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PXI Express Chassis - Modular Platform for Automation and Test Systems

Whitepaper

nVent SCHROFF

PXI Express Chassis - Modular Platform for Automation and Test Systems

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1. INTRODUCTION: MARKET REQUIREMENTS FOR PXI EXPRESS

The open industry platform PXI Express (Developed by the PXI Systems Alliance) is an adaptation of the PXI platform which uses the PCI Express bus and CompactPCI Express form factor. Its primary application is a wide range of high-performance, PC-based test and measurement applications in industry, research, and development.

PXI Express, based on PC architecture, is specifically defined for measurement and automation systems with high demands on synchronization and flexibility as well as the scalability of measurement systems. The primary innovations compared to PXI are higher data transfer rates, extended timing & synchronization functions, as well as backwards compatibility. A steadily increasing proportion of PXI Express system deployments are a result of these developments. In addition, there has been an increased tendency to customize and adapt systems. Both of these developments have led to a need for customized PXI Express systems, and require a high degree of flexibility from manufacturers.

This paper explains how a functional PXI Express chassis is put together in order to comply with market demands for increased data transfer and flexibility.

2. PXI EXPRESS – MODULAR APPROACH

2.1 Requirements for a PXI Express Chassis

Compared with other systems like CompactPCI where the chassis merely includes a passive backplane and needs to meet requirements for mechanical protection, power supply and cooling, a PXI Express chassis also provides precise timing functions and PCI Express & PCI Signal architectures.

The following requirements apply in order to achieve this:

- Provision of a 10 MHz single-ended clock, a differential 100 MHz clock and a differential SYNC signal for each slot.
- Delay-free and interruption-free source changing (external / internal / standalone) of these clock signals in system operation is also important.
- Expansion of the PCI Express bus with additional ports via one or more Express switches allows for larger measurement systems. This is necessary due to the limited link count of the system controller of 4 ports maximum, limiting the number of direct point-to-point PCIe connections.
- Implementation of a PCIe-to-PCI bridge enables operation of PXI cards in the chassis in addition to the PXI Express cards via their parallel 32bit PCI bus.
- Active control of cooling performance minimizes noise emissions, which is important when used in a laboratory.

All of these requirements drive cost in the design of a PXI Express chassis with significantly more and complex components than many other systems.

2.2 Advantages of a Modular PXI Express Chassis

As with most modular systems, PXI Express system structure fits into two categories. One area concerns the plug-in boards (processor cards, measurement cards, IO cards) that are used in various combinations depending on the application, providing the function of the PXI Express system.

The second area includes the PXI Express chassis providing the necessary infrastructure including cooling, signal infrastructure, clock conditioning, etc., to operate the plug-in cards. At the system level, the requirement for modularity is met via interchangeable function blocks/modules of the complex function throughout the system. By dividing the chassis functions focused modules can be developed once and be used repeatedly in various systems.

This concept can also be used to build a PXI Express chassis. This means that the necessary complex functions of the chassis such as clock generation, data switching and cooling, are implemented as separate and interchangeable components.

The modular structure of such a chassis greatly simplifies the development of new modifications or expansions of existing systems. This not only reduces the time to market for the project, it also considerably decreases development costs and risks. Function modules developed once can be used in many different projects and do not have to be subjected to new development, modification, and qualification.

