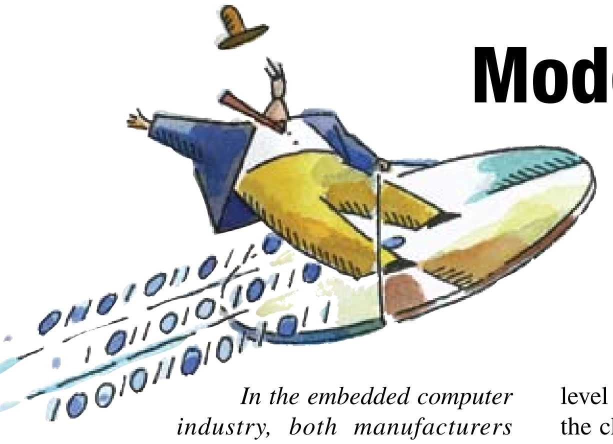


Modern interfaces in light of embedded computer integration

By Andreas Geh

In the embedded computer industry, both manufacturers and users are facing the challenge of selecting the right solution from a formidable multitude of bus, interface, and communication standards. Furthermore, this process becomes even more difficult in times of major technological changes, as is the case with the current transition from parallel to serial standards. This article first describes the most important interfaces that play a role in most x86-based embedded systems. After that, it highlights the advantages and disadvantages of current and future standards for embedded computer applications and points out special design-in considerations.

Embedded computers can only fulfill their purpose if the interfaces that they have to provide are efficiently configured. Making the right decision is a matter of trade-offs between size requirements and flexibility, power-saving capabilities and performance, long-term availability and future compatibility, as well as marketing considerations and genuine needs. The embedded computer industry is currently experiencing a radical change that is creating new perspectives: Consumer-oriented trends have to be tested for suitability for industrial applications. Serial interfaces are replacing parallel interfaces, and some finished developments first have to prove their usefulness in embedded environments. Decision makers for new projects and products have to do more than just examine the processor components, which are frequently overemphasized in marketing. They must also be familiar with a multitude of interface standards and then carefully select and scale them. Since it is not possible to comprehensively examine the huge number of interfaces, one can categorize the interfaces according to the level on which they operate: interfaces on the chip, board, peripheral, and network levels (xAN). For system developers, the chip level is no longer critical because module concepts are widely used in this area. Consequently, the following aspects will concentrate on the interfaces that are primarily relevant for design-in (board and peripherals).

In recent years, the computer industry has been transitioning from standards for parallel interfaces to standards for serial interfaces. This change has far-reaching consequences for the embedded computer industry, which must now determine how long it will continue to support older standards and which peripheral components will still be available in the future, whether the new standards are *embedded-capable* and how they can be checked during the development process.

Important new serial standards on board level:

- PCI moving to PCI Express (PCIe)
- ISA to Low Pin-Count Bus (LPC)
- TTL to Digital Video Output (DVO)

And on the peripheral level:

- IDE P-ATA to Serial Advanced Technology Attachment (SATA)
- LPT, Floppy, PS/2 to Universal Serial Bus (USB)
- PC Card to ExpressCard

Type	Speed	Type of transmission	Number of conductors	Max. length	Number of subscribers
ISA	(16-bit/8 MHz) 16 MBps (theoretical) ~ 4 - 8 MBps (actual)	Parallel Single ended 3.3 V (5 V)	87	30 cm	5 - 10
LPC	~ 4 MBps	Serial Single ended 3.3 V	6 - 13	30 cm	5 - 10
PCI	(32-bit/33 MHz) 133 MBps (theoretical) ~70 MBps (actual)	Parallel Single ended 3.3 V (5 V)	70	30 cm	4 - 8 (No. of interrupts)
AGP (2/4/8)	32-bit/2 (4/8) x 66 MHz 533 – 3132 MBps	Parallel Single ended			1
PCIe (1 Lane)	250 MBps bidirectional	Serial Differential	4	30 cm	1

Table 1

From the angle of embedded computer solutions, the new standards offer only limited suitability for use. Furthermore, they present system developers with new challenges.

The assessment of an interface for embedded computers in industrial environments depends on several essential characteristics. On the physical side of the evaluation are such criteria as data rate (transfer volume in megabytes per second), number of conductors, type of transmission, maximum and minimum conductor lengths, as well as the number of subscribers, addresses, and interrupts. As far as integration is concerned, availability of components, suitability for use under harsh environmental conditions, susceptibility to EMC problems, connector and cable definitions, backwards compatibility, costs of integration and parts, as well as presence of software support are among the crucial criteria. Tables 1 and 2 show the most important interfaces at the board level for x86 embedded computer systems.

