

# 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<sup>®</sup>**

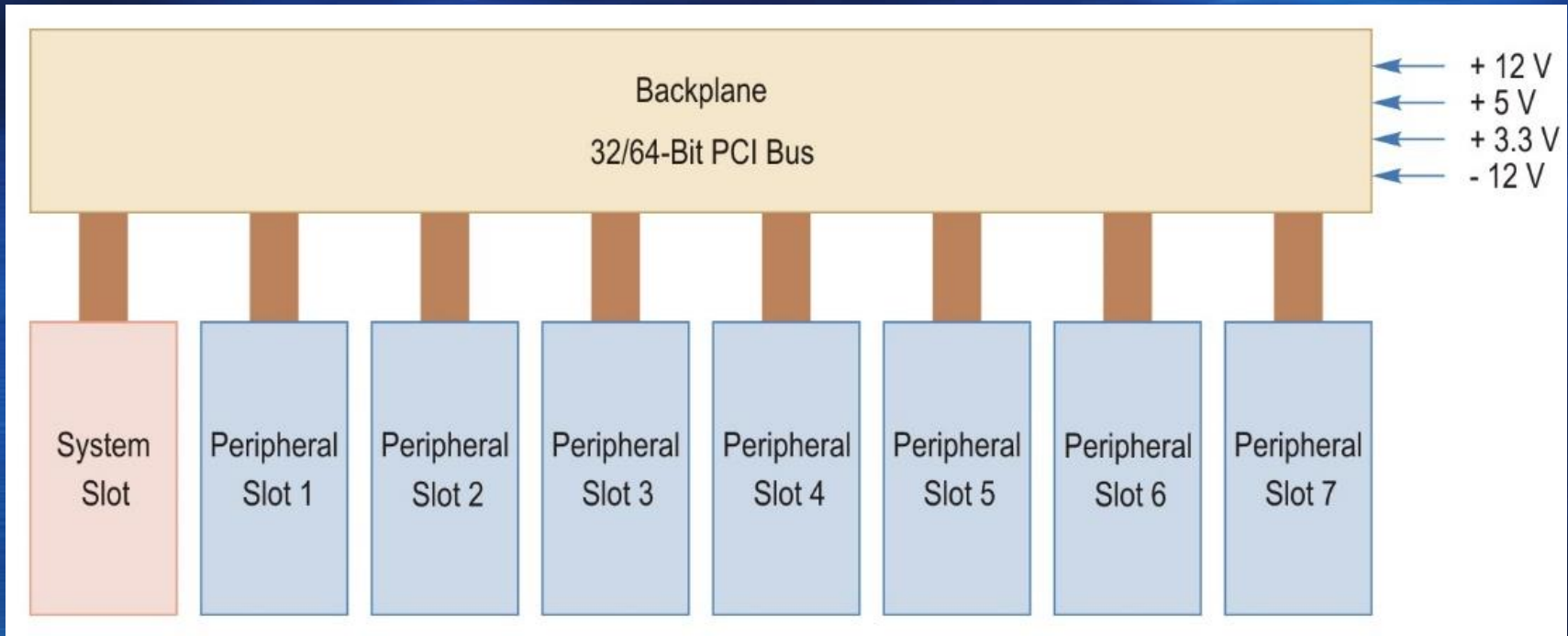
- CompactPCI, cPCI
- Industrial standard for modular computer systems
- Developed by the *PCI Industrial Computer Manufacturers Group* (PICMG)
- Aim: replacing the **VME** bus with the **PCI** bus
  - Combining the electrical specifications of the parallel PCI bus with the **3U** and **6U Eurocard**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