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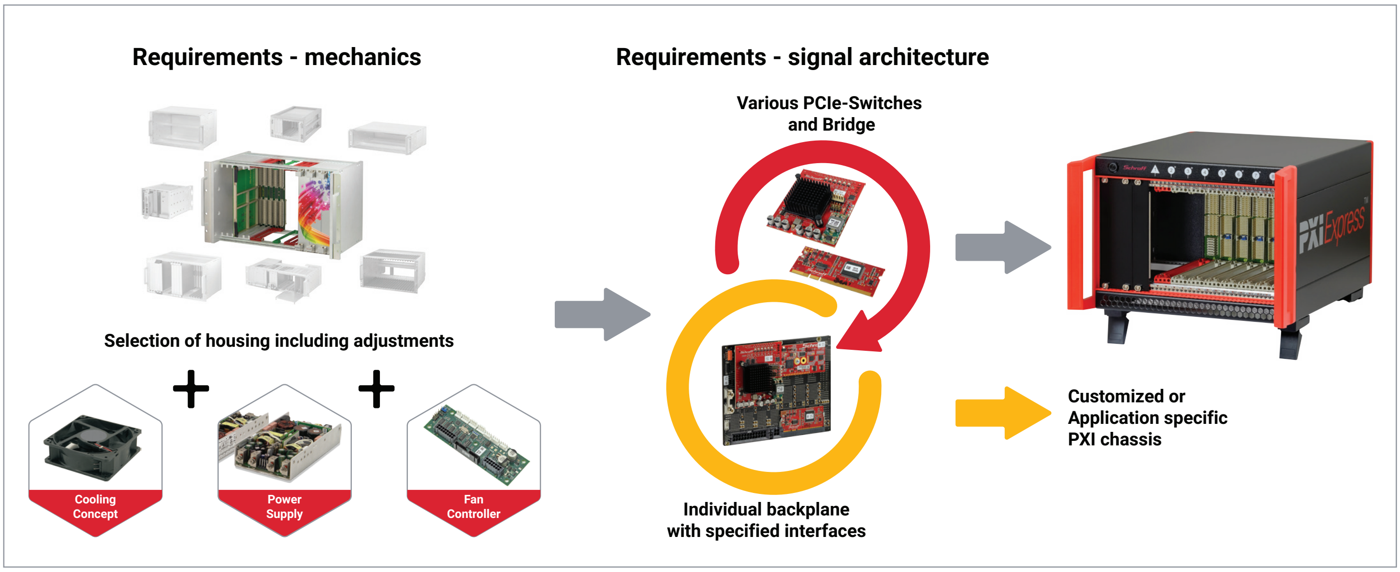
3. PXI EXPRESS CHASSIS STRUCTURED ACCORDING TO THE MODULAR PRINCIPLE

The modularity mentioned enables a PXI Express chassis to be developed or modified with an already existing and qualified range of function modules. The use of functional modules is based on the requirements that the user has for a given project.

If, for example, a PXI Express chassis with 12 hybrid slots and a horizontal slot arrangement is required, a suitable enclosure must first be selected. Additional changes to the chassis design such as size, color, handles or other features can be changed. As indicated above, the modular approach considers not only PXI Express-specific functions such as clocking, PCIe switching, etc. as function modules, but all functions and features of a PXI Express chassis. This also means the chassis size, EMC properties, durability, design, cooling approach, power supply, and other parameters. An appropriate power supply is chosen from a range of PXI Express power modules based on the performance requirements of the plug-in cards in the chassis. The cooling design is then put together from existing function modules to comply with the required cooling capacity. Additional modifications are made, and the required cooling capacity is verified using simulation tools.

The image below provides a schematic of the composition of the modules/functions of a PXI Express chassis with the backplane as the central element of the chassis.

Schematic composition of a PXI Express chassis



3.1 Mechanical Enclosure

The requirements for durability, EMC properties, noise emissions, etc. differ depending on where the chassis is used, e.g. medical technology, train and traffic engineering, or aviation. Therefore, it is advantageous to have access to a wide range of previously developed chassis designs to minimize the economic risk. In addition, design and color adjustments or changes to front plates and rear walls are often made. This requires a high degree of flexibility from chassis manufacturers. For example, nVent SCHROFF offers a large selection of proven, modular cases, enclosures or 19" cabinets.

Figure 1: Selection of different SCHROFF subracks and cases

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3.2 Power Supply

An accurate and stable power supply is the basis for all functions of a PXI Express chassis and must meet the highest requirements for quality. However, there are certain aspects to consider when selecting a suitable power supply. Since the PXI Express architecture is based on PC architecture, voltage levels and management signals are identical to an ATX specification. Therefore, it is possible to use conventional ATX power supplies, but not recommended. The requirements for voltage stability and control performance overwhelm most conventional ATX models. In addition, the temperature range, frame size, noise emissions, and ATX power supplies lacking certification for the intended purpose lead to additional challenges. Other difficulties with respect to load distribution in a PXI Express chassis may arise. Depending on the size and composition of the PXI Express system, +5.0V and +3.3V are in heavy demand, but available ATX models cannot always provide this.

