MicroTCA.4 AT SIRIUS AND A CLOSER LOOK INTO THE COMMUNITY

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Abstract

More and more facilities have been adopting MicroTCA.4 as the standard for new electronics. Despite the advertised advantages in terms of system manageability, high availability, backplane performance and supply of high quality COTS modules by industry, the standard still lacks a greater acceptance in the accelerators community. This paper reports on the deployment of MicroTCA.4 systems at Sirius light source, which comprised the development and manufacturing of several open hardware modules, development of a generic gateware/software framework and re-implementation of MMC IPMI firmware as an open source project. A special focus will be given to the difficulties found, unforeseen expansions of the system and general architectural aspects. Based on this experience and on a survey carried out among other MicroTCA.4 adopters, the perceived strengths and weaknesses of the standard will be discussed and a tentative outlook on how it could be evolved to better suit the accelerators community will be presented.

INTRODUCTION

The debate around the adoption of an unified electronics standard for particle accelerators and physics experiments can be traced back to the early days of the International Linear Collider (ILC) project, around 2004 [1]. Taking as reference the successful cases of NIM, CAMAC, FASTBUS and VME standards in the past electronics generations, the ILC collaboration sought to establish a new standard for the years to come, trying to solve not only the pressing issue of the slow parallel buses, but also paving the way to meet the very stringent ILC requirements of communication bandwidth, high availability and remote hardware management [2,3]. After a search among the emerging standards, the collaboration chose PICMG Advanced Telecommunications Computing Architecture (ATCA) as the most promising standard. A series of ATCA workshops and meetings among SLAC, DESY, FNAL, ANL and KEK culminated in a series of technology demonstrations for the ILC, later on joined by other laboratories such as CERN, IHEP, IN2P3, ESS-Bilbao, IPFN, ITER for interests beyond the international collider. In 2009 a PICMG working group called "xTCA for Physics" was formed by several laboratories and companies aiming at extending ATCA and its downscaled version, MicroTCA, for particle accelerators, large HEP detectors and fusion experiments. Those efforts were presented in the upcoming years [4].

As the host of the TESLA Test Facility (TTF) international collaboration, which played a key role in demonstrating the superconducting RF technology required for the ILC, and urged to build superconducting FEL facilities as both light source facilities and demonstrators of the ILC technologies, DESY soon took a prominent role in the development of ATCA and MicroTCA standard extensions for physics. An evaluation campaign for both standards was launched around 2007 [5] and reported on 2009 [6, 7], with ATCA-based LLRF demonstration and an AMC timing receiver developed in collaboration with the University of Stockholm. In the following years MicroTCA.4 was fully embraced by FLASH and European XFEL projects. More recently, an R&D and technology transfer center has been established, the MicroTCA Technology Lab [8].

CURRENT STATUS

The latest revision of the MicroTCA standard was released on November 2016, MicroTCA.4.1, extending the MicroTCA.4 standard to include auxiliary backplanes, Rear Power Modules (RPMs), MCH-RTM, protective board covers and application classes of RTMs, the later being the ratification of DESY's Zone 3 Connector Pin Assignment Recommendation.

A prominent example of commercially available auxiliary backplane is the RF backplane [9], which was designed by the Institute of Electronic Systems of the Warsaw University of Technology (WUT-ISE) for the European XFEL. It integrates high quality LO signal, clock and interlocks distribution for RTM modules to the crate. The RF backplane has become commonplace in the latest LLRF designs.

In 2017 PICMG released a set of 4 guidelines formulated by the PICMG Software Working Group (SWG) composed of laboratories and industry representatives [10] aiming at the standardization of software interfaces and procedures:

- **SHPP**: hot plug procedure for uninterruptible replacement of modules [11].
- **SHAPI**: common API for configuration and data readout of addressable register-based devices [12].
- **SPM**: platform-agnostic low-level software interfaces, such as thread-scheduling, inter-thread communication, thread synchronization and timing services [13].
- **SDM**: platform-agnostic access to external devices [14].