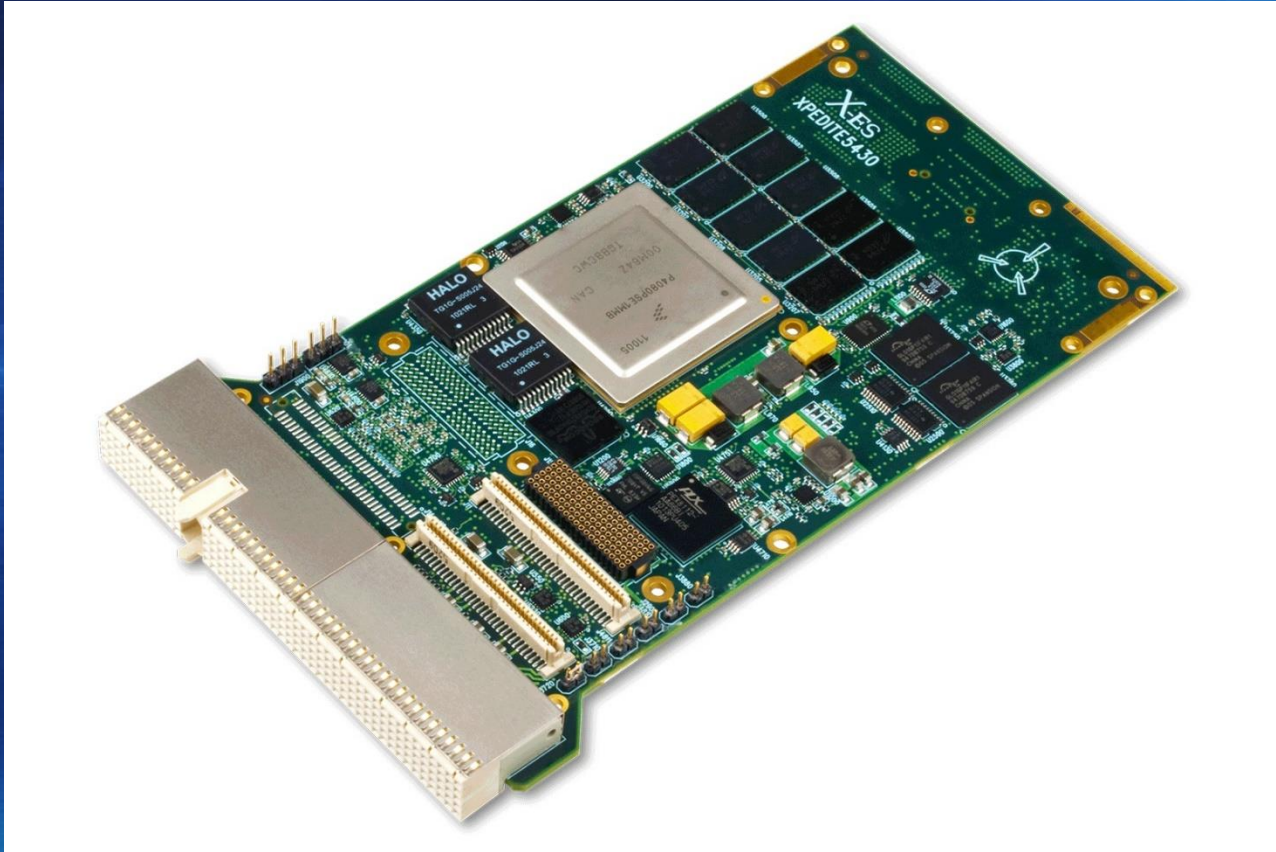


# CompactPCI Overview (4)

- **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

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  - 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

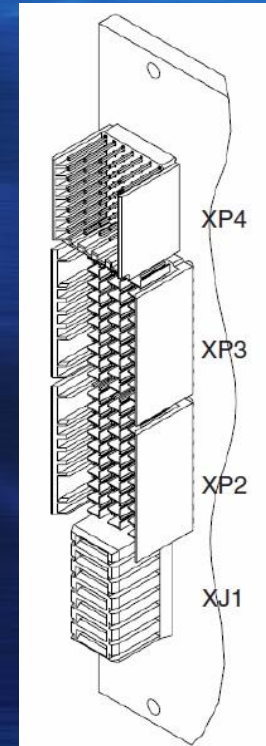
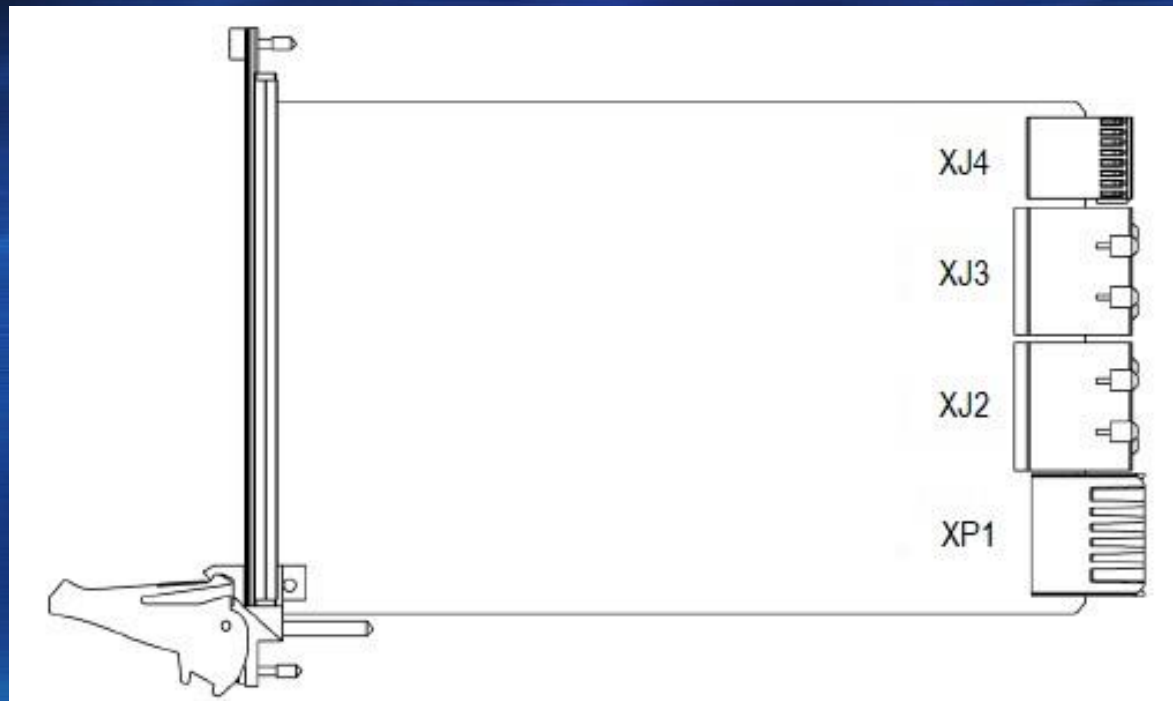
# CompactPCI Express Modules (3)