The following table shows an example of the load distribution in an 8 slot PXI Express chassis with 7 hybrid slots.

	5V	3.3V	+12V	-12V	5Vaux	Total Power
8 slot PXI Express Chassis						
1x System controller slot	9A	9A	11A	-	1A	140W
1x System timing slot	-	3A	2A	-	0	30W
7x Hybrid slot	14A	21A	14A	1.75A	0	7x30W =210W
Total Power Requirements	23A	33A	27A	1.75A	1A	380W
ATX-PSU (reference model)	**25A**	**25A**	**144A**	**1A**	**3A**	**>1000W**

Table 1: ATX-PSU current capability vs. PXI Express 8 slot power supply minimum required continuous current

The selection must additionally ensure that power supplies are available over the entire expected project lifetime. The saves on costly recertification for the PXI Express chassis and system. nVent therefore uses industrial power supplies in the PXI systems. These are now also available with typical PC primary voltages and a standby voltage to wake the system up from hibernation. Such power supplies are also available with a modular structure. Here, the power on the individual voltage circuits is adapted to the respective requirements via exchangeable modules.

3.3 Cooling

Homogeneous system cooling must be achieved, depending on the mechanical enclosure used with regard to the maximum permissible power loss per slot. This depends, on one hand, on the allowable temperature increase (ΔT) and on the volume of air that can be conveyed. Generally, the larger the air volume and permissible temperature increase, the larger the dissipation power loss within the system. In applications such as a desktop case in a laboratory measurement, the noise emissions resulting from cooling must be considered accordingly. The differences between the theoretical maximum power densities of peripheral cards with 50 Watts per slot and that of the system controller of up to 140 Watts per slot require a suitably designed airflow within the system. For an 8 slot chassis, the power loss reaches a value of up to approx. 390 W. For a measured airflow of 120 m^3/h, a temperature increase of less than 15 K would be achievable. This also allows the chassis to be used in environments that are exceptionally warm. In addition to the maximum airflow, a homogeneous air distribution along all slots is important in order to prevent the buildup of hot spots. Backflows and air short cuts within the system are to be avoided. For this reason, the use of baffles, grids, covers, etc. is advisable.

Figure 2: Cooling Simulation & Measurement and Acoustic Noise Measurement

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In addition to airflow and cooling when the system is at full capacity, one must also consider how the system behaves at partial load or in idle mode as well. With a suitable temperature-controlled fan controller such as the SCHROFF FCM2, the fan speed, and thus the air quantity and volume is automatically adjusted for the respective operating mode, saving energy and reducing noise emissions. Ideally, the user can still set different control curves when controlling fans and thus independently decide whether it is more important that the system operates quietly or at lower temperatures.

3.4 Backplane

The backplane represents the central elements of a PXI Express chassis and handles many essential system functions. It combines all components and measurement cards with one another, and its properties significantly influences the quality of a PXI Express system.

As already mentioned, a stable power supply for measurement cards is an essential requirement for a PXI Express chassis. Not only does this require a high-quality power supply, but the EMC properties and power integrity of the backplane are also crucial. For example, the type and position of the decoupling capacitor and the backplane power routing influences the stability and oscillation tendency of the supply voltages. Particularly critical, even in the DC range, are the 3.3V and 5.0V voltages. Under certain circumstances, even low voltage dips can lead to card damage or sporadic measuring inaccuracies. These malfunctions can lead to false measurements which are then very difficult to detect during later measurements. In order to counteract this problem, the backplane and frequency behavior of the power supply must be considered. In addition, a maximum DC voltage drop of approx. 50 mV at full load is not to be exceeded for each supply voltage.

In order to synchronize the PXI and PXI Express cards with each other, the backplane provides synchronized clock signals from the clock source and the timing slot to all slots radially. Here, the smallest possible delay difference for all components in the chassis is essential. The PXI Express specification defines a maximum allowable slot-to-slot delay of <150 ps and for differential clock pairs a maximum intrapair delay of <25 ps. However, runtime differences of less than 10 ps in the backplane are recommended for accurate system functionality and high signal quality. This reliably ensures that the measurement cards will function precisely.