An effort to provide EPICS use cases following the above guidelines is being treated by the SWG, but have evolved in slow pace. Another software development that is worth mentioning is the universal PCIe driver available as a common ground for general PCIe functionalities and kept up to date with the SHAPI standard [15].

A mature, although small, ecosystem of companies providing COTS MTCA.4 infrastructure modules (*e.g.* crates, CPUs, MCHs, power modules) and payload AMC and RTM modules (*e.g.* picoammeters, high voltage source, fast digitizers, frequency converters, CAN interfaces, scaler/discriminator, Ethernet switches, piezo driver) exist.

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Some companies frequently supplying the particle accelerators market are: CAENels, Candox, Concurrent Technologies, Creotech, D-TACQ, ELMA, esd, IOxOS, Mitsubishi TOKKI, N.A.T., PowerBridge, Struck, Teledyne SP Devices, Pentair/Schroff, TEWS, Wiener and Vadatech.

A wide breadth of accelerator timing system options in AMC form factor does exist: E-XFEL timing, MRF EVG and EVR, Instrumentation Technologies MRF-compliant ExRx, White Rabbit on open hardware AMC FMC Carriers (AFC, AFCK, AFCZ) and FAIR timing module (FTRN-AMC). Moreover, there are commercial options for White Rabbit on MCH clock tongue [16] and on RF backplane eRTM slots 14 and 15 [17] with distributed DDS functionality. SINAP timing integration has also been demonstrated [18].

MTCA.4 AT SIRIUS

At Sirius, the 4th generation synchrotron light source being commissioned in Brazil, 21 MicroTCA.4 crates were deployed for the Beam Position Monitors (BPMs) system (Fig. 1), and only one crate is in use for the Linac LLRF systems of a 500 MHz cavity and 3 GHz accelerating structures. The former followed an open hardware/open source approach [19]. More details about the development, manufacturing and deployment processes can be found in [20]. The later delivered as part of the turnkey Linac provided by SINAP.

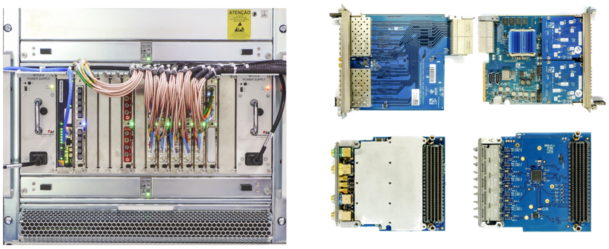

Figure 1: Sirius BPM and Orbit Feedback MicroTCA.4 crate on the left and open hardware designs developed or funded by LNLS on the right.

Hardware Platform Selection

The decision to adopt MicroTCA.4 for Sirius BPM electronics and Fast Orbit Feedback (FOFB) was taken on April 2012, only 6 months after the official release of the standard by PICMG. Besides covering the Sirius use cases in terms of architecture and performance, the selection of MicroTCA.4 aimed at following the main trend of electronic standards in the accelerators community, thus opening up possibilities of collaboration and design reuse among other institutes. For that reason, other standards such as cPCI, PXIe and SHB Express, with larger product portfolio at that time but not widely adopted in the Beam Diagnostics community, were rejected in the early stages of the selection process. ATCA and openVPX were considered expensive and not widely disseminated in the community as well. The main contender paradigm was the Network-Attached Device (NAD), also known as "pizza box" or standalone electronics. However, in that point in time the NAD approach raised several concerns in terms of risks for long term support, hardware design effort and low potential for future collaborations.

Although adopting the recently introduced MicroTCA.4 standard, which featured rear transition modules (RTM) for I/Os, it had been decided to build an AMC FMC Carrier and use fast ADCs in FMC form factor instead of RTM, since a large FMC portfolio was already abundant and rapidly expanding, with designs available at the CERN Open Hardware Repository and products comprehensively offered by the military, aerospace and telecom industries. Additionally, the number of pins on RTM connectors were not sufficient to interface 8 parallel-interface 16-bit ADCs.

