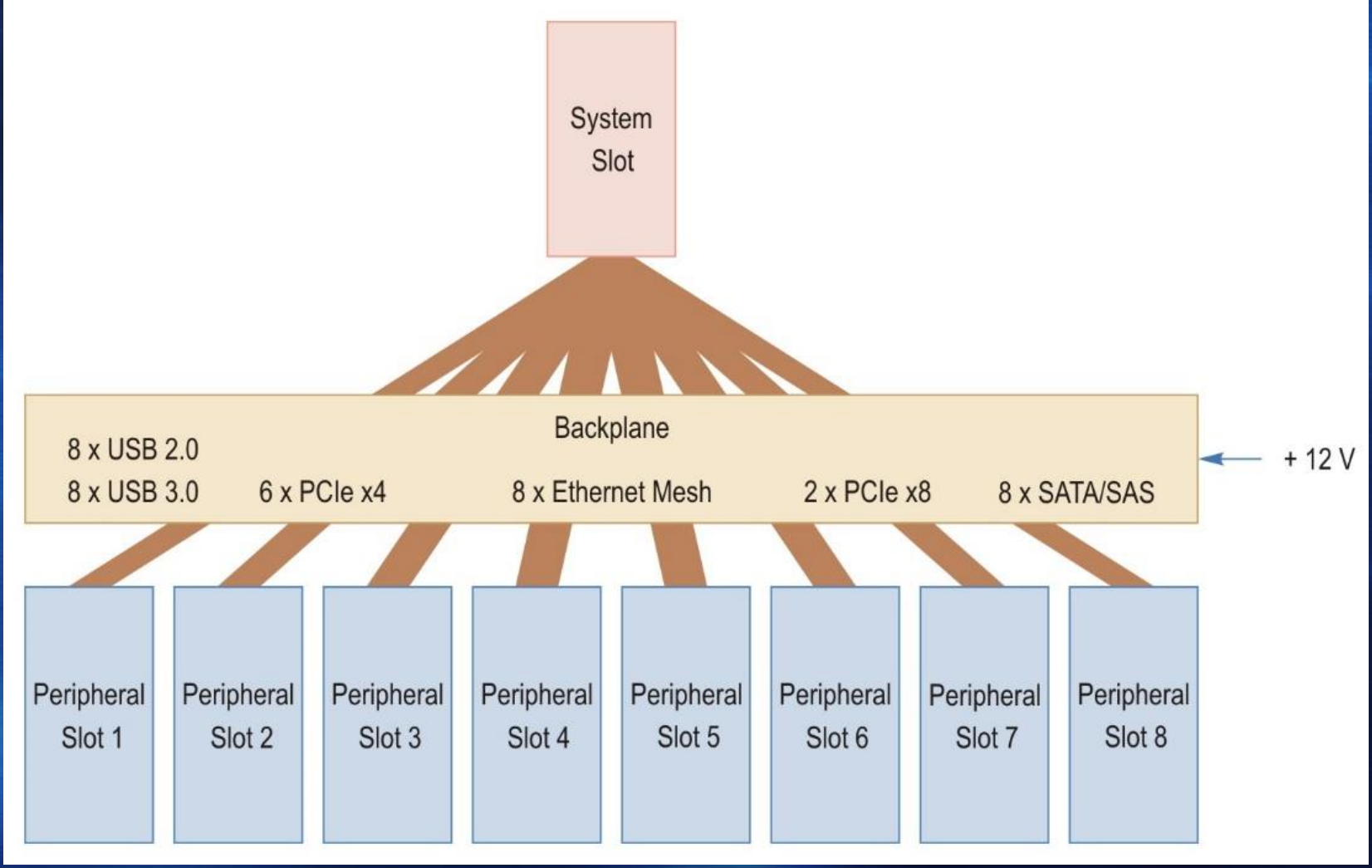
CompactPCI Modules

- CompactPCI Modules
  - CompactPCI Overview
  - CompactPCI Express Modules
  - CompactPCI PlusIO Modules
  - CompactPCI Serial Modules

CompactPCI Serial Modules (1)

- PICMG CPCI-S.0 extension
  - Completely replaces the parallel PCI bus with high-speed serial interconnects
  - The original HM connectors are replaced with new connectors to support differential signaling
  - 3U and 6U Eurocard form factors, with convection cooling or conduction cooling
  - Supports hot swap of modules
  - Fully passive backplane

