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ORIGINAL PAPER

Design and development of module management controller for MicroTCA.4 standard

Gan Nan[1] · Ma Xinpeng[1] · Peng Yongyi[1,2] · Li Jingyi[1]

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Abstract

Objective The MicroTCA.4 (MTCA.4) standard systems have been widely used in large-scale scientific facilities such as synchrotron radiation light sources and FELs over the world, covering RF control, beam instrumentation, timing, machine protection, and so on. The MTCA.4 module management controller (MMC) realizes intelligent management of the boards in the chassis through bus protocol and system interaction. It is an important functional module in MTCA.4 standard system.

Methods In order to meet the requirements of the large scientific facilities, an MMC module was designed and developed. This design can realize power management of Advanced Mezzanine Card (AMC) and Rear Transition Module (RTM) boards, as well as monitoring the temperature, voltage, and current during operation. The core part of this module is limited into an area of 3 cm × 3 cm on the AMC board, leaving large space for subsequent development of functional circuit.

Results An AMC board was developed to verify functions of the MMC. Test results indicate that this board is compatible with existing MTCA.4 standard system.

Conclusions This MMC solution can be directly and modularly applied to the design of MTCA.4 standard hardware.

Keywords Micro Telecommunications computing architecture (MTCA) · Module management controller (MMC) · Advanced mezzanine card (AMC) · Rear transition module (RTM)

Introduction

With the development of large scientific facilities such as synchronous radiation light sources and free electronic lasers, high precision and high reliability control technologies for acquiring high quality particle beams have been becoming one of the important development trends of accelerator control system. The VME and CPCI-based systems has been used in accelerator controls for decades. However, their bandwidth and speed of signal processing could not meet the increasing requirements of accelerator operation. The PICMG (PCI Industrial Computer Manufacturers Group) proposed a hardware architecture, named Micro Telecommunications Computing Architecture (MicroTCA), with high bandwidth, high performance, modular, high flexibility in 2006 [1]. The MTCA.4 is one of its important branches which strengthens backplane I/O and high-precision timing. The MTCA.4 based hardware has been widely used in accelerator controls, such as low-level RF control, timing, and beam control [2–4]. The Advanced Mezzanine Card (AMC) of the MTCA.4 standard is composed of the management module and function module. The core part of the management module is the module management controller (MMC), which is responsible for board parameter monitoring, e.g. voltages or temperature, hot-plug capability, payload power management and communication with the MCH, etc. There are many commercially available MMCs from companies such as N.A.T. and Samway. However, these commercial MMCs have limitations in developing dedicated software and hardware. To solve this problem, we developed a modular, fully autonomous MMC module. This module can be used for the development of MTCA.4 standard boards. The challenge in developing the MMC is to achieve all management functions in a stable and reliable manner, while keeping the structure as compact as possible to reserve the maximum free space on the board for functional modules. This paper introduces the hardware and software development, and test of the MMC.

✉ Gan Nan
gann@ihep.ac.cn

1 Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

2 School of Nuclear Sciences and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

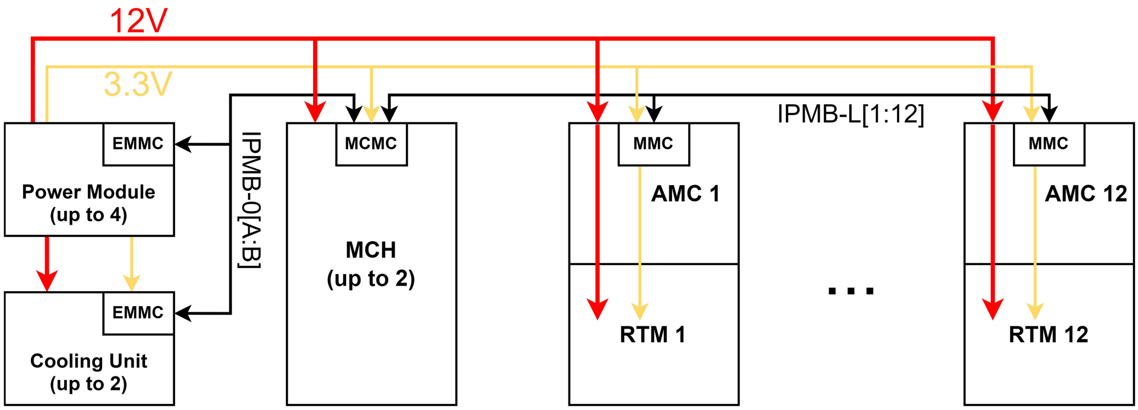


Fig. 1 Management defined in MicroTCA.4 system

Review of MTCA.4 and MMC

The MicroTCA standard offers a higher bus bandwidth than those of VME and CPCI. It provides a single bandwidth capacity of at least 3.125 GB/s between different channels, enabling each channel to achieve bit rate exceeding 10 GB/s. Furthermore, the MicroTCA standard provides greater reliability, reliability level as high as 99.999% with completely redundant system [5].

