



## Using PC/104 Embedded-PCs in Mobile and Portable Applications

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### EMBEDDED COMPUTER REQUIREMENTS

Since the birth of the microprocessor in the mid-1970s, there has been continuous exponential growth in CPU performance and memory capacity (for both program execution and data storage). By the end of the '70s, a few megahertz and a few kilobytes were the norm. In the '80s, this grew to tens of megahertz and tens of megabytes. Currently, embedded computer CPUs are clocking upwards of 200 MHz, RAM capacities can exceed 64 megabytes, and mass storage is measured in gigabytes!

As embedded computer speeds and memories have grown ever larger, embedded applications have become decoupled from the embedded computer *architecture*. Now, the "magic" is in the unique software, interface technology, peripherals, and packaging. Embedded system developers can thus devote more energy and time to being *product* architects instead of *computer* architects.

Today's embedded computer is increasingly viewed as a platform on which to run the application's software. Accordingly, embedded *software* has become the dominant technology concern, rather than embedded computer *hardware*. Consequently, the preferred embedded computer architecture is the one that optimizes the application's software development process, resulting in faster development cycles, reduced technical risks, and improved system sophistication. In today's fast-moving and competitive market for technology-based systems, any and all efficiencies are greatly welcomed.

An obvious way to simplify and speed embedded system development is to employ standardized hardware and software building-blocks, if available. This would minimize the need to design from scratch. How can this be accomplished? In response to this question, embedded system development teams have looked to the highly popular PC architecture to provide a standardized hardware/software architecture.

## BENEFITS OF A PC ARCHITECTURE

The enormous popularity of the PC architecture (“over 300 million sold”) has generated a vast resource of *desktop* software and hardware. Can these be applied to embedded systems? If so, billions of dollars in R&D investment can be harnessed for the benefit of the embedded market. Here are some of the technologies and components of interest . . .

- **CPUs** — driven by the high volumes of the desktop market, the “Intel architecture” (“x86”) CPUs offer the best microprocessor price/performance ratios available. Multiple CPU vendors constantly vie with each other for faster and cheaper chips, with the result that the speeds and features continually go up, yet the prices stay roughly the same. Today’s 64-bit Pentium processors cost little more than yesteryear’s 16-bit 8086s.
- **Operating systems** — a wide range of choices, including DOS, Windows 95, and Windows NT from the desktop PC world, as well as many real-time operating systems (RTOSes), support the desktop PC “standard”. Importantly, it’s not necessary to “port” a RTOS to a system that complies with the PC standard, since most RTOSes already support the PC.
- **User interface** — one of the areas of greatest emphasis for product differentiation in the desktop PC world has been ease-of-use and richness-of-display. Consequently, there have been great advances in “graphical user interface” (GUI) capabilities, both from the software and hardware perspective. Display devices, including CRT monitors and flat panels (e.g. LCDs), have evolved greatly in resolution and color depth, while prices have stayed constant or even dropped. GUI software is now a standard feature of the OS itself (i.e. Windows); GUI acceleration hardware is a standard function of the display controller ICs.
- **Mass storage** — PC hard disk controllers have become obsolete, absorbed by the disk drive itself (IDE). Exponential growth in demand for hard disk capacity, fueled by blindingly fast PC CPUs coupled with increasingly complex operating system and application software, has generated the hard disk R&D budgets necessary to simultaneously shrink costs and explode capacities (now in the gigabytes). In addition, investments in “solid state” storage technologies, needed for reliable laptop and notebook PC operation, have also yielded dividends in the form of cost-effective “Flash” memory technologies. Another important mass storage development from the desktop PC market is the CD-ROM: it offers extremely high data density and durability, at very low cost; and it connects directly to a PC’s IDE interface without requiring an additional controller.
- **Communications and networking** — as the speed, memory capacity, and functional sophistication of the desktop PC increases, vastly larger quantities of data need to be communicated and shared. RS232C serial interfaces, the standard in the past, are no longer adequate. In response to this growing need, great strides in both wired and wireless communications technologies have been made. Modem speeds double annually and have now attained rates thought impossible a few years ago. Ethernet, implemented within a single chip, is rapidly replacing RS232C as a standard inter-computer “serial” port; and “plug-and-play” Ethernet drivers are provided directly within Windows 95 and other OSes.
- **New system interfaces** — a variety of new interfaces and peripheral devices have evolved to support the needs of desktop and laptop PCs. IDE, SCSI, and PCMCIA are all readily available and relatively mature, though all three continue to evolve in capabilities and