CompactPCI Serial Modules (2)

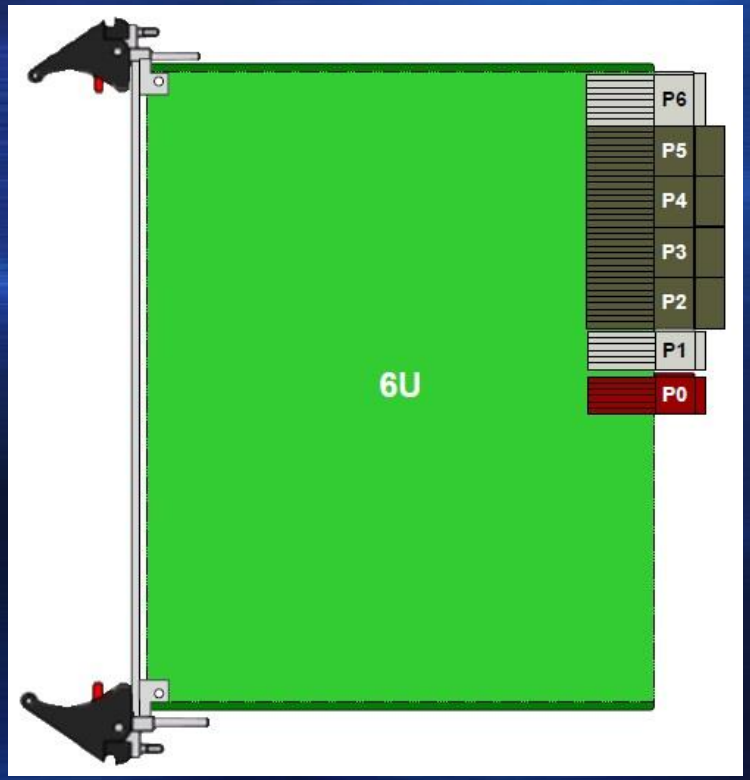


CompactPCI Serial Modules (3)

- Interfaces supported by peripheral slots:
  - One PCIe link (up to x8)
  - One SATA/SAS interface
  - One USB 2.0 interface
  - One USB 3.0 interface
  - Up to 8 Ethernet interfaces
- Connectors
  - The plug connector is placed on the module
  - AirMax connectors: support transfer rates of 12 Gbits/s; up to 184 pairs on a 3U module

CompactPCI Serial Modules (4)

- 3U modules: up to 6 connectors, P1 .. P6
- 6U modules: up to 7 connectors, P0 .. P6
- P2 .. P6: provide 360 user-defined I/O pins
- The pin assignment is identical for 3U and 6U modules
- P0 connector: provides additional Ethernet interfaces for servers



4. Expansion Modules for Embedded Systems

- Requirements for Embedded Systems
- VME Modules
- CompactPCI Modules
- Mezzanine Modules
- COM Express Modules

Mezzanine Modules

- Mezzanine Modules
  - Overview of Mezzanine Modules
  - Previous Mezzanine Modules
  - Switched Mezzanine Card
  - FPGA Mezzanine Card

Overview of Mezzanine Modules

- Mezzanine modules: small cards designed to plug onto main (carrier) modules
  - Placed in a plane parallel to the main module
  - Provide flexibility to a main module
  - Can extend the functions of the main module when there is not enough space
- Defined by industry standards
  - More cost-efficient than proprietary I/O modules
  - Carrier modules may use any architecture, e.g., VME, VXS, VPX, CompactPCI Serial