The MTCA.4 standard system consists of one or two MicroTCA Carrier Hubs (MCHs), up to 12 AMC boards and 12 Rear Transition Module (RTM) boards, power modules, cooling units, interconnect backplane, and other modules [6]. The power module, cooling module, and interconnect backplane form the chassis of an MTCA.4 system. The MCH, AMC, and RTM operate on the interconnect backplane of the chassis. These modules are managed through the Intelligent Platform Management Interface (IPMI) [7]. Two Intelligent Platform Management Buses (IPMB) are defined in the MTCA.4 standard, namely IPMB-0 and IPMB-L. The IPMB-0 bus is used for communicating between the MCHs, power modules, and cooling modules, while the IPMB-L bus is between MCH and AMC modules. The intelligent management of an MTCA.4 standard system is shown in Fig. 1.

There is a management module on each of the MCHs, Power Modules, Cooling Units, and AMC boards. The management module on a MCH is called MicroTCA Carrier Management Controller (MCMC), Enhanced Module Management Controller (EMMC) on power module and cooling unit, and module management controller on AMC boards.

The MCH manages and controls the AMC boards according to the information from corresponding MMCs as followings:

1. After an AMC board being inserted into the backplane, the power module first provides 3.3-volt management power to the MMC module of the AMC board;
2. The MMC module performs hardware verification of the AMC board. If the AMC board meets all the MTCA.4 hardware standard, the MMC would inform the MCH to control the power module to supply 12-volt main power to the AMC board;
3. During normal operations of an AMC board, its MMC module monitors the temperature, voltage, and current of the board, and the status of the hot-plug switch. The 12 V power supply is controlled accordingly based on the status of the hot-plug switch [8, 9];
4. If there is an RTM board plugged, the MMC is also responsible for managing the power control and temperature monitoring.

In summary, the MMC in a MicroTCA system serves as the central management and control unit, overseeing the various components to ensure they work together cohesively and reliably. It provides essential functions for system monitoring, management, fault handling, and configuration. This is crucial for maintaining the stability, reliability, and modularity of the MicroTCA system in various applications.

The existing MMC solutions generally use ATMEL's ATmega, STMicroelectronics's STM32 or NXP's LPC series microcontrollers as the core controller. DESY, one of the promoters of the MTCA.4 standard, used the ATmega128 for its MMC solution, which was first used in the Euro-XFEL [2]. Nowadays, DESY has developed another MMC solution based on ARM Cortex-M4 chip for commercial sale. The Warsaw University of Technology develops an MMC solution using LPC1764 microcontroller and an open-source project OpenMMC as accompanying firmware, this solution has been applied to LNLS (Laboratorio Nacional de Luz Sincrotron) [9]. Table 1 briefly summarizes the basic features of several solutions in the market. Compared to other solutions, the MMC described in this article employs independently designed circuits and open-source firmware. This enables

Table 1 Comparison of existing solutions

	N.A.T	CERN	DMMC-STAMP	Samway	MMC in this paper
MCU	AVRxmega128	ATmega128	Atmel SAM	Kinetis K10	LPC176X
MicroTCA.0	Y	Y	Y	Y	Y
MicroTCA.4	Y	Y	Y	Y	Y
Schematic reference	Y	Y	N	Y	Y
Layout reference	N	N	N	N	Y
Firmware source	Y	Y	Y	Y	Y
Mezzanine format	N	Y	Y	N	N

free hardware and software customization for various application scenarios, offering a higher degree of flexibility.

