» Whitepaper «

Hardware- and software-compatible ISA support on PC/104 SBCs with latest processor technology

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With its stackable card concept and extremely compact footprint, PC/104 has enjoyed many years of success in the market for long-term available and robust applications. Thanks to the broad ecosystem of SBCs and expansion modules PC/104 fulfills all current demands of OEMs regarding minimized development effort, optimized time-to-market and high investment security. PC104 is available in five different standards, interfacing ISA to PCI Express. But still today more than 86 percent of PC/104 expansion boards being sold are in the PC/104 and PC/104-Plus form factor, according to VDC. Both standards are based on the ISA bus and the installed basis of ISA-based applications is huge. But with the obsolescence of processors and chipsets with native ISA support, OEMs today are faced with the problem of how to best support their existing long-lifecycle applications. The most cost-effective strategy would be an upgrade with ISA-based SBCs. Although PC technology features software backwards compatibility, providing full hardware backwards compatibility for ISA-based expansion boards is not a simple task. Several preconditions need to be fulfilled by the SBC design and firmware as well as the chipset and processor. As one of the current SFF low-power processors, the AMD Embedded G-Series APU is a good candidate as a successor design. This whitepaper explains what developers need to know in order to migrate from existing platforms to the new Kontron PC/104-plus single board computer MICROSPACE® MSM-eO(-N).

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The ideal form factor for robust long lifecycle applications

PC/104, which was standardized in 1992 by the PC/104 Consortium, is one of the standards for smallsized single board computers which has been available for the longest period of time. And with its dimensions of only 90 x 96 mm, it is still one of the most compact SBC form factors for PC technology available today. As well as defining the physical footprint, PC/104 also directly defines the extension bus to connect COTS expansion boards. In contrast to the originating PC technology, the expansion boards are stacked parallel to the SBC via a rugged embedded connector. Up to five expansion boards can be stacked on top of or below the central SBC. Corner mounting holes are used to fix the boards. This solution makes PC/104 not only an extremely compact embedded form factor, but also one that features immanent resistance against mechanical and thermal stress. Furthermore, PC/104 designs feature connectors which are 100% embedded to facilitate most flexible routing of the interfaces to the housing, a very cost-effective solution for standard series production volumes of embedded systems.

From ISA to PCI Express

The original PC/104 standard is based on the PC Industrial Standard Architecture (ISA) and uses a rugged connector with 104 pins, hence the name PC/104. Parallel to advances in computer technology and the introduction of faster bus systems, PC/104 evolved and integrated these new possibilities of increased bandwidth and signal density. Without digressing from its mechanical footprint and its interoperability, PC/104 is constantly adapting new technological developments in PC technology such as PCI and PCI Express without omitting backwards capability. Today five standards with different interconnects are available (See table 1).

PC/104 Standards

Layer	Specified by PC/104 Consortium in	ISA bus	PCI bus	PCI Express bus
PC/104	1992	Yes	No	No
PC/104-Plus	1997	Yes	Yes	No
PCI-104	2003	No	Yes	No
PCI/104-Express	2008	No	Yes	Yes
PCIe/104	2008	No	No	Yes

PC/104 - in the pole position for SFF system designs

And exactly this instant stackable concept with validated, long-term available COTS building blocks and the integrated high flexibility in expansion busses make PC/104 today more interesting than ever: Time-to-market and development costs are crucial criteria for OEMs when choosing an embedded form factor. That is why OEMs more and more rely on building blocks which can be directly put to use. So it is hardly surprising, that countless solutions are implemented based on the stackable x86-based off-the-shelf platform PC/104. Application areas are found in nearly every embedded market segment including those with extreme demands for long-term availability and rugged designs such as transportation, automation and military, which are characterized by long product lifecycles and individual I/Os.

Ready for the future. But what about legacy support?

Today, the latest PC/104 SBCs with current processor technology enable OEMs to build new applications with the latest bus systems. Also, upgrades of existing applications are possible to extend the lifecycle for the next five to seven years. So PC/104 is more than ready for a bright future along with the SFF trend and OEMs have within one embedded standard the complete range of generic PC busses and existing I/O extension boards at their fingertips – as long as ISA support is not discontinued. And right now, this is exactly a major concern of OEMs and engineers.