throughput. Newer arrivals include the enhanced parallel port (IEEE 1284) as well as two new high speed serial interfaces: Universal Serial Bus (USB), and FireWire (IEEE 1394).

- **Development tools and support** — not to be underestimated is one of the greatest benefits of using a PC architecture: the rich assortment of tools and support. Books and magazines document all aspects of the PC's hardware, software, and applications. Development tools for the PC platform are plentiful, cost-effective, and easy to use. Nearly every engineer, programmer, and technician is knowledgeable in the use of PC hardware and software.

In short, a PC compatible architecture can bring great savings to development time and costs, can reduce product material costs (due to less expensive chips and peripherals), and can minimize maintenance and support headaches. These are the key reasons why the PC architecture is increasingly being used in embedded applications.

## REQUIREMENTS OF MOBILE AND PORTABLE SYSTEMS

Mobile and portable applications place demands on embedded computer size, weight, and operating conditions. These factors differ greatly from the requirements of the desktop PC market, wherein price pressures impose severe limitations on reliability, ruggedness, and quality. Some physical characteristics of relevance to mobile and portable applications include . . .

- **Size and weight** — space is generally scarce in mobile and portable environments. The “right” size varies, however; it depends on whether a portable application is “hand held” or “man pack”, or on the type of vehicle (truck, boat, plane, etc.) in a mobile application. Weight is another important factor in most portable and airborne applications.
- **Power consumption** — battery life is naturally an key consideration in the design of battery-operated portable and mobile equipment. Also, since heat generation is proportional to power consumption, reduced power consumption may be required to support operation in high ambient temperatures.
- **Shock and vibration** — mobile and portable systems are subjected to a wide range of gentle and harsh motions, during both operation and storage. Large and small repeated movements subject components, connections, and solder joints to continual mechanical stress. Chips, modules, and boards may become partially or fully dislodged or disconnected. Connector pin conductivity can be degraded by corrosion due to electrochemical effects that are exacerbated by vibration. Data integrity becomes an issue when disk drives are used.
- **Temperature and humidity** — most mobile and portable systems are subjected to relatively uncontrolled thermal and moisture conditions. Sealing an enclosure protects its contents from dampness, but raises the high end of its operating temperature range, due to trapped internal heat. In consideration of these factors, electronics for mobile or portable systems must typically support operation without failure from -40 to +85°C.
- **EMI, ESD, and power supply irregularities** — electrostatic and electromagnetic interference, both generated and received, are also of concern. High frequency microprocessor clocks must not interfere with the wireless communications functions that often accompany mobile and portable applications. With PC CPU clock rates commonly in the range of 33 to 166 MHz, there is obvious risk of generating HF, VHF, and UHF interference. Also, mobile or portable systems often are used in the vicinity of strong radio or

radar signals. Another problem, is electrostatic and electromagnetic fields generated by spark plugs, motors, and other sources in moving systems. Consideration must also be given to input and output of conductive interference on power supply connections. System crashes, false resets, and damage to electronics can result from irregularities of vehicle power sources, such as during the starting of an engine.

- **MTBF and MTTR** — Repairing systems on the move is inconvenient, if not impossible. Spares are less available. Therefore, high mean-time-between-failure (MTBF) and low mean-time-to-repair (MTTR) is more critical than with fixed systems. Also, the higher thermal and mechanical stresses associated with mobile and portable environments diminishes MTBF values; therefore, the higher the MTBF, the better.

