CompactPCI Serial specification for modular embedded computer systems

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This article reviews the new basic specification of CompactPCI Serial, and explains why it was necessary to develop this specification when two basic specifications already existed in the PICMG consortium (ATCA and MicroTCA) and one in the VITA consortium (VPX/OpenVPX). It highlights the advantages of the different system architectures for specific tasks.

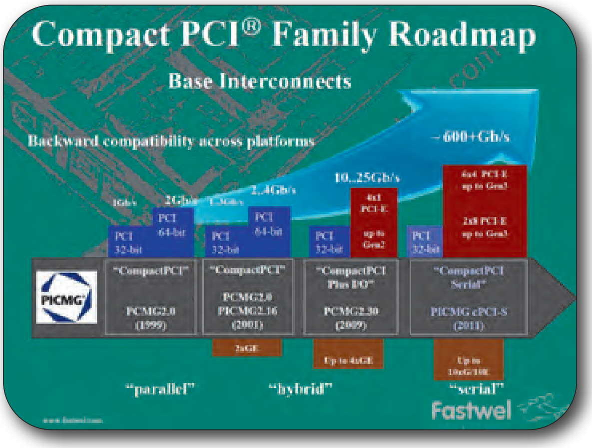

Figure 1. Development of interconnects of intermodular data exchange of the PICMG CompactPCI standards family

Embedded computer systems fall into two classes according to their internal architecture: monolithic (for example, the automobile computer or the electronics modules of printers or scanners), and modular, consisting of different units or boards (for example, radar data processing). The first class are generally made by big companies in millions of copies, allowing to allocate huge engineering resources for their development, and quickly recovering the development cost. With the second class of systems it is far more complicated, since volumes range from a few units to a maximum of some thousands, and the intended tasks are often impossible for just one controller or processor, while the consolidated resources consume tens, if not hundreds of watts. For combining electronic modules, it is necessary to use the one or the other technology.

Most of the world's modular embedded computer systems are developed on the basis of open standards, describing mechanical construction, heat sink, electrical connections and very often even logical protocols of communication between the system modules. Such standards simplify the development of industrial electronics products, using modules from different vendors without losing the novelty and maintainability of the solution itself. The technology of standards lies in ensuring compatibility of modules from different vendors for creation of integral systems. The question of the right selection of standards is difficult for systems developers mainly due to two reasons. The first is that the standards themselves evolve over time in the technical aspect. This can be rather difficult to follow: changes must be monitored and upgraded versions acquired. The second reason is that the standard itself can be very interesting from the technical point of view but not popular in the market. Thus, it will be difficult to find the necessary modules both at the system development stage and, what is worse, at the mass production stage.

The CompactPCI specifications were supplemented in 2011 by the CompactPCI Serial specification. It was developed to renew the data exchange interconnects between modules in Comp ctPCI systems, and thereby to ensure the solution of the task of creating modular systems over the next 15 to 20 years.

The CompactPCI history began in 1999 (figure 1) when the first basic specification was published, combining the Euromechanics standard (IEC 60297) with the PCI bus. At that time the data exchange between modules was provided by the 32-bit PCI bus with throughput capacity about 1 Gbit/s. This bus fulfilled the function of universal interconnect, providing both data exchange for collaborative computing and data exchange with peripheral and storage modules. In the following 10 years two specifications were issued, each of which added serial interconnects to the parallel PCI bus: 2 Ethernet channels were added in PICMG 2.16 and 4x1 PCI-E channels and 2 more Ethernet channels were added in PICMG 2.30. And at last, in 2011 the CompactPCI Serial specification was adopted, substantially increasing throughput capacities in all types of interconnects: for data exchange - PCI-E and Ethernet; for storage systems – SAS/SATA; and for input/output systems for general profile peripherals - USB 2.0/3.0.