Hardware design

Design principles

The MMC should be implemented at least the following functions: controlling power on/off, and monitoring the temperature, voltage, and current of both the AMC and RTM boards. The core controller of the MMC module needs at least three I2C buses to communicate with monitoring devices on the MCHs, AMC boards, and RTM boards. In addition, the MTCA.4 standard has reduced the size of the board compared to the PCI/ISA standard of PICMG 1.0 and the CPCI standard of PICMG 2.0 to achieve high integration. Therefore, the MMC module should occupy as small board space as possible to reserve the largest space possible for functional modules, while keeping high signal quality and full functions. In our design, all core components of the MMC module will be limited to an area of 3 cm × 3 cm. Among the MicroTCA standard board sizes, including double-width/half-height, single-width/half-height, double-width/full-height, and single-width/full-height, the AMC board in this design adopts the single-width/full-height size to realize RTM management. The MMC module in this design can also be used for managing half-height AMC boards without RTM management requirements.

Chip selection

Due to the current limitation of the management power supply, most MMC solution uses NXP or Atmel's low- and medium-range MCUs. This design uses NXP's 32-bit embedded chip LPC1764 as the core controller for the MMC. The chip adopts the Cortex-M3 architecture, with 128kB of flash memory, 32kB of data storage, supports three sets of I2C buses, 8 channels of 12-bit ADC, and up to 70 general-purpose input and output pins. This chip is one of the commonly used chips for MMC modules and its functionality has been verified. The current management chip uses INA226 from TI, the I2C buffer uses PCA9547 from NXP, and the I/O expander of the RTM board uses PCA9554 from TI.

Circuit design

The circuit schematic of this MMC design is shown in Fig. 2, and its components and their functional implementation are as follows:

1. The MCU is the core controller of the management module, responsible for the overall control of the AMC board and communication with MCH via IPMB-L
2. The AMC power control is achieved by providing an enable signal to the TPS53126 power chip by the MMC. When the power module provides 12 V power to the AMC board, the MMC pulls up the ENABLE pin of the power chip, and the power chip converts the 12 V voltage into 3.3 V, 5 V and other voltages to provide power to the AMC functional modules
3. The voltage and current detection module mainly consist of the INA226 and current sensing resistors, which obtain voltage and current information by detecting the voltage across the resistor
4. I2C Buffer is a bidirectional buffer, and mainly used for the I2C communication between the AMC board and RTM backplane. It is also used for isolating the I2C bus of the RTM backplane from the I2C bus of the AMC board
5. The I/O expander is responsible for controlling the LED status lights and monitoring the hot-plug switch status of the RTM
6. A mechanical latch device is usually integrated on an AMC board used for the hot swapping. When the hot-swap switch is pushed in, the board is locked on the chassis and cannot be removed. State changing of the switch will change the voltage level of the general-purpose input/output (GPIO) pin of associated MCU or the I/O pin of the I/O expander. The MCU will send the 12 V