There is little incentive for manufacturers of desktop-PC systems, boards, and peripherals to satisfy these requirements of portable and mobile applications; doing so would raise system costs and render the resulting systems uncompetitive in the consumer market. Some of the above factors are at least partially addressed by *laptop* PCs — one reason why laptops cost so much more than desktop PCs — but laptops don't particularly lend themselves to use as *embedded* computers.

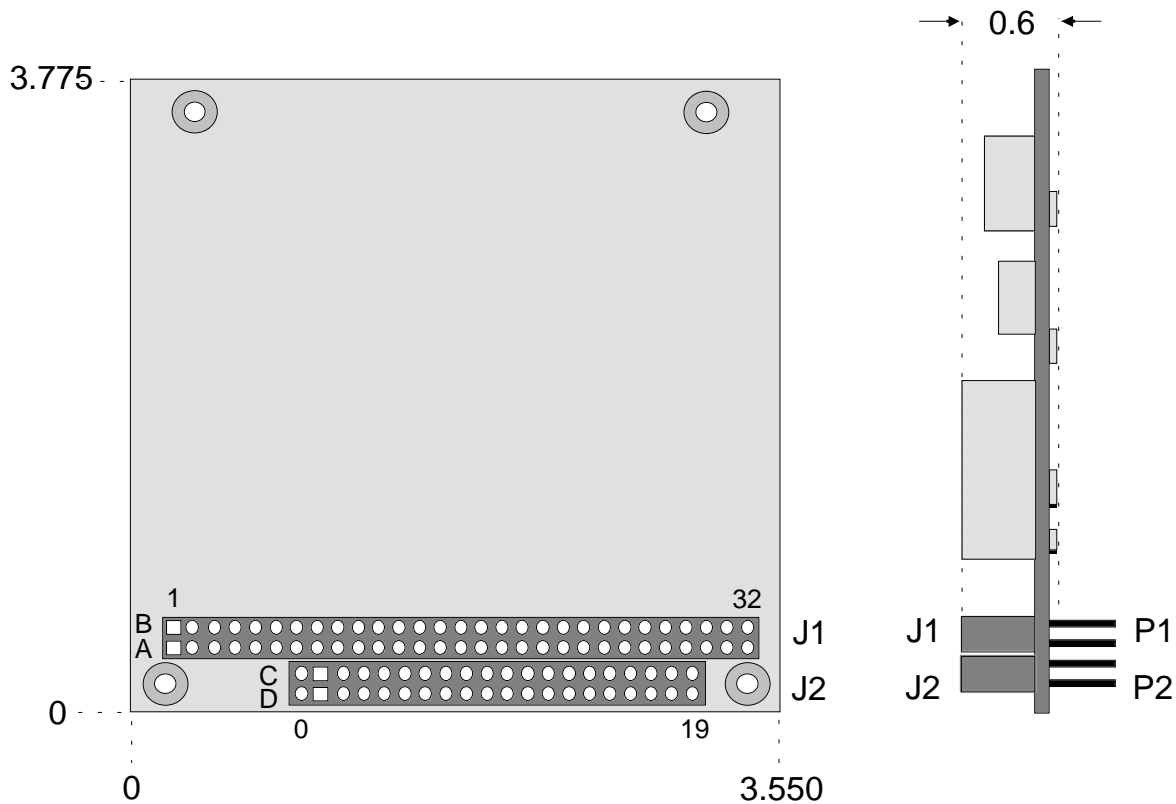
## THE PC/104 ALTERNATIVE

Short of disassembling a laptop PC and building its components into an embedded system, is there anything else that can allow designers of mobile and portable embedded systems to take advantage of PC technology?

The PC/104 Embedded Computer Modules standard was introduced, in 1992, to provide a modular building-block approach to incorporating PC hardware and software technologies into embedded systems. PC/104 modules are intended for a wide range of embedded systems applications — including fixed, portable, and mobile environments.

Basically, PC/104 defines how to repackage desktop PC functions in a manner that satisfies the ruggedness, reliability, and size constraints of embedded systems. PC/104 offers full hardware and software compatibility with the desktop PC architecture, but in the form of compact (3.6" x 3.8"), self-stacking, modules. Consequently, PC/104 provides a practical way to incorporate a PC-compatible architecture into an embedded system, based on off-the-shelf building blocks.