## ● 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

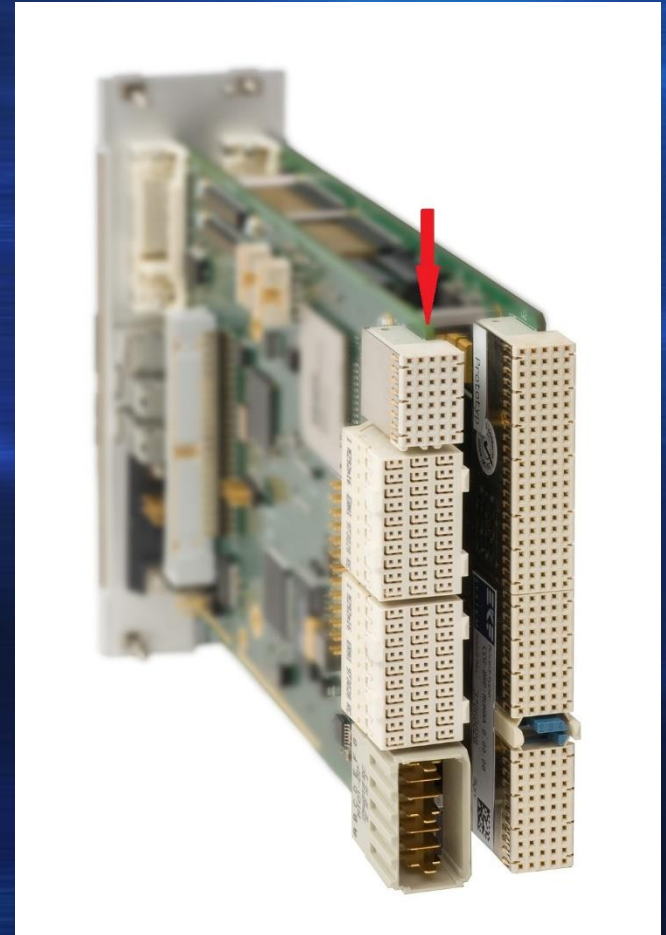


# CompactPCI Express Modules (4)



# CompactPCI Express Modules (5)

- 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

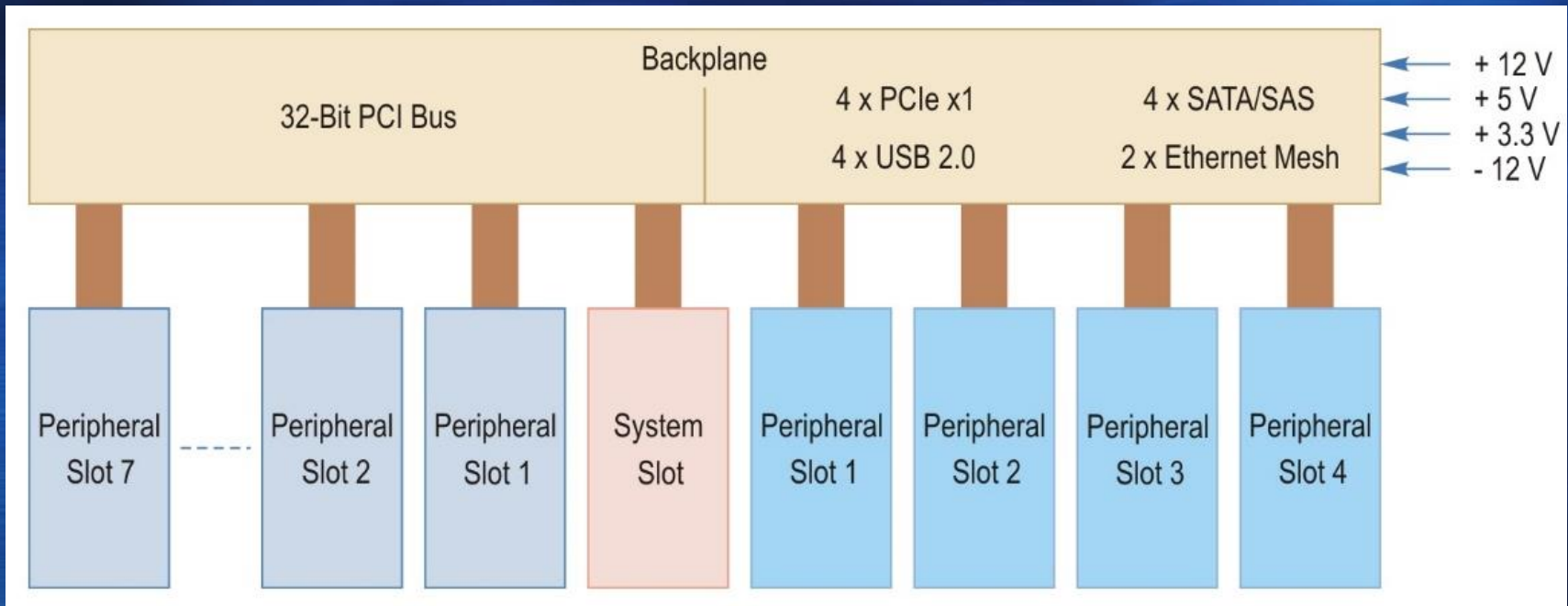
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# CompactPCI PlusIO Modules (1)