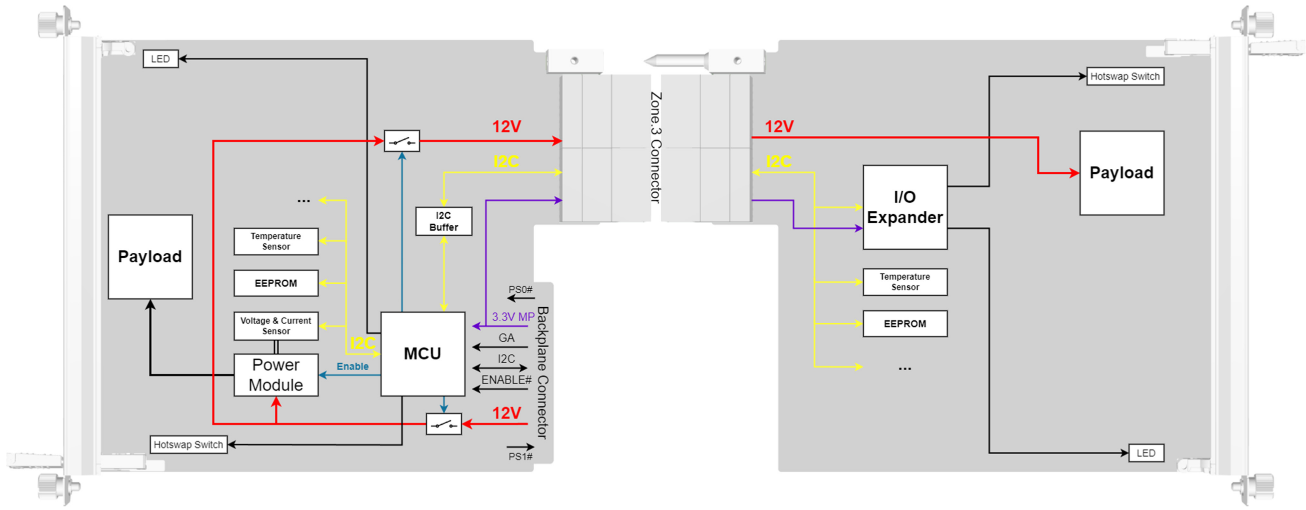


Fig. 2 Board logical block diagram

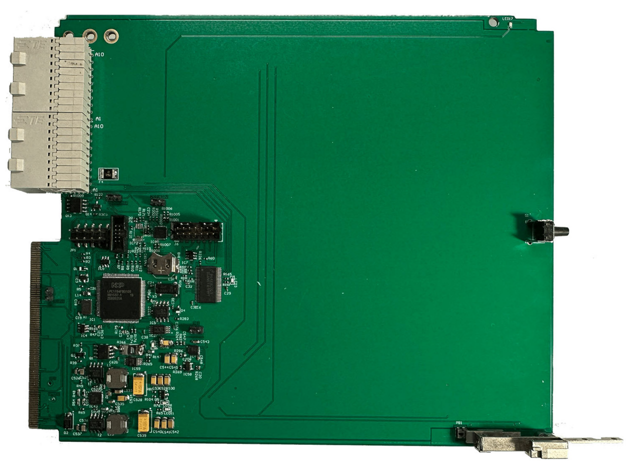


Fig. 3 Prototype board for MMC testing

main power supply on/off request according to the switch status

7. Both of the AMC board and the RTM board have 3 LED status lights: blue LED, red LED, green LED. The blue LED is the hot plug status indicator, and the red and green LEDs are the board status indicators
8. Electrically-Erasable Programmable Read-Only Memory (EEPROM) is used to store Field Replace Unit (FRU) information, including module name, serial number, manufacturer, etc.
9. The temperature sensor is used to monitor the temperature of key components on the board, and a warning signal will be issued when set limit is reached.

Several versions of prototype of testing board were developed and evolved. A fully functional version is shown in Fig. 3.

Module interface design

The AMC board has a 274-pin AMC connector and can be inserted into the interconnect backplane of the chassis. The management interface pins, including PS1# and PS0#, ENABLE#, GA [2...0], IPMB-L (including SCL and SDA), have the following functions:

1. PS1# and PS0# are the last paired pins connected to the AMC connector at both ends. They are used to detect whether the AMC module is properly plugged into the slot. When the AMC module is plugged into the backplane, the PS0# pin is connected to logic ground, and the PS1# pin is pulled up to 3.3 V management power through a resistor. PS1# is connected to PS0# via a diode. If the diode is conducting, PS1# will also be pulled down to a low level. If PS1# is low, power module will supply 3.3 V management power to the AMC module's MMC module and enabling the ENABLE# signal
2. ENABLE# is an active low input pin of the MMC module. When the MMC module is operating normally, the ENABLE# pin must remain at a low level. When the ENBALE# pin is invalid, the MMC module cannot read GA[2...0] and IPMB-L.
3. GA stands for Geographic Address. Each GA pin has three states: G (grounded), U (unconnected), and P (pulled up to Management Power). The GA[2...0] pins are used to determine which slot the AMC board is inserted into, based on which the module's address on the IPMB-L and communicate can be determined accordingly.
4. IPMB-L consists of a clock line SCL and a data line SDA, with which the I2C communication between the MMC module on the AMC board and the MCMC module on the MCH can be realized.