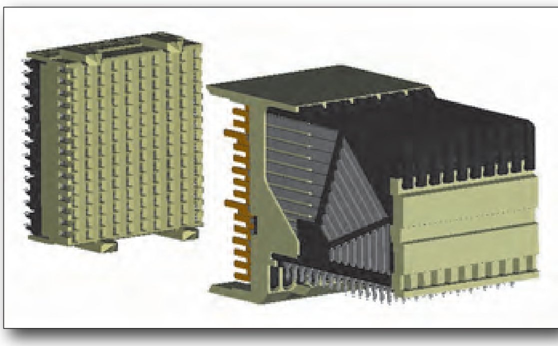

Figure 2. External view of the FCI CompactPCI Serial AirMax VS connectors installed on motherboards (on the left) and blade modules (on the right)

CompactPCI Serial at first looks to be a logical continuation of the tendency of step-by-step transition from parallel buses to serial interconnects of point-to-point type, but if you look at it more deeply and familiarize yourself with details, you will see that the CompactPCI Serial specification represents the new basic specification of the standard family, and this is very important for the industry and developers of embedded systems.

CompactPCI Serial has five key innovations: new connectors, high speed interconnects, new layout of connectors on 6U boards, a new power supply scheme and conductive cooling technology. Connectors: CompactPCI Serial uses new high-density connectors for data transfer both on the side of blade modules and on the side of motherboards (figure 2). Testing of connectors, for example, FCI AirMax connectors, showed high quality of signals transmission up to 12.5 GHz.

Connectors structure allows installation from different sides of the board, allowing thereby to apply the mezzanine concept of blade modules creation with connection of mezzanines directly to motherboards. Interconnects: CompactPCI Serial outlines expressly the four types of interconnects pins (pinout) designation and one I2C check bus on the system controllers and peripheral connectors: 8 PCI-E channels, two of which are 8 and the remaining six are 4; eight Ethernet Base-T channels; eight SAS/SATA channels; eight USB 2.0 or USB 3.0 channels; I2C bus for control and monitoring of system service parameters. At the physical level each channel consists of two differential pairs, providing data transfer from source to receiver and reverse. As all CompactPCI Serial interconnects are serial, the specification describes their topology, namely: PCI-E, SATA and USB have star topology with the system controller (Syst) as a host, while Ethernet has a full mesh topology or, in other words, "each-to-each" topology (figure 3). It is important to note that the CompactPCI Serial standard does not impose restrictions on the configuration of motherboards, leaving this decision up to the customer and motherboard manufacturer. Respectively, some systems can be designed for connection of only one application or peripheral (Per.) module, the others - for connection of up to 24 application modules. CompactPCI Serial for 6U modules describes an additional connector on the system controller module, providing two additional Ethernet channels which can be used for ensuring compatibility with PICMG 2.16, and an additional power supply.

The mechanical structure underwent few changes but resulted in significant consequences for the 6U systems. Thus, all connectors for connection to the motherboard are now located in the upper half of the 6U plate, while the lower half remains free and can be used for installation of connectors according to customer specifications and/or for direct connection to a rear I/O module (figure 4). If the organization of the 6U system does not require support of PICMG 2.16 and additional power supply, 3U motherboards can be used in such systems.

Figure 5 illustrates different options for the implementation of CompactPCI Serial systems (a, b, c) and hybrid systems (d) with monolithic (a, c) and composite (b, d) motherboards. Advantages consist in the reduction of prices for motherboards - they now became smaller and simpler to manufacture, as well as the possibility of supporting inherited (i.e. inherited from previous specifications) interconnects (Ethernet and PCI), and the creation of hybrid systems. In addition to the improvements already mentioned, there is one special mechanical element