Mezzanine Modules

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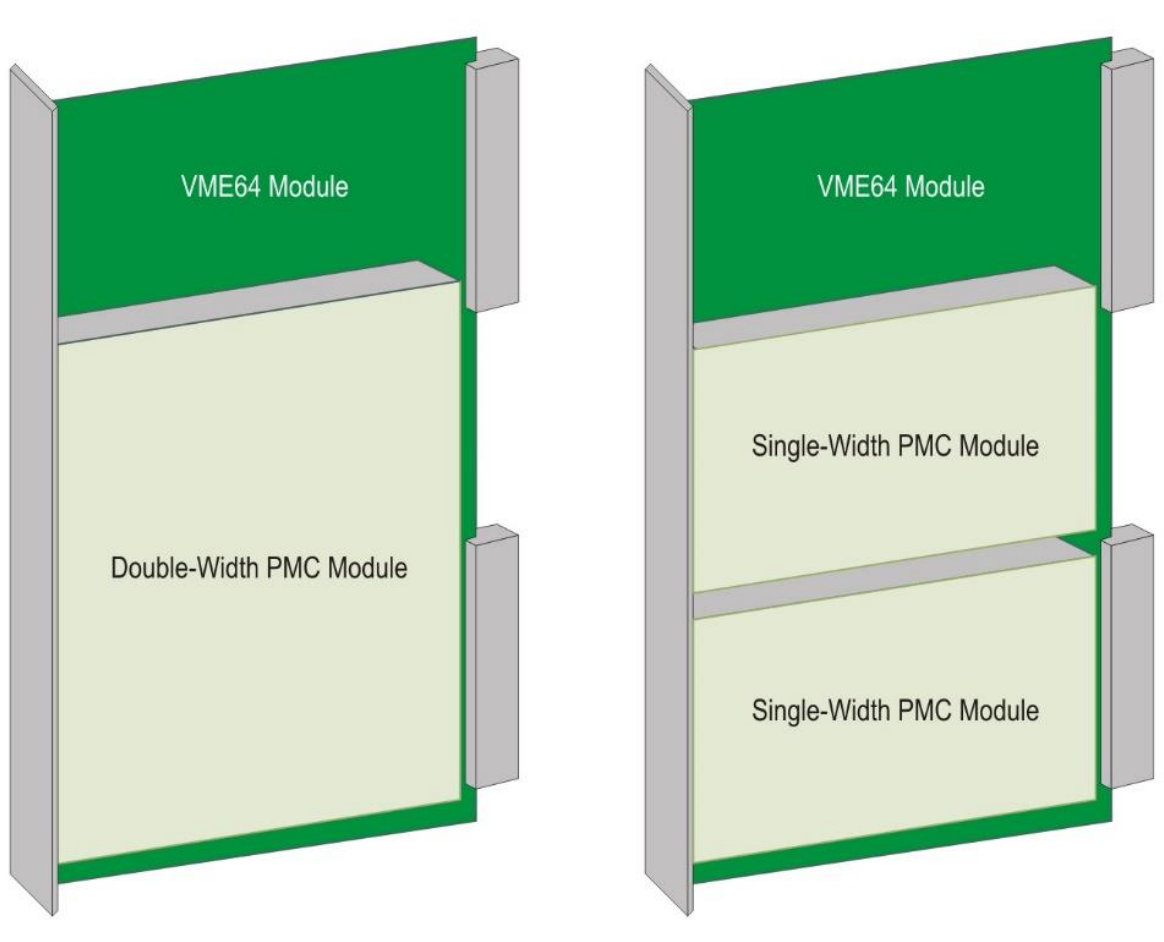
Previous Mezzanine Modules (1)

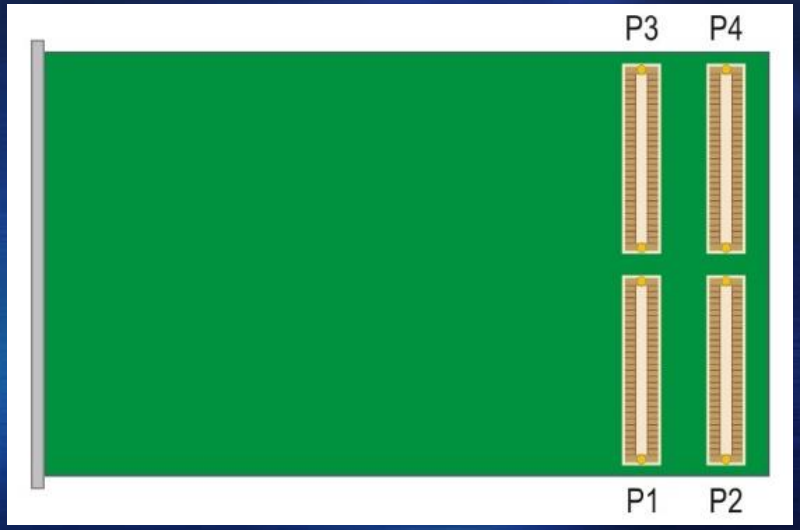
- Common Mezzanine Card (CMC)
  - IEEE 1386 standard
  - Specifies a card and connector for VME bus
- PCI Mezzanine Card (PMC)
  - Extension to the IEEE 1386 standard
  - Combines the electrical features of the PCI bus with the mechanical features of CMC
  - Single-width and double-width PMC modules
  - Carrier modules: 3U or 6U Eurocard