With the invention of new PC busses, like PCI and PCI Express, many of the PC/AT motherboard components which were originally integrated, such as BIOS ROM, realtime clock, interrupt and DMA controllers, were moved from dedicated components to the chipsets. So current hardware is still software-compatible, but as the ISA resources (I/O ports, interrupts, DMA) were automatically handled by the OS, and not by the user, the hardware compatibility to ISA expansion boards went missing.

ISA support with current platforms?

This also had influence on the LPC bus, which was used for connecting the above-named PC/AT components to the CPU and enabled a user-defined configuration to connect individual ISA expansion boards. Due to this, the PC technology also had to forgo the capability to flawlessly interact with application-specific ISA expansion boards. Other items such as configurable DMA, required for ISA hardware compatibility, experienced the same fate. For example, with the Intel® controller hub ICH6 and its successive generations, Intel even made the typical ISA memory area, which is required for data exchange and communication between CPU and ISA board, inaccessible to the user. This led to a near complete extinction of ISA hardware compatibility on chipsets following the Intel® ICH6 and makes ISA support with today's processors and chipsets a challenge.

ISA support – only full compatibility brings full benefits

Consequently, full hardware-compatible ISA support needs to be provided by the embedded board vendor because processor vendors have no worries about hardware compatibility. And although current processors and chipsets are ISA software-compatible to support legacy OS such as MS DOS, they no longer deliver the required preconditions to support ISA expansion boards out of the box. However, the market demand for ISA is still massive in the PC/104 sector. Independent researchers say, that at least 50% of all PC/104 installations are based on either PC/104 (ISA) or PC/104-Plus (ISA and PCI). The task in hand, therefore, is for board-level vendors to work on PC/104-Plus SBCs that fully support ISA and PCI because only with this support will they be able to provide a real drop-in replacement for all ISA and PCI expansion boards - eliminating the need for OEMs to adopt their hardware or software.

What is required to be ISA compatible?

In order to provide a full hardware- and software-compatible ISA support on latest processors and chipsets the following important preconditions on the hardware side have to be fulfilled:

» Allocatable interrupts within the range of IRQ 0 to IRQ 15 to initiate actions in the user space
» ISA compatible 8 and 16 bit I/O ports in the address range from 000h to 3FFh for the CPU to communicate to the ISA board
» ISA compatible, accessible 8 and 16 bit memory area from C8000h (0A0000h) to DFFFFh for the ISA board to provide application data to the CPU
» Definable DMA 0 – 3 (8-bit) and DMA 5 – 7 (16-bit) for the ISA board to write data directly into the system memory

Native PCI support on the AMD Embedded G-Series APU enables ISA support

Fulfilling these four preconditions, however, is not that easy with latest processor technology. With the typical low pin busses like LPC and SPI being inapplicable to provide full ISA hardware support, Kontron had to look for a special processor/chipset combination, to provide full ISA compatibility. One solution that offered ideal preconditions for combining ISA with latest processor technology is the new AMD Embedded G-Series APUs.

But what makes the AMD Embedded G-Series APUs especially interesting for PC/104? The answer lies in its dedicated embedded controller hub AMD A55E that offers full PCI support. In particular, the possibility to map the ISA memory area to the PCI bus before it is omitted enabled Kontron to use a PCI to ISA bridge that enables full control of the memory to provide hardware-compatible ISA support on the Kontron PC/104-plus single board computer MSM-eO(-N). Implementing a suitable PCI to ISA bridge though is just the first step in this complex process, which requires not only a high level of in-depth hardware knowledge, but also a lot of software expertise to enable DMA control, for example. Table 1 compares the IRQs, I/O ports, memory area and DMA of the original ISA bus with the ISA bus found on the Kontron MICROSPACE® MSM-eO(-N). The following paragraphs describe the steps it took to provide compatible interrupts, I/O areas and DMA.

Table 1

Resource	Full ISA bus	Kontron MICROSPACE® MSM-eO(-N)
Interrupt	IRQ 0 – 15	IRQ 0 – 15
I/O ports	000h – 3FFh (10-bits decoded with alias)	000h – 3FFh (all bits decoded, no alias)
Memory	0A0000h – 0FFFFFh 0FFFFFh – 7FFFFFh	C8000h – DFFFFh *1 (A0000h – DFFFFh for MSM-eO-N)
DMA	DMA 0 – 3 (8-bit) DMA 5 – 7 (16-bit)	DMA 0 – 3 (8-bit) *2 DMA 5 – 7 (16-bit) *2
Access types	8/16 bit for I/O, memory and DMA	8/16 bit for I/O, memory and DMA