Another challenge in designing the PXI Express backplane are the high-speed PCI Express bus data lines. In order to achieve the system bandwidth of up to 16 GB/s currently required (4 link system slot, 16 lanes PCIe Gen3) or 24 GB/s (2 link system slot, 24 lanes PCIe Gen3), it is not sufficient to simply control the line impedance. Various adjustments must be made with respect to signal integrity, material, and component selection, as well as signal routing strategies. Here, the use of Signal Integrity Simulation tools is recommended in order to qualify all parameters before completing the routing. When making final measurements, the quality of the design must be verified with the corresponding specifications.

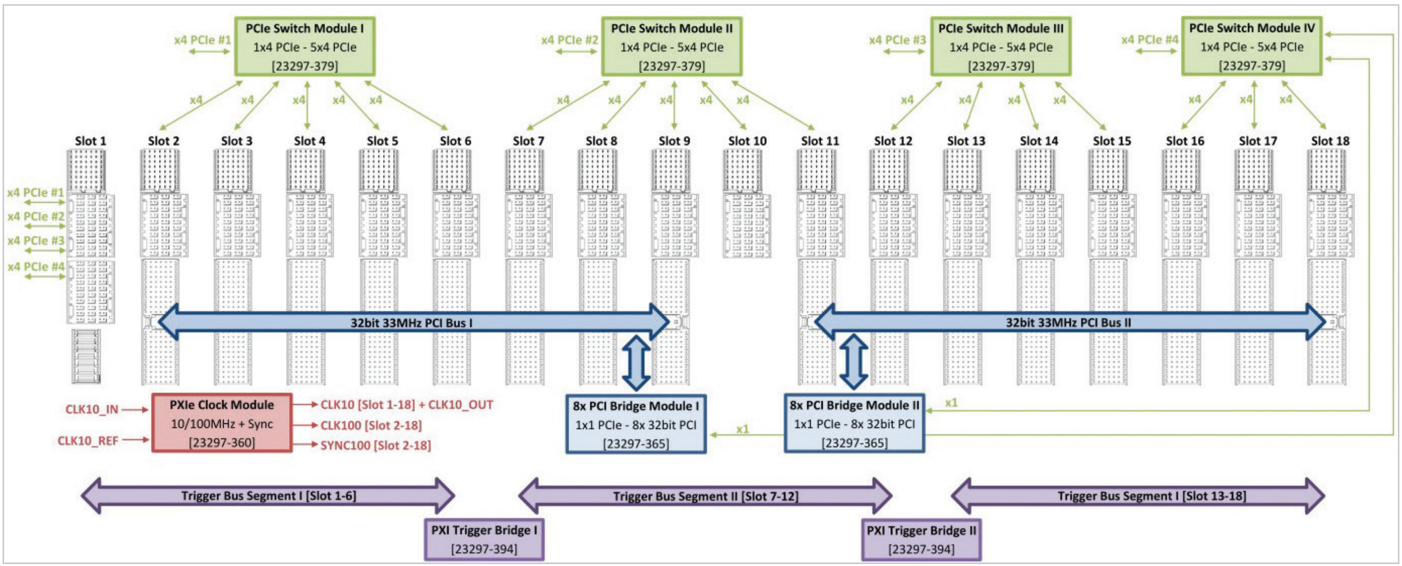

Figure 3: Signal topology of an 18 slot full-hybrid backplane with a 4 link system slot

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One disadvantage of the PXI Express signal architecture is that the system slot only has two (x16 + x8) or four PCIe ports (4 x4 configuration). This port number is sufficient for small systems when connecting all cards to the system slot. The backplane does not require active circuit elements. However, if an increased number of peripheral slots or backward compatibility with PXI is required, additional PCI Express switches and/or PCIe-to-PCI bridges are necessary. Additionally, reference clock generation and switching is another important feature of the PXI Express chassis. Figure 3 shows an example of the signal architecture of an 18 slot PXI Express backplane with 16 hybrid slots.