Previous Mezzanine Modules (2)



Previous Mezzanine Modules (3)

- Mezzanine connectors on a PMC module
  - P1, P2: for the 32-bit PCI bus
  - P3: for the 64-bit PCI bus
  - P4: for 64 user-defined I/O signals



Mezzanine Modules

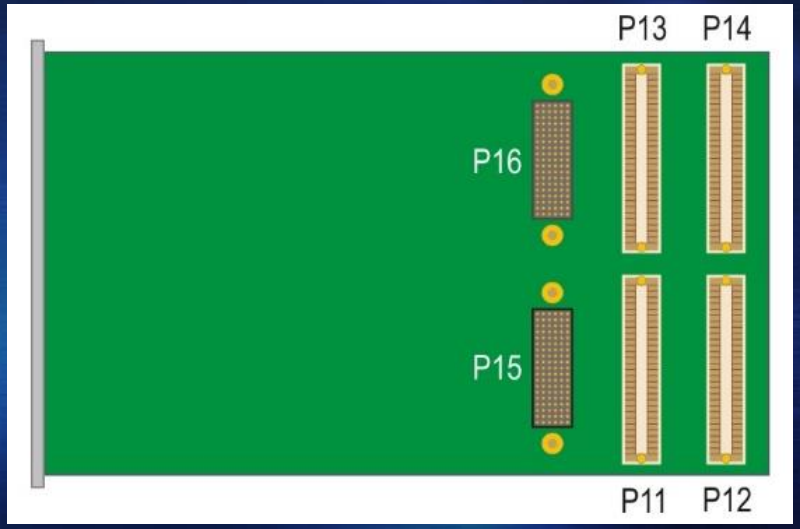
- Mezzanine Modules
  - Overview of Mezzanine Modules
  - Previous Mezzanine Modules
  - Switched Mezzanine Card
  - FPGA Mezzanine Card

Switched Mezzanine Card (1)

- XMC – ANSI/VITA 42 standard
- Extends the PMC format with high-speed serial interconnects and new connectors
- ANSI/VITA standards
  - ANSI/VITA 42.0: Base specification
  - ANSI/VITA 42.2: Serial RapidIO protocol
  - ANSI/VITA 42.3: PCIe protocol
  - ANSI/VITA 42.6: 10 Gigabit Ethernet protocol
- XMC modules are compatible with previous PMC modules

Switched Mezzanine Card (2)

- Mezzanine connectors
  - 1 .. 4 connectors for the PCI bus: P11, P12, P13, P14 → same as P1, P2, P3, and P4
  - 1 .. 2 high-density connectors for Gigabit serial interfaces: P15, P16



Switched Mezzanine Card (3)

XMC mezzanine module and CompactPCI Serial carrier module (© EKF Elektronik GmbH)

Mezzanine Modules

- Mezzanine Modules
  - Overview of Mezzanine Modules
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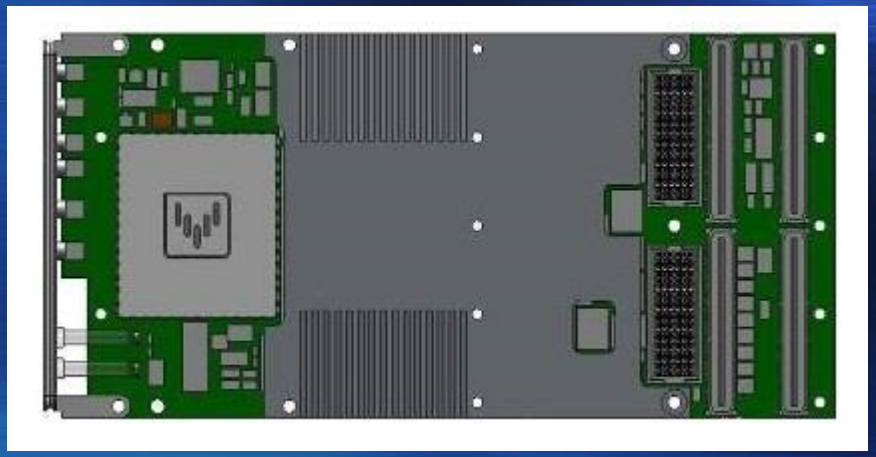
  - FPGA Mezzanine Card