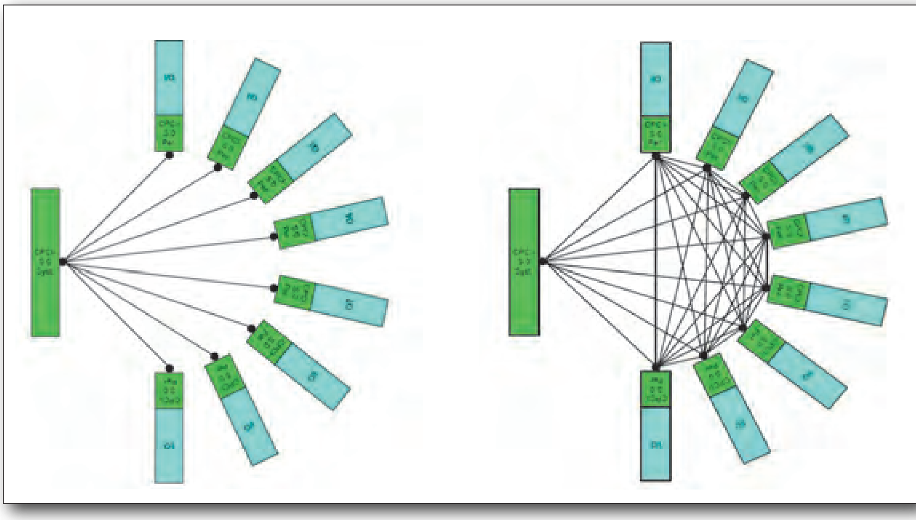

Figure 3. Intermodular interconnects topologies in the CompactPCI Serial specification: a) PCI-E, SATA and USB; b) Ethernet

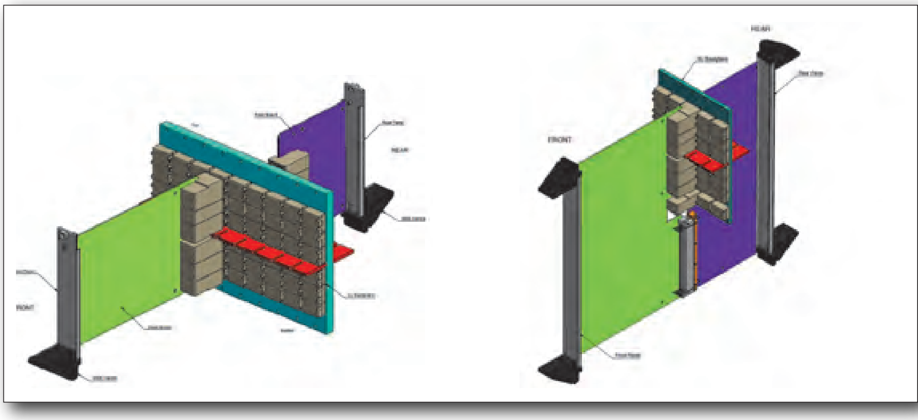

Figure 4. Examples of connection of front and rear I/O cards to CompactPCI Serial motherboards for the 6U (a) and 3U (b) systems

in 3U modules and two mechanical elements in 6U modules, directing and centering the boards when connecting to the motherboard to simplify the processes of systems assembling and modules replacement for repair.

New connectors also allowed improving the power supply system. Specifically, CompactPCI Serial requires only one supply voltage (+12V) with maximum input power of 79.8W for each 3U module and 171W for each 6U module, needed for provision of power supply to 8HP or 12HP high-productive modules, or for provision of power supply to modules with conductive or liquid cooling. CompactPCI Serial provides the system controller with the possibility to control the power supply, for example, upon occurrence of events (wake on LAN or wake on modem). Therefore, the functions implemented in all modern processors and chipsets can be used for creating an embedded system. The CompactPCI Serial specification offers developers a simple option for implementation of systems with conductive cooling. This option assumes packing of the standard board in a metal holder which is inserted into the system with the 5HP step between modules. Very often the success of new technical solutions is based on the support of legacy technologies. A good example is the success of the x86 processor architecture, supporting operation of the previously written program code. In the family of CompactPCI specifications, the new CompactPCI Serial specification provides systems developers with very wide possibilities of integration of inherited PICMG 2.0, 2.30 and 2.16 modules within one system. The CompactPCI 2.30 (PICMG 2.30) peripheral and application modules use identical connectors and are completely compatible to CompactPCI Serial.