Standard PXI Express backplanes often cover all functions mentioned on-board. This is usually advantageousness for high quantities. However, if you want to remain flexible for various applications and make adjustments and new developments quickly & inexpensively, the design cost and development time of the backplane will increase significantly in the on-board variant. Custom modifications or new designs typically lead to an extremely high design and certification cost. This can lead to delays, costs, and risks within the project.

At this point, the advantages of the modular PXI Express chassis become even more clear. Previously designed PCIe switch functions, PCIe-PCI bridge functions, and clock functions are designed as standalone function modules and offloaded from the backplane. The interfaces between the backplane and modules are defined and used as a standard for all customer specific projects. As a result, the backplane can largely function without active components, and the backplane placement or routing can be adapted to the project requirements relatively easily (e.g., slot count, slot types). This approach often makes the backplane the sole element in the PXI Express chassis for custom applications and other custom PXI Express projects with a modular approach designed to meet specific project needs. Any modules with offloaded functions can be used multiple times for different projects.

The following image shows a modularly-constructed PXI Express backplane.

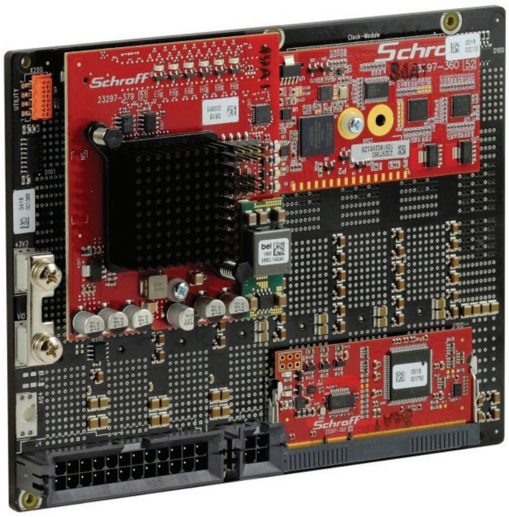

Figure 4: 8-slot PXI Express backplane with installed modules (PCIe switch, PCIe-PCI bridge and clock module)

This approach reduces the development time of the project-specific backplane by limiting it to signal routing. The production processes of the printed circuit board and the backplane are also simplified (simpler production processes, no BGA components, etc.) and thus more reliable.

In addition, the division of functions into modules not only facilitates system maintenance, it also makes it possible to later expand the system with new or additional modules.

4. PXI EXPRESS CHASSIS – FUNCTION MODULE

4.1 PXI Express Clock Module

The module enables synchronization based on precisely correlated system clocks in order to accurately coordinate between measurement cards. According to the PXI Express platform, the module provides a PXI-1-derived, TTL/CMOS-compatible 10 MHz clock, a differential 100 MHz LVPECL clock, as well as a configurable differential SYNC signal per slot. With a specified, closed time relationship between these reference clocks, system applications with the highest requirements for synchronization accuracy and clock stability can be supported regardless of the number of slots. The required long-term accuracy below 25 ppm is achieved by a high-quality independent reference oscillator with appropriate clock conditioning.

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Another advantage of modularity is the better handling of EMC emissions, which then reduces the impairment of clock quality despite high signal concentration within the measuring system. Runtime differences of less than 50 ps between the slots are achieved via coordinated routing strategies and component selection focused on low additive jitter along the transmission path.