During the design-in for an embedded system, it is a good idea to use module concepts that employ several bus standards and/or scalability between parallel and serial buses. LPC and PCI should be used for the conventional peripheral components and when ISA is required, the connection should be made using conventional bridge chips or FPGAs. Using PCIe is only to be recommended when a high-performance graphics cards is to be used or when other high-speed processes (such as Gigabit, Firewire, and

Type	Area of application	Connector / cable	Advantages	Disadvantages	Availability
ISA	• Simple peripherals • I/O functions • Small bus systems • Proprietary controllers	• PC/104; DIMM • Simple plug connectors, etc.	• Software support can be integrated • Proprietary solutions	• Bandwidth • Outdated power consumption	Decreasing number of components for proprietary solutions
LPC	• Primarily for legacy support (SuperI/O controller) • BIOS extensions • µC interface	No standardization	Reduced conductors	Software support for LPC to ISA compatibility problems	High
PCI	• Peripherals • Bus systems • LAN / framegrabbers / graphics controllers / PC Card, etc.	• PC/104-*Plus* • CompactPCI • MiniPCI • PCI slots • PISA • Proprietary connectors	• Widely in use • Software support	• Wide buses • Few subscribers in parallel	High
AGP (2/4/8)	Only for graphics cards	Special AGP slots		No other applications	High for graphics
PCIe (1 Lane)	• Fast peripherals • Gbit Ethernet • ATA150 • High-end graphics	PCIe slot	• High bandwidth • Few conductors	Stringent development requirements	• Increasing • Little chip support so far

Table 2

graphics) are to run simultaneously in addition to Gigabit Ethernet or when an ExpressCard is planned as a removable media.

The peripheral level can be divided into three areas:

- User interface
- Storage media
- Devices

User interface: video

Every modern embedded system is equipped with fast components in order to master the data transmission tasks. One category that takes on special significance in this respect is the video interface with its different standards. Video interfaces are closely connected to the application and meet different applications' requirements. As shown in Table 3, the decisive factors for selecting a video interface depend on the chipset, BIOS or display, dynamic or fixed detection, or on physical factors such as the conductor length, resolution, and timing.

The conditions for the display control for modern x86-based systems are changing. The embedded graphics controllers that have been in use until now are being phased out of the market, and new chipsets and graphic controllers no longer support the TTL interface. Adaptations to the BIOS are becoming increasingly complex and more difficult for manufacturers to produce. Moreover, the drivers in the operating system are also becoming increasingly complex. Modern displays are equipped with automatic detection mechanisms such as DDC/EDID, and the requirements for graphic performance (bandwidth) are simultaneously on the rise. The short life cycles for LCDs are also extremely problematic.

For external monitors, CRT (VGA) solutions were the standard choice until now, and TTL or LVDS solutions were used for LCDs. Integration required checking the monitor data, adapting the video BIOS (timing) and making a suitable adapter cable. The advantages were the low hardware expense and trouble-free adaptation of exotic displays. The disadvantages were the high expense for integrating the software, the permanent choice of a display type, and the problems associated with this in conjunction with product discontinuation or with adjustments to the BIOS.

In the future, DVI-I will be the standard solution used with external monitors. With LCDs, it will be LVDS or DVI. The examination of the monitor data, the generation of an Extended Display Identification Data (EDID), and the integration of DDC functionality (I2C bus) will be required. The new technology offers several advantages: It makes the solution independent of the display hardware, enables automatic recognition of display data (such as the resolution, for example) through the BIOS or operating system, and does not require any adaptation of the BIOS. One disadvantage, however, will be the greater hardware complexity for the DDC and EEPROM in the display or on the baseboard.

For the development of embedded systems, the following guidelines are recommended:

1. If the monitor is only used for support and installation, it makes sense to continue to use the analog CRT connection.
2. For systems with external displays, DVI should generally be used.
3. For the use of integrated LCDs in the system, LVDS lends itself well as the interface combined with the integration of DDC with an EDID on the baseboard or in the display.

User interface: input and audio

Since many systems have a Super I/O chip, which is usually required by the BIOS, the PS/2-interface can be used inexpensively for input/output. When designing new systems with a user interface, USB

Type	Area of application	Connector / cable	Advantages	Disadvantages	Availability
TTL	• LCDs with low resolution (<VGA) • Usually passive LCDs for text or graphics	• Simple plug connectors, etc. • Flat ribbon cable • Up to 50 cm	Inexpensive	• Outdated • Short conductor lengths • No established signals	Modern graphics controllers hardly provide support any more
VGA	Standard output for analog monitors	• D•SUB, 15•pole • Shielded cable, COAX • Up to 5 m	• Widely used • Established standard	• Susceptible to noise • Stringent requirements for the cable • Limited bandwidth	High
DVI	Control of modern LCD monitors	• DVI connector • Shielded cable • Up to 12 m	• Noise resistant • Defined standard • High bandwidth	• Complex display control • Large connector	High
LVDS	Direct connection of LCDs in systems	• Simple plug connectors • Twisted pair • Flat ribbon cable • Up to 8 m	Direct control of LCDs	Coding varies widely	High

Table 3

should generally be preferred because this alternative is increasingly replacing PS/2. For audio applications, the AC97 bus from Intel will remain a frequently used and simple possibility for employing codecs for diverse requirements.