- 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

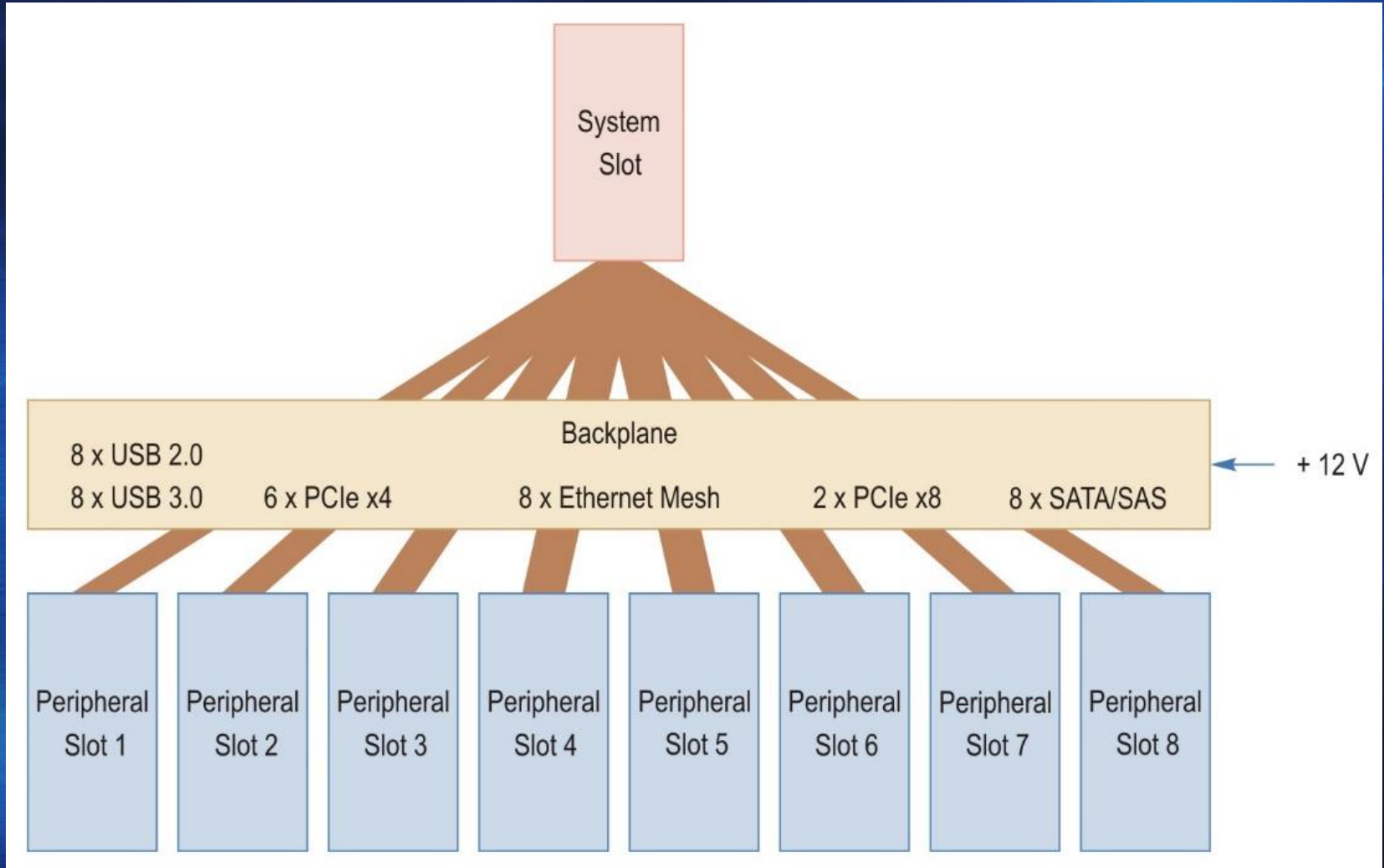
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# CompactPCI Serial Modules (1)

**CompactPCI®  
Serial**

- 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)



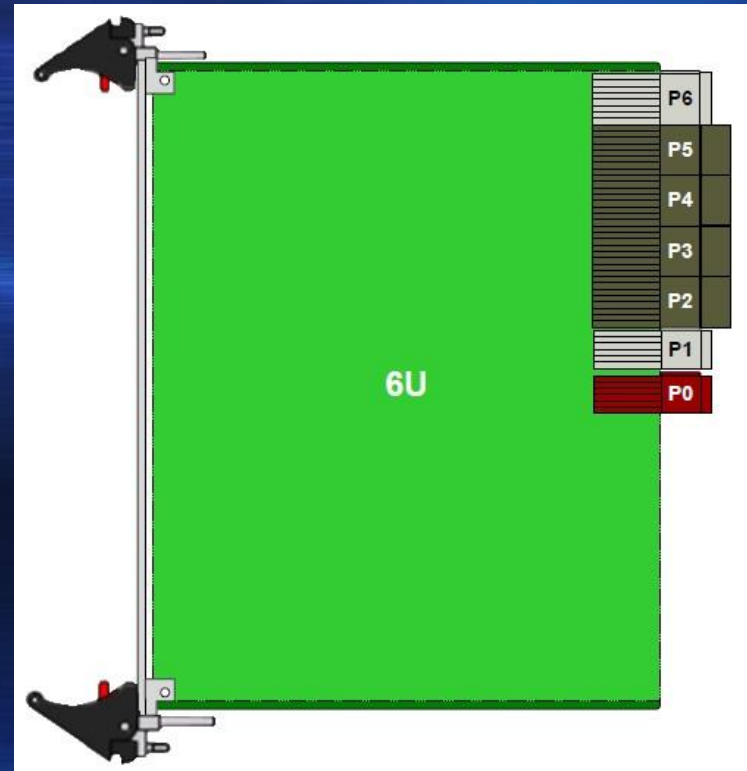


# CompactPCI Serial Modules (3)

- 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

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- 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