ISA compatible interrupt system

The first thing that needs to be addressed is a configurable interrupt system for ISA compatible device handling. Why? Originally, PCs provided 16 interrupt lines connected to two programmable interrupt controllers (PIC) for interrupt handling. Today theses PICs are no longer available. Modern systems moved over to Advanced Programmable Interrupt Controllers (APIC) with Message Signaled Interrupts (MSI) as an interrupt delivery mechanism. So they are not limited to only 16 IRQs and have no fixed mapping of IRQ to functions. For ISA-based applications the PIC-based legacy interrupt handling had to be rebuilt, in order to provide a compatible environment for ISA expansion boards. Figure 1 shows PIC interrupt usage on the Kontron MICROSPACE® MSM-eO(-N). In order to offer as many free IRQs as possible, Kontron freed the interrupts connected to legacy devices which are no longer used. This included, for example, the IRQs reserved for the floppy drive and PS/2 mouse. Therefore these interrupts are now available for user-specific needs. Only one interrupt is blocked for PCI interrupt routing and the four on-board COM1-4 UARTS. This leaves 7 interrupts free for application-specific use. If these are not enough, the four COM ports can additionally be disabled to free 4 more interrupts. So in the basic configuration, on the Kontron MSM-eO the interrupts 1, 5, 6, 9, 12, 14, 15 are available to developers, which can be maximized to 11, if the four on-board serial ports are disabled.

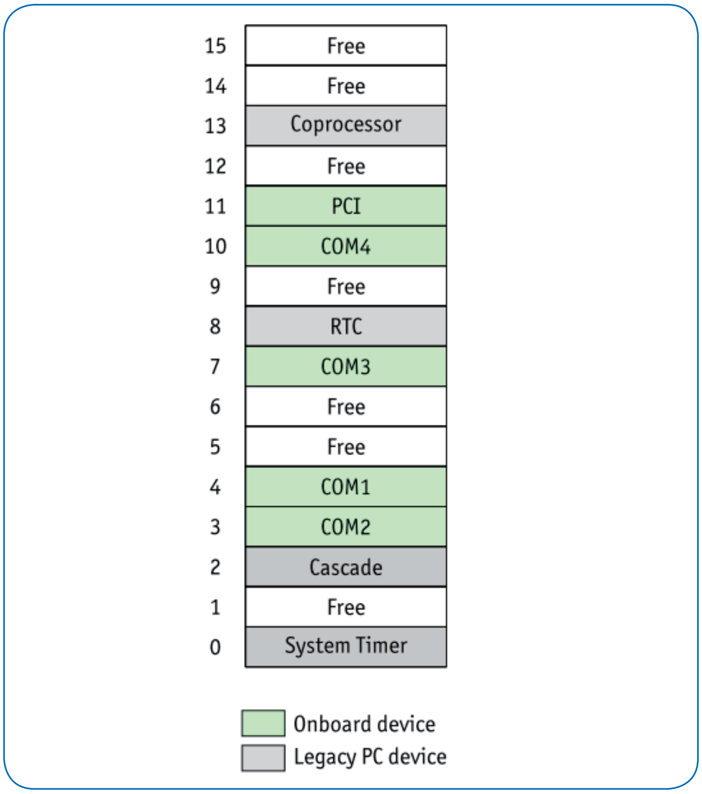

Image 1: Legacy interrupt map for the Kontron MICROSPACE® MSM-e0(-N)

A side note on ISA Plug & Play
Plug & Play was introduced on the ISA bus in order to simplify resource allocation for ISA-based systems. However, most industrial designs do not use ISA PnP as the PnP process adds unnecessary delay to the boot sequence. Furthermore, compared to former PC installations, where it was common to occasionally exchange an extension card, embedded applications usually run in a defined configuration for years. Therefore to improve system availability, ISA PnP is not implemented in the standard BIOS of the Kontron MICROSPACE® MSM-e0(-N). In order, however, to provide full compatibility to applications that use PnP, it can be integrated into the BIOS upon customer request.