As the project evolved, the selection of standards and the chosen architecture have shown great advantages but also major drawbacks. The following sections details those consequences to the project.

Successes

LNLS Beam Diagnostics group sought reusable, affordable and collaborative modules that could satisfy the BPM and FOFB requirements. In the absence of such modules at the time, LNLS initially funded two open hardware designs: a generic, low-cost, AMC FMC Carrier, AFC, and a fast digitizer FMC module, FMC ADC 16-bit 130 MS/s [19], later moved to a 250 MS/s version. Both were designed by LNLS and WUT-ISE and envisioned to maximize the cost-performance trade-off, in the sense that these boards could be manufactured and used by other institutes in high board count applications.

The modular and standardized design, brought by the use of a generic AMC carrier board and FMC modules, allowed LNLS to achieve a flexible, yet highly-integrated solution inside a single crate. The BPMs of a full Sirius sector can be digitized, beam-synchronized and processed with 9 slots for up to 4 X-Ray BPMs, 14 RF BPM electronics (Booster and Storage Ring), 1 slot for FOFB Controller and 1 slot for a timing receiver, all slots employing the AFC as FPGA board.

The COTS MTCA.4 infrastructure, i.e. crate and MCH, CPU, JSM and power supply modules, provided by N.A.T. and Wiener, proved to be high quality in terms of hardware. Most of the issues fell into the management software side, as described in the next sections.

A point-to-point full mesh (11-slot) topology was adopted in the backplane, as customized by Pentair/Schroff. Since no MCH redundancy or SATA usage was envisaged, Fat Pipe 2 and SATA links were used in conjonction with the p2p links to implement the mesh.

Mistakes

As previously mentioned, the analog RFFE was chosen to be a separate analog box, shielded, and connected to AMC-FMC digitizer via RF cables. The consequences of that decision led to a high density on RF cabling at the front of the MTCA.4 crate (8 RG316 cables per AMC board), leading to difficulties in replacing AMC boards, increasing maintenance and rack assembling costs. Moreover, many RTM slots were left unused and the RFFE boxes needed separate management and communication infrastructure as it cannot benefit from the MTCA.4 capabilities.

Struggles

Along the development phase, many interoperability issues between different modules (e.g. MCH, CPU, crate, power supply, fan tray) have been encountered, especially in the early stages, when modules from more diverse vendors were mixed [21]. After struggling with different crate setups, LNLS decided to chose a typical MTCA.4 setup employed in many other facilities to minimize compatibility risks. This approach, although effective as workaround, does not contribute to achieve true reusability of modules from different vendors.

Today, interoperability issues still exist. For instance, power supplies hot swap operates reliably most of the time, but can lead to unexpected behaviors in some cases. Moreover, not in rare occasions, the MCH would not power up all of the AMC cards on initialization or, sometimes, would stop responding remote commands (*e.g.* SSH, telnet), leading to a lack of confidence in the overall system.

Other issues, like no standard FPGA upgrade method via JSM module, for instance, brings an extra development effort to the users that could be better integrated into the existing MTCA solutions.

Lastly, mechanical insertion and removal of AMC cards can be extremely difficult at times, especially for the case of a 4-tongue MCH module.

ADOPTION IN ACCELERATORS

Since the ratification of MicroTCA.4 standard in 2009, many accelerator or laser facilities have adopted the standard for new projects. A non-exhaustive listing is shown in Table 1. Other proof-of-concept setups or evaluation test benches are also present in other facilities and research groups, for instance Soleil [22] and NSRRC. Additionally, TARLA and NICA have procured turnkey LLRF system directly from the MicroTCA Technology Lab [23].

Not shown in the table but known to be developing MicroTCA.4-based applications are: GANIL (Spiral2) and HZB (bERLinPro, BESSY II) [24].