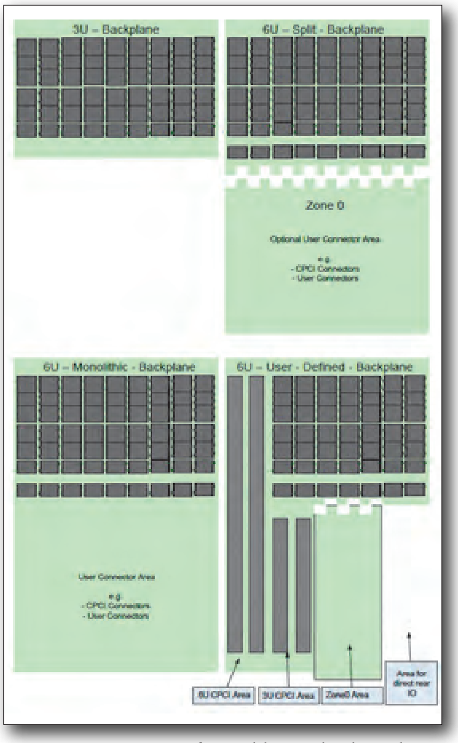

Figure 5. Options of possible motherboard creation: a) 3U CompactPCI Serial, 8 peripheral slots; b) 6U CompactPCI Serial, 8 peripheral slots, composite motherboard; c) 6U CompactPCI Serial, 8 peripheral slots, monolithic motherboard; d) 6U hybrid composite motherboard with support of 2 CompactPCI 2.0 peripheral blade modules and 6 CompactPCI Serial peripheral slots.

The system controllers and peripheral 3U modules can be used in 6U systems. More Information on the compatibility of standard modules of the CompactPCI specifications family is provided in table 1. The CompactPCI Serial specification allows to implement hybrid systems in which the peripherals are based both on serial interconnects and on the inherited 32 or 64-bit PCI buses. In the 3U format the hybrid system can be implemented, for example, by means of the PCI-E/PCI bridge module connected by a cable to the system controller, and two motherboards, locating, for example, the PCI segment on the left, and the CompactPCI Serial segment on the right. Such an option is implemented by the MEN company. In the option offered by Fastwel, the bridge is implemented on the mezzanine on the left for the CPC510 system controller, which allows installing it in the PICMG 2.30 system controller slot and supporting both of the ompactPCI and PICMG 2.30 peripherals. The implementation of compatibility with inherited modules on the basis of PCI bus in the 6U format is already described. Compatibility with PICMG 2.16 is supported in the 6U format by an additional connector with two Ethernet channels.

The increase in input power up to 79.8 W (for 3U) and 171 W (for 6U) for the CompactPCI Serial system controllers allows installing practically any processors of PowerPC or x86 architecture. This way, using the advantages of mechanical structure, on the double width modules one can install not only soldered processors from the CPU suppliers mobile segment, but also server socket processors and vertically installed DIMM or SO-DIMM. We recall that the CompactPCI specification defined a power input of only 50W for both 3U and 6U modules, requiring application of proprietary methods for installation of server processors. The informed reader may ask why it was necessary to develop a new specification based on serial interconnects, if two basic specifications have already existed in the PICMG consortium (ATCA and MicroTCA) and one in the VITA consortium (VPX/OpenVPX). This is a good question, and the answer is very important from the point of view of understanding the advantages of the different system architectures for specific tasks. Let’s look at this in more detail.

First of all, let’s compare such basic parameters as board areas, the possibilities of routing various interfaces for data input-output, and installing different components on board, as well as heat budgets. The overall dimensions and heat budgets of CompactPCI (CPCI) and VME modules are identical, therefore they can be reviewed jointly. The AMC blade modules used in the MicroTCA standard may have 3HP, 4HP or 6HP width and two board sizes – single or double. If we compare the areas of the CPCI/VME boards with the size of the AMC and ATCA boards, we arrive at two obvious conclusions as regards locating electronic components, radiators and air heat sinks. 1) The ATCA modules are non-comparable and therefore do not compete in any way with CPCI/VME and MicroTCA (figure 6a). 2) The CPCI/VME modules in 3U format have comparable characteristics with the single-size AMC blade modules for the MicroTCA systems, while the CPCI/VME modules in 6U format show substantial advantages (plus 60 %) over MicroTCA.

It is necessary to note that the CPCI/VME manufacturers widely use the possibility of increasing the board width up to 8HP, and even up to 12HP, by installing additional boards and locating the functions required thereon, while the AMC functional modules manufacturers cannot go over the maximum size of 6HP, as this size is defined by the restriction on mezzanine thickness in (AMC is a mezzanine for ATCA). The conclusion is thus: the CPCI/ VME specifications allow installing a bigger number of components, and components of a bigger size, on the blade modules, as well as tolerating heavier heat loads with air cooling, than the AMC modules in the MicroTCA systems. If we look at the areas of the front panels which determine the possibilities for installing connectors and the input/output possibilities for the different interfaces, the advantage of the CPCI/VME modules becomes obvious (figure 6b).