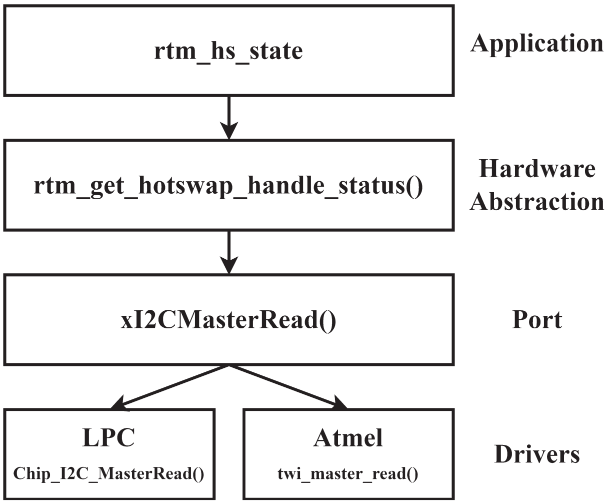


Fig. 4 Implementation of RTM hotswap function

Firmware design

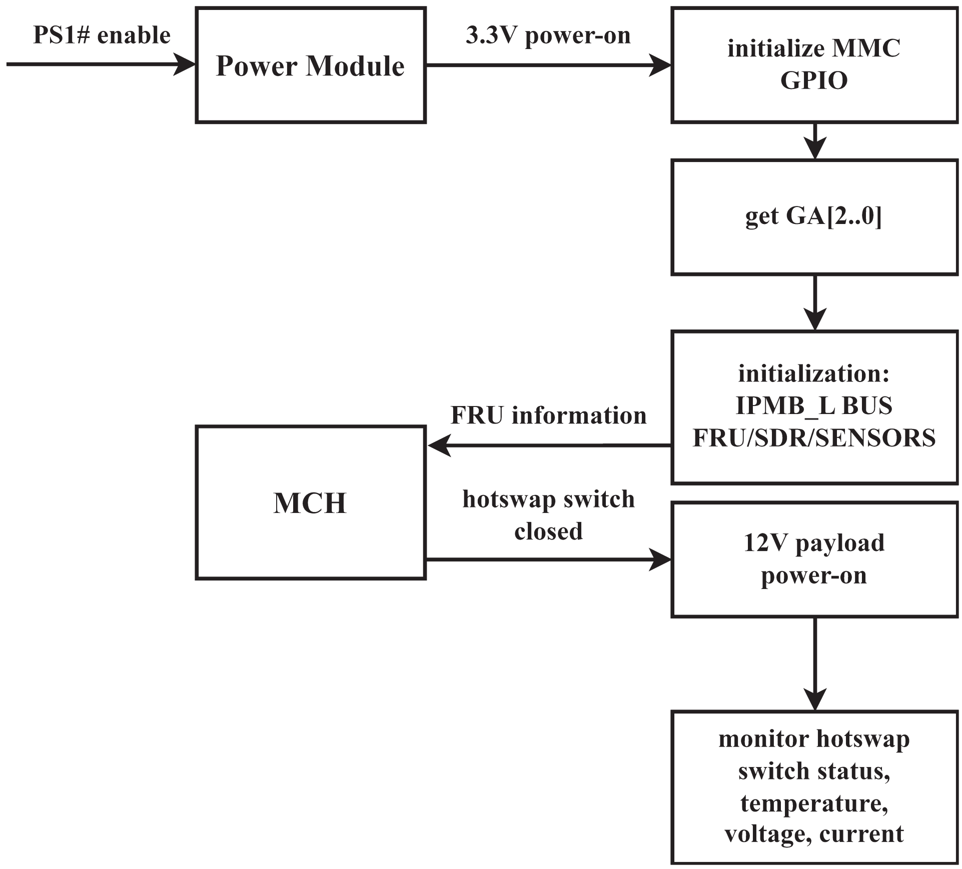
The MMC firmware mainly has two functions: power management and operation status monitoring. Both AMC and RTM boards have FRU information stored in their EEPROM. When a module is activated, the MCH sends a read command to corresponding MMC for reading the FRU information. The MMC responds the command by returning the FRU information. The MCH determines whether the power-on conditions are met based on the received information and takes appropriate actions. During normal operation, the MMC module continuously monitors the temperature, voltage, and current of the board. When either of the values exceed the set threshold, the MMC will send a warning message to the MCH.

The firmware for the MMC in this design was developed based on the openMMC architecture developed by the open-source project [10, 11] for easy portability to different boards and controllers. The firmware can be divided into four different layers: application, hardware abstraction, port, and drivers, as shown in Fig. 4. The application layer is the topmost layer. Most of its functions are implemented based on state machines. The application layer periodically checks the board status and updates the state machine status. For example, the state corresponding to RTM hot-plug is rtm_hs_state. When the RTM board meets the power-on condition, rtm_hs_state is set to 0, and then provides the RTM board with 12 V main power. The hardware abstraction layer is used to connect the application layer with specific ports. For example, the application layer monitors the hot-plug switch status and updates rtm_hs_state by calling the hardware abstraction function rtm_get_hotswap_handle_status. The port layer is used to connect the driver and the hardware abstraction layers, and defines common functions for driving different controllers. The upper layer program can call the common functions provided by this layer instead of directly calling the controller driver. For example, when it is necessary to read I2C bus host data to obtain hot-plug switch status information, the port function xI2CMasterRead is called. The driver is the bottom layer, and since the chip used in this design is LPC1764, the driver function Chip_I2C_MasterRead is used to read I2C bus host data. The firmware is programmed into the MCU using the LPCXpresso IDE software after it is fully developed and configured.