MicroTCA.4 has also been employed in High Energy Physics (HEP) [25] experiments such as CMS (LHC), CBM (FAIR) [26], PANDA (FAIR) [27], IHEP [28], DUNE Dual-Phase Detector, CANDLES experiment [29], STEREO (IN2P3) [30], MCORD (NICA) [31], Recycler Collimator (Fermilab) [32] and NIKA2 (IN2P3) [33], as well as in fusion experiments such as Wedelstein X-7 (Max Planck IPP) [34] and KSTAR (NFRI) [35].

COLLABORATION

There are plenty of opportunities for collaboration and synergies inside the accelerators MicroTCA.4 community. However, the authors consider the Module Management Controller (MMC) firmware development as being the most relevant contribution to encourage more widespread adoption of the standard at the present state of evolution of the MicroTCA.4 ecosystem. For brevity, only the MMC firmware implementation will be discussed herein.

MMC Firmware Implementations

Despite having a strict set of rules defined in the IPMI standard, many MMC implementations co-exist across the community and in industry with incompatible behaviors. The lack of a common MMC firmware implementation in the early stages of the MicroTCA.4 standard has pushed many vendors and developers to implement their own designs. This contributed to various compatibility issues between vendors and in-house developed boards, diminishing reuse and restricting users to a set of known interoperable modules. To help tackle this problem, some MMC implementations have been thought with modularity in mind, such that its codebase could be extended to support other vendors and corner cases without major efforts. Some examples of such projects developed at DESY, CERN and LNLS are briefly described below.

DESY Developed in collaboration with TUL-DMCS [36], DESY MMC v1.00 features a hardware design alongside a firmware implementation aiming to be a simple drop-in solution for AMC boards. This was one of the first projects to be compliant with the MTCA.4 standard and supporting RTM board management. It is used in many industry-provided AMCs as well as in FRIB under DESY licensing agreements.

CERN The CERN MMC implementation was based on early code provided by DESY and evolved separately in collaboration with CPPM (Centre de Physique des Particules de Marseille) [37]. It has a similar approach to the original project in the sense that it also features a small drop-in board as hardware solution, but differs on the licensing model, as adopting GPL. The firmware was originally developed for Atmel ATMega128L and later ported to AT32UC3A3256 controller in order to be used in CMS (LHC) AMC modules.

LNLS - openMMC The openMMC firmware was designed to be a simple MMC solution that could be readily ported to different hardware setups [38]. Being hardware-agnostic, its implementation suits either AMC hardware projects at design phase or an existing hardware. The firmware project was initiated by LNLS as an open source design, with the ambition of being the basis for future implementations. To date, CERN CO group is the only that has reported is reusing openMMC outside LNLS and contributing back to the project.

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Table 1: MTCA.4 projects on accelerator facilities (non-exhaustive list). a) LLRF, b) BPM Electronics, c) BAM Electronics, d) Beam Diagnostics (other than BPM and BAM Electronics), e) Synchronization/Timing, f) Machine Protection, g) Feedback Control, h) Image Processing, i) Experiment Control, j) Massive Data Processing.