How to provide the ISA I/O ports

In a second step, it was necessary to provide the typical ISA I/O ports to enable communication between ISA devices and the processor. The I/O port range was addressable via 16-bit. Therefore a maximum of 65,536 ports could be addressed. On early ISA designs the ISA peripherals only decoded the lower 10-bits of the address. This limited the usable I/O range on the ISA bus to 1024 ports, which made them a rare ressource. And these 1024 ports had been divided into two sections - those for the fixed system peripherals (port 0 to FFh) and those for the rest of the system (port 100h to 3FFh). Modern systems decode the full 16-bit address. They map the lower part (0 to FFFh) to the internal peripherals and/or LPC and the higher part (1000h to FFFFh) to PCI. On PCI systems the higher addresses are used for Plug & Play PCI configuration and usually do not route any of the higher ports to ISA. On the Kontron MICROSPACE® MSM-e0(-N) all unused PCI cycles are mapped to ISA (see figure 2) and are now usable for ISA. By this, OEMs gain additional valuable resources for the application-specific I/O boards, which simplifies ISA board configuration.

There are only a few limitations that engineers need to be aware of: for mixed PCI / ISA applications, the nature of Plug & Play cannot guarantee that addresses over 400h are available on ISA, since the availability depends on the installed PCI cards and the Plug & Play resource allocation. For non-standard ISA cards with extended addressing requirements, testing with a logic analyzer may be necessary to confirm the availability of resources.

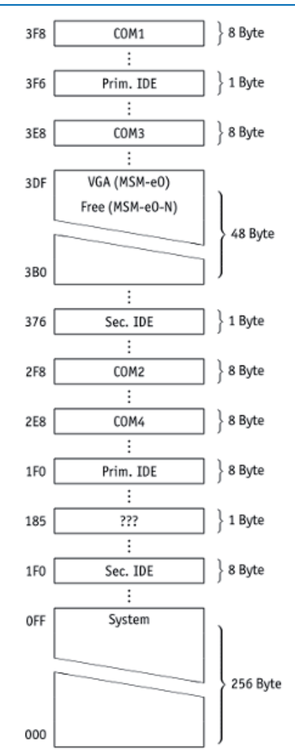

Figure 2: ISA I/O map for MSM-e0(-N)

Image 2: ISA I/O port map for the Kontron MICROSPACE® MSM-e0(-N)

How to bring back the ISA memory map

The third premise is an ISA-compatible 8 and 16 bit memory area. In contrast to current Intel chipsets and processors, which deny access to the ISA memory area between the typical 640 kB to 1 MB (A0000 to DFFFFh), which is used for data exchange between the ISA expansion board and the CPU, the AMD Embedded G-Series APU maps this area to the PCI bus. On the Kontron MICROSPACE® MSM-e0(-N) the chipset was configured to make this address range accessible to the user. Figure 3 shows the memory map for the region below 1 MB. The BIOS occupies the top 128kB range starting from E0000h. The onboard VGA (if present) occupies the area from A0000 to C7FFFh. The Kontron MICROSPACE® MSM-e0(-N) maps the unused areas from A0000h to DFFFFh to the ISA bus and leaves the area starting from C8000h (A0000h if no graphics is used) to DFFFFh available to the user.

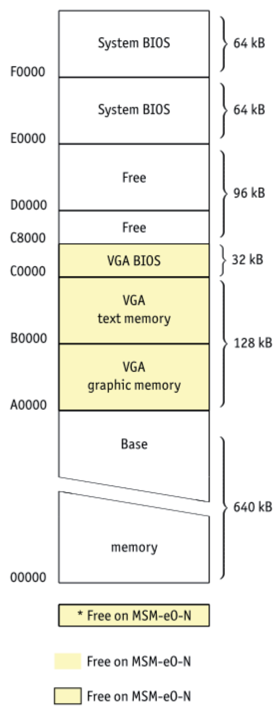

Figure 3: Conventinal memory map of MSM-e0(-N)

Image 3: Conventional memory map of the Kontron MICROSPACE® MSM-e0(-N)

Enabling configurable DMA

Last but not least, the Direct Memory Access (DMA) for the expansion boards has to be adopted to provide full 8 bit and 16 bit DMA support. This feature was one of the most complex tasks and required individual firmware programming. Since the integrated DMA controllers in the AMD controller hub A55E grant no access to the PCI to ISA bridge, Kontron used a combination of dedicated hardware and firmware programming to provide ISA-compatible DMA access. The chipset on the Kontron MICROSPACE® MSM-e0(-N) provides two 8237 DMA controllers for full PC/AT compatibility. The DMA controllers can initiate transfers between the LPC and host bus. This provides the option of adding an LPT or floppy controller to the LPC port with DMA support. But the chipset DMA controller cannot initiate PCI to host bus transactions. To enable ISA-conform DMA, the ITE 8888 PCI to ISA bridge integrated on the Kontron MICROSPACE® MSM-e0(-N) features two additional 8237 DMA controllers. Distributed DMA is implemented to operate the ISA DMA controllers and the chipset DMA controllers simultaneously. The DMA channels used on the ISA bus are configured in the BIOS setup and the system remaps the channel from the system controller to the ITE8888 DMA controller.