Prior to the availability of PC/104, the only choices for embedding a PC architecture were to use a motherboard or backplane-based approach, which is bulky and unreliable, or to create a custom embedded-PC based on individual chips, which is costly and time consuming. PC/104 modules are small enough to fit where a backplane-based approach won't (see Figure 1), so they provide an excellent space-efficient "middle ground" for most portable and mobile applications.



**Figure 1. PC/104 Module Dimensions**

PC/104 modules match the requirements of mobile and portable applications quite well, as shown in Table 1. Note, however, that the degree to which specific modules comply with particular environmental specifications (e.g. temperature, shock, vibration, ESD, etc.) varies according to the module manufacturers' published standards. Therefore, be sure to check with the manufacturers of the modules for information regarding their environmental specifications.

## AN OVERVIEW OF THE PC/104 STANDARD

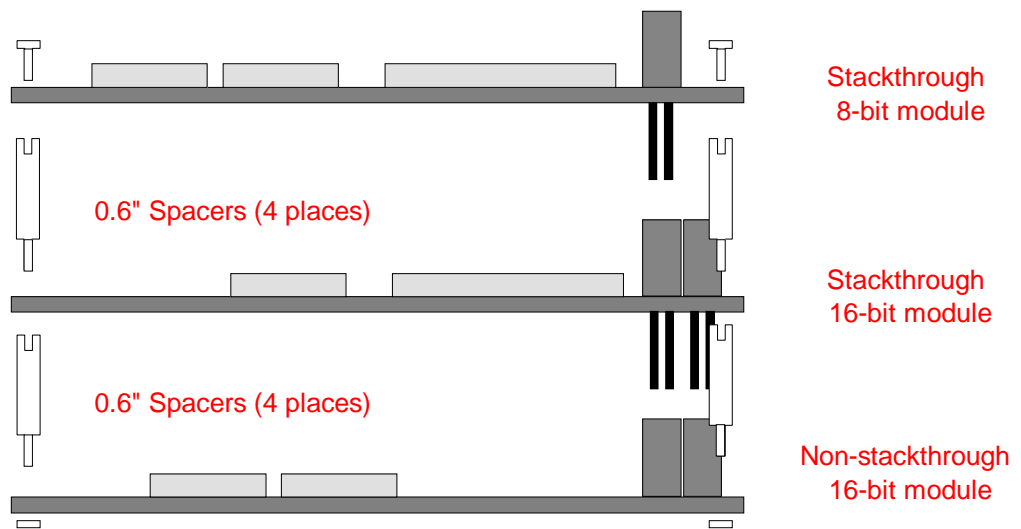
The differences between PC/104 and the "normal" PC are primarily mechanical. There are no software differences. Here is a summary of what is contained in the PC/104 specification . . .

- **Miniature form-factor** — Instead of the usual PC or PC/AT expansion card form-factor (12.5" x 4.8") each PC/104 module is just 3.550 by 3.775 in. There are two bus formats, for 8- and 16-bit modules. Unlike the 8- and 16-bit expansion cards of desktop PCs, both PC/104 versions are the same size, except the 8-bit version omits the P2/J2 bus connector.
- **Self-stacking bus** — To eliminate the complexity, cost, and bulk associated with conventional motherboards, backplanes, and cardcages, the PC/104 expansion bus is based on a unique self-stacking ("stackthrough") bus connector. Multiple modules stack directly with each other, as shown in Figure 2. Stacked modules are spaced 0.6 inches apart and are securely attached to each other by four metal or nylon standoffs.