Storage interfaces

The storage interface is normally used for three types of storage:

1. The system/ data memory for the operating system and operating data
2. The main memory (not examined here) because its control is usually integrated in the chipset
3. Removable storage media, such as a PC Card, ExpressCard, or USB-based media

The EIDE/ATA interface is widely used as a solution for mass storage devices. Enhanced Intelligent Drive Electronics (EIDE) defines the interface's electrical properties, and Advanced Technology Attachment (ATA) defines the protocol. In 1998, ANSI added AT Attachment Packet Interface (ATAPI) to the ATA standard for connecting CD/DVD drives using EIDE. Table 4 contains a summary of ATA standards.

When comparing ATA and SATA (see Table 5), it is important to remember that transfer rates higher than 33.3 MBps (UDMA2) are rarely implemented with embedded systems, because higher speeds (> ATA-4 or UDMA2) require use of the special 80-conductor cables. These cables are not suitable for embedded applications.

When developing embedded systems, it is still a good idea to use EIDE/ATA as a standard interface, because it is anticipated that hard drives will be available for a long time. Furthermore, the 44-pin EIDE connectors and cables are very well-suited for use in harsh environments (shock/ vibration). SATA is only suitable for systems with external drives or high data transmission rates. Nevertheless, using a lockable SATA connector is advisable. In order to be able to support both standards, it makes sense to use scalable modules such as DIGITAL-LOGIC's SM855 and SM915 modules.

	ATA-1	ATA-2	ATA-3	ATA-4	ATA-5	ATA-6
PIO modes added	0, 1, 2	3, 4	—	—	—	—
DMA modes added	0, 1, 2 Multiword 0	Multiword 1, 2	—	—	—	—
UltraDMA modes	—	—	—	0, 1, 2	3, 4	5
Max. transfer rate	11.1 MBps	16.6 MBps	16.6 MBps	33.3 MBps	66.6 MBps	100 MBps
Cable	40 conductors	40 conductors	40 conductors	40/ 80 conductors	80 conductors	80 conductors
ANSI standard, year	X3.221-1994	X3.279-1996	X3.298-1997	NCITS 317-1998	NCITS 340-2000	NCITS 347-2001
Features added	—	Block transfers, LBA, drive identification	SMART, reliability features	CRC, 80-conductor cable	—	48-bit LBA
Known as	ATA/IDE	ATA/IDE	ATA/IDE	Ultra DMA/33	Ultra DMA/66, ATA/66	Ultra DMA/100, ATA/100

Table 4

	EIDE/ATA	SATA
Speed	33 MBps (UDMA 2) Up to 100 MBps (UDMA5)	150 MBps 300 MBps (SATA II)
Cable	44-pin flat ribbon cable (0 – 40 cm) 80-pin flat ribbon cable (0 – 20 cm) beginning with UDMA3 (66 MBps)	Special SATA cable, 7-pin (up to 1 m)
Signals	Parallel; single ended; 5 V	Serial; differential; 0.5 V
Advantages	• Widely used • Connector suitable for embedded use • Flexible cable lengths • CF-connection possible	• Thinner cable • Noise resistant • High bandwidth • Completely compatible to ATA • Beginning with SATA II: hot plug
Disadvantages	• High number of pins • EMC issues	• No connector suitable for embedded use • Long standard cable (>0.45 m) • Only one device / channel • Still no CD/DVD drives

Table 5

Removable storage media: PC-Card vs. ExpressCard

ExpressCard technology is the name given to an add-in card that was developed by the Personal Computer Memory Card International Association (PCMCIA) and will be replacing the PC Card over the next few years. This plug-in card, which is only half the size of a conventional PC Card, uses the scalable, high-bandwidth serial PCI Express and USB 2.0 interfaces. The USB 2.0 interface is primarily suited for technologies such as Bluetooth cards or Flash memory cards. The high-speed PCI Express variant is predestined for devices with high transfer rates, such as 1394b- or Gigabit Ethernet cards. As already defined with the PC Card, the ExpressCard is equipped with hot-plug functionality, which can be used for the PCI Express and the USB 2.0 interface. In addition, a sophisticated power management system enables the plug-in card to make efficient use of the limited energy resources of a corresponding energy-dependent device.