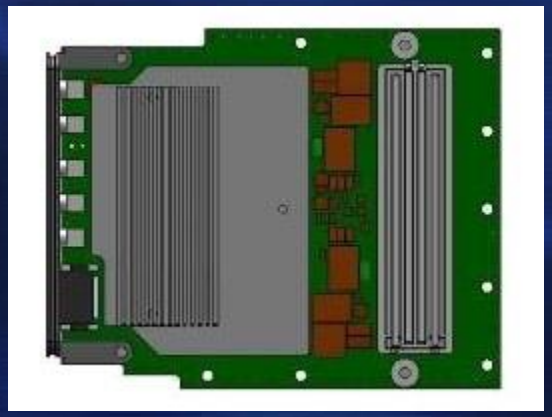
FPGA Mezzanine Card (1)

- FMC – ANSI/VITA 57.1 standard
  - Developed because PMC/XMC modules are not optimal for FPGA designs
  - Specifies a mezzanine board, connectors, and modular interface to FPGA devices on a carrier board
  - Carrier board: contains one or more FPGA devices; implements common functions
  - FMC module: implements functions that can be variable within a system

FPGA Mezzanine Card (2)

- Single-width FMC module
  - 69 mm x 76.5 mm, one connector (P1)
- Double-width FMC module
  - 139 mm x 76.5 mm, 1 .. 2 connectors (P1, P2)





Single-width XMC module (left); Single-width FMC module (right)

FPGA Mezzanine Card (3)

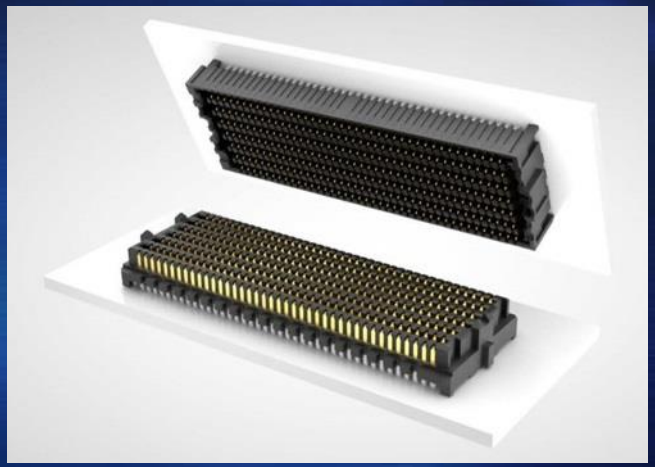
- Low Pin Count (LPC) connector
  - 160 contacts
  - 68 single-ended or 34 differential signals
  - One full-duplex serial lane → direct connection to a serial transceiver of an FPGA device
- High Pin Count (HPC) connector
  - 400 contacts
  - 160 single-ended or 80 differential signals
  - 20 differential pairs → connection to 10 serial transceivers
  - 4 differential clock signals, one I^2C bus

FPGA Mezzanine Card (4)

- FMC+ – ANSI/VITA 57.4 standard
  - Improved connector: up to 24 multi-gigabit serial lanes, 28 Gbits/s per lane
  - Defines triple-width FMC modules
  - Enables to extend the length of the original FMC module by 10 mm → new connector with 8 serial lanes
  - Aggregate data rate with the new connector: 32 x 28 Gbits/s = 896 Gbits/s

FPGA Mezzanine Card (5)

- Connectors
  - High Serial Pin Count (HSPC): 560 contacts (14x40)
  - HSPC extension (HSPCe): 80 contacts (4x20)
  - Mechanical design: SEARAY (Samtec, Inc.)



HSPC SEARAY connector (© Samtec, Inc.)

FPGA Mezzanine Card (6)

ADC/DAC FMC module (© VadaTech, Inc.)