Facility	**Location**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**Number of Crates**
DESY (E-XFEL, FLASH) [39]	Germany	x	x	x	x	x	x	x	x	x	x	200+
ESS [40, 41]	Sweden	x	x	-	x	x	x	-	-	-	-	101-200
ORNL (SNS) [42]	USA	x	-	-	-	-	x	x	-	-	x	101-200
GSI (FAIR) [43]	Germany	x	x	-	x	x	-	x	x	x	-	51-100
Spring-8/SACLA [44, 45]	Japan	x	x	-	x	x	-	x	-	-	-	51-100
CERN (SPS) [46]	Switzerland	x	-	-	-	x	-	x	-	x	-	21-50
FRIB [47]	USA	-	x	-	x	x	x	-	-	-	-	21-50
LNLS (Sirius) [20]	Brazil	x	x	-	-	x	-	x	-	-	-	21-50
APS-U [48]	USA	x	-	-	x	-	-	x	-	-	-	21-50
IHEP (HEPS)	China	x	-	-	-	x	x	-	-	-	-	21-50
ELI Beamlines [49]	Czech Republic	-	-	-	-	x	-	-	-	x	-	21-50
PAL (PAL-XFEL)	South Korea	-	x	-	-	-	-	-	-	-	-	21-50
CSNS (IHEP)	China	x	-	-	-	-	-	-	-	-	-	11-20
Diamond [50]	UK	x	-	-	x	-	-	x	-	-	-	6-10
KEK (SuperKEKB, STF-2) [51]	Japan	x	x	-	-	-	-	-	-	-	-	6-10
SINAP (SXFEL, SHINE) [52]	China	x	-	-	-	-	-	-	-	-	-	6-10
KIT (FLUTE) [53]	Germany	x	x	-	x	x	-	x	-	x	-	1-5
CANDLE [54]	Armenia	x	-	-	x	x	-	-	-	-	-	1-5
Soleil	France	x	-	-	-	-	-	-	x	x	-	1-5
USTC (HLS-II)	China	x	x	-	-	-	-	-	-	-	-	1-5
HZDR (ELBE) [55]	Germany	x	-	-	-	x	-	-	-	-	-	1-5
ANSTO (AS) [56]	Australia	-	-	-	-	-	x	-	-	-	-	1-5
Elettra	Italy	-	-	-	-	-	-	x	-	-	-	1-5
ESRF	France	-	-	-	-	-	-	x	-	-	-	1-5
IMP/CAS (ADS) [57]	China	x	-	-	-	-	-	-	-	-	-	1-5
J-PARC [58]	Japan	x	-	-	-	-	-	-	-	-	-	1-5
JGU (MESA [59])	Germany	x	-	-	-	-	-	-	-	-	-	1-5

TRENDS FOR BEAM DIAGNOSTICS

BPM Electronics

MicroTCA.4 was born targeting a wide range of frequencies for analog signals processing and digitizing, from DC to a few GHz. With the extension of an auxiliary backplane in the MicroTCA.4.1 revision, clean LO and reference clock signals as required in analog down- and upconversion were made available. All of these building blocks make it possible to implement BPM electronics in a very compact crate setup.

Different design approaches were taken across the community. For instance, PAL-XFEL designed a custom RTM BPM in partnership with SLAC [60], used in conjunction with Struck SIS8300 AMC digitizer. A similar approach was followed by DESY for FLASH low charge BPMs, for which a custom RTM BPM electronics was designed [61]. Spring-8 and HEPS have adopted the same architecture using analog AMCs, but having designed in-house both AMC and RTM modules.

FRIB took a different path and leveraged the digital AMC FPGA board already designed for LLRF and machine protection systems and designed an RTM fast digitizer.

At Sirius (LNLS) [20] and CRYRING (GSI) [43] a third approach was taken: instead of RTM analog front-ends or digitizers such as the typical use case of MicroTCA.4, FMC ADC boards were used in AMC FMC carriers. Signal conditioning electronics resides outside the crate, in dedicated enclosures.

ESS BPM electronics design employed both COTS AMC digitizer and RTM down-conversion electronics. All BPM-specific analog signal conditioning is done in a separate electronics outside the crate [62].

Libera Brilliance+ (I-Tech) uses a distinct approach from all others by placing all analog and FPGA digital processing for one BPM in one single AMC. The AMC module is MicroTCA.0-compliant only, since the hardware architecture was decided before the release of MicroTCA.4. Customization to make a MTCA.4 AMC module would be possible but so far no request has been made by clients [63].

Multibunch Feedback

A turn-key MTCA.4-based solution for multibunch feedback systems have been developed by Diamond, the Diamond Multibunch Feedback (DLS-MBF) [50], and is currently being deployed at BESSY II, ESRF and Elettra. It makes use of available COTS modules on the market: Vadatech AMC525, Innovative Integration FMC-500 and Open Hardware FMC-DIO-5chttl. Each set of those 3 modules is able to process 2 beam planes (*e.g.* horizontal, vertical and/or longitudinal).