The management process of the MMC module during normal operation in this design is shown in Fig. 5. It also can be described as follows:

1. PS1# active: when the AMC board is inserted into the chassis, the diode between PS1# and PS0# conducts, and the voltage of PS1# drops to the low level to activate the power supply module to provide a 3.3 V management power for the board, and the MMC module starts
2. MCU pin initialization: the MMC initializes the MCU's GPIO pins, configures the GPIO input and output direction, and turns the power on to lit the LED status light
3. Read GA[2...0] status: GA0, GA1, and GA2 are all connected to another GPIO pin GA_TEST of the MCU through a resistor. GA_TEST is set to high and low in turns, and the status of GA0, GA1, and GA2 is read at the same time. If the status of a GA pin is high in both readings, it is defined as P. If the status of a GA pin is low in both readings, it is defined as G. If the status of a GA pin is high in one reading and low in the other, it is defined as U. By performing this test, the GA[2...0] status is determined
4. Initialize the IPMB-L BUS: based on the GA[2...0] status, the MMC determines the address of the MMC module's IPMB-L bus, and initializes the IPMB-L bus, FRU, SDR (Sensor Data Record), and SENSORS
5. Power on 12V: the MMC sends the board's FRU information to the MCH via the IPMB-L bus. If the FRU information is correct and the hot-swappable function is enabled, the MCH notifies the power supply module to provide the 12 V main power for the board, and the board starts normal operation. If there is an RTM board, and the compatibility check is passed and the hot-swappable function is enabled, the AMC board would provide 12 V main power for the RTM board
6. Status monitoring: during normal operation of the AMC board, the MMC module monitors the temperature, voltage, and current of the board. If the sensor readings exceed the thresholds, the MMC sends a warning message to the MCH via the IPMB-L bus. The MMC also monitors the status of the hot-swap function and controls power on/off.
7. Power off the 12 V power: when the MMC detects that the hot-swap function is pulled out, it notifies the MCH.

Fig. 5 Software function flow chart



The MCH then controls the board to turn off the power according to the FRU power-off process.

Test

In order to fully test the functions of the MMC, we conducted detailed testing on a digital IO board which contains the MMC module based on the design described above. The PCB circuit board is shown in Fig. 6. In the figure, the MMC management circuit locates in the area indicating by a red frame. This board includes 8 bi-directional digital IO interfaces and 2 pairs of optical signal input/output interfaces. It can be used to fanout clock, timing, and interlock signals to other digital boards through the backplane MLVDS link.

We built a testing platform using PowerBridge's chassis, N.A.T.'s power supply and MCH, as well as a Struck's RTM board. Detailed functional verification and stability testing were performed on firmware and hardware of this platform.

Function verification

First the hot swap handles for the AMC and RTM cards are closed and then pulled out; both cards can be powered on and off under the control of MMC. The hot-swap status LED

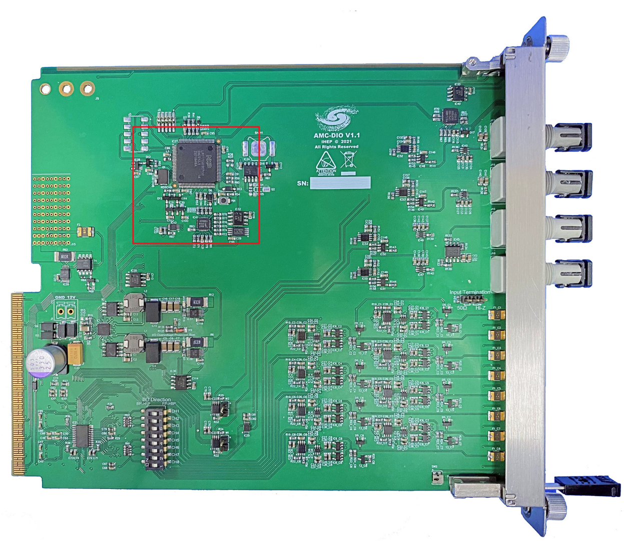


Fig. 6 DIO AMC board with MMC module

and card status LED correctly change with the hot-swapping status.