4. Expansion Modules for Embedded Systems

- Requirements for Embedded Systems
- VME Modules
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- COM Express Modules

COM Express Modules (1)

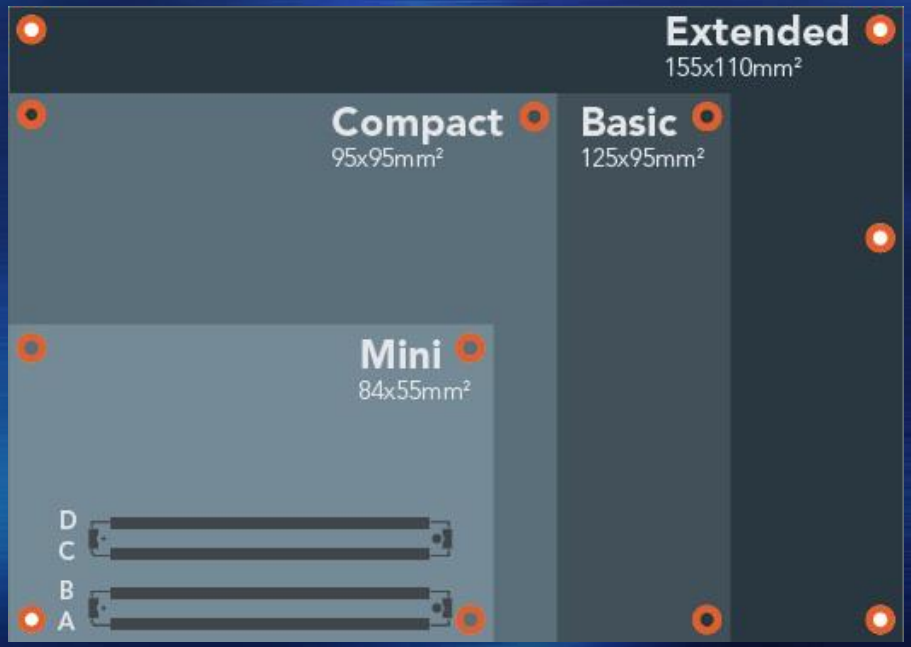
- Computer on Module Express
  - Family of modules of different sizes and pinout types
- A COM Express module may be used as:
  - Single-board computer
  - Processor mezzanine module connected to a carrier board
- Each COM Express module contains:
  - Processor; memory; high-speed serial buses and interfaces

COM Express Modules (2)

- Specification developed by the PICMG consortium
  - Current revision: 3.1 (2022)
  - Targeted for processors based on the x86 architecture (Intel, AMD)
- Module sizes
  - Mini (84 mm x 55 mm)
  - Compact (95 mm x 95 mm)
  - Basic (125 mm x 95 mm)
  - Extended (155 mm x 110 mm)

COM Express Modules (3)

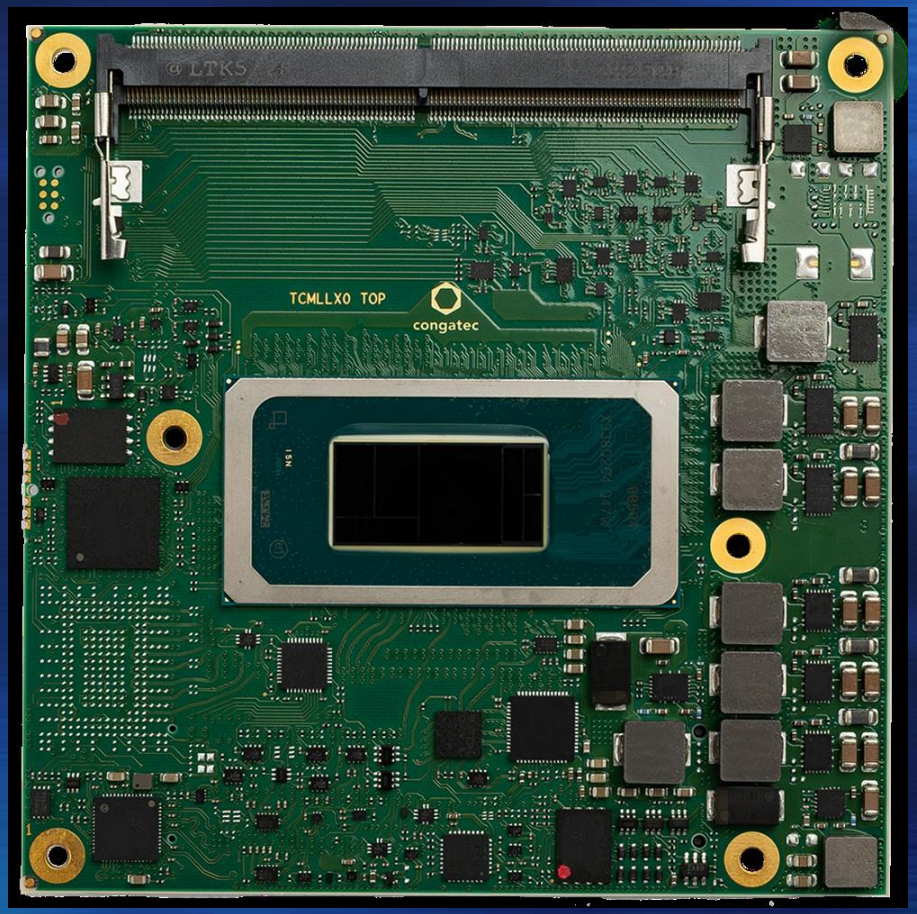
- Signals are routed to one or two high-density connectors (step of 0.5 mm)
  - A-B, C-D (220 pins each)