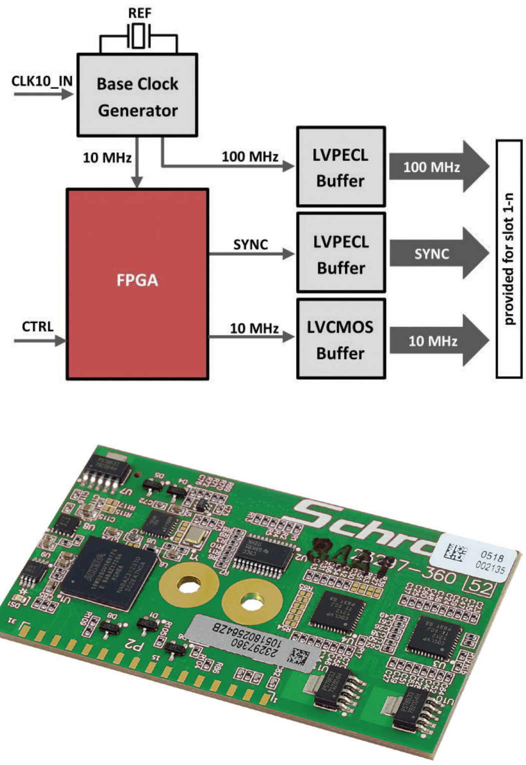

Figure 5: PXIe Clock-Module

A delay-free switch between internal and external precision clock sources is implemented in order to fully exploit PXI timing functionality. In addition, the function of the PXIe_SYNC_CTRL and PXIe_SYNC100 signals can be modified via the user interface during system operation. A qualified module design and the physical reproducibility in series production guarantee consistent quality and meet the precise timing requirements of test and measurement applications.

4.2 PCI Express Switch Module

Due to the limitation in available PCI Express ports on the PXI Express system controller (2 or 4 link configuration), the various slots must be connected to the system controller via PCI Express switches for increased peripheral slots. In the modular approach presented here, this function is assumed by the PCI Express switch module. It permits the expansion of a PCI Express port to numerous peripheral slots by the system controller. The individual scalability of slot count as well as the availability of dedicated upstream ports on the system controller further facilitates the implementation of PCI Express switch functionality on a modular assembly.

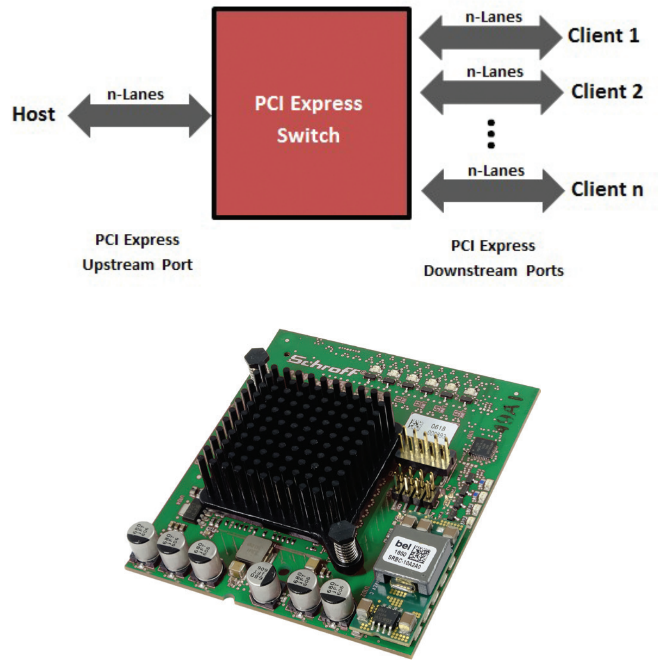

Figure 6: PCIe Switch-Module

Compared to the on-board variant where switch functionality is implemented directly at the backplane, the modular design allows a more compact stackup of the switch module multilayer and thus finer layout structures with reduced parasitic effects such as signal stubs, coupling capacities, and much more, along the entire transmission path. High-quality module reproducibility by combining the high-speed connector, a total insertion loss of less than 3 dB @ 8 GHz, an optimized design, and independent compliance measurements. The module can be made future-proof and also adaptable to the upcoming PCI Express Generation 4.0 through the selection of components and optimized signal routing. To get the most out of the system bandwidth, the switch module configuration ensures efficient uplink and downlink bandwidth tuning in order to avoid bottlenecks between the peer-to-peer endpoints.

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In addition, the space-saving mezzanine structure on the Z-axis (switch module behind the backplane, see Fig. X), the decreasing density of active circuit components on the backplane, and a well-chosen PCIe switch port multiplier make the signal integrity of the backplane far more efficient versus a switch on the backplane approach.

4.3 PCI Express to PCI Bridge Module

To maintain backwards compatibility with PXI-1 modules, a bridge device must provide an interface between the PCI Express serial bus from the system controller and the parallel 32 bit / 33 MHz PCI bus of the PXI-1 compliant slots.