- **Pin-and-socket connectors** — Rugged and reliable 64- and 40-position male/female “head-er” connectors substitute for the standard PC motherboard’s 62- and 36-position (P1 and P2) edgcard connectors. The PC/104 bus connectors contain gold plated pin-and-socket contacts on 0.1 inch centers.
- **Bus signal function and pin assignment** — All PC/104 bus signal functions are identical to their counterparts on the “normal” PC/AT bus. Their assignments to the one hundred and four locations of the PC/104 bus connectors is defined in the *PC/104 Specification*.
- **Reduced Bus Drive** — To help reduce power consumption (to several Watts per module) and also to minimize chip count, bus drive was lowered from 24 mA (for the “normal” PC) to 4 mA. This permits “HCT” logic and many VLSI ICs to drive the bus directly, without additional buffer chips. An additional benefit of this reduced bus drive is reduced radiated electromagnetic emissions.

**Table 1. Summary of Typical PC/104 Environmental Specifications**

<b>Factors Critical to Mobile &amp; Portable Applications</b>	<b>Typical Characteristics of PC/104 Modules</b>
Size	3.550 x 3.775 x 0.6 in.
Weight	2 to 3.5 oz.*
Power consumption	1 to 5W*
Shock	50G 3-axis peak (per MIL-STD-202F, Method 213B, Table 213-1, Condition A)
Vibration	11.95G 3-axis RMS at 100-1000Hz (per MIL-STD-202F, Method 214A, Table 214-1, Condition D)
Operating temperature	0 to +70°C, standard -40 to +85°C, extended
Storage temperature	-55 to +85°C
Humidity	5 to 95%, non-condensing
EMI compliance	EN 55022 Class B (radiated & conducted emissions)
EMC and ESD compliance	IEC 801-2 (electrostatic susceptibility) IEC 801-3 (E/M field susceptibility) IEC 801-4 (fast transient susceptibility)
MTBF	ground mobile, at 55°C: 30,000 to 70,000 hrs* ground fixed, at 55°C: 150,000 to 650,000 hrs* (per MIL-HDBK-217)
* These values vary according to the specific module.	



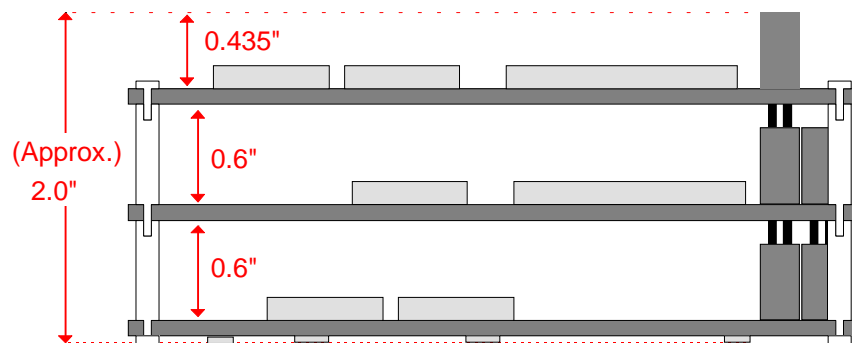
**Figure 2. PC/104 Modules Stack Without Backplanes and Cardcages**

## HOW PC/104 IS TYPICALLY USED

Although configuration and application possibilities are practically limitless, there are two basic ways PC/104 modules are typically used in actual mobile and portable systems.

### Module Stacks

PC/104 modules are sometimes used like ultra-compact bus boards, as illustrated in Figure 3, except that they form compact stacks without the need for backplanes and cardcages. PC/104 stacks can be “bolted” inside an embedded system’s enclosure, in an otherwise empty space. In this manner, the equivalent of an entire PC is often *embedded* directly within a system that would otherwise require an external, *attached* PC for its operation. PC/104 stack enclosures are available from a number of vendors, for packaging PC/104-based subsystems in both fixed and mobile environments.