Fast Synchrotron Radiation Monitors

An ever increasing demand for fast beam profile monitoring in accelerators makes the usage of bulk image processing embedded on FPGAs or MPSoCs an appealing case for MicroTCA.4, especially for those applications requiring feedback control for some beam parameters such as coupling and transverse size. Besides the full integration with the accelerator's control and timing systems, it can leverage existing COTS FPGA modules providing direct connectivity to Camera Link, 1 GbE or emerging 10 GbE cameras.

Although the hardware modules are all commercially available and ready for this solution, no out-of-the-box solution do exist in the accelerators community to enable complete system integration. At present, the MicroTCA Tech Lab carries out R&D work to make a GigE Vision interface and processing solution available to be licensed for companies and laboratories under DESY terms.

In the accelerators community it is possible to find experimentations of direct integration of camera systems to the MTCA.4 platform at the European XFEL, Spring-8 [64] and FAIR [43].

Digitization-based Diagnostics

It is fair to say that the most mature application on MTCA.4 today is the digitization, synthesis and frequency conversion of RF signals, which can be directly explored by LLRF and RF BPM designs. Many of these modules comes from the European XFEL LLRF designs which have been licensed to industry. In some cases, such as at FRIB, the same RF digitizer can be combined with a standalone trans-impedance amplifier to serve as readout system for AC current transformers. For wideband digitization, bandwidths up to 3 GHz are readily available. For narrowband signals with bandwidths below 100 MHz, frequency conversion covering the range from 350 MHz to 6 GHz is also readily available. Some examples of modules are: Struck SIS8300, DWC8300 and DS8VM1, SIS8900, DWC8VM1 product families, SP Devices ADQ7DC and esd AMC-ADIO24. A variety of AMC FMC carriers are available, for instance CAENels DAMC-FMC20 and DAMC-FMC25, Struck SIS8160, IOxOS IFC_1410 and IFC_1420, Vadatech AMC560 and AMC580, Open Hardware AFC and AFCK. Combined with a large number of FMC modules available in industry or open hardware designs, they can vastly expand the options for digitization.

Having these hardware building blocks available it is possible to cover diagnostics readout systems such as current transformers, filling pattern monitors and faraday cups.

Other applications requiring the direct digitization of low currents, at bandwidths ranging from DC up to 300 kHz, can make use of readily available modules on the market, such as the CAENels FMC-Pico-1M4. In conjunction with a AMC FMC carrier it can cover applications such as blade-, diamond- or photodiode-based photon BPMs and ion chambers-based diagnostics. Such use is made at Sirius (blade XBPMs), FRIB (BLMs and profile monitors) and ESS (APTM-GRID and Ion Chamber BLMs). A high voltage AMC module is also available for those applications requiring a bias voltage, the CAENels HV-PANDA, and is in use at FRIB.

Motion-based Diagnostics

As a spin-off of the European XFEL, direct integration of motor (DFMC-MD22, FMC form factor) and piezo (DRTM-PZT4, RTM form factor) drivers are also available for those diagnostics requiring motion solutions, such as screen monitors, wire scanners, slits, scrapers, collimators, BAMs and laser synchronization.

Particle Detectors

Limited options exist for COTS particle detector building blocks. The only published use of MTCA.4 in accelerators for this purpose to the present date is GSI's combination of Struck SIS8800 Scaler AMC and SIS8980 Discriminator RTM used for beam loss detectors and plastics scintillators [43]. COTS Open Hardware FMC TDC 1ns 5cha module can also find applications for bunch purity monitors.

SURVEY

In order to evaluate the reach of MicroTCA.4 adoption in particle accelerators and look for shared impressions and challenges among the institutes, a survey was carried out in the community. In total 26 facilities answered a questionnaire collecting objective facts as well as opinions concerning their experience with MicroTCA.4. Table 1 summarizes the projects currently employing MicroTCA.4 at the facilities who participated in the survey and a size estimate of the installations measured by the number of crates deployed or to be deployed.

Besides the 10 classes of projects presented to the respondents, some specific usages were mentioned by the users: laser, klystron, magnets, vacuum, kicker, transverse deflecting system and spectrometer controls (DESY), RF phase and power monitoring (Australian Synchrotron), injection kicker magnet waveform monitoring (ORNL), and experiment data acquisition (ELI Beamlines).