To be fair, it is necessary to note that the new MicroTCA.4 standard adopted in 2011 supports the possibility of directly connecting

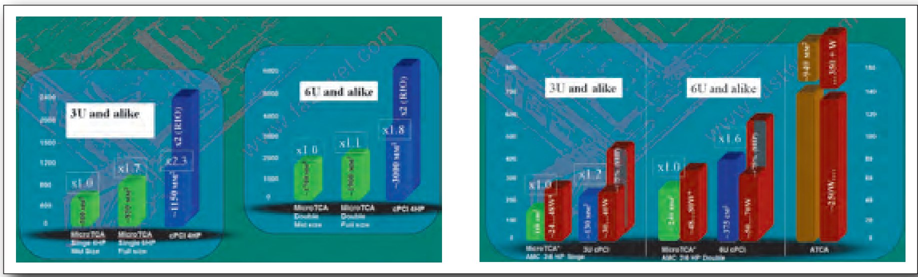

Figure 6. Comparison of CPCI/VME, MicroTCA and ATCA technologies: a) according to useful areas on boards for location of electronic components and heat sink and air cooling capabilities; b) according to useful areas of panels for location of I/O connectors.

front modules to rear modules of the same size, thereby doubling the area for components installation, and increasing the output capacity by roughly 50%. Thus, in regard to board area extension and components installation thereon, it can be said that the CompactPCI and VME specifications benefit compared with MicroTCA, while in regard to the input-output capabilities, they have substantial advantage over MicroTCA.

The VPX/OpenVPX family standards were developed by a group of contracting companies for the United States Department of Defense, with the target task of updating the VME specification and inventing a new technology for creating modular embedded systems for their customer. Originally the VPX standard (ANSI/VITA 46.0-2007 VPX: Base specification) was based on the use of new plated MultiGig RT2 connectors from Tyco Electronics with throughput capacity of 6.25 GHz; this allowed using 64 differential pairs for ensuring intermodule communication in the system on the basis of 3U boards and 192 pairs for 6U. Recently, a new connector with a throughput capacity of 10 GHz comparable to CompactPCI Serial has been standardized for the VPX/OpenVPX systems (ANSI/VITA 60.0-2012 VPX: Alternative connector for VPX). Accordingly, the VPX modules and systems manufacturers have no barrier to increasing the speed; only the timely and organized migration to use the new connector is required as the VITA 46 modules and motherboards are incompatible with VITA 60.

The next and, probably, the most important difference is the approach to description of pinouts in the CompactPCI Serial and VPX/OpenVPX standards. Namely, the CompactPCI Serial standard expressly defines at which connector pin the signal should be present. The OpenVPX standard gives this determination to the so-named profiles (pins designation and interconnection topology). These are subdivided into the modules, slots and motherboard profiles, with the number of profiles of each type described in the OpenVPX specification for 3U and 6U modules designated in tens and sometimes in hundreds (table 2). Besides, the list of standardized interconnects is wider than in CompactPCI Serial, and the topologies of their connections include a double star, a ring, a mesh and others. In fact, OpenVPX appears as the reference manual (and the OpenVPX developers do not hide it even in the standard name: ANSI/VITA 65.0-2010 OpenVPX Architectural Framework for VPX), describing a great diversity of intermodular exchange technology implementations, while CompactPCI Serial describes specific implementations of technology. The consequences are simple and complex at the same time: intermodular compatibility is possible only within compatible profiles, which in practice means – from one manufacturer. By contrast, CompactPCI Serial allows the assembly of systems with modules produced by different companies, since the intermodular compatibility is guaranteed by the specification. And logically we see that CompactPCI Serial performs the function of facilitating creation of modular systems, so long as the modules are known to be compatible with each other.

The VPX/OpenVPX specification allows very high values of input power for the module which can be used for construction of systems with liquid cooling, as well as a bigger number of differential pairs in the 6U VPX/OpenVPX systems in comparison with ompactPCI Serial, enabling higher speeds of intermodular exchange when using a number of high-productive profiles.