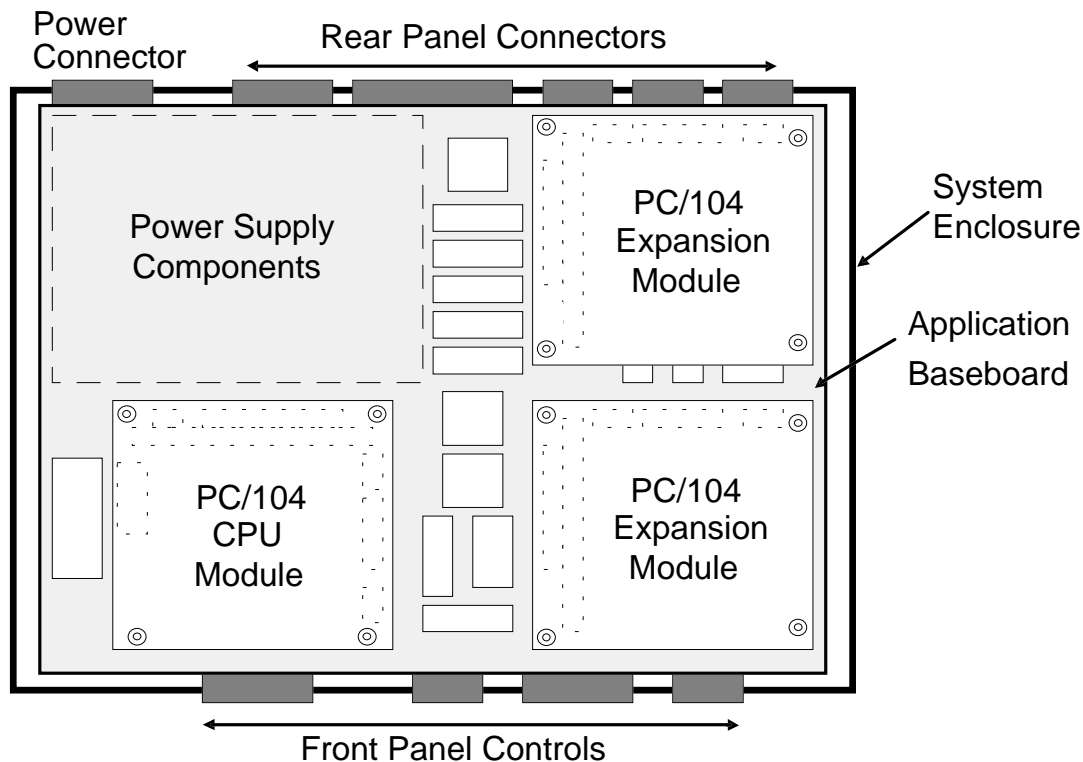
**Figure 3. Typical PC/104 Module Stack**

## Macrocomponents on Application Baseboards

Despite the familiar image of a stack of PC/104 modules equivalent to a desktop PC, that fits in the palm of your hand, most PC/104-based system designs aren't actually based on module stacks. Instead, PC/104 modules are more often distributed *horizontally* — plugged into custom, “application baseboards” like multichip “macrocomponents.” This is illustrated in Figure 4.

The PC/104 application baseboard usually contains all interfaces and logic that aren't available on — or, for whatever reason, aren't desired on — PC/104 modules. In mobile or portable applications, the baseboard generally includes: power conversion or power supply components; signal conditioning logic; specialized interfaces such as J1708; “real-world” I/O connectors; a GPS receiver; etc. Devices on the baseboard don't necessarily need to interface with the PC/104 bus, but might be included there to eliminate unnecessary electronic assemblies.

What size and shape should the application baseboard be? Generally, it takes the shape of the *system*, which may be square, rectangular, or even round! Whatever fits best! Often, the application baseboard provides multiple PC/104 stack locations. This approach allows the PC/104 modules to be distributed side-by-side (instead of stacked on top of each other), resulting in a flatter or thinner system profile. It's always a good idea to provide a spare PC/104 module location — or at least an extra 0.6 inches of vertical clearance (above the top PC/104 module) — to accommodate upgrades, addition of modules for system test, debug, repair, or for other unanticipated future requirements.



**Figure 4. PC/104 “macrocomponents” on an “application baseboard”**

## COMBINING PC/104 WITH PCMCIA

Many PC/104-based mobile and portable system designs have combined two compact PC-compatible standards: PC/104 *with* PCMCIA. These two PC-related standards can work together synergistically to efficiently meet the requirements of mobile and portable embedded applications. Table 2 compares some of the key attributes of PC/104 and PCMCIA.