COM Express Modules (4)

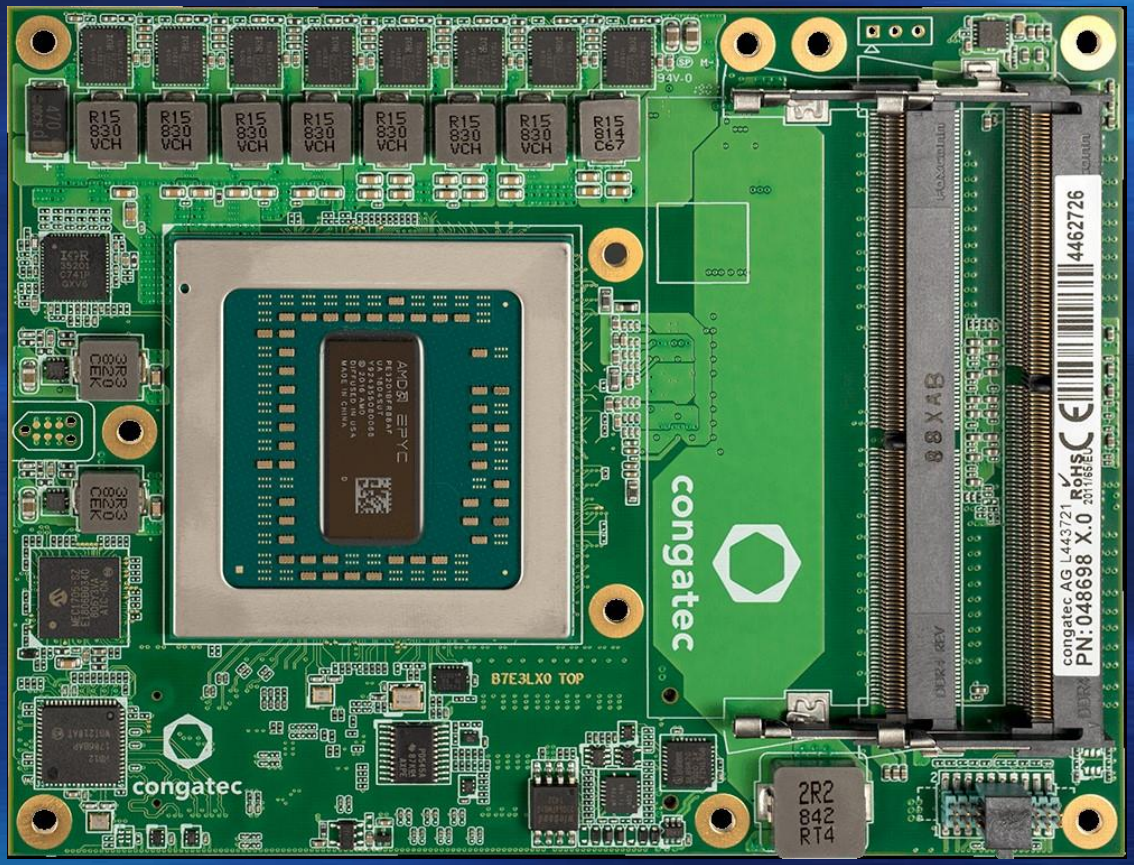
- Module Types
  - Each type contains certain interfaces and has different pinout configuration
  - Currently defined module types: 1, 10, 2, 3, 4, 5, 6, and 7
  - Type 1, Type 10: a single connector
  - Most used: Type 10, Type 6
  - Type 7: defined in Revision 3.0 for servers
  - Power consumption: 68 W (one connector), 137 W (two connectors)