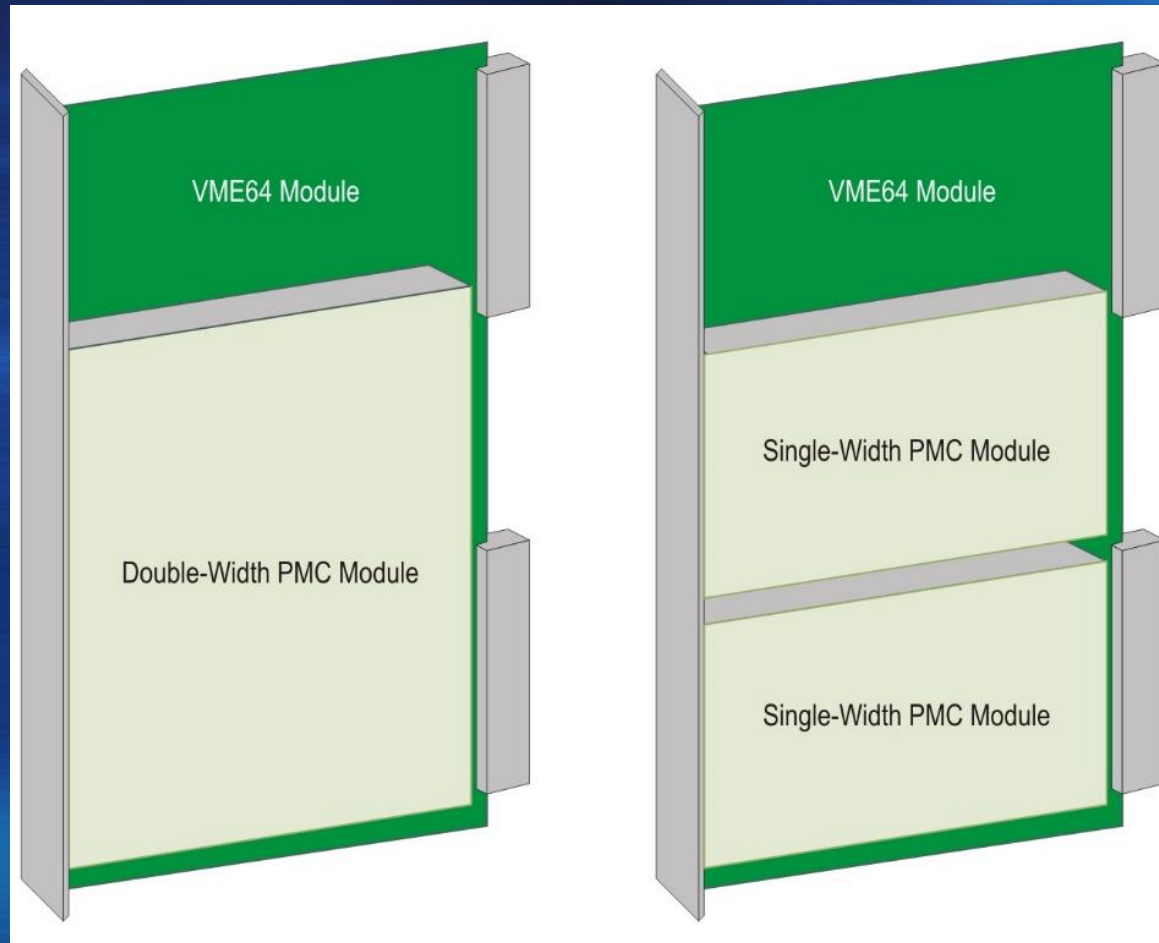
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# Previous Mezzanine Modules (1)

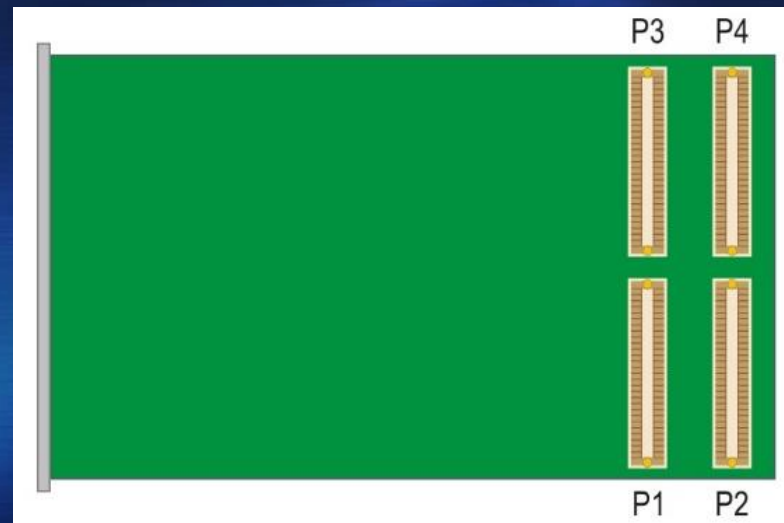
- Common Mezzanine Card (CMC)
  - IEEE 1386 standard
  - Specifies a card and connector for VME bus
- PCI Mezzanine Card (PMC)
  - Extension to the IEEE 1386 standard
  - Combines the electrical features of the PCI bus with the mechanical features of CMC
  - Single-width and double-width PMC modules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