A question of software: The right timing

Despite Kontron's efforts to ensure ISA implementation is as compatible as possible, there is still one issue that developers should keep in mind: old drivers and tools may not run correctly on a CPU that is as fast as the AMD Embedded G-Series processor, which offers frequencies beyond 1 GHz. Timing loops with calibration can throw divide-by-zero exceptions and unexpectedly terminate the tool. Fixes for most timing loop-related issues exist. There are binary patches available for some of them, others need recompilation or re-linking to fixed libraries. Kontron offers its customers corresponding services including software porting and evaluation for a real hard- and software- compatible drop-in-replacement of the previously installed obsolescent ISA SBC. Kontrons services include also third party products, such as application-specific I/O boards. OEMs thus receive comprehensive support for all levels of their application. They can fully concentrate on their core competencies and leave the hardware and hardware-related software to the embedded vendor.

Conclusion:

When it comes to implementing latest processor technology in existing and new applications, PC/104 offers a broad portfolio for current and legacy PC busses. With the Kontron PC/104-plus single board computer MSM-e0(-N) Kontron now also offers the latest processor technology for the upgrade of ISA- and PCI-based designs. By this, OEMs benefit from increased investment security of their existing designs. So PC/104 is still one of the best standards for rapid development of long-term available and robust SFF applications. OEMs still get the appropriate boards for their legacy boards. But they can also choose to move towards new system designs. This means that the choice they made in the past today puts them in a position to implement the most flexible design alternative on COTS level. What more could they ask for?

The Kontron PC/104-plus single board computer MICROSPACE® MSM-eO(-N) with the AMD Embedded G-Series APU features full ISA support.

The AMD Embedded G-series APU in brief
AMD's Embedded G-Series is one of the most versatile low-power SFF processors currently available. The Accelerated Processing Unit integrates up to two 64-bit x86 cores running at up to 1.6 GHz as well as a high-performance, programmable AMD Radeon graphics unit, all on a footprint of only 19 mm x 19 mm. The graphics unit provides outstanding performance on par to that of dedicated graphics cards and it can also be used as a "number cruncher" for massive parallel data processing. The AMD Embedded G-Series APU is also available as a headless version – i.e. without an integrated graphics unit, for deeply embedded systems not requiring a graphics output. With this scalability, it can be used in an extremely wide application range: from graphics-oriented applications, such as HMIs, down to deeply embedded systems like safety and security systems in trains. All that with a high performance-per watt ratio and with an extremely low-power footprint.

The Kontron PC/104-plus single board computer MICROSPACE® MSM-eO(-N) in detail

Kontron offers the PC/104-plus single board computer MICROSPACE® MSM-eO in two versions: the Kontron MICROSPACE® MSM-eO with the AMD T44R APU with 1.2 GHz and AMD Radeon HD6250 graphics unit offers OEMs the most powerful embedded graphics currently available for PC/104-based SBCs. It supports the latest 3D graphics libraries such as OpenGL 3.2 and DirectX11. It is also ideally suited as an upgrade for existing PC/104-plus designs that need more graphics performance with low-power consumption.

The Kontron MICROSPACE® MSM-eO-N is a cost-saving and low-power solution for deeply embedded systems that need no display support and have no graphic requirements. This space-saving, two-chip solution based on the AMD Embedded processor T24L and Fusion Controller Hub A55E is ideal for fanless Small Form Factor (SFF) designs that run purely as number crunchers.

About Kontron

Kontron is a global leader in embedded computing technology. With more than 30% of its employees in Research and Development, Kontron creates many of the standards that drive the world's embedded computing platforms. Kontron's product longevity, local engineering and support, and value-added services, helps create a sustainable and viable embedded solution for OEMs and system integrators. Kontron works closely with its customers on their embedded application-ready platforms and custom solutions, enabling them to focus on their core competencies. The result is an accelerated time-to-market, reduced total-cost-of-ownership and an improved overall application with leading-edge, highly-reliable embedded technology.

Kontron is listed on the German TecDAX stock exchange under the symbol "KBC".
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