In a modular PXI chassis this is achieved via a PCIe-PCI bridge module operated in forward mode, which corresponds to the PCI Express to PCI Bridge Specification 1.0. The PCIe-to-PCI bridge module connects up to eight PXI and/or cPCI devices with a bandwidth of 133 MB/s to a PXI Express system controller, thus ensuring optimum utilization.

The module design and components used meet the requirements for an increased temperature range in industrial applications in addition to VIO compatibility with +3.3V and +5.0V. Because of its full transparency, the PCIe-to-PCI bridge module does not require any additional drivers or software modifications. It is recognized and integrated via plug & play by modern operating systems.

This results in cost-efficient and interchangeable high-performance backward compatibility with common peripheral cards from the PXI-1 range. This reduces project costs and keeps qualification requirements to a minimum.

The following image shows a block diagram of the bridge module:

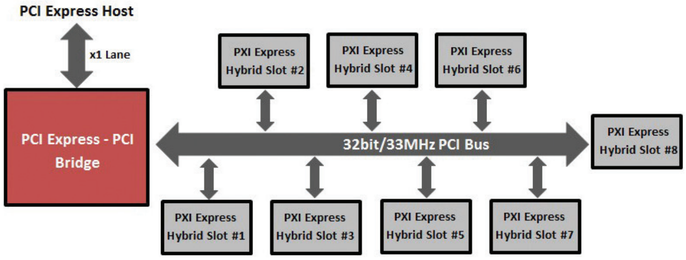

Figure 7: Block diagram of PCIe-PCI bridge module

4.4 Bridge Module Trigger

According to the PXI Express PXI-5 specification, a trigger bus segment may consist of a maximum of eight bus users, but communication between the individual trigger bus segments must be ensured. Therefore, with a higher number of slots, it is necessary to divide the entire trigger bus into permissibly large bus segments by means of a trigger bridge. The software of the trigger bridge must allow a dedicated and individual configuration of individual PXI_TRIG [7: 0] trigger signals in order to connect or disconnect the bus segments.

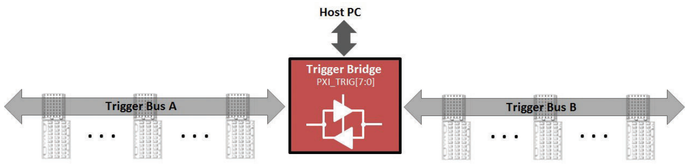

Figure 8: Bridge Module Trigger

5. SUMMARY

Today's market demands require a high degree of flexibility from chassis manufacturers. Users do not expect catalog parts, but have individual requirements when it comes to the design and technical features of their products. This means that many projects require modifications or even an entirely new design of the PXI Chassis. Because of the increased complexity compared to other platforms, the development of a PXI chassis is significantly more complex and often leads to higher costs and risks in development, design, and series production. nVent SCHROFF builds based on a modular system approach in order to minimize these costs and risks as much as possible. Modular PXI Express chassis designs with passive backplane and additional separate functional modules for complex PCIe switches, PCIe-PCI bridges and clock functions that are connected to the backplane via select interfaces offers numerous advantages. This also applies with regard to high availability, reduced project times, considerable cost savings, general customization, and high ease of maintenance.

The development and implementation of the described components and blocks of a modular PXI Express chassis requires expert knowledge in various disciplines. Starting with the mechanical system, especially 19” technology, to knowledge and experience in the area of cooling and power supply, all the way to power and signal integrity know-how.

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Christian Ganninger, born 1971, studied electrical engineering at the University of Applied Science in Karlsruhe, Germany. Subsequently, he worked as design engineer und technical coordinator backplanes and later as project manager backplanes & systems in a company, which develops and produces 19"-systems and backplanes. Since May 2005 he is Product Manager Backplanes at nVent. Later he took over the Product Management for MicroTCA, Power Supplies and Rugged Enhanced Systems too. After one year being Category Manager Systems EMEA in 2011 he took over the Product Management Systems EMEA. Since January 2014 he is Global Product Manager Systems.

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