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  - FPGA Mezzanine Card

# Switched Mezzanine Card (1)

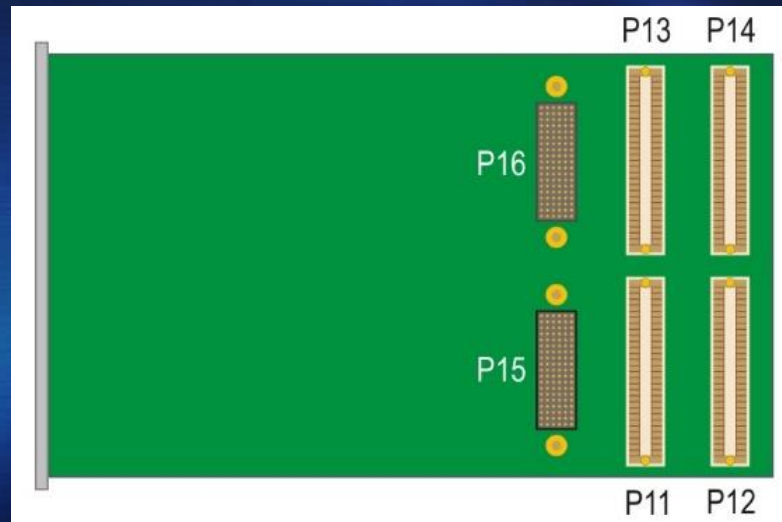


- XMC – ANSI/VITA 42 standard
- Extends the PMC format with high-speed serial interconnects and new connectors
- ANSI/VITA standards
  - ANSI/VITA 42.0: Base specification
  - ANSI/VITA 42.2: Serial RapidIO protocol
  - ANSI/VITA 42.3: PCIe protocol
  - ANSI/VITA 42.6: 10 Gigabit Ethernet protocol
-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

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  - **FPGA Mezzanine Card**

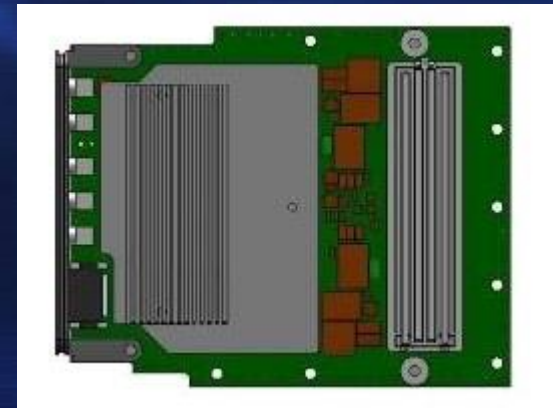
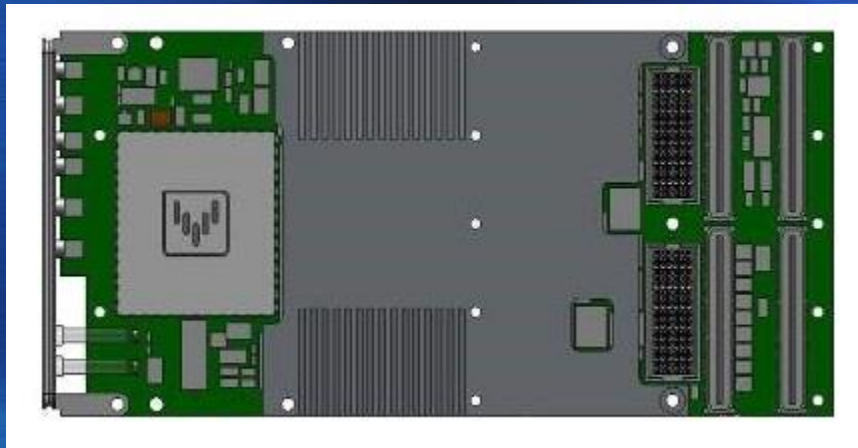
# FPGA Mezzanine Card (1)

- FMC – ANSI/VITA 57.1 standard The logo for FMC (Field Programmable Mezzanine Card) consists of a stylized grid of orange squares to the left of the letters 'FMC' in a blue, sans-serif font.
- 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<sup>2</sup>C bus

# FPGA Mezzanine Card (4)

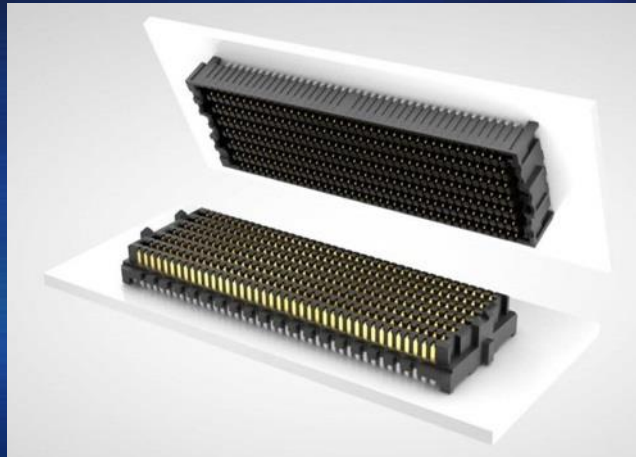


- FMC+ – ANSI/VITA 57.4 standard
  - Improved connector: up to 24 multi-gigabit serial lanes, 28 Gbits/s per lane
  - Defines **triple-width FMC** modules
  - Enables to extend the length of the original **FMC** module by 10 mm → new connector with 8 serial lanes
  - Aggregate data rate with the new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



# 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
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- COM Express Modules



# COM Express Modules

- COM Express Modules
  - COM Express Overview
  - Type 10 COM Express Modules
  - Type 6 COM Express Modules
  - Type 7 COM Express Modules

# COM Express Overview (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 Overview (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 Overview (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 Overview (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 commonly used: **Type 10, Type 6**
- **Type 7**: defined in Revision 3.0
- Power consumption: 68 W (one connector), 137 W (two connectors)