In addition, two opinion-based questions were made, as literally transcripted below:

- *"What are the perceived strengths of MicroTCA.4 for your use cases?" (pros)*
- *"What are the perceived downsides and flaws of the MicroTCA.4 standard and "ecosystem"?" (cons)*

By extracting the pieces of meaningful information from each answer, a total of 158 sentences were made available for analysis. By manual classification of each of those sentences in a few topics, the chart depicted in Fig. 2 was obtained.

The presented data is ordered according to the topics which are mentioned the most, either positively or negatively. The following section discusses each topic in detail.

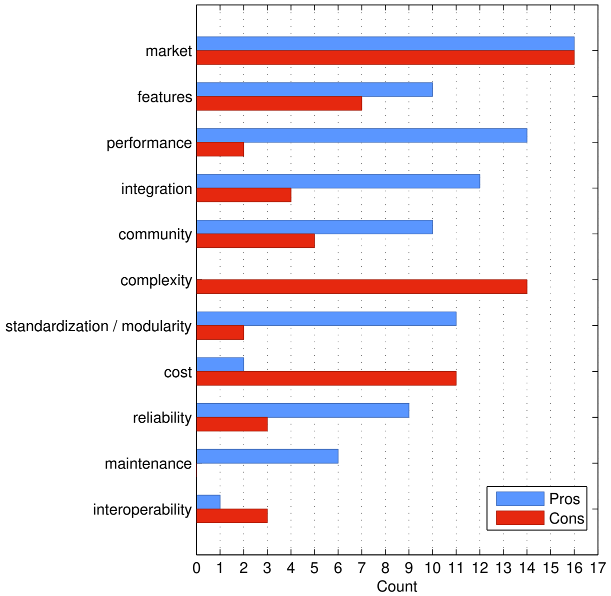

Figure 2: Clustering of opinions of MicroTCA.4 users in the accelerators community.

Perceived Strengths, Downsides and Flaws

Market The main point raised by the survey participants concerns the market of available MTCA.4 products, more specifically its size, quality and diversity of COTS modules, technical support and documentation, long-term sustainability, and price risk for the parts provided by a single vendor. For most of those topics, pros and cons are presented in roughly the same proportion.

Features In general, most of the features provided by the standard satisfies the users, such as RTMs, Fat pipes, RF backplane, point-to-point links and E-keying. However, the lack of star or mesh backplane topologies, PCB sizes and mechanical weaknesses of the standard are pointed by some users, with a prevalence of the later, which can be traced to the excessive force to insert and remove AMC modules to the crate.

Integration Integration is the third most relevant subject of the survey. In general, the compact hardware solution provided by MicroTCA.4 by putting timing, fast point-to-point serial links, analog I/O, networking and RF infrastructure integrated to the crate in high channel density is seen as a positive point for most users. The negative counterpart comes from the lack of a universal solution for software and FPGA frameworks to support the development of applications.

Performance The performance of MTCA.4 is praised by the majority of users. The high data bandwidth, high processing power and good analog signal quality are mentioned 14 times, whilst only 2 occurrences bring the limitation of PCIe bandwidth for massive camera interface and slow speed of FPGA configuration over JSM module to attention.

Community Many users are positively impressed by the number of laboratories adopting MicroTCA.4 around the world and have expectations that this will lead to possibilities of collaboration and design reuse. On the other hand, the lack of open source solutions was mentioned 4 times and the high and harmful diversity of MMC projects was mentioned by one user.

Cost From the 13 users mentioning cost in this survey, 11 considers it high, although 3 remark this is the case for sparsely populated crates. 2 users see cost as an advantage, especially when the price per channel ration is taken into account.

Complexity The greatest consensus for downsides of MTCA.4 is complexity. Several users report difficulties to develop applications on top of the platform due to complicated MMC, MCH and steep learning curve of MTCA.4-specific features as well as having FPGA programming as entry level for developers.