COM Express Modules (5)



Type 6 Compact COM Express module with Intel Core Ultra processor (© congatec GmbH)

COM Express Modules (6)



Type 7 Basic COM Express module with AMD EPYC Embedded 3000 processor (© congatec GmbH)

COM Express Modules (7)

- Advantages of COM Express modules
  - High performance: due to the high-speed serial buses and interfaces
  - Flexibility: various module sizes and types
  - Can be used standalone or with a user-supplied carrier board
  - Reduced cost and development time
  - Simple upgrades when used with a carrier board

COM Express Modules (8)

- Applications
  - Industrial control
  - Railway transportation
  - Data acquisition
  - Medical equipment
  - Military vehicles, aerospace modules
  - Internet of Things (IoT)
  - Type 7 modules: in data centers and for video surveillance

Summary (1)

- Requirements for embedded systems: high reliability, simple maintenance
  - Pin-and-socket connectors
  - Front panels and guiding systems
  - Passive backplanes
- Parallel VME modules
  - 3U, 6U, and 9U Eurocard form factors
  - P/J connector pairs
  - Standard, VME64x, and VME320 backplanes
  - Conduction-cooled modules are available

Summary (2)

- VXS (*VMEbus Switched Serial*) modules
  - Switch boards have point-to-point connections to payload boards
  - Payload boards maintain compatibility with VME modules; contain an additional serial connector
  - VXS backplane topologies: single star, dual star, mesh, daisy chain
- VPX modules
  - Use only serial interconnects
  - Connectors: MultiGig RT2 (Gen 4 VPX, 16 Gbits/s), MultiGig RT3 (Gen 5 VPX, 25.8 Gbits/s)

Summary (3)

- CompactPCI combines the parallel PCI bus with the 3U and 6U Eurocard form factors
  - Passive backplane
  - Larger number of peripheral slots
- CompactPCI Express modules and backplanes use the PCIe technology
  - System, peripheral, switch boards/slots
  - Improved connectors
- CompactPCI PlusIO maintains the 32-bit PCI bus and extends it with serial links/interfaces

Summary (4)

- CompactPCI Serial replaces the parallel PCI bus with serial point-to-point interconnects
  - Star topology
  - PCIe links and various interfaces: SATA/SAS, USB, Ethernet
- Mezzanine modules are designed to plug onto main modules in a stacking configuration
- The Switched Mezzanine Card (XMC) is based on the previous PCI Mezzanine Card (PMC)
  - Extends the PMC format with serial interconnects and new mezzanine connectors

Summary (5)

- The FPGA Mezzanine Card (FMC) format has been developed for communication with FPGA devices located on a carrier board
  - The FMC+ format uses an improved connector and increases the number of serial lanes
- COM Express defines a family of module sizes and pinout types
  - Can be used for single-board computers
  - Module sizes: Mini, Compact, Basic, Extended
  - Commonly used pinout types: Type 10, Type 6, Type 7

Concepts, Knowledge (1)

- Requirements for embedded systems
- Form factors for parallel VME modules
- Conduction-cooled VME modules
- VXS switch boards
- VXS payload boards
- VXS backplane topologies
- Features of the CompactPCI format
- Advantages of CompactPCI
- CompactPCI Express boards and slots

Concepts, Knowledge (2)

- CompactPCI PlusIO buses and interfaces
- CompactPCI Serial architecture and interfaces
- Advantages of mezzanine modules
- Features of the XMC format
- Features of the FMC format
- Improvements introduced by the FMC+ format
- COM Express module sizes and types
- Advantages of using COM Express modules