# COM Express Overview (5)

- 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 Overview (6)

## ● 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

# COM Express Modules

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# Type 10 COM Express Modules (1)

- Implemented in the **Mini** form factor
  - Targeted to processors with low power consumption
- Limited number of interfaces
  - **PCIe** bus with 1 .. 4 lanes
  - **Serial ATA** (SATA) ports (1 .. 2)
  - **Gb Ethernet** port (1)
  - **Serial** ports (0 .. 2)
  - **LPC** (*Low Pin Count*) bus → for connecting low-speed peripherals

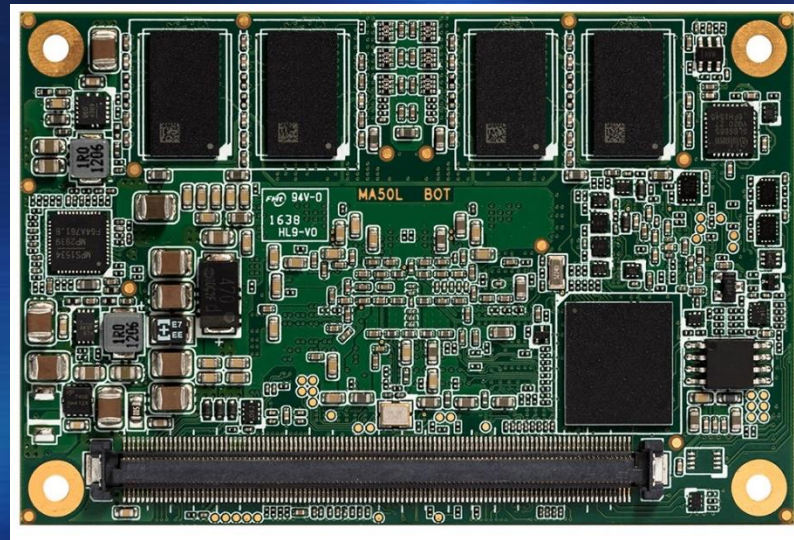


# Type 10 COM Express Modules (2)

- **SPI** (*Serial Peripheral Interface*) (1 .. 2)
- **System Management Bus** (1)
- **I<sup>2</sup>C bus** (1)
- **CAN** (*Controller Area Network*) interface (optional)
- **USB 2.0** ports (4 .. 8)
  - Optionally: 2 ports can be configured as **USB 3.x**
- **DDI** (*Digital Display Interface*) (optional)
  - It can be adapted to: **DVI**, **HDMI**, **DisplayPort**, or **SDVO** (*Serial Digital Video Out*)

# Type 10 COM Express Modules (3)

- LVDS (*Low-Voltage Differential Signaling*) channel (optional)
- Embedded DisplayPort (eDP) on the LVDS pins (optional)



Type 10 COM Express module (© congatec GmbH)

# COM Express Modules

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# Type 6 COM Express Modules (1)

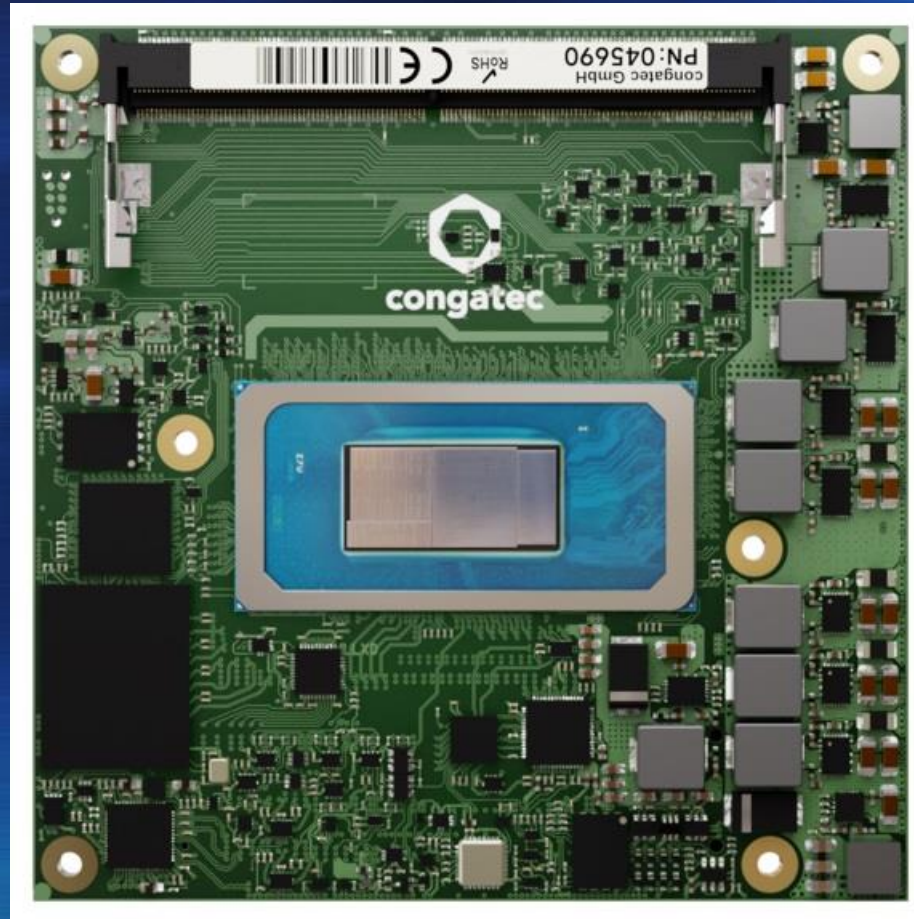
- Based on **Type 2** modules
- Available in the **Compact** and **Basic** form factors
  - Targeted to processors with higher performance
- Two **connectors**
  - First connector: nearly the same pinout as that of **Type 2** modules
  - Second connector: support for current and future serial interfaces