Then, the "show_fru" command of MCH [12] is used to obtain information on all FRU devices in the chassis, including MCH, MCMC, AMC cards, cooling unit modules CU, power modules PM, MCH clock modules, MCH PCIe switch

```
nat> show_fru

FRU Information:
----------------
 FRU  Device   State  Name
==========================================
  0   MCH       M4    NAT-MCH-CM
  3   mcmc1     M4    NAT-MCH-MCMC
  7   AMC3      M4    DIO AMC
 40   CU1       M4    Schroff uTCA CU
 50   PM1       M4    NAT-PM-AC600D
 60   Clock1    M4    MCH-Clock
 61   HubMod1   M4    MCH-PCIe
 64   MCH1-RTM  M4    MCH-RTM-ComEx
 92   AMC3-RTM  M4    DIO RTM
==========================================
nat>
```

Fig. 7 FRU information of system devices

modules, and RTM cards, as shown in Fig. 7, indicating the status of each component. The status "M4" indicates that the FRU has been activated. Command "show_fruinfo" can be used to obtain the FRU information for a specific device in the chassis, as shown in Fig. 8.

The AMC SDR is another important information. It has multiple formats:

1. "Full" represents the Full Sensor Record, which occupies 64 bytes space. The SDRs for voltage, current, and temperature are of this type
2. "Compact" represents the Compact Sensor Record. It occupies 48 bytes space. The SDR for hot-plug (HOTSWAP) is of this type
3. "MDevLoc" (Management Controller Device Locator Record) is used to identify management controllers on IPMB and other internal channels. The SDR for MMC is of this type.

The SDR information for the AMC and RTM boards can be obtained using the "show_sensorinfo" command. The SDR of AMC3 (device 7) and RTM3 (device 92) are shown in Figs. 9 and 10, respectively. As shown in the figures, the temperature and voltage monitoring functions of the AMC board and the temperature monitoring function of the RTM backplane work properly.

As the 12 V power supply of the RTM board is provided by the AMC board, only the voltage and current of the AMC board need to be monitored.

Fig. 8 FRU information of AMC (device 7)

```
nat> show_fruinfo 7
---------------------------------------
FRU Info for device 7:
---------------------------------------
Common Header    : 0x01 0x00 0x00 0x01 0x07 0x10 0x00 0xe7
---------------------------------------
Internal Use Area : -
---------------------------------------
Chassis Info Area : -
---------------------------------------
Board Info Area           : at offs=8, len=48
Manufacturer(05)          : IHEP
Board Name(08)            : AMC-DIO
Serial Number(10)         : SN:000000
Part Number(04)           : DIO
FRU file ID(08)           : DIO-FRU
---------------------------------------
Product Info Area         : at offs=56, len=72
Manufacturer(05)          : IHEP
Product Name(08)          : AMC DIO
Product Number(08)        : DIO:1.0
Part Version(04)          : 1.0
Product Serial Number(10): SN:000000
Asset Tag(12)             : Generic FRU
FRU file ID(08)           : DIO-FRU
---------------------------------------
Multi Record Area  : at offs=128

Record(0): Type ID=0xc0, PICMG Record ID=0x16, offset=0x000, len=11
Module Current Requirements Record:
    Current Draw: 4.0 A
```

Fig. 9 AMC SDR information (device 7)

```
nat> show_sensorinfo 7
Sensor Information for FRU 7 / AMC3
==================================================================
 #   SDRType  Sensor Entity Inst  Value   State    Name
------------------------------------------------------------------
 -   MDevLoc         0xc1   0x63                    DIO AMC
 1   Compact  0xf2   0xc1   0x63  0x01              HOTSWAP AMC
 2   Full     Voltage 0xc1  0x63  3.28 V   ok       AMC +3.3V
 3   Full     Voltage 0xc1  0x63  5.04 V   ok       AMC +5.0V
 4   Full     Voltage 0xc1  0x63  0.00 V   <=lnr    RTM +12V
 5   Full     Temp   0xc1   0x63  30.5 C   ok       TEMP 1
 6   Full     Temp   0xc1   0x63  33.0 C   ok       TEMP 2
 7   Full     Temp   0xc1   0x63  30.5 C   ok       TEMP 3
 8   Full     Temp   0xc1   0x63  31.0 C   ok       TEMP 4
 9   Compact  0xf0   0xc1   0x63  0x10              HS 007 AMC3
------------------------------------------------------------------
nat>
```