PC/104's compactness, ruggedness, reliability, and PC-compatibility make it an ideal "platform" for the "core" embedded system functions. For example, a small stack of PC/104 modules can easily provide all basic system functions including CPU, serial/parallel ports, mass storage, display interface, etc. Also, because of the secure way PC/104 modules attach to each other and to other system components, they resist shock and vibration quite effectively.

Because PCMCIA was created for the laptop-PC market, the cards' small size, low power requirements, and rugged specs make them suitable for use in portable and mobile *embedded* systems. In addition, because PCMCIA was created for *PC-compatible* environments, they are well endowed with software support for the PC architecture (hence, the "PC" in PCMCIA).

A good use for PCMCIA cards in PC/104-based embedded systems is for interfaces and options that are popular in the laptop-PC market, especially in the areas of communications and solid-state storage. Communications options include: wireless WANs and LANs, wired LAN adapters, and modems. Mass storage options include: Flash memory cards, nonvolatile RAM cards, and card-sized magnetic-media hard disks (called "PCMCIA-ATA" cards). GPS receivers, now available in PCMCIA card format, are seeing wide use in mobile systems.

**Table 2. Comparison of PC/104 and PCMCIA**

	PC/104	PCMCIA
Size (sq. in.)	13.7	7.2
Max. component thickness (in.)	0.435	Type 1: 0.13 Type 2: 0.20 Type 3: 0.40
Power (typical)	1-5 W	0.1 - 0.3 W
Operating temp. (standard)	0 - 70° C	0 - 55° C
PC architecture compatible	yes	yes
Supported by DOS drivers	yes	yes
Rugged and shock resistant	yes	yes
Rigidly attached	yes	no
Self stacking	yes	no
Field removable	no	yes

Functions and interfaces specific to “real world” data acquisition and control applications, on the other hand, are more readily available on PC/104 modules than on PCMCIA cards. Examples of PC/104 real world interface modules are . . .

- Analog and digital I/O
- Relay drivers
- Counter/timers
- Stepper and servo motor controllers
- Touch interfaces
- Video frame-grabbers
- CRT and flat panel display interfaces
- Specialized “field buses”: Profibus, CAN bus, VAN bus, MIL-STD-1553, ARINC-429, Echelon LON, IEEE-488,
- Digital signal processors
- Vehicle power supply modules

An important distinction between PC/104 modules and PCMCIA cards is how they physically “mount” within the system. PC/104 modules stack rigidly with each other (and other system components), making them “permanent” (factory installed) system components. PCMCIA cards, on the other hand, were designed to be easily user-insertable. This makes PCMCIA especially useful if field access is required.

One advantage of PCMCIA in mobile and portable embedded systems, is that the popularity of PCMCIA in laptop-PCs will continue to generate a growing variety of PCMCIA card functions that can be useful in mobile and portable applications. On the other hand, the designer of a mobile or portable system containing a PCMCIA card needs to provide a mechanism that holds the PCMCIA card securely in its socket. This is readily accomplished by means of simple metal brackets with rubber compression strips.

## **SUMMARY AND CONCLUSIONS**

There are many good reasons to use the PC architecture as the hardware and software basis for mobile and portable embedded systems. However, standard PCs don’t meet the space, power, ruggedness, and reliability requirements of such applications.

The compact, modular PC-compatible PC/104 standard was developed specifically to provide PC architecture compatibility in space-constrained embedded applications. Modules designed to this standard possess many characteristics required by mobile and portable applications.

Designers of mobile and portable embedded systems can utilize PC/104 modules in a variety of ways, including: simple module stacks; plugging the modules into application baseboards, like macrocomponents; using PC/104 together with PCMCIA, in a flexible hybrid design.

By using PC/104, development of mobile and portable embedded systems can be greatly simplified, resulting in faster project completion, reduced development costs and risks, and improved system features and sophistication due to heightened focus on the application itself.