With reference to modular platforms, granularity is an important parameter for developers who plan to release a line of products based on one of these technologies but with different characteristics, for example, for provision of services to a different number of subscribers or with different computational power. The granularity metrics can be different and be expressed in units of power, volume or cost, measured by a number of operations per second, etc.

Systems built on the basis of the 3U CompactPCI Serial standard have the lowest granularity, namely about 30W and $1000, and the 6U systems – about 70W and $3000. Such values of granularity are well-suited for creation of dif-

	Peripheral and coprocessor modules				
	PICMG 2.0 (32 bit)	PICMG 2.0 (64 bit)	PICMG 2.16	PICMG 2.30	PICMG CompactPCI Serial
System controllers					
PICMG 2.0 (32 bit)	Fully compatible	Limited compatibility	Not applicable	Not compatible	Not compatible
PICMG 2.0 (64 bit)	Fully compatible	Fully compatible	Not applicable	Not compatible	Not compatible
PICMG 2.16	Not applicable	Not applicable	Fully compatible	Not compatible	Not compatible
PICMG 2.30	Fully compatible	Not compatible	Not applicable	Fully compatible	Limited compatibility
PICMG CompactPCI Serial	Implementation is possible	Implementation is possible	Fully compatible for 6U only	Fully compatible	Fully compatible

Table 1. Cross-compatibility of system controllers and peripherals modules for the CompactPCI range standards

	CompactPCI Serial		VPX/OpenVPX	
	3U	6U	3U	6U
Connector bandwidth	> 12.5 GHz		up to 6.25 GHz (VITA46.0) or up to 10 GHz VITA (60.0)	
Number of Differential Pairs	152	160	64	192
Connectors Pinout	Defined by cPCI-Serial Specification		Defined by Profiles for modules(>170), Slots (26) and Crosspanels (16)	Defined by Profiles for modules (7), Slots (10) and Crosspanels (19)
Base High Speed Interconnect	PCI-E/ SRIO : 2x8 and 6x4 channels		PCI-E / SRIO / Infiniband / Ethernet / SATA / SAS : up to 20 x 4 depending on topology (Star, Dual Star, Extended Star, Daisy Chain, Mesh, Ring...) and Profile	
Common Interconnect	1/10 GE : 8 channels, Single Mesh	1/10 GE : 8 channels, Single Mesh and 2 to crosspanel		
Storage Interconnect	SATA/SAS : 8 каналов	SATA/SAS : 8 каналов		
General I/O Interconnect	USB 2.0/3.0 : 8 channels		none	
Switches for Serial Interconnects	Embedded Into cPCI-S System Controller (based on capability of modern CPUs platforms)		Separated VPX System module(s)/component(s)	
Power Supply	79.8 W / 12 V	171 W / 12 V and optional 91,2 W / 48 V	276 W / 3.3 and 12 V	768 W / 3.3 and 12 or 48 V
Conduction cooling	via standard module encapsulation and 5HP slot pitch		via initial module design for conduction cooling with reduced board space for components placement	
Compatibility of Modules	Guaranteed by cPCI-S Specification Compliance		within : 1) Profiles and 2) connectors (VITA 46.0 or VITA 60.0)	within: 1) Profiles, 2) Connectors (VITA 46.0 or VITA 60.0) and 3)Input Power scheme

Table 2. Comparison of the CompactPCI Serial and VPX/OpenVPX technologies

ferent control and supervisory complexes, and measuring equipment. And if the 3U systems are more suitable due to their capacity for execution of customer tasks, the 6U systems have, mainly, server functionality and designation. The VPX systems given the same size and computing parameters show at least twice the cost. Accordingly, their granularity in relation to cost is higher, which may lead in some cases to going over the limits of the permissible budget when creating a line of products.

The ATCA standard-based systems have the biggest granularity – about 300W and the cost of modules about $50 to $8000. Thus it makes sense to use these systems for tasks with heavy loads on the switching or computing subsystems, measured in teraflops and tens of Gbit/s.

The CompactPCI Serial standard supports different back-up and hot-swap technologies. The systems developers have all possibilities open for back-up implementation. For example, peripheral modules can be duplicated or triplicated, and the replacement of an inoperable module is possible without switching the system off (hot-swap). The full intrasystem duplication can be organized by synchronization of operation of two CompactPCI Serial segments through Ethernet channels (for the 3U and 6U systems), or using intrasystem switches (only for the 6U system).