Fig. 10 RTM SDR information (device 92)

```
nat> show_sensorinfo 92
Sensor Information for FRU 92 / RTM3
==================================================================
  #   SDRType  Sensor Entity Inst  Value   State    Name
------------------------------------------------------------------
  -   FDevLoc         0xc0   0x61                   DIO RTM
 32   Full     0xf2   0xc0   0x61  0xa1             RTM Hot Swap
 33   Compact  0x0b   0xc0   0x61  0x00             0x00  RTM_ID_123456789
 34   Full     Temp   0xc0   0x61  31.5 C    ok     Temp 1
 35   Compact  0xf0   0xc0   0x61  0x10             HS 090 RTM3
------------------------------------------------------------------
nat>
```

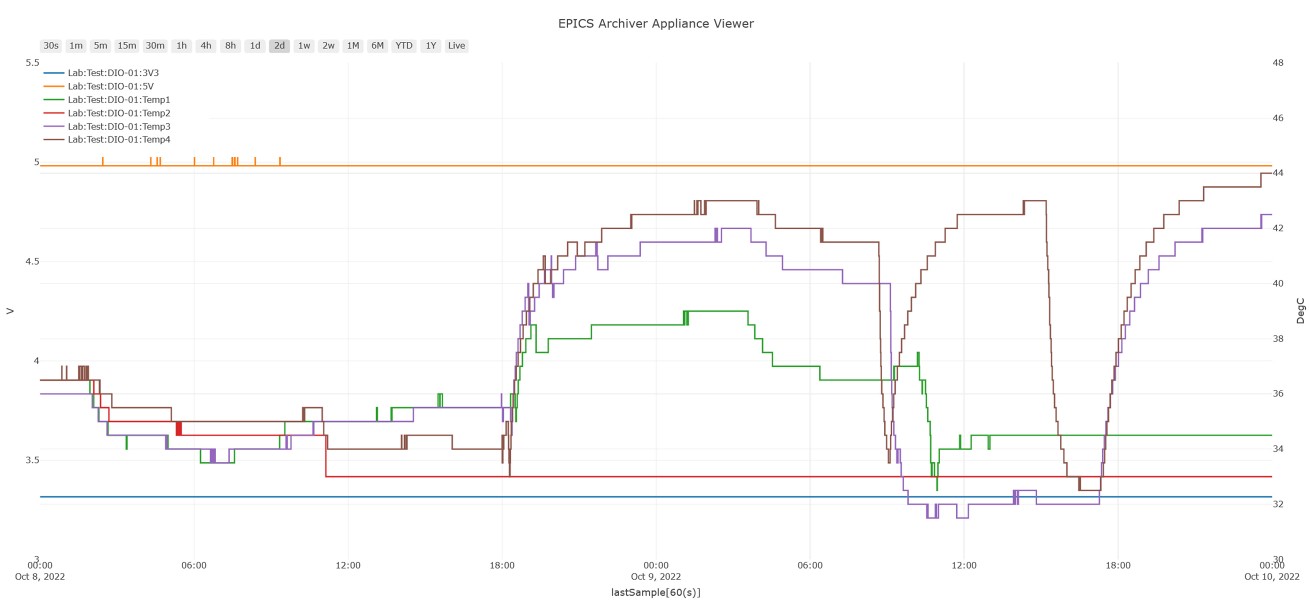


Fig. 11 AMC board voltage and temperature in 48 h

Stability test

To verify the stability and reliability of the MMC module, an EPICS IOC program was developed to monitor long-term sensor data. The IOC program communicates with the MCH via an Ethernet interface using the EPICS AsynDriver. The program sends IPMI message requests and then receives and parses the received IPMI messages to obtain chassis device sensor data and FRU information. The parsed FRU information is stored in corresponding records. High-level clients can exchange data through the channel access (CA) or PV access (PVA) protocols. The EPICS Archiver Appliance is used to archive the values of these records for further analysis, diagnosis and troubleshooting. Figure 11 shows the 48 h of board temperature and voltage information stored in the archiver database. It can be seen that the MMC sensor acquisition and data communication are stable.

Summary

This paper introduces a self-developed MMC management module. This MMC module can be directly applied to the research and development of MTCA.4 standard AMC and RTM boards. The core component of the MMC module is limited into 3 cm × 3 cm of area on the AMC board, leaving a large free space for subsequent development. Detailed testing shows that the main functions of the MMC have been fully implemented and can operate stably and reliably. The MMC has been applied to a digital IO board and has been running steadily on the HEPS linac for 1 year. In the future, the MMC can be designed in the form of a sub-board for plug-and-play use, improving the scalability.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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