Standardization / Modularity Most of the users are satisfied with the maturity and quality of the standard as well as the way the defined interfaces enables modularity and brings flexibility to the platform. Two divergent opinions warns to the fact the standard is still emerging and vendors have different opinion on which directions to evolve.

Reliability The overall evaluation of reliability is positive, with redundancy being sparsely mentioned. One user praises the solid engineering for low MTBF and a second one reports a 1.5 years period without failures in his RF monitoring system. On the other hand an assertive comments tells "the promised fail safe self management by the MCH does not always work and e.g. modules can not be put into defined states anymore without a hard system reboot", which is followed by a report of instabilities and overadvertised MCH and CPU redundancy.

Maintenance For the surveyed opinions, maintenance is a topic for which MicroTCA.4 has a positive consensus. Some of the standard's features, such as hot swap, remote hardware management and serviceability are mentioned as positive points.

Interoperability Interoperability issues are mentioned 3 times referring to incompatibilities among vendors. In one occurrence, the interoperability among modules is seen as an advantage.

A total of 3 users have declared they do not see any downside or flaw in MicroTCA.4 so far.

THE COMPETITOR PARADIGM

Some facilities have moved away from ATCA and MicroTCA as standard for new electronics. A few see more advantages to adhere to other standards such as openVPX [65], CompactPCI, PXIe or single board computers, for reasons ranging from availability of diverse COTS modules, prices of hardware and development gateware and software environments available. Many others maintain VME and VXS as long as no major upgrade is planned.

However, the major divide in terms of control and data acquisition hardware platform resides in the interfaces to be standardized. Encouraged by the increasing CPU processing power being pushed to the FPGA and SoC side, many facilities choose Ethernet as the sole hardware interface to comply with. The devices following this approach are called "Network-Attached Devices" (NADs). Lately, many designers of such systems have adopted FMC as standard for I/O extension, although this is not as a strong consensus as Ethernet connectivity. A short list of recent NAD implementations is given below:

- DAnCE (ESRF) [66].
- DBPM3 (PSI) [67].
- Elettra BPM Platform (Elettra) [68].
- Marble (LBNL) [69]
- Panda box (Soleil and Diamond) [70].
- SINAP BPM platform [71].
- zDFE (BNL) [72].

In the design of NADs the hardware designers have to provide the "services" that a crate standard such as MTCA.4's already provides, for instance, enclosure mechanics, power supply, cooling, timing interfaces, high-bandwidth communication among boards and remote hardware management by their own. Conversely, no constraints are present to the designer, which can be a decisive point for both edges of performance and hardware cost.

SUMMARY

MicroTCA.4 is majorly seen by its adopters in the particle accelerators community as a high performance and feature-rich standard providing high integration in compact crates. It is also consentually regarded as costly and difficult to develop for. On average, the existing market of COTS hardware modules, many of which directly derived from the accelerators community, is not considered fully mature, however points towards an increasing adoption by new projects. A fairly uniform LLRF architecture is adopted across several institutes and low current readout-based diagnostics gives indication of becoming widely adopted in the future.

The relevance of the community is also expressed by the respondents in the presented survey. Many facilities adopt MicroTCA.4 having as expectation not only the reuse of COTS module but also the exchange of ideas and actual projects with its peers. The exchanges nowadays are very successful in LLRF projects, given the unified architecture being employed, but not for beam diagnostics. The hardware-diverse MicroTCA.4-based BPM solutions deployed along the years corroborates this observation.

The stringing up-time requirements of the ILC project has driven the requirements for a new electronics featuring high availability and full hardware manageability. Fine modularity was also pursued in order to ease development cycles, *i.e.* smaller parts of the system can be designed and evolved at different paces. Many smaller facilities do not have such demanding requirements and tend to see them as overkill in terms of hardware costs, complexity or human resources. Nevertheless, the original goal of unifying the community still seems possible and worthwhile for many facilities, where large scale MicroTCA.4 systems have been deployed.

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