It will be fair to note that complete intrasystem back-up is rarely used nowadays. More often distributed back-up is applied, allowing to increase the systems operability with power supply from different sources and use of distributed communication lines. The high level of intermodular switching and support of a large number of standard interfaces, such as Ethernet, is the key to success in creating systems with distributed back-up on the basis of the CompactPCI Serial specification.

Originally, the first CompactPCI standard was designed for use in the public telecommunication networks core. But since the end of the 1990s telecommunication networks have changed a lot, and the switching capacity provided by the CompactPCI systems (1 to 2 Gbps) became insufficient. Now their place in the public networks core is occupied by the 10 to 40 Gbps ATCA systems and the rack-mount server-based solutions. But how about CompactPCI Serial?

With updated high values of the internal interconnects throughput capacity, the CompactPCI Serial standard can be successfully used in the IP-based systems intended for creation of network infrastructure. But new possibilities for CompactPCI Serial now more likely exist not in the cores of public telecommunication networks, but in their peripheral and boundary sections. Regardless of the customer type, whether a digital house, digital transport, digital office or subscribers, the equipment for their network access should be able to recognize different wire and wireless data transfer protocols, to aggregate and convert these flows in TCP/IP and to carry out their preprocessing. The CompactPCI Serial capacity, competitive prices and low granularity values – this is a partial list of the advantages which play a key role here.

If we have a look at a private network, for example at the process equipment control network or at the vehicle control network, the CompactPCI Serial system switching capacities allow its use for resolution of tasks in the core of such a private network. Already there are some successful applications, for example, the Wi-Fi Internet system in European trains.

The possibilities of the 6U CompactPCI Serial standard are also interesting for creating the wire network infrastructure connected with the support of technology of the customer devices power supply via the network cable (Power over Ethernet – PoE). Such devices include IP surveillance cameras, panel computers, controllers and other devices, consuming up to 40W. By means of the P0/J0 connector, the 6U CompactPCI Serial modules can be provided with an additional power supply of – 48V via the motherboard, with maximum current of 1.9A (91.2W).

The CPCI/VME standards have taken a strong position in many niche markets, such as production automation, complex process equipment and programmable-controlled machines management, control and communications on transport, defense systems and many others. The new CompactPCI Serial standard allows simplifying the system creation process. The system developer has the possibility to choose between 4 types of interconnects, allowing to reduce significantly the number of bridges for communication of peripherals with the system controller. Direct connection of SATA drives, including the use of chipset-integrated RAID, connection of USB cryptokeys or controllers with USB ports, CompactFlash, SD and microSD USB card readers – and this is a far from full list of the CompactPCI Serial capabilities whose implementation does not require bridge microchips and their drivers. The possibilities of releasing the PCI-E-based peripherals are extremely wide. Let's begin the list of examples with the simplest ones – expansion modules for wire or wireless data transfer, CAN controllers and COM ports on the basis of 1 1 PCI-E. Then we continue with the lower level graphic coprocessors, controllers with „copper" or optical interfaces – Gigabit or 10Gigabit Ethernet. We close the list with graphic and network DSP or FPGA top level coprocessors on the basis of 1 8 PCI-E. It is important to note that CompactPCI Serial overall dimensions allow creating these application boards in the form of monolithic boards, or in the form of carriers of MiniPCI Express, PCI-E, XMC, FMC cards and even of the PC/104 family.

The real-time system developers and the developers of the high-productive complexes intended, for example, for processing of Fourier conversions, should see the true value of CompactPCI Serial, as the specification providing the data exchange interconnect with low latency (PCI-E is supported by the system controller, there are no additional switches with their time delays) and high speeds of the intermodular exchange, thus allowing the creation of clusters combining the resources of several modules.

For example, the Fastwel CPC510 module has the semi-transparent PCI-E bridge, allowing to insert it into the system controller slot and into the PCI-E peripherals slot, using it as the 4-core computing coprocessor where each core can execute up to 8 instructions of double accuracy with floating decimal point in one cycle. ■

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