The fundamental advantages that ExpressCard technology has to offer are high transfer rates, universal use, and favorable form factor. Another plus point for the ExpressCard standard is owed to the low cost due to the low number of circuit paths. On the other hand, this technology requires a new connection architecture on the system boards and new plug-in cards such as the ExpressCard/34 and the ExpressCard/54. Although applications for embedded systems are currently still lacking, ExpressCard technology offers interesting perspectives in the midterm compared to the PC Card (shown in Table 6), which is widely used but has significant restrictions in embedded environments.

When developing embedded systems, it is better to do without the PC Card if possible and instead use USB 2.0 intensively for removable storage media and as a simple, high-speed interface (see Figure 1).

The ExpressCard lends itself well when interchangeable high-performance peripheral cards become important in the system. It is also possible to use scalable modules that support both the USB 2.0 and the PCIe standards without passing on existing solutions, as is the case with

Figure 1

the SM855 and SM915 smartModules from DIGITAL-LOGIC.

Implementation example: smartModule

The smartModule is a small Pentium M module with ideal scalability for all important interfaces. This module solution allows scalability despite the switch of technology from parallel to serial interfaces. Furthermore, it fits in between PC/104-*Plus* connectors. For customers, these two aspects protect investments over the long term despite the technological transition and ensure the realization of expandable system solutions of minimal size. The smartModules feature a mature, integrated cooling concept and are configured with a completely encapsulated design including mechanical mounting for DRAM (for automotive and avionics applications).

The new SM915 smartModule shown in Figure 2 is based on the Intel 915GM chipset and uses a Pentium M processor with clock speeds of 0.6 to 2.2 GHz as its CPU. Equipped with a large, 2 MB L2 on chip cache, the 2.2 GHz Pentium M765 achieves performance levels comparable to a 4.4 GHz Pentium 4 processor. The maximum main memory is 1 GB of DDR-RAM. The CPU and memory are mounted interchangeably, but they are mechanically protected against vibrations or shock.

Another of the smartModule's strengths is its graphics performance. The SM915 uses the i915GM chipset that is integrated into the video controller and supports up to 256 MB of video memory as well as DirectX9 compatibility. The video controller uses two 18-bit LCD connections to control the most common LCD technologies. It reaches a resolution of up to 2048 x 1536 pixels with a maximum color depth of 256 bits. It is also equipped with two PS/2 ports for a mouse and keyboard, a serial interface, a floppy interface, eight USB-2.0 interfaces, an AC97/HDA-compatible sound interface with DTS-7.1 output, a watchdog, an RTC battery, and EEPROM support. For connecting additional mass storage media, there are a P-ATA133 and two SATA150 hard drive interfaces available. Furthermore, all required power supplies and progressive Speedstep power management functions have been integrated. For connecting to a TCP/IP-based LAN or to the Internet, the smartModule is equipped with a 10/100Base-T Ethernet controller. The module can be expanded via the PCI or PCI-Express bus.

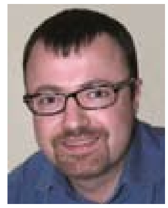
The SM855 and SM915 require a supply voltage of 5 V (expandable to modern point-of-lead concepts, 4.5 – 30VDC) and run on all conventional operating systems. Equipped with a flash BIOS that has a dual-BIOS option makes it possible to boot from different media such as the hard drive, a floppy disk, USB, or via LAN. The modules operate within a standard temperature range from -20 °C to +60 °C. At low clock rates (600 MHz) they are also approved for use in the extended temperature range from -40 °C to +85 °C. The smartModules feature

	PC-Card	ExpressCard
Speed	132 MBps in theory 50 - 70 MBps in reality	300 MBps
Applications	Memory cards Peripheral cards (LAN, WLAN, Firewire, field buses)	Memory cards Peripheral cards (Gbit-LAN, WLAN, Firewire, field buses)
Connectors	68-pin (type I, II, III)	26-pin (type 34, 54)
Signals	32-bit (PCI), single ended, 3.3 V	PCIe 1x + USB 2.0
Advantages	Widely used	• Small form factor (34 mm) • Noise resistant • High bandwidth • Two standards in one (USB) • Hot plug
Disadvantages	• Limited suitability for embedded use • EMC issues	• PCIe required • Few cards available • Consumer oriented

Table 6

Figure 2

a sophisticated cooling concept: The cover consists of a milled aluminum block with high resistance and a fixed supporting surface on the PCB and is mounted on the CPU on a special copper core to ensure ideal heat dissipation. This perfectly flat surface enables an ideal connection to the side of a device's enclosure or to a cooling element. The cover simultaneously provides EMC protection. Since all of the i855GME/i915GM chipset's power-saving functions are supported, the smartModules typically only consume 10 watts of power.



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