# Type 6 COM Express Modules (2)

## • Interfaces

- Same as on Type 10 modules: Gb Ethernet, serial, LPC, SMBus, I<sup>2</sup>C, CAN, USB 2.0
- PCIe bus with 1 .. 24 lanes
- SATA ports (1 .. 4)
- 4 USB ports can be configured as USB 3.x
- Up to 3 DDI channels (optional)
- Up to 2 LVDS channels (optional)
- PCI Express Graphics (PEG) (optional): x16 PCIe connector

# Type 6 COM Express Modules (3)



Type 6 Compact COM Express module (© congatec GmbH)



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# Type 7 COM Express Modules (1)

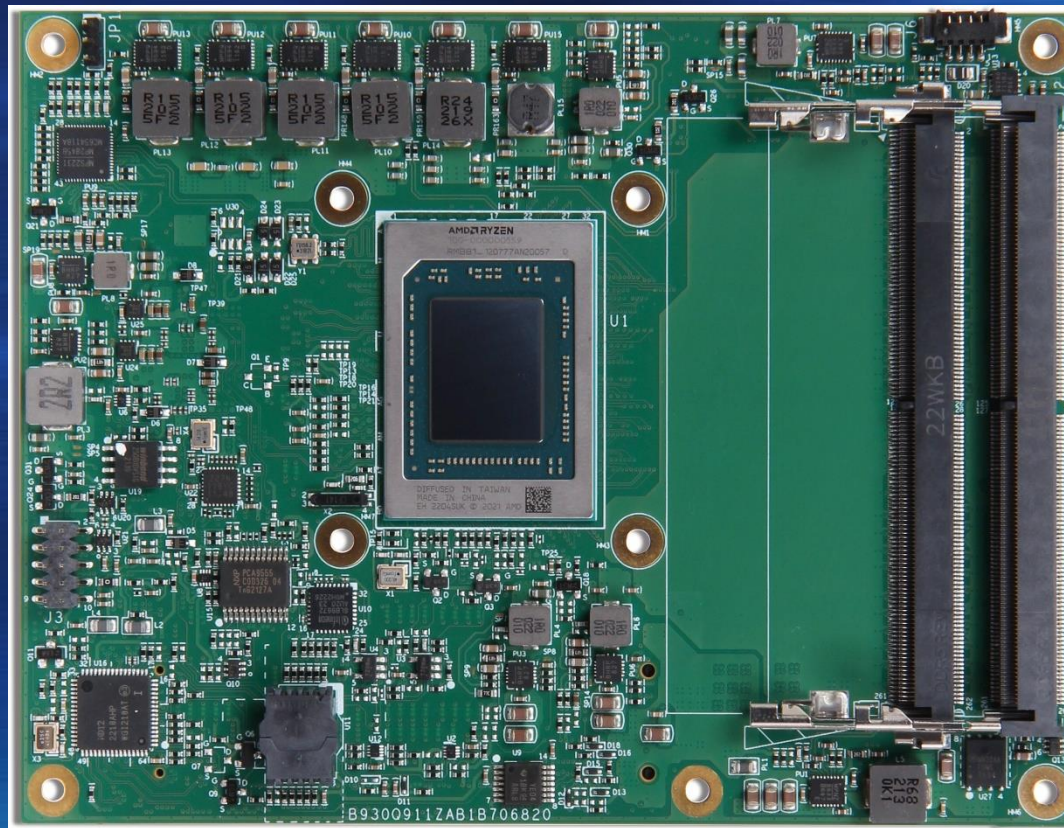
- Developed for modular server designs
- Available in the **Basic** and **Extended** form factors
  - Targeted to processors designed for servers
- Interfaces removed:
  - 4 **USB 2.0**, 2 **SATA**, all display interfaces
- New buses/interfaces:
  - **PCIe** lanes (8)
  - **10-Gb Ethernet** (1 .. 4): physical transmission layer not implemented on the module

# Type 7 COM Express Modules (2)

- Reasons for removing **SATA** ports:
  - Gradual replacement of hard disk drives by **solid-state drives (SSDs)**
  - Replacement of **SATA** interface by the **NVMe (Non-Volatile Memory Express)** interface
- **Interfaces**
  - Same as on **Type 6** modules: **serial, LPC, SMBus, I<sup>2</sup>C, CAN, Gb Ethernet**
  - **PCIe** bus (up to x32), **2 SATA, 4 USB 2.0** (each configurable as **USB 3.x**), **10-Gb Ethernet**



# Type 7 COM Express Modules (3)



Type 7 Basic COM Express module (© American Portwell Technology, Inc.)

# 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)

- Features of the CompactPCI format
- Advantages of CompactPCI
- CompactPCI Express boards and slots
- CompactPCI PlusIO buses and interfaces
- CompactPCI Serial architecture
- CompactPCI Serial interfaces
- Advantages of mezzanine modules
- Features of the XMC format

# Concepts, Knowledge (2)

- Features of the FMC format
- Improvements introduced by the FMC+ format
- COM Express module sizes and types
- Advantages of using COM Express modules
- Buses and interfaces included on Type 10 COM Express modules
- Differences between Type 6 and Type 10 COM Express modules